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Analysis of Temporal and Spatial Distribution and Large-Scale Circulation Features of Extreme Weather Events in Shanxi Province, China in Recent 30 Years

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Abstract

Extreme weather events such as persistent high temperatures, heavy rains or sudden cold waves in Shanxi Province in China have brought great losses and disasters to people's production and life. It is of great practical significance to study the temporal and spatial distribution characteristics of extreme weather events and the circulation background field. We selected daily high temperature data (≥35˚C), daily minimum temperature data and daily precipitation data (≥50 mm) from 109 meteorological stations in Shanxi Province, China from 1981 to 2010, then set the period in which the temperature is ≥35˚C for more than 3 days as a high temperature extreme weather event, define the station in which 24 hour cumulative precipitation is ≥50 mm precipitation on a certain day (20 - 20 hours, Beijing time) as a rainstorm weather, and determine the cold air activity with daily minimum temperature dropped by more than 8˚C for 24 hours, or decreased by 10˚C for 48 h, and a daily minimum temperature of ≤4˚C as a cold weather process. We statistically analyze the temporal and spatial characteristics and trends of high temperature, heavy rain and cold weather and the circulation background field. We count the number of extreme weather events such as persistent high temperatures, heavy rains and cold weather frosts in Shanxi, and analyze the temporal and spatial distribution characteristics, trends and general circulation background of extreme weather events. We analyze and find out the common features of the large-scale circulation background field in various extreme weather events. Through the study of the temporal and spatial distribution characteristics of extreme weather events in Shanxi, including persistent high temperature, heavy rain or sudden cold wave frost weather, we summarize the large-scale circulation characteristics of such extreme weather events. It will provide some reference for future related weather forecasting.

Keywords

Extreme Weather, Spatial and Temporal Distribution, Circulation, Feature Analysis

1. Introduction

Extreme weather and climate events mean that the state of the weather and climate deviates significantly from its average state and is statistically a small probability event (i.e., an event that is unlikely to occur). Although the frequency of extreme events is low, it often has a great impact on the natural environment and human society. In recent years, the extreme weather and climate events have become more and more harmful to society and nature. For example, the catastrophic floods in the Yangtze River Basin in 1998 caused more than 3000 deaths and economic losses of up to 36 billion US dollars. In the summer of 2003, heat waves hit Europe, and high temperatures caused more than 22,000 people died; in August 2005, Katrina attacked the southern coastal areas of the United States, killing more than 1300 people, leaving more than 1 million people homeless and economic losses as high as $81.2 billion. Due to the vast territory of China and the influence of the Southeast Asian monsoon year-round, various types of extreme weather and climate events often occur. For example, cold air in winter often affects most of the northern part of China; in summer, high temperature and drought weather often occur in southern China. Drought occurs in northwestern China, and floods often invade the middle and lower reaches of the Yangtze River.

In recent years, extreme weather and climate events have occurred frequently throughout the world. Meteorologists at home and abroad have made research from different angles. Karl et al. (1991; 1993), Horton (1995), and Cooter & Leduk (1993) have the highest and lowest temperature research results in the world, showing their performance in the global warming process in recent years. The asymmetry of the temperature change between day and night is obvious, and the daily difference is small. According to Gruaz et al. (1999), the extremely high temperature days in Russia showed a significant increase, and the rate of extremely low temperature days decreased more than the rate of extremely high temperature days (Frich et al., 2002). The work of Ren & Yan (1998) and Zhai et al. (1999) pointed out the seasonal characteristics and regional differences of extreme events in China. Ma et al. (2003) studied the extreme temperature trends in northern China, showing that the frequency of the lowest temperature in the arid and semi-arid regions of northern China has decreased significantly in the past 50 years, and the highest temperature occurred in most regions before the 1990s. There is no significant change in frequency, but there has been a clear increase in the past 10 years. Lin & Wu (1998) analyzed the climatic characteristics of the cold wave activity in Guangdong Province in the past 44 years. The research shows that since 1960, the total number of cold waves in Guangdong and the number of cold waves above medium intensity have been decreasing. Shan et al. (2005) analyzed the climatic characteristics of cold wave weather in Weifang area. The results show that the cold wave weather in the past 40 years is decreasing year by year, the cold wave process in the 1960s and 1990s is strong, and the cold wave in the 1970s and 1980s. The process is weak. In recent years, China's temperature has risen markedly, especially in the winter. Some studies have found that in the context of this warming, the frequency and intensity of the cold wave in China have also changed significantly; Wei (2008) pointed out that after the climate warming, the frequency of cold wave in North China decreased and the intensity weakened. In addition, some meteorologists have also done some research on the causes of the cold wave in China, and have reached meaningful conclusions. For example, Wang & Ding (2006) analyzed the climate characteristics and changes of the cold wave in China, and discussed the reasons for the frequent reduction of the cold wave in China, and pointed out that the intensity of Siberian high and winter winds weakened. The low temperature of low-rise cold reactors over Siberia and the significant increase in surface temperature in China are the reasons for the cold wave in China and the accompanying reduction in the frequency of winds. Shanxi meteorological workers (Zhou et al., 1989) summarized the climatic characteristics and forecasting techniques of the torrential rains in Shanxi, China before 1974. In recent years, a number of meteorological work colleagues have done a lot of diagnostic analysis of the study of heavy rain in Shanxi (Zhao & Cheng, 2006; Zhao, 2005; Zhao et al., 2007; Zhao & Li, 2003).

