OVERVIEW OF SMOS LEVEL 2 OCEAN SALINITY PROCESSING AND FIRST RESULTS

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ABSTRACT

SMOS (Soil Moisture and Ocean Salinity), launched in November 2, 2009 is the first satellite mission addressing the salinity measurement from space through the use of MIRAS (Microwave Imaging Radiometer with Aperture Synthesis), a new two-dimensional interferometer designed by the European Space Agency (ESA) and operating at L-band. This paper presents a summary of the sea surface salinity retrieval approach implemented in SMOS, as well as first results obtained after completing the mission commissioning phase in May 2010. A large number of papers have been published about salinity remote sensing and its implementation in the SMOS mission. An extensive list of references is provided here, many authored by the SMOS ocean salinity team, with emphasis on the different physical processes that have been considered in the SMOS salinity retrieval algorithm.

Index Terms— Microwave radiometry, remote sensing, sea surface salinity

1. INTRODUCTION

SMOS (Soil Moisture and Ocean Salinity) is the European Space Agency's water mission [13], a component of its Living Planet Program Earth Explorer Opportunity Missions. It is aimed at providing global and regular observations of these two climatic variables that are key to understand and predict the evolution of the water cycle on our planet. Ocean salinity relates the Earth global water cycle to ocean circulation. It is modified through processes that increase or decrease the fresh water amount in the ocean surface, mainly precipitation and evaporation. These changes in surface salinity are transferred to the deep ocean and spread to other regions. This generates slight differences in dissolved salt content between the different water masses that are sufficient to play a major role in ocean dynamics. Knowing the salinity distribution at global scale and its annual and interannual variability is crucial to better understand the ocean's role in the climate system, regulated by this circulation and water and heat fluxes between atmosphere and ocean [6, 7, 15, 17].

The remote measurement of ocean salinity is feasible as at low microwave frequencies the radiation spontaneously emitted by the ocean surface is related to the physical temperature of the topmost ocean layer through a proportionality coefficient (emissivity) linked to the dielectric properties of the emitting body. In this case this is depending on seawater conductivity, that in turn is a function of ocean salinity [6, 7, 15, 17, 18, 26].

2. OBJECTIVES AND APPROACH FOR SMOS SALINITY MEASUREMENT

Within the microwave L-band (1-2 GHz), where sensitivity of emitted power to salinity is maximized, a narrow frequency band centered at 1.413 GHz is ideal for soil moisture and ocean salinity measurement, as it is devoted to passive observations and hence protected from human-made emissions. However, even at this optimal frequency, the retrieval of sea surface salinity (SSS) requires special care because of the low sensitivity of brightness temperature (Tb) to SSS: from 0.8 K to 0.2 K per salinity unit (pss), which depends on ocean temperature, radiometer incidence angle, and polarization [29].

The technical limitations in achieving highly stable and calibrated radiometric measurements, together with the complexity of the relationship between SSS and the Tb actually measured by an antenna on a satellite, limit now the expected accuracy of the SMOS SSS retrieval in a single satellite overpass to a range of 1-2 pss, depending on the position of the pixel within the field-of-view (FOV) and to environmental conditions [8]. Further objective analysis of data from several orbits should decrease the noise level until reaching an uncertainty of the order of 0.1 pss in boxes of 100-200 km and 10-30 days of temporal averaging. Taking into account these limitations, the objectives for SMOS salinity determinations were set to deliver SSS maps useful for improving seasonal to interannual climate prediction, ocean rainfall estimates and global hydrologic budgets, and monitoring large scale salinity events and thermohaline convection [7, 8].

The technical approach implemented in SMOS to achieve adequate radiometric accuracy, as well as spatial and temporal resolution in a trade-off between land and ocean science requirements, is polarimetric interferometric radiometry, the same principle used in radiotelescopes [6, 7]. This allows observing a single point on the surface under different geometrical conditions, then providing redundant Tb information to be used in enhanced SSS retrieval. The instrumental principles, as well as the proposed data processing methodology at the different levels, have been presented in many IGARSS symposia for more than ten years now. A summary can be found in [7].

3. OCEAN SALINITY RETRIEVED BY SMOS

Transforming the signals recorded by the 69 elements of the SMOS Y-shaped antenna array into SSS is a long and complex process. It goes from generating a Tb image on the 1000 km-wide SMOS alias-free FOV (level 1, L1) until retrieving salinity values through a comparison between these measured Tb and those simulated by forward models of the ocean surface L-band emission that include guessed salinities (level 2, L2). The SMOS L2 ocean salinity processor contains the different algorithms needed for salinity retrieval, including pre-processing steps to filter out or flag Tb values that do not fulfill specified quality standards, the different modules of the emission forward model (flat sea emissivity, roughness effects, atmospheric attenuation, impact of radiation emitted by external sources, etc.), and finally the convergence loop where the guessed salinity is modified until reaching an optimal fit between measured and modeled Tb. Several of these modules and algorithms require auxiliary information like sea surface temperature, roughness descriptors predicted by the European Centre for Medium-range Weather Forecasts operational system, and the total electron content predicted at the Center for Orbit Determination in Europe. A detailed description of the SMOS L2OS processor components and their implementation and testing can be found in [30]. This processor has been designed and implemented by a team formed by SMOS-BEC/ICM-CSIC (Barcelona), LOCEAN-IPSL (Paris), IFREMER (Brest), ACRI-ST (Sophia-Antipolis) and ARGANS (Plymouth). Due to the exploratory character of SMOS and the lack of preceding missions using the same technology and data processing approach, many of the components of the forward model are fully new and never validated before with real data. One of the consequences of this is that the effect of roughness on sea surface emission has been implemented using three alternative formulations, and then three different SSS values are delivered at each grid point in the L2OS data product. These formulations are to be tuned and modified when long consistent SMOS data sets are available, and at the end some of them can be discarded or selected for use under different geophysical conditions.

