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Vegetation dynamics and responses to recent climate change in Xinjiang using leaf area index as an indicator

Guli·Jiapaer[a,*], Shunlin Liang[b,c], Qiuxiang Yi[a], Jinping Liu[a,d]

[a] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[b] Department of Geographical Sciences, University of Maryland, College Park, MD 20740, USA
[c] State Key Laboratory of Remote Sensing Science, College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China
[d] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

There is a strong signal showing that the climate in Xinjiang, China has changed from warm-dry to warm-wet since the early 1980s, leading to an increase in vegetation cover. Based on a regression analysis and Hurst index method, this study investigated the spatial–temporal characteristics and interrelationships of the vegetation dynamics and climate variability in Xinjiang Province using the leaf area index (LAI) and a gridded meteorological dataset for the period 1982–2012. Further analysis focused on the discrimination between climatic change and human-induced effects on the vegetation dynamics, and several conclusions were drawn. (1) Vegetation dynamics differ in mountain and plains regions, with a significant increasing trend of vegetation cover in oases and decreasing trend of vegetation growth in the Tienshan and Altay Mountain. The Hurst exponent results indicated that the vegetation dynamic trend was consistent, with a sustainable area percentage of 51.18%, unsustainable area percentage of 4.04%, and stable and non-vegetated area ratio of 44.78%. (2) The warm-dry to warm-wet climatic pattern in Xinjiang Province since the 1980s mainly appeared in the western part of the Tienshan region and North Xinjiang. Temperatures increased in all seasons over the majority of Xinjiang, and precipitation showed a significant increasing trend in the mountainous regions in spring, summer and autumn, whereas the rate of precipitation change was higher in the plains region in winter compared with that in other seasons. (3) A correlation occurs between the climate variables (precipitation and temperature) and mean LAI, and this correlation varies at the seasonal and regional scales, with coniferous forest, meadow and grassland more correlated with precipitation in spring and summer and not correlated with temperature, which indicated that precipitation was the dominant factor affecting the growth of mountain vegetation. The mean LAI of vegetation in the plains exhibited significant correlation with precipitation in winter and temperature in spring and summer. (4) A residual analysis showed a human-induced change that was superimposed on the climate trend and exhibited two effects: vegetation regeneration in oases throughout Xinjiang and desertification in the meadow located in the mountainous area of the western Tienshan Mountains and Altay Mountains. (5) Grassland is the most sensitive vegetation type to short-term climatic fluctuations and is the land-use type that has been most severely degraded by human activity; thus, local governments should take full advantage of this climatic warm-wet shift and focus on protecting vegetation to improve this fragile arid environment.

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1. Introduction

Global surface temperature data have shown an increase of approximately 0.74 °C over the last century (IPCC, 2007), and the average air temperature in China increased between 0.5 °C and 0.8 °C. With global warming, it is predicted that humid regions will become warmer and more humid and most arid regions will become warmer and drier (Mellilo et al., 1993; Herrmann et al., 2005; Huxman and Smith, 2001; Whitford, 2002; Lioubimtseva, 2004; Jarlan et al., 2005; Donohue et al., 2009; Yi et al., 2013; Poultera et al., 2013). However, many studies have documented a warmer and more humid pattern in northwestern China, which includes arid and semi-arid areas, from the early 1980s (Shi et al., 2002, 2003, 2007; Chen et al., 2005, 2009; Xu et al., 2010). As a

* Corresponding author. Present address: No. 818 South Beijing Road, Xinjiang Institute of Ecology and Geography, Urumqi 830011, China. Tel.: +86 991 7823131; fax: +86 991 7885378.
E-mail address: glmr@ms.xjb.ac.cn (Guli·Jiapaer).

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consequence of this climatic change, the vegetation cover in the area has increased (Dan et al., 2004). This pattern has led to the optimistic expectation that the fragile arid habitat can be improved.

Most previous local studies have used time series of remotely sensed indicators of vegetation conditions, primarily the Normalised Difference Vegetation Index (NDVI) or net primary productivity (NPP), and climatic measurements from ground stations to analyse the vegetation response to climate change in Xinjiang Province (Zhang et al., 2006; Peng et al., 2008; Duan et al., 2011; Zhao et al., 2011; Fang et al., 2013). Based on the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) NDVI and temperature and precipitation data for western China for the period 1982–2000, Zhang et al. (2006) found that vegetation is increasing along with temperature in northern Xinjiang in spring, summer and autumn and noted that increased precipitation is also an important reason for the increased vegetation cover. Using the NOAA/AVHRR NDVI data, Peng et al. (2008) estimated the NPP in Xinjiang and assessed the seasonal variation of NPP for different land-cover types in response to climate change. The results showed that the NPP of different land-cover types exhibits a similar correlation with air temperature, precipitation and sunshine percentage, with precipitation the major climatic factor influencing the seasonal variation of NPP in Xinjiang. Duan et al. (2011) used the AVHRR NDVI data at an 8-km resolution and climatic measurements to characterise the vegetation response to climate and found that there was a significant upward trend over most of Xinjiang Province for the period 1981–2006. Only the vegetation in the northwestern part of Xinjiang Province declined, and the correlation between NDVI and precipitation was higher than that between NDVI and temperature; thus, precipitation is the controlling factor than affects changes in NDVI. Fang et al. (2013) analysed the trend of climate and vegetation in Xinjiang and found that NPP decreased in the Yili region and northernmost regions of Xinjiang from 2000 to 2010 and increased in the areas near the Junggar Basin in the north and Tarim Basin in the south. Whereas previous studies focused on the trends of climate change and vegetation indices and relationships between them, limited efforts have been made to analyse the dynamics of different types of vegetation and their response to climatic change or the changing trends of different vegetation types in the future or to distinguish between the effects of climatic change and human activity on vegetation dynamics. In general, changes caused by climate and human activities, separately or jointly, affect vegetation dynamics on global and regional scales (Rees et al., 2001; Tucker et al., 2001; Fang et al., 2001; Buermann et al., 2003; Neigh et al., 2008); thus, it is important to understand the response regularity of different types of vegetation to climate change to differentiate among the effects caused by climate and human activities and assist governments in developing effective environmental management and protection policies.

