RICE MAPPING AND MONITORING USING ENVISAT ASAR DATA

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ABSTRACT
Radar remote sensing technology has become an important method for stable and long-time rice monitoring for its capability to operate in all weather conditions. In this paper, ENVISAT Advanced Synthetic Aperture Radar (ASAR) alternative polarization VV/HH data was used for rice monitoring in Xinghua rice experiment site in the middle of Jiangsu Province. Firstly, a threshold classification method was developed for mapping rice growth area, according to the different characteristic of backscatter coefficients between paddy rice and other land surface objects. Then, relational models were built for retrieving rice growth parameters from ASAR image, based on correlation analysis between backscatter coefficients and field measurements. Meanwhile an optical multi-spectral image was used as ancillary data for rice parameters retrieval. As expected, the retrieved rice growth parameters were consistent with those of field measurements.

1. INTRODUCTION
Rice is one of the world’s two major staple foods. It accounts for 15% of the world’s total cultivated area [1], and China is the first rice producer and consumer. In China, information such as rice fields’ acreage, number of crop per year, rice growing conditions which are essential for governments’ decisions concerning crop monitoring, yield prediction or water distribution is often absent or inexact. Therefore, an accurate, reliable and consistent rice growth monitoring and yield prediction systems are necessary, which will allow organized production to satisfy food needs for the population and to ensure economically viable overseas exports.

Traditional rice growth monitoring methods based on field checking are still used for collection of rice paddy production information. But the result is that the accuracy of the collected data is in doubt and limited in local scale, especially that concerning planted or harvested areas. The availability of remote sensing data from different sensors gives the opportunity to rice growth monitoring in large regional scale [2], [3], [4]. However, as the main rice growth areas are in the southern China, it is difficult to ensure successful acquisitions with optical sensors such as LANDSAT or CBERS-01/02 because of the frequent cloud cover. Therefore, Radar satellites are more appropriate for this purpose, since they can collect images independently of the meteorological conditions.

Since the launch of the European ENVISAT satellite, rice monitoring has become one of the most important subjects of application of ENVISAT Advanced Synthetic Aperture Radar (ASAR) data [5], [6]. ASAR works at C-band (wavelength 5.6cm), for which the canopy volume scattering dominates, and operates on five working modes. Alternative Polarization Mode (APMode) product contains two co-registered multi-polarization images. It has been successfully used for crop mapping and monitoring [7], [8], flood detection [9], soil surface parameters inversion [10], [11]. In this paper, we
assessed the efficiency of single-date APMode product containing VV and HH polarizations for rice mapping and monitoring. As for rice mapping, a threshold classification method was constructed based on the rice dual-polarization backscatter differences. For rice monitoring, relational models were built to try to retrieve rice growth parameters from ASAR image, based on a correlation analysis between rice backscatter coefficients and field measurements. Meanwhile, an optical multi-spectral image from CBERS-02 sensor was used as ancillary data in developing relational models.

2. STUDY AREA AND FIELD EXPERIMENTS

2.1 Study area

Figure 1. Red square in the image shows the location of Xinghua rice experiment site in Jiangsu Province.

Study area is located in Xinghua rice experiment site (approximately 32°51’N-32°58’N and 120°00’E-120°06’E) in the middle of Jiangsu Province (Fig. 1). In this region, land surface is rather flat, and height above sea level is about 1 m. Rice season begins in early June and harvested in late October. Other plants are also grown during the rice season, such as soybeans, cotton and various garden vegetables.

2.2 Field experiments

During an extensive field survey in 2006, seven rice growth monitoring areas about 0.5-1 ha each were selected within the study area, and each of them had five sampling sites. Rice growth parameters including plant height, plant fresh/dry biomass, leaf area index (LAI), plant water content and so on were then measured from the 35 (7×5) sampling sites. Observations began from June 20 to October 20 every ten days. Moreover, boundaries of each site were recorded using differential GPS devices; one cotton field boundary was also recorded at the same time.

3. ASAR DATA AND PREPROCESSING

Under the framework of Dragon project, eight ASAR APMode images were received from ESA in 2006 covering the study area, but only half of them were available during the rice season. In this paper, the image of date August 4 was selected for rice mapping and rice monitoring, summary of which was shown in Tab.1. Image preprocessing including radiance calibration, geo-correction, speckle reduction and backscattering image generation was carried out in BEST software. Output of the preprocessing was converted to GeoTIF image type for further analysis.

