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Monitoring rapid vegetation succession in estuarine wetland using time series MODIS-based indicators: An application in the Yangtze River Delta area

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ABSTRACT

Frequent and continuous time series is required for the detection of plant phenology and vegetation succession. The launch of novel remote sensor MODIS (moderate resolution imaging spectroradiometer) provided us with an opportunity to make a new trial of studying the rapid vegetation succession in estuarine wetlands. In this study, the spatiotemporal variations of vegetation cover and tidal flat elevation along a transect (covering 6 pixels of MODIS) of an estuarine wetland at Dongtan, Chongming Island, in Yangtze River estuary, China were investigated to assess its rapid vegetation succession and physical conditions. By combining the field data collected, the time series of MODIS-based VIs (vegetation indices), including NDVI (normalized difference vegetation index), EVI (enhanced vegetation index) and MSAVI (modified soil adjusted vegetation index), and a water index, LSWI (land surface water index) were utilized to characterize the rapid vegetation succession between 2001 and 2006. We found that NDVI, EVI and MSAVI exhibited significant spatial and temporal correlations with vegetation succession, while LSWI behaved in a positive manner with surface water and soil moisture along with the successional stages. In order to take the advantages of both VIs and water index, a composite index of VWR (vegetation water ratio) combining LSWI and EVI or MSAVI was proposed in this paper. This index facilitates the identification of vegetation succession by simply comparing the values of VWR at different stages, and therefore it could track vegetation succession and estimate community spread rate. Additionally, this study presented an attempt of using MODIS datasets to monitor the change of tidal flat elevation, which demonstrated a potential remote sensing application in geodesy of coastal and estuarine areas.

1. Introduction

Since the first launch of man-made earth resources observation satellites, scientists have studied and established various approximate relationships between spectral response and vegetation coverage (Banari et al., 1995). VIs (vegetation indices) are simply effective and experiential measurements for vegetation features on the earth surface through using different band combinations. Vegetation's response to the electromagnetic spectrum is influenced by factors such as the differences in chlorophyll content, nutrient levels, water content, and underlying soil characteristics (Sivanpillai and Latchininsky, 2007). The band combinations follow a basic criterion—a band centered in a reflectance peak and another

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in a specific absorption valley. This is a very effective technique, for example, the band combinations covering red and infrared wavelengths of the electromagnetic spectrum offer a very effective approach to studying vegetation because these bands include more than 90% information of the vegetation (Baret et al., 1989). However, observations over a relatively short time span do not often reflect vegetation features meaningfully, because different plant species may have similar spectral properties in a growing season. Furthermore, leaf structure and chemistry vary seasonally, resulting in seasonal dynamics of spectral properties (Zhang et al., 2006b). Monitoring seasonal changes in vegetation features and plant phenologies over a long time is essential for many applications (Anderson et al., 2006; Sakamoto et al., 2005). Space-borne remote sensing is not suitable for monitoring phenological events at the level of individual plant because of the coarse ground resolution, although it is a useful tool for characterizing ecosystems (Churkina et al., 2005). Identifying phenological stages of plants with remote sensing may enable us to distinguish vegetation types or determine the stages of ecological succession (sere). Over the last decade, different techniques have been developed to determine vegetation dynamics through using the time series NDVI (normalized difference vegetation index) from AVHRR (advanced very high resolution radiometer). However, because AVHRR was not designed for land application, these data are generally not suitable for monitoring vegetation dynamics (Zhang et al., 2003). Additionally, Fensholt (2004) found that the MODIS-based VI was better correlated with LAI (leaf area index) than AVHRR-based VI.

