SURFACE SALINITY DRIFTERS FOR SMOS VALIDATION

By S. Morisset[1], G. Reverdin[1], J. Boutin[1], N. Martin[1], X. Yin[1], F. Gaillard[2], P. Blouch[3], J. Rolland[3], J. Font[4], J. Salvador[4]

[1] LOCEAN/IPSL, UMR CNRS/UPMC/IRD/MNHN, Paris, France
[2] LPO, IFREMER, Plouzané France
[3] CMM, Météo-France, Brest, France
[4] ICM/CSIC, Barcelone, Spain

Introduction

The ESA/SMOS (European Space Agency/Soil Moisture and Ocean Salinity) satellite mission provides new measurements of Sea Surface Salinity (SSS) using L-band radiometry. After correcting SMOS brightness temperatures from systematic biases, SMOS sea surface salinity (SSS) reproduces quite well large scale expected SSS variations [Font et al., 2012].

At L-band frequency, the skin depth is 1 centimetre while most in situ SSS measurements are taken at a few meters depth. A preliminary study based on ARGO vertical profiles [Henocq et al., 2010] indicated that vertical salinity differences between 1m and 10m depth higher than 0.1 psu are observed in the 3 oceans, mainly between 0° and 15°N, coinciding with the average position of the Inter Tropical Convergence Zones characterized by high precipitation rates.

In order to better document the variability of salinity near the sea surface, which is currently not often measured by other in situ observations (current Argo uppermost data is between 5 and 10m depth, whereas TAO-type measurements are near 1 or 2m depth), surface drifters have been equipped with Conductivity-Temperature (C-T) cells near a depth of 50 cm, which proved reliable for mid-latitude deployments [Reverdin et al., 2007]. Since then, two manufacturers of SVP (Surface Velocity Program) drifters, Metocean and the Pacific Gyre have instrumented SVP drifters with sensors measuring conductivity at 30-50cm depth. In addition, new light floats named SURPLAS have been built at LOCEAN laboratory to measure conductivity at 15cm depth for a duration of a few weeks to a few months. SURPLAS floats have been tied to SVP drifters allowing the study of the SSS and SST (Sea Surface Temperature) stratification between 15cm and 50cm depth. In addition, ICM/CSIC has buit slightly larger drifters with C-T cells also near 50 cm depth, but without an anti-fouling protection of the cell. The sampling characteristics of the different drifters are slightly different. The SURPLAS drifter provides a value (average over 8”) every 15 minutes of T (Temperature) and S (Salinity); the Pacificgyre SVP-BS drifter, a value every 30 minutes (average over 5 minutes), the Metocean SVP-BS drifter, a value every hour (average of 7 values over 10 minutes), and the ICM/CISC provide values at the time of Argos transmissions (not averaged). Most of the drifters and floats transmit through Argos, although Metocean drifters since 2009 mostly transmit data (and a 3-hourly gps position) through iridium communication.

Since 2007, we deployed 37 Metocean SVP-BS drifters, 29 Pacificgyre drifters, 21 ICM/CSIC drifters and 17 surplas floats. In 2010 and 2011, simultaneous to the first two years of SMOS measurements, 68 SVP drifters (49 Metocean and PacificGyre and 19 ICM drifters) and 13 SURPLAS floats have been deployed by the French and Spanish teams involved in the SMOS Cal/Val projects mostly in the North Atlantic, in the Bay of Biscay, in the equatorial and subtropical South Atlantic and in the western tropical and equatorial Pacific Ocean. Altogether in 2010-2011, they recorded measurements during 13500 days (Metocean+PacificGyre 8821, Surplas 472, ICM 4266).

In this paper, we will first comment on the data return of these drifters, on our efforts to quality control and correct the data. Then, we will summarize results on tropical SSS freshening events linked to rain events as recorded at various depths by autonomous drifters and as deduced from the SMOS radiometer measurements.

