# Towards an Operational System for Rice Crop Inventory in The Mekong River Delta, Vietnam Using Envisat ASAR Data

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**Key words**: SAR, Envisat ASAR, rice, Mekong Delta

**SUMMARY**

Food security has become a key global issue due to rapid population growth in many parts of Asia, as well as the effect of climate change. For this reason, there is a need to develop spatio-temporal monitoring system using remote sensing methods that can accurately assess rice area planted and rice production.

Changes in rice cultivation systems have been observed in various countries of the world, especially 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 radar data. The objectives of the study were to understand the relationship between radar backscatter coefficients and selected parameters (e.g. plant age and biomass) of rice crops over an entire growth cycle, and to develop a rice crop inventory system 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 polarisation (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. However, the polarisation ratio (HH, VV) of rice fields at a single date during a long period of the rice season could be used to derive the rice/non-rice mapping algorithm. The predictive model based on multiple regression analysis between in situ measured yield and polarisation ratios at 3 dates during the crop season attained good results and thus proved to be a potential tool for estimating rice production in the study area.

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## 1. INTRODUCTION

Rice (*Oryza sativa*) is one of the world's major agricultural crops and is the staple food for more than half of the world population. In Asia, more than 2,000 million people obtain 60 to 70 percent of their calories from rice and its products (FAO, 2004). Food security has become a key global issue due to the Asian region's rapid population growth, extensive conversion of arable lands, and declining overall productivity in some areas because of climate effects (floods, water shortage, low or high temperature) and plant diseases. To maintain a close balance between rice production and food demand, effective rice monitoring programs are necessary at regional, national and global levels. In particular, there is a need to develop spatio-temporal monitoring system that can accurately assess rice cultivated area, crop vigour and health, and can predict crop yield.

Vietnam is one of the world's largest rice exporting countries since the mid-1990s and the fifth producer country in the world with about 5.5% of the global production (FAOSTAT, 2007). Of which, the fertile Mekong River Delta at the southern tip of Vietnam accounts for more than half of the rice production (GSO, 2007a). In addition, the Vietnamese are among the world top five rice consumers (FAO, 2004). This makes the rice growing areas of the Mekong River Delta a good test region to assess the rice monitoring system using remote sensing techniques.

In the past years, many research projects on rice crop monitoring have been carried out using remote sensing data (Le-Toan et al., 1989, Aschbacher et al., 1995). Among them, space-borne *Synthetic Aperture Radar* (SAR) data was used as main data source. Since the 1990s, a new era of wide-scale availability of radar imagery data has emerged, particularly those collected from earth observation satellites, such as ERS-1 and 2, JERS-1, and Radarsat-1 (Kurosu et al., 1995, Liew et al., 1998, Rosenqvist, 1999). This trend continued into the new century with the most advanced satellite radar systems launched as Envisat in 2002, ALOS in 2006, Radarsat-2 and TerraSAR in 2007, and RISAT-2 in 2009 (Stankiewicz, 2006). More sophisticated radar remote sensing systems are scheduled for deployment in the near future, for example Sentinel-1. Thus, the field of space-borne radar remote sensing continues to provide technological advances, an expanding range of data sources, and new opportunities for research on rice monitoring.

The Mekong River delta is also a good region to study the impacts of rice cultural practices on remote sensing methods. In the last ten years, changes from traditional to modern rice cultivation system gradually adopted. The changes consist of a) increasing the number of crops from 1 or 2, to 2 or 3 crops per year; b) changing from transplanting to direct sowing;

c) using water-saving technology; d) using short-cycle seed varieties (85 to 105 days); and e) using fertilizer and pesticide more intensively.

In this context, the goal of the study was to evaluate the use of SAR data in monitoring the growth and yield of rice crops with changing cultivation conditions, towards an operational system for rice crop inventory in the Mekong River Delta.

## 2. TEST SITE AND DATA

### 2.1 Test site

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. Dike system has been built and intensified in recent years to block the floodway into the fields during the flood season in order to increase 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. As a result, two or three rice crops in a year have been planted, resulting in an increase in rice production from 12.8 million tons in 1995 to 19.3 million tons in 2005, i.e. raising 51% in ten years (GSO, 2006). These multiple crops are made possible by the availability of short cycle rice varieties.

