Application of multi-temporal Sentinel-1 SAR data for yield estimation of rice crops in An Giang, Vietnam

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Abstract. Rice is one of the main agricultural crops and plays an important role in food security. Therefore, it is essential to propose a method for monitoring the distribution of rice yield. Radar remote sensing data sources provide a sustainable solution for rice monitoring challenges in the countries located in the tropical monsoon region like Vietnam. The SAR (Synthetic Aperture Radar) remote sensing data from the Sentinel-1 satellite provided by the European Space Agency (ESA) is free of charge, has a large coverage and high spatial-temporal resolution. In this paper, rice growing areas in the An Giang province of Vietnam Mekong Delta were analyzed, which demonstrates the potential applications of multi-temporal data and proposes a method to estimate rice yield for agricultural management. The analysis results showed that in 2018 the Winter-Spring rice crop has the highest yield, and the Autumn-Winter crop has the lowest yield. Accurate and timely estimation of rice yield and production can provide important information in terms of spatial distribution and seasonal yield for government and decision-makers in policy making related to import and export.

1. Introduction
Rice is one of the five important grains and is the staple food for most of the world's population. In 2018, about 161.6 million hectares of the world's area was used for rice cultivation with a global production of about 728 million tons [1]. In which, Vietnam produced about 6% of the world's rice production, with a rice growing area of about 7.76 million hectares and a production of about 44.88 million tons [1]. Rice yield and production monitoring has an important significance in agricultural management [2]. Besides, food security has become important due to the rapid population growth of developing countries in Asia including Vietnam, with the majority of the population work mainly in the agricultural sector. Being the 5th rice producing country in the world (in 2018) [3], the information related to rice production
becomes even more urgent. Therefore, it is necessary to have an effective solution to estimate rice yield accurately and timely to support agricultural production management and ensure food security.

Nowadays, most applications of radar remote sensing use backscatter characteristics of rice plants according to growth stages to determine rice growing areas. Applying the backscatter threshold value from the C-band polarizations of RADARSAT-2 imagery in the study of Chen et al. [4] in Taiwan area, Oyoshi et al. [5] in Japan proved the effectiveness in rice monitoring. In terms of rice monitoring using C-band data with single polarization like ERS-1&2 and RADASAT-1, the classification method is based on temporal changes of backscatter intensity which is extracted from multi-temporal images [10–12]. Using HH and VV dual polarization data of ENVISAT ASAR images (C-band) gives better classification results than using only single polarization [13,14]. In particular, the recent Sentinel-1A and Sentinel-1B satellites, which acquire images with a 12- or 6-day period (received from two satellites in some areas), have become a source of free C-band radar images with high spatial resolution (20 m for Interferometric Wide (IW) swath mode). This is an important data source in agricultural monitoring applications, it is especially beneficial for developing countries in the tropics with limited funds, and the ability of radar remote sensing to acquire images is very little affected by weather conditions.

As for the application of radar imagery, recent studies have demonstrated the ability of radar remote sensing in rice monitoring [15] and yield estimation [16]. For estimating rice yield and production, many studies have been conducted using agro-meteorological modeling methods like ORYZA2000 [17] [16] and experimental regression models between radar backscatter values and in situ rice yield [14]. However, when applying the ORYZA model, a lot of ground data is needed. Moreover, there are some other methods using radar remote sensing data as the main input such as: experimental regression [14,18,19], neural network [20], random-forest [21]. In which, the commonly used method is the experimental regression model. Shao et al. [18] used a self-recommended model for the RADARSAT data, based on three different times in three rice growth stages, and achieved an accuracy of 91%. The rice yield estimation model using ENVISAT ASAR APP data [14] and TerraSAR-X StripMap [22] achieved the results with high accuracy when compared with statistical data. In addition, there were also studies that have applied this model to estimate rice yield and production using X-band COSMOSKYMED and C-band RARDASAT-2 [23]. Lam Dao [14] applied an experimental regression model to estimate rice yield from C-band ENVISAT ASAR data. The study then used dual polarization TerraSAR-X data to estimate rice yield and calculate rice production [19]. The main objective of this study was to apply an experimental regression model to estimate rice yield based on rice age [24], which was developed for the study area using C-band multi-temporal Sentinel-1 data for rice yield estimation and for analyzing the spatial and seasonal rice yield distribution in 2018 in An Giang province.

