APPLICATION OF IEM MODEL ON SOIL MOISTURE AND SURFACE ROUGHNESS ESTIMATION

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ABSTRACT

Monitoring spatial and temporal changes of soil moisture are of important to hydrology, meteorology, and agriculture. This paper reports a result on study of using L-band SAR imagery to estimate soil moisture and surface roughness for bare fields. Due to limitations of the Small Perturbation Model, it is difficult to apply this model on estimation of soil moisture and surface roughness directly. In this study, we show a simplified model derived from the Integral Equation Model for estimation of soil moisture and surface roughness. We show a test of this model using JPL L-band AIRSAR data.

INTRODUCTION

Estimates of soil moisture are of great importance in numerous environmental studies, including hydrology, meteorology, and agriculture. In spite of its importance, soil moisture data is not generally used in resource monitoring or prediction because they are difficult and costly to measure on a routine basis over large areas.

Our previous work (Shi, 1992) indicated that the ratio of the co-polarization signals could be used for soil moisture retrieval at longer wavelengths (L-band) and at larger incidence angles (> 40°). The algorithm to infer soil moisture from imaging radar data was based on a first-order surface scattering model - the Small Perturbation model. This model predicts that the co-polarization ratio is sensitive to soil moisture at large incidence angles but not to surface roughness. However, due to the surface roughness parameters of most of natural surface are outside the range of the valid conditions for the Small Perturbation and Geometric Optical models, application of these surface scattering models are greatly limited to certain types of the surface roughness conditions. This results in an underestimation of soil moisture when the first-order Small Perturbation model was applied to imaging radar data.

The recently developed Integral Equation Model (IEM) (Fung, 1992) allows a much wider range of the surface roughness conditions, making it possible to estimate soil moisture using IEM model. However, it does not allow to apply this model directly to infer geophysical parameters because of the complicity of this model and the limited independent observations provided by SAR measurements.

Washita '92 was a cooperative experiment between NASA, USDA, several other government agencies and universities with the objective of testing the usefulness of remotely sensed data in hydrologic modeling. During the experiment, a time series of spatially distributed hydrologic data, focusing on soil moisture and evaporative fluxes, using both conventional and remotely sensed methods, were collected over the Little Washita Watershed and a few immediately surrounding areas in Chickasha, OK. Data collection was conducted during the period of June 10 through June 18, 1992. The observations followed a period of very heavy rains over several weeks that ended on June 9 provided saturated soil conditions with standing water at the beginning of the experiment. No rainfall occurred during the experimental period thus allowing the observation of drying conditions. NASA provided support for two aircraft; the

C-130 and the DC-8. The DC-8 flew the three frequency synthetic aperture radar which provided data for this analysis. Figure 1 shows two L-band VV/HH ratio images, where the brightness is proportional to soil moisture at a given incidence angle and inversely related to the surface roughness parameter, taken on June 10 and 18, 1992 of the study site - the Little Washita Watershed.

This study shows our continue efforts on developing and testing the algorithm for retrieval soil moisture and roughness parameters using L-band JPL AIRSAR data. We show (1) a simplified surface backscattering model particularly derived for soil moisture conditions with a random rough surface from the numerical simulations by IEM model, and (2) soil moisture retrieval model test and comparison with ground measurements using L-band AIRSAR data.

INTEGRAL EQUATION MODEL SIMPLICATION

The surface backscattering is a function of the permittivity of soil and the roughness of the air-soil interface which is described by the auto-correlation function of random surface height, the standard deviation of the surface height, and the correlation length. Due to the surface roughness parameters of most of natural surface are outside the range of the valid conditions of the tradition surface scattering models, such as the Small Perturbation and Geometric Optical models, application of these surface scattering models are greatly limited to certain types of the surface roughness conditions. The recently developed Integral Equation Model (IEM) (Fung, 1992) allows a much wider range of the surface roughness conditions.

Due to complicity of IEM model and the limited number of independent observations from the polarimetric SAR, we need to minimize or combine these factors in order to separate the effects of the surface roughness and the dielectric constant of soil. As shown by Fung (1992), when the random surface height s is small, I_{pp}^{n} can be approximated to α_{pp} which reflectivity function of the Small Perturbation Model. This makes it possible to simplify IEM model for a relative smooth surface. Using IEM model, we simulated the surface backscattering coefficients of σ^{vv}, σ^{hh}, and σ_{s}^{vvhh*} at L-band for the most common soil moisture and surface roughness conditions. The simulated backscattering coefficients cover the ranges for soil moisture from 5 percent to 50 percent by volume at interval 5 percent, for the incidence angle from 20° to 70° at interval 5°, for the standard deviation of random surface height from 0.2 cm to 3.0 cm at interval 0.2 cm, and for the surface correlation length 2.5 cm to 25 cm at interval 2.5 cm. The total simulated backscattering coefficients is 23,475 for different combinations of incidence angle, soil moisture and surface roughness parameters.

Through statistical analysis, we found a simplified form for the backscattering coefficients

$$\sigma_{pp} = |\alpha_{pp}|^{2}\left[\frac{Sr}{(a_{pp}(\theta_i) + b_{pp}(\theta_i)Sr)}\right] \tag{1}$$

and the ratio of σ_{hh} to σ_{vv}

$$\frac{\sigma_{hh}}{\sigma_{vv}} = \frac{|\alpha_{hh}|^{2}}{|\alpha_{vv}|^{2}}exp[a_r(\theta_i) + ks(b_r(\theta_i) + c_r(\theta_i)W)] \tag{2}$$

where pp represents polarization. Sr, which is $Sr = (ks)^{2}W$. W is the Fourier transform of the power spectrum of the surface correlation function. a_{pp}, b_{pp}, a_r, b_r, and c_r are the coefficients only depending only on the incidence angle and polarization.

As shown in Figure 2 for σ_{vv} and $\frac{\sigma_{hh}}{\sigma_{vv}}$, the simplified model agrees well with the IEM model for the simulated conditions. For VV polarization, the maximum absolute error between the IEM model and the simplified model is 1.2 dB and the absolute error within 0.23 dB can be obtained with 95 percent confidance interval. For the ratio, the maximum absolute error is 0.89 dB and 0.17 dB for 95 percent confidance interval.

Notice that there are three unknowns in the IEM model: the dielectric constant, random surface height, and correlation length. The simplified model in Equation (1), has only two unknowns the dielectric constant through the reflectivity $|\alpha_{pp}(\theta, \epsilon)|$ and the surface roughness parameter Sr. When we use two polarization measurements, both the dielectric constant ϵ and surface roughness Sr can be solved simultaneously. The task is to select the best pair of the simplified backscattering model for different polarizations. We have evaluated all pairs of σ_{vv}, σ_{hh}, and σ_{vvhh} and their linear combinations. We found that the best pair is σ_{vv} and σ_{vvhh}. Using two of Equations of (1) for σ_{vv} and σ_{vvhh}, we found the relationship:

$$\frac{|\alpha_{vv}|^2}{\sigma_{vv}} = a_{vx}(\theta_i)\frac{|\alpha_{vvhh}|^2}{\sigma_{vvhh}} + b_{vx}(\theta_i) \tag{3}$$

Using Equation (3), we can infer soil moisture directly by varying the dielectric constant through $|\alpha_{vv}|^2$ and $|\alpha_{vvhh}|$. The $a_{vx}(\theta_i)$ and $b_{vx}(\theta_i)$ are coefficients pre-determined from statistical analysis. Then, the surface roughness parameters ks and W can be found by using Equations (1) and (2).

ESTIMATE SOIL MOISTURE USING AIRSAR

To perform the algorithm for measuring soil moisture and surface roughness parameter the stokes matrix was determined by the mean value within a 3 × 3 window in order to reduce the effect of image speckle. In addition to the model simplification, image speckle, antenna thermal noise and the calibration error will also decrease the measurement accuracy. We expect that the measurement of soil moisture and surface roughness parameter can not be done for some pixels and that some degree of uncertainty exists in the estimated soil moisture surface roughness parameter. In post-processing, an average value from surround pixels within a 5 × 5 window was applied to reduce the uncertainties.

Figure 3 on top and bottom show three images of the inferred soil moisture, ks, and W from AIRSAR data-take on June 10, and 18, 1992, respectively. The image brightness is proportion to the soil moisture, ks, and W. The black regions in Figure 3 are the SAR measurements outside surface scattering model predictions, such as vegetation covered fields. The field measurements indicated that there was a significant drop of soil moisture from 28.7 the inferred soil moisture from SAR measurements. Figure 3 on middle and right show the images of the inferred surface roughness parameters: ks and W. They are almost constant for the bare fields except the vegetated fields. Those vegetations may cause significant scattering contribution, especially at large incidence angle, which affects both the backscattering magnitudes and the difference between two polarizations. As a result it will under-estimate soil moisture and over-estimate surface roughness parameters.

REFERENCES

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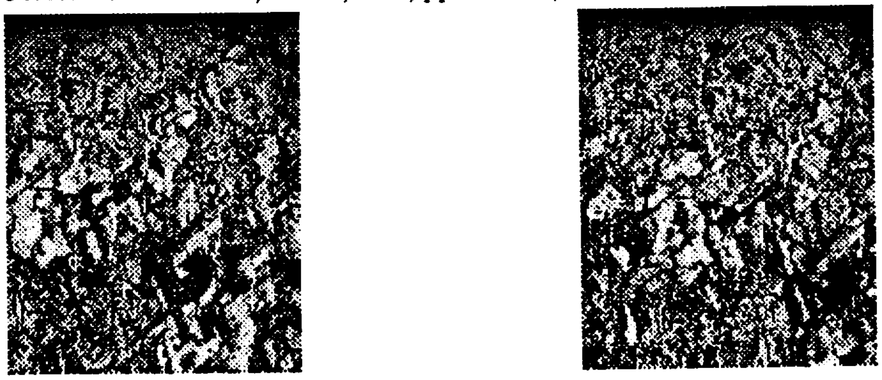

