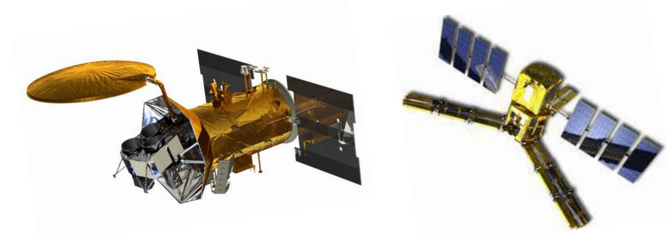
P044E-3205

Variability and Uncertainty in Satellite Sea-surface Salinity Observations

E. Bayler[1] and Li Ren[2,1]

[1]NOAA/NESDIS Center for Satellite Applications and Research (STAR)

[2]Cooperative Institute for Climate Studies (CICS), University of Maryland



ABSTRACT:

When employing satellite sea-surface salinity (SSS) observations in studies of observed and modeled ocean variability and change, assessments must consider the variability and uncertainty contained within the satellite SSS data that may or may not reflect physical processes. Coherent temporal and spatial structures exists in the differences between the ascending (south to north) and descending (north to south) nodes of both NASA's Aquarius mission and ESA's Soil Moisture – Ocean Salinity (SMOS) mission, introducing non-physical variability into the data. When examining "simultaneous" match-ups of both Aquarius and SMOS satellite observations with Argo float *in situ* observations (triple match-up), the Aquarius and SMOS data exhibit different temporal and spatial variabilities with respect to the *in situ* data, as well as with respect to each other. While physical differences will exist between the skin salinity (approximately 1cm) observed by the satellites and the near-surface salinity (approximately 5 m) observed by Argo floats, when using satellite SSS observations, non-physical variability may intrude into assessments of ocean salinity variability.

DATA:

This effort examines the data for the period **1 January 2012 through 31 December 2014** for each of the following data sets:

- ESA SMOS Level-2 SSS data; Level-2 Operating System processor **version 5.50**
- Aquarius Data Processing System (ADPS) Level-2 SSS **v4.0 data**; NASA Jet Propulsion Laboratory (JPL) Physical Oceanographic Distributed Active Archive Center (PO.DAAC)
- Aquarius Combined Active-Passive (CAP) Level-2 SSS **v4.0 data**, without precipitation adjustment; NASA JPL PO.DAAC
- Argo salinity profiles – ungridded, USGODAE Monterey Server

All sources in this analysis are ungridded data: satellite Level-2 swath data and the *in situ* U.S. GODAE server database. Salinity values are referenced to the UNESCO Practical Salinity Scale of 1978 (PSS-78).

METHODOLOGY:

A satellite's "ascending" node is the portion of the satellite's polar orbit where the satellite travels from the South Pole to the North Pole and the "descending" node is the portion of the orbit from the North Pole to the South Pole. For Aquarius data files, both the NASA Aquarius Data Processing System (ADPS) "official" data and the NASA JPL Combined Active-Passive (CAP) data, were first separated into ascending and descending nodes based on the satellite's zenith angle (*zang*), where *zang < 180* is the ascending portion of the orbit and *zang > 180* is the descending portion of the orbit. The SMOS data were identified as ascending/descending node data files based on that characterization within the included metadata. For calculating the ascending minus descending differences, the ascending and descending observations were separately binned (1° × 1° latitude/longitude), accumulating over a single period of full global coverage (SMOS = 3 days, Aquarius = 7 days), averaged within each bin, then the bin value for the descending node was subtracted from the bin value for the ascending node.

The triple point analysis compares simultaneous collocated observations by *in situ* Argo profiling floats, SMOS SSS retrievals and Aquarius SSS retrievals. Simultaneity is defined as observations occurring within the 7 days, centered on the day of the specified Argo observation. Collocation is defined as being within a radius of 75 km of the specified Argo observation.

DISCUSSION:

Notable spatial and temporal differences exist between ascending and descending node retrievals, particularly for SMOS retrievals.

Ascending-Descending Node Retrievals - Spatial Differences

Figure 1 depicts the annual mean ascending-descending node retrieval differences for SMOS (Fig. 1.a), Aquarius-ADPS (Fig. 1.b), and Aquarius-CAP (Fig. 1.c). White areas indicate that one node or the other is missing data (e.g., due to data quality filtering), precluding a comparison. It is immediately obvious that SMOS is subject to the greatest and most extensive differences. Strong negative shadows exist in the SMOS data, particularly along the western coasts of land masses, indicating that descending node values are notably larger, with magnitudes approximately twice the mission's accuracy requirement. **Please note that the difference scale for the SMOS data (Figs. 1.a and 1.d) has twice the range as that for the Aquarius data (Figs. 1.b,c and 1e,f).** The ADPS and CAP data are much less affected by ascending/descending node differences, with the CAP having smaller and fewer data gaps (white areas), perhaps due to differences in how data quality criteria are applied, e.g. the radio-frequency interference flag. The SMOS data also shows persistent marked differences, positive and negative, along the coast of Antarctica, with large positive differences in the vicinity of the Drake Passage. Between approximately 60°S – 45°S, both the ADPS and CAP data sets exhibit a spatial pattern of positive and negative difference regions of that circles the globe, alternating about every 45° longitude on the multiples of 45°. This cyclical characteristic is not evident in the SMOS data. Figures 1.d-f show the spatial distribution of the root mean square (RMS) differences for the SMOS, ADPS, and CAP data sets, respectively. Overall, the ADPS data has the smallest RMS errors.

