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Abrupt spatiotemporal land and water changes and their potential drivers in Poyang Lake, 2000–2012

Lifan Chen [a], Ryo Michishita [a], Bing Xu [a,b,c,*]

[a] College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China
[b] Ministry of Education Key Laboratory for Earth System Modelling, Center for Earth System Science, and School of Environment, Tsinghua University, Beijing 100084, China
[c] Department of Geography, University of Utah, Salt Lake City, UT 84112, USA

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ABSTRACT

Driven by various natural and anthropogenic factors, Poyang Lake, the largest freshwater lake in China, has experienced significant land use/cover changes in the past few decades. The aim of this study is to investigate the spatial–temporal patterns of abrupt changes and detect their potential drivers in Poyang Lake, using time-series Moderate Resolution Imaging Spectroradiometer (MODIS) 16-day maximum value composite vegetation indices between 2000 and 2012. The breaks for additive seasonal and trend (BFAST) method was applied to the smoothed time-series normalized difference vegetation index (NDVI), to detect the timing and magnitude of abrupt changes in the trend component. Large part of Poyang Lake (98.9% for trend component) has experienced abrupt changes in the past 13 years, and the change patterns, including the distributions in timing and magnitudes of major abrupt trend changes between water bodies and land areas were clearly differentiated. Most water bodies had abrupt increasing NDVI changes between 2010 and 2011, caused by the sequential severe flooding and drought in the two years. In contrast, large parts of the surrounding land areas had abrupt decreasing NDVI changes. Large decreasing changes occurred around 2003 at the city of Nanchang, which were driven by urbanization. These results revealed spatial–temporal land cover changing patterns and potential drivers in the wetland ecosystem of Poyang Lake.

1. Introduction

Many wetland ecosystems have experienced dramatic changes in the past few decades, driven by natural disturbances and human activities. For example, increasing temperature and decreasing precipitation in the warmest months of the year in Yellowstone National Park have significantly changed the regional hydrologic landscape, resulting in the loss of suitable habitats for amphibians (McMenamin et al., 2008). Sea-level rise could cause losses of coastal wetlands when its rate exceeds a defined threshold. It was estimated that up to 20% of the world's coastal wetlands could be lost by the 2080s as a result (Nicholls, 2004).

Ecosystems of many lakes and ponds in China have also been altered by climate changes or human-induced pressures, in term of water balance, water volume and spatiotemporal dynamics of land cover (Feng et al., 2012b). For example, four lakes southeast of Nagqu, Tibet, have increased water areas in the past 30 years, closely related to climate changes such as increasing precipitation, rising air temperature, permafrost degradation, and decreasing evaporation rate (Li and Wang, 2009). Land use change, including land reclamation for agricultural and industrial development and returning cultivated land to forest, and climate change have significantly affected the regional hydrological cycle of Poyang Lake (Guo et al., 2008; Shankman and Liang, 2003). In addition, local levee construction and lake sedimentation are also likely factors resulting in more severe floods in the Poyang Lake area (Shankman and Liang, 2003).

Various change detection approaches have been proposed to investigate environmental change patterns and derive their indicators, using multi-temporal remotely sensed images (Chan and Xu, 2013; Gong and Xu, 2003; Lu et al., 2004). The common methods include principal component analysis (PCA), Tasseled Cap (KT) transform, vegetation index, and post classification comparison. The former ones reduce redundant data and highlight change information in the new components, while post classification comparison separately classifies multi-temporal images, and then

* Corresponding author at: College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China.
E-mail address: bingxu@tsinghua.edu.cn (B. Xu).

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detects changes by comparisons of the classified images (Gong and Xu, 2003; Lu et al., 2004). Through integration of PCA and hybrid classification method, Deng et al. (2008) detected land use changes in Hangzhou city, China between 2000 and 2003. By separately classifying four images into different land cover types and then comparing the results, Munyati (2000) detected the reduction of dense green vegetation in the Kafue Flats upstream wetlands, Zambia. In many previous studies, several change detection methods were simultaneously applied and compared to choose the best one. For example, Guild et al. (2004) compared three change detection methods, including multi-date KT, PCA, and image differencing in the investigation of deforestation and land cover conversion in Rondônia, Brazil, between 1984 and 1992.

Most existing change detection methods have focused on short periods using 2–5 time-series remotely sensed images, which ended to fail in detecting the disturbances between image acquisitions. This is especially problematic when handling abrupt changes caused by sudden ecological events such as flooding, drought, or fire (Coppin et al., 2004; Verbesselt et al., 2010a). In addition, common used change detection methods, such as image differencing has the disadvantage of the need to select thresholds (Lu et al., 2004). Moreover, the limited number of existing change detection techniques proposed to analyze time-series images, such as PCA encounters problems in minimizing seasonal variation and labeling change components (Verbesselt et al., 2010b).

