

Review of Hutchinson et al. “Improving Antarctic Bottom Water precursors in NEMO for climate applications”

Reviewer: Xylar Asay-Davis

I wish my name to be relayed to the authors, as I feel I am always a better reviewer when I am not anonymous and I encourage others to consider reviewing non-anonymously whenever they feel able.

General Comments:

This paper presents two 1-degree NEMO simulations, one with closed ice-shelf cavities and another with open cavities for the three selected ice shelves: Filchner-Ronne, Ross and Larsen C. The authors validate the simulations using gridded climatological data, CTD sections and satellite-derived products. They show that the simulation with three open cavities (“Open”) leads to important improvements in water mass properties compared with the reference simulation without any open cavities (“Closed”). They propose that the configuration they present is an important stepping stone toward full representation of Antarctic ice sheet-ocean processes in a coupled Earth system model (ESMs), and that NEMO is an especially good model for this work because it is used in several ESMs.

The paper was a pleasure to read, is well organized and makes a strong argument for why the inclusion of open cavities could significantly improve ESMs. I enjoyed the writing style of the introduction in particular: I found it to be far less dry than typical introductions because of the lighter and more literary writing style.

I have some minor recommendations for improving the paper, as I will go into in more detail in my specific comments and formatting suggestions below. I want to comment more generally on four of them here. First, I suggest including some discussion of the lack of tides in this model configuration, as the higher resolution NEMO configurations that you compare to seem to all include tides (or compare configurations with and without tides, finding that configurations with tides are better). Does this configuration include any attempt to capture the effects of tides on melting/freezing below ice shelves, given that tides aren’t modeled explicitly? Could you speculate on what the effects might be if tides were included, and comment on the feasibility of including tides in global ESM simulation with NEMO?

Second, and somewhat related, I think there is a little too much reliance on the namelist options provided in the Zenodo link for the model configuration. That file is 6 GB, which makes it quite a monster to download for a model developer that is interested in knowing more details about your configuration. The Zenodo package is wonderful for a NEMO developer interested in reproducing your work or using it as a stepping stone for future work. But it is considerably less helpful for developers of other models that might just want to know a bit more about what parameterizations and parameters you are using. For one, we may be unfamiliar with NEMO’s namelist options. I took a look and I didn’t find it super easy to wade through. The namelist filenames (namelist_ref and namelist_core_ia_cfg) don’t make very clear which is “Open” and which is “Closed”. Diffing the namelists show hundreds of

differences, making it hard to know which are relevant. All this is to say that I think some more details (e.g. in a table or in the supplementary information) would go a long way.

Third, this may just be my ignorance but isn't Amery also thought by some in the community to be a major source of AABW? This may just be an area where I'm out of touch but I think I recall hearing several talks that made this claim over the years. In the literature, what I'm able to find is Williams et al. (2016), which seems to suggest that it isn't as major a player. In any case, it might be worth including a little more explanation about why Amery was not included even though it's a larger ice shelf than Larsen C (60,000 km² vs. 46,000 km² according to Rignot et al. 2013). Maybe that explanation is simply that you deemed it to be less relevant to AABW productions than the three cavities you included. In the conclusion, you mention that Amery along with Riiser-Larsen and Fimbul would be candidates for inclusion as a next step, so I think it might be worth saying a bit more about why they weren't included yet here.

Finally, all the figures in this paper have some gray artifacts along the boundary. In most figures (e.g. Fig. 1), these show up as if the panels have white backgrounds but they are on top of an overall figure with a gray background. In some figures (Fig. 6, 7, 8 and S5), there appears to be a dotted gray boundary around the figure. All of this should be cleaned up for final publication. I don't think this is my viewer, as I used several viewers and see the same issues.

I hope my comments are helpful to you in revising the paper. I feel it is in good enough shape that I do not need to review it a second time and will be happy to leave it up to you and the editor to decide which of my comments to address.

Specific Comments:

l. 18, 305, 308, 315, 317, 321 and perhaps elsewhere: You use "melt rates" to describe quantities in GT/yr that I would refer to as "total melt fluxes". Perhaps this distinction isn't well established in the community but to me a "melt rate" is in m/yr (or could be in kg/m²/s) and a "total melt flux" is in GT/yr.

l. 44-45 and 128-130: Is your conclusion that the Amery region is not a major contributor to AABW? As I said, I may be a little out of touch with the latest literature there but I had a sense it was considered another contributor.

Fig. 1: Very nice figure!

l. 159-160: "...we decide to scale horizontal eddy viscosity south of 65°S according to grid cell size." Can you say more about this? What form of eddy viscosity are you using (Δx^2 , Δx^4 , something else?)? Does the viscosity scale linearly with the grid-cell size or some other way?

l. 164-165: I think it's probably necessary to expand these 3 acronyms: ETOPO2v2, IBSCO and TEOS-10.

I. 168-170: “For more information regarding the choices of advection and diffusion schemes, mixing coefficients, and eddy parameterizations, please refer to the copy of the namelists provided in the accompanying data repository.” As I mentioned in my general comments, I don’t think this is sufficient or very accessible. Could you spend a paragraph here or in the supplementary information (and perhaps including a table) describing each of these in a little more detail for a non-NEMO expert?

