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NASA/RSS SMAP Salinity Version 5.0 Validation Analysis

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SMAP Salinity Validation Analysis; Data Version 5.0

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1. Introduction

The purpose of this report is to document the Soil Moisture Active Passive (SMAP) sea surface salinity (SSS) measurement uncertainty characteristics, including residual errors in the latest version (**V5.0**) of the SMAP data product provided by Remote Sensing Systems (RSS), which is sponsored by the NASA Ocean Salinity Science Team. This dataset is available at www.remss.com and was released in March of 2022. This release should not be confused with CAP (Combined Active Passive), the SMAP SSS data published by NASA's Jet Propulsion Laboratory (JPL). While both data sets were originally created from the same raw SMAP retrievals, the processing workflow and final products differ.

We document the improvement from the Remote Sensing Systems (RSS) V4.0 to V5.0 data sets by comparing each version of SMAP data with Argo and additional in situ data. It should be noted that the matchup statistics (e.g., Section 4 and 5) between SMAP and in situ observations not only include SMAP SSS uncertainty, but also the sampling differences (e.g., spatial scales) between SMAP data (averaged over SMAP footprint) and the point-wise in situ measurements. In addition to this horizontal component of the sub-footprint variability, a vertical difference in sampling between in situ measurements and L-Band radiometry exists under conditions of haline stratification, which further contributes to the sampling differences (Boutin et al., 2016).

Here, we use 87 months of data for SMAP V4.0 and V5.0 (from April 2015 to June 2022) for validation analysis. The major improvements of SMAP throughout each version are as follows: V3.0 reduced the spurious biases in the open ocean that were observed in V2.0. V4.0 further enhanced the land corrections and included more data closer to the coasts. V5.0 directly ingested Advanced Microwave Scanning Radiometer 2 (AMSR-2) T_b measurements for sea-ice flagging and sea-ice side-lobe correction instead of using an external sea-ice concentration product as in the earlier versions (Meissner et al. 2022; Meissner and Manaster, 2021). The changes to sea ice correction allow salinity retrieval closer to the sea-ice edge and help detect large icebergs in the polar regions. Some other changes from V4.0 to V5.0 include: (1) Formal uncertainty estimates are added in V5.0. The uncertainty estimates will be compared with the salinity differences between SMAP and in situ data in Sections 4.4. (2) Ancillary atmospheric data are used for the salinity retrieval algorithm changed from NCEP 1° product in V4.0 to NCEP 0.25° resolution product in V5.0. (3) f_{land} threshold for moderate land contamination is increased from 0.001 in V4.0 to 0.005 in V5.0, meaning fewer data are excluded after applying the flag. (4) In V4.0, rain-filtered (RF) products are provided in separate NetCDF files. In V5.0, rain filtered Level 3 (L3) products are included in the L3 files as an additional field. More details and other minor changes are documented in Meissner et al. (2022).

Readers of this document are assumed to be familiar with the SMAP mission and sensor design, sampling pattern, and salinity remote sensing principles as described by Meissner et al. (2018, 2022) and the SMAP handbook. The L1B T_A is resampled onto a fixed 0.25° earth grid with Backus-Gilbert type optimal interpolation (OI). Based on the spatial resolution, there are 40-km and 70-km products. The 40-km product uses an elliptical footprint of 39x47 km^2. The target of the 70-km product is a circle whose diameter is approximately 75 km. Results in this document are based on the standard (70-km) products. It should be noted that from V4.0 on, the 70-km product is derived using simple-neighbor averaging from the 40-km product instead of using BG OI as in V3.0. The differences between the BG OI in V3.0 70-km product and the smoothed V4.0 and V5.0 products are small in the open ocean. More details are described in Meissner et al. (2022).

The SMAP V4.0 and V5.0 Level 2C (L2C) salinity retrieval algorithms have been adapted from Aquarius V5.0 salinity retrieval algorithm to facilitate a continuous data record of SSS. The ancillary SSS data have been derived from the US Navy HYbrid Coordinate Ocean Model (HYCOM) daily averaged data-assimilative analysis (Chassignet et al. 2009; Metzger et al., 2008a,b). The operational data are produced by the U.S. Naval Oceanographic Office (NAVO), and the digital output is distributed by Florida State University. The HYCOM global mean salinity over the open ocean has been used as an ocean calibration target for the sensor.

The SMAP SSS project produces three data sets: Level 1a (L1a; raw data), Level 2 (L2; science data in swath coordinates and matching ancillary data), and Level 3 (L3; gridded ¼ degree 1-day running, 8-day running average, and monthly salinity). This validation analysis will start with L2 data evaluation followed by L3 monthly average analysis. Salinity measurements are on the practical salinity scale (PSS-78), technically a dimensionless number, but in some figures labeled as practical salinity units (psu).

The near-surface in situ salinity data used here are from EN.4.2.2 with Gouretski and Reseghetti (2010) bias corrections applied and include Argo data as well as additional in situ data (supported by the Met Office Hadley Centre Climate Programme; Good et al., 2013). Since EN4 relies extensively on Argo data, "Argo" is used interchangeably with "EN4". The shallowest sampling depths of the Argo data are generally 3-5 meters below the surface. Under most conditions (e.g., moderate to high winds) the surface ocean mixed layer extends much deeper, and the floats provide an accurate measure of the 1-2 cm surface layer that emits the microwave signal seen by the satellite. However, under persistently rainy conditions (especially under low winds when vertical mixing is small), there are often vertical gradients between the surface and the buoy measurement depth. Argo floats rise to the surface once every 10 days and remain at the surface for a few hours. The data are collected randomly at any time of day.

In this report, we have generated the same matchup analysis with Soil Moisture and Ocean Salinity (SMOS) data for comparisons. The SMOS L2 SSS products used here are L2 OS Version 700 released by European Space Agency (ESA; Reul et al., 2022; Boutin et al., 2018). The SMOS L2 data are available at https://earth.esa.int/eogateway/catalog/smos-science-products. The flags used for validation are the recommended flags from the SMOS L2 SSS data release note. SMOS L3 data is provided by Centre Aval de Traitement des Donnees SMOS (CATDS, 2022). The gridded data are de-biased with land-sea contamination and latitudinal bias based on L2Q products.

2. Methodology for the Matchup

2.1 Level 2 (swath) data

"All-in-box" match-ups indicate that for each in-situ observation, satellite data that fall within the 50 km search radius and ±3.5-day time window will be averaged for comparisons. The goal of the in situ-centered L2 validation in this document is to estimate the salinity data quality of SMAP SSS with greater temporal and spatial averages. The results are useful for general users to examine and compare salinity data quality from different satellite observations.

The steps for the All-in-box match-up are:

1) Gather one day (day 0) of in situ (Argo) data.
2) Retrieve all the SMAP data within a ±4-day time window.
3) Apply the flags to the SMAP data as described in Section 3.
4) For each in situ observation obtained from Step 1, search for all of the SMAP data gathered in Step 3 that are within the 50-km search radius, regardless of the look direction.
5) Exclude the matchup if the time difference between Argo and SMAP is more than 3.5 days.
6) For all the SMAP footprints found within the search radius and time frame, average all the SMAP salinity values for the match-up. SMAP salinity data will come from several orbits within the 7-day time window.
7) Then, move to the next day of the in situ data and repeat the processes (Step 1 to 6). Therefore, a single in situ observation will only be used once to find a match-up since the in situ-centered method searches one Argo report at a time.

2.2 Level 3 (gridded) data

The detailed steps for SMAP L3 match-up validation processes are as follows:

1) Download one month of SMAP L3 0.25° × 0.25° gridded salinity map
2) Retrieve all the in situ (Argo) data within the 1-month time window.
3) For each grid cell on the SMAP salinity maps, search the in situ data from step 2 and find the in-situ data that are within a 50-km search radius. The average of the individual Argo floats is used instead of using gridded Argo data to mitigate the biases induced by the gridding algorithm in regions with sparse in situ data.
4) For each SMAP cell, the salinity value averaged from all the in situ data within the 50-km search radius are used as a match-up.
5) Repeat the validation (Step 1 to 4) with each monthly gridded map.

3. Quality Control (Q/C) Flags

Flag #0	no valid radiometer observation in cell
Flag #1	problem with OI
Flag #2	strong land contamination
Flag #3	strong ice contamination
Flag #4	MLE in SSS retrieval algorithm has not converged
Flag #5	sun glint angle
Flag #6	moon glint angle < 15°
Flag #7	high reflected galaxy
Flag #8	moderate land contamination (thresholds are different in V4.0 and V5.0)
Flag #9	moderate ice contamination (thresholds are different in V4.0 and V5.0)
Flag #10	high residual of MLE in SSS retrieval algorithm
Flag #11	low sea surface temperature SST (*surtep*-273.15<5°C)
Flag #12	high wind speed (*winspd* > 15 m/s)
Flag #13	light land contamination (*gland* > 0.001)
Flag #14	light ice contamination (thresholds are different in V4.0 and V5.0)
Flag #15	rain flag (IMERG rain rate > 0.1 mm/h)
Flag #16	no sea-ice check possible (new flag in V5.0)

In this document, L2 data are validated with two scenarios (**Table 1**): First, only minimal flags (Flag #0-7 and Flag #10) are applied. In this case, more salinity data will be included, and only heavily contaminated data are excluded. The validation analysis will be performed closer to land/ice and in higher latitudes. Second, all the flags are applied to help us know the best performance of satellite observations. Salinity data contaminated or influenced by land/ice, radio frequency interference (RFI), rain, low SST, or high wind speed are removed in this validation analysis. The same two scenarios and flags are also applied for the L2 triple point collocation analysis (described below).

For L3 files, there are also two scenarios applied for triple point analysis as shown in **Table 2**. Since L3 data does not include flags, values of *gland*, *fland*, *gice*, SST, and wind speed were used to filter the data. Values applied for each filter align with descriptions of the L2 flags. For example, the L2 moderate flag case has flag 14 (light sea-ice contamination, observation falls within sea-ice zones 1 or 2) applied for sea ice. For the L3 moderate flag case, observations with *gice* > 0.002 were removed, a value which corresponds with sea ice zone 1 (see Table 4 in SMAP V5.0 documentation, Meissner et al., 2022)

Table 1. Two sets of Q/C flags used for L2 validation

Q/C flag for L2 validation	**Minimal flags applied**	**All flags applied**
Rain	Non rain-filtered data	Flag (15) applied
Land contamination	Flag (2) applied	Flag (13) applied
Ice contamination	Flag (3) applied	Flag (14) applied
Low SST	All SST included	Flag (11) applied SST < 5° C removed
High Wind speed	All wind speed included	Flag (12) applied Wind speed > 15 m/s removed
No valid radiometer observ	Flag (0) applied	Flag (0) applied
Problem with OI	Flag (1) applied	Flag (1) applied
MLE not converged	Flag (4) applied	Flag (4) applied
sunglint	Flag (5) applied	Flag (5) applied
moonglint	Flag (6) applied	Flag (6) applied
High reflected galaxy	Flag (7) applied	Flag (7) applied
High residual of MLE	Flag (10) applied	Flag (10) applied
no sea-ice check possible	Flag (16) applied	Flag (16) applied

Table 2. Two sets of Q/C flags used for L3 triple point analysis

Q/C for L3 triple point analysis	**Minimal flags applied**	**All flags applied**
Rain	Non rain-filtered data	Rain-filtered data
Land contamination (gland, fland)	*gland* > 0.1 or *fland* > 0.1 removed	*gland* > 0.001 removed
Ice contamination (gice)	No data filters applied	*gice* > 0.002 removed
Low SST (surtep)	No data filters applied - All SST included	SST < 5°C (278.15K) removed
High Wind speed (winspd)	No data filters applied - Winds > 20 m/s removed during L3 gridding by RSS	Wind speeds > 15 m/s removed

4. Level 2 Validation Analysis

4.1 Global maps of the salinity biases

We start with global maps comparing the SMAP L2 samples with Argo data. **Figure 1** shows the SMAP retrieved salinity at the in situ matchup points for 87 months of V4.0 and V5.0 observations from April 2015 to June 2022. In **Figure 1**, only minimal flags are applied to the SMAP data to include the salinity observations close to land/ice (see **Table 1** for details). We also include SMOS V700 and Argo salinity data at the same matchup points. The correspondence is visibly quite clear with SMAP L2 data resolving the salient large-scale ocean features. Global salinity maps from SMAP V4.0 and V5.0 are very similar. SMAP V5.0 includes more data in high latitudes due to the improved sea-ice masking. SMOS V700 also captures the major patterns of salinity. However, SMOS salinity values in the polar regions and Southern Ocean are much lower compared to Argo and SMAP salinity.

Based on **Figure 1, Figure 2** shows the satellite minus Argo salinity differences (dSSS) with the same match-ups for SMAP V4.0, V5.0, and SMOS V700. In the open ocean, both SMAP V4.0 and V5.0 show small differences with Argo and no observable differences between the two versions. The patterns of salinity differences in the high latitudes are generally the same. One major difference is that V5.0 includes more data near the sea ice with improved sea-ice flagging and masking based on AMSR-2 TB measurements. It is noticed that there are some large positive biases in the high latitude in the Northern Hemisphere observed in both V4.0 and V5.0. These are caused by the problematic SSS data in the first few months of the SMAP mission, possibly related to instrument calibration. The actual cause for the biases is still unknown. These positive biases in the Northern Hemisphere are not visible in V2.0 (not shown) and more investigations are needed to understand the sources of the errors.

In comparison, SMOS L2 data has more noise in the open ocean and larger biases in higher latitudes. Different from SMAP, which has positive biases around Greenland and Norway, SMOS tends to have negative differences in the polar regions and Southern Ocean.

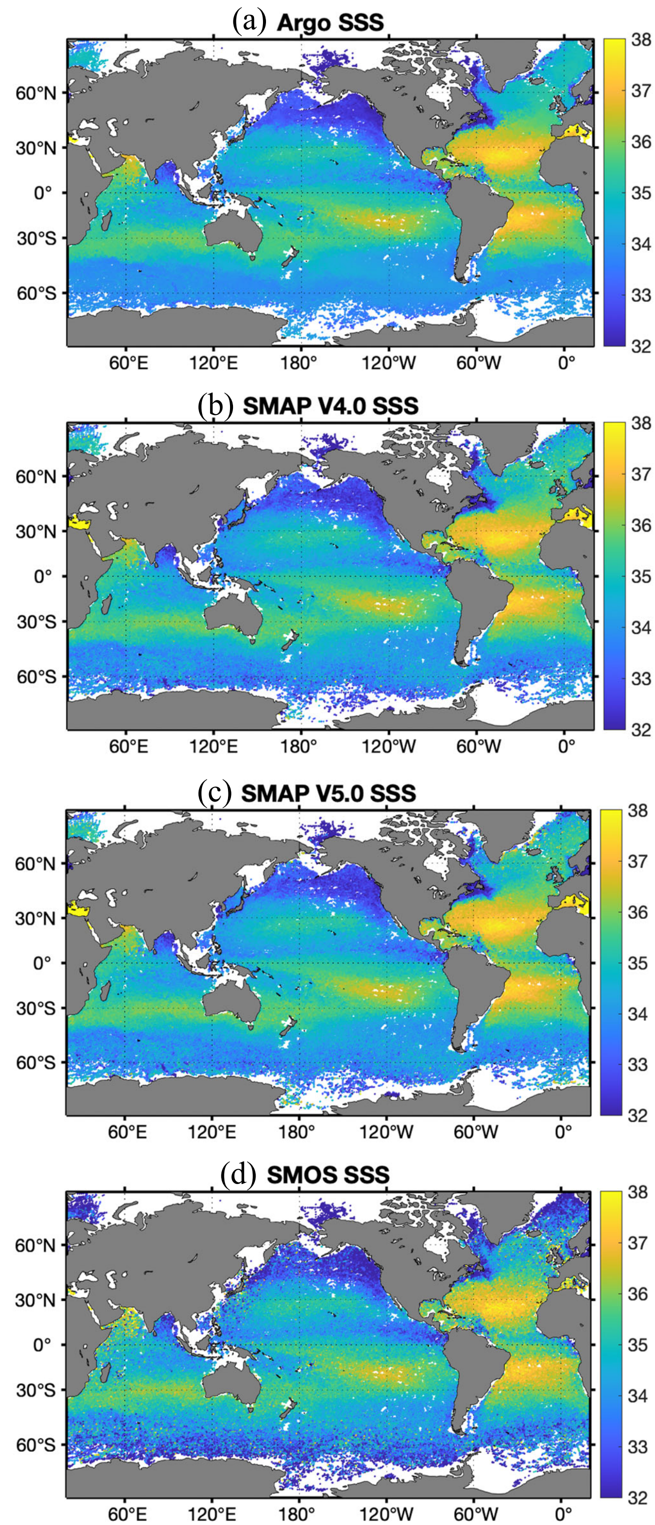

Figure 1. Global maps of sea surface salinity observed by (a) Argo floats, (b) SMAP V4.0, (c) SMAP V5.0 and (d) SMOS V700 in psu.

