Regional Scale Rice Yield Estimation by Using a Time-series of RADARSAT ScanSAR Images

Yan LI[1, 2], Qifang LIAO[2], Shengdong LIAO[2], Guobin CHI [1], Shaolin PENG[3]
South China Normal University (Guangzhou, 510631)[1]
Guangzhou Institute of Geography (Guangzhou , 510070)[2]
Guangdong Academy of Sciences (Guangzhou, 510070)[3]

Abstract

This paper demonstrates that RADARSAT ScanSAR data can be an important data source of radar remote sensing for monitoring crop systems and estimation of rice yield for large areas in tropic and sub-tropical regions. Experiments were carried out to show the effectiveness of RADARSAT ScanSAR data for rice yield estimation in whole province of Guangdong, South China. A methodology was developed to deal with a series of issues in extracting rice information from the ScanSAR data, such as topographic influences, levels of agro-management, irregular distribution of paddy fields and different rice cropping systems. A model was provided for rice yield estimation based on the relationship between the backscatter coefficient of multi-temporal SAR data and the biomass of rice.

Key Words: Remote sensing, RADARSAT ScanSAR, Rice Yield Estimation, China

1. Introduction

Crop yield estimation can provide important information for local governments in arranging agricultural activities. Nevertheless, as the limitation of the data acquisition for optical remote sensing, it is very difficult to carry out promptly a real-time monitoring of crop growth and estimate rice yield. RADARSAT ScanSAR data are the dominant data sources that are provided re-visit schedules, all weather and day/night monitoring for a large area in tropic and sub-tropical regions. This study demonstrates that the images can be conveniently used to estimate rice yield in a large region with only small costs of data acquisition and data handling. An operational system was established in Guangdong province where has the largest base of rice production in China. The information had then been available to the Guangdong government for facilitating the decision-making concerning agricultural activities in the province.

Since the system was proposed to be an operational one, some important issues, such as the reduction in costs of data acquisition and the heavy workloads in data processing, had to be faced. And it is also important to find the methods to reduce the influences of a lower resolution data, topographical features, different crop systems on the rice yield estimation, Radar RS rice yield estimation model and its accuracy evaluation etc.

2. The study area and data selection procedure

2.1 The study area

Guangdong is located in the South China between 20°08′ to 25°32′N latitude and 109°40′ to 117°20′E longitude. It has about 178,080 km^2 on the terrestrial area in which the terrain changes drastically, from flat and low in the southern part to undulating and high mountains in the northern part. The foothill areas and mountains are distributed widely. There are about 31% of mountains, 28.5% of foothills, 16.1% of mesa and 23.7% of plain area. The climate characteristics are not only taken on latitudinal variations but also longitudinal. The average change of latitudinal distribution increases from north to south. The paddy fields are mainly distributed on the flat plain, mesa and intervals of hills and mountains.

2.2 Data selection criteria

As one of the seven beam modes provided by RADARSAT, the standard mode was used in the previous researches of crop study (Li, 1999; Shao, 1999). At least 31 scenes are required to cover the study area with this mode of data. There is a need to test the possibility of reducing the costs of data acquisition and labor by using another mode – SNB (ScanSAR narrow band), which only uses five scenes to cover the whole province. By the comparison of both modes to recognize terrain objects, we found that the spatial resolution differences of the two modes lie solely in the boundary of objects. Although some very small objects may disappear as the resolution decreases, the paddy fields are large enough to detect rice related information. In order to ensure the SNB data can keep enough information for paddy fields after edge enhancement, we carried out a quantitative evaluation for sampling areas. It seems that the SNB images may lose 25% of rice related information, but this can be restored to keep at least 95% of the information of the standard mode after edge enhancement and aggregation with the majority filter. This result makes us much more confident of using only five scenes of SNB data to replace the standard mode with a much lower cost for purchasing and processing data.

3. Methodology

3.1 Rice Cropping Atlas

Through setting up the rice cropping atlas, a solution of rice information extracting difficulty was found for reducing the topographic influence. The atlas includes: 1) the maps for the distribution of different cultivation systems; 2) the maps for the intensity level of paddy field managing; 3) the climate maps; 4) the geomorphologic maps; 5) the maps of paddy calendar; 5) the synthesized assessment of land suitability. All these spatial variations are stored in a GIS database. And according to the atlas, the time-series of RADARSAT ScanSAR images were determined to reflect the complex environmental settings in the whole province for data acquiring. In practice, the data acquisition was still restricted by the temporal resolution of re-visiting circles, fixed paths, and possible occupation by other users. It is strongly suggested to divide the whole region into many smaller zones for SAR classification according to atlas.

3.2 Rice field mapping

The rice field mapping was based on the separability between rice and other types of crops. The separability can be enlarged by using the dynamic information in the whole rice growing period instead of using a single date of SAR data. Before the rice information extraction, a procedure for the SAR image pre-processing (Li, 1999) was carried out to deal with the radiometric disturbance. It includes the frost filtering to reduce the speckle noise, and precise geometric correcting.

