C-band/HH Backscattering Characteristics of Paddy Fields: Implications for Rice-growth Monitoring

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KEY WORDS: SAR Backscatter, Rice Growth Stages, Growth Monitoring

ABSTRACT

A study was conducted to investigate the backscattering characteristics of paddy fields and the potential of C-band/HH RADARSAT Fine Beam mode SAR data for rice growth monitoring. Measurements of field parameters were made concurrent to image acquisition. The SAR data was fully calibrated by correcting the LUT scaling gain and incidence angle variation. Results of the study showed very characteristics radar backscattering signature of paddy fields, with a dynamic range of about 12 dB. Paddy fields appear very dark during the early vegetative phase and turn brighter during the reproductive and ripening phases. The good correlation between plant height and SAR backscattering coefficient makes possible the production of a map showing paddy fields at different height classes, which correspond to the growth stages of rice. Several implications for rice-growth monitoring could be concluded from the findings: (a) plant height is a good parameter to map growth stages of rice. However, since plant height does not change significantly from the reproductive phase, adequate information on biomass may contribute to better understanding of the changes in radar backscatter from reproductive phase onward; (b) between-field variability in backscatter necessitates segregating measurements from different rice varieties; (c) within field variability in backscatter implies careful selection of homogeneous area for extracting mean intensity value; and (d) the possibility to segment rice and non-rice areas from single SAR image using the lower and upper threshold values of the backscattering coefficient of paddy fields.

1. INTRODUCTION

Agriculture is one of the main potential application areas of remote sensing in recent years. The 1990's, in particular, have seen major developments in the use of satellite remote sensing for agricultural monitoring and yield forecasting. This trend is a result of the growing need for regular information on crop growth cycles and acreage, which is very important to estimate production for each year or for any particular production period.

In South East Asia, rice remains the most important crop and plays a very important role in the economy. Consequently, decision makers place great importance on the collection of information about the actual and predicted production of rice. This information is necessary to ensure that adequate stock is available for domestic consumption, and for planning import or export of the commodity. There is currently no reliable way of collecting this information, which in most cases are gathered using interviews or records from farmers. Therefore, monitoring of rice growing areas and growth stages by satellite remote sensing has become a great challenge. The use of radar data is considered more appropriate than the high-resolution visible and infrared images because of the persistent cloud cover and unfavorable weather conditions that characterize the region.

Judging from the past proceedings of ACRS, research interest on the use of radar remote sensing for rice monitoring in Asia dates back to the early 90s. To cite few examples, RAO et al. (1994) concluded that ERS-1 SAR is suitable for identification and acreage estimation of paddy crop in India. The study of Karnchanasutham et al. (1995) in Thailand revealed that it is difficult to identify rice crop from single-date ERS-1 SAR, but is possible with multi-temporal ERS-1 SAR data (Aschbacher et al.,

1995) to the extent that phonological growth stages of wetland rice field could even be classified into 5 stages as suggested by Bahari et al. (1997).

The potential use of RADARSAT for rice monitoring has also been investigated early. The work of Staples et al. (1994) demonstrated, to limited extent, the identification of rice crops using a single RADARSAT simulated standard mode image. The report on paddy rice monitoring with RADARSAT-1 in China (Ross et al., 1998) showed that rice exhibits a 12dB change from the beginning to mid-growing season and remains relatively constant at –15dB during the second half of the growing season. However, similar study by Yun and Treuhaft (1999) in China reported a dynamic range of about 20 dB from the start to the middle of growing season and remains relatively constant at about –8dB.

The radar backscattering coefficient [dB] of paddy fields is related to various phenological parameters on a field-by-field basis (Aschbacher et. al, 2002), thus the use of radar data does not guarantee a straightforward solution in identifying different growth stages of the crop. In particular, radar data is sensitive not only to the structure and moisture content of vegetation canopies, it is also sensitive to soil roughness and moisture content in the case of non-flooded fields. Second, paddy fields in the study area are of small units and often with mixed production pattern (e.g., different planting dates, different varieties).

