Comparison between Theïa and Copernicus surface soil moisture products over southern France

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COMPARISON BETWEEN THEIA AND COPERNICUS SURFACE SOIL MOISTURE PRODUCTS OVER SOUTHERN FRANCE

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ABSTRACT

A comparison between the Sentinel-1/Sentinel-2-derived Soil Moisture Product at plot scale (S^2MP) and the new Copernicus Surface Soil Moisture "C-SSM" product at 1-km scale over a wide region in southern France was carried out. Both products show generally good agreement with in situ measurements. The results show that using in situ measurements collected over agricultural areas and grasslands, the accuracy of the C-SSM is good (RMSD = 6.0 vol.%, ubRMSD = 6.0 vol.% and R=0.48) but less accurate than the S^2MP (RMSD = 4.0 vol.%, ubRMSD = 3.9 vol.% and R=0.77). The intercomparison between the two SSM products shows that both products are highly correlated over areas mainly used for cereals (R value between 0.5 and 0.9 and RMSE between 4 vol.% and 6 vol.%). Over areas containing forests and vineyards, the C-SSM values tend to overestimate the S^2MP values (beyond 5 vol.%). In the case of well-developed vegetation cover the S^2MP doesn't provide SSM estimations while C-SSM sometimes provides underestimated SSM values.

Index Terms – Soil Moisture, Theia, S^2MP, Copernicus SSM, Sentinel-1, South France

1. INTRODUCTION

Soil moisture data at high spatial resolution is essential for agricultural management, such as monitoring of irrigation practices and water requirements of agricultural areas [1]–[4] Soil moisture values are mainly obtained through the inversion of either physical [5] or statistical models [6]–[10]. While statistical models require site calibration, physical models can always be used to simulate the radar backscattering from radar configuration. Among the physical models, the Integral Equation Model (IEM) [5] is the most commonly used to estimate soil moisture over bare soil or soil with little vegetation cover. Baghdadi et al. [11], [12] proposed a semi-empirical calibration of the IEM to compensate between the large difference observed between IEM simulation and real SAR data. To estimate soil moisture over vegetated areas, the Water Cloud Model (WCM) developed by Attema and Ulaby [13] is commonly used. In the WCM the radar backscattering signal is modeled as a sum of the direct vegetation contribution and the soil contribution multiplied by the attenuation factor. Several studies have parametrized the WCM for different SAR band configurations and for several crop types [2]. In addition to the inversion of statistical or physical models for soil moisture retrieval, recent studies have started reporting the estimation of soil moisture using the change detection method [14].

Recently, the arrival of the Sentinel-1 (S1) SAR satellite provided users with free open access SAR data at a high spatial resolution (10 m x 10 m) and high revisit time (six days over Europe). The S1 mission from the European Space Agency (ESA) is a constellation of two polar orbiting SAR satellites (Sentinel-1A and Sentinel-1B) operating in the C-band (~5.4 GHz). The SAR data of the S1 mission at high spatial and temporal resolutions have encouraged mapping soil moisture in an operational mode. Paloscia et al. [8] used the neural network technique to invert the Sentinel-1 SAR C-band and estimate the SSM values. Recently, El Hajj et al. [15] developed an operational method to map soil moisture at the plot scale over agricultural areas based on coupling S1-SAR data and Sentinel-2 (S2) optical data using the neural network technique (S^2MP). The French Land data center Theia (https://www.theia-land.fr/en/) use the algorithm developed by El Hajj et al. [16] for the provision of soil moisture maps at the plot scale for several sites over the world (South France, Italy, Spain, Morocco, Lebanon, etc.). Most recently, the Copernicus Global Land Service has started providing SSM of the soil's topmost 5 cm over the European continent from Sentinel-1 sensors at 1 km x 1 km spatial resolution using the change detection method [17]

The comparison between the Copernicus product C-SSM and the Theia product S^2MP was carried out over a wide region in south France (Figure 1). Both products are first evaluated against in situ measurements of soil moisture. The new Copernicus SSM product was then intercompared with the SSM estimations from the S^2MP. Section 2 presents the study site, the SSM products used, and the in situ SSM measurements. The results and discussions are presented in Section 3. Finally, Section 4 presents the main conclusions.

