MEASUREMENT AND MODELING TO ESTIMATE SOIL MOISTURE USING MICROWAVE SCATTEROMETER

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ABSTRACT: A laboratory experiment was conducted to measure microwave scattering on soil surface for the analysis of drought using satellite-borne synthetic aperture radar (SAR) sensor data. Measurements at 0, 20 and 35-degree zenith angles were examined for X, C and L bands. Specimens of a 30-cm depth of soil were produced in a fiber reinforced plastic (FRP) tube. They had different volumetric soil moisture, i.e. 8.9 % 18.9 % and 27.2 %. After the measurement of the specimen with 27.2 % volumetric soil moisture was completed, 3-cm depth of water was put onto the soil surface. In 14 hours, the water had infiltrated the soil layer and the water layer vanished. This specimen had 29.4 % volumetric soil moisture. The results for X band show that the backscatter at 0, 20 and 35 degree zenith angles with 29.4 % volumetric soil moisture had a negligible increase compared to the backscatter with 27.2 % volumetric soil moisture. The results for L band show that the backscatter at 0 degree zenith angle with 29.4 % volumetric soil moisture had an increase compared to the backscatter with 27.2 % volumetric soil moisture while the backscatters at 20 and 35 degree zenith angles with the same volumetric soil moisture had decrease.

1. INTRODUCTION

As drought is one of the most common disasters worldwide, satellite remote sensing has attracted attention as an effective tool to monitor drought phenomenon and mitigate the damage. Among several parameters and indices, soil moisture is one of the most effective indicators of drought. Based on the backscattering coefficient obtained by SAR and other parameters such as surface roughness, soil moisture can be estimated through physical models. So far, the authors have examined the Integral Equation Method (IEM) model, one of the most useful models of microwave scattering, to estimate volumetric soil moisture from temporal Japanese Earth Resources Satellite-1 (JERS-1)/SAR data. As a result to compare with actual volumetric soil moisture, it was found that the IEM model cannot function to properly represent microwave scattering on paddy fields, especially inundated paddy fields because the IEM model assumes scattering on bare soil. While results to measure backscatter of L, C, X and Ku bands of microwave on paddy fields were reported [2], there is no available model of microwave backscatter on paddy fields, i.e. landcover functioning as bare soil, inundated soil, inundated vegetation and vegetation without inundation. In the present research, the authors have conducted laboratory experiments to measure microwave scattering on bare soil and the results are reported. In the near future, the experimental results for the scattering on inundated soil will be reported.

2. EXPERIMENTS

An experiment was conducted from August 8 to 12, 2007 in an anechoic radio wave chamber of Microwave Energy Transmission Laboratory (METLAB), Research Institute for Sustainable Humanosphere (RISH), Kyoto University. A vector network analyzer produced 50 MHz to 40 GHz incident microwave. X-band (8.5-9.6 GHz), C-band (4.0-5.8 GHz) and L-band (1.7-2.6 GHz) antennas were used. Single antenna transmitted and received HH-polarized microwaves. The amplitude was calibrated as transmitted microwave equal to 0 dB.

Hereafter, X, C and L bands denote frequency at 9.4 GHz, 5.3 GHz and 1.7 GHz, respectively. In fact, satellite-borne L band SAR sensor has 1.2 to 1.3-GHz frequency, e.g. 1.275 GHz for JERS-1/SAR and 1.27 GHz for Advanced Land Observation Satellite (ALOS)/Phased Array type L-band Synthetic Aperture Radar (PALSAR). However, as the L band antenna covering this frequency was not available to the authors, the antenna for 1.7 to 2.6 GHz was used and the 1.7-GHz frequency data was exploited to represent L band data in the present research.

Figure 1: Soil specimen after compaction was completed

Specimens of soil were produced in a FRP tube, which is normally supposed to be used as a bath tube. The tube had $70 \times 60 \times 60 cm^3$ volume. A 30-cm depth of soil layer was composed of two layers. The lower layer had 17-cm depth, and the volumetric soil moisture of the layer was 8.9 %. The upper layer had 13-cm depth, and different volumetric soil moisture of the upper layer was examined, i.e. 8.9 % 18.9 % and 27.2 %. Figure 1 shows one of the specimens. Following a geotechnical engineering test, soil was mixed with water homogeneously with a mixing machine, and then the soil was put into the tube through compaction. The soil density was 1.61 g/cm^3 for 8.9 % and 18.9 % and 1.78 g/cm^3 for 27.2 %. The surface roughness of the specimens was measured by laser scanner, shown in Figure 2. In the case of the specimen with 27.2 %, the standard deviation of the surface roughness was 1.1 cm. Measurements at nadir (0-degree), 20-degree and 35-degree zenith angles were examined. When the zenith angle was changed, the tube on the chassis was moved to a specific position manually. After the measurement of the specimen with 27.2 % volumetric soil moisture was completed, 3-cm depth of water was put onto the soil surface. In 14 hours, the water had infiltrated the soil layer and the water layer vanished. The volumetric soil moisture of this specimen at the 5-cm depth from the surface was 29.4 % ($1.81 g/cm^3$).

