Science of the Total Environment 649 (2019) 75–89

Contents lists available at ScienceDirect

Science of the Total Environment

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

Spatial and temporal variability in extreme temperature and precipitation events in Inner Mongolia (China) during 1960–2017

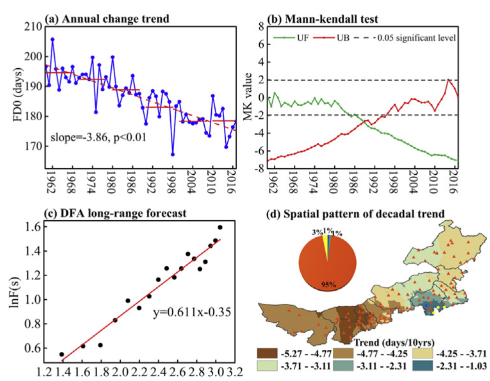
Siqin Tong [a,b,c,1], Xiangqian Li [a,1], Jiquan Zhang [a,b,*], Yuhai Bao [c], Yongbin Bao [a], Li Na [a], Alu Si [a]

[a] School of Environment, Northeast Normal University, Changchun 130024, China
[b] Key Laboratory for Vegetation Ecology, Ministry of Education, Changchun 130024, China
[c] College of Geography, Inner Mongolia Normal University, Hohhot 010022, China

HIGHLIGHTS

- Warm extreme indices significantly increased, while cold extreme indices decreased.
- Nighttime warming was higher than daytime warming in Inner Mongolia.
- Extreme temperature and precipitation events had long-range correlation based on DFA.
- ENSO, AO, and IOD had positive (or negative) impacts on warm (or cold) extremes.

GRAPHICAL ABSTRACT



Linear regression trend (a), Mann-Kendall abrupt change detection (b), DFA long-range forecasting (c), and spatial pattern of decadal trend (d) of frost days (FD) during 1960-2017.

ARTICLE INFO

Article history:
Received 1 May 2018
Received in revised form 14 August 2018
Accepted 20 August 2018
Available online 21 August 2018

Editor: Jay Gan

Keywords:
Extreme climate events
Spatial and temporal variation
Detrended fluctuation analysis
Atmospheric circulation
Influence
Inner Mongolia

ABSTRACT

Due to global warming, extreme climate events have become an important issue, and different geographical regions have different sensitivities to climate change. Therefore, temporal and spatial variations in extreme temperature and precipitation events in Inner Mongolia were analyzed based on the daily maximum temperature, minimum temperature, and precipitation data during the period of 1960–2017. The results showed that warm extreme indices, such as SU25, TX90p, TN90p, and WSDI, significantly increased, whereas the cold extreme indices, such as FD0, TX10p, TN10p, and CSDI, significantly decreased; all indices have obvious abrupt changes based on the Mann-Kendall test; nighttime warming was higher than daytime warming. Extreme precipitation indices slightly decreased overall. All of the extreme temperature and precipitation indices had long-range correlations based on detrended fluctuation analysis ($a > 0.5$), thereby indicating that the extreme climate indices will maintain their current trend directions in the future. ENSO, AO, and IOD had a strong positive influence on warm extremes and a strong negative influence on cold extremes in Inner Mongolia. NCEP/NCAR and ERA-20CM reanalysis showed that strengthening anticyclone circulation, increasing geopotential height, decreasing daytime cloudiness and increasing nightime cloudiness contributed to changes in climate extremes in Inner Mongolia.

* Corresponding author at: School of Environment, Natural Disaster Research Institute, Northeast Normal University, Changchun 130117, China.
E-mail address: zhangjq022@nenu.edu.cn (J. Zhang).

[1] Siqin Tong and Xiangqian Li equally contributed to this work.

https://doi.org/10.1016/j.scitotenv.2018.08.262

1. Introduction

The IPCC SREX (2012) reported that an extreme event is generally defined as the occurrence of a weather or climate variable at a value above (or below) a threshold value that is near the upper (or lower) ends ("tails") of the range of observed values of the variable. In recent years, the global climate has continuously warmed, and extreme climate events have occurred frequently (Leonard et al., 2013; Hao et al., 2013). This has resulted in a clear upward trend in the occurrence of meteorological disasters and has increased socioeconomic losses (Botzen and van den Bergh, 2009). According to recent statistics, the economic losses caused by global climate change and associated extreme weather events have increased by 10 times over the past 40 years (Ding et al., 2002). Asia is one of the continents that most frequently suffer from natural disasters, and natural disasters accounted for 43% of all extreme climate events in the world from 1990 to 2000, and the trend was becoming more serious after entering the 21st century with the global warming (Hou et al., 2008). Observations have shown that regional climate change has resulted in changes in various natural and biological systems, such as glacial retreat, permafrost melting, and the extension of the growing season in mid-high latitude areas (Shea et al., 2015; Rangecroft et al., 2016; Douville, 2006). In recent years, a series of meteorological disasters around the world (such as Hurricane Andrew in Florida in 1992, a catastrophic flood in China in 1998, and large-scale snow disasters in 2008) have caused a large number of casualties and substantial economic losses. This shows that studying the changing controls on and formation mechanisms of extreme climate events is not only necessary for scientific development but is also an urgent requirement of society (Barrett et al., 2015).

