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SCIENCE DIRECT
Remote Sensing of Environment 95 (2005) 480–492
Remote Sensing of Environment
www.elsevier.com/locate/rse

Mapping paddy rice agriculture in southern China using multi-temporal MODIS images

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Received 8 September 2004; received in revised form 21 December 2004; accepted 24 December 2004

Abstract

Information on the area and spatial distribution of paddy rice fields is needed for trace gas emission estimates, management of water resources, and food security. Paddy rice fields are characterized by an initial period of flooding and transplanting, during which period open canopy (a mixture of surface water and rice crops) exists. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor onboard the NASA EOS Terra satellite has visible, near infrared and shortwave infrared bands; and therefore, a number of vegetation indices can be calculated, including Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Land Surface Water Index (LSWI) that is sensitive to leaf water and soil moisture. In this study, we developed a paddy rice mapping algorithm that uses time series of three vegetation indices (LSWI, EVI, and NDVI) derived from MODIS images to identify that initial period of flooding and transplanting in paddy rice fields, based on the sensitivity of LSWI to the increased surface moisture during the period of flooding and rice transplanting. We ran the algorithm to map paddy rice fields in 13 provinces of southern China, using the 8-day composite MODIS Surface Reflectance products (500-m spatial resolution) in 2002. The resultant MODIS-derived paddy rice map was evaluated, using the National Land Cover Dataset (1:100,000 scale) derived from analysis of Landsat ETM+ images in 1999/2000. There were reasonable agreements in area estimates of paddy rice fields between the MODIS-derived map and the Landsat-based dataset at the provincial and county levels. The results of this study indicated that the MODIS-based paddy rice mapping algorithm could potentially be applied at large spatial scales to monitor paddy rice agriculture on a timely and frequent basis.
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Keywords: Paddy rice fields; MODIS images; Land surface water index; Enhanced vegetation index

1. Introduction

Rice is one of the world's major staple foods and paddy rice fields account for approximately 15% of the world's arable land (IRRI, 1993). A unique physical feature of paddy fields is that the rice is grown on flooded soils. This feature is significant in terms of both trace gas emissions and water resources management. Seasonally flooded rice paddies are a significant source of methane emissions (Denier Van Der Gon, 2000; Li et al., 2002; Neue & Boonjawat, 1998), contributing over 10% of the total methane flux to the atmosphere (Prather & Ehhalt, 2001), which may have substantial impacts on atmospheric chemistry and climate. Agricultural water use (in the form of irrigation withdrawals) accounted for ~70% of global fresh water withdrawals (Samad et al., 1992), and the majority of Asian rice agriculture is irrigated (Huke, 1982; Huke & Huke, 1997). Intensification in rice farming practices in the near future could have significant impacts on the emissions of various greenhouse gases and

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doi:10.1016/j.rse.2004.12.009

availability of water (Li et al., 2002; Wassmann et al., 2000).

Accurate assessment of methane emissions at regional and global scales requires geospatial datasets of paddy rice fields. Several global datasets of paddy rice were developed in the late 1980s and early 1990s (Aselman & Crutzen, 1989; Matthews et al., 1991; Olson, 1992; Wilson & Henderson-Sellers, 1992) and used in global-scale analyses of climate and trace gas emissions. Most of these global datasets have a coarse spatial resolution (from 0.5° to 5° latitude and longitude). Recently, a global cropland data product was developed at a spatial resolution of five arc minutes, which contains a category of paddy rice fields (Leff et al., 2004). At the regional scale, an Asian rice dataset was generated using statistical data of rice agriculture at sub-country administration units from the 1970s, including a base map at a scale of 1:4,500,000 (Huke, 1982). The Asia rice dataset was later updated (Huke & Huke, 1997), using agricultural census data of the sown area of rice agriculture in the early 1990s. This updated Asia rice database was used to estimate methane emissions in Asia (Knox et al., 2000; Matthews et al., 2000). Regional-scale analyses of trace gas emissions, food security, and water resource management require updated datasets of paddy rice fields at a finer spatial resolution.

