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Decreased vegetation growth in response to summer drought in Central Asia from 2000 to 2012

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A B S T R A C T

Climate change scenarios predict that Central Asia may experience an increase in the frequency and magnitude of temperature and precipitation extremes by the end of the 21st century, but the response regularity of different types of vegetation to climate extremes is uncertain. Based on remote-sensed vegetation index and in-situ meteorological data for the period of 2000–2012, we examined the diverse responses of vegetation to climate mean/extremes and differentiated climatic and anthropogenic influence on the vegetation in Central Asia. Our results showed that extensive vegetation degradation was related to summer water deficit as a result of the combined effect of decreased precipitation and increased potential evapotranspiration. Water was a primary climatic driver for vegetation changes regionally, and human-induced changes in vegetation confined mainly to local areas. Responses of vegetation to water stress varied in different vegetation types. Grasslands were most responsive to water deficit followed by forests and desert vegetation. Climate extremes caused significant vegetation changes, and different vegetation types had diverse responses to climate extremes. Grasslands represented a symmetric response to wet and dry periods. Desert vegetation was more responsive during wet years than in dry years. Forests responded more strongly to dry than to wet years due to a severe drought occurred in 2008. This study has important implications for predicting how vegetation ecosystems in drylands respond to climate mean/extremes under future scenarios of climate change.

1. Introduction

Concerns over biodiversity reduction and habitat degradation are rising as we strive to use remote sensing techniques to evaluate climatic and anthropogenic influence on vegetation changes (Gould, 2000). The Normalized Difference Vegetation Index (NDVI) represents the first useful tool with which to couple climate and vegetation at large temporal and spatial scales (Pettorelli et al., 2005). Many studies based on satellite-derived NDVI with medium to coarse spatial resolution have improved our understanding of the intra and inter-annual variations of vegetation activities on a regional to global scale (Fensholt et al., 2009). Drylands cover approximately 40% of the Earth's land surface (Chen et al., 1998), and may play critical roles in the global carbon budget (Keller and Goldstein, 1998). However, a quantitative assessment of changes in vegetation in these lands remains a challenge due to sparse vegetation, multiple species, and considerable bare ground (Tueller, 1987). Consequently, the relative contribution of vegetation in dryland ecosystems to the inter-annual global carbon cycle variability is highly uncertain (Poulter et al., 2014).

Central Asia comprises one of the largest dryland regions in the Northern Hemisphere (Cowan, 2007), which gains its global significance for carbon cycle research (Ahlström et al., 2015). Although there is an increasing interest in studying the responses of vegetation ecosystems to global climate change (Cao and Woodward, 1998), many unknowns remain regarding the projections of the responses of the Central Asia drylands to regional environmental change (Gessner et al., 2013; Lioubimtseva et al., 2005; Lioubimtseva and Cole, 2006). In the past 20 years, the Central Asia drylands attracted less than 16% of the papers that focused on vegetation changes and its relationship with climate variables in Web of Science and Google Scholar (Zhang et al., 2016). Moreover, limited efforts have been made to study the diverse responses of vegetation to climate change (de Beurs and Henebry,

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2004; Kariyeva et al., 2012; Mohammat et al., 2013) and distinguish between the effects of climate change and human activities on vegetation (de Beurs et al., 2009; de Beurs et al., 2015; Wright et al., 2012; Zhou et al., 2015).

Vegetation ecosystems in Central Asia are seasonally or episodically under water stress and could be particularly vulnerable to water deficit (Liu and Piao, 2013). Environmental processes and ecosystem functions, such as water and energy fluxes, erosion rates, fodder production and agricultural yields, are linked to vegetation (Indoitu et al., 2012). The sustainability of natural vegetation and croplands in Central Asia, however, is under the threat of the current and projected climate change (Sommer et al., 2013). Over recent decades, the overall regional trend in Central Asia showed a significant increase in temperature and a small decrease in precipitation (Lioubimtseva and Cole, 2006; Lioubimtseva and Henebry, 2009), but there was lots of uncertainty in precipitation estimates (Stocker et al., 2013). The Coupled Model Intercomparison Project Phase 5 (CMIP5) forecasted increased summer and winter temperature over Central Asia, and a majority of the CMIP3 models predicted decreased spring and summer precipitation during the 21st century (Christensen et al., 2013). These results suggested that droughts might intensify in Central Asia as a result of increased potential evapotranspiration and decreased precipitation (Sheffield and Wood, 2008), although there were great uncertainties over the simulated precipitation among climate models (Mannig et al., 2013). The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) indicated that Central Asia might experience an increase in the frequency and magnitude of warm daily temperature extremes and extreme precipitation events by the end of the 21st century (IPCC, 2012). Nonetheless, the degree to which climate extremes affect vegetation activities in Central Asia remains largely unknown (de Beurs et al., 2009; de Beurs et al., 2015; Mohammat et al., 2013), for the vulnerability of vegetation ecosystems to climate extremes may vary in different vegetation types (Vicente-Serrano et al., 2013; Wu and Chen, 2013). A climate extreme is defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (IPCC, 2012).

