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Spatiotemporal variations in precipitation across the Chinese Mongolian plateau over the past half century

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ABSTRACT

Precipitation, as affected by climate change, controls the growth of steppe grasses and grassland degradation/desertification in semiarid/arid regions, including the Chinese Mongolian plateau. This study examined the spatial variability and temporal trends in precipitation across the plateau in terms of four indexes: total precipitation (P), number of rainy days (W_d), number of precipitation events (N), and average precipitation intensity (I_{mean}). Although seldom published in the literature, this information is vital for efforts to develop adaptive measures to sustain this vulnerable pasture economy. Seven hundred time series were formulated by preprocessing the data on daily precipitation over the period 1960 to 2012 at 25 weather stations scattered across the plateau. The results indicated that although the plateau was becoming drier overall, the intensity of storm events increased markedly, as indicated by decreasing trends for P, W_d and N but an increasing trend for I_{mean}. On average, P decreased by 0.65 mm yr^{-1} over the study period, while I_{mean} increased by 0.2 mm d^{-1} yr^{-1}. Across the plateau, the western part was becoming wetter, while the central-eastern part was becoming drier. This spatial discrepancy in the precipitation trends was particularly obvious in the winter dry season, with I_{mean} tending to increase more rapidly in the central-eastern than western part, especially in the spring dry season. It is expected that these trends will continue, thus further challenging the already vulnerable eco-environment of the plateau.

1. Introduction

Climate change, resulting in trends in precipitation and/or air temperature, has been widely cited as an important reason for alterations in the natural hydrologic cycle and ecological environment in many regions across the world (Ziegler et al., 2003; Cannarozzo et al., 2006; Allan and Soden, 2008; Stephen et al., 2010; Liang et al., 2011; Bindoff et al., 2013; Sagarika et al., 2014), including the low- (< 50° N) and middle-latitude (50 to 60° N) Mongolian plateau (Dan et al., 2013). Previous studies on climate change have been primarily conducted in North America and Europe (e.g., Lettenmaier et al., 1994; Groisman et al., 1999; Zhang et al., 2000; Ventura et al., 2002; del Rio et al., 2005; Cannarozzo et al., 2006; Bocheva et al., 2009; de Lima et al., 2010; Karpouzos et al., 2010; Martinez et al., 2012; Gocic and Trajkovic, 2013; Rougé et al., 2013; Sagarika et al., 2014; Sayemuzzaman and Jha, 2014; Sayemuzzaman et al., 2014), largely because long-term climate data are available for many locations in these regions (Hegerl et al., 2015). Besides, a number of studies have been conducted in the primarily agricultural areas of large Asian countries such as China, India, and Turkey (Türkeş, 1996; Gong and Wang, 2000; Wang and Zhou, 2005; Zhai et al., 2005; Partal and Kahya, 2006; Qian et al., 2007; Liu et al., 2008; Krishnakumar et al., 2009; Pal and Al-Tabbaa, 2009; Piao et al., 2010; Liang et al., 2011; Subash et al., 2011; Tabari et al., 2011; Xu et al., 2011; Zhang et al., 2011, 2012; Some'e et al., 2012; Pingale et al., 2014; Wang et al., 2014a). These previous studies invariably predicted a generally upward trend in air temperature, but when they came to precipitation the picture was more mixed, with some researchers anticipating greater, whereas others predicting less, precipitation in the future. This inconsistency suggested that precipitation trends are likely subject to considerably more spatial heterogeneity than those for air temperature, making it necessary to examine trends of precipitation in areas beyond those reported in existing literature.

Gong and Wang (2000) examined summer storm events in east China and found that summer precipitation in this region exhibited a significant downward trend from the 1950s to mid-1970s but a positive trend thereafter. Hereinafter, significance level of $\alpha = 0.05$ was used in the statistical trend tests. Wang and Zhou (2005) analyzed trends of

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extreme precipitation events and annual and seasonal precipitation across China for the forty years from 1961 to 2001, and found that although the annual precipitation increased significantly in southwest, northwest and east China, it decreased significantly in central, north and northeast China. The upward trend in the east of the country primarily occurred in summer, whereas, the downward trends in the central, northern and northeastern areas occurred in spring and autumn; the upward trend in most of the northwest occurred in all four seasons. These inconsistent findings for precipitation trends in east China can be attributed to that these two studies used time series data for different record periods.

Zhai et al. (2005) analyzed annual/seasonal trends in total and extreme-daily precipitation in China. The results indicated that for the country as a whole, the total precipitation exhibited no significant trend. However, when analyzed by regions, the total precipitation did exhibit significant trends. For the northern region, which includes the area of this study (i.e., Chinese Mongolian Plateau), the annual and summer total precipitation had a significant downward trend; although the number of rainy days tended to decrease, the rainfall intensity tended to increase. On the other hand, Qian et al. (2007) showed an overall downward trend from 1961 to 2005 for light rainfall events across China but region-specific trends for moderate rainfall events. Liu et al. (2008) found that the annual precipitation in Yellow River Basin exhibited significant spatial variability from one longitude zone to another and that for a given zone the annual precipitation had a significant downward trend from 1961 to 2006.

