The Use of Envisat ASAR APP Data for Rice Yield Estimation – A Case Study of Mekong River Delta, Vietnam

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Abstract

Rice cultivation systems in various countries of the world have been changing in recent years. These changes have been observed in the Mekong River Delta, Vietnam. The changes in cultural practices have impacts on remote sensing methods developed for rice monitoring, in particular, methods using new generation radar data. The objectives of the study were to understand the relationship between radar backscatter coefficients and selected parameters (e.g. plant height, biomass, and age) of rice crops over an entire growth cycle, and to develop a rice yield prediction model using time-series Envisat (Environmental Satellite) Advanced Synthetic Aperture Radar (ASAR) imagery.

Field data collection and *in situ* measurement of rice crop parameters were conducted in An Giang province, Mekong River Delta in 2007. The average values of the radar backscattering coefficients that corresponded to the sampling fields were extracted from the ASAR Alternative Polarisation Precision (APP) images. The temporal rice backscatter behaviour during crop seasons were analysed for HH (Horizontal transmit and Horizontal receive), VV (Vertical transmit and Vertical receive), and polarisation ratio data. The relationships between rice biomass and backscattering coefficient of HH, VV, and polarisation ratio were established.

This study showed that the radar backscattering behaviour was much different from that of the traditional rice reported in previous studies, due to changes brought by modern cultural practices. HH, VV and HH/VV radar values were not strongly related to biomass. Therefore, an agro-meteorological model-based method for rice yield prediction could not be applied. The predictive model based on multiple regression analysis between *in situ* measured yield and polarisation ratios attained good results (97%) and thus proved to be a potential tool for estimating rice production in the study area.

1. Introduction

A primary objective of rice monitoring is rice yield estimation. Accurate crop production estimates can provide important information for agricultural planners and managers in both regional and national scales. This information can be computed on the basis of an estimated yield and rice acreage.

Traditionally, estimates of rice planting area and productivity are based on ground survey data. It is often time-consuming and expensive. In the early 1980s, much attention was paid to using optical remote sensing for crop yield estimation all over the world. Remarkable achievements were obtained after many studies were carried out (Li et al., 2003). Nevertheless, because of the limitations of the data acquisition for optical remote sensing, it was very difficult to carry out real-time monitoring of crop growth and estimate rice yield promptly based on these methods. Hence, radar remote sensing is the obvious choice as the most appropriate data source for agricultural monitoring and crop yield estimating in large areas in the tropical and sub-tropical regions (e.g. Ribbes and Le-Toan, 1999, Li et al., 2003, Chen and Mcnairn, 2006).

Accurate statistics within each rice cycle can be generated by analysing space-borne earth observation data to determine rice acreage. On the other hand, rice yield, production and harvest time are estimated in a predictive way using an approach based on agro-meteorological and a statistical model. The agro-meteorological model (AMM), which is built around a crop growth model, can determine crop yield (ton/ha) based on the parameters for soil characteristics and the rice crop variety. This also includes a full series of daily meteorological data (i.e. minimum/maximum/average temperature, sun radiation, relative humidity, wind speed, sun illumination hours, and precipitation) and the transplanting dates based on satellite data. The production estimate is simply calculated by combining yield estimation and the acreage (ESA/EOMD, 2006).

A methodology for rice yield estimation using agro-meteorological model and radar data was developed by Ribbes and Le Toan (1999). The approach consisted of coupling ERS-SAR data and the ORYZA rice production model (Le-Toan and al., 1999) in order to simulate plant growth and thus the final yield. Seeding date and plant biomass as a function of time were key parameters that could be both retrieved from SAR data and were necessary inputs to production models.

In traditional rice cultivation system, radar backscatter was found to be strongly correlated with certain rice parameters, i.e. plant height and biomass (Le-Toan et al., 1997). Backscatter of rice fields increases steadily during the growing stage and then reaches a saturation level. In this study, an analysis of the relationship between radar backscatter and modern cultivated rice biomass in An Giang province, Mekong River Delta was delineated (Lam-Dao et al., 2008). HH and VV polarisation data increased strongly until the plant fresh biomass reaches 1000 g/m^2 (about 30 days after seeding). Nevertheless, for non-flooded fields, the increase in HH was smaller and VV even decreased. A saturation level of backscatter was reached at around 2000 g/m^2 at the middle of crop cycle. After saturation level, radar backscatter remains stable and slightly reduced for HH and rose for VV until biomass got to maximum values.

