

APPLICATIONS OF REMOTE SENSING IN THE MONITORING OF RICE CROPS

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ABSTRACT

Remote sensing, which is the science of acquiring information regarding the earth's surface without physical contact, is becoming increasingly important in many fields today. Recently, remote sensing is finding its way into rice monitoring applications. Studies on satellite images have shown that rice fields produce different brightness patterns at different plant growth stages, allowing the fields to be classified. However, there is a need for further research into understanding the interactions between electromagnetic waves and rice fields through the development of a theoretical model. This paper describes the development of a theoretical model that can be verified by field measurements to enable correct interpretation of remote sensing data and rice growth monitoring by using the change detection method. Not much is known about how electromagnetic waves interact with rice fields and how rice crops scatter these waves back to the satellite. Even though rice fields can be classified using the backscattering values and the rice growth can be monitored, a comprehensive study of the theoretical scattering model is crucial to ensure correct application of remote sensing data. The objectives of this study are to investigate the relationship between microwave backscatter signatures and rice growth and to monitor rice growth using satellite images. Results using multi-temporal RADARSAT imagery have confirmed that the backscatter can create a good separation for rice planting stages.

Keywords : Microwave Remote Sensing, Rice Field Monitoring, Satellite Image Classification, Theoretical Modeling

1. INTRODUCTION

Through the ages, human beings have been using the five senses of sight, smell, sound, taste and touch to observe the world. However, vast improvements in science and technology have allowed us to learn much more than our five senses could ever tell us about the world, through the development of different instruments and techniques for observing the world. We now have telescopes that allow us to see much further than our naked eyes can see. All sorts of measuring instruments allow us to 'see' electromagnetic waves outside the visible wavelengths.

One of the key technologies that has greatly improved our observation and understanding of the world in which we live in is remote sensing. Remote sensing is the science of acquiring information regarding the earth's surface by detecting and measuring the radiation, particles and fields associated with it. There are two types of remote sensing, passive sensing and active sensing. Passive remote sensing detects electromagnetic waves from the Sun that have been reflected off the surface of the earth whereas active remote sensing employs a radar system, normally carried on an aircraft or a satellite which transmits electromagnetic waves at the target and analyzes waves that are reflected back towards the radar. The process in which the electromagnetic waves from the radar interact with the earth's surface and are transmitted in all directions is called scattering. The scattered waves that travel back towards the antenna in the backscattering process are called the backscattered waves. The time delay between transmitting the pulse of electromagnetic radiation and recording the returned signal after it has been scattered back from a scatterer allows the distance of the scatterer and the radar system to be calculated [1]. These backscattering returns measured by the radar are also

influenced by the targets and thus contain information on the targets. The returns can be converted into an image from which much information about the targets can be derived.

Remote sensing applications vary widely, and are used in areas such as military strategic planning, weather forecasting, fossil fuel exploration, urban planning, natural disaster monitoring and even in off-world explorations of other planets. This article, however, is focused on ongoing research in Malaysia for the application of remote sensing in monitoring rice crops in Malaysia.

In Malaysia, as well as in most other Asian countries where rice is the staple food, the production of rice has become a major part of the economy. A delicate balance exists between the production of rice and the needs of consumers. It is critical that rice resources be able to continue to sustain an ever increasing world population. There is therefore a need for an effective means by which rice production can be monitored as well as predicted with reasonable accuracy, reliability and cost effectiveness. There is an increasing amount of international interest in the area of implementing space-borne radars and sensors in the remote sensing of rice fields in the hope that it will replace traditional land-based monitoring systems. However, rice crops are mainly cultivated in warm tropical climates where rainfall is high and cloud cover is dense throughout the year. Hence, the main thrust of such research activities has been in the use of microwave remote sensing, since microwaves can penetrate through clouds and has all-weather capabilities.

The use of Synthetic Aperture Radar in discriminating among different agricultural crop species has been demonstrated in several studies [2 - 4]. The accuracy of classification depends on the sensitivity of the used

backscattering coefficients to the differences of the biomorphological structures of the plants, hence to the different interaction behavior between the electromagnetic wave and the structure of the canopy [5]. Multitemporal single frequency, single polarisation data collected by repeated overpasses can improve the accuracy as they are affected by the peculiar variations induced in backscattering by the growth cycle of a given plant [6 - 8].

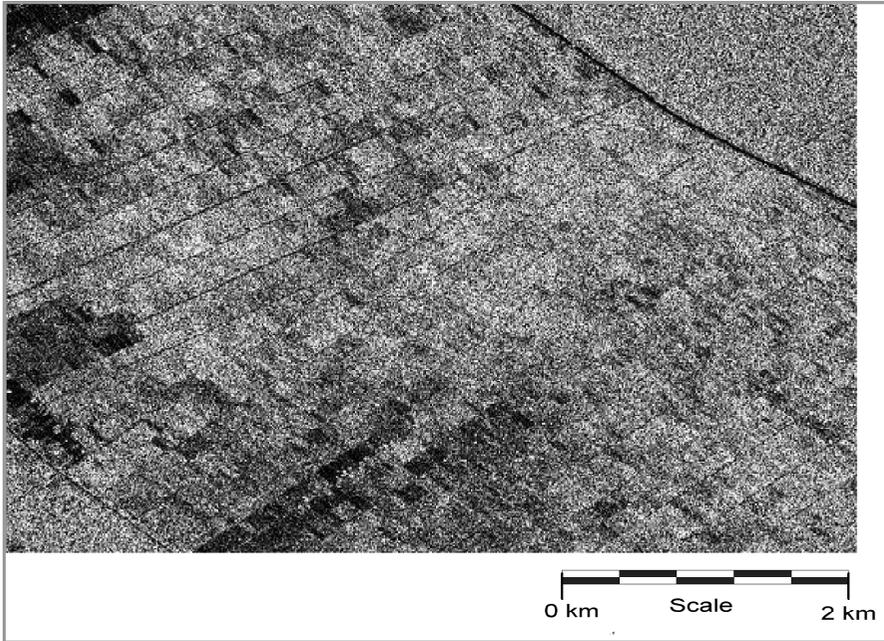


Figure 1: A Microwave Remote Sensing Image Acquired on the 20th of September, 2004 Showing Rice Fields at Sungai Burung, Selangor

Initial studies [6;9] conducted on microwave satellite images of rice fields have revealed that rice fields containing rice crops of varying ages will produce differing patterns on the images, as shown in Figure 1. These studies have shown that as the rice crops grow, the rice fields will show up as brighter and brighter patches on the image due to an increase in the intensity of the backscattered microwaves. One way of expressing the intensity of the backscattered waves is the backscattering coefficient. A higher backscattering coefficient will represent a higher intensity of the backscattered waves. Figure 2 shows the comparison results of the age of the rice crops for rice field in Sungai Burung, Selangor with its corresponding backscattering coefficient.

