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Monitoring the impact of aerosol contamination on the drought-induced decline of gross primary productivity

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ABSTRACT

Southwestern China experienced a period of severe drought from September 2009 to May 2010. It led to widespread decline in the enhanced vegetation index (EVI) and gross primary productivity (GPP) in the springtime of 2010 (March to May). However, this study observed a spatial inconsistency between drought-impacted vegetation decline and the precipitation deficit. Significant aerosol loads that correspond to inconsistent areas were also observed during the drought period. After analyzing both MODIS GPP/NPP Collection 5 (C5) and the newer Collection 5.5 (C55) data, a large area observed to be experiencing GPP decline in the eastern part of the study area proved to be unreliable. Based on EVI data, after atmospherically contaminated data were screened from analysis, approximately 20% of the study area exhibited browning whereas 33% displayed no change or greening and the remaining area (approximately 47%) lacked sufficient data to document changing conditions. Correlation analysis showed that fire occurrences, aerosol optical depth, and precipitation anomalies during the two drought periods (from September to February and from March to May) all contributed to a decrease in GPP. C55 data remains vulnerable to aerosol contamination due to a much higher correlation coefficient with aerosol optical depth compared to C5 data. In the future, users of remotely sensed data should be cautious of and take into account impacts related to atmospheric contamination, even during drought periods.

Introduction

Forest ecosystems, which contain 861 ± 66 Pg carbon, play a critical role in the global carbon cycle (Pan et al., 2011). However, this carbon stock is vulnerable to extreme climate events, such as drought and anthropological activity (Malhi et al., 2008; Saleska et al., 2003; van der Molen et al., 2011). Driven by global warming, drought events are predicted to increase in intensity and frequency over time (Dai, 2013; Malhi et al., 2008). Droughts can cause a decrease in photosynthetic activity (Cornic and Massacci, 2004; Reddy et al., 2004), an increase in fire disturbances (Aragão et al., 2007; Xiao and Zhuang, 2007), insect outbreaks (Dobbertin et al., 2007; Kurz et al., 2008), tree mortality (Allen et al., 2010; Mueller et al., 2005; Carnicer et al., 2011; Peng et al., 2011), and a reduction in plant productivity (Zhao and Running, 2010) and carbon uptake (Ma et al., 2012; Schwalm et al., 2012), all of which strongly impact regional hydrology and surface energy budgets (Bonan, 2008).

There are a variety of methods available to monitor and assess drought impacts on vegetation (Zhang et al., 2013). For large-scale and persistent droughts, remote sensing plays an important role. Using the latest sensors, we can obtain information related to vegetation response, temperature anomalies, fire disturbances, etc. (Aragão et al., 2007; Saleska et al., 2007; Toomey et al., 2011; Xu et al., 2011) In addition, researchers have developed a variety of satellite-based drought indices to assess the spatial extent and severity of drought (Kogan, 1995; Peters et al., 2002). However, we are also facing a number of problems and challenges when using such types of data, primarily related to data quality and model accuracy (Zhang et al., 2013).

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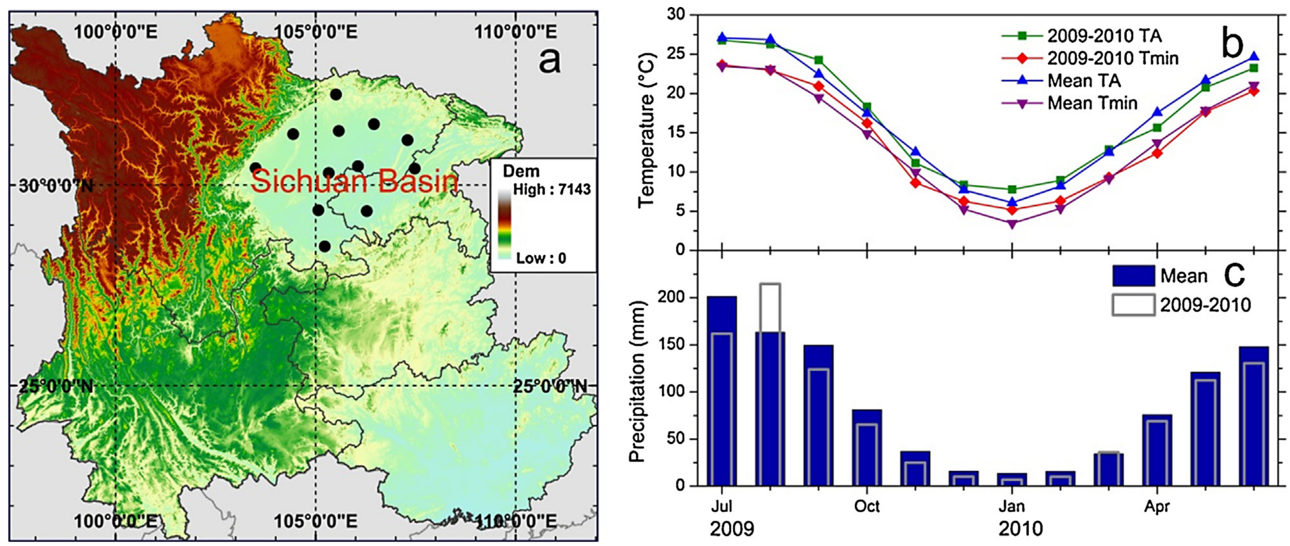