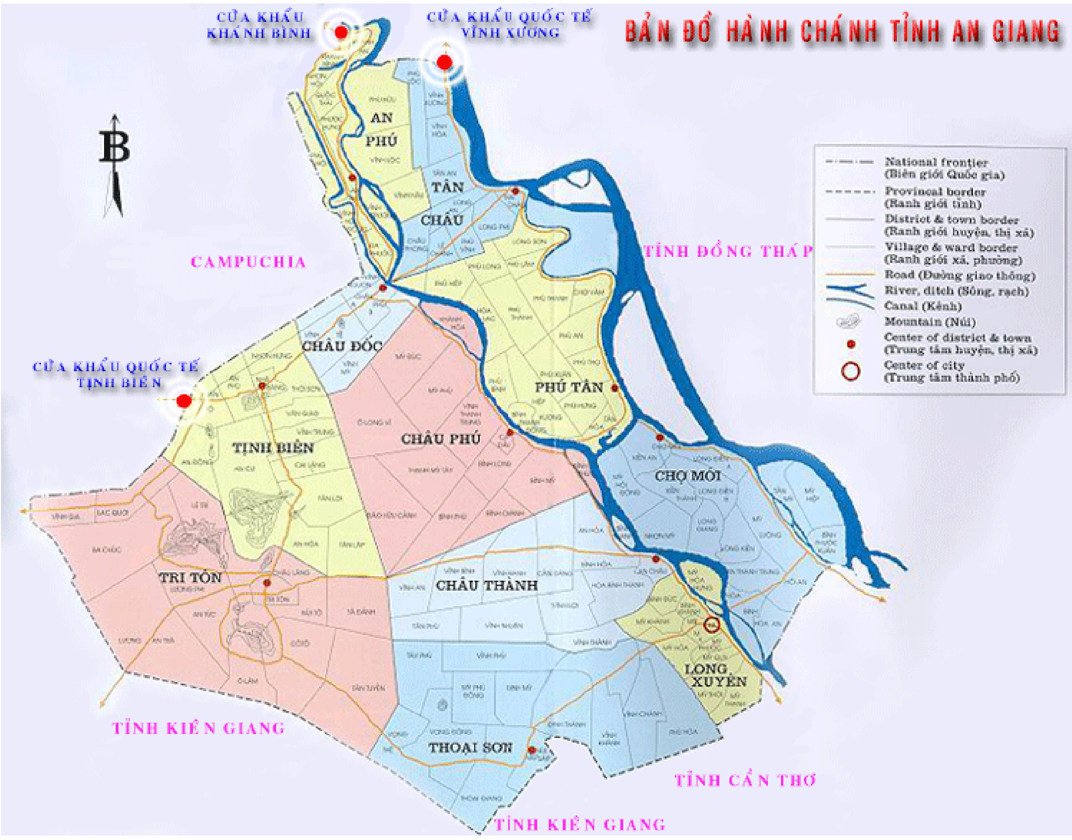



**Figure 1. Administrative boundary map of An Giang province** (www.angiang.gov.vn).

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 and is covered by the entire 100 x 100 km Envisat ASAR scene IS2 mode. 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, 2007b).

An Giang is located in a tropical monsoon climate with an average temperature of 26 to 28 °C. The temperature is 35 to 36 °C in April and May and 20 to 21 °C in December and January. A northerly wind blows from November to April and a south westerly wind from May to October. The annual rainfall is around 1,400 – 1,500 mm (AGDPI, 2009). In the provincial acreage, agricultural land covers the largest area (280,494 ha or 79.3% provincial acreage); of which is dominated (262,649 ha) by rice farms (AGDARD, 2007).

## 2.2 Data

### 2.2.1 Imagery used

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 were available at the following dates during the year of 2007 (Table 1). 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. The mosaic of two ASAR APP scenes covers most the study area. The total number of ASAR APP images used for WS and SA rice crops under study was 12. Sample image taken at the middle of WS crop was presented in figure 2.