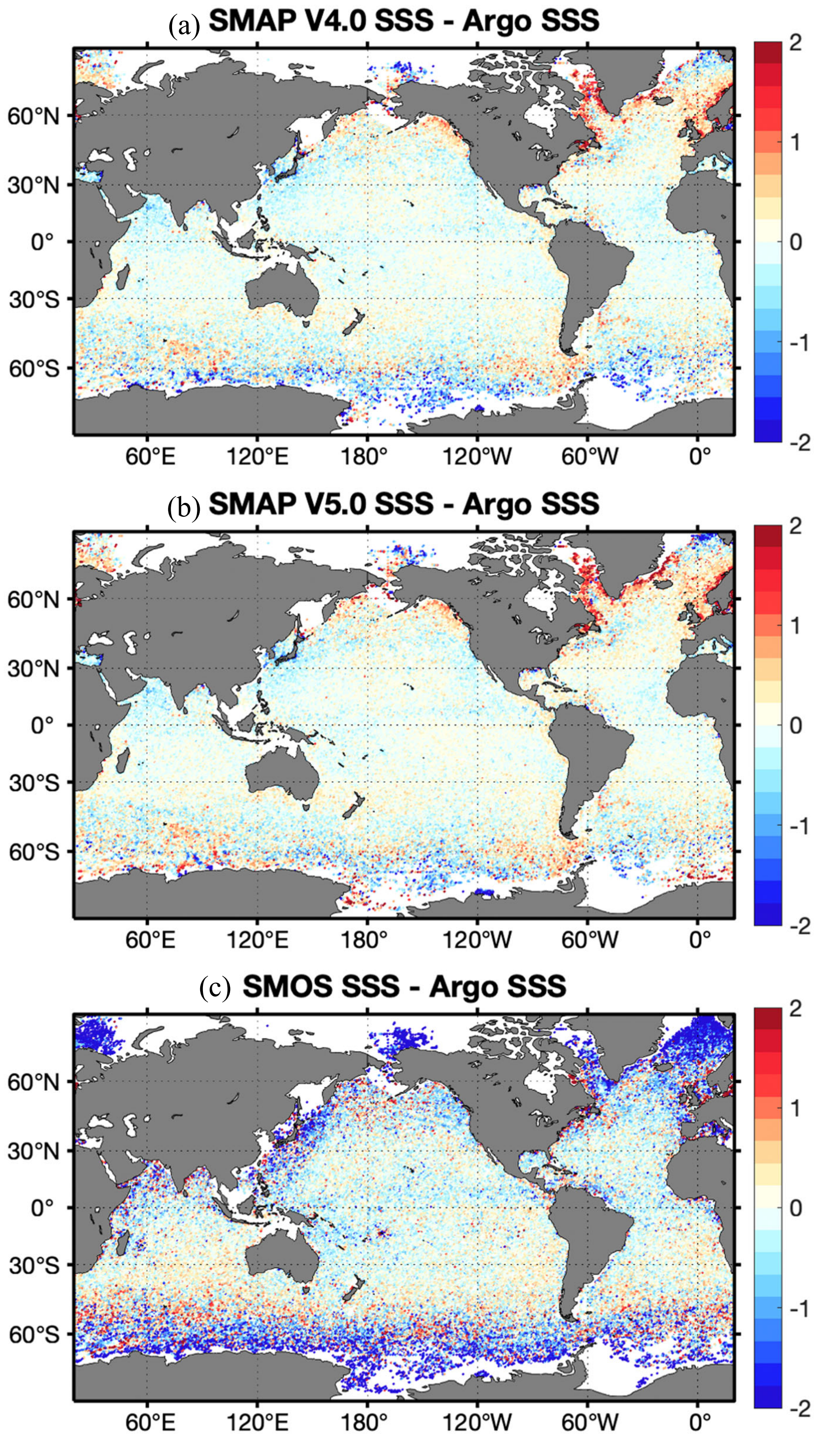

Figure 2. Global maps of SSS differences in psu defined as (a) SMAP V4.0, (b) SMAP V5.0 and (c) SMOS V700 salinity minus co-located Argo salinity.

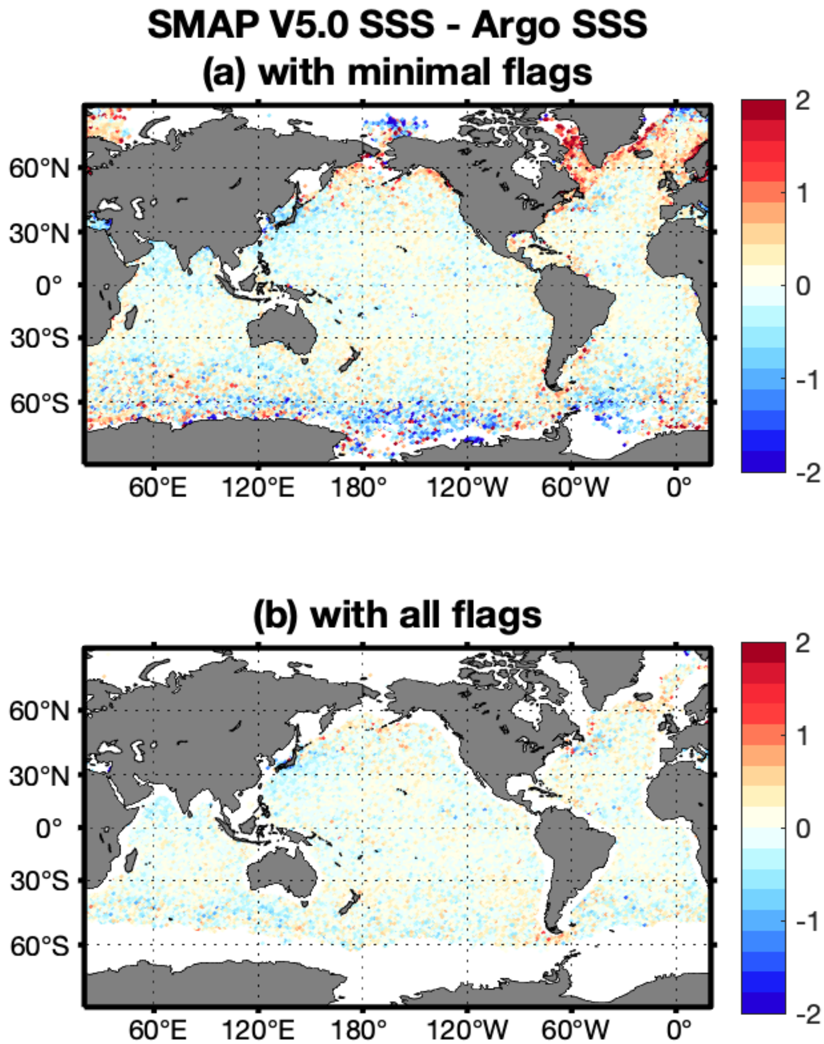

Figure 3. Global maps of SSS differences between SMAP V5.0 and Argo with (a) minimal flags and (b) all the flags applied to SMAP data.

Figure 3 also shows the global salinity differences between SMAP V5.0 and Argo data, but with different sets of flags applied to SMAP data. **Figure 3a** is the same as **Figure 2b**, only minimal flags are applied, so much more data are available, especially in the high latitudes (>60°), near the coasts and the inland seas. In comparison, anomalous values are removed if all the flags are applied to SMAP data (**Figure 3b**). Most of the data are in the open ocean, and the salinity differences between SMAP and Argo are generally smaller than 1 psu.

4.2 Comparisons between HYCOM and Argo SSS

The top layer salinity in HYbrid Coordinate Ocean Model (HYCOM) are used as a salinity reference in SMAP L2 data (sss_ref) (Meissner et al., 2018; Chassignet et al., 2009). The HYCOM surface salinity is interpolated to the time and location of each SMAP footprint. Here, in **Figure 4**, these reference salinity data are evaluated against the Argo measurements with the same matchup processing as SMAP L2 data for the whole SMAP mission period. In other words, the HYCOM data are collocated and compared with the in situ data. The one-to-one match between HYCOM and Argo are also calculated but similar results are obtained with smoothed or not-smoothed HYCOM data. There are regional long-term systematic biases between HYCOM salinity and the in situ data. It is interesting to notice that differences appear in regions with strong salinity gradients (salinity fronts), including polar fronts, Bay of Bengal, south boundary of Intertropical Convergence Zone (ITCZ), north Pacific fronts, Gulf stream, and east coast of South America. Over much of the mid-latitudes the bias is slightly negative. These differences exist even though most of the Argo data used here are assimilated by HYCOM and therefore not fully independent data. It should be noted that SMAP is calibrated with HYCOM, but only on global averages, which are very close between Argo and HYCOM (**Figure 4b**).

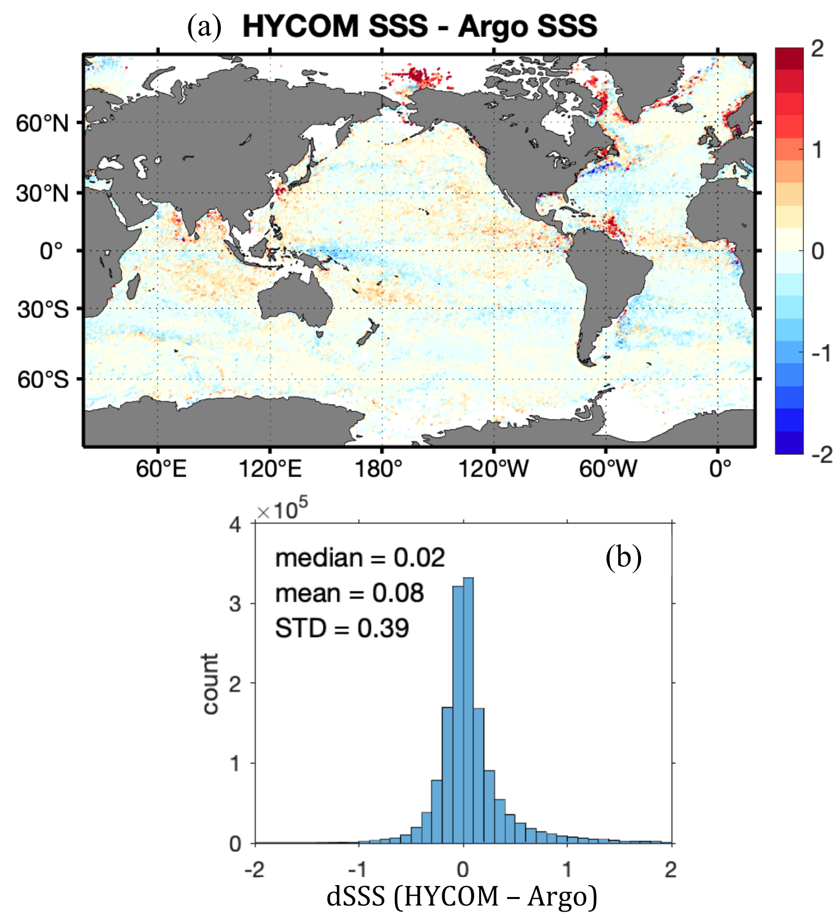

Figure 4. (a) Global map and (b) histogram of salinity differences between co-located HYCOM and Argo.

4.3 Latitudinal variations of the salinity biases

Figure 5 shows the in situ difference statistics in discrete latitude bands for SMAP V4.0 and V5.0 and SMOS V700 data. Blue lines are the medians of the salinity differences and red lines are the standard deviations (STD) of the salinity differences. The medians of dSSS are very close in SMAP V4.0 and V5.0, but V5.0 shows smaller standard deviations in the high latitudes. **Figure 5c** shows the latitudinal variations of SMOS salinity differences. The results correspond to **Figure 2c** with smaller median and STD observed in lower latitude (40°S to 30°N), but large negative biases appear in the high latitudes (>50 degrees) in both hemispheres.

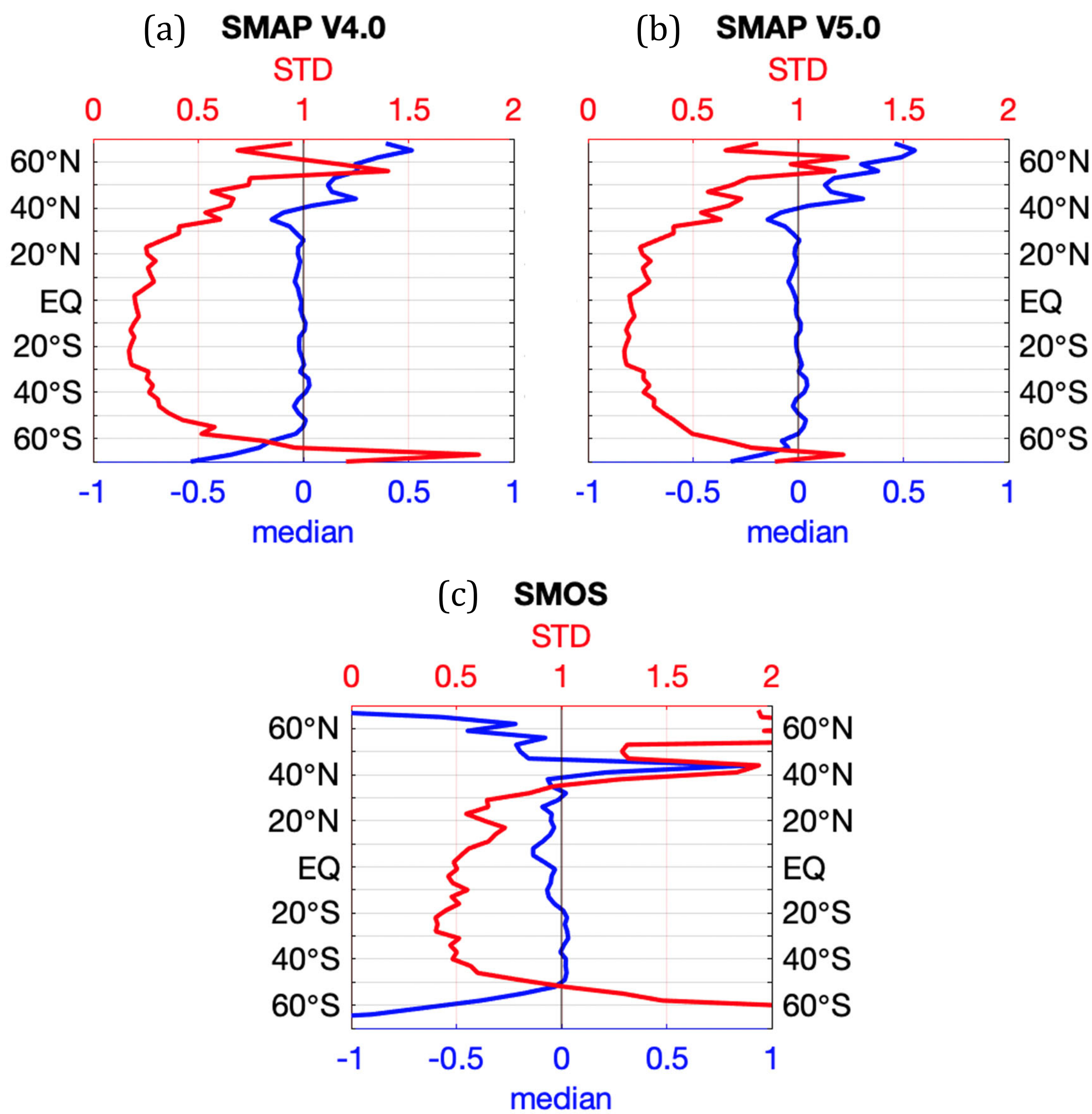

Figure 5. Differences of (a) SMAP V4.0, (b) SMAP V5.0 and (c) SMOS V700 L2c data and Argo salinity matchup by latitude bands.