Table 1. Features of selected APMode image

<table>
<thead>
<tr>
<th>Date</th>
<th>Polarization</th>
<th>Resolution(m)</th>
<th>Coverage(km)</th>
<th>Swath</th>
<th>Incident angle</th>
<th>Product ENL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-8-4</td>
<td>VV/HH</td>
<td>30</td>
<td>100</td>
<td>IS2</td>
<td>19.2°-26.7°</td>
<td>1.9</td>
</tr>
</tbody>
</table>

4. RICE FIELD MAPPING WITH ASAR APMODE DATA

After image preprocessing, backscatter coefficient (VV and HH) was retrieved from the image, and polarization difference (HH-VV) was also calculated. Fig. 2 shows a composite image of the experiment site with VV polarization as red band, HH as green band and HH-VV as blue band. Consulting our differential GPS sampling records, we can easily identify from the figure that most paddy rice was shown in light blue color, waters in very dark color and buildings in yellow color. Therefore, it is
very clear that paddy rice has distinctive characteristic of backscatter behavior from other land surface objects.

Fig. 3 shows the average backscatter coefficients of different land surface objects. The vertical bars show the standard deviation. Four kinds of land surface objects were chosen. Each of them displays different HH and VV polarization backscatter coefficients. It is obvious from the illustration that waters have lowest HH and VV backscatter coefficients, because of specular reflection occurred between radar wave and waters surface. Contrarily, buildings have highest HH and VV polarization backscatter coefficients, this could be for the reason of volume scattering and strong corner reflectance, but marked discrepancy appears in HH polarization backscatter coefficient. At the acquisition date (2006-8-4) low canopy coverage and coarse canopy surface of cotton fields resulted in high VV and HH polarization backscatter coefficients. Large discrepancy was also observed in VV polarization backscatter coefficient, which indicated that interaction between VV polarization wave and cotton fields was influenced by some factors, which could not be ignored. Rice was in the booting stage at the acquisition date with high canopy coverage about 0.3, together with its vertical plant structure and high water content, which have significant impact on the radar wave backscattering. Shown as in the Fig. 3, VV polarization backscatter coefficient of paddy rice was lower than HH polarization backscatter coefficient about 4 dB. The similar result was also found in other studies [12], [13], but it is still difficult to account quantitatively for the different response of the two polarization waves to plant parameters (plant structure, plant water content and biomass). Comparing with cotton fields, rice fields had no apparent change of average HH polarization backscatter coefficient. However, VV polarization backscatter coefficient of paddy rice was lower, this could be for the reason that canopy surface of paddy fields was flat correspondingly and higher attenuation occurred due to vertical structure of rice plant. Therefore, plant structure has great influence on VV polarization backscattering.

It is clear that paddy fields have distinctly dissimilar backscatter behavior of HH and VV polarization in relation to other land surface objects. Thus, a threshold classification method could be applied to retrieve paddy rice optimally. The principle is to threshold the HH-VV image to identify image pixels that change by more than $x$ dB. Nevertheless, in order to reduce uncertainties, other threshold values are obtained by statistical analysis from HH or VV polarization backscatter images. The threshold classifier used in this paper was displayed in Fig. 4. Then a rice/non-rice segmentation image was produced base on the resulting classification image.
Validation of classification accuracy was implemented by using differential GPS sampling records. Formulas to calculate the classification accuracy were introduced in reference [14], but which will not be provided here for its lengthy description. Tab.2 listed the validation results.

Table 2. Validation results of rice mapping

<table>
<thead>
<tr>
<th>Pixels of validation regions</th>
<th>Overall accuracy (%)</th>
<th>Rice identification accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR1) 3888; RO2) 721; OO3) 3907; OR4) 1107</td>
<td>81.00</td>
<td>84.36</td>
</tr>
</tbody>
</table>

1) RR: Rice in validation regions is classified into rice; 2) RO: Rice in validation regions is classified into non-rice; 3) OO: Non-rice in validation regions is classified into non-rice; 4) OR: Non-rice in validation regions is classified into rice.

5. RICE MONITORING WITH ASAR APMODE DATA

In a previous study [15] by Le Toan et al in 1997, a theoretical model of the backscatter behavior of rice fields was developed, determining the physical phenomenon responsible for the rice field radar response at C band-VV polarization-23º of ERS data. The results showed that the most important rice growth parameters accountable for the radar backscattering were the plant height, the plant biomass per volume, the gravimetric water content and the plant structure. However, at any given time, rice growth parameters, and therefore their backscatter behavior, will be different according to the growing stages of the rice and vary spatially. In the following analysis, an emphasis will be put on the rice growth parameters retrieval from the selected ASAR data.

One scene of optical remote sensing data of August 3 from CBERS-02 sensor was obtained as ancillary data, which contains 5 bands covering visible and near-infrared spectrum. Radiance calibration and image geo-correction were implemented before the optical data being applied. The normalized vegetation index (NDVI) was calculated by a ratio of $(\frac{\text{band}4}{\text{band}3} - \frac{\text{band}3}{\text{band}4})$ and $(\frac{\text{band}4 + \text{band}3}{2})$.

