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Multi-decadal spatial and temporal changes of extreme precipitation patterns in northern China (Jing-Jin-Ji district, 1960–2013)

Chao Mei [a], Jiahong Liu [a, b, *], Min-Te Chen [c, **], Hao Wang [a, b], Meng Li [a], Yingdong Yu [a]

[a] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[b] Engineering and Technology Research Center for Water Resources and Hydroecology of the Ministry of Water Resources, Beijing 100044, China
[c] National Taiwan Ocean University, Keelung, Taiwan, China

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A B S T R A C T

Observations of changes in daily extreme precipitation from local to global scales provide essential information for assessing the anthropogenic forcing driving natural climate. This study presents an analysis of daily precipitation records over the past half century (1960–2013) from 26 meteorological stations in northern China (Jing-Jin-Ji district) and attempts to identify spatial and temporal changes based on ten indices for extreme precipitation. Our analysis showed that all regionally averaged extreme precipitation indices were characterized by decreasing trends, of which the maximum one-day and five-day precipitation amounts (RX1day and RX5day) exhibited significant decreasing trends. We further considered possible triggering mechanisms for these trends, such as the recent continual weakening of the East Asian summer monsoon, although the detailed physical mechanisms need further study. Our analysis also showed that extreme precipitation patterns have varied spatially and exhibited a clear increasing trend from the northwest to the southeast except for consecutive dry days (CDD) and consecutive wet days (CWD). A correlation analysis showed that all indices except CDD had significant positive correlations with annual total precipitation(ATP); all indices except CDD and CWD had negative correlations with station elevation. Our results highlight the importance of understanding the patterns of changes in precipitation extremes that provide essential information for water resource management, natural hazard prevention and mitigation, and reliable future climate and environmental projections for policy makers in the Jing-Jin-Ji district. The results indicated that a higher spatial and temporal resolution analysis of extreme precipitation is needed in the study area.

1. Introduction

Precipitation is a key component of the hydrological cycle in all meteorological variables, as it directly and significantly affects life and human society (Barrett and Santos, 2014; Guan et al., 2014), as well as being one of the most important variables in diagnosing climate change (Chen et al., 2015; Wang et al., 2016). Evidence shows that the water cycle is being altered by the impacts of global warming, producing changes in the magnitude, frequency, and probability of extreme precipitation in many areas around the world (Bengtsson and Rana, 2014; Du et al., 2014). Because of its potentially severe impact on human life, economics, and natural ecosystems and the uncertainties surrounding climate change, changes in extreme precipitation have raised the concern of hydrometeorologists and policy makers worldwide in recent years (Zolina et al., 2010; Zhang et al., 2015b).

Over the last few decades, many studies have examined the patterns of changes and trends in total precipitation and precipitation extremes based on observations and global climate models (Chen et al., 2014; Zhang et al., 2017). Alexander et al. (2006) and Donat et al. (2016) reported that extreme precipitation events showed a general rising trend in the past half-century on a global scale. In the US, wet days and heavy precipitation have increased across the country, except in western regions (Kunkel et al., 2013; Gallant et al., 2014). In Europe, significant increasing trends in annual precipitation extremes have been detected in different

* Corresponding author. State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China.
** Corresponding author.
E-mail address: liujh@iwhr.com (J. Liu).

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regions (Bartholy and Pongracz, 2007; Łupikasza et al., 2011). In Australia, one study showed a statistically significant increase in precipitation extremes of 0.9% per decade from 1950 to 2012 (Gallant et al., 2014). In China, Qu et al. (2016) reported that annual precipitation increased by 1.10 mm/decade, but with obvious spatial differences. In eastern China (i.e., the Yangtze River Delta), most extreme precipitation indices exhibited increasing trends, especially the average precipitation on wet days (SDII) (Wang et al., 2016). In western China (i.e., the Loess Plateau) the annual total wet day precipitation (PRCPTOT) showed non-significant trends and the regionally averaged SDII exhibited significant decreases (−0.14 mm/d/decade), whereas consecutive dry days (CDD) significantly increased (1.96 d/decade) from 1960 to 2013 (Sun et al., 2016). Furthermore, in the entire Arab region and the Greater Horn of Africa, though not highly significant, increases have been detected for consecutive wet days (CWD) and for heavy precipitation (Omondi et al., 2014; Donat et al., 2014). Conversely, decreasing precipitation trends have been reported in Greece and western Africa (Mavromatis and Stathis, 2011). These results highlight the tendencies and characteristics of extreme precipitation for different regions, showing that the long-term spatial and temporal trends of extreme precipitation have varied regionally around the world, indicating the importance of more localized studies.

