Monitoring spatial and temporal variations of the rice backscatter coefficient ($\sigma^o$) at different phenological stages in Sungai Burong and Sawah Sempadan, Kuala Selangor

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Abstract. Monitoring rice growth and yield estimation using optical remote sensing data constitutes a big challenge largely due to cloud conditions that are typical of tropical regions. Using Radar remote sensing data helps because it overcome the cloud issue and as well distinguishes the behaviour of the radar backscattering of rice crops specifically. This study indicated the temporal change of rice backscatter ($\sigma^o$) at two different growth stages using HH polarimetric Radarsat-2. The aims of this study are: (1) to identify crop with different life spans based on the backscatter coefficient's values from a single polarisation for understanding the backscatter characteristic of rice over the entire growth cycle, and (2) to understand the advantages and limitations using the RADARSAT-2, C band with HH polarisation. The values of backscattering coefficients have been related to the Malaysia rice crop calendar to get the information of the growth status. The result shows strong backscatter coefficient values on the 21st of May that referred to the reproductive-maturity of rice in the Sawah Sempadan area, and out of season for the Sungai Burong area. While for the August 1st imagery, the result shows weak backscatter values which refers to early vegetative and vegetative-reproductive. The values of backscattering coefficient are found to be much less for early vegetation compare to mature rice crop. In this paper, we have also performed a classification of a rice field using Landsat 8 OLI.

1. Introduction

Advanced satellite technology has in turn spawned remote sensing technology, allowing observation of the earth from space using a wide range of sensors. Agriculture, natural disasters, and ecological system monitoring and forecasting has become a priority field in remote sensing based space observation. Remote sensing data, both optical and radar, have the capability of earth surface observation such as forecasting, monitoring changes, detecting object, predicting and estimating. The Synthetic Aperture Radar (SAR) has become an indispensable tool to understand vegetation's problem and characteristics. The biophysical and quantitative approach of SAR-based technology is very powerful for rice vegetation observation.
Oryza sativa (rice) is one of the important crops in developing countries since rice is a global staple food for humans supplying a large fraction of the needs for energy-rich materials and generally a significant proportion of the intake of other nutrients as well. Because of the growth of the population increasing day by day, there is a high demand for the rice production to meet the demand. Rice becomes the concerning crop in the Group of Earth Observation (GEO) Global Agriculture Monitoring Initiative (GEOGLAM) in improving the crop yield assessment and forecasting at a global level to monitor agriculture and support crop prediction in order to better plan for food availability and cope with the world's demand. Rice crop monitoring is important for a sustainable resource and food security. The purpose of GEO GLAM is to improve food security information using Earth Observation (EO) at national, regional, and global scales [1].

Monitoring at every stage of rice's phenological stages is an important trait that determines the grain production of rice, which is mainly affected by certain factors, including tillering, plant height, and panicle morphology. Other than these, other factors such as pest occurrence, weather conditions, water supply, fertilizer, and pesticide practices also affect the rice production. It is a must to have timely monitoring work on the rice plant development. However, timely monitoring and the high accuracy of information is a challenge in remote sensing based on rice agriculture monitoring and observation. With the high resolution of spatial and temporal polarimetric data such as Radarsat-2 along with the support of statistical data from the agricultural department, the issue will be solved.

Polarimetric SAR is a very powerful tool for extraction of information for identification and classification of different natural features, as each polarisation is sensitive to different surface characteristics and properties. Furthermore, SAR data will overcome the cloud, and weather problems as well as distinguish the behaviour of radar backscattering of rice crops, specifically because at these tropical regions, heavy clouds and rainfall make it difficult to acquire optical remote sensing data [3].

The relationship between radar backscattering coefficients and rice crop parameters using European Remote Sensing (ERS-1) satellite C-band SAR VV polarisation data was the first result gained in the year 1995 [6]. Using the ERS-1 satellite, C-band SAR, a simulation on the Monte Carlo rice canopy was applied in the theoretical model that described the rice canopy backscatter mechanism [7].

