Quaternary International 333 (2014) 26–39

Contents lists available at ScienceDirect

Quaternary International

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

Changes in precipitation extremes over the Pearl River Basin, southern China, during 1960–2012

Yifei Zhao, Xinqing Zou*, Liguo Cao, Xinwanghao Xu

School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China

ARTICLE INFO

Article history:
Available online 25 April 2014

Keywords:
Pearl River Basin
Precipitation
Extreme climate
Continuous wavelet transform

ABSTRACT

Based on daily precipitation dates at 42 meteorological stations in the Pearl River Basin, the spatial and temporal changes in precipitation index are analyzed during 1960–2012, eleven indices of precipitation extremes are studied. The results show that wet day precipitation, consecutive wet days and numbers of heavy precipitation days exhibit non-significant decreasing trends in the study area. Consecutive dry days and simple daily intensity index have increased and are significant at the 95% level, while other extreme precipitation indexes have non-significant increasing trends. Spatial changes of precipitation extreme indices show obvious differences, and they are not clustered either. On the whole, the number of rainy days has decreased over the Yunnan–Guizhou Plateau and hilly Guangxi, and the spatial distribution reflects the regional climatic complexity. Continuous wavelet transform analysis indicates that there are significant periodic variations with periods of ~7 and ~14 years in extreme precipitation, and that there is also a 6-year period and a 14-year period with the Pacific Decadal Oscillation (PDO) and Southern Oscillation Index (SOI), respectively, which are very consistent. The PDO and SOI are important influential factors for precipitation. In addition, except for consecutive dry days, the other extreme precipitation indices have significant correlations with annual precipitation. Large scale atmospheric circulation changes derived from NCEP/NCAR reanalysis reveals that a strengthening anticyclonic circulation, increasing geopotential height, weakening monsoonal flow, and vapor transportation over the Eurasian continent have contributed to the changes in precipitation extremes in southern China.

1. Introduction

With the global hydrological cycle accelerating subsequently in the background of climate warming, the frequencies of extreme precipitation events are increasing worldwide, causing significant damage to agriculture, ecology, and infrastructure (Suppiah and Hennessy, 1998; Zhai et al., 1999b; Trenberth et al., 2003; Christensen and Christensen, 2004; Alexander et al., 2006; Re and Barros, 2009; Marengo et al., 2010; Penalba and Robledo, 2010; You et al., 2010). Therefore, extreme weather and related societal impacts are becoming an increasingly interesting area and also has received much more attention in many regions around the world, including Southeast Asia (Endo et al., 2009), North America (Kunkel, 2003), Central America and northern South America (Aguilar et al., 2005), Emilia-Romagna (Pavan et al., 2008), India (Pal and Al-Tabbaa, 2011), Middle East (Zhang et al., 2005), Greece (Kioutsioukis et al., 2010), South Portugal (Durao et al., 2010), Southern and West Africa (New et al., 2006) and Germany (Tromel and Schonwiese, 2007; Zolina et al., 2008). On the global scale, daily climate extremes also have been analyzed (Alexander et al., 2006), indicating that the changes in precipitation extremes present a complicated pattern and have apparent regional characteristics. Increasing precipitation extremes are present in large areas, but there are downward trends in some areas of Germany, and no trends in Southern and West Africa. In China, extreme precipitation events are also increasing and show apparent spatial differences (Zhai and Pan, 2003). You et al. (2011) reported that regional annual total precipitation exhibited an increasing trend, and that most precipitation indices are strongly correlated with annual total precipitation. Regional studies, including the Yangtze River Basin, southeastern China and northwestern China, show the strongest positive trends, while the strongest negative trends exist in the Yellow River Basin and northern China (Zhai et al., 1999a, b; Zhai and Pan, 2003; Qin et al., 2005; Wang and Zhou, 2005; Su et al., 2006; Jiang et al., 2007; Yang et al., 2008; Wang et al., 2013a,b,c).

The Pearl River Basin has a subtropical climate and is mildly rainy. The Pearl is the second largest river in China in terms of

---

* Corresponding author.
E-mail addresses: zouxq@nju.edu.cn (X. Zou), lgcaonju@126.com (L. Cao).

http://dx.doi.org/10.1016/j.quaint.2014.03.060

streamflow, with a thriving regional socio-economy. Approximately 80% of the total discharge occurs from April to September. The spatial and temporal variations of water resource in the Basin are closely related to precipitation changes (Yang et al., 2008b; Zhang et al., 2009a,b). To a certain degree, uneven spatial and temporal precipitation distribution negatively affects the effective human use of water resources. Therefore, due to its crucial role in the socio-economic development of China, the changes in precipitations extremes and possible underlying causes in Pearl River basin have attracted some scholars' attention in recent years. Yang et al. (2010) explored regional frequency analysis and spatio-temporal pattern characterization of rainfall extremes in the Pearl River Basin by using the regional frequency analysis method, and found that the seasonal distributions of extreme precipitation in different areas are different. Zhang et al. (2012) analyzed spatial-temporal changes of precipitation structure across the Pearl River Basin by defined annual total precipitation amount, annual total rainy days, annual precipitation intensity and annual mean rainy days and indicated that precipitation is decreasing mainly in the middle and upper Pearl River basin and a decreasing number of rainy days is detected almost over the entire basin. Chen et al. (2011) discussed the seasonal precipitation variability in the Dongjiang River associated with large-scale circulation by using a continuous wavelet transform method, Mann–Kendall trend test, and a simple regressive technique, and indicated that the intensity of the south-east Asian monsoon carrying excess moisture is the main driving factor for precipitation changes in Dongjiang River. Luo et al. (2008) analyzed precipitation trends in North River Basin by using Mann–Kendall trend test and Sen's *T* test. These previous studies primarily paid attention to the average of the precipitation or some kinds of extreme precipitation events, which have great significance in revealing spatial and temporal variation characteristics of precipitation change. However, fewer extreme precipitation indices were applied in these previous investigations. There are limitations in using the comprehensive indices to analyze precipitation extreme events, and they do not completely reveal spatial-temporal change characteristics of precipitation.

The aim of this study is to further study the precipitation regulation evolution and provides a better understanding the changes in precipitation extremes in the Pearl River Basin during 1960–2012, based on 42 meteorological stations where the sequences of observed data selected are complete. The eleven extreme precipitation indices are generated by the joint CCl/CLIVAR/JCOMM ETCCDI (http://cccma.seos.uvic.ca/ETCCDI), a widely used approach. In addition, spatial and temporal variability of changes in these indices and relationships between large scale atmospheric circulation patterns and these changes are discussed.

2. Data and methods

2.1. Study area

The Pearl River in southeast China is the second largest river (in terms of mean annual water discharge) in China with a drainage area of 4.42×10^5 km^2, from 3°41′to 29°15′N and from 97°39′to 117°18′E (PRWRC, 1991;; PRWRC, 2006; Zhang et al., 2008a,b). The Pearl River Basin consists of three major rivers (PRWRC, 1991), West River, North River and East River. The West River is the largest river, accounting for 77.8% of the total drainage area of the Basin. The North River is the second largest tributary, having a length of 468 km and drainage area of 46,710 km^2. The East River is about 520 km long with a drainage area of 27,000 km^2, and accounts for 6.6% of the total area of the Pearl River basin (PRWRC, 1991; PRWRC, 2006; Chen et al., 2010). The Pearl River Basin is located in the tropical and sub-tropical climate zones with the annual mean temperature from 14 to 22 °C. Precipitation during April–September accounts for 72–88% of the annual total (Zhang et al., 2008a). The multi-annual average humidity is between 71% and 80% (PRWRC, 1991).

2.2. Data and methods

The observed daily precipitation data covering 1 January 1960 to 31 December 2012 was collected from 42 national standard rain stations in the Pearl River Basin (Fig. 1 and Table 1). All of the daily precipitation data was provided by the National Meteorological information Center of China Meteorological Administration (http://www.nmic.gov.cn). Southern Oscillation Index (SOI) and Pacific Decadal Oscillation (PDO) were used to represent large-scale climate anomalies, and the data are from http://climexp.knmi.nl/.

Table 1
List of observation stations with WMO (World Meteorological Organization) number, latitude, longitude, altitude and altitude(m).

WMO number	Site name	Latitude (N)	Longitude (E)	Altitude (m)
59493	Shenzhou	22°33′	114°06′	18.2
59478	Taishan	22°15′	112°47′	32.7
59462	Luoding	22°46′	111°34′	53.3
59431	Nanning	22°49′	108°21′	73.1
59417	Longzhou	22°20′	106°51′	128.8
59298	Huiyang	23°05′	114°25′	22.4
59294	Zengcheng	23°18′	113°49′	38.9
59293	Heyuan	23°44′	114°41′	40.6
59287	Guangzhou	23°08′	113°19′	41.0
59278	Gaoyao	23°03′	112°28′	71.0
59271	Guangning	23°38′	112°26′	56.8
59265	Wuzhou	23°29′	111°18′	114.8
59254	Guiping	23°24′	110°05′	42.5
59242	Laibin	23°45′	109°14′	84.9
59218	Jingxi	23°08′	106°25′	739.4
59211	Baise	23°54′	106°36′	173.5
59209	Napo	23°25′	105°50′	793.6
59102	Xunwu	24°57′	115°39′	303.9
59096	Lianping	24°22′	114°29′	214.5
59087	Fogang	23°52′	113°32′	67.8
59082	Shaoguan	24°48′	113°35′	69.3
59065	Hexian	24°25′	111°31′	108.8
59058	Mengshan	24°12′	110°31′	145.7
59046	Liuzhou	24°02′	109°24′	96.8
59037	Du'an	23°56′	108°06′	170.8
59023	Hechi	24°42′	108°03′	211.0
59021	Fengshan	24°33′	107°02′	484.6
59007	Guangnan	24°04′	105°04′	1249.6
57996	Nanxiong	25°08′	114°19′	133.8
57957	Guilin	25°19′	110°18′	164.4
57947	Rongan	25°13′	109°24′	121.3
57932	Rongjiang	25°58′	108°32′	285.7
57922	Dushan	25°50′	107°33′	1013.3
57916	Luodian	25°26′	106°46′	440.3
57906	Wangmo	25°11′	106°05′	566.8
57902	Xingyi	25°26′	105°11′	1378.5
57806	Anshun	26°15′	105°55′	1392.9
56985	Mengzi	23°23′	103°23′	1300.7
56886	Luxi	24°32′	103°46′	1704.3
56875	Yuxi	24°21′	102°33′	1636.7
56786	Zhanyi	25°35′	103°50′	1898.7
56691	Xianning	26°52′	104°17′	2237.5

Data quality control and homogeneity assessment (Fig. 2) were attained using the RClimDex software (available from http://cccma.seos.uvic.ca/ETCCDI/software.shtml). RClimDex is developed and maintained by Zhang and Yang (Li et al., 2012) at the Climate Research Branch of Meteorological Service of Canada. Its initial development was funded by the Canadian International Development Agency through the Canada China Climate Change