The potential for rice crop monitoring is strong, but more work is required to make operational use of RADARSAT imagery for rice acreage and yield estimation (Staples and Hurley, 1996; Ross et al., 1998). In this context, the Food Security Project has been conducted from January 2001 in Pathumthani, Thailand to investigate the potential of RADARSAT Fine Beam mode SAR data for rice growth monitoring. The project is a collaborative research by the Asian Center for Research on Remote Sensing (ACRoRS) at AIT, Thailand and the National Institute of Agro-Environmental Sciences (NIAES) of Japan.

2 RADARSAT SAR BACKGROUND

RADARSAT is an advanced Earth observation satellite system developed by Canada to monitor the environment and to support resource sustainability. It is equipped with an advanced radar sensor called a Synthetic Aperture Radar (SAR), a powerful microwave instrument that transmits and receives signals to obtain high-quality images of the Earth's surface in all weather conditions. It uses a single frequency C-Band (5.3 GHz frequency), with HH polarization. The RADARSAT SAR has the unique capability to shape and steer its radar beam over a 5000-km range. Users have a variety of SAR beam mode selections than can image swaths from a narrow 45 km to a large 500 km width, with resolutions ranging from 8 to 100 meters and at incidence angles from 10 to 60 degrees.

2.1 SAR Data Specifications

The RADARSAT SAR data is fine-resolution mode path image acquired about 500 km offset right from nadir. It has a swath width of about 50 km and range and azimuth resolutions of 8-9 and 9 m, respectively. The image is single look, with an incidence angle of 38.41 degrees at the center of the image swath. Pixel resolution is 6.25 meters. Data specifications of the data are described in Table 1 below.

Table 1. Data specifications of the RADARSAT Fine Mode SAR data

	RADARSAT SAR data
Acquisition date (local time)	29 January 2001
Acquisition time (local time)	18:29:51
Ascending/descending	Ascending
Orbit number	79-158A
Absolute orbit	27339.0367
Beam number	FR1
Center incidence angle	38.41
Area coverage (sq km)	2,258
Coverage (%)	100
Lat./Long. Of image center	14 03'N 100 34'E
Lat./Long. Of NW corner	14 14'N 100 19'E
Lat./Long. Of NE corner	14 19'N 100 43'E
Lat./Long. Of SW corner	13 47'N 100 24'E
Lat./Long. Of SE corner	13 52'N 100 49'E

Source: RSI RADARSAT Technical Proposal, November 2000

3. METHODOLOGY

The overall project work could be summarized into 3 major components: (a) field survey to measure plant height and biomass, water depth, and gather other relevant information such as planting date, seeding rate, rice variety, age of crop at the time of survey, length of growing period, and yield; (b) satellite data acquisition and processing; and (c) modeling and generation of rice height map.

3.1 Field Survey

Field surveys were conducted to measure plant/field parameters and gather relevant information necessary to compliment the SAR data. Plant heights were measured from the water surface (in case of paddy fields with standing water) to the top of canopy. On the same locations, water depths were also measured. Plant biomass were measured from a 50 x 50 sq. cm plot. The rice plants were cut from the ground (for non-flooded field) or from the water surface (for fields with standing water). The wet and dry plant biomass were calculated after weighing the fresh and dry weights of the rice straws and grains, respectively. Locations of field boundaries were identified using GPS.

3.2 Radiometric and Geometric Corrections

The SAR data was corrected for LUT scaling and incidence angle variation following the procedures outlined for extracting sigma nought from RADARSAT CDPF products (ALTRIX Systems, 2000). The LUT scaling and incidence angle corrections were carried out using the IDL procedures provided by RS-Tech Consulting Co., Ltd. The corrected amplitude data were rescaled to a calibration constant of $K=3x10^8$ (Intensity) in order for the data to fit within the unsigned integer range.

Geometric correction of the SAR data was made to assure that the location of a target in the SAR image matches the real geographic location on the ground. To facilitate geometric correction, 5 small, passive trihedral corner reflectors were designed, constructed and installed in areas that have presumably low backscatter contribution. The exact locations of the corner reflectors were determined using differential GPS.

