Dear Editor and reviewers,

Please find below our responses to the two anonymous referees' comments on the paper entitled "Estimating Parameters in a Sea Ice Model using an Ensemble Kalman Filter" by Yong-Fei Zhang et al. submitted to The Cryosphere. We would like to thank Editor Petra Hell for coordinating the review process and the reviewers for giving valuable comments and suggestions generously, especially in this difficult time. We have made revisions carefully according to your reviews. Please see detailed responses below. Questions and comments from the reviewers are listed in Italic and our responses are in bold.

Sincerely,

Yong-Fei Zhang

Interactive comment on "Estimating Parameters in a Sea Ice Model using an Ensemble Kalman Filter" *by* Yong-Fei Zhang et al.

Anonymous Referee #1

Received and published: 4 July 2020

This study utilizes a perfect model study with the sea ice model CICE5 and a Ensemble Kalman Filter in order to demonstrate the usefulness of varying a selected parameter. In this case the Snow grain size (Rsnw). The study investigate both a constant Rsnw and a Rsnw that varies in spaces. The spatially varying Rsnw improves the results near the sea ice edge but degrades the results in the central Arctic.

Results are based on a series of 18 month experiments that includes a data assimila- tion period of 6 month during summer as Rsnw only influences the results here.

A general note is that studies like these is valuable for calibration purposes, however with a model like CICE that is very complex it can be hard to extract one parameter and calibrate this without calibrating the entire model. This nicely outlined put in from line 215 to 220 where the author describes a potential less obvious mechanism that causes a slightly unexpected result.

The study is conducted as a perfect model study which means that all state variables are available and the truth is known. Can this be transferred to a real observation? I would like to see some comments about this as for instance ice thickness based on altimetry is not available in summer, which is the period chosen for the calibration.

With some minor corrections I find the study worthwhile for publication.

I would like the authors to check the figure references as they seems to point to wrong figures from time to time. Especially in the description of figure 3.

Thanks very much pointing it out. The figure references have been corrected.

Abstract : I would like a comment on the variation of Rsnw vs the constant.

We've added a comment on the results from the spatially varying Rsnw experiments in the Abstract.

Relaxing the requirement that the estimated parameter be the same everywhere has benefits along the sea ice edge but degradations in the central Arctic, suggesting that spatially varying parameters will likely improve PE performance at local scales and should be considered with caution.

Line 39. Despite DA being a normal acronym for data assimilation I would write it in full potentially adding the short version. One should be able to read the abstract without reading the rest in order to find acronyms.

Thanks for the comment. We have spelled DA out.

Line 64: Calibration of the none model state parameters are still calibrated in order to improve model state (in this case ice concentration ice thickness). I would rephrase this a bit.,

We particularly refer parameters to those tunable parameters in the parameterization schemes, not model state variables. To clarify the point, we've changed 'the parameters in the sea ice component' to 'the parameters in sea ice parameterization schemes'.

Line 80: The aim is to improve sea ice forecast all year (I would assume) but the parameter that is chosen is active in summer therefore it makes sense to focus on summer. A slight reformulation is desirable.

By targeting summer we mean the DA experiments are done in summer but the forecast is for the full year. To make it clearer, we rephrase the sentence to 'we conduct DA experiments with PE in summer'.

Line 108. I assume that this is only Rsnw that is updated beside the state vector. This is mentioned later but I would like it to be here.

Thanks for the comment but we think it's fair to use general terms here since we are introducing the DA framework. The details of our experiments including the parameter to be tuned are described in Section 3.

Line 127 – 164: I think that it would make it easier to read if you start describing the free run, then the data assimilation runs (constant Rsnw), and at last the experiments with varying Rsnw (either spatially constant or spatially varying).

Thanks very much for the comment. We agree that it's clearer to describe experiments this way. We've modified the paragraph accordingly.

Line 185 RAB?

The typo is corrected. Thanks.

Line 192. How does figure 1b show the positive increment of Rsnw? Is it 1c? Line 238 Is it Figure 3a and 3d?

Sorry for making the confusions. All figure references are corrected.

Linr 253 Any explanation for the ice thickness? This is lacking a bit.

Thanks for the comment. We've added the following discussion on the SIT DA results.

Besides the improvements along the sea ice edges, the SIT DA also has benefit in the inner ice pack (Figure 3e), which is consistent with the results of the first pair of experiments that

SIT in general provides more information than the SIC observations, especially in the regions where SIC has little variability. However, spatially varying R_{snw} has small advantages over spatially invariant R_{snw} in the ice marginal regions but degradations in the central Arctic too (Figure 3f).