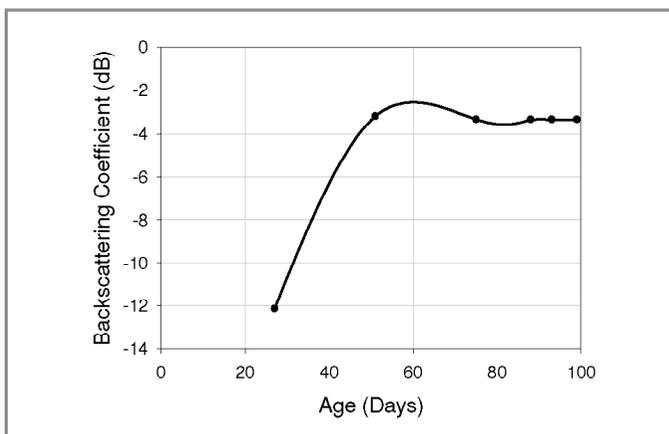


Figure 2: Plot of Backscattering Coefficient vs. Plant Age for Rice Fields in Sungai Burung, Selangor

As the rice crops grow, the backscattering coefficient will increase until it reaches its peak when the rice crops are about 60 to 100 days old, depending on the rice crop variety. After that, it starts to decrease slowly until the crops are harvested. By using this information, the age of the rice crops of each rice field can be determined from satellite images, so the aforementioned studies have attempted to use these data to classify the rice fields based on their age and growth stage.

Hence, these early studies have shown that remote sensing data can be used in the monitoring of rice crops. Other studies [10] have shown that such data can even be used for yield prediction purposes so that the total output of rice fields in a particular region can be estimated.

Although a considerable amount of research has been done in the application of satellite images for the classification and monitoring of rice crops, little is known about the actual interactions of electromagnetic waves with rice canopies. To be able to better understand such interactions, theoretical models that can help us to explain how electromagnetic waves are scattered off rice crops need to be developed. Of course, such models must be validated by measurement data. These theoretical models will ensure a correct understanding and application of remote sensing data, as well as provide a means from which physical parameters of rice canopies can be retrieved from radar data through inversion

algorithms. In addition, the study of such models will prove to be indispensable in future analysis of radar images for rice crop monitoring. The objectives of this study are to investigate the relationship between microwave backscatter signatures and rice growth and to perform rice growth monitoring using satellite images.

In this article, the introduction will be followed by a brief description of data that have been collected from rice fields in our research (Section 2). It also includes short explanation of rice plant morphology and rice cultivation practices in Malaysia. Section 3 describes the development of a theoretical model that will help us to better understand the scattering phenomenon involved in the remote sensing of rice fields. In Section 4, the current methods in which satellite images are processed and rice fields are classified are explained.

2. DATA COLLECTION

As part of our research, field trips were carried out at 12 day intervals from 27 August 2004 to 1 December 2004 at Sungai Burung, Selangor, Malaysia. Ground truth measurements were acquired from 6 different test fields in the region. Parameters that were measured include plant geometry such as plant height, leaf length, leaf width, leaf thickness and leaf inclination angle, plant density, plant water content and plant biomass. However, only the measurement results of the important parameters are presented in this paper. The plant wet biomass is defined as the weight of rice plants, including the water contained, per square meter of rice field. On the other hand, the plant dry biomass is defined as the weight of dried

plants (where its water content has been removed) per meter square of rice field. These measured parameters are shown in Figure 3 corresponding to the dates in which the measurements were obtained.

The seeds of rice plants are broadcast evenly over an entire rice field. About 8 days later when rice shoots have emerged, the fields are flooded. The rice plants are now considered to be in the vegetative stage. During this vegetative stage, tillers (or small stems) will split from the main stem as leaves increase in number until its peak at about 30 days old. After that, the number of tillers decrease [Figure 3(a)] as competition for natural resources increases and some tillers die off. However, the plants continue to grow in size and its biomass continues to increase steadily as can be observed in Figures 3(b) and 3(c). The water content remains almost constant during this stage. At the end of the vegetative phase, plant growth slows down tremendously and the rice plants begin to flower. In fact, plant height remains relatively constant. In Figure 3b however, the plant height measured from above the water surface continues to increase only because the fields have been drained. The plants are now in the reproductive stage. As the grains form, water from the fields is drained. The water content of the plants also drops a little [Figure 3(d)]. The rice crops are harvested when they are about 100 days old.

