

## Response to referee comments - Referee 1

Referee comments are shown in black, our response in blue, and changes to the manuscript in red.

### Summary

A standalone sea ice model (CICE5.1.2) is used to investigate the impact of incorporating a sub-grid scale sea ice thickness distribution by coupling to the LETKF using the latest version of PDAF. The source of the ice thickness data is from monthly means of CryoSat-2. Multiple experiments are performed consisting of a control run (no assimilation), assimilation of ice concentration only (NASA Bootstrap), assimilation of ice concentration and mean ice thickness, and assimilation of ice concentration, mean ice thickness, and a monthly sea ice thickness distribution. Experiments with 100 ensemble members were performed in which ensemble spread was generated by perturbing the NCEP-2 atmospheric forcing. They find that a forgetting factor of 0.995, amplification factor of 1.5 and localization radius of 100km worked best in these studies. The authors state that this is the first time that a sub-grid scale thickness distribution product has been assimilated. The authors find that the experiment assimilating concentration, mean ice thickness and sub-grid scale thickness distribution performed best in the four thinnest sea ice categories. Comparisons were made against unassimilated CryoSat-2 observations.

I find this to be a well written paper with a thorough description of the techniques and analysis methods used. The graphics and tables are well laid out. I find that this research will be valuable to the community. I recommend publication with minor revisions noted below. General and specific comments are below.

**Response:** We would like to thank the reviewer for their time spent reviewing the paper and their helpful feedback.

### General Comments:

Use CryoSat-2 (not Cryosat-2) throughout the paper.

In the section with lines 55-60; please add these additional references for model forecast systems assimilating sea ice concentration:

Smith GC, Roy F, Rezka M, Surcel Colan D, He Z, Deacu D, Bélanger J-M, Skachko S, Liu Y, Dupont F, Lemieux J-F, Beaudoin C, Tranchant B, Drévillon M, Garric G, Testut C-E, Lellouche J-M, Pellerin P, Ritchie H, Lu Y, Davidson F, Buehner M, Caya A, Lajoie M. 2014. Sea ice forecast verification in the Canadian Global Ice Ocean Prediction System. *Q. J. R. Meteorol. Soc.*, <https://doi.org/10.1002/qj.2555>

Hebert, D. A., R. A. Allard, E. J. Metzger, P. G. Posey, R. H. Preller, A. J. Wallcraft, M. W. Phelps, and O. M. Smedstad (2015), Short-term sea ice forecasting: An assessment of ice concentration and ice drift forecasts using the U.S. Navy's Arctic Cap Nowcast/Forecast System, *J. Geophys. Res. Oceans*, 120, 8327–8345, doi:10.1002/2015JC011283.

**Suggested change in manuscript:** thank you, added additional references to model forecast systems

Papers by Massonnet et al. (2011) and Smith et al. (2022) examined the impact of a 15-category ice thickness distribution on seasonal and climate modeling studies. Please speculate on the potential impact of increasing the number of ice categories (ignoring the additional computational cost) in your

study.

Massonnet, F., Fichefet, T., Goosse, H., Vancoppenolle, M., Mathiot, P., and Knig Beatty, C. (2011). On the influence of model physics on simulations of Arctic and Antarctic sea ice. *The Cryosphere*, 5(3), 687–699. <https://doi.org/10.5194/tc-5-687-2011>

Smith, M. M., Holland, M. M., Petty, A. A., Light, B., and Bailey, D. A. (2022). Effects of increasing the category resolution of the sea ice thickness distribution in a coupled climate model on Arctic and Antarctic sea ice mean state. *Journal of Geophysical Research: Oceans*, 127, e2022JC019044. <https://doi.org/10.1029/>

If we were to increase the number of ice thickness categories in the model, it would also require the reprocessing of the thickness distribution observations, and we would like there to be a sufficient number of data points in each category for the data to be meaningful. For 15 categories this would be much more difficult and there would be little data in many of the categories. We considered a separate experiment in this study with how the assimilation effects are changed by the number of ice thickness categories. A larger number of categories can represent the ice thickness distribution more realistically, however the thickness distribution observations provided are for the chosen five categories (default in CICE). As you mention the computational cost for our large ensemble run would also increase considerably. Given these limitations we have decided to stick with 5 categories. An increase of categories would be beneficial if the observations can support this. We will add a justification in the manuscript and a discussion of the possibility of increasing categories within the discussion section.