MODIS (moderate resolution imaging spectroradiometer) is a novel sensor combination in space on a single platform providing both image and spectrum (Tank et al., 2006). MODIS has 36 visible bands from the near infrared to the far infrared, covering the electromagnetic spectrum of 0.4–14.4 nm. Of them, seven bands are allocated for studying vegetation and land surfaces. The daily global imagery is provided at spatial resolutions of 250–1000 m with a scanning width of 2330 km. Generally, it is difficult to acquire the data with tripartite high resolutions (*i.e.*, high spatial resolution, high temporal resolution, and high spectral resolution) simultaneously, due to the bottlenecks in data acquisition and transmission in remote sensing. MODIS overcomes these bottlenecks in practice through balancing above tripartite performances in space, time and spectrum, and provides frequent (twice a day), multiple narrow-band (36 bands) coverage of the earth's surface at a moderate spatial resolution (250–1000 m) (Xiong and Barnes, 2006), which has made MODIS a powerful tool in the field of earth resources observation. The data from MODIS have improved our understanding of global dynamics and processes, and are playing an important role in the development of validated, global, interactive earth system models to accurately predict global change (http://modis.gsfc.nasa.gov/about/). Historically, it was difficult to obtain adequate remotely sensed data to perform a frequent time series analysis, because various technical difficulties are inherent in traditional earth resources satellites. The launch of MODIS has provided us with an opportunity to explore new methods of remote sensing. Recently, time series MODIS datasets have been widely used in the fields of earth system and environmental sciences. For example, Gu et al. (2006) developed an enhanced estimation of LAI (leaf area index) of vegetation through smoothing the original time series MODIS LAI data, and generated the LAI data used for numerical weather prediction. Kang et al. (2003) developed a regional phenology model for detecting the onset of vegetation greenness through using year 2001 MODIS land products in Korea. Similarly, Zhang et al. (2003) identified phenological dates by finding points on the time course of the VI where the rate of curvature is the highest. Obviously, these studies have shown the multiple uses of time series MODIS datasets.

Estuaries are the important interfaces between marine, freshwater and terrestrial ecosystems, commonly regarded as intermediate transitional zones where various ecosystems join and interact (Attrill and Rundle, 2002). The relatively rapid change in estuarine areas produces a narrow ecological zone between two types of plant communities. Estuarine wetlands experience frequent flood and ebb. Sediment accumulation is controlled by estuarine processes that are highly dynamic and usually unstable, which may increase tideland elevation and result in a zone of environmentally stochastic stresses (Grosholz, 2002) or sometimes lead to a considerable sediment accretion and rapid vegetation succession (Chen et al., 2005a). One of the features of estuarine vegetation (salt marshes, brackish and tidal freshwater marshes) is the zonal distribution of plant communities. For this reason, the vegetation in these areas is an ideal setting for studying vegetation succession (Wang et al., 2007a).

The wetland in the Yangtze River Mouth, China is rapidly growing through the deposition of sand, silt and mud carried by river runoff (Yang, 1999). The river transports 4.68×10^8 t of sediment per year into the East China Sea (Chen and Zong, 1998), with nearly half of the sediment settling in the area of river mouth (Chen et al., 1985) and forming new mudflats of about 5 km^2 per year. In order to speed up sediment accretion for land reclamation, *Spartina alterniflora* (smooth cordgrass, hereafter *Spartina*) was introduced to Chongming Island in 2001, which has led to a rapid expansion of *Spartina* and hence a significant growth of wetland since then (Chen et al., 2004). The ecosystems on the island characterized by rapid succession have attracted various interests of scientists. Previous studies in this area have been performed on the ecophysiology of dominant plants (Chen et al., 2005b), interspecific competition between plants (Chen et al., 2005c), topographical influence on plant growth (Shi et al., 2007; Sun et al., 2001), mechanisms of plant dispersion (Zhang et al., 2006a), and the effects of *Spartina* invasion on native biodiversity (Chen et al., 2007; Gao et al., 2006; Ma et al., 2004), and short-term nutrient cycling of ecosystems (Mei and Zhang, 2007). Moreover, several studies investigated vegetation identification by remote sensing and GIS techniques (Gao and Zhang, 2006; Wang et al., 2007b). However, relatively few studies have been conducted to examine the succession processes of plant communities (Tang and Lu, 2003). The previous studies are limited to fragmented temporal and spatial scales, which are not suitable for the detection of the whole succession process. The time series of MODIS data can provide an opportunity for monitoring vegetation succession through integrating temporal and spatial scales.

The main aim of this study was to determine if a proper remote sensing-based indicator could be identified to monitor