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Innovative trend analysis of annual and seasonal air temperature and rainfall in the Yangtze River Basin, China during 1960–2015

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ABSTRACT

The variation characteristics of air temperature and precipitation in the Yangtze River Basin (YRB), China during 1960–2015 were analysed using a linear regression (LR) analysis, a Mann-Kendall (MK) test with Sen's slope estimator and Sen's innovative trend analysis (ITA). The results showed that the annual maximum, minimum and mean temperature significantly increased at the rate of 0.15°C/10yr, 0.23°C/10yr and 0.19°C/10yr, respectively, over the whole study area during 1960–2015. The warming magnitudes for the above variables during 1980–2015 were much higher than those during 1960–2015:0.38°C/10yr, 0.35°C/10yr and 0.36°C/10yr, respectively. The seasonal maximum, minimum and mean temperature significantly increased in the spring, autumn and winter seasons during 1960–2015. Although the summer temperatures also increased at some extent, only the minimum temperature showed a significant increasing trend. Meanwhile, the highest rate of increase of seasonal mean temperature occurred in winter (0.24°C/10yr) during 1960–2015 and spring (0.50°C/10yr) during 1980–2015, which indicated that the significant warming trend for the whole YRB could be attributed to the remarkable temperature increases in winter and spring months. However, both the annual and seasonal warming magnitudes showed large regional differences, and a higher warming rate was detected in the eastern YRB and the western source region of the Yangtze River on the Qinghai-Tibetan Plateau (QTP). Additionally, annual precipitation increased by approximately 12.02 mm/10yr during 1960–2015 but decreased at the rate of 19.63 mm/10yr during 1980–2015. There were decreasing trends for precipitation in all four seasons since 1980 in the YRB, and a significant increasing trend was only detected in summer since 1960 (12.37 mm/10yr). Overall, a warming-wetting trend was detected in the south-eastern and north-western YRB, while there was a warming-drying trend in middle regions.

1. Introduction

In recent decades, climate change characterized by increasing air temperatures and changing precipitation properties has generated worldwide attention (Shen and Varis, 2001; Gerten et al., 2008; Kurane, 2010; Tian et al., 2016). Investigations of the characteristics of variations in regional temperature and precipitation are particularly important for identifying and understanding the impacts of climate change on the atmospheric/hydrologic cycle, agriculture, eco-environment and human society (Karl, 1998; Piao et al., 2014; Friedlingstein et al., 2010; Chen et al., 2014; Yu et al., 2014; Wang et al., 2017). Therefore, it is essential to detect the variation trends of temperature and precipitation at different spatial and temporal scales around the world.

According to the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC AR5, 2013; IPCC, 2013), the Global Mean Surface Temperature (GMST) has risen by 0.89 °C during 1901–2012. It is certain that the maximum and minimum temperatures over land have increased at a global scale since 1950 (IPCC, 2013); however, the magnitude of the changes varied greatly both in space and time (Zhang et al., 2008). Sun et al. (2014) stated that the largest warming trends were observed in Antarctica and Middle Africa during 1948–2010. Jin et al. (2015) showed that most cities in China experienced warming during 1955–2012, but the warming trend was higher in the north than in the south (Ge et al., 2013). Meanwhile, numerous studies have been focused on variations in precipitation using various precipitation indices (Gemmer et al., 2011). Sun et al. (2014) showed that 62.26% of the world became wetter in the

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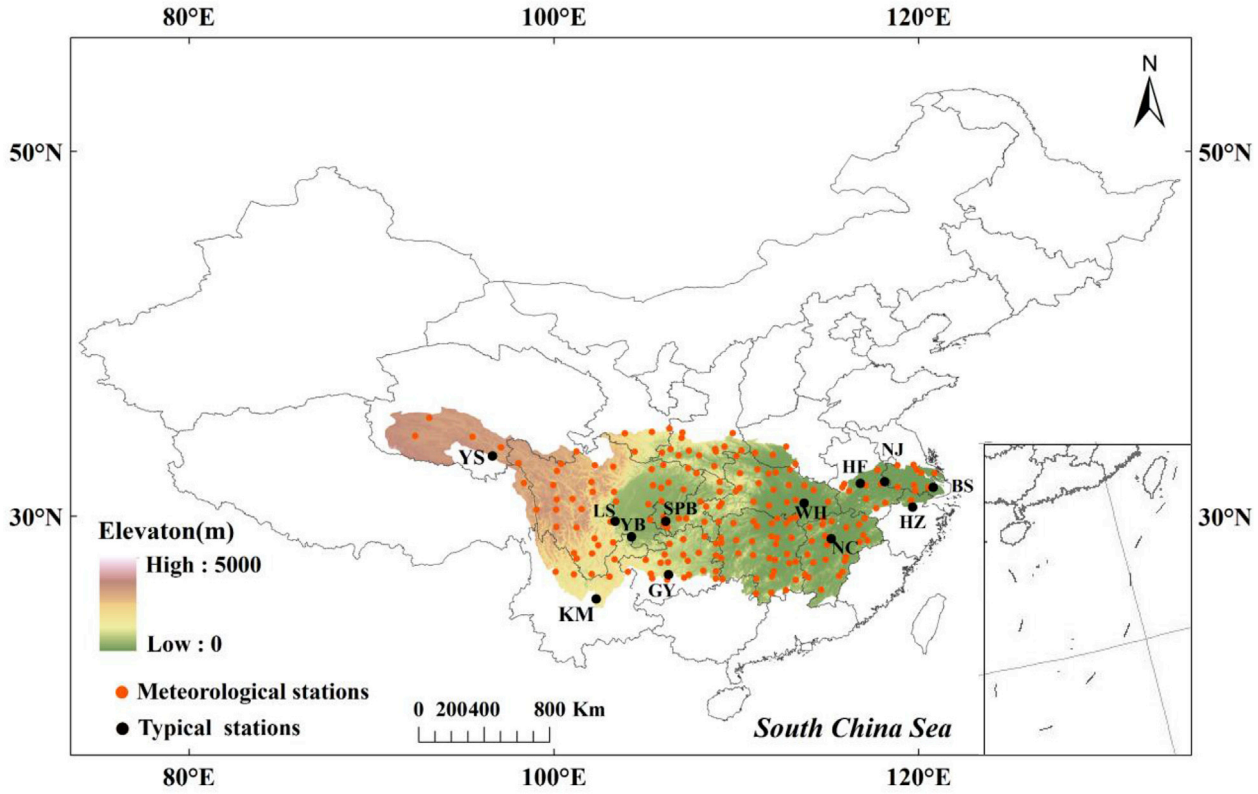

