Extracting Tempo-Spatial Features of Paddy Rice Using Time-Series MOD09A1-A Case Study in Hunan, China

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Abstract. Time-series of 8-day composite MODIS surface reflectance product (MOD09A1) data were used to identify the spatial patterns of double-season early rice, single-season middle rice and double-season late rice of Hunan Province, China in 2010. Firstly, the available MODIS images of transplanting and heading stages were assured in accordance with the schedules of local traditional paddy fields tillage in 2010, and then time-series NDVI images were smoothed by Harmonic Analysis of Time Series (HANTS) algorithm to remove the noise and the atmospheric effects. Secondly, the spatial distribution and planting acreage of three types of rice were derived from combining the Enhanced Vegetation Index (EVI) and Land Surface Water Index (LSWI) according to the water background and variation characteristics of NDVI values at transplanting and heading stages. Finally, the accuracy evaluation was performed by the statistical data. The results showed that three types of rice were mainly distributed along the Dongting Lake Basin in Hunan Province and the relative errors were −10.99 %, 1.46 %, −5.87 %, respectively.

Keywords: Spatial pattern · Time-series MODIS · Paddy rice · Vegetation index

1 Introduction

Paddy rice is the most important grain crop for Hunan Province and its planting acreage and total yield also rank the top in China. It is of great significance to learn about the cropping system, planting intensity and spatial distribution by studying the tempo-spatial characteristics in such a typical study area. However, the tempo-spatial difference is greatly noticeable in different planting zones due to rice varieties, meteorological features, soil types, topography, relief as well as social development levels [1]. Consequently, it is vital to monitor the spatial patterns of paddy rice and estimate the acreage of fields as accurately as possible.

In recent years, remote sensing has been applied in identifying various kinds of rice information due to its wide swath, fast information acquisition, shorter revisiting cycle, and large amount of spatio-temporal information [2–5]. In comparison with other moderate resolution remote-sensing data, Landsat series images have been widely used

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in monitoring growth, estimating planting area and other applications. Although the resolution of moderate images can reach to dozens of meters, their revisiting cycle is relatively longer. They cannot satisfy the demands of continually monitoring the fast change information of physiological and biochemical status of paddy rice at specific growth periods. Microwave and Radar data are also used in monitoring paddy rice because of its characteristics of penetrating cloud and frost, but their swath is usually very small. It can obviously improve the image quality by confusing multi-source images, strict geometric correction and more varieties of images are required. Conversely, high temporal resolution images can provide fruitful information in monitoring and identifying paddy rice [6, 7].

As a major producer of rice in China, the rice production in Hunan Province accounts for 80 % of its total grain production. Both the planting area and total yield hold the first place in China. Taking Hunan Province as the study area, this study is to find out the spatial distribution patterns of paddy rice based on time-series MODIS product. In order to achieve this goal, several spectral indices were calculated: normalized difference vegetation index (NDVI), normalized difference water index (NDWI), normalized difference soil index (NDSI), land surface water index, (LSWI), and enhanced vegetation index (EVI). According to the water background during the growing progress, Harmonic Analysis of Time Series (HANTS) software was used to smooth time-series NDVI. The identification results were evaluated by the field GPS positioning points and the statistical data.

2 Materials and Methods

2.1 Data Sources

Time-series MODIS/Terra data sets (8-day MOD09A1 V005) in 2010 were freely downloaded through the Land Process Distributed Active Archive Center (LPDAAC, http://reverb.echo.nasa.gov/reverb/). A total of three MODIS HDF tiles are required to cover the whole study area (Fig. 1). MOD09A1 provides Bands 1–7 at 500-m resolution in an 8-day gridded level-3 product in the Sinusoidal projection. There are hundreds of images for different MOD09A1 bands in a year, so batch processing must be performed to improve work efficiency. Here, Cygwin tools, which provide a Linux look and feel environment for Windows, were combined with MODIS Reprojection Tools (MRT) to change data format, transform projection and mosaic images to cover the whole Hunan Province.

