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The roles of convective and stratiform precipitation in the observed precipitation trends in Northwest China during 1961–2000

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ABSTRACT

Northwest China is one of the most arid areas in East Asia. Previous studies pointed out that some regions of Northwest China experienced a dry to wet climate change in the past half century. This study analyzed the observed daily precipitation during 1961–2000 in Northwest China. Results show that the annual precipitation in Northwest China has different trends in the western region and the eastern region. The western region has a significant increasing trend as shown in previous studies, while the eastern region has a decreasing trend. It is found that the increasing trend in the western region is caused by the increase of the heaviest precipitation in summer, while the decreasing trend in the eastern region is caused by the decrease of the heaviest precipitation in autumn. In order to find out the dominating precipitation type in the change of precipitation, a simple parameter is used to distinguish convective precipitation from stratiform precipitation. It is found that the increase of the heaviest precipitation in summer in the western region resulted from the increased frequency of convective precipitation, and the decrease of the heaviest precipitation in autumn in the eastern region was caused by the decreased frequency of stratiform precipitation.

1. Introduction

Since last century, precipitation amount and spatial distribution have changed worldwide, especially in the middle and high latitudes in the northern hemisphere (Hartmann et al., 2013; New et al., 2001). Precipitation in China has experienced significant spatial and temporal changes (Li et al., 2010; Liu et al., 2005; Song et al., 2015; Wang and Zhou, 2005; Xu et al., 2011; Ye et al., 2013; Zhai et al., 2005). Precipitation change in the arid and semi-arid areas in China has especially been focused recently (Deng et al., 2014; Shi et al., 2002, 2007).

Northwest China is located in one of the most arid areas in East Asia. There are complicated terrains including the Taklimakan desert, Gobi desert, high mountains and glaciers that are important for Asian climate. The melted water of glaciers and snows on high mountains are the origins of major rivers and provide the major water resources for local people. Thus, changes of precipitation in this area have significant effects on local agriculture, ecology, environment as well as water resources. It is important to investigate the characteristics and changes of precipitation in this area, and the reasons for the changes.

Previous studies indicate that the climate in the arid Northwest China has experienced a dry to wet change during the second half of the 20th century (Liu et al., 2005; Qian and Lin, 2005; Shi et al., 2007; Zhai et al., 2005). However, the change is only confined to the western region of Northwest China, i.e. Xinjiang, Hexi Corridor, Qilian mountainous areas and parts of Qinghai. In eastern Northwest China including east of Qinghai, Ningxia and Shaanxi, the annual precipitation shows a decreasing trend (Li et al., 2003; Shi et al., 2007). In addition, the precipitation trend differs in mountain, oasis and desert areas in Northwest China (Li et al., 2013). Precipitation increased by 10.15 and 6.29 mm decade^{-1} in the mountain and oasis areas respectively, but did not increase significantly in the desert areas (Li et al., 2013). The precipitation trends differ with seasons. Zhou and Huang (2010) found that summer precipitation in Northwest China had an interdecadal increase since 1978. Previous studies indicated that precipitation in the western region of Northwest China especially in north Xinjiang increased in all seasons with summer having the largest contribution (Liu et al., 2011). However, autumn precipitation in eastern Northwest China decreased significantly (Song and Zhang, 2003). The reasons of the changes of precipitation in Northwest China remain to be found.

In the other areas of China, it is also found that precipitation can increase or decrease during the second half of the 20th century. The annual precipitation decreased significantly in southern northeast China, North China Plain, Sichuan Basin, and increased significantly in the Yangtze River Valley, and the southeastern coast (Zhai et al., 2005).

Some researches point out the changes of precipitation are caused by the following factors: microphysical, dynamical, and water vapor supply changes. Aerosols can affect precipitation through changing cloud microphysics. In Huashan Mountain, which is located in eastern Northwest China, Rosenfeld et al. (2007) found that air pollution is a

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major cause for suppressing orographic precipitation in the mountain areas. Increased aerosols also play an important role in the decreasing trend of light rain in eastern China through the microphysical processes such as the suppression of droplet collision-coalescence (Qian et al., 2009). Huang et al. (2006) found that the semi-direct effect of dust aerosols may play a role in cloud development over arid and semi-arid areas of East Asia and contribute to the reduction of precipitation. Aerosols are also the reason for precipitation reduction in eastern central China through dynamical processes (Zhao et al., 2006). Based on observed precipitation, MODIS data, and meteorological sounding data over eastern central China, Zhao et al. (2006) proposed a possible positive feedback cycle, where more aerosols reflect more sunlight, making the lower troposphere cooler and enhancing the atmospheric stability. As a result, precipitation is decreased, the efficiency of washout of aerosols is reduced, leading to more aerosols in the atmosphere. Zhou and Huang (2010) revealed that in Northwest China the summer temperature decreased at 300 hPa but increased near the surface after 1978 which enhances convective instability, strengthens ascent, and increases summer precipitation. In addition, the changes of precipitation are linked to water vapor content closely. Shi et al. (2007) suggested the increased precipitation in western Northwest China is caused by two facts: abrupt increase of atmospheric vapor content in western Northwest China since 1987 and the strengthening of water cycling resulted from global warming.

