A review of “Regime-dependence when constraining a sea ice model with observations: lessons from a single column perspective” by Molly M. Wieringa and Cecilia M. Bitz

This paper aims to quantify the influence that assimilating different observations of sea ice can have under different sea ice conditions. The authors use a single column sea ice model and use an ensemble data assimilation to test the assimilation of synthetic observations of sea ice concentration, sea ice thickness, radar and lidar freeboard in an idealized experiment. The authors investigate the effects of the assimilation on both the aggregate sea ice concentration, sea ice volume and snow volume, as well as the thickness categories. It was found that the assimilation of sea ice thickness provides the largest, positive impact. Laser freeboard was found to be the second most impactful observation to assimilate, and unlike radar freeboard, it did not degrade the snow volume. For the different regime conditions of sea ice, the study showcases a need to carefully treat the categorized state variables when assimilating observations. The paper is well written and the methods are well described. The figures are well thought out and interpreted thoroughly for the results section.

Novelty

The main novelty from the paper is in the assessment of ice thickness and freeboard (both radar freeboard and laser freeboard) and how the assimilation affects different regimes of the sea ice. The novel approach finds a potential best-case scenario for assimilation of different types of sea ice observation. The study will provide a lot of insight for those interested in sea ice data assimilation, and particularly for the assimilation of thickness and freeboard, which is an emerging field of study in sea ice. A key result showed that summer and early autumn assimilation of SIT shows strong skill in reproducing the true sea ice state, summer SIT observations were only first produced a few years ago, and their benefit in data assimilation and sea ice studies has not yet been fully explored. The study also provides insight into comparison of freeboard and thickness assimilation and interestingly shows that freeboard assimilation may be less effective than SIT assimilation. The insight into the effects of the assimilation of different observations on the sub-grid scale categories of the state variables is interesting for those interested in implementing sea ice data assimilation themselves, particularly in the implementation of sub-grid scale thickness assimilation.

General Comments

Were any specific criteria chosen to determine locations of the pack, seasonal and first year sea ice i.e. in terms of sea ice concentration or sea ice age (e.g. 0.8 commonly being used to separate pack ice from seasonal ice). Alongside this, a map clearly showing the

locations of the three defined types of sea ice (pack, seasonal, first year), which are described in the first paragraphs of the results section, would be beneficial.

Could the authors provide details of how the nonphysical modeled values in the state vector are post-processed after the assimilation, when they occur?

The discussion (or conclusion) could be further enhanced if the paper outcomes were compared to real world available observations. For example the authors find that summer and late autumn observations are key, and that SIT observations have the most impact. However they do not then reference to Landy et al., 2023 (although it is listed in the references, I could not find it referenced in the paper itself). This could be done for other observations also, which would increase the papers usefulness and insightfulness for others in the field.

Figures

For figure 2, the ticks for the top 2 rows of figure and the bottom rows are different, and the labels are only shown on the bottom row, the authors could make the x-axis ticks consistent between all the figures, so that the figure is easier to read.

The authors should add panel labels to the figures and each subfigure, which would allow easier reference to them in the text. On line 211 they refer to figure 4 panel labels but the labels do not exist in the figure.

Minor Comments

Line 9: DA is not defined yet.

Line 34-35 add references to SIC assimilation papers

Line 77 add references to mushy-layer and delta-eddington scheme

Line 141-142 confusing wording/sentence – seems like a list is introduced but then not continued.

Line 167 missing word “table”

There are a number of references which appear in the references list which do not seem to be cited in the paper e.g.:

Brennan and Hakim, 2022, Chen et al., 2024, Holland & Kwok, 2012, Landy et al., 2023