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Land use and land cover change in Inner Mongolia - understanding the effects of China's re-vegetation programs

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ABSTRACT

During the past decades, overuse of land resources has increasingly contributed to environmental crises in China. To mitigate wide-spread land degradation, actions have been taken to maintain and restore ecologically valuable landscapes such as natural forests. However, the effects of the various vegetation protection policies that have been implemented in China since the late 1990′s still remain largely unknown. In this paper, we therefore focus on mapping land use and land cover change (LULCC) in Inner Mongolia, one of the key regions targeted by Chinese ecological restoration programs. We used 250-m MODIS time series and a random forest classification approach to generate annual probabilities for each land cover class between 2000 and 2014. We then applied a trajectory-based change detection approach based on a modified version of the Landsat-based detection of trends in disturbance and recovery (LandTrendr) algorithm to the probability time series and mapped land cover change trajectories. We found that our trajectory-based approach achieved high accuracies (overall accuracy 0.95 ± 0.02). It provides spatial-temporal land change maps that allow a land-use related interpretation of change patterns. Our change maps show that i) forest loss decreased rapidly after 2000 (from 15,717 ± 1770 ha in 2001 to 1313 ± 165 ha in 2014) and forest gain (190,645 ± 28,352 ha during 2001–2014) occurred in the ecological program zones, leading to a net forest increase in Inner Mongolia, and ii) cropland retirement (212,979 ± 54,939 ha during 2001–2014) mostly occurred at the early stage of ecological programs and mainly concentrated in drier environments and steep terrain. Overall, land cover mapping and trajectory-based land use analyses allowed a consistent characterization of LULCC over large areas, which is crucial for gaining a better understanding of environmental changes in the light of rapidly changing environmental policies and governance regimes in China.

1. Introduction

Land use and land cover change (LULCC) is one of the most important processes related to global change (Foley et al., 2005). Political decisions or institutional change, however, often cause non-linear trends in land systems (Lambin and Geist, 2006). Land laws or regulations largely determine whether or not land is developed or utilized. Rapid land system changes are often directly related to changing governance regimes, e.g. reduced deforestation rates after a logging ban (Barsimantov and Antezana, 2012; de Blas and Perez, 2008), cropland expansion on grassland (Miao et al., 2013; Ojima et al., 2004), or land abandonment in post-communism after the breakdown of the Soviet Union (Alcántara et al., 2013; Hostert et al., 2011; Kuemmerle et al., 2006; Renwick et al., 2013).

In the face of the environmental consequences of land over-use, some developing countries have taken political decisions to preserve and restore ecosystems (Nesheim et al., 2014). Among them, China has the largest land restoration initiatives worldwide in terms of spatial scale, resources invested, and duration (Liu et al., 2008). China suffers from widespread environmental consequences caused by over-exploitation of land resources, particularly in ecologically vulnerable arid and semi-arid regions (Ding, 2003; Wang et al., 2013). Since 2000, ecological programs have been in place to reduce deforestation, promote forest gain, and relieve human pressure on land through converting cropland to grassland (Uchida et al., 2005; Wang et al., 2012; Zhang et al., 2000).

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Inner Mongolia is considered being one of the most severely degraded areas in China and consequently almost all of the national land restoration projects for environmental protection were implemented there, making it the province with the highest investment in environmental restoration programs in China (SFA, 2015). By adopting the nation-wide Natural Forest Conservation Program (NFCP) in 2000, Inner Mongolia intended to maintain natural forests by decreasing deforestation and increasing the productivity of forest plantations (Guo et al., 2013; Li, 2012). Also launched in 2000, the Returning Farmlands to Forest and Grassland Project (also known as "Grain to Green Program", GGP) is intended to convert farmland on steep slopes or with low yields as well as grassland into forest (Uchida et al., 2005; Wang et al., 2007). Starting from 2001, phase I of the Beijing and Tianjin Sandstorm Source Treatment Project (BTSST) aims at reducing the sources of sandstorms that affect Beijing and its neighboring Tianjin Municipality through re-vegetating cropland areas (Li and Zhang, 2004).

Land use patterns changed substantially in Inner Mongolia after the establishment of the People's Republic of China (PRC) in 1949. Vast grasslands in the cropping-grazing transitional zones were cultivated and the area of cropland was doubled by the end of the 20th century (Lin and Ho, 2003; Sorgog et al., 2013). Forest ecosystems, too, changed substantially in Inner Mongolia after 1949 (Liu et al., 2008). Since the goal of PRC's forest management in the early years was to maximize timber production to support the economy, forest was heavily harvested and the forested area shrunk significantly (Song et al., 2014; Zhang and Song, 2006). Apart from human factors, natural disturbances, especially fire, also played an important role in the forest loss in Inner Mongolia (Tao et al., 2013). With more afforestation and reforestation efforts in the 2000′s, the forest cover has been reported to increase in general (IMARBS, 2015).