A previous study, used RADARSAT-1 HH polarisation data to monitor rice crops and retrieve rice growth parameters [3, 9] However, for single polarisation, such as ERS-1/2 VV and RADARSAT-1 HH data, limited information was provided. When ENVISAT was launched, various polarisation mode data were investigated [2, 4, 10, and 12] With the successful launch of RADARSAT-2, multi-temporal and quad-polarisation data have become available for crop monitoring. Classification for rice field in differentiating between rice and non-rice has been also carried out using RADARSAT, ENVISAT, ALOS and ERS images based on the SAR polarisation, [2,3,4,7,6,9,10,7, and11].

2. Materials and method
2.1. Study area
Tanjung Karang in Kuala Selangor is a famous rice granary area in Selangor, Peninsula Malaysia. In this study, we selected two test sites, Sawah Sempadan and Sungai Burong, located approximately around latitudes 3°27’41.61”N and 3°30’99” N, and longitudes 101°12’38.30”E and 101°09’29.90”E respectively. The rice growing area is the fourth-largest area of rice cultivation land in Malaysia and is under monitoring by the Integrated Agriculture Development Area (IADA), Barat Laut Selangor. The topography of Tanjong Karang is a coastal area characterised by a relatively flat landscape as shown in Figure 1.
2.2. Dataset description
Two types of datasets had been used, Radarsat-2 (Figure 2(a)) and Landsat 8 OLI (Figure 2(b)). The Radarsat-2 data was HH polarisation with a Fine Wide beam mode, acquired on the 21st of May and 1st of August 2014 respectively covering the rice growing season in the study area. Both Radarsat-2 images were 12.5m resolutions. Similarly, Landsat 8 OLI with 30m resolutions were used for retrieving the LULC of the granary area.

2.3. Malaysian rice crop calendar
In monitoring paddy rice, it is significant to know the phases of the paddy rice growth. Target dates or months for satellite images play an important role in the developing stage like discriminating between paddy rice varieties [7]. The growth calendar stipulates the classification of rice growing stages in the month as shown in Table 1. The timing of sowing, planting, growing and harvesting follows the growth calendar. Rice's cultivation practices in Malaysia is twice a year based on double cropping. This is because the climate factors in the equatorial regions have wet and dry seasons continuously. It is important to identify the time and weather conditions to determine the growth period before planting. Weather conditions must be suitable for every growth stage.

In the Rice Growth Outlook, weather involves precipitation, solar radiation and temperature. Excellent weather condition will produce a good harvest whiles, bad weather will produce a poor harvest (weather disaster, growth injury, and other damages such as disease and insects)[9]. In Tanjung Karang, rice growth stages can be divided into three stages: i) planting-early vegetative (January-February, July-August), ii) vegetative-reproductive (March-May, August-October) and iii) reproductive-maturity (June-July, October-December). Rice planting in Tanjong Karang follows the schedule as in Table 2 for every season.
### Table 1. Temporal differences in rice crop growth stages in Malaysia, MADA, 2015.

| Days after Planting | Description                          | Paddy Rice Stages | Growth Phases Based on Malaysian Crop Calendar |
|---------------------|--------------------------------------|-------------------|-----------------------------------------------|
| 0-20                | Pre-flood, Germination               | Germination       | Planting - Early Vegetative                   |
| 20-30               | Tiller initiation                    | Vegetative        | Vegetative - Reproductive                     |
| 30-40               | Early Tiller, mid-tilling            | Reproductive      | Reproductive - Maturity                       |
| 40-55               | Panicle initiation                   |                   |                                               |
| 55-70               | Booting, heading, flowering          |                   |                                               |
| 70-115              | Milky, dough, yellow, ripe, mature   | Ripening          |                                               |

### Table 2. Malaysian yearly rice crop calendar at Sungai Burong and Sawah Sempadan, MOA, 2014.

| Region      | J1 | J2 | F1 | F2 | M1 | M2 | A1 | A2 | M1 | M2 | A1 | A2 | S1 | S2 | O1 | O2 | N1 | N2 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Sawah       | 1  | 1  | 2  | 2  | 2  | 3  | 3  |    | 1  | 1  | 2  | 2  | 2  | 3  | 3  |    |
| Sungai      |    |    |    |    |    |    |    |    |    |    | 1  | 2  | 2  | 2  | 3  | 3  |    |

1 = Planting - Early Vegetative, 2 = Vegetative - Reproductive, 3 = Reproductive - Maturity, and Blank = Out of Season

