Technical Report on processing and validation of

Salinity data from surface drifters

Meike Sena Martins, University Hamburg, CEN, February 2016

The SMOS mission provides global sea surface salinity fields since 2010 in an unprecedented spatial and temporal resolution. In the frame of the SMOS calibration and validation project "SMOS Cal Val", two sets of surface drifters equipped with salinity sensors were launched in two different key regions of the world ocean, one in the coldest and another one in the warmest region of the global oceans' surface, in order to get two calibration or at least validation points for the salinity data resulting from the SMOS mission.

A most thorough validation of satellite derived salinity is performed by comparing them to the salinity also measured directly at the sea surface. However, measuring the salinity at the ocean's surface is a challenging task, as bio fouling, pollutants and wave induced bubbles influence the measurement within a conductivity cell. Moreover, the alignment of conductivity with temperature in order to calculate the accurate salinity at heavy sea state is complicated, since the flushing of the conductivity cell is faster than presumed in calm weather conditions.

Usually, the in situ measuring devices on ships - underway and on station - and from the Argo buoys are prevented from measuring in the upper few meters due to the complications involved. New devices have been developed for high resolution measurement near to or at the surface following the movements by the waves, but not yet implemented in the global network, and they still do not measure directly at the surface but at a few centimeter depth (Anderson et al, 2014).

The drifter type used here is the widely used surface drifter manufactured in our case by Pacific Gyre™ which was designed for tracking the ocean surface currents in the Surface Velocity Program (SVP).

The drifters were equipped with a salinity measurement device. This measurement device has so far been used on a project basis (Reverdin et al., 2014; Hormann et al., 2015), for global use the quality and usefulness of the salinity data for the validation of space born salinity has to be proven. The present study contributes to this proof.

The surface drifter consists of a spherical float of about 38 cm diameter (Figure 1) which contains the telemetry device. Below the float, a device is mounted carrying the measuring instruments. A drogue having a diameter of 91 cm and a length of 10 m is attached by a steel cable of about 10 m length. The Seabird conductivity cell (Modell SBE37) is installed at a centered depth of 38 cm below the assumed water line, the second thermistor at about 45 cm depth, having a distance of 7 cm between each other. At about 15 cm below the water surface, a supplementary thermistor measures temperature with an accuracy of 0.05°C. Seven drifters of an older type launched in the Greenland Sea were equipped with only one thermistor at 45 cm having an accuracy of 0.1°C.

Two sets of drifters were launched in the frame of the German SMOS Calibration and Validation (CalVal) project by ships of opportunity in one of the warmest world's ocean region, in the tropical Pacific, and one of the coldest region, the Greenland Sea, with the aim to get validation samples for the satellite derived salinity at the ocean's surface in the extreme temperature ranges. The exact launch position and dates can be found in Table 1. Here, a summary is given:

Ten drifters were launched in March 2010, along 14° S in the western tropical Pacific, within 2 clusters, one at 164° W, the other at 160° W. Other fourteen drifters were launched in June 2010 in the North Atlantic Ocean, the Greenland Sea, along 75° N in clusters of three to four drifters at 6° W and 2° W, 1° W and at 1° E. A last drifter was launched later in September 2010 at 78° 36.65' N/2° 24.74' E. For launching the drifters, opportunities were taken from several RVs passing at or even deviating their cruise tracks to the planned positions.

The drifters kept their drogue 346 days on average, all drifters have transmitted during 545 days on average. Four drifters launched in the Greenland Sea failed or transmitted only once (3), or died after some days (1) in the cold sea. Drifter 83299 was launched later and very near to sea ice, perhaps there has been a collision with some ice, therefore only 9 days of reasonable data are available. Details about lifetime and fate of the drifters, loss of the drogue and availability of the salinity and temperature data are given in Table 2.

