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Monitoring the vegetation activity in China using vegetation health indices

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ABSTRACT

Terrestrial vegetation plays pivotal roles on land-atmosphere interactions, and even global climate change. However, limited attempts have been taken to elucidate the responses of vegetation activity to weather-related drivers (e.g., droughts, floods). This is especially in China with vast area and changeable meteorological conditions. In this paper, the performance of two satellite-based indices, namely vegetation condition index (VCI) and vegetation health index (VHI) were analyzed to detect the vegetation responses to weather-related variations. The dynamics of vegetation activity in China were further examined for the period 1982–2013. We found widely-distributed vegetation stresses in the entire country for a long period (about an average of two months per year) from the VCI and the VHI. In addition, both the two indices indicated increasing vegetation activities over most parts of China during 1982–2013. However, there is no consensus between the two indices at spatial pattern and regional totals. This discrepancy can be due to the negative-correlation assumption of the VHI between the VCI and bright temperature. However, we found that the relationship between the VCI and temperature could be changeable in different regions, especially in China with complex topography, diverse climate conditions and different vegetation types. The findings of this paper highlight the necessity to account for dominant controls on vegetation growth when using the VCI and the VHI to analyze vegetation activity.

1. Introduction

Terrestrial vegetation poses crucial effects on energy budget, water cycle and biogeochemical cycle in ecosystems through vegetation activities (refer to the ability of vegetation interacting with surrounding environments, e.g., photosynthesis, respiration and transpiration) (Piao et al., 2014), and therefore affects earth's climate system (Bala et al., 2007; Peng et al., 2014). In contrast, vegetation activities are sensitive to natural factors (e.g., climate change, atmospheric CO_2 increase and nitrogen deposition) and human disturbances (e.g., afforestation and urban expansion). For instance, vegetation activity was found to be increased through CO_2 concentration increase (Piao et al., 2012), afforestation (Peng et al., 2014) and climate-adaptation (Challinor et al., 2014). However, climatic droughts and urban land development reduced vegetation activity as well (Ji and Peters, 2003; Pei et al., 2013a, 2013b). It is of great concern to monitor the vegetation activity in the scientific community worldwide during past decades.

Satellite data have an advantage in observing a large area to monitor the vegetation activity, in comparison with traditional field-based studies. In past decades, many vegetation indices (VIs) were established to retrieve canopy characteristics to minimize the effect of external factors such as soil background reflectance. Most of the VIs were developed by combining two spectral bands: red and near-infrared band. As a surrogate of vegetation coverage or productivity, the normalized difference vegetation index (NDVI) is one of the widely used VIs to examine vegetation activity at regional to global scales (Fang et al., 2004; Piao et al., 2014). For instances, Peng et al. (2011) evaluated the trends of vegetation growth in China from 1982 to 2010 by using NDVI. Piao et al. (2011) analyzed the relationships between temperature variability and vegetation activity by using the NDVI as a surrogate. de Jong et al. (2011) examined the monotonic greening and browning trends by using global NDVI time-series. Due to weaker short-term signals (i.e., weather-related signals) in a NDVI measurement than long-term ecological one (e.g., soil, topography), the NDVI is difficult to identify vegetation stress to weather anomaly (e.g., droughts) from that of cumulative effects (Kogan, 1995; Seiler et al., 1998). To solve such problems, the vegetation condition index (VCI) was developed to separate the weather-related signals from the ecological one in the NDVI (Kogan and Sullivan, 1993; Seiler et al., 1998). To differentiate the effects of excessive wetness from that of droughts, vegetation health

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index (VHI) was further proposed to monitor meteorological droughts by combining the VCI and the hotness of vegetation canopy (Kogan, 1995; Kogan et al., 2011). The VCI and VHI were widely employed and proved effective in evaluating vegetation health and crop production (Kogan 1990; Orlovsky et al., 2011).

As one of vast countries with diverse natural environment, China showed complex trends of vegetation activity due to land-use change and climate fluctuation. For instances, Peng et al. (2011) pointed that the vegetation activity in China increased in the growing season from 1982 to 2010 at the national scale. Lü et al. (2015) found a great spatial heterogeneity of both vegetation greening and browning during 2000–2010. It is still uncertain about trends of vegetation activity in China in past decades, especially vegetation response to changeable conditions (e.g., weather variations). This paper aims to monitor the vegetation activity in China during past decades using two vegetation health indices, the VCI and the VHI over the period 1982–2013. When examining variations of vegetation activity, vegetation index in growing season is often employed as a surrogate of vegetation growth in a whole year. Growing season refers to the period of time in a given year available for plant growth and biomass accumulation. The growing season change is frequently explored by using phenology, satellite data, and surface air temperatures (Linderholm, 2006). The phenological growing season and satellite-based growing season, which are derived from phenology and the NDVI, have significant impacts on competition and fitness of plants, and thus may have profound ecological consequences (Walther et al., 2002). However, for many applications such as monitoring droughts or insect activity, a plant-independent and more general definition are of more interest (e.g., climatological growing season) (Menzel et al., 2003). Chen and Pan (2002) found that mean temperature and growing degree days above 5 degree Celsius (°C) are the most important controls on the beginning and end dates of the growing season in the temperate region of eastern China. Liu et al. (2010) found that the length of growing season is highly correlated with mean temperatures from March to November except in southeast China at the base temperature of 5 °C. A daily temperature of 5 °C for more than 5 days is often used to define growing season (Linderholm, 2006; Song et al., 2010). In this paper, weekly mean temperature of 5 °C was employed to match the growing season length and the composited period of satellite-based images when using the VCI and the VHI (Kogan, 1997). Namely, the growing season in China was spatially identified as when mean temperature in the first (or last) week is above (or below) 5 °C. The VCI and the VHI in the growing season were employed to assess the vegetation activity dynamics in China from 1982 to 2013. The performances of the VCI and the VHI were analyzed and compared from aspects of spatial pattern and regional totals. The trends of vegetation activity dynamics were examined over China from 1982 to 2013 by using least squares fit method.

