Estimation of Soil Moisture from X-band Backscattering Coefficients of Vegetation Fields

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Abstract

This paper presents soil moisture retrieval form measured polarimetric backscattering coefficients of a vegetation field. The backscattering coefficients of soybean field were measured by scatterometer(HPS: Hongik Polarimetric Scatterometer) system in 2010. Surface soil moisture is retrieved using measured backscattering coefficients. Surface scattering of soybean field is extracted using semi-empirical water-cloud model. Then Soil moisture is retrieved by surface scattering using Oh et al.'s model.

Keywords : Soil moisture, water-cloud model, vegetation field, backscattering coefficients

1. Introduction

Synthetic aperture radar (SAR) can be of significant assistance to obtain information of various earth surfaces, such as the forests, farming fields, and bare surfaces [1]. The soil moisture which can be measured by the SAR is one of the most important information that is used in agriculture, global change monitoring and etc. Polarimetric radar response can be modeled quite accurately for bare surfaces [2]. Based on the accurate scattering model, both the soil moisture and surface roughness can be retrieved from the polarimetric backscatter measurements with a good accuracy for bare-soil surfaces [3]. However, although many studies have been done on soil moisture retrieval from vegetation canopies, the accuracy of such techniques still remains to be validated. Therefore, an accurate soil moisture retrieval technique is needed in the vegetation canopy.

The Hongik Polarimetric Scatterometer (HPS) has been used to collect the backscattering coefficients of various vegetation fields [4]-[5], such as rice fields and green-onion fields, at L- and C-bands. The HPS is a vector-network-analyzer-based scatterometer with an 8-m-long antenna support, antenna/OMT (orthogonal-mode transducer) sets, an automatic angle-control unit, and automatic data acquisition unit. A sub-circuitry for an X-band operation has been added for this experiment campaign. The ground-based X-band HPS can be used for an excellent test-bed for satellite SAR systems at X-band.

The semi-empirical water cloud model, as defined for remote sensing purposes, was first proposed in 1978 by Attema and Ulaby[6]. It was developed to improve the efficiency of empirical regression models without incorporating complex geometrically based mathematical models of microwave-crop interaction. They simplified the vegetation canopy by fitting the model with experimental data[3]. The model parameters are dependant on the vegetation type and the polarization.

In this paper, at first, we extracted the surface scattering term from the radar backscatter of the soybean fields using water-cloud model. Then, we retrieved the soil moisture of the soybean field using the empirical scattering model [2]. The extracted soil moisture is compared with in-situ measured soil moisture contents for verifying this inversion algorithm.

2. Measurements

The radar backscatter from a soybean field has been measured using the ground-based X-band polarimetric scatterometer (HPS) at 9.65GHz and vv-, hh-, hv-, and vh-polarizations in an angular range from 20° to 60° in 2010. The HPS is movable with wheels so that we can easily measure many independent samples for a fixed incident angle and polarization. In this case we collected 60 independent samples at each incidence angle and polarization while manually trolling the HPS system.

At the same time, we also collected ground truth data of the soybean field, such as soil moisture, surface roughness parameters (root-mean-square height and correlation length), soybean height, cluster density, stem density, branch density, leaf density, water contents of branches and leaves, leaf thickness, leaf size, branch length and diameter, vertical angles of the branches, etc. The measured ground truth data were used as input parameters of the RT model for verification. Fig. 5 shows the comparison between measurements and RT model for the polarimetric backscattering coefficients. The model agrees quite well with the measurements for co-polarized backscatters, while the estimated cross-polarized backscatters are about 4.5dB higher than the measurements.

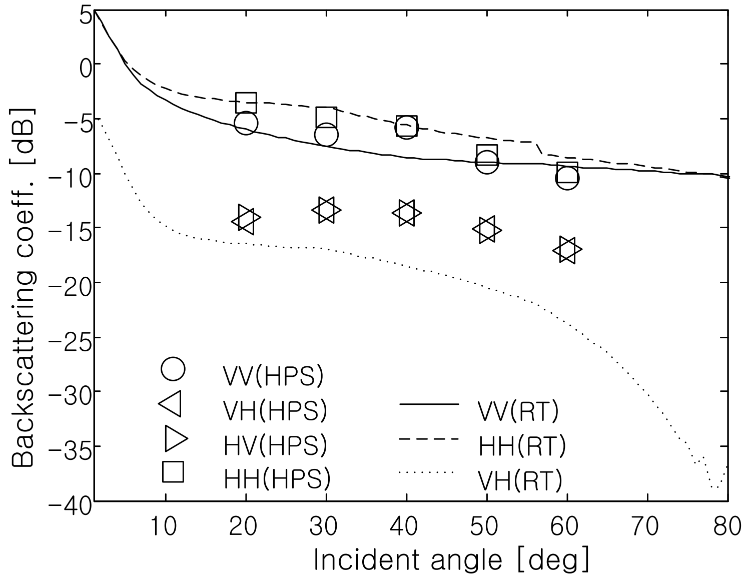

Figure 1: Comparison between measurements and RT model.