**Table 1. List of Envisat ASAR APP data used.**

| ASAR mode | Observation date | Rice crop |
|---|---|---|
| ASAR APP | 13/01/2007 | Winter Spring |
| | 17/02/2007 | |
| | 24/03/2007 | |
| | 28/04/2007 | Summer Autumn |
| | 02/06/2007 | |
| | 07/07/2007 | |

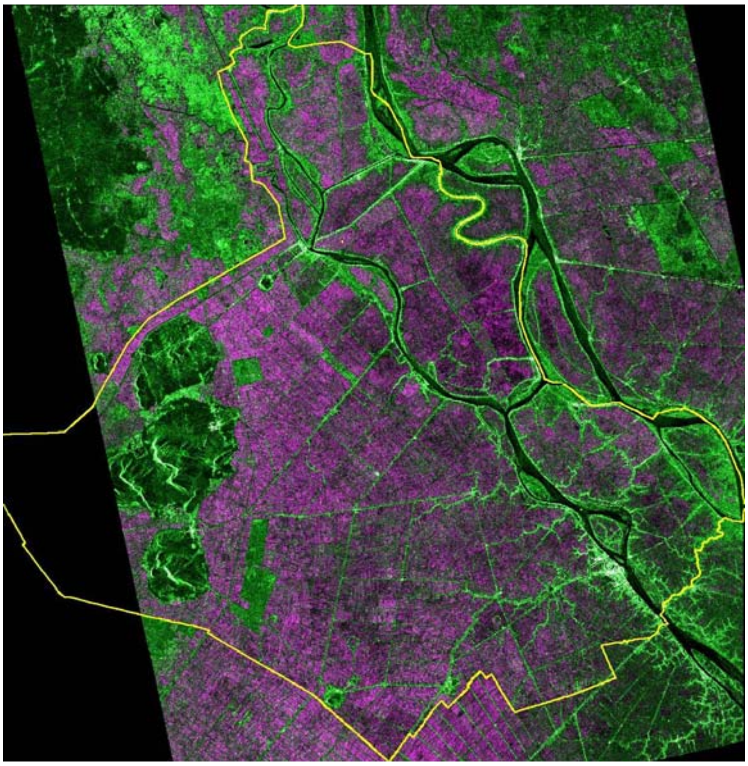


**Figure 2. Colour composite ASAR APP image acquired on 17 Feb. 2007 (R=HH, G=VV, B=HH), provincial boundary in yellow polyline.**

### 2.2.2 Maps

Topographic maps with a scale of 1:50.000, published by the Department of Survey and Mapping of Ministry of Natural Resource and Environment, and their digital maps were used to establish base map GIS data layers, such as water bodies, road network, administrative boundaries, etc.

The existing land use map of An Giang province prepared in the year 2005 was sourced from the An Giang Department of Natural Resource and Environment. This map was used for setting up sample areas and as reference data for accuracy assessment of rice classified images.

### 2.2.3 Ground truth and survey data

Seven sampling areas which were located in districts of Chau Phu, Chau Thanh, Thoai Son, and Cho Moi were selected to meet the research objectives. The main criteria used for the selection of sampling areas were representativeness of rice growing regions in term of physiographic stratification, variety of crop type and cultural practices, and accessibility of the area for ground data collection (Le-Toan, 2002). The measurements were done on five rice fields in each of the seven sampling areas. The size of fields was ranging from 0.2 to 1.7 ha. The parameters measured for each field include general parameters (rice variety, method of planting, sowing/transplanting and harvesting date, plant phenological stage, water layer height, yield), plant, leaf and panicle parameters. Each parameter of plant, leaf or panicle was estimated over 3 to 5 sampling plots of 0.50 x 0.50 m within the fields (according to the field uniformity).

All field works were accomplished during or near the time of the satellite pass. Location of rice fields were identified on the reference map scale of 1:50,000 and measured on the ground using hand-held GPS receivers with a location accuracy of approximately 10 meters.

## 3. METHODS

### Image pre-processing

The ASAR data was pre-processed for image analysis, it consisted of a) image calibration or conversion to the radar backscattering coefficient sigma nought ($\sigma^o$); b) image geo-correction; 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 $\sigma^o$. Image geo-correction was performed to reproject the calibrated images to the selected cartographic projection, i.e. UTM, ellipsoid WGS-84. Spatial filtering was then done to reduce the speckle effect in the image. In this work, enhanced Frost spatial filter was applied to each image (Lopes et al., 1990, Shi and Fung, 1994, Li et al., 2003, Thiel et al., 2007). The software BEST - Basic Envisat SAR Toolbox (ESA/ESRIN, 2009) and ENVI (ITT Visual Solutions) were used for these processing steps.

