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Changing contribution rate of heavy rainfall to the rainy season precipitation in Northeast China and its possible causes

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ABSTRACT

Based on the daily precipitation data from 208 meteorological stations in Northeast China, NCEP/NCAR reanalysis monthly mean wind, sea level pressure data and NOAA reconstructed monthly mean sea surface temperature (SST) data from 1961 to 2013, the contribution rate of heavy rainfall to the total rainfall (hereafter referred to as "heavy rainfall contribution rate" or HRCR) during the rainy season in Northeast China was investigated. The changing characteristics of HRCR in the context of global warming are analyzed. The relationship between the HRCR and the contemporaneous atmospheric general circulation and early SST anomaly was analyzed to understand the possible physical mechanism responsible for the changing HRCR before and after the warming. Results show that during the whole study period (1961–2013), no evident trend in the HRCR has been detected. However, during cold period (1961–1979), the HRCR showed a significantly declining trend, while during warm period (1981–2013), the HRCR does not exhibit any trend. During cold period, the anomalous North Pacific summer monsoon and March North Atlantic tripole SSTA are the main factors affecting the HRCR, while the West Pacific summer monsoon, the East Asian subtropical westerly jet and March North Pacific dipole SSTA are responsible for the HRCR in the warm period. In the cold period, due to the air-sea interaction, March Atlantic tripole SSTA can influence the North Pacific summer monsoon in the late July–August, in turn affecting the HRCR. In the warm period, March North Pacific dipole SSTA tends to cause anomalies in the West Pacific summer monsoon and the position of the East Asian subtropical westerly jet axis in the July–August through air-sea interaction, thereby affecting the HRCR. During 1961–1979, the weakening of the North Pacific summer monsoon might have been the primary cause of the significant decline in the trend of the HRCR in the cold period. In 1981–2013, the absence of significant trends of the West Pacific summer monsoon and subtropical westerly jet position might be the main reason for the lack of an obvious linear trend of HRCR in the warm period.

1. Introduction

East China locates in the typical monsoon climate zone, significantly affected by the advance and retreat of the East Asian monsoon, and the precipitation here has distinct phases and regional characteristics (Zhu, 1934). Many scholars have investigated the rainy seasons precipitation in different phases and regions, including precipitation in the pre-flood season in South China (Zheng et al., 2006), the Meiyu in the Yangtze-Huaihe River basin (Ding et al., 2007), autumn rains in West China (Bai and Dong, 2004), the rainy season rainfall in Southwest China (Yan et al., 2013), the rainy season precipitation in the northern part of China (Zhao, 1994), and that in Northeastern part of China (Fang et al., 2014, 2016; Gong et al., 2015b). These studies have greatly improved our understanding on climate characteristics in China.

Additionally, lots of researches have been performed to investigate the climate change under the background of the global warming (Zhao et al., 2010; He et al., 2016). It is found that the global warming has led to evident changes in the frequency and intensity of the extreme

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weather events in many parts of the world (Tosnis, 1996; Pourtouiserkani and Rakhshandehroo, 2014). Since the mid-1990s, with the increase in extreme climate change research, study on changes in the magnitude and types of precipitation has also increased. Yan and Yang (2000) reported that “drizzle” has decreased in China. Qian et al. (2007) showed that as the climate has warmed, the frequency of the light rain has declined significantly in China. Sun et al. (2007) found that the annual days of light rain events decreased in Northeast China during 1951–2002, but the intensity increased. Sun and Ao (2013) also suggested that as China's regional winter temperature rises, China's regional winter precipitation and extreme precipitation show a consistent increasing trend. Lu et al. (2016) studied the relative importance of precipitation frequency and intensity to the inter-annual variability of summer precipitation in China. Their results showed that the precipitation frequency and intensity primarily affect heavy and weak precipitation, respectively. Other scholars have conducted related research in this field (Wang and Zhai, 2008; Chen and Dai, 2009).

The above findings show that the study of precipitation volume is not equal to the study of precipitation intensity. At present, research on precipitation in China is primarily concentrated on the average rainfall or extreme precipitation events (Kunkel et al., 2013; Gong et al., 2015a; Jury, 2015; Ren et al., 2017; Zittis et al., 2017). However, analysis of the contribution rate of precipitation with different intensities is less common. The diagnostic analysis of the contribution rate of precipitation at various levels to total rainfall in the Northeast China rainy season can determine whether predictions of rainy-season precipitation should emphasize heavy or light precipitation. This determination can indicate the direction for rainy-season rainfall forecasts and has scientific value for disaster prevention and mitigation as well as for promoting economic development. The contribution rate of heavy rain precipitation to total rainfall in the Northeast China rainy season is the focus of the present study. The objective is to analyze the changing characteristics and genesis of heavy rain in the context of global warming to provide theoretical support for the prediction of the contribution rate of heavy precipitation in the Northeast China rainy season.

