Estimation of rice growth parameters by X-band radar backscattering data

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ABSTRACT: Microwave remote sensing has great potential, especially in monsoon Asia, since optical observations are often hampered by cloudy conditions. The radar backscattering characteristics of rice crop were investigated with a ground-based automatic scatterometer system. The system was installed inside a shelter in an experimental paddy field at the National Institute of Agricultural Science and Technology (NIAST) before transplanting. The rice cultivar was a kind of Japonica type, called Chuchung. The scatterometer system consists of X-band antennas, HP8720D vector network analyzer, RF cables, and a personal computer that controls frequency, polarization and data storage. This system automatically measures fully-polarimatric backscattering coefficients of rice crop every 10 minutes, accompanied by a digital camera that takes pictures in a fixed position with the same interval. The backscattering coefficients were calculated by applying a radar equation. Plant variables, such as leaf area index (LAI), biomass, plant height and weather conditions were measured periodically throughout the rice growth season. We have performed polarimetric decomposition of paddy data such as single, double and volume scattering to extract the scattering information effectively. We investigated the relationships between backscattering coefficients and the plant variables.

KEY WORDS: Microwave remote sensing, rice crop, scatterometer system, rice growth, backscattering coefficients

1. INTRODUCTION

Microwave remote sensing has great potential, especially in monsoon Asia, since optical observations are often hampered by cloudy conditions. Especially a ground-based polarimetric scatterometer has advantage of monitoring crop conditions continuously using full polarization and various frequencies. Many plant parameters such as leaf area index (LAI), biomass, plant height are highly correlated with backscattering coefficients although the degrees of correlation ard different and according to frequency and polarization between plant parameters and backscattering coefficients was different (Ulaby, 1984; Bouman, 1991; Brisco & Brown, 1998). Le Toan *et al* (1997) was among the first that showed the potential of using SAR backscattering data for rice crop monitoring based on both satellite and ground based scatterometer measurements. Hong *et al* (2000) analyzed RADARSAT data (5.3 GHz, HH-polarization, and incidence angles between 36° and 46°) for monitoring the rice growth and found a good agreement between backscattering coefficients and rice growth parameters in Korea. Polarimetric SAR (POLSAR) has the potential to estimate volume scattering, surface scattering and double bounced scattering through the data decomposition methods. As backscattering coefficients from a ground scatterometer are often affected by weather condition such as precipitation and wind the necessity of near-continuous automatic measurement has arisen by the experiment of previous year (Kim *et al*., 2007). In this study, we analyzed scattering characteristics of paddy rice obtained from an automatic scatterometer system and investigated the relationships between backscattering coefficients and the plant parameters.

2. MATERALS AND METHODS

The test site was located in NIAST experimental field (37° 15' 28.0" N, 126° 59' 21.5" E) Suwon, Korea. The rice cultivar was a kind of Japonica type, called Chuchung. The size field was about 660m^2. The system was installed inside a shelter in an experimental paddy field. The scatterometer system consists of X-band antennas, HP8720D vector network analyzer, RF cables, and a personal computer that controls frequency, polarization and data storage. The VNA-based polarimetric scatterometer operates in a stepped-frequency sweep mode. Polarimetric scatterometer provides a time domain radar return from a target as a fully polarimetric (hh, hv, vh, vv) amplitude and phase data. This system automatically measures fully-polarimatric backscattering coefficients of rice crop every

10 minutes, accompanied by a digital camera that takes pictures in a fixed position with the same interval.

Radar backscattering measurements was begun on 15 May 2008 before the transplanting at a fixed incidence angle of 45°. Growth data for the rice canopy, such as LAI, fresh and dry weight and plant height, have been acquired in a regular basis.

Table 1. Specification of the Automatic scatterometer system

Specification	X-Band
Center Frequency	9.65 GHz
Bandwidth	1 GHz
Number of Frequency Points	1601
Antenna Type	Dual polarimetric horn
Antenna Gain	22.4dB
Polarization	HH, VV, HV, VV
Incident Angle	45°
Platform Height	4.16m
Measurement interval	1 per 10minutes

Backscattering coefficients were calculated by applying the following radar equation (Ulaby *et al.*, 1990).

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{1}$$

Where G_t and G_r are the gains of the transmitting and receiving antennas in the direction of the target, λ is the wavelength, and σ is the RCS of the target.

Backscattering coefficients of each band were calculated as the follow expressions.

$$X-band : \sigma°(dB) = 20\log U + 32.21(dB) + 30\log R + 10\log\cos\theta_i \tag{2}$$

We analyzed pauli decomposition for scattering characters. The Pauli decomposition expresses the measured scattering matrix $[s]$ in the so-called Pauli basis. If we considered the conventional orthogonal linear (h, v) basis, in a general case, the pauli basis is given by the following four 2x2 matrices (Cameron *et al.*, 1990; Pottier *et al.*, 2005)

$$[s]_a = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \tag{3}$$

$$[s]_b = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \tag{4}$$

$$[s]_c = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \tag{5}$$

$$[s]_d = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} \tag{6}$$

It has been always considered that $s_{hv}=s_{vh}$, since reciprocity applies in a monostatic system configuration. Consequently, given a measured scattering matrix $[s]$, it can be expressed as follows (Cameron *et al.*, 1990; Pottier *et al.*, 2005)

$$[s] = \begin{bmatrix} s_{hh} & s_{hv} \\ s_{hv} & s_{vv} \end{bmatrix} = \alpha[s]_a + \beta[s]_b + \gamma[s]_c \tag{7}$$