Ascending – Descending Node Differences: Annual-mean Spatial Distribution

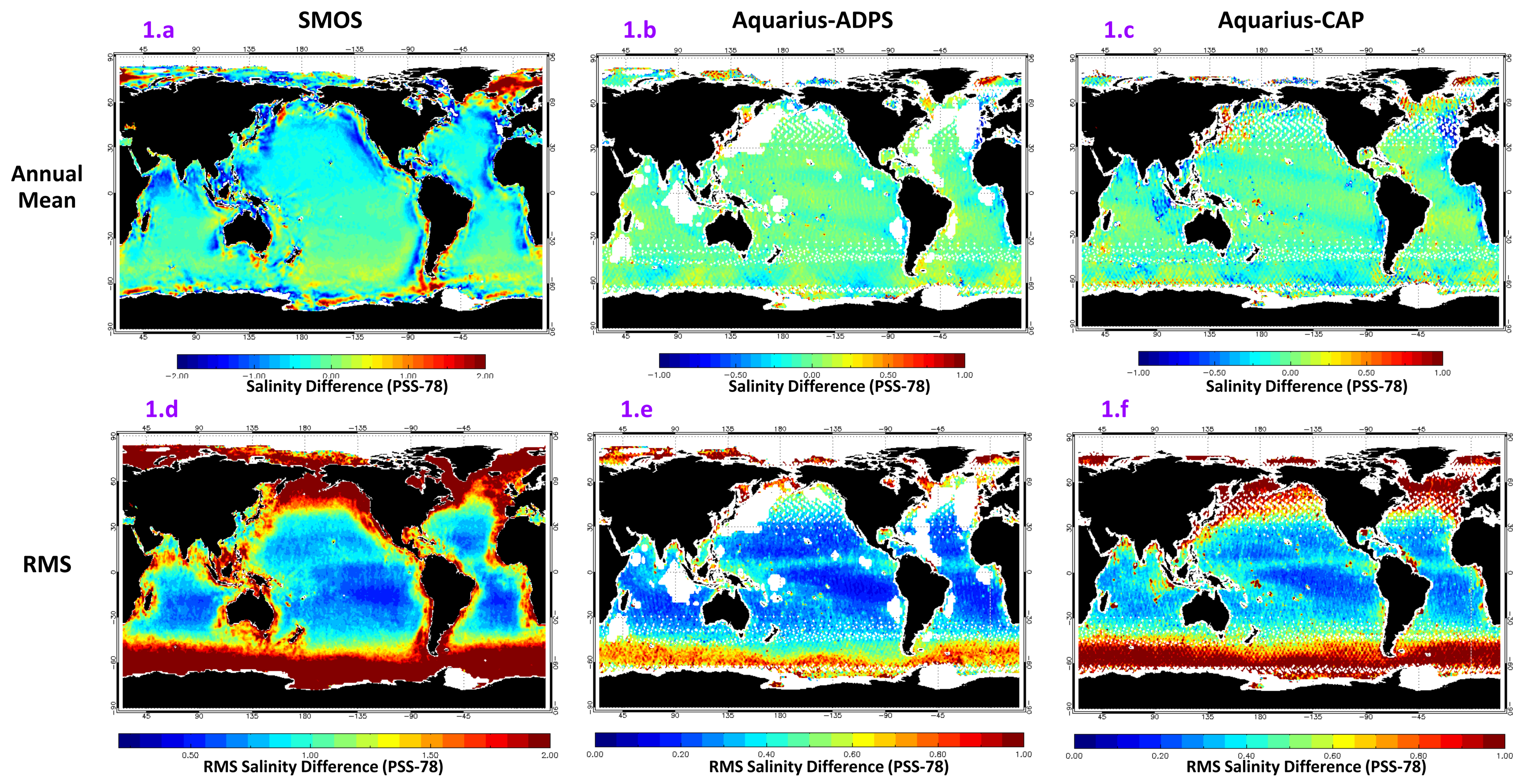


Figure 1. Satellite sea-surface salinity (SSS) ascending minus descending node retrieval differences: Annual mean difference a) SMOS, b) Aquarius ADPS, c) Aquarius CAP; Root mean square (RMS) difference d) SMOS, e) Aquarius ADPS, f) Aquarius CAP.

