The application of ENVISAT ASAR data for rice growth monitoring based on semi-empirical backscattering model

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Abstract: Most paddy rice in the world grows in warm, humid and rainy environment where it is hard to acquire optical remote sensing data. Synthetic Aperture Radar (SAR) can acquire remote sensing information due to its all weather imaging and frequent revisit capability in the areas. A semi-empirical backscattering model was used to estimate leaf area index (LAI) from ENVISAT ASAR (Advanced Synthetic Aperture Radar) data over Zhaoqing in the growing season of rice in south China's Guang Dong province in this study. The results show that ASAR data is capable of estimating rice LAI with certain accuracy and have potential in rice yield estimate.
***Keywords*:** Rice growth; backscattering model; ENVISAT ASAR; LAI .

1. Introduction

Rice is a heat and water favorite crop. Most paddy rice in the world grows in warm, humid environment with heavy cloud cover and rainfall. It is hard to acquire optical remote sensing data in rice growing regions. Synthetic Aperture Radar (SAR) can find wide use for agriculture monitoring in tropic and sub-tropic regions due to its all day and all weather imaging capability and frequent revisit schedule. Many experimental activities, such as the ERS-1, RADARSAT, SIR-C/X-SAR campaigns, have been carried out to investigate the sensitivity of radar to rice parameters over many test areas worldwide[1]-[4].The research results have shown that SAR data could be used to estimate rice acreage and biomass.

The research results have shown that crop variable leaf area index (LAI) is important as a measure for rice growth and rice yield estimate. LAI is also important parameter in many agriculture model [5]-[6]. Best results are obtained by using (reflective) optical remote sensing data in estimating the LAI regularly during the growing season and subsequently calibrating the growth model based on periodic LAI estimates [7]. This study used a semi-empirical backscattering model based on simplified Michigan Microwave Canopy Scattering (MIMICS) Model [8]-[9] to estimate rice LAI from ENVISAT ASAR data over growing season of rice taking Zhaoqing of south China's Guang Dong Province as test site, where it is cloud-prone and rainy all year. The accuracy of obtained LAI is compared with ground truth measurements.

2 Data and test site

2.1 Test site and rice Calendar

The Zhaoqing test site is located in Guangdong Province, south of China center at latitude 22.30, longitude 112.30. It is sited at the northwestern end of Pearl River Delta. The test site was firstly imaged by airborne SAR in 1993 under the GlobeSAR program [8]. The Shuttle Imaging Radar C-band (SIR-C) and X-band SAR (X-SAR) also flew over the area on April 18, 1994.

In the Zhaoqing test site, there are two kind of rice per year: early season rice and late season rice. There are five major growth periods in the life cycle of rice. 1) Transplanting period: rice plant seedlings are transplanted from the seedbed to the paddy field. The transplanting date depends on the weather, especially temperature; 2) Seedling developing period: the seedling splits up and begins to develop a root system; 3) Ear differentiation period;

4) Heading period: headings begin to form; 5) Mature period: the rice plants mature and are ready to be harvested. Temporally, these five periods for early season rice are March 25-April 5, April 15-25, May 10-30, June 10-25, July 5-31. For late season rice, the growth stages occur as follows: July 20-August 5, August 10-20, September 1-30, October 1-20, November 1-25 respectively. Early season rice is taken into consideration in this study. The main growth stage is shown in figure 1.

[Insert Figure 1 here]

2.2 ENVISAT ASAR Data

Advanced Synthetic Aperture Radar (ASAR), operating at C-band, ASAR ensures continuity with the image mode (SAR) and the wave mode of the ERS-1/2 AMI. It features enhanced capability in terms of coverage, range of incidence angles, polarization, and modes of operation. The feature of ASAR imaging mode swath can be seen in Table 1 (ENVISAT ASAR handbook). Alternating polarization mode precision images of ASAR with nominal resolution of 30m, nominal pixel spacing of 12.5m were selected in five growth stages of rice in 2003 in this study. Alternating polarization is VV/HH and imaging mode is IS6, which are considered suitable for rice monitoring[7]-[8]Toan et al. 1997 and Shao Yun et al.1997).The backscatter coefficients are shown in figure 2.

[Insert Figure 2 here]

[Insert Table 1 here]

2.3 Ground measurements

LAI , water content and height of the rice were measured at the same time in the whole growth season of the rice. The measurements are shown in figure 3-5. Based on these measurements, the assumption is made as follow :

$$LAI = a*m_g*h +b \qquad (1)$$

Where a and b is parameters, m_g (%) is water content of rice canopy, h (mm) is the height of rice. I n this study, a and b has the value of 8.2 and -8.9 respectively, correlation coefficient is 0.78.