In addition, the administrative boundary data of Hunan, a total of 64 GPS field survey data of paddy rice in 2010 were also acquired in Taoyuan County, Linli County and Hanshou County. These data are important to understand the real situation on the ground for paddy rice identification. High resolution imagery zoom-in-views from Google Earth can also provide visual information on various landscape features and types such as agriculture, forests and barren land. The statistical data of planting acreage in paddy rice by cities were also acquired from Hunan Province Statistical Bureau, which can be used to compare to the satellite-derived estimates at the city level.

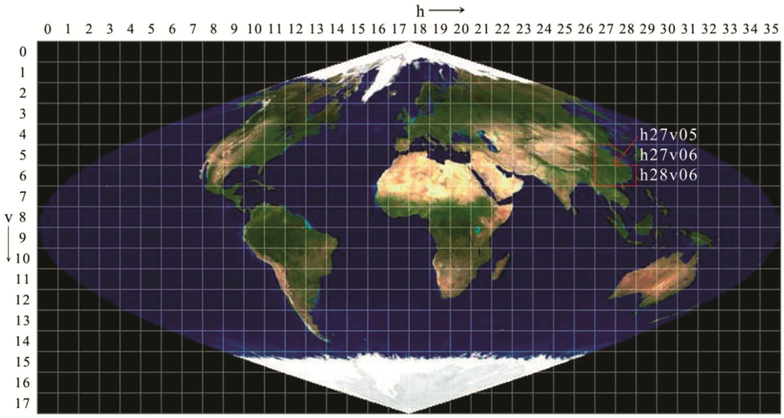

Fig. 1. Paths/rows of Hunan province located in the sinusoidal (SIN) projection.

2.2 Smoothing Time-Series MODIS NDVI Data

A HANTS algorithm for time series dataset analysis has been developed [8] and successfully applied in vegetation index analysis on the European continent [9]. The primary thought of HANTS is that the growth status of vegetation has extreme seasonal fluctuation as NDVI describes. It can be described by a series of low-frequency Sine functions with different phases, frequencies and amplitudes. Cloud and other intervention factors always randomly change and they can be made as the high-frequency noise. In order to smooth the time series NDVI images, the first step is to transfer observational samples from time domain to frequency domain; then, a new time series can be reconstructed using a reversed Fourier Transformation or synthesis, which can generate values of the variable at any desired time. A Fast Fourier Transformation (FFT) is often used in the Fourier Transformation process in order to save computational time. In order to smooth different time-series dataset, National Aerospace Laboratory (NLR) developed the NLR HANTS software package. Figure 2 shows the flow chart of smoothing time-series NDVI images.

2.3 Identification of Paddy Rice Fields

In comparison with other crops, a unique physical feature of paddy rice fields is that rice plants are grown on flooded soils. With the temporal dynamics of paddy rice fields, three main periods can be used: (1) the flooding and rice transplanting period; (2) the growing period (vegetative growth, reproductive, and ripening stages); and (3) the fallow period after harvest [10, 11]. At different growth stages, the mixture of surface water, soil and green rice plants show different combination forms. As a result, the dry land and the paddy field can be distinguished according to such a feature. In addition to the intervention of dry land, some other surface features which have similar reflectance characteristics must be also weeded out. Due to the unique spectral features of paddy rice fields during transplanting stage, the LSWI has been used in conjunction with the NDVI to map paddy rice fields using time-series satellite imagery [11, 12]. Additionally, some other spectral vegetation indices were also needed in this study (Table 1).

Table 1. Calculated spectral indices and corresponding expressions for identifying paddy rice.