Ascending-Descending Node Retrievals - Temporal Differences

SMOS data node differences have notably stronger cyclical temporal variability than the Aquarius ADPS and CAP data, ranging approximately 20 times the mission accuracy requirement of 0.1 PSS-78. **Again, note that the SMOS difference scale for Fig. 2.a has twice the range as the scale for the Aquarius data, Figs. 2.b, c**. SMOS's strong seasonality has positive differences (larger ascending node values) approximately October through about January in the Southern Hemisphere extending equatorward to about 40°S, with negative differences (larger descending node values) for the remainder of the year. The transitions between the phases is relatively abrupt. At about the same time in the Northern Hemisphere, there is a similar large positive difference, extending equatorward to about 20°N; however, north of about 60°N this positive difference extends for most of the year, cycling negative during approximately June through October. In the Northern Hemisphere, SMOS transitions from positive to negative difference are significantly more diffuse. The Aquarius ADPS and CAP data have muted seasonal signals. In the Southern Hemisphere (SH), cyclical variability is largely confined to poleward of about 25°S, with positive differences November through June and comparable negative magnitude differences July through October. For the ADPS data, SH positive peak magnitude April through June, while the corresponding CAP peak is much narrower and confined to May. The Northern Hemisphere (NH) has a band of cyclical temporal variability poleward of about 60°N that exhibits notably focused negative difference pulse during July and August. In this band, for the periods outside this pulse, the CAP data exhibits notably larger differences than the ADPS data. The CAP data has an additional band of variability between 30°N and 60°N that has a negative difference pulse February through March. Temporal variability of ADPS ascending-descending differences is more muted than that for the CAP data. Unexplained is the significant negative difference in the CAP data spanning 30°S to 60°N during March-April 2014.

Ascending-Descending Node Retrievals – Annual Mean of Zonal Means

Figure 3 depicts the annual mean of the zonal mean ascending-descending node difference. It is striking that the SMOS data exhibits an overall negative difference trend, falling from a positive difference of about 0.07 pss at the only positive peak (~ 45°S) to a negative difference of -0.55 pss (~40°N), significantly exceeding the SMOS mission requirement for accuracy . The Aquarius ADPS and CAP data sets, however, are, in the mean, nearly flat across nearly all latitudes, with notably larger variability of zonal differences poleward of 30°N. As previously seen in Fig. 2.c, the CAP node differences are biased negative, while the ADPS differences are, in the mean, generally minimal, with large zonal fluctuations north of 30°N. North of 40°N, SMOS's large negative differences reduce in a poleward trend. The reason(s) for the distinct and significant SMOS node difference trends is(are) not obvious. If the Northern Hemisphere land mass distribution is a contributing factor, it is not clear why it would be so asymmetrical.

