Responses to Referee 1:

We are grateful for your comments and constructive suggestions which are quite important to further improve our paper both in quality and presentation. In the following text, we will answer all the questions or comments (in italic with black color) one by one with the blue color.

The paper "Assimilation of sea surface salinities from SMOS in an Arctic coupled ocean and sea ice reanalysis" looks at the effect of assimilating the latest version (V3.1) of SMOS surface salinity data into the Arctic region. It does this by comparing the results to model runs which either did not assimilate SMOS data, or used an earlier version (V2.0) of the data. Validation was done against a variety of in-situ sources. The broad conclusion is that the V3.1 data does bring some benefits.

My comments, both minor and major, on the manuscript can be found in the accompanying PDF. The results in the manuscript will clearly be of interest to readers of EGUspehere. I also cannot see any major errors with the approach taken and how the results were obtained. That being said, and to be blunt, the paper is currently in a very poor state and needs to be considerably improved before publication.

-A: Thanks for this comment. We will improve the paper through the following aspects:

   I.   Illustrate the approach to reduce misunderstandings, and correct the equations.

  II.   Adding one figure to visualize the differences between both SSS products in summer;

 III.   Adjusting Fig. 3 to highlight the monthly SSS differences in ExpV2 and ExpV3 compared to Exp0;

 IV.   Replacing Fig. 9 to show the increments of SIC and SST which are more interesting to the readers;

  V.   Replacing four panels of Fig. 10 to show the FWC differences in ExpV2 and ExpV3 compared to Exp0.

 VI.   All the scatterplot figures will include the correlation coefficient and the significance test where possible.

VII.   The text consistency has been checked.

Some, but not all, of my major issues are:

- *The English is very poor, and nearly indecipherable in places. Most of my 230+ comments relate to the English. I appreciate that the authors are not native English speakers and that writing in English may be difficult. However, I recommend getting a native English speaker to proofread any future version before resubmitting.*

-**A**: We thank the referee for the helpful suggestions and recognize that those language corrections are not the reviewer's duty. We will improve the language as much as we can and found a native speaker willing to proofread the revision.

- *There is a lack of care with the mathematics; three of the six equations in the paper look to be wrong.*

-**A**: Sorry for some technical errors in the equations. For example, the Eq. 6 will be redefined as:

$$FWC = \int_{z_0}^{z_{ref}} \left(1 - \frac{S_{(z)}}{S_{ref}}\right) dz \tag{6}$$

And the Eqs. 4 and 5 will be corrected as:

$$Bias = \frac{1}{\sum_{i=1}^{N} O_i} \sum_{i=1}^{N} \sum_{1}^{O_i} (H\overline{X}_i - y_i) \tag{4},$$

$$RMSD = \sqrt{\frac{1}{\sum_{i=1}^{N} O_i} \sum_{i=1}^{N} \sum_{1}^{O_i} (H\overline{X}_i - y_i)^2} \tag{5},$$

For Eqs. 1 and 2, there are some misunderstandings, we will change the concerned illustration in this section.

- *The authors claim to use the DEnKF assimilation system, but their description, and mathematics, more closely relate to the EnKF – which is not the same.*

-**A**: Thank you for reminding us of the consistency of the illustration for the implemented approach. Indeed, the DEnKF is an approximation of the square root EnKF, but they are quite similar. The DEnKF was modified from the square root EnKF for simplicity and computational efficiency, but these differences would have no influence on the results presented here. In this study, the illustration of the mathematical equations of Eq. 1 and Eq. 2 is general concept equations used to introduce the concepts of innovations, increments, localization, and inflation, which are common to all variants of the EnKF. Firstly, this section will be rephrased to avoid misunderstanding. In this study, only the DEnKF will be mentioned in the method description. Finally, the DEnKF will only simply be described in a short text because the calculations can be found in the cited literature.

- *The authors do much of their analysis on absolute fields, which all look very similar to each other. This makes it hard to believe their conclusions. It would be much more informative to look at the difference fields.*

-A: Thanks for this suggestion. Figure 3 will be partly replaced by the monthly SSS differences between ExpV2/ExpV3 and Exp0. This should make the difference from the SSS assimilation runs more obvious.
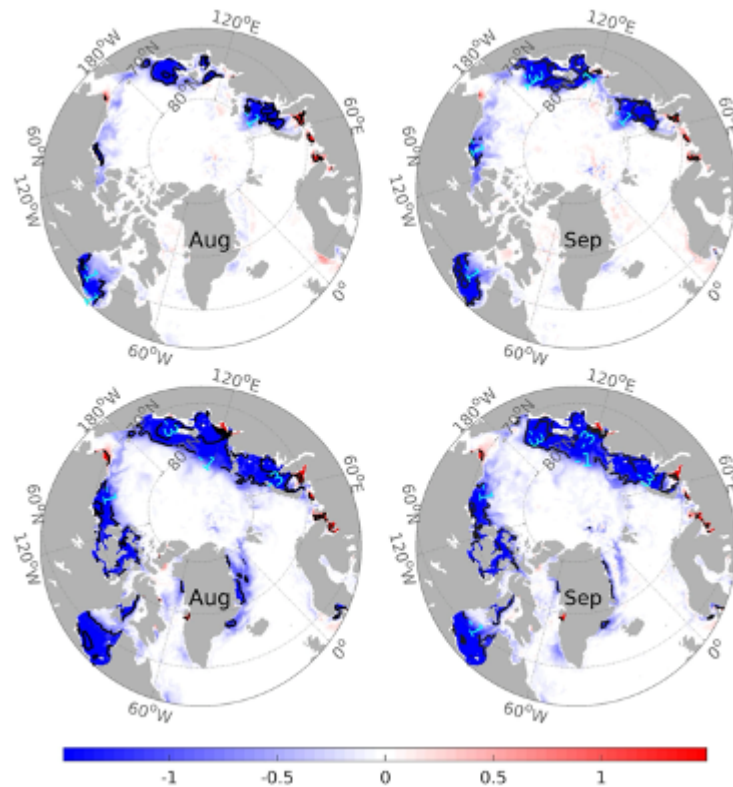
Fig. A1 Monthly SSS differences of ExpV2 (top line) and ExpV3 (bottom line) relative to Exp0 in August and September. The black lines are -3, -1, 1, and 3 PSU.

- *The authors need to give correlation coefficients between the model results and the in-situ observations. Regardless of the data being assimilated, some of the plots in figures 4, 6 and 7 make it look like the model is doing very poorly at representing salinity changes. It would be useful to see this quantified.*

-A: Although we do not claim to own the best model, we believe these scatterplots are sadly representative of the current state of ocean models. Other models may better represent the surface salinity processes but we have not seen more convincing scatterplots in the literature.

Given these points, and my comments in the attached PDF, I am recommending that the paper is accepted, bit only after major, and extensive, revision.

-A: Thanks for this comment. We also answer the highlighted comments in PDF one by one as follows.

Line by line comments from PDF file :

Line 12: "…depending on areas and put the latest product to its advantage."
-A: It is corrected as "... depending on areas, and highlight the importance of assimilating satellite salinity data. "

Line 13: "The time series of Freshwater Content (FWC) further show that its seasonal cycle can be adjusted by assimilation of the SSS products, which is encouraging for its use in a long-time reanalysis to monitor the Arctic water cycle."

-A: Change it into "The time series of Freshwater Content (FWC) further shows that its seasonal cycle can be adjusted by assimilation of the SSS products, which is encouraging for its use in a long-time reanalysis to better reproduce the Arctic water cycle."

Line 19: "The Arctic Ocean is undergoing a dramatic warming, causing the loss of sea ice area coverage visible on satellite data (Johannessen et al., 1999; Stroeve and Notz, 2018)."
-A: It is replaced by "*The Arctic Ocean is undergoing a dramatic warming, resulting in the loss of sea ice documented by previous studies (Johannessen et al., 1999; Stroeve and Notz, 2018)."*

Line 23: "A recent update of the review paper showed …"
-A: It was changed to "A recent review paper showed a stabilization of the Freshwater Content (FWC) in the Arctic Basin…" and moved to Line 35 in the next paragraph.

Line 25: ", contrary to "
-A: It is changed to Line 22:"The Arctic observing system, compared to other oceans, lacks the capability to provide a complete picture of ocean salinity, particularly because of obstruction by sea ice."

Line 34: Here and elsewhere. Use of 'the' is incorrect. In English 'the' is the "Definite Article". This means that it is used to refer to a single specific thing. It can't be used to refer to a collection of things as have you have done here. In such cases just write the plural of the noun without the 'the' prefix.

-A: It is deleted as a suggestion.

Line 36: delete "among others"
-A: It is deleted and changed to Line 32: "as done in Kaminski et al. (2015) and Xie et al. (2018)".

Line 39: delete "The"
-A: Yes, it can do.

Line 49: Please state why being free of EM interference is important.
-A: The L-band range of frequencies has been protected but this protection has not always been respected by radio emitters. As a consequence EM interferences have caused data corruption in large areas around the sources. This explains why we did not attempt to assimilate the data in the early years of 2011 and 2012 when the protection was not followed strictly.

Line 50: Could you say something about the timeliness of the SMOS data?
-A: Yes, we can add a sentence like Line 69: "Level 1 data from the satellite is available within 24 hours but the additional processing steps require high-quality auxiliary data so that the Level 3 and 4 SSS are only provided in delayed mode. " and Line 49: "During the last 12 years, large improvements have been introduced in the SMOS data processing chain, increasing the accuracy and coverage of the salinity data up to levels that were unthinkable at the beginning of the mission (Martin-Neira et al. 2016, Olmedo et al., 2018; Reul et al., 2020; Boutin et al., 2022)."

Line 58: delete "to investigate"
-A: It is replaced to Line 60: "However, very few studies investigated the impact of assimilating SSS products in the Arctic or high latitudes".

Line 62: Gap between the two lines is too large. It looks like you have started a new paragraph.
-A: It is corrected.

Line 63: No 'and' in a semi-colon delineated list. 'and' is used in the more common comma delineated list

-A: It is deleted.

Line 64: delete "from which climate change has deprived us."

-A: Yes, it is deleted.

Line 69: delete "the"

-A: It is deleted.

Line 69: "with a regular grid by 25 km resolution"

-A: It is replaced by Line 90: "on a regular 25 km grid"

Line 70: "(http://bec.icm.csic.es/; last accessed March 2019)." I'm reviewing this paper in mid-2022, so this is too long ago. Please check it is still available from this location.

-A: Thanks. The data is no longer accessible and can be obtained on request from BEC.

Line 72: "this earlier SSS", Earlier than what?

-A: It is deleted and the related sentences are rewritten as Lines 74-76: " Xie et al. (2019)

evaluated the V2.0 SSS product and another gridded Arctic SMOS SSS product developed by LOCEAN (Boutin et al., 2018) during the years 2011-2013".

Line 73: "the six SSS products", Description of the Xie paper is very poor. One product suddenly becomes five!

-A: Thanks for this comment. It will be rewritten as

Lines of 76-83: "These two SSS observations, together with an Arctic reanalysis (Xie et al.,

2017) and one objective analysis product (Verbrugge et al., 2018), were validated against in-situ observations and compared with two climatology datasets: the World Ocean Atlas of 2013 (WOA2013; *ref.*, Zweng et al., 2013) and the Polar science center Hydrographic Climatology (PHC 3.0; *ref.*, Steele et al., 2001)."

Line 76: "..further developing the non-Bayesian scheme" Restate the reference.

-A: Yes, it is replaced by Line 86: "the non-Bayesian scheme (Olmedo et al., 2017)"

Line 77: ", the effective resolutions were enhanced..." Resolution of what?

-A: Although these two products are on grids with the same resolution of 25 km, more small-scale features are present in the V3.1 product (ref. to Martínez et al., 2020; Martínez et al.,

2022). In order to clearly show their differences, one figure to show the monthly SSS maps from these two products is added.

Martínez, J., Gabarró, C., and Turiel, A.: Algorithm Theoretical Basis Document, Arctic+Salinity ITT, Tech. rep., BEC, Institut de Ciencies del Mar-CSIC, https://doi.org/10.13140/RG.2.2.12195.58401, 2020.
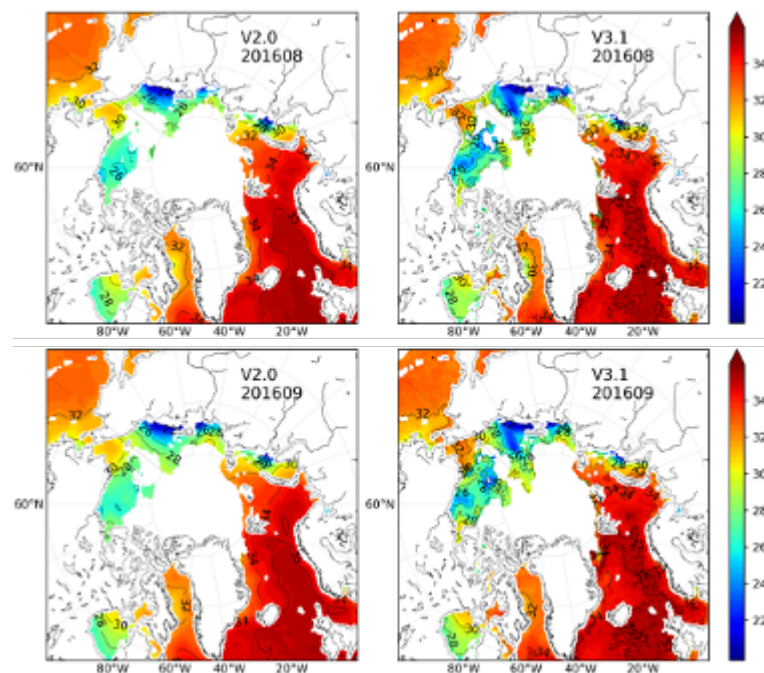
Fig. A2 Monthly SSS of Aug (top line) and Sep (bottom line) in 2016 from SMOS products of BEC V2.0 (left) and V3.1 (right). Note: the solid isolines of SSS are 22, 26, 28, 30, 32,34 and 35 psu.

Line 78: "The new version of SSS product (V3.1)" Which SSS product? I assume you mean the one from Xie et al, but you need to be clear.
-A: The new version of the aforementioned Arctic salinity product (the V3.1 SSS) shows advantages for monitoring the mesoscale. In the study of Xie et al.(2019), we used the BEC SSS product V2.0. It is clarified by the rewritten sentences in the revision.

Line 78: delete "advantages for"
-A: It is deleted.

Line 79: delete "the"
-A: It is deleted.

Line 80: delete "also"

-A: It is deleted.

Line 81: delete "the"
-A: Deleted also.

Line 81: Please state whether these products are level 3 (not in-filled) or Level 4 (in-filled).
-A: The products are actually filled level 4.

Line 87: delete "The"
-A: It is deleted.

Line 87: change "SSS products are assimilated in"
-A: It is replaced by "SSS products are assimilated into"

Line 89: "which consistes the Arctic reanalysis in the Copernicus Marine Services at that time." Reference needed. Also, I think you are trying to say that your control run is the Copernicus product, but this is not clear.
-A: Thanks for this comment. More precise information about the product ID is added like at Line 100: "which is identical to the product ARCTIC_REANALYSIS_PHYS_002_003) in the Copernicus Marine Services."

Line 91: delete "will show"
-A: Deleted, and changed it to Line 101: "The model validation against independent observations presents the differences stemming from these two SSS products,...".

Line 92: delete "are originating"
-A: It is corrected by Line 102: "although they are from the same initial data source (SMOS)".

Line 93: delete "also"
-A: it is deleted.

Line 99: delete "the"
-A: Deleted also.

Line 100: delete "contents in"
-A: Deleted and changed it to Line 111: "the freshwater simulated by the model.".

Line 106: delete "consistently"
-A: It is replaced by "to simultaneously assimilate".

Line 107: delete "in"

-A: Replaced by "for".

Line 108: delete "uses the"

-A: Replaced by "uses".

Line 109: delete "of"

-A: Replaced by "with"

Line 110: "sea ice model" What is the name of the sea ice model?

-A: Unfortunately, it had not been named in a long time. So the related references have been cited in the text for explanation. We indicate CICE as the origin of part of the code.

Line 111: delete "the dynamics of the"

-A: It is corrected by Line 125: "and dynamics by the modified elastic-viscous-plastic rheology"

Line 112: Please provide a figure showing the model domain.

-A: Thanks for this comment. We added more explanation in Lines 126-127: "The model covers the whole Arctic Ocean (shown in Fig. 1 in Xie et al., 2017). "

Line 113: delete "is imposed across Bering Strait, based"

-A: This detail is important for the surface freshwater so we keep it.

Line 118: "… timescale, and the relaxation is turned off wherever the difference from climatology exceeds 0.5 psu." What is the justification for turning off the relaxation? Won't this mean that the model will drift from climatology if the bias is big enough?

-A: The SSS relaxation does more harm than benefits if the model is too far off the target. It can typically create artificial stable freshwater layers on the top of the water column. The SSS relaxation was not turned off but capped where differences to climatology exceed 0.5 psu. The text is changed to Line 132: "... the relaxation is suppressed wherever the difference from climatology exceeds 0.5 psu to avoid the artificial formation of stable surface freshwater layers."

Line 126: "Copernicus Marine Environment" Provide reference to the CMEMS portal here.

-A: Yes, it is added as Line 150: "the Copernicus Marine Environment Monitoring Services (CMEMS; https://marine.copernicus.eu)."

Line 130: I believe these equations, and the following description to be incorrect.

The DEnKF is a 3 step process, not 2 steps: 1: Ensemble propagation (your equation 2). 2: A mean update using Kalman's equation, with the Kalman gain generated using the ensemble covariance - this looks similar to your equation 1, but operates on the ensemble mean (a vector), not an "ensemble matrix". 3: A redraw of the ensemble using the expected analysis covariance.

