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Does drought in China show a significant decreasing trend from 1961 to 2009?

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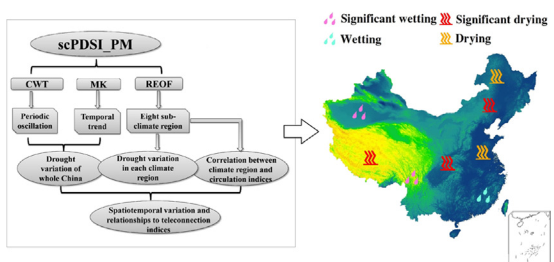
HIGHLIGHTS

- High-accuracy scPDSI_PM is utilized to explore drought variation of China.
- Significant wet trend is detected in China as a whole.
- A clear spatial structure with eight distinct sub-climate regions is achieved.
- Relationships between climate sub-region and circulation indices are investigated.

GRAPHICAL ABSTRACT



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ABSTRACT

In recent decades, the occurrence and severity of drought in China has had devastating impact on social and economic development. The increase in drought has been attributed to global warming. We used the high-accuracy self-calibrating Palmer Drought Severity Index (scPDSI) to investigate the variation in drought in China between 1961 and 2009 using the Mann-Kendall (MK), continuous wavelet transform (CWT) and the rotated empirical orthogonal function (REOF) methods. We also analyzed the relationship between the rotated principal component time series (RPCs) and 74 circulation indices. The results revealed that: 1) all of China experienced a significant wet trend at annual and seasonal scale; an abrupt change in the drought pattern occurred around 1970 with a 2–8-year significant period; 2) eight major sub-climate regions were identified: Northwest China, Northeast-Inner Mongolia Plateau, Greater Khingan Range area, Northern Tibetan Plateau, Southern Tibetan Plateau, Central China, Huang-Huai-Hai Plain and Southeast China. Of these regions, the Southern Tibetan Plateau experienced a significant wet trend, but the Northeast-Inner Mongolia Plateau and Northern Tibetan Plateau became significantly drier. Using either annual or seasonal scales, Northwest China became significantly wetter and Central China became more arid. In addition, the period of each sub-climate region shared a significant 2–8-year band; 3) the polar vortex exhibited dominant patterns that affected most areas of China. The Pacific Decadal Oscillation had a significant influence on drought evolution, especially for Northwest China and the Huang-Huai-Hai plain. Additionally, the El Niño-Southern Oscillation also affected drought evolution, and the Central China was impacted by the Indian Ocean Dipole.

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1. Introduction

Droughts are recognized as environmental events with devastating impacts on regional agriculture, economy, water resources and the environment, with far-reaching impacts in an increasingly globalized world (Piao et al., 2010). Drought as a meteorological disaster has occurred in many parts of the world, even in wet and humid regions (Mishra and Singh, 2010; Chen and Sun, 2015). The global percentage of dry areas has increased by about 1.74% per decade from 1950 to 2008, suggesting that drought has become a threat to human survival and can lead to other severe environmental issues (Dai, 2011). In this context, it is critical to analyze the variation drought cycles, as it can provide the epistemological foundation to understand drought events and prepare for the consequences.

Drought can be quantified and described both in absolute terms and via relative measures. However, several recent studies have presented apparent conflicting results on how drought is changing due to climate change (Trenberth et al., 2013). Sheffield et al. (2012) concluded that there was little change in global drought over the past 60 years, whereas Dai (2012) observed an increase in global drought over nearly the same period, which caused much confusion in understanding the actual characteristics of drought. Similar contradictory results have been reported regarding drought in China, with two main viewpoints on drought variation with regard to the global climate change. The first viewpoint is that there is no obvious change in drought across China. For instance, Zou et al. (2005) evaluated the variations of drought using the Palmer Drought Severity Index (PDSI) for the years 1951–2003, and discovered no long-term upward or downward trends in the percentage of drought areas. Similarly, Wang et al. (2015a) investigated drought change in China using the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) for 1961–2012 and found no evidence of an increase in drought severity throughout China. The second viewpoint, which is supported by a greater number of experts, is that drought in China exhibits an increasing trend. This viewpoint is reinforced by the fact that China has suffered from increasingly severe drought disasters in the latter half of the 20th century, and those events have caused massive economic and social losses (Zhai et al., 2010; Wang et al., 2011; Yu et al., 2014). For instance, Li et al. (2009) investigated moisture variability using PDSI across China and Mongolia (CM) during 1951–2005 and detected a significant decreasing trend in mean moisture availability. Wang et al. (2011) simulated soil moisture in China for 1950–2006 and discovered that China exhibited a general drying trend with an increasing risk of drought. Yu et al. (2014) examined various characteristics of drought across China based on the SPEI and determined that severe and extreme droughts had become increasingly serious since the late 1990s throughout China, and that the dry area had increased by 3.72% per decade. Chen and Sun (2015) also detected changes in drought characteristics in China using the SPEI and reported that since the late 1990s, droughts had become more frequent and severe across China, especially in some regions of northern China.

