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Original Articles

sc_PDSI is more sensitive to precipitation than to reference evapotranspiration in China during the time period 1951–2015

Yajie Zhang[a], Gaopeng Li[b], Jing Ge[b], Yao Li[a], Zhisheng Yu[a], Haishan Niu[a,*]

[a] *College of Resources and Environment, University of Chinese Academy of Sciences, No. 19A Yuquan Road, Beijing, China*
[b] *Shanghai Institutes for Biological Sciences, Chinese Academy of Sciences, No. 320 Yueyang Road, Shanghai, China*

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ABSTRACT

The self-calibrating Palmer Drought Severity Index (sc_PDSI) is developed within the frame of the PDSI model, but is considered to be more appropriate for global drought monitoring. The sc_PDSI can automatically calibrate itself at any location using dynamically computed values and can calculate evapotranspiration using the FAO-56 Penman–Monteith (P–M) equation. However, the correlation of the sc_PDSI(P–M) with some factors that drive drought, such as precipitation (P) and the reference evapotranspiration (ET_0), is still unclear in China. With the aim of solving this issue, we analyzed the correlation of the detrended sc_PDSI(P–M) with the detrended P and ET_0 on different timescales (one, three, six and 12 months) in China for the period 1951–2015. The results show that both the P and ET_0 are highly correlated with the sc_PDSI(P–M) on a 12-month timescale. On this timescale, the sc_PDSI(P–M) is more sensitive to P than to ET_0 on the national scale, except for northeastern China. Thus the sc_PDSI(P–M) may effectively fit the long-term variations in these drivers of drought, especially P. These results provide guidance on the use of the sc_PDSI(P–M) to detect the impacts of climate change on drought severity under the climatic conditions found in China.

1. Introduction

Extreme climate and weather events cause significant disruption to human societies and anthropogenic climate change is expected to increase the occurrence, magnitude and/or impact of these events in the future (Coumou and Rahmstorf, 2012). Drought is an extreme phenomenon caused by low and irregular precipitation and high rates of evapotranspiration over an extended period of time. Droughts have long-term impacts on crucial water resources, agricultural production and socioeconomic activities (Hanson, 1991; Ding et al, 2011). China is affected by frequent and severe droughts and historical records show that large-scale droughts have occurred many times, although the situation has deteriorated since the 1990s (Zou et al., 2005; Shen et al., 2007; Dai, 2011a,b; Miyan, 2015). Nationwide droughts now occur almost every year and cause severe famine, water shortages, desertification and dust storms in many areas (Zhang, 2003; Dai et al., 2004; Zou et al., 2005; Zhai et al., 2010). Monitoring the variations and trends in droughts could provide important information for use as a reference in improving the management of agricultural production, water resources and in the prediction of disasters (Zhao et al., 2015; Zhang et al., 2017).

Droughts are a result of the integrated effects of multiple factors, such as precipitation, evapotranspiration and total water storage (Yu and Gao, 1991). In meteorology, precipitation (P) is defined as any product of the condensation of atmospheric water vapor that falls under gravity, whereas evapotranspiration is the sum of evaporation and plant transpiration from the Earth's land and ocean surfaces to the atmosphere. In agricultural applications, the actual evapotranspiration of crops can be derived from the reference evapotranspiration (ET_0), which indicates the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop (grass) that completely shades the ground, is of uniform height and has an adequate water status in the soil profile using the correct crop and water stress coefficients (Kite and Droogers, 2000; Rana and Katerji, 2000). Several equations are available for estimating ET_0 (e.g., Penman, 1948; Blaney and Criddle, 1950; Hargreaves and Samani, 1985). Among these, the FAO-56 Penman–Monteith (P–M) equation, which incorporates both energy balance and aerodynamic theory, is considered to be the most appropriate model to predict ET_0 and is recommended by the Food and Agriculture Organization of the United Nations as the standard for computing ET_0 from full climate records (Allen et al., 1998). As major components of the water cycle, P and ET_0 are always considered as factors that indicate the degree and determine the duration of drought (Heim, 2002).

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[*] Corresponding author.
E-mail address: niuhs@ucas.ac.cn (H. Niu).

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Fig. 1. Topographic and geographical zones of China (modified from Zhang et al. (2018)).

Numerous drought indices have been developed to quantify complicated drought processes and to manifest the actual hydrological conditions in a single number (Wilhite and Glantz, 1985; Heim, 2002). Drought indices can be classified as precipitation indices, water budget indices, soil moisture indices, hydrological indices and aridity indices, all of which indicate the moisture conditions and the deficiency or surplus of water for a given area from different points of view (Szép et al., 2005). One of the most commonly used indices is the Palmer Drought Severity Index (PDSI), which uses precipitation, temperature and the local available water content to assess the precipitation deficit/surplus with respect to a value that is climatologically appropriate for the existing conditions in a given region (Palmer, 1965). In the PDSI, the water balance is calculated using a two-layer bucket-type model in which the soil fills with precipitation and empties through actual evapotranspiration and runoff on a monthly timescale (Hobbins et al., 2008). The range of values of the PDSI is between −4 and +4. Negative (positive) PDSI values indicate dry (wet) periods, whereas those near zero presume a near-average state (Palmer, 1965). The PDSI provides a comprehensive method with which to assess the impact of climate change on drought on a monthly basis because it requires specific climate variables as inputs and is intended to be of reasonably comparable local significance in both space and time (Heim, 2002; Dai et al., 2004; Sheffield et al., 2012; Vicente-Serrano et al., 2012; van der Schrier et al., 2013; Zoljoodi and Didevarasl, 2013). However, as a result of the application of weighting and duration factors derived from empirical calibrations against a limited amount of data observed over the US Great Plains, the PDSI has proved to be unsuitable for applications in different climatological regions (Palmer, 1965; Liu et al, 2004). To solve this drawback, the self-calibrating PDSI (sc_PDSI) model, which automatically calibrates itself at any location using dynamically computed values, was developed within the frame of the PDSI model and is considered to be more appropriate for global drought monitoring (Wells et al., 2004; Dai, 2011a,b; van der Schrier et al., 2011, 2013). In the traditional formulation of the PDSI, evaporative demand is derived from an approach that can be traced back to Thornthwaite (1948) and is solely a function of air temperature. However, the evapotranspiration calculated using the FAO-56 Penman–Monteith equation, which incorporates both the energy balance and aerodynamic theory, is now considered to be more appropriate (Penman, 1948; Allen et al., 1998; van der Schrier et al., 2011; Sheffield et al., 2012; Trenberth et al., 2014). Many studies have been conducted in China to evaluate and apply different drought indices and the PDSI (P–M) and sc_PDSI(P–M) are considered to be the best indices of drought (Wei and Ma, 2003; Lu et al., 2015).

The standardized precipitation index and standardized precipitation evapotranspiration index are both sensitive to the factors driving drought (e.g., the standardized precipitation evapotranspiration index shows equal sensitivity to P and ET_0) (Guttman, 1998; Hayes et al., 1999, 2000; Vicente-Serrano et al., 2012, 2015). However, there have been insufficient studies focused on the correlation of the sc_PDSI(P–M) with variations in P and ET_0. Hu and Willson (2000) showed that the PDSI is equally affected by temperature and precipitation when both have similar magnitudes of anomalies. Vicente-Serrano et al. (2015) showed that the PDSI was not equally sensitive to P and ET_0 and the