Spectral index	Expression
NDVI	NDVI = $(R_{NIR} - R_{RED})/(R_{NIR} + R_{RED})$
NDWI	NDWI = $(R_{RED} - R_{SWIR})/(R_{RED} + R_{SWIR})$
NDSI	NDSI = $(R_{SWIR} - R_{NIR})/(R_{SWIR} + R_{NIR})$
LSWI	LSWI = $(R_{NIR} - R_{SWIR})/(R_{NIR} + R_{SWIR})$
EVI	EVI = $G*(R_{NIR} - R_{RED})/(L + R_{NIR} + C_1R_{RED} - C_2R_{BLUE})$

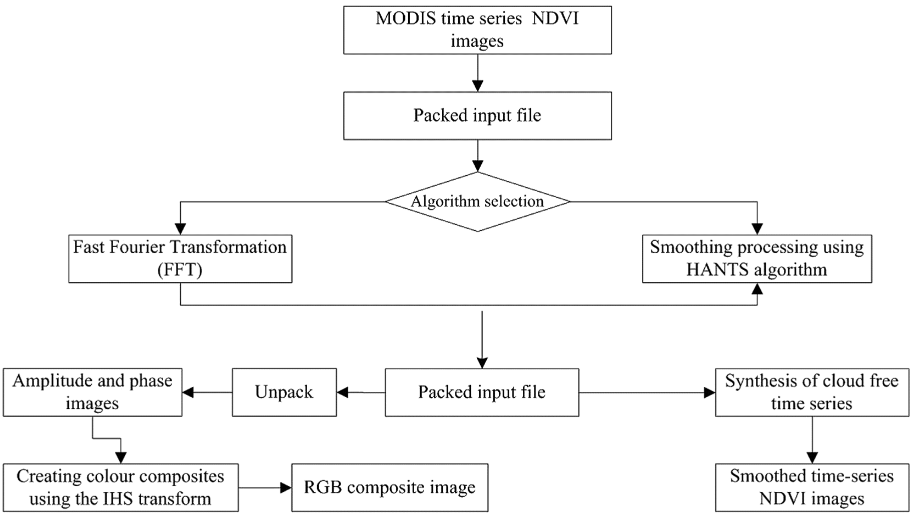

Fig. 2. Flow chart of smoothing time-series NDVI images by HANTS algorithm.

where L is a soil adjustment factor, and C_1 and C_2 are coefficients used to correct aerosol scattering in the red band by the use of the blue band. The R_{BLUE}, R_{RED}, R_{NIR}, R_{SWIR} represent reflectance at the blue (MODIS-Band3, 459–479 nm), red (MODIS-Band1, 620–670 nm), Near-Infrared (NIR, MODIS-Band2, 841–876 nm), and Short-Wave Infrared (SWIR, MODIS-Band6, 1628–1652 nm) wavelengths, respectively. In general, G = 2.5, C1 = 6.0, C2 = 7.5, and L = 1.

3 Results and Discussions

3.1 Mapping Paddy Rice Fields

Three maps were derived from time-series MOD09A1 products and other ancillary datasets (Fig. 3) and their identified acreage were 1152.3 kha, 1265.0 kha and 1309.2 kha, while they were 1294.6 kha, 1246.8 kha and 1390.6 kha according to the China Statistical Yearbook 2010. The relative errors were −10.99 %, 1.46 % and −5.87 %, where the positive value indicated that the calculated acreage was greater than the statistical values, while it was reverse for the negative value.

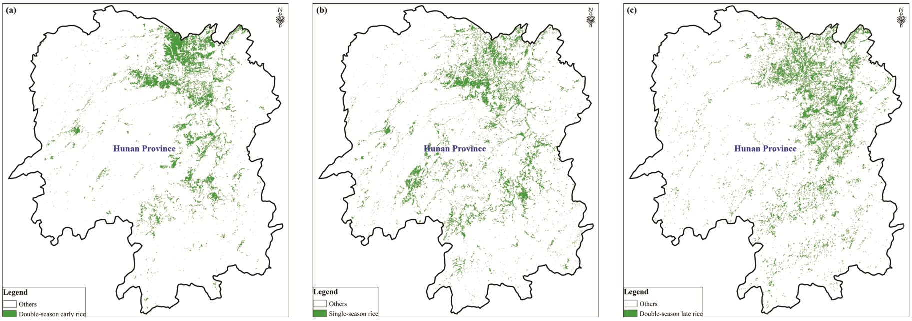

Fig. 3. Distribution of the early, middle and late rice of Hunan province in 2010.

