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Diurnal and Row Effects on Paddy Rice Backscatter

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Abstract

Rice is a very important crop providing not only a staple in the daily food requirements of many people but also an important source of income for rice exporting countries such as Thailand and Vietnam. Due to the prevalence of cloud cover in important rice producing regions, radar remote sensing provides an attractive source of data for mapping and monitoring objectives. This paper addresses the use of RADARSAT for mapping and monitoring paddy rice. The underlying water surface in paddy rice production systems enhances the radar backscatter from the rice plants such that identification and monitoring appears very promising. Due to the desire to use both ascending and descending orbits for this temporally dynamic monitoring application, the effect of time of day and look direction was evaluated in this study. The results show that at some times data from different orbits can be used without correction for diurnal plant moisture changes or azimuth look direction effects, but in other cases row direction influences or time of day effects may be significant. This has implications on developing RADARSAT data acquisition scenarios for monitoring paddy rice. Additional work is required to determine the magnitude of change over a growing season, as a function of incidence angle, to fully evaluate this effect.

1.0 Introduction and Background

The monitoring of the earth's surface with satellite imagery has, in the past, been largely dependent on the weather and time of day. Today, microwave sensors such as Canada's RADARSAT, are broadening the world of remote sensing as they are capable of imaging day or night, and regardless of weather conditions. There are many applications of remote sensing imagery which can benefit from particularly dynamic phenomena such as crop monitoring (Brown et al., 1993;1995). This paper will focus on the use of RADARSAT imagery for rice crop monitoring.

Rice is a very important crop because it provides a staple food for a large part of the world's population, especially in Asia. In some regions, it is also important economically as an export product. Since most rice producing regions are found in tropical and sub-tropical regions with high amounts of rainfall and therefore cloud cover, the traditional approach of using vegetation indices in the visible and infra-red (VIR) region are not practical. The fragmented land cover and small size of many of the rice paddies also precludes the use of a low-resolution high repeat coverage sensor like NOAA's AVHRR which can often use a temporal compositing technique to overcome the persistent cloud cover problem. Fortunately, the presence of water beneath the plant canopy, typical of paddy rice production systems, enhances the sensitivity of radar backscatter to rice (Le Toan et al., 1989; Aschbacher and Paudyal, 1993; Kurosu et al., 1993; Brisco et al., 1996; Le Toan et al., 1997). This is due to the domination of the backscatter process by canopy scattering and water surface-canopy interaction terms, because no direct surface contribution comes from the underlying water surface. Consequently, RADARSAT in particular and Synthetic Aperture Radar (SAR) satellite systems in general, are very promising tools for developing a rice mapping and monitoring capability.

In order to fully utilize RADARSAT's data collection capability for monitoring rice it is necessary to know the effect of radar look direction with respect to rice growth parameters which in turn make it possible to effectively use both descending and ascending orbit data. Previous research has demonstrated significant row effects on the magnitude of radar backscatter from dryland row crops (Ulaby and Bare, 1978; Hutton et al., 1987, Brisco et al., 1993). This effect has been attributed to the underlying soil surface appearing rougher when looking across the rows and thus significant effects would not be expected from a rice canopy, especially after tillering when the canopy approaches 100 % plant cover. The other implication of using data acquired on both ascending and descending orbits is the potential for examination of diurnal effects related to the movement of water in the plant-soil system over a 24 hour period (Ulaby and Batlivala, 1976; Brisco et al., 1993). Once again, these diurnal effects are expected to be small for wetland rice production.

The objectives of the study being conducted at CCRS are to:

1) Evaluate the effects of azimuth look direction relative to row direction and diurnal movement of plant moisture on radar backscatter from paddy rice crops;

2) Relate the results with respect to objective 1 to rice mapping and monitoring with RADARSAT and make recommendations as to optimal timing of data acquisitions; and

3) Identify additional research efforts required to support rice crop monitoring with RADARSAT.

These objectives will be fully achieved through in-depth research in the future. Early results of the study are presented in this paper.