3. Water-Cloud Model

Radiative transfer model(RTM) is one of the most well-known scattering model for the vegetation layer. However, RTM is complicated because of too many input parameters. Therefore, Attema and Ulaby (1978) simplified the vegetation canopy in eq. (1). This model assumed that only single scattering is existed. and the dielectric water cloud used in the model is assumed to be comprised of identical water particles, uniformly distributed throughout the medium[7].

$$\sigma^0_{pq} = \sigma^0_{pq1} + T^2 \sigma^0_{s,pq}$$

With

$$T = \exp\left[-B\sqrt{m_w}\sec\theta\right] \qquad (1)$$

And

$$\sigma^0_{pq1} = A\sqrt{m_w}\cos\theta\left(1 - T^2\right)$$

where σ^0_{pq1} is scattering of the vegetation layer, $\sigma^0_{s,pq}$ represents the scattering from the soil layer, T is the two-way vegetation transmissivity, m_w is the vegetation water content(kg/m^2), A and B are parameters depending on the canopy type.

To retrieve soil moisture, the surface scattering from the underlying soil surface was retrieved. Surface backscattering coefficients was calculated from total backscattering coefficients through parameter A and B of soybean field, which are determined by fitting the models against experimental data. The estimated values of A_{vv}, A_{hh}, A_{vh}, B_{vv}, B_{hh}, and B_{vh} are 0.161 0.410, 0.060, 0.295, 0.080, and 0.1, respectively.

The vegetation water mass M_w can be estimated from days after transplanting. Fig. 2 show the comparison between days after transplanting and vegetation water mass M_w. Then, the unknown constants were determined by data-fitting with in-situ measurements as follows;

$$M_w = -0.0001t^2 + 0.02661t - 0.06139 \quad (2)$$

where t is day after transplanting.

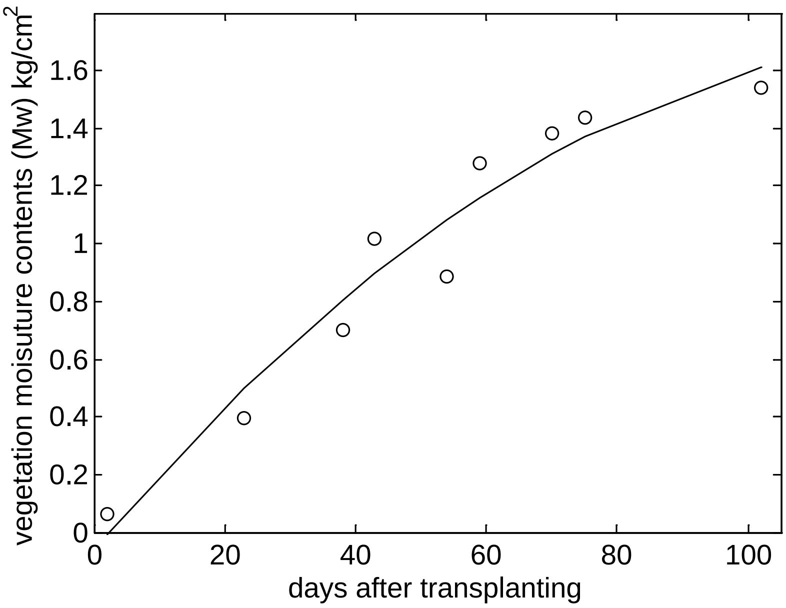

Fig. 2. Comparison between the vegetation water mass and soil moisture contents.