Concerning the polarisation ratio (HH/VV), only the increase of HH/VV at the beginning of the season was clearly observed, however, this increase was restricted to the first month or a limit of 1000 g/m^2. After this date, the backscatter of non-flooded fields had a large dispersion with respect to biomass. Thus, retrieving rice biomass using HH, VV or HH/VV was not applicable to modern rice practices that prevailed in the study area. Consequently, the use of agro-meteorological model was not pursued due to the poor radar-biomass relationships. Instead, this study implemented the statistical model as presented in this paper.

2. Study area and data used

In the Mekong River Delta of Vietnam, the rainy season usually lasts for seven months from May to November, and floods annually occur starting from August. A dike system has been built and intensified in recent years to block the floodway into the fields during the flood season. This has increased the number of crops during the wet season from one crop to two crops of rain-fed rice, named Summer Autumn (SA) and Autumn Winter (AW) crops. In the dry season, an irrigated rice crop, Winter Spring (WS) has been grown

The study area is the An Giang province (Figure 1), extending from 10^{o} 12’ to 10^{o} 57’ N latitude and 104^{o} 46’ to 105^{o} 35’ E longitude. The province is located in the Mekong river plain, South of Vietnam and is surrounded by Kien Giang, Can Tho and Dong Thap provinces, and Cambodia. Located about 190 km from Ho Chi Minh City, An Giang has an area of 3,536.8 square kilometres, with a population of about 2,231,000 people (GSO, 2007).

Source: www.angiang.gov.vn

Figure 1. Location of An Giang province in the country.

The Envisat ASAR APP data of C-band (5.3 GHz frequency and 5.6 cm wavelength), HH&VV polarisation, IS2 incidence angle (19.2^{o} - 26.7^{o}), and ascending mode at 35-day repeat interval were available during the year of 2007. APP images have a nominal spatial resolution of 30 m x 30 m and pixel size of 12.5 m x 12.5 m with a swath width of about 100 km.

3. Methods

For pre-processing of multi-temporal ASAR APP data, there are several steps. They consisted of a) image calibration or conversion to the radar backscattering coefficient sigma nought (σ^{o}), b) image registration, and c) image spatial filtering. Image calibration consists of correcting SAR images for incidence angle effect and for replica pulse power variations to derive physical values. This transformed SAR precision images into intensity images expressed in σ^{o} in dB (decibel). Image registration was performed to register the calibrated images (dual polarizations and multi-date) using control point methods. Spatial filtering was done to reduce the speckle effect in the image. In this work, enhanced Frost spatial filter has been applied to each image (Lam-Dao et al., 2008).

By using multiple regression analysis, the correlation between backscattering coefficients σ^o of multi-date ASAR APP images acquired during the crop season and the *in situ* measured yield was derived. The distribution maps of estimated rice yield were then produced on the basis of that relationship. Consequently, rice production was finally estimated on the basis of these yield maps and rice/non-rice maps (Lam-Dao et al., 2008) (Figure 2).

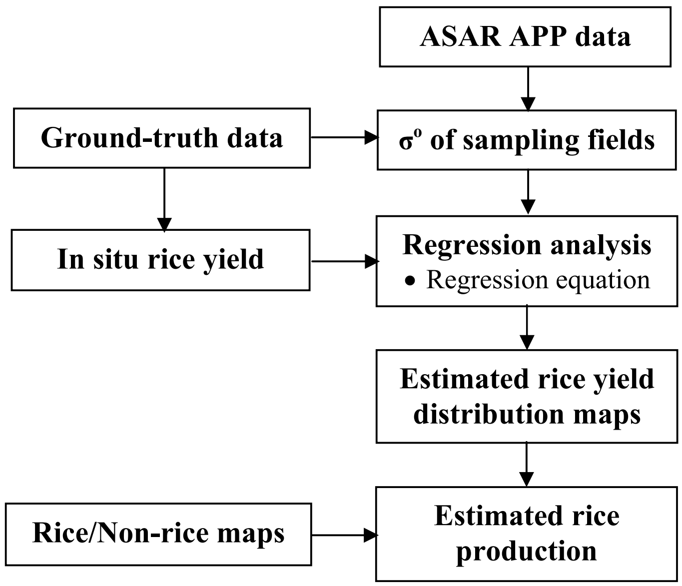

Figure 2. Methods used for rice yield estimation.