In lines 365-370 you state that using a forgetting factor of 0.995 (Fig. 1) does not lead to any model crashing. What is the cause of spikes seen in January – May, and Oct-Dec, evident in all runs except for the control?

These spikes are caused by the ice thickness assimilation which occurs between January and April and October to December, the assimilation happens at one timestep in each month, and the updates can be large in the central ice pack where the observation errors are lower, so this can cause jumps in the thickness and volume estimates. These also occur in concentration/area/extent on the first day that assimilation of concentration takes place.

In lines 430-432 you state: “for the assimilation runs that the decrease in concentration in late August in the Fram Strait leads to a remarkable increase in the sea ice thickness at the same time in these runs.” I do not see any “remarkable increase”. Please clarify, reword, or delete this sentence.

**Suggested change in manuscript: Sentence deleted, thank you.**

Lines 537-538: I disagree that all runs with assimilation of sea ice concentration showed very similar results. I agree they are similar to Bootstrap for any given year, but not amongst themselves. Please reword this section or provide additional details to me on what I seem to be missing.

**Suggested change in manuscript: Clarified to mean that they are similar within the given year**

Specific Comments:

Line 26: “rise at roughly twice this” amount.

**Suggested change in manuscript: added quotation marks**

Line 63: A comparison of fourteen ocean-sea ice reanalyzes (provide reference)

Suggested change in manuscript: thank you, added reference

Line 95: Somewhere in this section, please provide the horizontal resolution of the CICE model used in this study.

Suggested change in manuscript: added reference to horizontal resolution where grid cell sizes are discussed.

Line 163: (Gaspari and Cohn, 1999) do not appear in references. Please add.

Suggested change in manuscript: added to references, thank you.

Line 170: Is a reference missing where I see a “?” ?

Suggested change in manuscript: reference to previous section was missing, corrected.

Line 238: Reword phrase “Grid cells In CICE-PDAF we use...” awkward

Suggested change in manuscript: removed words “Grid cells” which don’t belong in this sentence.

Line 333: “and CS2 thickness observations are assimilated monthly”. Please clarify as there are not CS2 observations available for May – September.

Suggested change in manuscript: clarified that thickness observations are not available between May and September.

Figure 2: label on top and bottom for “c” and “h” I assume should be “`assim_conc_hi_loc100?`”

As localisation of 100 km is used for further experiments in the paper, I only use `assim_conc_hi` for 100 km loc experiment here and for the remainder of the paper to

Figure 2 caption should be “Columns show CryoSat-2 and 4 CICE-PDAF runs...”

Suggested change in manuscript: Thanks, corrected.

Figure 3: Legend should be “`assim_conc_hi_amp2`” The “amp2” is missing.

Suggested change in manuscript: Figure has been corrected - see further below.

Line 450: I do not see a gold line in the legend.

Suggested change in manuscript: Should refer to black line, corrected.

Figure 6: With the exception of the control run (green), the 3 other experiments are difficult to see except for the `assim_conc_hi_4hd`. They must be very similar. Can `assim_conc_hi_4hd` be drawn first? Maybe `assim_conc` and `assim_conc_hi` will be easier to see.

Suggested change in manuscript: Will draw `assim_conc_hi_4hd` and also specify that other experiments are difficult to see as they are similar.

Line 468: Table 2 shows value of “0.62”. Which is correct?

Suggested change in manuscript: Should be 0.63 in table, adjusted.

Lines 507-508: The assimilation of only concentration does not show an increase versus the control in the first year. Please modify sentence.

Suggested change in manuscript: modified sentence to say that first year ice volume is not increased by assimilation of only concentration in first year.

Line 511: I do not see a gold line in Fig 10. Please clarify.

Suggested change in manuscript: Should refer to black line, corrected.

Line 795: Hollinger et al. reference not cited.

Suggested change in manuscript: Added to reference list, thanks.

Line 878: Zhang and Krishnamurti (1999) not cited.

Suggested change in manuscript: Added to reference list, thanks.