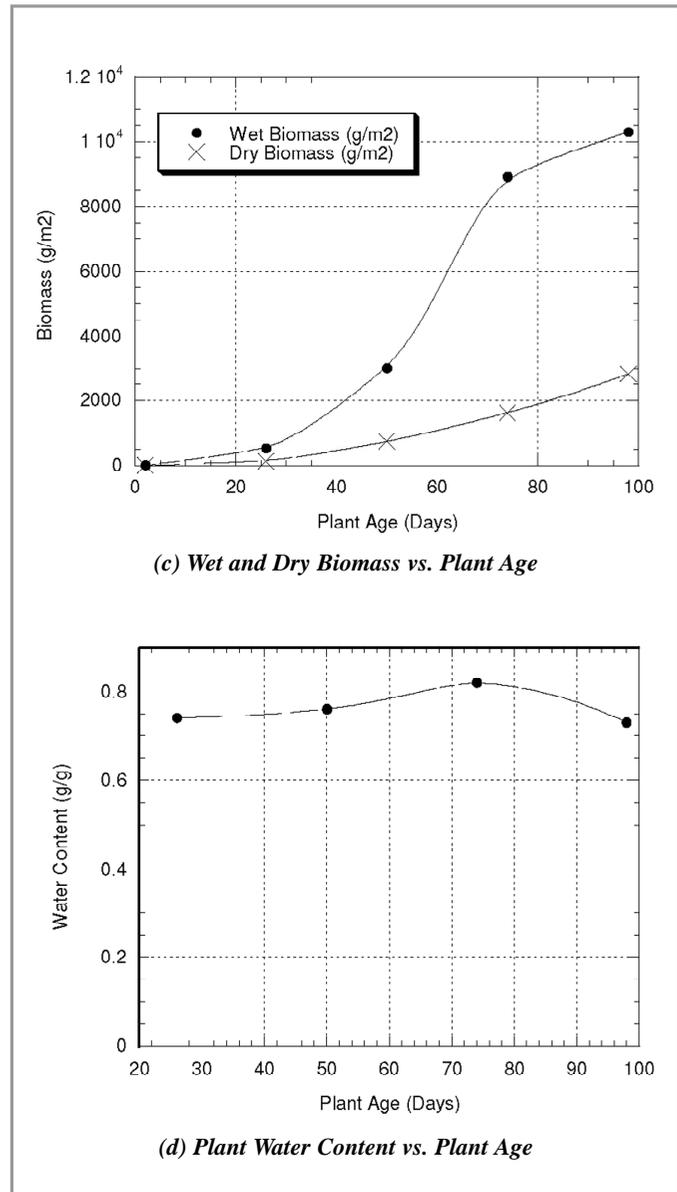
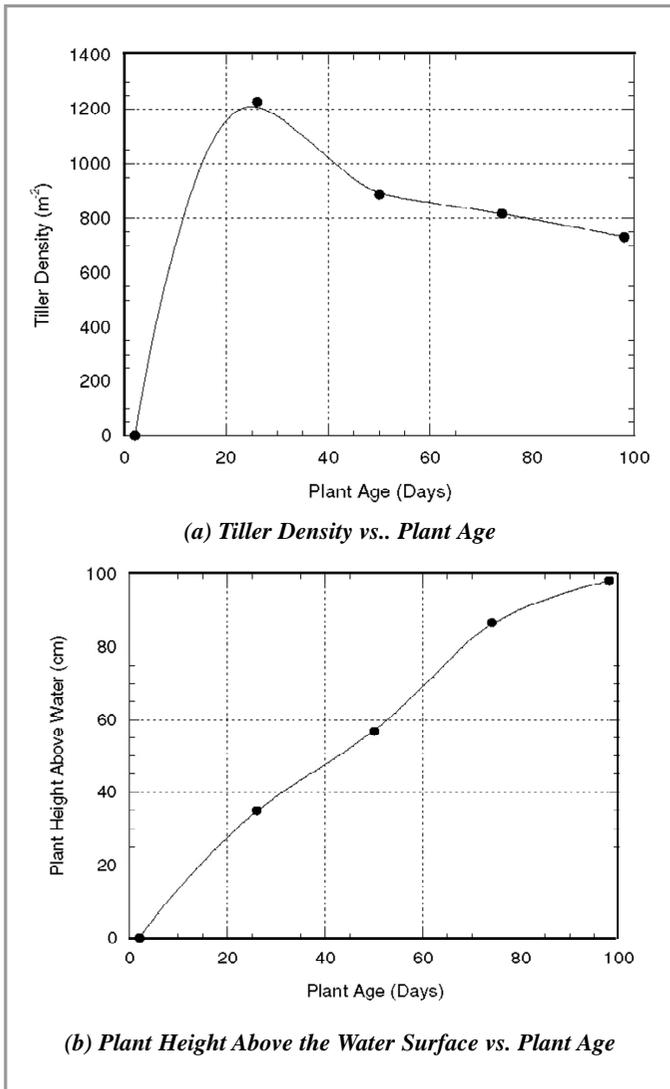


Figure 3: Graphs of the Measured Ground Truth Parameters of Rice Plants for Test Field 4 Showing The Plots of (a) Tiller Density vs. Plant Age, (b) Plant Height Above the Water Surface vs. Age, (c) Wet and Dry Biomass vs. Age and (d) Plant Water Content vs. Age

Besides ground truth data, satellite images were also obtained from the Canadian Earth Observation Satellite RADARSAT where the satellite data can be obtained through the Ground Receiving Station in Temerloh, Pahang, operated by the Malaysian Center for Remote Sensing (MACRES). The operating frequency for RADARSAT is 5.3 GHz (C Band) and this is suitable for rice crop monitoring as from our theoretical study, higher microwave frequency will be attenuated more by the rice crops and may not reach the bottom portion of rice crops whereas lower microwave frequency will largely penetrate through the rice crop layer and the returns will be influenced by the scattering effects between the water surface and the rice crops.

The RADARSAT satellite operates at a frequency of 5.3 GHz and uses HH polarized waves, meaning that the radar transmits as well as receives waves that have electric fields that are horizontally oriented. RADARSAT operates in different modes, each with a different image resolution. Fine Mode 2

was chosen for this research, meaning that the satellite would be at an angle of about 40° from the earth's surface (normally called 'inclination angle') when the images are captured, and the images obtained would have a resolution of 7.6 m. From our theoretical study, the angle chosen was suitable as larger angle would cause more attenuation to the wave as it passes through the crop layer and smaller angle would provide shorter path for the wave to interact with the rice crops. The satellite passes by the same exact spot every 24 days, so the images were obtained on 4 separate occasions with 24 day intervals; 27th of August, 20th of September, 14th of October and 6th of November of 2004, which coincided with 4 field trips.

3. DEVELOPMENT OF A THEORETICAL MODEL

Scattering models can generally be divided into two main categories; surface scattering models, in which scattering occurs between the boundary of two media (Figure 4) and volume scattering models, in which scattering occurs due to the inhomogeneities in the medium (Figure 5). One early, widely used surface scattering model is the Kirchhoff model [11] which is applicable to surfaces where the average horizontal dimension is large compared to the wavelength of the electromagnetic wave. Hence, the electromagnetic waves impinging upon a local region are assumed to be reflecting off a tilted infinite flat plane. However, when the average horizontal dimension of the surface is smaller than the wavelength of the electromagnetic waves, the small perturbation model [12] is used.