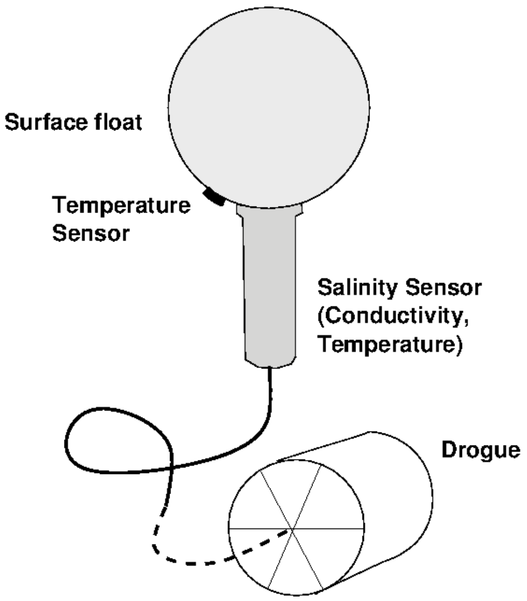

Figure 1: Schematics of a surface drifter manufactured by Pacific Gyre ™ in the ordered configuration.

The drifters measured temperature and conductivity every minute during a 5 minute interval before transferring averaged values of temperature and salinity of the 5 minute periods at intervals of half an hour.

Data from the drifters were transmitted via satellite by the ARGOS system. The data were transmitted whenever the constellation of the ARGOS satellites is adequate, only data with a quality index ``Location Class'' 3 or 4 were used. They include header information (Time, latitude and longitude, submergence, battery voltage and quality index) and additionally temperature and salinity data each 30 minutes during the preceding 3.5 hours for the newer types, and the preceding 5.5 hours for the older ones, respectively. The shorter measurement period is due to the second temperature sensor, increasing the number of data to be transmitted.

The 'age' of the most recent measurement was transmitted too, and allows reconstructing the time of measurement of the preceding hours. The 'checksum' was considered to discard data with bad transmissions. Good transmissions occur each 50 minutes.on average, containing data series of 4 (for the newer drifter types) or 6 hours (for the older types), so time coverage is multiple on an irregular basis.

The constellation adequate for data transmission lasts for about one minute and data are transmitted repeatedly each 10 seconds. In more detail, the streams of temperature or salinity data only transmit one absolute value, the other data are relative in respect to the last one, i.e. if the only absolute datum is erroneous, the whole data stream had to be erased. In case of ambiguous salinity or temperature data, the whole message has been erased. Moreover, the salinity in a message in some cases showed a shift of its value comparing to the preceding and following message. An empirical criterion was chosen to select out bad data, by allowing single changes to be less than 0.1 within a 20 minute interval in either positive or negative direction. If this error is due to the erroneous transmission of the whole message in spite of a 'good' checksum or due to the erroneous measurement is not clear, however, it is considered unrealistic and was erased.

A data set was produced at half hourly resolution, and the processing is done by applying the following steps:

- Data were discarded if they were out of the range 25 g/kg < S < 40 g/kg.
- The standard deviation (std) of salinity during the 4 or 6 hours of measurements was calculated and values exceeding 2 times the std were discarded, if the std(S) > 0.01 g/kg.
- All the salinity and temperature data were superposed and sorted according to their time of measurement, however latitude and longitude as well as submergence and quality index is available only at the time of transmission.
- A filter was set which discarded data exceeding 3 times the std over the whole trajectory from the median value.
- A more detailed filter despiked the data on a monthly basis afterwards, hereby allowing 2 times std(S) in the positive direction, and 3 times the std(S) in the negative direction because of eventual rain events.
- Then, data were interpolated onto 1 hour intervals, applying a rectangle median average of the data occurring within the 3 hours interval. Though a thoroughful despiking was done before, there were still data showing a salinity offset of 0.1 g/kg to 1 g/kg to neighbouring values. So another filter was set up: if the mean value and the most frequent value within a 5 hour interval differed by more than 0.05 g/kg (which is an empirical value), salinity data exceeding the median value in that interval by 2 times std(S within 5 hours) were discarded and a new median value within the 3 hours was computed.
- A last filter was applied to detect erroneous data in the hourly data: within a moving 17 point rectangular window a difference of the middle value to the median salinity was allowed to be 1.5 times the std(S within 17 h). For deviations higher than this critical value, the salinity was forced to a median average of the 17 point window. This subjective criterion erased spikes additionally.
- Conductivity was measured at about 8 cm distance to the temperature sensor. So in cases of temperature gradients, the salinity was calculated from not aligned values. These conditions prevail during days of very nice weather, i.e. strong diurnal heating with weak wind (wind speed < 2 m/s). Then salinity spikes could occur in both directions, because the temperature gradient might be waved around the conductivity cell. In order to detect these cases automatically in the drifter data with only one temperature sensor, the temperature time series was low pass filtered (cutoff frequency = 2.25 days) and subtracted from the original one. Absolute differences between the filtered and the original time series of more than 0.25 $^{\circ}$C were excluded.