Data return of the drifters – validation/correction of the data

The SVP and ICM drifters had an average life time in the water that was most commonly shorter than 1 year, mostly because of recovery by fishermen (7 in the Bay of Biscay and near Atlantic region, 6 near South America/Caribbean and one each off Ivory Coast and off Queensland), because of landing most commonly after a drogue loss. In some instances (in the Bay of Biscay, Queensland coast or off Ireland), the recovery was done on purpose and the drifter redeployed soon after (but we consider this as two separate drifters in our accounting). For some of the drifters (6 Metocean with mean liftime of 14 month, and one Pacificgyre with lifetime of 21 months), the death occured through normal battery loss.

Data interruption occurred quickly through switch problems for 4 Pacificgyre, through electronic problems for 2 Pacificgyre, and through unknown reasons for 4 Pacificgyre. For two Metocean drifters, there was C-T data loss after a while, and for 9 Metocean drifters, end of life probably happened through electronics or leak after a short while (5 presented a visible fast fall of the battery tension beforehand).

Drogue loss seems to have happened often within less than 6 months at sea, although we did not investigate carefully the issue of drogue loss of these drifters, and it is possible (Gordsky and Lumpkin, 2011) that residual errors in drogue loss detection might be present in this data set (although, we use a larger drifter model than the ones that are suspicious according to Gordsky and Lumpkin (2011)).

In another paper, we have commented that there are errors in the regular hull temperature sensor of the drifters (Reverdin et al., 2009). We assume that the biaises on the T sensor of the C-T cell is very small (could be of the order of 0.01°C according to Seabird after 1 year in the water); thus we can use this T to validate the hull temperature sensor (referred here as SST). We find rather large (0.5°C or larger) anomalies in 2010 on both Metocean and Pacficiyre drifters, but which have been explained by conditions in which this temperature was controlled. The problem has disappeared with later deliveries in 2011, but there are still issues with this measurement on 2011 Pacificgyre drifters (data become very noisy and unusable after a few to six months, probably as the result of leak or electronic issues).

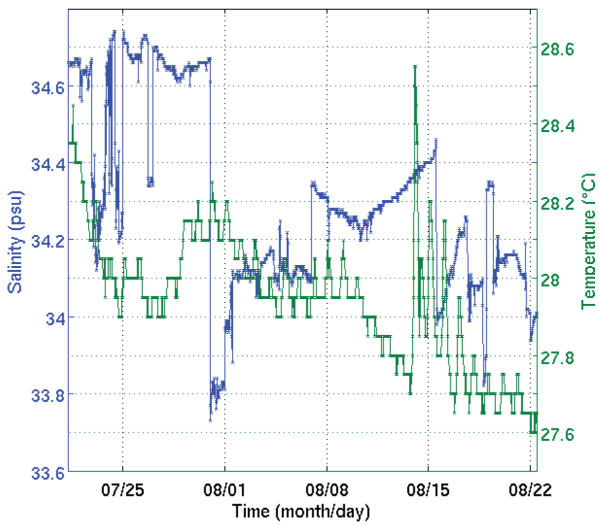
Five Metocean drifters deployed in the Amazone plume or off French Guyana presented large drops of salinity that are surely attributable to algae or other floating objects that got stuck in the cell. One of these drifters was recovered, rinsed and redeployed with no indication of sensor fouling. For most of the ICM drifters deployed in the subtropical gyres, large drops in salinity occured within a few months that could be due either to objects stuck in the cells or fouling, as these drifter sensors were not protected by anti-fouling. In these cases, we dont feel that we can recover a usable salinity data, and prefer to remove the estimated S from the final files.

This leaves an average 5 month of usable salinity data by Pacificgyre drifter and 6 months by Metocean drifter. On these data, we apply the following checks to eliminate dubious portions of the records.

First, we check temperature measurements. Some isolated measurements can be incorrect in the first hours after deployment (hull temperature) or due to bas transmission (example 0.01% of data for long-lived PacificGyre 92546). Associated salinities are removed.

Removal of salinity for periods with unusual high noise level (probably some moving objects or electronic problems) as well as removal of isolated salinity spikes with a filter is performed. The filter identify isolated values deviating from the median of salinity measured between 6 hours before and 6 hours later and larger than twice the standard deviation for the same period. We then check whether there is regular increase of salinity during the two following points after the isolated spike, in which case we retain the isolated value (which could result from front or rainfall passing) (the removed isolated data represent 0.4% for PacificGyre drifter 92546).