Currently there are researches focusing on the role of different precipitation types in total precipitation changes instead of analyzing physical mechanisms directly (Rulfová and Kyselý, 2013). Different precipitation types, i.e., stratiform or convective, may respond to microphysical and dynamical factors differently. Convective precipitation and stratiform precipitation result from different processes (Ruiz-Leo et al., 2013). Stratiform precipitation is related to mid-latitude fronts, horizontal large-scale convergence, or orographic forcing, with weak updraft (Houze, 1997; Ruiz-Leo et al., 2013). Convective precipitation develops from thermodynamically unstable conditions and is featured by strong ascents (Xu, 2012). It is often intense and local (Rogers and Yau, 1989; Ruiz-Leo et al., 2013). It has been shown that the vertical latent heating profiles in stratiform and convective precipitation are different (Lin et al., 2004; Mapes and Houze, 1995). Thus, different precipitating processes have different effects on atmospheric circulation and in turn affect precipitation differently. It has also been shown that extremes of stratiform and convective precipitation respond to temperature change in different degrees (Berg et al., 2013). Extremes of stratiform precipitation increase with temperature at approximately the Clausius–Clayepron rate, while the intensity of convective precipitation increases at a faster rate with temperature (Berg et al., 2013). Since 1960 the air temperature of Northwest China has been significantly rising with a rate of 0.343 °C decade^{-1} higher than that of average of China and the world (Li et al., 2012). Temperature rising at so fast rate may imply high increase of convective extreme events. It is estimated that temperature will increase in this century due to the release of greenhouse gases (Gao et al., 2001; Li et al., 2003; Shi et al., 2007) and therefore it is possible that convective precipitation keeps increasing. Figuring out the dominating precipitation type in precipitation change in Northwest China may reveal the underlying reasons of the change and it will benefit the prediction of precipitation trend in the future. Moreover, it will help the administration to make appropriate decision to prevent disasters and reduce damages. There are rare studies pointing out whether convective or stratiform precipitation dominates the change of precipitation in Northwest China.

This study uses the observed data to investigate the dominating type of precipitation that is responsible for the precipitation trends in Northwest China. We first investigate which season contributes the most to the trends of the annual precipitation. We then find out which category of daily precipitation in that season makes the largest contribution to the trends of the annual precipitation. Thirdly, we study whether this category is mainly caused by convective or stratiform precipitation. Finally, the text is organized as follows: Section 2 introduces the data used and methodology involved; Section 3 shows the main results and Section 4 will conclude the whole study and suggest future research.

2. Data and methodology

The complete dataset of daily (24 h) precipitation amount at 126 stations in Northwest China from January 1, 1961 to December 31, 2000 is used in this study. The datasets are from the National Climatic Centre of China, China Meteorological Administration and have passed the quality control before they were released (Feng et al., 2004). Among the daily precipitation data of 126 stations during 1961–2000, there are only 6 missing values in winter. Before or after the 6 data points, there is no precipitation or very little precipitation. Therefore we interpolated each of the 6 data points by the 2 data points before and after. The studied area includes 6 provinces: Xinjiang, Gansu, Ningxia, Qinghai, Shaanxi, and the western parts of 112°E of Inner Mongolia. The geography of the studied area and the distribution of stations are shown in Fig. 1.

The studied area is divided into two parts roughly according to the precipitation amount and their opposite precipitation trends in recent 50 years: region A is located to the west of 100°E and region B is located to the east of 100°E. The 100°E line is the same as in the study of Chen and Dai (2009) dividing the two parts of the studied area based on the opposite annual precipitation trends during 1958–2005. The division of the studied area is also a result of considering the different climatic features and wind fields in the two regions. The research of Xie (2000) indicates that region A (the west of Northwest China) is mainly dominated by the westerlies, while region B (the east of Northwest China) is more influenced by the monsoon systems. The climatic seasonal wind field of 850 hPa reveals that the two regions generally have different wind fields and hence may have different water vapor sources. In summer when the precipitation is the largest contributor to the annual precipitation, region A is mainly dominated by the wind from the north and east, while region B is mainly dominated by the wind from the south that contains heat and moisture for precipitation formation. There are 66 stations in region A and 60 stations in region B. It is obvious that the distribution of stations in region A is sparse while in region B the stations distribute more densely. In the studied area, there are also 25 stations that have uncontinuous precipitation records, or station repositioning adjustment, and therefore those stations are not included in the 126 stations in this study.

The annual precipitation for each station is calculated by summing up daily precipitation in every year. The seasonal precipitation is calculated in a similar way. In this study, spring includes the months of March, April, and May; summer includes the months of June, July, and August; autumn includes the months of September, October, and

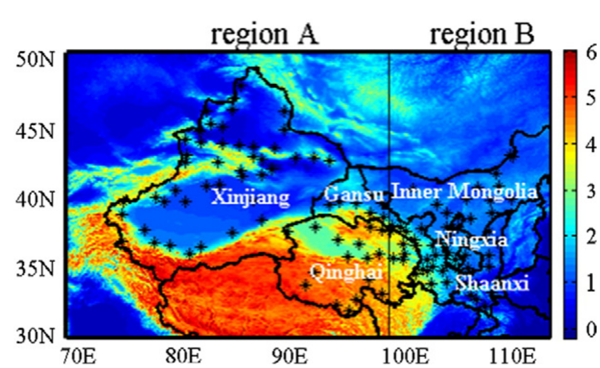

Fig. 1. Distribution of meteorological stations (black asterisks) in Northwest China and the elevation (in km) of the area. The black line along 100°E divides the area into two parts: region A and region B. The names of the six provinces in the area are also shown in the figure. For Inner Mongolia, only the west parts of 112°E are included in this study. A total of 126 stations are in the area. There are 66 stations in region A and 60 stations in region B.