Review on
„Arctic Mission Benefit Analysis: Impact of Sea Ice Thickness, Freeboard, and Snow Depth Producs on Sea Ice Forecast Performance “

General comments

The authors present a formalism to assess possible benefits of different Earth Observation (EO) products for reanalysis Arctic sea ice data. The authors consider seven satellite products: sea ice thickness and free board, radar free board (derived from satellite data), and the hypothetical data laser freeboard and snow depth, the latter both in higher and lower accuracy.
The question focused on in the assessment is how uncertainties of EO products are reflected in (user) defined variables, so called target quantities. An outcome of this study could be to identify those kind of EO products, which lead to the fewest uncertainties in the target quantities. The authors consider snow volume and and sea ice volume as target quantities.
Sources of uncertainties are not only found in the EO products, but also in the model and experimental setup, such as initial and boundary conditions, parameterization and a formulation of the physics. To identify the impact of these onto the uncertainty propagation towards the target quantities, a so called control vector finds application in the formalism, containing representations of these sources.
Their findings are different for the target quantities:
Discussing the satellite EO products:
In an attempt to forecast sea ice volume with the MPI-OM, it appears most beneficial to use either SIT or RFB as EO product, compared to SIFB.
If one attempts to forecast snow volume, the results are different: it is most beneficial to use RFB, while SIT lead to highest uncertainties. SIFB appeared to be in the middle.
Second, using the hypothetical products:
The authors conclude, that using a hypothetical LFB product with low accuracy is better (for both SIV and SNV) than using SIT but could not reach the performance of RFB. Improving the accuracy of the LFB product improves the performance.
Using an approach where any of the above EO products is used in combination with snow depth products leads to improved performance. Again, EO products with higher accuracy lead to improved performance.

As such, I consider the work the authors introduced to be a novel and valuable contribution in the process of optimizing the use of EO products in reanalysis and thus in prediction frameworks. However, I consider the presentation of the work poor, which strongly hinders an easy approach.

The manuscript lacks conciseness and does not follow basic rules of scientific writing. For instance, notions are either wrongly introduced (such as the Jacobian), or not explained , such as M and N or the „Jacobians“ or the perturbations, which appear to be crucial in the QND formalism. The explanation of the basic equations are erroneous and in the introduction of the sea ice-ocean model MPI-OM it is explained, that this model consists of the equation of the ocean – while neglecting the sea ice. It is added later in the text. A reader not familiar with the set of equations will be confused. There are partly wrong explanations – widely extended – of topics irrelevant for the understanding of the proposed algorithms of the manuscript while relevant explanations are missing.
Moreover, the captions of Figures do not (sufficiently) explain the graphs, graphs are lacking labeling of the axes, units are lacking, captions do not fit with the graphs/tables; Figures are neither properly explained in the text. The discussion of results (most likely shown in the graphs) lack references to the graphs at all, and if they refer to a graph (which might be quite complex), they do not explain, which bar and which of the many boxes in the graph they are referring to. This makes the argumentation very hard to follow.

There is a lot of jumping within the graphs, which are spread over the entire manuscript, such that the reader often finds himself in searching the graphs/tables, than in following the argumentation. I suggest to move them all to the end of the manuscript.

Moreover, the authors introduce the QND formalism, but in the development of the text it is not clear, what is precisely done. There are some indications on the procedure, for instance on how sensitivities are derived. It is not clear (for instance), how and when the EO products or the information on uncertainties are incorporated into the QND formalism.

Due to the poor/sloppy form and logic of the paper, I may have missed some principal issues that will appear better in a reviewed version of the paper

My assessment for this manuscript is: major revisions.

Specific comments

Comments on the arrangement of the manuscript

The current sectioning of the article is:

1. Introduction
2. Methods
    - 2.1 QND
    - 2.2 Target Quantities
    - 2.3 Model
    - 2.4 Control Vector
    - 2.5 Data Sets and Observation Operators
3. Target and Observation Jacobians
4. Sea ice and snow volume uncertainty (Rename: „Uncertainties in the target values“)
5. Discussion
6. Summary and conclusions

This is unfortunate. For instance, in the methods subsections the authors use terms (such as „the model“, the control vector, ...) before introducing them. I suggest to first introduce the QND formalism, then to introduce the model, followed by the Data Sets and Observation Operators, Control Vector and Target Quantities. Beside, the model section (as also mentioned below) contains topics, that should be shifted into a separate section that contains a concise description of the experimental setup. This is missing so far. Yet, it is not clear to me, why hindcast experiments are discussed in this section. This is definitely not part of a model description and should be moved into a section, where results are presented and discussed.