The average values of the radar backscattering coefficients for the sampling fields were extracted from the pre-processed ASAR APP images. Then, the polarisation ratio (Ra) which is the polarisation difference when the backscattering coefficient is expressed in dB was computed on the basis of the following formula (1):

$$Ra = \sigma^0_{HH} - \sigma^0_{VV} \tag{1}$$

where: $\sigma^0_{HH}$ is backscattering coefficient of HH data in dB
$\sigma^0_{VV}$ is backscattering coefficient of VV data in dB.

### Image classification

For mapping the rice area planted in the study site, the thresholding method was applied. The principle inherent in this method was to threshold the maximum or minimum values of the HH, VV, and HH/VV image to identify image pixels that satisfy by more or less than x dB.

### Classification accuracy assessment

This was done by a sampling approach in which a number of pixels were selected and both the classification result and the reference data were compared. The recommended sampling strategy in the context of rice cropping systems is stratified random sampling (McCoy, 2005). The choice of the testing set of pixels for accuracy assessment is an important consideration. In practice, one may wish to choose between 30 and 60 samples per category (Richards and Jia, 2006). Comparison is done by creating an error matrix from which widely used accuracy measures can be calculated, such as the overall accuracy and kappa statistics.

### Statistical model-based method

By using multiple regression analysis, the correlation between backscattering coefficients $\sigma^o$ of multi-date ASAR APP images acquired during the crop season and the in situ measured yield was derived. The 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.

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, except nine sampling fields in Cho Moi district where three data collection times were done. Therefore, on the basis of regression analysis, Cho Moi district was chosen for examining rice yield estimation in WS and SA 2007 seasons.

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

## 4. RESULTS

### Analysis of rice backscatter

With the present technique of direct sowing, at the early stage of the rice crop cycle, the fields in the test site were wet soil. After 10-20 days, the fields were filled with water. Backscatter temporal variations of HH and VV polarization data for the rice crops in the year 2007 were described as follows: 1) At the beginning of the rice season (<20 days after sowing), flooded and non-flooded rice fields have low and high backscatter, respectively; 2) During the period of 20-70 days, flooded and non flooded fields have similar high backscatter response; 3) After the age of 70 days, almost backscattering coefficient values of the rice fields without water are slightly lower in HH and higher in VV compared to that of fields with standing water; 4) In general, the polarization ratio increases until the period 30-60 days, then decreases until harvest (Lam-Dao et al., 2008).

The radar values of HH, VV and HH/VV were not significantly related to modern practiced rice fields with coefficients of determination $r^2$ of 0.229, 0.161, and 0.645, respectively. In contract, previous studies on traditional practiced rice fields reported that the backscattering coefficient (analysed as a function of age), such as Ribbes and Le-Toan (1999b), showed a coefficient of determination of 0.90 for the case of Radarsat HH data.

An analysis of the relationship between radar backscatter and rice biomass in the study site of An Giang was carried out. The HH and VV data as a function of biomass with a coefficient of determination of 0.374 and 0.019, respectively. HH and VV polarisation data increased strongly until the plant fresh biomass reached 1000 g/m$^2$ (at 30 days after seeding). However, 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 gets to maximum values (Lam-Dao et al., 2008).

The polarisation ratio (HH/VV) as a function of rice biomass had a coefficient of determination of 0.494. 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 1000g/m$^2$. After this date, the backscatter of non-flooded fields had a large dispersion (no correlation) with respect to biomass. Consequently, HH, VV and HH/VV were not strongly related to plant biomass as in the reported traditional rice results, and thus retrieving rice biomass using HH, VV or HH/VV was not applicable to modern rice practices (Lam-Dao et al., 2008). Therefore, other methods need to be explored to retrieve rice information relevant to rice yield estimations.

### Rice mapping

The previous analysis results showed that the ratio HH/VV was a good classifier during the period of 30 days to 60 days after seedling. Classification method based on HH/VV ratio was tested on the image taken in the middle of WS and SA crop cycle (i.e. February and June) to map rice. A threshold of HH/VV (Ra) value = 3dB was used to segment rice and non-rice area. In order to reduce the confusion of rice with other non-rice classes having high HH/VV ratio values (e.g. reed or marshland with vertical structure of the plants, other crops, etc.), an additional criteria was added: VV < -6 dB.

