IMPROVEMENT OF BARE SURFACE SOIL MOISTURE ESTIMATION WITH L-BAND MULTI-POLARIZATION RADAR

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Soil moisture is a key parameter in numerous environmental studies, including hydrology, meteorology, and agriculture. It plays an important role in the interactions between the land surface and the atmosphere, as well as the partitioning of precipitation into runoff and ground water storage. Therefore, the spatial and temporal dynamics of soil moisture are important parameters for various processes in the soil-vegetation-atmosphere-interface. The Soil Moisture Active and Passive Mission (SMAP) with both Active/Passive L-band instruments will be launched by NASA in 2013 for global mapping of soil moisture and freeze/thaw status. It will provide the first quick repeat (3-days) capability of the multi-polarization (VV, HH, and HV) measurements with the constant incidence angle and the moderate resolution (1-3 km).

During past years, investigations have demonstrated the capability of active microwave instruments on soil moisture mapping. The sensitivity of this response to the soil moisture and surface roughness has been extensively studied over the past years. To retrieve the soil moisture and surface roughness, some empirical formulas were developed based on the field measurements (Oh et al., 1992, 1994, 2002 and Dubois et al., 1995). The empirical models developed from a limited number of observations might have site-specific problem due to the great variations of the surface roughness properties. Indeed, some inconsistencies between the measurements and empirical formula have been reported (Zribi et al., 1997). The other inversion method was based on the theoretical IEM model but with a fixed correlation function (Shi et al., 1997). It is well known that radar backscattering is controlled by surface dielectric and roughness properties. The later is described by the surface height probability distribution function and surface correlation function (Ogilvy, 1991). The height probability distribution function of random rough surfaces is usually assumed as Gaussian function. The commonly used surface correlation functions are either Gaussian or exponential correlation functions. They represent two extreme cases: the purely single scale random rough surfaces and the multi-scale random rough surfaces. However, the actual correlation functions from field measurements are very complicated and often range between them. Some of field measurements have shown that the correlation functions of natural soil surfaces are close to the exponential for the smooth surfaces and Gaussian for the very rough surfaces (Oh et al., 1992). The others showed that the correlation functions of natural soils usually vary between Gaussian and exponential functions only for lag distances close to the origin. Away from the origin, the experimental trends are extremely variable. In particular, values of below zero for the experimental correlation functions have been often observed. How to reduce the effects of the surface correlation function has become one of the major problems in soil moisture retrieval algorithm development. This study investigates the techniques to estimate surface soil moisture of bare surfaces under SMAP radar sensor configuration: L-band (1.26 GHz), multi-polarization (VV, HH, and HV), and 40° incidence radar measurements.

We first established a model simulated data-base using the AIEM model (Wu, et al., 2001) with the random rough surface assumption to simulate the wide range of soil moisture and roughness conditions for co-polarized signals and the Oh's semi-empirical model to the depolarization factor VH/VV of the surface backscattering, then, the cross-polarized signals can be obtained using AIEM simulated VV polarization signals. Table 1 summarizes the surface parameters that used to generate the simulated data-base.

Parameters	Minimum	Maximum	Interval
Surface rms. height	0.5 cm	3.0 cm	0.25 cm
Correlation length	2.5 cm	35 cm	2.5 cm
Soil moisture	2.5%	45%	2.5%
Correlation function	Gaussian	1.5 power	Exponential

Table. 1 Surface parameters used to generate the data-base for algorithm development.

We describe a simple backscattering model that consists of the two functions: a dielectric function and a roughness function

$$\sigma_{pq}^{s} = Sr_{pq} \cdot R_{pq} \qquad (1)$$

Sr_{pq} is the roughness parameter that depending on the polarization, incidence angle, surface RMS height, correlation length, and the correlation function form. It represents an overall effect of the surface roughness. R_{pq} represents the surface reflectivity and can be written as

$$R_{pq} = \begin{cases} |\alpha_{vv}|^2 & \text{for VV} \\ |\alpha_{hh}|^2 & \text{for HH} \\ |\alpha_{hh}|^2 \cdot \Gamma^0 & \text{for VH} \end{cases} \qquad (2)$$

where $|\alpha_{pp}|^2$ is the polarization magnitude from the Small Perturbation Model. The selection of $|\alpha_{pp}|^2$ is very reasonable since we consider L-band in this study only. Γ^0 is the reflectivity for the flat surface at normal incidence.

Due to the radar cross-polarization measurements are extreme sensitive to the present of vegetation cover, our focus in this study is only for the co-polarization measurements. Through analyses of the model simulated data-base, we developed a technique to estimate surface soil moisture under SMAP radar sensor configuration using the co-polarization measurements. In considering (1) and (2), we can see that the surface reflectivity functions at the different polarizations are well described by the surface dielectric properties and radar incident angle. They do not vary with the different surface correlation functions. In the algorithm development, the most difficult problem or the uncertainty that reduces the accuracy on soil moisture estimation is how to describe the relationship between the surface roughness parameters Sr_{pq} at different polarizations in order to reduce the number of unknowns. For instance, if Sr_{vv} and Sr_{hh} in (1) were highly correlated and could be well described, they could be considered as only one unknown for the surface roughness parameter. However, if their correlations were rather poorly, then, they had to be considered as two unknowns. Unfortunately, the surface roughness parameters Sr_{pq} in (1) are affected by not only surface rms height and correlation length but also the form of the surface correlation functions. Therefore, we first developed a technique to estimate the surface roughness index parameter. This can be done based on the relationship between R_{vv} and R_{hh}, from which the dielectric property effect on radar measurements can be cancelled out by using (1) and (2). As expected, these surface roughness index parameters are found to vary greatly for the same surface rms height and correlation length when with the different correlation functions. Through analyses, however, we find that the relative differences between Sr_{vv} and Sr_{hh} have only the limited affect by the correlation functions and can be estimated from the surface roughness index parameters. In this way, the relationship between Sr_{vv} and Sr_{hh} can be described with the certain level of the accuracy. This significant finding makes it possible to develop a soil moisture retrieval algorithm for using the dual co-polarization measurements from SMAP. We will demonstrate this algorithm development in details and its validation with the field experimental data.