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Relationship between large scale atmospheric circulation, temperature and precipitation in the Extensive Hexi region, China, 1960–2011

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A B S T R A C T

This study investigates the relationship between large scale atmospheric circulation and changes in temperature and precipitation within the Extensive Hexi region during the period 1960–2011. This was accomplished by statistically analyzing data from 26 meteorological stations along with monthly mean geopotential height, wind fields at 500 hPa, SLP data and the NCEP/NCAR reanalysis data set. The variation of large scale atmospheric circulation has contributed greatly to regional warming, especially via the increasing geopotential height. Regional warming is further caused by increased anticyclonic circulation in the summer and increased anomalous cyclonic circulation and westerly currents in winter. The strong convergence of water vapor in part explained the precipitation increase. Additionally, warm and wet flow moving to the north and west brought more precipitation under the strong western pacific subtropical high. Moreover, precipitation and precipitation extremes showed positive anomaly in the La Nina I and El Nino I years, whereas they displayed negative anomalies in the La Nina II and El Nino II years.

1. Introduction

Global climate change has been evident in many places worldwide (Peterson et al., 2002; Zhang et al., 2005; New et al., 2006; Aguilar et al., 2008; You et al., 2010, 2013a, 2013b; Li et al., 2011, 2012a, 2012b). Annual mean temperature increased by 0.4–0.5 C° from 1860 to 2005 in China (China Meteorological Administration, 2006). The warming trend is more pronounced in western China, particularly in the northwest (Ye et al., 2004; Liu et al., 2005). With temperature and precipitation rising, regional climate is experiencing the change from warm-dry to warm-wet in northwestern China (Shi et al., 2002, 2003). Forming a comprehensive understanding of climate change and its effects is critical for climate change adaptation.

The Extensive Hexi region lies in northwestern China and encompasses the Heihe river basin, the Qilian Mountains, the Hexi corridor, and two deserts. Climate research in the study region has mainly concentrated on the variation of average temperature and precipitation in the Qilian Mountains or the Hexi corridor. We still lack a comprehensive understanding of climate change in the whole region, and there is essentially no research on the variation of climate extremes. Based on the research by Lan et al. (2001), annual mean temperature exhibited a fluctuating increase in the past 50 years and accretive warming since the 1990s. Zhang and Guo (2002) confirmed that the eastern Qilian Mountains showed obvious warming in the 1990s, while other regions were already warming in the middle 1980s. Yin et al. (2009) found that annual mean temperature growth accelerated after the mid-1980s. The temperature of the Hexi corridor manifested a rising trend from 1950 to 1999, and the precipitation in middle and west regions increased distinctly (Chen et al., 2002). The temperature and precipitation of the upper region of the Heihe River has been increasing since the 1950s (Li and Liu, 2004a,b). Tang (1985) showed that temperature was increasing significantly after the middle of the 1980s in Qilian Mountains, mainly related to the rise of temperature in autumn and winter. The same author reported that precipitation experienced an increasing trend from the 1960s–1980s, decreasing trend in the 1990s. The precipitation trend was on the increase again after 2000 according to Jia et al.

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(2008). Chen et al. (2007) studied the regional difference in precipitation patterns in the eastern and western Qilian Mountains. Zhang et al. (2007) hypothesized that water vapor was mainly brought by the westerly winds in the northwestern Qilian Mountains, by the South Asian monsoon in the middle-south Qilian Mountains and by the East Asian monsoon in the northeastern Qilian mountains.

The objectives of this study are to investigate the relationship between the changes in temperature and precipitation during 1960–2011 and the large scale atmospheric circulation in Extensive Hexi region. This should lead to a better understanding on the effects of climate change and thereby improve water resource management and the development of Hexi oases.

2. Study area

The Extensive Hexi region (36°–43°N; 92°–107°E) lies in northwestern China and covers an area of 31.55 × 10^4 km^2 that includes the Qilian Mountains and the Hexi corridor. The region encompasses three inland river basins: the Shiyanghe River basin, the Heihe River basin and Shulehe River basin (Fig. 1). There are also two deserts in the region: the Badain Jaran desert and the Tengger desert. The Qilian Mountains lie in the northeastern edge of Qinghai–Tibet plateau of China. They are made up of several parallel mountains and valleys, stretching 850 km from northwest to southeast and extending 200–300 km from south to north. In the Qilian Mountains, the altitudes of about 30% of the mountains are above 4000 m, and its highest peak is Tuanjie Peak with an altitude of 5826.8 m. The temperature varies by altitudinal change from valley to mountain. The annual mean precipitation, which displays a decreasing trend from east to west and from south to north, varies from 400 to 700 mm. The Qilian Mountains are very important to Hexi oases because they are the source of the Shiyanghe, Heihe and Shulehe Rivers. The Hexi Corridor is located at the western end of the Wushaoling Mountains and includes five cities: Wuwei, Zhangye, Jiuquan, Jinchang and Jiayuguan. The corridor covers an area of 271,100 km^2 and crosses an arid to semiarid part of China. The annual mean precipitation is 50–200 mm, and precipitation decreases from east to west. Annual potential evaporation increases from more than 2000 mm in the east to 3500 mm in the west. The five main cities in the Hexi Corridor are situated within inland watersheds with an annual mean runoff that totals 1.6 billion m^3 in the Shiyanghe watershed, 3.2 billion m^3 in the Heihe watershed and 1.72 billion m^3 in the Shulehe watershed.

