Parameterized Exponentially Correlated Surface Emission Model for L-band Passive Microwave Soil Moisture Retrieval

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Abstract

Soil Moisture and Ocean Salinity (SMOS) satellite observations offer a unique resource for near-surface soil moisture retrievals. It could provide multi-angular microwave emission signals at L-band and thus provide an entree to infer soil moisture and roughness for bare soil. In this study, a simple model for simulating the L-band microwave emission from exponentially correlated surface was developed and implemented into soil moisture retrieval algorithm. The approach was based on the parameterization of an effective roughness parameter in relation with surface roughness variables (root mean square height and correlation length) and incidence angle. The parameterization was developed on a large set of simulations by a physical model of the advanced integral equation model (AIEM) over a wide range of geophysical properties. This methodology was then implemented using SMOSREX observations to estimate both soil roughness and surface soil moisture content. Results indicated the model developed in this paper can be very useful in understanding the effects of surface roughness on microwave emission and soil moisture retrieval algorithms from L-band passive microwave observations.

1. Introduction

Current Soil Moisture Ocean Salinity (SMOS) [1], Aquarius/SAC-D and future Soil Moisture Active Passive (SMAP) missions operate at L-band, and could provide valuable information for mapping soil moisture at a global scale. Accurate modeling of microwave emission from rough soil surface is essential for better estimation of soil moisture from these L-band microwave radiometers. Various models have been developed to account for the roughness effects. Semi-empirical models are commonly used in soil moisture retrieval algorithms thanks to its simplicity and speed of execution. However, microwave emission dependences of polarization, look angle are incompletely characterized compared to theoretical models, and their parameters are site-dependent as only being calibrated on limited field measurements. In addition, the surface correlation function controls angular behaviors of the microwave emission, which cannot be distinguished in semi-empirical models. Therefore, the development of an efficient parameterization of roughness effects described in physically-based model could be very useful for soil moisture retrieval at L-band.

In this study, microwave emission from a rough soil surface is analyzed by characterizing its dependences of polarization and incidence angle based on an analytical solution of Advanced Integral Equation Model (AIEM) [2]. Using the same set of physical surface variables of root mean square (RMS) height and correlation length, modelling results are compared between the Gaussian and exponential correlated surface. A simple model for the exponentially correlated surface was developed on a large set of simulations by AIEM over a wide range of roughness validity. The approach was based on the parameterization of an effective roughness parameter in relation with physical surface variables and incidence angle. The parameterized model was then validated with field measurements obtained from a long term experiment of SMOSREX-2006. Results indicated the model developed in this paper can be very useful in understanding the effects of surface roughness on microwave emission and soil moisture retrieval algorithms from L-band passive microwave observations.

2. Roughness Effects Analysis

In theoretical models, the autocorrelation function (ACF) of the soil profile is needed to fully characterize the surface roughness condition. Often two types of autocorrelation functions are used: the Gaussian and exponential

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function. To explore characteristics of microwave emissivity from rough surfaces under different autocorrelations, AIEM was used to compute the L-band soil emissivity at 40° for soil moisture content of 15% (as in Figure 1). It shows that the non-coherent scattering component of the Gaussian function was greater than that of exponential function. Further simulations indicate the difference is more significant at smaller incidence angles. These results indicate that there are emissivity differences between the Gaussian and exponential correlation functions for the same setting of physical roughness parameter, and in turn would affect the soil moisture retrievals. The reason for this is the Gaussian function describes a smoother surface than the exponential one. The exponential function characterizes the smaller correlations at small lags, with a better description of the micro-roughness in the soil profile than the Gaussian one. Measurement results of SMOSREX show the exponential correlation function is a more realistic choice. Therefore, it is important to explore a roughness parameterization method for exponential correlation surface.

