Answer to comments by reviewer #2

This is a fine study with a focus on the Weddell Sea. It is well written and the only complains I have is that is that the reader is expected to fully trust the model. To do so, she must be given much more details.

We thank the reviewer for the positive feedback on our paper. Please see below for details on how we have incorporated all comments into the revised version of the manuscript.

line 83: What is the quality of the present day forcing? It seems to come from a coupled model, so there should be figure with biases in sea-ice and winds at least.

Semmler et al. (2020) assessed the contribution of the AWI Climate Model (AWI-CM) to the 6th phase of the "Coupled Model Intercomparison Project" (CMIP) in detail and showed that the AWI Climate Model outperforms the CMIP5 multi-model average in representing atmospheric quantities such as winds or temperature, especially in the Antarctic. Nonetheless, biases remain compared to observations. A comparison of the simulated winds in the AWI-CM used to force the ocean-only model simulations in this study to the ERA5 reanalysis between 1990 and 2009 (Hersbach et al., 2023) reveals that the average winds in the AWI-CM are too strong over the Weddell Sea (Fig. 1 below). Further, a comparison of the simulated average sea-ice concentrations between 1990 and 2009 in FESOM1.4 to the NOAA/NSIDC Climate Data Record of passive microwave sea-ice concentration (Meier et al., 2021) reveals that the average sea-ice cover is too low throughout the Weddell Sea, in particular in the open ocean in the northwestern Weddell Sea near the Antarctic Peninsula (up to 25% too low; Fig. 2 below). Acknowledging a negative bias of similar magnitude on the southeastern Weddell Sea continental shelf (possibly facilitated by too strong offshore winds in the area, see Fig. 1 below), average sea-ice concentrations are overall better simulated on the southern continental shelf than in the open ocean.

In the revised manuscript, we have added the following sentence to the method section:

"Semmler et al. (2020) showed that the AWI Climate Model outperforms the CMIP5 multi-model average in representing atmospheric quantities such as winds or temperature for the period 1985-2014 in the Antarctic. Compared to ERA5 reanalysis (Hersbach et al., 2023), simulated near-surface winds in the AWI Climate Model are overall stronger in the Weddell Sea. "

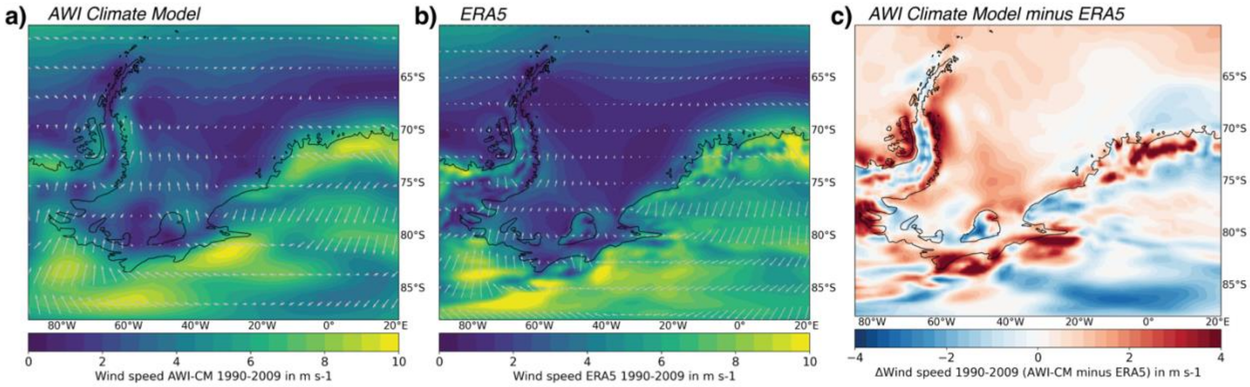

Fig. 1: Averaged near-surface winds between 1990 and 2009 in a) the AWI Climate Model used to force the ocean-only model experiments in our study and b) ERA5 (Hersbach et al., 2023). Colors denote the average wind speed, and wind direction is shown by the grey arrows. Note that the wind direction is not shown for every available grid cell to enhance readability of the figure. c) Difference in wind speed between panel a) and b).

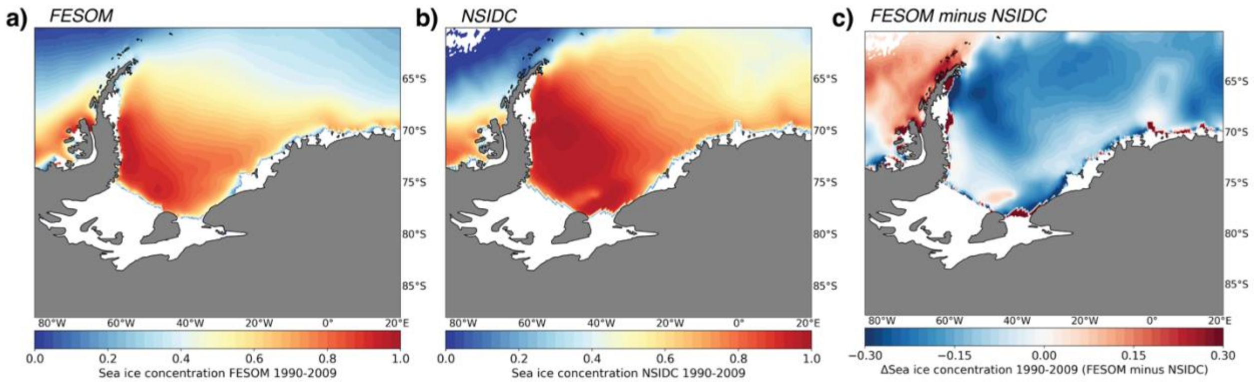

Fig. 2: Average sea-ice concentration between 1990 and 2009 in a) FESOM used in our study and b) the NOAA/NSIDC Climate Data Record Version 4 (Meier et al., 2021). c) Difference in sea-ice concentration between panel a) and b). Fields were interpolated to the same regular mesh for better comparability, note the unrealistic interpolation artefacts near the ice-shelf front in all panels.

What is fidelity of the ocean circulation? Can you show a comparison with some data, in particular with velocity- if available?

Evaluating ocean circulation at high latitudes is still difficult due to the scarcity of observations, especially on and near the Antarctic continental shelf. Reeve et al. (2019) report volume transports based on Argo floats across a variety of transects in the open-ocean Weddell Sea. Overall, in comparison to these data, the simulated volume transports in FESOM1.4 are biased low. The average inflow across the prime meridian in the eastern Weddell Sea south of 65°S amounts to 5.6 Sv in FESOM1.4 (based on monthly-averaged velocity fields 1990-2009), which is lower than the inflow suggested by the float data (17±3 Sv). We note that substantial seasonal variability in the inflow has been reported based on ship-based data (2-24.4 Sv; Cisewski et al., 2011). In FESOM1.4, in agreement with these observations, the inflow is strongest in winter (June-August), when it amounts to 11.8 Sv. Similarly, the outflow in the northwestern Weddell Sea west of 45°W is strongest in winter when it amounts to 17.4 Sv (1990-2009). Averaged over the whole year, the simulated transport in FESOM1.4 amounts to 10.9 Sv, i.e., just below the range indicated by the float-based observations (18±6 Sv; Reeve et al., 2019). North of the Weddell Sea, the simulated transport across Drake Passage between 1990 and 2009 lies within the range suggested by an observation-based estimate (Donohue et al., 2016; Fig. 3 below). In the revised manuscript, we have included information on the evaluation of simulated velocities in the method section (also in response to a comment by reviewer #1):

"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."

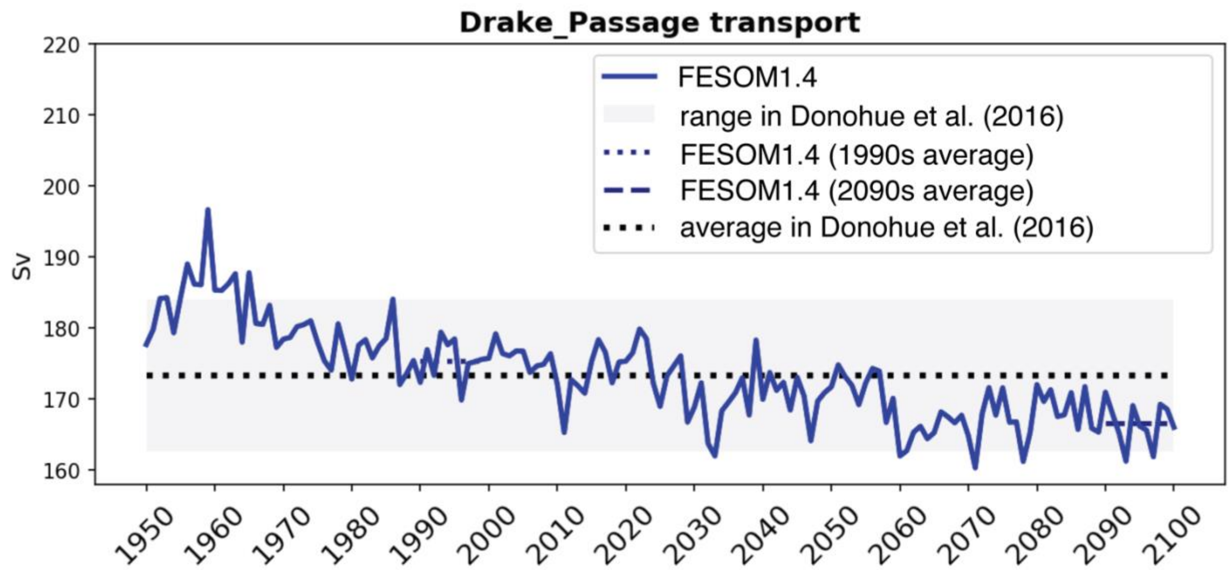

Fig. 3: Water-column integrated transport across Drake Passage in FESOM1.4 (historical + SSP5-8.5 scenario) in blue as compared to an observation-based estimate for the period 2007-2011 from Donohue et al. (2016). The dotted black line and the grey shading represent the mean and range of the observation-based transport, respectively.

The model has some 5km resolution, so if the particles are advected with daily (mean, snapshots?), the structure of the mesoscale is lost. Does that matter? What is the advection time step?

In our experiments, the Lagrangian particles are advected with a time step of one hour using daily-averaged velocity fields from the model (see methods of the paper). In agreement with the reviewer, we acknowledge that by using daily-averaged model output, some structure of the mesoscale is not resolved by the velocity field underlying our Lagrangian experiments. The effect of not fully resolving the mesoscale on the results cannot be quantified without further model simulations to store the simulated velocity fields at higher frequency, for which we unfortunately do not have the computational resources. However, we note that all Lagrangian experiments in our study are likely affected in a similar way by this shortcoming. Assuming that the projected long-term change in the mean current field outweighs any change in shorter-term variability, the impact of not fully resolving the mesoscale on the results presented in this paper are therefore probably small.

In the revised manuscript, we have included a statement on this in the limitation section:

“Lastly, by using daily-averaged velocity fields to advect Lagrangian particles, we acknowledge that the mesoscale is not fully resolved. Yet, as all of these points can be expected to impact both time slices in a similar manner, we assume the qualitative results of our study to only be marginally affected by these limitations.”

Section 4. I would probably move it to section 2.1, as part of the model setup. Your statements here suggest that open ocean convection is not important in the Weddell Sea, and the z - levels make a downslope current unlikely. So how do the particles get deeper? Is it simply flow along isopycnals? Or are they advected across density fronts (see comment above)? Can you provide a plot that shows some of particle trajectories in a vertical plane?

In our Lagrangian experiments, particles are advected with a 1-hourly time step using the resolved velocity fields from FESOM1.4, meaning that particles can only get deeper (shallower) when the model resolves a downward (upward) movement in the vertical velocity component. As illustrated by the example trajectories shown in Fig. 4 and Fig. 5, particles are often advected across isopycnals while moving upwards or downwards. At the same time, other particles moving downward show little change in density along their respective trajectory (Fig. 4), demonstrating the existence of downslope currents along isopycnals despite using a z level coordinate in the model. Lastly, while we appreciate the reviewer's suggestion on the location of the limitation section, we have decided to keep the section at its current location in the manuscript.

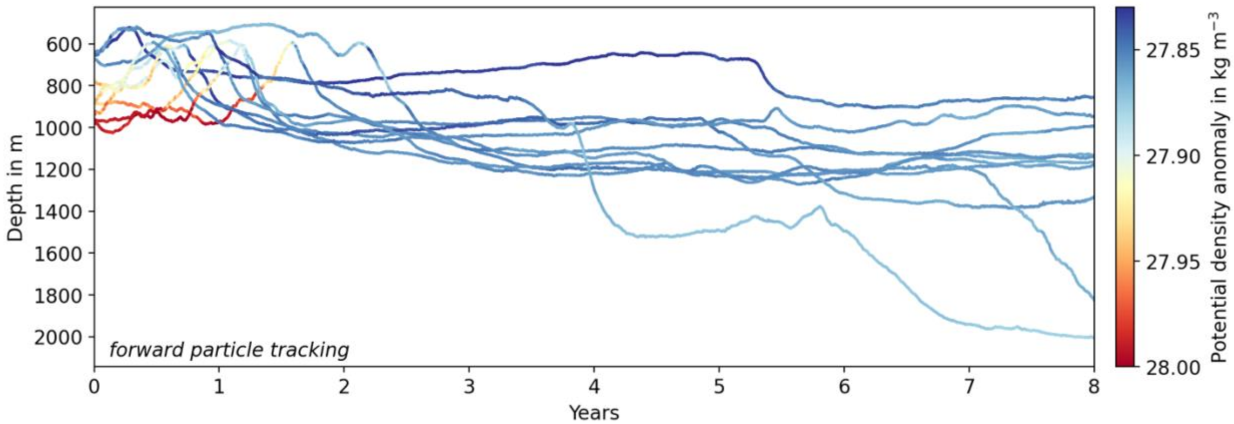

Fig. 4: Ten randomly-chosen example trajectories as a function of depth from the present-day time slice of the forward particle tracking experiment. Trajectories are colored as a function of the potential density anomaly along their path.

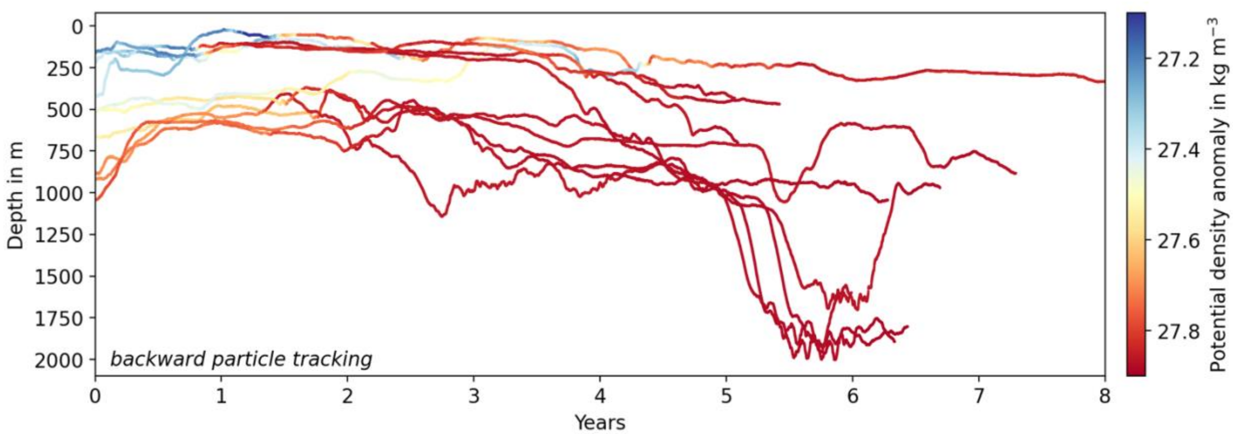

Fig. 5: Ten randomly-chosen example trajectories as a function of depth from the future time slice of the backward particle tracking experiment. Trajectories are colored as a function of the potential density anomaly along their path.

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