Line 347. Is this a report? Can it be found?

This refers to the CICE5 documentation. The reference has been corrected.

Table 1: Two different RMSE's are defined in section 2. Which one is referred to here. Figure 1 The classical ice concentration/volume annual time series. The problematic part is that the variation from summer to winter is much larger than the variation be- tween ensembles, truth and mean which is the interesting part. I think that it would make sense to normalize with the truth. I don't see the green line in the legend of c.

Yes we defined two RMSEs, one calculated over time and the other over space. The one calculated over time does not generate a spatial map so we dropped the subscript of $RMSE_s$ to clear up the confusion.

Thanks for checking the figure caption. Yes there's no green line, we've corrected the caption.

As for Figure 1, we thank the reviewer for kind suggestion but we think that the original plots are intuitive to show how Arctic sea ice area and volume evolve with season and it's straightforward to compare the true member with the rest of the ensemble members.

Interactive comment on "Estimating Parameters in a Sea Ice Model using an Ensemble Kalman Filter" *by* Yong-Fei Zhang et al.

Anonymous Referee #2

Received and published: 22 July 2020

Based on the OSSE framework, this paper extends the functionality of DART/CICE to do parameter estimation through the EAKF as well as updating the model states, and explored these impact on the simulation as well as the prediction of Artic sea ice. This study is systematic and well organized. However, I have some questions:

1. To avoid inconsistencies with the rest of the parameterization scheme, Rsnw is selected to be adapted via DA in this study. However, the snow conductivity is also important as mentioned in the introduction (Line 76). Why not tune snow conductivity through DA? In addition, Urrego-Blanco et al. (2015) suggests the interaction between Rsnw and snow conductivity, and how to consider this interaction in DA?

Our study aims to demonstrate the feasibility of converging the ensemble of a parameter to its true value via sea ice data assimilation. We agree that there are other parameters worth exploring in the sea ice model, including snow conductivity and drag coefficients that will likely increase the model ensemble spread in winter as discussed. As you mentioned, it is tricky to factor in the interaction between different parameters, we need to proceed with caution updating multiple parameters. For example, if we want to create an ensemble of the snow conductivity parameter, shall we pair it with R_{snw} for each ensemble member? If so, what's the correlation between Rsnw and snow conductivity? We believe those are interesting research questions worth exploring in our future work.

2. Although this study is based on OSSE, the simulated observations should mimic the real observations unless the goal of OSSE is to help evaluate the new observing system. To our knowledge, the large scale SIT observations are mainly retrieved from satellites, while retrieval algorithms fail in the presence of water on the ice (e.g., SMOS and CryoSat-2). Thus, it is worth discussing whether assimilating SIT observation in summer is reasonable.

Thanks for the comment. Yes the current SIT observations retrieved from satellites lack in the summer season. Other sea ice DA studies and seasonal predictability studies have suggested the importance of having SIT observations in late spring and summer, here we demonstrate that the SIT observations also provide more information for parameter estimation. Although we updated only one parameter in this study, we speculate the SIT observations would have more updates in most parameters than the SIC observations given the SIC variability is only large in ice marginal regions. So we'd like to advocate the needs of extending the coverage of SIT observations into late spring and summer, which is actually possible in ICESat-2 (Kwok et al., 2020).

3. For SIV, the bias of DAsit is less than that of DAsicPEcst until 1 July 2006 (Fig. 4b). Hence, the conclusions drawn need to be more cautious, such as "The results in the forecast period

indicate that by updating parameters as well as state variables, assim- ilating SIC observations only is comparable to assimilating SIT observations" (Lines 295-296).

Thanks for the comment. Our conclusion is only for the forecast period (from April to September) since seasonal sea ice forecasts normally won't start from winter. We agree that we need to make it more specific. We've added the forecast period in the text to clear up the confusion.

4. Rsnw increments cannot be found in Fig. 1b (Line 192). Is it in Fig. 1c? 5. Green line cannot be found in Fig. 1 (Line 453).

The figure references and captions are corrected. Thanks!

References

Kwok, R., Cunningham, G. F., Kacimi, S., Webster, M. A., Kurtz, N. T., & Petty, A. A (2020), Decay of the snow cover over Arctic sea ice from ICESat-2 acquisitions during summer melt in 2019. *Geophysical Research Letters, 47,* e2020GL088209. https://doi.org/10.1029/2020GL088209.