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The relative roles of climate variations and human activities in vegetation change in North China

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ABSTRACT

Using SPOT-VEGETATION Normal Difference Vegetation Index (SPOT/NDVI) data from 1998 to 2011 and climate data obtained from 223 weather stations in or near North China, vegetation variation characteristics within North China were analyzed. Vegetation variation characteristics under the influence of climate variations and human activities were distinguished through a residual analysis. Based on the results of that analysis, the relative roles of climate variations and human activities in vegetation variation were calculated. The results showed that NDVI observed by remote sensing (SPOT/NDVI) increased from 1998 to 2011. The relative roles of climate variations and human activities in vegetation increase were 30.82% and 69.18%, respectively, indicating that human activities played a major role. And observed NDVI showed an increasing trend for different land cover types overall. While NDVI increase in shrub was mainly caused by climate variations, NDVI increases in forest, grassland, farmland, deserts and urban were all primarily caused by human activities. For areas with increasing vegetation, as identified by remote sensing observations in North China, the relative roles of climate variations and human activities in vegetation change were calculated at 14.85% and 85.15% respectively, again indicating that human activities played an important role in vegetation increase. For areas of decreasing vegetation, as identified by remote sensing observations in North China, the relative roles of climate variations and human activities in vegetation change were calculated at 87.72% and 12.28% respectively, indicating that climate variations had large negative effects on vegetation condition. In addition, the relative roles of climate variations and human activities on vegetation variation have obvious spatial differences in North China. Human activities played a positive role in vegetation growth in North China. However, we cannot ignore the function of human destruction on vegetation variation in some areas.

1. Introduction

As the primary land cover throughout terrestrial ecosystems, vegetation acts as an “indicator” of global change, and to a large extent, it characterizes the overall status of regional ecological environments. Long-term dynamic monitoring and evaluation of vegetation is important for global change research and for the assessment of ecological environments (Sun et al., 1998; Xin et al., 2007). The Normal Difference Vegetation Index (NDVI), which is recognized as the most commonly used remote sensing data in the characterization of vegetation change, is closely related to vegetation coverage, growth conditions, biomass and photosynthesis intensity, and with multiple dates of data, differences in NDVI can be used to help document changes in aspects of vegetation (Ji and Peters, 2004; Anyamba and Tucker, 2005). At present, NDVI data have been widely used in the evaluation of vegetation change, and great strides have been made in the identification of influential factors that contribute to this change (Jeremy et al., 2004; Li et al., 2005; Piao et al., 2006; Chen and Wang, 2009; Jong et al., 2011; Song et al., 2011; Li et al., 2012; Zhang et al., 2013; Rigge et al., 2013; Dagbegnon et al., 2015). Vegetation changes is the result from various factors that mainly include climate variations and human activities. Both the domestic and foreign scholars have studied the effects of climate variations on vegetation, they have discovered that vegetation change and climate conditions correlate to a certain degree and that climate variations affects vegetation growth in different regions to different extents (Schmidt and

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Gitelson, 2000; Camberlin et al., 2007; Chen et al., 2008a, 2008b; Zhong et al., 2010; Liu et al., 2011; Zhang et al., 2011a). Some researchers also noted that human activities, especially some ecological construction projects, greatly influence vegetation change (Cao et al., 2006; Zhuo et al., 2007; Wang et al., 2009; Li et al., 2011; Huang et al., 2012). It is clear that climate variations and human activities both impact vegetation; however, it is unknown how much vegetation change is caused by climate variations and how much is caused by human activities.

As an important industrial and agricultural production base, North China has increasingly faced ecological problems in recent years caused by progressively drier climate conditions and intensifying human activities (Ma and Fu, 2006). The Chinese government has carried out a series of ecological construction projects to manage the environment, including the Beijing and Tianjin sandstorm source control project, encouraging ecological migration and returning farmland to forest and grassland. Under the effects of climate variations and human activities, what changes have occurred in vegetation patterns throughout North China in recent years? How extensive are the impacts of climate variations and human activities on vegetation change? The answer to these questions will play an important role in guiding the development of ecological engineering in North China. Compared to the effects of climate variations, the effects of human activities on vegetation change in North China have been less studied up until now (Zhang et al., 2008; Sun and Guo, 2012; Liu et al., 2013). This research uses SPOT-VEGETATION Normal Difference Vegetation Index (SPOT/NDVI) data from 1998 to 2011 to quantitatively evaluate the impacts of climate variations and human activities on vegetation change in North China over the past 14 years to understand the trends and driving mechanisms of vegetation change. The results of this study will provide the scientific basis for further development of ecological construction projects.