Furthermore, you should use standard bold lettering for vectors and matrices.

-A: Thank you for this suggestion. Eqs. 1 and 2 recap the two steps in any sequential DA system, and splitting the update of the mean from the update of the anomalies would only add unnecessary details for the purpose of this paper. In order to avoid the possible misunderstanding, the order of this paragraph was changed.

Furthermore, more words about the DEnKF calculation have been added as

Lines 146-156: The **K** matrix (Kalman gain) is calculated using the ensemble covariance matrix. ... Like other square root versions of the Ensemble Kalman Filter, the DEnKF splits Eq. 1 into two steps: the K calculation is applied to the ensemble mean, and the anomalies are updated to match a target analysis covariance (more details in Sakov et al., 2012).

*Line 132: "represented by the operator **M**" The model is a non-linear operator and cannot be represented by a matrix. Therefore M should be in italic, not bold.*

-A: Thanks, it was corrected.

Line 134: "The vector y" Should be in italic

-A: It was corrected.

Line 139: "provides a 10-days' forecast of ocean physics and biogeochemistry in the Arctic everyday via the CMEMS portal." Provide reference.

-A: Thanks. One reference was added for that.

Bertino, L., Ali, A., Carrasco, A., Lien, V., and Melsom, A.: THE ARCTIC MARINE FORECAST- ING CENTER IN THE FIRST COPERNICUS PERIOD. 9th EuroGOOS International conference, Shom; Ifremer; EuroGOOS AISBL, May 2021, Brest, France. pp.256-263. hal-03334274v2. (Available from https://hal.archives-ouvertes.fr/hal-03334274v2/document)

Line 142: delete "The"

-A: It was deleted as suggested.

Line 144: I think you should give the experiments more descriptive names. It never hurts to reduce the memory burden on the reader. In particular Exp0 should be called something like CNTL. EXPV2 should be ExpV2.0 and ExpV3 -> ExpV3.1

-A: Thanks for this suggestion. In this study, the short names of V2.0 and V3.1 were kept for representing the two SSS products.The Exp0 means without any SMOS SSS product used by assimilation. And ExpV2 and ExpV3 are explicitly related to the concerned product for these two assimilation runs. In addition, Table 1 lists the differences among the three assimilation runs so we believe the present experiments' names are clear and easy for the readers.

Line 149-158: I found this paragraph to be incoherent, and should be completely rewritten. I think you want to say that the observation error used is taken from equation 3, and the text is the justification for this - but, as I say, the text is very poor.
Also you need to say why we care about this number.

-A: Thanks for this comment. So before this paragraph, the reason was added why we highlight this parameter in

Lines 165-168: "The observation error is a key parameter in any DA system: too small values lead to overfitting, while too large values make the assimilation inefficient. The salinity errors from Passive Microwaves were previously estimated by Vinogradova et al. (2014): the zonal average of standard errors north of 60°N was estimated at 0.6 psu."

Afterward, the concerned sentences were rewritten as

Lines 168-176: "In a recent study, Xie et al. (2019) evaluated the SMOS-based SSS products using in-situ observations and revealed strong regional dependence for the V2.0 product errors: smaller than 0.4 psu in the Northern Atlantic but increasing dramatically to 1 psu in the Nordic seas and over 2 psu in the central Arctic. Undoubtedly, the salinity observation errors from Passive Microwaves are higher in high latitudes than elsewhere. Furthermore, in the Beaufort Sea (as Fig. 12a in Xie et al., 2019), the error of the SSS V2.0 product and the Arctic reanalysis product from TOPAZ (same as Exp0 used in this study) both show an inverse relationship between SSS values and SSS errors. "

Line 159: sigma^2 is the normal character used for variance - you should use that rather than delta.
 -A: Thanks for this suggestion. For the HYCOM model community, sigma potentially means the density layer. So to avoid possible confusion, it was replaced by the letter "E" in this Eq. 3 as follows:

$$E_{SSS} = max \left\{ E_{int}, \left[0.6 + \frac{6}{1+exp\left(\frac{SSS-16}{5}\right)} \right]^2 \right\} \quad (3)$$

Line 162: delete "reduce"
-A: It was replaced by "prevents"

Line 162: "inconsistencies caused by strong assimilation updates." This is not correct. Increasing the observation error makes the increments smaller; i.e it prevents "strong assimilation updates". what you have written implies that it changes how the model responds to the updates (which is not the same thing).
-A: Right, if increasing the observation error makes the increments smaller, but the inconsistencies of model stats are also possibly caused by a strong assimilation update when the observation error is too small.

So in the revision, it was changed to Line 181: "which also prevents the discontinuities caused by strong assimilation updates (as an example noticed by Balibrea-Iniesta et al., 2018). "

Line 167: "ignoring that the more recent product is a priori expected to be more reliable." Not sure what you mean by this. Do you mean they are not treated equally?
-A: Thanks for this comment. It was corrected by "ignoring the apriori expectation that the most recent product should be more reliable" for more easy understanding.

Line 171: delete "The"
-A: It was deleted

Line 172: "sanity-checked" Please provide more detail on how you conducted the quality control. At minimum you need to provide a reference on how it was done.
-A: It was replaced by Lines 192-194: "The sanity check procedures include: i) location check to ensure observation in the water grid same as the model used; ii) omit the invalid profiles if the top depth is deeper than 8 m; iii) remove redundant observations. " in the revision.

Line 218: delete "vessel"
-A: It was deleted.

Line 221: "diurnal cycle" How was this done?
-A: It happened for the high-frequency automatic records of water samples under the cruise. The observed SSSs are averaged daily to march with the model simulation.

Line 229: The mean is a vector not a matrix and so should be lower case.

Also matrices and vectors should be in bold.

-A: Before the operator H is active the ensemble mean should be a matrix and to avoid misunderstanding, the related two equations are corrected as follows:

$$Bias = \sum_{i=1}^{N} \sum_{1}^{O_i} (H\bar{X}_i - y_i) \, / \sum_{i=1}^{N} O_i \qquad (4)$$

$$RMSD = \sqrt{\sum_{i=1}^{N} \sum_{1}^{O_i} (H\bar{X}_i - y_i)^2 \, / \sum_{i=1}^{N} O_i} \qquad (5)$$

Where *i* is the *i*th day, O_i represents the observation number on this day, and N represents the total number of days depending on the collective observations. Then $\bar{X}_i$ represents the model daily average at the observation time through the ensemble mean by 100 model members here.

Line 230: "The RMSD should include a square root! Have you actually calculated the RMSD, or have you just used the mean square departure as you have written here."
-A: Yes, it was corrected, see the above response.

Line 231: These equations are wrong and are missing a sum over the number of observations. Otherwise, you don't get the scaler number that is expected
In general Hx-y on any day is a vector of the same length as y (i.e. the number of observations for that day). You can only sum these vectors if they are the same length; i.e., the number of observations is a constant each assimilation cycle. Even if you can sum them, the result would still be a vector, not the scaler you are plotting in the figures below.
-A: Thanks for this comment. A new parameter Oi was introduced in the two Eqs. These two Eqs. are changed as the above response and the related paragraph in the revision can be found as the above response.

Line 239: "The SSS innovations" Should not be in italic.

 -A: It was corrected.

Line 246: "the opposite of the bias" Why have you swapped the sign? I recommended that you don't as it will likely lead to confusion.
 -A: Thanks for this comment. It was deleted and the concerned sentence was changed in Lines 277-280: "but the mean of SSS innovation, calculated as the observation minus the model simulation (cf. the bracket in Eq.1), shows the saline bias of 0.4 psu, highest in

September. However, in ExpV3 the salinity bias quickly disappears after a few data assimilation cycles."

Line 246: "(Eq.1)" Do you mean equation 4
-A: No. It means Eq.1, but we corrected it as the above-mentioned.

Line 246: delete "shows a positive salinity bias"
-A: Yes, it was deleted. And this part of the sentence was changed into Line 279: "shows the saline bias of 0.4 psu, highest in September. "

Line 256: delete "sound"
-A: Yes, it was deleted. And this sentence was changed at Line 288: "which indicates that the observation errors for the V2.0 SSS have been overestimated."

Line 286-257: It is hard to verify what is written here. The images in the figure look very similar to each other to me - they certainly don't look to differ in any significant way.
A lot of the argument seems to be about changes in where the iso-lines have been plotted. But the iso-lines are just an arbitrary threshold and their changes could simply be due to very small adjustments in salinity. The authors should be plotting the differences between the experiments, not the absolute values. This would be more convincing given the small apparent differences.
-A: Thanks for this comment. The related figure will be replaced by the monthly SSS map from Exp0 and the SSS difference between ExpV2 (ExpV3) and Exp0 as the suggestions. So this part text is rewritten as Lines 309-321 in the revision.

Line 287: delete ", the central Arctic is excluded, "
-A: It is replaced by Line 329: "the central Arctic is not discussed, since the region is covered by sea ice and the effect of assimilation is indirect."

Line 294: replace "marginal seas" by "marginal sea"
-A: Yes, it was corrected as Line 336: ", separately considering marginal seas."

