SOIL MOISTURE DETECTION USING KOMPSAT-5 SAR DATA

Yisok Oh[1], Soon-Gu Kwon[2], and Ji-Hwan Hwang[2]

[1] Department of Electronic and Electrical Engineering, Hongik University, Seoul, Korea (He is now a visiting professor at Stanford University, USA), Email: yisokoh@hongik.ac.kr

[2] Department of Electronic Information and Communication Engineering, Hongik University, Seoul, Korea. soongu-kwon@mail.hongik.ac.kr, ji-hwan_hwang@mail.hongik.ac.kr

1. INTRODUCTION

Soil moisture content is an essential parameter of the earth's water, energy and carbon cycle, and in particular, agriculture and hydrological processes, climate prediction, and flood and drought monitoring. Retrieval of soil moisture from microwave synthetic aperture radar (SAR) measurements has been extensively investigated in the past decades [1] for high-resolution soil-moisture mapping. However, the retrieval of soil moisture from a set of radar data is not an easy task yet, because the radar measurement of an earth surface is affected by the surface roughness condition as well as the vegetation canopy in addition to the soil moisture of the surface. The soil moisture retrieval from polarimetric SAR data for bare soil surfaces has been successful [2]-[5], while the task for vegetation-covered surfaces is still a challenging problem because of the complicate scattering mechanisms in the vegetation canopy and between the vegetation canopy and the ground surface. Soil moisture retrieval for vegetation canopies can be approached either using so-called 'time-series' or 'change detection' techniques based on the experimental data sets [6-7], or using model-based inversion techniques [8-9].

Most inversion algorithms for soil moisture retrieval are based on multiple SAR data sets with multi-polarizations, or multi-frequencies, or multi-angles. Retrieving the soil moisture from a single SAR data set of single polarization, single frequency, and single incidence angle will be a very difficult problem, because the radar backscatters of soil surfaces are sensitive to the surface roughness as well as vegetation type. In this paper, we present a feasibility study on the soil moisture retrieval from the vv-, hh-, or hv-polarized backscattering coefficients of bare or vegetation-covered soil surfaces which can be obtained by the KOMPSAT (Korea Multi-Purpose Satellite)-5 SAR images. At first, an empirical scattering model for bare soil surfaces [10] is closely examined to find the validity for use in a single-polarization data set. Then, the examination is extended to vegetation-covered soil surfaces as in Section 3.

2. BARE SOIL SURFACES

A fully polarimetric semi-empirical scattering model for the vv-, hh-, and hv-polarized backscattering coefficients and phase-difference statistics parameters of bare soil surfaces has been provided in [10]. Employing the simi-empirical form of cross-polarized ratio q in [5], the vv-, hh-, and hv-polarized backscattering coefficients can be written as

$$\sigma_{vv}^{0} = 1.16\, M_v^{0.7} \left(\cos\theta\right)^{2.2} \left(0.13 + \sin 1.5\theta\right)^{-1.4} \left[\left(1 - e^{-0.32(ks)^{1.8}}\right)\left(1 - e^{-1.3(ks)^{0.9}}\right)^{-1}\right], \tag{1}$$

$$\sigma_{hh}^{0} = \sigma_{vv}^{0} \left[1 - \left(\theta/90\right)^{0.35\, M_v^{-0.65}} \cdot e^{-0.4\,(ks)^{1.4}}\right], \tag{2}$$

$$\sigma_{hv}^{0} = 0.11\, M_v^{0.7} \left(\cos\theta\right)^{2.2} \left[1 - e^{-0.32\,(ks)^{1.8}}\right] \tag{3}$$

The exponential terms of (1) and (3) in [⋯] approach to 1 as the roughness parameter *ks* increases, where *s* is the RMS (root-mean-square) height of a soil surface and *k* is wave number $k = 2\pi/\lambda$. The approximate range of the surface RMS height of natural soil surfaces is 0.4 cm ≤ *s* ≤ 4.0 cm, which gives the range of the roughness parameter *ks*, 0.8 ≤ *ks* ≤ 8.0 at 9.65 GHz. Analyzing the *ks*-dependency of the scattering model, we could replace the […] terms in (1) and (3) with constant values, and simplify the scattering model for the vv-, hh-, and hv-polarized backscattering coefficients within about ±0.63 dB errors for the co-polarized backscattering coefficients and about ±0.85 dB for the cross-polarized backscattering coefficients at the range of the roughness parameter k*s* ≥ 2, which corresponds to the range of the RMS height *s* ≥ 1 cm at X-band.

Therefore, for a relatively rough bare soil surface (*s* ≥ 1 cm), an X-band measurement of vv-, or hv-polarized backscattering coefficient can provide an approximate soil moisture content *Mv* using the simplified scattering model with a single measurement. In this study the simplified scattering model was applied to retrieve soil moisture from single-polarization radar measurements of bare soil surfaces. It was found the retrieved soil moisture contents using the simple model agree quite well with the field-measured soil moisture contents for single-polarized measurements.

