Classification of RADARSAT-2 full polarization time-series for irrigated rice plantation and yield estimation

Chonthicha Chitpaiboon Amornchai Prakobya and Jiratiwan Kruasilp

Geo-Informatics and Space Technology Development Agency
120 The Government Complex Building B 6th Floor, Lak Si, Bangkok 10210, THAILAND
iam_thicha@hotmail.com

ABSTRACT

Thailand is one of the world's top rice producers and exporters. The estimation of rice yields and cultivation areas are important to make decisions and policies. Nowadays, Remote Sensing techniques are widely used for rice monitoring. The objectives of this study were to classify the rice plantation and to estimate rice yield in Suphan Buri province, Thailand. The RADARSAT-2 full polarization time-series were used to examine the correlation between SAR backscattering coefficient and biophysical parameters of rice. In this study, the irrigated rice plantations were classified by using a combination of the k-means and maximum likelihood classification method. Then, the integration of Support Vector Machine (SVM) and spatial data such as behaviors and skills of farmers as well as water management were observed and analyzed in rice plantation. Additionally, the regression analysis was also used to estimate rice yield. The results showed that the backscattering coefficient is highly correlated with rice high, Leaf Area Index (LAI), age, and biomass. The SVM method could be used for classification of the rice plantation especially in irrigation zone where the different plantation dates are. The high accuracy of the rice yield estimation was found at regional scale. Further study for evaluating the output of satellite data is accurate in the area. Future studies should be performed in conjunction with other information, such as meteorological data, together with the estimated dry weight (Dry matter) from satellite data. Using the model to calculate the yield of harvest index is more accurate.

Key Words: Rice classification, Yield estimation, RADARSAT-2, Time-series

Introduction

Rice is the staple food of more than half of the world's population. In most cultivation areas, rice is grown in tropical and subtropical regions. The world's dominant rice export region is Southeast Asia, where production exceeds consumption. Generally, the rice-growing season is covered by heavy cloud and frequent precipitation. Thus, a major advantage of Synthetic Aperture Radar (SAR) imagery is appropriate for monitoring and estimating rice cultivation under climatic conditions. [1] The Radar system has been received greater attention in agricultural applications. The multi-temporal SAR data have been used to monitor the growth conditions of rice. The backscattering coefficient (σ^0) of rice fields is associated with the flooding of paddy in prior to transplanting stage, which low backscatter results from the backscattering from water surface. At this stage, rice field can be easily separated from other non-rice areas in the Radar imagery [2], [3] and [4]. Aschbacher, J. [5] investigated backscattering coefficient based on European Remote Sensing 1 (ERS-1), showing that the rice fields appear very dark during the flooded vegetative phase and turn brighter during the reproductive and ripening phase. The backscattering coefficient also shown good correlated with rice plant height. Le Toan [3] found a close correlation between rice height and planting date at two different test area using ERS-1 imagery. Chakraborty and et al. [6] and Shao and et al. [1] determined the rice growth due to the different techniques of rice cultivation based on multi-temporal SAR imagery. Inoue [7] found a high correlation between the backscattering coefficient of C-band and Leaf area index (LAI). Bouvet and Le Toan [8] developed the time series of dual-polarization Advanced SAR (ASAR) data from the Environmental Satellite (ENVISAT) data for the production of rice maps in the Mekong Delta. Wu and et al. [9] found that the HH/VV polarization ratio derived from

RADARSAT-2 was sufficient for discriminating of rice, banana, forest, and river area. Ribbes [10] found the correlation among SAR backscatter coefficient, plant age, plant height, and biomass. Hoang and Bernier [11] investigated the temporal variation of backscattering coefficients based on RADARSAT-2 in Horizontally (HH) and cross-polarized (HV) polarization and the Support Vector Machine (SVM) algorithm for classification of rice field. The result showing that the HH is better than HV polarization for rice detection. Yan Li and et al. [12] demonstrated that the RADARSAT ScanSAR data can be used to rice yield estimation based on the relationship between the backscattering coefficient of multi-temporal SAR data and the biomass of rice.
The main objectives of this study were to classify the rice plantation and estimate rice yield in Suphan Buri province, Thailand. The RADARSAT-2 full polarization time-series were used to examine the correlation between SAR backscattering coefficient and biophysical parameters of rice.