Line 300: ", but otherwise show a reasonably linear relationship" I don't agree. The scatter around the best fit lines is very large. What is the correlation coefficient?
-A: Thanks for this comment. All the concerned scatter plots will be accompanied by correlation coefficients in the revision. Here, the correlation coefficient for SSS in Exp0 is 0.59 which is significant.

Line 303: "a bias reduction" "Range" is not the same as bias.

-A: Right, this sentence was changed to avoid a misunderstanding like that in

Lines 344-346: "The range of SSS in ExpV2 is slightly improved to 28-30.5 psu. Further, the bias is reduced by 0.5 psu, corresponding to bias and RMSD reductions of respectively 13.5% and 10.5% with respect to Exp0. "

Line 304: "13.5% and 10.5% with respect to Exp0" Is this statistically significant?

-A: Thanks for this comment. To answer this question, we would like to use Student's t-test to evaluate whether the SSS error changes in the three runs are significant or not.

Compared to in situ observations, the SSS misfits in Exp0 are the error array $\mathbf{e_1}$. The corresponding error array from ExpV2 or ExpV3 is called $\mathbf{e_2}$. Thus, considering the null hypothesis H0: $\underline{e_1}$ and $\underline{e_2}$ are the means of indiscernible random draws, the t-value can be calculated as follows:

$$t = \frac{|\bar{e}_2 - \bar{e}_1|}{\sqrt{s_1^2/(n_1 - 1) + s_2^2/(n_2 - 1)}}$$

Where $s_1(s_2)$ is the standard deviation in the $\mathbf{e_1}(\mathbf{e_2})$, and n_1 (n_2) is the number of observations. For every t-value, the p-value from the above equation is the probability that random errors would prove H0 wrong. Low p-values (<0.05) indicate that the change of bias due to assimilation is significant.

 So for this case in BS, the bias reduction in ExpV2 is significant relative to in Exp0.

Line 308: "robust reduction of 26.0%" What do you mean by "robust"

-A: It was replaced by "a stronger reduction by 26.0%".

Line 310: delete "more efficient"

-A: It was replaced by "more beneficial"

Line 317: delete "the"

 -A: It was deleted.

Line 318: delete "By"

-A: Deleted and this sentence is changed to Lines 360-362: "The comparison to underway surface water samples (Fig. 6b) also shows an error reduction of around 15%, though fewer differences between ExpV2 and ExpV3. "

Line 319: delete "the"
-A: It was deleted.

Line 320: delete "errors"
-A: Yes, it was redundant and deleted.

Line 321: It is clear from figure 6 that outliers are having a massive impact on your results. This should be discussed and results presented with the outliers removed.
-A: I agree that outliers have a strong impact on linear regression also. We tried to distinguish when and where the outliers happen. For example, errors are scatterplots against longitude, latitude, or the distance to the coastline. However, we cannot find a reasonable clue to exclude the outliers in this study so they were kept at present.

Line 334: delete "if" and "these"
-A: Thanks for this comment. It is rephrased as Lines 374-376: "Considering first all SSS observations from OMG, the SSS misfits in the three runs (shown in the middle panels of Fig. 5) show smaller bias and RMSD than in the BS and the CS."

Line 338: delete "the V2.0 SSS product loses the benefit around there by DA in this system."
-A: It was changed to Line 378: "Notably, the SSS misfits in ExpV2 are almost identical to Exp0, which indicates that the V2.0 SSS product was not informative there."

Line 342: "also these two regions are listed as S5 and S6 in Table 2" Don't have two separate names for the same regions.
-A: Thanks for this suggestion. It was corrected as "Fig. 2 (also listed in Table 2)", and all the names as S1-S6 are deleted for simplicity.

Line 343: delete "real condition"
-A: It was deleted and this sentence is changed to Line 382: "This large range includes fresh coastal waters, Arctic water until Atlantic Water."

Line 344: delete three "the"
-A: they are deleted.

Line 352: delete "even"
-A: It is replaced by "but".

Line 357: delete "so"
-A: It is replaced by "as"

Line 358: delete "in"

-A: It is replaced by "in the"

Line 363: delete "this" and "brings a bias reduction of"

-A: It is changed by "shows that data assimilation can reduce the bias by 15% compared to Exp0".

Line 365: delete "Seas will"

-A: It is deleted.

Line 366: delete "the SSS retrieve"

-A: It is replaced in Line 403: "the next challenge for future versions of the SSS product."

Line 370-373: "these two satellite products …. SSS in 2016" Split into two sentences.

-A: Thanks for this comment, it is deleted due to the concerned rephrase.

Line 373: "(Fig. 8)" Figure 8, according to its caption, shows the mean increments - your text here implies that it shows the total change in salinity. These are not the same thing.

-A: Thanks for this comment, it is deleted due to the concerned rephrase.

Line 375: delete "As a control reference,"

-A: It can be deleted.

Line 378-379: "This is an indication that the presently assimilated observations in Exp0 are not able to correct the surface salinity very much." Is it not an indication that there are few in-situ observations in open water?

-A: Not only that, but the assimilation scheme being multivariate, sea ice and SST assimilation can change the SSS using flow-dependent background covariances (See Sakov et al. 2012 for a discussion).

Line 381: delete "has an underestimation for"

-A: Deleted due to this paragraph will be replaced by a discussion of the SIC and SST increment.

Line 382-385: English is poor and It is confusing which region is being described in which sentence.

-A: Deleted for the above reason.

Line 387: delete "much" and "the"

-A: -Deleted for the above reason.

Line 388: delete "increment centers"
-A: Deleted for the above reason.

Line 392: delete "much"
-A: Deleted for the above reason.

Line 392: delete "dipole of"
-A: Deleted for the above reason.

Line 393: delete "increment regions"
-A: Deleted for the above reason.

Line 393: delete "the benefits of" and "the"
-A: Deleted for the above reason.

Line 394-397: "In addition, …, Chukchi Sea shelf" English is confused and I couldn't follow it.
-A: Deleted for the above reason.

Line 400: delete "for both runs"
-A: Deleted for the above reason.

Line 403: delete "are" and "the"
-A: The first is replaced by "is", and the latter is rephrased.

Line 404-405: delete "Based on these assimilation runs,"
-A: It is deleted for the rephrasing.

Line 408: You never define what "FWCL" is? Here it implied to be the same as FWC, but later text makes me doubt this. ""
-A: Thanks for pointing out this inconsistency. All "FWCL" are replaced by "FWC".

Line 409: "and the vertical integral is computed from surface on all the waters fresher than S_{ref}." I think you are defining z_1 and z_2 here, but I am having to infer this as you don't say it - be more explicit. In fact, I suggest just rewriting the integral as between 0 and s_{ref}, where s_{ref} is the reference iso-line (or the sea bed).
-A: Thanks for this comment. We will rewrite the definition of Eq. 6, and introduce Z0 and Zref which represent the sea surface and the depth at the reference salinity or the sea bed.

$$FWC = \int_{z_0}^{z_{ref}} (1 - \frac{S_{(z)}}{S_{ref}}) dz \qquad (6)$$

Line 415: delete "During the"

-A: It is replaced by "More".

Line 416: delete "an obvious increase compared with before"

-A: It is replaced in Line 458: "When compared to the earlier reference period, the FWC in the BS has increased and its centre has shifted westward.". This paragraph has been adjusted in the revision.

Line 421: FWC on line 421 and FWCL on line 422. Are these not the same thing?

-A: It was corrected by deleting all the "FWCL".

Line 428: As in Figure 3, you are relying on the reader seeing small differences on plots of the absolute value. You should be showing the differences.