2.0 Site and Data Description

2.1 Study Site

The study site is near the city of Zhao Qing (23°02'N, 112°29'E) in the Guangdong Province of South China. This area was used as a test site for the GlobeSAR project and numerous RADARSAT images of the area were acquired (Yun et al, 1995). The site is characterized by its flat topography and wide variety of agricultural crops and plants including rice, bananas, sugar cane, oranges, and euryale ferrox. The fields are generally small (usually around 50 to 150 meters wide) and are clearly delineated by the ditches, dikes and roadways which separate them. The weather is cloudy and rainy most of the year, making the soil moisture content quite high. This site has been used for studies in the past and is generally considered to be representative of most regions of Southern China where rice production is the dominant form of agriculture.

2.2. Data

Three pairs of RADARSAT images have been analyzed so far. In order to minimize backscatter differences related to crop growth and development, there is a maximum of 5 days difference between data pairs. Each pair represents a different stage in the rice crop growth cycle with the first acquisition in August, 1996 and the last image acquired in early December 1996 as shown in Table 1. Incidence angles for S6 are approximately 41 to 46 degrees and approximately 43 to 46 degrees for F4 (RSI, 1996). A plot of the incidence angle of the sample areas within our study site indicated a variation of less than one degree between different scenes.

Acquisition Date and local time	Beam	Orbit	Stage of Rice Growth Cycle
96 August 23 18:41:49 local	S6	Ascending	Early
96 August 28 06:18:41 local	S6	Descending	Early
96 September 16 18:42:04 local	S6	Ascending	Mid
96 September 21 06:18:58 local	F4	Descending	Mid
96 November 27 18:42:14 local	S6	Ascending	Late
96 December 02 06:19:18 local	F4	Descending	Late

Table 1. RADARSAT Data Acquisitions

A land cover map was provided by the Institute of Remote Sensing Applications (IRSA) in China. This map, along with ground data and crop type information, were used to determine sample sites of each of the land cover types which were then used for the extraction of the data.

Three land cover classes were chosen for preliminary analysis: rice, bananas, and water. It was expected that the water (including aquaculture and river locations) would exhibit little or no change, while bananas may exhibit some diurnal effects, but not row effects, due to the more random distribution of canopy elements and plants themselves. It was expected that rice may show both row and diurnal effects. These three classes thus represent a good mix of expected target responses.

3.0 Methodology

3.1 Calibration

In order to utilize RADARSAT data quantitatively, they must first be calibrated which includes correction for the antenna gain patterns. As of February 1997, RADARSAT beams S1 to S7 and W1 to W3 were declared calibrated by the Canadian Space Agency (CSA) (Srivastava et al, 1997). In the case of this study, the data were collected during 1996 and therefore had less than optimal corrections applied. A program developed at CCRS (Wolfe and Hawkins, 1997) for retro-active calibration was used to correct the images using the best available payload parameter file. This was carried out on all six RADARSAT images used in this study. The fine mode beams have not yet officially been declared calibrated, however the most up-to-date payload parameter file was used for correcting these data. It is anticipated that these data will not differ significantly from the officially released version, expected by the end of May 1997 (personal communication, B. Hawkins).

PCI SAR Radiometric Calibration routines (PCI, 1997) were used to convert the image data from DN (digital numbers) to radar brightness ($\beta°$) values. A task within the program created a table of incidence angles which were user with the $\beta°$ values to obtain $\sigma°$ values.

Further details with regards to RADARSAT data and their calibration can be found in Srivastava et al, 1997 and Shepherd, 1997.

3.2 Image Processing and Manipulation

Ground control points were automatically collected using an in-house program and all six images were registered together into one database of six 32-bit channels. This procedure included resampling of the fine mode scenes to 12.5 metre pixel spacing. In order to reduce the file size to a manageable level, a sub-image was selected to cover the study site.

3.3 Data Extraction and Statistical Analysis

As indicated in section 2.2, there were three classes of land cover chosen for the this study: rice, banana, and water. For each class, three separate sample sites were delineated. These areas vary in size, but all contain an area of known land cover. The sizes of these sites are given in Table 2.