Section 3 belongs also into a section regarding the experimental setup. In such, it should also stated clearly (among a concise explanation of what and how the authors perform in the QND formalism), that and how hindcast experiments are performed and assessed. The authors should also consider to properly introduce M and N – and what they call Jacobian, as these appear to be crucial part of the algorithm.

I suppose, that section 4 is meant to be a discussion on results of the QND scheme. If so, then it should be named along that line.

The authors mention that the mean state is of little importance although it obviously impacts the derivatives: the model bias is not accounted as model uncertainty and should lead to even more optimistic benefit analysis, even with larger control vectors.

This issue should be flagged upfront and in the discussions of the results.

Content

1) Referring to abstract, l.7 and throughout the paper: It is not clear, what you exactly did in your experiments.

2) Introduction p.3 l.15f: Do not refer to results in this paper in the introductory part! This section is dedicated to the documentation of already existing work and for motivating the content of the manuscript at hand. Instead of referring to your own (unpublished) work of this manuscript, cite (published) articles supporting your suggestions. If there aren‘t any, I suggest you to reformulate your statements as hypothesis and provide reasons/indications for its validity.

3) p.4 l.12 ff: I would slightly restructure the enumeration to something like (which you could refer to these by naming or referring to the numbering):

1. **Structural uncertainty**: caused by the representation of individual processes and their numerical implementation.
2. **Parametric uncertainty**: of the constants in the parameterization of these processes
3. **Boundary value and forcing uncertainty**: of relevant processes, e.g. uncertainties in the forcings such as surface winds or precipitation.
4. **Initial state uncertainty**.

In the following I would also rename „factor“ as „uncertainty type“. E.g. in l.19: it could be rephrased along the line: „The choice of the control vector is subjective. A good choice should take into account all input uncertainty categories (2. to 4. in the upper list)“

4) Be more concise and introduce the notions and used quantities and mechanisms thoroughly:

4a) p.4 l.26: Clarify what the „observational information“ is. Is this the uncertainties in the observations?

4b) p.4 l.28ff: A motivation for the use of the PDF covariance matrices, the assumption of their Gaussianity is lacking. Where is it used? Explicitly in the backpropagation step? As well, you have *constants* in the control vector, don‘t you (see Table 1, rows 1-31 – out of 45)? How are they transformed into the required structure?
Indicate, how the PDF covariances are constructed . In this section it could be referred to Section 2.4 Control Vector. In that section (2.4), it should be mentioned, how the PDF covariance matrix is build for each type of entry. Currently, in this section it is explained, that a perturbation is added to the fields themselves and all the discussion is about the fields, but not about the control vector itself. This is confusing. Beside, it is lacking, which law the perturbations follow – the N(0,sigma) would be a natural choice, but it is not mentioned, neither the size of sigma. Motivate the necessity of the perturbations.

4c) p.5 l3: „For the first QND step we use the model M as a mapping from control variables onto equivalents of the observations.“ - It is unfortunate to say „the model M“ without introducing it before. If M is just the mapping from control variables to the observational space, then it might be better to write:
„In the inverse step we use a mapping from the control vars onto the observational space. In the upcoming we refer to this operator as the model M.“

4d) In Section 2.1 QND explain concisely the role of the control vector, what the outcome for the target vector is dependent on the observation products and their (which?) additional information. Moreover, you list the sources of uncertainties for the model, but not for the EO products. Elaborate on these as well!
After the explanation of the terms in equation (3) on page 5: It is not clear, how the forecast/assimilation is involved. It is not clarified throughout the manuscript.
It might be beneficial to introduce N more properly. It is not really clear to me, which role the control vector plays at this stage, not how it is involved in the QND structure.