-A: Thanks for this comment. The figure will be replaced to show the SSS difference between ExpV2/ExpV3 and Exp0, as shown in the following:
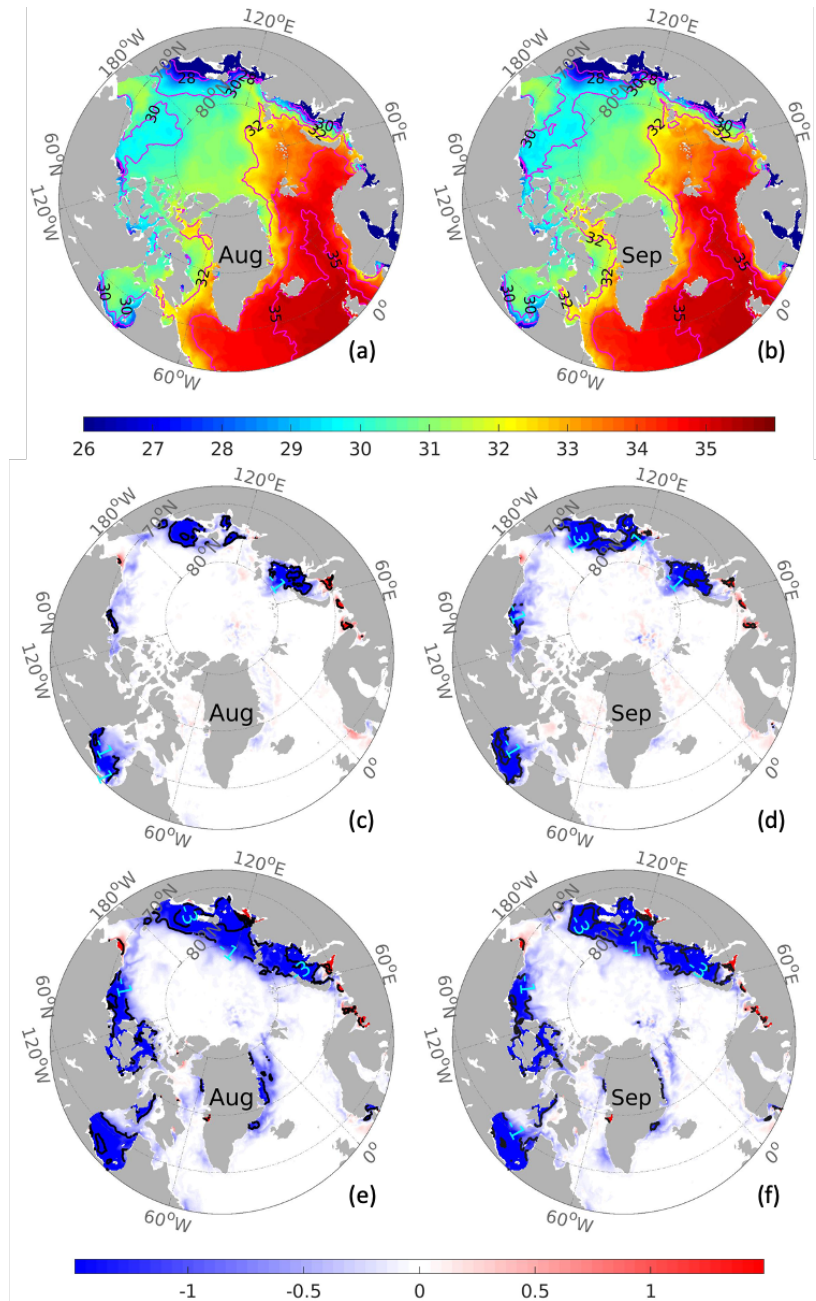
Fig. A3 Top: Monthly simulated SSS (unit: psu) from Exp0 in August (left column) and September 2016. The black isolines indicate the 26, 28, 30, 32, 34 and 35 psu isolines. **Middle and bottom**: the monthly SSS differences in ExpV2 (middle line) and ExpV3 (bottom line) with respect to that in Exp0. The black lines are -3, -1, 1, 3 psu for SSS.

Line 433: delete "in the end" and "so far"
 -A: They are deleted.

Line 446-448: "although the amplitude of the seasonal FWC seems too small in all experiments, which can be related to insufficient thick ice in TOPAZ4 (Uotila et al., 2019)." How do you know the amplitude is too small - what are you comparing it to? You should plot the expected FWC on figure 10.

-A: In the full Arctic, the seasonal variability about the FWC still has a large uncertainty and has no expected FWC. It mainly results from there are having no enough in situ observation to represent.

Line 453: delete "to track the water property" and "the"

-A: They are deleted. This paragraph has been rewritten as:

Lines 499-504: "The gridded SSS products from the SMOS satellite undoubtedly provide a way to constrain errors in salinity, especially for an ocean reanalysis system. The present study is the first observing system simulation experiment for the assimilation of SMOS SSS in the Arctic. In this study, based on the TOPAZ reanalysis system, we compared the reanalysis assimilating conventional observations with and without the assimilation of two successive SMOS SSS products from BEC."

Line 456: delete "constraining the"

-A: It is replaced by "to constrain".

Line 457: delete "the"

-A: it is deleted.

Line 458: delete "to investigate"

-A: It is deleted for the above reason.

Line 459: delete "reanalysis"

-A: It is deleted.

Line 460: "on the coupled ice-ocean data assimilative" State the name of the sea-ice system here.

-A: It is replaced by "the TOPAZ reanalysis system".

Line 466: delete "the"

 -A: It is deleted.

Line 467: "cruise underway" You have data from multiple cruises, not just one, and they should be referred to in the past tense.
-A: It is replaced by "the cruises"

Line 477: delete "show"
-A: Yes, delete it and the concerned sentences are rephrased as

Lines 510-513: "Around Greenland, the difference between the two products is even more pronounced, with a significant reduction in the SSS bias (32.6%) and RMSD (9.4%) in ExpV3, while there is no notable improvement in ExpV2. The difference is larger in the East Greenland Sea."

Line 478: delete "the"
-A: It is deleted.

Line 479: delete "markable"
-A: it is deleted.

Line 484: delete "as in Exp0"
-A: It is deleted due to the new rephrasing of the SIT/SIC increment analysis as:

Lines 519-521: "Conversely, when considering the multivariate impact of SSS on SIC (in Fig. 9) we find that the assimilation of the V2 product does not affect the assimilation of sea ice concentrations while the V3.1 product causes an increase in the negative increments, which could be an indication of excessive freshening along the Siberian coasts. In contrast, the increments of SST in the open ocean are smaller in ExpV3, indicating a synergy effect of SST and SSS."

Line 485: delete "the" and "other"
-A: They are deleted due to rephrasing as the above-mentioned.

Line 490: delete "be benefited"
-A: It is deleted as Lines 525-527: "Furthermore, this study shows error reductions of SSS when assimilating the V3.1 product from SMOS even outside of the central Arctic in the Nordic Seas and along the Norwegian coast."

Line 498: "but how the seasonal cycle varies with time still needs a longer assimilation time."
Not sure what you mean by this. Do you not have a long enough data series? Or is more
data needed to correct the results?

-A: It means the limit of this study is due to the assimilation runs last half a year only. A
longer assimilation run will be helpful to verify or correct some partial conclusions. It will be
an interesting topic in the future. To avoid misunderstanding the main findings of this study,
this sentence is replaced as

Lines 528-531:" The time series of averaged FWC north of 70°N shows that the FWC in the
whole central Arctic can be increased by about 25 cm using DA. Our experiments show that
the Arctic FWC can be redistributed horizontally after assimilation, but the latter effect
requires a longer assimilation run to be evaluated."

Line 502: delete "upgrade"
-A: It is deleted due to rephrasing as above.

Line 505: "impact indexes" What do you mean by "impact index" This has not been defined?
-A: It is replaced by "Overall score" and the concerned sentence about how to define will be
added like:

Lines 532-536: "As a summary of the quantitative SSS comparisons (Table 2), the overall
score of each assimilation setup for each subregion can be defined by its ability to reduce
the SSS bias and RMSD by more than 9% relative to Exp0 (Fig. 2). If both bias and RMSD
meet the objective, we give a score of 1, but of 2 if only one of them is met. If neither of them
exceeds 9%, the score is set to 3."

Line 509: delete "the"
-A: It is deleted.

Line 519: delete "is"
-A: It is deleted due to rephrasing.

Line 521: "still have a gap for more precisely measuring the SSS changes" Not sure what
this means. Are you implying that the data is poor in coastal regions?
-A: Yes. The SSS gradients are much smaller in the Nordic Seas than in the Central Arctic: 34.9
and 35 psu belong to different water masses so the effective precision is much higher.

It is changed as Line 542: "These may require higher accuracy to distinguish the Atlantic
waters from other water masses of salinity only slightly below 35 psu."

Line 526: delete "retrieves"

-A: It is deleted due to rephrasing.

Line 528: delete "the reanalysis" and "the"

-A: It is deleted.

Line 531: delete "the states"

-A: Changed to Line 548: "as indicated".

Line 584: Replace dots with words.

-A: it is corrected.

Line 598: "DOI" Lower case in other references

-A: it is corrected.

Line 614: "ev- idence" Fix this.

-A: it is corrected.

Line 692: Some references have "doi:" before the DOI number, but other (like this one) do not.

-A: it is corrected.

Line 710: "fromthe" and "onthe" Fix this

-A: They are corrected.

Table 2: Why is 9% 'significant'? You should do a proper significance test.

-A: Thanks for this comment. Here the "significant" will be deleted. 9% is a threshold to calculate the overall score.

Why do you have two names for the same area - this is just confusing.

-A: Right, the short names with "S?" are deleted.

Figure 1: In my opinion the inverted and non-inverted red triangles are not sufficiently distinct. Please change the colour of one of them.

-A: Right, the color for the inverted triangles is replaced by blue.

Figure 2: These plots are of the innovation statistics, not the innovations themselves; please describe them as such.

Grey line needs to be in key

-A: The caption is corrected by using "innovation statistics" and the observation number is represented by the gray line.

Delete "weekly assimilation runs" and "innovation" in the caption of Fig. 2
-A: They are deleted.

Figure 6: It is obvious that the outliers are heavily affecting these lines. Without the outliers the gradient would be much steeper - especily in the left and middle pannels.
-A: Right, in the Beaufort Sea the dots have a considerable spread around the regression line, and it becomes worse after the assimilation of SSS products. However, in the Chukchi Sea, the SSS spread in ExpV3 seems better than in Exp0. It could result from sea ice pollution to different extents locally.