I. 182-184: “For the reference “Closed” cavity configuration, a fixed freshwater flux corresponding to the volume of basal meltwater estimated by Depoorter et al. (2013)...”: You say later that the melt fluxes from Depoorter et al. (2013) are lower than other satellite-derived estimates of melt fluxes and call them into question. It might be worth mentioning why you chose to use these as opposed to newer estimates (e.g. Adusumilli et al. 2020). Maybe these were available from previous work by Mathiot et al. (2013) so it was more convenient? That’s an acceptable explanation if that’s what happened.

I. 184-185: “...for each ice shelf is added into the ocean evenly between the ocean floor and the base of the ice shelf at the location of the ice shelf front...”: I believe this is the case but can you explicitly state if the melt flux is also uniform horizontally along the calving front? From this sentence, it was only clear to me that it is vertically uniform.

I. 190: “the temperature, salinity and velocities are averaged over a fixed boundary layer thickness of 30m...”: Could you say how the 30-m thickness was chosen?

I. 191-193: If you make a table with other model parameters as I suggested above might be a good idea, please move these 3 parameters to the table for easier readability.

I. 206: Did you use CORE interannual forcing because it was more convenient than more up-to-date alternatives like JRA? If so, that’s fine but it’s probably worth stating.

Sec. 2.3: I’m not sure if this is the right place or the previous section but somewhere here I think you need to have a discussion about not having tides here and any parameters that were used to mimic or parameterize tides in the ice-shelf flux calculation.

I. 213-214: “For all simulations, global ocean properties were initialized using the 1981-2010 climatology of World Ocean Atlas 2013 (WOA2013; Locarnini et al., 2013; Zweng et al., 2013).”: Later on, you compare to WOA18 for validation. So it seems odd to initialize with WOA13. Perhaps this was convenient because it had been used in previous studies. If so, please state this.

I. 214-230: I really appreciated the care you took in this process. I know from my own experience how tricky choices can be about initializing these cavities and this seems like a simple but very clever and effective method. Thank you for providing these details.

Fig S2: Is this showing the Open or Closed simulation?

Formatting, Typographical and Grammatical Suggestions:

I. 18 “36 + 7” and “112 + 22” should be “36 ± 7” and “112 ± 22”

I. 26-30: Maybe EGU sphere gives guidance on these plain language summaries. I did a quick search and didn't find anything helpful. My sense would be that the terms “lower limb”, “salinity bias” and “water mass” might be too specific to oceanography to count as “plain language”. Maybe these can be reworded?

I. 62: I would change the word “valuable” to something a little less subjective.

I. 95 and 618: This is obviously a stylistic choice but I think references to “the authors” are a little strangely indirect, and I would suggest just using “we”.

I. 96 “Then, work needs to be done...” (a comma after “Then”.)

I. 127: “We choose to keep all other ice shelves closed...” I would change “ice shelves” to “ice-shelf cavities”.

I. 128-129 “RIS, FRIS and LCIS were chosen due to their role in the formation and setting of properties of the parent waters of AABW...” I would suggest rewording “setting of” to something like “influence on”.

I. 132: “geometry, as coupling can introduce...” (a comma after “geometry”).

I. 153: “For this study version 4.2 of NEMO is used...” I suggest active voice – it reads much better and gives credit where it's due: “For this study, we use version 4.2 of NEMO...”.

I. 166: “...absolute salinity, which, for the purposes of this study, were converted to...” (3 missing commas).

I. 181: “Results from two configurations are presented here...” Again, a great opportunity for active voice: “Here, we present results from two configurations...”

I. 182: “...prescribed in a way to mimic the ice-shelf overturning...”: “to mimic” should probably be “that mimics”.

I. 223-225: “[−2 °C and 34.76 for FRIS (Janout et al., 2021), −1.95 °C and 34.74 for LCIS (Nicholls et al., 2004; Hutchinson et al., 2020), and −1.94 °C and 34.76 for RIS (Bergamasco et al., 2003; Budillon et al., 2003)].”: A pet peeve of mine (and I will admit a losing battle) is nested parentheses. I'd ask you to consider using square brackets for the outer parentheses here. Regardless, you are missing a second end parenthesis or bracket.

I. 234-236: “To assess the existing biases in the representation of dense water properties in NEMO v4.2 eORCA1 standard configuration (“Closed”), **we compare** full depth temperature versus salinity plots along with bottom temperature and salinity ~~are compared with~~ World

Ocean Atlas (WOA 2018)": Again, my preference for active voice.

I. 237: "Weddell and Ross Seas, respectively": comma after "Seas"

I. 242: "(Figs. 2a and 2b)": I think this should be "(Figs. 2b and 2c)"

I. 248: "...in the model output (ISW box Fig. 2d), as in this...": comma before "as"

I. 261: "...CTD results from Hutchinson et al. (2020; **their** Fig. 3b), we find the Closed configuration to be too saline...": comma missing before "we" but also I think you must mean "their Fig. 3b" since Fig. 3b in this paper shows temperature, not salinity, and doesn't seem to be relevant to this discussion.