Study area

The study area is located in Suphanburi province between 14° 28′ N latitude and 100° 4′ E longitude (Figure 1). It is about 25 km^2 in the Central Plain of Thailand where rice is one of the major crops. The annual average temperature of the study area is about 33° Celsius. Most of the total irrigated area is planted to rice. Growing of rice is double-crop rice cycles that are early-season and late-season of the year. The first irrigated rice cultivation period start from November and harvest in February. However, there is some area started planting rice in December or January and harvested in March or April. The second rice crop is cultivated in May or June and harvest in September. Some areas will be planted in the third crop which begins preparation for planting in late September and harvest in December (**Table 1**). The planting and harvesting are depending on the farmer's skills and rice plant species used.

Table 1 Rice system of study area

Crop cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
First crop												
Second Crop												

Cultivated Harvested

Materials

Eight scenes of Fine Quad Polarization modes (Single Look Complex product) RADARSAT-2 images at C-band (5.3 GHz) were programmed throughout the growing season in 2011 over the study area. The swath width of the image is about 25 km. Most of images are specified in terms of incidence angle range from 41 - 42.4 degrees (excepted on 19 March 2011) (Table 2). The ground measurement of rice parameters were conducted in parallel to the SAR data acquisition.

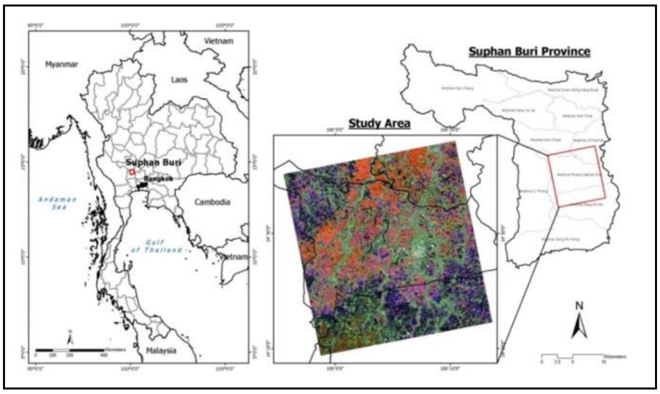


Figure1 The red frame shows the study area in Suphanburi province. The RADARSAT-2 Quad polarization image was acquired on 23 June 2011. The HH, HV, and VV polarization were shown in red, green, and blue color, respectively.

Table 2 The date of the RADARSAT-2 imagery for 2011

Beam mode	Acquisition date	Incidence angle (deg.)	Pass	Polarization (*)
FQ22	23 Feb	41 – 42.4	ASC	HH, HV, VH, VV
FQ26	19Mar	44.4 – 45.7	ASC	HH, HV, VH, VV
FQ22	6 May	41 – 42.4	ASC	HH, HV, VH, VV
FQ22	30 May	41 – 42.4	ASC	HH, HV, VH, VV
FQ22	23 Jun	41 – 42.4	ASC	HH, HV, VH, VV
FQ22	17 Jul	41 – 42.4	ASC	HH, HV, VH, VV
FQ22	10 Aug	41 – 42.4	ASC	HH, HV, VH, VV
FQ22	3 Sep	41 – 42.4	ASC	HH, HV, VH, VV

(*) HH = Horizontal polarization, HV = Horizontal and Vertical polarization, VH = Vertical and Horizontal polarization, and VV = Vertical polarization

Methodology

The process can be divided into four steps: (1) Pre-processing, (2) correlation analysis, (3) rice area classification, and (4) rice yield estimation (**Figure 2**)