Figure 9: Equation 6 computes relative anomalies. The units are meters, but I don't know how that translates into what you are referring to as 'depth". What does "depth" actually mean here?
-A: Right, the "depth" is a redundant concept and is deleted in the revision.

Response to Referee 2:

We are greatly appreciative of your comments and constructive suggestions which are quite important to further improve our paper from quality to scientific dissemination. In the following text, we will answer all the questions or comments (in italic with black color) one by one with the blue color.

This article presents the impact of satellite sea surface salinity assimilation on an Artic coupled ocean and ice system. Different version of SSS maps derived from SMOS observations in the Arctic are tested. Results show significant impact depending on the region and the product version. In situ observations from different campaigns are used to assess if those changes correspond to improvement or degradation toward the real state of the ocean. They allow to demonstrate the globally positive impact of the assimilation of the latest version compared to the previous one and the simulation without SSS data assimilation. The impact of SMOS SSS data assimilation is also assessed on a more climate- oriented diagnostic, the Fresh Water Content north of 70°N.

This article is well introduced with a clear description of the data and assimilation system used. The results are clearly and rigorously analyzed. The article is original since it shows the benefit of assimilating very recent satellite Sea Surface Salinity product dedicated to the Arctic to constrain a coupled ocean and ice system. Few satellite SSS impact studies were conducted in other regions but not in the Arctic, at my knowledge. I addition, until very recently, the accuracy of such satellite product did not allow their assimilation into ocean forecasting system in the Artic. The perspectives from this study are important. It shows that today Arctic satellite SSS product can be used to monitor and constrain operational system toward more realistic representation of the SSS in the Artic, where in situ salinity observations are sparse. I would recommend the publication of this article after minor revisions.

General comments

I would suggest showing maps of the different SSS satellite products for August and September to complement figure 3 (model fields). This will highlight differences between the product versions and between the different experiments presented in figure 3. It may also help to understand the differences in the increments in the ESS, LS and KS regions shown in figure 8. Since the increments (figure 8) are quite different in regions where no in situ data allows to evaluate their realism, it may be interesting to compare them to the mean SMOS

innovations to see if it can explain the increment differences in expv2 and expv3. As it is difficult to see the SSS differences between the different experiments and the observations when looking at the absolute fields, showing maps of differences may be more efficient to illustrate the results.

-**A**: Yes, the monthly mean for Aug. and Sep. from the two products will be interesting as the reference for understanding the results in Fig. 3 and Fig. 8 as well.
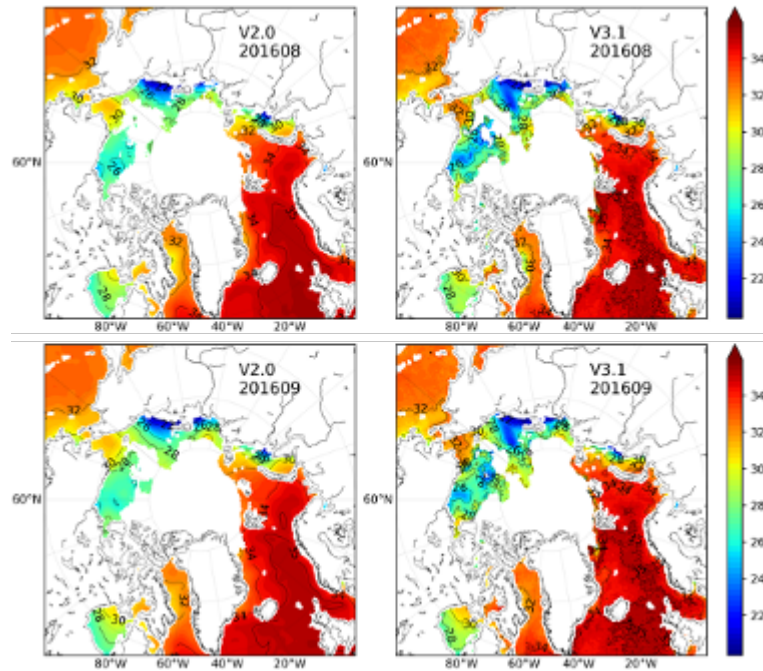
Fig. A1 Monthly SSS of Aug (top line) and Sep (bottom line) in 2016 from SMOS products of BEC V2.0 (left) and V3.1 (right). Note: the solid isolines of SSS are 22, 26, 28, 30, 32,34, and 35 psu.

In addition, Fig. 8 has been carefully considered and is partly replaced by the SSS difference between ExpV2/ExpV3 and Exp0 in the revision.

In many regions, the model salinity shows less variation than the in situ observations (scatterplots), even if it is still improved with assimilation. For the Chukchi Sea, it is attributed to the climatology relaxation, but do you have any possible explanations for the other regions?

-**A**: The model salinity also used the relaxation to constrain the possible model drift as stated in Section 2.1 at Lines 128-134: "At all lateral boundaries, the temperature and salinity stratifications are relaxed to a climatology combining version 2.0 of WAO2013 and version 3.0 of PHC with a 20-grid cells buffer zone. To avoid a potential model drift, the surface

salinity is relaxed to the combined climatology as mentioned above, with a 30-day timescale, but the relaxation is suppressed wherever the difference from climatology exceeds 0.5 psu to avoid the artificial formation of stable surface freshwater layers."

Overall, the model has less variability in salinity than the observations. One of the intrinsic reasons is that the resolution of the model itself is too coarse to be representative of in situ observations.

In few places in the article, regions are referred with "S number" that may be removed completely with just the use of the acronyms presented in figure 1.

-**A**: Thanks. It will be a good suggestion for well understanding.

Line by line comments :

l.21: Sea ice melt contributes freshwater: missing words?
-A: There is no missing.

l.119: Can you confirm that "the relaxation is turned off wherever the difference from climatology exceeds 0.5 psu." And not the opposite?
-A: Thanks for this comment. It is changed in Lines 132-134: "the relaxation is suppressed wherever the difference from climatology exceeds 0.5 psu to avoid the artificial formation of stable surface freshwater layers. "

L160: "observation" error: can you give a range for the errors attributed to the different versions? l.230: the root is missing.
-A: The observation error varied in a range of 0.8-1.0 psu as Fig. 3 shown. The missing root is corrected and identical to in Eq. 5.

l.239: The beginning of the sentence is in italic letters.
-A: It is corrected.

L.257: Adding the SMOS "equivalent maps" may help to interpret the differences between the different experiments. Does those differences follow the product differences or "remote differences" exist?

-A: Yes, as you comment it could be a good idea to add these maps. The middle and bottom panels in this figure will show the SSS differences in August and September 2016 between the SSS assimilation runs and the control run as follows:
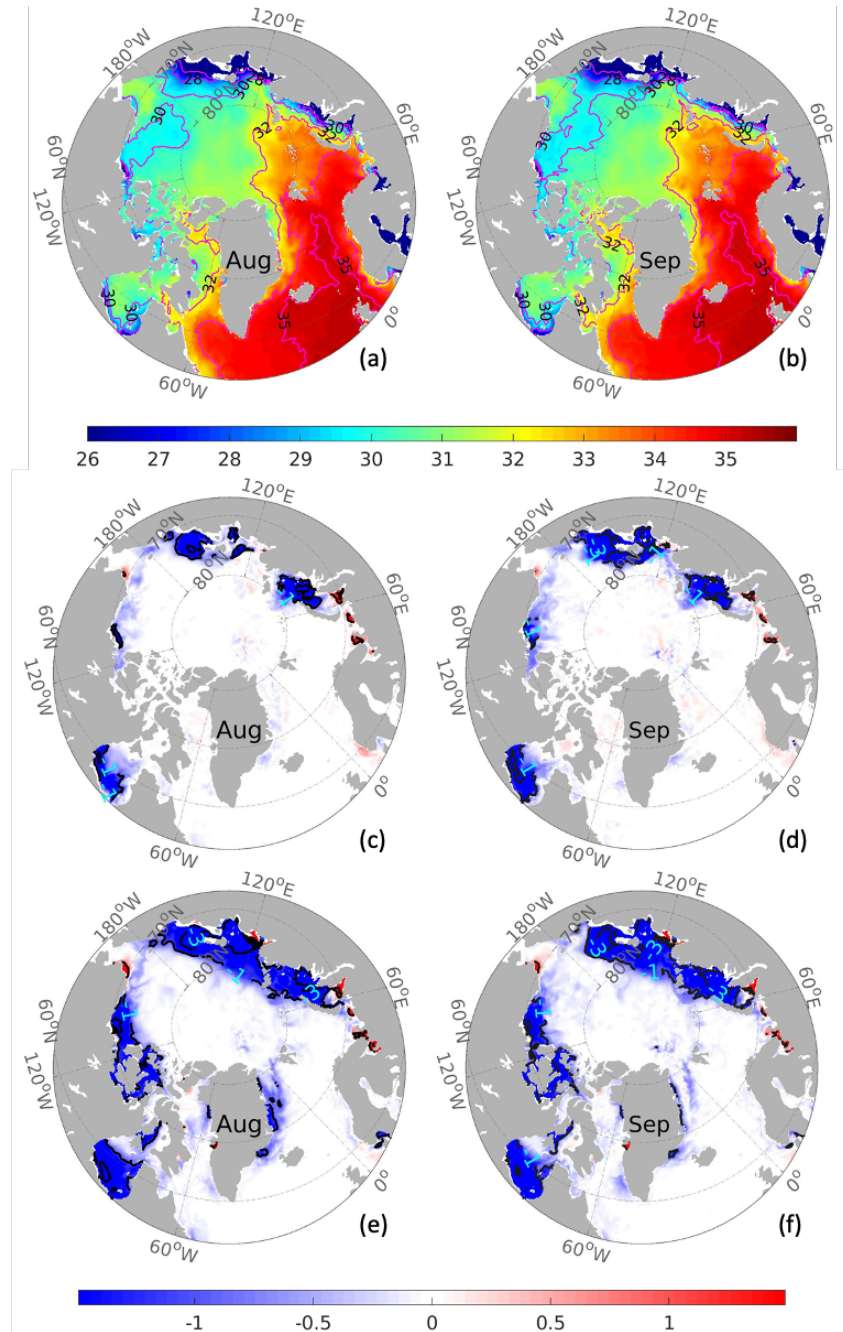
Fig. A2 Top: Monthly simulated SSS (unit: psu) from Exp0 in August (left column) and September 2016. The black isolines indicate the 26, 28, 30, 32, 34, and 35 psu isolines. **Middle and bottom**: the monthly SSS differences in ExpV2 (middle line) and ExpV3 (bottom line) with respect to that in Exp0. The black lines are -3, -1, 1, and 3 psu for SSS.

