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# Analysis on spatio-temporal trends and drivers in vegetation growth during recent decades in Xinjiang, China

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ABSTRACT

Vegetation plays an important role in regulating the terrestrial carbon balance and the climate system, and also overwhelmingly dominates the provisioning of ecosystem services. In this study, a non-stationary 1982–2012 AVHRR $NDVI_{3g}$ time series, the newest dataset, were used to evaluate spatio-temporal patterns of seasonal vegetation changes in Xinjiang province of China at regional, biome and pixel scales over progressively longer periods from 18 to 31 years, starting in 1982, and their linkages to climatic factors and human activities were analyzed. At regional scale, the increases were statistically significant for autumn NDVI during fourteen periods, for growing season and summer NDVI during the most periods, and for spring only during the first four periods. The rates of NDVI increase in growing season and all seasons significantly decreased over fourteen periods. At pixel scale, areas with significant browning rapidly increased over fourteen periods for growing season and all seasons, and these areas were mainly concentrated in northern desert of Xinjiang. Vegetation growth in Xinjiang was regulated by both moisture and thermal conditions: the response of NDVI in spring and autumn was more sensitive to thermal factors, such as temperature and potential evapotranspiration, and correlations between NDVI and precipitation and between NDVI and humidity index were stronger in summer and growing season. Extensive use of fertilizers and expanded farmland irrigated area increased vegetation growth for cropland. However, the rapid increase in the proportion of cotton cultivation and use of drip irrigation may reduce spring NDVI in the part of farmlands. Trend analysis during the multiple nested time series may contribute to a better and deep understanding of NDVI dynamic and foreseeing changes in the future. Accordingly, NDVI in Xinjiang will continuously increase at regional scale and the areas showing significant browning will also furthermore grow.



## Introduction

Vegetation is the most critical element of the terrestrial ecosystem, serving as a medium in water circulation, material cycling, energy flow, and information transfer. Vegetation plays a crucial role in regulating the terrestrial carbon balance and climate system (Peng et al., 2012, 2011; Piao et al., 2011). Therefore, it is important to monitor vegetation changes. Changes in the spatial and temporal pattern of vegetation alter the structure and function of landscapes, consequently influencing biodiversity and ecological processes (Li et al., 2012). Vegetation growth can be strongly affected by climate change and human activity (Goetz et al., 2005; Myneni et al., 1997; Nemani et al., 2003; Peng et al., 2012). The study of vegetation dynamics has become one of the key issues in global change (Peng et al., 2012). There are large inter-annual variations and intra-annual dynamics in vegetation growth because precipitation typically has large inter-annual variations in amount and distribution within a year (Buyantuyev and Wu 2009; Li et al., 2012; Qi et al., 2009; Wessels et al., 2007). The influence of climate change on vegetation growth is therefore more evident (IPCC, 2007). Due to high spatial coverage and a long time series, remotely sensed data have become the most important source for monitoring vegetation dynamics at large scales (Fensholt et al., 2012; Pettorelli et al., 2012; Wessels et al., 2007). The normalized difference vegetation index (NDVI) dataset, which was often used as a proxy for vegetation productivity, is one of the key metrics of land

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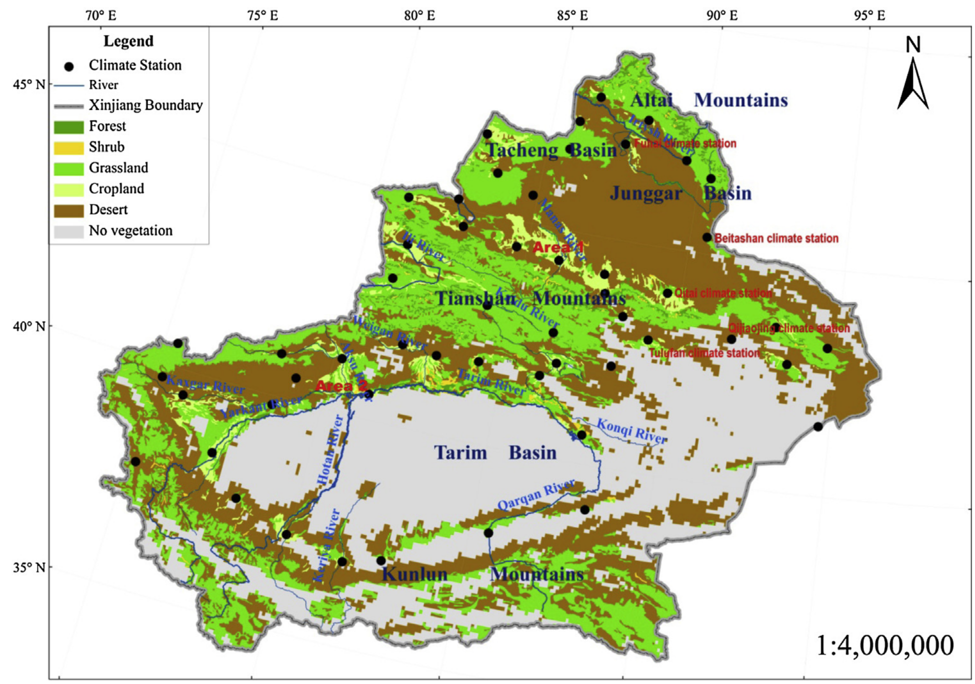


