L. Bertino (Referee)

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The manuscript by Mathiot and co-authors presents an ambitious data assimilation experiment in a coupled ice-ocean model, assimilating both ice concentration and ice thickness measurements. The study consists of a controlled experiment assimilating synthetic data plus a realistic experiment assimilating real satellite data. The exercise is of great interest both for operational forecast models and upcoming climate prediction systems. It is also timely in view of the upcoming availability of satellite ice thickness data from the CryoSAT mission. I believe this is the first time that a global system successfully assimilates real ice concentrations and freeboard observations simultaneously over several years.

The manuscript is generally good and well structured which only misses a few complements of information to become a very good publication. The modelling and data assimilation methods used are both at the state of the art, and the results from the experiments are of direct practical interest for the community.

There are however missing pieces of information:

1) The generation of the initial ensemble the magnitude of observation errors and other details of the setup (localization radius and inflation if any).

> **P. Mathiot and co-authors:** All the missing details have been added to the new version of the manuscript. The localisation radius is 800 km and no inflation is used in this study. More informations about the observation errors, such as details about the magnitude, are now given for both data types. The following sentences have been added in Sections 3 and 4 : " … . We use the localized analysis presented in Sakov et al. (2010) to address the limitations due to the relative short size of our ensemble size (25 members) compared to the size of the state space. The localization radius applied in this study is 800 km. … . It is worth mentioning that no inflation is applied to enlarge the spread of the ensemble. … . The uncertainties in the synthetic observations are identical to the ones of the real observations. … . The uncertainties in sea ice concentration vary in time and in space. During summer, the error is estimated up to 20%, while during winter the deviation between ice concentration measurements and ice charts are around 10%. Close to the ice edge or in areas with very compact sea ice (sea ice concentration of about 100%), the uncertainties are lower, about 7%. … . As for sea ice concentration data, ice freeboard data are interpolated on the model grid each day. Uncertainties in ice freeboard data are assumed equal to the standard deviation of all data available in each model grid cell, i.e. 15 cm in average over all the data points and over all the periods."

2) Another missing element is the evidence that the EnKF is in good health: i.e. That the errors expected by the Kalman filter (forecast + observation errors) are commensurate to the actual innovations. This is particularly a critical point for the perturbed observation EnKF used with a rather small ensemble size (25 members) and a high frequency of assimilation (once a day). I can imagine that in a coarse resolution model the numbers of degrees of freedom is probably small, but I still expect serious sampling errors, which may result in a shrinking of the ensemble spread.

I would like the authors to present some measure of the expected KF errors, in the form of time series or whiskers regularly spaced (once in summer, once in winter) along the existing time series (Fig. 3 or 5 for example), as well as some information about the initial error and measurement errors applied.

P. Mathiot and co-authors: As suggested, we have compared the error covariance matrix estimates to the innovation vector following the method described in Lisaeter et al. (2003), in order to estimate possible sampling errors. The results are presented in the new Figure 11. The results show that the innovation and total error covariance (model plus observations) have similar magnitude. However, it appears that this is due to the large observation errors. When we look at the contributions of each term (not shown in the manuscript), the model error covariance have a smaller magnitude compared to the observation covariance as suspected in the comment. Consequently, the perturbation method has to be improved if we want to apply this method to observations with lower errors. Reminder: the estimates of the observation errors are provided by OSISAF and are 2 or 3 times larger than the ones applied in Lisaeter et al. (2003). The manuscript has been modified to take into account this discussion. A new figure and a new section have been added in Section 6 (real sea ice concentration).

Regarding the initial error and measurement errors, the details has been added to the manuscript in Section 3 (Ensemble generation) and Section 4 (data description): see response to first comment.

Detailed comments:

- **P. 1635, L. 13. Performing the analysis in ensemble space prevents observation errors from being correlated, but localization does not.**
  P. Mathiot and co-authors: The mistake has been corrected in the revised version: **"**The analysis update is calculated in the ensemble space (Hunt et al., 2007). This technique does not permit observational errors to be correlated. So, we assume independent observational errors. Advantages of this technique are to reduce the cost of the EnKF and avoid scaling issues among different variables."

- **Same place, please indicate localization radius.**
  P. Mathiot and co-authors: Done, see response to first comment.

- **P. 1637, Section 3.2. Lisæter et al. (2007) recommend to perturb both the winds and heat fluxes for best efficiency, why not perturbing heat fluxes in your case?**
  P. Mathiot and co-authors: Heat and momentum fluxes in our study are computed by bulk formulae. Consequently, the heat flux is proportional to the wind speed. The perturbations of the wind affect thus both momentum and heat fluxes. New informations about this issue are now given in the paragraph describing the ensemble generation: "…Winds are particularly important for both the sea ice motion and surface heat budget in both hemispheres (Wanatabe et al., 2005; Bitz et al., 2002). Consequently, to generate the ensemble of model states (25 members in our case), we have chosen to perturb only the wind forcing field. As the surface fluxes are computed by the CLIO atmospheric bulk formulae in our experiments, a perturbation of the wind field affect both the momentum and heat fluxes. This ensures the dispersion of our ensemble. … "