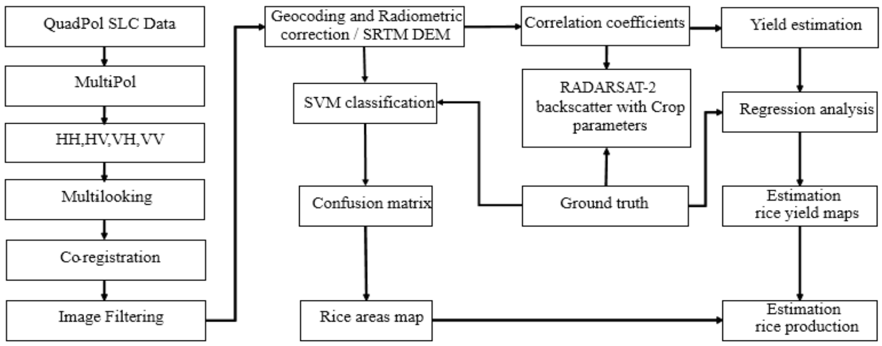


Figure 2 The flowchart methods

1. Pre-processing

The step used to pre-process the Fine Quad Polarization modes (Single Look Complex product) RADARSAT-2 images consisted of conversion of the data into the radar backscattering coefficient (dB), images co-registration are achieved by using a set of tie point which bring two images into the same coordinate system, and the Gamma filtering of 5 × 5 kernel size was used to suppress the speckle noise over the SAR data application. The equation for RADARSAT-2 calibration is given by[13]:

$$\sigma_{ij} = 10 * \log_{10}((DN_i^2 + A_0) / A_i) + 10 * \log_{10}(\sin(\theta_i))$$

σ_{ij}^0 is radar backscattering coefficient, i is pixel, θ is incidence angle, and A_0, A_i are scale offset and gain constants.

The Shuttle Radar Topography Mission (SRTM) 90 meter Digital Elevation Data (DEM) from the National Aeronautics and Space Administration (NASA) were used to determine geocoding and radiometric calibration in order to reduce the amount of image distortion.

2. Correlation analysis

The correlation analysis measures the relationship between rice biophysical and backscattering coefficients. The ground measurement of rice parameters were conducted in parallel to the SAR data acquisition. Measurements were taken for thirteen rice sampling sites measuring 100 x 100 meters. Collected measurement included: measurement height, date, biomass, leaf area index (LAI).

3. Rice area classification

The Support Vector Machine (SVM) classification method is applied to separate the rice crop area and the other area [12]. The SVM is a supervised learning model derives from the statistical learning theory, used for a classification system.

4. Rice yield estimation

The ground measurement of rice parameters were conducted in parallel to the SAR data acquisition. Measurements were taken for 200 sample plots measuring 1× 1 km^2. Collected measurement included: wet and dry weight of rice. The equation for grain yield is given by:

Grain yield (kg/ha) = Number of panicle (m^{-2}) × spikelet per panicle × filled spikelet (%) × grain weight (g) × 10^{-5} [14]

Then, a more accurate way of finding the fit curve is the least square method. The multiple linear regression was used to obtain the relationship between the backscattering coefficient and grain yield.

Result

1. The RADASAT2 Quad- polarization data provides the single polarization such HH, HV, VH and VV. and the ratio of dual polarization includes HH/VV, HV/HH and HV/VV. The correlation between backscatter coefficient and biophysical of rice was shown in Figure3. In general, HH-polarization is obviously highest stepwise change in all four polarization. The stepwise change in HV/VH-polarization was greater than VV-polarization. The total backscattering of HH-polarization is also the highest value except seeding development period which VV-polarization has higher backscattering than HH-polarization. A high correlation has been found between HH-polarization and LAI which is 0.8540. The correlation between VV-polarization and LAI is the lowest.

