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Interactive comment on "The benefit of using sea ice concentration satellite data products with uncertainty estimates in summer sea ice data assimilation" *by* Q. Yang et al.

Q. Yang et al.

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We appreciate very much the constructive and helpful comments from the reviewer. Addressing the revisions recommended by the Reviewer #1 (Author's Response follow "AR:" in text).

We also have re-organized the texts to make the storyline of this MS more constructive: 1) We do data assimilation experiments in summer, 2) Using the provided uncertainties for sea ice concentration in summer does improve the sea ice concentration forecast, 3) No improvement (and sometimes worse) ice thicknesses, 4) We link the sub-optimal thicknesses on two little spread of the model fields after assimilation, 5) We link this

two little spread on the uncertainties provided with the observations, 6) This leads us to the mismatch between the radiometric and physical concentrations in summer, which is something the community (both modelling and satellite) is only recently recognizing.

From here two paths: 7a) for this short paper, LSEIK-3 was a pragmatic solution; 7b) for future research, we need to develop better DA methodologies.

Authors perform sea ice concentration assimilation for 3-month period (June-August) in 2010 (April). They use two observational datasets, and different uncertainties associated with this data. The paper explores performance of the model in terms of sea ice concentration and thickness after data assimilation with different uncertainties.

##General comments The topic of the paper is very interesting. It is one of the first studies that explores effects of spatially and temporarily variable uncertainties of sea ice concentrations on its assimilation in to the model. However the paper leaves an impression of being written in hurry, with a lot room for improvement. It certainly has to be expanded to make results more conclusive, especially in terms of sea ice thickness analysis. I do not recommend publishing the paper in the present form in “The Cryosphere”.

##Specific comments Description of the data, that is used for assimilation have to be very clear. Now it is hard to understand where exactly the data came from. Use of the selected time period (summer 2010) have to be also justified, especially considering attempts to perform sea ice thickness analysis. There are some satellite data on sea ice thickness in recent years, which can serve for comparison. Not including September in the analysis, the month with maximum melting, also have to be justified. Evaluation of the sea ice concentration simulated by the model is based on comparison with NSIDC dataset that can hardly serve as an independent data source. Moreover it is not shown how NSIDC data compares with OSISAF and SICCI and if being closer to NSIDC data is actually mean being closer to reality.

I find discussion on the sea ice thickness comparison very weak. It is based only on

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two point stations, and can't serve as a basis for very broad conclusions presented by the authors. All discussions about thickness should be ether excluded, or better expanded to compare with more representative data.

AR: 1) We have corrected the texts to describe the sea ice concentration data clearly. 2) At present, there are some available satellite based sea ice thickness data, e.g., Cryosat-2 and SMOS. However, both data sets are only available in the cold season, there is no useful satellite based ice thickness data in summer, and so the validation of sea ice thickness forecasts are much more difficult than the validation of sea ice concentration. In the revision, we further calculated the mean in-situ ULS ice thickness using two state-of-the-art satellite based sea ice concentrations (SICCI and NSIDC), so the comparisons are more conclusive than in the previous version.

3) We acknowledge that September could have been included in the analysis. In this particular year, however, there was open water in the interior pack near the North Pole as early as Jul12, so that we can assume that there are melting conditions everywhere in the Arctic Ocean in August. Hence, including September does not add new or different melting situations.

4) As suggested by the other reviewer, it is not necessary to compare LSEIK-1 and LSEIK-2 because the different sensors and different resolutions between SICCI and OSI-401-a. So we decided to focus on the LSEIK SICCI assimilation series, and removed the original LSEIK-1 experiment, which assimilated the OSISAF OSI-401-a data set.

5) In the revised MS we now compare sea ice concentration to the assimilated but state-of-the-art SICCI and non-assimilated NSIDC data sets. We also added Table 1 to better show this comparison.

##Detailed comments ###Abstract Abstract reads rather strange – you begin with description of the results, skipping the setup of the experiments (data assimilation with constant and varying uncertainties). So the "how" section of your abstract is incom-

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plete.

AR: We have re-written the abstract: Recently, the European Space Agency Sea Ice Climate Change Initiative (ESA SICCI) released ice concentration data complete with error estimates that depend on space and time. These data are used to in data assimilation experiments that aim at improving ice concentration and thickness forecasts in Arctic summer. The data assimilation system uses the MIT general circulation model (MITgcm) and a local Singular Evolutive Interpolated Kalman (LSEIK) filter. The effect of using sea ice concentration satellite data products with appropriate uncertainty estimates is assessed by three different experiments: in one experiment the SICCI concentration data is used with constant uncertainties; in two further experiments the same SICCI data are included along with their provided uncertainties; they differ only in imposing different minimum uncertainties. Using the observation uncertainties that are provided with the data improves the ensemble mean state of ice concentration compared to using constant data errors, but ice thickness is not affected in a systematic way. Further investigating this lack of impact on the sea ice thicknesses leads us to a fundamental mismatch between the satellite-based radiometric concentration and the modelled physical ice concentration in summer: the passive microwave sensors used for deriving the vast majority of the sea ice concentration satellite-based observations, cannot distinguish ocean water (in leads) from melt water (in ponds). New data assimilation methodologies that fully account or mitigate this mismatch must be designed for successful assimilation of sea ice concentration satellite data in summer melt conditions. In our study, thickness forecasts can be slightly improved by adopting the pragmatic solution of raising the minimum observation uncertainty, to inflate the data error and ensemble spread.