The classification accuracy was determined by randomly selecting a testing set of 174 pixels from the rice/non-rice maps and checking their labels against classes determined from the reference data. The classification accuracy of the resulting maps of WS and SA 2007 crop seasons were presented in the classification error (or confusion) matrices (Tables 2 and 3).

**Table 2. A confusion matrix of rice/non-rice map in WS 2007 crop.**

| **Classification data** | **Reference data (Pixels)** | | |
|---|---|---|---|
| | **Rice** | **Non-rice** | **Total** |
| Rice | 120 | 3 | 123 |
| Non-rice | 7 | 44 | 51 |
| **Total** | **127** | **47** | **174** |

Producer's accuracy
Rice = 120/127 = 94%
Non-rice = 44/47 = 94%

User's accuracy
Rice = 120/123 = 98%
Non-rice = 44/51 = 86%

Overall accuracy = 164/174 = 94%
Kappa coefficient = 0.86

The values listed in the confusion matrices represented the number of testing pixels, in each case, correctly and incorrectly labelled by the classifier. The overall classification accuracies were 94% for WS 2007, whereas 87% for SA 2007 crop season.

**Table 3. A confusion matrix of rice/non-rice map in SA 2007 crop.**

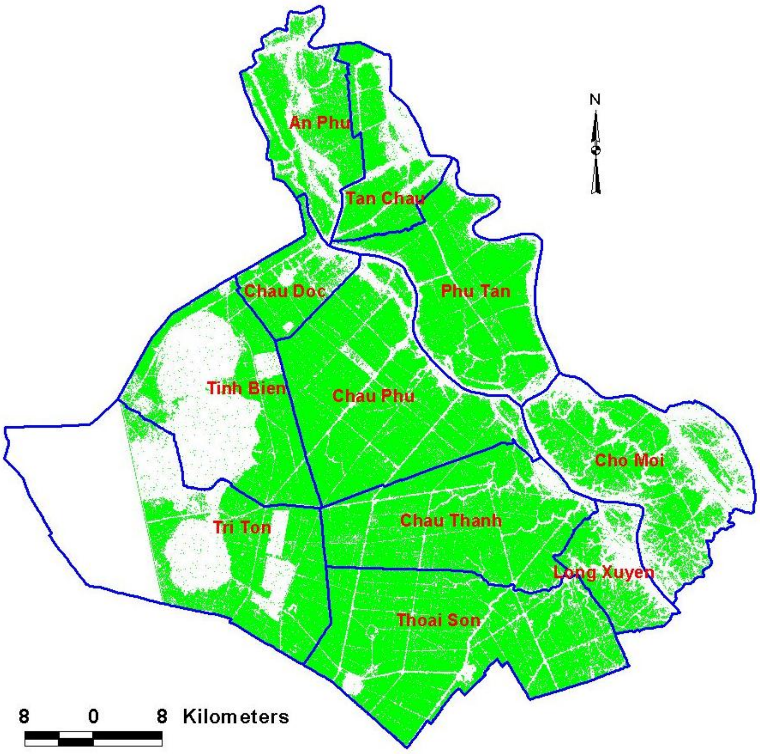
| Classification data | Reference data (Pixels) | | |
|---|---|---|---|
| | **Rice** | **Non-rice** | **Total** |
| Rice | 113 | 8 | 121 |
| Non-rice | 14 | 39 | 53 |
| **Total** | **127** | **47** | **174** |