### 2.4. SAR data processing.

Image processing was performed using NEST 5.1 (Next ESA SAR Toolbox), an open source software for exploiting ESA and other satellite data. The data processing in NEST can be divided into four parts; sigma nought calibration, geometric correction and co-registration, multi-temporal speckle filtering and terrain correction. Figure 3 below shows the workflow of the processing. The methods of Radarsat-2 data processing in this study were employed as follows;

![Figure 3](image-url)  
**Figure 3.** An outline of the flow of process in monitoring crop rice growth stages.
2.4.1 Graph Builder
Developed to automate the processing in NEST, a network of processing chains has been designed to allow for batch processing on the stack of Radarsat-2 multi-temporal images, which included the sigma nought calibration (from amplitude to normalised radar backscatter coefficients). The backscatter coefficients (\(\sigma^o\)) were calculated using the following calibration equation (1):

\[
\sigma^o = 10^\ast \log \left( DN^2 \ast A_o + A_j \right) + 10 \ast \log \left( \sin I_i \right) i
\]

where DN is the digital number of the Radarsat-2 image, \(A_o\) and \(A_j\) are the automatic gain control factors and \(I_i\) is the local incidence angle of each pixel across the range direction.

2.4.2 Satellite orbit parameters
With the satellite orbit parameters in the images header files, geometric correction and automatic co-registration performed on both Radarsat-2 images, it produced high positional accuracy. The RMSE for the co-registration was set up at 0.5 m.

2.4.3 Filtering technique
An Enhanced Lee filter with a 3x3 kernel was used for multi-temporal speckle filtering of the radar imageries to reduce the noise and small patches over the paddy parcels prior to data analysis.

2.4.4 Terrain correction
Doppler range radar terrain correction was performed on the multi-temporal images using 3’ SRTM which showed an obvious difference between the area with a higher elevation and the flat area (Sungai Burong and Sawah Sempadan) located near the coastal region of Kuala Selangor.

2.4.6 Linear to dB
The conversion of radar backscatter coefficients (\(\sigma^o\)) from linear to dB from pixel intensity values to physical quantities is shown below (Figure 4).

![Figure 4. Conversion of Radarsat-2 images’ radar backscatter coefficients (\(\sigma^o\)) from linear to dB](image-url)
2.5 Determining the characteristics of radar backscatter in rice crop fields

Basic statistics were calculated for paddy rice parcels in the Sungai Burong and Sawah Sempadan areas based on the land parcel data retrieved from the Department of Survey and Mapping Malaysia NDCDB (National Digital Cadastral Database). The extracted backscatter coefficient values were achieved by masking Radarsat-2 multi-temporal images using ESRI shapefile vector data of the rice field parcels. From the NDCDB vector data obtained from DSMM, 62 parcels were chosen for Sawah Sempadan and 24 parcels were chosen for Sungai Burong. These parcels are chosen randomly without any specific requirements being used to entail the selection.

2.6 Classification of LULC to monitor the distribution of crop rice in the study area

The ESRI shapefile of the land parcels and Radarsat-2 multi-temporal images were exported to Google Earth .kml file. These datasets were overlaid with Google Earth to identify the land cover types such as paddy rice, water bodies, other vegetation, urban areas and others. Google Earth ENVI Jump to Location was also used to verify the land cover types to be used as ROIs. For the rice field, the classes were identified according to their growth stages specified in the Rice Crop Calendar: i) planting-early vegetative, ii) vegetative-reproductive, and iii) reproductive-maturity. It must be noted, however, that these stages were assigned based on a mere visual interpretation of the Landsat 8 OLI image collected on 21st of May 2014. This image was fused with Radarsat-2 images also taken on the 21st of May 2014.

Due to a heavy percentage (>50%) of cloud cover during the period when both Radarsat-2 datasets were used, the 21st of May 2014 and 1st of August 2014, a proper data fusion of Landsat 8 OLI and Radarsat-2 datasets on these dates for LULC classification using the Neural Network classifier and accurate delineation of the growth stages of the rice were difficult to be achieved. Even if the classification was performed, the accuracy of the LULC classification result would have been low due to the misclassification of several classes that were affected by the cloud cover. The purpose of the LULC classification using SAR-multispectral datasets in this study was also not to monitor the growth stages of the rice crops but rather to analyse the distribution of rice crops in the study areas. It was to analyse visually, whether it was fit with the location of the Sungai Burong and Sawah Sempadan parcels that were used as masks to generate the statistical data, prominent in the analysis of this study.