Ascending – Descending Node Differences: Zonal-mean Temporal Variability

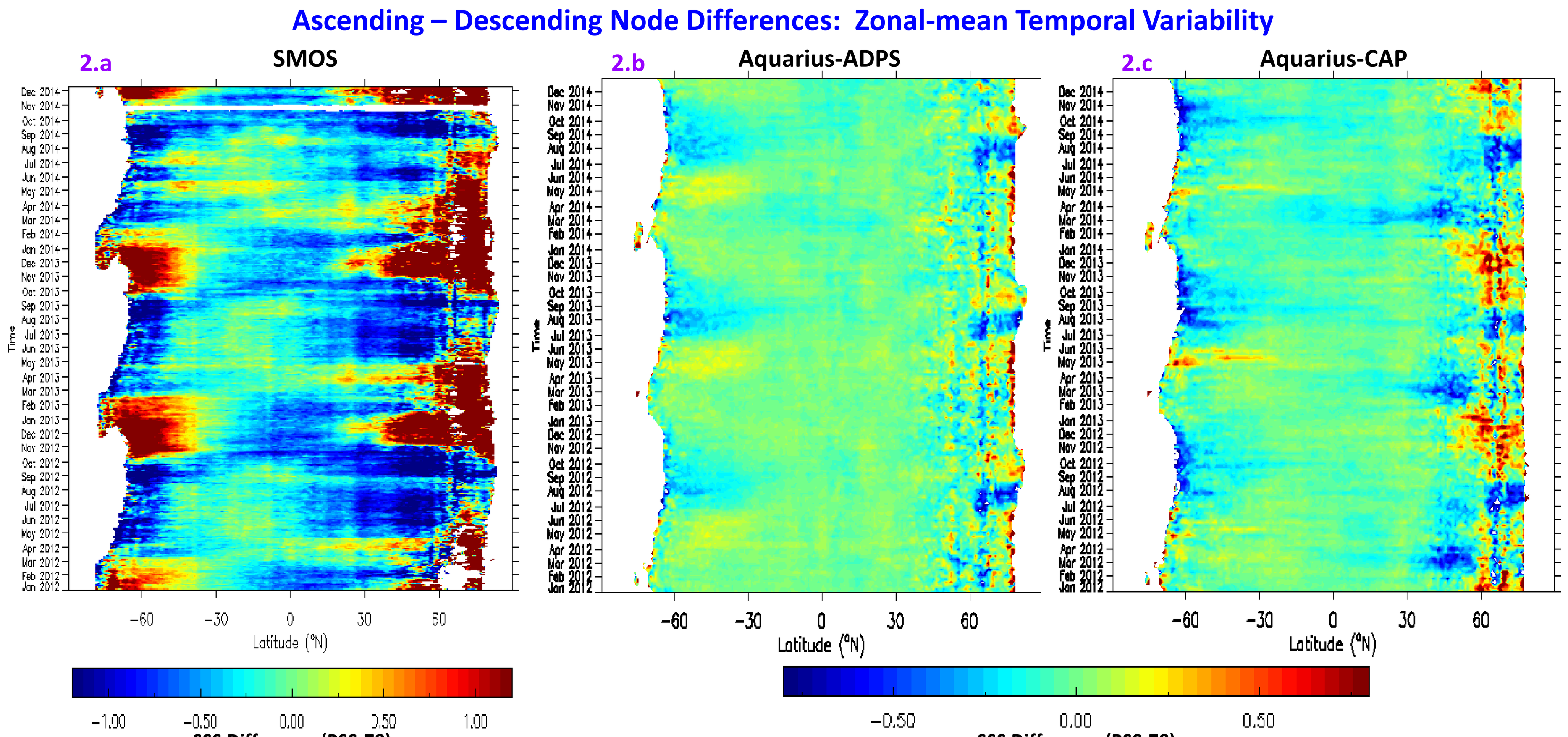


Figure 2. Temporal variability of the zonal (1° bins) mean satellite sea-surface salinity (SSS) ascending minus descending node retrieval differences: a) SMOS, b) Aquarius ADPS, c) Aquarius CAP

Ascending – Descending Node Differences: Annual Mean of Zonal Mean

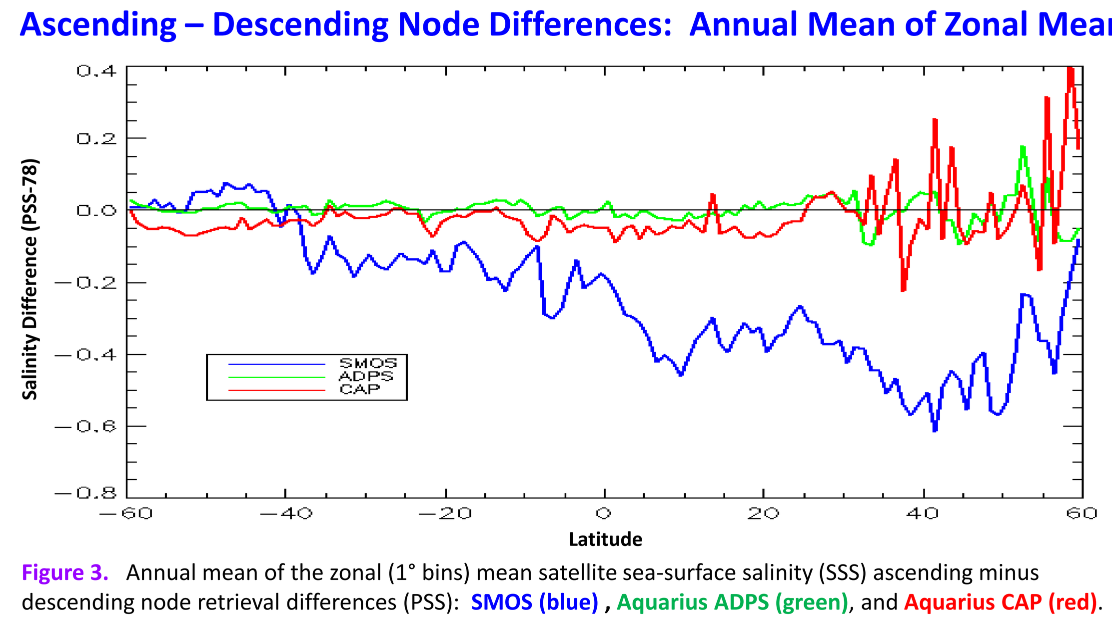


Figure 3. Annual mean of the zonal (1° bins) mean satellite sea-surface salinity (SSS) ascending minus descending node retrieval differences (PSS): **SMOS (blue)** , **Aquarius ADPS (green)**, and **Aquarius CAP (red)**.

