

## Reply on RC2

*Dear reviewer, your insightful review is greatly appreciated. All of your suggestions have been tacked into account.*

### General comments:

This study aims to estimate the improvement of liquid freshwater content by adding satellite sea surface salinity to reanalysis salinity at depth in the ice-free region of the Beaufort Sea. The analysis combines the salinity data from the TOPAZ4b reanalysis at various depths with the SMOS SSS values for the layers above the three specified fixed mixed layer depths. The authors suggest a clear improvement in the liquid freshwater content estimation when adding satellite sea surface salinity above the fixed mixed layer depths, especially in areas close to ice melting.

The authors' idea of adding the salinity satellite data to the reanalysis in estimating the high latitude liquid freshwater content is rational and vital for monitoring one of the key processes - the large-scale changes in Arctic freshwater content. However, there are some validation and methodological issues to the calculation of liquid freshwater content that require further examination. The manuscript should be suitable for publication once these issues are clarified.

### Specific comments:

Line 10-11. There are many different definitions for calculating mixed layer depths. A sharp halocline near the sea surface could "create" a shallow surface mixed layer that is much shallower (but more realistic) than a "conventional" mixed layer depth that is estimated by bulk SST and SSS measurements and deeper profiles. Therefore, it would be very helpful to say something like "when adding satellite sea surface salinity above the mixed layer that is calculated by deeper/bulk SSS".

*We have rephrased this phrase as: 'The results highlight the underestimation of the freshwater content using reanalysis data in the Beaufort Sea and a clear improvement in the freshwater content estimation when adding satellite sea surface salinity measurements in the mixed layer.' The information on how the MLD is calculated is detailed in paper by Toole et al., 2010 cited in section 2.4.*

Line 29: Lenton et al. 2019 may not be suitable for the statement: "since 1997, high atmospheric pressure has triggered strong anticyclonic winds over the Beaufort Gyre area".

*We have deleted the reference in this line.*

For section 2.4. Are you considering or evaluating the feasibility of combining SMOS SSS and in-situ ocean salinity data (e.g., CTD, XCTD, and UCTD) mentioned in section 2.3?

*In section 2.4 we explain how we combine SMOS SSS with TOPAZ4b to compute FWC, in section 2.3 we explain the in-situ based estimation of FWC produced as described in Proshutinsky et al 2009. For the moment we are not considering to combine in-situ with SMOS SSS but we will consider your suggestion for future research.*

Figure 1: please clarify the mean uppermost salinity level of TOPAZ4b used at least in the figure captions. The uppermost salinity level from

[https://data.marine.copernicus.eu/product/ARCTIC\\_MULTIYEAR\\_PHY\\_002\\_003/description](https://data.marine.copernicus.eu/product/ARCTIC_MULTIYEAR_PHY_002_003/description) is 0m. Is it the level of TOPAZ4b in this study?

*Yes, this is the level used, we have clarified this point in section 2.2 when presenting TOPAZ4b*

Line 157-158: Please clarify if the authors combine the salinity data from the TOPAZ4b reanalysis at depths above the MLD and only replace the surface level of TOPAZ4b salinity with SMOS SSS values for computing the freshwater content. It would be beneficial to state it in section 2.

*We combine the salinity data from the TOPAZ4b reanalysis at depths below the MLD and replace the levels of TOPAZ4b above MLD with SMOS SSS values in areas free of ice for computing the freshwater content, we explain this point in Section 2.4.*

Also in the caption of Figure 3 (also the paragraph starting in Line 160) the author states that “The freshwater content difference is computed as freshwater content from TOPAZ4b salinity minus the freshwater content from TOPAZ4b adding SMOS up to 16 meters.”. Could the authors please clarify if the freshwater content in Figure 3 (b) and Figure 3 (e) is calculated. What does adding SMOS up to 16 meters mean? Does it replace all the TOPAZ4b salinity above 16 m with SMOS SSS or just replacing the top level (0m?) of TOPAZ4b salinity to SMOS SSS?