While M is a mapping from the EO product to the model equivalent, I guess, that the ocean ice model is already somehow involved here and some of the parameterizations etc (see uncertainty types) are involved (explanation, how this is done, is missing).
In step one you thus estimate the sensitivities of this mapping (how?). In the second step, you basically aim to assess the propagation of the uncertainties within the sea ice ocean model (how?), if I understood you right. As an outcome of this step 2 you also get an estimate of the uncertainty quality of the model parameterization on the uncertainty of the target quantities. It is not clear to me, how/if the EO products are incorporated into the process.
Particularly, it is not clear, how the scheme as sketched in Fig.1 is related to the procedure as sketched in Fig. 12, which comes into play without any motivation.
These questions should be clarified.

4e) p.6 l.5: In the QND it is mentioned that there are two models involved: represented by the operators N and M. Moreover, in Section 2.3, a sea ice-ocean model is being introduced, that seems to be not incorporated into the QND (see the definition of M and N). This is confusing. A clarifying explanation on this is strongly desired.
Moreover, the authors mention, that it is crucial to have a realistic propagation of the *sensitivities* of the uncertainties to the target quantities (via both, N and M, I guess), instead of a r*ealistic representation of the simulation of the target quantities*. I do not understand, how these two are disconnected. In particular, the authors compare model output with EO products, (see e.g. Fig.6-9) which contradicts their own argumentation. This needs to be clarified.
How do the authors access that the sensitivities are represented realistically?

4f) Figure 2: caption: Explain what it is seen, what are the shaded lines, what the darker? What do the x-axis and the y-axis represent? What are the units? Why are there two d_i involved and how and why at different time steps? This is explained neither in the caption nor at any point in the manuscript! What is contained in C(d_i), what in sigma(y_i)?
These are basics. The graph is not self-explaining and does not help the reader to understand the graph nor the algorithm.
This confusion also occurs in p.7 l.7, where it has not been clarified beforehand, how the observations are incorporated into the „model“ (whichever model). In the abstract you also talk about forecasting. How does this agree with a scenario which appears to be a reanalysis scenario?
How is this Figure 2 connected to Figure 1 and how to Figure 12?

5) Deducing from (5), where you define the uncertainty reduction as (sigma(y0)-sigma(y))/sigma(y0), the posterior target uncertainty in equ. (4) is not sigma^2 but sigma!
Moreover, it is confusing, that in the text above you mentioned, that you do not consider sigma(ymod), and come up with it here.

6) p.7 l.26: Here it is said that predictions are performed, but from the preceding it appears that (in some way) the incorporation of the EO products into the model appears in a reanalysis framework (see e.g. Fig. 2). It is not clear, how the QND procedure fits with the argumentation.
What I make up from the preceding is that in some way you will use different types of observations and will get different SNV and SIV . If so, it is not clear how uncertainties/sensitivities are then derived. The entire procedure needs clarification!

7) Section 2.3 Model: The detailed explanation is not of relevance for the purpose of the manuscript. It is not relevant to explain, what an ocean-sea ice model is, and what the particularities for MPI-OM are. Just refer to Jungclaus and Niederdenk (2013). Beside, the description has parts which are seriously wrong:

- p.8 l.7 ff: A short explanation: Due to the complexity of the 3D Navier-Stokes equations, it is common practice to apply a couple of approximations, such as the the hydrostatic

approximation or the Boussinesq approximation. You can skip that information, this is nothing special. What follows is incorrect and should be skipped due to the already mentioned non-explicitness of the MPI-OM with respect to the primitive equations and an equation for the balance of the thermodynamics.

- Particularly, you introduce the MPI-OM by saying, that is consisting of the three balance equations – which are solely related to the ocean (without mentioning) while skipping the second set of equations for the sea-ice component.