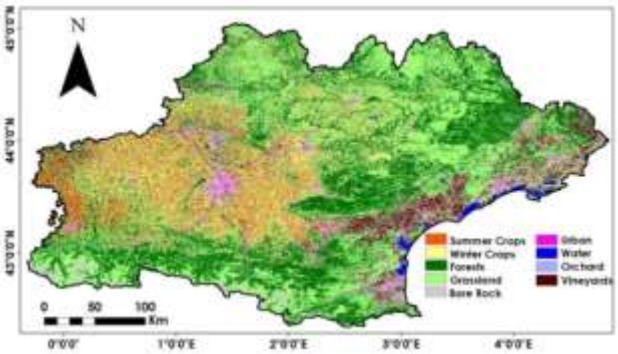


Figure 1. Land cover map of Occitanie region (Fr).

2. MATERIALS

2.1. Study Site

Our study site corresponds to the Occitanie region of southern France ($2^{\circ}30'$ E and $43^{\circ}30'$ N, Figure 1). The region has a variety of landscape and is mainly covered by agricultural areas in the middle and western parts. The northern regions are generally covered with a mix of forests, grassland and agricultural crop land. The eastern region is generally covered with a mix of agricultural crop land, grassland and vineyards. The climate in the eastern part of the region is considered Mediterranean (700 mm average annual precipitation), whereas that of the western part is more humid and oceanic (1200 mm average annual precipitation).

2.2. S²MP Product

The S²MP product is obtained by coupling Sentinel-1 SAR data and Sentinel-2 optical data. The S²MP product provides SSM estimates over the agricultural areas at plot scale with 6 days revisit time [16]. To estimate the SSM values, El Hajj et al. [16] inverted the WCM parameterized by Baghdadi et al. [18] for C-band combined with the IEM, as modified by Baghdadi et al. [11]. The inversion approach uses the neural network (NN) technique to invert the radar signal into SSM value. To operationally map the soil moisture, the developed NN uses the C-band SAR signal in VV polarization, SAR incidence angle, and the Normalized Differential Vegetation Index "NDVI" as the inputs. While the SAR signal and incidence angle are derived from the S1 data, the NDVI value is derived from Sentinel-2 images. The S²MP maps are produced for agricultural areas (it is not applied to vineyards and orchards). Forest and urban areas are masked using the land cover map of Inglada et al. [19]. Additionally, areas with slope greater than 20% are masked in the soil moisture product (calculated from SRTM DEM at 30 m spatial resolution). The S²MP are available in free open access mode via the Theia French Land Data Center (http://www.theia-land.fr/en/thematic-products). The S²MP maps were derived mainly using the ascending acquisition mode of the S1 sensors (time ~17:40 UT) to avoid the presence of frozen soil when using the descending mode that passes by our zone at 6:00 UT.

2.3. Copernicus SSM Product

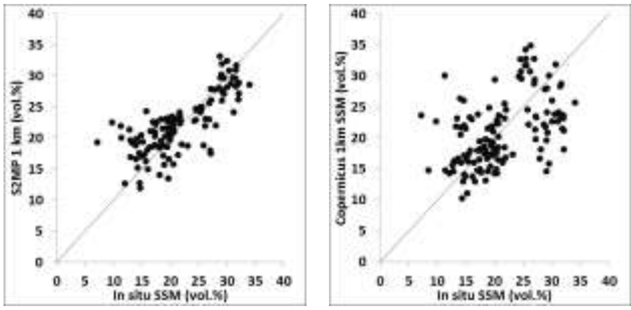
Recently, Copernicus Global Land Service began to distribute the first soil moisture estimations over the European continent at a 1-km spatial resolution using S1 data in C-band [17]. The SSM retrieval algorithm is based on the TU (University of Technology) Wien Change Detection Model already applied for the ASCAT data and adapted for Sentinel-1 data. In the applied model, the changes observed in the SAR backscattered coefficient (σ^0) are interpreted as changes in the soil moisture values, whereas other surface properties, such as the geometry, the surface roughness and the vegetation cover, are interpreted as static parameters. The C-SSM products at 1-km spatial resolution are retrieved from the Sentinel-1 radar backscattering images acquired in IW mode and VV polarization. The product delivers relative SSM values in percentages ranging between 0% and 100%. The C-SSM product values were converted to a volumetric unit (vol.%) in order to compare the C-SSM estimations produced in relative units (%), with measured soil moisture being given in absolute volumetric unit (vol.%) [20]