On the other hand, volume scattering and can be modeled using two different approaches. One such approach is to use the

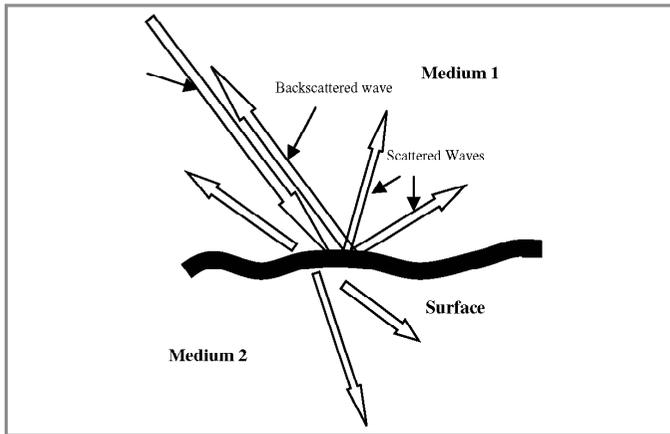


Figure 4: Surface Scattering

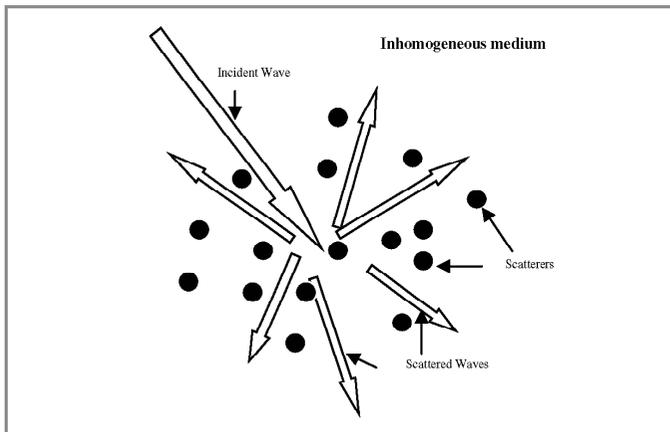


Figure 5: Volume Scattering

wave method [13] which is based on Maxwell's wave equations. This approach first assumes that the inhomogeneous medium is homogenous with a mean permittivity (which is an inherent property of the medium).

A fluctuating permittivity is then added to the formulation to take into account the inhomogeneities, thus generating a continuous random medium model. This approach, however, involves a lot of complexities in its formulation and calculation.

The other approach is not as complex as the wave method, and is called the intensity approach [13]. In this approach, the radiative transfer theory [14] is used to describe the change in intensity of electromagnetic waves due to scattering and absorption as it travels through an inhomogeneous medium. The lower medium is modeled as a background host medium embedded with discrete scatterers that have orientations and distributions described by statistical functions. The interactions between the electromagnetic waves and the medium are described by phase matrices that are incorporated into the radiative transfer equations. The radiative transfer equation is given by:-

$$\cos\theta \frac{d\bar{I}}{dz} = -\bar{\kappa}_e \bar{I} + \int \bar{P}\bar{I} d\Omega \quad (1)$$

where \bar{I} is the Stokes vector that describes the intensity of the wave, while $\bar{\kappa}_e$ and \bar{P} are the extinction matrix and phase matrix of the medium, respectively. The scattering and absorption losses of the intensity along the propagation direction are taken into account by the extinction matrix. The phase matrix \bar{P} relates the scattered intensities to the incident intensities on unit volume of scatterers. After solving for the intensity of the backscattered waves in the radiative transfer equation, the backscattering coefficient can be obtained using this equation:-

$$\sigma_{pq} = \frac{4\pi \cos\theta_s I_{sp}}{I_{iq}} \quad (2)$$

where p and q represent the incident and backscattered polarizations respectively and can be v or h . θ_s is the angle of the scattered field with respect to the normal of the medium. I_{sp} is the intensity of the backscattered waves, while I_{iq} is the intensity of the incident wave.

Conventionally, models that use the intensity approach are based on the assumptions that the discrete scatterers are independent of one another and that their effects are incoherent. This means that the waves that are scattered off a scatterer do not affect waves that are scattered off another scatterer. This holds true for media that contain scatterers that are sparse and far away from one another. However, in an electrically dense medium, where the average distance between scatterers is smaller than the wavelength of the electromagnetic wave, these assumptions are no longer accurate as the waves scattered from each scatterer will interact with waves scattered from other scatterers. Also, the scatterers are within the near field of one another. Therefore, the near field effects need to be taken into account, as opposed to conventional models where only the far field effects are considered.

One of the techniques used to extend the radiative transfer theory to encompass dense media is called the dense medium phase and amplitude correction theory (DM-PACT) [15]. In an earlier study [16], it has already been shown that amplitude corrections need to be performed on the phase matrices of dense media to take into account the near field effects of the scattered fields. The DM-PACT approach utilises antenna array theory to formulate a phase correction term to take into account the coherent effects of the scatterers, in addition to the amplitude corrections. This is done by introducing an array phase correction factor to the Stokes matrix to obtain the phase matrix of the medium. The phase matrix is thus given by:

$$\overline{\overline{P}}(\theta_s, \phi_s; \theta_i, \phi_i) = \langle |\Psi|^2 \rangle_n \cdot \overline{\overline{S}}(\theta_s, \phi_s; \theta_i, \phi_i) \quad (3)$$

where $\overline{\overline{S}}$ is the Stokes matrix that describe the scattering by a scatterer $\langle |\Psi|^2 \rangle_n$ and is the array phase correction factor given by [17 – 19] k_i and k_s are the propagation vectors in the incident and scattering directions, l is the array correlation length, d denotes the average distance between scatterers and σ is the standard deviation of scatterers from their mean positions.

$$\langle |\Psi|^2 \rangle_n = \frac{1 - e^{-k_{si}^2 \sigma^2}}{d^3} + \frac{e^{-k_{si}^2 \sigma^2}}{d^3} \sum_{q=1}^{\infty} \frac{(k_{si}^2 \sigma^2)^q}{q!} \cdot \left[\left(\frac{\pi}{q} \left(\frac{l}{d} \right) \right)^3 \exp\left(\frac{-k_{si}^2 l^2}{4q} \right) - a(k_x) a(k_y) a(k_z) \right]$$