3. Result and analysis

3.1 Experimental lot

From the NDCDB vector data obtained from DSMM, 62 parcels were chosen for Sawah Sempadan and 24 parcels were chosen for Sungai Burong (Figure 5). These parcels were chosen randomly without any specific requirements being used to entail the selection. The characteristics of \( \sigma^0 \) in the rice crop fields involving the correlation between the strength of the radar \( \sigma^0 \) and the growth stages of the rice crops, were reviewed to provide an analysis of their growth in terms of the visual perspective.
Figure 5. Land parcels of Sungai Burong and Sawah Sempadan lots obtained from DSMM NDCD.

3.2. Visual Interpretation

Figure 6: Bright features indicating strong backscatter on the 21st of May 2014, whereas parcels with dark patches indicate weak backscatter on the Radarsat-2 image acquired on the 1st of August, 2014.

From the visual interpretation, the results can be assumed to mean that the first imagery has strongest backscatter values than the second imagery. The spatial variations in the $\sigma^0$ strength are represented by different contrasts of dark patches in each parcel of the two lots. Features appear with various tones of radar brightness. Some parcels had bright a colour, intermediate, and dark colour. There is a strong indication that both lots in the both images were under different season from sowing to vegetative and the vegetative to the reproductive periods. This situation can give the assumption that, the cultural practice is different in every parcel in both lots. The rice tree in these parcels may experience a difference in the growth of the rice crop in any of these stages: germination, tiller initiation, early tillering, mid-tillering or panicle initiation. The rices fields show up as brighter and brighter patches in the growth of the rice crops, [8, 15]. This is due to an increase in the intensity of the backscattered microwaves.
Based on the agriculture statistics from the Department of Agriculture, Kuala Selangor, around seven types of rice varieties were planted at Sawah Sempadan and Sungai Burong for both seasons, which were, MR 220CL1 & CL2, MR219, MR253, MR263, MR269, and MR325. Different varieties of rice will have different maturity period and life cycles. For example, the rice type of MR253, MR263 and MR269, have less than the 120-day maturity period. Other characterisation such as the shape of the plant and height, resistance to disease, and capacity of grain production are also different. This type of rice is the highest quality and gives a high yield [13]. The rice variety also is one of the important factors that influence the rice yield.

In the other cases, very bright parcels or targets appeared due to the corner reflector or double bounce effect, where the radar pulse bounced off the horizontal ground towards the target, and was then reflected from one vertical surface of the target back to the sensor [5]. Built-up areas and many man-made features usually appear as bright patches in a radar image due to the corner reflector effect. Some of the areas in Sawah Sempadan and Sungai Burong were built with houses, community places and shop lots. So in these cases, buildings reflected most of the radar energy back to the sensor.

Besides, surface roughness and moisture content of bare soil will affect the backscatter values. The brightness of areas covered by bare soil may vary from very dark to very bright depending on its roughness and moisture content [5]. Typically, rough bare soil appears bright in the image. For similar soil roughness, the surface with a higher moisture content will appear brighter. For flooded area, it will appear dark because all of radar energy specularly reflected away. The familiarity of ground conditions of the areas imaged, makes us difficult to interpret. In Radar, there is a rule which is, the higher the backscattered intensity, the rougher is the surface being imaged. Some of the flat surface such as road and water bodies will appear dark because radar the incident radar pulses are specularly reflected away [5]. All this situation resulting the images appear in various tones of brightness and darkness.

### 3.3. Average backscatter coefficient in Sungai Burong and Sawah Sempadan

From the two growth periods, the $\sigma^o$ on the 21st of May (from 55 to 115 days after transplanting) was the highest as compared to the backscatter coefficient on the 1st of August (Figure 7). At Sawah Sempadan, on the 21st of May, during the reproductive-maturity period, the mean $\sigma^o$ was -7.80 dB, showing a strong backscatter between -33.91 dB (minimum) to 22.37 dB (maximum). The mean $\sigma^o$ at Sungai Burong followed the same trend with the mean $\sigma^o$ on the 21st of May being -6.42 dB at the range between -32.88 dB (minimum) to 22.06 dB (maximum).