2.4. In situ Soil Moisture Measurements

The SSM values were measured on 23 reference plots (10 grassland and 13 wheat) during the period between 1 January 2017 and 31 May 2017 [16]. The SSM values were measured within 2 hours of the S1 acquisition time in 22 different campaigns at different dates of S1 acquisition. For each plot, 25 to 30 volumetric soil moisture measurements were taken from the top 5 cm layer using a calibrated TDR (Time Delay Reflectometer). Then, within each plot, the SSM measurements were averaged to obtain a mean value for each plot. The measured soil moisture values varied between 7.0 vol.% and 36.3 vol.%.

3. RESULTS AND DISCUSSIONS

The SSM values of each product were evaluated using the in situ SSM measurements during the period between January 2017 and May 2017. Figure 2 shows the comparison between the SSM products and the in situ SSM measurements. The S²MP shows a higher *R* value (0.78) than that of the Copernicus SSM (0.48). Additionally, the RMSD is lower for the S²MP (4.0 vol.%) than for the Copernicus SSM (6.0 vol.%). Notably, the *p*-value of the comparison for both products is lower than 0.01, which indicates that the correlation is significant.

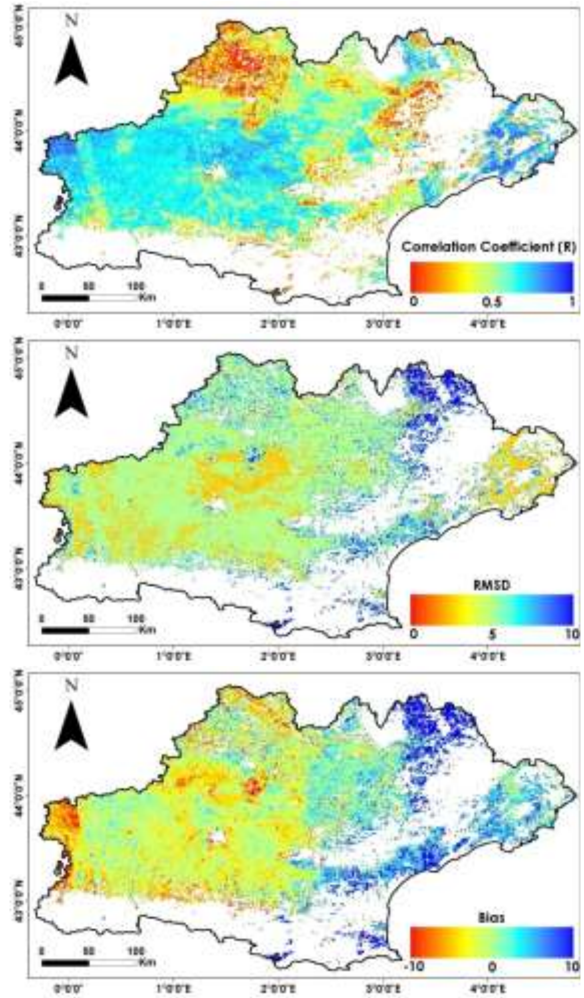


(a) (b)

Figure 2: SSM products against in situ measurements. (a) S^2MP-1 km, (b) Copernicus SSM-1 km.