P2544 7-9: I don't think this information belongs to the abstract. AR: Removed.

###Introduction 21-22: Using IPCC report as a reference for such a statement is a bad practice. You should at least point the reader to the chapter in the report, or even better just cite individual researches that support your statement. AR: We updated

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the reference to the exact chapter in the IPCC report: Vaughan, D.G., J.C. Comiso, I. Allison, J. Carrasco, G. Kaser, R. Kwok, P. Mote, T. Murray, F. Paul, J. Ren, E. Rignot, O. Solomina, K. Steffen and T. Zhang, 2013: Observations: Cryosphere. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

P2545 13-29: Here you discuss OSISAF and SICCI datasets that have temporal coverage of 1978-2009 and 1992-2008. On the next page you state, that you are going to use this datasets to study summer 2010 sea ice concentration. This sounds a bit strange. In the next section, you mention that it is actually OSI-401-a and SICCI AMSR-E. Please make it very clear what you use exactly. If you still want to discuss sea ice re-analysis products in the introduction, then you have to connect them to the data you are actually using. AR: Corrected. Currently, the OSISAF OSI-409 and SICCI are the only two data sets that provide uncertainty estimates, so we gave a brief review here. Following the other reviewer's comments, we removed the original LSEIK-1 experiment that assimilates the OSI-401-a data set (See AR to General Comment 4) Further, we have rephrased the text to make the description of these data sets clearer.

###Forecasting experiment design P 2546 22: Define SEIK. Before you define LSEIK with the same references. Is it the same thing? AR: SEIK and LSEIK are different. We corrected the texts: "...and using the same ensemble-based Singular Evolutive Interpolated Kalman (SEIK) filter (Pham et al., 1998; Pham, 2001) in its local form (LSEIK, Nerger et al., 2006)."

P2547 5: Why this time period is chosen? AR: This period was chosen as it was very particular. The open water was first found in the interior pack ice near the North Pole as early as July (http://nsidc.org/arcticseaicenews/2010/07/). We have rephrased the text to clarify this point

7-9: You use EOF information, but how s exactly initial conditions for your ensembles were generated? Please clarify. AR: We have extended the text to “The leading Empirical Orthogonal Functions (EOFs) of the considered model variability are transformed by second-order exact sampling to generate the initial ensemble of ice concentration and thickness.”

23: Here you use LSEIK again. Is there a difference between SEIK and LSEIK, and if there is, please explain it. AR: Now we have explained their differences in the Introduction.

P2548 4-9: I strongly doubt that this product can be considered to be independent. The SSM/I and SSMIS are deliberately made quite comparable, so that the satellite measurements record started in 1978 can be continued. So SSMIS is improved version of SSM/I but it is in no way it can be considered as producing results “independent” of SSM/I. AR: This is correct, the two datasets were not enough independent. We now assimilate the SICCI product from AMSR-E (using a blending of the Bootstrap Frequency Mode, and Bristol algorithms) and compare with NSIDC data (NSIDC; Cavalieri and others, 2012; http://nsidc.org/data/docs/daac/nsidc0051_gsfc_seaice.gd.html). For summer 2010, it uses SSMIS from DMSP-F17 and the NASA-Team algorithm. We also add the sentence: "We note that both the SICCI and NSIDC products are computed from channel combinations of relatively similar passive microwave instruments and that they cannot be regarded as strictly independent. Using a different instrument and a different algorithms is nevertheless often the best we can use for passive microwave sea ice concentration data."

###Results P2549 18: You don’t mention how you handle missing data around the North Pole in NSIDC during the comparison. Was this region excluded, or you assume some constant concentration? AR: During the comparison, the North Pole area were excluded. We corrected the texts.

18: Your model and NSIDC data have different resolutions and different grids, so I

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assume for comparison you have to interpolate sea ice concentrations at some common grid. Details of this interpolation should be provided. Such interpolation can lead to quite significant local changes in sea ice concentration, so these effects must be considered in your comparison. AR: We did the comparison after interpolating the observation to the model grids. This could have some influences on the comparison, but it is very difficult to quantify them. We added one more sentence to remind the reader that the possible effects of the interpolation were not discussed in the comparison.

P2550 2-5: The sentence is hard to follow, consider rephrasing. AR: As the original LSEIK-1 experiment which assimilated the OSISAF OSI-401-a data was removed, so we deleted this sentence.

