Quaternary International xxx (2015) 1–9

Contents lists available at ScienceDirect

Quaternary International

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

Spatial and temporal variations of annual precipitation during 1960–2010 in China

Yanjiao Wang [a], Xianyan Chen [a], Feng Yan [b,*]

[a] Laboratory for Climate Studies, National Climate Center, China Meteorological Administration, Beijing 100081, China
[b] Institute of Desertification Studies, Chinese Academy of Forestry, Beijing 100091, China

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Precipitation
Spatial pattern
Temporal variation

ABSTRACT

China is situated in the East Asian Monsoon zone, and the heterogeneity of the temporal and spatial characteristics of precipitation might result in serious flood and drought disasters. Based on precipitation data from 1840 stations across China, the empirical orthogonal function (EOF) analysis and the rotated empirical orthogonal function (REOF) analysis were used to analyze the spatiotemporal characteristics of precipitation variations in China in 1960–2010. Results showed that: (1) precipitation in the East China witnessed changes in the late 1970s, from the late 1980s to early 1990s, and in the early 21st Century respectively, featuring the recurrent south-north shifts of the rainbelt in both directions. Precipitation in Northwest China experienced an abrupt change in the mid-1980s, showing that the western part of Northwest China became wet from the previous dry conditions, whereas the eastern part of the region became dry from the previous wet conditions. However, precipitation in Northeast China underwent abrupt changes in early 1980s and late 1990s respectively, when precipitation changed from near normal in the previous period to more than normal in early 1980s and from more to less than normal in late 1990s. Evident phases in changes in precipitation had been detected over Southwest China, showing that the precipitation changes over both western and northeastern parts of this region were almost opposite; (2) decadal changes of precipitation in East China were closely correlated with the East Asian summer monsoon and the atmospheric circulation, while as important external forcing factors, the Pacific SST and snow cover on the Tibetan Plateau also had indirect impacts on the precipitation in the region through their influences on the East Asian summer monsoon and the atmospheric circulation.

1. Introduction

With climate warming, the earth experienced frequent extreme weather conditions, and the global land area suffered severe extreme weather events. Situated in the East Asian monsoon zone, China is subject to the impacts of global climate change, which is characterized with evident regional precipitation changes. Many scholars have studied the characteristics of precipitation changes in different regions in China over the past 50 years (Weng et al., 1999; Chang et al., 2000; Ren et al., 2000; Ding et al., 2008; Lei et al., 2011). The major results included summer precipitation in eastern China shifting southward in the late 1970s (Zhang et al., 2008; Zhao et al., 2010), an increase in national average precipitation with increasing precipitation in spring but slightly decreasing in autumn in the last decades (Ding et al., 2007) and the frequency of heavy precipitation events increasing in China (Trenberth et al., 2007). Mechanisms have also been proposed to explain precipitation changes (Zhao et al., 2010; Ye and Lu, 2011; Duan et al., 2013; Zhu et al., 2014). Affected by decadal changes of the global climate system, precipitation in China is characterized with significant decadal changes, especially since the 1990s, and the increased global warming plus the re-enhanced East Asian monsoon are bound to influence the regional precipitation distribution and its changing trend. Precipitation changes might greatly affect regional climate stability, hydrological processes, and water availability. The spatial and temporal inhomogeneity of precipitation distribution increased, which might result in an increase in the threat of droughts and floods. In order to better perform disaster prevention and mitigation of humans in China, the government and production management must further understand the spatial and temporal patterns and the causes of precipitation.

The objective of this research was to: (1) investigate the spatial distribution patterns of precipitation in China; (2) explore the

* Corresponding author.
E-mail address: njuyf@163.com (F. Yan).

http://dx.doi.org/10.1016/j.quaint.2014.12.047
1040-6182/

variability of precipitation in each sub-region on annual timescales, especially the new variability of precipitation in each region since the 1990s; (3) provide the possible causes for the summer precipitation changes in East China. The results of this study are important both for understanding of the climate system and providing important information for the planning of future water resources and flood protection in China.

2. Data and methods

2.1. Data

The data used in this paper included: (1) the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) atmospheric reanalysis data in 1960–2010; (2) annual precipitation data sets of 2425 stations in China were provided by the National Climate Centre (NCC) of the China Meteorological Administration (CMA), plus monthly mean surface air temperature (SAT) and surface land temperature (SLT) data sets of 60 stations as well as snow depth data sets of 91 stations in the Tibetan Plateau (TP), with all data being observed in 1960–2010; and (3) data sets of monthly mean Pacific Decadal Oscillation (PDO) index from the NCEP in 1900–2010. For the annual precipitation data sets of 2425 stations in 1960–2010, the quality of the data were checked using the cumulative deviations test (Feng et al., 2004) and the 1840 stations with continuous time series in 1960–2010 were used in this paper (Fig. 1).

2.2. Methodology

2.2.1. EOF and REOF analyses

The EOF and REOF analyses are convenient and effective methods extensively used in climatic research (Lian and Chen, 2012; Liu et al., 2013). The EOF analysis introduced by Lorenz (1956) can identify and extract spatiotemporal modes that are ordered by considering their representations of data variance. EOF analysis output includes spatial patterns (EOFs), temporal coefficients (principal components, PCs) and eigenvalues. The REOF analysis introduced by Richman (1986) uses an orthogonal rotation matrix to make the loading vectors (LVs) correlated to the principal components of initial EOF modes rotate, so as to maximize the variance of the squared correlation coefficient between the temporal coefficients of each REOF mode and original EOF mode. With the REOF analysis, the meaning of principal components mainly lies in the representation of spatial distribution characteristics of correlations for the variable. This makes the high LVs correlated to principal components concentrate only in a small area, and the LVs in most of areas as close as possible to zero (Wang et al., 2014). Therefore, the REOF analysis yield localized structures by compromising some of the EOF properties, and has been found to be good for dividing climatic zones (Kim and Wu, 1999).

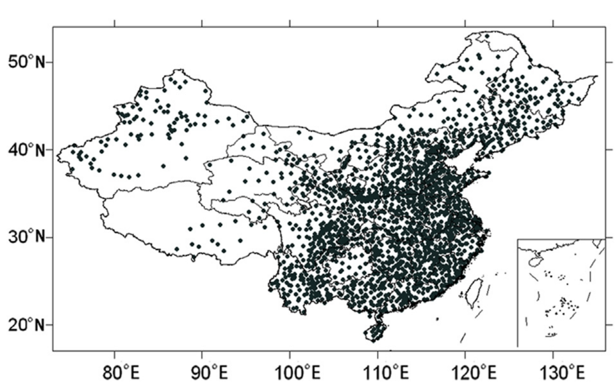

Fig. 1. Geographical distribution of the 1840 stations in China.

2.2.2. Identification of the major rainbelt location

The method proposed by Zhao et al. (2008) is adopted to identify the locations (in latitudes) of the summer major rainbelt in the monsoon zone over East China in 1900–2010. In this research, the monsoon zone over East China is divided into 4 rainfall patterns: E1 (rainbelt is mainly located in the Yellow River basin and North China), E2 (rainbelt is located between the Yellow and Yangtze rivers), E3 (rainbelt is found over the Yangtze River basin), and E4 (rainbelt is located in the Jiangnan and Huanan), and the zonal locations of rainbelt are 38°N for E1, 34°N for E2, 30°N for E3, and 26°N for E4, respectively. These rainfall patterns and locations are redefined according to the annual precipitation records.

2.2.3. Algorithm of the heating intensity index

An algorithm developed by Xu et al. (1990) and Li and Chen (1990) is used to derive the index of the heating intensity over the TP in winter. The intensities of the heating conditions over the TP, which are derived using both SLT and SAT measurements from 60 in-situ stations, are decomposed in terms of EOF, and the *Yushu* and *Shigatse* with the maximum loading capacity are selected as two representative stations to calculate monthly mean anomaly index of the heating intensity at these two stations in 1960–2010, which represent the heating intensities on the surface of the TP. The formula of the index is expressed as

$$\Delta(B-H)_p = A + B(T_s - T_a)_S + C(T_s - T_a)_Y - \overline{M} \quad (1)$$

where $(T_s - T_a)_S$ and $(T_s - T_a)_Y$ are the differences between the monthly mean SLT and SAT in the *Yushu* and *Shigatse*, respectively (unit; C°), $\Delta(B-H)_p$ is the monthly mean anomaly index of the heating intensity (unit: kw·h/m^2), A, B, C are the coefficient, $\overline{M}$ is the climatological normal of the heating intensity in the *Yushu* and *Shigatse*. The values of these parameters (A, B, C and $\overline{M}$) are given in the reference (Li and Chen, 1990). The positive (negative) values of the index indicate the more (less) than normal heat intensities over the TP, the values being larger mean more heating intensities on the TP.

2.2.4. Algorithm of snow depth

A processing method proposed by Ma and Qin (2012) is utilized to calculate the average snow depth on the TP, in which if the valid monthly values are equal or greater than 20d, all valid data in the given month will be averaged; if the values are less than 20d or the snow depth is missing in any one month of a given season, the whole month or season will be treated as lacking observations. This paper uses the climatology in 1971–2000, and for seasonal partitions, DJF is defined as winter; MAM as spring; JJA as summer; and SON as autumn.

3. Results

3.1. Spatial analyses of precipitation with EOF and REOF

Annual normalized precipitation data sets of 1840 stations in 1960–2010 were analyzed with the EOF analysis, which yielded a set EOF/PC pairs. Table 1 shows the variance contributions of the first 12 LVs to the total variance of precipitation variations. The accumulative contributions of the first 12 LVs to the total variance account for about 68.9%, which represents the main precipitation information. The fact that more than 60% of total variance is captured by the first 12 LVs indicates the complexity of the precipitation spatial pattern in China.

Please cite this article in press as: Wang, Y., et al., Spatial and temporal variations of annual precipitation during 1960–2010 in China, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2014.12.047