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Automatic mapping afforestation, cropland reclamation and variations in cropping intensity in central east China during 2001–2016

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ABSTRACT

Accurate and automatic monitoring and assessment of vegetation changes are important to support food security, ecosystem balance and global climate regulation. Compared with urbanization and deforestation, vegetation changes such as afforestation, cropland reclamation and variations in cropping intensity were understudied. This study aimed to propose an Automatic Method for detecting Multiple vegetation Changes (AMMC) through a knowledge-based strategy. Five temporal indices were proposed in order to fully characterize different vegetation types from four aspects: vegetation abundance, temporal dispersion, primary/minor temporal continuity, and growing season length. The AMMC takes advantage of the knowledge on the expected temporal trajectories of vegetation dynamics, which could be tracked based on their corresponding trends in these temporal indices. The efficiency of the proposed AMMC method was verified with its applications in central east China using 500 m 8 day composite MODIS datasets from 2001 to 2016. An overall accuracy of 94.75% was achieved when evaluated with 3,011 reference sites. Results revealed that there were totally 7,180 km^2, 3,610 km^2 and 3,280.5 km^2 areas of afforestation, cropland reclamation and variations in cropping intensity in central east China, respectively. This study verified that afforestation efforts were succeeded, but "Grain for Green" project was not as expected since more cropland was reclamation implemented at less favorable biophysical conditions than cropland retirement.

1. Introduction

Land cover change is among the primary drivers of global environmental change (Foley et al., 2005). Understanding and monitoring land cover distribution and dynamics are important factors in environmental studies (Grekousis et al., 2015). Updated and accurate land cover information is required for science, monitoring, and reporting (Gómez et al., 2016), particularly in rapidly developing counties such as China (Deng and Li, 2016). Remote sensing imageries have been widely utilized in mapping land cover distribution and dynamics (Verbesselt et al., 2012; Huang and Friedl, 2014; Zhu and Woodcock, 2014; Rufin et al., 2015). Intra-annual time series of remote sensing imageries have been proven of great value to acquire phenological insights for land cover mapping (Melaas et al., 2013). Land cover changes such as deforestation and urbanization have been increasingly investigated based on time series images (Kennedy et al., 2010; Verbesselt et al., 2010; Jamali et al., 2015; Schmidt et al., 2015; Ahmed et al., 2017; Hirschmugla et al., 2017; Santos et al., 2017).

Despite of progress in technology and data availability, generation of large-area land cover products is still challenging (Gómez et al., 2016), and even more difficult for vegetation mapping (Iizumi and Ramankutty, 2015; Thyagharajan and Vignesh, 2017). Diverse vegetation resources (agricultural crop or natural vegetation) might play distinct roles in food security, ecosystem and global climate regulation (Bonan, 2008; Waldner et al., 2015; Qiu et al., 2016). Therefore, accurate and automatic monitoring and assessment of vegetation changes is important to implement the agenda of sustainable development (Waldner et al., 2015; Qiu et al., 2016; Huang et al., 2017). Remarkable progress has been made in developing efficient change detection methods based on time series images (Zhu, 2017). Widely applied algorithms included the Landsat based detection of Trends in Disturbance and Recovery (LandTrendr), the Vegetation Change Tracker (VCT), the Breaks for Additive Season and Trend (BFAST), the Continuous Change Detection and Classification (CCDC) (Zhu, 2017). Most of these algorithms detected one particular vegetation change such as forest

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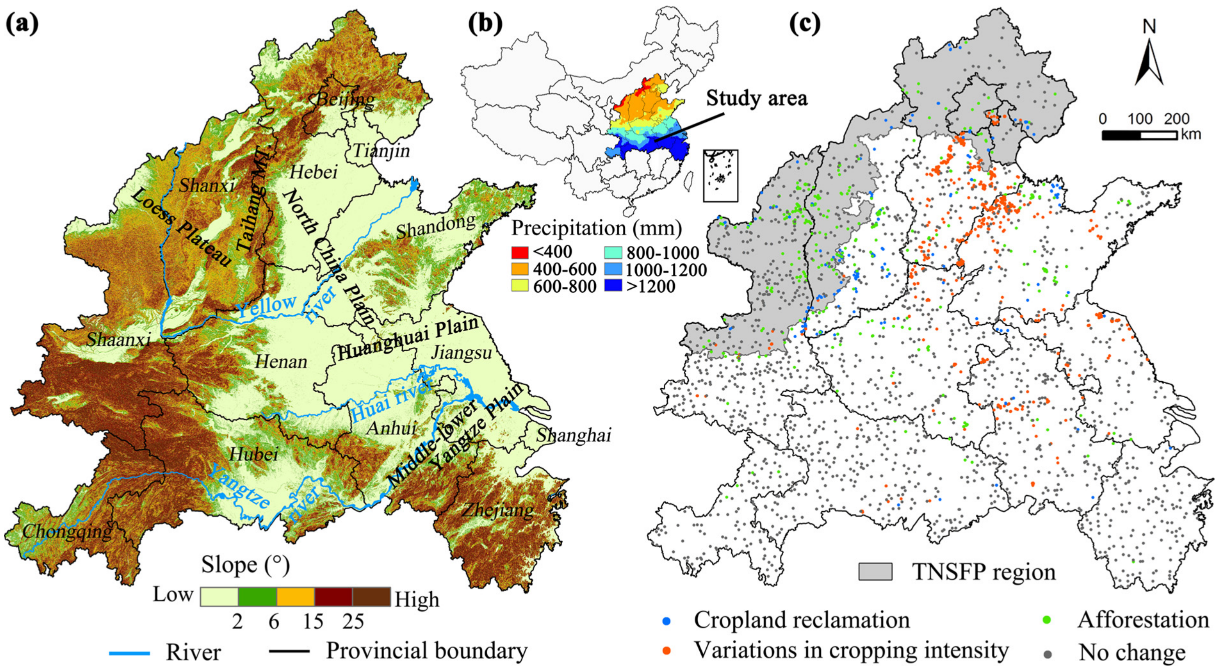