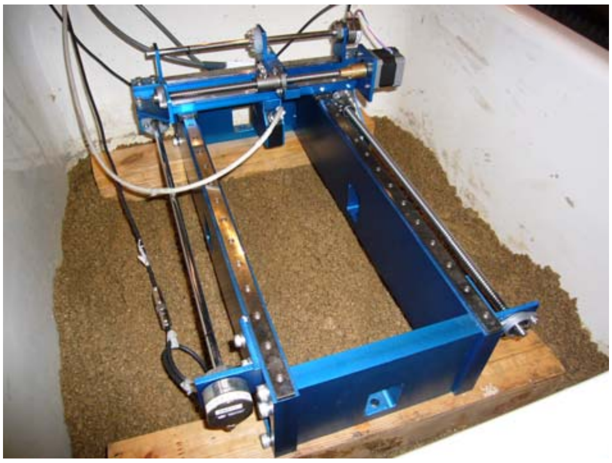

Figure 2: Measurement of soil surface roughness by laser scanner

In such experiments, the antenna should be more than Fraunhofer distance away from the target in order to detect plane waves. The Fraunhofer distance can be calculated as $2D^2/\lambda$ where D denotes aperture length and λ denotes wavelength. For example, the Fraunhofer distance for 9.4 GHz with the antenna used in this experiment was $2 \times 15.5^2/3.19 = 151$ cm. When the authors conducted preliminary experiments, in which the distance was set as 200 cm, longer than the Fraunhofer distance for L and X bands, significant differences could not be found in the results under different conditions, especially different water depths.

The FRP tube used in the experiment was not so big, and the length of soil/water surface along H-polarization plane was 70 cm. Antenna patterns of X and C bands, shown in Figure 3, indicated that more than 29.4-degree azimuth angle had less than -20 dB amplitude. With calculation of 35 cm / tan(29.4 deg) = 63.1 cm, the distance was fixed as $70 cm$, and then it was also applied for the measurement with L band antenna. Figure

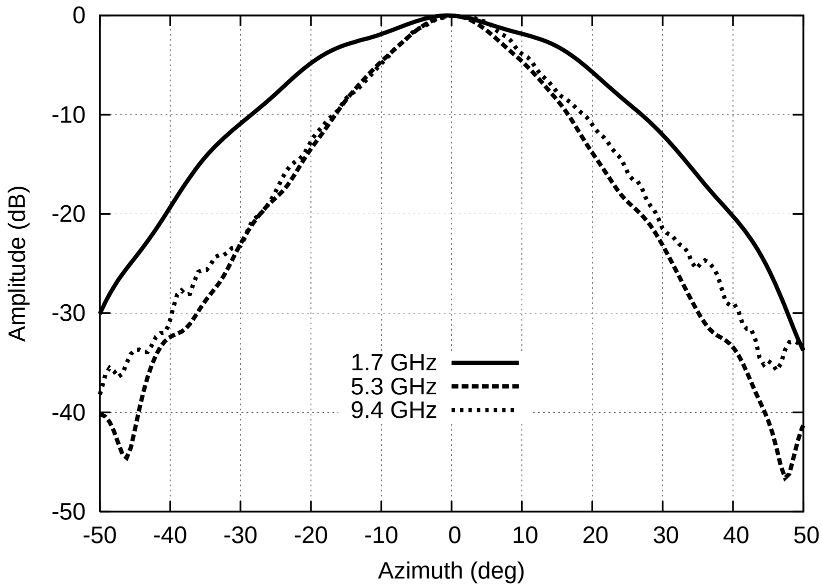

Figure 3: Antenna patterns for X, C and L bands

4 shows the measurement with 35-degree zenith angle X band antenna. The distance between the bottom edge of the antenna and the center of the soil surface was set as 70 cm. Figure 5 shows the backscatter amplitude for X (upper) and L (lower) bands by changing the volumetric soil moisture from 8.9 % cm to 29.4 %.

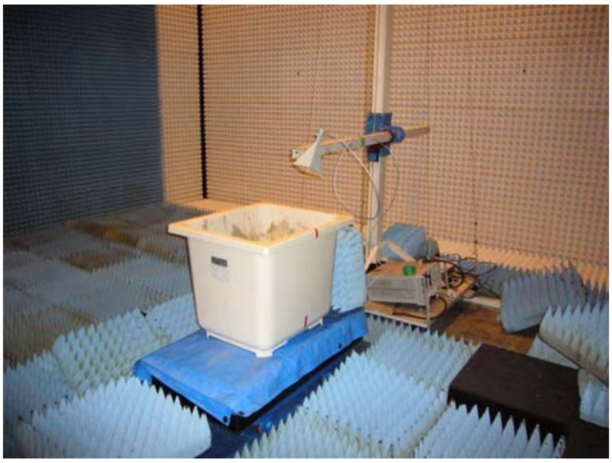

Figure 4: Measurement with 35-degree zenith angle X band antenna. The distance between the bottom edge of the antenna and the center of the soil surface was set as 70 cm.