Despite important ecological and socioeconomic implications of these developments, spatially and temporally coherent documentation of land use and land cover change is still missing for Inner Mongolia. A large number of studies examined the effectiveness of ecological projects in China based on trend analysis using coarse resolution NDVI time series (e.g. Tian et al., 2015; Tong et al., 2017; Yin et al., 2012; Zhang et al., 2012). However, trend analysis based on NDVI cannot provide detailed change information such as land conversions between different land cover types. Also, most assessments were limited to local studies (Du, 2006; Peng, 2010) and do not provide a coherent picture of change regimes (Cao et al., 2010; Yang et al., 2010). For example, Zhou et al. (2012) found GGP induced forest increase in the dry Loess Plateau using multi-temporal Landsat imagery. A field survey conducted by Song et al., 2014concluded low deforestation risk for forests created by GGP, although risk varied greatly across sites. However, Cao, 2008 and Wang et al., 2010 argued that large-scale afforestation failed in arid and semi-arid China, based on local observations and meta-analyses. Previous remote sensing based LULCC monitoring in Inner Mongolia, however, usually took the land cover information observed by two single-date satellite images to deduce changes (e.g. John et al., 2009).

Remote sensing has a long tradition of mapping land use and land cover changes across local to global scales (Clark et al., 2012; Lambin et al., 2003; Loveland and Defries, 2004; Meyer and Turner, 1992). With the release of more and more advanced sensors as well as the open access data policy, a boom in land use and land cover change monitoring using multi-temporal satellite imagery has been emerging in the recent decade (Pouliot et al., 2014; Wulder et al., 2012). Taking advantage of the dense observation of remote sensing time series, long-term land use change could be more reliably separated from short-term changes in highly resilient land system. Several time series algorithms, such as Landsat-based detection of trends in disturbance and recovery (LandTrendr, Kennedy et al., 2010), Breaks For Additive Season and Trend (BFAST, Verbesselt et al., 2010), TimeStats (Udelhoven, 2010), and Continuous Change Detection and Classification (CCDC, Zhu and Woodcock, 2014) have been developed and applied to monitor land surface change from regional to global scales. In the past, trajectory-based methods have been applied to indices derived from a certain number of spectral bands, such as Normalized Difference Vegetation Index (NDVI), Normalized Burn Ratio (NBR) and Tasseled Cap (TC) components (DeVries et al., 2015; Grogan et al., 2015; Pflugmacher et al., 2012; Senf et al., 2015). However, using indices from a few spectral bands for change analysis does not fully exploit all the spectral information, which is important to detect various types of land changes. Yin et al. (2014) developed a method that utilizes land cover probabilities derived from a random forest classifier to characterize changes between multiple land cover classes at annual intervals, such as forest to grassland or grassland to cropland conversions. Rather than detecting the from-to change from two- or multiple-date land cover maps, the approach takes advantage of the hyper-temporal resolution of the MODIS archive and the spectral information to explore detailed changes using a trajectory-based approach, capturing the rapid and gradual transformations in the land system.

We here refined and extended this approach to map annual land cover change for Inner Mongolia to better understand how the land system is altered against the background of national land restoration programs. We focused on three specific land cover change processes that closely correlate with China's ecological programs across the region (Fig. 1): forest loss, forest gain and cropland retirement. Specifically, our objectives were to address the following research questions:

1. What were the rates and spatial and temporal patterns of forest change in Inner Mongolia from 2000 to 2014?
2. What were the rates and spatial and temporal patterns of cropland retirement in Inner Mongolia from 2000 to 2014?
3. How can land changes in forests and agriculture be interpreted against the background of Chinese environmental protection policies?

2. Methodology

2.1. Study area

Inner Mongolia is an autonomous region located in Northern China with twelve prefecture-level divisions, which are subdivided into 102 counties (Fig. 1). It covers an area of about 1.18 million km^2 with a population of 27 million people in 2010 (IMARBS, 2015). Lying in a climatic transitional zone from sub-humid to dry environments, land covers in Inner Mongolia follow a distinct gradient. With higher precipitation, the northeastern part of the region is dominated by mostly deciduous forests in mountainous areas, while the lowlands are used for agriculture. Croplands dominate the East, with the share of grasslands gradually increasing westwards. Between the forested North-East and the vast desert in the West, land cover is dominated by grassland ecosystems.

2.2. Image data and reference data generation

We predicted land cover probability for four land cover classes: cropland, forested land, grassland and others (including waterbody, build-up land and unused land) between 2000 and 2014 using two MODIS Collection 5 Vegetation Index (VI) products from Terra (MOD13Q1) and Aqua (MYD13Q1). The MOD13Q1 and MYD13Q1 comprise the Normalized Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI), surface reflectance in the blue, red, near-infrared (NIR), and shortwave-infrared (SWIR) wavelengths, as well as pixel quality data. Both MODIS products have a nominal spatial resolution of 250 m and a composite time interval of 16 days. We first reprojected all the MODIS imagery from its original sinusoidal projection to Albers using the nearest neighbor resampling approach. To increase the observation density, we combined the indices and spectral reflectance acquired from Terra and Aqua. For each pixel, the temporal