At present, research on extreme climate events mainly includes the study of extreme values, intensity, frequency, and changing trends of various indices and also includes conducting analyses and discussing the various factors involved in extreme climate events, among other topics (Gao et al., 2015; Planton et al., 2008; BrÖ et al., 2004; Brown et al., 2010). Researchers have studied extreme temperature and precipitation and have found that extreme temperature changes are generally associated with global warming, while extreme precipitation changes are less spatially correlated with global warming, making their trends difficult to understand (Alexander et al., 2006; Anders and Jones, 2005; Aguilar et al., 2005; Hidalgo-Muñoz et al., 2011; Omondi et al., 2013; Coumou et al., 2013; Coumou and Rahmstorf, 2012).

The frequency and intensity of extreme climate events in China have changed since 1951. Zhai and Pan (2003) indicated that the frost period in the eastern part of northern China is lengthening, and the number of extreme precipitation events in the northwest is increasing. Ma et al. (2003) studied extreme temperatures in northern China and concluded that the occurrence frequency of the highest temperatures in most parts of the northern region showed a significant increasing trend after the 1990s; these researchers also noted that the decrease in the frequency of extreme low temperatures and the increase in the low temperatures themselves are closely related to regional warming. Additionally, researchers have studied extreme climate changes in Shandong, Xinjiang, Chongqing, eastern China, southern China, and the Yangtze River Basin (Jiang et al., 2011; Zhang et al., 2012; Su et al., 2017; Chen and Sun, 2015). These changes in extreme climate events are closely related to regional climate warming and atmospheric circulation (Diffenbaugh et al., 2017; Abiodun et al., 2013; Swain et al., 2016). Therefore, many large-scale atmospheric circulation indices, such as the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Arctic Oscillation (AO), North Atlantic Oscillation (NAO) and Southern Oscillation (SO), were applied to examine these relationships (Pascual et al., 2013; Muhire et al., 2015; Zhou and Wu, 2010; Chan and Zhou, 2005; Suo et al., 2008; Wan et al., 2010; Gong et al., 2009). However, there is little research on the effects of multiple atmospheric circulation indices, such as ENSO, NAO, AO, the Indian Ocean Dipole (IOD), and PDO, on the temporal and spatial changes in extreme temperature and precipitation events in Inner Mongolia.

Inner Mongolia contains one of the largest grasslands in China and is an important ecological barrier in the north of China. It is also an important agricultural and animal husbandry production base in China (Sun and Wang, 2008). Thus, it is a sensitive area in terms of global warming (Wang et al., 2008). Vegetation coverage can reflect the overall condition of the ecological environment in Inner Mongolia; therefore, the change in vegetation and its relationship with climatic factors has been a topic of interest in the scientific community (Wang et al., 2010). The decline in water levels, grassland degradation, and land desertification are closely related to climate change. At present, many studies exist on temperature and precipitation in Inner Mongolia (Bao et al., 2010; Chen et al., 2009; Bao et al., 2011), but studies that analyze extreme climate events are rare. Therefore, it is necessary to conduct a comprehensive study on the characteristics and evolution of extreme climate events in Inner Mongolia by analyzing the extreme temperature and precipitation indices, influencing factors, and future predictions, which have great significance for predicting catastrophic climate events and preventing and reducing disasters in Inner Mongolia.

2. Data and methods

2.1. Study area

The Inner Mongolia autonomous region was selected as the study area. It is located in the northern part of the People's Republic of China and lies between 37°24′N and 53°23′N and 97°12′E and 126°04′E (Fig. 1a). It has a total area of approximately 1.18 million km^2, which occupies 12.3% of China's total area and makes it the third largest province in China. It is located in the interior of the Eurasian continent and is under the influence of the East Asian monsoon because it falls within the zone of transition between humid and semi-humid monsoon climate and arid and semiarid climate (Sun et al., 2010). Due to the gradient in rainfall and temperature, its vegetation types, from the northeast to the southwest, are forest, grassland, and desert (Shi et al., 2011). The annual mean air temperature progressively increases from approximately −4.5 °C in the northeast to 9.8 °C in the southwest (Fig. 1b), but the annual precipitation decreases from the northeast to the southwest (Fig. 1b). In addition, the elevation increases from the northeast to the southwest, ranging from 86 to 3526 m. Altitude also has an important influence on the distribution of temperature and precipitation; therefore, we use cokriging, a method that takes elevation into consideration, to interpolate the meteorological data and obtain the spatial distribution of extreme temperature and precipitation indices (Daly et al., 2003; Goovaerts, 2000).

2.2. Data sources and quality controls

The data used in this study were acquired from the Resource and Environment Data Cloud Platform (www.resdc.cn/), which included the daily maximum temperature, minimum temperature, and precipitation data during the period of 1960–2017.

Data quality control is necessary before the analysis of temperature and precipitation variation because erroneous outliers can impact trends (Gao et al., 2015). Data quality control was performed using RClimDex software (http://cccma.seos.uvic.ca/ETCCDI/software.shtml), which was developed and maintained by Zhang and Yang (Li et al., 2012) at the Climate Research Branch of the Meteorological Service of Canada. It was used to check for inaccurate temperature and precipitation data, such as precipitation values below 0 and minimum temperatures that exceed maximum temperatures. Additional quality control involved identification of potential outliers; in particular, identifying whether the recorded data were consistent with the actual meteorological conditions in the region. Three times the standard deviation was defined as the threshold for quality control of the data. This threshold can detect almost all erroneous