3. DISCUSSIONS

In the experiment, the distance between the antenna and the specimens was much shorter than Fraunhofer distance in order to highlight the differences between backscattering

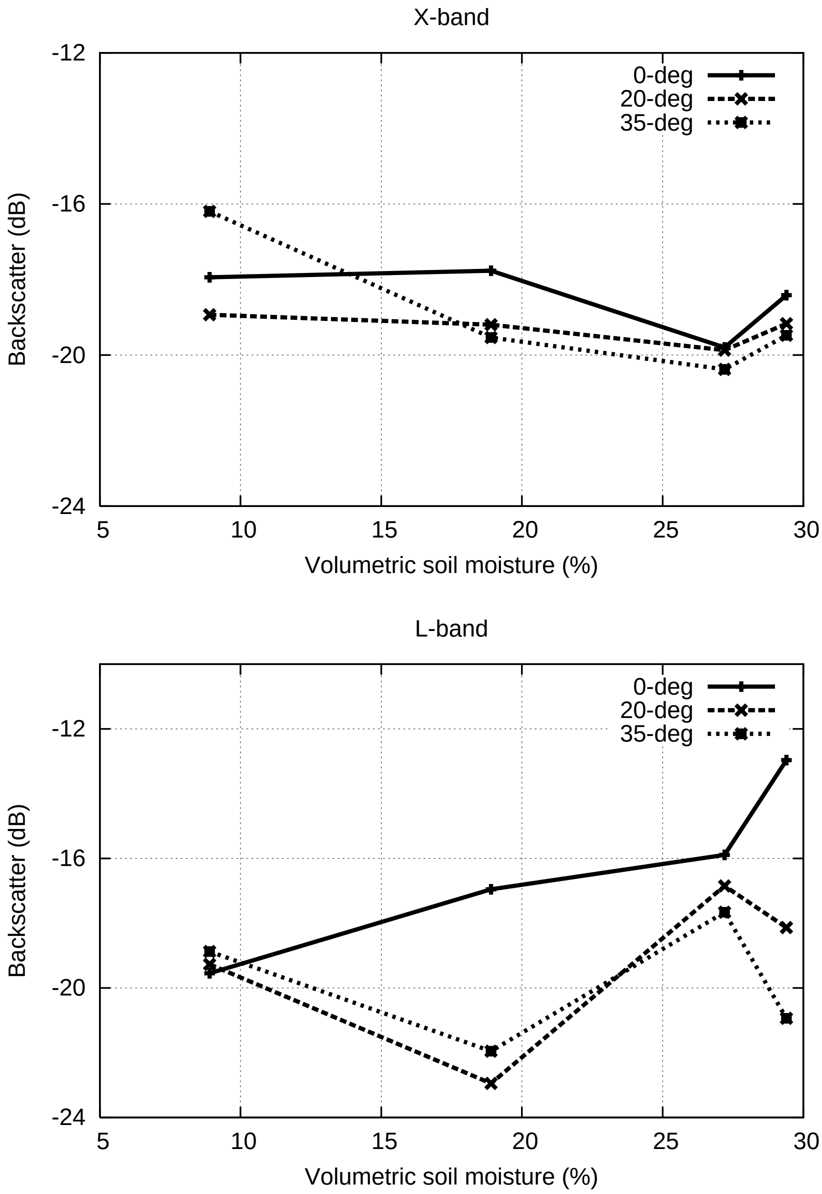

Figure 5: Backscatter amplitude for X (upper) and L (lower) bands by changing the volumetric soil moisture from 8.9 % cm to 29.4 %

amplitudes in different frequencies and water depths. This decision could be one of the most important factors to affect the backscattering feature. Measurements at longer than Fraunhofer distance using bigger specimens would be desirable.

The results for X band show that the backscatter at 0, 20 and 35 degree zenith angles with 29.4 % volumetric soil moisture had a negligible increase compared to the backscatter with 27.2 % volumetric soil moisture. The results for L band show that the backscatter at 0 degree zenith angle with 29.4 % volumetric soil moisture had an increase compared to the backscatter with 27.2 % volumetric soil moisture while the backscatters at 20 and 35 degree zenith angles with the same volumetric soil moisture had decrease.

4. CONCLUSIONS

In the present paper, laboratory experimental results were reported to measure backscatter from soil surface in order to understand the backscatter from paddy fields and apply the analysis using satellite-borne SAR images. The specimen had different volumetric soil moisture, and HH-polarized backscatter from the surface was measured in X, C and L bands.

These results will be utilized for more advanced experiments to measure backscatter from simulated paddy fields, and to discriminate the backscatter caused by water content in paddy from the water surface.

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