Ecological Indicators 89 (2018) 101–109

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Relationship between vegetation change and extreme climate indices on the Inner Mongolia Plateau, China, from 1982 to 2013

Chunlan Li[a,b,c], Jun Wang[a,b,*], Richa Hu[d], Shan Yin[d,e], Yuhai Bao[d,e], Desalegn Yayeh Ayal[f]

[a] School of geographic sciences in East China Normal University, Shanghai 200241, China
[b] Key Laboratory of Geographic Information Science of Ministry of Education, East China Normal University, Shanghai 200241, China
[c] Hamburg University of Applied Sciences, Research and Transfer Center"Sustainable Development, and Climate Change Management" and School of Science and Environment, Manchester Metropolitan University, Chester Road, Manchester M1 5GD, UK
[d] College of Geographical Sciences in Inner Mongolia Normal University, Huhhot 010022, China
[e] Key Laboratory of Remote Sensing and Geographic Information System in Inner Mongolia, Huhhot 010022, China
[f] Addis Ababa University, College of Development Studies, Center for Food Security Studies, Addis Ababa 150129, Ethiopia

ARTICLE INFO

Keywords:
Climate extremes
Normalized Difference Vegetation Index (NDVI)
Correlation
Inner Mongolia Plateau (IMP)

ABSTRACT

Climate extremes have resulted in substantial vegetation changes during the last several decades, especially in high latitude regions of the Northern Hemisphere. As a climatically-sensitive region, the Inner Mongolia Plateau (IMP) is currently experiencing prominent climate extremes. To identify how climate extremes affect vegetation in the IMP, we calculated 11 indices of climatic extremes for 6 sub-regions of the IMP based on daily maximum and minimum temperature and precipitation. Long intervals of Normalized Difference Vegetation Index (NDVI) derived from the Global Inventory Modeling and Mapping Study (GIMMS), as well as their correlations with climate indices, were investigated at different temporal scales (annual, seasonal and monthly). The results show that on an annual scale, NDVI has the same trend as precipitation extremes and extreme low temperatures, while it has the opposite trend with extreme high temperatures. In contrast, on monthly and seasonal scales, most of the extreme climate indices are significantly positively related with NDVI. In addition, a spatial heterogeneity analysis indicates that the vegetation in desert steppe and steppe desert was relatively less sensitive to the extreme temperature indices in summer, while in general the vegetation in forest and sand desert was insensitive to the extreme precipitation indices in summer. NDVI has a significant relationship with the extreme temperature indices with a time lag of least three months, and with the extreme precipitation indices with a time lag of two months. Finally, our results suggest that extreme climatic events have become more frequent and intense under ongoing global warming.

1. Introduction

As noted by the Intergovernmental Panel on Climate Change (IPCC, 2013), global warming is indisputable and will eventually have a large effect on vegetation patterns (Xu et al., 2016). Moreover, current evidence suggests that global warming has already had major effects on vegetation during the past 20 years (Zhang et al., 2011), especially in high latitude areas of the Northern Hemisphere (Zhou et al., 2001; Xu et al., 2016). Climate change can affect plant metabolism, eventually affecting vegetation growth (Parmesan and Yo, 2003). In addition, vegetation may adapt to changing climatic conditions by introducing generalized mortality or by modifying its own living conditions (Lloret et al., 2012; Tan et al., 2015). However, the nature of these events may differ in different locations and at different times, making the analysis of changes in the occurrence of specific extreme climatic events more difficult (Vincent and Mehis, 2006). However, calculation of climate change indices based on daily meteorological data can provide useful insights into extreme climatic events (Peterson et al., 2001).

Temperature and precipitation are typically considered to be the most important factors affecting the distribution of vegetation (Zhou et al., 2007). In addition, vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), are widely used to represent vegetation coverage on different spatial and temporal scales (Bao et al., 2007), especially in semi-arid regions which have year-round vegetation cover (Zhang et al., 2011). Many studies have examined the relationship between vegetation cover and climatic variables (Shi et al., 2011; Wang et al., 2012; Bao et al., 2012, 2013; Li et al., 2014; Zhou et al., 2014), and have focused on the responses of NDVI to changes in

* Corresponding author at: School of geographic sciences in East China Normal University, Shanghai 200241, China.
E-mail addresses: jwang@geo.ecnu.edu.cn (J. Wang), huricha@imnu.edu.cn (R. Hu), yinshan@imnu.edu.cn (S. Yin), baoyuhai@imnu.edu.cn (Y. Bao).

https://doi.org/10.1016/j.ecolind.2018.01.066
Received 27 May 2017; Received in revised form 26 January 2018; Accepted 30 January 2018
1470-160X/

mean climatic parameters and examined the results in the context of different vegetation types (Bao et al., 2013; Hang et al., 2014; John et al., 2013). However, relatively little attention has been paid to how climate extremes influence different vegetation types. In fact, under global warming, the increased climate extremes have significantly affected the growth of vegetation in recent years (Zhao et al., 2017) and had an extensive effect on vegetation dynamics (Tan et al., 2015). For example, Reichstein et al. (2013) summarized how forest, grassland and cropland were affected by climate extremes; and Liu et al. (2013) studied the influence of climate extremes on eight biomes, finding that the decreases in temperate broadleaf forest and temperate grassland in Amazonia had the strongest correlation with extreme low precipitation. Importantly, knowledge of the relationship between climate extremes and vegetation may help evaluate the resilience and vulnerability of vegetation to climate extremes (Tan et al., 2015) which could facilitate adaptation to and mitigation of climate extremes. However, although much attention has been paid to climate extremes on different spatial scales and to the various descriptive indicators (Alexander et al., 2006), assessment of their impacts on vegetation are scarce. This may be partly because of the diversity of the impacts of changes in climate extremes on the growth of vegetation (Tan et al., 2015).

