DETECTING RICE CROP PHENOLOGY FROM TIME-SERIES MODIS DATA

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ABSTRACT: Information on rice crop phenology is important for crop management. This study aimed to detect rice crop phenology in the Vietnamese Mekong Delta using time-series MODIS data in 2007. Data processing steps included: (1) constructing time-series MODIS NDVI data, (2) filtering noise from the time-series data using empirical mode decomposition (EMD) and wavelet transform, (3) detecting rice crop phenology (sowing, heading, and harvesting dates) using local maxima algorithm, and (4) verifying the results using field survey data. The results indicated that EMD produced more accurate results in rice crop phenology detection than did wavelet transform. Comparisons between the estimated sowing and harvesting dates achieved by EMD and the field survey data indicated the root mean squared error (RMSE) values of 7.5 and 8.2 days, while those by wavelet transform were 21.3 and 21.6 days, respectively. The error of the estimated sowing date was generally smaller than that of the harvesting date. This discrepancy was due to the fact that the timing for rice harvesting was partly dependent on the weather conditions, especially for the second crop in the rainy season. This study demonstrated the merit of using EMD for rice crop phenology detection. The information of rice crop phenology produced from this study would be further used for studies of rice crop mapping and monitoring.

1. INTRODUCTION

Rice is the world's third largest crop behind maize and wheat. It is the major food source of more than half of the world's population. Rice plays an important role in the economy of Vietnam and provides employment and income for rural populations. More than 80% of the rice exported from Vietnam is produced in the Mekong Delta (Nguyen et al., 2004), which hosts more than 53% of Vietnam's rice growing land. Because of the significant amount of rice growing land, monitoring rice crop growth is important for crop management. For years, information related to rice crop phenology was collected from field surveys. A number of studies of rice crop monitoring have been conducted using multi-temporal satellite data based on crop phenology information (Sakamoto et al., 2005a; Viña et al., 2008; Wang and Tenhunen, 2004; Xin et al., 2002; Zhang et al., 2003). Filtering techniques are often applied prior to the analysis of vegetation index time series in order to reduce noise because the time series can be contaminated by clouds or affected by errors from satellite sensors.

Common methods proposed for noise filtering of the time series of vegetation index data for each pixel include Fourier and wavelet transforms (Galford et al., 2008; Mingwei et al., 2008; Sakamoto et al., 2005a; Zhang, 2008), although these methods have disadvantages. For instance, when the Fourier transform is applied to a non-stationary signal, large sets of physically meaningless harmonics are often produced (Huang et al., 1999). The wavelet transform method is limited by the determination of an appropriate filter function prior to decomposition (Li, 2006). The present study uses the empirical mode decomposition (EMD) (Huang et al., 1998) to filter noise from the time-series MODIS normalized difference vegetation index (NDVI) data. EMD is advantageous in that it does not assume that the time-series is stationary or non-stationary prior to analysis. This method can adaptively generate many sets of intrinsic mode functions (IMFs) and a residue. Low-pass, high-pass and band-pass filters can then be designed from the IMFs and the residue (Gloersen and Huang, 2003; Huang et al., 1999; Huang et al., 2003; Rao and Hsu, 2008). Here, we designed a low-pass filter to filter high-frequency components from the NDVI time-series data.

The main objective of this study was to detect rice crop phenology in the Vietnamese Mekong Delta using time-series MODIS data in 2007. The data were processed using EMD. However, wavelet transform also used for noise filtering of the time-series NDVI data to verify the effectiveness of EMD.

2. STUDY AREA

The study area (Figure 1) located in the northwest part of the Vietnamese Mekong Delta covers approximately 3406.2 km^2. Agricultural land covers up to 72.6% of the area, and more than 82% of the agricultural land is allocated for rice cultivation (GSO, 2007). The region has two distinct seasons: wet and dry. Three rice cropping systems were being practiced in the region: single crop rain-fed rice, double-cropped irrigated rice, and triple-cropped irrigated rice. The single-cropped rain-fed rice used long-term rice varieties (160 days) and was practiced the rainy season (Jul−Aug to Dec−Jan). The double- and triple-cropped rice used short-term varieties (90 days). The double-cropped rice was practiced in the winter-spring season (Nov−Dec to Feb−Mar), and summer-autumn season (Apr−May to Jul−Aug). In triple-cropped rice system, depending on area, an extra crop of either autumn-winter (Jul−Sep to Oct−Dec) was added.