*It is replacing salinity values of TOPAZ4b with SMOS SSS values in all levels of TOPAZ4b up to 16 meters.*

The main concern is that SMOS SSS may be representative for the very fresh but thin of the surface layer from sea ice melting. SMOS SSS could possibly be representative for less than the upper 5 m of the surface layer. Could the authors plot vertical profiles merging “SMOS SSS as the surface salinity value” and “the collocated in-situ profiles (the uppermost level shallower than 2~3 m would be great or at least shallower than 10 m)” in the area to confirm if this method is representative to the vertical structure. Toole et al. (2010) that is cited in section 2.4 and 3.1 mention (in their section 2.1) that their ITPs were programmed to sample the water column between 7 and 750m. Many of their ITP profiles in midsummer indicate that the Canada Basin ML is frequently thinner than 10m. Their abstract also suggests that “The July–August mean mixed layer depth based on the Ice-Tethered Profiler data averaged 16 m (an overestimate due to the Ice-Tethered Profiler sampling characteristics and present analysis procedures)”. The point is, even though replacing the entire 16, 25 or 29 m of TOPAZ4b salinity to SMOS SSS increases the FWC estimation, this method likely overestimates the contribution of SMOS SSS. The deviation of overall near-surface thermohaline structure of TOPAZ4b/ reanalysis from the observations may contribute to much of the underestimation of the FWC compared to in-situ measurements.

*Indeed, the reason why the reanalysis system underestimates FWC compared to in-situ measurements not only lies in the near-surface thermohaline structure but may also be affected by the use of a river climatology that underestimates discharge or coupled with an ice model that underestimates ice thickness. As you point out, it is possible that our method may overstate the importance of surface salinity by adding SMOS salinity throughout the entire mixed layer. However, it is clear from our experiments that integrating the surface salinity observed by SMOS in the upper ocean substantially improves the freshwater depth in the Beaufort Gyre.*

*In this work we aim to emphasize the value of satellite surface salinity data in the study of FWC. Sure, we make assumptions about how representative surface salinity is of the mixed layer. We acknowledge that the depth of the mixed layer can be further refined, and we want to address this point in the near future. We account for this source of uncertainty conducting the tests with three different mixed layers to account for the spatiotemporal variability of the MLD, and the errors associated to our need to integrate surface salinity using a fixed-layer model.*

Line 206: Please specify what the slope is indicated. Is this the slope estimated in Figure 7? It is better to specify what the slope is in Line 225 as well.

*Yes, it is related to Figure 7, we have integrated this information in the text.*

Line 215 states that “the results show a significant improvement in terms of bias” but in figure 7 the biases on the two figures are both 1.81. Please clarify.

*The bias on the Figure 7a is 1.81 and the Figure 7b is 1.18*

Line 219: It is not very clear what dispersion is. Is it the difference between the estimation of TOPAZ only or TOPAZ+SMOS SSS? Please specify. Also, it is not very clear what “the dispersion remains stable” means. Does it mean the difference between the two (not sure what the two are) does not change with time or ?

*The dispersion refers to the standard deviation, and the error remains stable, refers in the three experiments, we have clarified that in the text.*

#### **Technical corrections:**

Line 53: SMAP should be launched and has become operational since 2015.

*Changed*

Line 137: Might want to add parentheses to the citations.

*Done*

Line 137-139: This sentence “Note that even if TOPAZ4b reanalysis assimilates SMOS SSS, the resulting surface salinity does not seem to reproduce the same SSS dynamics as seen by SMOS.” seem to belong to the next paragraph. Please consider reconstructing these two paragraphs.

*Changed*

Figure 3 captions: Please move (a,d) (b,e) (b,e) (c,f) (top row) (bottom row) to before the items described.

*Done*

Table 1: Please consider an option of adding the values in table 1 to an additional subfigure of Figure 4 for easier reading instead of stating the yearly mean in numbers. Even though it will

be only about 10 data points for each fwc estimate, it would be easier to visualize the yearly mean variation and the differences between different fwc estimates.

*If I understand correctly, the information you're requesting is already included in Figure 6, where we have also incorporated the estimation from in-situ data.*