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Spatio-temporal variation of vegetation coverage and its response to climate change in North China plain in the last 33 years

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ABSTRACT

Global climate change has led to significant vegetation changes in the past half century. North China Plain, the most important grain production base of china, is undergoing a process of prominent warming and drying. The vegetation coverage, which is used to monitor vegetation change, can respond to climate change (temperature and precipitation). In this study, GIMMS (Global Inventory Modelling and Mapping Studies)-NDVI (Normalized Difference Vegetation Index) data, MODIS (Moderate-resolution Imaging Spectroradiometer) – NDVI data and climate data, during 1981–2013, were used to investigate the spatial distribution and changes of vegetation. The relationship between climate and vegetation on different spatial (agriculture, forest and grassland) and temporal (yearly, decadal and monthly) scales were also analyzed in North China Plain. (1) It was found that temperature exhibiting a slight increase trend (0.20 °C/10a, $P < 0.01$). This may be due to the disappearance of 0 °C isotherm, the rise of spring temperature. At the same time, precipitation showed a significant reduction trend (−1.75 mm/10a, $P > 0.05$). The climate mutation period was during 1991–1994. (2) Vegetation coverage slight increase was observed in the 55% of total study area, with a change rate of 0.00039/10a. Human activities may not only accelerate the changes of the vegetation coverage, but also c effect to the rate of these changes. (3) Overall, the correlation between the vegetation coverage and climatic factor is higher in monthly scale than yearly scale. The correlation analysis between vegetation coverage and climate changes showed that annual vegetation coverage was better correlatend with precipitation in grassland biome; but it showed a better correlated with temperature i the agriculture biome and forest biome. In addition, the vegetation coverage had sensitive time-effect respond to precipitation. (4) The vegetation coverage showed the same increasing trend before and after the climatic variations, but the rate of increase slowed down. From the vegetation coverage point of view, the grassland ecological zone had an obvious response to the climatic variations, but the agricultural ecological zones showed a significant response from the vegetation coverage change rate point of view. The effect of human activity in degradation region was higher than that in improvement area. But after the climate abruptly changing, the effect of human activity in improvement area was higher than that in degradation region, and the influence of human activity will continue in the future.

1. Introduction

Vegetation, as an important component of the ecosystem, strongly affects the energy transfer among the components of the ecosystem, such as atmosphere and soil (Wang et al., 2012). Normalized difference vegetation index (NDVI), which has positive correlation with vegetation coverage, is an indicator of vegetation density and growth status (Sun et al., 1998). Temperature, precipitation change and seasonal fluctuations have important effects on the growth and distribution of plants (Zhao and Running, 2000). Climatic change also leads to NDVI fluctuation in a certain range (Piao et al., 2006). Especially with the rising of global climatic change, the volatility of water and heat combination is increasing (Climate change, 2013; Ren et al., 2005). As an important part of the global ecological system and the climatic system, vegetation coverage change has attracted much attention in the Global Change Research (Jia, 2013). Therefore, the study on vegetation coverage changes

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affected by natural environment and human activity is critical to reveal the relationship among vegetation coverage change, climatic change, and human activity, and is important to the feedback effects between climatic change and human activity.

Myneni et al. (1997) and Tucker et al. (1999) found that vegetation coverage of long time series showed an increasing trend, especially in the northern Hemisphere mid-latitude regions. This was attributed to the global warming. Some research showed that in different regions, the increase or decrease trends of vegetation coverage were not consistent. Park and Sohn (2010) and Piao et al. (2011) concluded that the trends were the same in Eurasia. Wang et al. (2011) and Zhang et al. (2012) found that the trends were reversed between northwest and northeast in North America. Existing studies have shown that the vegetation coverage and climatic factors had internal relationship, especially for temperature factor and precipitation factor (Jing et al., 2011; Bi et al., 2005; Sun et al., 2001). The research results indicated that the change of vegetation coverage was consistent with the change of precipitation in Northwest China. There was a positive correlation between vegetation index and precipitation, while the correlation of vegetation coverage and temperature was low. Based on the above studies, it was found that the changes of vegetation coverage had the regional differences, and the spatial heterogeneity of climatic factor was strong. Meanwhile, the climatic factors changed abruptly in a certain time scale (He et al., 2013). The abrupt changes of climate definitely affect the change of growth of plants and animals and the ecological structure. Therefore, the discussion of the response of vegetation coverage to the abrupt change of climate has a great significance to protect the biodiversity and ecological safety.

Based on the close relationship of the vegetation coverage changes and the climatic factor, and the spatial heterogeneity of the time and space change in vegetation coverage, North China plain was chosen as the research region, and the spatial distribution characteristics and the change trends of vegetation coverage were discussed in this paper. From the perspective of the climate, combined with ecological system partition, beginning from different time and spatial scales, the goals objectives of this study were to analyze the time and space response of the inter-decadal changes, inter-annual changes, and monthly changes of the vegetation coverage to the precipitation factor and temperature factor for agro-ecological, grassland ecological and forest ecological zones (Fig. 1).