Generally, China is especially vulnerable to climate change (Ding et al., 2007); in addition, arid and semi-arid regions, which occupy a large part of northern China, are more vulnerable than other climate zones. The Inner Mongolia Plateau (IMP), which is dominated by various types of grassland vegetation, is a typical arid and semi-arid inland region (Hu et al., 2015). The climate of the region varies inter-annually and extreme climate events have become more frequent and serious with ongoing global warming. In recent years, the IMP has experienced several extreme climate events, such as droughts, floods and frost, which have damaged a total area of more than 288,424 hm^2/10 a (Bai et al., 2007). These events have resulted in very large economic losses, numerous fatalities, and have caused serious damage to agriculture and animal husbandry. Moreover, in addition to the main area of animal husbandry in China, the IMP also has an important ecological value, with the southern part of the region acting as a windbreak and zone of sand stabilization. These factors make the IMP more vulnerable to climate change, and therefore the analysis of extreme climate change is of critical importance for protecting and improving the grassland and for ensuring the sustainable development of animal husbandry.

Several workers have analyzed the relationship between the vegetation in the grassland areas of the IMP and variations in average climatic conditions, and the results suggest that precipitation was the key factor affecting vegetation growth, especially in the summer season (Bao et al., 2013; Dai et al., 2014; Miao et al., 2014). However, most of this work was based on short intervals of NDVI data. The present study complements previous work by analyzing a longer time series of NDVI data, and it also examines the importance of climatic extremes; in addition, different types of grassland vegetation are considered in the analysis. To the best of our knowledge, this is the first comprehensive investigation of the responses of the NDVI to climatic extremes in the IMP. The main aims of the study are: (1) to determine the temporal relationship between NDVI and extreme climate indices, (2) to determine the spatial distribution of the degree of correlation of NDVI and extreme climate indices, and (3) to determine how NDVI responds to extreme climate indices.

2. Study area

The Inner Mongolia Plateau (IMP) is located within 97°12′–126°04′E, 37°24′–53°23′N in northern China (Fig. 1). It is the third largest province in China and covers an area of 1.18 million km^2, accounting for 12.3% of the national territory. Elevations range from 82–3430 m (Wang et al., 2013). Agriculture and animal husbandry are the economic basis of the IMP, contributing 26% of the region's gross domestic product; 80% is from animal husbandry alone (Li et al., 2018). Grassland dominates the eastern part of the region while desert is widespread in the west. The study area is vast and spans several climate zones, from arid and semi-arid in the northwest inland region to humid and semi-humid in the southeast coastal region. Winters are long, cold and dry with frequent blizzards (Zhang et al., 2012); there are major sandstorms in spring; while warm or hot and relatively humid in summer. The mean annual temperature ranges from −1 to 10 °C and precipitation ranges from 50 to 450 mm. Precipitation decreases gradually from east to west, with nearly 70% occurring in June to August. The IMP can be divided into five climatic zones based on the spatial distribution of precipitation. From east to west, the zones are: humid, semi-humid, semi-arid, arid, and hyper-arid; and the corresponding grassland vegetation types are meadow steppe, typical steppe and desert steppe (Wu, 1980). In the present study, based on the field research of Li (1962) and Li et al. (1990), and digitized results obtained via ArcGIS by Su et al. (2015), the IMP was divided geographically six subregions study: desert steppe, forest, forest steppe, sand desert, steppe desert and typical steppe (Li et al., 2018).

There are 1.32 billion mu of grassland in the IMP, accounting for 76.5% of the total area, and the region is ranked as the first of the five major grasslands in China. From the annual variation of NDVI, plant growth in the IMP occurs mainly from May to October, with the maximum biomass value in August (Fig. 2). July is an important seasonal turning point, after which precipitation and temperature both decrease dramatically. There is an obvious time-lag between vegetation growth and climate.

3. Datasets and methodology

3.1. Datasets

3.1.1. NDVI dataset

The NDVI is a widely-used indicator of vegetation and was directly estimated by satellite images. There are many examples of its use in analyzing vegetation responses to climate change (Sun et al., 2010; Miao et al., 2014). Vegetation growth and vegetation characteristics can be represented very effectively by the average NDVI value within the different steppe types in the IMP. The vegetation data used in this study are based on NDVI3g values obtained from the Global Inventory Monitoring and Modeling Studies (GIMMS) group at the National Aeronautics and Space Administration (NASA) (available at https://nex.nasa.gov/nex/projects/1349/). The GIMMS NDVI3g datasets have a spatial resolution of 8 km and a 15-day temporal interval for the period from January 1982 to December 2015. Data are validated by radiometric calibration, atmospheric attenuation, cloud screening, orbital drift, sensor degradation, view and illumination geometry and other effects that were irrelevant to vegetation change (Tucker et al., 2005); in addition, they are corrected to minimize effects such as sensor degradation, calibration loss and volcanic eruptions. Thus, the data can reliably be used to identify long-term trends in vegetation (Strauch and Volk 2013; Xu et al. 2014; Li et al., 2018).

Monthly NDVI values were generated from the processed biweekly NDVI composites (Tan et al., 2015). The monthly and seasonal NDVI data were constructed using the Maximum Value Composite (MVC) procedure because of its ability to minimize the effects of cloud contamination. Seasons are defined as spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).

3.1.2. Extreme climate indices

We calculated 11 extreme climate indices (2 precipitation-based and 9 temperature-based) (Tank et al., 2009) based on daily meteorological data for sub-regions of the IMP using RClimDex1.1 software for quality control and RHtest V4 software to conduct a homogeneity test. The 11 selected indices are defined in Table 1.