If you really want to make a distinction, then cite the articles related to the ocean models and those related to the ice models. You can discuss the relevant parts (like snow loading treatment in the discussion section, as you already do) when it is needed (and refer then in the discussion to the literature).
Also, the discussion of the mesh is unnecessary. If it is really necessary (which I do not see) I recommend to mention the structure in short and provide a source. If there is anything particular you implemented due to the necessity of the algorithm, then mention it along the line „In addition to the standard MPI-OM we implemented… in order to … based on [literature]".
The part starting from p.7 l.30 to p.8 l.5 is OK. If I understand the authors correctly, then they use the last sentence in there to justify/indicate that the MPI-OM gives realistic dependencies. If this is the case, then I would formulate exactly this – e.g. by „Thus, we consider the model results to be reasonably realistic." The remainder of the model description should be removed.

8) Remark on Section 2.3 Model:
I understand that in this section the authors introduce the model and refer to related literature, introduce the forcing (though it should be indicated in the Section title as well). Starting from p.10 l.11, the authors describe the initialization of the MPI-OM. This belongs to the presentation of the experimental design. I suggest to separate the experimental setup from the description of the model. I suggest to dedicate a separate section with a clear description of the experimental setup, starting from initialisation, perturbation strategies of the control vector variables, etc.

9) p.10 l.20ff- until the end of the section: A motivation of the upcoming paragraphs is missing and I do not see the point why it is placed in the model description section. Place it into a different section with an appropriate title. Moreover, if you aim to present an assessment of the MPI-OM hindcasts due to observations and a discussion on their uncertainties, then indicate this in the abstract – and motivate this in the beginning of a possible new section, where you perform this discussion.
Alternatively, the authors could shortly indicate, that they consider the MPI-OM to represent the physics well, and present a summary. At this point this is not clear, how this discussion is related to the QND.

10) p.10 l.26 and the discussion related: In earlier passages, the authors stated, that they are not interested in the realm of the model results, but rather in the sensitivities. This is not reflected/discussed in the comparison of concrete values against observations.

11) -p.10 l.28: „only small misfits": you should exclude the marginal ice zones out of this, as I consider a misfit of about 50% as noticeable. And it could be explained by stronger transport and errors in the advection schemes. As well, it is possible that in those regions there are different (weaker) tolerances in the accuracies of the observations.

12) p.11 l.3: it is not clear to me that you look at hindcasts. Clarify this beforehand, for instance in a separate section explaining the experimental setup.

13) p.13 3f: How much sense does it make to compare multi-annual means in a period of sea ice decline? Is the interdecadal trend insignificant?

14) p.15 l.2: Describe where the uncertainties are derived from and how.

15) p.15 l.5: If you want to be indepth: you could explain, why it is numerically cheaper to divide big vectors into several smaller ones. Or is it rather due to the fact, that it is beneficial to get to know where the uncertainties stem from? At least this was the impression in the extensive argumentation that comes later in the manuscript.

16) p.15 l.12ff: How can uncertainties have diagonal form?
It looks like what you mean by uncertainties also contains information about cross-correlations between the different control variables. Elaborate more on that, or repeat it here in a concise way. Otherwise it does not make sense. Uncertainties themselves will form no matrix but a vector.

17) p.20 l.1 : What is the retrieval chain and how can this (as well as Fig. 12) be brought into agreement with the QND formalism introduced in Fig. 1. This section lacks explanation on how this incorporates into the QND formalism.

18) -p.20 l.5: the Jacobian is a matrix which contains derivatives. This I do not see reflected in the right hand side of Fig. 12. What I see is that the observational equivalents of the left hand side products are being derived and – so it seems – compared. Maybe, sensitivities is a better word. Anyhow, I do not see this reflected in the graph. If it is a Jacobian, it could be useful to give a formula
-p.20 l.7f: I do not see where you derive variables that describe the changes in the variable (due to changes in the control vector) – this is why you have the control vector, right?
Moreover, the comparison regarding the complexity is not clear and should be explained.

19) -p.20 l.12f: „SIT refers to the grid cell average, i.e. for the Jacobian...“: grid cell average vs dividing by SIC is not coherent to me. Please correct.

20) p.23 l.14: relating to the Beaufort Gyre: If this is the case, shouldn‘t there be then a negative correlation seen in those regions, 7 or 8?

The language could be improved throughout the manuscript. Here, I give suggestions to some of the parts, which I considered most worthy to be improved. The author should consider to use short and flat structured sentences.:
- abstract l.10: remove the institutes name, it appears awkward, just „all derived from CryoSat-2“.