Where

$$\alpha = \frac{s_{hh} + s_{vv}}{\sqrt{2}} \tag{8}$$

$$\beta = \frac{s_{hh} - s_{vv}}{\sqrt{2}} \tag{9}$$

$$\gamma = \sqrt{2}s_{hv} \tag{10}$$

In general, $[s]_a$ is referred to single bounce scattering. Thus, the complex coefficient α, given at (8), represents the contribution of $[s]_a$ to the final measured scattering matrix. The second matrix, $[s]_b$ represents the scattering mechanism of a dihedral oriented at 0 degrees. In general, this component indicates a scattering mechanism characterized by double bounce scattering. Consequently, β stands for the complex coefficient of this scattering mechanism. Finally, the third matrix $[s]_c$ corresponds to the scattering mechanism of a diplane oriented at 45 degrees. As it can be observed in (4), and considering that this matrix is expressed in the linear orthogonal basis (h,v), the target returns a wave with a polarization orthogonal to the one of the incident wave. From a qualitative point of view, the scattering mechanism represented by $[s]_c$ is referred to those scatterers which are able to return the orthogonal polarization, from which, one of the best examples is the volume scattering produced by the crop or forest canopy (Pottier *et al.*, 2005).

3. RESULTS AND DISCUSSION

Backscattering coefficients of paddy fields at X-band range from about -50dB ~ -5dB. Fig. 1 shows temporal variations of backscattering coefficients at polarization and incident angle 45° for the X-band. VV-polarized backscattering coefficients higher than hh- and hv/vh-ones during rooting stage. The hh-, vv-polarized $\sigma°$ steadily increased toward panicle initiation stage and thereafter decreased and again increased about mid-September. Change of $\sigma°$ in X-band at 45° is similar to last year (Kim *et al.*, 2007).
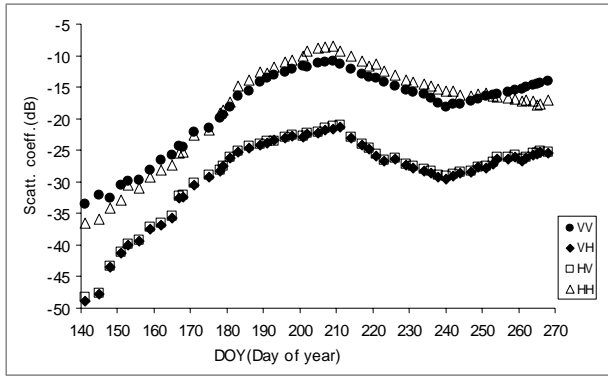
Fig 1. Temporal variations of backscattering coefficients at polarization and incident angle 45° for the X-band.

We have performed polarimetric decomposition of paddy data such as single, double and volume scattering to extract the scattering information effectively.   value which represents single bounce scattering increased as rice growth peaked at panicle formation stage and thereafter decreased.   value which stand for volume scattering increased toward panicle formation stage and value change lowed. In general, as crop was grow up volume scattering was increased. However, this results   value higher than   value during rice growth. At present, we analyze scattering characteristics of paddy rice using others decomposition such as krogager, Cameron decomposition.
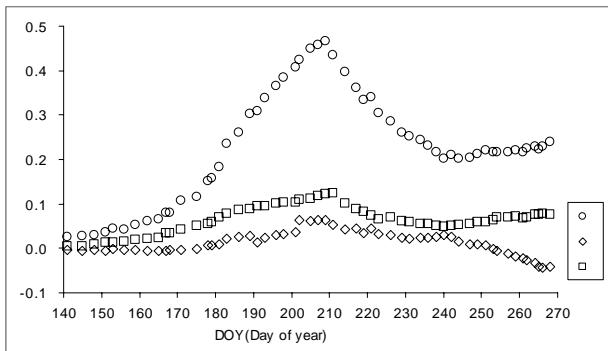
We conducted a correlation analysis between the backscattering coefficients from band and plant variables such as LAI, biomass and grain weight. The lower frequency bands, such as L and C, were closely related with the mass information of the whole canopy such as LAI, biomass, while the higher-frequency band, such as X, is weakly correlated with them but closely correlated with the other variables such as grain weight (Inoue *et al*, 2002; Kim *et al*, 2007).

Table 2 shows relationship between backscattering coefficients in X-band and rice growth parameters. Backscattering coefficients in X-band were weakly correlated with LAI and biomass. Grain weight was correlated with backscattering coefficients with vv-polarization in X-band.

Table 2. Relationship between backscattering coefficients at X-band and plant variables

	LAI	Biomass (g/m²)	Plant height(cm)	Grain weight (g/m²)
VV	0.43[*]	0.48[*]	0.40[*]	0.83[**]
HH	0.68[*]	0.75[**]	0.72[**]	0.62[*]
HV/VH	0.60[*]	0.68[*]	0.73[**]	0.48[*]

4. CONCLUSIONS

Backscattering coefficients of rice crop were investigated with an automatically-operating ground-based scatterometer. The temporal variations of the backscattering coefficients of the rice crop at X-band during rice growth period. We have performed polarimetric decomposition of paddy data such as single, double and volume scattering to extract the scattering information effectively. We investigated the relationships between backscattering coefficients and the plant parameters.

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