Comparison of SMOS level 2 and level 3 soil moisture at the SMOSREX site

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Abstract

The ESA (European Space Agency) satellite mission SMOS (Soil Moisture and Ocean Salinity) was launched in November 2009 and has been providing data on ocean salinity and soil moisture over continental surfaces for the last 4 years. SMOS satellite is a passive L-band (1.4 GHz) interferometer that measures the surface soil moisture (top 5cm) with an overpass time at 6 am and 6 pm (local time) and a radiometric resolution of ~ 43 km in average. With a quasi polar orbit, it covers the entire Earth surface in 3 days.

The CATDS (Centre Aval de Traitements des Données SMOS) ground segment developed by the French space agency CNES, provides so called "level 3" soil moisture products that are time aggregated products, on the EASE (Equal Area Scalable Earth) Grid with a ~25 km spatial resolution. The retrieval algorithm is based on the radiative model L-MEB (L-band Microwave Emission of the Biosphere).

The aim of this paper is to present the different soil moisture products that are delivered by the CATDS such as daily products, 3-day and 10-day composites, monthly averages, discuss different features of the product contents, and also presenting the validation of the SMOS data. Several in-situ sites are equipped with various soil moisture sensors providing soil moisture measurements for different climate areas. For instance, the SMOSREX (Surface Monitoring of the Soil Reservoir Experiment) site was developed to test the SMOS soil moisture retrieval algorithm.

Two fields (bare soil and grassland) were monitored with Delta-T theta probes and a cosmic ray neutrons probe that measures the soil moisture over a large area (~ 700m). This site was stopped in 2012 which provides us with more than two years of data that can be compared to SMOS derived soil moisture values.

I - INTRODUCTION

The ESA (European Space Agency) SMOS satellite mission (Soil Moisture and Ocean Salinity) was launched in November 2009 and has been providing data on ocean salinity and soil moisture for the last 4 years. SMOS is a passive L-band (1.4 GHz) interferometer measuring the surface soil moisture (top 5cm) with an overpass time at 6 am and 6 pm (solar time). With a quasi polar orbit, it covers the entire Earth surface in 3 days (Mecklenburg et al., 2012).

Three ground segments have been producing and delivering SMOS data. The focus here is put on ESA level 2 soil moisture (Mecklenburg et al., 2012) and CNES (Centre Nationales d'Etudes Spatiales, France) level 3 products from the CATDS (Centre Aval de Traitement des Données SMOS) (Guibert et al., 2013). The main differences are: i) the level 3 algorithm takes advantage of three SMOS overpasses and uses a correlation function (Al Bitar et al., 2010) for the vegetation components; ii) ESA level 2 is on the isea4h9 grid with a spatial resolution of 15 km (Kerr et al., 2012) whereas the CATDS level 3 products are on the EASE Grid (Equal Area Scalable Earth Grid) defined at ~ 25 km ; iii) level3 products use the NETCDF (Network Common Data Form) format, commonly used and for which many tools exist to read the data, whereas the level 2 is using the binX format.

Validation efforts have been established for the SMOS soil moisture level 2 products at different sites such as Australia, the US (Al Bitar et al. 2012, Leroux et al. 2014), in Denmark (Bircher et al. 2012), in Spain (Wigneron et al. 2012). The aim of this study is to present the SMOS level 2 and level 3 over the experimental site SMOSREX (Surface Monitoring Of the Soil Reservoir EXperiment, de Rosnay et al. 2006) located in the South of France.