Piao et al. (2010) showed that the summer and fall precipitation in the arid regions of north China exhibited a downward trend and that the number of rainy days across the entire country also declined overall. Liang et al. (2011) reported that the annual and summer precipitation in northeast China trended down from 1961 to 2008. Those authors attributed these downward trends to the southeast-northwest trajectory of East Asian monsoon. In contrast, Zhang et al. (2011, 2012) showed that for China as a whole, although the maximum number of consecutive wet days was not significantly changed, the total number of rainy days exhibited a significant upward trend. Across the Pearl River basin of south China, the precipitation and its intensity had an increasing trend from 1960 to 2005, whereas, the occurrence and number of wet days had a decreasing for this same period.

The above studies in China were primarily conducted for agricultural areas, examining the factors that are important for food production such as amount of precipitation and number of rainy days. In contrast, few studies have looked at what happened and is happening on the steppe grasslands of the Chinese Mongolian plateau, where precipitation controls forage production and grassland degradation/desertification (Hu et al., 2014), but it is most sensitive to climate change (Klein Tank and Koennen, 2003; Brommer et al., 2007; Zolina et al., 2010; Zhang et al., 2012). The objective of this study was therefore to examine spatial variability and temporal trends in precipitation across the Chinese Mongolian plateau (Fig. 1) for the period 1960 to 2012. The examination used four derivative indexes, namely total precipitation (P), number of rainy days (W_d), number of precipitation events (N), and average precipitation intensity (I_{mean}), at annual and seasonal temporal scales.

2. Materials and methods

2.1. The Chinese Mongolian plateau

The plateau is located in north China and covers the entire 1,180,000 km^2 Inner Mongolian Autonomous Region (97°12′–126°04′ E, 37°24′–53°23′ N). Its topographic elevation varies from 90 to 3259 m above mean sea level (Fig. 1). The primary land cover is steppe grasses and forests, accounting for about 70% of the total area. Sandy soils dominate in the west and black cryudoll soils in the northeast, with chestnut and chernozem soils in the central area (Wen and Liang, 2001). The plateau has a continental temperate and/or arid/semiarid climate, with dry and cold/windy winter and spring, relatively wet and warm summer, and temperate and cool fall; the annual average temperature varies from 0 to 8 °C, depending on the geographic location.

The annual average precipitation varies from 35 mm in the northwest to 468 mm in the southeast, with about 80% of this falling in the wet season (June through September). The precipitation is most in summer (June, July, and August) but least in winter (December, January, and February) (Fig. 2). July is the wettest month, whereas, January is the driest month.

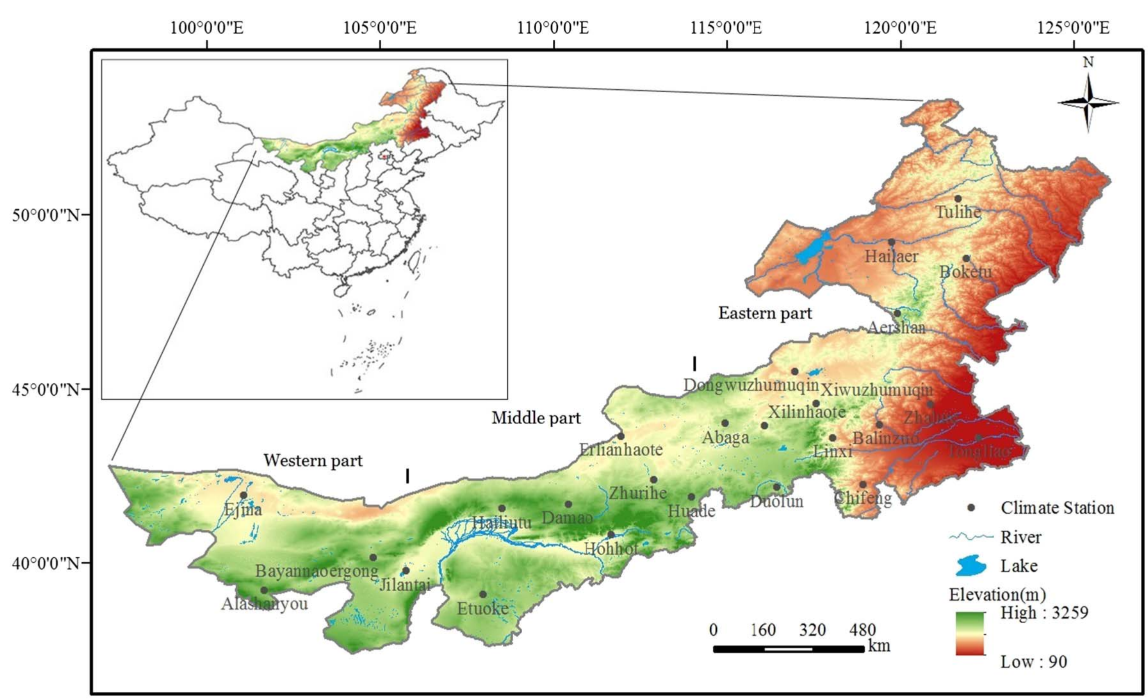

Fig. 1. Map of the Chinese Mongolian Plateau showing the locations of the 25 weather stations listed in Table 1.