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Application of the Sahebi-model using ALOS/PALSAR and 66.3-cm long surface profile data

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Soil moisture is important information for agricultural fields in which erosion of upper soil layers depends upon the soil moisture and in which the yield depends on soil water content during sowing, growing, and harvest periods. Although sensitivity of microwave backscatters to soil moisture is well understood, several factors such as surface roughness and incidence angle can interfere with the estimation of soil moisture using SAR data. In this letter, we evaluated the influence of these variables using ALOS/PALSAR data and 66.3-cm long surface profile data using the Sahebi-model. The model applied in this study has a Root Mean Square (RMS) error of only 1.34 dB which suggests that 66.3-cm long surface profile data are effective for characterization of surface roughness effects on backscattering coefficients.

1. Introduction

Monitoring soil moisture is important for irrigation and drainage efficiency. Microwave remote sensing is sensitive to soil moisture because of the dielectric constant of soil is strongly influenced by water content. However, the backscattering coefficient is not only related to soil moisture, but also to surface roughness and system parameters such as incidence angle and polarization. Therefore, to estimate soil moisture information

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from backscattering coefficient data, the influence of other factors on backscattering coefficient must be evaluated.

In order to solve this problem, Sahebi *et al.* (2003) proposed a model using incidence angle and RMS height calculated from 2-m long surface profiles. It is known that RMS height can be used to estimate correlation length (Baghdadi *et al.* 2000, Verhoest *et al.* 2000). Correlation length has been shown to be highly dependent on the profile length (Bryant *et al.* 2007), and optimum profile lengths ranging from 2 metres (Baghdadi *et al.* 2000) to hundreds of metres (Verhoest *et al.* 2000) have been suggested. In this research, focusing on bare agricultural fields, our hypothesis was that very short profiles, extending over a minimum of two cultivation ridges in the field, would be sufficient for calculating RMS height. Thus, the objective of this study was to examine whether 66.3 cm surface profile data can be used to calculate a roughness index for estimation of soil moisture using ALOS/PALSAR data.

2. Study area

The study area (Figure 1) included fields along the Chitose River, covering an area of approximately 5.6 km² near Eniwa City and Kitahiroshima City, Hokkaido, Japan (141° 33' 52" to 141° 40' 08" E, 42° 54' 35" to 43° 00' 33" N). The study area is located in Southern Ishikari plain and at an elevation between 5 and 20 m. The average annual temperature is 7.7 C°. The soils consist of mainly peat and dune deposits.

3. Data

3.1 Ground data

Simultaneously with ALOS/PALSAR observation on 1 August 2007, 3 May 2008 and 31 May 2008, ground measurements were acquired from the 18 bare soil fields shown

in Figure 1. To measure soil moisture, a Thetaprobe soil moisture instrument (Moisture Meter type HH2; Delta-T Devices Ltd.) was used. The instrument is capable of measuring the average volumetric soil moisture content in the top 0 to 5 cm of the soil. A total 20 to 100 (average of 35.2) soil moisture measurements were made for each field, and the average value for each field was calculated. A needle profiler was used for soil moisture measurements. The profiler had needles at intervals (Δx) of 1.7cm, with a total of 40 needles over the 66.3 cm length measured. The profiler allows the needles to drop down to the soil surface, the needle profile is digitized, and the RMS value of the needle heights calculated. In general, Δx should be chosen such that $\Delta x < 0.1\lambda$, where λ signifies the wavelength of the microwaves studied (Ulaby *et al.*, 1982). Based on this relationship, Δx should be to be ≤ 2.4 cm for this study, and consequently a value of 1.7cm was chosen.

3.2 Satellite data

Details of PALSAR images are presented in Table 1. The device operates in the L band (1.27 GHz) at several polarizations and several off-nadir angles. However, the radar dataset of our experimental campaigns is limited to HH polarization because soil moisture is best estimated with HH polarization (Paloscia *et al.* 2004). Fine Beam Single Polarization mode (FBS) and Fine Beam Double Polarization (FBD) images were used. Because there was no difference in the center frequency and the noise equivalent σ^0 between the image types, they were not treated separately. In a related study, Weimann *et al.* (1998) found it necessary to separate ascending mode and descending mode data when fog is present at the time of acquisition with either mode. In this study, fog was not an issue, and thus the ascending and descending images were

not analyzed separately. The incidence angle was estimated according to ALOS/PALSAR Level 1.1/1.5 product Format description procedures (JAXA. 2008).

The PALSAR images were converted from digital numbers to backscattering coefficients using equation (1):

$$\sigma^0 = 10 \log_{10} DN^2 + CF, \quad (1)$$

in which σ^0 is backscattering coefficient in dB, DN is a PALSAR image digital number and CF is the calibration factor (for PALSAR L1.5 products CF=−83.0 dB).

In order to compensate for spatial variability and to avoid problems related to uncertainty in georeferencing, the average σ^0 (dB) was assigned to each field, which represented between 34-61 pixels.

4. Methods

For each profile, RMS height was estimated using equation (2) (Ulaby et al., 1982).

$$s = \sqrt{\frac{\sum_{i=1}^N Z_i^2}{N-1}} \quad (2)$$

where s is RMS height (cm), N is the number of profile points (in this study, $N=40$); the values of Z_i are the profile data, defined by equation (3):

$$Z_i = H_i - H_{ref} \quad (3)$$

where, H_i is the value of vertical height and H_{ref} is the mean value of Z_i .

Sahebi *et al.* (2003) evaluated the influence of the surface roughness, the soil moisture and incidence angle for estimation of soil moisture using RADARSAT-1 SAR data and then proposed a model as follows:

$$\sigma^0 = A_1 + A_2 \cos^3(\theta) + A_3 \ln(s) + D(VSM) \quad (4)$$

where θ is the incidence angle and VSM is volumetric soil moisture. A_1 , A_2 , A_3 , A_4 and D are coefficients that depend on the frequency, incidence angle and polarization. The original model, which was developed for the Chateauguay watershed, south-east of Montréal, Canada, had a RMS error of 1.21dB. The parameters for that study were $A_1=-27.14$, $A_2=17.50$, $A_3=0.25$, $A_4=-0.31$ and $D=1.85$. For the range of roughness values encountered over agricultural surfaces, the angular decay of backscattering coefficient varies as $\cos^n(\theta)$ with n close to 3 (Oh *et al.* 1992). Therefore, in this study, a value of $A_3=3$ was used.

First, the coefficients of the model were estimated for the study area from the measured values of 1 August 2007 and 3 May 2008. The backscattering coefficients were then simulated using the measured volumetric soil moisture, and incidence angle and RMS height values calculated with 66.3-cm surface profile data. The 31 May 2008 dataset was used for the descending mode data.

5. Results and discussion

5.1 σ^0 – Volumetric soil moisture relationships

The relationship between backscattering coefficients and the volumetric soil moisture (Figure 2) suggests that the backscattering coefficient is useful for estimating volumetric soil moisture.

5.2 Fitting the Sahebi-model

The constants A_1 , A_2 , A_4 and D were calculated for ALOS/PALSAR HH polarization data. The following values were obtained for this study area: $A_1=-56.76$, $A_2=76.69$, $A_4=-1.75$ and $D=0.13$. A determination coefficient of $r^2=0.78$ was observed.

Using this model, we obtained estimated backscattering coefficients, which are compared in Figure 3 with measured backscattering coefficients. Because the RMSE was 1.34 dB for the ascending data, it appears that the model can describe the backscattering coefficients. Next, the estimated volumetric soil moisture values and measured values on 31 May, 2008 were compared to validate the model. The model was found to have an estimated precision of 1.13 dB RMSE for the descending data.

6. Conclusion

The Sahebi-model was applied to examine whether 66.3-cm surface profile data can be used to evaluate the effect of roughness on backscattering. The model was fitted using ALOS/PALSAR data, incidence angle, and RMS height calculated with 66.3-cm surface profile data. The modified model had a RMS error of 1.34 dB for the data used to fit the model and 1.13 dB RMS error for the validation data.

These observed values were relatively comparable with the measured values, indicating that the proposed roughness measurement length may be useful for modeling surface roughness in this region. In future studies, it will be necessary to test whether the same result is achieved with a shorter profile. In addition, an operational methodology for mapping surface moisture in agricultural fields will be tested.

Acknowledgments

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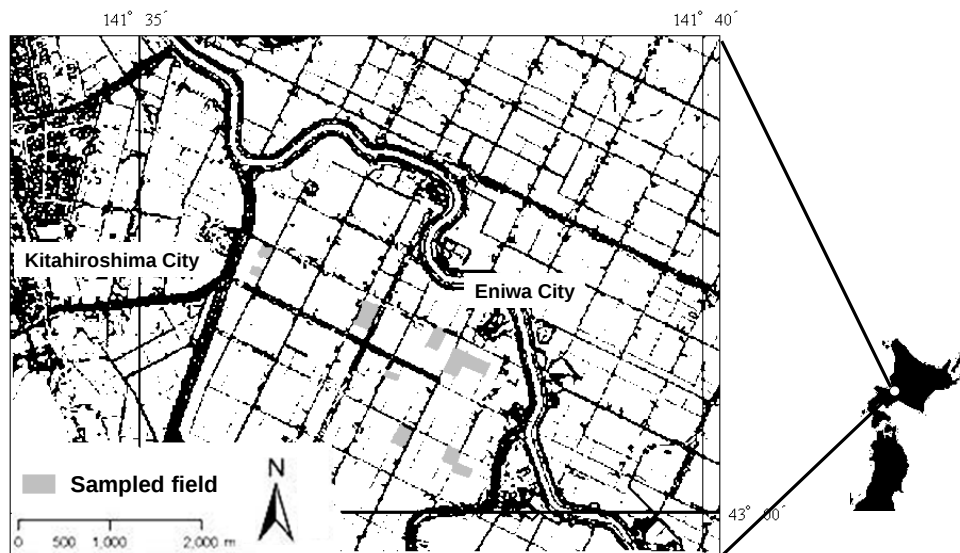


Figure 1. The study area (the background map shows the roads and the causeways).