- For the drifter data containing two temperature measurements the temperature gradients (dT) were calculated. On days with strong diurnal heating the dT was often > 1 ^{o}C. The salinity data showing spikes on these days were excluded.
- Finally, a Hamming filter was applied over 30 hours with a cutoff frequency of 1/8 h, in this last step salinity was interpolated, but accuracy cannot be better than 0.01 g/kg. Interpolated and filtered data of salinity was stored.

The percentage of data excluded is different for each drifter. High fractions of salinity spikes occur indirectly due to the loss of the drogue, especially drifters no. 92793 and 92795 show very noisy temperature records and therefore also salinity is useless. Why the other drifters' salinity records are not affected by the loss of drogue in the same manner is not clear.

A higher number of outliers is presumed to occur in the case of loss of the drogue because the drogue has a stabilizing effect in strong waves. Even without bubbles in the conductivity cell, it may be flushed with high velocity not corresponding to the prescribed alignment of temperature and conductivity and thus salinity is erroneous.

In general, there is no clear leaning of the spikes to either side of the mean monthly values, showing a general good alignment of conductivity and temperature. Drifters entering the fresher surface water (Drifters 82042, 82043 and 92785, not shown) tend to have more negative spikes. Drifters subject to bad weather and probable bubbles in the conductivity cells (i.e. lower conductivity measured in the cell) or subject to some biological material stuck or grown in the cell presumably show negative salinity spikes. Though these disturbances are likely to occur in the Greenland Sea or in the Pacific subtropical waters, it cannot be shown that dominantly negative spikes occur in the range of the monthly standard deviations. Hormann et al. (2015) showed a dominance of negative salinity spikes which, in the author's opinion, occurs due to the averaging of salinity prior to data transmission.

In general, salinity outliers are negative, because the processes perturbing the conductivity measurement mentioned before result in fresher salinity values. However, there are cases of strong daily heating giving rise to positive salinity anomalies due to the vertical temperature gradient and consequent misalignment of temperature and conductivity.

Validation of drifter salinity

For validation of the drifters' salinity, there are a few Argo profilers providing independent salinity data, with measurements at 5 to 10 dbar depth, and several TSG measurements from VOS. The drifters' salinities are compared to these data sets by selecting pairs of data within a distance of +/- 50 km and a time period of +\- 2 days. If there are more than one datum of salinity within the considered period, the average and the standard deviation (std) within the period of coincidence are calculated.

Figures 3 and 4 show the comparisons between the salinity from drifters and Argo profiler measurements and between the drifter salinity and underway ship data with error bars indicating the std during the collocation period.

The comparison reveals neither significant bias nor temporal drift (not shown) within the drifters' measurements. The RMS difference amounts to 0.15 g/kg between the drifter and Argo salinity and to a similar value of 0.13 g/kg between drifter and TSG salinity data. The standard deviation (std) within the period of 10 days given by the bars in the Figure 4 shows, that the sampling error of the single measurements may explain the high RMS difference. On the other hand, there are not many in situ measurements for validating the drifters' salinity, 134 data pairs in case of Argo data and 41 pairs in case of TSG measurements. Local spatial distance (marked in Figure 3) and temporal mismatch may cause uncertainties in the differences. However, a dependence on the distance between the measurement from drifter to shipboard TSG or Argo instruments was not conclusive and within the RMS difference.

