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Sensitivity of multi-parameter soil moisture retrievals to incidence angle configuration

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ABSTRACT

This paper focuses on the sensitivity of L-band multi-parameter retrievals across the range of angular measurements available from the SMOS (Soil Moisture and Ocean Salinity) mission. The SMOS core algorithm was used to evaluate two-parameter retrieval scenarios including soil moisture and one of either i) vegetation water content, ii) surface roughness, iii) vegetation temperature, or iv) surface soil temperature. For all pairs a range of parameter value combinations were compiled to run the model in forward mode. Subsequently, the resulting angular brightness temperature simulations with two unknown parameters were compared against the brightness temperature response derived from reference simulations using data from the National Airborne Field Experiment 2005 (NAFE'05) in Australia. This paper showed that the two-parameter retrieval accuracy of soil moisture is strongly affected by the surface moisture conditions, the polarization of the brightness temperature data, and the choice of the secondary ancillary parameter to be retrieved. The synthetic analysis demonstrated a tendency for better retrievals from dual-polarized data at large incidence angles (40–50°). Validation with airborne brightness temperature observations at L-band did not demonstrate such a strong angular dependency, although it confirmed that the simultaneous retrieval of soil moisture and vegetation properties is not preferable as opposed to i) soil moisture and surface roughness or ii) soil moisture and surface soil temperature, especially under dry moisture conditions.

1. Introduction

Passive microwave observations have been proven as one of the most promising techniques for near-surface soil moisture measurement (Jackson, 1993; Njoku & Entekhabi, 1996; Schmugge, O'Neill, & Wang, 1986; Walker & Houser, 2004; Wigneron et al., 2003). The high sensitivity to moisture and the robustness of the sensor signal in response to surface roughness and vegetation canopy effects make brightness temperature measurements in the protected microwave range of 1–2 GHz (L-band) the spectrum window of choice. A range of retrieval algorithms have been developed and tested using data collected from a series of small-scale truck and tower-based experiments, and airborne radiometers to a more limited extent (e.g. de Rosnay et al., 2006; Jackson et al., 1999; Saleh et al., 2004; Schmugge, Wang, & Asrar, 1988; Schmugge, Jackson, Kustas, & Wang, 1992; Wigneron, Calvet, Kerr, Chanzy, & Lopes, 1993; Wigneron, Kerr, Chanzy, & Jin, 1993; Wigneron, Schmugge, Chanzy, Calvet, & Kerr, 1998). These results ultimately contributed to the design of the first spaceborne instrument dedicated to global soil moisture mapping: the Soil Moisture and Ocean Salinity (SMOS) mission (Kerr, Font, Waldteufel, & Berger, 2000).

SMOS was launched by the European Space Agency (ESA) in November 2009 and operates in the 1.400–1.427 GHz L-band (McMullan et al., 2008). The satellite incorporates a novel interferometric synthesized antenna concept, utilizing over 69 small antenna patches distributed along the Y-shaped satellite arms and central hub (Kerr et al., 2010). This innovative satellite design yields multi-incidence angle brightness temperature observations ranging from 0° to 60° across a 900 km swath with an approximately 45 km spatial resolution and a 2–3 day recurrence interval at 6 A.M. and 6 P.M. local time. The sequence of snapshots obtained over the same pixel but at different incidence angles is intended to enhance the soil moisture retrieval to meet the target accuracy of 0.04 $m^3\ m^{-3}$, when the biomass density is lower than 4 kg m^{-2} (Kerr et al., 2001).

The estimation of soil moisture from microwave observations becomes more complex with the presence of a vegetation layer above the surface compared to bare soil conditions. Although it is expected that at around 6 A.M. overpass time, conditions will be such that the vegetation and the soil surface will be close to thermal equilibrium, the additional interaction of the emitted energy with the vegetation canopy still needs to be accounted for. Consequently, a larger set of ancillary input parameters is required to accurately describe the ground

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Table 1
Overview of the L-MEB input parameter values for the two experiment days.

Date	NAFE'05 ground measurements				Ancillary data					
	SM (std) [$m^3\ m^{-3}$]	VWC [$kg\ m^{-2}$]	T_{veg} [K]	T_{surf} [K]	H_R[a] [–]	N_R[b] [–]	b[a] [–]	ω[b] [–]	tt_H[b] [–]	tt_V[b] [–]
09.Nov	0.43 (±0.06)	1.9	309	303	0.8	0	0.08	0	1	8
23.Nov	0.14 (±0.05)	0.7	309	303						

[a] Sourced from Peischl et al. (2012).
[b] Sourced from Wigneron et al. (2007).

state. While much of these ancillary data can be obtained from i) point measurements at monitoring sites, ii) other spaceborne sensors, and iii) data assimilation models, there are issues with spatial and/or temporal discrepancies due to the variety of data sources. Therefore Wigneron, Waldteufel, Chanzy, Calvet, and Kerr (2000) considered the use of dual-polarized microwave data, acquired at multiple incidence angles by the same instrument, as an approach to overcome the need for ancillary data from external sources. They demonstrated the potential for simultaneous retrieval of soil moisture together with ancillary data, described as multi-parameter retrieval. Multi-angle observations also provide a possibility to reduce the impact of noise, such as radio frequency interference as experienced by SMOS (e.g. Camps et al., 2010; Castro, Gutierrez, & Barbosa, 2012; Oliva et al., 2012) by being able to identify RFI sources through angular anomalies.

If compared to the SMOS configuration only a very narrow range of angular observations is available, or if the SMOS angular range is reduced for some reason, then the benefits of multi-angle soil moisture retrievals might be compromised. In this context, it is necessary to assess the multi-parameter retrieval capability under alternate angular ranges and subsets of angles, to see if equivalent retrieval results can be achieved. Since the main parameters of interest beside soil moisture "SM" are: i) the vegetation water content "VWC" (through the vegetation optical depth), ii) the surface roughness conditions "H_R", iii) the surface soil temperature "T_{surf}", and iv) the vegetation temperature "T_{veg}" (in case of non-early morning brightness temperature measurements), these variables will be the focus of this study. Specifically, the questions addressed by this paper include:

1. What range of incidence angles for brightness temperature observations provides optimal multi-parameter results considering a maximum angular range for radiometric measurements of 0–50°?
2. Would a combination of brightness temperature observations from different angular groups yield better results compared to a specified range of incidence angles only?

A variety of land surface conditions are studied, including dry and wet soils under a mature wheat canopy with moderate and high vegetation water contents, to investigate these questions. This study differs from previous work on the sensitivity of multi-angle data measurements in so much that it includes a validation of findings from synthetic experiments using airborne L-band observations acquired at farm-scale resolution, while others have focused solely on ground-based observations (e.g. Calvet et al., 2011; Wigneron et al., 2000, 2004).

2. Radiative transfer model

The radiative transfer model used to simulate the wheat canopy emission at L-band, and to test the multi-parameter retrieval across varying ranges of incidence angles, is one of the core algorithms applied to SMOS data (Kerr et al., 2011, 2012). A detailed description of the L-band Microwave Emission for the Biosphere model (L-MEB) can be found in Wigneron et al. (2007), together with a parameter analysis for crop application and derived values for wheat canopy analysis. The inversion of the model allows the retrieval of soil moisture and ancillary data by minimizing the root mean square error between the simulated and reference brightness temperatures.

The interaction and individual contributions of the soil and vegetation media on the composite brightness temperature (TB) are accounted for in L-MEB using a radiative transfer approach, also called the tau-omega model (Mo, Choudhury, Schmugge, Wang, & Jackson, 1982):

$$TB_{(P,\theta)} = \left(1-\omega_{(P)}\right)\cdot\left(1-\gamma_{(P,\theta)}\right)\cdot\left(1+\gamma_{(P,\theta)}\cdot r_{G(P,\theta)}\right)\cdot T_C + \left(1-r_{G(P,\theta)}\right)\cdot\gamma_{(P,\theta)}\cdot T_G, \quad (1)$$

with P representing the measured polarization (H for horizontal, and V for vertical, respectively), θ the incidence angle, and T_G and T_C corresponding to the effective soil and vegetation temperature [K],

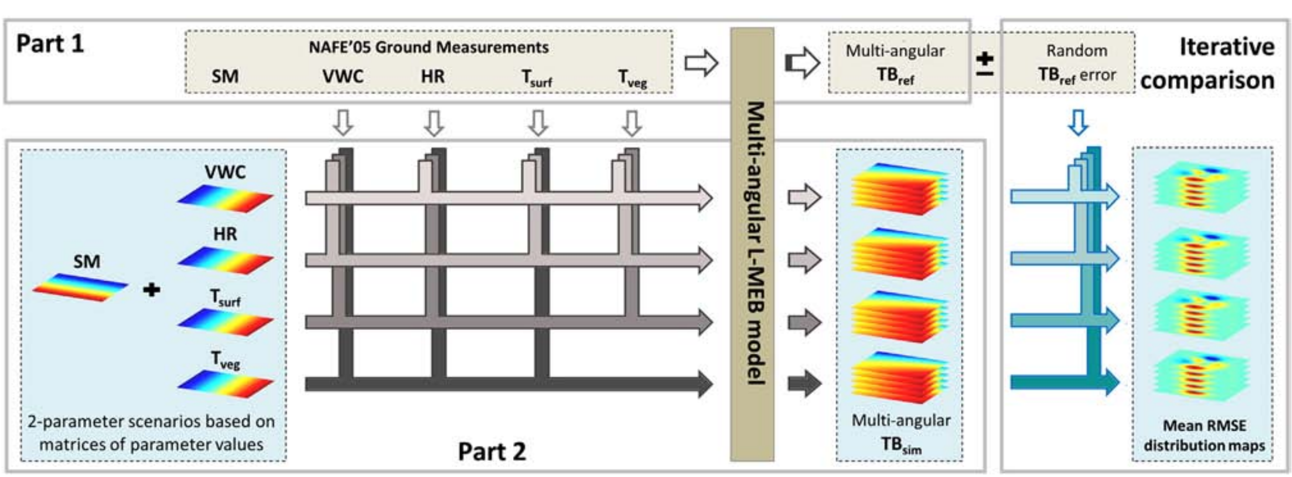

Fig. 1. Schematic of simulating synthetic multi-angular brightness temperature data (TB) using the forward model L-MEB. Part 1 illustrates the simulation of synthetic TB_{ref} based on NAFE'05 ground measurements. Part 2 describes the simulation of synthetic TB_{sim} based on NAFE'05 ground measurements and a matrix of two parameter value combinations depending on the scenario chosen (scenario: SM–VWC; SM–HR; SM–T_{surf}; or SM–T_{veg}). The final iterative comparison considers inclusion of a random TB error of maximum ±2 K for TB_{ref} and calculates the root mean square error between the varying TB_{ref} and TB_{sim} for each iteration step to arrive at a mean TB RMSE map.