II - SMOS DATA

SMOS ESA level 2 soil moisture data are produced per half-orbit and separate the ascending (~ 6 am, local solar time) from the descending (~ 6 pm, local solar time) overpasses. The complete description of the algorithm is available in Kerr et al. (2012). Data that are used in this paper are obtained using the version 5.51 of the processor. The CATDS level3 products are time composite products (Jacquette et al. 2010), aggregated over several time windows: 1 day, 3 days to have a complete coverage of the Earth Surface; 10 days containing the minimum, the median and the maximum of soil moisture values observed during that period; monthly averages. These products have different applications from weather forecast (level 3 1-day product) to water management (level 3 10-day product) and contain the derived parameters such as the soil moisture and the optical thickness among other useful information (such as quality flags). A complete description of the content of the products is available in Berthon et al. (2012) and the data are obtained using version 2.5 of the level 3 processor. These versions of level 2 and level 3 are also different for the computation of the dielectric model (Kerr et al. 2011, Kerr et al. 2012) of soil. The dielectric constant depends on soil properties (texture, soil temperature) and on soil moisture especially at L-band. The dielectric constant controls the soil emission and so the brightness temperatures monitored by passive instruments like radiometers and SMOS interferometer. The SMOS level 2 data uses the Dobson model (Dobson et al. 1985, Hallikainen et al. 1985, Peplinski et al. 1995) whereas the level 3 uses the Mironov model (Mironov et al. 2009), which can lead to a slight difference in terms of derived soil moisture values. Globally, the use of the Mironov dielectric model tends to retrieve higher soil moisture values compared to the Dobson model (Mialon et al. 2012).

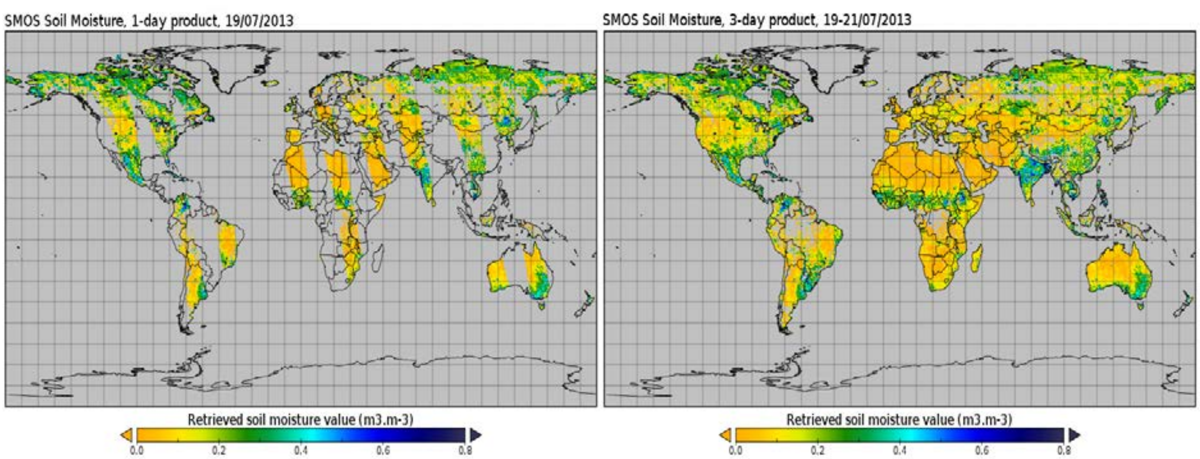

Figure 1 : Example of SMOS level 3 soil moisture map, from 1-day product (left figure) and from 3-day product (right figure)

Figure 1 shows an example of the soil moisture values as provided in a 1-day product for the ascending orbits of July 19, 2013 (left Figure), where the overpasses do not cover the entire Earth surface. Right Figure 1 presents a 3-day product obtained by selecting the best estimation of the soil moisture over a 3 day window, July 19-21, 2013. This selection is based on a data quality index (Kerr et al. 2013) associated with each retrieved parameter. Using a 3-day window allows a better surface cover compared to the 1-day product. The low values of soil moisture over Europe are consistent with the dry and hot weather conditions observed in mid-July 2013. On the other hand, Eastern Australia reported rain events[1] that lead to an increase in the surface soil moisture.

Although SMOS is operating in a protected band it is facing the important problem of man-made RFI (Radio Frequences Interferences) (Oliva et al. 2012, Richaume et al. 2010) increasing the brightness temperatures and so hampering the retrieval of soil moisture. It is thus necessary to filter out the data affected by these interferences based on indicators provided in the SMOS product. Generally it was found that SMOS derived soil moisture values associated with data quality index values lower than 0.07 m^3/m^3 and a RFI probability lower than 10 % (less than 10% of brightness temperatures affected by RFI) can be used with confidence.

III-SMOSREX site

SMOSREX was an experimental site near Toulouse in the South West of France. This site was developed to improve the SMOS algorithm over bare soil and grassland and was operational from 2003 and 2012, with the last 2 years in common with SMOS.