The satellite was launched on November 2, 2009, and the mission commissioning phase was completed on May 20, 2010. The operations phase started with the radiometer set on full polarization mode. This acquisition mode, although it provides noisier data than a simpler dual polarization, due to a lower sampling rate, provides additional polarimetric information to be used in further processing improvements, e.g. better estimation of the Faraday rotation effect in the ionosphere or identification of radio frequency interferences (RFI) in the data streams.

3.1. Main SSS retrieval issues

Once calibrated L1 data were available, in December 2009, the characteristics of the reconstructed SMOS Tb field and several aspects of the L2 processing steps could be examined by the L2OS team. In spite of several configuration and calibration changes, and different L1 processing options being tested during commissioning, it was possible to analyze Tb snapshots along some open sea orbits, especially in the eastern Pacific Ocean, under relatively moderate surface roughness conditions and far from continental areas.

Even after L1 data were fully calibrated using a flat target response (open sky image), it appeared that a residual misfit was present between averaged measured and modeled Tb. The persistent spatial pattern of this bias, as seen in the antenna cosinus-director frame, and its similitude when computed using the different roughness models, lead to the conclusion that it was probably due to instrumental and image reconstruction imperfections.

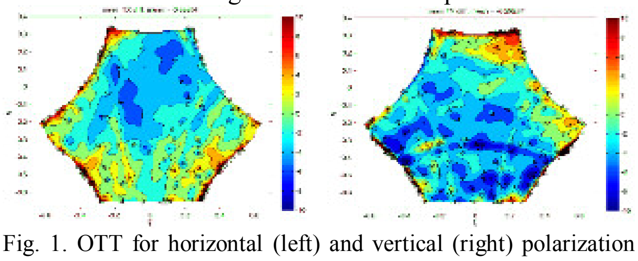

Fig. 1. OTT for horizontal (left) and vertical (right) polarization from a Pacific Ocean orbit on February 2010 (by X. Yin)

While the problem is fully investigated and different bias removing techniques are proposed and tested, a working solution has been implemented in the processor to cope with this residual bias in the first L2OS products delivered to the SMOS calibration/validation community in

July 2010. It consists in introducing Ocean Target Transformation (OTT) look-up tables to the level 1 products before running salinity forward models. This transformation (Fig. 1) basically consists in applying a constant offset (computed over a homogeneous ocean area) to the Tbs depending on their coordinates in the antenna frame (incidence and azimuth angles).

A major problem observed in SMOS salinity data is the contamination from the continents as soon as they enter the SMOS very wide antenna FOV. This is generally a brightness temperature effect on the order of 2-4 K which may reach 7-8 K and depends on the distribution of Tb of the land masses far away from the scene for which SSS is retrieved. This effect impacts strongly the quality of the retrievals in spatial bands following the world major coast-lines and spanning over more than 1000 km offshore, depending on the orbit orientation (Fig. 2). The source for this spurious effect is still under investigation, and preliminary simulations independent from the SMOS L1 processor, don't show this strong land contamination (I. Corbella, ESA Living Planet Symposium, 2010). The problem is being addressed at the image reconstruction stage by the L1 team and improvements are expected to be introduced in further versions of the processors.

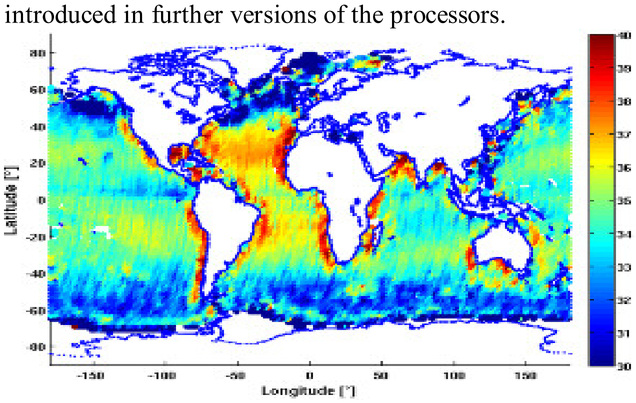

Fig. 2. Weekly global SSS map (27 April – 4 May 2010) generated from L2OS products with data weighted by their radiometric accuracy after discarding flagged values (by R. Sabia)

3.2. Preliminary SMOS SSS data validation

All the available L2OS data for March 2010, without filtering or separating by the different acquisition or processing configurations, have been averaged by bins of 0.5º in latitude and longitude (by N. Reul). Those being far from land and ice transitions have been compared to objectively analyzed in situ data (7296 SSS values from Argo floats vertical profiles). The results show biases in the range 0.05-0.60 pss and standard deviations 0.45-0.57 pss depending on the three different roughness models used. This does not yet fulfill the mission requirements, but indicates we are approaching them and still have margin for significant progress both at L2 and in analyzed maps.

4. CONCLUSIONS

First retrieved SMOS SSS are very encouraging as they were processed using models defined previous to SMOS launch, i.e. without any tuning to real measurements, except the reported systematic bias correction. Future improvements are expected from validation of direct models using SMOS data and from improved image reconstruction.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

In the ESA Living Planet Symposium held in Bergen, Norway, 28 June – 1 July 2010, a special section was devoted to SMOS. A total of 4 oral presentations and 14 posters were related to ocean salinity aspects, including from details of the retrieving process to studies on potential applications. These papers are to appear in the ESA Special Publications series (SP-686) on CD-ROM.

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