2. Study area and data source

2.1. Study area

As shown in Fig. 1, North China includes the administrative areas of Beijing and Tianjin, Hebei Province, Shanxi Province and the Inner Mongolia Autonomous Region. The region, which is influenced by a monsoon climate, typically experiences high temperatures and rainfall in the summer and is cold and dry in the winter. Average annual temperature is approximately 7 °C, and precipitation decreases gradually from the coast inland. Average annual rainfall is approximately 400 mm, most of which falls from July to August (Xu and Wei, 2006). Land cover types are complex and diverse and include forest, shrub, grassland and farmland et al. (Xu et al., 2005). North China is the political and cultural center of the country, with a large population and rapid economic development. However, the trend toward a more arid climate is significant (Ma and Fu, 2006). In recent years, its ecological environment is fragile and easily influenced by human activities and climate variations.

2.2. Data sources and preparation

In this study, we used SPOT/NDVI data provided by the Flemish Institute for Technological Research to study vegetation change in North China and such data are available free of charge at the Vlaamse Instelling voor Technologisch Onderzock (VITO) Image Processing centre (Mol, Belgium) (http://www.vgt.vito.be). The data had 1 km × 1 km spatial resolution and was taken at ten-day intervals from April 1998 to December 2011. Cloud and atmospheric noise was removed from all images, which increased the quality of the data and made it more reliable and suitable for the research of large scale vegetation change, especially when compared with other NDVI data (Yan et al., 2008). These NDVI data were reprojected to the Albers equal area projection and WGS-84 datum using Arcmap10.2 software. To represent vegetation growth status, we then derived annual maximum NDVI by using the Maximum Value Composite method (MVC) (Zhang et al., 2011b). NDVI data collection began in April, 1998; therefore, the maximum NDVI values were taken from mid-April to December in that year. Because the highest rates of vegetation growth in North China occur between June and September, the lack of data in the earlier months did not affect the annual maximum NDVI value. Finally, by combining data for the entire North China area administrative boundary, we obtained an annual maximum NDVI dataset for 14 years, from 1998 to 2011.

The meteorological data, consisting of monthly temperature and monthly precipitation data from 223 meteorological stations in and around north China were collected from January 1998 to December 2011 and were provided by the China Meteorological Data Sharing Service System. To process the data, we first calculated 6 climate indices for each station: average annual temperature, annual precipitation, aridity index, sum of monthly average temperatures >0 °C, biological heat index and biological dry humidity index. Then, by applying a Kriging interpolation to the 6 climate indices with Arcmap10.2 software, we obtained 84 grid maps of climate index throughout North China from 1998 to 2011. The projection method and spatial resolution of these data were kept consistent with the NDVI data. The formulas for the aridity index, biological heat index and biological dry humidity index were as follows (Ni, 1997)

$$\mathrm{r} = \frac{PEm}{P} \tag{1}$$

where r is the aridity index, *P* is the annual precipitation (mm), *PEm* is annual potential evapotranspiration (mm), and it is calculated using the Thornthwaite method.

$$BWI = \sum_{i=1}^{n} (T - 10) \tag{2}$$

$$BK = \frac{\mathrm{P}}{BWI + 40} (BWI \le 80) \tag{3}$$

$$BK = \frac{2\mathrm{P}}{BWI + 120} (BWI > 80) \tag{4}$$

where *BWI* is biological heat index (°C), BK is biological dry humidity index (mm/°C), T is monthly mean temperature >10 °C (°C), P is annual precipitation (mm), *n* is the number of months of monthly mean temperature >10 °C.

Other data included land cover data and administrative map of China. Land cover data came from the China land cover database with 1 km spatial resolution, a part of GLC2000. It was produced by using unsupervised classification method and FAO land cover classification system (LCCS) with SPOT VGT S10 data over a period of 01 January 2000 to 31 December 2000 and the multi-spectral data of the last decade of August 2000 (Xu et al., 2005). Administrative map came from China geographic dataset (1:1000,000).

3. Methods

3.1. Trend analysis

The slope of the linear regression was used to analyze the trend in vegetation change as shown through the NDVI data. The slope is calculated as follows: