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Roughness and vegetation parameterizations at L-band for soil moisture retrievals over a vineyard field

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ABSTRACT

The capability of L-band radiometry to monitor surface soil moisture (SM) at global scale has been analyzed in numerous studies, mostly in the framework of the ESA SMOS and NASA SMAP missions. To retrieve SM from L-band radiometric observations, two significant effects have to be accounted for, namely soil roughness and vegetation optical depth. In this study, soil roughness effects on retrieved SM values were evaluated using brightness temperatures acquired by the L-band ELBARA-II radiometer, over a vineyard field at the Valencia Anchor Station (VAS) site during the year 2013. Different combinations of the values of the model parameters used to account for soil roughness effects (H_R, Q_R, N_{RH} and N_{RV}) in the L-MEB model were evaluated. The L-MEB model (L-band Microwave Emission of the Biosphere) is the forward radiative transfer model used in the SMOS soil moisture retrieval algorithm. In this model, H_R parameterizes the intensity of roughness effects, Q_R accounts for polarization effects, and N_{RH} and N_{RV} parameterize the variations of the soil reflectivity as a function of the observation angle, θ, respectively for both H (Horizontal) and V (Vertical) polarizations. These evaluations were made by comparing in-situ measurements of SM (used here as a reference) against SM retrievals derived from tower-based ELBARA-II brightness temperatures mentioned above. The general retrieval approach consists of the inversion of L-MEB. Two specific configurations were tested: the classical 2-Parameter (2-P) retrieval configuration where SM and τ_{NAD} (vegetation optical depth at nadir) are retrieved, and a 3-Parameter (3-P) configuration, accounting for the additional effects of the vineyard vegetation structure.
Using the 2-P configuration, it was found that setting N_{Rp} ($p = H$ or V) equals to -1 provided the best SM estimations in terms of correlation and unbiased Root Mean Square Error (ubRMSE). The assumption $N_{RV} = N_{RH} = -1$ simplifies the L-MEB retrieval, since the two parameters τ_{NAD} and H_R can then be grouped and retrieved as a single parameter (method here defined as the Simplified Retrieval Method (SRP)). The main advantage of the SRP method is that it is not necessary to calibrate H_R before performing the SM retrievals. Using the 3-P configuration, the results improved, with respect to SM retrievals, in terms of correlation and ubRMSE, as the structural characteristics of the vineyards were better accounted for. However, this method still requires the calibration of H_R, a disadvantage for operational applications. Finally, it was found that the use of in-situ roughness measurements to calibrate the roughness model parameters did not provide significant improvements in the SM retrievals as compared to the SRP method.

1. Introduction

Passive microwave radiometry at L-band (1–2 GHz) is one of the most efficient techniques to monitor surface soil moisture (SM) at global scale. Satellites such as ESA SMOS (Soil Moisture and Ocean Salinity) and NASA SMAP (Soil Moisture Active Passive) can provide global maps of soil moisture (Entekhabi, Njoku, et al. 2010; Kerr, Waldteufel, Richaume, et al., 2010; Kerr, Waldteufel, Wigneron, et al., 2010). The sensitivity of brightness temperature (TB) measured at horizontal ($p = H$) and vertical ($p = V$) polarization with respect to SM is due to the fact that soil emissivity in the microwave domain is highly related to the soil dielectric constant which is mainly determined by SM. TB is also affected by other factors such as soil texture and roughness (Jackson et al.,

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1980; Njoku & Entekhabi, 1996; Wigneron, Chanzy, De Rosnay, Rudiger, & Calvet, 2008), vegetation cover and litter (Grant et al., 2007; Jackson et al., 1980; Saleh, Wigneron, De Rosnay, Calvet, & Kerr, 2006), and by soil and vegetation temperatures (Wigneron et al., 2007). Measured TB generally increase with increasing soil roughness, while vegetation attenuates soil emission and adds its own contribution to the upwelling TB measured above the scene.

The effects of soil roughness at L-band have been evaluated in studies based on modeling (Lawrence, Wigneron, Demontoux, Mialon, & Kerr, 2013; Parrens et al., 2014; Ulaby et al., 1982; Schwank, Volksch, et al., 2010), satellite data (Patton & Hornbuckle, 2013), or in-situ data (Escorihuela, Chanzy, Wigneron, & Kerr, 2010; Mialon, Wigneron, De Rosnay, Escorihuela, & Kerr, 2012; Wigneron, Laguerre, & Kerr, 2001). In the SMOS retrieval algorithm, based on the inversion of L-MEB (Wigneron et al., 2007), a simple modeling approach based on four parameters (H_R, Q_R, N_{RH} and N_{RV}) was selected to model the roughness effects (Wang & Choudhury, 1981). This approach was generally found to be simple and accurate (Escorihuela et al., 2007; Mialon et al., 2012; Wang, O'Neill, Jackson, & Engman, 1983; Wigneron, Schmugge, Chanzy, Calvet, & Kerr, 1998; Wigneron et al., 2011).

In SM retrieval studies based on the inversion of L-MEB, the values of the four soil roughness parameters (H_R, Q_R, N_{RH} and N_{RV}) have to be estimated. Some studies have investigated the relationship between the empirical H_R parameter and soil physical parameters, such as the standard deviation σ of surface heights and the autocorrelation length Lc of the surface, based on experimental data (Choudhury, Schmugge, Chang, & Newton, 1979; Wigneron et al., 1998) or modeling approaches (Lawrence et al., 2013). The roughness parameters were calibrated for different types of land surfaces or land uses.

In this paper, optimal values of the four roughness parameters have been evaluated for the Valencia Anchor Station (VAS) region that is a long-term validation site for the SMOS products (Cano et al., 2010; Fernandez-Moran et al., 2014; Schwank, Wigneron, et al., 2012; Wigneron et al., 2012). The area is mainly composed of vineyards (65–70% cover fraction) and other Mediterranean vegetation species (shrubs, pine-, almond- and olive-trees, etc.). The European Space Agency (ESA) selected the VAS site for the installation of one of the three ELBARA-II prototype radiometers (Schwank, Wiesmann, et al., 2010) in September 2009 over a vineyard field that was called MELBEX-III (Mediterranean Ecosystem L-band Characterization Experiment), under the responsibility of the Climatology from Satellites Group of the University of Valencia. ELBARA-II is an automated L-band microwave radiometer system that accurately measures TB at horizontal (p = H) and vertical (p = V) polarizations over a range of observation angles θ (Schwank, Wiesmann, et al., 2010; Schwank et al., 2012).

In the VAS area, the vine phenological cycle extends from April to October and the surface remains under almost bare soil conditions for the rest of the year. Since a large part of the VAS area is dedicated to the production of wine, different agricultural practices are regularly performed along the year aiming at an optimal grape development. These agricultural practices include plowing, vine shoot pruning, tying up long branches to trellis wires, sulfate fertilization and grape harvest in October. Most of these practices, as well as strong rainfall events, usually lead to frequent and significant changes in soil roughness. These changing soil conditions and the opportunity to use long-term observations from ELBARA-II, make the VAS site a fairly adequate place to investigate the impact of changes in soil roughness conditions on the SM estimates retrieved from L-band microwave radiometry.

In this study, we evaluated several combinations of values of the four roughness parameters (H_R, Q_R and N_{Rp}, p = V, H) used to retrieve SM from multi-angular measurements made by ELBARA-II. The SM retrieval approach based on the inversion of L-MEB is also the basis for the SMOS level 2 soil moisture processor used to retrieve simultaneously vegetation optical depth (τ_{NAD}) and SM (Kerr et al., 2012; Wigneron et al., 2007). In a first step, several combinations of values of the roughness parameters were evaluated, by comparing SM retrievals with in-situ SM measurements, considered here as reference. The evaluation was made using all available ELBARA-II observations at 6 am and 6 pm during 2013 (323 days of full data; 42 days missing due to power input failures). In a second step, in-situ measurements were used to calibrate the values of the roughness parameters based on models developed by Lawrence et al. (2013). The evaluation was made over 13 dates during 2013 and the results were compared to those obtained in the first step of the study, using the Simplified Retrieval Method (SRP).

2. Materials

Results shown in this paper are based on measurements made with the ELBARA-II radiometer over the MELBEX-III site during 2013. This site, within the VAS region, is located at the "*Finca El Renegado*" (39° 31′ 18.18″ N, 1° 17′ 29.64″ W), a vineyard field of "Tempranillo" variety. The row spacing is 3 m and the spacing between plants is 2 m. The maximum LAI (Leaf Area Index) is usually reached in August being close to 2.2 $m^2 \cdot m^{-2}$ (Schwank et al., 2012; Wigneron et al., 2012). Several instruments are deployed over the site together with the ELBARA-II L-band radiometer and a number of automatic instruments used to characterize the soil and vegetation conditions. The year 2013 was selected in this study where we could gather a good dataset of SM automatic measurements together with an accurate monitoring of all agricultural practices performed over the vines.

ELBARA-II is a dual polarization L-band microwave radiometer with two measuring channels (1400–1418 MHz and 1409–1427 MHz) attached to a 23.5 dB gain horn antenna with a field of view of $\approx \pm 12°$ at −6 dB sensitivity (Schwank, Wiesmann, et al., 2010). The observed TB_p (p = H, V) used in this study are averages of the brightness temperature values measured in two 11 MHz frequency channels within the protected part (1400–1427 MHz) of the microwave L-band. The radiometer is placed on a 15 m high platform over the vineyard to measure TB_V and TB_H automatically for observation angles in the range of $\theta = 30°$–$150°$ (relative to nadir). The instrument footprint areas at −9 dB antenna sensitivity (corresponding to ±9° around the antenna main direction) range from ≈ 33 m^2 at $\theta = 30°$ to ≈ 800 m^2 at $\theta = 70°$ (Fig. 1b in Schwank et al., 2012). The ELBARA-II system performs automated measurements following a protocol consisting of: (i) sky calibration measurements (every day at 23:55) at $\theta = 150°$, (ii) angular scans (θ = 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°) every 30 min, and (iii) observations at a fixed angle of $\theta = 45°$ every hour at 10, 20, 40 and 50 min past the hour (Schwank et al., 2012). The measured multi-angular TB_p data were filtered out when the presence of radiofrequency interferences (RFI) was suspected. The filtering was made when either: (1) TB_p exceeds a maximum value (temperature of the air in kelvin) or is below a minimum value (set here at 50 K), (2) the brightness temperatures TB_p measured in the two frequency channels differ from more than 0.2 K, or (3) anomalies with the thermal stabilization of the instrument or short burst of RFI (e.g. from radars) were detected by a statistical analysis of the data samples at 800 Hz.

Two Delta-T ML2x soil moisture probes (ThetaProbes) are placed in the MELBEX-III site to estimate SM, 3 m away from the edge of the 30° ELBARA-II footprint. They provide the volumetric soil moisture (m^3 m^{-3}) of the top 0–5 cm soil layer. These probes are installed vertically in the soil and the calibration is based on results obtained by Wigneron et al. (2012) for a large range of SM conditions. One of the ThetaProbes is placed close to a vine stump and the other is in the middle of two rows. Averages of the measurements performed with these two probes were assumed to be representative of the soil moisture conditions in the MELBEX-III field site, and thus considered as the SM reference in this study. A larger number of probes is desirable to better estimate the average soil moisture value in the field. However, this was not feasible due to tractor operations and agricultural practices that regularly damaged the in-situ sensors (at the beginning of the experiment,