The soil is characterized by a clay content of 17%, a sand content of 36% and a silt content of 47% (de Rosnay et al. 2006). A set of soil moisture probes monitors the soil moisture content every 30 minutes at different depths, from surface (top 0-6 cm) down to 90 cm. For this study we focus on the bare field soil. As SMOS measures the soil moisture content of the top 5 cm or even less (Escorihuela et al. 2010), only the top surface probes are considered

[1] Australian Bureau of Meteorology, see http://www.bom.gov.au/jsp/awap/rain/archive.jsp?colour=colour&map=totals&year=2013&month=7&day=21&period=week&area=nat

for this study. Five Delta-T theta probes (ML2X) [2] were installed at the surface covering an area of ~ 2 m^2 and calibrated individually with the following protocol : at sixty occasions during the experiment time, soil samples were collected (6 samples each time), weighed and dried to obtain the soil moisture content (Schmugge et al .1980). The corresponding probe outputs (in Volt) and the measured soil moisture contents allowed us to define a linear relationship (as recommended by the manufacturer) between the probe measurements and the soil moisture. For the present study, we consider the average of the ML2X theta probe soil moisture as our reference. Since February 2011, a cosmic-ray probe was installed, also referred to as COSMOS (COsmic-ray Soil Moisture Observing System, Zreda et al. 2008). This probe measures soil moisture over a footprint with a diameter of ~ 670 m (86% of the signal) on an hourly basis. This encompasses the bare soil field but also the grassland part. The influencing soil depth depends on the soil moisture content from the top layer (~12 cm) for wet conditions to deeper layers (~ 76 cm) for dry conditions (Zreda et al. 2012). The monitored layer is different from the one that SMOS is sensitive to, but the probe presents the advantage of integrating the signal over a large footprint contrary to the Delta-T theta probes measuring the soil moisture content at a single location. This probe has also been calibrated for site specific conditions using ground samples (more than 100) so that the associated error is ~ 0.01 m^3/ m^3. A complete description of the procedure for cosmos probes calibration is detailed in Zreda et al. (2012) and the following parameters have been found for the SMOSREX site to convert the cosmic-ray outputs to soil moisture values: cutoff rigidity of 5.34 GV, mean pressure of 990 mB, lattice water of 3%, soil organic carbon content of 0.76% and maximum count rate of 2575 per hour.

IV- RESULTS

IV-A- Soil Moisture Calibration

The theta probe devices are commonly used to monitor soil moisture (Wigneron et al. 2012). A calibration function is given to convert the measured signal in volts into a soil moisture value (m^3/m^3). It is recommended to perform a site specific calibration using soil samples collected on site which is presented in Figure 2.

[2] Mention of manufacturers is for the convenience of the reader only and implies no endorsement on the part of the authors

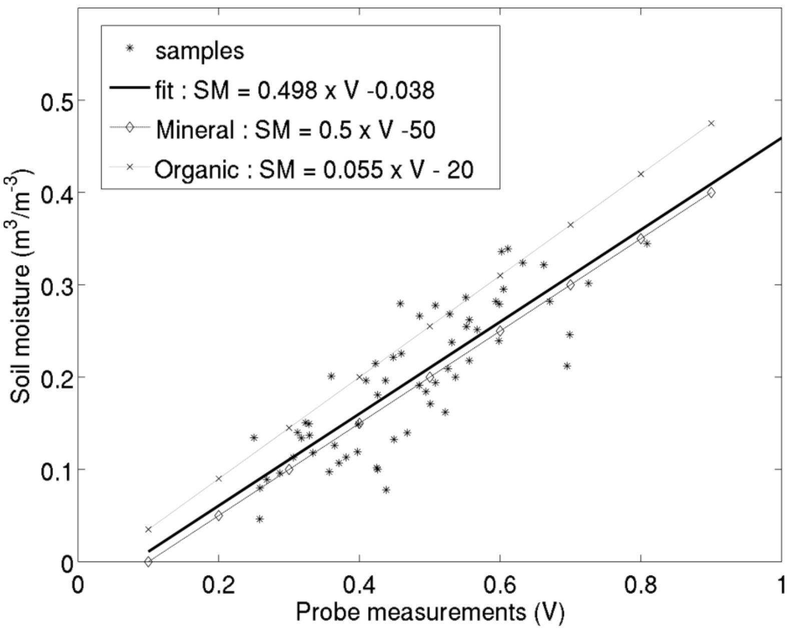

Figure 2: Relationship between soil moisture and theta probe output. Stars are the soil samples; black line is the best fit; light grey line with crosses is the manufacturer's relationship for organic soils and grey line with diamonds is the manufacturer's relationship for mineral soils.