For paddy rice in each experiment area, average backscatter coefficients of HH polarization, VV polarization, HH-VV, and average NDVI were retrieved from images. Rice growth parameters measured in August 5 that one day after the ASAR sensor passed the region were also averaged among each experiment area. Tab.3 shows the averaged backscatter coefficients, NDVI and measured rice growth parameters of five experiment areas (The rest two experiment areas were unavailable at this date). Seen from the Tab.3, plant water content appears quite stable among the experiment areas, but large variation appears in the plant dry biomass, the plant height and LAI. Because of the poor field management (no enough fertilizer and suffering from crop pest) after the rice transplanting in D site, it shows the lowest value of rice growth variables (NDVI, LAI, the plant height, the plant dry biomass) in Tab.3 except the plant water content. Next, we conducted a correlation analysis between the backscatter coefficients and parameters mentioned above. The results were shown in the Tab.4.
Table 3. Averaged backscatter coefficients, NDVI and measured rice growth parameters

<table>
<thead>
<tr>
<th>Sites</th>
<th>HH polarization (dB)</th>
<th>VV polarization (dB)</th>
<th>HH-VV (dB)</th>
<th>NDVI</th>
<th>LAI</th>
<th>Plant dry biomass (g/m²)</th>
<th>Plant height (cm)</th>
<th>Plant water content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-6.0188</td>
<td>-10.0166</td>
<td>3.9978</td>
<td>0.6851</td>
<td>3.63</td>
<td>285.36</td>
<td>61.2</td>
<td>83.35</td>
</tr>
<tr>
<td>B</td>
<td>-6.6702</td>
<td>-10.8533</td>
<td>4.1831</td>
<td>0.7322</td>
<td>3.86</td>
<td>325.26</td>
<td>68.1</td>
<td>83.17</td>
</tr>
<tr>
<td>C</td>
<td>-5.8161</td>
<td>-11.0374</td>
<td>5.2213</td>
<td>0.7102</td>
<td>3.37</td>
<td>264.81</td>
<td>64.1</td>
<td>83.90</td>
</tr>
<tr>
<td>D</td>
<td>-6.1920</td>
<td>-8.5037</td>
<td>2.3117</td>
<td>0.6152</td>
<td>1.79</td>
<td>130.27</td>
<td>53.2</td>
<td>83.53</td>
</tr>
<tr>
<td>E</td>
<td>-7.6029</td>
<td>-10.6861</td>
<td>3.0832</td>
<td>0.6748</td>
<td>3.57</td>
<td>312.09</td>
<td>67.5</td>
<td>83.00</td>
</tr>
</tbody>
</table>

As shown in the Tab.4, VV polarization was highly correlated with the NDVI, and with most rice parameters, while it was poorly correlated with the plant water content. The HH polarization was less well correlated with most rice growth parameters than VV polarization, but high positive correlation coefficient was found between HH polarization and the plant water content ($r^2 = 0.875$). HH-VV containing information from both HH polarization and VV polarization showed good correlation with NDVI and LAI. Close correlations between NDVI and LAI, and between LAI and the plant dry biomass coincided with the facts. One the whole, our results suggest that HH polarization is more sensitive to the plant water content, and VV polarization is more sensitive to the plant structure and other parameters such as LAI, plant biomass and NDVI.

Table 4 Correlation matrix of backscatter coefficients, NDVI and measured parameters

<table>
<thead>
<tr>
<th>Correlations</th>
<th>VV</th>
<th>HH-VV</th>
<th>NDVI</th>
<th>LAI</th>
<th>Plant dry biomass</th>
<th>Plant height</th>
<th>Plant water content</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH</td>
<td>0.234</td>
<td>-0.006</td>
<td>-0.270</td>
<td>-0.421</td>
<td>-0.517</td>
<td>0.849</td>
<td></td>
</tr>
<tr>
<td>VV</td>
<td>-0.781</td>
<td>-0.905*</td>
<td>-0.891*</td>
<td>-0.889*</td>
<td>-0.935*</td>
<td>0.095</td>
<td></td>
</tr>
<tr>
<td>HH-VV</td>
<td>0.839</td>
<td>0.656</td>
<td>0.558</td>
<td>0.539</td>
<td>0.457</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDVI</td>
<td>0.887*</td>
<td>0.850</td>
<td>0.845</td>
<td>-0.054</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAI</td>
<td>0.986**</td>
<td>0.909*</td>
<td>-0.362</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant dry biomass</td>
<td>0.952*</td>
<td>-0.474</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant height</td>
<td>-0.430</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.