In this present work, rice yield and crop calendar of the sampling fields collected on the ground and the new generation dual-polarisation Envisat ASAR data were used. During the rice crop season with 100-day rice varieties used, three ASAR APP images can be, in principle, collected in most cases. However, in the WS 2007 crop, almost sampling fields were collected and measured at only two times. Therefore, on the basis of regression analysis, rice areas grown in SA 2007 season of Cho Moi (CM) district were chosen for examining rice yield estimation.

Regression analysis between rice yield and radar backscattering coefficients derived from three-date ASAR APP images was performed using the line- and curve-fitting functions "LINEST" and "LOGEST" on Microsoft Excel®.

4. Results and discussion

In order to derive the relationship for predicting the rice yield by district, multiple linear and non-linear regression analysis were performed using LINEST and LOGEST functions respectively. The coefficients of determination between yield and polarisation ratio of Cho Moi were higher than that between yield and HH or VV (Table 1). The results showed that the coefficients of determination in both cases (LINEST and LOGEST) were nearly the same.

Table 1. Correlation between HH, VV, HH/VV and sample rice yield in SA 2007 crop of Cho Moi district.

Function	r^2		
	HH	**VV**	**HH/VV**
LINEST	0.653	0.328	0.833
LOGEST	0.659	0.326	0.834

The regression equations between rice yield and polarisation ratios of sampling fields at Cho Moi district in SA 2007 crop using LINEST and LOGEST functions were determined as follows (1, 2):

$$Y_{Ra} = 0.072\ Ra_1 - 0.017\ Ra_2 - 0.002\ Ra_3 + 0.503 \quad (1)$$

$$r^2 = 0.833,\ se_y = 0.11 \text{ ton/ha}$$

$$Y_{Ra} = 1.16^{Ra_1} * 0.965^{Ra_2} * 0.995^{Ra_3} * 0.503 \quad (2)$$

$$r^2 = 0.834,\ se_y = 0.22 \text{ ton/ha}$$

where

Y_{Ra} : rice yield (kg/m^2),
Ra_1 : polarisation ratio of first date image,
Ra_2 : polarisation ratio of second date image,
Ra_3 : polarisation ratio of third date image,
r^2 : the coefficient of determination,
se_y : the standard error for the y estimate.

In the case of the LINEST function used, the values of r^2 and se_y were 0.833 and 0.11 ton/ha, respectively. It indicates that the relationship is positive and can be consequently used to predict the yield for all rice fields planted in SA 2007 crop season of the Cho Moi district.

The detected rice fields were classified into 17 yield levels, ranging from 0.5 to 10 ton/ha through analysis of the relationship between rice yield and backscattering coefficients of three-date ASAR APP images acquired over the rice growing period.

The yield of rice fields planted in SA 2007 crop at Cho Moi district was estimated on the basis of the correlation between *in situ* rice yield and polarisation ratios (Equation 1). The rice fields with estimated yield levels ranging from four to six ton per hectare were dominant and occupied 89.8% total of rice area planted in this crop season (Table 2), whereas the statistical average yield of rice in SA 2007 crop at the district was 4.86 ton/ha (AGSO, 2008). Consequently, there was a good agreement between rice production estimated from ASAR APP and the official statistics with the difference of 3.2% between them (Table 3). This accuracy of yield estimation was higher than those reported in the previous studies (e.g. Ribbes and Le-Toan, 1999, Li et al., 2003, Chen and Mcnairn, 2006).

Table 2. Yield estimation for SA crop in Cho Moi district using three-date polarisation ratio and LINEST regression analysis.

	Rice area (Ha)	**Estimated yield (Ton/Ha)**	**Estimated production (Ton)**	**Percentage (%)**
	5.4	0.5	2.7	0.0
	21.1	1.5	31.7	0.0
	120.8	2.5	302.1	0.4
	1033.0	3.5	3615.3	4.4

	2621.6	4.25	11141.7	13.6
	6476.5	4.75	30763.6	37.6
	4614.0	5.25	24223.5	29.6
	1279.9	5.75	7359.3	9.0
	374.9	6.25	2343.0	2.9
	132.3	6.75	893.2	1.1
	58.5	7.25	424.2	0.5
	28.1	7.75	217.5	0.3
	15.0	8.25	123.8	0.2
	10.0	8.75	87.2	0.1
	6.7	9.25	62.1	0.1
	4.8	9.75	46.8	0.1
	18.2	10	182.0	0.2
Sum	**16820.8**		**81819.7**	**100**

Table 3. Percentage error between rice production in SA 2007 crop at Cho Moi district derived from three-date polarisation ratio data using LINEST function and statistical data.