3.3 Data Analysis and Modeling

A fully calibrated SAR data was generated after geometric and radiometric corrections. This led to further analysis and integration with the field data (Figure 1). The regions of interest (ROIs) were delineated based on the GPS locations of the field boundaries. Careful considerations were made to include only the homogeneous area within each field. This means that the ROIs had to be redefined until their coefficient of variation (CV) is about 1. After satisfying this condition, the backscatter coefficient (σ^o) was calculated for each ROI.

$$(\sigma^o) = 10\log_{10} \langle I \rangle - 10\log_{10} K; \quad \text{where: } \langle I \rangle = \text{mean intensity; } K = 84.77 \text{ dB} \quad (1)$$

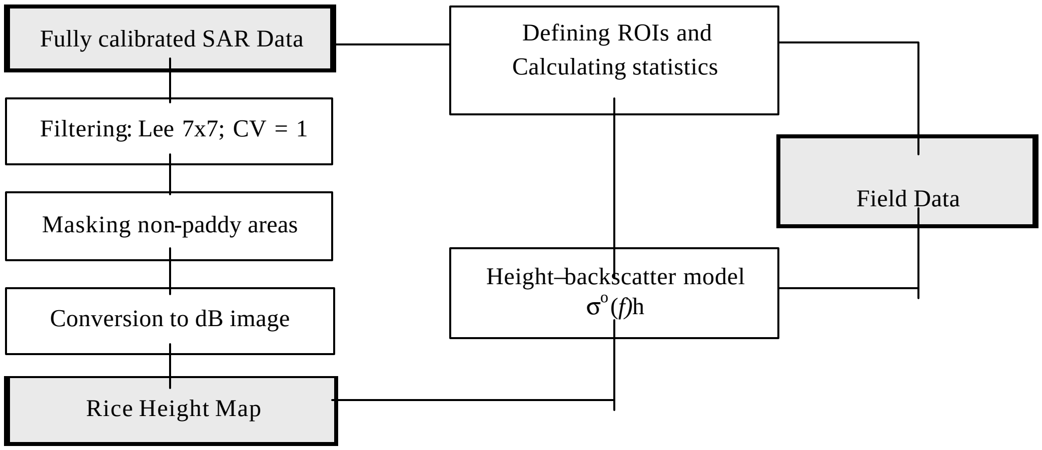

Figure 1. Processing steps to generate rice height map from height-backscatter model

Lee filtering of the fully calibrated SAR data was performed in 4 iterations, using a 7x7 window and a CV of 1. Non-paddy areas from a GIS data were masked out of the filtered image, followed by conversion to dB image. A regression analysis was performed to examine the height-backscatter relationship. Applying the derived backscatter- height model to the dB image, a rice height map was generated using 5 classes (Table 2).

Table 2. Description of rice height classes

Class	Height (cm)	Growth Stage
1	<21	Early vegetative
2	21 – 38	Middle vegetative
3	39 - 60	Late vegetative
4	61 – 78	Reproductive
5	>78	Ripening

4. RESULTS AND DISCUSSION

Analyses on the interrelationship between yield related parameters (height vs. wet and dry biomass) were made. Results revealed no significant relationship between plant height and biomass (Figure 2). This could be attributed to the following: (a) the biomass samples were from different rice varieties; (b) irregularity of planting density in broadcast seeding; and (c) limited number of samples (13) used in the analysis. Since plant height does not change significantly from the reproductive to ripening and harvest phases, adequate information on biomass may contribute to better understanding of the changes in radar backscatter at these phases.