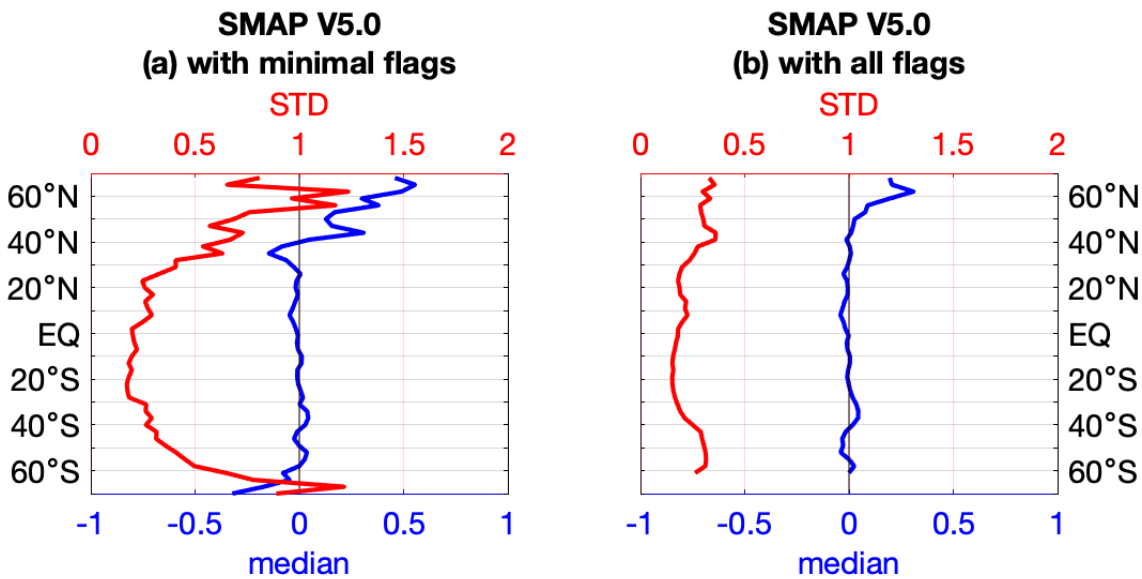

Figure 6. Same as Figure 5, but for SMAP V5.0 with (a) the minimal flags and with (b) all the flags.

Figure 6 shows the comparisons of latitudinal variation of salinity differences (a) with minimal and (b) with all flags applied in SMAP V5.0. The results show that when all the flags are applied, large salinity differences are largely removed. The median (blue) is close to zero at most of the latitudes, except around 60°N, and the standard deviations are decreased from up to 1.2 to around 0.3 (red).

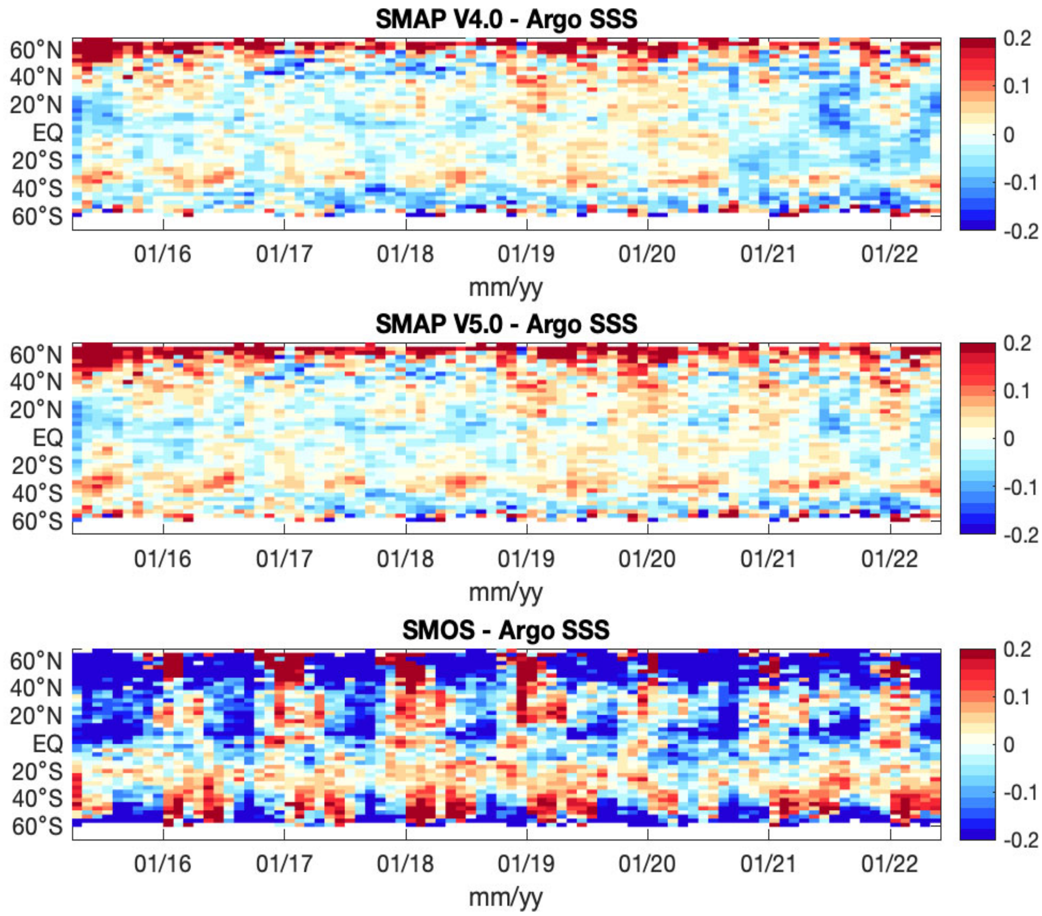

Figure 7. Latitudinal distribution of zonally averaged salinity differences between Argo and (a) SMAP V4.0, (b) SMAP V5.0 and (c) SMOS V700.

Figure 7 shows the latitudinal distribution of zonally averaged salinity differences throughout the SMAP operating period (April 2015 to June 2022) with all the flags applied. SMAP V4.0 and V5.0 both have the largest positive variations at around 60°N, especially in the first few months of the mission. A slight seasonal cycle occurs at 40°S with positive values in June, July. Anomalies in the north Pacific also vary with time. Positive differences appear in 2019-2020, and negative differences appear in 2021. Strong seasonal cycles, observed in SMOS salinity, dominate the high latitudes and intertropical convergence zones.

4.4 Regional salinity biases and formal uncertainty estimates

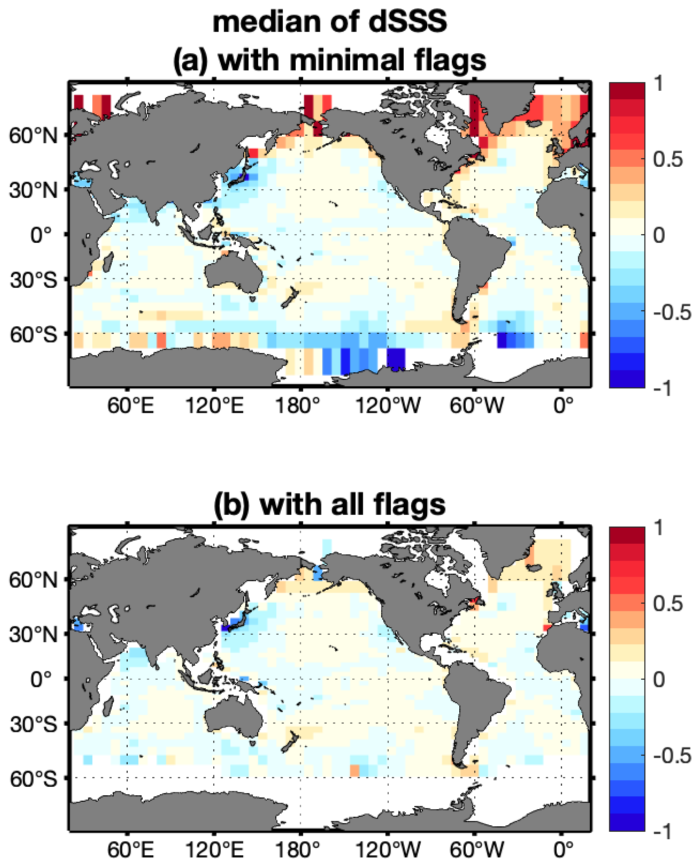

Figure 8. Global maps of SMAP V5.0 and Argo SSS difference averaged in each grid cell with (a) the minimal flags and with (b) all the flags.

Figure 8 shows the global mission-long salinity differences statistics for SMAP V5.0 data using (a) minimal flags and (b) all flags. To weight the areas in each grid cell, we use an equal-area map projection with 500-km spatial resolution. The cylindrical equal-area projection is designed to have no distortion on 45°S and 45°N. For each grid cell, we aggregate all available Argo profile data for the mission (April 2015 to June 2022), then calculate the median from the salinity differences (SMAP minus Argo). Only the strong land/ice contamination (flags 2 and 3) regions are excluded, so the data in this map is very close to land/ice. Consistent with **Figure 2b**, **Figure 8a** shows that positive biases appear at high latitudes around 60°N, especially near the coastal regions. Negative biases are observed around 30°N, near Japan, eastern Mediterranean Sea, and Arabian Sea. With more flags applied to the validation analysis (**Figure 8b**), most of the areas have salinity differences <0.5 psu. The results suggest that after excluding some conditions (low SST, high wind speed, and land/ice contaminations), SMAP measures the SSS with high accuracy compared with in situ observations.

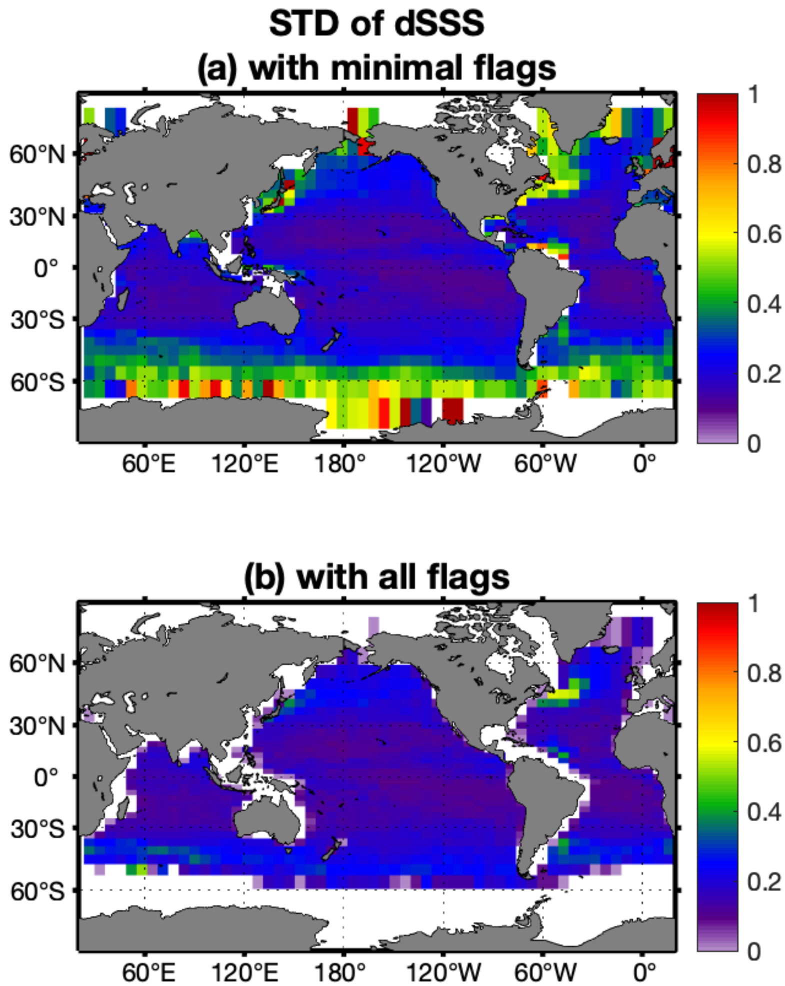

Figure 9. Standard deviations of SMAP V5.0 and Argo SSS difference averaged in each grid cell with (a) the minimal flags and (b) all the flags.

Figure 9a shows higher STD in high latitudes and the coastal regions with strong river outflow (e.g., Amazon) or strong surface currents (e.g., Gulf Stream). In the subtropical gyres, salinity differences have the lowest STD due to the small salinity variations throughout the whole year. With all the flags applied, standard deviations of salinity differences are reduced to less than 0.5, except for the Gulf Stream. Some grid cells near the coasts have small variations because these data are weighted with grid cell land fractions for the calculation of global averages.

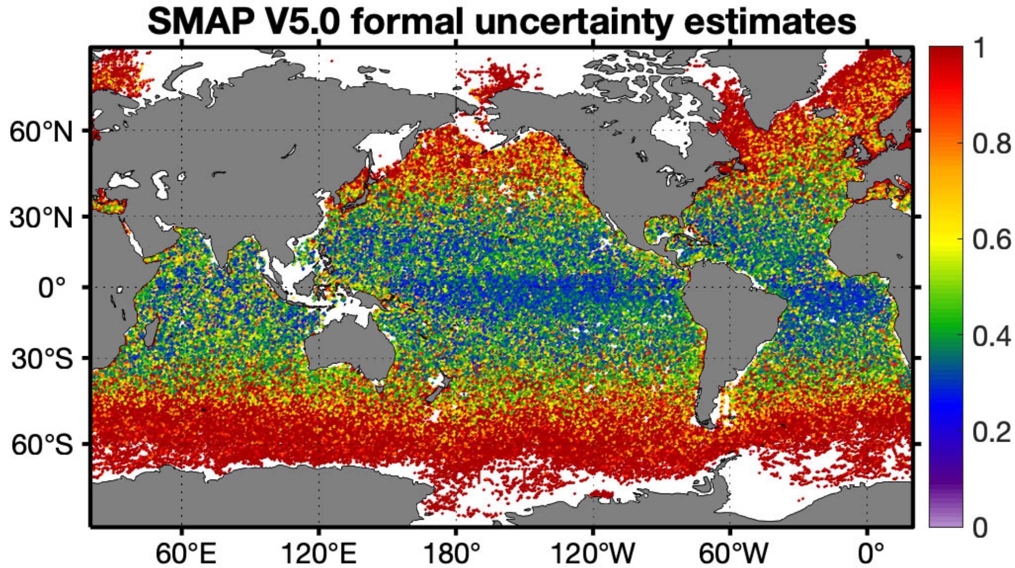

Figure 10. SMAP V5.0 formal uncertainty estimates.