21) -p.31 l9: it is not clear how your assessment is linked to this forecast. When did you apply your QND framework? In which period? How did you treat the nonstationarity?

<u>Phrasing&Structuring</u>

1. abstract l.7 „observation impact (added value)“: replace by "added value of observations" or „We assess the added value of different EO data products in terms of ...„
2. abstract l.9: „the assessments cover“ replace by „We assess seven...“
3. abstract l.11f: concerning the phrases in brackets: I suggest to replace both by „(low and high accuracy)“ each
4. abstract l.20: „Providing“ instead of „the provision of“
5. p.2 l.7: Mention that this forecast is done with one particular model, namely MPIOM.

6. -p.3 l.7: Write instead „Forecasts of the ice and the ocean state are …“, as the sea ice-ocean models not only contain equations describing the dynamics of the system, as you also introduce later in the manuscript.
7. p.3 l.8: A minor suggestion: formulate in a positive way: „In order to derive reliable forecasts, uncertainties in the model initial state, of the atmospheric b.c.s and in the parameterizations of physical processes should be minimized.“
8. - p.3 l.9: remove „only“. For instance, observations of bad quality are of no advantage. And improvements in modeling, parameterization etc. also contribute to improved model output.
9. p.3 l.21: „observation impact“ : change to „the impact of observations“
10. p.3 l.23: optimized for what?
11. p.3 l.27f: „successfully demonstrated“ sounds weird.
12. p.4 l.9: Do not use control vector at this stage, it is confusing, when it is not introduced yet and does not lead to a further understanding. I would just skip it.
    Furthermore, maybe it is better to formulate, that with the QND formalism you are able to assess how the uncertainty propagates from the observations (raw data?) to a certain target quantity.
    To my mind it is not of interest at this point to add information on the modeling chain. It is just confusing.
13. p.4 l.10f: I would remove „hence“, as this is the 4 factors you identify. („We distinguish 4 types of ...“). Remove „influence“ at end of line 10, as it is redundant and confusing. Instead you could consider to use the phrase „sources of uncertainties“.
14. p.4 l.17: remove „(code)“, this is redundant.
15. p.4 l.22: Keep the message as short as possible to maintain comprehensibility. For instance remove „any potential model output“ and replace „, for example a process parameter such as the albedo of the snow“ by „(such as the albedo of snow)“. The phrase „process parameter“ only adds confusion.
16. p.4 l.26f A suggestion to rephrase: „In a first step, we reduce the uncertainty in the control vector by making use of a given inverse model and information (to be specified by the authors) on the observations. „ Then start a new sentence for the second step.
17. p.4 l.28ff: You could shorten it to „Within the QND formalism, we present all involved variables/quantities by probability density functions (PDF).“ The explanation does not add new information.
18. p.4 l.8: „based on algebra“ sounds weird. I would just phrase it as „ and is partly based on...“
19. p.5 l.5 I would replace „absorbed“ by „incorporated“.
20. p.5 l.7: „with covariance C(x), i.e. the uncertainty is given by“: There is an inconsistency. Why is C(x)^-1 the uncertainty, and why are the data uncertainties C(..) and not C(..)^-1? I would rather replace that by: „with covariance C(x), which is given by/defined as“
21. p.5 l.12: Is „observational constraint“ the correct word? Shouldn‘t it rather be the given uncertainty of the observations?
    Furthermore, to improve readability, use C(dmod) instead of „the second term“. Also mention here, that this is a subjective choice, instead of coming back to that 10 lines later when discussing different equations.
    For a better understanding, I suggest a reformulation from line 9: „where the data uncertainty C(d) is a combination of two factors: [formula]. The term C(dobs) expresses the uncertainty in the observations and C(dmod) the uncertainty in the projection operator M . Its/Their (both?) formulation is a subjective choice.“
    For the formula (2) you could also shortly explanation/indication, why you used the quadratic form. I guess, the reason is smoothness and higher regularity due to the inversion step. Or do you aim to account more for larger uncertainties than for smaller? (Which is what the L2 norm does compared to the L1 norm)