Producer's accuracy
Rice = 113/127 = 89%
Non-rice = 9/47 = 83%

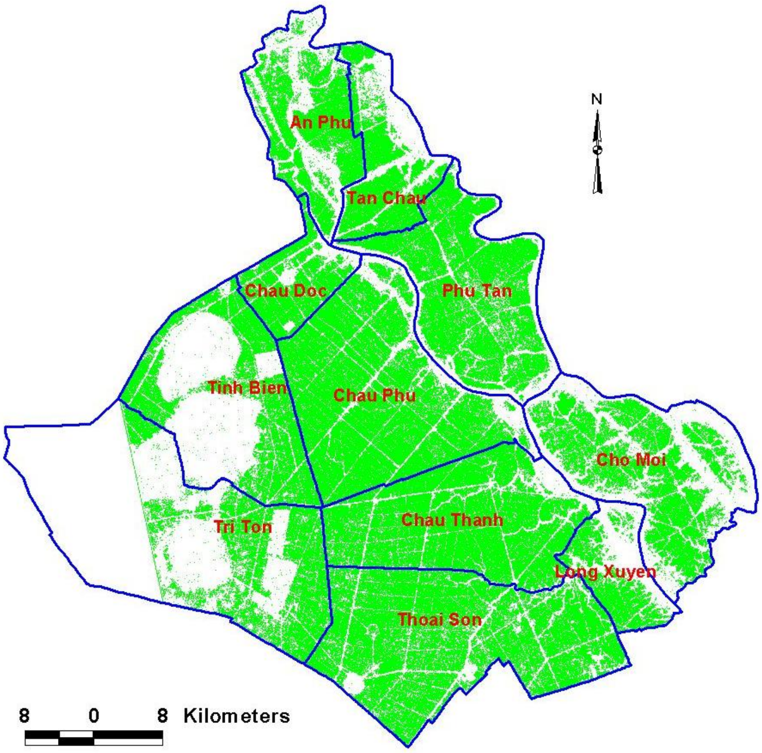
User's accuracy
Rice = 113/121 = 93%
Non-rice = 39/53 = 74%

Overall accuracy = 152/174 = 87%
Kappa coefficient = 0.69

**Figure 3 shows the pixel based mapping results of WS and SA 2007 crops using the optimum thresholds, i.e. Ra ≥ 3 and $\sigma^0_{VV}$ ≤ -6dB.**



(a) WS 2007 crop




(b) SA 2007 crop

**Figure 3. Rice and non-rice maps (rice in green) of WS (a) and SA 2007 crop (b).**

### Rice yield estimation

Since HH, VV and HH/VV at each of the acquisition dates were not strongly related to biomass (hence to the yield), multitemporal values of these measurements were explored. In order to derive the relationship for predicting the rice yield by district, multiple linear regression analysis of the yield as function of the backscattering coefficients (HH, VV and HH/VV) at 3 dates for WS and SA crops was performed using LINEST function. The coefficients of determination between the in situ measured yield of ten sampling fields and their radar measurements were significantly high, except in one case (VV, SA crop), and polarisation ratio were higher than that between yield and HH or VV (Table 4).

**Table 4. Correlation between sample rice yield and HH, VV, HH/VV by rice crop using LINEST function (n=10).**

| Rice crop | $r^2$ | | |
|---|---|---|---|
| | **HH** | **VV** | **HH/VV** |
| WS 2007 | 0.575 | 0.661 | 0.675 |
| SA 2007 | 0.653 | 0.328 | 0.833 |

The regression equations between rice yield and polarisation ratios of sampling fields at Cho Moi district in WS and SA 2007 crops using LINEST function were determined as follows (2, 3):

WS crop: $Y_{Ra} = -0.033\ Ra_1 + 0.017\ Ra_2 + 0.019\ Ra_3 + 0.628$ (2)

$r^2 = 0.675$, $se_y = 0.38$ ton/ha

SA crop: $Y_{Ra} = 0.072\ Ra_1 - 0.017\ Ra_2 - 0.002\ Ra_3 + 0.503$ (3)

$r^2 = 0.833$, $se_y = 0.11$ 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 WS and SA crops, the values of $r^2$ were 0.675 and 0.833, and $se_y$ were 0.38 and 0.11 ton/ha, respectively. It indicates that the relationship is stronger in SA than in WS 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 3). 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, whereas the statistical average yield of rice in the same 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 5). This accuracy of yield estimation was higher than those reported in the previous studies (e.g. Ribbes and Le-Toan (1999a), Li et al. (2003), Chen and Mcnairn (2006)).

In the case of WS 2007 crop, using regression equation (2) rice production was estimated. About 80% of total rice area planted had the estimated yield from 4.5 to 8 ton/ha, whereas the statistical mean yield of the district was 7.36 ton/ha. Consequently, the rice production in WS 2007 crop of Cho Moi district was underestimated, i.e. 19.4% lower than the agency statistics (Table 5).

