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Long-term change of wet and dry climatic conditions in the southwest karst area of China

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ABSTRACT

Using the daily precipitation and temperature data at 153 stations in the karst area of Southwest China from 1959 to 2009, the long-term change characteristics of wet and dry climatic conditions are analyzed by the Mann–Kendall test. This study shows that: 1) the annual average temperature has increased at 88% of the stations with an average rate of +0.16 °C/10-year. This increase rate is greater than +0.30 °C/10-year in the southeastern, northeastern, and western parts of the study region. Very warm days and abnormally warm days were seen increased at 47% and 63% of the stations, respectively. Very cool days and abnormally cool days in a year have reduced at respectively 94% and 95% of the stations; 2) no clear change trend was found for average annual precipitation over the entire area as a whole, but regional and seasonal changes were quite obvious. The annual total precipitation has decreased by −22.5 mm/10-year in the central part but increased by +8.9 mm/10-year in the western part of the region, and summer and winter seemed to become wetter while spring and autumn became drier. Although the number of rainy days in a year has decreased at almost 53% of the total stations with an average rate of −3.9 days/10-year over the entire area, the number of extremely heavy rainy days has increased by +0.2, +0.4 and +0.4 days/10-year in the southern Sichuan Province, the central part of Yunnan Province, and the northeastern Hubei Province, respectively; and 3) the extreme drought became more serious. The consecutive dry days has increased significantly at nearly 46% of the stations, especially in the western Guangxi Autonomous Region, the southern Guizhou Province, and the eastern Chongqing Municipality. The extreme drought remained at a high frequency at the beginning of the 21st century. It has shifted gradually from the eastern and western parts to the south-central part which is characterized by medium-high rocky desertification. Hopefully findings from this study will help for a better understanding of the impacts to some eminent geological hazards such as rocky desertification, increased frequency of drought and storms, and landslides in recent years.

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1. Introduction

Regional wet and dry conditions have experienced considerable change in the world over the past several decades (Allen and Ingram, 2002; Gu et al., 2007). Changes in the spatial and temporal distribution characteristics of precipitation have been identified in Europe (Haren et al., 2013), in America (Matsuyama et al., 2002; Barros et al., 2008), in Africa (Mxolist et al., 2011), and also in Asia (Zhai and Zou, 2005; Goswami et al., 2006). Drought frequencies have increased at various degrees from the late 20th to the early 21st centuries (Dai et al., 2004; IPCC, 2007). Changes in temperature and the wet and dry conditions in China are also noticeable. An analysis by Xu et al. (2011) indicated that the average temperature has increased by about +0.2–0.3 °C/10-year in northern China and around +0.1 °C/10-year in southern China. You et al. (2011) has found that the annual extreme low and high temperatures had a consistent increase in north, northeastern, and northwestern China, cold days and cold nights had decreased by −0.47 and −2.06 days/decade respectively, and warm days and warm nights had increased by +0.62 and +1.75 days/decade, respectively. Qi and Wang (2012)'s study showed that summer average, minimum and maximum temperatures all displayed a significant increase trend throughout China. The average temperature increase in north China was as high as +4.47 °C/decade since the early 1990s. For precipitation, no clear change trend was found for the average annual precipitation in China as a whole, but regional and seasonal changes are quite obvious (Li, 2011; Ye et al., 2013). Studies by Zhai et al. (2004) and Sui et al.(2013) indicated an increasing trend of annual precipitation in northwestern China and the middle to lower reaches of the Yangtze River valley but a decreasing trend in southern, northeastern, and northern China. Ma and Ren (2007) specified that northern, northeastern and southwestern China were getting drier over the past 50 years. Analyses

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by Sui et al. (2013) and B.L. Wang et al. (2013) indicated that the extremely heavy rains have increased significantly across the entire China. W.G. Wang et al.'s study (2013) showed a clear change trend in precipitation, i.e., more precipitation in the summer and winter seasons but less precipitation in the spring and autumn in the Yellow River Basin.

The climatic condition in southwestern China, largely a karst area, has been considerably variable in the past several decades as well. A study by Fan et al. (2010) showed that the annual temperature had increased with a rate of +0.3 °C/10-year from 1961 to 2004 in the Yunnan Plateau, and the average increases of the winter and summer temperatures reached +0.33 °C/10-year and +0.26 °C/10-year, respectively. Xu et al. (2011) found that the frequency of annual extreme warm days has increased by 1.8% since the 1990s in Southwest China. In general, summer and winter seem to become wetter but spring and autumn become drier (Du et al., 2013). Although the number of rainy days has decreased significantly over almost of the entire southwestern China (Gemmer et al., 2011), the number of extremely heavy rains has increased in most of the region (Zhai et al., 2004). The study by M. Zhang et al. (2013) indicates that extreme drought has occurred more frequently and has become one of the most serious hazards in recent years in Southwest China. Barriopedro et al. (2012) reported that the severe autumn drought in 2009 destroyed more than 80% of the vegetation cover in the Yunnan and Guizhou Provinces and in the Guangxi Autonomous Region. More than 60 million residents suffered drinking water shortages during this drought (W.J. Zhang et al., 2013).