Where

$$k_{si} = |\bar{k}_s - \bar{k}_i| \quad \text{and} \quad a(k_r) = \sqrt{\frac{\pi}{q}} \left(\frac{l}{d} \right) \exp\left(\frac{-k_r^2 l^2}{4q} \right) \text{Re} \left\{ \text{erf} \left(\frac{(qd/l) + jk_r l}{2\sqrt{q}} \right) \right\} \quad (4)$$

Table 1: Various Models Used for The Different Growth Stages of Rice Plants Corresponding to Plant Age and Date of RADARSAT Image Acquisition

Date	Test Field	Age (days)	Growth stage	Model	Scatterers
20/9/04	1	27	early vegetative	single layer	needles
	4	26	early vegetative	single layer	needles
	5	29	early vegetative	single layer	needles
	6	21	early vegetative	single layer	needles
14/10/04	1	51	late vegetative	double layer	needles, stem cylinders
	4	50	late vegetative	double layer	needles, stem cylinders
	5	53	late vegetative	double layer	needles, stem cylinders
	6	45	late vegetative	double layer	needles, stem cylinders
6/11/04	1	75	early reproductive	double layer	needles, stem cylinders, grain cylinders
	4	74	early reproductive	double layer	needles, stem cylinders, grain cylinders
	5	77	early reproductive	double layer	needles, stem cylinders, grain cylinders
	6	69	early reproductive	double layer	needles, stem cylinders, grain cylinders

This theory has been used to model the phase matrix of media with spherical scatterers such as snow and ice [17]. The DM-PACT has also been extended to encompass media with cylindrical, disk-shaped and needle-shaped scatterers [18] so that it can be used to formulate the phase matrix of media with non-spherical scatterers such as forests [19]. The cylindrical scatterers are used to represent trunks, while the disk-shaped and needle-shaped scatterers are used to represent the leaves.

In the development of a theoretical model of rice crops, both the radiative transfer theory and DM-PACT for cylindrical and needle-shaped scatterers are used. The rice canopy is modeled as either a single layer or multilayer dense discrete random medium, depending on its growth stage, over a smooth water surface. Table 1 and Figure 7 shows the different

variations in the model used for the different growth stages of the rice crops corresponding to its age and dates of RADARSAT image acquisition. In its early vegetative stage, corresponding to the RADARSAT image obtained on the 20 September, the rice model consists of a single layer of needle-shaped scatterers, in the consideration of the uniform orientation distribution of the rice leaves. This is because the lower portions of the rice plants, including the stems, are submerged. Only the leaves are above the surface. Microwaves at C-band frequency are unable to penetrate into the water. This is shown in Figure 6(a).

For the image obtained on the 14 October, the rice plants are now in their late vegetative stage, and the canopy is modeled as a double-layer medium. The upper layer consists of needle shaped leaves, while the lower layer is a combination of needle shaped leaves and cylindrical stems, as depicted in Figure 6(b). During the reproductive stage, tiny cylinders are added to the upper layer of the model to simulate rice grains [Figure 6(c)]. This corresponds to the RADARSAT image acquired on the 6th of November. The RADARSAT image obtained on the 27 August will not be included in this study as the seeds have just been broadcasted and the only source of

backscattering is the soil. Test fields 2 and 3 have also been omitted due to incomplete data collection as a result of heavy rains and partial destruction of rice fields respectively.

The theoretical model is used to calculate the HH polarised backscattering coefficient of the rice canopies, at a frequency of 5.3 GHz and at an incident angle of 39° to match that of Fine Mode 2 of RADARSAT. To achieve this, the measured ground truth parameters such as the plant geometry and density are incorporated into the theoretical model equations for simulation. The simulation results for test fields 1, 4, 5 and 6 are compared to the corresponding backscattering coefficients obtained from the RADARSAT images, and are shown in Figure 7. As expected, both results show a large increase in the backscattering coefficient when the crops are about 60 days old,

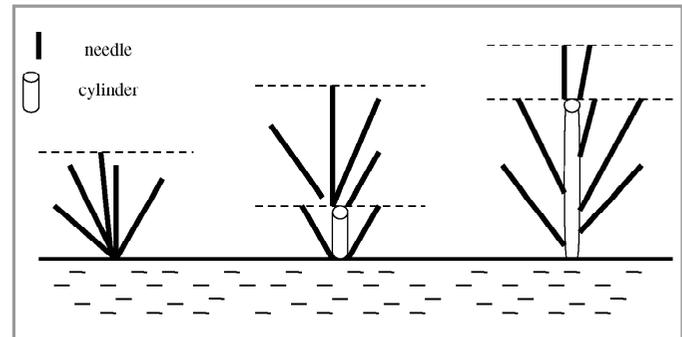


Figure 6: Variations in the Model Used for the Computation of Backscattering Coefficients of Rice Fields in the (a) Early Vegetative Stage, (b) Late Vegetative Stage and (c) Reproductive Stage

compared to when the crops are 20 days old. This is due to the rapid growth of rice plants in their vegetative stages, thus increasing the canopy height and the volume fraction of scatterers. There is then a slight decrease in the backscattering coefficient as the crops move into the reproductive stage and grains begin to form. This could be due to the decrease in the density of the rice canopy as smaller plants and stems die off. These trends agree with those that have been reported in other studies [9].