In SMAP V5.0, the data product for the first time includes formal salinity uncertainty estimates. The error sources include wind speed (random), NEDT-v-pol, NEDT h-pol, SST, wind direction, reflected galaxy, land contamination, sea-ice contamination, and wind speed (systematic). More details for the retrieval method and descriptions for error sources can be found in Meissner (2015) and Meissner et al. (2022). **Figure 10** shows the total uncertainty estimates. Larger uncertainties are mainly located in high latitude regions, with smaller uncertainties found over the ITCZ and coastal regions. When compared to the standard deviation of salinity biases (**Figure 9a**), large biases appear in both figures at high latitudes, but formal uncertainty appears to be overestimated overall.

Uncertainties from different error sources are further examined in **Figure 11**. The uncertainty from random propagation of wind speed errors contributes the most to the total uncertainty. The NEDT, SST, and systematic propagation of wind speed have more influence in high latitude regions. Wind direction and reflected galaxy show impacts in the Southern Ocean. Uncertainty from land and sea ice contamination appears near land and sea ice, as expected.

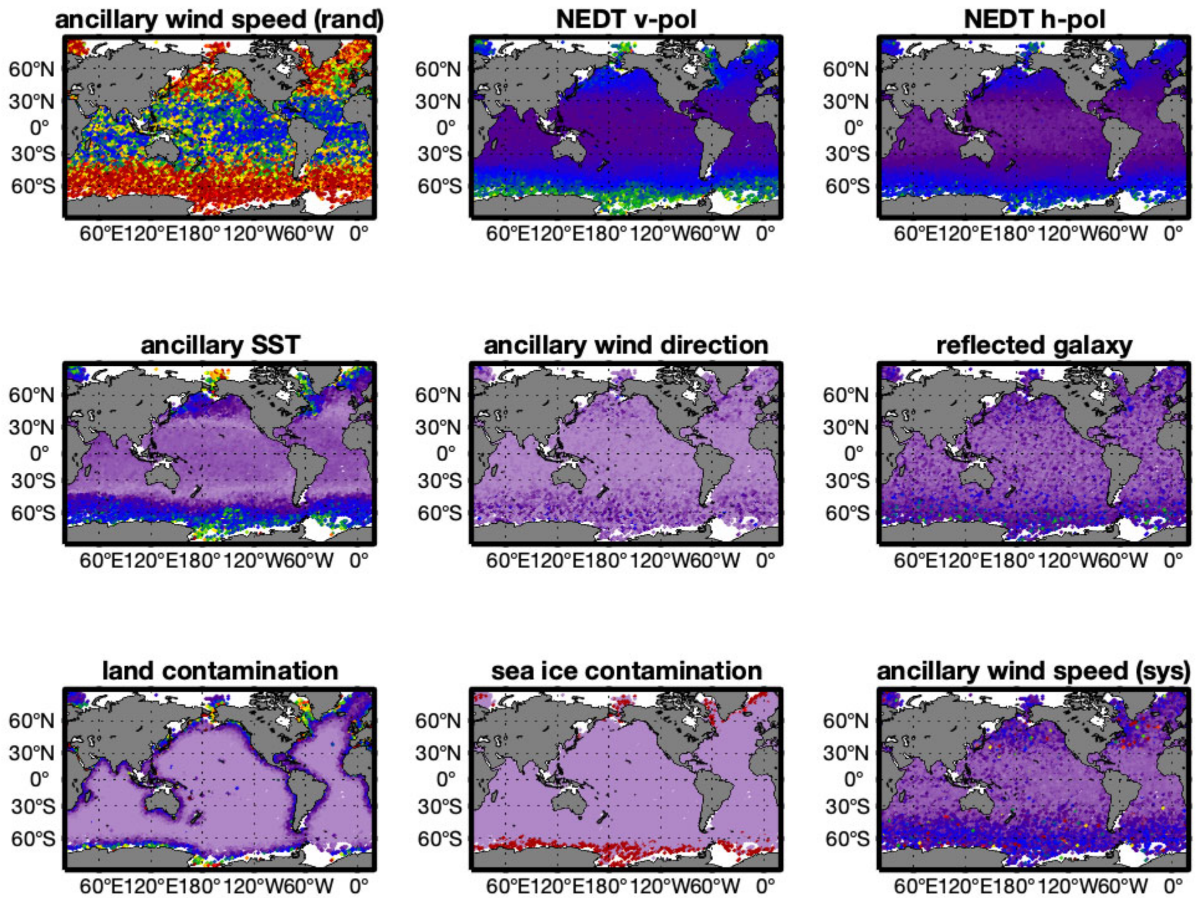

Figure 11. SMAP V5.0 formal uncertainty estimates from nine different error sources. Random (rand) and systematic (sys) propagations.

4.5 Sensitivity Tests

Figure 12 shows the salinity differences between SMAP V5.0 and Argo averaged by different sea surface salinity (SST), wind speed and land fraction. White lines show the salinity differences and red lines show the standard deviations of the salinity differences. In V5.0, STD of the salinity differences are larger in cold water (SST<5°C). Although there is little data in warm water (SST>30°C) regions, strong negative differences are shown. STD is the lowest

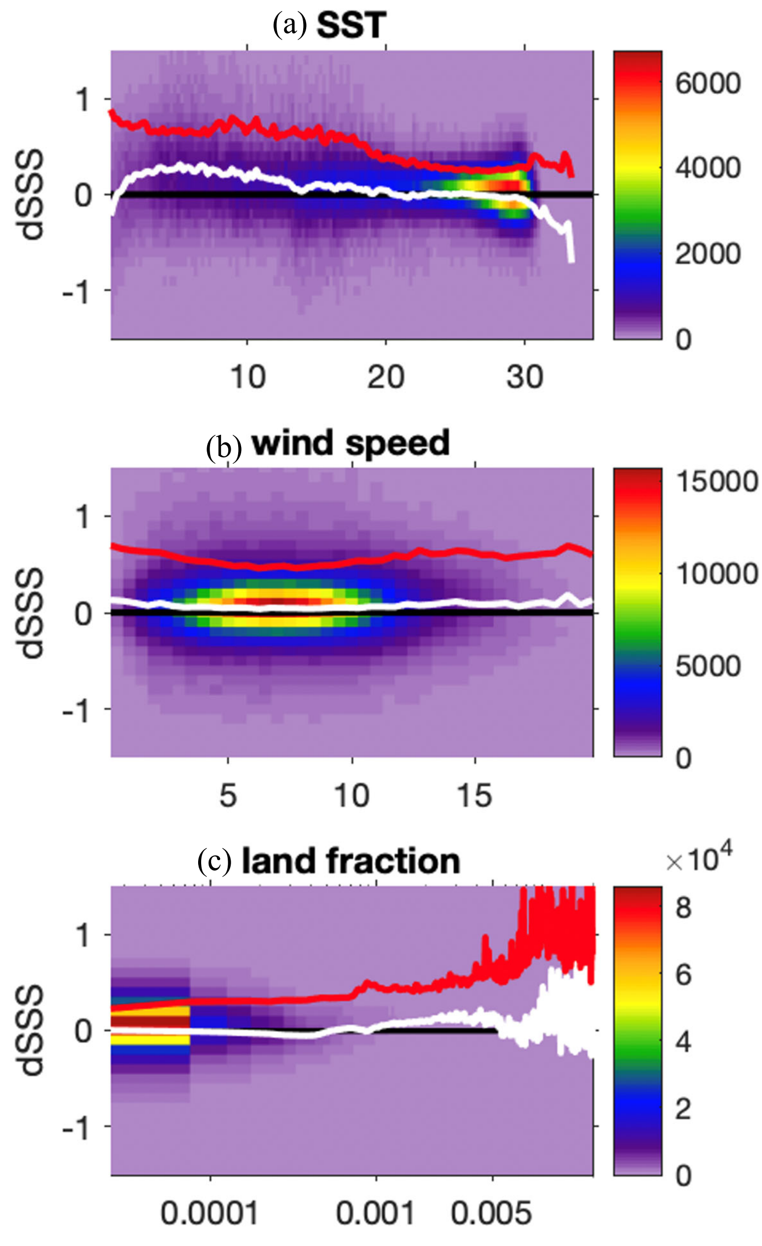

Figure 12. Differences of SMAP L2c data and in situ salinity compared with different (a) sea surface temperature in ºC, (b) wind speed in m/s and (c) land fraction in SMAP V5.0. White lines show the salinity differences and red lines show the standard deviations.

when the wind speed ranges from 5 m/s to 10 m/s. One update from V4.0 to V5.0 is that the *fland* threshold for moderate land contamination was increased from 0.001 in V4.0 to 0.005 in V5.0. **Figure 12c** shows that this change in the threshold could include more salinity data with slight increases in the median and STD of salinity differences.

Figure 13 shows the variations of salinity differences (SMAP minus Argo) corresponding to different rain rates in mm/hr. The rain rate data is from IMERG (Huffman et al., 2019) and the threshold for the rain flag (bit 15) is set to 0.1 mm/hr. It is important to remember that the Argo data are observed mostly at 5 m depth, so it is as expected that the vertical stratification caused by precipitation would cause negative differences, as the rain keeps the surface fresher than subsurface. The results suggest that Argo is not useful for satellite validation when the rain rate is large (> 15 mm/hr) and strong stratification exists.

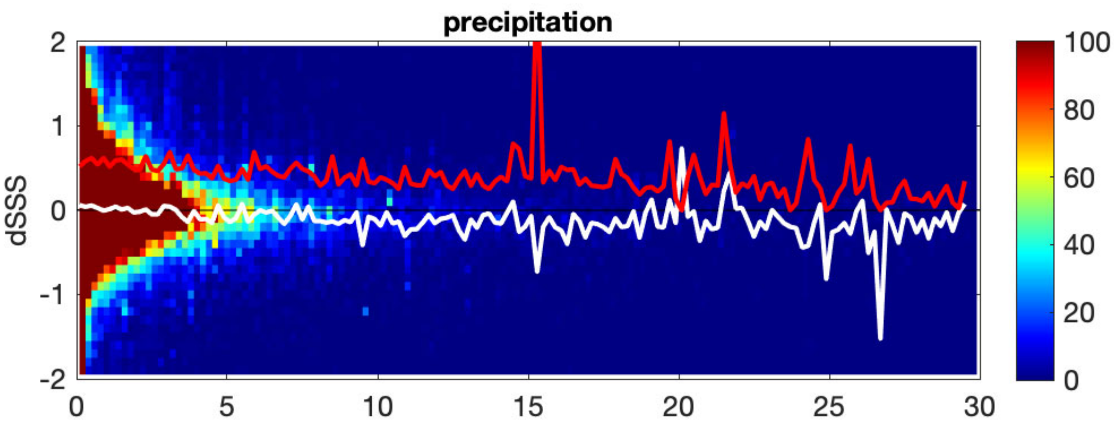

Figure 13. Differences of SMAP V5.0 L2C data and Argo salinity compared with precipitation in mm/hr. White line shows the salinity differences and red line shows the standard deviations.

4.6 In Situ Matchup Time Series and Scatter Plots

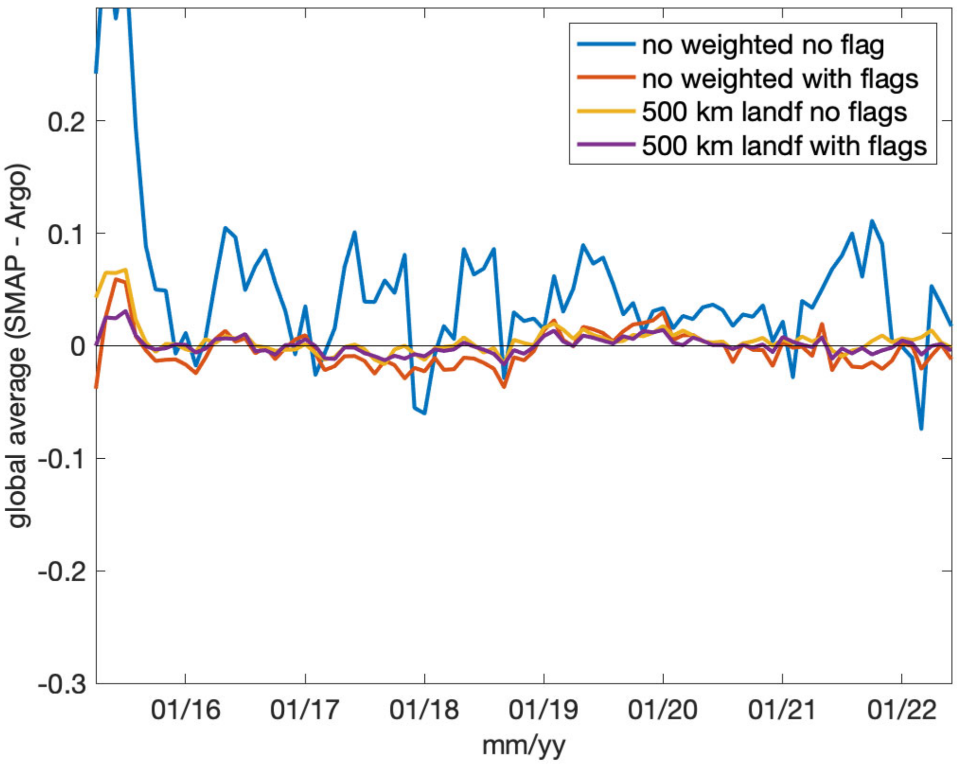

Figure 14. Time series of monthly, global averaged salinity differences between SMAP V5.0 and Argo using different weighting methods and flags.

To verify the temporal variations of the salinity differences, we calculate the monthly global average of the salinity differences. In **Figure 14**, we compared the results with different weighting methods and with different flags applied. The blue line shows the monthly variations of all the matchup data without any area-weighting and only minimal flags applied. Positive biases in the beginning few months of the SMAP mission period might be related to instrument calibration, but further investigation is needed to determine the exact cause. Slight seasonal variations of the salinity differences (~0.1 psu) are observed. The red line represents the validation with all the flags included. In this case, the seasonal variations are gone and the biases in the first few months are significantly reduced. The yellow line shows the analysis based on an equal-area projection with 500 km spatial resolution, so the biases caused by the different sizes of each grid cell are mitigated. The grid cells with land fractions are also weighted accordingly. Even though only minimal flags are applied in this case, salinity differences are greatly reduced due to the biases in high latitude and near coasts being weighted out. The purple line shows the analysis that includes the area-weighted method and all the flags applied. It shows the best performance with the smallest salinity differences including during the first few months of the operating period.

Time series of monthly variations of the global averaged salinity differences for SMAP V4.0 and V5.0 and SMOS are shown in **Figure 15**. Same as for the purple line in **Figure 14**, an equal-area map projection is used, the land fractions are weighted and all flags are applied for the validation analysis, so these validation results represent the best performance of each satellite observations. **Figure 15** shows that the results for SMAP V5.0 are close to SMAP V4.0, except that after July 2020, negative biases appeared in SMAP V4.0 but not in SMAP V5.0. This is consistent with **Figure 7** where SMAP V4.0 shows larger negative biases in the north Pacific after July 2020. In contrast, salinity differences between SMOS and Argo salinity shows strong annual cycle up to 0.08 psu. The positive biases show up in northern hemisphere spring and become negative in autumn. As seen in **Figure 7**, seasonal variations occur primarily in the high latitudes.