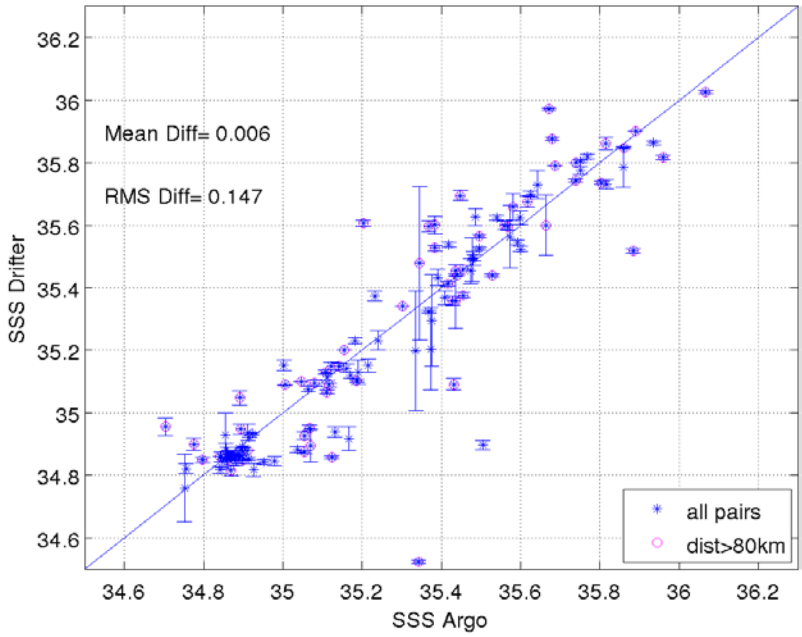

Figure 3: Comparison of collocated salinity values from Argo profilers nearby the surface drifters within a distance of up to 100 km and a time window of 10 days. Collocations with a distance of > 80 km are marked pink. The mean difference between all pairs and the root mean square (RMS) difference is given in the upper left. All units are g/kg.

The results presented here are part of a study by Reverdin et al. (2014) who showed occasional salinity shiftings in the time series of the drifters' data, thereby, the present validation results are included in the latter publication. The authors used Argo measurements nearby to correct the shifted salinity chunks. In the present time series, shifts in salinity by 0.1 or 0.2 g/kg are present, too. I checked the time series of salinity by calculating the differences between the low-passed salinity (cutoff frequency 1/35 h) to the original time series and inspected all abrupt changes in salinity exceeding 0.1 g/kg. Some shifts and spikes were identified and could be correlated to rain events.

The rain data was a combination of daily rain data from several satellite missions, the Special Sensor Microwave Imager (SSM/I), the Tropical Rainfall Measuring Mission (TRMM) with the TRMM Microwave Imager (TMI) and the Advanced Microwave Scanning Radiometer (AMSR). From the gridded data with a spatial resolution of 0.25° the surrounding grid boxes of the drifters' position were selected in order to account for the daily estimated drift of the instrument of about 25 km/day. Some coincidences were found between a salinity drop and precipitation. However, the most cases of salinity drops or shifts could not be correlated to any rain event recorded in the precipitation data. A lot of rain events had no subsequent salinity drops, either. I haven't found any correlation between salinity drop-offs with rain events. Based on the studies of Reverdin et al. (2014) I cannot rule out that the drifters' salinity is erroneous during some periods of time.