Given the potentially significant social, economic, and ecological impacts of precipitation extremes, up-to-date assessments of precipitation extremes at local scales are required for decision-making processes associated with water resource management and flood prevention under changing environments (Gao and Xie, 2014; Wang et al., 2015; Voskresenskaya and Vyshkvarkova, 2016). This study focuses on northern China's Jing-Jin-Ji district, an important socio-economic area that suffers from limited water resources. We assessed the temporal trends and spatial distributions of extreme precipitation patterns in this area to provide essential information regarding possible multi-decadal changes in extreme precipitation for use in developing new management strategies for policy makers.

2. Materials and methods

2.1. Study area

Jing-Jin-Ji district, in northern China (113°27′36″–119°50′53″E, 36°2′8″–42°37′19″N), has a total area of 21.8 km^2. Jing, Jin, and Ji are common abbreviations for Beijing, Tianjin, and Hebei Provinces, respectively; these are usually collectively referred to as the Jing-Jin-Ji district because of their close socio-economic ties. Fig. 1 presents the location of the study area using the Albers Equal Area Conic Projection (all subsequent maps are based on the same projection). This district is an important Chinese economic development center with a large population (110 million), but has recently faced severe water-related problems, such as urban flooding, water shortages, and water pollution.

2.2. Data and quality controls

Precipitation data from 30 meteorological stations that recorded daily observations within Jing-Jin-Ji district were initially compiled in this study, provided by the National Climate Center of the China Meteorological Administration (http://www.nmic.gov.cn). Most of the stations were established during the 1950s; we focused on data from the years 1960–2013. Stations were rejected if they had missing data for more than one consecutive month; ultimately only data from 26 of initial 30 stations were selected for further analysis (Table 1). Regionally averaged precipitation data were calculated as the arithmetic mean of the values from these 26 stations.

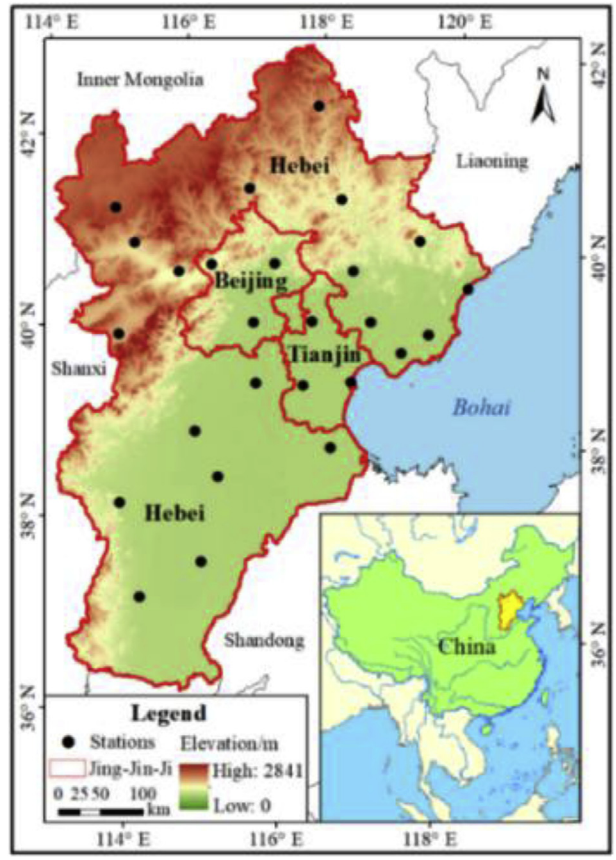

Fig. 1. Location of the study area and the 26 meteorological stations used for precipitation data.

To ensure reliability in calculating extreme precipitation indices, rigorous quality control was required, and several control methods were employed for quality control and homogeneity checks. First, the data quality control methods used by the National Meteorological Information Center of the China Meteorological Administration were applied to correct for errors (Wang, 2004). Subsequently, simple quality control and homogeneity assessment of the raw data was performed using RClimDex software (Zhang and Yang, 2004). Further, data homogeneity was verified using RHtest V3 software (obtained from http://cccma.seos.uvic.ca/ETCCDI/software.shtml).

2.3. Indices for extreme precipitation

Ten core extreme precipitation indices (Table 2) recommended by the Joint CCl-CLIVAR-JCOMM ETCCDI (http://etccdi.pacificclimate.org) were adopted for this study. The selected indices indicate changes in intensity, frequency, and duration of precipitation events (Zhang et al., 2011) and have been used widely in assessing changes in extreme precipitation under climate change conditions (Gao and Xie, 2016; Limsakul and Singhruck, 2016). These indices can be classified into two types: those for intensity evaluation (PRCPTOT, SDII, RX1day, RX5day, R95p, and R99p) and those for frequency evaluation (R10 mm, R20 mm, CDD, and CWD) (Sun et al., 2016). The combined usage of these indices supports the efficient integrated evaluation of extreme precipitation over longer spatial and temporal scales (Alexander et al., 2006) and allows the determination of multi-decadal spatial and temporal changes of extreme precipitation patterns within the study area.