[Insert Figure 3 ,4 and 5 here]

3. Semi-empirical backscattering model and LAI estimate results

3.1 Semi-empirical backscattering model

Different backscattering models have been developed most of which treat the vegetation as a continuous layer in the vertical direction. The scattering objects are considered to be uniform in size and dielectric constant to simplify the computations **[9].** The Michigan Microwave Canopy Scattering (MIMICS) Model was developed to predict backscatter from forest stands. The principal difference between the other models and the MIMICS backscattering model is that several different types of scatterers are considered in the vegetation cover and measurable features of the soil-vegetation environment. The MIMICS backscattering model uses radiative transfer theory to describe the backscattering behavior of tree. This theory is suitable for a medium like vegetation where scatterers have discrete configurations and dielectric constants much larger than that of the air. However , most of the model parameters are not easily related to the physical parameters of scattering objects due to complicated electromagnetic expression of the models. So semi-empirical backscattering model have been often adopted for practical application based on MIMICS. The basic structure of the model was employed for characterizing the backscatter from rice in this letter. But rice does not has long stalk compared with a tree, the scattering component associated with ground-trunk scattering in MIMICS was deleted. Research results showed that the extinction cross-section of a vegetation leaf (where first normalized to the extinction cross-section of a perfectly conductive leaf of the same size) varies approximately linearly with the gravimetric moisture, when both quantities are expressed on a logarithmic scale. So MIMICS can be further simplified to get a semi-empirical model for describing backscattering behavior of rice:

$$\sigma_{pq}^{0} =A*\cos\theta *(1-T_{pq}) +B*T_{pq} \qquad (2)$$

where σ_{pq}^{0} is the measured scattering cross section, A represents the contribution of rice canopy, B the contribution of soil with water and roughness information ,θ is the incidence angle of the radar beam, and T_{pq} the pq polarized one-way transmissivity of the rice canopy.

Based on the research results and figure 1,2,3, parameters in (2) can be assumed as :

$$A=a1*m_g^{b1} \qquad (3)$$

$$T_{pq}=\exp(\boldsymbol{-2*m_g*h*\sec\theta}) \qquad (4)$$

Where m_g represents the water content of the rice canopy, h is the height of the rice canopy, LAI is leaf area index of the rice canopy, a1 and b1 are parameters. Based on (1) , (3) and (4), (2) can be expressed as follow :

$$\sigma_{pq}^{0} = a1*((LAI-b)/(a*h))^{b1}*\cos\theta*(1-\exp(-2*((LAI-b)/a)*\sec\theta)) + B*\exp(-2*((LAI-b)/a)*\sec\theta) \quad (5)$$

3.2 LAI estimate results

Parameters in equation (5) can be obtained using measured LAI and backscatter coefficients, and then equation (5) is used to estimate LAI from ASAR HH and VV polarization data. The results are shown in figure 6, 7. The lines in figure 5 and 6 are linear fit line, which can show the accuracy of estimated LAI from ASAR data indirectly.

[Insert Figure 6 and 7 here]

The results indicate that ASAR C-band VV and HH polarization data are useful in estimating LAI of rice . When LAI of the rice is less than 2.5 , estimated LAI from the model (5) using VV and HH data have relatively high correlation . The correlation is low when LAI is greater than 2.5. The reason may be that the proposed backscattering model is based on simplified MIMICS , which ignore some backscattering components .

4. Conclusion

LAI is a very important parameter in many model of crop yield estimate. It can be obtained by optical remote sensing data with relatively high accuracy. But in rainy and cloudy areas where rice grows regular acquisition of optical remote sensing data is hampered by weather condition. The semi-empirical backscattering model is proposed to estimate LAI of rice using ENVISAT ASAR data in experimental site. The results show that the model can be used to extract LAI of the rice in growing season using ASAR alternating polarization precision data with certain accuracy when optical remote sensing data can not be acquired. The accuracy of the model can be improved using ASAR data of multi polarization and multi imaging mode in future research.

ACKNOWLEDGMENT

The “Fundamental Research on Digital Earth” (KZCX2-312) sponsored by CAS provided the ENVISAT images, the research grant ITS/006/03 of ITC of Hong Kong Government and the joint laboratory for Geoinformation Science of Chinese university of Hong Kong funded this research work.. The authors wish to take this opportunity to express their sincere acknowledgment to CAS, ITC of Hong Kong Government and the Chinese university of Hong Kong for their support.

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Table1. Specifications for ASAR Image Mode Swaths (for satellite altitude of 786 km).