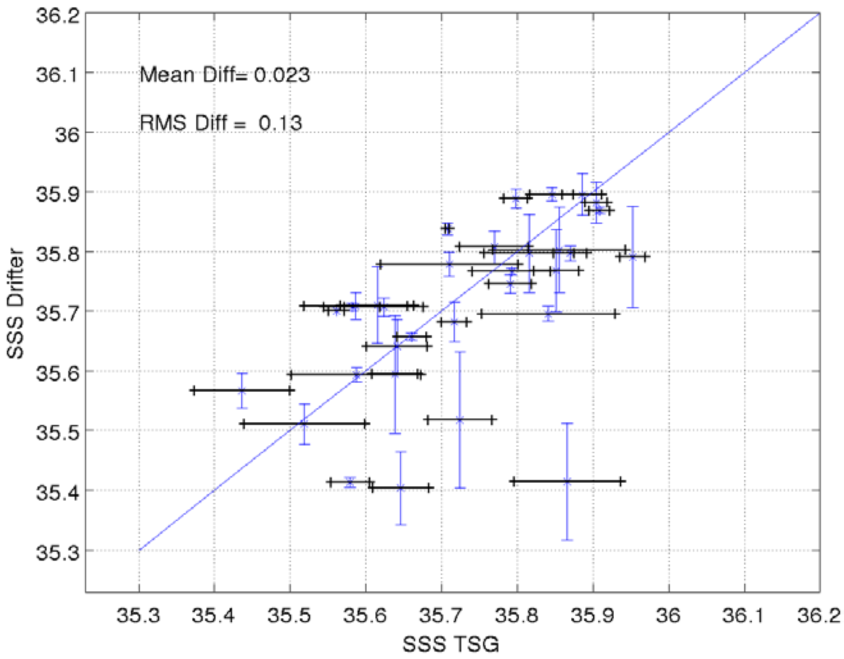

Figure 4: Comparison of collocated salinity values from TSG collected by voluntary operating ships nearby the surface drifters within a distance of up to 100 km and a time window of 10 days. The standard deviation of drifter and TSG salinity during the corresponding time and region is indicated by bars in the right panel. The mean difference between all pairs and the root mean square (RMS) difference is given in the upper left. All units are g/kg.

The final salinity data set of the surface drifters is publicly available at *http://icdc.zmaw.de/daten/ocean*. The data include an error estimate and flags indicating possible errors or corrected temperature values.

Table1: Launch position and dates

15 Drifters in the GIN Sea:

SN	Station	Date	Time UTC	Latitude	Longitude	water depth
82040	PS 76/027-5	6/20/2010	17:08	74°59.99´ N	06° 3.65´ W	3526 m
82041	PS 76/027-5	6/20/2010	17:10	74°59.99´ N	06° 3.56´ W	3526 m
82042	PS 76/027-5	6/20/2010	17:12	74°59.98´ N	06° 3.48´ W	3526 m
82043	PS 76/027-5	6/20/2010	17:14	74°59.96´ N	06° 3.30´ W	3526 m
83298	PS 76/050	6/24/2010	13:33	74°59.57´ N	02° 9.06´ W	3714 m
82044	PS 76/050	6/24/2010	13:35	74°59.62´ N	02° 8.78´ W	3713 m
92783	PS 76/050	6/24/2010	13:37	74°59.64´ N	02° 8.66´ W	3712 m
92785	PS 76/050	6/24/2010	13:37	74°59.66´ N	02° 8.53´ W	3711 m
92786	PS 76/052	6/24/2010	20:07	74°59.34´ N	0°54.94´ W	3748 m
92791	PS 76/052	6/24/2010	20:10	74°59.30´ N	0°54.42´ W	3748 m
92794	PS 76/052	6/24/2010	20:14	74°59.38´ N	0°54.32´ W	3748 m
92796	PS 76/057	6/25/2010	16:00	75° 1.46´ N	1° 0.97´ E	3775 m
92799	PS 76/057	6/25/2010	16:02	75° 1.45´ N	1° 1.14´ E	3775 m
92800	PS 76/057	6/25/2010	16:00	75° 1.42´ N	1° 1.52´ E	3775 m
83299	KV Svalbard	9/14/2010	18:58	78°36.65'N	2°24.74' E	

10 Drifters in the tropical Pacific Warm Pool:

SN	Station	Date Time	UTC	Latitude	Longitude	water depth
92784	Sonne	03/05/2010	1:10	13°59.98'S	163°59.91'W	5550.6
92787	Sonne	03/05/2010	2:33	14°00.00'S	163°50.04'W	5462.1
92788	Sonne	03/05/2010	3:54	14°00.00'S	163°40.00'W	5025.3
92789	Sonne	03/05/2010	4:53	14°00.00'S	163°30.00'W	5163.4
92790	Sonne	03/05/2010	5:52	14°00.00'S	163°20.00'W	5107.5
92792	Sonne	03/06/2010	0:56	14°00.00'S	160° 0.00'W	5144.2
92793	Sonne	03/06/2010	2:00	14°00.00'S	159°49.98'W	5126.2
92795	Sonne	03/06/2010	2:59	14°00.00'S	159°40.00'W	5101.6
92797	Sonne	03/06/2010	3:58	14°00.00'S	159°30.00'W	5174.6
92798	Sonne	03/06/2010	4:57	14°00.00'S	159°20.00'W	5106.6