We then remove S values during mid-day warming periods, as we had shown (for 2005 drifters) that the mismatch between C and T sensors can be the origin of large mid-day errors (Reverdin et al., 2005). For that, we check whether daily warming is larger than 0.8°C, and remove mid-day data , when they present variability (for example, this represents 3% of data for PG drifter 92546; note that this was difficult to apply on ICM drifters that often transmit data only during the 6 hours each day between 0 and 6 GMT).



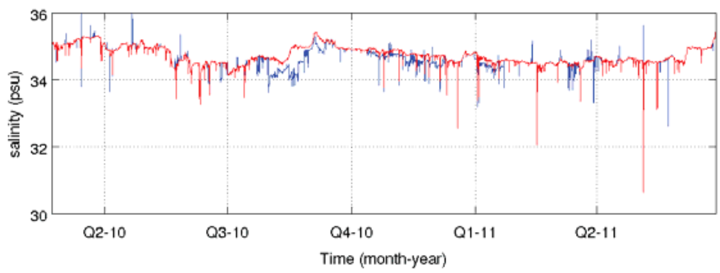


***Figure 1**: T and S records between July 22 and August 22 2010 for Pacificgyre drifter 92546 (left panel; S in blue and T in green). Right panel shows the 'original' salinity time series (blue) and the corrected time series (red) after removing the salinity 'jumps' in 2010-2011.*

In some data records, we observe sudden changes of S, with no corresponding change of T (changes less than 0.05°C). They are first a decrease of salinity, but can be also afterwards with a salinity increase. In a few cases, when we had a surplas float attached to the SVP drifter, we can clearly confirm that these jumps are not real S- jumps, probably associated with objects stuck in the cell. We also found at least one case with a jump of S, where the associated change in T was less than 0.05°C. This is an issue, as before the iridium Metocean models and the 2011 Pacificgyre models, the resolution in temperature was on the order of 0.05°C, and such a 'real' S-jump would be interpreted as erroneous. Nonetheless, we consider most of these S-jumps with no T-jump larger than 0.05°C as highly dubious, and we try to correct the data after the jump by adjusting their value to the one just before (clearly, this leaves an uncertainty in each adjustment of at least 0.01 pss). We present an example of a time series which presents such jumps, as well as the value at the shallowest level of ARGO float profiles.

This kind of sudden jumps happened in different instances for this drifter, and the final record is presented below. In this case, the upper values of nearby Argo profilers fit well with the corrected time series, and we have little doubts that the jumps were really related to objects getting stuck in the cell.

The drifter records were systematically compared with upper values (between 5 and 10m depths) of near-by ARGO profiles. We retain those values only if the ARGO temperature is close to the one measured by the drifter (at night). Often there are enough Argo profiles to be able to statistically identify (by grouping the comparisons over a long-enough period) a possible drift due to fouling of the sensor. We sometimes