Figure 2 shows the relationship SM = 0.0498 x V - 0.038 derived from 60 collected points (RMSE=0.043, R=0.83) spanning a wide range of soil moisture conditions. The manufacturer provides the users with two fitting curves for mineral and organic soils (light grey lines in Figure 2). The fitted curve is very close to the default one for mineral soil, the difference being within the accuracy of the probe, which is of +/- 0.05 m^3/m^3 according to the manufacturer. It was still decided to use the fitted relationship.

IV-B- Soil Moisture Comparison

Figure 3 presents time series of soil moisture values measured by theta probes (average of the 5 probes) and derived from SMOS observations (level2 and level3 products). Due to technical issues, some in-situ data are missing in October, November 2010 and January 2011.

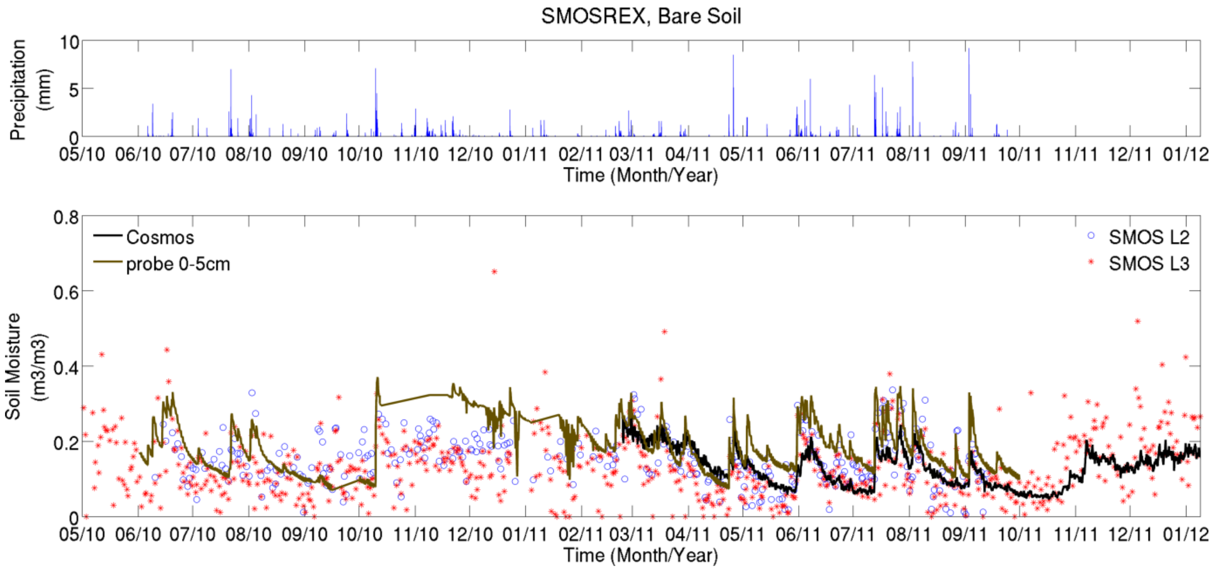

Figure 3: Measures at the SMOSREX site. Top is the precipitation, bottom is the soil moisture from : delta T theta probe sensors (average) in brown, cosmic ray in black, SMOS level 2 as blue circles and SMOS level 3 as red stars.

