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Short communication

Drought dynamics and impacts on vegetation in China from 1982 to 2011

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ABSTRACT

We investigated the drought dynamics and their impacts on vegetation change in China from 1982 to 2011 using the standard precipitation index (SPI) and the normalized difference vegetation index (NDVI) anomaly, which were calculated from meteorological and satellite-derived NDVI data, respectively. The trends in the change of SPI and vegetation were explored based on the non-parametric Mann–Kendall (MK) test and Sen's slope test, and the relationship between these trends was examined. The results were as follows: (1) For China as a whole, although the long term trend of drought-impacted areas changed little (−0.045% /10 a) over the past 30 years, Dry trends were identified in northeastern and southwestern China. (2) The annual vegetation growth at the national scale showed an increasing trend, with a rate of 0.008%/10 a from 1982 to 2011; cropland vegetation presented the largest increase in NDVI ($p < 0.05$). (3) Droughts that occurred during the growing season and pre-growing season both had large negative impacts on vegetation growth, and significant influences were found in northern China, especially in the northwestern area. Compared to the northern areas, the NDVI in southern China appeared to benefit from warming temperatures.

1. Introduction

Many parts of the world have suffered from serious droughts in recent years, which have greatly impacted socio–economic systems and the environment (IPCC, 2001). Major drought events have raised the question of whether droughts are becoming more frequent and more severe, as projected by climate change studies (Zhao and Running, 2010). Another concern is whether drought, which is one of the major disturbances to vegetation growth, may weaken the ability of vegetation to function as a carbon sink (Xu et al., 2011). For the improved understanding of the vulnerability of the terrestrial carbon cycle and the sustainable use of natural vegetation resources (Xu et al., 2012), it is of particular importance to understand and assess the consequences of drought on vegetation at different scales.

The impacts of drought on vegetation have been extensively studied on regional and global scales. For instance, a recent study indicated that droughts are counteracting the increase in global net primary productivity (NPP) caused by global warming (Zhao and Running, 2010). On a regional scale, the severe 2003 drought in Europe caused great impacts on a variety of land-cover types, and most ecosystems recovered to a normal state by early 2004 (Gobron et al., 2005). Rainforests in the Amazon region play an important role in the global carbon cycle, and extreme droughts in this region in 2010 seemed to cause a significant increase in tree mortality and carbon losses (Xu et al., 2011). Thus, serious droughts are causing adverse effects on terrestrial ecosystems.

Vegetation growth has significantly increased over the last three decades in China (He et al., 2007). This can be mainly attributed to national warming and ecological conservation projects, such as the Three-North Shelter Forest Program (TNSFP) (Duan et al., 2011), the Beijing–Tianjin Sand Source Control Program (Wu et al., 2013), the Grain for Green Project (Zhang et al., 2012a), and small-scale regional ecological engineering (Huang et al., 2012). During the 20th century, China experienced a series of drought events (Xiao et al., 2009), and the increasing drought stress associated with warming and reduced rainfall was found to contribute to the decrease in the growing season's normalized difference vegetation index (NDVI) in northern China after the 1990s (Peng et al., 2011). In 2010, southwest China suffered a severe and sustained spring drought, which reduced the regional annual gross primary productivity (GPP) and NPP by 65 and 45 Tg

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C/a, respectively, and both the annual GPP and NPP in 2010 were the lowest during the period of 2000–2010 (Zhang et al., 2012b). Obviously, drought has become one of the most important disturbances to vegetation growth in China. Furthermore, droughts lower the water levels of rivers, reservoirs, and lakes, which limits water availability for ecosystem and agricultural production and leads to ecological degradation and reduced food productivity (Piao et al., 2010; Zhang et al., 2012b; Yu et al., 2013).

Although previous studies have provided much information on the relationship between drought and vegetation growth, many efforts mainly focused on the impacts of single drought events were concentrated on a regional scale. In addition, the responses of vegetation to drought during the growing and non-growing seasons are still not clear. Our main goal is to explore the drought dynamics in China and their impacts on vegetation from 1982 to 2011. Firstly, the spatial-temporal characteristics of drought are analyzed based on drought area and the trend of drought index. Secondly, the relationships between drought variations and vegetation growth are used to explore how a drought will impact vegetation growth. Our results will provide scientific information for drought prediction and forest management in China.