Argo-SMOS-Aquarius Triple-point Analysis

Simultaneous collocated measurements from Argo, SMOS, and Aquarius permit more direct comparisons of performance and consistency. Figures 4.a-c depict how well the satellite retrievals match the Argo *in situ* observations for SMOS, ADPS, and CAP, respectively. Best fit regressions are noted, with the ideal match-up being $y = x$. From a scatter plot perspective, the ADPS values most closely match Argo observations. SMOS data has a notably poorer agreement with *in situ* observations, while CAP data exhibits greater scatter, implying greater uncertainty. With respect to the spatial distribution of triple match-up differences, Figure 5, SMOS differences from Argo (Fig. 5.a), do not display the positive zonal differences seen at higher latitudes in the ADPS and CAP data, but do exhibit a broad distribution of negative bias. The Aquarius (ADPS and CAP) data differences from Argo hint at the location of the Intertropical Convergence Zone (ITCZ). The ADPS data better matches Argo data in coastal regions than the CAP data. The far western Pacific is a region of negative bias for all three satellite data sets, which likely results from radio-frequency interference (RFI). Figure 6 displays zonal-mean temporal variability. SMOS retrievals differences from *in situ* Argo data (Fig. 6.a) show notable temporal variability exceeding the SMOS mission accuracy requirement in both positive and negative differences. These SMOS-Argo differences have cyclical negative differences November-January and positive differences March-October, with a notable negative anomaly June-August 2014. What is interesting is that the positive/negative character of the anomalies is synchronized across all latitudes and is not seasonally dependent by hemisphere. The Aquarius (ADPS and CAP) data have seasonality that synchronizes with the hemispheres' season, predominantly in the Southern Hemisphere, with ADPS (Fig. 6b) having the strongest signal and CAP (Fig. 6.d) having the weakest signal.

Argo-SMOS-Aquarius Triple-point Match-ups

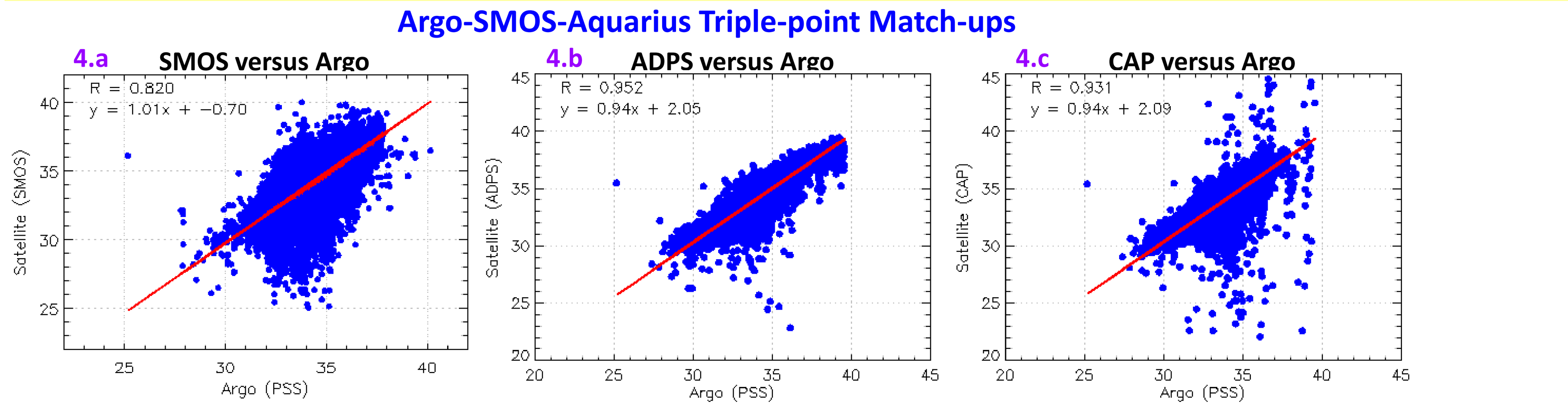


Figure 4. Triple-point matchups, Argo-SMOS-Aquarius, within 75 km and 7 days, centered on the Argo observation: a) SMOS versus Argo, b) Aquarius-ADPS versus Argo, and c) Aquarius-CAP versus Argo.

Satellite-*In situ* Triple-point Differences: Spatial Distribution

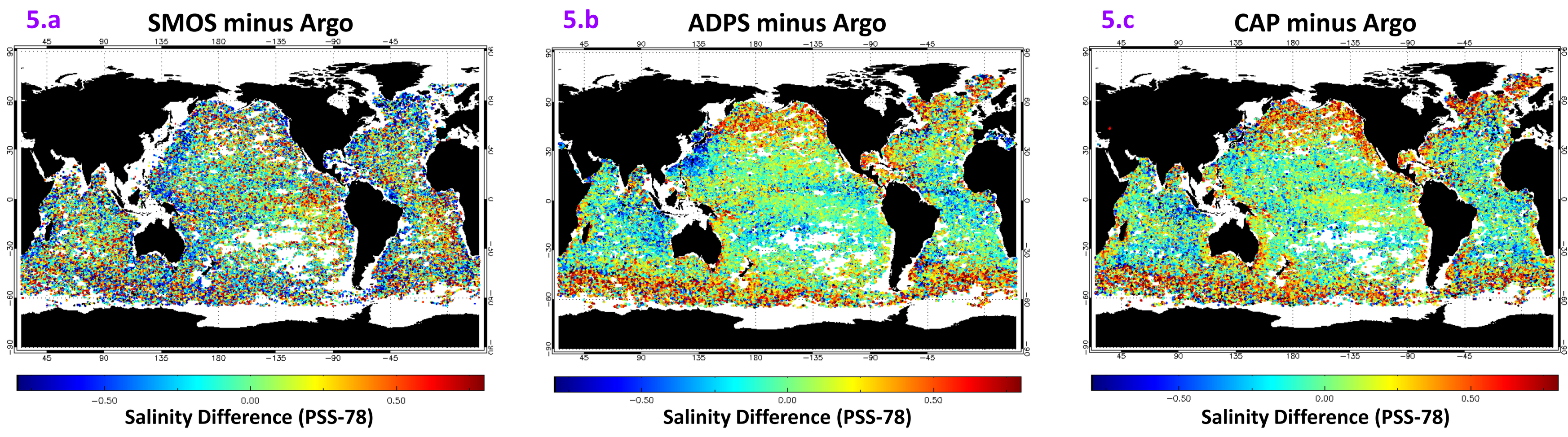


Figure 5. Satellite minus *in situ* salinity differences (pss) at Argo-SMOS-Aquarius triple-point match-ups (within 7 days centered the Argo observation and 75 km): a) SMOS minus Argo, b) Aquarius-ADPS minus Argo, and c) Aquarius-CAP minus Argo.

Satellite-*In situ* Triple-point Differences: Zonal Mean Variability

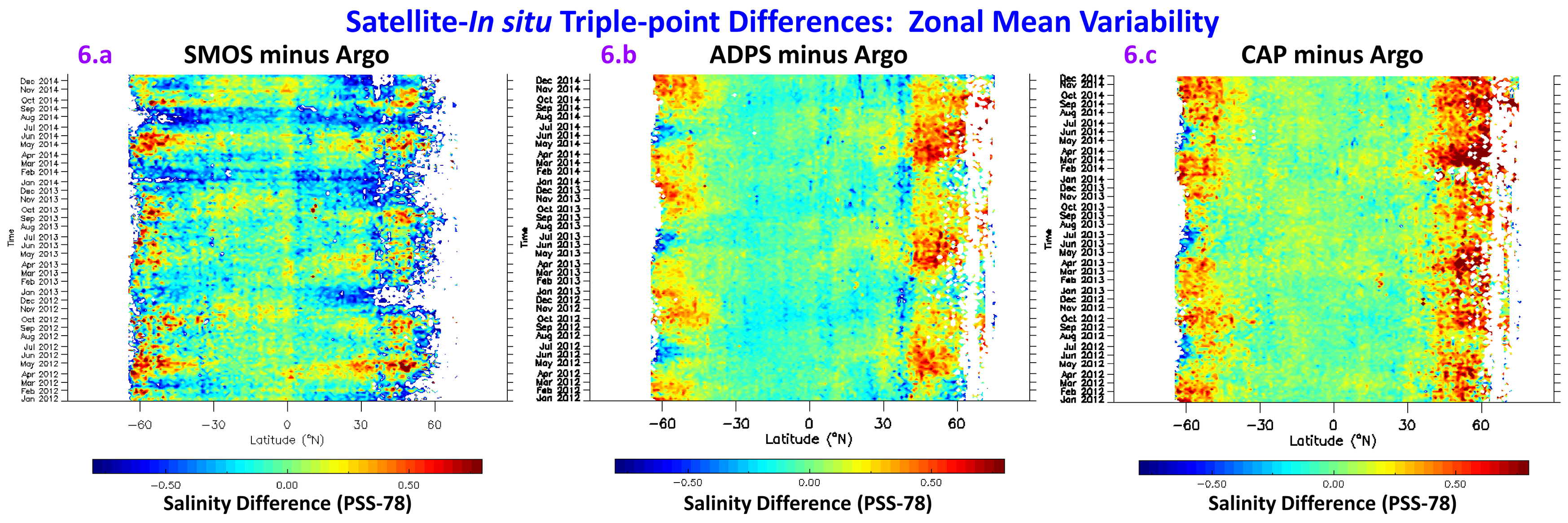


Figure 6. Temporal salinity differences (pss), satellite retrieval minus *in situ* observational Argo-SMOS-Aquarius triple-point match-ups (within 7 days centered the Argo observation and 75 km): a) SMOS minus Argo, b) Aquarius-ADPS minus Argo, and c) Aquarius-CAP minus Argo.

The annual mean of the zonal mean satellite-Argo differences (Fig. 7) for the triple point matchups highlights that, in a mean sense, Aquarius ADPS best matches Argo *in situ* observations across all latitudes. The Aquarius data sets experience large positive differences from Argo data for latitudes poleward of 40°S/N, while SMOS data has very large negative differences poleward of about 50°N. All three satellite data sets depict an unusual abrupt large unexplained negative difference with respect to Argo data between 35°N-40°N.

Figure 8 displays the differences between SMOS and the Aquarius retrievals for the triple point matchups. Some common characteristics emerge. The differences along land boundaries tend to be negative, indicating low SMOS values. Regionally, SMOS values are higher in the eastern portions of the major Southern Hemisphere ocean basins, particularly in the equatorial Eastern Pacific Ocean and more broadly throughout the equatorial and South Atlantic Ocean.