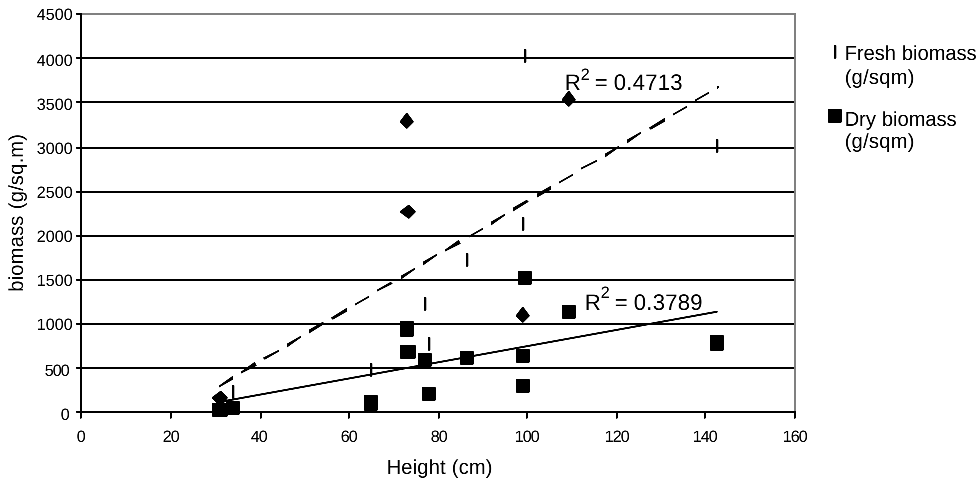

Figure 4. Scatter plot between plant height and biomass

4.1 Rice Growth Monitoring

There are 3 major crop growth phases of rice: vegetative, reproductive and ripening phases. The vegetative phase starts when young seedlings emerged from the broadcasted seeds until maximum tiller production. At the early vegetative phase, the low backscatter from the rice fields is attributed to smooth surface scattering of the standing water. As the plants grow and increase in height, backscatter also increases. The mean σ^o value is approximately –12 dB at the early vegetative phase (~3 weeks after broadcasting) to about –7 dB during late vegetative phase. This corresponds to mean plant heights above water surface of approximately 21 and 60 cm, respectively.

The plants continue to grow during the reproductive phase, which may begin during maximum tillering or just after the maximum tillering activities. The reproductive phase is marked by the development of young panicles until flowering. The backscatter coefficient of rice at this stage varies between –7 and –4 dB, corresponding to plant heights between 60 and 78 cm, respectively.

The ripening phase for most rice varieties lasts about 30 days (ESA, 1995; Luh, 1980). For a 100 day, short-cycled varieties, this means that ripening of the grains do not start after about 2 months from seeding. The average height of plants during the ripening phase varies depending on the variety, and could range from about 80 cm to 1 meter. This corresponds to a backscatter of above –4 dB. The radar backscattering coefficient of rice fields shows distinct temporal change during the growing cycle. As can be seen in Figure 3, the backscatter coefficient increases with the increase in height of the rice plants. Applying the relation between the backscattering coefficient and rice height to the dB image, rice height map with 5 classes was produced (Figure 4).

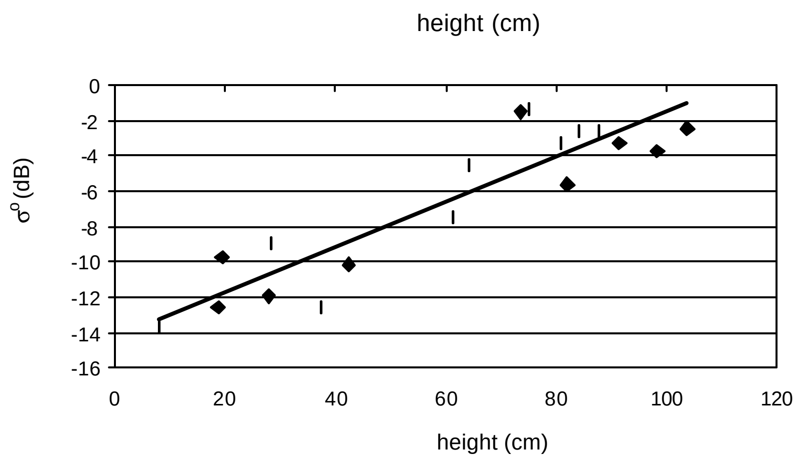

Figure 3. Radar backscattering coefficient vs. plant height (R^2 = 0.82).