The breaks for additive season and trend (BFAST), is a generic change detection method recently developed for the automatic detection of seasonal, trend, and abrupt changes in a complete long-term data set (Verbesselt et al., 2010a). It enables simultaneous description of continual process and specific events in the long time series, without the need to set a threshold, define change trajectories, or select a reference period (Verbesselt et al., 2010a,b). In the past few years, BFAST has been widely applied in various studies. Tsutsumida et al. (2013) analyzed urban expansion in the central part of Ulaanbaatar, Mongolia by the BFAST algorithm, using time-series normalized difference vegetation index (NDVI) derived from Moderate Resolution Imaging Spectroradiometer (MODIS) images. De Jong et al. (2011) and Jong et al. (2012) investigated trend changes in global greening and browning and abrupt changes in global long-term NDVI time series with BFAST. Although the BFAST method has received much attention, it has not previously been applied to wetland ecosystem.

The objective of this research is to investigate the spatial–temporal change patterns of Poyang Lake and derive their likely drivers, using BFAST. The timing and magnitude distributions of abrupt changes in the NDVI trend component were investigated, and the potential drivers for these changes were analyzed. In addition, the different change patterns between water bodies and surrounding land areas were also investigated. The abrupt changes in the NDVI trend component reflected various in-situ changes including the land cover type changes and the phenological changes of vegetation caused by the natural and anthropogenic disturbances. The important ecological implications indicated with the results of this study provide new knowledge for studying spatiotemporal change patterns of wetland ecosystems.

2. Study area and datasets

2.1. Study area

Poyang Lake (28°22′–29°45′N and 115°47′–116°45′E), located in northern Jiangxi province along the southern bank of the lower reach of the Yangtze River, is the largest freshwater lake in China (Fig. 1) (Chan and Xu, 2013). It experiences significant changes in annual and seasonal water levels. From April to June, the water area extends and all lowland marshlands are inundated with water from five main rivers (Xiushui, Ganjiang, Fuhe, Xinjiang, and Raohe). Between July and September, the water levels reach their peaks, filled by backflow from the Yangtze River. After that, the water area subsides and large areas of marshlands emerge again (Hui et al., 2008).

There are diverse precious natural resources in Poyang Lake, such as stretches of wetland vegetation, which are havens for some endangered species of animals. For example, wetland vegetation in Poyang Lake provides suitable habitats for wintering migratory birds, including approximately 98% of all migrating Siberian cranes (Hui et al., 2008). However, natural disasters including severe flooding and drought have increased in the past few decades in this region (Shankman et al., 2012). Poyang Lake experienced a notable flood in June 2010, which is the largest flood event after the severe flooding in 1998. The flood threatened thousands of local human lives and caused huge economic losses (Feng et al., 2012b). Comprehensive analysis of potential factors illustrated that a heavy rainstorm was the dominant cause of this natural disaster (Zi et al., 2011). After that in 2011, a serious drought occurred, leading to sharply reduced water bodies. This caused catastrophic damage to the local ecosystem and subsequently threatened the animals relying on it (Feng et al., 2012a). In addition, human activities such as the construction of the Three Gorges Dam (TGD) and urbanization have also caused problems on local ecosystems (Seto et al., 2002; Zhang and Xu, 2014).

2.2. Datasets and preprocessing

The time-series MODIS 16-day maximum value composite (MVC) NDVI images with 250 m spatial resolution in MODIS13Q1 products for 2000–2012 were used in our study. The data were obtained from Earth Explorer, operated by the United States Geological Survey (http://earthexplorer.usgs.gov/). Applying the MODIS re-projection tool, we re-projected time-series NDVI images from sinusoidal to UTM zone 50N using a nearest-neighbor resampling routine (Dwyer and Schmidt, 2006). Then, the Poyang Lake study area, including the major water bodies and the land areas surrounding them, was derived. As the original NDVI values were conserved in 16-bit signed integer format, we converted them to meaningful numeric values by multiplying the original data by a scale factor (0.0001).

Data contamination including cloud and atmospheric effects often depresses values in time-series NDVI, resulting in poor applicability of the datasets (Chen et al., 2004). Even with the preprocessed atmospheric correction and the MVC technique, there is significant residual noise in MODIS time-series NDVI (Jin and Xu, 2013). To reduce persistent noise and reconstruct high-quality time-series NDVI, we applied a smoothing technique, called Running median, Mean value, Maximum operation, Endpoint processing, and Hanning (RMMEH) (Jin and Xu, 2013). The improved performance of the filtering method on MODIS time-series NDVI has been confirmed in our study area (Michishita et al., 2014b).

3. Methods

BFAST is an iterative algorithm that decomposes time series into trend, seasonal, and remainder components, with techniques detecting structural changes in both trend and seasonal components (Fig. 2) (Verbesselt et al., 2010a,b). The general model is simply described with the following equation:

$$Y_t = T_t + S_t + e_t \quad (t = 1, \ldots, n,),$$

where Y_t is the observed data at time t, T_t is the trend component, S_t is the seasonal component, e_t is the remainder component charac-