In addition, climate change under the background of the global warming is one of heated topics in climate research. Alexander et al. (2006) has pointed out that the global precipitation indices show a tendency toward wetter conditions throughout the 20th century. Similarly, Chen and Zhang (2016) suggested that the frequencies of the global extreme severe precipitation events and the extreme high temperature events increase under significant global warming during the last 112 years. As to China, the entire country was dominated by apparent increase of the frequency of extreme precipitation (Gu et al., 2016). These research findings indicate that heavy rainfall events are increasing with global warming, these variation characteristics should be used considered for HRCR prediction.

2. Data and methods

2.1. Data sources and research methods

The datasets used in this study include the observational daily precipitation data from 208 stations in Northeast China (three northeastern provinces and four cities in eastern Inner Mongolia) during 1961–2013, NCEP/NCAR reanalysis monthly mean wind field data, sea level pressure (SLP) data (Kalnay et al., 1996; http://www.esrl.noaa.gov/psd/), and the National Oceanic and Atmospheric Administration (NOAA)-reconstructed monthly mean sea surface temperature (SST) data (Huang et al., 2014; http://www.esrl.noaa.gov/psd/). The station data was provided by the National Meteorological Information Center of China, which is available at http://data.cma.cn. Fig. 1a shows the geographic location of the northeastern China, and the stations selected are shown in Fig. 1b.

The empirical orthogonal function (EOF) decomposition, Mann-Kendall test, correlation analysis, composite analysis, regression analysis and other statistical analysis methods are used in current study.

Mann-Kendall method has been widely used to check the abrupt point or trend of a given time series. For a time series$x_1, x_2 \ldots, x_n$, we can calculate the statistical variable d_k as following:

$$d_k = \sum_{i=1}^{k} P_i (2 \le k \le n) \tag{1}$$

where P_i denotes the cumulative samples where $x_i > x_j (1 \le j \le i)$.

Suppose that the original time series are random and independent, the mean and the variance of d_k can calculated by:

$$E[d_k] = \frac{k(k-1)}{4} \tag{2}$$

$$\mathrm{Var}[d_k] = \frac{k(k-1)(2k+5)}{72} (2 \le k \le n) \tag{3}$$

Under the above assumption, the forward sequential statistic UF_k (MK test based on the data) is calculated as:

$$\mathrm{UF}_k = \frac{d_k - E[d_k]}{\sqrt{\mathrm{Var}[d_k]}} k = 1, 2, 3 \ldots, n \tag{4}$$

where UF_k satisfies the normal distribution and the null hypothesis can be rejected at the significance level of α, if $|\mathrm{UF}| > \mathrm{UF}_{1-\alpha/2}$. Also, $\mathrm{UF}_{1-\alpha/2}$ is the critical value of the standard normal distribution with a probability exceeding $\alpha/2$. The backward sequential statistic UB is calculated based on the adverse sequence of the data. When UF and UB curves intersect, the intersection point denotes the jumping (or turning) point. In other words, the sequential version of the Mann-Kendall is considered as an effectual way of locating the beginning year of trend.

2.2. Index definition

2.2.1. North Atlantic SST tripole index

The March North Atlantic SST tripole index for 1961–1979 was sourced from the projection index given by the National Climate Centre website, and the definition refers to http://ncc.cma.gov.cn.

2.2.2. North Pacific dipole index

The North Pacific dipole index is defined as the difference between the SST of the North Pacific in the region (165°E-140°W, 45°N-55°N) in March of 1981–2013 and that in the region (170°E-155°W, 25°N-37.5°N) at the same time.

2.2.3. North Pacific and West Pacific summer monsoon index

In this paper, the East Asian summer monsoon primarily reflects the difference in SLP. Therefore, the North Pacific summer monsoon index is characterized by the difference in mean SLP between the North Pacific (165°E-170°W, 50°N-65°N) and the Chinese mainland (90°E-110°E, 35°N-50°N) in July–August of 1961–1979. The West Pacific summer monsoon index is characterized by the difference in SLP between the West Pacific (125°E-140°E, 28°N-36°N) and Siberia to the north of Lake Baikal (90°E-120°E, 55°N-65°N) in July–August of 1981–2013.

2.2.4. East Asian subtropical westerly jet position index

The East Asian subtropical westerly jet position index is defined as the difference in mean 200-hPa zonal wind velocities between the (110°E-140°E, 45°N-55°N) area and (110°E-140°E, 28°N-38°N) area at the 200-hPa zonal wind field in July–August of 1981–2013 for standardization, the definition is similar to Yan et al. (2017). The larger (smaller) index indicates the East Asian subtropical westerly jet locates northward (southward).