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Temporal–spatial variations and influence factors in freeze-up period over the Tibetan Plateau, from 1961 to 2014

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ABSTRACT

The freeze-up period is the pentad average temperature below or equal to 0 °C (≤0 °C), which belong to extreme low temperature events but more rigorous. And analyzing it will contribute to the sparse knowledge of the freeze-up period in the Tibetan Plateau and provide scientific base for animal husbandry production in pastoral area of Northern Tibet and agricultural production in Qaidam Oasis. This paper based on the daily average temperature from a 0.5° × 0.5° gridded data range from 1961 to 2015, the beginning pentad, the ending pentad and the pentads of freeze-up period over the Tibetan Plateau (TP) were calculated. In order to investigate the temporal–spatial variations of the freeze-up period, some methods were applied such as climatic trend rate, the non-parametric Mann–Kendall test, Kriging Interpolation method, wavelet transform and Power Spectrum, etc. The main results were as follows: the annual average beginning pentad had a delaying trend at the rate of 0.24 pentad/decade, the ending pentad was advanced at the rate of 0.35 pentad/decade, but the pentads of freeze-up period had a significant decreasing trend of 0.64 pentad/decade in recent 54 years, additionally, the most remarkable period appeared in 1990s when the freeze-up period shorten. The abrupt change revealed that the year of abrupt change for the beginning pentad and the pentads of freeze-up period was in 1994, and the year of abrupt change for the ending pentad was in 1994, 1995 and 1996. There existed significant regional differences for the freeze-up period, it is noteworthy that the freeze-up period showed a decreasing trend from northwest to southeast over the study region. The significant wavelet power spectra of the beginning pentad were 3.77 years, 4.57 years and 7.14 years and there were obvious periodic oscillations of 3.39 years, 6.49 years for the ending pentad, and the pentads of freeze-up period varied with period of 3.34 years, 4.57 years and 5.46 years, which were consistent with the atmospheric circulation quasi-period of 2–4 years. Furthermore, the correlation coefficient analysis presented that the freeze-up period were mainly controlled by the circulation factors, including the TPI, NHSHII, WPSHII, NHPVAI, NHPVII and APVAI. Moreover, altitude, latitude and longitude were the main influencing factors to the freeze-up period in the Tibetan Plateau.

1. Introduction

Recent decades have been characterized by global warming and increased frequency of weather-induced extreme events (Liang et al., 2014; Spinoni et al., 2015; Zhang et al., 2015). The appearance of extreme climate is more unnatural and sensitive to climate change (Liu et al., 2014; Zheng et al., 2014) and the extreme climate events are often more important to natural and human systems than their mean values (Ling et al., 2012; Nie et al., 2012). Moreover, it is universally accepted that the climatic change and increased frequency of extreme climate events will have remarkable influences and catastrophic damage to ecological system and social system in different regions (Nie et al., 2012; Wang et al., 2013). Therefore, it is particularly important to facilitate the study of extreme climate events that associated with climate change (Ling et al., 2012). The extreme maximum and minimum temperatures in the United States during the winter of 1961–1980 was studied by Parker in 1980s and preluded to the research of extreme climate (Parker, 1989). The number of days of extreme minimum temperature decreased gradually in the Australian and New Zealand during the twentieth century (Plummer et al., 1999).

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Most extreme temperature showed a significant warming trend, and cold spells demonstrated an insignificant increase tendency in the southeastern United States and Southeast Europe (Keggenhoff et al., 2014; Milanovic et al., 2015) and the impact range, intensity and duration of summer heat wave events in eastern Europe in 2010 were greater than in the 2003 event (Jiang et al., 2016). In addition, some studies have verified that the extreme warm events have become more common, but the extreme cold events is under little attention over the South Asia and central-South Asian in a warming world (Klein Tank et al., 2006; Sheikh et al., 2015). Furthermore, in recent years, the cold waves break out over North China in winter frequently, while hot days and heat waves are commonly seen in South China in summer (Jiang et al., 2016), and the temporal and spatial characteristics of extreme temperature has attracted more attention in different regions of China (Ma et al., 2003; Zhou and Ren, 2011), for the sake of improving our understanding of changes in the extremes in these regions, and establishing a network for scientists working on climate change (Yu and Li, 2015). Studies included the Yellow River Basin (Liang et al., 2014), Yangtze River Basin (Guan et al., 2015), Pearl River Basin (Liu et al., 2015), Huaihe River Basin (Zhang et al., 2015), Qinling Mountains (Jiang et al., 2016) and the Loess Plateau (Sun et al., 2016). And the changes in extreme temperature events showed great regional differences (Yu and Li, 2015), however, the freeze-up period is extreme low temperature event but more rigorous, it has not been reported yet.