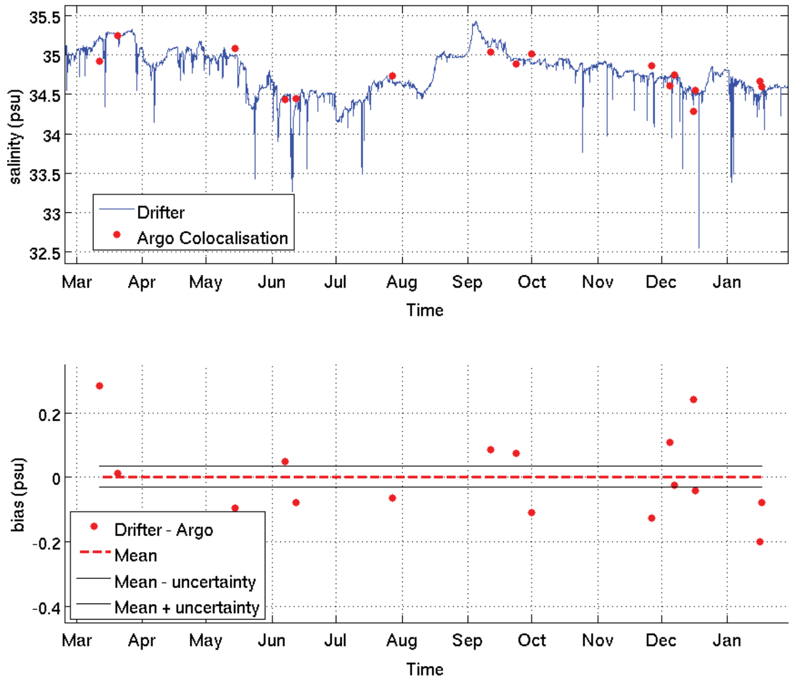


Figure 2: upper panel, the corrected S records of the 92546 salinity drifter with the colocated ARGO profiles values (red) from February 2010 to January 2011. The lower panel show the differences (red dots) with the suggested bias (dashed line with the 1-sigma uncertainty range).

also have samples collected at recovery or when a ship passed near-by that provide another estimate of the drift. Often, these comparisons suggest that the bias is small in the first 6-months of the drifter life (except for the ICM drifters). When we have more than one such comparison (usually only for mid-latitude or high latitude drifters), we assume that the drift varies linearly in time. Clearly, this degrades the accuracy of the drifter data (typically, for the ones we have compared, only after a year or more).

The longer time series in the tropics can be analysed in relation to rainfall events, but also to possible daily cycles. So far, and except close to Africa, the salinity daily cycles identified have been very small (on the order of 0.01 psu or less), which is consistent with earlier analyses of the TAO/TRITON mooring data).

Freshening events observed by the drifters

[Reverdin et al., 2012] have analyzed the drifter measurements in the tropical oceans in 2007-2010 and have isolated individual freshening events by seeking salinity drops larger than 0.1 psu that are nearly compensated (80) within one day. These events which average 0.56 psu at 45 cm are often related (at least 50% of the cases) with local rainfall. When two measurement levels are available (with a surplas float attached to a SVP drifter), the initial salinity signal is larger by more than 20% at the shallow depth (15 cm) compared with the deeper measurement level (near 50 cm) (Figure 2).

These salinity drops are often associated with a temperature drop which also presents a gradient between the two levels. This temperature drop gradient is to some extent related to the cooler temperature of the drops, but also to the surface stratification created by the rain, such that the heat loss related to the latent (and sensible) heat losses is trapped very close to the surface.

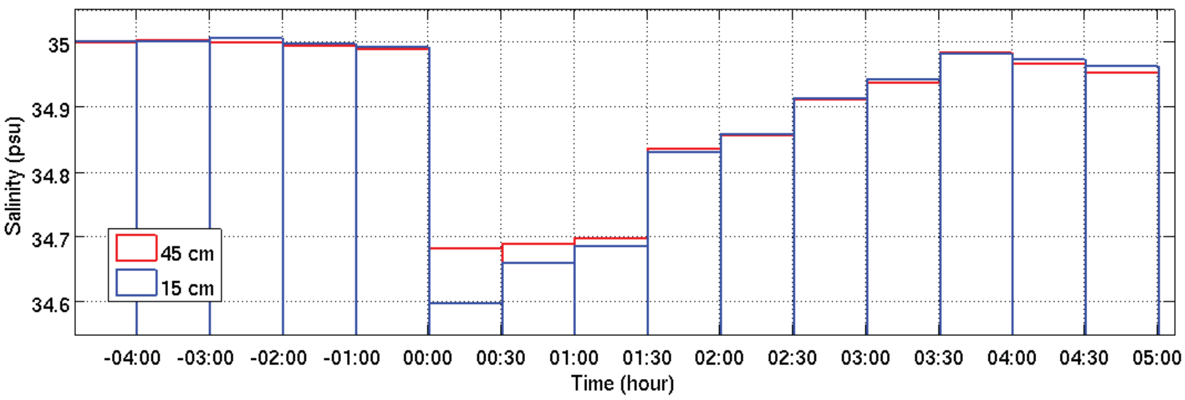


***Figure 3**: Average composite cycle of salinity among 20 salinity drop events observed by both SVP-BS at 45 cm depth (red) and Surplas drifters at 15 cm depth (blue) (relative to a common time of beginning of event). Individual records are shifted to a common salinity value at the initial drop time.*

