The Cryosphere Discussions

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Reply on RC1

Martin Mohrmann et al.

Author comment on "Southern Ocean polynyas in CMIP6 models" by Martin Mohrmann et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-23-AC1, 2021

Reply to reviewers comments on “Southern Ocean polynyas in CMIP6 models”, submitted to The Cryosphere by Martin Mohrmann, Céline Heuzé and Sebastiaan Swart

We thank both reviewers for their careful reading of our paper and the proposed improvements. We are convinced that the additional clarifications will increase the readability and scientific value of our paper. Here, we are addressing the comments of anonymous reviewer 1. We acknowledged the importance of the reviews in the acknowledgment section:

“We thank the anonymous reviewer, Carolina Dufour and Rebecca Beadling for their comments, which greatly helped us improve the quality of our writing and frame the presented research in a wider scientific context.”

- **Comment from Anonymous Referee #1 and our responses**

This manuscript examines the representation of polynyas in CMIP6 models as compared to observations. Some of these comparisons are not straightforward, due to lack of CMIP model variables, limited observations, and the different metrics that could be used to define polynyas, but the authors are transparent in these limitations and convey the information clearly. Modelled coastal polynyas are often too large, likely as a result of coarse horizontal resolution. Modelled open water polynyas are often too small compared to observations, and there is a large inter-model spread in the frequency of open water polynyas. The authors examine vertical ocean profiles in polynyas versus sea ice covered regions in a subset of the models and in float data. The Discussion contains a number of useful insights on the reasons behind the intermodel variation in polynya activity, relating to resolution, simulation of the ACC and overflow parametrizations.

I found this to be a very interesting and thorough paper. It is well within the scope of TC and presents novel results and conclusions. The methods are clearly explained and the analysis code has been made publicly available. It is generally well-written, apart from some of the latter sections, and the figures and tables are appropriate. I am selecting ‘major revisions’ only because of section 5.2, which I think would benefit from a second round of reviews.

1.1 Main comments

Section 5.2 - I found the arguments here a bit hard to follow. I would like to see additional subplots for the other relationships discussed here added to Figure A6. As you mention the results from this section in the abstract and conclusions, the figure should also be brought into the main paper. It seems like the results here would be interesting to a wide audience, so I think it is worth spending some more time on the presentation.

☐ Thank you for this suggestion. We added the discussed relationships to the Figure A6 and brought it into the main paper. We also added some additional explanations to Section 5.2.

Section 4.3 or Section 2.3 - Please give some more details on the domain of the SOCCOM float - e.g. time period, number of profiles etc. Please also describe how you extracted the profiles from the CMIP6 models - is this one profile per grid cell in the Weddell Sea region? Is there some time averaging?

☐ We agree that this information was lacking and have now added a more detailed description of our method:

"We concentrate on the models that form most OWPs (see Table 2) and show only the top three models (MPI-ESM1.2-HR, ACCESS-ESM1.5, BCC-ESM1) in Fig. 10. For comparison, we present the observed hydrographic data of a SOCCOM profiling float (Johnson et al., 2018), which was deployed in January 2015 and surfaced two times in the Maud Rise Polynya in winter 2017 (Campbell et al., 2019). To provide regionally and seasonally comparable data sets for the models and the profiling float, we chose to extract vertical profiles during the month of September from within a rectangle around the profiling float trajectory (see Campbell et al., 2019) with the edge coordinates 61°S-66°S, 0°E-6°E in the Weddell Sea. This region includes the northern flank of Maud Rise, where we found OWPs to be most common (Fig. 3, A3, A4).

For the SOCCOM profiling float, we use the information provided in Campbell et al. (2019) to differentiate vertical profiles when the float surfaces within an open water polynya from those sampled under the sea ice. For the models, we use our algorithm to differentiate and group the grid points by whether they are within an OWP or not. Based on this criteria, we extract and group the vertical salinity and conservative temperature profiles (monthly) and plot them in either blue (under sea ice) or red color (OWP) in Figure 10."

L329: 'To evaluate the effect of OWPs on vertical stratification' - 'To evaluate vertical stratification in OWPs' (also L371) - as there isn't a clear cause and effect relationship here.