22. p.5 l.14: replace „in the second step“ by „in the propagation step“ … you already introduced that notion. As well it is now confusing, which model you consider. Better to first introduce the model and then what is done in this propagation step. A proposition:
    „The model N involved in the second, the propagation step, is the mapping from the control vector onto the target quantities. The Jacobian of N, (N‘) is used to estimate how the posterior uncertainties in C(x) propagate to the “
    - I am confused here: before equation (1) you say, that C(x) is the covariance of the Gaussian PDF of the posterior control vector. And here you say, that that C(x) is the control vector. Use unique formulation.
23. - p.5 l.18: For improved readability, I would proceed chronologically in the order of occurrence of the terms (start from the beginning of the equations), introduce the meaning of the single terms and indicate subject choices then. My suggestion for p.5 l.18-p.6 l.4:
    „The first term, N‘C(x)N‘T, reflects the propagation of the posterior uncertainty C(x) to the target uncertainties via the model N, while sigma(ymod) reflects the remaining uncertainties (see types 2-4 in the list above), that are not yet represented in the control vector. Like C(dmod), this quantity is set due to subjective choice. In our work, we skip this term in order to sharpen the contrast between the EO products, and only mention two plausible estimates. „
24. -p.7 l.13: „does not require real observations“: This phrase is unnecessary. Instead you could just say, that the QND formalism can be used to assess/evaluate hypothetical… ,
25. -p.7 l.15: here you use d as the set of observations, and in l.7 you use d1 and d2. Introduce the definition of d (using vector notation) before you use it (or components of the vector without mentioning). For instance, Fig. 2 could be introduced after such a definition. A suggestion: First say, that it is possible to evaluate a network of observations, that do not need to have the same structure, nor be available on the same grid. In particular, this enables the study of the benefit of using hypothetical data networks. As is done in this work.
26. p.10 l.11: „from a restart file a dd.mm.yyyy generated ...“, remove (start time of ERA-Interim).
27. p.10 l.15: The initial ocean state is assumed to be at rest, the initial sea ice...
28. p.12 Fig6: Explain what blue and what red colors mean! How is misfit defined? How do you assess with this comparison the sensitivities instead of real values?
29. p.12 l.7: „ is linear in time plus a quadratic time-dependent component, i.e. it does not contain year-to-year variability.“ this correlation is not clear to me. Explain or remove!
30. p.12 l4: explain the ice thickness regression procedure.
31. p.14 caption Fig. 8: Needs to be improved along the line already mentioned (Think of self-explaining!, colors, notions, etc.)
32. p. 15 Add to the title of the control vector: „and Uncertainty specification“
33. Section 2.4: Give a little introduction into the purpose of the control vector. Do you gain information by using that one? What is the difference in the outcome when using a large or a small control vector? Somewhat trivial: Add, why you do not modify the control vector, while you do so with the observations.
34. p15 l 2: Consider to add „ , C(x0), “ after „uncertainties“ Moreover, I would shorten: „(2015), and are listed in Table 1.“
35. p.15 l.7ff: In order to avoid confusion, the part in the brackets where it is said that perturbation is added to the entire part of the simulation, should be put out of the brackets.
36. -p.15 l.11: Either use present tense („results“), or reformulate: „Thus, the control vector contains in total 157 control variables.“
37. Section 2.5: This section is not understandable at all. As introduction of this section clarify where you apply the data sets and where the observation operators in the QND framework!
38. - p.16 l.8: when you use the word „link“, you should say between what. Right now you only use from model‘s state variables, but lack the to-part.

