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, Eq. 6 will be redefined as:

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

And Eqs. 4 and 5 will be corrected as:

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

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

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.
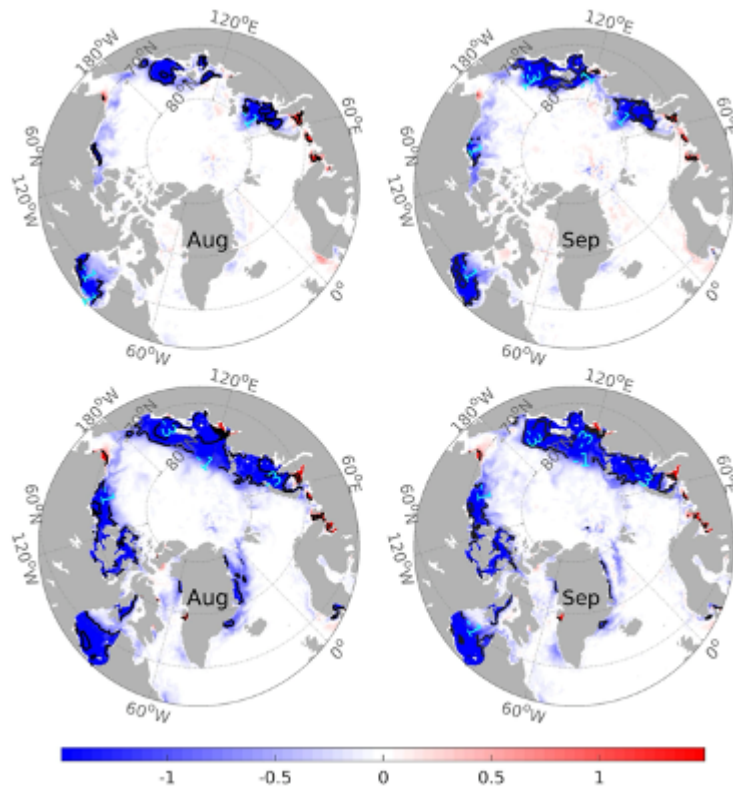
Fig. A1 Monthly SSS differences of ExpV2 (top line) and ExpV3 (bottom line) relative to Exp0 in August and September. The black lines are -3, -1, 1, and 3 PSU.

- *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 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 behave better 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 the next paragraph.

Line 25: ", contrary to "
-A: It is changed to"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 the suggestion.

Line 36: delete "among others"
-A: It is deleted and changed to "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 has caused data corruption in large areas around the sources. This explains why we did not attempt to assimilate the data in early years 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 "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 "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 "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 "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: 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.

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 "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 (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 replace by "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.
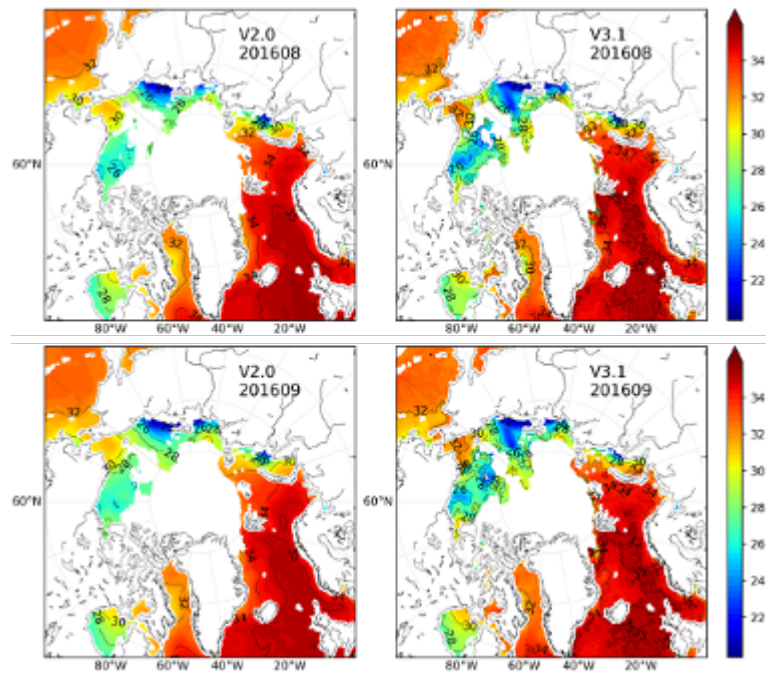
Fig. A2 Monthly SSS of Aug (top line) and Sep (bottom line) in 2016 from SMOS products of BEC V2.0 (left) and V3.1 (right). Note: the solid isolines of SSS are 22, 26, 28, 30, 32,34 and 35 psu.

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.

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 "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 "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 "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 "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 "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 as "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 "... 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 "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: 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 like "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."

Afterwards, the concerned sentences were rewritten as

"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:

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

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 possible caused by a strong assimilation update when the observation error is too small. So in the revision, it was changed to "which also prevents the inconsistencies of model states caused by strong assimilation updates. "

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 " 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. " It will be added 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:

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

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

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 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. 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 bracket term in Eq.1" for easy understanding.

Line 246: *delete "shows a positive salinity bias"*
-A: Yes, it was deleted. And this part of the sentence was changed into "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 as "which indicates that the observations 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 will be rewritten in the revision.

Line 287: delete ", the central Arctic is excluded, "

-A: It is replaced by "the central Arctic is not discussed, since the region is covered by sea ice and the effect of assimilation is indirected."

Line 294: replace "marginal seas" by "marginal sea"

-A: Yes, it was corrected.