2. Datasets and methods

2.1. Datasets

The monthly precipitation (mm) data from 1982–2011 at 752 meteorological stations in China were collected from the China Meteorological Data Sharing Service. To avoid the possible effects of artificial shifts in the data caused by the relocations of measurement sites and equipment observation error, the meteorological data were checked for homogeneity with reference to a previously used method (Ren et al., 2008). Stations with less than 30 years of data were also rejected (Yu et al., 2013). A total of 603 stations were selected for this study according to the data availability criteria in China.

The NDVI is usually used for measuring vegetation growth. In this study, we used the National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR) NDVI dataset, which was produced by Global Inventory Modeling and Mapping Studies (GIMMS) (Tucker et al., 2005). The dataset spans the period from 1982–2011 and has a 0.083° spatial resolution and a 15-day interval. The GIMMS NDVI has been corrected to remove non-vegetation effects, including sensor degradation, inter-satellite differences, and volcanic aerosol effects (Zhou et al., 2001). The monthly NDVI was derived from two images from each month using the maximum value composite (MVC) method (Holben 1986). Our analysis was mainly confined to the growing season, which was defined as April–October and was constantly applied across the whole country (Zhou et al., 2001). Based on vegetation maps with a scale of 1:1,000,000 from the Atlas of China's Vegetation, the vegetation was classified into four types: forest, shrub, grassland, and cropland (Zhao et al., 2011).

2.2. Methods

The standardized precipitation index (SPI) (McKee et al., 1993) was selected to assess drought variations in China. The SPI is a widely used drought index, which is derived from precipitation data alone to determine a water deficit and surplus and can be calculated for short or long time scales (Paulo et al., 2003). The multi-time scale SPI allowed us to analyze the relationship between drought and vegetation at various time scales. The criteria for drought classification was referenced in McKee's study (McKee et al., 1993).

The non-parametric Mann–Kendall (MK) test was applied for the SPI trend tests. The MK test is a rank-based procedure, which is suitable for detecting non-linear trends (Kendall, 1975). It is frequently used for detecting trends in hydrological and meteorological time series (Hamed, 2008). Confidence probabilities of 95% ($p < 0.05$) was considered to be significant.

The Sen slope estimator was applied to obtain the trend in vegetation growth from 1982 to 2011 (Sen, 1968). This estimation did not require the data to be distributed normally and has been widely applied in vegetation growth studies (Fernandes and Leblanc, 2005).

The bilinear interpolation method was used to extract the NDVI values for the station data based on grid vegetation data with a spatial resolution of 0.083° (Vu et al., 2012). The monthly NDVI sequence data were generated at station in China and spans the period from 1982 to 2011. Finally, the Pearson correlation analysis was used to explore the relationship between the NDVI anomaly and drought (SPI less than −1.0) (Madden and Williams, 1978; Trenberth and Shea, 2005). The data processing and calculations were conducted with the Interactive Data Language (IDL) program and the ArcGIS9.3 software.

3. Results

3.1. Temporal and spatial characteristics of drought

The inter-annual variation in the percentage of drought-impacted areas (SPI of less than −1.0) in China from 1982–2011 are shown in Fig. 1(a). Relatively large dry areas occurred in the middle of the 1980s, the late 1990s, the early 2000s, and the most recent 1–2 years. The largest drought-impacted area percentage (27.69%) occurred in 1986 and represented approximately one-quarter of China's total territory. This value was followed by 26.07% in 2001, 25.1% in 1997, and 22.51% in 2011. Despite the large inter-annual variability, the long-term trends in the drought-impacted areas in China as a whole decreased slightly (by 0.045%/10 a) over the past 30 years.

The annual trends of SPI for each station in China were also investigated based on the MK test. The positive and negative results indicated trends towards wetter and drier conditions, respectively (Fig. 1(b)). The SPI trends showed great spatial variability. Dry trends were identified in northeastern and southwestern China, but significant wet trends were detected in western China.

3.2. Trends in vegetation growth over the past 3 decades

Inter-annual variations in the NDVI for different vegetation types are shown in Fig. 2(a). The NDVI increased remarkably for all vegetation types ($p < 0.05$). The largest increases appeared in croplands and shrubs, with values of 0.015/10 a and 0.01/10 a respectively, followed by 0.007/10 a for grasslands and 0.006/10 a for forests. At the national scale, the average NVDI for all annual vegetation in China demonstrated a significant increasing trend, with a rate of 0.007/10 a. The annual NDVI trend patterns were dramatically spatially heterogeneous (Fig. 2(b)). Significant increasing trends in vegetation growth occurred in central, eastern, and southern China, and significant decreasing trends occurred in the northwestern and northeastern areas and some parts of the southwestern area.