The Tibetan Plateau (TP) is a “promoter region” that affects weather changes and the century scale climate changes in China (Feng et al., 1998), which is considered to be a “Driver and Amplifier” of global climatic changes (Pan and Li, 1996), moreover, it is an Controlled Region of atmosphere system in China, Asia and even the northern hemisphere through its thermal and mechanical forcing (Liu and Lu, 2010). The Plateau has attracted more attentions because of its high sensitivity to climate change under the context of global warming (Song et al., 2012; Wang et al., 2013). Many evidences (Liu and Chen, 2000; Cai et al., 2003; Wu et al., 2005) have demonstrated that a significant climate warming occurred there during recent decades, and its warming rate is significantly higher than the same period in China and the Northern Hemisphere (Li and Kang, 2006; Wang et al., 2012), furthermore, the warming tendency in winter was remarkable than it in summer (Liu and Lu, 2010).

As for the high-altitude areas with glaciers and perennial snow cover, the frequent climate extreme events may cause profound consequences (Wang et al., 2013). Therefore, there are a few studies to the extreme temperature in the TP. The occurrence of extreme warm days and nights has increased and extreme cold days and nights has decreased in the eastern and central TP (Liu et al., 2006; You et al., 2008a), and the number of frost days and ice days showed statistically significant decreasing trends in the Eastern Edge of the TP (Zhao et al., 2014), the diurnal temperature ranges showed a decreasing trend with statistical significance, whereas the growing season lengths have increased significantly in the western Tibetan Plateau (Wang et al., 2013). In recent years, it has been revealed that the warming trends in minimum temperature extremes are of greater magnitude than those for maximum temperature extremes in Mt. Qomolangma (Du et al., 2016). In terms of decadal variations, the cold indices presented a significant warming trends and the warm indices demonstrated an insignificant increasing trend in the Source Area of Three Rivers (You et al., 2008b), Yarlung Zangbo River Basin (You et al., 2009) and Qinghai province (Shen et al., 2012), but the cold indices were of greater magnitude than the warm indices. For the Tibet, The extra-maximum temperature and extra-minimum temperature generally increased and the linear trend magnitudes of extreme temperature indices were larger than those in the whole country, the Tibetan Plateau and its surrounding areas (Du et al., 2013). These studies concluded that widespread changes in temperature extremes are associated with global warming, the research for extreme climate change in the TP have great significance accordingly.

However, the extensive research on the extreme temperature in the TP has been confined to the middle and eastern region at present due to the scarce meteorological stations in the TP (You et al., 2008a; Wang et al., 2013), and the main study methods is the extreme temperature evaluation index, the model or the definition of percentile threshold method. Additionally, most studies only based on the annual, quarterly, monthly and daily data, relatively few of the pentad data at present, and the research for the pentad average temperature only limited to Chengdu city and Inner Mongolia (Hao et al., 2007; Pei and Hao, 2009). And the freeze-up period that based on the pentad temperature data, is a stricter extreme low temperature event index, however, for the Tibetan Plateau with an average altitude of 4000 m, the freeze-up period has not been reported yet. How the freeze-up period of the TP responds to the global warming, as well as the beginning pentad and the ending pentad? Are not clear, it is a scientific question worthy to explore.

Therefore, the purpose of this paper is to identify the spatial and temporal variations of the freeze-up period in the TP that response to climate change under the background of global warming through statistic calculated the onset pentad, the upset pentad and the pentads of freeze-up period. Analyzing it is conductive to enhance a better understanding of the changes in the frequency, intensity and duration of extreme climate events in the TP, moreover, studying it will have a great significant to the disaster prevention and mitigation and provide scientific base for animal husbandry production in pastoral area of Northern Tibet and agricultural production in Qaidam Oasis.

2. Study area

The Tibetan Plateau (26°00′12″~39°46′50″N, 73°18′52″~104°46′59″E) is the highest plateau in the world with an area of 257.24×10^4 km^2 that accounting for 26.8% of the land area in China and an average elevation of 4000 m (Zhang et al., 2002), which is surrounded by Hengduan Mountains, Himalayas and Kunlun Mountains and has long been known as the Third Pole and the roof of the world. Due to the effect of the fierce topography incision in periphery, the TP exhibits huge terrain contrast and the topography declines from northwest to southeast (Sun and Zheng, 1998). Owing to the complex terrain, the average annual temperature and precipitation exhibit significant regional differences. Moreover, the TP contains the frigid continental climate, the sub-frigid continental climate, the temperate continental climate, the temperate monsoon climate and the subtropical monsoon climate. Additionally, the main soil types are two major systems including continental desert soil, continental steppe soil, continental meadow soil and marine forest soil and the main vegetation types are Mountain–desert, Alpine desert, Alpine steppe and Alpine shrub grassland (Zhao and Chen, 1999).

3. Data and methods

3.1. Data sources

The research on the changes of temperature in the TP has been confined to the eastern and central region at present due to the limitation of the distribution and the number of the existing stations and the research on the western TP is relatively scarce primarily owing to the lack of easily available data collection for the