District name	Agency data (Ton)	Estimated Production (Ha)	Percentage error (%)
Cho Moi	79256	81819.7	3.2

A distribution map of estimated yield of the rice fields planted in SA 2007 crop at Cho Moi district using three-date polarisation ratios and LINEST regression analysis was plotted (Figure 3). Most of the rice fields with yield ranging from four to six ton /ha were distributed throughout the district.

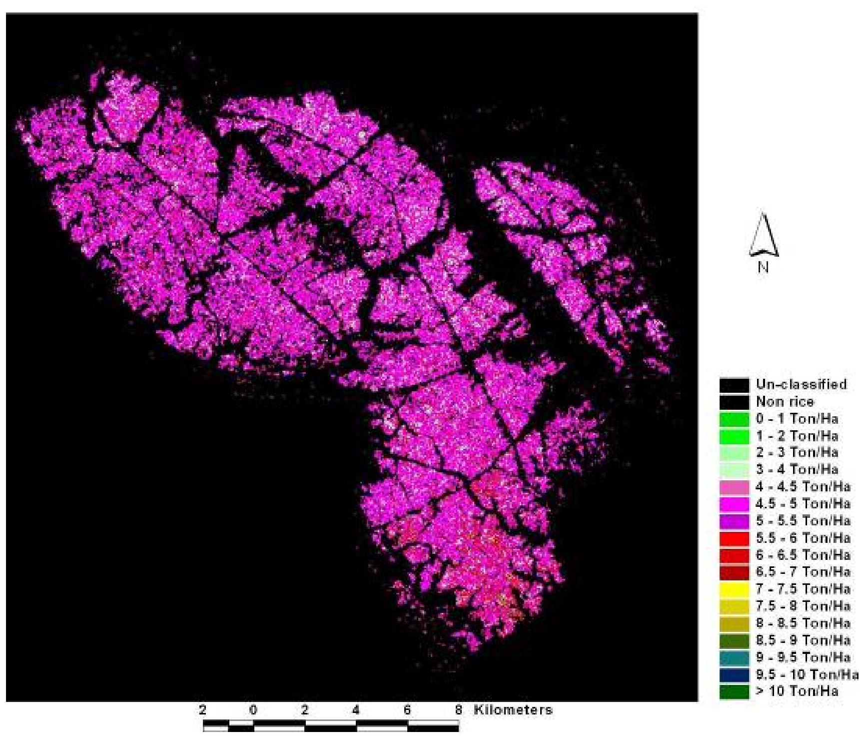

Figure 3. A distribution map of estimated rice yield in SA 2007 crop at Cho Moi district using three-date polarisation ratio and LINEST regression analysis.

The results of the above analysis using a linear regression equation proved that the statistical model-based method worked very well in the case of SA 2007 crop at Cho Moi district where the relationship between in situ yield point data and polarisation ratio data was positive with the high correlation coefficient of 0.913.

5. Conclusions

The statistical model-based method worked very well in the case of Cho Moi district where the relationship between in situ measured yield point data and polarisation ratio data derived from three-date ASAR APP images was positive with the high correlation coefficient. The high accuracy of 97% was found when the rice production estimated from ASAR APP data in this case was compared to the government statistics. This accuracy result is better than that of other previous studies.

The rice yield estimation model varies from region to region, where the cultural practices and crop calendar were significantly different in the study site. Therefore, the yield mapping strategy using time series ASAR APP data is proposed as follows: a) Stratification approach should be firstly used in order to separately classify rice fields in the province into areas with the same cultural practices in the districts, b) Multiple regression analysis between polarisation ratio data and *in situ* rice yield is implemented for each district, c) Based on this correlation, rice yield map is established, and d) rice production is estimated on the basis of the yield map and rice/non-rice map.

Further research should be done to improve and validate the statistical model-based method for predicting the rice production in the study area, Mekong River Delta using dual polarisation ASAR data.

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