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Annual and seasonal changes in means and extreme events of precipitation and their connection to elevation over Yunnan Province, China

Fenli Chen [a,*], Hongmei Chen [b], Yanyan Yang [a]

[a] College of Geography and Environment Science, Northwest Normal University, No. 967 Anning East Road, Anning District, Lanzhou, Gansu 730070, China
[b] College of Tropical Crops, Yunnan Agricultural University, China

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ABSTRACT

Based on daily precipitation records at 29 meteorological stations over Yunnan province, the spatial and temporal changes in precipitation index are analyzed during 1960–2013. Eleven indices of precipitation extremes are studied. The results show that regional annual total precipitation shows a significantly decreasing trend and most other precipitation indices are strongly correlated with annual total precipitation. Seasonally, a significant increase in precipitation was discovered for spring, while a decrease in precipitation was found for winter, summer, and autumn. Two significant decreasing trends are found for summer and autumn. Average consecutive dry days, number of heaviest precipitation days, very wet day precipitation, extremely wet day precipitation, maximum 1-day precipitation and simple daily intensity index show increasing trends, but only the last is statistically significant. Decreasing trends are found for consecutive wet days, wet day precipitation, number of heavy precipitation days, number of very heavy precipitation days and maximum 5-day precipitation, but only the first is significant at the 95% level. Spatial changes of precipitation extreme indices show differences, and they are not clustered. For maximum 1-day and 5-day precipitation, the spatial and temporal changes in monthly precipitation are not the same. There are no significant correlations between elevation and trend magnitude of precipitation extremes. An enhanced sensitivity of precipitation extremes at higher elevations is apparent.

1. Introduction

Precipitation is one of the most important variables in diagnosing climate change as well as revealing the eco-environmental response to climate change on a regional scale (Cannarozzo et al., 2006). The temporal and spatial patterns of the precipitation and its impacts on the surface ecosystem have become one of the key issues in the hydrology and ecology (Delitala et al., 2000), and are important from both the scientific and practical points of view (Rodriguez-Puebla et al., 1998; Tosic, 2004). In the context of global warming, one of the most far-reaching impacts concerns the hydrological cycle (Alexander et al., 2006; IPCC, 2007). Due to the increase in greenhouse gases intensifying and downwelling infrared radiation, the global surface temperature is becoming higher, indicating greater water-holding capacity of the atmosphere as well as increased evaporation (Trenberth, 1999). Atmospheric moisture should increase (Groisman et al., 2005; Kharin and Zwiers, 2005; Tebaldi et al., 2006). The intensified hydrological cycle may increase the frequency and intensity of extreme precipitation events (Huntington, 2006). Extreme hydrometeorological events, such as floods and droughts, can have significant environmental, societal, and even political impacts (Zhang et al., 2012a). Precipitation extremes increase in regions where total precipitation has increased, decreased or remained constant (Katz and Brown, 1992; Wagner, 1996; Heino et al., 1999; Folland et al., 2001). From a global view, the changes of precipitation patterns in extremes are not clear, although there are increases in heavy precipitation (Frich et al., 2002). Many studies in many regions around the world have concluded that the increase and decrease in the aspect of precipitation extreme events show spatial differences (Schmidli and Frei, 2005; Choi et al., 2009; Pal and Al-Tabbaa, 2009; Brown et al., 2010; You et al., 2011). Coupled atmosphere–ocean general circulation models (AOGCMs) have also demonstrated agreement in a weaker consensus of changes in precipitation

* Corresponding author.
E-mail address: chenfenli1102@163.com (F. Chen).

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extremes (Tebaldi et al., 2006; Kharin et al., 2007). Several studies have reported that the majority of precipitation indices are correlated with the annual total precipitation, indicating that annual total precipitation is well correlated with extreme precipitation (Han and Gong, 2003; You et al., 2011). In addition, global climate models show that heavy precipitation increases with temperature for daily precipitation extremes (Kharin et al., 2007; O'Gorman, 2012), and that precipitation extreme events in future will become extreme in the context of doubled concentration of greenhouse gases (Zwiers and Kharin, 1998; Pal et al., 2004).

Yunnan Province, located in southwest China, is climatically dominated by the combination of the Southwest and East Asian Monsoons and hence has contrastingly dry and wet seasons (Wen, 2006). High temperature and drought is the most severe event in this region, especially in recent 20 years (Liu et al., 2007). The increase in drought trend in Yunnan leads to a combination of meteorological changes and water needs escalation (Wang and Meng, 2013), especially from November 2009 to March 2010 when a large-scale drought disaster threatened millions of residents with shortage of drinking water and bared farmland because of dearth of rain and irrigation (Mao et al., 2010; Wang et al., 2011; Lü et al., 2012). In most parts in Yunnan, abnormal continuous drought from autumn to early summer of next year results in economic losses, especially in 2005 (Liu et al., 2007). The reason for drought in Yunnan province is not insufficient annual precipitation, but an imbalance in seasonal allocation or temporal and spatial distribution (Yang et al., 2011a). In recent years, all kinds of extreme weather and climate events have frequently occurred in Yunnan. Scholars have studied extreme precipitation from the aspect of the cause of exceptional drought in spring (Yan et al., 2007), severe drought in summer (Liu and Xie, 1998; Xie et al., 2005), the causes of spring–summer consecutive drought (Peng et al., 2010), drought in later spring and early summer (Tao et al., 2009), an analysis of the severity of drought from a perspective of society (Wang and Meng, 2013) and a heavy snow event (Ma et al., 2008) in Yunnan province. However, these previous studies mainly focused on one or some kind of precipitation extreme events, and few articles analyze precipitation extreme events using multiple indices.

