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Changes of precipitation extremes in arid Central Asia

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ABSTRACT

Despite growing evidence of increasing precipitation extremes around the world, research into extreme precipitation events in Central Asia (CA) is still scarce. In this study, based on daily precipitation records from 22 meteorological stations, several methods were used to detect the spatial-temporal distribution, abrupt change and return periods for six extreme precipitation indices as well as the total annual precipitation during 1938–2005 in CA. The results show that all precipitation indices experienced increasing trend except for annual maximum number of consecutive dry days (CDD), which had a significant decreasing trend. Abrupt changes for most of precipitation indices mainly occurred around 1957 during 1938–2005. Return periods for all seven precipitation indices concentrated in 10-year period. Meanwhile, all precipitation indices showed spatial diversity and heterogeneity, and the entire area tended to be wetter and experienced fewer dry conditions. Understanding these changes of precipitation extremes in CA will definitely benefit to water resource management, natural hazard prevention and mitigation, and reliable future projections in this region.

1. Introduction

Extreme precipitation events (EPEs) can occur under normal climate conditions. However, global warming affects the water cycle and aggravates the frequency and intensity of EPEs, which then can have profound social, economic and environmental influences (Easterling et al., 2000; Meehl et al., 2000; Allan and Soden, 2008; Liu et al., 2009; Trenberth et al., 2015). Changing trends of precipitation extremes and their effects on ecological systems and society have been put tremendous attentions in the fields of geography, ecology and the environment.

Many scientists have analyzed and estimated the variation tendencies of total precipitation and precipitation extremes in different arid areas based on observations and global climate models. Alexander et al. (2006) and Donat et al. (2016) found that, globally, EPEs showed a general rising trend in the past half-century. In the arid region of northwest China, especially in arid Xinjiang, EPEs had a significant increasing trend except in maximum number of consecutive dry days (CDD), which showed a significant reverse trend from 1960s to 2010s (Wang et al., 2013a, 2013b, 2013c; Chen et al., 2014; Xu et al., 2015a). In contrast, in the entire Arab region and the Greater Horn of Africa, only insignificant increases were detected in consecutive wet days and heavy precipitation (Omondi et al., 2014; Donat et al., 2014), and only a small portion of the Sub-Saharan Africa showed significant increases in EPEs (Chaney et al., 2014). Wet days and heavy precipitation increased across the USA except for western regions (Kunkel et al., 2013; Gallant et al., 2014), and drought increased significantly in the southwest arid area (Peterson et al., 2013; Wang et al., 2014). In South America, the increase in EPEs was insignificant on the east Pacific coast and arid regions of east Argentina, and CDD actually decreased in east Argentina while increasing in Chile (Skansi et al., 2013). In Australia, Gallant et al. (2014) found a statistically significant increase in component 0.9%/10a through using a modified climate extremes index during 1950–2012, and the results of Alexander and Arblaster (2009) predicted that the precipitation indices of simple daily intensity, consecutive dry days and very heavy precipitation contribution were also set to more than double within the next 100 years.

From the above, we can find that the changing trends of total precipitation as well as EPEs in arid areas in the world were more complicated. In some arid areas, EPEs had somewhat increasing trend and dry conditions had decreased, such as the northwest China (Wang et al., 2013a, 2013b; Chen et al., 2014; Chen et al.,

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2015) and the east Argentina (Skansi et al., 2013). While in other arid areas, the dry conditions or CDD had increased, such as the southwest of USA (Peterson et al., 2013) and Australia (Alexander and Arblaster, 2009). Central Asia (CA) is the main portion of the Asian arid regions, which is the largest non-zonal arid area in the world, however, the studies in this area are not enough in-depth.

CA is located in the hinterland of the Eurasian continent, and is far from any oceans, as a result of which only weak water vapor can get here (Chen et al., 2016). Less precipitation makes here as one of the driest areas in the world (Josef et al., 1997). Arid CA zone is extremely sensitive to climate change and is also expected to be severely impacted by projected future warming (IPCC, 2007). In CA, the most serious threat to society from climate change and human activities is the shortage of water resource, which in turn threatens the ecosystem safety, the social-economic sustainability and regional stability (Feng, 2013; Li et al., 2015). The evolution of EPEs will also have significant influence on these aspects as well as lives of people. Therefore, in this paper, we use station-based daily precipitation records during 1938–2005 (68 years) to study spatial-temporal variations, abrupt changes and return periods of EPEs in CA. The research on EPEs under the context of climate change is of great importance for ecological protection and regional economic development in this region.