Fig. 1. The spatial distribution maps of slope (a), location of the study area plus annual mean precipitation (b), and test sites (c).

disturbance. Although, the CCDC algorithm has expanded the change target from forest to many land surface types (Zhu, 2017), thresholds or training are definitely required in applying these automatic algorithms.

There are typically two groups of approaches for vegetation changes detection: the machine learning algorithms and knowledge-based methods (Xie et al., 2008; Qiu et al., 2017b). Machine learning methods are attracting increasing research interests along with the growing availability of big datasets from different resources (Zhang et al., 2016; Qiu et al., 2017b). However, the machine learning algorithms are often constrained by the expensive and subjective task of requiring sufficient training data (Shih et al., 2015). The incapability of performing robustly across different years also compelled its further applications (Waldner et al., 2015). Compared with these automatic machine learning algorithms, knowledge-based approaches not only rely less on large training data but also underline explanations and geographic understandings. A knowledge-based approach encompasses variables, rules and hypotheses to improve remote sensing classification and change detection techniques (Mahyou et al., 2016). Knowledge-based approaches have deserved increasing interests from land surface observation and mapping communities (Waldner et al., 2015; Lambert et al., 2016; Mahyou et al., 2016; Qi et al., 2017). A knowledge-based approach permits a better classification of cropland based on relevant temporal and spectral features (Lambert et al., 2016). For example, five knowledge-based temporal features that remain stable over time were presented for cropland mapping. It was shown that interpolation of the knowledge-based features increased the stability of the classifier allowing for its re-use from year to year without recalibration (Waldner et al., 2015).

Till now, information on specific vegetation changes (i.e. cropland reclamation and cropping intensity) is generally achieved through mapping annually (Zhang et al., 2014; Waldner et al., 2015; Qiu et al., 2017c). Compared with urbanization and deforestation, vegetation changes such as afforestation, cropland reclamation and variations in cropping intensity were understudied (Esch et al., 2017; Cohen et al., 2018). Updated spatiotemporally continuous information on croplands and cropping intensity is essential for improving decision making on food security (Waldner et al., 2015; Qiu et al., 2017c). The biggest challenge for efficient cropland/natural vegetation mapping is in the lack of algorithms that accurately reproduce cropland products year after year or season after season (Ramachandran et al., 2018). Automatic knowledge-based approaches for mapping multiple land cover changes (i.e. afforestation, cropland reclamation and variations in cropping intensity) are very important and algorithms fulfilling these requirements are highly demanded (Zhu and Woodcock, 2014; Waldner et al., 2015; Yin et al., 2018).

This study aims to fill this requirement through developing a novel automatic knowledge-based approach for tracking multiple vegetation changes with reference to trends in multiple temporal indices. Trends in the vegetation indices time series have been successfully applied for land surface classifications (Kennedy et al., 2010; Chen et al., 2014). However, the temporal profiles of vegetation indices could easily disturbed by frequently cloud cover and other uncertainties, particularly resulted in extremely low values (Qiu et al., 2013). Temporal indices derived based on the subset of temporal profiles of vegetation indices above particular percentiles demonstrated powerful capability in identifying different vegetation types (Qiu et al., 2016). The purpose of this study is to extend these temporal indices for simultaneously mapping afforestation, cropland reclamation and variations in cropping intensity. Specifically, two tasks are included in this research: 1) to develop an Automated Method for tracking Multiple vegetation Changes (AMMC); 2) to validate the proposed AMMC method and track afforestation, cropland reclamation and variations in cropping intensity in central east China during the early 21st century.

2. Study area and MODIS time series datasets

2.1. Study area

Our study area is located between 27°9′36″N-42°33′36″N latitude, 105°18′36″E-122°40′48″E longitude, in central East China (Fig. 1). It includes nine provinces (Shanxi, Shaanxi, Hebei, Shandong, Anhui, Jiangsu, Henan, Hebei and Zhejiang) and four directly-controlled municipalities (Beijing, Shanghai, Tianjin and Chongqing). The central and east parts are dominated by the North China Plain and the middle-lower reaches of the Yangtze River Plain, surrounded by mountains and hills in the west and south (Fig. 1). Double cropping with a rotation of winter wheat plus maize are dominant in these plains (Qiu et al., 2017d). Two primary land cover dynamic patterns took place in the study area: