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Modeling soil reflectance spectra in the solar domain (400-2500 nm) as a function of moisture content: Improvement of the MARMIT model

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Abstract: An improved version of the MARMIT model is proposed. Wet soil is represented as a dry soil layer surmounted by a layer of a mixture of water and soil particles. © 2021 The Author(s)

1. Introduction

Soil moisture content (SMC) is a key variable of the critical zone, with many applications in agriculture, meteorology, hydrology, defense and planetology. It can be estimated in situ by destructive and spatially limited methods that are not suitable at large scale. Since the 1970s, remote sensing proved to be a reliable tool to assess SMC. The solar domain (400-2500 nm) enables to estimate surface soil moisture since light enters the soil less than a few millimeters. The challenge to quantify soil water content is to link the reflectance spectra to the SMC. Our approach is to develop a physically-based model to simulate soil reflectance for various SMC over the solar domain and to invert it to assess SMC. MARMIT [1] (MultiLayer Radiative transfer Model of soil reflectance) is a two-layer radiative transfer model based on previous work ([2], [3], [4]). It depicts a wet soil as a dry soil topped with a thin layer of pure liquid water. Although it predicts SMC with a relatively good accuracy, the fit between the measured and the modeled reflectance spectra was unsatisfactory, especially in the water absorption bands around 1.4 and 1.9 μm . This paper introduces a new version of the model in which soil particles are included in the water layer that leads to improved performance.

2. The MARMIT model

The MARMIT model [1] is illustrated in Figure 1.

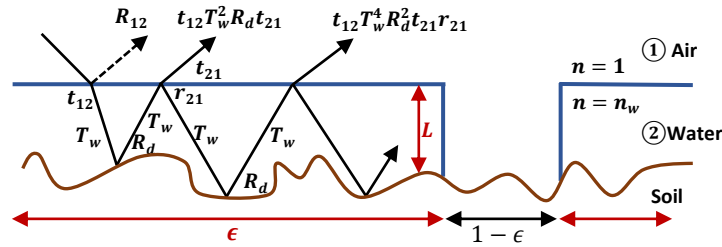


Figure 1: Schematic representation of the MARMIT model.

The reflectance of a wet soil, R_w , is expressed as a function of the reflectance of a dry soil, R_d , as follows:

$$R_w = \frac{t_{12}t_{21}R_dT_w^2}{1 - r_{21}R_dT_w^2} \quad (1)$$

t_{12} is the Fresnel transmission coefficient at the air/water interface; t_{21} and r_{21} are the Fresnel transmission and reflection coefficients at the water/air interface; they are both integrated over a hemisphere as light is supposed to be diffuse inside the water layer. T_w is the transmission of the water layer expressed with the Beer-Lambert law as a function of the thickness of the water layer L (cm). The reflectance of a wet soil is modeled as:

$$R_{mod} = \epsilon R_w + (1 - \epsilon)R_d \quad (2)$$

with ϵ ($0 \leq \epsilon \leq 1$) the area fraction of wet soil. The Python codes and the databases used for the validation of MARMIT are about to be released online.

3. Improvement of the MARMIT model

The new MARMIT model includes soil particles in the water layer, the diameter of which is assumed to be small compared to the wavelengths. It calculates the effective dielectric permittivity of the water and soil particles mixture using the Maxwell Garnett approximation [5, 6] and then infer an effective refractive index that modifies the optical properties of the water layer. To express the effective absorption coefficient of the water and soil particle layer, we assume that the absorption coefficients are additive. Data on soil inherent optical properties are scarce in the literature so, after some attempts, we set the complex refractive index of soil particles to $1.53 + 10^{-3}i$ which is consistent with values measured for minerals [7]. Figure 2 shows reflectances measured for the Luvisol soil of Bab16 database [1] at various moisture levels and reflectances predicted with MARMIT and our new version of MARMIT. The inclusion of soil particles in the water layer enables a better reflectance fit, particularly in water absorption bands.

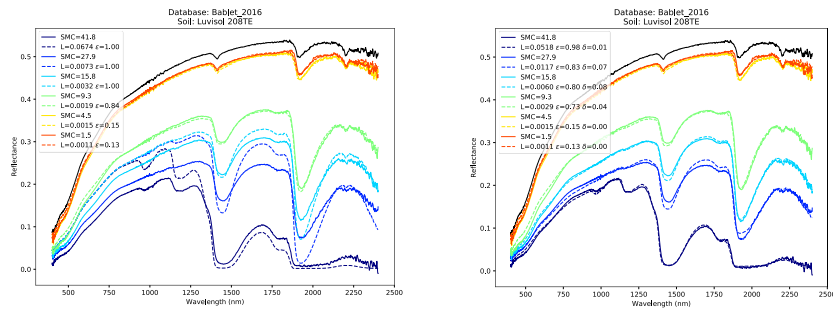


Figure 2: Measured (solid lines) and modeled (dashed lines) reflectances of a silt soil for several moisture levels with (left) MARMIT and (right) the improved version of MARMIT.

Figure 3 shows the root mean square error (RMSE) between the measured and modelled reflectance spectra for the two versions of MARMIT. It is the mean RMSE for 225 soil samples of our database that contain dry and wet soil spectra. The insertion of soil particles in the water layer leads to a significant reduction of the RMSE over the entire spectral range.

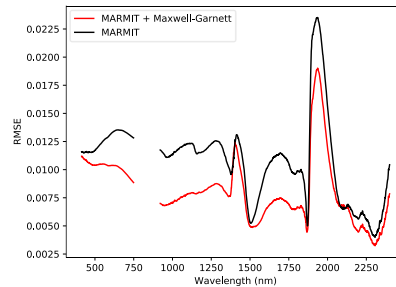


Figure 3: Mean RMSE between the measured and the modeled reflectance for 225 soil samples.

4. References

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