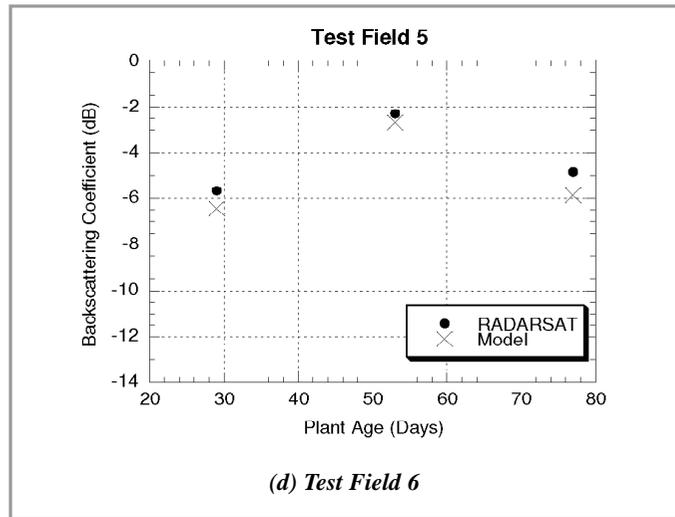
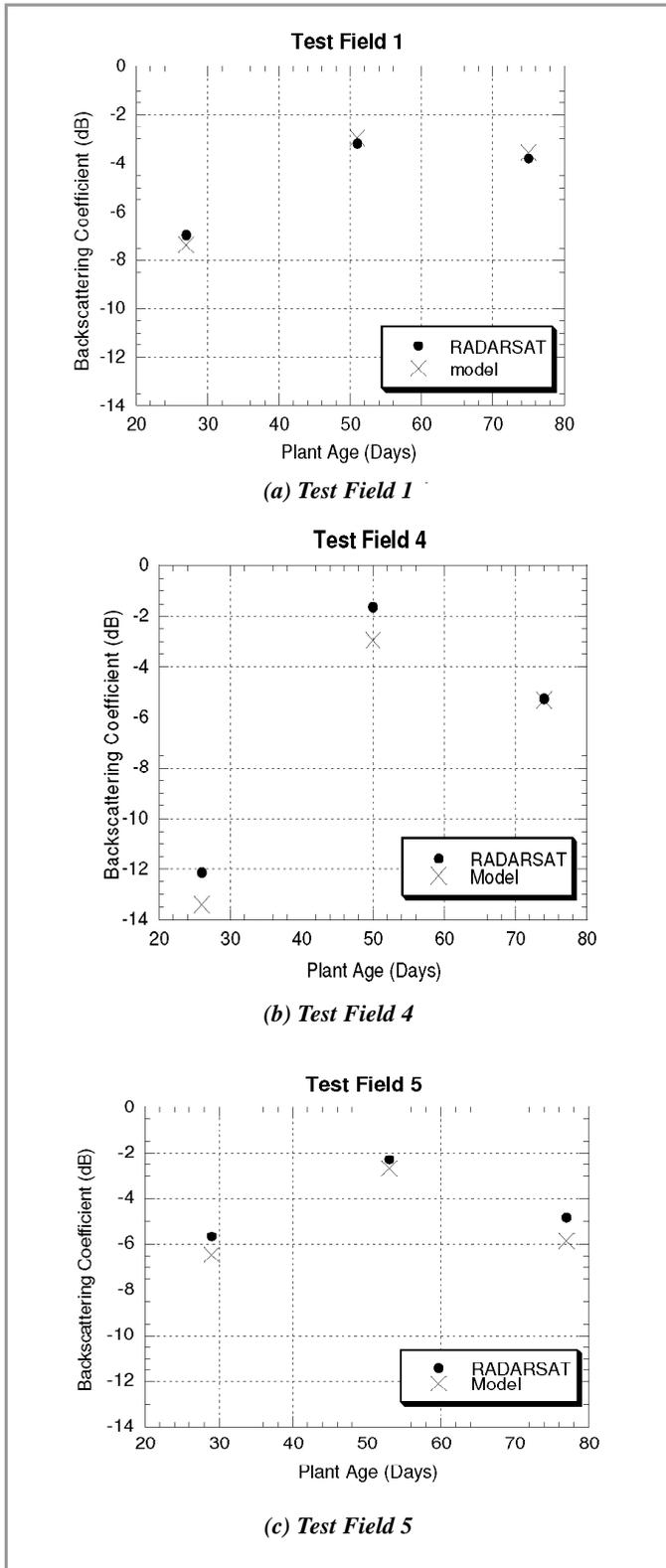


Figure 7: Comparisons of Theoretical and Measured HH Polarized Backscattering Coefficients of Rice Canopies for (a) Test Field 1, (b) Test Field 4, (c) Test Field 5 and (d) Test Field 6 at Various Stages of Growth

Comparisons between the backscattering values obtained from the RADARSAT images with the values calculated using the theoretical model show promising results. Generally, the measured values compared very well with the calculated values, with errors of less than 2 dB. Since the parameters used in the model calculations were obtained through statistical sampling of the rice fields, the error is small and within the acceptable range.

4. IMAGE PROCESSING AND CLASSIFICATION OF RICE FIELDS

Radar images are composed of many pixels. Each pixel in the radar image represents the radar backscatter for that area on the ground. Bright features mean that a large fraction of the radar energy was reflected back to the radar which indicate high backscatter while dark features imply that very little energy was reflected which indicate low backscatter. In radar image analysis, the brighter the pixels on the image, the rougher the surface being imaged. Vegetation is usually moderately rough on the scale of most radar wavelengths and appears as grey or light grey in a radar image. In addition, the brightness of the image is sensitive to the water content. Rice field with high water content indicates bright pixel. However, there is exception to waterbody, which will reflect incoming energy away from the radar and thus, depicting dark pixels on the image. When mapping any portion of the surface of the earth that is larger than a few square miles, a map projection is required because of the fundamental problem of the earth's surface being spherical while the surface of a map is flat and rectangular. A map projection is a system of transformations that enables locations on the spherical earth to be represented systematically on a flat map. Each projection preserves some properties of the mapped area, such as uniform representation of areas or shapes, and preservation of correct bearings. Therefore, the multi-temporal RADARSAT images acquired on the 27 August, 20 September, 14 October and 7 November 2004 are geometrically corrected during pre-processing so that it conforms to its corresponding map projection and adjustment. In this case, the images are scaled to the projection properties of Kertau 1948 (West Malaysia and Singapore). The information is included in the image header file,

thereby making the geographical data available to the image processing software called 'PCI Geomatics'. Figure 8 shows the four satellite images that were obtained. They are depicted in gray scale where brighter pixels represent higher backscattering coefficient values, as mentioned previously.