2. The geographical and ecological division of the research area

The North China Plain (30°00′–40°24′N, 112°48′–122°45′E) includes most parts of five provinces (Hebei, Henan, Shandong, Anhui, and Jiangsu) and two cities (Beijing and Tianjin). The total area of North China Plain is approximately 400,000 km^2 out of which 330,000 km^2 is plain area. It is important to note that 72% of the entire area is arable. The study area belongs to the temperate continental monsoon climate, rich in solar-thermal resources. Precipitation is heavy and concentrated in June to September. Winter wheat and summer corn are the dominant crops and cropping pattern is two crop per year (Liu et al., 2010; Mo et al., 2011).

Based on Wu's research, the research area was divided into eight geographical zones as Fig. 2 shown (Wu et al., 2003). These are as follows: (1) Huainan and Yangtze River geographical zone, (2) Hanzhong basin geographical zone, (3) North China geographical zone, (4) Luzhong hilly geographical zone, (5) Liaodong-Jiaodong hilly geographical zone, (6) North China hilly geographical zone, (7) South of Daxing' anling geographical zone, and (8) East of Inner Mongolia Plateau and plain geographical zone. In order to study spatial and temporal variation of vegetation cover in different geographical zones, the existing natural zones were combined into three larger zones: forest ecological zone, grassland ecological zone and agro ecological zone. Grassland ecological zone is mainly located in the northwest of Hebei Province, including Zhangbei region and Mulan Paddock. This zone belongs to the mix zone of temperate semi-humid and semi-arid areas of China, mainly including warm meadow grassland, mountainous meadow and warm grassland (Xu et al., 2009a). Forest ecological zone includes Yanshan Mountains, the Taihang-Funiu Mountains and hilly mountain of Shandong Peninsula. From the foot to the tnop of the hill, vegetation types include deciduous forest, broadleaf and coniferous forests, coniferous forest, and alpine shrub grass with pine forest, Platycladus orientalis forest, and oak forest (Hou et al., 2012). The remaining part of the research area is agro-ecological zone.

3. Data preparation and research methods

3.1. Data preparation and consistency check

The GIMMS (Global Inventory Modelling and Mapping Studies)-NDVI dataset provided by University of Maryland contains half months maximum synthetic data from 1981 to 2006, which comprised of spatial resolution of 8 km × 8 km. After radiation calibration, geometric calibration and atmospheric calibration and removing cloud, GIMMS dataset has higher quality than other NDVI data (Chen and Wang, 2009). GIMMS dataset is currently the longest time series of NDVI data, which has better correlations with other high resolution data and has been widely used in global and regional vegetation dynamics studies (Zhao et al., 2009; Tucker et al., 2005). MODIS-NDVI dataset provided by NASA contains MOD13Q1 products of North China Plain from 2000 to 2013, and the time resolution is 16d and spatial resolution is 250 × 250 m, MODIS Reprojection Tools (MRT) software was used for data projection conversion, data combining and other data processing.

MVC (Maximum Value Composites) is widely used to get vegetation coverage, which is used to obtain monthly and annual NDVI data based on the 15 days' NDVI data. The equation is as follows (Zhang et al., 2008):

$$NDVI_i = \mathrm{Max}(NDVI_{ij})$$

Where $NDVI_i$ is the NDVI data of month i or year i, and $NDVI_{ij}$ is the NDVI data of j^{th} 15-day of month i or month j in year i.

GIMMS and MODIS dataset are needed to conduct consistency check (Xin et al., 2007; Zhang et al., 2011a,b), because they come from different sensor. In this study, time series data of GIMMS-NDVI for the period of 1981–2006 and time series data of MODIS-NDVI for the period of 2000–2013 were used with a total of 33 scene image data points. Based on seven years overlapping data (2000–2006), the correlation analysis was conducted. Stationing random points of 100 in the study area using ARCGIS10.2 were used, and the pixel values of vegetation coverage were extracted from MODIS and GIMMS data using the extract model. Inversion model was constructed using the extracted two sensor data in the same year, then the data were validated using the data of the other years. The experimental results shown that the inversion model constructed by 2003 was the best model. The mean of root-mean-square error of pixel was 0.11. The correlation coefficient between GIMMS and MODIS is 0.801 with $p < 0.05$, which indicates that the two annual data have significant consistency on a regional scale. The linear regression equation is:

$$\mathrm{NDVI}_{\mathrm{GIMMS}} = 0.5886 * \mathrm{NDVI}_{\mathrm{MODIS}} + 0.0965 (r^2 = 0.6417, n = 7, \mathrm{P} < 0.05)$$

The same method was used to conduct the monthly consistency check on GIMMS and MODIS dataset. The correlation coefficient