The present study focused on the characteristics of multi-temporal-scale variation of vegetation and its response to precipitation and temperature; the leaf area index (LAI) was selected as the indicator of vegetation status. The LAI is defined as one-half of the total leaf area per unit ground surface (Chen and Black, 1992). In general, the LAI indicates the growing status of natural vegetation and crops and is used to model many biophysical and physiological processes, including photosynthesis, respiration, transpiration, carbon cycling, NPP, energy carbon exchange and climate regulation (Jonckheere et al., 2004; Hardin and Jensen, 2007); thus, the analysis of LAI variability and its response to climate change contribute to the understanding of broader biophysical and physiological processes under global climate change. The objectives of this research were to (1) further explore the trends and spatial patterns of different types vegetation; (2) estimate the sustainability of the different types vegetation variations; (3) analyse the vegetation response to local climatic change; (4) analyse this relationship to further distinguish between the influence of climatic and human-induced change on the vegetation dynamics; and (5) identify the vegetation types that are sensitive to climatic change in the Xinjiang region. It is expected that understanding the variation characteristics and patterns of the vegetation LAI in the Xinjiang Province will promote regional ecological protection and maintain ecological construction achievements under local warming and increasingly humid climatic change patterns.

2. Study area

Xinjiang Uygur Autonomous Province is located in northwestern China from 73°20′ E to 96°25′ E and from 34°15′ N to 49°10′ N and covers an area of over 1.66 million km^2. Xinjiang Province is a fragile ecological zone characterised by its complicated arid and semi-arid natural environments. Most of the plains surface is covered with short, simple and sparse vegetation, and the fractional vegetation coverage of the natural vegetation is typically less than 20%, sometimes reaching 0%. Natural oases are also present, and they have slightly higher moisture conditions and ground cover characterised by *Populus euphratica, Tamarix hispida, Haloxylon* and *Phragmites australis* species. In contrast, the mountainous region is characterised by abundant pasture and coniferous forest because of the vertical zonality and high precipitation.

Xinjiang exhibits varied topography (Fig. 1). The province includes three mountain ranges, including the Tienshan Mountains in the middle, Altay Mountains in the north and Karakoram Mountains in the south, and two basins, the Junggar Basin and Tarim Basin. With the Tienshan Mountains as the divide, the southern part of Xinjiang Province is named South Xinjiang and the northern part is named North Xinjiang. Remote from the ocean and enclosed by high mountains, the climate of Xinjiang features a temperate continental arid and semi-arid climate with an annual precipitation rate of 145 mm, which is 23% of the national average (630 mm), and an annual temperature range of 2.5–10 °C. Because of the vast area of the province, the regional precipitation varies widely and can reach over 500 mm in the western Tienshan region to under 100 mm in the south. The Tienshan Mountains separate the dry south from the slightly less arid north; thus, the northern slopes of the Tienshan are more humid than the southern slopes.

Research in glaciology, dendrochronology and meteorology has shown that for the period from the end of the Little Ice Age to the 1980s, the climate in northwestern China was warm-dry, air temperature increased by 1.3 °C and precipitation in the central Tienshan Mountains decreased by 50–65 mm (Wang, 1991). However, evidence has shown that the climate has changed to warm-wet from 1987 to the present and that there has been a continuous increase in air temperature and annual precipitation. The annual temperature was 0.7 °C higher from 1987 to 2000 compared with that from 1961 to 1986, and the annual precipitation was 10–30% higher from 1987 to 2000 compared with that from 1961 to 1986. This effect of the warm-wet pattern shift on the ecology of the region has attracted the interest of scientists, governments and the public.

3. Materials and methods

3.1. Data sources

The datasets used here include LAI data, climatic data (precipitation and temperature), elevation data, vegetation data and available water holding capacity data.

Five typical global LAI products are used worldwide: the MODIS, CYCLOPES, GLOBECARBON, Geoland2 and GLASS datasets. In this

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