Based on the correlation analysis, relational models were built to associate each value of backscatter coefficient to a plant height, an amount of plant water content, plant biomass or LAI. First, a linear regression model (see equation (1)) was built to retrieve plant height from ASAR image using VV polarization. The R square value of 0.875 indicated a statistically significant linear relationship between VV polarization and the derived plant height. The root mean squared error (RMSE) was also shown following each equation.

$$Height = 6.835 - 5.478 \sigma^o_{VV}$$

$$r^2 = 0.875$$

$$RMSE = 2.472$$

(1)

Then plant water content could also be retrieved from ASAR image by a linear regression model (see equation (2)) using HH polarization backscatter coefficient.

$$Wp = 86.062 + 0.414 \sigma^o_{HH}$$

$$r^2 = 0.721$$

$$RMSE = 0.211$$

(2)

Following this, linear regression models to extract the LAI and plant biomass from ASAR image were also developed. For inversion of LAI, NDVI was first calculated from equation (3) and then substituted into equation (4) with VV polarization as input. Since LAI has a strong correlation with the plant biomass, we further transformed the plant biomass and LAI using a linear regression model (see equation (5)) to examine the plant biomass variation in the experiment areas.

$$NDVI = 7.6029 - 10.686$$

$$r^2 = 0.875$$

$$RMSE = 1.922$$

$$LAI = 0.986**$$

$$r^2 = 0.909*$$

$$RMSE = 0.362$$

$$Plant biomass = 0.952*$$

$$r^2 = -0.474$$

$$RMSE = 0.430$$

(3)

(4)

(5)
\[NDVI = 0.353 + 0.014\sigma_{HH-VV} - 0.027\sigma_{VV}\]
\[r^2 = 0.864 \quad \text {RMSE} = 0.023 \quad (3)\]
\[LAI = -6.486 - 0.392\sigma_{VV} + 8.368NDVI\]
\[r^2 = 0.829 \quad \text {RMSE} = 0.486 \quad (4)\]
\[Bio = -37.065 + 92.67LAI\]
\[r^2 = 0.973 \quad \text {RMSE} = 14.863 \quad (5)\]

For an immediate comparison, equation (3) was used first to retrieve NDVI of rice growth area from the ASAR image as ASAR NDVI. Then, each value of ASAR NDVI and CBERS-02 NDVI within the seven rice monitoring areas was retrieved and compared as shown in Fig.4. It is evident that most CBERS-02 NDVIs are overestimated and limited in the range of 0.65 to 0.76 in the ASAR NDVIs. Dispersion around the reference line is noticeable which could be for the reason of uncertainties caused by speckle, but further analysis is needed. The RMSE of observed and simulated NDVIs is 0.0296, which gives a good message that the result is acceptable in the following analysis.

For other rice growth parameters, however, there are no measured data in other locations within the study area, and thus there are no data for statistically assessing the accuracy of estimated rice parameters. As an alternative, maps (Fig. 5) of retrieved rice growth parameters covering the study area are generated, and compared with our field survey records. Different colors are assigned to pixels in each map according to their values. According to the field survey records, the variations of derived rice parameters in the maps are highly consistent with the actual rice growth conditions.

![Figure 4 Comparison between simulated ASAR NDVI and observed CBERS-02 NDVI at the middle period of rice growth.](image)

**6. CONCLUSION**

In conclusion, the major aim of this research was to assess the efficiency of ENVISAT ASAR APMode data for identifying rice growth area and retrieving rice growth parameters from radar images. Based on the ground experiment data and differential GPS records, backscatter behavior of different land surface objects was analyzed, especially for the paddy rice; a threshold classification method was developed to identify rice fields from the ASAR APMode data.

Furthermore, many rice growth parameters such as LAI, the plant biomass, the plant water content and the plant structure are significant correlated with the backscatter coefficient. According to the correlation analysis, we found that VV polarization was highly negative correlated with most rice growth parameters except the plant water content, but HH polarization was more sensitive to the rice plant water content. Therefore, relational models were developed to retrieve plant water content and plant height using HH and VV polarizations. Other rice parameters were also derived base on the relationship between the experiment data and backscatter coefficients. Maps of derived rice parameters indicated the variation of derived parameters was highly consistent with the actual rice growing conditions, but uncertainties due to speckle effect, ground measurement uncertainties and so on still remained which reduced the accuracy of derived rice parameters.
Figure 5 Maps of rice parameters covering the study area. Blue background color with pixel value of zero represents non-rice area in the figure (b), (c), (d), (e) and (f). (a) NDVI of rice fields calculated from CBERS-02 data; (b) Derived NDVI of rice fields from ASAR image; (c) Derived plant height (cm); (d) Derived plant water content (100*%); (e) Derived LAI of rice fields; (f) Plant dry biomass (g/m²) retrieved directly from the map of LAI using a linear regression model.

REFERENCES