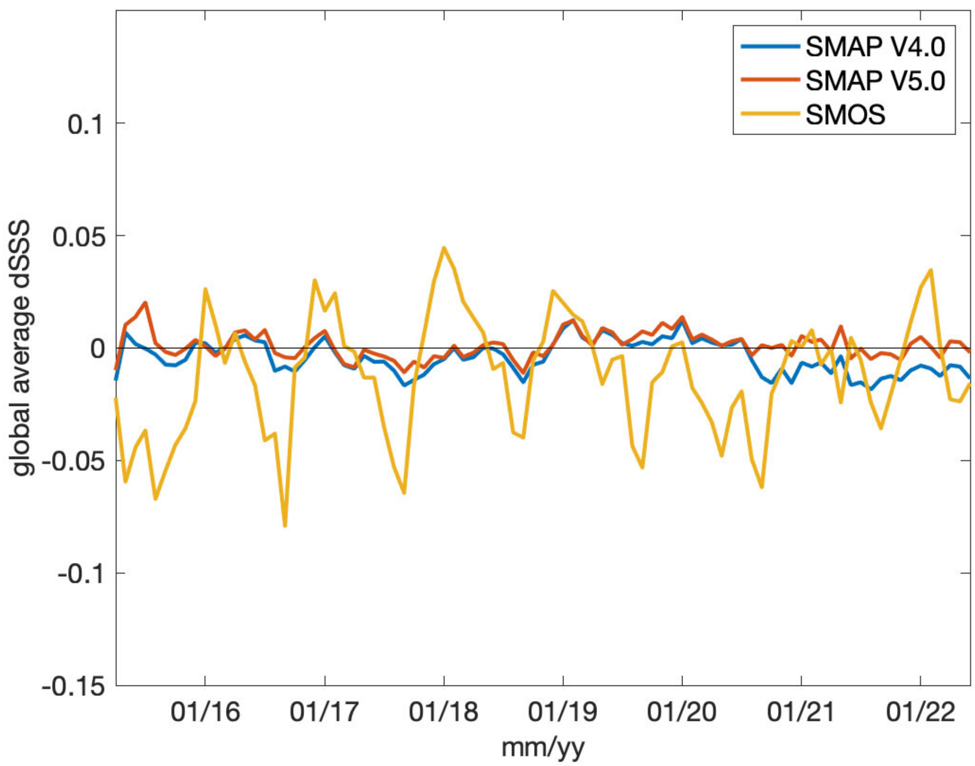

Figure 15. Time series of monthly global weighted averaged salinity differences between Argo and different satellite data.

Figure 16 is the same as **Figure 15** shows the standard deviations of salinity differences. SMAP V4.0 and SMAP V5.0 have comparable variations around 0.1 to 0.14 except for the first few months. In comparison, SMOS has standard deviations around 0.25.

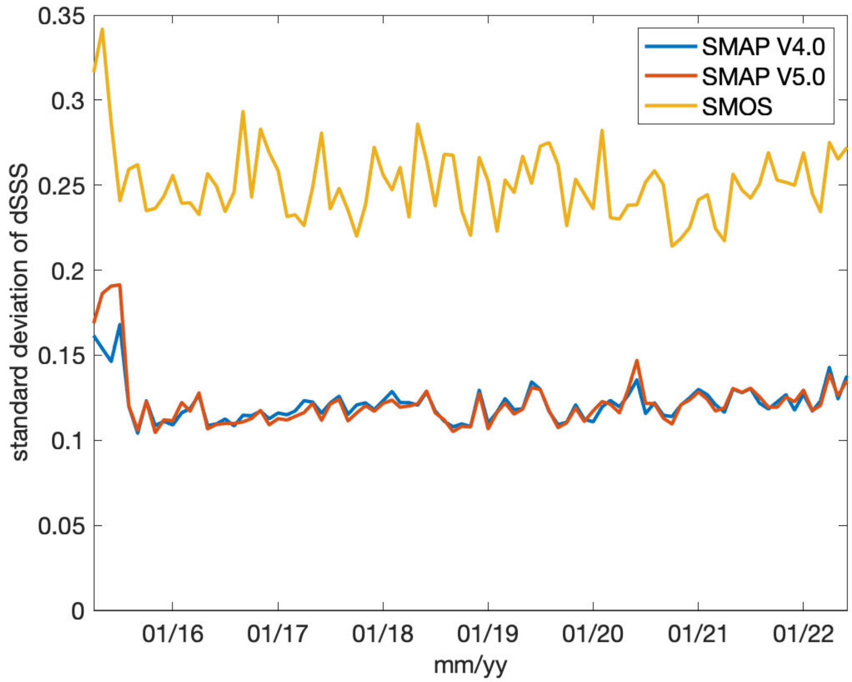

Figure 16. Time series of monthly standard deviations of salinity differences between Argo and SMAP V4.0, SMAP V5.0, and SMOS satellite data.

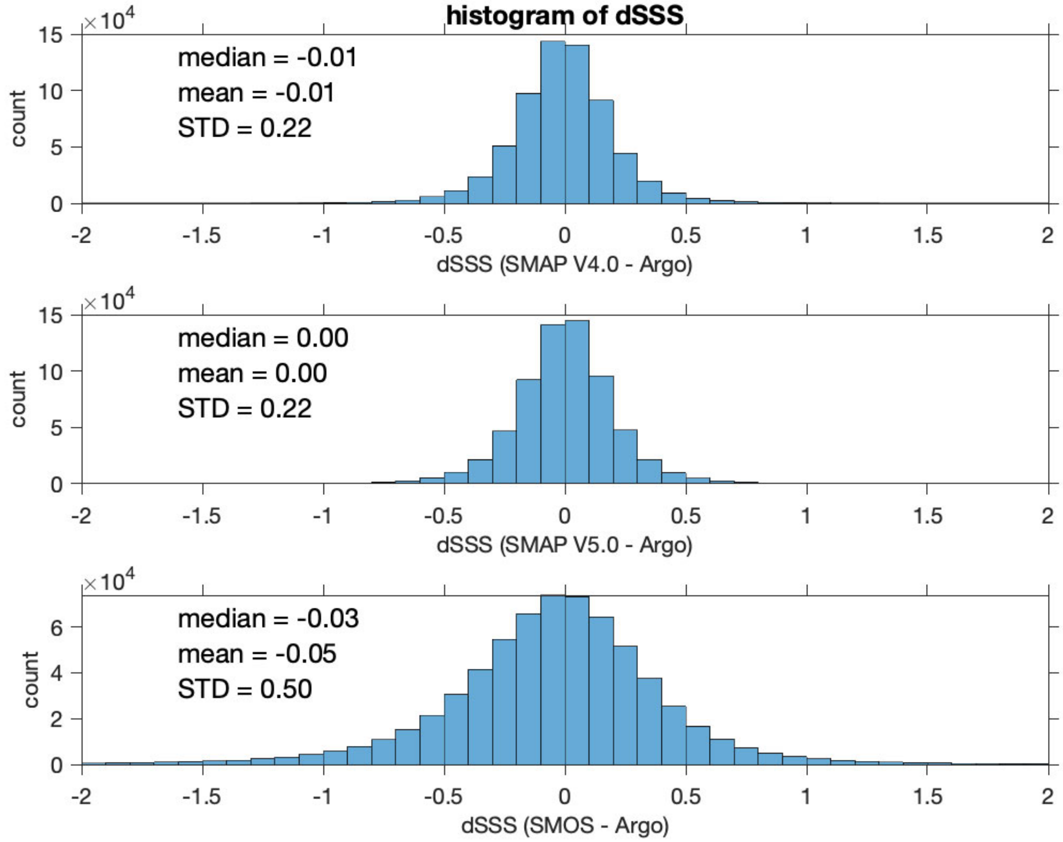

Figure 17. Histograms of salinity differences between (a) SMAP V4.0, (b) SMAP V5.0 and (c) SMOS V700 and co-located Argo data.

Histograms of salinity differences between Argo and SMAP/SMOS data are shown in **Figure 17**. Statistics for SMAP V4 and V5 SSS are very close because the major differences of two versions occurred in the ice area and most observations in the open ocean are the same. There are almost no biases on global average and the standard deviations are around 0.22. Statistics for SMOS shows slight negative differences, meaning SMOS SSS are 0.03 psu fresher than Argo on global averages. Standard deviations of SMOS minus Argo SSS are around 0.5.

4.7 Triple Point Differences & Collocation Analysis of SMAP, SMOS, and EN4 In Situ Data

For the triple point difference and collocation analysis, we use the same data sets from the matchup analysis presented above – L2 RSS SMAP V5.0, L2 SMOS v700, and EN4 in situ profiles with Gouretski and Reseghetti (2010) bias corrections. Likewise, the same "in situ-centered matchup" criteria are implemented - for each in situ data profile in EN4, we average all the SMAP or SMOS L2 data within ± 3.5 days and 50-km search radius for a match up. A total of 1,296,231 in situ profiles matched with both SMAP and SMOS within the matchup criteria. Applying data flags for the minimal flag case did not remove any additional triple points and 1,296,231 matches were included for that scenario. 653,272 triple match points were included in all flags applied scenario. Locations of the triple point matches are shown in **Figure 18**. For both scenarios, matchups are used to explore dataset differences, difference distributions, and triple point error variance using triple point collocation analysis detailed below.

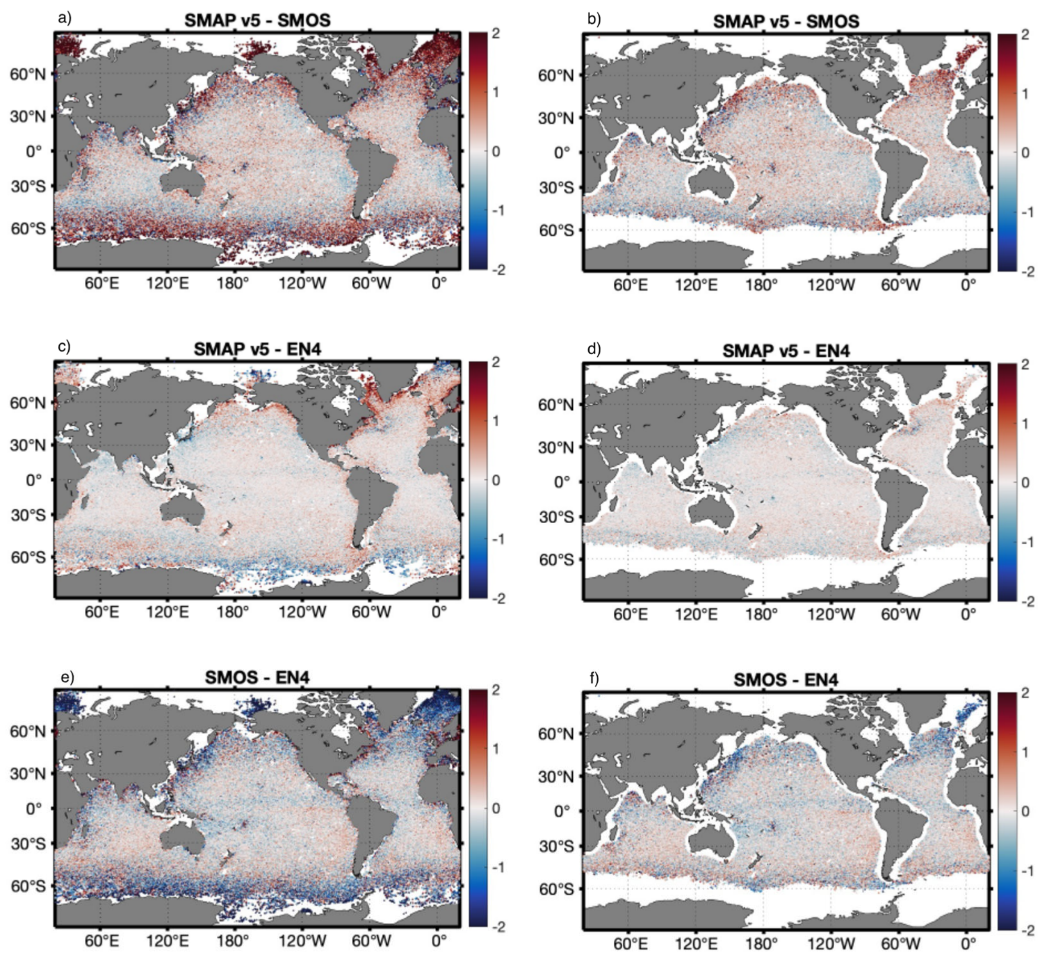

Figure 18. Global maps of (a, b) SMAP minus SMOS, (c,d) SMAP minus EN4 in situ and (e,f) SMOS minus EN4 in situ at the matchup locations where triple point analysis was completed for minimal flags (a,c,e) and all flags (b,d,f) scenarios.

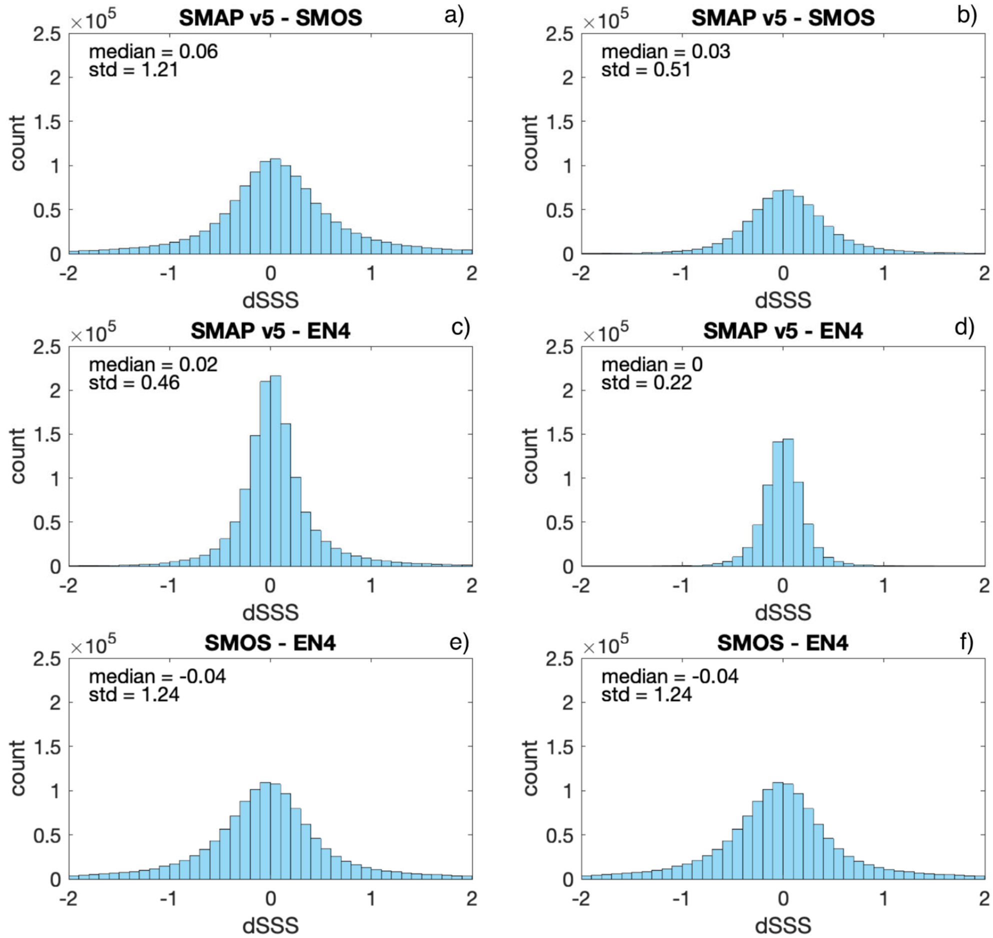

Figure 19. Co-located difference histograms SMAP minus SMOS (a,b), SMAP minus EN4 (c,d) in situ and SMOS minus EN4 in situ (e,f) for minimal flags(a,c,e) and all flags (b,d,f) scenarios.