Rice growth in the study area involves 3 main periods: sowing, growing and harvesting fallow periods (Le-Toan et al., 2003). During the sowing period, a high-density field of grains is sown directly into flooded soil under 2-5 cm water. The growing period involves the vegetative, reproductive and ripening stages. The vegetative stage is characterized by increases in the plant height and the number of tillers and by the development of leaves on reaching to a heading phase. After heading, the plant changes from the vegetative stage to the reproductive stage. During this stage, rice crops cease to increase in height and biomass and the leaves begin to wither and die. The vegetative stage lasts for approximately 60 days (the exact length of time is dependent on the variety), and the reproductive stage lasts for approximately 30 days (Yoshida, 1981). The ripening stage lasts for approximately 30 days and is characterized by a decrease in leaf and stem moisture content and a decrease in the number of leaves (Yoshida, 1981). After harvesting, in the fallow period, the rice fields are either bare or dry at the end of the dry season or are covered with weeds during wet conditions.

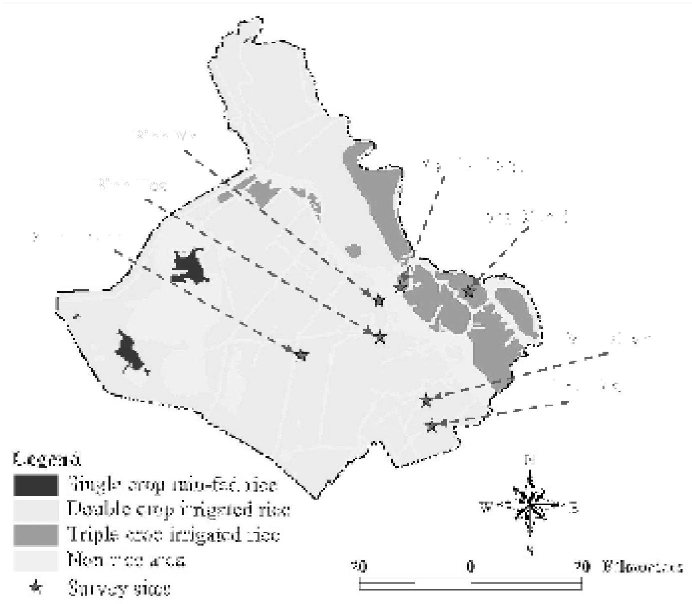

Figure 1. Rice crop map of the study area in 2002 showing the survey sites (blue stars), was used for field surveys.

3. DATA

This study used the 8-day MODIS/Terra MOD09Q1 data (MODIS/Terra Surface Reflectance 8-Day L3 Global 250m SIN Grid V005) acquired from NASA for the 2007 (Dec 2006−Dec 2007) rice cropping seasons. MOD09Q1 product provides two spectral bands, red (620-670 nm) and near-infrared (841-876 nm). The uncertainties of the data product has been validated for stage 2 or well defined over a range of representative conditions. The data are thus ready for use in scientific publications (Vermote et al., 2008). The field investigation data, in terms of sowing and harvesting dates, which were used to verify the rice crop phenology in the temporal NDVI profile. The field investigations were conducted during the 2006-2007 rice cropping seasons. The survey sites are shown in Figure 1.

4. METHODS

4.1 Data pre-processing

The MOD09Q1 data were formatted using a sinusoidal projection. In this study, we reprojected the data to the Universal Transverse Mercator (UTM) coordinate system (Zone 48 N), and subset over the study area. The NDVI was used to study the temporal responses of rice fields. This index is sensitive to quantitative changes in the vegetation canopy. To create the time-series NDVI datasets for the 2002 and 2007 rice cropping seasons, we first calculated the NDVI for every 8-day MODIS scene. 51 NDVI scenes were consequently created for the rice cropping season in each year. These NDVI scenes were then stacked into single, multi-temporal 8-day composite scene with 51 bands. Due to cloud cover, noise still presents in the time-series NDVI data. Thus, filtering such noise from the time-series data is necessary before the analysis. For this, we used EMD (Huang et al., 1998). This method created a number of IMFs and a residue. We designed a low-pass filter to filter noise from the time-series

NDVI data by adding together the last two IMFs and a residue. In this way, we could separate high-frequency components or noise from the time-series data to reconstruct the smooth NDVI profile for each pixel in the image.

