N94-16755

EVALUATION OF POLARIMETRIC SAR PARAMETERS FOR SOIL MOISTURE RETRIEVAL

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This paper reports on results of ongoing efforts to develop an algorithm for soil moisture retrieval from SAR imagery. Estimates of soil moisture are of great importance in numerous environmental studies, including hydrology, meteorology, and agriculture. Previous studies [1] using extensive scatterometer measurements have established the optimum parameters for moisture retrieval as C-band HH radar operating at incidence angles between 10° to 15°. However, these parameters have not been tested or verified with imaging radar systems. The results from different investigators have shown considerable variability in the relationship between soil moisture and radar backscattering. This variability suggests that those algorithms are site-specific. Furthermore, the small incidence angle requirement limits the spatial application, especially for airborne radar systems.

The imaging radar polarimeter permits measurement of the full polarization signature of every resolution element in an image. The radar polarization signature of an object permits a more accurate description of the object of interest than single-polarization measurements [2]. Thus, the solution for geometric shape and dielectric constant of an object is less ambiguous, making the development of a quantitative algorithm for soil moisture retrieval from Synthetic Aperture Radar (SAR) data possible. Our previous work [3] indicated that the ratio of the co-polarization signals, that is, the ratio of σ^{hh} to σ^{vv}, 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. This model predicts that the co-polarization ratio is sensitive to soil moisture at large incidence angles but not to surface roughness. However, the polarization signal ratio measurements are sensitive to the radar system noise and the other scattering contributions such as the multi-surface and volume scattering even if these effects only contribute a small portion of the total signal in the measurements. These factors result in an under-estimation of soil moisture when the first-order surface scattering algorithm was applied to imaging radar data.

To address these problems, JPL AIRSAR data, in May 1988 and in September 1989 acquired over an agricultural area near Fresno, California, were used to test the algorithm. We evaluated the effects of the radar system noise, the multi-surface scattering [4] and the volume scattering from soil [5] on the co-polarization ratio measurements.

Assuming the noise power to be the same in all channels, the effect of system noise on the ratio measurement of σ^{vv}/σ^{hh} can be expressed as

$$\frac{\sigma^{vv} + noise}{\sigma^{hh} + noise} >= \frac{\sigma^{vv}}{\sigma^{hh}} \tag{1}$$

for all values under the condition of $\sigma^{hh} < \sigma^{vv}$. This results in an under-estimation of the soil moisture especially at larger incidence angle range because the signal to noise ratio typically decreases as incidence angle increases. Based on the assumption that the noise power in the two co-polarized channels is typically of the same magnitude, the amount of noise in all channels can be estimated. This estimated noise can be then used to adjust the observed measurement before inferring soil moisture. We will show the principle and comparison of the estimated with the measured system noise power.

The surface scattering models assume that the scattering medium is a homogeneous dielectric half-space. In practice, natural soil is not a perfectly homogeneous dielectric medium. Instead, it is a mixture of soil particles, air pockets, and liquid water. This results in dielectric discontinuities inside the soil. Because soil is a densely packed medium, the effects of these discontinuities will be reduced for longer wavelengths, especially when the distance between scatterers is much smaller than the wavelength. The result is that the volume scattering of soil contributes only a small portion of the observed signals at longer wavelengths and that the dominant scattering source is the surface backscattering at the air-soil interface. In evaluating the magnitude of each co-polarization signal, the surface scattering can be used to explain the general relations between the backscattering measurements and soil physical properties. However, in attempting to relate the polarization ratio or difference to the physical properties of soils, the volume scattering contribution becomes significant even if it only contributes a small portion in the observed backscattering returns. This effect is also expected when using long-wavelength sensors because of deeper penetration. To overcome the volume scattering effect on estimation of soil moisture, we have developed an algorithm which is based on the first-order scattering model considering both the surface and volume scattering contributions [5].

