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Comparison of remote sensing and simulated soil moisture datasets in Mediterranean landscapes

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ABSTRACT

This paper presents the comparison of three global soil moisture products (ASCAT, AMSR and SMOS) versus a land surface model over a region representative of several Mediterranean landscapes located in the Northeast of the Iberian Peninsula. Our approach has been for agricultural and water management applications at the regional and local scale. Despite being a rather small area, we were able to observe different signal behaviours corresponding to major land cover classes in Mediterranean areas i.e.: dryland and irrigated crops, forests and natural vegetation (grass-shrubs). The area also allowed assessing the impact of topography. The first result of the study is that the results are very dependent on the normalizations used to make the data comparable, thus their impact must be carefully analysed. In this study, we applied two different normalisation methods (called ZV35 and ZV) and different moving average windows (1, 10 and 30 days) in order to enhance seasonal effects. Using no smoothing window, ASCAT is the soil moisture product that correlates best with the LSM over all cover classes, whatever the method. Using smoothing window, AMSR-E tends to outperform other soil moisture products with the ZV method. The ZV35 method is not able to identify a small heavily irrigated area. The reason for these different results is that ZV35, tends to eliminate the monthly scale soil moisture memory and therefore becomes more sensitive to precipitation and less sensitive to the monthly evolution of superficial soil moisture. The comparison shows in general good agreement for all soil moisture products with the LSM on the temporal series simulated over flat, non irrigated areas which are not close to the sea. SMOS has difficulties in areas close to the sea and in areas with steep relief and the current version of the L2 Operational Algorithm (V5.51) depicts few values in forested areas. ASCAT, in its turn, shows some limitations over agricultural and natural vegetation where it shows an increase of soil moisture from June to October probably due to increase of penetration depth in dry soil moisture conditions. AMSR-E LPRM shows a clear vegetation cycle over all the land cover classes. From all the remote sensing products, SMOS is the only one able to see irrigation and the only that does not show clear vegetation or roughness effects. In this study, we were able to assess the impact of higher resolution soil moisture products to map irrigated areas.

1. Introduction

Soil moisture is a critical variable in many physical processes related to agriculture, hydrology, meteorology or climatology. This is especially true in the Mediterranean context, where soil moisture is often a limiting factor and thus affects the soil–atmosphere coupling and the characteristics of land processes such as droughts and floods. Unfortunately, this variable is not widely observed in situ, so we lack data on its time evolution and spatial structure. Remote sensing and land-surface modelling have been used to overcome such limitation. These techniques are very useful because they provide comprehensive data over large surfaces. However, both have limitations.

In the remote sensing domain, soil moisture (SM) has been a challenging variable. Microwave brightness temperature is sensitive to soil moisture because water in soils has a large impact on soil dielectric constant. The lower the microwave frequency, the higher the relative sensitivity of brightness temperature to soil moisture and at the same time the lower the sensitive to vegetation and other perturbing factors such as roughness and atmospheric disturbances such as cloud liquid water or integrated water vapour. Therefore L-band microwave radiometry is among the best ways to estimate soil moisture by remote sensing. (Kerr, 2007).

Recent technical developments have allowed the outgrowth of space borne L-band microwave radiometry. Thanks to that, currently two new satellite missions, the Soil Moisture and Ocean Salinity (SMOS) launched November 2nd, 2009 (Kerr et al., 2010) and the Soil Moisture Active Passive (SMAP) launched January, 31st 2015 (Entekhabi et al., 2010) provide global mapping of surface soil moisture based on

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radiometric measurements at L-band (21 cm, 1.4 GHz). Focused on salinity retrieval from radiometric measurements at L-band, Aquarius launched on June 10th 2011 and operational until June 7th, 2015, has also shown to be able to deliver soil moisture products (Bindlish et al., 2015). The global Water Cycle Observation Mission (WCOM) to be launched before 2020 will provide continuity to L-band satellite radiometry measurements (Shi et al., 2014).

On the other hand, algorithm development has also allowed the emergence of global soil moisture datasets from other instruments which were not optimized for soil moisture retrieval. The first available global soil moisture dataset was derived from scatterometer measurements in 2002 (Wagner et al., 2003). Shortly after, with the launch in 2002 of the Advanced Microwave Scanning Radiometer — Earth Observing System (AMSR-E) on-board Aqua another global soil moisture dataset was available. AMSR-E is a multi-channel passive microwave instrument that measures brightness temperatures at five frequencies in the range of 6.9 to 89 GHz (Njoku et al., 2003). Several algorithms to estimate soil moisture from AMSE-E data exist, they commonly use the lower available frequencies (6.9, 10.7, and 18.7 GHz) because of their higher sensitivity to soil moisture.

Although backscatter data from active sensors have potential to monitor soil moisture, there is currently no operational soil moisture product from SAR active microwave. This is notably due to the difficulty to model in time and over extended areas the impact of vegetation cover/structure and surface roughness on the backscatter signal and thus the need for site-specific calibration. Currently, the only active global soil moisture dataset is derived from the backscatter measurements acquired by the Advanced SCATterometer (ASCAT) at C-band. ASCAT was designed to observe wind speed and direction over the oceans but has been shown to be useful to measure large-scale soil moisture (Wagner et al., 2013).

The availability of such a variety of Soil Moisture datasets has awaken the interest of the scientific community and caused an increment in the number of studies comparing their strengths and limitations.