2. Study area and data processing

2.1. Study area

The study area is located in China, the eastern part of Eurasia continent (Fig. 1). The country spans across multiple climate regimes, including monsoon climate zone across tropical, subtropical and temperate area, temperate continental climate zone and plateau climate zone. The annual average temperature in China varies from above 20 °C in southern China to below −20 °C in Qinghai-Tibetan Plateau. The annual average precipitation ranges from greater than 2400 mm in southern China to less than 100 mm in northwestern China. In addition, the topography in this country is extremely rugged, ranging from −154 m in the Ayding Lake to 8848 m in the Mount Everest in the Qinghai-Tibetan Plateau. Particularly, average elevation in the Qinghai-Tibetan Plateau reaches 4000 m. Because of diverse topography and climate condition, natural vegetation in China contains most of the vegetation types in northern hemisphere from desert and steppe in the arid northwest to the forests in the wet southeast China, and mountain vegetation in the Qinghai-Tibetan Plateau. Since 1978, China experienced an unprecedented urbanization under the economic reform policy. The urbanization brought about dramatic changes in land use and land cover, such as urban land development in Yangtze River delta and Pearl River Delta. In addition, recent climate change also showed important impacts on the vegetation activity in China (Solomon et al., 2007).

2.2. Meteorological data

The gridded meteorological dataset, which covers 32-year period (1982–2013), includes daily mean temperature and daily total precipitation. The dataset was retrieved from the Chinese National Meteorological Information Center/China Meteorological Administration (NMIC/CMA). Specifically, the meteorological datasets were originated from records of 2472 meteorological stations in China. The records were then interpolated to a grid at a resolution of 0.5 × 0.5°. Considering general spatial dependence of meteorological conditions on topography and the complex terrain in China, interpolation was performed by combining thin plate smoothing splines and GTOPO30 elevation data (Hutchinson, 1998; Hong et al., 2005). A cross-validation technique was employed to control the quality of the gridded data. To fit the calculation of the data with other data, the gridded meteorological datasets were reprojected and resampled to a resolution of 4-km, although the data processing did not increase the effective resolution of the datasets.

2.3. Remote sensing data

The vegetation health datasets during 1982–2013, including vegetation condition index (VCI) and vegetation health index (VHI) data at a resolution of 4-km, were derived from the Center for Satellite Applications and Research (STAR) from the National Oceanic and Atmospheric Administration (NOAA). These datasets were produced from the Global Area Coverage (GAC) dataset observed by the Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA-7, 9, 11, 14, 16 and 18 with afternoon orbits. Daily records from the satellite observation were aggregated to a seven-day period by using the AVHRR GAC Level 1B dataset (Kogan et al., 2011). The average values of the VCI and the VHI in the growing season were then calculated as a surrogate of annual vegetation health when analyzing the vegetation activities. Because of the morning satellite orbits from September 1994 to February 1995, both the VCI and VHI data were not available. For ensuring the continuity, the missing data were substituted using average values of the VCI and the VHI of the corresponding records before and after the year 1994.

Monthly NDVI images at 1 km resolution in 2013 were obtained from MODIS product (MOD13) to mask nonvegetated area in China. In addition, land cover type data at annual scale were also obtained from MODIS L3 product (MCD12). Both the MOD13 and MCD12 data were downloaded from the Earth Observing System Data Gateway at the Land Processes Distributed Archive Center (http://lpdaac.usgs.gov/). All the images were then aggregated to a resolution of 4 km × 4 km. In addition, the method of maximum value composite (MVC) was conducted to obtain annual NDVI. Furthermore, the pixels with average NDVI less than 0.1 were marked as non-vegetated area.

2.4. Crop production records from statistical yearbook

The crop production data, including yields of rice, wheat, maize, soybean and millet, were collected at provincial level over the period of 1982–2013 from China Statistical Yearbook. The China Statistical Yearbook was compiled by State Statistical Bureau, People's Republic of China. A total of 30 provinces were selected excluding Hainan Province and Chongqin City because of some missing records in the two regions.