Table 1: Launch positions and time for several drifters with serial number SN and launched from research vessels Polarstern (PS), the Norwegian Kvalbard and from RV Sonne.

Table 2: Drifter's life time with and without socket, and salinity days:

Serial No.	Data Transmission (submergence>82%)	Days	Data with socket	Days	Date until S > 28	Days of S avail.
82040	06/21/10-06/21/10	never				
82041	06/20/10-12/04/10	168	06/20/10-10/17/10	119	12/04/10	167
82042	06/20/10-11/20/11	519	06/20/10-10/08/11	475	11/19/11	517
82043	06/20/10-03/06/12	626	06/20/10-09/17/10	89	03/06/12	625
82044	06/24/10-02/23/11	245	06/24/10-11/15/10	144	02/23/11	244
83298	06/24/10-03/06/12	622	06/24/10-10/04/11	467	03/06/12	621
83299	10/02/10-10/10/10	9	10/02/10-10/10/10	8	10/10/10	8
92783	06/24/10-03/06/12	622	06/24/10-01/26/12	582	03/06/12	621
92784	03/08/10-11/30/11	632	03/08/10-10/25/10	232	11/29/11	631
92785	06/24/10-07/25/11	397	06/24/10-03/26/11	275	07/24/11	395
92786	06/24/10-03/06/12	622	06/24/10-10/16/10	114	10/22/10	120
92787	03/08/10-03/06/12	730	03/08/10-12/29/11	662	11/13/11	615
92788	03/08/10-10/30/11	601	03/08/10-10/13/11	584	04/13/11	401
92789	03/09/10-03/06/12	728	03/09/10-02/12/11	340	09/02/11	542
92790	03/09/10-12/26/11	657	03/09/10-10/17/10	222	12/26/11	657
92791	06/24/10-12/26/11	551	06/24/10-11/07/11	501	12/26/11	550
92792	03/08/10-10/13/11	584	03/08/10-08/22/11	533	06/21/11	470
92793	03/09/10-01/30/12	692	03/09/10-10/28/10	234	11/28/10	264
92794	06/24/10-06/24/10	never				
92795	03/09/10-06/05/11	453	03/09/10-11/16/10	252	11/06/10	242
92796	06/25/10-06/25/10	never				
92797	03/08/10-03/06/12	730	03/08/10-12/17/10	284	03/06/12	730
92798	03/08/10-01/17/12	680	03/08/10-10/14/11	585	09/18/11	560
92799	06/25/10-06/28/10	2				
92800	06/25/10-01/15/12	569	06/25/10-01/15/12	569	09/15/11	447
Mean:		**545**		**346**		**449**

References

Anderson, J. E., and S. C. Riser (2014), Near-surface variability of temperature and salinity in the near-tropical ocean: Observations from profiling floats, Journal of Geophysical Research, Oceans, 119 (11), 7433–7448, doi:10.1002/2014JC010112.

Hormann, V., L. R. Centurioni, and G. Reverdin (2015), Evaluation of drifter salinities in the subtropical North Atlantic, , Journal of Atmospheric and Oceanographic Technology, 32 (1), 185–192, doi:doi:10.1175/ JTECH-D-14-00179.1.

Reverdin, G., S. Morisset, J. Boutin, N. Martin, M. Sena-Martins, F. Gaillard, P. Blouch, J. Rolland, D. Stammer and J. Font (2014), Validation of salinity data from surface drifters, Journal of Atmospheric and Oceanographic Technology, 31 (4), 967–983, doi:10.1175/JTECH-D-13-00158.1.