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Synergy of SMOS Microwave Radiometer, Thermal data and Vegetation Index for monitoring the water status of forest and natural vegetation

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ABSTRACT.- Soil moisture is the water held in the soil generally within reach of plant roots and is one of the most important land environmental variables, relevant for land surface climatology, hydrology, and ecology. In fact, variations in soil moisture have a strong impact on surface energy balance, regional runoff, and vegetation productivity (potential crop yield). In this framework, the Soil Moisture and Ocean Salinity (SMOS) mission was recently launched to observe soil moisture over the Earth's land surfaces and salinity over the oceans. The baseline SMOS payload is an L-band (1.4 GHz) two dimensional interferometric radiometer that aims at providing global maps of soil moisture with an accuracy better than 0.04 m^3 m^{-3} every 3 days and with a resolution better than 50 Km. SMOS operations make use of the so called 'SMOS L2' processor to retrieve soil moisture and other surface parameters (e.g. vegetation optical thickness and roughness) taking advantage of the dual-polarised multi angular brightness temperatures that this sensor provides. These temperatures, in addition to nominal parameters and physical algorithms, are used to deliver the SMOS level-2 products following the established user requirements. Soil moisture is a very important index to monitor the ecosystem functioning and mass and energy exchanges at the soil- vegetation-atmosphere interface. However it cannot provide by itself an accurate information about the vegetation water status, that depends also on key parameters such as the vegetation root system and soil depth, among others. In this study, improvements in monitoring the vegetation water status consider the use of the synergy between passive microwave and visible/thermal remote sensing data. This work establishes some semi-empirical relationships between both land surface temperature and vegetation index products provided by Moderate Resolution Imaging Spectroradiometer (MODIS) and passive microwave data, in addition to the monitoring of water status using Meteosat Second Generation-Spinning Enhanced Visible and Infra-red Imager (MSG SEVIRI)nd Reanalysis information. While redacting this work, SMOS Level-2 products were still under commissioning phase, therefore results presented here will be improved continuously to establish clear patterns for the synergy between passive microwave and other remote sensing data when SMOS Level-2 products are available for scientific community.

Keywords: Soil Moisture, Land Surface Temperature, SMOS, MODIS, MSG2-SEVIRI, synergy

1. INTRODUCTION

Soil moisture has been widely recognized as one of the most important variable for live development. It is a key parameter in describing water and energy exchanges, which establishes the basic conditions for crop growth and hydrology/climate modeling (Zhang et al., 2007).

Soil moisture is widely refered to as the water content in the root zone (0.00 to 1.0 m depth) and it constitutes an indispensable variable to take into account in environmental studies. Typically, soil moisture has been estimated by conventional point measurements, which are scarce, complex and expensive (Mallick et al., 2009). However, one way to improve the spatial soil moisture measurements is throughout remote sensing techniques which fulfil an important role for generating soil moisture maps at different spatial scales. In this context, the Soil Moisture Ocean Salinity (SMOS) space mission is the first satellite to make specific observation in the L-band (1.4 GHz) and providing global soil moisture maps with an accuracy better than 4%v/v every 3 days with a resolution better than 50 km (Kerr et al., 2001).

This satellite was launched in November 2009 and is currently in the commissioning phase. However, the coarse spatial resolution retrieved by SMOS is a challenge that is being carried out. In fact, in order to improve the spatial resolution of the soil moisture estimated by SMOS, there are some attempts in using downscaling methods and surrogate Optical/Infrared variables such as land surface temperature or vegetation indexes (Merlin et al., 2008; 2009). These techniques which relate optical/IR and microwave frequency enhance the ability of extracting information on soil moisture conditions. A thorough analysis of advantages/drawbacks of these remote sensing techniques is presented in Moran et al. (2004), where the strong relation between soil moisture surface temperature and vegetation index is one of the most important advantages when using TIR emittance.