Temporally, Figure 9 depicts large seasonal differences with respect to Aquarius data (ADPS, CAP), with positive maxima from April through July and minima from November through February. SMOS values are generally larger between 30°S and 30°N. The differences between ADPS and CAP also display a seasonal signal, with maxima (May-Sep)/minima (Oct-Apr) poleward of 30°N. There are hints of a similar signal in the Southern Hemisphere, offset to align with the corresponding season. The ADPS and CAP data have negligible differences between 30°S and 30°N. These differences appear to result largely from ascending-descending node differences.

Annual Mean of Zonal Mean Difference from Argo

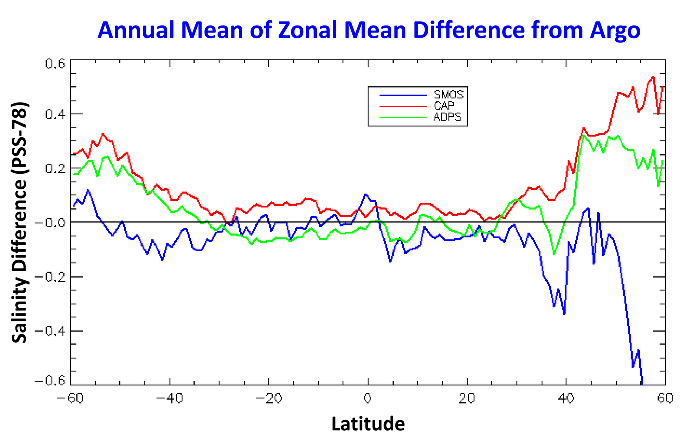


Figure 7. Annual mean of the zonal (1° bins) mean satellite sea-surface salinity (SSS) ascending minus descending node retrieval differences (PSS): **SMOS (blue)**, **Aquarius ADPS (green)** , and **Aquarius CAP (red)**.

Satellite-Satellite Triple-point Differences: Spatial Distribution

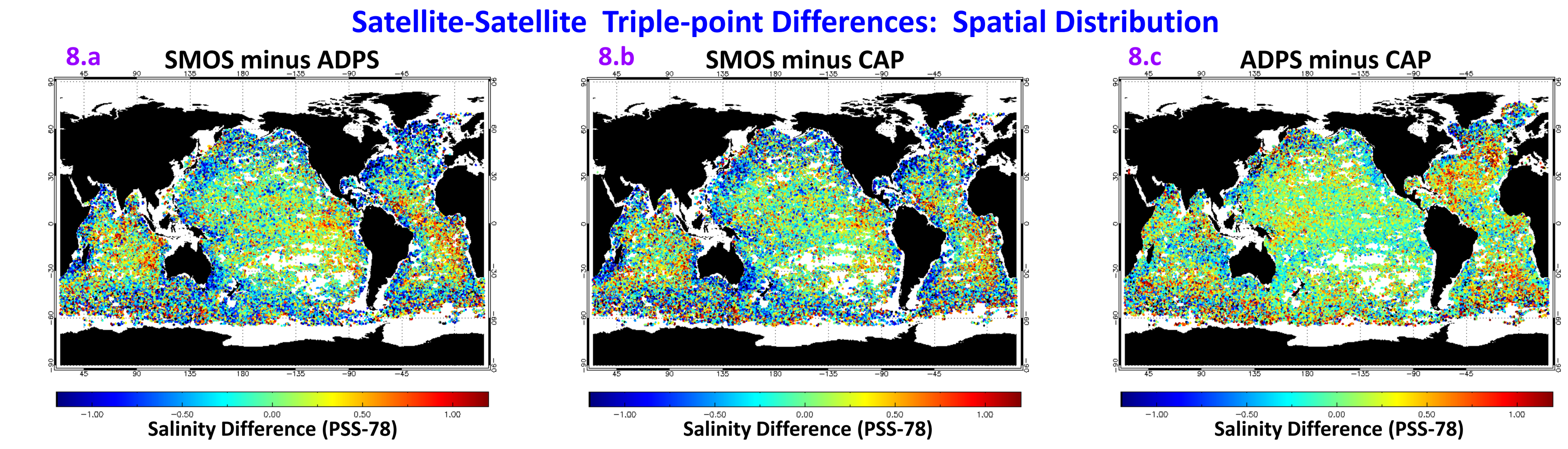


Figure 8. Differences between satellite salinity retrievals (pss) at Argo-SMOS-Aquarius triple-point match-ups (within 7 days centered the Argo observation and 75 km): a) SMOS minus Aquarius-ADPS, b) SMOS minus Aquarius-ADPS (with SST bias correction), c) SMOS minus Aquarius-CAP.