Figure 3 represents the maps of statistical metrics calculated from the comparison between the SSM from the S^2MP and C-SSM products during the period between October 2016 and October 2017 (the correlation coefficient R between the two products, the root mean square difference values “RMSD”, and the bias values (C-SSM - S^2MP). Moderate to high correlation values between the compared products are observed, mainly in the western, middle and eastern part of Occitanie (R between 0.5 and 0.9). Figure 3b shows that the RMSD values for these parts are approximately homogeneous and ranging between 4 and 6 vol.%. Between these parts, only the eastern part shows high positive bias values (between 2 and 4 vol.%). The correlation map (Figure 3a) shows low values mainly in the northern part of Occitanie, where R is less than 0.3 with moderate RMSD values (between 6 and 8 vol.%). High RMSD values (more than 8 vol.%) are observed for the northeastern part. The bias map for the northern area shows high positive values (> 6 vol.%) (Figure 3c).

The statistical metrics obtained from the comparison of both SSM products are analyzed as a function of the land cover (Figure 1). The S^2MP product provides soil moisture estimation over agricultural crop land only grown in summer and winter (urban, forest, grassland and vineyards are masked), which should be considered before analyzing the effect of the land cover. Thus, we suppose that the soil moisture calculated from the S^2MP product is the same for the whole cell of 1 km × 1 km (not composed only of crops). The results reveal that the western and middle parts show the highest R values with smallest bias and RMSD values. In the land cover map, this area shows a majority of summer and winter crops (more than 65% of the area). The eastern part that shows high correlation values but moderate to high bias values is composed of a mix of vineyards (30%), grassland (30%) and summer-winter crops (14%). The northern part, with the lowest R and moderate RMSD and bias values, is generally occupied with a mix of grassland (60% of the area) and forests (23% of the area). This part comprises no more than 9% agricultural areas. Finally, the northeastern part (high RMSD and bias values) is mostly covered by a mix of forests (40%) and grassland (40%).



(a) (b) (c)

Figure 3: Statistical metrics maps at 1-km grid generated from the comparison between the C-SSM and S2MP. (a) Correlation coefficient R map, (b) RMSD map, (c) Bias map.

The analysis of the SSM products’ quality according to land cover type reveals that over areas mainly used for cereals and market gardening (the case of the middle and western parts), the correlation between the SSM products is high, indicating high consistency in soil moisture estimation between the products. When the area becomes more occupied by grassland (the case in the northern part), the correlation decreases but keeps moderate RMSD and bias values. However, when the forested area dominates and the land cover becomes more heterogeneous (forests, grassland, agricultural…) (the case in the northeastern part) an overestimation of C-SSM with respect to S^2MP is observed. Moreover, when the vineyards are dominant in the land cover (the case of the eastern part) overestimation of C-SSM with respect to S^2MP is observed. The limitation observed over heterogeneous land cover for the C-SSM product could be related to the spatial resolution because the product is produced at a 1-km pixel size and not at a fine scale.

4. CONCLUSION

The aim of this study was to assess the accuracy of Surface Soil Moisture (SSM) in southern France estimated by the Sentinel-1/Sentinel-2-derived Soil Moisture Product at plot scale (S^2MP) and the new Copernicus Surface Soil Moisture "C-SSM" product at 1-km scale. The results reveal that both products show good reliability with in situ measurements. However, S^2MP shows higher accuracy (RMSD = 4.0 vol.%, R = 0.77) than the C-SSM (RMSD = 6.0 vol.%, R=0.48) when compared to in situ measurements over agricultural areas and grasslands. The analysis of the intercomparison between the products as a function of the land cover shows that the S^2MP and C-SSM are highly correlated over dense agricultural areas (mainly cereals of winter and summer). When the land cover becomes more heterogeneous (mix of forests, grassland and vineyards with agricultural areas) the correlation between the products decreases. The C-SSM tends to overestimate SSM values over cells containing vineyards and forests. In addition, the C-SSM sometimes shows underestimated SSM values when the vegetation is well developed. However, the validation of the new soil moisture product of Copernicus needs additional experimental sites to allow stronger conclusions.

5. ACKNOWLEDGMENT

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