The wavelet transform was also applied to filter noise from the time-series NDVI data. This analysis was done in respect to the comparison of its noise filtering performance with EMD. In a study of rice crop phenology detection in Japan, the Coiflet wavelet (order 4) used in the wavelet transform has been demonstrated to give the best results among Daubechies wavelets (9, 13, 17) and Symlet wavelets (6, 12, 14) (Sakamoto et al., 2005b). This Coiflet 4 was thus selected and used in this case study for the decomposition of the time-series NDVI data.

4.2 Crop phenology detection

Detecting phenological dates of rice crops comprises 3 steps: (1) a 3×3 kernel was used to extract pixels at the survey sites. The pixels extracted from these homogeneous areas containing abnormal patterns were excluded from the analysis using a fuzzy composition (Witold, 1989); (2) the heading date was identified as follows: from the smooth time profile of NDVI, it was found that the maximum NDVI value was above 0.4 during the peak reproductive stage. Thus, a threshold of 0.4 was first set to eliminate unrealistic heading dates or peaks. The local maxima method was then used to identify the heading date as the maximum NDVI value in the time profile; and (3) the sowing date and harvesting dates were determined; based on the information recorded from field surveys and the results documented in the literature (Le-Toan et al., 2003; Sakamoto et al., 2005a; Yoshida, 1981), the sowing and harvesting dates were detected by examining the smooth time profile of NDVI data. The sowing date was defined as being less than 60 days from the estimated heading date, and the harvesting date was more than 30 days after the estimated heading date. Moreover, the duration of a rice cycle in the study site is approximately 90-110 days. The interval between two heading dates should thus be longer than 80 days (Sakamoto et al., 2006). The number of rice crops practiced per year is finally defined by the number of heading dates per year, and sowing and harvesting dates were consequently detected. The results of the estimation were compared with the field survey data to ensure that the smooth NDVI patterns describe the phenological profiles of the rice cropping systems.

4. RESULTS AND DISCUSSIONS

4.1 Time-series NDVI profiles of rice cropping patterns

The curves showed the temporal pattern characteristics of the rice cropping systems (derived from EMD) throughout the years of the study (Figure 2). The noise in the signatures was significantly mitigated. Rice cropping patterns in the study area showed that the single-cropped rain-fed rice has one peak (at the heading date) in the smooth NDVI time profile around the last cropping season (Figure 2a). The double-cropped irrigated rice has two peaks: the first peak indicates the heading date of the first crop and the second peak indicates the heading date of the second crop (Figure 2b). The triple-cropped irrigated rice system should have three peaks because three crops were harvested each year (Figure 2c).

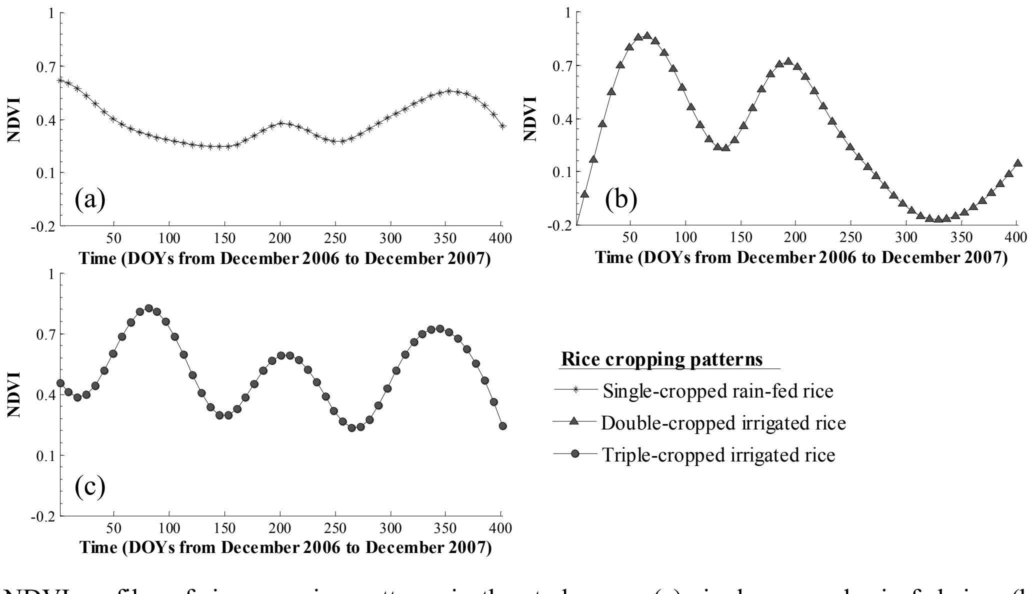

Figure 2. NDVI profiles of rice cropping patterns in the study area: (a) single-cropped rain-fed rice; (b) double-cropped irrigated rice, and (c) triple-cropped irrigated rice.

