Atmospheric Research 204 (2018) 1–11

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Spatial-temporal changes of maximum and minimum temperatures in the Wei River Basin, China: Changing patterns, causes and implications

Saiyan Liu[a], Shengzhi Huang[a,*], Yangyang Xie[a], Qiang Huang[a], Guoyong Leng[b], Beibei Hou[a], Ying Zhang[a], Xiu Wei[a]

[a] State Key Laboratory of Eco-hydraulics in Northwest Arid Region of China, Xi'an University of Technology, Xi'an 710048, China
[b] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

ARTICLE INFO

Keywords:
Annual maximum temperature
Annual minimum temperature
Cloud model
Cross wavelet analysis
Atmospheric circulation anomaly
Precipitation extremes

ABSTRACT

Due to the important role of temperature in the global climate system and energy cycles, it is important to investigate the spatial-temporal change patterns, causes and implications of annual maximum (Tmax) and minimum (Tmin) temperatures. In this study, the Cloud model were adopted to fully and accurately analyze the changing patterns of annual Tmax and Tmin from 1958 to 2008 by quantifying their mean, uniformity, and stability in the Wei River Basin (WRB), a typical arid and semi-arid region in China. Additionally, the cross wavelet analysis was applied to explore the correlations among annual Tmax and Tmin and the yearly sunspots number, Arctic Oscillation, Pacific Decadal Oscillation, and soil moisture with an aim to determine possible causes of annual Tmax and Tmin variations. Furthermore, temperature-related impacts on vegetation cover and precipitation extremes were also examined. Results indicated that: (1) the WRB is characterized by increasing trends in annual Tmax and Tmin, with a more evident increasing trend in annual Tmin, which has a higher dispersion degree and is less uniform and stable than annual Tmax; (2) the asymmetric variations of Tmax and Tmin can be generally explained by the stronger effects of solar activity (primarily), large-scale atmospheric circulation patterns, and soil moisture on annual Tmin than on annual Tmax; and (3) increasing annual Tmax and Tmin have exerted strong influences on local precipitation extremes, in terms of their duration, intensity, and frequency in the WRB. This study presents new analyses of Tmax and Tmin in the WRB, and the findings may help guide regional agricultural production and water resources management.

1. Introduction

According to the latest Intergovernmental Panel on Climate Change (IPCC) report, the global average temperature increased by approximately 0.72 °C during the period of 1951–2012, due to the combined effects of climate change and human-induced greenhouse gas emissions (IPCC, 2013). The rising temperature trends have been accompanied by the increasing maximum temperature (Tmax) and minimum temperature (Tmin) across the globe (Kruger and Sekele, 2013; Fonseca et al., 2015). Since temperature plays a crucial role in the global climate system and energy cycles, more frequent occurrences of Tmax and Tmin are likely to significantly impact hydrology, agriculture, ecosystems, and many aspects of human life, such as mortality, morbidity, health, and comfort (Trenberth, 2011; Wang et al., 2013; Huang et al., 2014a; Leng et al., 2015; Ngo and Horton, 2015; Liu et al., 2017). Furthermore, there is growing evidence that Tmax and Tmin may become more extreme and occur even more frequently in the future (Orlowsky and Seneviratne, 2012; Wang et al., 2013; Fonseca et al., 2015). Therefore, investigations of Tmax and Tmin have been strongly utilized to improve our understanding of climate change, the scientific prevention and mitigation of disasters, and water resources management.

To date, numerous studies focused on Tmax and Tmin have been performed globally and regionally. For example, on the global scale, Donat and Alexander (2012) concluded, based on daily global observations, that changes in daily Tmax and Tmin were the result of a combination of changes in their mean, variance and skewness. At the regional scale, an increasing trend in Tmax was mainly observed in the Gobi Desert of Mongolia, while a significantly increasing trend in Tmin has been confirmed across the entirety of Mongolia (Dashkhuu et al., 2014). In Australia, changes in Tmax and Tmin were identified, when statistically significant trends in Tmax showed marked regional and seasonal variations, but the increase in Tmin typically exceeded the increase in Tmax (Jakob and Walland, 2016). In Pakistan, Tmin showed clearly positive trends in the pre-monsoon season and on the annual

* Corresponding author at: State Key Laboratory Base of Eco-Hydraulic Engineering in Arid Area, Xi'an University of Technology, Xi'an 710048, China.
E-mail address: huangshengzhi@xaut.edu.cn (S. Huang).

https://doi.org/10.1016/j.atmosres.2018.01.006
Received 19 May 2017; Received in revised form 5 January 2018; Accepted 5 January 2018