This study is focused on analyzing the yearly and seasonal mean precipitation and extreme changes, and discusses the relationships between mean precipitation and extremes. Relationships between precipitation extremes and elevation are also discussed. This study aims to identify if the weather in the study areas in the context of global warming is getting more extreme in terms of precipitation. The main goal is to find changes in extreme daily precipitation using a set of 11 indices generated by the joint CCl/CLIVAR/JCOMM ETCCDI (http://cccma.seos.uvic.ca/ETCCDI), a widely used approach.

2. Data and methods

2.1. Study region and data quality

Yunnan Province, ranging from 28°8′ to 29°16′N and from 97°31′ to 106°12′E, is located in southwestern China. Located on a plateau with an average elevation of 1980 m with mountains mainly in the north and west, the climate in Yunnan Province is typically tropical and subtropical, with an annual precipitation of 1100 mm, a rainy summer and a warm dry winter. A vast region in eastern and central Yunnan is karst topography. A total of 29 meteorological stations in Yunnan province were selected to research the changes in precipitation extremes during 1960–2013 (Fig. 1). Four meteorological stations are excluded because some data for certain time periods are unavailable. Daily precipitation data from the stations is provided by the National Climate Center, China Meteorological Administration.

In order to assure the reliability in climate change research and a prerequisite for calculating climatic indices, data quality control is needed (dos Santos et al., 2011). Methods in data quality control are attained by the National Meteorological Information Center of China Meteorological Administration to correct the errors (Li and Xiong, 2004; Wang, 2004). At the same time, a simple quality control and homogeneity assessment of raw data are operated using RClimDex V1 software (Zhang and Yang, 2004) and RHtest V3 software (Wang, 2008), respectively. The programs are obtainable from http://etccdi.pacificclimate.org.

2.2. Extreme climate indices and methods of trend analyses

We selected eleven extreme precipitation indices from the core indices recommended by the Joint CCl-CLIVAR-JCOMM ETCCDI (http://etccdi.pacificclimate.org). The indices were previously widely used to assess climate changes of the extreme precipitation in different regions of the world (Klein Tank et al., 2006; Vincent et al., 2011; You et al., 2011; Croitoru et al., 2013; Wang et al., 2013a,b). The extreme precipitation indices used can be divided into three types (Croitoru et al., 2013). Indices based on fixed thresholds, heavy precipitation days (R10), very heavy precipitation days (R20), extremely heavy precipitation days (R25), consecutive dry days (CDD) and consecutive wet days (CWD), are those defined on a certain fixed threshold of recorded precipitation amounts and they may vary according to the analyzed region (Hundecha and Bardossy, 2005). Indices based on station-related thresholds, such as very wet days (R95p) and extremely wet days (R99p), are those indices defined on a percentile-based threshold, and defined as days surpassing the long-term percentiles (El Kenawy et al., 2011). Non-threshold indices class includes those indices computed considering the absolute values recorded in the area yet not considering any threshold, which are focused on the monthly absolute values of the precipitation recordings (Croitoru et al., 2013). Five indices were considered: maximum 1-day precipitation amount (RX1day), maximum 5-days precipitation amount (RX5days), simple daily intensity index (SDII) and annual total wet-day precipitation (PRECPTOT).

The calculation of the 11 extreme indices based on precipitation data (Table 1) in this study is performed using the software RClimDex. The non-parametric Sen's method (Sen, 1968) is applied to estimate the long-term trend magnitudes of precipitation indices on seasonal and annual basis. Regional averages are calculated as an arithmetic mean of values at all stations in the study, and the correlations among these indices are also analyzed. Mann–Kendall test (Kendall, 1955) is employed to calculate significant trend at the 0.05 level. A trend is considered statistically significant at 95% significance level. The number of stations with the same trend as that for the whole region has been counted for each index, and stations with significant trends have also been identified. In addition, the 10-year smoothing average is used to show the interannual variation of climatic extremes. For spatial differences of the climate extreme events, the spatial distribution maps are drawn by inverse distance weighted in ArcGIS 9. Factor analysis is used to partition the data set into clusters with in-cluster similarities and between-cluster dissimilarities (Li et al., 2012a).

3. Results

3.1. Changes in annual and seasonal total precipitation

The trends of annual and seasonal total precipitation during 1960–2013 over Yunnan province are shown in Fig. 2. The annual