4.2 Comparisons between detected rice crop phenology and field survey data

The comparison results between the estimated sowing and harvesting dates (derived from EMD and wavelet transform) and the field survey data indicated that the error of the estimated sowing date was smaller than that of the harvesting date in both cases (Table 1). This discrepancy was due to the fact that the timing for rice harvesting was partially dependent on the weather conditions, especially for the second crop, which matured for harvest in the rainy months. Comparing the estimated sowing and harvesting dates achieved by the EMD with the field survey data gave the root mean squared error (RMSE) values of 7.5 and 8.2 days, respectively, while the values by the wavelet transform were 21.3 and 21.6 days. The results of rice crop phenology detection indicated that EMD acted a good filter, and slightly outperformed the wavelet transform (using Coiflet 4) for noise filtering of the time-series MODIS 250-m NDVI data. The NDVI profiles extracted from the EMD-based filtered NDVI data could preserve the amplitude of NDVI values better than those extracted from the wavelet transform. The smooth time profiles reflected the temporal characteristics of rice cropping patterns throughout the year. This characteristic was important for understanding the temporal NDVI responses from different rice field cropping systems in the region.

Table 1. Comparison of the estimated phenological dates with the field survey data.

Sampling site	Heading date		Sowing date			Estimated harvesting date		
	EMD	Wavelet	EMD	Wavelet	Observed	EMD	Wavelet	Observed
Binh My								
I	02/09/07	01/24/07	12/15/06	11/29/06	12/10/2006	03/13/07	02/25/07	03/11/07
II	06/17/07	06/09/07	04/22/07	04/14/07	04/23/2007	07/19/07	07/11/07	08/03/07
Vinh Binh								
I	01/24/07	01/24/07	11/29/06	11/29/06	11/29/2006	02/25/07	02/25/07	03/10/07
II	06/25/07	07/03/07	04/30/07	05/08/07	04/10/2007	07/27/07	08/04/07	07/20/07
Binh Hoa								
I	02/01/07	01/24/07	12/07/06	11/29/06	12/12/2006	03/05/07	02/25/07	03/14/07
II	06/17/07	06/01/07	04/22/07	04/06/07	04/22/2007	07/19/07	07/03/07	08/02/07
Vinh Chanh								
I	02/01/07	01/24/07	12/07/06	11/29/06	12/12/2006	03/05/07	02/25/07	03/14/07
II	06/17/07	06/01/07	04/22/07	04/06/07	04/22/2007	07/19/07	07/03/07	08/02/07
Phu Hoa								
I	02/17/07	02/01/07	12/23/06	12/07/06	12/16/2006	03/21/07	03/05/07	03/21/07
II	06/17/07	05/24/07	04/22/07	03/29/07	04/26/2007	07/19/07	06/25/07	07/26/07
Long Dien B								
I	02/25/07	03/13/07	12/31/06	01/16/07	12/25/2006	03/29/07	04/14/07	03/30/07
II	07/03/07	07/27/07	05/08/07	06/01/07	05/02/2007	08/04/07	08/28/07	08/07/07
III	11/16/07	12/02/07	09/21/07	10/07/07	09/05/2007	12/18/07	01/03/08	12/15/07
My Hoi Dong								
I	02/25/07	03/21/07	12/31/06	01/24/07	12/28/2006	03/29/07	04/22/07	03/28/07
II	07/03/07	07/27/07	05/08/07	06/01/07	05/07/2007	08/04/07	08/28/07	08/07/07
III	11/16/07	12/10/07	09/21/07	10/15/07	09/17/2007	12/18/07	01/11/08	12/16/07
RMSE (days)			7.8	21.3		8.2	21.6	

5. CONCLUSIONS

The main objective of this study was to detect rice crop phenology in the Vietnamese Mekong Delta. The results indicate that EMD outperformed the wavelet transform for noise removal of MODIS NDVI time-series data. The comparisons between the estimated sowing and harvesting dates and the field investigation data showed RMSE values of 7.8 and 8.2 days, while the values achieved by wavelet transform were 21.3 and 21. 6 days, respectively. The results achieved by EMD were reasonable because of the eight-day interval between the MODIS images. This study demonstrates the value of EMD for noise filtering of the time-series NDVI data. The methods were thus proposed for noise filtering of the time-series satellite vegetation indices to detect crop phenology that was important for crop monitoring.

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