2. Study area, materials, and methods

2.1. Study area
The study area is in the region from latitude 10°12’ to 10°57’N and longitude 104°46’ to 105°35’E. An Giang is one of the leading provinces regarding rice production area in Vietnam Mekong Delta. (Figure 1). Therefore, this province was selected to experiment the application of radar remote sensing in rice growing area monitoring and yield estimation. Table 1 presents the main rice crop calendar in the study area with three crops including Winter-Spring, Summer-Autumn and Autumn-Winter crops. The study area has two distinct seasons: the dry season from December to April, with rainfall accounting for only 10% of the total annual rainfall; the rainy season lasts from May to November, accounting for nearly 90% of the total annual rainfall [25].
Figure 1. Location of the study area, An Giang province and sample fields.

Table 1. Main rice crop calendar in An Giang, Vietnam (WS: Winter Spring crop; SA: Summer Autumn crop; AW: Autumn Winter crop).

| Month | 10 | 11 | 12 | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Rice season |    |    |    | WS |    |    |    | SA |    |    |    |    |    |    | AW |

2.2. Materials
Data used are VH-polarized Sentinel-1 images with IW acquisition mode, spatial resolution of 20 m. For the study area, Sentinel-1A&B satellites have a repeat acquisition time of 6 days. The acquisition period of Sentinel-1 data for rice crops in 2018 was from November 1st, 2017 to November 30th, 2018. These data are used to map rice growing area and estimate rice yield. In addition, the study also collected in situ data in 60 sample fields in the study area. The data collected at the sample fields included sowing date, harvest date, rice yield, etc. These data were divided into two datasets including: training dataset consisting of 41 samples (~70%) and validation dataset with 19 samples (~30%).

2.3. Methods
The study evaluated the ability to estimate rice yield in the 2018 crops by analyzing VH polarized Sentinel-1 data with in-situ data as shown in Figure 2. Radar images were collected during one rice crop, then go through the following steps: a) Pre-processing [26, 27]; b) Rice mapping: applying threshold method for multi-temporal images acquired during the crop season [14, 28]; c) Extracting radar backscatter values according to rice age at the sample fields [29, 30]; d) Regression analysis and mapping estimated rice yield [24].
3. Results
The result of mapping estimated rice yield distribution for the 2018 rice crops was established based on an experimental regression model [24]. Sentinel-1 data were collected in each crop season to estimate rice yield. Figure 3 shows maps of rice yield distribution for the Winter-Spring crop, Summer-Autumn crop, and Autumn-Winter crop in 2018. These results show that it is possible to estimate rice yield of all crop seasons using multi-temporal Sentinel-1 data.

The map of estimated rice yield distribution in the 2018 Winter-Spring crop (Figure 3a) was created by an experimental regression model which based on the correlation between Sentinel-1 VH polarization data and in situ rice yield. The estimated yield distribution result shows that the yield was mostly in the range of 6 to 8 tons/ha. Similarly, the map of estimated rice yield distribution in the 2018 Summer-Autumn crop is shown in Figure 3b. Figure 3b shows that the estimated rice yield is fairly evenly distributed, concentrated in the range of 5 to 7 tons/ha. Finally, the map of estimated rice yield

Figure 2. Process of mapping estimated rice yield using Sentinel-1 remote sensing data.
distribution for the 2018 Autumn-Winter crop is shown in Figure 3c, which shows that the estimated rice yield is also relatively evenly distributed, mainly in the range of 4 to 6 tons/ha.

![Map of estimated rice yield distribution](image)

**Figure 3.** Map of estimated rice yield distribution of Winter-Spring crop (a), Summer-Autumn crop (b), and Autumn-Winter crop (c) in 2018 in An Giang province.

### 4. Discussion

The maps of estimated rice yield distribution by crop season in 2018 were established after validating the classification results of radar remote sensing images based on in situ data collected in the study area and statistics. Validation dataset was collected from 19 samples to validate the model. The results of the
analysis showed that the estimated rice yield of the Winter-Spring crop in 2018 and the in-situ yield is similar, 6.5 and 6.6 tons/ha, respectively, and the RMSE (root mean square error) was 0.8 tons/ha [24]. Therefore, this model shows potential for estimating rice yield in the study area using Sentinel-1 data.