The aim of this work is to analyze some biophysical interactions between the SMOS soil moisture data and optical/IR data provide by Moderate Resolution Imaging Spectroradiometer (MODIS) using a non-parametric equation basically constituted by the land surface temperature (LST) and vegetation index (NDVI, a definir). Additionally, the relation between the precipitation and soil moisture has also been assessed with Meteosat Second Generation-Spinning Enhanced Visible and Infra-red Imager geostationary data (MSG-SEVIRI) and Reanalysis products.

2. DATA

2.1 Study Area

In this work, two study areas have been used. One is located in eastern Australia, where several SMOS calibration/validation field campaigns were carried out (Panciera et al. 2008). The other area is located in south of Africa where the images provided by the MSG geostationary satellite match with SMOS. Both study areas are shown in figure 1.

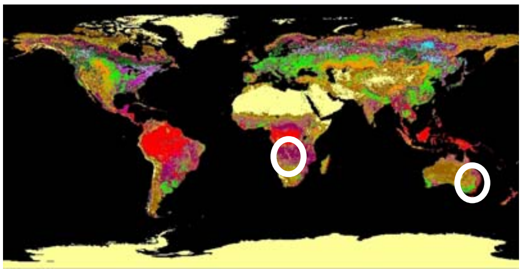

Figure 1.Global land cover map. White circles indicate the study area of Africa and Australia.

2.2 SMOS data

Soil moisture data from SMOS level-2 products were used for the two study area (Africa and Australia). These two products were filtered by the quality flags presented in the products (DQX and RFI). However, at the moment of this work, the SMOS data was finishing the commissioning phase, so the results presented here are not definitive and necessary deserve further analysis.

2.3 MODIS data

Daily MODIS LST (MOD11L2) and NDVI (MOD13C1) products were acquired for the 9th February 2010 over the study area located in the east part of Australia. These were processed using the quality flags images and georeferenced. LST and NDVI were separated for each cover type described in the next section.

2.5 Cover Map

The Global Land Cover 2000 (GLC2000) has been used to link the data obtained from MODIS products and the land cover classification for Australia (Bartholomé & Belward). The cover map presents tree main classes: forest 6%, shrublands 72%, grasslands 13% and bare soil 9%.

2.4 METEOSAT Data

The METEOSAT SEVIRI data were acquired for the 7th July 2010 between 03 and 06 UTC every 15 min. These images were acquired by the Global Change Unit antenna station and were georeferenced using the provided metadata file.

2.5 NCEP-1 data

The National Center of Environmental Prediction (NCEP) and the National Center of Atmospheric Results (NCAR) founded the Reanalysis project which generate several meteorological and climatological variables at global scale (2,5º x 2,5º latitude – longitude) since January 1948 (Kalnay et al., 1996). In this work, the precipitation rate and the soil moisture for 3 March 2010 and 7 March 2010 have been used to compare the synoptic information retrieved by Numerical Prediction Model with the Information retrieved by SEVIRI and SMOS. The NCEP-1 information was processed every 6 hours for the African continent.

3. METHODOLOGY

In this work, LST and NDVI were compared to obtain the wet and dry zones using the universal triangle (Carlson et al. 1994). Then, simple non-linear equations were generated to estimate the soil moisture for each land cover class following equation 1.

$$SM = \sum_{i=0}^{2}\sum_{j=0}^{2} a_{ij} T^{*(i)}\, NDVI^{*(j)} \qquad (1)$$

where *SM* is the soil moisture, *T** and *NDVI** is the modified surface temperature and vegetation index respectively (see Chauhan et al. 2003). This procedure was applied for both Africa and Australia study areas. The obtained soil moisture was directly compared with SMOS soil moisture estimation. It is important to keep in mind that this work was carried out during the SMOS commissioning phase, therefore the obtained results will have to be deeply analyzed when SMOS data are definitive.

On the other hand, SEVIRI data were used to analyse a strong rainfall event. To this end, the NCEP-1 precipitation rate and soil moisture (0 -10 cm) data were used to compare the strong rainfall event with SEVIRI total liquid clouds and soil moisture from SMOS Level-2. The land surface temperature (LST) of each Seviri images was obtained using the algorithm proposed by Sobrino and Romaguera (2004). Then, LST and SEVIRI visible bands were combined with a simplification of the method proposed by Roebling et al (2006) to estimate the total liquid clouds. The obtained results were combined with SMOS and Reanalysis data to analyze the rainfall and the soil moisture during that event.

4. RESULTS

Figure 2 shows the universal Triangle generated by LST and NDVI values over the Australian study area. This figure also shows the low and high level of soil moisture presented in the Australia Study Area. Most pixels present a low content of soil moisture in agreement with the date of the analysis (February-Summer-Dry season) and the land cover types provided by the GLC2000 fo this area (shrublands: 70%). However, the empirical relationship obtained for this zone is non-significant. Despite this fact, the empirical relationship is significant for grasslands and bare soil types, which was expected since the method applied here was established and validated for low NDVI values (Table 1).

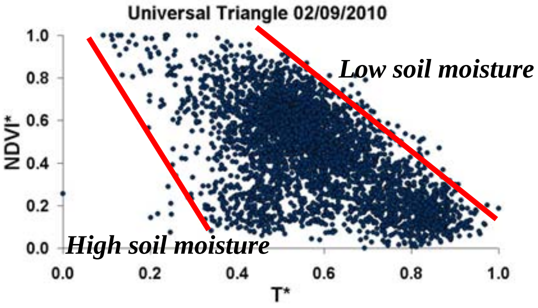

Figure 2. Universal triangle over Australia study area for 9th February 2010.

On the other hand, for the Africa study area, Figure 3a,b shows the precipitation rate and soil moisture retrieved by NCEP-1. It presents the intrusion, at synoptic scale, of high water amounts into the continent, which generates high levels of soil moisture. In coincidence, figure 3c presents a short temporal evolution of the calculated liquid clouds from Seviri in the study area. These results coincide with high soil moisture values in the same region (white rectangle) retrieved by SMOS (figure 3d). The same case was observed for 3rd March 2010. A high rate of convective precipitation and soil moisture is retrieved by NCEP-1 in the south-east part of Africa (Figure 4a,b). Using SEVIRI data (Figure 4c), the liquid clouds are identified in the same area with high level of soil moisture showed in SMOS products (Figure 4d). These results present an illustration to assess the hydrological status of a given region using the synergy between optical, thermal and passive microwave data.

Table I. Retrieved empirical equation based on MODIS and SMOS data. Significant relationships appear in bold.

GLC 2000 Class type	Equation	R2	Number of points
Forest	SM =1.08814 - 0.830718*LST* - 2.29676*NDVI* + 0.0338988*LST*^2 +1.59529*NDVI*2 + 0.821799*NDVI*LST*	0.18	190
Shrublands	SM = 0.41874 - 0.623923*LST* - 0.346135*NDVI* + 0.2513*LST*^2 + 0.422697*NDVI*^2 + 0.120616*LST*NDVI*	0.27	2225
Grasslands	**SM = 0.305739 - 0.328528*T* + 0.109447*NDVI + 0.033086*LST*^2 - 0.0375956*NDVI*2 - 0.265069*NDVI*LST***	**0.78**	**393**
Bare soil	**SM = 1.26109 - 2.8222*LST* - 2.60481*NDVI* + 1.61762*LST*2 + 2.35666*NDVI*2 + 2.88995*NDVI*LST***	**0.84**	**290**

5. GENERAL CONCLUSIONS

The synergy between visible, thermal infrared and passive microwave data presents several advantages to assess meteorological and climate variables. In this work the soil moisture was analyzed to establish empirical equations over several land cover types in Australia, where MODIS data products (NDVI and LST) have been used in addition to soil moisture retrieved by SMOS. On the other hand, SEVIRI geostationary data (visible and thermal infrared data) have been used to retrieve liquid clouds, which properties are correlated with the precipitation rate and soil moisture from NCEP-1 and soil moisture retrieved by SMOS.

As a first step, soil moisture retrieved by passive microwave data like SMOS can be useful to generate more accurate results in the assessment of water status over natural vegetation. This new data can be combined with other data source (visible and thermal infrared) using the synergy presented here. However, the results presented here have to be validated with additional SMOS level-2 products during more observed time and using other study areas with different cover types.

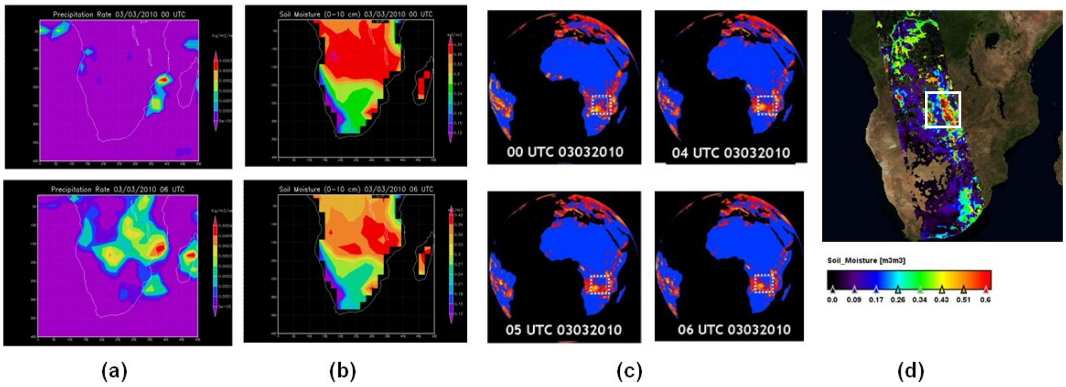

Figure 3. Precipitation rate (a) and Soil Moisture (b) retrieved by NCEP-1, Total liquid clouds estimated from SEVIRI (c) and SMOS Soil Moisture (d) on 3rd March 2010

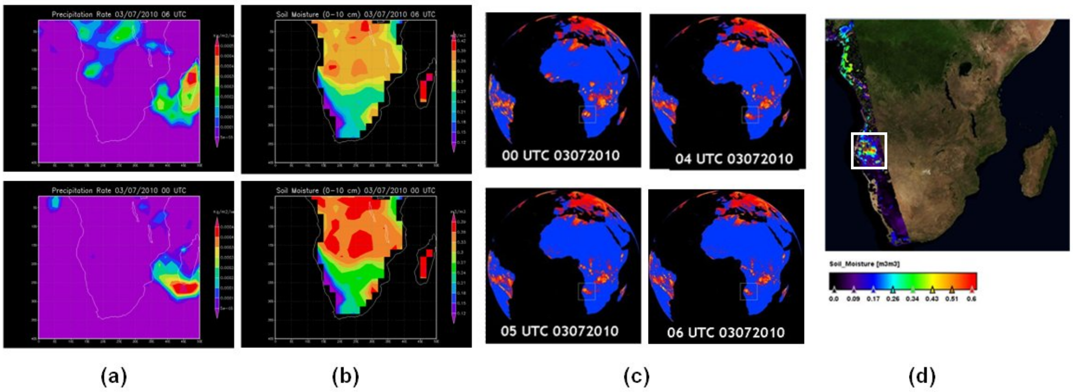

Figure 4. Precipitation rate (a) and Soil Moisture (b) retrieved by NCEP-1, Total liquid clouds estimated from SEVIRI (c) and SMOS Soil Moisture (d) on 7th March 2010

5 ACKNOWLEDGMENTS

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