Figure 1. *L-band VV/HH ratio images on June 10 (left) and 18 (right) of study site.*

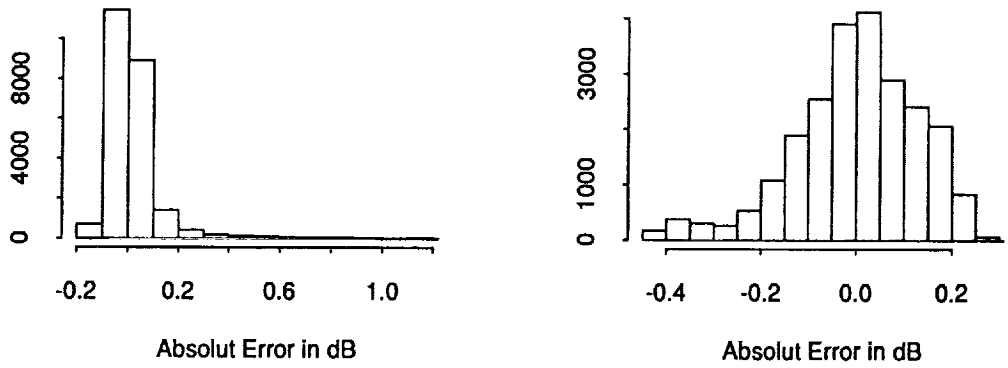

Figure 2. *Comparison the absolute error of the Simplified Model with Integral Equation Model for backscattering coefficients VV on left and HH/VV on right*

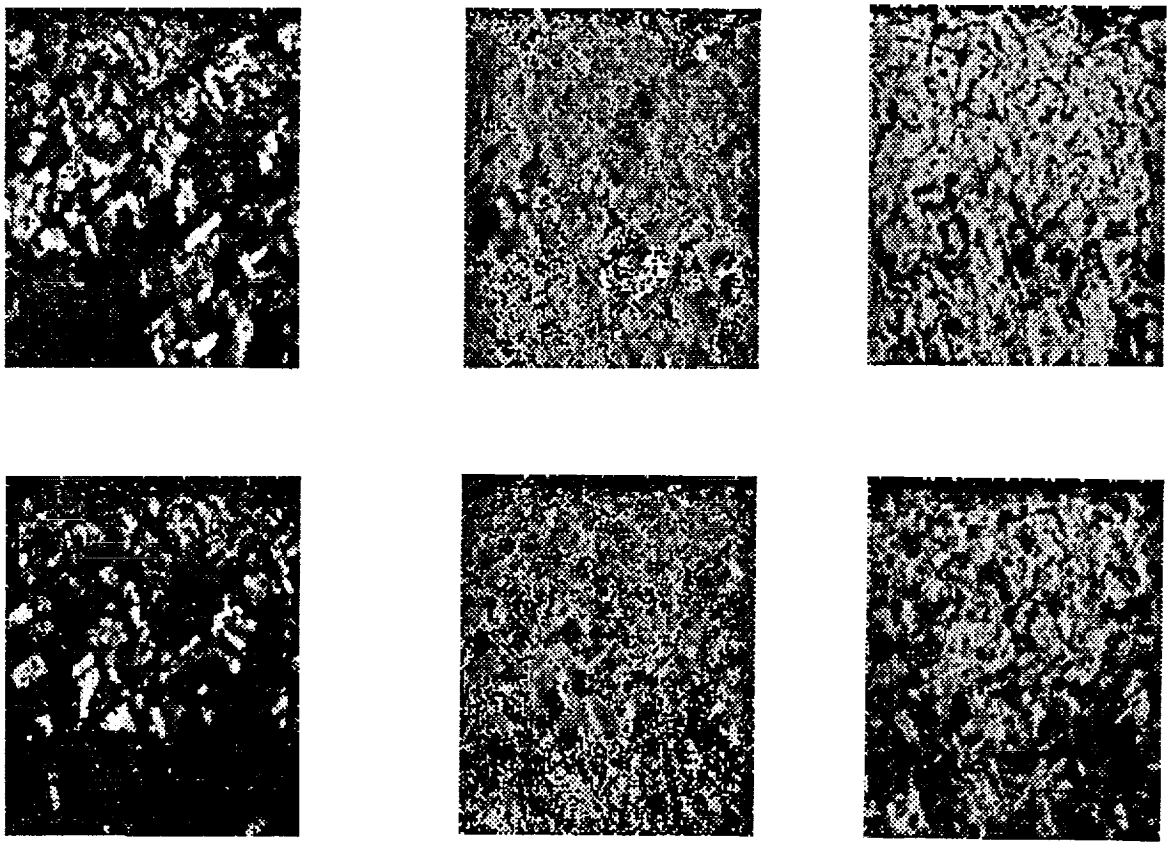

Figure 3 *L-band SAR derived soil moisture and surface roughness parameter maps.*