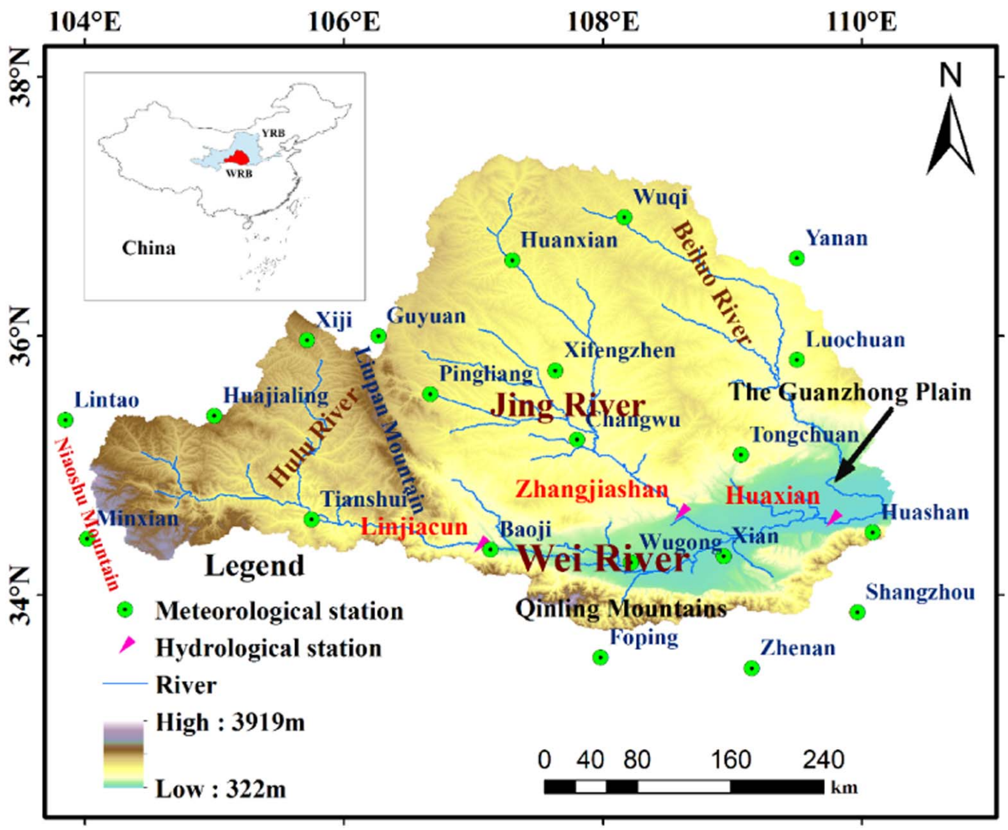

Fig. 1. Location of the WRB and relevant hydro-meteorological stations.

scale, while Tmax increased faster than Tmin in all seasons and on the annual scale in the northern areas of the country. Similar changes in Tmin and Tmax were also observed in China with pronounced magnitude and regional differences (Zhou and Ren, 2011; Yu and Li, 2015; Jiang et al., 2016; Zhang et al., 2017).

These previous studies provide key insights towards understanding the changing characteristics of Tmax and Tmin at various temporal and regional scales. However, most of the investigations thus far have been focused on variations of mean, variance, and trends in temperature extremes, which only reveal certain aspects of Tmax and Tmin characteristics. To more fully represent the uncertainties in modelling these phenomena, Li et al. (1998, 2009) developed a cognitive model called "the Cloud model", based on the fuzzy set theory and probability measures. It has been proven to be robust in estimating the uniformity and stability of qualitative concepts and quantitative data (Huang et al., 2015a; Zhu et al., 2016). Thus, the Cloud model is now widely used in data mining, image processing, uncertainty reasoning, etc. (Li et al., 1998; Yang and Chen, 2007; Wang and Deng, 2007). However, it has rarely been used in the investigation of spatial-temporal changes in annual Tmax and Tmin. Since there are many uncertainties in annual Tmax and Tmin, it is important to adopt the Cloud model to fully and accurately analyze the spatial-temporal change patterns in annual Tmax and Tmin. This offers a new approach and quantitative measure for assessing the stability and uniformity of annual Tmax and Tmin series.

Many factors affect temperature variations, such as solar activity (Kristoufek, 2016), large-scale atmospheric circulation patterns (Nyeko-Ogiramoi et al., 2013; Zhong et al., 2017), and topography (Jiang et al., 2016). Recently, the role of soil moisture (SM) in the occurrence of temperature extremes in transitional climate regions has been highlighted by several regional studies. For example, it was found that there was a negative relationship between SM and the summer monthly Tmax in Europe (Brabson et al., 2005; Hirschi et al., 2011; Whan et al., 2015). With an increasing number of extreme temperature events, it is worthwhile to identify the driving mechanisms behind changes in annual Tmax and Tmin to improve prediction accuracy. Thus, the responses of annual Tmax and Tmin to solar activity, large-scale atmospheric circulation patterns, and SM were fully explored in this study. In contrast to previous studies, a new method called the cross wavelet analysis was adopted to reveal linkages in both time and frequency domains, rather than simply calculating their correlation coefficients.

The impacts of annual Tmax and Tmin on agriculture are also key concerns because temperature plays an important role in vegetation growth and development. The potential for annual Tmax and Tmin changes most likely influence vegetation productivity (Hatfield and Prueger, 2015). Therefore, it is necessary to explore the response of vegetation to the changing annual Tmax and Tmin which would help to develop adaptation strategies under varying environments. Moreover, increasing temperature tends to speed up the hydrological cycles, which, in turn, would lead to changes in precipitation. Theoretical models show that extreme precipitation intensity could exponentially increase with rising temperatures (Allan and Soden, 2008; Westra et al., 2013; Herath et al., 2017) at a rate determined by the Clausius–Clapeyron relationship (Herath et al., 2017) in the absence of SM limitation (Wang et al., 2017). However, little has been done was done to investigate the impacts of annual Tmax and Tmin on the frequency or duration of extreme precipitation events, which is why we included it in this study.

Situated in the edge of the monsoon zone, the Wei River Basin (WRB) belonging to the largest tributary of the Yellow River Basin is a climate-varied sensitive district (Zhu et al., 2016). The Guanzhong Plain, located in the middle and south of the WRB, is a major agricultural production base in western China. Local governments try to designate the plain as a national core economic development area, which will play an important role in stimulating the economic development of the surrounding areas (Huang et al., 2015a,b,c; Zhu et al., 2016). Given the significance of food security and sustainable development, a comprehensive understanding of the changes in annual Tmax and Tmin is of important significance in the WRB. Additionally, as a