Despite the growing recognition of the vital importance of vegetation ecosystems in Central Asia for the global carbon cycle, large uncertainties exist regarding how different vegetation types respond to climate change and human disturbance (Lioubimtseva and Henebry, 2009). Based on remote sensing and in-situ meteorological data from 2000 to 2012, we focused on the diverse responses of vegetation growth to thermal and hydrological conditions, and the discrimination between climate and human-induced changes on the vegetation in Central Asia. We used NDVI as an indicator of vegetation growth as it was correlated highly with green-leaf density and vigor (Myneni et al., 1997). The Standardized Precipitation Evapotranspiration Index (SPEI) was used to show water balance in wet and dry periods (Vicente-Serrano et al., 2010). Our primary goal was to evaluate the impact of changes in climate mean/extremes on the vegetation in Central Asia and determine the relative contribution of climate change and human activities to vegetation changes. This study may be helpful for the agriculture water management and ecological protection in dryland regions under likely future scenarios of more climate extremes (Chen et al., 2013; Sommer et al., 2013).

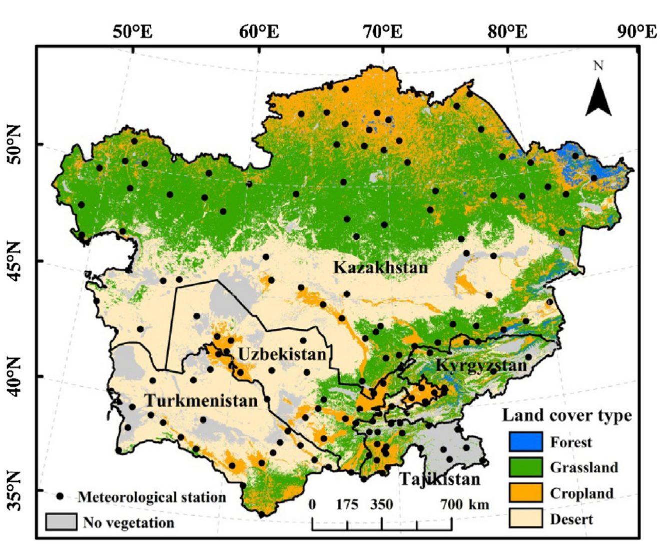

Fig. 1. Spatial distributions of meteorological stations and different land cover types in Central Asia. Non-vegetated areas in grey include bare areas, water bodies, and permanent snow and ice.

2. Materials and methods

2.1. Study area

Central Asia (46°29′–87°19′E, 35°07′–55°26′N) is in the inner center of Eurasia, which comprises Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan and covers an area of approximately 4×10^6 km^2 (Fig. 1). Elevation increases from the coast of the Caspian Sea in western Kazakhstan and Turkmenistan to the mountainous ranges of Altai, Tien Shan and Pamir in eastern Kazakhstan and Uzbekistan and across Kyrgyzstan and Tajikistan (de Beurs et al., 2015). Temperature and precipitation follow a gradient from the north to the south and from mountains to basins. The study area has a temperate continental climate characterized by hot-dry summer and cold-moist winter (Lioubimtseva et al., 2005). According to a long-term climate record over the period of 1981–2010, mean annual temperature (MAT) ranges between 2 °C in northern Kazakhstan and more than 18 °C in southern Turkmenistan and Uzbekistan with the exception of mountainous areas showing MAT below 0 °C (Mohammat et al., 2013). Mean annual precipitation (MAP) varies from approximately 400 mm in northern Kazakhstan to less than 100 mm in northern Turkmenistan and southern Uzbekistan with the exception of mountainous areas receiving MAP between 600 and 800 mm (Klein et al., 2012). Major land cover types in Central Asia include forests, grasslands, croplands and deserts, which account for 1.5%, 41.1%, 19.6% and 37.8 of the vegetated areas, respectively (Fig. 1). The deserts include sparse vegetation and closed to open shrublands. The growing season of vegetation in most of the study area lasts from April to October as winter temperature controls vegetation growth (Gessner et al., 2013). Natural forests are distributed mainly in the high mountains of Kazakhstan and Kyrgyzstan. Grasslands cover most of Kazakhstan and Kyrgyzstan, southeastern Turkmenistan and eastern Uzbekistan. Deserts dominate most of Uzbekistan, Turkmenistan, and southern Kazakhstan. Continental climate supports rain-fed agriculture in northern Kazakhstan, while irrigated agriculture is practiced mainly along Amu Darya and Syr Darya Rivers.

2.2. Datasets

The Normalized Difference Vegetation Index (NDVI) product measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) was used as a proxy for vegetation growth (Myneni et al., 1997). Tarnavsky et al. (2008) reported a good agreement between AVHRR, SPOT-VGT, and MODIS NDVI products, although some variability was dependent on land cover types. The 16-day composition TERRA MODIS NDVI product (MOD13A2) with a spatial resolution