This is then followed by a change detection method to determine the changes between two successive images using the technique of 'image ratioing'. In this technique, the ratio r of each pixel for two successive images is generated by dividing the backscattering intensity of each pixel of one image, $P1$ by the backscattering intensity of the corresponding pixels in the second image, $P2$ as shown in (5). The r value is scaled in the logarithmic form to adapt to the dynamic range of power, where C is the output ratio pixel in dB as shown in (6). The C values for each pixel are then used to generate a different image, which contains the difference of backscattering coefficients between two images

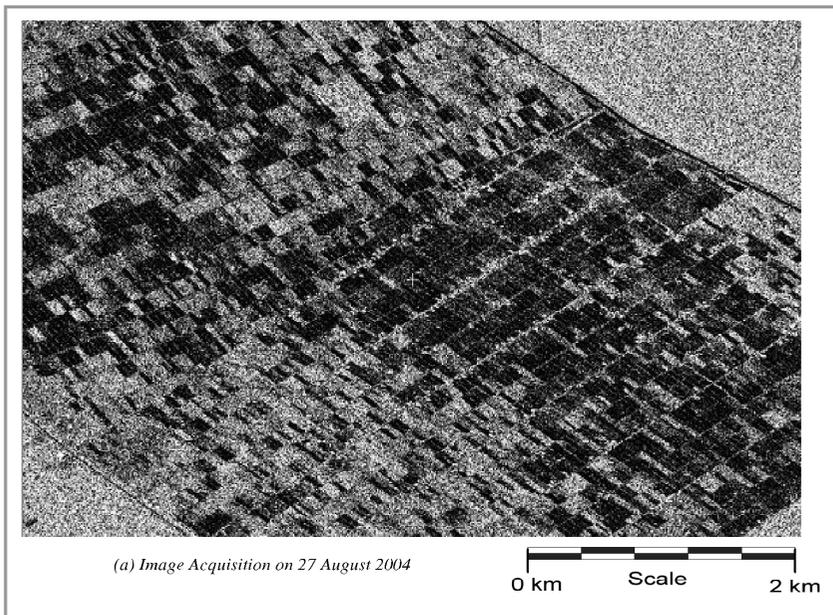
$$r = P1 / P2 \tag{5}$$

$$C = 10 * \log_{10}(r) \tag{6}$$

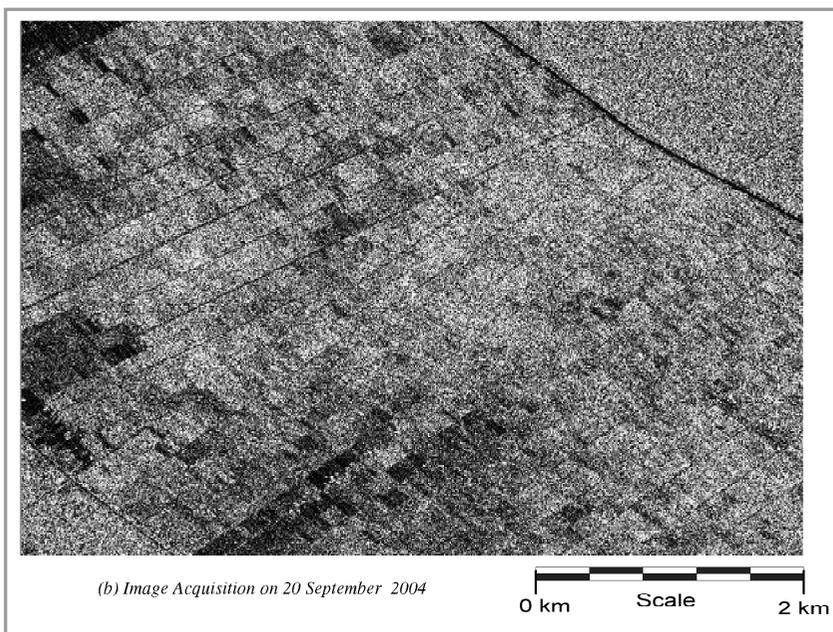
As it is performed on a pixel-by-pixel basis, difference images produced by using 2 successive RADARSAT images provide an accurate representation of the temporal changes in the backscattering coefficients of rice fields.

From the difference images between Figure 8(a),(b),(c) and (d), it is possible to classify the rice fields into different categories based on the planting schedule proposed by the related authorities. Since the Malaysian government proposes a planting schedule to synchronize the agricultural activities involving the rice fields in a particular region, the rice fields can be classified according to whether the farmers adhered to the proposed schedule or were late. By comparing the difference in backscattering coefficients with the trend of the

graph in Figure 2, the rice fields are classified as on schedule rice planting, late rice planting and very late rice planting. For example, if the ratio of the backscattering intensity on 20 September 2004 to that of 27 August 2004 of the rice field is very high, the rice field is in its vegetative stage and is classified as 'On Schedule Rice Planting'. If however, the difference between the backscattering coefficients is very high between 20th September and 14th October, the rice field will be classified as either 'Late Rice Planting' or 'Very Late Rice Planting', depending on whether the backscattering coefficients increased or decreased between the first two images. It is found that the different planting schedules have led to the different trends of backscatter coefficient throughout the planting period as they are affected respectively by the irrigation plan and rainy season. Figure 9 shows the plot of the radar backscattering coefficient against the acquisition dates of the radar images for the three categories of rice fields. It is peculiar nature of interaction between radar signals and the rice plant structure that allows for the clear view of the different categories of rice fields using multi-temporal data.