4. Soil Moisture Inversion

Oh et al.'s model[2] can be used for retrieval of soil moisture from the surface scatter component by inversion of the following equations.

$$\sqrt{p} = \sqrt{\frac{\sigma_{hh}^0}{\sigma_{vv}^0}} = 1 - \left(\frac{2\theta}{180}\right)^{\frac{1}{3\Gamma_0}} \cdot \exp(-ks) \quad (3)$$

$$q = \frac{\sigma_{hv}^0}{\sigma_{vv}^0} = 0.23\sqrt{\Gamma_0}\left[1 - \exp(-ks)\right] \quad (4)$$

$$\sigma_{vv}^0 = \frac{g\cos^3\theta}{\sqrt{p}}\left[\Gamma_v(\theta) + \Gamma_h(\theta)\right] \quad (5)$$

$$g = 0.7\left[1 - \exp\left(-0.65(ks)^{1.8}\right)\right] \quad (6)$$

Γ_0 is the Fresnel reflectivity of the surface at nadir, θ is the incidence angle, k is the wave number, s is the RMS (root-mean-square) height of the bare soil surface. We can directly invert the model to obtain estimates of s and the soil moisture content M_v from observation of σ_{vv}^0, σ_{hh}^0 and σ_{vh}^0. By eliminating ks from (4) and (3), we obtain the following nonlinear equation for Γ_0:

$$\left(\frac{2\theta}{\pi}\right)^{1/3\Gamma_0} \cdot \left[1 - \frac{q}{0.23\sqrt{\Gamma_0}}\right] + \sqrt{p} - 1 = 0 \quad (7)$$

where θ is in radians. After solving for Γ_0, we can calculate the real part of the dielectric constant ε_r assuming a simple relation between ε_r' and ε_r''[1]. Then, the volumetric soil moisture content M_v could be retrieved from the empirical relation between ε_r and M_v in [8].

The retrieved soil moisture contents are compared with the in-situ measured soil moisture contents. Four of five data(20°,30°,40°,50°, and 60°) are retrieved. Consequently, the difference between estimated and the measured M_v for two of them is 0.15, for the others 0.02.

5. Concluding Remarks

The polarimetric radar backscatters of a soybean field were measured using the ground-based X-band polarimetric scatterometer (HPS) in an angular range from 20° to 60° in 2010. The backscattering coefficients of the soybean field were computed using the first-order RTM with field-measured input parameters. It was found that the estimated backscattering coefficients agree quite well with the field-measured radar backscattering coefficients. The surface scattering from the underlying soil surface was retrieved using water-cloud model. Then, the soil moisture of the soybean field could be retrieved from the surface scattering using the empirical surface scattering model. The retrieved soil moisture contents were compared with the in-situ measured soil moisture contents. This study will help for soil moisture retrieval from X-band SAR images for vegetation fields.

References

1] F.T. Ulaby, M.K. Moore, and A.K. Fung, Microwave Remote Sensing, Active and Passive, vol. 2, Artech House, Norwood, MA, USA, 1982.

[2] Y. Oh, K. Sarabandi, and F. T. Ulaby, “An empirical model and an inversion technique for radar scattering from bare soil surfaces,” *IEEE Trans. Geosci. Remote Sensing*, vol. 30, no. 2, pp. 370-381, mar. 1992.

[3] Y. Oh, “Quantitative retrieval of soil moisture content and surface roughness from multipolarized radar observations of bare soil surfaces,” *IEEE Trans. Geosci. Remote Sensing*, vol. 42, no. 3, pp. 596-601, Mar. 2004.

[4] Y. Oh and S.-G. Kwon, “Development of a simple scattering model for vegetation canopies and examination of its validity with scatterometer measurements of green-onion fields,” *IGARSS2009*, July 2009.

[5] Y. Oh, S.-Y. Hong, Y. Kim, J.-Y. Hong, and Y.-H. Kim, “Polarimetric Backscattering Coefficients of Flooded Rice Fields at L- and C-Bands: Measurements, Modeling, and Data Analysis,” *IEEE Trans. Geosci. Remote Sensing*, vol. 47, Issue 8, pp. 2714 – 2721, Aug. 2009.

[6] E. P. W. Attema, and F. T. Ulaby, “Vegetation modelled as a water cloud,” Radio Science, Vol. 13, pp. 357-364, 1978.

[7] Y. Oh, and S-G. Jung, “Inversion algorithm for soil moisture retrieval from polarimetric backscattering coefficients of vegetation canopies,” *IGARSS 2008*, pp. II-402-405, July. 2008.

[8] M. C. Dobson, F. T. Ulaby, M. T. Hallikainen, M. A. El-Rayes, “Microwave dielectric behavior of wet soil-part II: dielectric mixing models,” *IEEE Trans. Geosci. Remote Sensing*, vol. GE-23, pp. 35-46, Jan. 1985.

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