A masking technique was applied to exclude some obvious non-paddy pixels from further analysis by using the existing GIS database developed by previous projects (Li, et al.1998). This is important for improving the accuracy of rice recognition. For example, the water class (e.g. rivers) in the GIS database can be used to mask it out of the further analysis. In addition, all locations with slope greater than 13 degrees are impossible for growing paddy rice. They should be also masked out for obtaining better results. According to field investigations, paddy rice cannot be grown in places of high elevations in the region. Thresholds can, therefore, be defined to mask out the sites with elevations greater than certain values. According to the rice cropping atlas, these thresholds can vary from place to place, dependent upon according geographical characteristics. For example, the threshold is 100 m in the flood plains in the southern part of the province, but becomes 200 m in the mountainous areas in the northern part of the province. Under some very extreme conditions (e.g. very remote mountain areas), the threshold is 600 m.

3.3 Rice yield estimating relationship with SNB time series data

The next step is to derive the relationship for rice yield estimation. The detected rice fields need to be classified into nine yield levels through analysis of the relationship between backscatter coefficient (σ^0) and rice biomass in each growing period on the SNB images. The backscatter coefficient is in a 32-bit floating format, but would be better in an integer format which is obtained using the following formula:

$$DN = (\sigma^0 + 50) \times 1000$$

The linear transformed DN value can be conveniently used for establishing the relationships between the backscatter coefficient and the rice biomass. Previous studies have indicated that there is a good correlation for the relationships (Ribbes and Toan, 1999, Hong et al. 1999, Shao et al., 1999). Three dates of SNB data over rice growing period were used to build up the relationships. The regression model is as follows:

$$Y = -27.212X1 + 34.848X2 + 13.584X3 + 431.992 \qquad (R=0.908)$$

Where Y：Yield (Kg); X1：σ^0 of first temporal image; X2：σ^0 of second temporal image; X3：σ^0 of third temporal image; R：Correlation efficient.

The latter is 0.908, which is far greater than the required threshold 0.742 at 0.001 confidence level. It means that the relationship is very positive and the relationship can be used to estimate the rice yield. The final results for the rice yield estimation are presented in two early and late rice estimation maps.

4. Results and discussion

4.1 An operational system of rice yield mapping

The operational system begins with pre-processing of SNB images (Figure 1.), then masks out some obvious non-paddy pixels based on knowledge and GIS database to reduce the uncertainties of rice detection. Maximum likelihood classification was carried out to delineate rice fields from SNB images. A multivariate regression model based on radar remote sensing was established to reveal the relationship between the backscatter coefficient of time-series SNB data and rice yield. Distribution maps of rice yields were obtained after the classification of rice fields on SNB images.

4.2 Accuracy evaluation

The accuracy of the classification was examined by using 4 methods:

1) The first way is to compare the detection results with the paddy fields in the most updated land use maps.
2) Since TM images have a higher spatial resolution than SNB images, TM images were also used to verify the accuracy of the relationship. However, they were just used as ancillary data for checking;
3) Based on the above results, field trips were arranged to collect ground data and location co-ordinates from GPS and to verify the validity of the classification. A correlation analysis was carried out to analyze the collected data. It was found that the both R and R^2 are greater than 0.999 and T check value is 1.212 at 0.05

confidence level. The results indicate the accuracy that the relationship can reach 95% in the flat areas, such as in the Pearl River Delta, but only 80% in the mountainous areas in the northern part of the region. The average accuracy of estimating rice fields is about 90%.

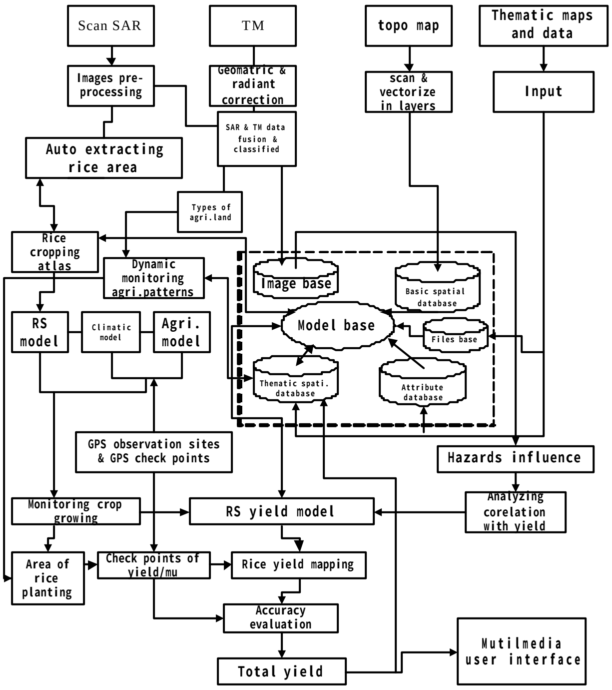

Figure 1. Flowchart illustrated the operational system for rice yield estimation.

4) Table 1 shows another way in which the correlation analysis was calculated between the results of SAR estimation and the statistical data for the early rice and late rice of 2000 in Guangdong. The regression indicates a good correlation between them for the two estimations. The correlation coefficients of R and R^2 were greater than 0.99 with a confidence level reached at 0.055. The accuracies of the estimations were over 94%. This indicates that the relationship is efficient, reliable and operational.

Table 1 Accuracy Evaluation of SAR yield estimation

Eval. Obj.	Regression equation	R	R square	Std. error of estimate	F check	F Sig.	T	T Sig.
Early rice production	Y=1.32x-6384.989	0.999	0.999	31170.46	61274.894	0.000	1.940	0.055
Late rice production	Y=1.135x-561.007	1.000	0.999	229455.26	116142.111	0.000	1.948	0.055
Total production	Y=1.223x-6627.66	0.999	0.999	47449.6	107220.76	0.000	1.994	0.055

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