Fig. 1. (a) The digital elevation model (DEM) of the study area. The Shuttle Radar Topography Mission (SRTM) DEM with a spatial resolution of 90 m × 90 m was used in this study. DEM data can be obtained from the Global Change Master Directory Discover Earth science data and services [http://gcmd.nasa.gov/records/GCMD_CGIAR_SRTM_90.html]. Black dots denote weather station locations in Sichuan Basin. (b) Temperatures from these weather stations are provided in (a). T_A and T_{min} refer to the average and minimum air temperature per day, respectively. Mean values refer to means from 1951 to 2008. (c) Precipitation data from weather stations located within Sichuan Basin.

Southwestern China experienced a severe drought in 2009 and 2010 (Qiu, 2010; Stone, 2010). This persistent drought began as early as September 2009 in certain areas and reached its peak from October 2009 to February 2010 (Yang et al., 2012). Because the affected area is a major grain-producing region that includes a large population and complex land cover, this severe drought event not only significantly affected the daily lives of millions of people but also impacted the structure, function, and services of terrestrial ecosystems (Qiu, 2010). Zhang et al. (2012) recently reported on a severe decline in ecosystem productivity in southwestern China in the springtime of 2010. Nearly 63% of the region exhibited a decline in vegetation productivity (e.g., a reduction of 4% and 5% in regional annual GPP and NPP in 2010, respectively). However, their study did not exclude aerosol- or cloud-contaminated pixels and consequently incorporated invalid data into their findings. Recent research suggests that aerosol- and cloud-contaminated data may cause significant uncertainties, leading to controversial results in estimating GPP and annual NPP from satellite data (Samanta et al., 2011; Zhou et al., 2014). Cloud, haze, and anthropogenic-generated aerosol are a persistent problem in southwestern China, even during drought periods. This is especially true in Sichuan Basin, located in the northeastern region of Sichuan Province (see Fig. 1), due to its particular location and level of anthropogenic pollution (Li et al., 2003; Qian and Giorgi, 2000). Climatological aerosols significantly affect EVI quality (Vermote and Kotchenova, 2008). This will result in biased GPP and annual NPP estimates if such contaminated data are not excluded. In addition, interference from aerosols can cause inconsistencies between satellite-based GPP and EVI and the spatial extent and peaks of drought reported by field observations (Li et al., 2010; Yang et al., 2012). This study concluded that this in fact took place in the eastern part of the study area.

To reconcile these inconsistencies, this study examined the quality of data used in the recent study by Zhang et al. (2012). The main objectives of this study aimed to address the following questions: (1) Was the MODIS GPP product affected by atmospheric contamination during the 2010 springtime drought period? (2) Why were unscreened MODIS data ultimately unreliable? (3) What was the spatial pattern of the 2010 drought? (4) Why do discrepancies still exist between GPP C5 and C55 data even after screening of contaminated data?

Data

Satellite gross primary production data sets

Both Collection 5 (C5) and Collection 5.5 (C55) gross primary production (GPP) products from the MODIS instrument on the Terra satellite were used in this study. Note that the NASA term "collection" has the same meaning as "version". The 8-day composite MODIS GPP product (MOD17A2) uses a light use efficiency model that operates with both satellite and meteorological data (Running et al, 2000). The main difference between C5 and C55 is that the latter uses temporal filling of the unreliable fraction of absorbed photosynthetically active radiation (FPAR) (Zhao et al., 2005). These two data sets were obtained from the NASA LAADS website [http://ladsweb.nascom.nasa.gov/data/] for 2000–2010.

Satellite vegetation data sets

Enhanced vegetation index (EVI) C5 data from the EOS Terra satellite were used in this study. EVI is a satellite-derived index developed by Huete and Liu (1994) to monitor vegetation greenness. It demonstrated a good correlation to plant productivity (Huete et al., 2006). MOD13A2 data, retrieved from the Terra satellite, were obtained from the NASA LAADS website [http://ladsweb.nascom.nasa.gov/data/] for 2000–2010.

Satellite precipitation data sets

Monthly precipitation data from the Tropical Rainfall Measuring Mission (TRMM) 3B43-Version 7 were used in this study. The TRMM 3B43-V7 data set combines basic TRMM data with the infrared-based Geostationary Operational Environmental Satellite Precipitation Index (GOES-PI) along with a global gauge data network (Huffman and Bolvin, 2013). This data set was acquired from the NASA GES DISC website [http://disc.sci.gsfc.nasa.gov/precipitation/documentation/TRMM_README/TRMM_3B43_readme.shtml].