Fig. 1. Location of the Yangtze River basin.

past 60 years, with the largest precipitation increase occurring in Northern Europe, while 22.01% of the world showed drying trends, with the fastest drying occurring in Western Africa. Ren et al. (2015) showed that no significant trend in annual precipitation during 1956–2013 was found in mainland China, but obvious regional differences were detected. Decreases in precipitation mainly occurred in North China, central and southern Northeast China and Southwest China, and increases in rainfall mainly occurred in the mid- and lower reaches of the Yangtze River, the south-eastern coastal region, the Qinghai-Tibetan Plateau (QTP) and Northwest China (Ren et al., 2015). There are large differences in the spatial-temporal variations of air temperature and precipitation in the different climates of China or other regions, which need to be qualitatively and quantitatively investigated.

The quantitative trends of temperature and precipitation have been analysed using different methods, such as the MK test, Sen's slope, Spearman test and LR (Jonsdottir et al., 2008; Ceribasi et al., 2013; Kazmierczak et al., 2014). Westra et al. (2013) used the MK test to study the trends in annual daily maximum precipitation, and significant increasing trends have been detected in global scale. Pingale et al. (2014) applied the MK test and Sen's slope to investigate the spatial-temporal trends of mean and extreme rainfall and temperature in Rajasthan, India, and both positive and negative trends were observed in the urban centres of Rajasthan State. Martínez-Austria et al. (2015) investigated the significant increasing trends for temperature and heatwaves in northwest Mexico using LR and the Spearman test. Wang and Zhou (2005) used LR to analyse trends in annual and seasonal mean precipitation in China during 1961–2001, and the results showed that the increasing trends in eastern China occurred mainly in summer, while the decreasing trends in central, north and northeast China occurred in both spring and autumn. Gemmer et al. (2011) used the MK test to analyse the spatial-temporal characteristics of precipitation trends in the Zhujiang River Basin, South China. The results showed that few stations experienced trends in precipitation indices on an annual basis, but on a monthly basis, significant positive and negative trends were detected in all months except for December. Recently, the ITA method, introduced by Sen (2012a), has been successfully applied to investigate trends of hydrological and meteorological variables (Markus et al., 2014; Sen, 2014). Wu and Qian (2016) analysed the trends in annual and seasonal rainfall at 14 rainfall stations in Shanxi Province, China using the MK test, LR and the ITA method. They found that the trend results were in broad agreement among all tests and in complete agreement among tests with significant trends, which supported the use of the ITA method for the analysis of precipitation trends. However, very few studies have focused on the spatial-temporal variations of temperature and precipitation trends in other regions of China (or around the world) using different methods and compared the associated trends in different periods.

The YRB, the largest river basin in China, has experienced climate warming in the past 50 years (Tian et al., 2016). However, the spatial distribution of precipitation over the whole basin is extremely uneven, which is more likely due to the effects of climate warming on the hydrological cycle. The impacts of climate change on the YRB tend to be devastating due to the dense population and rapid economic development. Therefore, research on the long-term variation trends of temperature and precipitation in the YRB will be of vital importance for forecasting meteorological disasters (e.g., floods and droughts) and management of water resources. The objectives of this paper are to (1) investigate the spatial-temporal variations of temperature and precipitation in the YRB using three different methods to analyse the trends; (2) analyse and compare the trend results in the periods of 1960–2015 and 1980–2015; and (3) evaluate the capability of the ITA method.

2. Materials and methods

2.1. Study area

The Yangtze River, the longest in Asia and the third longest in the world, originates on the Tibetan Plateau in western China, flows 6300 km from the western mountainous area to the eastern plain, and finally