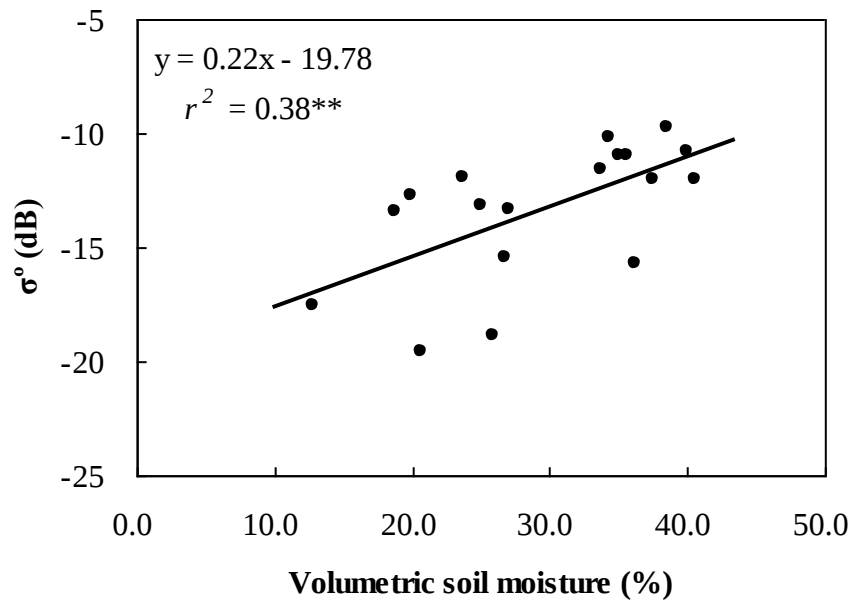


Figure 2. Relationship between volumetric soil moisture and σ° (** indicates $p < 0.01$).

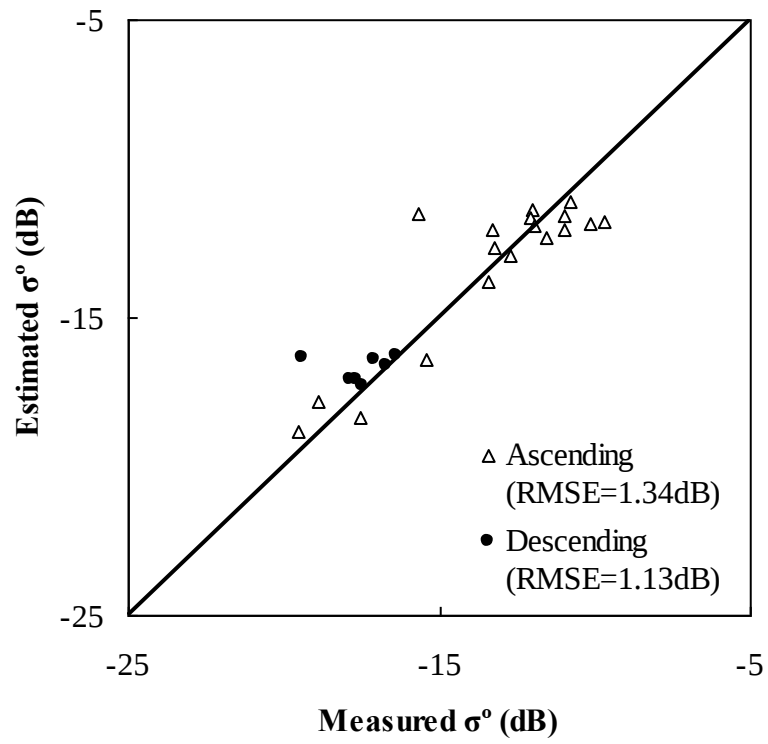


Figure 3. Relationship between estimated and measured σ^0 .

Table 1. Characteristics of the satellite images used.

Date	ALOS/PALSAR mode	Off-nadir angle (°)	Pixel spacing (m)	Orbit	Path
01 August 2007	FBS	34.3	6.25	Ascending	399
03 May 2008	FBD	34.3	12.5	Ascending	399
31 May 2008	FBS	34.3	6.25	Descending	57