We could know the spatial distribution of three types of rice: (1) the early rice in Hunan Province intensively located in the Dongting Lake Basin and basins in the mountain valleys, especially in the south plains of Dongting Lake Basin; (2) the single rice distributed in the northwest of Dongting Lake and in the western mountains; and (3) the late rice was mainly accumulated in the regions of the Dongting Lake Basin and the central plains, but the spatial distribution was relatively dispersed.

3.2 Analysis of Identification Errors

Two reasons can be used to analyze the deification errors of paddy rice fields using the time-series MODIS products: (1) the image qualities of MODIS products were worse due to the weather-related effects (e.g., cloud, fog, rainfall) at transplanting and heading stages, and sometimes most of the study area was even shaded by the thick clouds (e.g., 105 tile in Fig. 4A and 265 tile in Fig. 4F); (2) the spatial resolution of MODIS09A1 products is only 500 m, which could have a relatively good identification accuracy for the large areas of rice-planted regions, but it was worse for the dispersed and small paddy fields. In our study, in comparison with the early and late rice with the relative errors worse than 5.0 %, the identification accuracy was best with an only relative error of 1.46 % for the middle rice. The reason for this phenomenon was that the image qualities were worse for the early or late rice at transplanting or heading stage (e.g. Figure 4B and E), but conversely they were better for the middle rice at the two growth stages (e.g. Figure 4C and D). Consequently, the best image of the three images but not the average was used to identify the paddy rice fields.

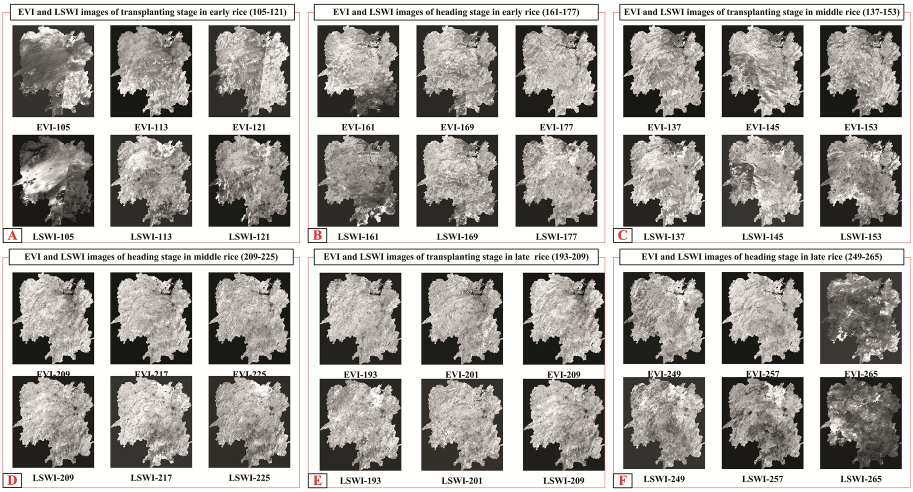

Fig. 4. MODIS-EVI and -LSWI images of three types of rice during the transplanting and heading stages.

4 Conclusion

A time series of MODIS 8-day composite products can be used to identify paddy rice fields, but the accuracy is usually affected due to the constraint of spatial resolution and available tiles at the two key growth stages of transplanting and heading. Fortunately, the spatial patterns of paddy rice can be well reflected based on time-series MODIS products. More ancillary data are usually needed to assist scholars in identifying the corresponding information of paddy rice on the regional scale. The reasons for under or over estimating the paddy rice acreage based on MODIS imagery can attribute to several factors: (1) failure of the moderate resolution data in identifying minor types like wastelands and settlements among the fields, especially on the small paddy rice fields; (2) similarities of some spectral indices (e.g., NDVI, LSWI) between paddy rice plants and some aquatic plants; (3) uncertainty occurred during the MODIS imagery reconstruction process; (4) the alternative planting of three types of rice caused the acreage errors for each rice; and (5) uncertainty existed in the statistical data for validating the identification accuracy.

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