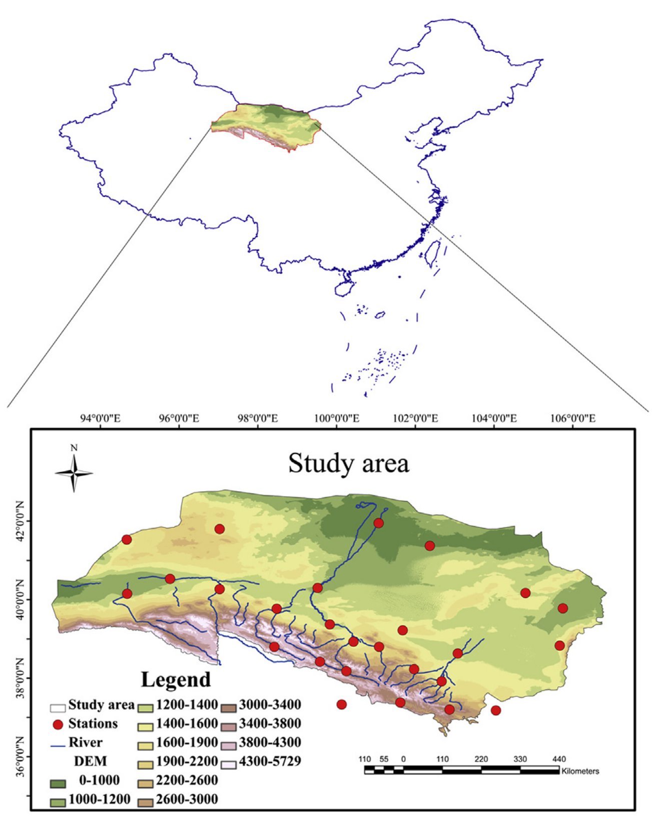

Fig. 1. Extensive Hexi region and its location in China.

The Badain Jaran Desert (39°N to 41°N; 100°E to 104°E) spans approximately 50,000 km^2 within the Alashan Plateau and is considered the fourth largest desert in China. It is bordered by mountain ranges to the south and southeast (the Heishantou and Yabulai Mountains, respectively), and it is adjacent to the lowland areas of the Gurinai grassland and the Guezi Hu lacustrine plains to the west and north. The landscape consists primarily of unconsolidated sand dunes. Climatically the area is strongly continental and is regarded as a cold desert. Daytime temperatures in summer months range up to 40 °C, mean monthly temperatures fall to −10 °C in January and minimum temperatures are below zero for most of the year. The southeastern Badain Jaran is near the current northern extent of the East Asian monsoon which provides the primary source of precipitation, 70% of which falls from July to September. Cold and dry continental air masses from prevailing westerly winds dominate in winter. The Tengger Desert is located in the arid-semiarid area of northwestern China with a total area of 36,000 km^2. The desert is bounded by the Qilian Mountains in the southwest and by the Yabulai Mountain in the northwest. The Helan Mountain, a barrier for the East Asian Monsoon, separates the Tengger Desert from the Mo Us sandy land to the east. To the south, the desert stretches as far as the Loess Plateau. Climatically, the area is situated at the conjunction of the arid-hyperarid northwest, the arid-semiarid southeast, and the cold mountain-plateau regions in the southwest. The annual mean temperature and precipitation are 7.8 °C and 115 mm, respectively, while the annual mean potential evaporation is approximately 2600 mm. The Tengger Desert is primarily covered with mobile sand dunes.

3. Data and methods

The daily precipitation, maximum temperature and minimum temperature data were provided by the National Climate Center, China Meteorological Administration (CMA) (http://www.nmic.gov.cn/). The modern nation-wide network of weather observing stations in China began operation in the 1950s. There are 36 stations in the original data set that have maintained daily observations since the 1950s or 1960s. We selected 26 stations from the dataset based on quality control and homogenization procedures described in Li et al. (2011). The selected 26 stations all have data available since 1960. The monthly mean geopotential height and wind fields at 500 hPa were obtained from the National Oceanic and Atmospheric Administration-Cooperative Institute for Research in Environmental Sciences (NOAA-CIRES) Climate Diagnostics Center reanalysis R1 dataset (available from http://www.cdc.noaa.gov/). This data set covers January 1948 to the present with a spatial resolution of 2.5° × 2.5° and with continuous global coverage (Kalnay et al., 1996; Kistler et al., 2001). The index of El Nino is from NOAA Climate Prediction Center (CPC), and the index of the Western Pacific subtropical high is provided by the National Climate Center, CMA. The intensity of the westerly flow is represented by the Zonal Index calculated using the SLP data and from the NCEP/NCAR reanalysis data based on the definition by Rossby (1939).