

Dear editor,

We are resubmitting the manuscript, “An Algorithm to Transform Arctic SMAP-derived Skin Salinities into Bulk Surface Salinities,” to *Remote Sensing*. We have 1) changed the argument that the size of the biases relative to the SMAP-derived SSS uncertainties matter because the latter are underestimates, 2) emphasized that the bias-correction our algorithm provides is more important than the skin-effect adjustments to the SMAP-derived SSS, 3) added a subsection where we described the OAFlux product and a discussion section where we argue that the OAFlux product allows us to adjust some of the ancillary fields relevant to SSS retrievals (like wind stress, SST, and ice cover), and 4) made the figures look better. We have also made some additional minor corrections according to the reviewers’ suggestions. We address each of the reviewer’s points below.

1 Reviewer #1 (Comments to Author (shown to authors):

- I cannot recommend the manuscript for publication, as I believe there is a serious flaw in the whole line of argumentation: A). The authors observe and report biases between satellite (SMAP, SMOS) SSS and in-situ measurements in the polar oceans. They attribute these biases to the difference between skin salinity, as measured by the satellites and bulk salinity (at 5 m depth), as measured by the in-situ sensors. They then attempt to develop a correction algorithm for that difference. I do not see any convincing reason at all why the observed satellite – in-situ difference is caused by the vertical salinity stratification. In fact, there is a long list of possible

systematic errors in the satellite salinity retrievals, which are much more likely causing these observed biases.

- We thank you for your thoughtful review. It appears that we were not clear about what our algorithm does to correct for the biases between the satellite-derived surface salinity and *in-situ* measurements of salinity. We are correcting for both the skin-effect and inconsistencies with the OAFlux air-sea flux product. The skin-effect, as you correctly argue, is the less important correction, which is why we include so many air-sea flux terms in our algorithm. We may have misled the reader with the title of our manuscript, by focusing so much on the skin-effect, and by quantifying the correlations between the skin-effect corrected salinities from the Yu (2010) theory and the *in-situ* measurements of salinity. If we only account for the skin-effect, the root-mean-square error (RMSE) does not get cut by even 10% of the overall reduction we find with our full algorithm.
- For instance, in the order of my estimated importance: 1. Errors in the model for the electromagnetic permittivity (dielectric constant) of sea water, which governs the L-band emission from a flat ocean surface, and which plays a pivotal role in the satellite salinity retrievals. 2. Systematic errors in the ancillary wind fields or the wind roughness model that are used in the surface roughness correction of the SSS retrievals. 3. Systematic errors in the ancillary SST fields that are used in the SSS retrievals. 4. It is my understanding that the Version 5 of the JPL SMAP SSS and also the BEC SMOS SSS attempt to undertake a correction for

sea-ice contamination. That is difficult to do as the ancillary sea-ice products that go into that correction are not accurate enough close to the sea-ice edge. That could easily result in over or under correction of the sea-ice contamination. 5. SMAP has the notorious problem of an emissive reflector (antenna dish), which has a strong seasonal signature. It is difficult to correct because it requires accurate information of the physical temperature of the antenna dish, which is not available. 6. There could be issues with the reflected galactic radiation or sun glint. These effects need to be corrected for in the SSS retrievals, which could result in residual uncertainties. 7. Combinations of some or all of these.

- **These are excellent points that are connected to the terms in our algorithm. For example, the OAFlux fields we use in our algorithm are correcting for errors introduced by the ancillary wind and SST fields. Also, the OAFlux fields are not defined where there is sea-ice so restricting our estimates to locations where the OAFlux fields have values should help with the ancillary sea-ice product issue. We are not likely correcting for errors in the model for the dielectric constant of seawater, but a future study could potentially include the tidal signals of satellite magnetometry data (e.g., as *Sabaka et al.* (2016) have done) or an inverted estimate of the dielectric constant itself in the predictors of our algorithm to correct for this source of error.**
- The fact that the observed satellite – in-situ salinity differences exceed the reported errors in the satellite SSS data is not a valid argument, as this reported errors in the satellite SSS could easily (and I believe most likely does) underestimate the true

error in the retrieved SSS. One should note here that because of the low sensitivity of the L-band brightness temperature (TB) to salinity in cold water (1 K TB error = 4 psu SSS error), even small radiometric errors can lead to large errors in the observed SSS.

- **We agree there is a potential issue with underestimating the true error in the retrieved SSS from satellites and have rewritten the text to reflect this. Specifically, we have removed the argument that the biases in surface salinity exceeding the reported SSS errors makes them significant. Because the *in-situ* measurements have more smaller errors than satellite-derived values at high-latitudes, the *in-situ* measurements are more reliable than the satellite-derived values so a smaller root-mean-square error between them is our goal.**
- In order to assess the observed satellite – in-situ salinity differences, one would first need to exclude the aforementioned error sources, before considering attributing them to skin-bulk differences. That requires to look in detail into the geophysical signature of the observed biases (seasonal and zonal variations, differences between look direction, differences between ascending and descending swath). That is not a simple task. A potential way to go about it is to look at satellite SSS retrievals from other algorithms (NASA/RSS SMAP SSS, LOCEAN SMOS SSS) and see if the observed biases are about the same as in the JPL SMAP or the BEC SMOS data. At least that would give a hint if the biases were caused by the SSS retrieval algorithm or not.
- **This comparison (across satellite-derived SSS products) exercise has been**

done by *Fournier et al.* (2019) in the high northern latitudes. But one important detail to note is that our algorithm is different for different satellite-derived SSS retrieval products. We only use one SMAP product in our study, but we also explored applying our algorithm to a SMOS product, which also experienced improvements. We include the SMOS-derived SSS versus *in situ* salinity in the top-5 meters comparisons here in this document with a figure for reference to demonstrate that the biases look fairly similar across the two different data products. We decided not to include that SMOS product because the main reason to include another product is to assess why there are differences in their biases, which we are not able to do with our algorithm. We are only able to determine whether the RMSE was reduced for each product after applying our algorithm (which it was for each product).