**Table 5. Percentage error between rice production in WS and SA 2007 crops at Cho Moi district derived from three-date polarisation ratio data using LINEST function and statistical data.**

| Rice crop | Statistical data (Ton) | Estimated Production (Ha) | Percentage error (%) |
|---|---|---|---|
| WS 2007 | 131595 | 106128 | -19.4 |
| SA 2007 | 79256 | 81820 | 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 4). Most of the rice fields with yield ranging from four to six ton /ha were distributed throughout the district.

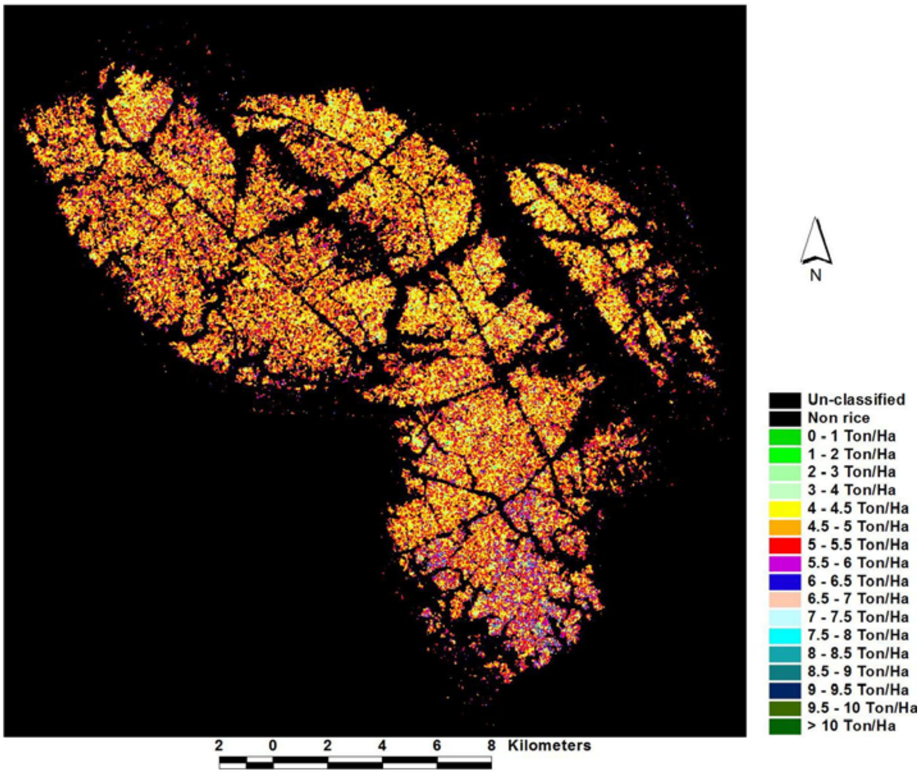



**Figure 4. A distribution map of estimated rice yield in SA 2007 crop at Cho Moi district using three-date polarisation ratio and LINEST regression analysis.**

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 radar backscattering behaviour of rice in the study site is much different from that of the traditional rice plant. Therefore, methods using the temporal change of HH and VV for rice mapping will not work for fields which are not inundated at the beginning of the season. However, the polarisation ratio HH/VV of the single ASAR APP image acquired in the middle period of the crop season (i.e. during the second half of the vegetative stage and the first half of the reproductive stage) is a good rice classifier. Retrieving rice biomass using radar backscattering coefficient of HH and VV data or polarisation ratio data is not applicable to modern rice growing practices that prevailed in the study area.

Thresholding method for rice mapping provided high accuracy of 94 and 87% of WS and SA 2007 crops, respectively, when compared to the reference map. In the case of changing cultural practices in the future, this method can also be used by paying attention to the threshold values of polarisation ratio and VV. These values need to be examined before applying the method.

The Agro-meteorological model-based method for yield prediction could not work in this case study. A statistical model-based method for rice yield estimation, based on the relationship between the in situ measured yield and polarisation ratios extracted from the three-date ASAR APP images taken during the crop growth was established from the multiple regression analysis. Then, pixel-based rice yield was estimated on the basis of this relationship, and the production of rice area was finally computed. The method provides good results in Cho Moi district in 2007, and need further validation using new datasets at different places in order to towards an operational system for rice crop inventory in the Mekong River Delta.

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## BIOGRAPHICAL NOTES

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