Studies by Liu et al. (2010) and Jiang et al. (2014) have shown that changes in temperature and the wet and dry conditions would have a direct impact to the hydrologic cycle, ecological environments, and economic development in the southwest karst region. Quantifying changes in climatic conditions, particularly changes in temperature and wet and dry conditions in the region is not only essential for water resource management but also crucial in combating geological hazards such as rocky desertification and landslides. The goal of this paper is to conduct a comprehensive analysis on the change characteristics of temperature and the wet and dry conditions in the entire southwest karst area by using the daily precipitation and temperature data from 1959 to 2009 from 153 monitoring stations.

2. Data and methodology

2.1. Study area

The karst area of Southwest China, located between the longitudes of 97°39′E and 117°18′E and latitudes of 23°41′N and 29°15′N, is one of the largest karst geomorphologic distributing areas in the world (Huang et al., 2008). The eight provinces, namely Yunnan Province, Guizhou Province, Guangxi Autonomous Region, Sichuan Province, Chongqing Municipality, Guangdong Province, Hunan Province, and Hubei Province, have more than 0.51 million km^2 of exposed/outcropped carbonate rock areas (Fig. 1), 5.8% of the total land (Table 1). In particular,

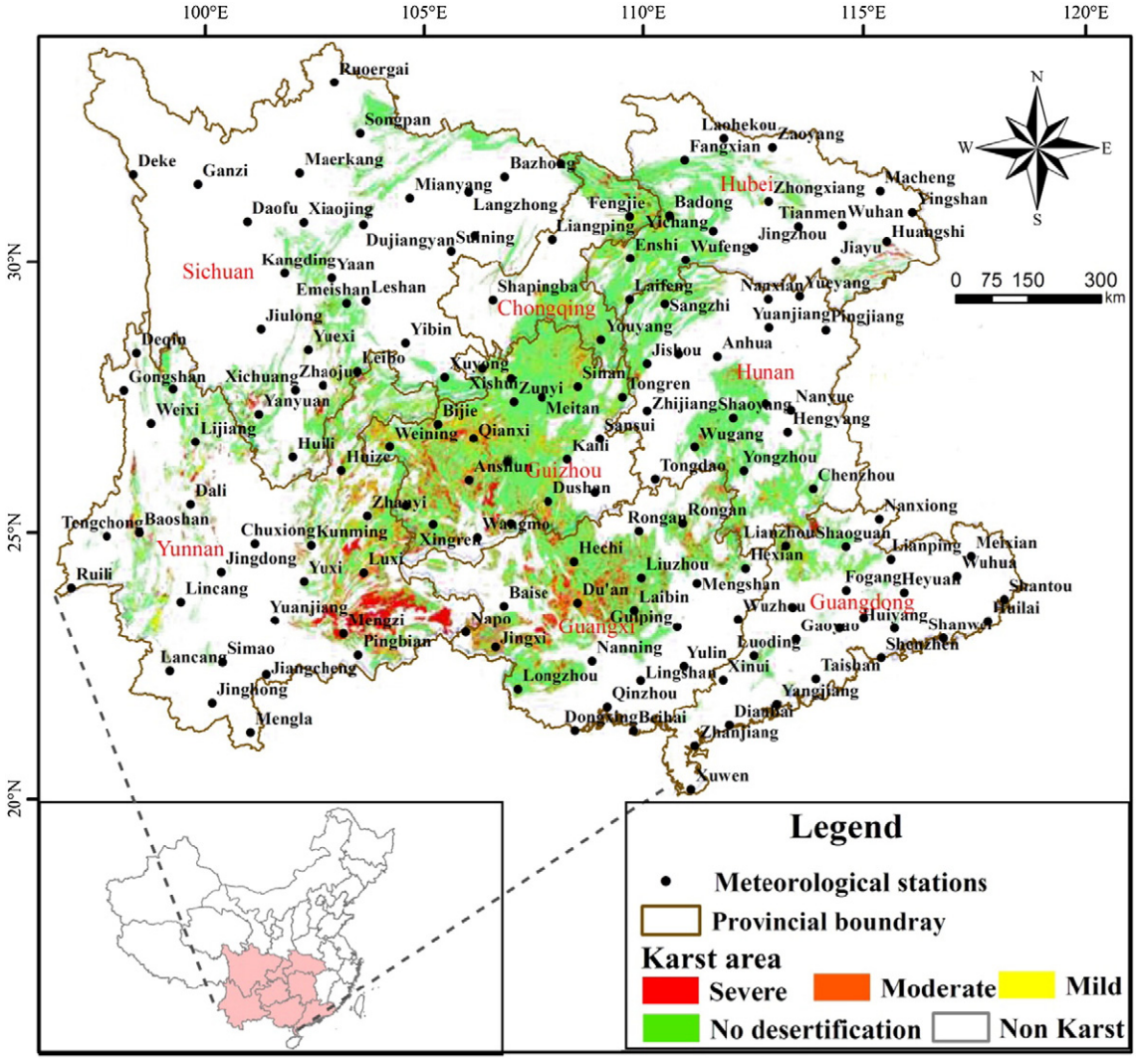

Fig. 1. Distribution of meteorological stations and rocky desertification areas in Southwest China.

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