Figure 18 shows global maps of triple-point matchups for SMAP V5.0 minus EN4, SMAP V5.0 minus SMOS, and SMOS minus EN4 (at the in situ locations) over the entire period. Larger differences between the three datasets are expected to correspond with larger error variances in the following section. Differences are largest at high latitudes and in dynamic regions. SMAP tends saltier than in situ profiles in northern hemisphere high latitudes, while SMOS tends to be fresher. SMAP-in situ differences in southern hemisphere high latitudes are generally smaller and show both fresh and salty biases. This pattern is seen in both the minimal flags and all flags scenarios. SMAP and in situ profiles are more tightly coupled than SMAP and SMOS or SMOS and in situ as reflected in smaller standard deviations/less spread in difference histograms (**Figure 19**). SMAP EN4 difference/standard deviation is 0.46/0.22 versus 1.21/0.51 for SMAP and SMOS and 1.24/1.24 for SMOS and EN4. Application of all flags improves the overall agreement between datasets. Likely this is primarily a result of the reduction of high latitude measurements via the light ice and low temperature flags.

Next, we apply triple collocation analysis to assess L2 SMAP, L2 SMOS, and in situ EN4 random error. Triple point collocation is a method to determine errors for three datasets of the same variable. A benefit of triple collocation analysis is that it does not require a priori assumptions about which dataset is the truth. Rather, errors for all three datasets are determined simultaneously. Here, we use the covariance notion of Stoffelen (1998) and Gruber et al. (2016). Use of the covariance notion to complete the triple collocation analysis does not require first scaling the datasets into a common dataspace. The unscaled error presented here represents a combination of both the instrument and representation errors for each dataset. The unscaled error variance (σ_ε^2) is:

$$\sigma_{\varepsilon_X}^2 = \sigma_X^2 - \frac{\sigma_{XY}\sigma_{XZ}}{\sigma_{YZ}}$$

$$\sigma_{\varepsilon_Y}^2 = \sigma_Y^2 - \frac{\sigma_{YX}\sigma_{YZ}}{\sigma_{XZ}}$$

$$\sigma_{\varepsilon_Z}^2 = \sigma_Z^2 - \frac{\sigma_{ZX}\sigma_{ZY}}{\sigma_{XY}}$$

where, σ_i^2 is the dataset variance and σ_{ij} are the dataset covariances. RMSD is $\sqrt{\sigma_\varepsilon^2}$ for positive error variances. A detailed discussion of the underlying assumptions (signal error linearity, signal and error stationarity, error orthogonality, zero error cross-correlation, and dataset representativeness) can be found in Gruber et al. (2016).

For each in situ profile that matched with both SMAP and SMOS observations and passed flag checks, the triple point error analysis is completed to compute both spatially averaged, monthly mean temporal error variances and temporally averaged, spatial error variances. Global error variances over the entire 87-month period are also computed. For all error variances, data were aggregated spatially into equal area regions using a cylindrical equal-area projection with 500-km resolution and no distortion at 45° N/S. Data were then temporally debiased by averaging all data points collected in a month (independent of year) in each spatial region. Global average values (**Table 3**) were weighted by mean ocean fraction of the equal-area regions.

Spatial error variances for the equal area aggregated and monthly binned data are shown in **Figure 20**. Blank locations are regions where the sensitivity of the datasets (2nd term on right-hand side of equation above) is more than the dataset variance (1st term on the right-hand side of equation above). Errors are smallest at low latitudes where waters are warm. SMAP error variances are ~2 times larger north and south of 55° as they are at the equator. SMAP has smaller errors compared to SMOS at all latitudes as well as in the global average (**Table 3**). The effect of applying strict flags does not reduce errors drastically in each individual region but has a large effect on the global average by removing regions with large errors next to the coast and at high latitudes.

Table 3, SMAP V5.0 global average L2 error variance is 0.090. The error variance for SMOS and EN4 are 0.294 and 0.065, respectively. These are much larger than the median differences, and smaller than the standard deviation of the differences (**Figure 19**). For the all flags applied case, global L2 error variance is reduced for all datasets; SMAP (0.053), SMOS (0.160), and EN4 (0.043). As with previous data reports (Kao et al., 2018), the in situ dataset has smaller error variances than the satellite datasets. Applying more aggressive filtering to SMAP data (and therefore the other datasets) reduces error variances for the in situ data base the least (SMAP (42%), SMOS (45%), EN4(34%)). L2 errors are much larger than error variances for gridded monthly L3 data as will be discussed later in Section 5.3. This indicates that errors associated with near surface stratification and subfootprint variability are largest for in situ datasets. Likewise, errors due to cold water, land, ice, etc. have a larger effect on the satellite datasets.

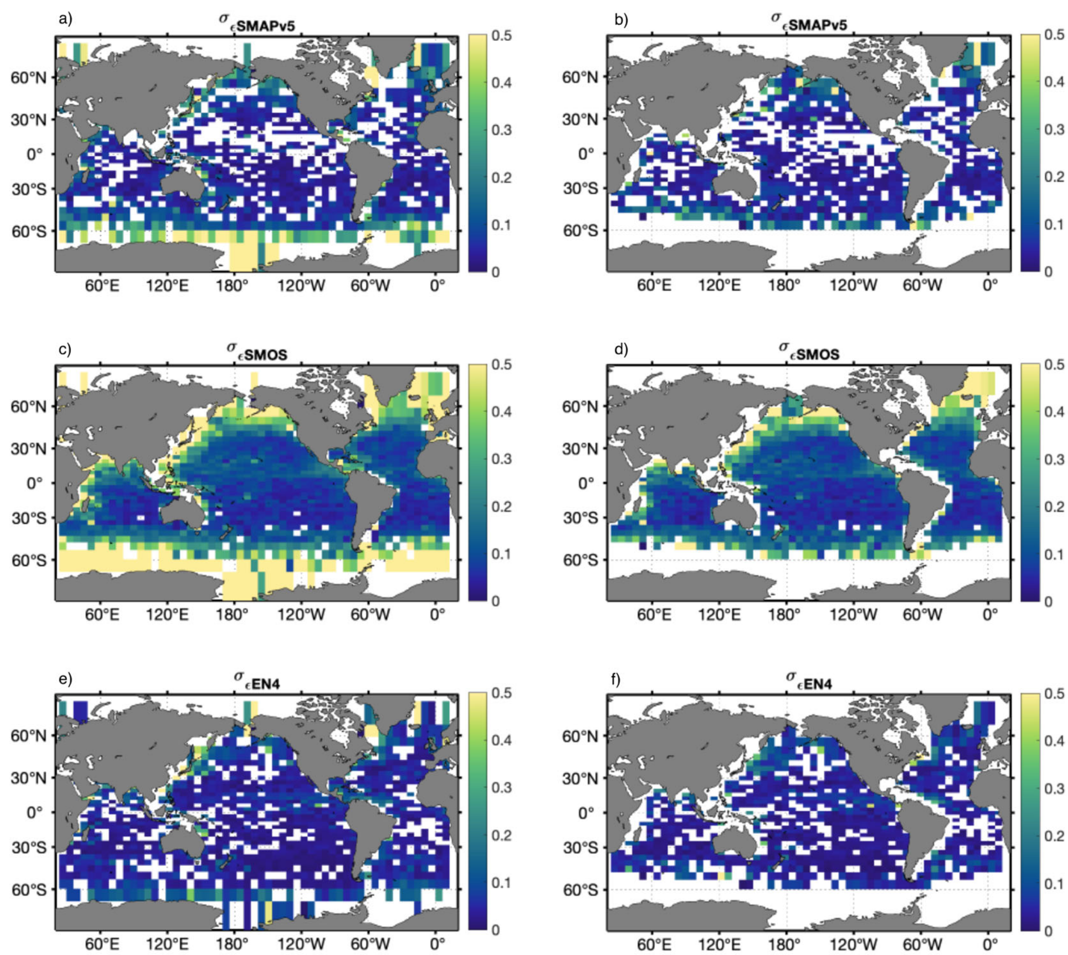

Figure 20. L2 Triple point analysis spatial error variance for SMAP V5.0 (a, b), SMOS 700 (c, d), and EN4 in situ profiles (e, f) for the minimal flags (a, c, e) and all flags (b, d, f) scenarios.

Table 3. L2 triple collocation analysis, equal area, globally averaged unscaled error variance for SMAP V5.0, SMOS, and EN4.

	SMAP v5	SMOS	EN4
Minimal Flags	0.090	0.294	0.065
All Flags	0.053	0.160	0.043

5. Level 3 in situ Matchup

Next, we examine in situ difference statistics of SMAP V5.0 monthly 0.25° × 0.25° L3 salinity data maps. The L3 maps are generated from L2 salinity data by averaging all valid L2C observations within each grid cell without any added adjustment for climatology, reference model output, or in situ data. The standard SMAP L3 data produced by RSS uses the L2C Q/C checks and flag (5, 6, 7, and 10). *Therefore, when using the RSS/SMAP L3 mapped data, the users should be careful when analyzing the salinity data near the coasts. Averaged gland, fland, and gice are included in each grid cell for reference.* Detailed descriptions for the flags applied are summarized in **Table 2**. Data with wind speed exceeding 20 m/s are also excluded during the L3 mapping by RSS. For each grid cell, Argo float profiles located within the 50-meter search radius are averaged for comparisons. The purpose of using averaged Argo float data instead of gridded Argo is to avoid the biases introduced by the climatology and errors in the gridding algorithm. Due to the scarcity of Argo data, many grid cells may have few matchups on monthly maps. However, the grid cells with matchups are obtained with real Argo data. For additional information, see Section 3 in this document or Section 7 in the SMAP V5.0 release note (Meissener et al., 2022).

5.1 SMAP – in situ monthly difference statistics

Figure 21 shows the results of L3 monthly validation for SMAP V5.0. SMAP global weighted and averaged sea surface salinity ranges from 34.73 to 34.98 psu from April 2015 to June 2022 with a slight seasonal cycle. Note that only grid cells with Argo data available for matchup are used for calculation, so some grid cells near sea ice are not included in this global average. Global weighted averages of Argo SSS range from 34.74 to 34.92 psu. The differences between SMAP and Argo range from -0.02 to 0.05 psu, except the first 5 months when the differences are as large as 0.14 psu. Note that when running the SMAP salinity retrieval algorithms, HYCOM is used for the ocean target calibration to ensure that the global average of SMAP matches the global average of the reference salinity field. Therefore, it is not surprising to see very small differences observed in SMAP and Argo global average salinity. The tabulated monthly standard deviations range from 0.28 to 0.42 during the whole mission period. The higher STD occurs at the first few months of the SMAP mission and the months when part of the time SMAP radiometer was in safehold mode (June and July 2019).

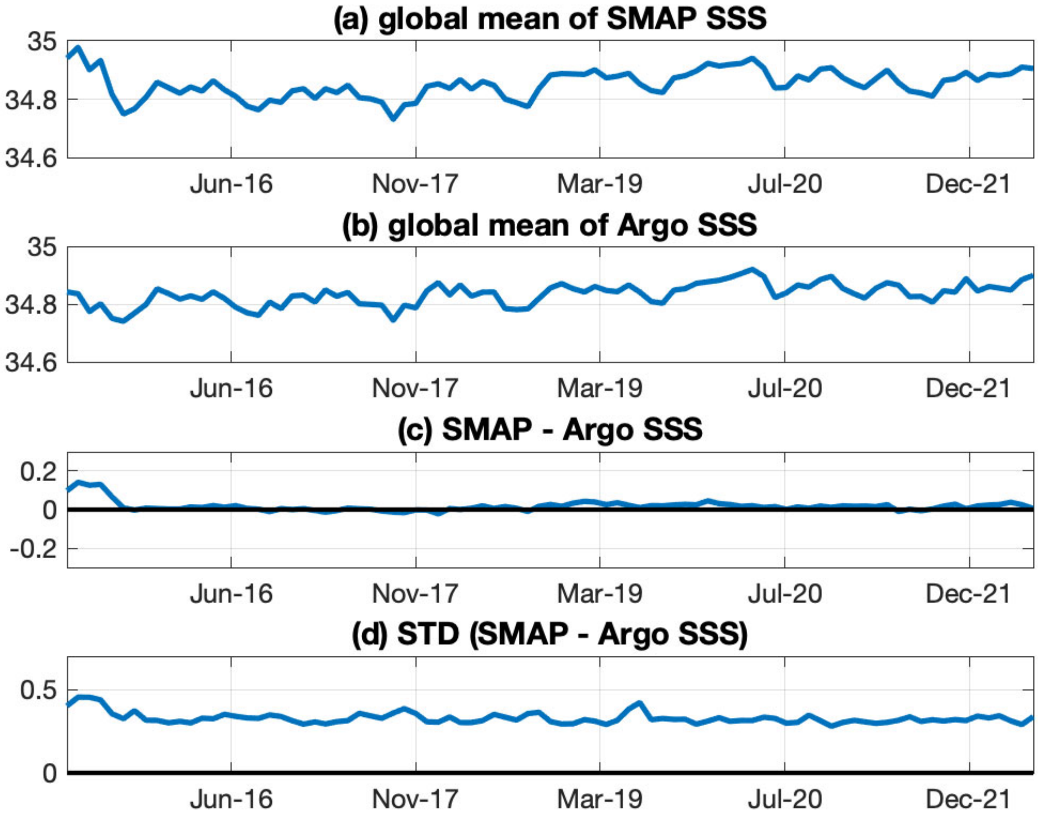

Figure 21. Time series of global weighted averaged SSS calculated from (a) SMAP V5.0 L3 monthly maps and (b) Argo floats. (c) is the global weighted average of salinity differences and (d) shows the standard deviation of the salinity differences.

5.2 Global maps of salinity monthly biases

The maps of SMAP V5.0 monthly biases for the first year of observations (April 2015 to March 2016) are shown in **Figure 22**. Large positive biases are observed in the coastal regions in the higher latitudes in the North Atlantic, Labrador Sea, and Norwegian Sea from April 2015 to August 2015. Positive differences are still observed after September 2015, but the values are smaller. Positive salinity differences are also seen near the coasts of Australia, New Zealand, and Argentina, and these anomalies are reduced after September 2015. This is consistent with **Figure 9** in that larger STD show up during the first few months of SMAP mission.