l.267: "On the European side of the Arctic, the characteristics of the saline Atlantic water are very similar in all the three runs. This is an indication that the model ensemble has a lower standard deviation of SSS." Could it be also due to smaller innovations/higher observation error in those regions?

-A: At least by deriving the pure radiometric error it does not appear that the original SSS field has a higher error in the region (figure from technical note doi.org/10.13140/RG.2.2.12195.58401
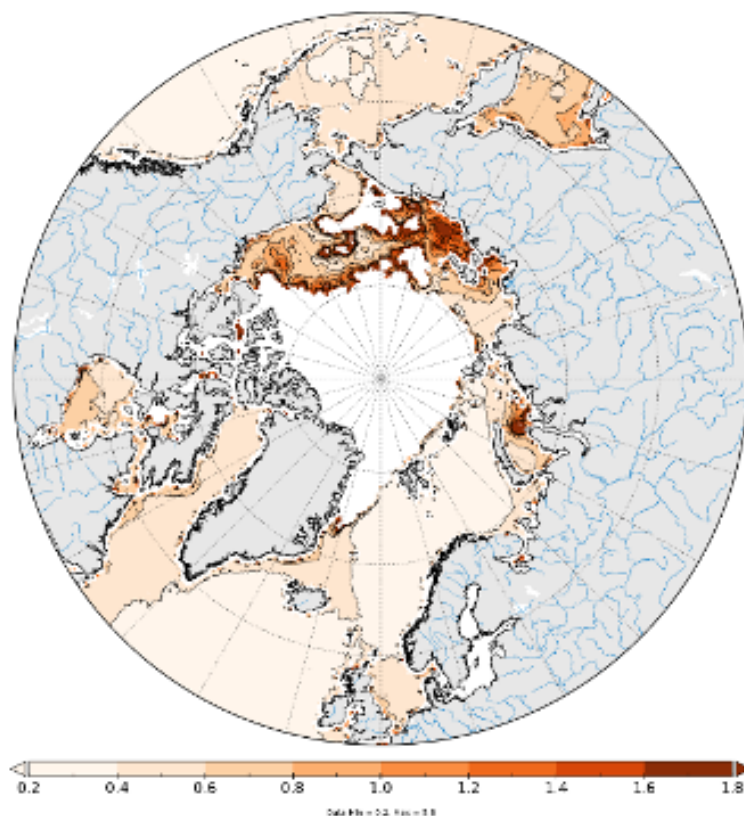
Figure 33: Salinity error derived from the radiometric error. Arctic+ v3.1 map of the period August 11-19, 2012.

However, the SSS gradients are much smaller in the Nordic Seas than in the Central Arctic: 34.9 and 35 psu belong to different water masses so the effective precision could be much higher.

l.408: the acronym FWCL is not defined.

-A: They are corrected by "FWC".

l.476: S5 and S6 regions are mentioned but only appear in table 2 and not in figure 7.

-A: These kinds of statements about S5 and S6 are deleted for easy understanding.

l.492: S1 is mentioned for Figure 1 but do not appear on it.

-A: It is deleted the same as the above mentioned.

l.496: though DA -> through DA?

-A: Right, it is corrected.

l.510: I suggest to replace S6 with BB.

-A: Right, we skip all the S? names.

L.532: Space to remove between copernicus. and eu.

-A: Thanks, it is corrected.

L.540: Space to add between Competing and interests.

-A: It is corrected.

l.544: The "link" to PO.DAAC does not work in the pdf, or it appears in blue as a link but is not.

-A: We will check this issue when the new PDF is created because it worked in the initial word version.

l.594: the correct link is: https://doi.org/10.5670/oceanog.2016.100

-A: It is corrected.

Response to Referee 3:

We are greatly appreciated for your comments and constructive suggestions which are quite important to further improve our paper from quality to scientific dissemination. In the following text, we will answer all the questions or comments (in italic with black color) one by one with the blue color.

General Evaluation:

This work presents a good assessment of the usefulness of SMOS sea surface salinity data in Arctic Ocean modeling. The control vs SSS assimilation experimental design is valid, statistical error diagnostic is standard and the evaluation is well done by comparing with independent source of observations. Discussion is also informative and interesting. In general, I found it being a nice piece of research without major flaws. However, the following attentions need to be paid for improving the manuscript. 1) there are a few mistakes in the equations, although it seems that the authors did the correct diagnostics according to the figures presented.

-**A**: Sorry for the related errors in Eqs. like the Eq. 5 missing the sqrt. Further corrects in the Eqs will follow the common mathematical rules. For instance, Eqs. 4 and 5 are corrected as:

$$Bias = \sum_{i=1}^{N} \sum_{1}^{O_i} (H\bar{X}_i - y_i) \ / \sum_{i=1}^{N} O_i \qquad (4)$$

$$RMSD = \sqrt{\sum_{i=1}^{N} \sum_{1}^{O_i} (H\bar{X}_i - y_i)^2 \ / \sum_{i=1}^{N} O_i} \qquad (5)$$

Where *i* is the *i*th day, O_i represents the number of observations on this day, and N represents the total number of days depending on the source of observations. Then Xi represents the model daily average at the observation time as the ensemble mean of 100 model members. *H* is an operator to extract the SSS simulation from the model at the observed location.

2) some acronyms, data and analysis method are not clearly defined in the text - please see my specific comments.

-**A**: Thanks for this suggestion. The consistency in the text will be checked more strictly in the revision, especially in the related comments.

3) the English writing must be improved as some parts of the article reads awkward and confusing which makes it hard for readers to follow.

-**A**: Thanks for this suggestion. We will improve the language more fluent and ask a native speaker to proofread the revision.

Other suggestions about making changes to figures and writing are included in the annotated document. Overall, I would suggest a minor revision recommendation for this article.

-**A**: We work on these comments and give the official reply in PDF with one-by-one responses.

Line by line comments from PDF file :

Line 8-9: "two assimilation runs assimilated two successive versions of the SMOS SSS product," this sentence is not very clearly written. please rephrase and expand if necessary.
-A: It is changed into "Using the Deterministic Ensemble Kalman filter from July to December 2016, two assimilation runs respectively assimilated two successive versions of the SMOS SSS product, on top of a pre-existing reanalysis run. "

Line 17: "FWC" full acronym
-A: It is Freshwater Content (FWC) and its calculation is defined by Eq. 6.

Line 60: "(Yueh et al., 2001) (e.g, the sensitivity drops from 0.5 to 0.3 K PSU^{-1} when the sea surface temperature decreases from 15 to 5°C);" no need a separate parenthesis
 -A: It is changed in Line 63: "...larger SSS error (Yueh et al., 2001; e.g, the sensitivity drops from 0.5 to 0.3 K PSU^{-1} when sea surface temperature decreases from 15 to 5°C); "

Line 73: "six" what are the six products?
-A: Thanks for pointing this out, it is changed in the revision as

Lines 74-80: "Xie et al. (2019) evaluated the V2.0 SSS product and another gridded Arctic SMOS SSS product developed by LOCEAN (Boutin et al., 2018) during the years 2011-2013. These two SSS observations, together with an Arctic reanalysis (Xie et al., 2017) and one objective analysis product (its upgradated product is available to see Greiner et al., 2021), were validated against in-situ observations and compared with two climatology datasets: the World Ocean Atlas of 2013 (WOA2013; *ref.*, Zweng et al., 2013) and the Polar science center Hydrographic Climatology (PHC 3.0; *ref.*, Steele et al., 2001). "

Line 105: "TOPAZ" define full acronym

-A: Thanks for this comment, the system name has been branded as TOPAZ for more than 20 years and the reference to the original acronym is no longer used.