☐ Changed as suggested

Conclusions - I would like to see more of the polynya statistics summarised here. This could work well as a bulleted list.

☐ Our conclusions now start with a bullet list summarizing important polynya statistics and findings:

"In this paper, we evaluated the representation of Southern Ocean open water and coastal polynyas in CMIP6 climate models and their effects on the modelled Weddell Sea. We found that:

- All 27 analysed models have coastal polynyas around the Antarctic continent, while OWPs are present in only half of the models
- CMIP6 models show OWPs most commonly in either the Weddell or the Ross Seas
- The position of polynya formation is very similar for models of the same family and

likely determined by the model properties
- In comparison to observations, nine models underestimate polynya areas based on thickness threshold but overestimate them if based on concentration threshold method
- Coastal polynyas in CMIP6 have a large annual variability of at least a factor of 2.5
- With total polynya areas from 6.5 x 10^3 km2 up to 215 x 10^3 km2, CMIP6 models show a large intermodel spread"

1.2 Minor comments

L8 'presence or absence of OWPs are' > 'presence or absence of OWPs is'

☐ changed as suggested

L12 'that require to be addressed' > 'that should/must be addressed'

☐ changed to "should be addressed"

L30 requires citation

☐ added required citation (Tamura et al, 2008)

L85 Suggest adding a sentence on uncertainty in SIC observations

☐ Added as suggested.

"The uncertainty in sea ice concentration is less than 4% on average (Lavergne et al., 2019)."

Table 1 - please add units on R_o and R_a (otherwise a very nice table though!)

☐ added ([km]) (and thank you for the compliment)

L101 'not good' > 'poor'

☐ changed as suggested

L134 Please describe what a 'flood fill algorithm' is

☐ We added a brief description and a citation of the used python-library.

"With the aim of detecting polynyas, we start with the sea ice concentration or thickness (Fig. 1a). To mask out the open ocean beyond the northern sea ice extent, we use a "flood-fill" algorithm from the scikit-image library (Van der Walt et al., 2014). Starting from a grid cell with no sea ice, the seed, the algorithm detects similar cells below a specified sea ice concentration/thickness and masks them out, effectively "filling them" with ice (Fig. 1b). Afterwards, a maximum sea ice threshold filter returns all grid cells that are classified as polynyas".

Fig. 3 'propability' > 'probability' on colorbar. I would also make all of the ocean dark blue (not grey).

☐ We corrected the spelling in this Figure and found and corrected the same error in related Figures.

We discussed making the ocean dark blue in all the figures of the paper. While it would improve the clarity of the Figures, there is unfortunately no (easy) consistent way to mark the ice shelves in the CMIP6 models in another color than the ocean, as these areas are not differentiated in the sea ice output. In practice that means that we cannot easily color the ocean dark blue without coloring the ice shelves and (or) continent dark blue for some of the models. We estimate making the suggested color change work for all models would take some days of work on a relatively small visual only benefit, so we would prefer to leave it as it is.

Fig. 4 - shouldn't this be 'equivalent ice thickness' not 'floe thickness'?

☐ In Figure 4 we show that the floe thickness (CMIP6 variable name: sithick) cannot be used with our algorithm and therefore, we continue our analysis with the sea ice concentration and equivalent ice thickness variables (siconc and sivol). We find this naming scheme somewhat confusing, but want to stay as close as possible to the terminology used in the CMIP6 guidelines and documentation.

Fig. 6 'All data sets where' > 'All data sets were'; 'its' full length' > 'its full length'

☐ Corrected

Fig. 8 (and similar figures in the appendix). I like this visualisation, but I wonder if you can separate the coastal and open water polynya bars and make the whole figure taller so it is easier to see?

☐ We separated the color bars for OWPs and coastal polynyas with some white space in between and made all three figures taller.

L163 - Why doesn't the mean of daily data go from 1st May to the end of Nov?

☐ During the ice melting phase in late November, observed and modeled polynyas often become an order of magnitude larger than during the winter (Figure 9). We did not want these polynyas to dominate our results. Moreover, when we provide a comparison of the maximum yearly polynya area (computed according to Eq. 2) in Figure 6 (transparent bars), these maximum values often reflect mainly the large November polynyas, and no further time averaging within the season is done. We consider a comparison between the averaged values of November (Figure 6a) and the daily values of the 15th November (Figure 6b) more accurate than including values from the end of November and comparing those with values derived from the monthly averaged data.