Freshening events observed by SMOS

Comparisons between reprocessed SMOS SSS and ARGO SSS at 5m depth have been performed in the subtropical North Atlantic Ocean, in the region where the 2012-2013 "Salinity Processes in the Upper Ocean Regional Study" (SPURS) experiments dedicated to the calibration and validation of SMOS and Aquarius satellite measurements will take place. They indicate a standard deviation of the difference of 0.2psu once SMOS SSS are averaged over typical GODAE scales (10days-one month, 100kmx100km). On another hand, the same kind of comparison in the Intertropical Convergence Zone (ITCZ) of the Pacific Ocean indicates a standard deviation of the difference of 0.4psu and a mean difference 0.1psu lower in the ITCZ than in the SPURS region.

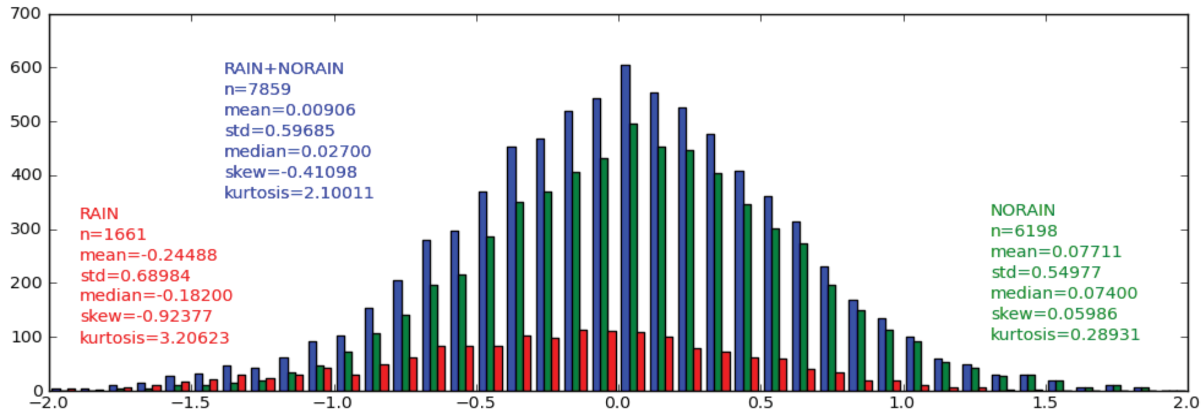


__Figure 4__: Statistical distribution of (SMOS SSS minus ARGO SSS) differences in the ITCZ of the Pacific Ocean (5°N-15°N-110°W-180°W) in July 2010. Blue distribution is obtained whatever the SSM/I rain rates (up to 10mm/hr) recorded within -80 mn before and +40 mn after SMOS measurement; green distribution corresponds to situations when no rain has been detected by SSM/I before SMOS measurement, red distribution corresponds to situations when SSM/I has detected non zero rain rates within 5 hours before SMOS measurement.

Collocations of (SMOS SSS minus ARGO SSS) differences with SSM/I rain rates recorded within -80 mn before and +40 mn after SMOS measurements show that the larger standard deviation and the negative difference in the ITCZ are mainly attributable to rain events.

In addition, we observe a significant correlation (r=0.47) between (SMOS SSS minus ARGO SSS) and SSM/I rain rates with a slope equal to 0.2psu/mm/hr.