8(a) Image Acquisition on 27 August 2004



8(b) Image Acquisition on 20 September 2004

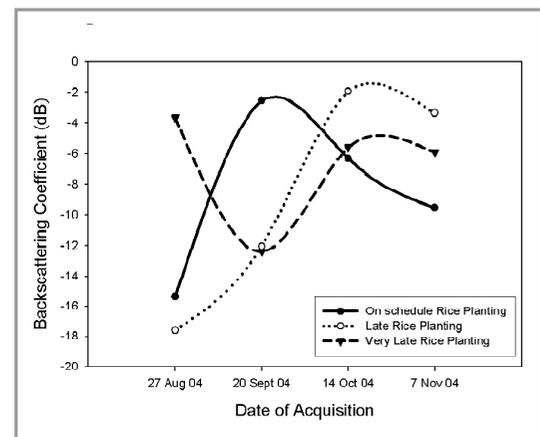
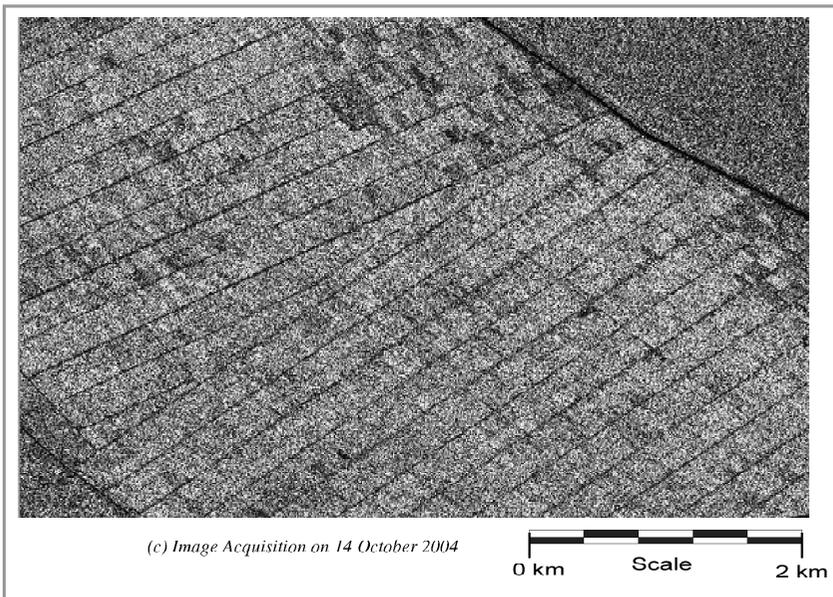
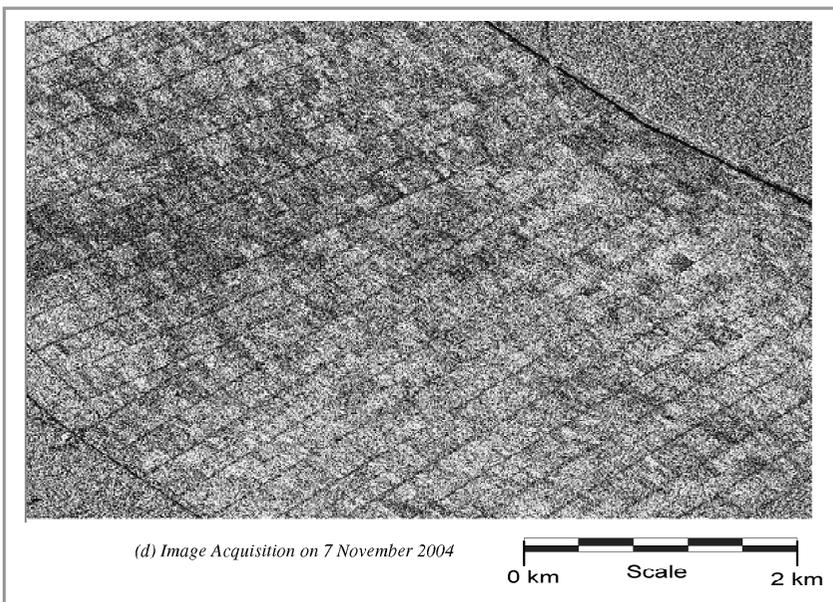


Figure 9: The Backscattering Coefficients of the 3 Categories of Rice Fields Corresponding to the Date of Acquisition of the Satellite Images



8(c) Image Acquisition on 14 October 2004



8(d) Image Acquisition on 7 November 2004

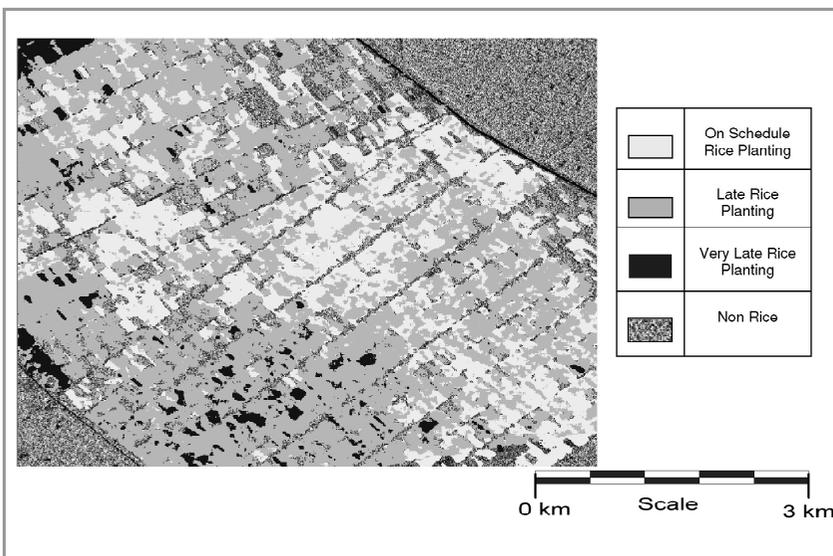


Figure 10: Rice Fields Classified into 3 Different Categories

Thus, it is possible to apply the ratioing technique to identify the different crop planting schedules [9]. According to Rignot and Zyl [20], there are two advantages of the image ratioing technique. Firstly, the ratioing method is independent of the absolute intensity values of the pixels. It represents the relative change in pixel intensity between the two images under comparison. Secondly, the ratioing method can cancel off the calibration errors made during the processing of the radar raw data.

By applying this technique, it is possible to classify the rice fields according to the above categories as shown in Figure 10. It is noticed that the majority of the rice fields are classified as 'Late Rice Planting' (61.4%), followed by the 'On Schedule Planting' (33.5%) and Very Late Rice Planting (5.1%).

5. CONCLUSIONS

Remote sensing has been widely used for decades to enable us humans to discover more about our universe, as well as to help us improve our lives, but it is only in the last decade or so that researchers and engineers have begun to recognize the potential of remote sensing in rice monitoring applications. Research into the application of remote sensing in the monitoring of rice crops is still a relatively new and exciting field of study, and will continue to bring benefits to the world at large, particularly in countries like Malaysia where rice is so important to our daily life.

In this paper, theoretical model has been developed to describe the scattering of electromagnetic waves off rice plants. Moreover, the comparisons between the backscattering values obtained from the RADARSAT images with the values calculated using the theoretical model show promising results. Different planting stages are able to be separated using the change detection method. Hence, it is possible to assist in the monitoring of rice field. Future work will include research into the extraction of physical data of rice plants from satellite images in a process called inverse modeling.

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