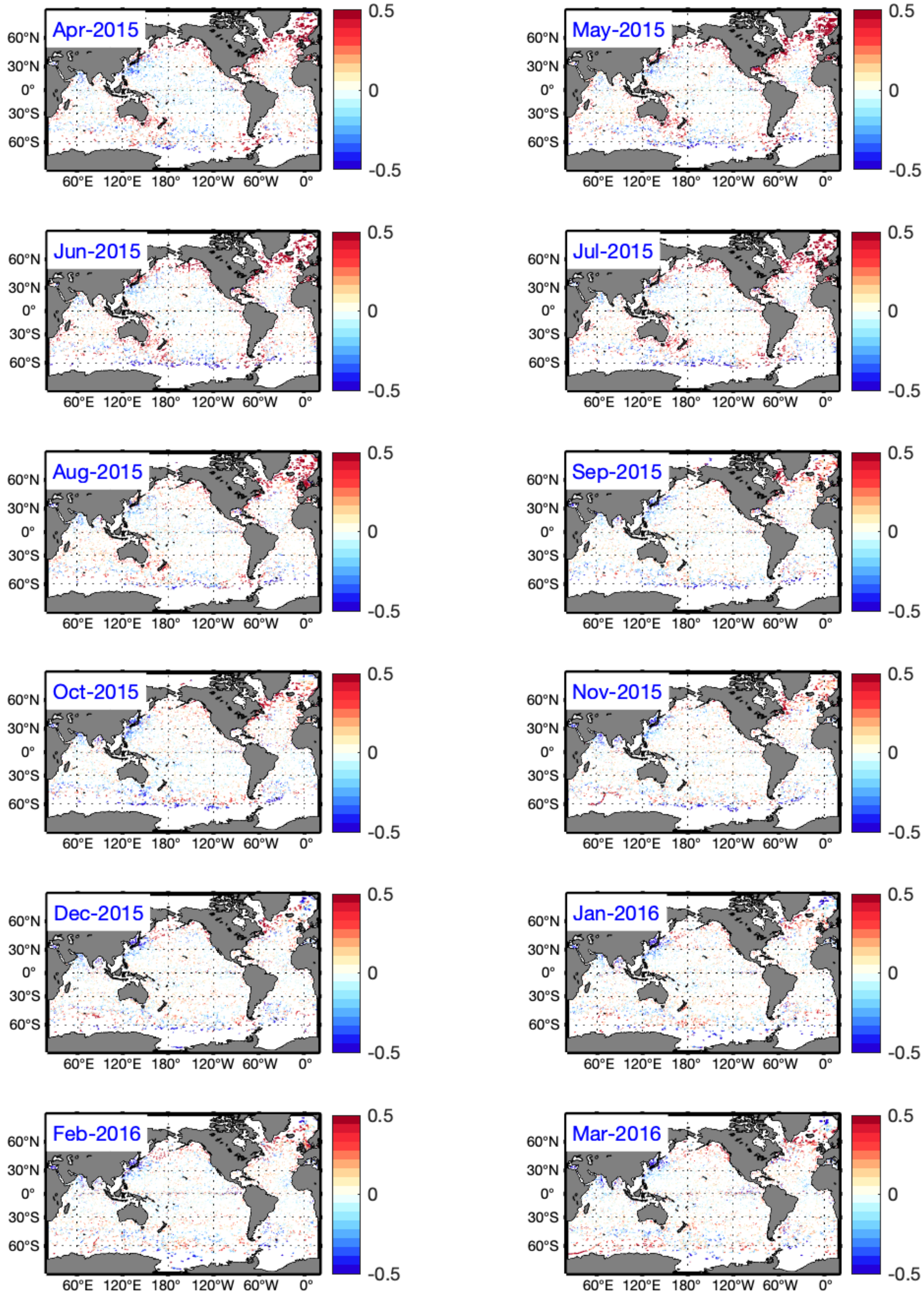

Figure 22. SMAP V5.0 monthly difference maps for the first year of observations.

5.3 Latitudinal distribution of zonally averaged salinity differences

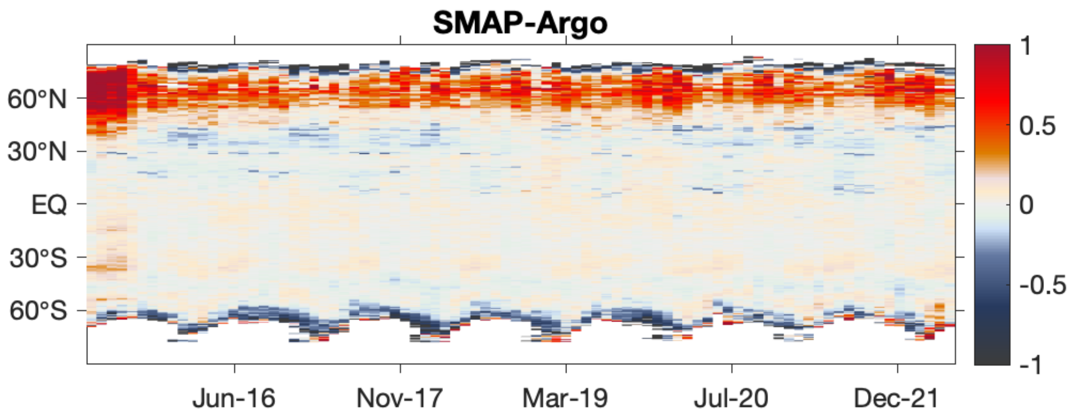

Figure 23. Latitudinal distribution of zonally averaged SMAP V5.0 - Argo salinity differences in psu.

5.4 Triple Collocation Analysis of Monthly Level 3 Gridded Data

As in Section 4.7, here we apply the triple collocation approach to assess SMAP, SMOS, and in situ EN4 L3 monthly random error under two different scenarios (**Table 2**). Both month-by-month, spatially averaged unscaled error as well as a spatial representation of the temporally averaged unscaled error are computed. Finally, an area-weighted global average over the 87-month analysis period is presented. As above, the unscaled error presented here represents a combination of both the instrument and representation errors for each dataset. Triple collocation results are compared with SMAP V5.0 error estimates along with an interpretation of the error sources.

The three datasets used for L3 triple collocation analysis are (1) monthly, 0.25° x 0.25° RSS SMAP V5.0 L3 salinity data maps (Meissner et al., 2022), (2) monthly, 50 km x 50 km, SMOS CATDS-CPDC salinity product (RE07: 74 months, April 2015 to May 2021; OPER: 13 months, June 2021 to June 2022) (Boutin et al., 2018; CATDS (2022), and (3) monthly, 1 x 1 degree objective analyzed EN.4.2.2 data with g10 bias adjustments from the shallowest depth available, (~5 meters, 0-10 meter band) (Good et al., 2013). In contrast to the previous L3 matchup validations, here we use a gridded in situ data product. This is done to more directly compare errors associated with datasets used by the scientific community. Datasets were regridded using linear 2-D interpolation to the coarsest, 1 x 1 degree dataset. For the minimal flags scenario, non-rain filtered SMAP data, non-rain-corrected SMOS data, and minimal additional data filters were used (**Table 2**). All spatial, temporal, and spatiotemporal averages for this scenario therefore include data near land and ice, in cold waters, collected during precipitation events, and collected during wind speeds up to 20 m/s (observations collected when winds are >20 m/s are removed by RSS during L3 gridding). For the all flags applied scenario, rain-filtered SMAP data, rain-corrected SMOS data, and additional filters were applied (**Table 2**). Averages for this scenario therefore exclude most data near land and ice, in cold waters, collected during heavy precipitation events, or collected during winds >15 m/s. Finally, as a requirement of the triple point analysis, grid points where any of the datasets do not have a valid observation (NaN) were also excluded.

Figure 24 and **Table A1** give the month-by-month, spatially averaged unscaled random error for all three data sets used in the triple collocation analysis. For the minimal flags case, EN4 has the largest error variance and seasonal cycle throughout the period followed by SMAP V5.0 and SMOS. SMAP V5.0 errors are similar to EN4 during northern hemisphere summer, and SMOS during northern hemisphere winter. Observation area (swath width), sampling frequency, upper ocean stratification, and measurement depth differences between SMAP V5.0/SMOS and EN4 may contribute to this. For the minimal flags case, both satellite data products are not rain filtered. The all-flags case shows smaller differences between SMAP V5.0, SMOS, and EN4 error variance. It is likely that use of rain filtered data in this case leads to better agreement due to reduction of data points potentially influenced by measurement depth mismatches. All data sets show seasonally varying errors largest during northern hemisphere summer/fall. This may be a result of additive effects of large seasonal activity in Northern Hemisphere dynamic regions (Gulf Stream, Kuroshio, Amazon

River outflow) with incomplete removal of celestial sky radiation seasonal activity in the Southern Hemisphere (Dinnat et al., 2009). In contrast to the Northern Hemisphere, Antarctic polar fronts have smaller seasonal variations in location and do not contribute to large seasonal peak (Kim and Orsi, 2014; Freeman et al., 2016).

Figure 25 gives a spatial representation of the temporally averaged unscaled error. For both satellite data products, errors are largest at high latitudes. This is reflective of lower instrument sensitivity in cooler waters. Conversely, EN4 has largest errors in highly dynamic and/or stratified regions such as the Amazon River outflow and the Bay of Bengal. While the satellite products also show slightly higher errors in these regions, they are significantly smaller than the in situ dataset. This highlights the strength of satellite salinity products in capturing higher spatio-temporal ocean dynamics. SMAP error variance difference between SMAP V4.0 and V5.0 also shows the largest changes at high latitudes (**Figure 26**). Spatial and temporal smoothing of L2 data and in situ point profiles leads to smaller globally averaged error variances for the L3 products (**Table 4)**. SMAP V5.0 equal area weighted, global averaged errors are 0.100/0.044 for L3 monthly averaged data.

The errors in **Figure 25** represent both measurement and representation errors. By making a few assumptions we can separate out the total error into these components. If it is assumed that SMAP uncertainties included with the data product are primarily representative of SMAP measurement errors, then by subtracting that from the total unscaled error, we can estimate the representation error of SMAP V5.0. **Figure 27** shows the SMAP data product error as well as this difference. Differences are again biggest in regions with larger spatio-temporal variability such as the Antarctic circumpolar current, western boundary currents, and river outflow regions. If we assume that the total error from EN4 is primarily due to representation error (a good approximation, since instrument accuracy and long-term stability for Argo float in situ salinity are <0.02 (Wong et al., 2020)), then representation errors for SMAP V5.0 are half of those from in situ datasets.

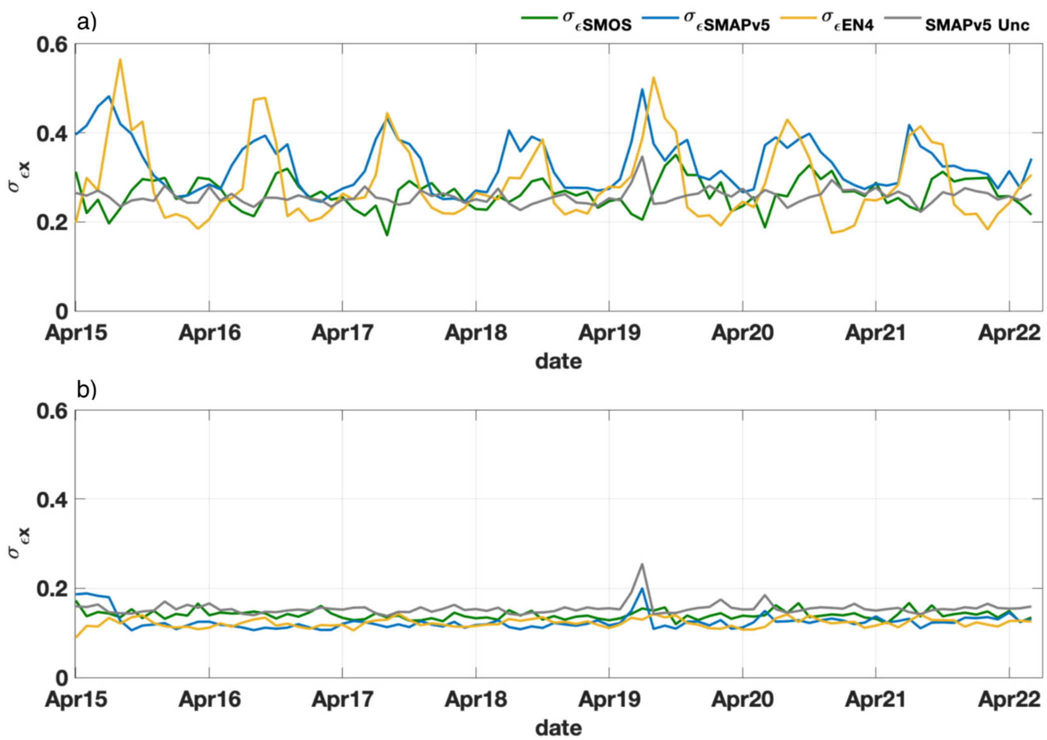

Figure 24. L3 triple collocation analysis monthly unscaled error variance for SMAP V5.0 (blue), SMOS (green), and EN4 (yellow) for the minimal flags (a) and all flags (b) scenarios. Monthly SMAP V5.0 uncertainty estimates (gray) are included for comparison.

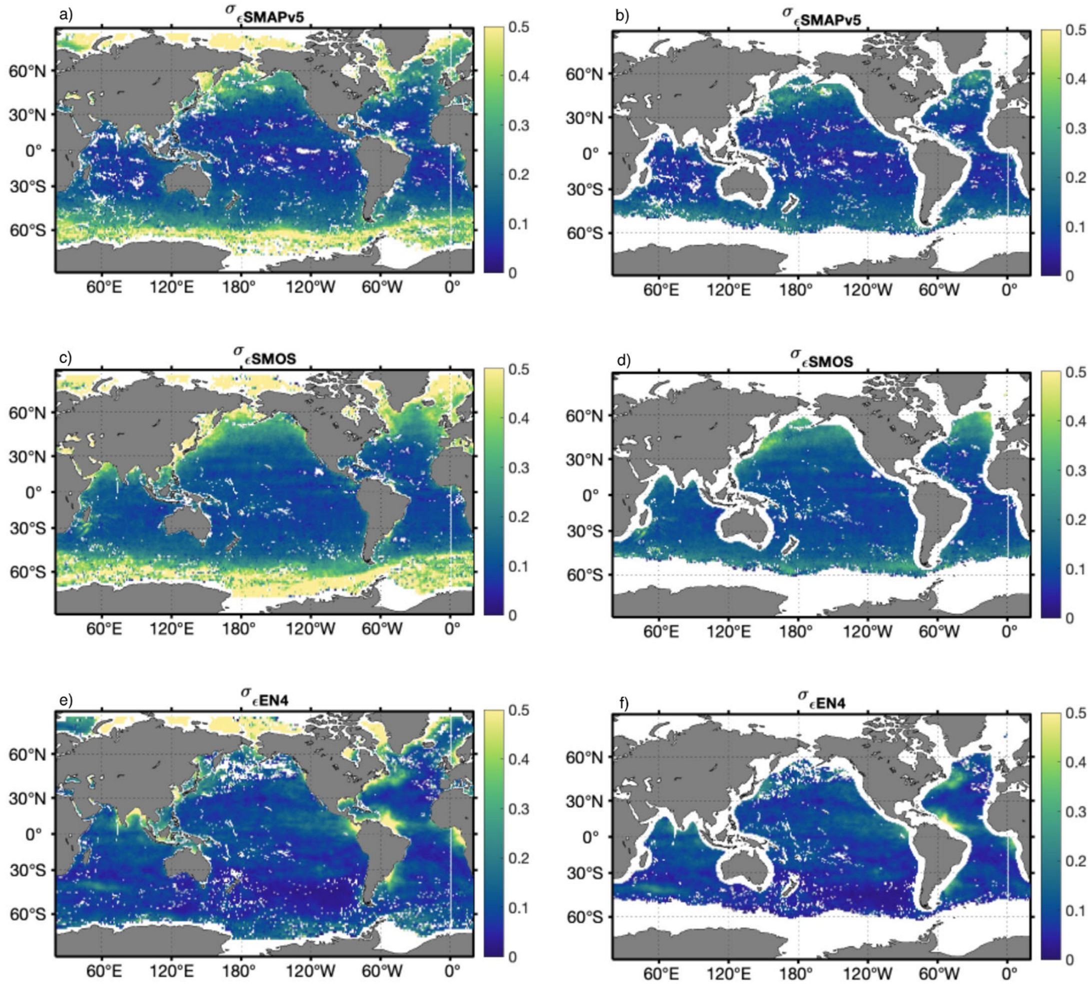

Figure 25. L3 triple collocation analysis temporally averaged monthly unscaled error variance for SMAP V5.0 (a,b), SMOS (c,d), and EN4 (e,f) for the minimal flags (a,c,e) and all flags (b,d,f) applied scenarios.