39. -p.17 check table caption against the table: column one lists the indices/place of occurrence of the quantities in the control vector, while column 2 the abbreviation.
    To enable easier reading you could section the table in 3 parts, the first being process parameters, the second initial fields and the third forcing fields. You could remove the third column and section by horizontal lines and note the type by writing „process parameters“ etc in vertical style left beside the index. Alternatively, insert additional rows that only contain „process parameters“ etc as sectioning of the table.
    The last column can be removed and instead it should be explained in the caption, that the parameters are unique values, while initial and forcing are given in the control vector individually for each of the 9 regions (and refer to the figure 10 where they are introduced).
    Column 5 lacks units in most of the entries. Caption and head of table disagree.
40. Fig. 12: What effect do the assessment boxes have? Which role do they have in the upcoming of the manuscript? Explain abbreviations in the graph, that have not been introduced yet, such as MSS.
41. The first time the notion „Archimedes' principle“ shows up, it could be shortly explained, if the author want to be self-explanatory.
42. - p.20 l.20: for consistency in notation, use formula for snow depth or write the following formulas in words, i.e. „densities of snow, ice and water“
43. -p.20 l.21: add names of f_i, f_r and f_l. It has so far only once been mentioned in Fig. 11.
44. - p.20 l.28: motivate -0.22hs/c: what is this and where do you take the formulas from.
45. - p.21, l5: remove „provided by AWI“, and use: the CryoSat-2 product files used in this work
46. -p.21 Caption of Fig. 13: time is missing (April 2015). l.6f: How do the uncertainties in the other times look like?
47. - I do not see how you incorporate the uncertainties into your algorithm. And: l.8: you introduced before the diagonal structure of the „uncertainties“. So I would refer to that by „Recall, that we assume uncertainties to be uncorrelated in space“
48. p.21 l.10: give a justification/reason, why you use the threshold 0.7 for SIC.
49. p.22 l.10: Does M refer to model MPI-OM? With respect to what is the derivative?
50. p.22 l.17: where do you derive sigma_i from – particularly for process parameters?
51. p.22 l.20: what is a 1-sigma change?
52. -p.23 l.2: It is easier if you explain, that this plot shows the sensitivities of the XXX due to changes in SIFB, LFB,….
    What does that mean: „the Jacobian for April means of SIT over a point“? One entry in the Jacobian is: partial f_j/partial x_i. Explain, what f_j, what x_i is?.
53. In the caption of fig 14 clarify that each bars in the plot corresponds to the uncertainty/sensitivity (?) of one entry in the control vector due to the changes in the values XXX in the black dot! Then explain that for instance for SIT there are 4 bars for each region – one for each EO product. It is very hard to read this figure without any further explanation.
54. - p.23 l.4: add information where you are referring your discussion to, for instance „SIT sensitivity (indicated as the XXX bars in the graph)“ – otherwise it is simply confusing. End of that sentence in l.6: add „in that region“.
55. - p.23 l.9: this has not been indicated in your model description. Just give a reference here .
56. -p.23 l.17: „the various...“ where do we see this in Fig.14? Do you still refer to this figure? Indicate which bars you are talking about! This applies for the entire section! Any statement you make – refer to the corresponding bars!
57. - p.23 l.28: what is the model N? Are you still in Fig.14?
58. -p.24 l.11: put „region 6“ out of the brackets, as this is a particular feature of region 6!
59. -p.25 l.3: Is „derive“ the right word? If so, say how you do this. Else, use „use“/“introduce“. In any case, motivate your choice.
60. -p.25 l.4 remove: „and listed in the last but one row“,
61. -p.25 l4: „model that perfectly simulates“…: where do you use this result and how?

62. -p.25l.6 „and listed in the last row“: remove
63. -caption of table 3: 4-6 are 3 columns, whereas prior and posterior are 2 values, confusing! Moreover, you could refer to the figure where they are depicted
    Is low or high accuracy used? Explain where you find „without additional product“, „with product with low accuracy“ and „product with high accuracy in the table“.
64. -p.26 l.8: better phrasing (and indicating what you are referring to): „the performance of SIFB (bars with magenta color in Fig. 16) is similar for “
65. -p.26 l.11: Figure 14: ...green bars in (?). explain what you are exactly comparing! This applies for the entire manuscript and I will not further mention any further occurrences.
66. -p.26 l.17: „has so good performance already“: and l.20 „the first thing to note, l.22 „with uncertain assumption primarily“: improve phrasing
67. -p.26 l20: which step? In which procedure? Refer to figure.
68. -p.26 l23: (right hand side of Fig. 12) instead of on the modeling side of Fig….
69. -p.27 l.20 Remove „We need to“ and „here“. And put „(Equation (2))“ at the end of the sentence!
70. -caption fig 14 and 15: write instead the dependencies/sensitivities of xxx to xxx. For instance it looks like in Fig. 14 you depict the outcome of step 1 (inverse step, see your Fig. 1) meaning the sensitivities of the control vector to the EO products, while in Fig.15 you depict the sensitivities of the target variables to the control vector. (forward step 2 in your Fig.1) – could that make sense?
71. -caption Fig.16: Uncertainty reduction due to what? Explain the different bars, the different color codes.
72. p.31 l-5 which setup do you mean? Regarding the spatial resolution: It is clear, that it is finer than the target regions… why do you mention that here?
73. -p.31 l12: what does that mean that you are not resolving changes in the initial conditions? Does that mean that in the considered period of integration, the model state does not develop that much away from the initialization? Furthermore you emphasized several times in the manuscript that you are not interested in the real state but in the realistic representation of sensitivities. How does that fit here?