**Fig. 1.** Distribution of vegetation types and climate stations in Xinjiang, China.

degradation, and it has been suggested that this index can be used as an integral measure of ecosystem services (Bai and Dent, 2009; Fensholt et al., 2012; Fensholt and Rasmussen, 2011). The GIMMS NDVI dataset is considered to be one of the best datasets available for long-term NDVI trend analysis (Alcaraz-Segura et al., 2010; Beck et al., 2011; Beck and Goetz, 2011; Fensholt et al., 2012). The long-term NDVI time series data provides a powerful tool to understand vegetation growth history, monitor current conditions and prepare for future changes (Piao et al., 2011; van Leeuwen et al., 2006). In 2014, released the newest NDVI dataset, calling AVHRR $NDVI_{3g}$, and the quality inspection of the dataset displayed the AVHRR $NDVI_{3g}$ show good quality (Pinzon and Tucker, 2014; Wang et al., 2014; Zeng et al., 2013). The linear trend analysis over an overall long-term series may obscure significant trend changes appearing within shorter duration (de Jong et al., 2012). The comparing analysis between results of multi-periods, changes in vegetation NDVI over the most recent several years and dynamics of NDVI trend yet have not been well researched in the arid area of northwestern China.

The Xinjiang province of northwest China is deep in the interior of Eurasia far from the ocean. It is the main part of China's arid regions and represents typical arid regions of Eurasia. Its complex topography, arid continental climate, desert soil and vegetation act together to form diverse biomes. In recent decades, the effect of climate change has become evident (Wang et al., 2013; Wu et al., 2010; Zhao et al., 2011b), especially in the terrestrial ecosystem of Xinjiang (Mohammat et al., 2013; Piao et al., 2003; Ren et al., 2007; Wang et al., 2011; Zhao et al., 2011a,b). A number of studies have also indicated that NDVI data showed greening of Xinjiang during recent decades, with increased precipitation as the main driving factor (Mohammat et al., 2013; Piao et al., 2011; Zhao et al., 2011b). However, other researchers state that the simple linear trend could not accurately show temporal patterns of changes in vegetation growth (Beck et al., 2011; de Jong et al., 2012; Piao et al., 2011; Wessels et al., 2007, 2012). As the studies mentioned above were conducted on larger spatial scales than Xinjiang, their conclusions may not be applicable to the Xinjiang region. In most cases the time period of these studies spanned the duration of the study, therefore the continuity and robustness of changing processes and trends are inadequate. Therefore, it is necessary to better understand the NDVI changes and their climate controls during longer time scales in different seasons with the newest dataset. The objectives of this study were to analyze vegetation growth dynamics relative to climatic and human activity at regional, biome and pixel scales during growing season in Xinjiang. To analyze temporal patterns and dynamic processes, we estimated NDVI trends and correlations between NDVI and climatic factors over fourteen time periods: 1982–1999, 1982–2000, 1982–2001, . . ., 1982–2011 and 1982–2012.

## Materials and methods

### *Study area*

The Xinjiang Uygur Autonomous Region covers a total area of 1665,000 $km^2$ and spans 34.25 °N–49.17 °N in latitude and 73.33 °E–96.42 °E in longitude (Fig. 1). It is a typical mountain–basin system including three east–west mountain ranges and two major basins between these three mountain ranges. These mountains consist of the Altai Mountains, Tianshan Mountains, and the Kunlun Mountains from north to south, and the basins consist of the northern Junggar basin and the southern Tarim basin.

This area has a typical inner-continental climate, featured by a wide range of temperatures, low precipitation, strong wind, and low humidity. The annual precipitation and annual average temperature in North Xinjiang ranges from 100 to 500 mm, and from 4 °C to 8 °C, respectively. In South Xinjiang, annual precipitation ranges from 20 to 100 mm, and average temperature from 10 °C to 13 °C, respectively. Vegetation type ranges from forest to meadow, steppe and desert in a vertical direction along mountains. This is especially evident in the Altai Mountains and Tianshan Mountains.

### *Data sources and processing*

The GIMMS $NDVI_{3g}$ dataset was derived from the NOAA/AVHRR dataset at a spatial resolution of $0.083° \times 0.083°$ over a 15-d interval from 1982 to 2012. The GIMMS $NDVI_{3g}$ dataset has been corrected