Figs. 2 and 3: I found that the resolution of these figures was too low to be able to see important details in the T-S diagram panels. The text labels on density in these panels are also too small to be readable (even with zooming on my tablet).

I. 287: "...there is no ISW in this standard configuration, as there is no explicit model representation...": comma after "configuration"

I. 315: "melt rate for RIS, while ~~being~~ higher than observational studies...": reads better without the word "being"

I. 344: "Opening the sub-ice shelf cavities in eORCA1 allows for the establishment of...": comma should be removed before "allows".

I. 356-358: "Comparatively warm and salty HSSW enters via the Ronne Depression, circulates from west to east, **melts** the base of the ice shelf mostly along the grounding line (cold, fresh signatures in Figs. 5c and 5d), and exits via the Filchner Trough as ISW.": I think you might want "melts" rather than "melting" but it might be fine either way.

I. 362-363: "It is therefore encouraging that eORCA1 captures these, as they could play an important role...": comma needed after "these".

Fig. 5: This figure needs to be higher resolution to be able to make out the size and direction of the arrows in the quiver plot.

I. 373: "Here, we notice a strong anticlockwise circulation..." comma needed after "Here".

I. 376: "...far east (Fig. 5g), which is not seen..." comma needed before "which".

I. 377: "...speeds are extremely slow.": I would use something less subjective than "extremely slow" here.

I. 402-403: "...be seen in the volumetric T-S plot (supplementary material Fig. S1a), where explicit ocean-ice shelf interaction...": comma needed before "where".

I. 408: "...conditions in the west, where in the reference run HSSW..." comma needed before "where".

I. 428: "...using PAGO, a ~~pre-existing~~ tool to analyze gridded ocean datasets (Deshayes et al., 2014)." I would take out the word "pre-existing" since the citation makes it clear that you didn't write this tool yourselves.

I. 438-439: "While the model struggles to capture the coherence of this sub-surface temperature maximum, the counterclockwise circulation cell **set up** on the central continental shelf in the open cavity...": "setup" should be "set up".

I. 443-445: "...while we cannot directly compare with the simulation output as the CORE forcing ends in 2009, ~~evidence for~~ the presence of a tongue of ISW focused on the western bank of Filchner Trough is evident in Fig. 3 of Janout et al. (2021)...": redundant "evidence for...is evident".

I. 483: "...both on the continental shelf adjacent to FRIS, where the depth of the base of the mixed layer...": comma needed after "FRIS".

I. 517-518: "But the question remains regarding the transfer of these now more realistic dense shelf waters offshore, to feed the globally important AABW...": No comma is needed after "waters".

I. 519: "...is too short to explore the impact of these changes far afield...": Neither hyphen is needed in "too short" and "far afield".

I. 524: "The thermohaline and ~~velocity~~ **salinity** cross sections of Filchner Trough...": This panel shows salinity, not velocity.

I. 538-541: "A cross section of the Challenger Trough (Fig. 9), reveals depth-varying thermohaline changes as opening the sub-ice shelf cavity has allowed for the water adjacent to the ice shelf to advect into the cavity leaving the bottom properties here slightly warmer, while the layer immediately above experiences cooling and salinification due to the outflow of ISW driven by the ice pump (Fig. 9c)." This is a lot to try to follow in one sentence. Maybe break it up?

I. 619: "...compare the model simulations with local ~~in-situ~~ observations...": "local" and "in situ" mean the same thing in this context.

I. 626-627: "Antarctic ice shelves and, while they are responsible for the formation of the majority of the parent waters of AABW, interactions with...": comma needed before "while".

I. 627-628 "...interactions with remote unresolved ice shelves **are** missing..."

All your references: You seem to have the publisher listed instead of the journal title. Also, one reference is in a weird typewriter font (but I guess the typesetter will fix that).

Figs. S3 and S4: I found it a little confusing that you used the same cmocool colormap for percentage and m/yr of ice production that is rightly used for depth in Fig. S2. Maybe use different colormaps for these other fields? “amp” or “matter” could work for a percentage, my group has used “dense” for sea-ice production but “ice” might also be appropriate.

Fig. S5: “Density” should presumably be “Density difference” and “kg/m3” should be “kg/m³” (superscript).

S1: I appreciated this discussion, though I agree that it was appropriate for the supplementary information. The comparison with observations is nuanced enough to be a little messy and the conclusion is that Open and Closed both have large biases, with neither clearly more realistic. So it does not refute, but neither does it really support, the main conclusions of the paper.

I. 1002-1003: “It is hard to conclude on more or less realistic polynya activity in the Open simulation.” I would suggest rewording this as “It is hard to conclude whether the polynya activity in the Open simulation is more or less realistic than in Closed”.

References

Williams, G., Herraiz-Borreguero, L., Roquet, F. *et al.* The suppression of Antarctic bottom water formation by melting ice shelves in Prydz Bay. *Nat Commun* 7, 12577 (2016). <https://doi.org/10.1038/ncomms12577>