Figure (A) shows an image of the inferred soil moisture map of the study sites from L-band SAR data. This map was produced using an first-order surface scattering model only. The soil moisture map shown in (B) was derived by the algorithm which includes both surface and volume scattering of soil. The black regions are vegetation covered fields. When applying the first-order surface scattering algorithm, only about 20 to 30 percent pixels were within the possible physical conditions predicted by the first-order surface scattering model. As shown in Figure (A), there are many pixels with missing values even after post-processing. It is especially evident at large incidence angles. However, applying the algorithm with both surface and volume scattering considerations, about 80 percent of the pixels were within the physical limits. During the SAR flights, the volumetric soil moisture for the sampled dry fields varied between 3 and 10 percent. Most bare fields were dry because none of them had been irrigated for at least several weeks. The inferred soil moisture from SAR data agrees well with the field measurements and value ranges from 2 to 14 percent were inferred.

To evaluate the polarimetric SAR parameters for retrieval of bare soil moisture, we examined (1) the applicability of the first-order surface scattering model through the measurements of the depolarization factor at P-, L-, and C-band from bare fields, and (2) all ratios of the co-polarized signals and their linear combinations through the model predictions.

The measurements of the depolarization factor at C-band indicate a significant multi-scattering involved in the C-band measurements, but not at L- and P-band. When the surface is relatively rough, the higher-order surface scattering decreases the difference between the co-polarization signals. This also causes an underestimation of the soil moisture if we apply the first-order inversion algorithm. When second-order terms are added in the scattering calculations [2], the co-polarization ratio measurements become sensitive to roughness differences, but this sensitivity is reduced at larger incidence angles and for smoother surfaces.

First-order surface backscattering models predict that the ratio of the backscattering coefficients of the co-polarizations is sensitive to soil moisture and insensitive to surface roughness. Similarly, the ratios of the linear combinations from the co-polarized returns have the same properties. The task is to select the measurements which maximize the sensitivity to soil moisture. Through the model simulations, we found that in all possible co-polarization ratios, σ^{vv}/σ^{hh} and $\sigma^{hh}/(\sigma^{vv} - \sigma^{hh})$ provide the greatest sensitivity to soil moisture at larger incidence angles.

As discussed above, the polarimetric SAR parameters for retrieval of bare soil moisture are likely to be L-band, the co-polarization ratios of σ^{vv}/σ^{hh} and $\sigma^{hh}/(\sigma^{vv}$-$\sigma^{hh})$, and incidence angles above 40°.

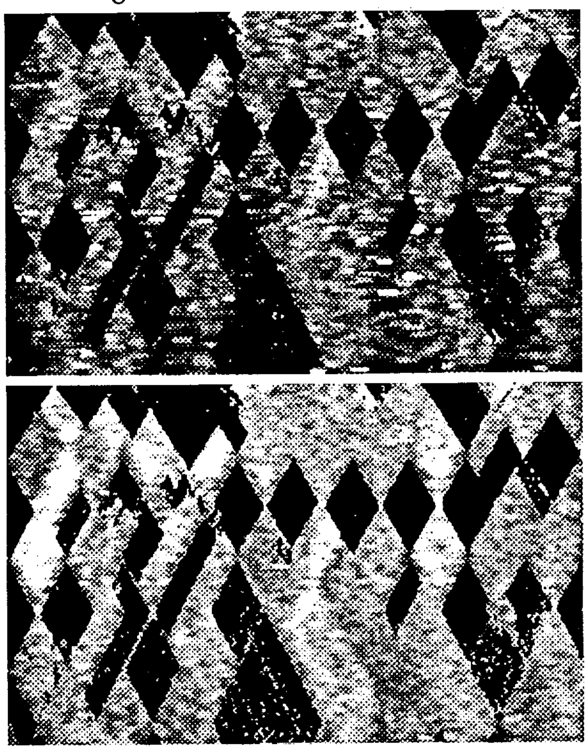

Figure. *Comparison of inferred soil moisture map by using the first-order surface scattering model at top in (A), and by the algorithm which includes both surface and volume scattering at bottom in (B). The image brightness is proportional to soil moisture ranging from 2 to 14 percent by volume.*

References

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