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# Assessment of MODIS spectral indices for determining rice paddy agricultural practices and hydroperiod

Lucia Tornos [a,*], Margarita Huesca [b], Jose Antonio Dominguez [c], Maria Carmen Moyano [a], Victor Cicuendez [d], Laura Recuero [d], Alicia Palacios-Orueta [d]

[a] Centre for Hydrographic Studies, CEDEX, Spain
[b] Center for Spatial Technologies and Remote Sensing (CSTARS), Department of Land, Air, and Water Resources, University of California, Davis, United States
[c] The National Distance Education University, UNED, Spain
[d] Departamento de Silvopascicultura, ETSIM, Universidad Politécnica de Madrid, Spain

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ABSTRACT

Rice agricultural practices and hydroperiod dates must be determined to obtain information on water management practices and their environmental effects. Spectral indices derived from an 8-day MODIS composite allows to identify rice phenometrics at varying degrees of success. The aims of this study were (1) to assess the dynamics of the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI(1) and NDWI(2)) and Shortwave Angle Slope Index (SASI) in relation to rice agricultural practices and hydroperiod, and (2) to assess the capability for these indices to detect phenometrics in rice under different flooding regimes. Two rice farming areas in Spain that are governed under different water management practices, the Ebro Delta and Orellana, were studied over a 12-year period (2001–2012). The index time series autocorrelation function was calculated to determine index dynamics in both areas. Secondly, average indices were calculated to identify significant points close to key agricultural and flooding dates, and index behaviors and capacities to identify phenometrics were assessed on a pixel level. The index autocorrelation function produced a regular pattern in both zones, being remarkably homogeneous in the Ebro Delta. It was concluded that a combination of NDVI, NDWI(1), NDWI(2) and SASI may improve the results obtained through each index. NDVI was more effective at detecting the heading date and flooding trends in the Ebro Delta. NDWI(1), NDWI(2) and SASI identified the harvest and the end of environmental flooding in the Delta, and the flooding in Orellana, more effectively. These results may set strong foundations for the development of new strategies in rice monitoring systems, providing useful information to policy makers and environmental studies.

## 1. Introduction

Approximately 180 million ha are under rice cultivation worldwide, and 475,000 ha are located in the European Union (MAGRAMA, 2013). Sustainable rice farming plays a key role in food security; according to the United Nations, more than 50% of the global population depends on rice for approximately 80% of its food requirements (FAO, 2002). Moreover, rice fields represent an important aquatic ecosystem, hosting a large variety of terrestrial and aquatic species (FAO, 2013) that typically remain flooded during the growing season. Despite the positive functions of rice systems, such systems also cause environmental degradation (Van Niel and McVicar, 2004). Rice water consumption and greenhouse gas emissions from paddy fields are especially critical issues (FAO, 2013). In upcoming years, the world will face the challenge of meeting global demands for rice while preserving land and water resources. Thus, monitoring these systems will become essential at both the local and global scale (Kerr and Ostrovsky, 2003).

Phenological data are used to estimate net primary production (Kimball et al., 2004), crop growth and yield (Bauman et al., 2001). These data may also be used to determine time boundary conditions in crop yield models (Bauman et al., 2001), to examine animal dynamics in crop-associated fauna (Pettorelli et al., 2005) and to support water management decisions (Dingkuhn and Le Gal, 1996). Moreover, rice hydroperiod determination as part of the rice

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* Corresponding author at: Centre for Hydrographic Studies, CEDEX, Paseo bajo de la Virgen del Puerto 3, 28005 Madrid, Spain.

*E-mail address:* luciatornos@gmail.com (L. Tornos).

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growing cycle is vital to rice monitoring and impact management and is expected to become more relevant in the near future (Torbick et al., 2011; Boschetti et al., 2014). This is particularly true in studies that examine rice paddy methane emissions (Xiao et al., 2005). The importance of rice water table depth and phenological fluctuations in methane (Meijide et al., 2011) illustrates the necessity to develop accurate rice agricultural and hydroperiod monitoring techniques.

Traditional studies focusing on phenology involve conducting on-site ground observations (Tang et al., 2009; Xu et al., 2012) and obtaining data at low temporal and spatial scales (Pettorelli et al., 2005). The growing importance of spatial and temporal continuous data in these studies (Delbart et al., 2005) has made remote sensing increasingly relevant, as this approach allows for large-scale and frequent sampling (Zhang et al., 2003). Advances in geospatial technology and remote sensing will further increase the relevance of such methods to agroecosystems management and monitoring by raising productivity and reducing environmental degradation (Van Niel and McVicar, 2004).

Remote sensing has proved to be instrumental to the monitoring of rice agricultural production (Lopez-Sanchez et al., 2011; Gumma et al., 2014) and flooding (Moré et al., 2011; Son et al., 2013; Boschetti et al., 2014) at both regional and global scales. One of the first space borne multispectral sensors developed for rice monitoring is the Landsat Multiespectral Scanner (MSS) (Ustin, 2004). Providing a spatial resolution of 30 m, Landsat images are frequently used in rice studies (Oguro et al., 2001; Báez-González et al., 2002; Moré et al., 2011; Li et al., 2012). Other sensors such as the NOAA Advanced Very High Resolution Radiometer (AVHRR) and SPOT-4 VEGETATION generate daily low spatial resolution images (1 km) (Xiao et al., 2002) and produce appropriate spectral bands that can be used in plant phenology studies. These sensors have been widely used for rice development monitoring in many studies (Fang et al., 1998; Kamthonkiat et al., 2005; Singh et al., 2006).