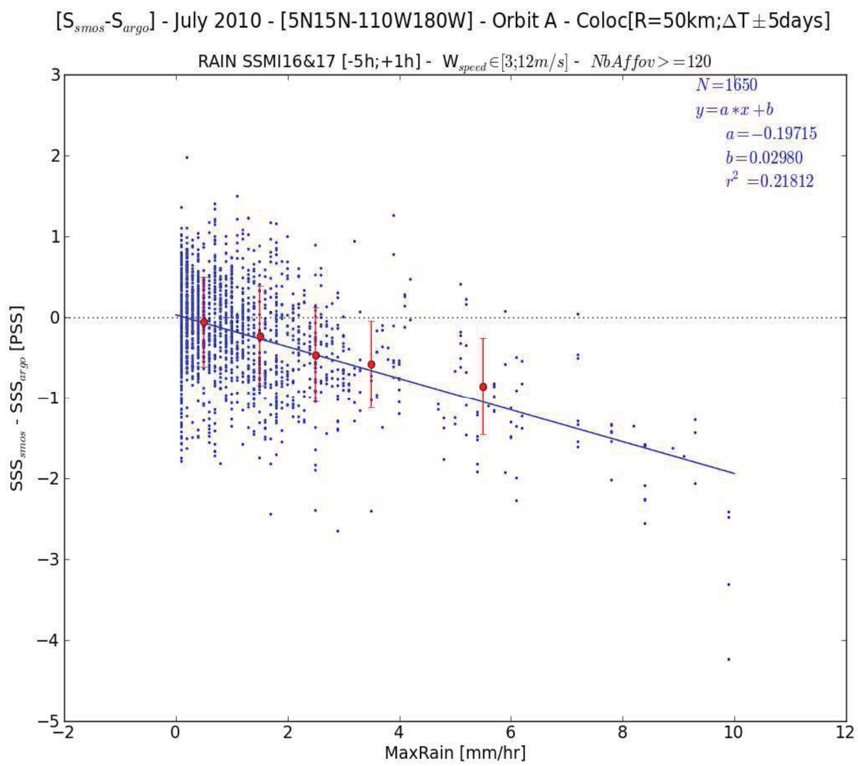


__Figure 5__: SMOS SSS minus ARGO SSS versus SSM/I rain rate observed within -80 mn before and +40 mn, after the SMOS SSS (July 2010; SMOS reprocessing version 5). Red points correspond to averages and standard deviations of SSS differences in 1mm/hr classes. The least square fit indicates a slope of -0.2psu/mm/hr.

Summary and perspectives

The surface drifters measuring sea surface salinity in the top 50cm of the sea surface provide a complementary source of data for validating L-band sea surface salinity. Previous comparisons with SMOS SSS indicate a precision of about .3psu in tropical regions, far from land. These comparisons will be re-evaluated with the 2011 SMOS reprocessing, in order to assess the improvement of the reprocessing especially close to land.

In addition, drifters identify significant rain salinity freshening in the tropical regions. The SMOS SSS reprocessing tested in July 2010 indicates a mean monthly freshening (-0.1 SSS bias averaged over the tropical Pacific between 5°N and 15°N) with respect to ARGO salinity at 5m depth. This salinity freshening is significantly correlated with rain events (identified on maximum SSM/I rain rate) occurring 5 hours before SMOS measurement (R=0.47) and is large:-0.2psu/mm/hr. Preparatory studies to SMOS [Schulz et al., 2002] and to Aquarius [Wentz, 2005] indicate that the atmospheric contribution of rain to L-band brightness temperature are smaller than at higher frequency, on the order of 0.2°K for a rain rate of 10mm/hr, which would correspond to a SSS bias of ~-0.4psu for a rain rate of 10mm/hr: this is an order of magnitude smaller than what we observe. In addition, according to [Schulz et al., 2002] and [Wentz, 2005], for non nadir measurements, the signature of rain atmospheric contribution is larger in horizontal polarisation than in vertical polarisation, contrary to what is expected from a contribution from sea surface salinity. Such a polarized signature should affect the SMOS retrieved wind speed, while salinity retrievals are only very slightly modified in rainy cases. In the next months, we will investigate further the angular signature of rainy events on SMOS brightness temperature in horizontal and vertical polarization (from 0° to 50° incidence angle) in order to better assess the precision of the sea surface salinity retrieved from SMOS measurements.

Salinity drifters will be deployed in 2012 and 2013 by various agencies, probably at the level of 100 drifters each year, in particular within the SPURS subtropical North Atlantic experiment, but also in the wet tropics. They will thus provide in those regions a significant amount of data complementing the other components of the upper ocean in situ observing system, and to help better understand near-surface stratification, when used together satellite retrievals from SMOS and AQUARIUS missions.

Acknowledgments

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