The reason for the different viewpoints is thought to lie in the use of different indices and/or the datasets used to determine the evapotranspiration (ET) component (Trenberth et al., 2013). Generally, different indices measuring droughts emphasize distinct factors, and these indices may consider different climatic factors, leading to inconsistent results. For example, the SPI is used to analyze drought characteristics but only considers the precipitation factor (Huang et al., 2010; Zhu et al., 2016). The SPEI takes into account precipitation, temperature, and ET and may produce a more realistic result than the SPI index. However, the SPEI index does not consider soil moisture and then is better suitable for analysis of meteorological drought (Yu et al., 2014; Chen and Sun, 2015). Some studies utilized the PDSI_Th to calculate evaporation by using the empirical Thornthwaite (Th) equation (Zou et al., 2005). The Th equation was formulated originally to describe the mean daily temperature and latitude, but not the potential evapotranspiration (PET) (Thornthwaite, 1948); therefore, this approach is not generally accepted (Chen et al., 2005). Other factors, such as temperature, high winds, sunlight, humidity and soil moisture also play a significant role in the occurrence of droughts (Mishra and Singh, 2010; Liu et al., 2013). Accordingly, a more comprehensive drought index would be more helpful.

Among the indices available for measuring drought change, the high-accuracy self-calibrating Palmer Drought Severity Index (scPDSI) obtained with the Penman-Monteith equation (scPDSI_PM) uses a more realistic estimate of PET and has improved spatial comparability by considering the factors of temperature, high winds, sunlight, humidity, and soil moisture (Dai, 2012). The scPDSI_PM may be applicable to global warming scenarios and allow for the discovery of new features associated with drought variation, however, few studies have used this index to analyze drought variation in China. Moreover, use of an improved index may reveal temporal characteristics, such as periodical features of drought in China. The influence of the various circulation systems on drought and the relationship between the circulation indices and drought in different sub-climate regions remain poorly understood.

The objectives of this study are the following: 1) to explore the spatiotemporal characteristics of drought in China based on the high-accuracy scPDSI_PM; 2) to analyze the mutation characteristics of drought and periodical features in each sub-climate region of China; and 3) to investigate the relationships between each sub-climate region and the circulation indices. The results of this study will contribute to our understanding of drought in China and provide important information for water planning and management.

2. Study area and data

2.1. Study area

The focus of this study is China, as the third largest country in the world with various climatic zones. Located in the east of Asia and on the west shore of the Pacific Ocean, China (Fig. 1) has many different types of topography, terrain that is higher in the west and lower in the east, and roughly a three ladder-like distribution (Yang et al., 2015). A temperate monsoon climate predominates in the northeast region and a temperate continental climate dominates the northwest region. A subtropical monsoon climate prevails in Southern China, except for the southernmost corner where a tropical monsoon climate is dominant. The Qinghai-Tibet Plateau is obviously dominated by the plateau alpine climate. Overall, the largest part of continental China is located within

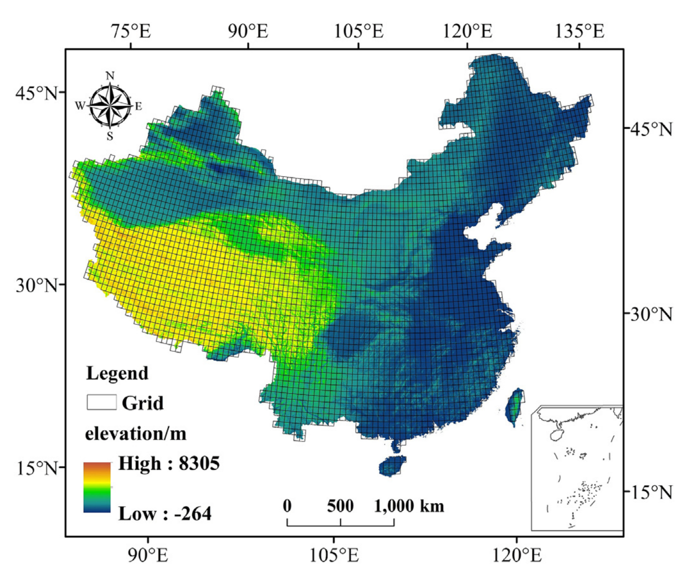

Fig. 1. Geographical position and territory of China.

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