- B) Looking at Figure 1, it appears that, on average, the satellite (skin) salinity is actual saltier than the in-situ (bulk) salinity. That is odd, as the mechanisms that could cause a mismatch between skin and bulk salinity (precipitation, river discharges, sea-ice melt) should make the skin salinity fresher. So, what mechanism could cause it getting saltier? Evaporation is a very unlikely candidate in polar regions. This is another strong indication that the observed satellite - in-situ salinity differences are NOT caused by skin – bulk differences but rather point to deficiencies in the satellite SSS retrievals.
- You are correct that this is further evidence that the biases in the satellite-derived SSS relative to the *in-situ* measurements are not due

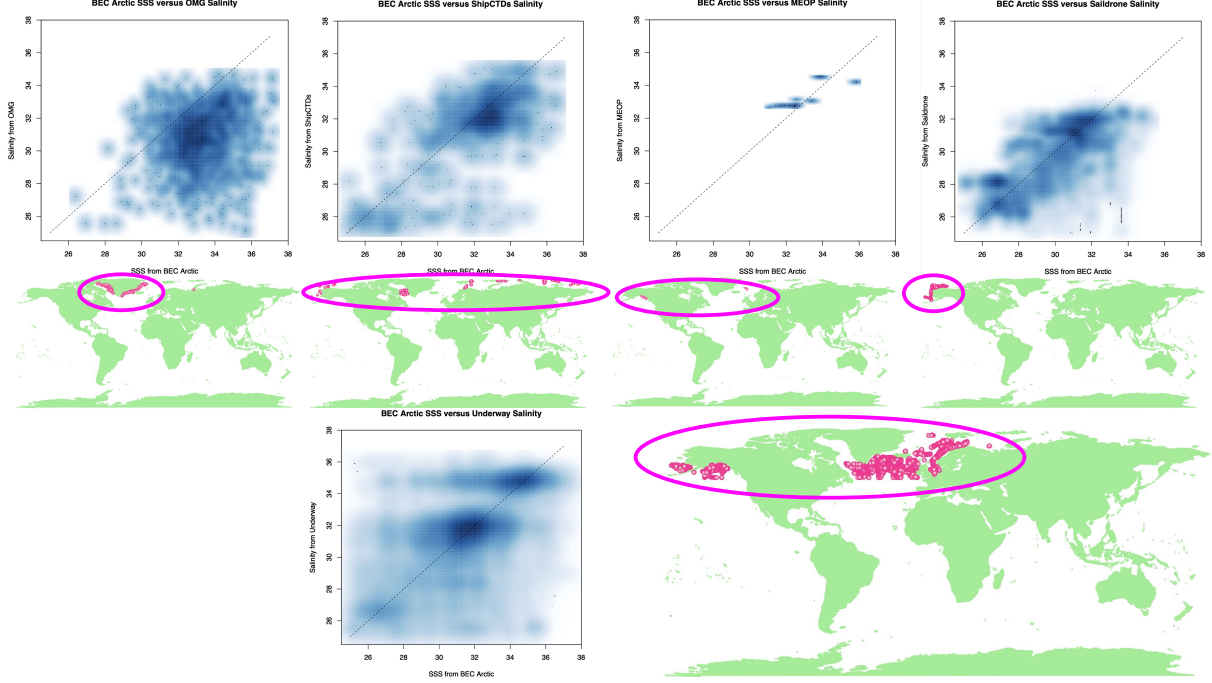


Figure 1: BEC SMOS Level-2 skin SSS for June 2010 to December 2020 (abscissa) sampled within 50 km and 3.5 days of all *in situ* observations in the top-5 meters versus the bulk SSS from *in situ* observations in the top-5 meters (ordinate) from the Oceans Melting Greenland (OMG – panel a), ship-based CTD hydrography (panel b), Marine Mammals Exploring the Oceans Pole to Pole (MEOP – panel c), Saildrone (panel d), and Underway (panel e) campaigns. The darker the shade of blue, the greater the number of points in the scatterplots; outliers are shown with single black dots. Also shown next to each scatterplot are the locations where the comparisons between the SMAP SSS product and the *in situ* observations are made (pink dots, regions circled).

to the skin-effect. Rather, they are due to deficiencies in the satellite-derived SSS retrievals, as you suggest.

- A couple minor issues that I observed: C) The axes labels in Figure 1 are very small and thus illegible.
- We have worked on this to make the labels more easy to read.
- D) Table 1: I believe the unit for the gravitational acceleration g should be m s^{-2} .
- This was a typographical error made by us and has now been corrected.