Both SMOS products perform relatively well catching all the precipitation events (red and blue in Figure 3) but they underestimate the soil moisture measured by the ML2X theta probe (brown in Figure 3) with a negative bias of 3% for the level 2 and 6% for the level 3 (Figure 4). SMOS level 3 data show lower values (higher absolute bias) compared to SMOS level 2 as the latter uses the Mironov dielectric constant model (Mironov et al. 2009) whereas the level 3 uses Dobson (Dobson et al., 1985). Since January 2014, both levels 2 and 3 of SMOS products are using the same dielectric model that is the Mironov one. The cosmic-ray measurements show similar results to SMOS level 3 (Figure 4) but agree better in terms of statistics (R=0.68 and a negative bias of 4.5%) with the theta probe measurements. Figure 4 presents the different soil moistures series (SMOS and Cosmos) as a function of delta-T theta probe data. SMOS level 3 (red in Figure 4) and cosmos (black circles in Figure 4) underestimate the ML2X theta probe soil moisture values, whereas the cosmos probe presents a better correlation coefficient. This result is expected as SMOS measurements cover a larger (radiometric resolution of ~ 40 km average, Kerr et al. 2012) and heterogeneous area (in terms of land cover) whereas the cosmos probe is representative of the field monitored by the probe even though the measurement depth is different.

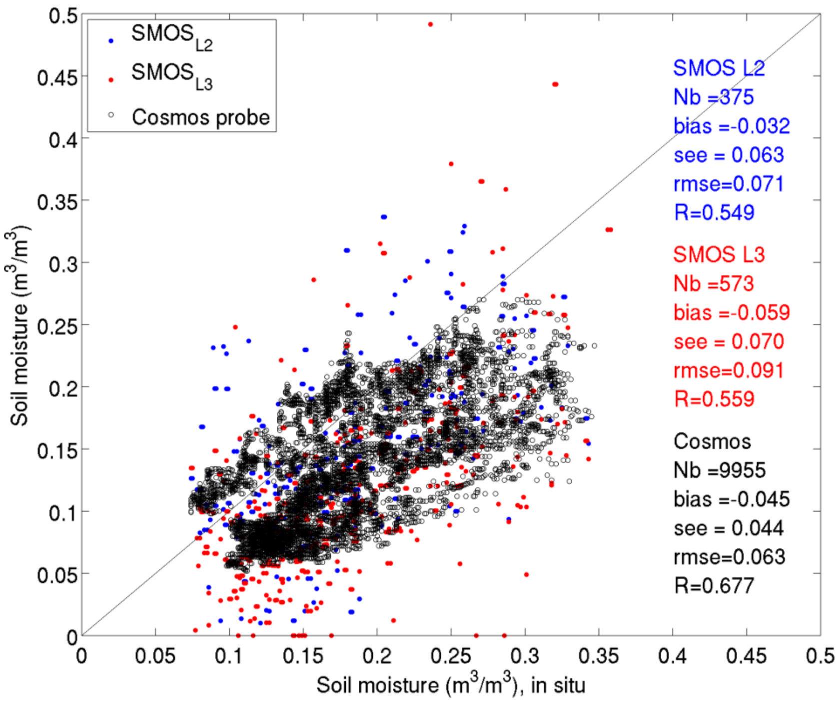

Figure 4: Soil moisture measured by the cosmic-ray probe (empty black squares), SMOS level 2 (blue dots) SMOS level 3 (red dots) as a function of delta-T theta probe soil moisture values (surface probes) at the SMOSREX site.

V- DISCUSSION AND CONCLUSION

This paper compares the SMOS products ESA level 2 and CATDS level3 for the SMOSREX experimental site in France. Two sorts of probe are used at this site to monitor soil moisture: Delta T Theta probes and a cosmic-ray probe. Both probes were calibrated by collecting soil samples to derive fitting curves to convert the probe output to soil moisture values based on site-specific soil characteristics. Some more work has to be done to derive a surface soil moisture value from the cosmic-ray probe to be comparable to SMOS data, but its spatial resolution is of real interest to validate satellite observations. One has to be careful when comparing data obtained at different scales (Wigneron et al. 2012), but SMOS level 2 and 3 agree relatively well with the Delta-T probe measurements and catch the rain events. Even though the probes give soil moisture values that are different from what is derived from SMOS due to the different scales, the good agreement between the dataset proves the interest of the SMOSREX site. The site provides us with a reference for the validation of SMOS data to evaluate the mission performance (Al Bitar et al. 2010, Leroux et al. 2014, Wigneron et al. 2012). Once the RFI are filtered out from SMOS dataset, the in situ measurements can be used to test and check the consistency of the different releases of the SMOS products (different versions of level 2 and level 3).

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