- **P. 1638, l. 10. p has units of anomalies but is called "scale factor" with a value of 0.5, this seems like a small error.**

  P. Mathiot and co-authors: This is a mistake. In the new manuscript, the scale factor is named α. The sentence has been corrected: "the perturbation **p** to get $\mathbf{x_p} = \mathbf{x_o} + \alpha\mathbf{p}$. In our case, $\mathbf{x_o}$ is … The scale factor α selected here is 0.5. We …"

- **P. 1638, l. 11. Assuming no temporal correlation between the perturbations effectively lets the model equations do the smoothing instead, which means that the perturbations may have a smaller effective standard deviation than the 0.5 scale factor specified.**

  P. Mathiot and co-authors: You are right. Some details have been added in the text in order to precise that the α is a theoretical scale factor and not an effective scale factor: "The scale factor α selected here is 0.5. We did not assume any temporal correlation between the perturbations. However, the model smoothes the effect of the perturbation. This leads to an effective scale factor lower than 0.5 (not diagnosed here)."

- **P. 1640, l. 7. What is meant by "data with elevation varying..." varying in space or time? - Section 4.2, the errors on the measurements are omitted.**

  P. Mathiot and co-authors: The sentence has been rewritten to highlight the important points. The new sentence is: "Islands, icebergs and land areas are filtered out with a criterion based on large elevation variations (more than 4 meters) along the track. A zero ice freeboard is assigned … Yi et al. (2010) give a complete description of the algorithms used to process the data. "

- **P. 1641, Section 5.2 has a little confusing logic, the discussion of the IC and FB experiments are done together instead of sequentially.**

  P. Mathiot and co-authors: Effectively, in the first paragraph, we discussed the differences between FREE, IC and FB, and in the second paragraph, we discussed FB. As suggested, we have removed the reference to FB in the first paragraph of this section to have a more logical discussion.

- **P. 1641, same paragraph, the last sentence about transforming multi-year sea ice into seasonal sea ice is also unclear.**

  P. Mathiot and co-authors: You are right, the sentence was unclear. We have rewritten it like this: "The adjustment of the sea ice volume ends after the first summer in both the NH and SH (Fig. 2). It is the time needed to transform the excess of multiyear sea ice still present during summer in FREE (compared to the synthetic observations) in seasonal sea ice in IC, which corresponds to the synthetic observations."

- **P. 1643, l. 27. The too strong reduction is not obvious to me, is that in the Chukchi Sea? Please specify names of areas.**

  P. Mathiot and co-authors: We have specified the period when the underestimation is really visible and also the location. The sentences have been modified like this: "Over all the ice pack and during both winter and summer (Fig. 5, Fig. 7 and Fig. 8), IC reduces the ice thickness overestimation seen in FREE. However, the decrease of ice thickness in IC is too strong along the ice edge, especially during summer in the central Arctic (Fig. 8). This is a sign that …"

- **P. 1644,l. 17. This indicates that the correlations between ice concentration and thickness are negative in the marginal seas. This could be tracked back to model biases**

(for example too cold waters below the sea ice).

P. Mathiot and co-authors: We have analyzed the mean increment during the month of August. It appears that the sea ice volume increases in all the ice pack when the EnKF is activated (except in the marginal zone of the Bering Sea), due to a slight increase in sea ice concentration during this period. This increase in ice volume is equivalent to an increase by 1 cm in sea ice thickness (at constant sea ice concentration) per assimilation step. We have added some details about this issue in the revised version: " … However, between July and September, each year, the EnKF creates sea ice. This may seem surprising as FREE still has too large an ice extent at this time when the center of the ice pack begins to freeze, but the marginal sea ice zone is still melting. EnKF is producing sea ice in the entire ice pack (except in the marginal ice zone of the Barents Sea) at a rate of about 1 cm of sea ice per assimilation step for the month of August 2006. This means that the ice does not consolidate fast enough in the pack and melt too fast in the sea ice edge in the Atlantic sector in NEMO-LIM. Causes of this behavior might be biases in the forcing or a too strong positive ice-albedo feedback during summer."

- **Fig. 4b) there are 5% of ice in almost the whole Arctic in the OSI-SAF obvervations, this looks strange to me. Could you double-check there is no error?**
  P. Mathiot and co-authors: We have checked it again. OSISAF show, in the file provided on the website and in our process data, a sea ice concentration of about 5% in summer in the whole Arctic.

Typos:

- **"Sea ice" is usually spelled without dash.**
  DONE

- **P. 1642, l. 8. "accompanied"**
  DONE

- **P. 1643, l. 3. "As expected": I envy your optimism.**
  As expected has been deleted.

- **P. 1646, l. 16. "Simulates an ice..."**
  DONE

- **Fig. 3b), p. 1659. A little smoothing would make the plot more readable.**
  DONE

- **Fig. 9. Please remove the line "Free (EnKF)", it is only adding confusion.**
  DONE