Around the early-vegetative to vegetative reproductive period (from 0 until 55 days after transplanting), the $\sigma^o$ also change with the decreasing trend. The HH $\sigma^o$ polarisation at Sawah Sempadan on the1st of August shows the mean of -10.51 dB, ranging from -36.26 dB (minimum) to 22.06 dB (maximum). The $\sigma^o$ at Sungai Burong followed the same pattern with the mean $\sigma^o$ at -11.45 dB, ranging from -39.37 dB to 21.70 dB. These $\sigma^o$ temporal variations from the HH polarisation Radarsat-2 datasets can be used as the function of the rice crop growth period which refers to the months of the year.
3.4. Spatial and temporal variation

**Figure 7.** The average backscatter coefficient value on the 21st of May and the 1st of August, 2014 in Sawah Sempadan and Sungai Burong.

**Figure 8:** Backscatter coefficients at selected parcels in (a) Sawah Sempadan and (b) Sungai Burong for both images.
Both Figures 8 (a) and (b) above show the pattern of $\sigma^o$ at each parcel in the two different growth periods. The computed statistics reveal that the growth phases in each parcel within the Sawah Sempadan and Sungai Burong lots were different, although they are categorised into the same growth period based on the Malaysian Rice Crop Calendar. Each parcel exhibited different $\sigma^o$ values in terms of their mean values, either lower or higher than one another. The differences in their mean values however were not too subtle, having a mean $\sigma^o$ ranging from -6 dB to -11 dB and -7 dB to -13 dB on May 21st and the 1st of August respectively, for both lots. However, in a certain parcel such as parcel no. 22 in Sawah Sempadan it shows high maximum values of $\sigma^o$ at both months (May and August) at 13.30 and 12.88 dB, respectively. Other parcels have maximum $\sigma^o$ values between -0.5 dB to 7 dB only for the observed period. This may be due to the existence of other features within that parcel such as dwellings which significantly change the $\sigma^o$ at that particular parcel.

The statistics for the sample parcels selected from Sungai Burong show the same $\sigma^o$ pattern. The mean $\sigma^o$ for the 24 sample parcels was between -4 dB to -7 dB and -7 dB to -20 dB for the 21st of May and the 1st of August respectively. The range (maximum/minimum) on the 21st of May and the 1st of August at the Sungai Burong sample parcels were -22 dB to 12 dB and -33 dB to 13 dB respectively. The significant difference is observed at lot 21009 with minimum/maximum $\sigma^o$ is -4.37 dB/-3.61 dB, and -21.54 dB/-18.52 dB in May and August respectively. The low $\sigma^o$ values of this parcel as compared to the others may be caused by other features in the parcel with low radar $\sigma^o$ such as flooded water or another feature(s) with high a moisture content.

![Temporal $\sigma^o$ at Sawah Sempadan](image1)

![Temporal $\sigma^o$ at Sungai Burong](image2)

**Figure 9 (a),(b), and Table 3.** Variations of the rice backscatter coefficients at both lots corresponding to the age of the crop based on the Malaysian rice crop calendar broadcasted by Radarsat-2 image acquisition.

| Area          | Date             | Growth Stages                    | Age (days) | Radarsat-2 $\sigma^o$ (dB) | Backscatter strength |
|---------------|------------------|----------------------------------|------------|---------------------------|---------------------|
| Sawah Sempadan| 21st of May 2014 | Out of season                    | -          | -7.8077                   | High                |
|               | 1st of August 2014 | Vegetative-reproductive              | 45-75    | -10.5177                  | Low                 |
| Sungai Burong | 21st of May 2014 | Reproductive-maturity              | 75-90     | -6.4216                   | High                |
|               | 1st of August 2014 | Planting-early vegetative          | 0-30      | -11.4455                  | Low                 |
Figure 9 and Table 3 have indicated the relationship between the radar $\sigma^o$ and the growth stages (refer to the days in the month when the images were acquired) on both rice field lots which can strongly differentiate the $\sigma^o$ in the two growth stages. The first date of the image (21st of May) results in a strong $\sigma^o$. This strong backscatter suggests that both lots were in their reproductive-maturity period of the rice crop growth. This situation occurred due to the rice crop height temporal variations. During the reproductive-maturity stage, the rice plant height increases rapidly, and the difference in the cultivation time of rice crops at Sungai Burong and Sawah Sempadan may have caused the difference in the rice crop height, increases in the number of leaves, grain filling, and thus caused the double bouncing between plants to occur, causing the image on the 21st of May to appear brighter (strong backscatter).