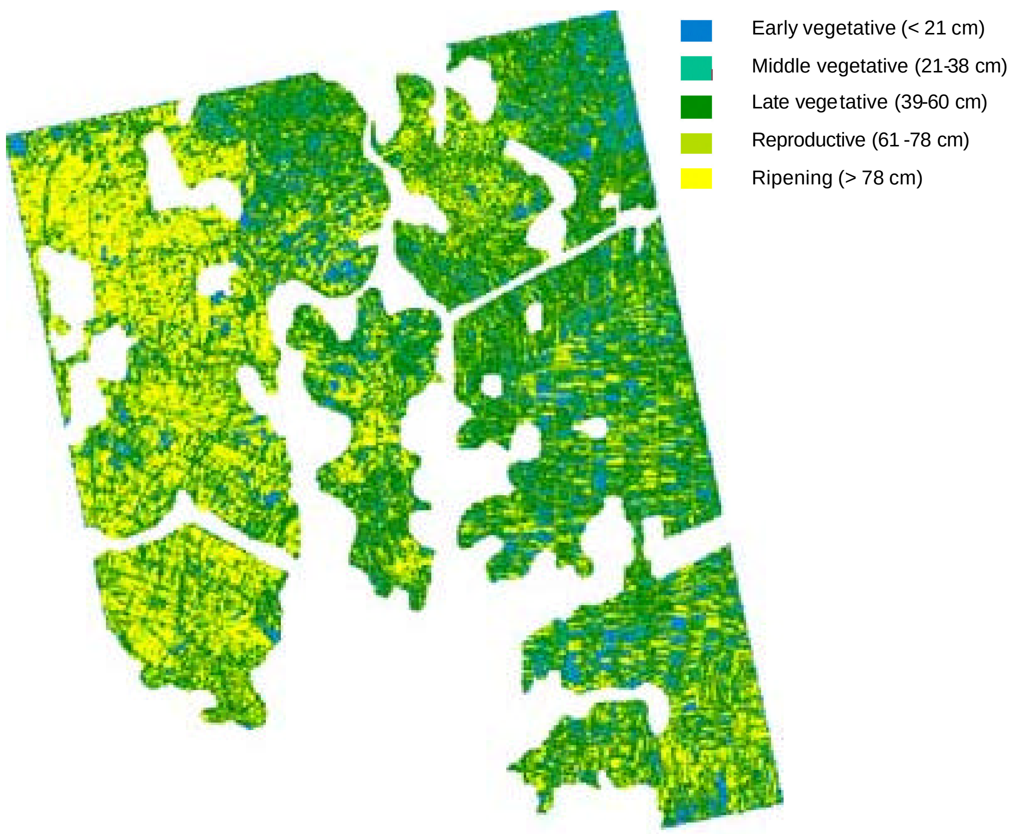

Figure 4. Height map representing different growth stages of rice

5. CONCLUSION AND RECOMMENDATION

The result confirmed the potential of RADARSAT Fine Beam SAR data for monitoring crop growth stages of rice. Good agreement between radar backscattering coefficient and plant height was achieved with R square equals to 0.82. Applying the backscattering coefficient and plant height model to the dB image makes possible the production of a map of the rice fields at different height classes, corresponding to the growth stages of rice.

The implication is that plant height is a good parameter for characterizing rice crop growth. While plant height is easier to obtain with accuracy than plant biomass, a good estimate of the latter is important to characterize backscatter signature of paddy fields, from reproductive to ripening phases, when plant height does not significantly change anymore. Field measurement of growth-related parameters may be improved by (a) collecting adequate number of samples for biomass measurement of plants during vegetative, reproductive and ripening growth stages; and by (b) segregating plant height, biomass and water depth measurements taken from different rice varieties.

Some points are worth exploring to improve the accuracy of the end product. These include the procedure to segment rice and non-rice areas in the image from single SAR data. A good geographic database of non-rice areas is a good starting point in masking out them out from the image. Further to this is to segment rice and non-rice areas using the lower and upper threshold values of the backscattering coefficient of rice. While this seems to work by masking out targets whose backscattering coefficients are higher than that of the rice upper threshold, this may be a problem for masking out non-rice areas with low backscattering coefficients similar to paddy fields with standing water.

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