Launched in 1999, Moderate Resolution Imaging Spectroradiometer (MODIS) includes advantageous features of both the AVHRR and Landsat. The 8-day composite MODIS data product provides medium spatial resolution images (500 m) of adequate temporal resolution and improved atmospheric correction (Vermote and Vermeulen, 1999). MODIS includes seven bands that are designed to detect water and vegetation, which allows to study plant phenology (Delbart et al., 2005; Sari et al., 2010; Xu et al., 2012) and flooding (Ordoyne and Friedl, 2008).

The MODIS spectral index time series has been used in several studies for monitoring rice phenology and dynamics (Sakamoto et al., 2006; Motohka et al., 2009; Jacquin et al., 2010). Among spectral indices, the Normalized Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), which are based on photosynthetic activity, exhibit a good dynamic range and sensitivity for monitoring spatial and temporal variations in vegetation (Huete et al., 2002). The NDVI has been widely used in rice monitoring studies (Gumma et al., 2014). This index effectively detects heading dates (Boschetti et al., 2009; Wang et al., 2012) and shows sensitivity to soil wetness, making the tool suitable for monitoring irrigation start and padding (Motohka et al., 2009). EVI has also been used for rice crop monitoring and mapping (Xiao et al., 2005; Peng et al., 2011; Son et al., 2014). This index exhibits low sensitivity to vegetation canopy background variations and resists saturation in a dense canopy (Huete et al., 2002; Motohka et al., 2009). Thus, while EVI is more effective at avoiding saturation within a dense canopy, NDVI best detects soil condition changes (Motohka et al., 2009) while maintaining a suitable capacity to monitor rice phenology.

Spectral indices based on shortwave infrared bands have also been used to detect phenological events and rice hydroperiod (Xiao et al., 2002; Boschetti et al., 2014). The Normalized Difference Water Index (NDWI(1)), which combines information included in the SWIR1 and NIR, is sensitive to soil and vegetation water response (Gao, 1996). The tool has proved useful in identifying vegetation statuses (Fensholt and Sandholt, 2003) and flooding events (Ordoyne and Friedl, 2008). Although this index was originally designed to detect vegetation water content, a number of works have also studied its effectiveness at monitoring surface water content (Boschetti et al., 2014). Additionally, NDWI(2), which combines SWIR2 and NIR bands, effectively detects significant increases in cropland surface water (Xiao et al., 2002) and monitors phenological stages (Delbart et al., 2005). Both of these capabilities (soil and vegetation water content detection) are essential to identify soil and crop water variations associated with rice phenology.

Other recent studies have demonstrated an interest in using new indices to characterize crop phenology and soil water content patterns (Das et al., 2013), as these indices can provide additional agricultural information that may be used to improve the results of other indices used separately. New approaches based on spectrum spectral shapes that combine angles formed by consecutive bands have been used successfully for this purpose in recent years (Palacios-Orueta et al., 2006). These new indices, referred to as Spectral Shape Indices (SSI), provide information of relationships between three consecutive bands, summarizing respective wavelength reflectance spectra. The Shortwave Angle Slope Index (SASI) (Khanna et al., 2007) in particular is based on the SWIR1 angle and is modified by including the slope between the NIR and SWIR2 reflectance. This index shows promising results in discriminating between land cover types and predicting soil and vegetation moisture content levels in laboratory and model simulated datasets. Das et al. (2013) illustrated the utility of SASI in determining soil wetness and dryness through threshold values, and Palacios-Orueta et al. (2012) used a modification of SASI, AS1, to monitor cotton key phenological stages. All these attributes make SASI potentially useful for detecting rice cycle dynamics: given its proved sensitivity to soil moisture changes, it may more effectively identify rice phenology and hydroperiod characteristics.

The monitoring of phenological crop stages and dynamics using spectral indices is frequently based on the derivation of time series phenological metrics (Sakamoto et al., 2005; Zhang and Xu, 2012), normally from NDVI, EVI and NDWI indices. These phenological metrics typically include transition dates such as the heading date (Boschetti et al., 2009; Wang et al., 2012), plant emergence and harvesting (Boschetti et al., 2009; Wu et al., 2010) and have been used with varying degrees of success. Methodologies applied for phenological metrics determination vary from the use of threshold values to the identification of maximum and minimum values. These studies focus on determining one or more phenometrics from one index or from a combination of indices (Sakamoto et al., 2005; Leinenkugel et al., 2013; Chumkesornkulkit et al., 2013).

Statistical time series analyses of data from multispectral sensors provide information on dynamics of crop growing patterns. In particular, the autocorrelation function (ACF) (Box et al., 1994) enables to conduct a quantitative evaluation of the stability of temporal patterns in terms of seasonality and periodicity, providing useful information of underlying processes (Dornelas et al., 2013). When used for crop monitoring, the ACF reveals meaningful information on crop dynamics and has been used to detect variations in cropping patterns (Setiawan et al., 2014). Therefore, a statistical approach based on the use of ACF for the study of spectral index time series may generate relevant information on vegetation and water dynamics.

Although several methodologies have been developed to explore specific phenometrics in rice and to provide tools for rice