Line 106: "consistently" what does consistently mean technically?

-A: One advantage of using EnKF is the multivariable adjustment even assimilates one type of observation in which other related model variables can be updated depending on the error covariance relationships. To avoid possible misunderstanding, it is replaced by "simultaneously".

Line 153: "discrepancies were a decreasing function of salinity" not a clear expression. please rephrase

-A: Thanks for this comment. The related sentences are rephrased as

Lines 168-176: "In a recent study, Xie et al. (2019) evaluated the SMOS-based SSS products using in-situ observations and revealed strong regional dependence for the V2.0 product errors: smaller than 0.4 psu in the Northern Atlantic but increasing dramatically to 1 psu in the Nordic seas and over 2 psu in the central Arctic. Undoubtedly, the salinity observation errors from Passive Microwaves are higher in high latitudes than elsewhere. Furthermore, in the Beaufort Sea (as Fig. 12a in Xie et al., 2019), the error of the SSS V2.0 product and the Arctic reanalysis product from TOPAZ (same as Exp0 used in this study) both show an inverse relationship between SSS values and SSS errors."

Line 170: "in situ" all "in situ" in this manuscript should be in italic form

-A: All are replaced by "in−situ" as an abjective in the text.

Line 230: "RMSD" incorrect equation. this should be a root mean.

-A: Yes, it is wrong and corrected.

Line 246: "(Eq. 1)" should be equation 4

-A: To avoid this misunderstanding, more explanation is added as "but the mean of SSS innovation, calculated as the observation minus the model simulation (cf. the bracket in Eq.1), shows the saline bias of 0.4 psu, highest in September."

Line 257: "Figure 3" it's hard to observe the difference between the experiments based on Fig. 3 which shows total SSS value. to facilitate comparison, one should show difference maps instead.

-A: It is also recommended by other referees so this figure has been partly replaced as follows.
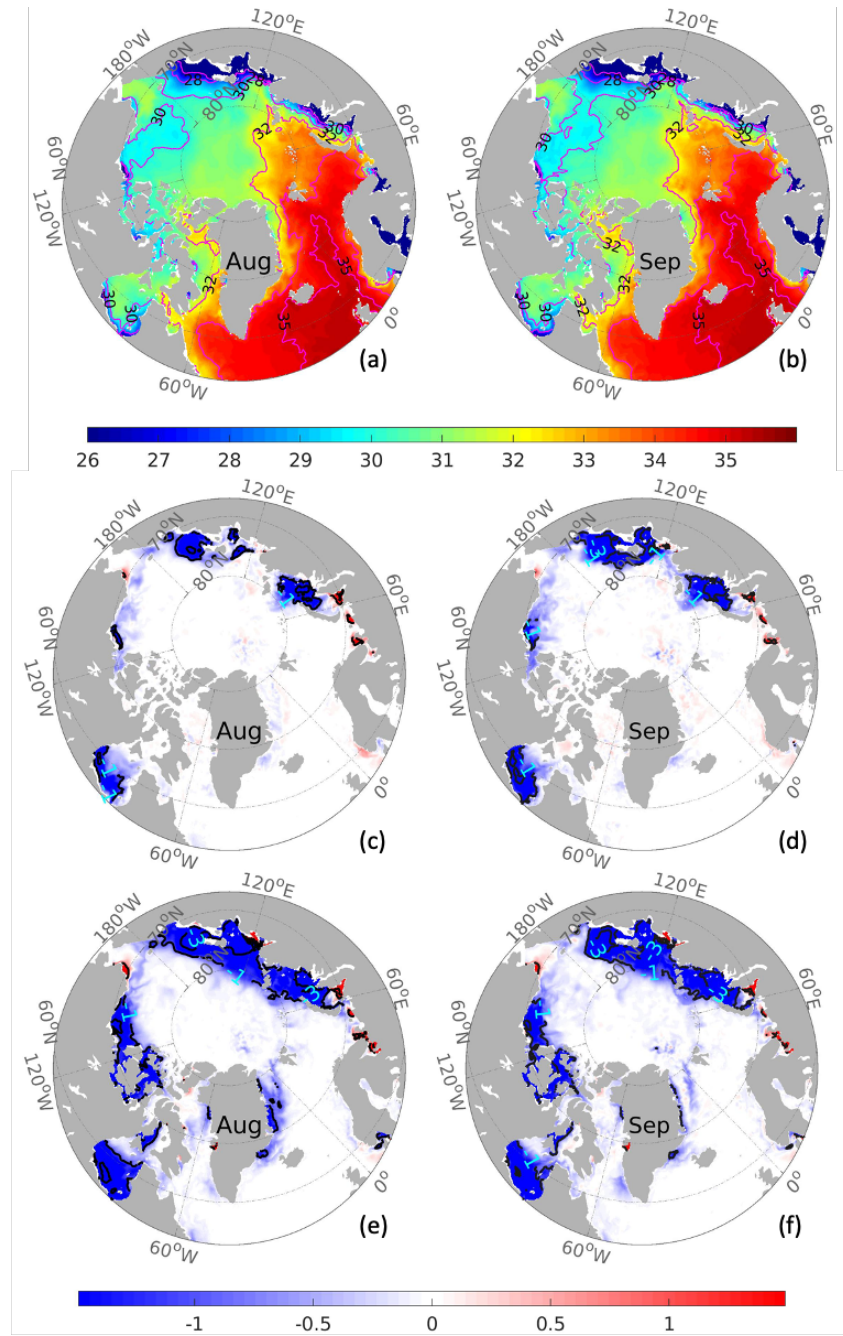
Fig. A1 Top: Monthly simulated SSS (unit: psu) from Exp0 in August (left column) and September 2016. The black isolines indicate the 26, 28, 30, 32, 34, and 35 psu isolines. **Middle and bottom**: the monthly SSS differences in ExpV2 (middle line) and ExpV3 (bottom line) with respect to that in Exp0. The black lines are -3, -1, 1, and 3 psu for SSS.

Line 337-338: *"*which suggests that the V2.0 SSS product loses the benefit around there by DA in this system.*"* is it due to the number of obs asimilated is small? or simply the data quality is not good? any further explanation?

-A: it is due to its quality limit around Greenland Island. For example, no more innovation information can be digged by the DA system if compared to the climatology of SSS.

Line 344: *"*the fresh Arctic water and the fresh coast water converge with the saltier Atlantic Water.*"* is this the reason why Expv2 and EvpV3 have no improvement?

-A: Due to this dynamic complexity, the SSS quality requires the resolution of the concerned SMOS SSS products both on space and time. The relative fine resolution of the V3.1 verifies its advantage compared to V2.0 here.

Line 349-353: *"*As indicated from SSS scatterplots of the three runs in BB (S6 in Table 1, also shown in bottom panels of Fig. 7), …, even has no significant reduction of the RMSD in GS.*"* what caused the unsatisfactory performance of ExpV2 and ExpV3 is still not clearly discussed.

-A: It may be because the SSS RMSD has been close to the smallest around 1.2 psu (as shown in Table 2), which seemly indicates the level of SMOS SSS uncertainty at high latitude areas at the current approaches. The SSS scatterplots in BB clearly show the simulated SSS between 30-32 psu in the model contains larger uncertainty compared to the salty SSS. Consequently, near the coastal regions like the BB and the Nordic, the retrieving process of the V3.1 SSS product still has no big difference compared to the previous V2.0.

Line 408: in Eq. 6, the acronym is confusing. what does L mean? please define.

-A: Thanks for pointing this out, it is replaced by FWC.

Line 434-437: *"*However, so far with the limited amount of in-situ data, it is not fair to conclude whether this is a change for the better or the worse. Significantly different from sparse in-situ observations in the Arctic, the reanalysis product can better represent the characteristics of FWC variations in space and time.*",* these two sentences read like contradicting one another. do you mean the changes due to DA do not guarantee an improvement, but it might be useful for describing spatiotemporal variation of the FWC?

-A: Not exactly. Thanks for this comment. The FWC figure is changed by adding the difference between ExpV2/ExpV3 and Exp0 so the related sentence will be rephrased in the revision.

Line 493: "other version of SSS product"

-A: It is corrected by "the V2.0 SSS product"

Line 505: "indexes" is this the same as "overall score" in Table 2? how do you define this index? this should be included in the methodology section. The plural form of index is indices, not indexes

-A: Right, the basic idea is trying to help us to distinguish the affected areas. So it can be replaced by "overall score" to avoid too many definition equations.

*Table 2: "*Overall score*"* same as the impact index mentioned in discussion?

-A: It is a good idea to use "overall score".

Figure 3: suggest to keep Exp0 maps as they are but show difference maps for Expv2 and v3

-A: Thanks for this suggestion. This figure was changed as the above mentioned.