An Giang province, like other provinces in the Mekong Delta (Vietnam’s rice granary), produces up to 3 rice crops per year and is one of the largest rice producing provinces in the country, just behind Kien Giang province. By 2018, the total cultivated area of An Giang in the whole year reached more than 680 thousand hectares; in which the rice growing area was more than 623 thousand hectares. The average rice yield in 2018 reached 6.3 tons/ha with a production of nearly 4 million tons [31]. The result of the estimated rice yield using Sentinel-1 remote sensing data showed a relative error of 12% when compared with the statistics for the 2018 Winter-Spring crop. This demonstrates the possibility of using Sentinel-1 data to map estimated rice yield and estimate rice production for An Giang province, towards building a process for applying remote sensing in near real-time to map rice yield for the whole Mekong Delta.

The results of the yield distribution map of the three rice crops showed that most of them have a yield of 5 to 8 tons/ha. Based on the assessment of An Giang Provincial People's Committee [32], after 10 years of implementing the project "Development of agricultural and forestry plant varieties, livestock breeds and aquatic strains" under Decision No. 2194/QD-TTg dated December 25th, 2009 of the Prime Minister, the rice varieties of An Giang province have undergone a drastic change. In the 2000s, the rate of using high-quality varieties was still low, then by 2018 about 70% of the area used high-quality varieties such as: OM6976, OM4218, OM5451, Jasmine, etc. [32], which increases the production and value of rice for farmers. Therefore, monitoring rice yield and production becomes a necessity in agricultural management to ensure sustainable rice production and food security.

The results of the rice yield distribution map of the 2018 Autumn-Winter crop (Figure 3c), showed that the rice yield was mostly in the range of 4 to 6 tons/ha, lower than the other two crops. Meanwhile, the 2018 Winter-Spring crop had a high rice yield mainly about 6 to 8 tons/ha (Figure 3a). Previously, the Mekong Delta in general and An Giang province in particular had two rice crops, Winter-Spring and Summer-Autumn, the Winter-Spring crop was the main crop due to its high yield, low cost, and the most commodity rice for export. This crop is sown around mid-October of the lunar calendar, when the weather is very favourable, in the dry season – no rain from sowing to harvest – the number of sunny days is high, the temperature is high, so the rice yields are high [33]. As for the third rice crop (also known as the Autumn-Winter crop), sowing is done around July - August of the lunar calendar. This crop is in the rainy season, so sowing is very difficult, when it rains, all seeds must be sown again, the number of rainy days is high (lower number of sunny days), the rice growing is not as good as the Winter-Spring crop, the yield is lower, the cost is higher due to the need to sow/transplant, care and harvest the damp rice; and it also requires to spend money to pump water out, and the money for dike construction and for the reinforcement every year is not yet included. An Giang province developed a system of dikes to prevent floods [34], which help increasing the area of rice cultivation in the Autumn-Winter crop during the rainy season.

This study demonstrated the potential of multi-temporal Sentinel-1 SAR data in monitoring the spatial distribution of rice yields for each crop season in 2018 at the provincial scale. The results show that the rice yield of each crop in the year is different, it depends on the cultivation conditions of each crop, so the average yield is different. This method of estimating rice yield is based on a special rice farming model for An Giang province in the Mekong Delta. The method can be modified to each study area, the calibration and validation steps need to be performed with the local conditions relevant to those areas, especially for the areas that have a rice farming model using different rice varieties, with different climatic and environmental conditions. This study also shows the potential for monitoring rice yield
distribution for each crop season using C-band SAR time series data, which is consistent with previous studies [22,24].

5. Conclusion
The study showed that Sentinel-1 radar remote sensing data can be used to estimate rice yield, which is important information for agricultural management and food security. The rice yield assessment model using Sentinel-1 data in one crop season proved to be an effective method for estimating rice yield at the provincial scale. The results of rice yield estimation compared with in situ yield data are reliable, demonstrating the applicability of multi-temporal SAR Sentinel-1 data to estimate rice yield for agricultural management. The results of the rice yield distribution map show that in 2018, the Winter-Spring crop had the highest rice yield and the crop with the lowest rice yield was the Autumn-Winter crop. These are important information in agronomic management to ensure sustainable rice production and food security. At the same time, the study also points out the necessity to expand the scope of research such as the Mekong Delta to validate the regional rice yield estimation model.

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