Image Swath	Swath Width(km)	Ground, position from nadir (km)	Incidence Angle Range	Worst Case Noise Equivalent Sigma Zero
IS1	105	187 - 292	15.0 - 22.9	-20.4
IS2	105	242 - 347	19.2 - 26.7	-20.6
IS3	82	337 - 419	26.0 - 31.4	-20.6
IS4	88	412 - 500	31.0 - 36.3	-19.4
IS5	64	490 - 555	35.8 - 39.4	-20.2
IS6	70	550 - 620	39.1 - 42.8	-22.0
IS7	56	615 - 671	42.5 - 45.2	-21.9

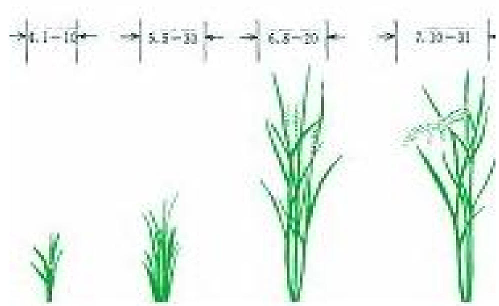

Figure 1. The size of rice over growing season

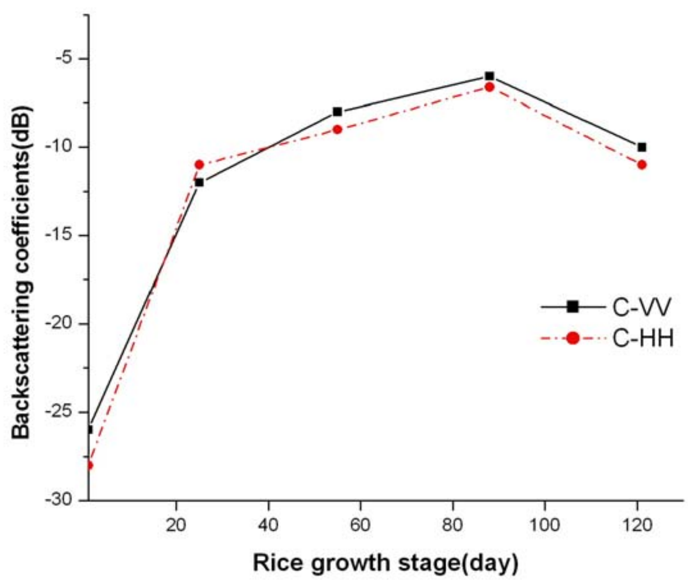

Figure 2. Backscattering coefficient of rice over growing season