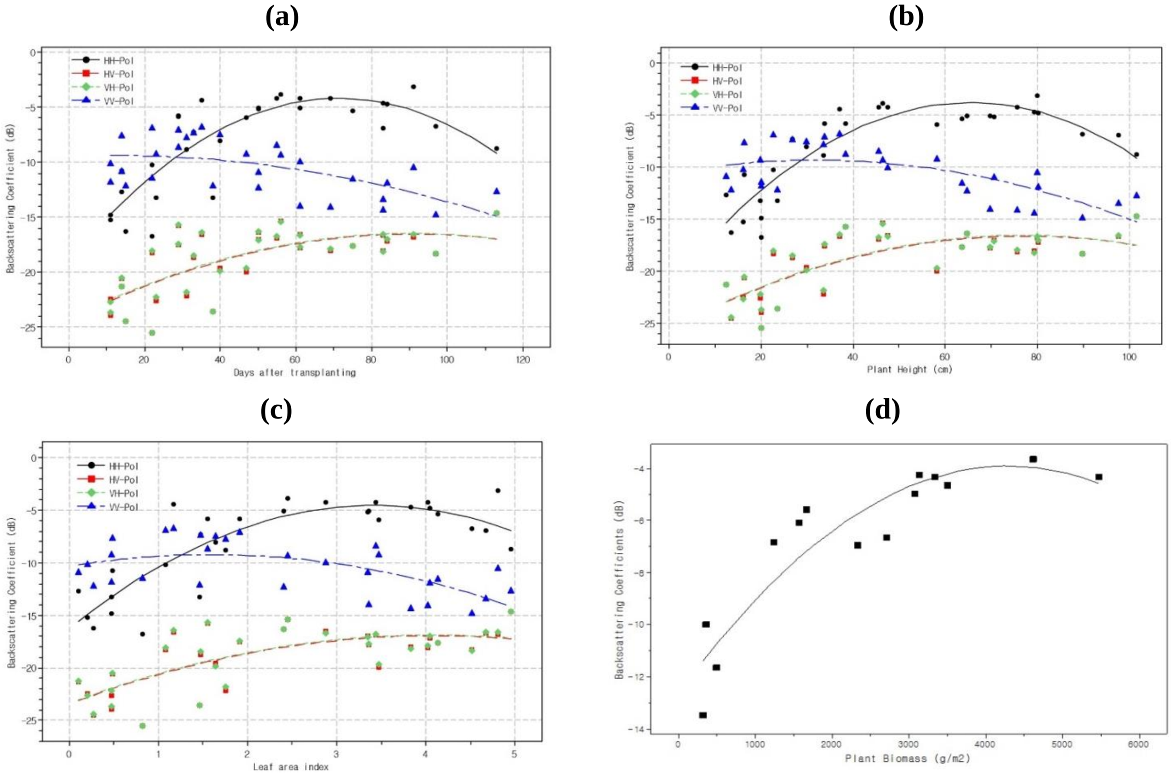


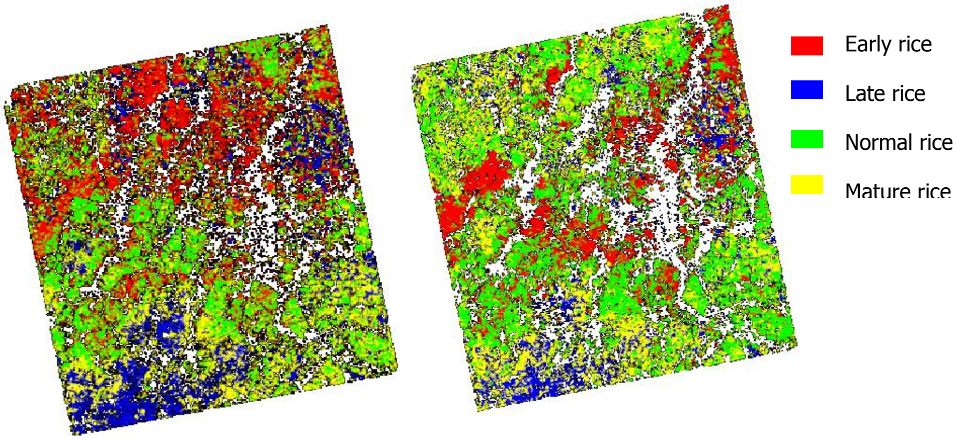
Figure 3 The correlation among backscattering coefficient (dB), days after transplanting, plant height, leaf area index, and plant biomass.