The bright features of the rice crop may have appeared in the image due to the corner reflector or double bounce effects where the radar pulses bounced of the horizontal grounds towards the targets and then, were reflected from one vertical surface of the targets back to the sensor [2]. However, the values of $\sigma^o$ in Sawah Sempadan were still high even though there was no vegetative growth at the time (out of season) because of the bare soil of rice field having rough surface with low moisture content.

On the 1st of August, the $\sigma^o$ was relatively weak during the planting to early vegetative and vegetative to reproductive periods. However, in Sawah Sempadan it was quite high compared to Sungai Burong because of the different volumetric scattering, and the number of leaves and panicle were less at this age. Furthermore, in the early stages, the moisture content of the crop and the soil moisture of the rice field is really high. In the optical range, early vegetation will appear greenish, indicating a healthy rice plant because of the high moisture content and nutrient level. Different from the microwave range, it will appear dark because of the energy being absorbed by the moisture or water content in the soil and rice plant. Daily weather conditions also cause changes in moisture content of the rice crop and the soil that will affect the strength of the $\sigma^o$ values.

3.5. Distribution of rice crop in the study area

Figure 10 shows the result of the LULC classification using Landsat 8 OLI and Radarsat-2 data fusion of the study area to show the distribution of rice crop covering the area. The areas marked by the white line polygon vector are the study areas of Sungai Burong and Sawah Sempadan. This map was created only for verifying the types of vegetative features covering the Sungai Burong and Sawah Sempadan land parcels. The majority of the LULC in this area was covered by rice crops. As we can see, the location of Sungai Burong and Sawah Sempadan are near the coastal areas.

To sum up, if an exact period of Landsat 8 OLI datasets are obtained during the day/period when Radarsat-2 images are acquired with cloud cover less than 10%, a proper visual analysis and classification map can be produced to monitor the rice crop growth stages using either the fused or combination of both SAR and multispectral datasets. Using the fused Radarsat-2 and Landsat 8 OLI datasets with different dates, the different growth periods as used in a small part of this study subjected to the analysis of the LULC classification were very limited, so as to show only the distribution of rice crops in the study area.
4. Conclusion
The values of the backscatter coefficients, which were related to the Malaysian rice crop calendar, easily differentiate the rice growth stages in the rice area. Results indicated, strong backscatter coefficient values on the 21st of May that referred to the reproductive-maturity rice in the Sawah Sempadan area and out of season for the Sungai Burong area. Whilst for the 1st of August imagery, the results show weak backscatter values, which were referred to as early vegetative and vegetative-reproductive. The values of the backscattering coefficient were much lower for early vegetation compared to mature rice crops due to temporal changes. Referring to the factor affecting the $\sigma^0$ values, moisture content and surface roughness of the target determine the values of $\sigma^0$ and strength of the scattering. The different contrasts of parcels in the same area and date showed spatial variations that were caused from different cultural practices amongst the farmers. This indicator can help to monitor the farmers' activities in order to ensure a high rice yield production. The limitation of this study is that it has only focused on the rice growth stages (age), the next study will examine various parameters such as biomass, moisture content etc., which can be correlated with the ground data.

5. Recommendations
As for this study, monitoring of the growth stages of the rice crop growth was performed by using the Multi-Temporal Radarsat-2 dataset using only one observation and only using single polarisation (HH). In the near future, another polarisation could be used to see the different results of monitoring the rice growth stages. In conjunction with using the SAR image, more parameters could be extracted and used for other purposes, such as rice plant height, LAI, biomass, moisture content etc. Apart from that, the backscatter coefficient from the image could be correlated with ground data to actual condition and get better accuracy.
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