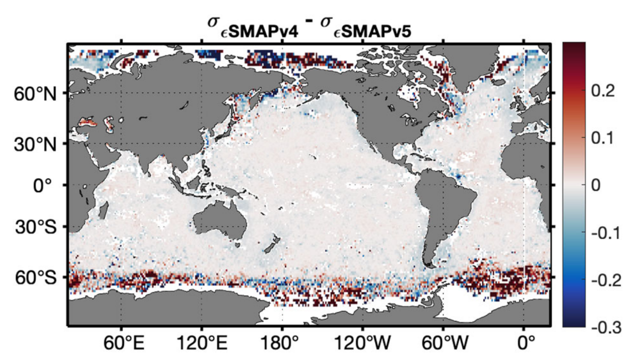

Figure 26. L3 triple collocation analysis temporally averaged monthly unscaled error variance for SMAP V4.0 minus SMAP V5.0 for the minimal flags scenario.

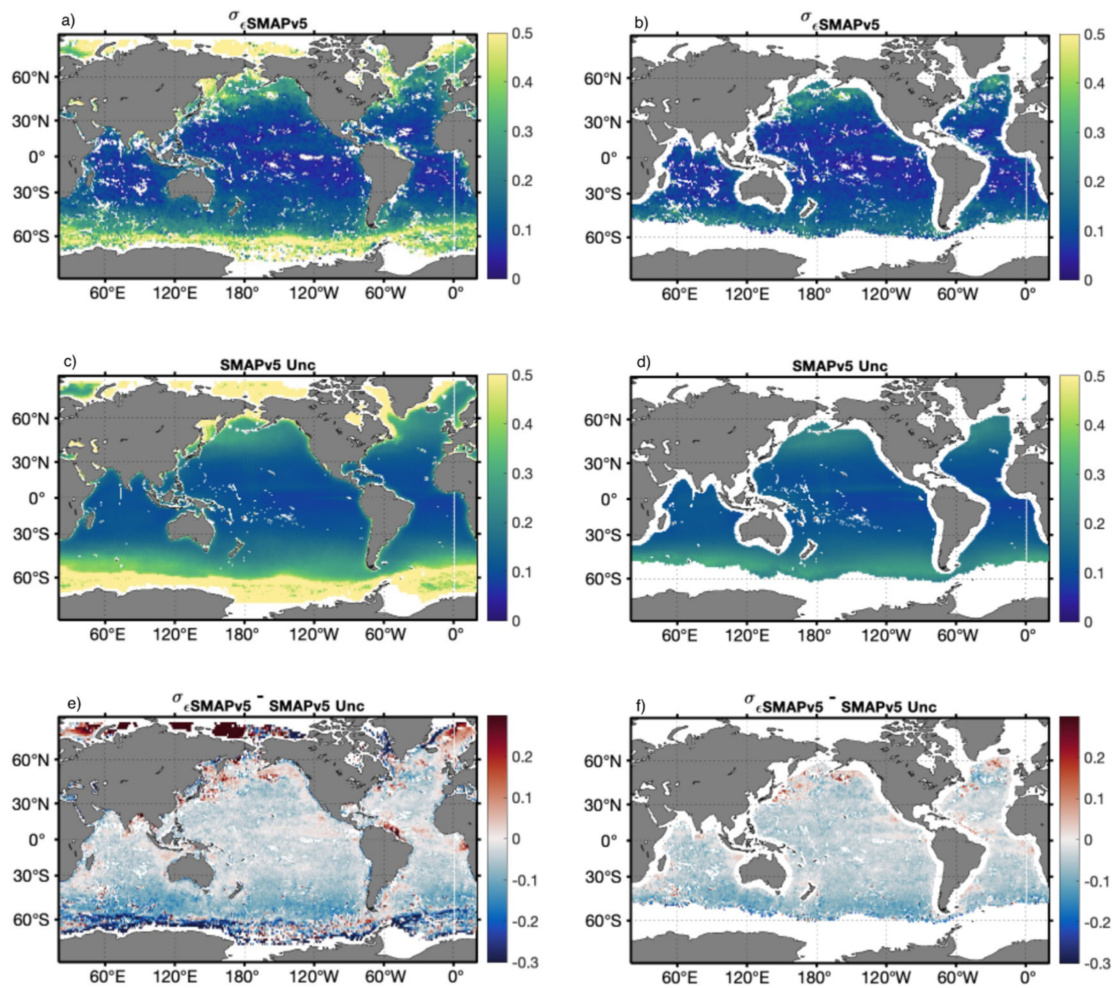

Figure 27. L3 triple collocation analysis temporally averaged monthly unscaled error variance for SMAP V5.0 (a,b), SMAP V5.0 total uncertainty (c,d), and SMAP V5.0 triple point error variance minus SMAP V5.0 total uncertainty (e,f) with minimal flags (a,c,e) and all flags (b,d,f) applied scenarios.

Table 4. L3 triple collocation analysis area weighted, globally averaged, unscaled error variance.

	SMAP v5	SMOS	EN4
Minimal Flags	0.100	0.121	0.078
All Flags	0.044	0.057	0.043

6. Summary, Conclusions, and Cautions

In this report, SMAP data Version 5.0 has been evaluated with multiple approaches. We document the improvements from V4.0 to V5.0 in science data processing and their effect on SMAP salinity data. There are negligible differences in the open ocean and low latitude regions as there are no major revisions in these areas. Analysis of error variance for L2 equal area weighted point matchups, and L3 monthly 1 x 1 degree regridded data consistently demonstrate that V5.0 errors are around ~0.1 psu. In Section 4.7, the L2 triple-point analysis resolved SMAP RMSD 0.090 (0.053) and SMOS RMSD 0.294 (0.160) for the minimal flags (all flags) scenarios point comparisons. On monthly time scales, Section 5.3 L3 triple-point analysis demonstrated a nominal RMSD 0.100 (0.044) for SMAP and 0.121 (0.057) for SMOS minimal flags (all flags) scenarios. By various measures, the L2 global RMS errors are close between V4.0 and V5.0, even though V5.0 includes more data near sea-ice by improving the ice flags.

6.1 Important achievement in each SMAP version

V3.0: The V3.0 algorithm uses the geophysical model function (GMF) from Aquarius V5.0 release adapted to SMAP V4.0 (Meissner et al. 2017, 2018). The Cross-Calibrated Multi-Platform (CCMP) product is used for near-real time ancillary wind speed and wind direction. V3.0 includes the NASA Global Precipitation Measurement (GPM) Integrated Multi-Satellite Retrievals for GPM (IMERG) rain rate for the atmospheric liquid cloud water correction and rain flags.

V4.0: The most important improvement in V4.0 is the land correction. The spatial resolution of the land tables is 1/2° in V3.0 and has been increased to 1/8° in V4.0. The land surface TB was based on a land surface emission model in V3.0 but is based on a monthly climatology of SMAP land TB measurements in V4.0. In V3.0, the sea-ice mask was from NCEP and is replaced with RSS AMSR-2 sea-ice maps in V4.0. The V4.0 salinity retrieval algorithm uses 40-km spatial Backus Gilbert Optimum Interpolation (OI). From the 40-km product, the smoothed 70-km product is derived using simple next-neighbor averaging. More details of the data updates are documented in Meissner et al. (2022).

V5.0: The sea-ice flagging and masking in V5.0 ingests 8-day averaged AMSR-2 T_b measurements directly, rather than an external, derived ancillary sea-ice concentration. In V5.0, salinity fields are classified into different sea-ice zones to show the level of sea-ice contamination in the antenna field of view based on nearest neighbor and next to nearest neighbors of observations that are flagged as sea-ice contaminated. Side-lobe correction for sea-ice contamination is applied to the measured SMAP T_b before salinity is retrieved.

6.2 Notes of Caution

Note of Caution, during early mission: Positive salinity biases are present near the coastal regions in high latitudes in the early SMAP mission (around April to August in 2015). The affected areas include coasts of Japan, Australia, New Zealand, South America, east coasts of North America, the Labrador Sea, and the Norwegian Sea. The actual cause is still unknown and further investigations are needed.

Note of Caution, rain masks: The rain-filtered (RF) data were included since V3.0 for monthly L3 data as separate datafiles. In V5.0, The RF salinity (sss_smap_RF) has been included as an additional field within the L3 files. The data are discarded when the IMERG rain rate, resampled to 40 km, exceeds 0.1 mm/h. If the users are interested in SMAP SSS under strong precipitation, data without RF should be used. Otherwise, data with rain masks should be used for general studies and for validation purposes.

Note of Caution, land fraction in the L3 mapped data: The RSS data uses *gland* > 0.04 and *fland* > 0.005 as criterion to include more data information near the coasts. *fland* was set to 0.001 in V4.0 and was increased to 0.005 in V5.0 to include more data near land. Based on the sensitivity tests (**Figure 12c**), regions with *fland* between 0.001 and 0.005 have slightly larger biases compared to regions with *fland* < 0.001. Users should be aware when using SMAP data very close to land.

7. References

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Appendix A Triple Point Analysis Monthly Error Variance Tables

Table A1. L3 triple collocation analysis monthly unscaled error variance for minimal flags and all-flags applied scenarios

	Minimal Flags			All Flags		
	SMAP v5	SMOS	EN4	SMAP v5	SMOS	EN4
Apr-15	0.396	0.313	0.198	0.186	0.172	0.089
May-15	0.417	0.220	0.299	0.188	0.137	0.116
Jun-15	0.459	0.250	0.270	0.183	0.147	0.114
Jul-15	0.482	0.197	0.420	0.180	0.143	0.134
Aug-15	0.420	0.230	0.565	0.127	0.135	0.121
Sep-15	0.397	0.271	0.405	0.106	0.153	0.135
Oct-15	0.347	0.296	0.425	0.116	0.133	0.140
Nov-15	0.304	0.292	0.266	0.119	0.150	0.122
Dec-15	0.283	0.299	0.209	0.122	0.131	0.115
Jan-16	0.256	0.251	0.217	0.108	0.142	0.112
Feb-16	0.259	0.260	0.208	0.117	0.139	0.114
Mar-16	0.272	0.299	0.184	0.125	0.166	0.108
Apr-16	0.284	0.296	0.206	0.125	0.139	0.112
May-16	0.273	0.276	0.245	0.118	0.145	0.122
Jun-16	0.326	0.239	0.253	0.116	0.143	0.114
Jul-16	0.363	0.222	0.274	0.112	0.144	0.123
Aug-16	0.382	0.213	0.474	0.106	0.148	0.130
Sep-16	0.394	0.258	0.479	0.112	0.144	0.134
Oct-16	0.353	0.309	0.378	0.109	0.132	0.116
Nov-16	0.374	0.319	0.213	0.112	0.142	0.121
Dec-16	0.285	0.280	0.230	0.120	0.136	0.114
Jan-17	0.251	0.255	0.201	0.112	0.146	0.109
Feb-17	0.245	0.268	0.209	0.107	0.160	0.118
Mar-17	0.261	0.250	0.228	0.107	0.143	0.117
Apr-17	0.275	0.256	0.264	0.120	0.134	0.118
May-17	0.283	0.229	0.251	0.126	0.128	0.106
Jun-17	0.314	0.214	0.255	0.124	0.131	0.123
Jul-17	0.386	0.237	0.306	0.119	0.144	0.128
Aug-17	0.433	0.170	0.444	0.113	0.135	0.130
Sep-17	0.385	0.272	0.386	0.119	0.139	0.143
Oct-17	0.375	0.292	0.356	0.113	0.127	0.129
Nov-17	0.342	0.273	0.266	0.126	0.128	0.117
Dec-17	0.264	0.287	0.232	0.119	0.133	0.121
Jan-18	0.251	0.258	0.219	0.114	0.126	0.118
Feb-18	0.252	0.274	0.218	0.125	0.145	0.114
Mar-18	0.245	0.245	0.230	0.112	0.137	0.113
Apr-18	0.270	0.229	0.265	0.118	0.133	0.115
May-18	0.266	0.227	0.259	0.119	0.135	0.119
Jun-18	0.313	0.258	0.251	0.128	0.129	0.119
Jul-18	0.406	0.245	0.299	0.113	0.151	0.131
Aug-18	0.358	0.259	0.298	0.108	0.139	0.127
Sep-18	0.392	0.291	0.342	0.115	0.149	0.131
Oct-18	0.380	0.298	0.385	0.111	0.130	0.135

Nov-18	0.311	0.263	0.242	0.122	0.138	0.123
Dec-18	0.277	0.270	0.217	0.119	0.130	0.125
Jan-19	0.277	0.259	0.227	0.116	0.136	0.120
Feb-19	0.276	0.268	0.218	0.120	0.139	0.126
Mar-19	0.270	0.231	0.259	0.128	0.132	0.118
Apr-19	0.274	0.246	0.279	0.117	0.128	0.111
May-19	0.296	0.252	0.277	0.122	0.133	0.119
Jun-19	0.379	0.218	0.303	0.149	0.142	0.134
Jul-19	0.498	0.205	0.388	0.199	0.155	0.129
Aug-19	0.375	0.270	0.524	0.109	0.150	0.142
Sep-19	0.338	0.326	0.433	0.116	0.157	0.135
Oct-19	0.368	0.351	0.403	0.109	0.119	0.139
Nov-19	0.384	0.305	0.233	0.125	0.139	0.122
Dec-19	0.303	0.305	0.212	0.125	0.129	0.118
Jan-20	0.295	0.252	0.215	0.117	0.138	0.110
Feb-20	0.315	0.289	0.192	0.129	0.144	0.109
Mar-20	0.292	0.224	0.223	0.109	0.132	0.116
Apr-20	0.267	0.236	0.245	0.112	0.138	0.107
May-20	0.273	0.256	0.233	0.124	0.137	0.108
Jun-20	0.372	0.188	0.286	0.149	0.139	0.113
Jul-20	0.390	0.262	0.371	0.125	0.162	0.133
Aug-20	0.366	0.257	0.430	0.126	0.145	0.141
Sep-20	0.385	0.303	0.394	0.128	0.166	0.124
Oct-20	0.398	0.327	0.342	0.122	0.135	0.139
Nov-20	0.357	0.296	0.255	0.128	0.138	0.128
Dec-20	0.334	0.315	0.175	0.132	0.141	0.121
Jan-21	0.296	0.268	0.180	0.128	0.139	0.124
Feb-21	0.283	0.269	0.192	0.120	0.144	0.124
Mar-21	0.274	0.258	0.251	0.123	0.135	0.111
Apr-21	0.285	0.288	0.248	0.137	0.131	0.116
May-21	0.282	0.242	0.258	0.123	0.122	0.123
Jun-21	0.287	0.254	0.284	0.127	0.142	0.112
Jul-21	0.418	0.234	0.394	0.132	0.167	0.127
Aug-21	0.370	0.225	0.415	0.110	0.137	0.141
Sep-21	0.354	0.296	0.379	0.123	0.162	0.129
Oct-21	0.324	0.313	0.374	0.124	0.137	0.128
Nov-21	0.326	0.291	0.239	0.122	0.142	0.128
Dec-21	0.316	0.297	0.217	0.134	0.145	0.114
Jan-22	0.314	0.298	0.218	0.133	0.141	0.123
Feb-22	0.307	0.299	0.183	0.135	0.148	0.118
Mar-22	0.275	0.257	0.218	0.130	0.134	0.114
Apr-22	0.314	0.258	0.242	0.145	0.149	0.126
May-22	0.276	0.240	0.280	0.125	0.124	0.127
Jun-22	0.342	0.216	0.306	0.130	0.134	0.125

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