Table 3 The correlation between backscattering coefficient and biophysical parameters

Polarization	Plant height	Days after transplanting	Leaf area index	Biomass
HH	0.8110	0.7132	0.7355	0.8481
HV	0.5592	0.4911	0.5154	0.4510
VH	0.5620	0.4869	0.5152	0.4489
VV	0.4493	0.3352	0.3630	0.5660
HH/VV	0.8012	0.8519	0.8540	0.8122

2. The figure 4 show the result from Support Vector Machine (SVM) classification method investigated that the rice plantation areas were distinguish into two phase: In the first crop, the early rice and late rice plantation areas were cultivated in February and March, respectively. The normal rice is growth stage that cultivated in November or December while mature stage has been harvested in April or May. In the second crop, the early rice is cultivated in early May while the late rice is cultivated in late-June and July. The growth stage is in May and June, then harvested in September.

3. For multi-date single polarization data, table 4 shows the confusion matrix of the classification result from early rice; the highest overall accuracy of mature stage is 94.76% and the kappa coefficient is 0.85. While the confusion matrix of the classification result from late rice; the highest overall accuracy of growing stage is 97.13% and the kappa coefficient is 0.88.



(a) **(b)**

Figure 4 The result from Support Vector Machine (SVM) classification. The left picture (a) is first crop and right picture (b) is second crop.

Table 4 The accuracy of rice classification

Classify	First Crop	Kappa coefficient	Second Crop	Kappa coefficient
Early rice	76.16	0.63	72.34	0.50
Late rice	85.25	0.78	89.76	0.81
Normal rice	91.08	0.82	97.13	0.88
Mature rice	94.76	0.85	96.29	0.84

4. The multiple linear regression analysis was used to estimate rice yield among crop cutting method, backscattering polarization, and rice acreage from RADARSAT-2 satellite imagery in 2011. Table 5 shows the correlation between HH, VV, and HH/VV polarization in six sampling sites.

Table 5 The correlation of difference polarized on 2011

Site	R^2		
	HH	**VV**	**HH/VV**
STG	0.917	0.923	0.986
PPY	0.875	0.662	0.891
WNY	0.916	0.909	0.967
BMP	0.769	0.828	0.921
SNK	0.663	0.554	0.450
KKR	0.931	0.873	0.886

The highest coefficient of determination was 0.986 in HH/VV polarization at STG site. The multiple regression analysis of time series of RADARSAT-2 according to the following equation:

$$Y = -16.356X_1 + 36.876X_2 + 17.790X_3 + 800.567$$

where Y (kg ha^{-1}) is rice yield prediction; X_1 is HH/VV of the first month; X_2 is HH/VV of the second month; X_3 is HH/VV of the third month. (Figure 5)

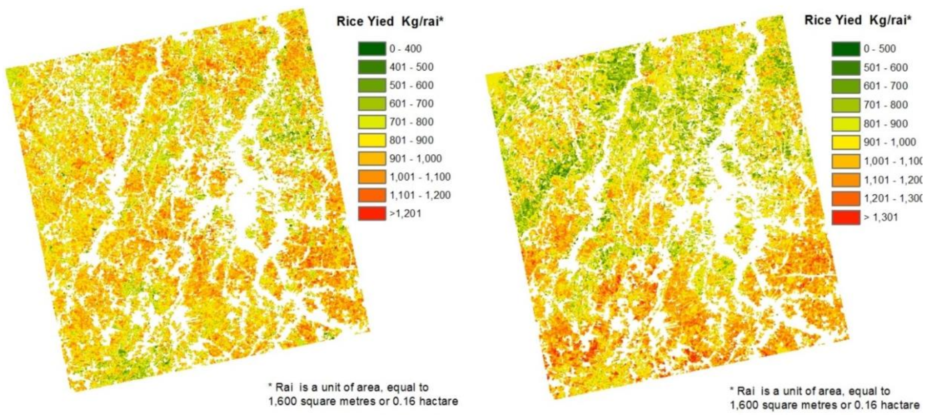


Figure 5 The rice yield map shown first (left) and second (right) crop

Conclusion and discussion

This research is part of pilot project for rice field estimation study. In this study, the RADARSAT-2 full polarization time-series were used to examine the correlation between SAR backscattering coefficient and biophysical parameters of rice. The integration of Support Vector Machine (SVM) is suitable for distinguished rice plantation area and other land use. In addition, it could be used to classify rice plantation area in different crop growth periods, cultivation method, and irrigated system. The rice yield estimation from satellite data show the high accuracy at regional scale. Future studies should be performed in conjunction with other information, such as meteorological data, together with the estimated dry weight (Dry matter) from satellite data. Using the model to calculate the yield of harvest index is more accurate.