10-12: I don't think that you can make such a statement. What you show is that LSEIK-3 is close to NSIDC data, but you did not show, that being close to NSIDC data mean being more realistic. It might be quite opposite. NSIDC data have a number of problems, especially in summer. What you doing here are comparing model after assimilation of more advanced sea ice products against presumably less accurate product. You at least have to show how NSIDC sea ice concentration compares with OSISAF and SICCI in terms of RMSE. AR: The reviewer is correct. In the new Fig. 3 (see attached Figure 1), we compared the assimilation results with both the assimilated SICCI (Fig. 3a) and the non-assimilated NSIDC (Fig. 3b). We report only the RMSE for grid location where the satellite products reports and ice concentration lower than 0.35. The texts below are added in the MS: These are thus mostly location along the ice edge. Fig. 3 thus mostly assesses how the data assimilation experiments constrain the envelope of Arctic sea ice, not the interior (cyan color on Fig. 1). The reason for choosing this range is that all sea ice concentration products from passive microwave instruments have challenges with high concentration values in the summer (Ivanova et al. 2015). In such a case, documenting that the assimilated state is closer to the NSIDC product is not very conclusive, since NSIDC and SICCI products are probably likewise challenged at high concentration values. Looking away from the ice concen-

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tration values and focusing on the outskirt of the sea ice cover make the conclusions somewhat more robust as the influence of melt-ponds is reduced, and the approaches over open water are different in both products (Weather Filters in NSIDC and explicit correction for atmosphere perturbations for SICCI).

13-29: It is hard to estimate performance of the model using only two observational points. This analysis can't serve as a ground for your statement in the abstract that "SICCI concentrations outperforms the assimilation of OSISAF data in both concentration and thickness forecasts", it is just simply too local. In my opinion this comparison should be excluded from the study, or considerably expanded by adding analysis of spatial thickness distribution

AR: We agree that the two data points cannot lead to general statements. We have toned down our conclusions (also in the abstract) and now say there cannot be any definite conclusions. We would still like to keep this comparison.

21: You use abbreviation DA here for the first time. Define it. AR: Corrected. We change "DA" to "data assimilation".

Discussion P2552 16: You use abbreviation SD here for the first time. Define it. AR: We corrected to standard deviations (STDs).

Conclusions P2553 14-15: This is just contradicts your statement at P2551 L13:14. AR: In the revision, as the original LSEIK-1 which assimilated OSISAF OSI-401-a was already removed, so we deleted this sentence.

Figures When plotting maps of the Arctic Ocean most of the time the 0th meridian is used as a central longitude. What is the advantage to use 45th meridian in this case? AR: The 45th meridian was used in our previous studies, and we think this format would be easier for us and the readers to follow the different works.

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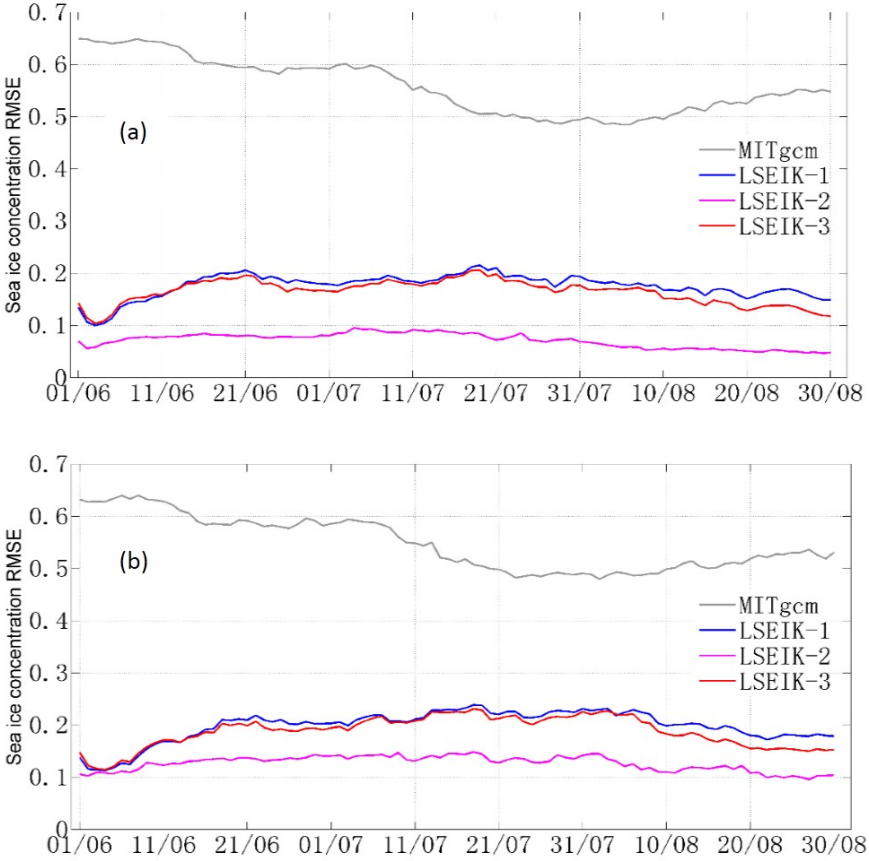

Fig. 1. Temporal evolution of RMSE differences between sea ice concentration forecasts and the SICCI (a) and NSIDC (b) ice concentration data where the satellite observations are lower than 0.35.

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