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 "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 "The comparison to underway surface water samples (Fig. 6b) also shows an error reduction of around 15%, though less 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 scatterplot 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 "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 "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 can be changed to "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 by "the next challenge for future versions of the SSS product."

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

-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 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 rephrase.

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.

$$FWC = \int_{Z_0}^{Z_{ref}} (1 - \frac{S_{(z)}}{S_{ref}})\, dz \qquad (6)$$

Where the reference salinity value S_{ref} is taken at 34.8 psu, z_{ref} is the depth of the reference salinity or the sea bed, and $S(z)$ is the salinity profile.

Line 415: delete "During the"

-A: It is replaced by "More".

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

-A: It is replaced by " been increased obviously"

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 as the following:
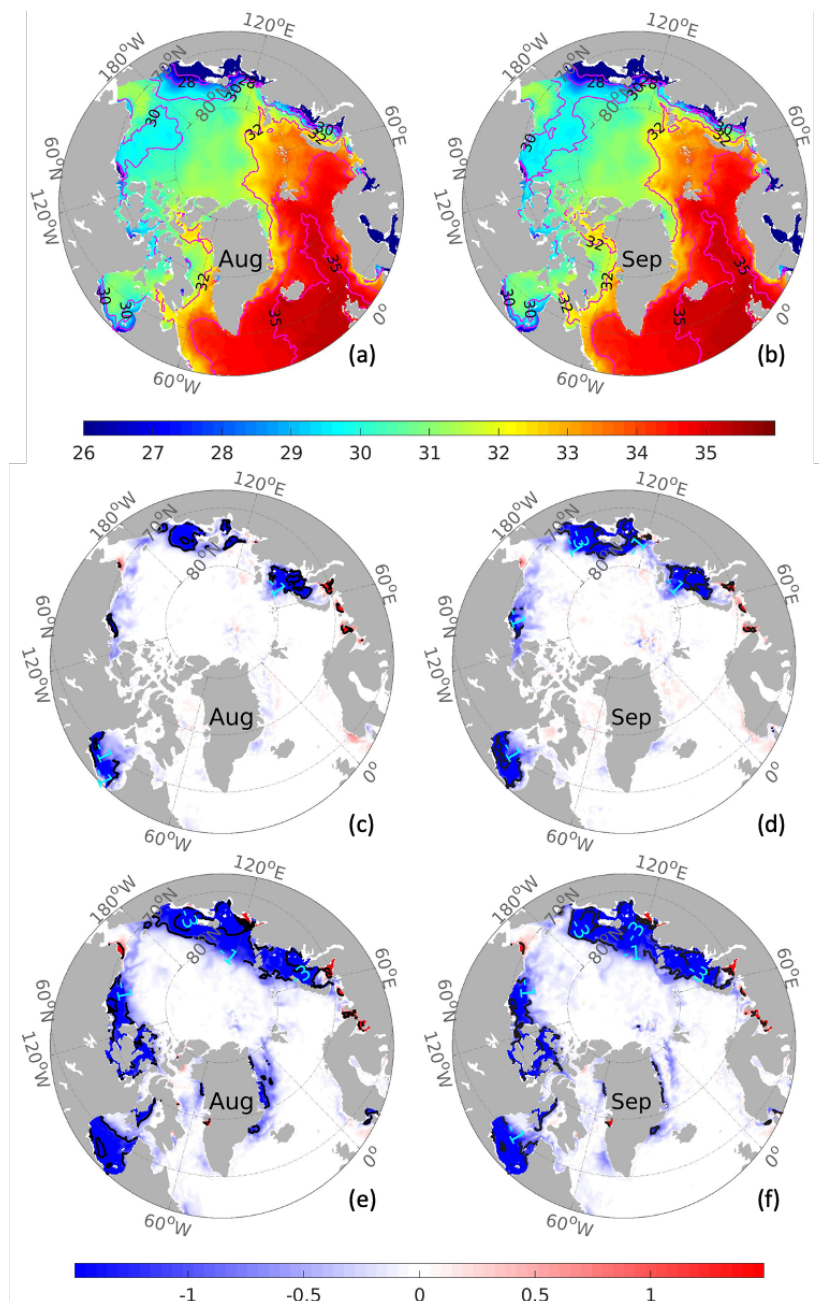
Fig. A3 Top: Monthly simulated SSS (unit: psu) from Exp0 in August (left column) and September 2016. The black isolines indicate the 26, 28, 30, 32, 34 and 35 psu isolines. **Middle and bottom**: the monthly SSS differences in ExpV2 (middle line)

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 the 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.

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 replaced by "to present".

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 "on the TOPAZ".

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 replace it with "the SSS in ExpV3 shows".

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 changed by "compared to Exp0".

Line 485: delete "the" and "other"

 -A: The former is deleted, and the latter is replaced by "more".

Line 490: delete "be benefited"

-A: It is replaced by "benefit".

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 to correct some partial conclusions. It will be an interesting topic in the future.

Line 502: delete "upgrade"

-A: It is replaced by "improvement"

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:

"Using the quantitative SSS misfits (Table 2), the overall score at each subregion can be defined by the reduction of SSS bias and RMSD over 9% relative to Exp0 (Fig. 2). If they are both hits, the score equals 1, and given 2 if only one of them is hit. If they are no more than 9%, the score is 3."

Line 509: delete "the"

-A: It is deleted.

Line 519: delete "is"

-A: It is replaced by "would be".

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.

Line 526: delete "retrieves"

-A: It is replaced by "measurements".

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

-A: It is changed to "improvements in both reanalysis and ocean forecasting".

Line 531: delete "the states"

-A: Changed to "stated".

Line 584: Replace dots with words.

-A: it is corrected.

Line 598: "DOI" Lower case in other references

-A: it can be 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"

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.