References

[1] Y. Shao, X. Fan, H. Liu, J. Xiao, S. Ross, B. Brisco, R. Brown, and G. Staples, “Rice monitoring and production estimation using multitemporal RADARSAT,” *Remote Sensing of Environment*, vol. 76, no. 3, pp. 310–325, Jun. 2001.

[2] M. Chakraborty, K. R. Manjunath, S. Panigrahy, N. Kundu, and J. S. Parihar, “Rice crop parameter retrieval using multi-temporal, multi-incidence angle Radarsat SAR data,” *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 59, no. 5, pp. 310–322, Aug. 2005.

[3] T. Le Toan, F. Ribbes, N. Floury, M. Fujita, and T. Kurosu, “Rice crop mapping and monitoring using ERS-1 data based on experiment and modeling results,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 35, no. 1, pp. 41–56, 1997.

[4] T. Kurosu, M. Fujita, and K. Chiba, “The identification of rice fields using multi-temporal ERS-1 C band SAR data,” *International Journal of Remote Sensing*, vol. 18, no. 14, pp. 2953–2965, Sep. 1997.

[5] J. Aschbacher, A. Pongsrihadulchai, S. Karnchanasutham, C. Rodprom, D. R. Paudya, and T. Le Toan, “Assessment of ERS-1 SAR data for rice crop mapping and monitoring,” *Geoscience and Remote Sensing Symposium, 1995. IGARSS ’95. “Quantitative Remote Sensing for Science and Applications”, International*, vol. 3, pp. 2183–2185, 1995.

[6] M. Chakraborty, S. Panigrahy, and S. a. Sharma, “Discrimination of rice crop grown under different cultural practices using temporal ERS-1 synthetic aperture radar data,” *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 52, no. 4, pp. 183–191, Aug. 1997.

[7] Y. Inoue, T. Kurosu, H. Maeno, S. Uratsuka, T. Kozu, K. Dabrowska-Zielinska, and J. Qi, “Season-long daily measurements of multifrequency (Ka, Ku, X, C, and L) and full-polarization backscatter signatures over paddy rice field and their relationship with biological variables,” *Remote Sensing of Environment*, vol. 81, no. 2–3, pp. 194–204, Aug. 2002.

[8] A. Bouvet and T. Le Toan, “Monitoring of the Rice Cropping System in the Mekong Delta Using ENVISAT/ASAR Dual Polarization Data,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 47, no. 2, pp. 517–526, Feb. 2009.

[9] F. Wu, C. Wang, H. Zhang, B. Zhang, and Y. Tang, “Rice Crop Monitoring in South China With,” vol. 8, no. 2, pp. 196–200, 2011.

[10] F. Ribbes, “Rice field mapping and monitoring with RADARSAT data,” *International Journal of Remote Sensing*, vol. 20, no. 4, pp. 745–765, Jan. 1999.

[11] K. Hoang and M. Bernier, “Identification of Rice Fields in a Complex Land-Use Region Using RADARSAT-2 Data,” *Eau-Terre-Environnement Center*, pp. 1–4, 2011.

[12] Y. Li, Q. Liao, X. Li, S. Liao, G. Chi, and S. Peng, “Towards an operational system for regional-scale rice yield estimation using a time-series of Radarsat ScanSAR images,” *International Journal of Remote Sensing*, vol. 24, no. 21, pp. 4207–4220, Jan. 2003.

[13] Canadian Space Agency., “Extraction of Beta Nought and Sigma Nought from RADARSAT CDPF Products,” vol. RSI-GS-026, 2000.

[14] S. Yoshida, “Fundamentals of rice crop science,” *The International Riec Research Instittute*, 1981.