Introduction

The SMOS (Soil Moisture and Ocean Salinity) objectives for sea surface salinity (SSS) are to provide global coverage with repetition rate and accuracy adequate for oceanographic, climatological and hydrological studies and increase the present knowledge on: Large-scale ocean circulation, Water cycle exchange rates quantitative estimation, Occurrence of natural catastrophic events, Management of water resources, Role of the ocean in the climate system. To this end the mission requirements were set to determine SSS values with an accuracy of 0.1, in boxes of 100-200 km and temporal averages of 10-30 days [1].

Even the SMOS frequency, 1413 MHz within the microwave L-band, is close to the maximum sensitivity of brightness temperature ($T_B$) to salinity variations, this sensitivity is much smaller than the one for soil moisture. The total range of ocean SSS spans a $T_B$ range of 5K, while for soil moisture is 100 K. This implies that the SSS retrieval by SMOS requires a higher performance of the MIRAS interferometric radiometer, the single payload on board [2].

The ESA SMOS Ocean Salinity Level 2 Processor (L2OS) has been designed from 2004 by the team that co-authors this manuscript, and is being now improved to increase its performance and solve the deficiencies observed since it entered into operation during the SMOS Commissioning Phase. It relies on a minimisation of the comparison between the $T_B$ at different incidence angles measured by SMOS when overflying a single ocean spot, and a modeling of the sea surface L-band emission that takes into account the actual environmental conditions and all the processes that impact or modify this emission [3].

In this paper we present the status of the L2 ocean products as they were operationally generated during the SMOS Science Workshop in September 2011, the improvements expected from the new processors (version 500) in operation by mid October 2011 and to be used also for the 2011 general reprocessing, and the issues on SMOS SSS retrieval still being investigated at that moment.
SMOS ocean salinity product by September 2011

The SMOS L2OS processor was first implemented using pre-launch information, including the expected performance of the MIRAS instrument and of the L1 processor, as well as the current knowledge on the physical processes involved in the salinity retrieval. After MIRAS first on board calibrations and L1 processor started operating, the analysis of the L2OS products indicated a reasonably good SSS retrieval along an orbit. However, a fundamental issue had to be previously solved [4]: there was a misfit between the averaged measured and modeled $T_b$ of the order of 5 K. Even with improved MIRAS calibrations, including the correction from a Flat Target Response, the misfit presented a persistent spatial pattern that was very similar along and in different orbits. Thus, it should be mostly related to instrument and image reconstruction (L1) imperfections and not to forward model deficiencies. It was necessary to introduce an additional correction on L1 images, the so called Ocean Target Transformation (OTT) computed as the residual bias when comparing measured and modeled $T_b$ over a relatively homogeneous ocean area.

![Figure 1: SMOS ocean salinity map built from averaging 10 days of L2 products generated by the operational processors as integrated in the processing chain in September 2011](image)

Level 3 maps allow reducing the expected noise present in L2OS products and better analyse the SMOS salinity retrieval performance. The global distribution of SSS as depicted in figure 1 shows spatial structures coherent with the known salinity variability, except for large positive biases along several continental borders and along the Antarctic ice extension. This was much stronger than an expected contamination over the ocean due to the abrupt $T_b$ land/sea transition, and was discovered later to be mostly generated by a problem in the L1 processor that was corrected in the new version 500. Another important issue that hampers the SSS retrieval in large ocean areas (masked in figure 1) is a corruption of measured $T_b$ due to illegal man-made emissions (radio frequency interferences, RFI) inside the protected frequency band used by SMOS.

Through the analysis of temporal series of data it was also evidenced that there was a small lack of stability in $T_b$ both at long term (seasonal drift) and at orbital scale (ascending/descending and latitudinal differences). This was not relevant for the more robust soil moisture retrieval but for sure required correction for salinity. Most of this variability was estimated to be due to the impact of Sun position variability on the physical temperature of the antennas along an orbit and along a year, and a new antenna loss model was proposed to improve the L1 processor.

The in-depth analysis of the retrieved SSS products by the L2OS team, and also of the reconstructed $T_b$ images (L1 product), revealed other less evident issues
that also required new solutions to be implemented, as for example a proper cancellation of the impact of the reflected Sun radiation over the ocean surface.

**New SMOS processors in October 2011 (versions 5.xx)**

The processing modifications proposed both at L1 and L2 to solve or mitigate the detected problems were implemented in new versions of the processors, which entered into operation in October 2011. Through tests with prototyped processors the expected impact of a better L1 and modifications of L2OS in SSS retrieval are:

- Strong decrease in contamination of SSS near to land/ice, now much closer to the theoretical pre-launch expectations
- Better quality retrievals due to outliers and RFI detection/mitigation in L2OS and flagging of alias free field-of-view border in L1 images
- Significant decrease in differences between ascending and descending passes due to correction of short-term drift by the new antenna loss model
- Maybe some improvement can be expected due to correction of Sun aliases, but difficult to assess with the available reprocessed data
- No reduction expected in long-term drift. This is probably a combination of still uncorrected instrumental drift plus changing geophysical conditions, such as bias caused by the impact of Sun and galactic radiation scattered on the ocean surface. This raises the need for a time-varying OTT to adequately compensate for the remaining and changing biases
- Sea surface roughness effect correction models, initially derived from theoretical formulations or scarce experimental data, have been fitted to SMOS data and result in improved SSS retrieval
- The use of the more complete World Ocean Atlas 2009 [5] for SSS climatology, instead of the 2005 issue, is also expected to slightly improve the flagging of erroneous retrievals

Figure 2 shows an SSS map as they are now operationally generated by the Spanish CP34 high level data processing centre after deployment of the new versions of L1, L2 and L3 processors. By comparing to figure 1 it can be easily seen that the huge contamination bordering the continents has disappeared, as well as the RFI corrupted areas have been reduced especially at high latitudes. However, several issues are still being investigated for further improvement of SMOS SSS retrieval in upcoming processor versions. These are mainly: Building an optimal additive/multiplicative OTT or alternative method for residual bias and long-term drift removal, Removing residual scene dependent bias due to land/sea transition, Improving RFI mitigation: selective removal of contaminated measurements, Upgrading still deficient galactic noise scattering and Sun
corrections, Using improved full polarimetric measurements (T3, T4), Continue improving the roughness correction models, mainly by expanding the usable range of wind speed, Searching for an improved SSS inversion technique.

Conclusions

Significant improvement has been made in the challenging SSS retrieval by SMOS two years after the satellite launch. Many foreseen or unexpected problems, mainly linked to instrument and Tb image reconstruction performance, have been solved or mitigated and continue to be analysed by the L1 and L2 teams for improvement. We have not reached yet the mission requirements for ocean salinity, and a global preliminary validation of the data shown in figure 2 indicates differences with the near-surface salinity field derived from the Argo floats array that have a fresh bias of 0.01 and a root mean square of about 0.7.

But detailed analysis of SMOS data in selected conditions [6, 7] or using a stricter L1 data selection and simplified inversion method [8] reduce the difference with Argo to a range of 0.3-0.4. We are also investigating new methods to fuse SMOS SSS maps with other sources of data to reduce noise and provide improved L4 products. Together with the expected L1 and L2 processing improvements, this allows us to anticipate that SMOS will be probably able to meet the SSS retrieval expectations in most ocean regions.

References:


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