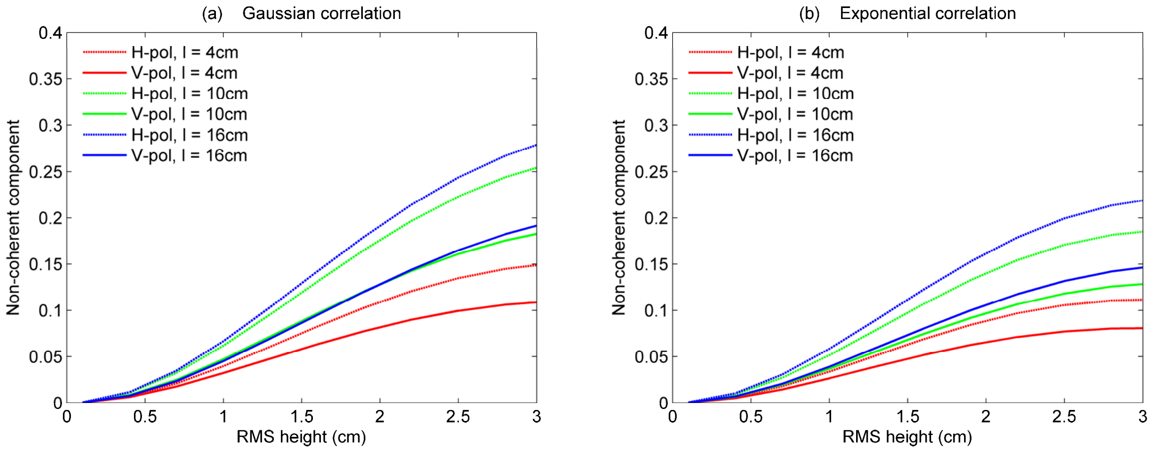

Figure 1. The roughness effects on non-coherent component for different autocorrelation functions

3. Parameterized Rough Soil Surface Emission Model

The most commonly used semi-empirical model is the so-called Q/H model proposed by Wang and Choudhury in 1981. This model computes the rough reflectivity based on three parameters *Q*, *h*, and *N*.

$$R_p^e = [(1-Q)\cdot r_p + Q\cdot r_q]\cdot \exp(-h\cdot \cos^N(\theta)) \tag{1}$$

Based on most of the published studies, the parameter *Q* is generally retrieved lower than 0.2. Especially at L-band, *Q* is commonly considered to be 0. In this study, we use a simple roughness parameter *Hp* to measure the roughness effects under different incidence angles.

$$R_p^e = r_p \cdot H_p \tag{2}$$

Our objective was to develop a simple parameterization of the roughness parameter *Hp*. The AIEM model has been proven to be accurate over a wide range of soil moisture, surface roughness conditions and incidence angles, and was widely applied in microwave remote sensing. With the soil permittivity calculated by the dielectric model, a microwave emissivity/reflectivity simulation database at L-band was generated by the AIEM model to investigate the roughness effects. This database covers a wide range of soil moisture, RMS height, correlation length, and incidence angle. Then the roughness parameter *Hp* was able to be retrieved for each radiometric condition. It is found that the roughness effects (*Hp*) are a function of incidence angle and "geometric roughness". For exponentially correlated surface, the best "geometric roughness" variable was found to be the slope which is defined as:

$$m = s^2 / l \tag{3}$$

By solving the nonlinear data-fitting problems using the least-squares method, the roughness parameter can be expressed as a function of the slope:

$$H_p = A_p \cdot \exp(B_p \cdot m^2 + C_p \cdot m) \tag{4}$$

The coefficients of *Ap*, *Bp*, and *Cp* are only dependent on the incidence angle. This angular dependence of the coefficients can be described well by a quadratic equation:

$$A_p, B_p, C_p = a\cdot\theta^2 + b\cdot\theta + c \tag{5}$$

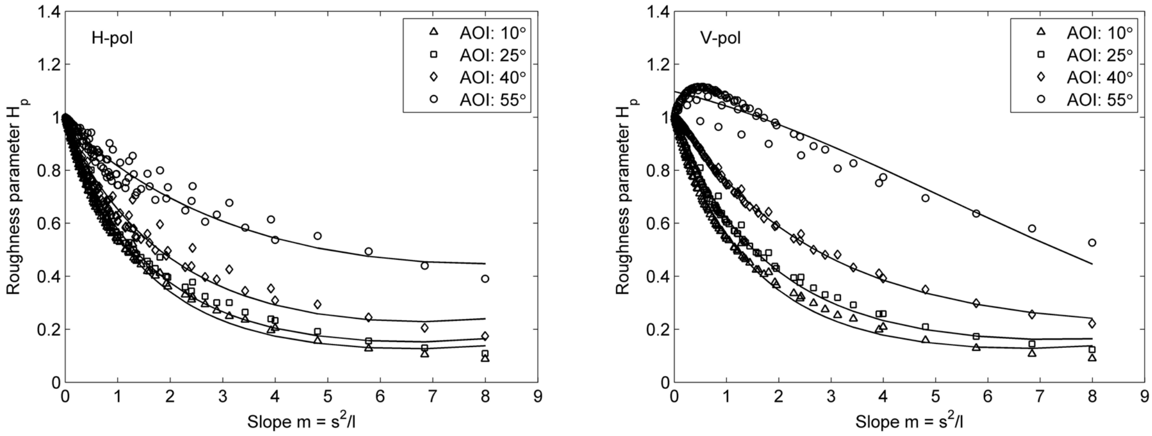

Figure 2. The roughness parameter *Hp* versus the slope parameter at different angles of incidence (AOI)

The relationship between the roughness parameter and the slope was shown in Figure 2. Smaller values of roughness parameter present larger roughness effects on the surface emission. It can be seen that the roughness parameter might decrease with the slope parameter increasing, and increase with incidence angle increasing. For most cases, the roughness parameter is less than 1. It means the roughness would actually reduce the reflectivity or increase the emission in comparison with that from a flat surface. The effects of roughness on V polarization would change in both magnitude and direction at big incidence angles. Especially for the V polarization at 55°, the roughness parameter may be bigger than 1.

4. Comparison and Validation

In this study, the roughness effects were simply parameterized in relation with a defined slope parameter m and incidence angle. To evaluate the accuracy performance, simulation results by this simple parameterized model were compared with the original AIEM outputs in Figure 3. The parameterized model well reproduced the AIEM model results at both H and V polarizations. There was a good linear relationship between parameterization results and original outputs. For H polarization, the accuracy basically decreased as the incidence angle increased, with the largest RMS error of 0.019 at 55°. For V polarization, it has the best accuracy around 0.003 at 35°. These results indicate that this parameterized model can be used in place of the AIEM model in the L-band soil emission predictions over a wide range of incidence angles, soil moisture and surface roughness conditions.

The parameterized model was then analyzed and validated based on a unique database acquired during a long term (Oct. 2005 - May. 2007) experiment of SMOSREX. The L-band brightness temperature was observed by LEWIS (L-band radiometer for Estimating Water in Soil). Surface roughness was measured by means of a two meter long needle board. The performance of other different parameterizations of roughness effects will also be evaluated. Further analysis is undergoing. This work will help in the development of L-band passive soil moisture algorithm.

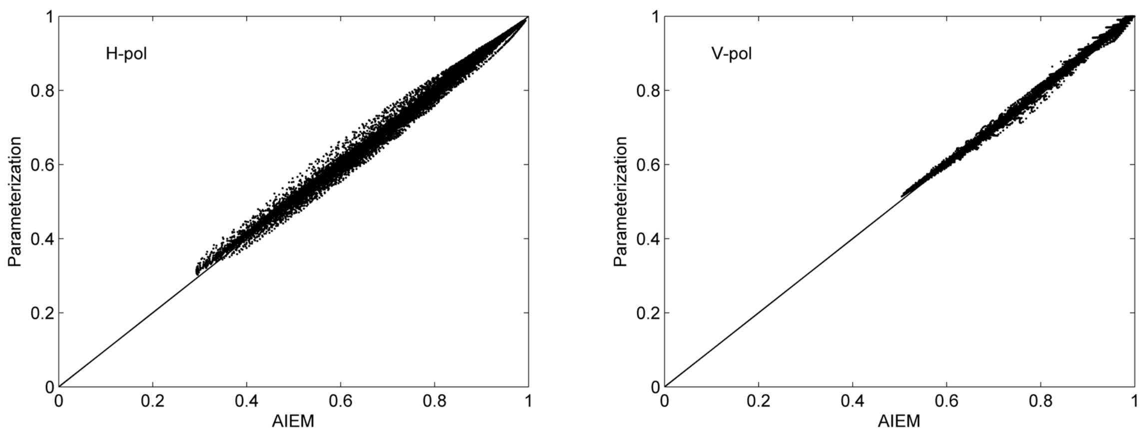

Figure 3. A comparison of the parameterized model with the AIEM model

5. Acknowledgments

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6. References

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