Optical satellite remote sensing provides a viable means to meet the requirement of improved regional-scale datasets of paddy rice fields. A number of studies have explored the potential of images from Landsat and NOAA Advanced Very High Resolution Radiometer (AVHRR) to identify paddy rice fields (Fang, 1998; Fang et al., 1998; Okamoto & Fukuhara, 1996; Okamoto & Kawashima, 1999; Tennakoon et al., 1992; Van Niel et al., 2003). Those studies that identified rice paddies using fine-resolution Landsat Thematic Mapper (TM) data primarily used image classification procedures. Those studies that used moderate-resolution AVHRR images were primarily based on the temporal development of the Normalized Difference Vegetation Index (NDVI; Eq. (1)) and local knowledge (e.g., crop calendars) of rice paddy fields.

A new generation of advanced optical sensors, including the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites, and VEGETATION (VGT) onboard the SPOT-4 satellite, provide additional shortwave infrared bands that are sensitive to vegetation moisture and soil water. For instance, the VGT sensor has four spectral bands: blue (430–470 nm), red (610–680 nm), near infrared (NIR, 780–890 nm) and shortwave infrared (SWIR, 1580–1750 nm). The availability of an additional SWIR spectral band in VGT provides an opportunity for developing and generating improved vegetation indices that are sensitive to equivalent water thickness (EWT, g H_2O/m^2), such as the Land Surface Water Index (LSWI; Eq. (2)) (Maki et al., 2004; Xiao et al., 2002a, 2002b). During the rice transplanting period and the early part of the rice growing season, paddy fields are a mixture of green rice plants and open water (Xiao et al., 2002d). Recently, we developed an algorithm to identify paddy rice fields, using temporal profiles of LSWI and NDVI data derived from 10-day composite VGT images (Xiao et al., 2002b). Rice paddies were identified as areas where the LSWI values increased (due to the greater surface moisture during the flooding period) and were temporarily greater than NDVI values (Xiao et al., 2002b).

The MODIS sensor has 36 spectral bands, seven of which are designed for the study of vegetation and land surfaces: blue (459–479 nm), green (545–565 nm), red (620–670 nm), near infrared (NIR_1: 841–875 nm; NIR_2: 1230–1250 nm), and shortwave infrared ($SWIR_1$: 1628–1652 nm, $SWIR_2$: 2105–2155 nm). Daily global imagery is provided at spatial resolutions of 250-m (red and NIR_1) and 500-m (blue, green, NIR_2, $SWIR_1$, $SWIR_2$). The MODIS Land Science Team provides a suite of standard MODIS data products to the users, including the 8-day composite MODIS Surface Reflectance Product (MOD09A1). Compared to the 10-day composite VGT product, the 8-day composite MODIS data have three advantages for paddy rice analyses: (a) finer spatial resolution (500 m versus 1 km in VGT), (b) slightly shorter temporal resolution (8-day in MODIS versus 10-day in VGT), and (c) improved atmospheric correction (Vermote & Vermeulen, 1999).

The objective of this study is to assess the potential of MODIS images for identifying inundation and paddy rice fields. Southern China was selected as the case study area for MODIS-based large-scale mapping of paddy rice fields because it has a large amount of paddy rice agriculture and fine-resolution cropland area reference data are available for the evaluation of MODIS-based results (Frolking et al., 1999, 2002; Xiao et al., 2003b). If successful, the algorithm we developed for MODIS images can be applied to other rice-producing countries in Asia to generate an updated continental database of paddy rice agriculture; such a product would support various analyses that address biogeochemical nutrient cycling, trace gas emissions, water management, food security, agricultural vulnerability and sustainability.

2. Study area, data and methods

2.1. Description of the study area

There are large spatial variations in agriculture and crop rotation systems in China (Frolking et al., 2002; Qiu et al., 2003). In this study we focused on 13 provincial-level administrative units (12 provinces plus Shanghai) in southern China (Fig. 1), which represent over 2.5 million km^2 of land area (Table 1). Two-crop rotation systems are dominant across southern China, because of a long warm season and abundant precipitation (Frolking et al., 2002; Qiu et al.,

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