Technical corrections

compact listing of purely technical corrections, typing errors etc.

1. Articles are lacking in many places, such as in (p.3 l.31), (p.4 l.28), (p.15 l.13), (caption in p.19), (p.23 l.4), (p.23 l.14), (caption of table 3), (p.25 l.21 and l.35), (p.26 l.2 and l.6), (p.33 l.14)
2. Check for doubling of words such as in p.32 l.14 (than than) and in p.13 l.6 (the the), p.24 l.8: „compared“
3. Check commas, they are missing in several places, such as in: (p.4 l 9: „as mentioned, ...“), (p.5 l.5: „In this case, ...“), (p.14 l.9), (p.16 l.8: after „In the following“), (p.20 l.12: after SIC in the brackets), (p.20, l.2 after „assessment“)
4. Fullstops are missing: end of eq (6) , (7), and eq. (10), and p.20 l.29
5. Put the Tables and Figures all at the end of the manuscript. The authors jump a lot back and forth between their Figures and Tables, some of them are placed in sections that are unrelated to the Figures/Tables. Having them all in one place would make it easier to follow the argumentation.
6. Addresses of authors should be consistent in their structure. For instance, (1) has street name, while others only list the town and the country. Address (3): Danish writing of Copenhagen, which should be changed to English.
7. Abstract l.21: clarify the abbreviation EO when used the first time.

8. p.3 l.9: typo: parametrisation: correct to parameterization (or to parameterization if BE is used)
9. p.9 l.10: „Recent EO products“
10. p.3 l.12: „The constraints“ (plural)
11. p.4 l.19 and in other parts: use vector notation for vectors, such as the control vector.
12. p.5 l.16: insert comma before sigma (y). otherwise sigma could be understood as target quantity.
13. p.10 l.34: no new paragraph
14. p.10 l.34: „underestimates“ instead of „is underestimating“
15. p.10 l.35: „target regions“
16. p.11 fig5: The figure does not add relevant information to the paper.
17. p.13 fig 7 (a-b) the color map is unfortunate. The reader does not see a lot of differences.
18. p.13 l 2 and p.23 l.11: no new paragraph.
19. p15 l 2: „prior uncertainties“
20. p.16 l.6: remove „by the AWI“, this is not relevant here and does not follow common rules. Instead move „(Rickers et al. 2014)“ after „Cryosat2 mission“. Also remove „by AWI“ in l.10.
21. p.19: Grey coloring not explained in the caption.
22. p.22, l.5: „For later use it...“ and „and the three...“
23. p.23 l.2: „a April means“ - correct
24. -p.24, l.14: the prior row is the first row and not the third.
25. -p.24 l.15: „uncertainties“ - It is not only 1 uncertainty
26. -p.24 l.17-25: I do not see why you list them here.
27. -p.25 l2: rows 3-18: say to which table you refrer to
28. -p.26 l7: regions 5 and 6
29. - p.26 l.9: In contrast to – instead of By contrast to
30. -p.27 l1: remove brackets
31. p.27 .l.6: comma after technically. This sentence is way to long. Split it!
32. -p.32 l.4: „of a grid cell to a grid-cell average“: use uniform writing
33. -p32, l.12: comma after assessment