Satellite-Satellite Triple-point Differences: Zonal Mean Variability

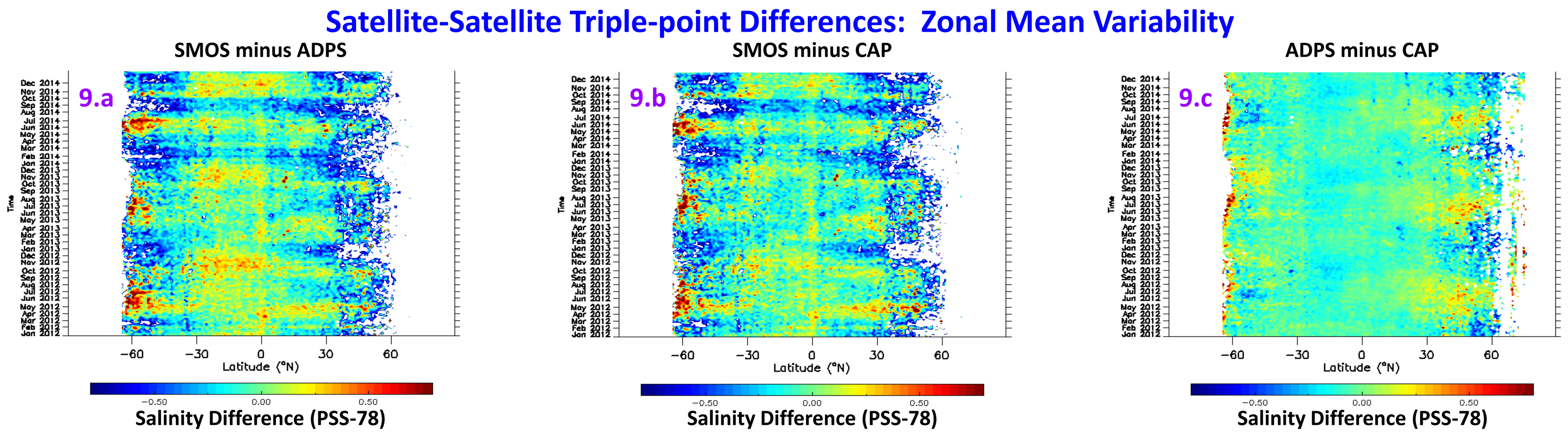


Figure 9. Temporal differences between satellite salinity retrievals (pss) at Argo-SMOS-Aquarius triple-point match-ups (within 7 days centered the Argo observation and 75 km): a) SMOS minus Aquarius-ADPS, b) SMOS minus Aquarius-ADPS (with SST bias correction), c) SMOS minus Aquarius-CAP.

CONCLUSIONS:

- Ascending-descending node differences:
  - Large magnitude differences are an issue for SMOS data, significantly exceeding the SMOS mission accuracy requirement
  - Seasonality of the differences in SMOS data is notable and quite different in character from that seen in Aquarius retrievals
  - Landmasses in SMOS data have extensive difference shadows with magnitudes that significantly exceeding the SMOS mission accuracy requirement
  - SMOS difference magnitudes have a strong latitudinal dependence
- Triple matchups:
  - There is generally good agreement between 30°N/S
  - While SMOS retrievals have greater seasonality, in the mean they more closely match Argo *in situ* measurements
  - The Aquarius data set (ADPS, CAP) differences from Argo data are latitudinally dependent, increasing poleward of about 30°N/S
  - SMOS values are generally less than Aquarius values near land.
  - SMOS values are generally larger than Aquarius values in the eastern equatorial portions of the ocean basins

Acknowledgements:

This research was supported by NOAA/NESDIS/STAR Product Development, Readiness, and Application (PDRA) / Ocean Remote Sensing (ORS) Program funding. Aquarius ADPS and CAP data was provided by the NASA/JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC). SMOS data (ESA®) is provided courtesy of the European Space Agency. The Argo data were collected and made freely available by the International Argo Program and the national programs that contribute to it. The Argo Program is part of the Global Ocean Observing System (http://www.argo.ucsd.edu, http://argo.jcommops.org).

References:

- ESA, SMOS L2 OS Algorithm Theoretical Baseline Document, SO-TN-ARG-GS-0007 Issue 3 version 11, 5 September 2014
- Aquarius User's Guide (see http://podaac.jpl.nasa.gov/SeaSurfaceSalinity/Aquarius)
- Frank Wentz, Simon Yueh, Gary Lagerloef. 2014. Aquarius Official Release Level 2 Sea Surface Salinity & Wind Speed Data Ver. 4.0. PO.DAAC, CA, USA. Dataset accessed daily at http://dx.doi.org/10.5067/AQUAR-2S1PS.
- Simon Yueh. 2014. Aquarius CAP Level 2 Sea Surface Salinity, Wind Speed & Direction Data Ver 4.0. PO.DAAC, CA, USA. Dataset accessed daily.
- Yueh,S.H., W.Tang,A.K.Hayashi,G.S.E.Lagerloef (2014). L-Band Passive and Active Microwave Geophysical Model Functions of Ocean Surface Winds and Applications to Aquarius Retrieval. IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING,51(9), 4619-4632
- Gould, J., *et al.* (2004), Argo profiling floats bring new era of in situ ocean observation, Eos Trans. AGU, 85, 185, doi:10.1029/2004EO190002
- Unesco (1981). The Practical Salinity Scale 1978 and the International Equation of State of Seawater 1980. *Tech. Pap. Mar. Sci.*, 36

AGU Ocean Sciences Meeting: 21-26 February 2016, New Orleans, Louisiana, USA