L334 'is resulting in' > 'results in'

☐ changed as suggested

L340 'Compared to the float data, ACCESS and BCC underestimate…'

☐ changed as suggested

L353 'deeper reaching' -> 'deeper-reaching' ?

☐ changed as suggested

L354: 'There are some profiles' - please be more quantitative

☐ changed to: About half of the profiles have a shallower and, for the MPI model, warmer temperature maximum compared to the under ice case.

L366: Define N^2 in the text

☐ changed to “the Brunt-Väisälä frequency squared (N^2)...”

Fig. 10 - Please add subplot labels (a, b, c, …) and refer to these in the main text. This will make the text easier to follow

☐ We added subplot labels and the corresponding references in the text.

L383 ‘This is consistent…’ Rephrase, it’s not clear here what you mean

☐ changed to:

“The decreased OWP activity we find for CMs in our CMIP6 dataset with ongoing global warming is consistent with the results of de Lavergne et al. (2014), in which OWPs in the Weddell Sea eventually stop at the end of the extended CMIP5 climate change runs, as the CM models show a stronger warming response than the ESM-versions (Dong et al., 2020).”

L386 ‘can usually be run’; remove ‘in our case’

☐ changed as suggested

L438 ‘All these parameters are positively correlated with OWP activity **in observations**’

☐ added as suggested

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- **Additional changes**

Changes that are not listed in this document can be found in our response to Carolina Dufour. Moreover, we received a helpful suggestion aside from the public review process, which we also want to address here. A reader of our preprint pointed out that we counted the total number of CMIP6 models in Table 2 of the cited Beadling et al. 2020 paper incorrectly, and that it would be preferable to stress which results were significant. Thank you for the corrections, we improved this part:

L436-438

Before: "However, Beadling et al. (2020) found that 30 of 35 CMIP6 models underestimated the ACC, 34 of 38 showed their wind stress curl minimum not sufficiently south and 33 of 38 underestimated the wind stress curl maximum. All these parameters are positively correlated with OWP activity (Campbell et al., 2019)"

Improved: "However, Beadling et al. (2020) found that out of the 34 CMIP6 models they analysed, 29 underestimated the ACC (of which 12 significantly), 30 show their wind stress curl not sufficiently south (5 significantly) and 30 underestimated the WSC minimum (9 significantly)"

Referenced in our responses (for further references see manuscript):

- Beadling, R., Russell, J., Stouffer, R., Mazloff, M., Talley, L., Goodman, P., Sallée, J., Hewitt, H., Hyder, P., and Pandde, A.: Representation of Southern Ocean Properties across Coupled Model Intercomparison Project Generations: CMIP3 to CMIP6, Journal of Climate, 33, 6555–6581, 2020.
- Griffies, S. (2015). A handbook for the GFDL CM2-0 model suite.
- Hasumi, Hiroyasu. "CCSR ocean component model (COCO)." (Version 4.0) (2015).
- Heuzé, C.: Antarctic Bottom Water and North Atlantic Deep Water in CMIP6 models, Ocean Science, 17, 59–90, 2021.
- Jungclaus, J. H., et al. "Characteristics of the ocean simulations in the Max Planck Institute Ocean Model (MPIOM) the ocean component of the MPI□Earth system model." *Journal of Advances in Modeling Earth Systems* 5.2 (2013): 422-446.
- Keen, Ann, et al. "An inter-comparison of the mass budget of the Arctic sea ice in CMIP6 models." *The Cryosphere* 15.2 (2021): 951-982.
- Madec, G., Bourdallé-Badie, R., Bouttier, P. A., Bricaud, C., Bruciaferri, D., Calvert, D., ... & Vancoppenolle, M. (2017). NEMO ocean engine.
- Van der Walt, S., Schönberger, J. L., Nunez-Iglesias, J., Boulogne, F., Warner, J. D., Yager, N., Gouillart, E., and Yu, T.: scikit-image: image processing in Python, PeerJ, 2, e453, 2014.