On the other hand, the scattering model in (1)-(3) as it is, can also be used for soil moisture retrieval for a series of measurements for a target area, assuming the surface roughness is not significantly changed during the time period between the measurements. In this case we also need to assume the vegetation activity is limited such as in the arid or semi-arid areas, sea shore areas, and unpaved roads. If the series of measurements cover the full range of soil moisture conditions from very dry to very wet, then a simple data-fit model can be used without field measurements of surface roughness. However, if the measurements do not cover the full range of soil moisture conditions, or the number of measurements is limited, then at least one field-measurement of surface roughness is necessary.

3. VEGETATION-COVERED SURFACES

For vegetated terrains, the backscattering coefficients can be estimated using the radiative transfer model (RTM) with numerous input data for vegetation type; for example, vegetation canopy height, leaf density, leaf size, leaf thickness, branch density, branch length, branch diameter, trunk density, trunk length, trunk diameter, water contents of leaf, branch, and trunk, the probability density functions (PDF) of the leaf size, branch size, branch diameter, trunk length, trunk diameter, and so on, in addition to the soil moisture and surface roughness parameters. Therefore, a direct inversion of the RTM for soil moisture is not possible without the information about the vegetation canopy. A series of measurements for a target area may be necessary to get a simple regression model for the soil moisture estimation from radar measurements.

In this study, a series of measurements in a growing season from seedling to harvest period for a corn field were used for verifying the inversion algorithm. The backscattering coefficients were obtained using an X-band ground-based scatterometer for vv-, hh-, and hv-polarizations at 20 and 60 degrees. The ground truth data of the corn field were also in-situ measured at the same time. These data sets were examined to apply the time-series (and change detection) method.

If the number of experimental data sets is limited, then we need the information for the vegetation canopy; for example, the growing pattern, the NDVI, or LAI. The information for the vegetation can be obtained by field measurements or other instruments in space. In this study, we examined the minimum requirements on the vegetation input parameters for proper soil moisture detection using KOMPSAT-5 SAR data for vegetated terrains.

4. CONCLUSIONS

A simplified scattering model at X-band for radar backscattering from relatively rough bare soil surfaces has been developed based on the existing semi-empirical polarimetric scattering model. An inversion algorithm based on this simplified scattering model is validated with radar measurements of bare soil surfaces. We also studied the soil moisture retrieval from the backscattering coefficients of the vegetated surfaces using the experimental data sets. These inversion algorithms for soil moisture detection will provide a basis for soil moisture mapping with the KOMPSAT-5 SAR.

5. REFERENCES

[1] F. T. Ulaby, M. K. Moore, and A. K. Fung, *Microwave Remote Sensing, Active and Passive*, vol. 3, Artech House, Norwood, MA, 1986.

[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, pp. 370–382, Mar. 1992.

[3] P. C. Dubois, J. van Zyl, and E. T. Engman, "Measuring soil moisture with imaging radar," IEEE Trans. Geosci. Remote Sensing, vol. 33, pp. 916–926, July 1995.

[4] J. Shi, J. Wang, A. Y. Hsu, P. O'Neill, and E. T. Engman, "Estimation of bare soil moisture and surface roughness parameter using L-band SAR image data," IEEE Trans. Geosci. Remote Sensing, vol. 35, pp. 1254–1265, Sept. 1997.

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

[6] Y. Kim and J. van Zyl, "Overview of hydros radar soil moisture algorithm," IGARSS 2005, vol. 4, pp. 2756 – 2758, 25-29 July 2005.

[7] M. Piles, D. Entekhabi, and A. Camps, "A Change Detection Algorithm for Retrieving High-Resolution Soil Moisture from SMAP Radar and Radiometer Observations," IEEE Trans. Geosci. Remote Sensing, vol. 47, no. 12, pp. 4125 – 4131, Dec. 2009.

[8] J. van Zyl and Y. Kim, "Estimating soil moisture for vegetated terrain: a discussion of possible approaches relevant to the HYDROS mission," IGARSS 2005, vol. 4, pp. 2763 – 2766, 25-29 July 2005.

[9] Y. Oh and S.-G. Jung, "Inversion Algorithm for Soil Moisture Retrieval from Polarimetric Backscattering Coefficients of Vegetation Canopies," *IGARSS 2008*, vol. 2, p. II-402 - II-405, July 2008.

[10] Y. Oh, K. Sarabandi, F. T. Ulaby, "Semi-empirical model of the ensemble-averaged differential Mueller matrix for microwave backscattering from bare soil surfaces". IEEE Trans. Geosci. Remote Sensing, vol. 40, no. 6, pp. 1348 –1355, June 2002.