2. Study area, data, and methodology

2.1. Study area

The CA is about 4 million km^2, which includes the five countries of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, and is generally confined to 50°–80°E and 35°–55°N. Mainly influenced by the west wind circulation and the North Atlantic oscillation, precipitation is greatest in spring and winter. The region has a temperate continental climate characterized by sharp temperature differences, intensive evaporation, and dry and rainless environments (Lioubimtseva and Henebry, 2009; He, 2016). In order to analyze the changing trend of EPEs in the different parts of CA, we take 66°E as a boundary to divide the entire area into the Eastern Region (ER) and the Central and Western Regions (CWR) (Table 1). ER comprises the West Siberian Plain, Kazakhskiy Melkosopochnik, Altai Mountain, Tien Shan Mountains, Pamirs, Balkhash Lake, etc., while CWR comprises Turgayskoye Plato, Turgay Valley, Turan Depression, Caspian Depression, Kyzylkum Desert, Karakum Desert, and the Aral Sea (Fig. 1).

2.2. Data and quality control

We selected 7 precipitation indices introduced by the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) (http://etccdi.pacificclimate.org/list_27_indices.shtml), including annual total wet-day precipitation (Prcptot), consecutive dry days (CDD), consecutive wet days (CWD), number of heavy precipitation days (R10), number of very heavy precipitation days (R20), max 1-day precipitation amount (Rx1), max 5-day precipitation amount (Rx5). These indices were selected to represent the overall precipitation, dry condition, wet condition, and the frequency and intensity of EPEs in CA (Table 2).

At present, due to the poor continuity of station-based daily precipitation data, grid data, re-analysis data, tree ring data and soil data are often utilized to detect climate change in CA (Klein Tank et al., 2006; Lioubimtseva and Henebry, 2009; Chen et al., 2009, 2011; Yatagai et al., 2012; He, 2016). Some studies also showed that grid data and re-analysis data tended to underestimate the frequency and intensity of EPEs (King et al., 2013; Mannig et al., 2013). However, only station-based continuous precipitation data can improve the research accuracy of EPEs.

We downloaded the daily precipitation records of 568 meteorological stations in CA from the National Oceanic and Atmospheric Administration (NOAA) (Menne et al., 2012). R ClimDex software package (R ClimDex) (http://etccdi.pacificclimate.org/software.shtml) (Zhang and Feng, 2004) was used to compute indices of precipitation extremes. Data Quality Control is a prerequisite for indices calculations. Through R ClimDex, we carried out data quality control including identified errors, searched for outliers. And we deleted those stations that missing data surpassed 5%. Due to there were numerous absences of meteorological station data during the 1990s and after that in CA, only 22 meteorological stations were available that passed quality control of R ClimDex, accessed to the most recent year to now, and covered the study area as many as possible (Table 1, Fig. 1). Finally, we compute 7 precipitation indices from the chosen 22 meteorological stations during 1938–2005 in CA through R ClimDex.

Table 1
Stations selected for this study with World Meteorological Organization ID, station name, latitude, longitude, elevation and time ranges of the data.

Id	Station name	North latitude	East longitude	Elevation (m)	Start–end year	
KZ000028676	PETROPAVLOVSK	54.8331	69.15	142	1938–2005	Eastern Region (ER)
KZ000029807	IRTYSHSK	53.35	75.45	94	1938–2001	
KZ000035078	ATBASAR	51.8167	68.3667	304	1938–2005	
KZ000035188	ASTANA	51.1331	71.3667	350	1938–2005	
KZ000035394	KARAGANDA	49.8	73.15	553	1938–2005	
KZ000035576	KZYLZAR	48.2994	69.6994	362	1938–2005	
KZ000035796	BALHASH	46.8	75.0831	350	1938–2005	
KZ000036729	UCH-ARAL	46.1667	80.9331	388	1938–2005	
KZ000036859	ZHARKENT	44.1667	80.0667	645	1938–2005	
KZ000036870	ALMATY	43.2331	76.9331	851	1938–2005	
KZ000038198	TURKESTAN	43.27	68.22	206	1938–2005	
UZM00038457	TASHKENT	41.27	69.2694	477	1938–2005	
UZM00038618	FERGANA	40.3667	71.75	577	1938–2005	
UZM00038927	TERMEZ	37.2294	67.2694	309	1938–2005	
KZ000028952	KUSTANAI	53.2167	63.6167	170	1938–2005	Central and Western Regions (CWR)
KZ000035108	URALSK	51.25	51.4	36	1938–2005	
KZ000035406	TAIPAK	49.05	51.8667	2	1938–2005	
KZ000035416	UIL	49.0667	54.6831	128	1938–2005	
KZ000035700	ATYRAU	47.1167	51.9167	−22	1938–2005	
KZ000035746	ARALSKOE MORE	46.7794	61.6694	62	1938–2005	
UZM00038413	TAMDY	41.7331	64.6167	237	1938–2005	
UZM00038262	CIMBAJ	42.95	59.8167	66	1938–2005	