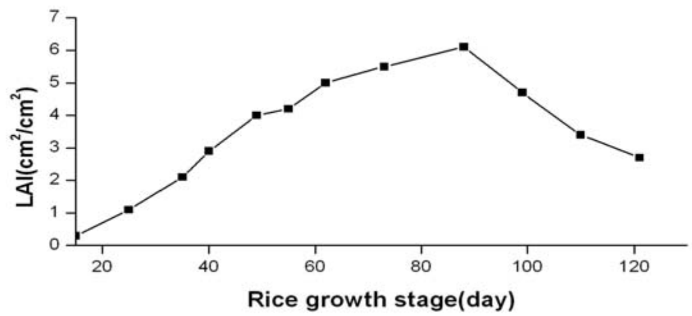

Figure 3. LAI of rice in growth stages

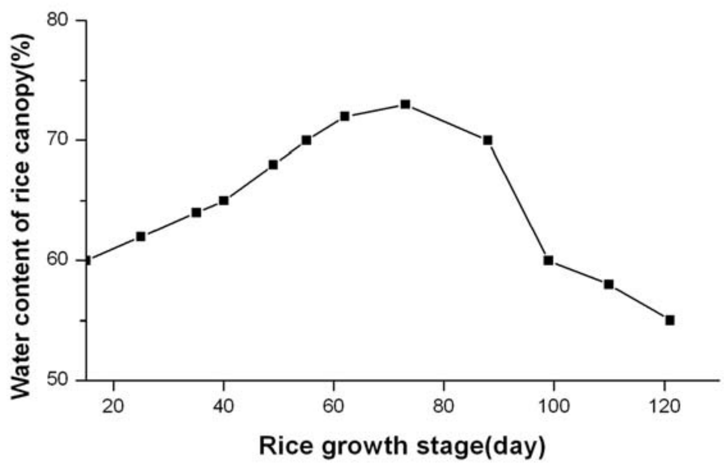

Figure 4. Water content of rice canopy in growth stages

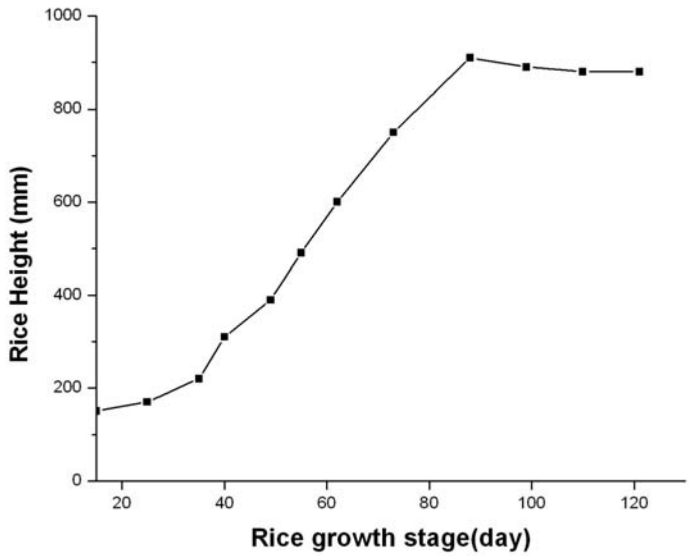

Figure 5 . Height of rice in growth stages

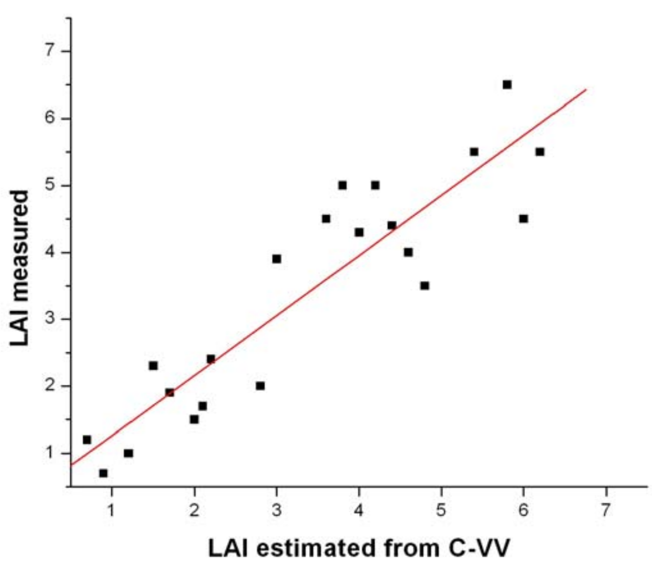

Figure 6. Relation between estimated LAI from proposed semi-empirical backscattering model in ASAR C-VV polarization.

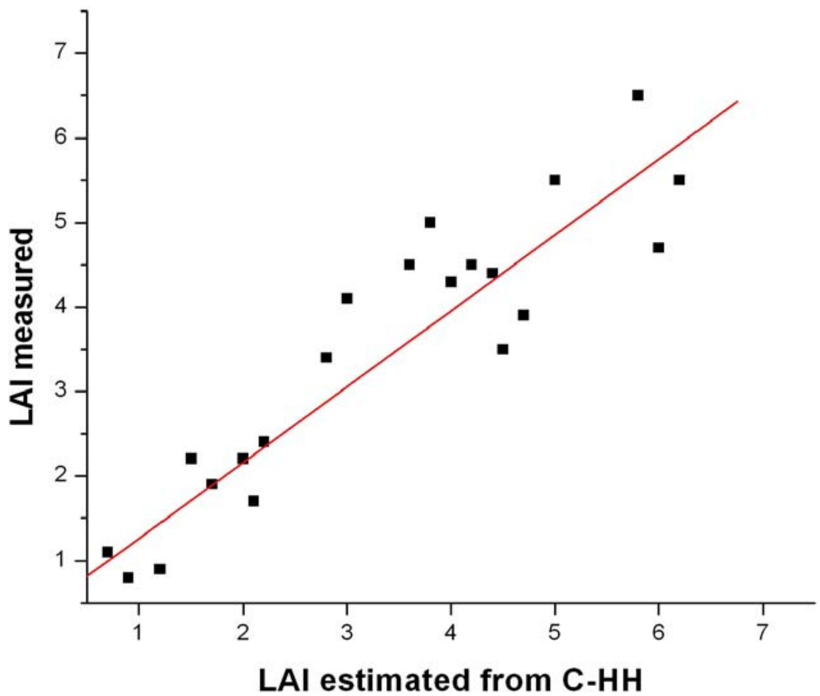

Figure 7. Relation between estimated LAI from proposed semi-empirical backscattering model in ASAR C-HH polarization.