Class	Sample	Size (pixels)
Rice	1	114
Rice	2	117
Rice	3	114
Banana	1	76
Banana	2	100
Banana	3	30
Water	1	60
Water	2	36
Water	3	444

Table 2: Land cover class sample sizes

The desirable statistics were extracted from the images and training sites. These numbers were provided as a value in power and required a conversion to dB. The mean values of σ° were determined for each class and for each image, and were compared to determine the level of change between scenes for each type of land cover. Results are presented in Table 3.

4.0 Results and Discussion

WATER

DATE	BEAM	ORBIT	σ° (dB)	$\Delta\sigma^\circ$ (dB)
96-August-23	S6	Ascending	-24.45869283	
96-August-28	S6	Descending	-24.13225184	0.326440991
96-September-16	S6	Ascending	-23.31545209	
96-September-21	F4	Descending	-23.07233455	0.24311754
96-November-27	S6	Ascending	-24.53368805	
96-December-02	F4	Descending	-24.24784331	0.285844733

RICE

DATE	BEAM	ORBIT	σ° (dB)	$\Delta\sigma^\circ$ (dB)
96-August-23	S6	Ascending	-11.28839078	
96-August-28	S6	Descending	-9.491801076	1.796589701
96-September-16	S6	Ascending	-7.186820352	
96-September-21	F4	Descending	-6.4432944	0.743525952
96-November-27	S6	Ascending	-9.061746377	
96-December-02	F4	Descending	-9.34223637	0.280489994

BANANA

DATE	BEAM	ORBIT	σ° (dB)	$\Delta\sigma^{\circ}$ (dB)
96-August-23	S6	Ascending	-5.351434505	
96-August-28	S6	Descending	-5.830092673	0.478658168
96-September-16	S6	Ascending	-5.006108723	
96-September-21	F4	Descending	-4.208580942	0.797527781
96-November-27	S6	Ascending	-7.126986761	
96-December-02	F4	Descending	-6.633247775	0.493738986

Table 3: Statistical results of the radar backscatter coefficient of water, rice paddies and banana for ascending and descending RADARSAT images.

In looking at the results, significant change is only noted for rice early in the growing season. With the processes carried out on the data prior to extracting statistical information, the authors feel confident that any such significant changes in backscatter within the data set could be attributed to time of day effects, row direction effects or other environmental factors. As expected, the differences in backscatter for the water and banana targets were insignificant since they are stable targets. For rice, however, a 1.8 dB increase was calculated between the August 23 and August 28 images. This result may be attributed to either row effects early in the growth cycle before the rice has completely tillered and covered the water surface, or to time of day effects related to the diurnal movement of moisture in the plant. Further analysis of these, and future data sets covering various time periods during the crop calendar are needed in order to clarify this observation.

It is recognized that these results could be attributed to environmental effects. However, based on the relatively stable results from the banana class for the same dates, it is likely that the observed change in backscatter between scenes for the rice paddies is related to row direction effects or diurnal moisture movement. Variation due to row direction is likely as the rice plant is emerging through the water at this early stage in the growth cycle. The growth rate of the rice is quite rapid at this time and scatter due to interaction between the vertical plant structure and the underlying surface, modulated by the row direction, may be the cause of the increased backscatter seen in the August data pair.

5.0 Summary

This study was a preliminary investigation into the diurnal and row direction effects in rice paddies in RADARSAT data. There is currently more in-depth research planned with existing data and a more complete data set will be acquired for further investigation. For the purpose of obtaining preliminary conclusions however, this study was found to give useful results and provide a focused direction for continued research.

The preliminary results showed that the only significant change in backscattering between scenes was for the rice early in the growing season. Because the data were updated to have the latest payload parameter file, the difference of 1.8 dB of the rice class is significant. It can most likely be attributed to row direction effects or the diurnal movement of water within the plant.

There is great potential for rice crop monitoring using RADARSAT. The results observed here show that there is a need for more in-depth research on the significant effects of the time of day and row direction effects on the backscatter from rice paddies This conclusion may imply a need for careful planning of RADARSAT data acquisitions for rice monitoring applications. This may also require development of more calibration and correction approaches to the imagery, or a willingness to accept the impact of significant uncertainty in the backscatter estimate.

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