Brocca et al. (2011) compared ASCAT and AMSR-E soil moisture products against in-situ soil moisture measurements across Europe. They found that among the three soil moisture products derived from AMSR-E sensor data, for most sites the highest correlation with observed and modelled data was found using the LPRM algorithm. Considering relative soil moisture values, the ASCAT product outperformed AMSR-E in general. Overall, the reliability of all the satellite soil moisture products was found to decrease with increasing vegetation density.

In Albergel et al. (2012), in situ soil moisture data from more than 200 stations located in Africa, Australia, Europe and the United States were used to determine the reliability of three soil moisture products, one analysis from the ECMWF (European Centre for Medium-Range Weather Forecasts) numerical weather prediction system (SM-DAS-2) and two remotely sensed soil moisture products: ASCAT and SMOS. Evaluation of the times series as well as of the anomaly values, showed good performances of the three products to capture surface soil moisture annual cycle and short term variability with similar correlation values for ASCAT and SMOS.

Wanders et al. (2012) compared surface soil moisture from three different microwave sensors, AMSR-E, SMOS and ASCAT with a stochastic, distributed unsaturated zone model (SWAP) in Spain. The averaged correlation coefficient was 0.71, 0.68 and 0.42 for ASCAT, AMSR-E and SMOS respectively, suggesting that temporal dynamics were best captured by AMSR-E and ASCAT. Root mean square errors for the three sensors were found to be very similar ($\pm 0.05\mathrm{m}^3\ \mathrm{m}^{-3}$). The satellite uncertainty was found spatially correlated and distinct spatial patterns were found over Spain (Wanders et al., 2012).

In a more recent paper, Al-Yaari et al. (2014) compared the SMOS L3 Soil Moisture and AMRS-E LPRM globally with the SM-DAS-2. The results were analysed in terms of biomes and Leaf Area Index (LAI). The results showed that both SMOS and AMSR-E captured well the spatio-temporal variability of SM-DAS-2 for most of the biomes. In terms of correlation values, the SMOSL3 product was found to better capture the SM temporal dynamics in highly vegetated biomes while best results for AMSR-E were obtained over arid and semi-arid biomes. The accuracy of the remotely sensed SM products was shown to be strongly related to LAI. Both SM products correlated well with the SM-DAS-2 product over regions with sparse vegetation. In regions with higher LAI, SMOSL3 showed better correlations with SM-DAS-2. This results are consistent with the expected higher sensitivity to soil moisture and lower to vegetation at lower frequencies.

The limitation of the two first analysis (Brocca et al., 2011; Albergel et al., 2012) is that the comparison is done against in-situ soil moisture and thus the representativity of the land cover analysed is reduced. Furthermore, in-situ point measurements might not be representative of the satellite spatial scales. Specifically, the soil moisture retrieved from AMSR-E (Njoku et al., 2003) and SMOS (Kerr et al., 2010) data have a spatial resolution of about 60 km and 40 km, respectively. Whereas ASCAT provides soil moisture at a nominal spatial resolution of 50 km (Wagner et al., 2013).

The use of Soil Moisture fields from models or reanalysis such as in (Wanders et al., 2012; Al-Yaari et al., 2014) allows to extend the analysis to different biomes and to characterise the different parameters influencing the errors. Wanders et al. (2012) found a influence of the distance to coast (error decreases with increasing distance) and LAI (error increases with increasing LAI) indistinctly of the RS product. In Al-Yaari et al. (2014) a different performance of products was found correlated with LAI. AMSR-E was outperforming SMOS for low LAI values, whereas SMOS was outperforming AMSR-E for high LAI values. The former studies have increased our understanding of the remote sensing soil moisture products, however a deeper analysis of performances as a function of land cover and time periods is still lacking.

Land Surface Models (LSMs) simulate the physical processes at the interface between soil, vegetation and atmosphere. These models are run offline, forced by a gridded dataset of screen-level meteorological variables, or online, coupled to an atmospheric model. LSMs are being extensively used to simulate the continental water cycle at different scales and resolutions. There are several global products based on LSMs (Rodell et al., 2004; Decharme et al., 2012; Balsamo et al., 2012), and there are also many applications at smaller scales, such as continental or national (Cosgrove, 2003; Mitchell, 2004; Chen et al., 2007; Habets et al., 2008; Szczypta et al., 2012; Barbu et al., 2014). The advantage of using offline LSMs is that they avoid the biases of atmospheric models as they are forced by gridded observational datasets. The applications of such systems are wide and range from the study of water resources, the initialization of meteorological models, the study of the continental water cycle and also the interpretation of satellite data, as we do in this paper.

One may assume that, being LSMs physical models, the soil moisture produced by such models is readily usable and comparable to the soil moisture calculated by other models. However, as Koster et al. (2009) point out, one of the limitations of the soil moisture calculated by LSMs is that it is not a real physical variable, it is, in fact, an index of the water content in the soil, which is not readily transferable from model to model.

This makes the comparison with in-situ or remote sensing data difficult. This problem is caused, among other reasons, by the difference in scale between the real point processes that the physical equations of such models describe and the resolution at which these models are applied. Even a resolution of 5 km, which is often considered as high in large scale simulations (national or continental), is very low compared to the scale of point processes. However, Koster et al. (2009) also point out that if the model soil moisture data is normalized (mean and standard deviation), then the behaviour of different models is very close and comparable. Thus, LSMs are useful provided the SM data they produce is adequately normalized.

The Mediterranean region is one of the most sensitive areas to climate change as demonstrated in many studies (Stocker et al., 2013).