Since the 1970s, severe droughts and rains have increased significantly from a worldwide perspective. In the last 20 to 30 years, the probability of global extreme weather and climate events has clearly exceeded the sum of extreme weather and climate events in the past few decades, even centuries, for global warming, this global Climate events, many experts and scholars at home and abroad have been studying this aspect for decades. Therefore, research on extreme weather and climate events has received increasing attention from people at home and abroad. Shanxi Province, China is located in the eastern part of the Loess Plateau. It is located in the edge of the East Asian summer monsoon. It is affected by the summer monsoon and the blocking high pressure in the mid-high latitudes of winter. The interannual variation of climate, especially precipitation, is very large, and it is easy to appear in some areas, extremely hot or cold weather frosty weather. In the process of climate change in recent decades, the temperature in Shanxi has shown a clear upward trend, and the incidence of drought has increased with the increase of climate temperature. The relevant literature points out that in the past 50 years, the climate of Shanxi In general, it has experienced three stages: drought, flood, and drought. At present, Shanxi Province is in a relatively dry climate. Under this climatic background, the probability of persistent high temperature, heavy rain or sudden cold wave frost weather increases a lot. This extreme weather event has brought great losses and disasters to people's production and life. Therefore, it is of great practical significance to study the temporal and spatial distribution characteristics of extreme weather events and the circulation background field under arid climate conditions.

2. Data and Methods

2.1. Source of Data

The weather station data used in this paper is taken from Shanxi Provincial Meteorological Information Center, China, and includes daily maximum temperature (≥35˚C) data, daily minimum temperature data and daily precipitation (≥50 mm) data from 1961 to 2010 in the province. Through the investigation of the data, it is found that the altitude and climate of Wutaishan Station are quite different from those of other stations. The number of stations with complete historical data for 50 years is only about 60%, and most stations have complete historical data for 30 years above. The World Meteorological Organization used the average of 30 samples in the past 30 years in history as the reference point for the perennial value of the corresponding climatic factors, and was updated 10 years. The average climate value that was launched in 2012 is the statistic data of 1981-2010 (Zhang et al., 2015; Zheng et al., 2013). Considering the different ages of station construction, the inconsistent length of time series and the continuity of data integrity, we selected 108 stations (excluding Wutaishan Station) to analyze the temporal and spatial characteristics and trends of high temperature and heavy rain, also selected 109 stations to analyze the temporal and spatial characteristics and trends of the cold wave, and determined the data analysis time as 1981-2010.

2.2. Maintaining the Integrity of the Specifications

The use of trend coefficients (Nishiya et al., 2010) and rate of change can be used to represent the nature and magnitude of trends in climate elements. The trend coefficient is calculated, as in

$$r_{kt} = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\sum_{i=1}^{n}\left(i - \bar{t}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n}\left(i - \bar{t}\right)^2}}. \tag{1}$$

where, r_{kt} is the trend coefficient; n is the time series length (years); x_i is the magnitude of the climatic element of the i-year; $\bar{x}$ is the sample mean; $\bar{t} = (n + 1)/2$.

3. Results and Analysis

3.1. Temporal and Spatial Distribution and Circulation Characteristics of High Temperature Days

The China Meteorological Administration stipulates that the maximum daily temperature is ≥35˚C for high temperature days, and the high temperature for more than 3 days is called high temperature heat wave. In this paper, the daily maximum temperature ≥35˚C, ≥37˚C, ≥40˚C is used as the quantitative characterization index. As long as there is one station with high temperature of 35˚C, 37˚C and 40˚C, it is recorded as a ≥35˚C, ≥37˚C, ≥40˚C high temperature day; a station with more than 3 days (including 3 days) with high temperature above 35˚C, which is marked as a continuous high temperature weather process.

Figures 1(a)-(c) are the spatial distributions of cumulative high temperature days of ≥35˚C, ≥37˚C, and ≥40˚C for 30 years from 1981 to 2010, respectively. Figure 1 shows that the number of high temperature days in Yuncheng and Linfen is the highest; the number of high temperature days decreases with the elevation of latitude, and the spatial distribution characteristics of the west are more than the east, the south is more than the north, and the basin is more than the mountain. The accumulated high temperature days of ≥35˚C in the central and western parts of Yuncheng City and the south of Linfen City are more than 500 days. The cumulative high temperature days in Datong, Zhangzhou, Changzhi, Jincheng, and Luliang North ≥35˚C are less than 50 days (Figure 1(a)). The cumulative high temperature days of ≥37˚C in the central and western parts of Yuncheng in the north and the south of Linfen are more than 120 days, and the accumulated high temperature days in other counties and cities ≥37˚C is less than 50 days (Figure 1(b)). The accumulated high temperature days of ≥37˚C in the central and western parts of Yuncheng and the south of

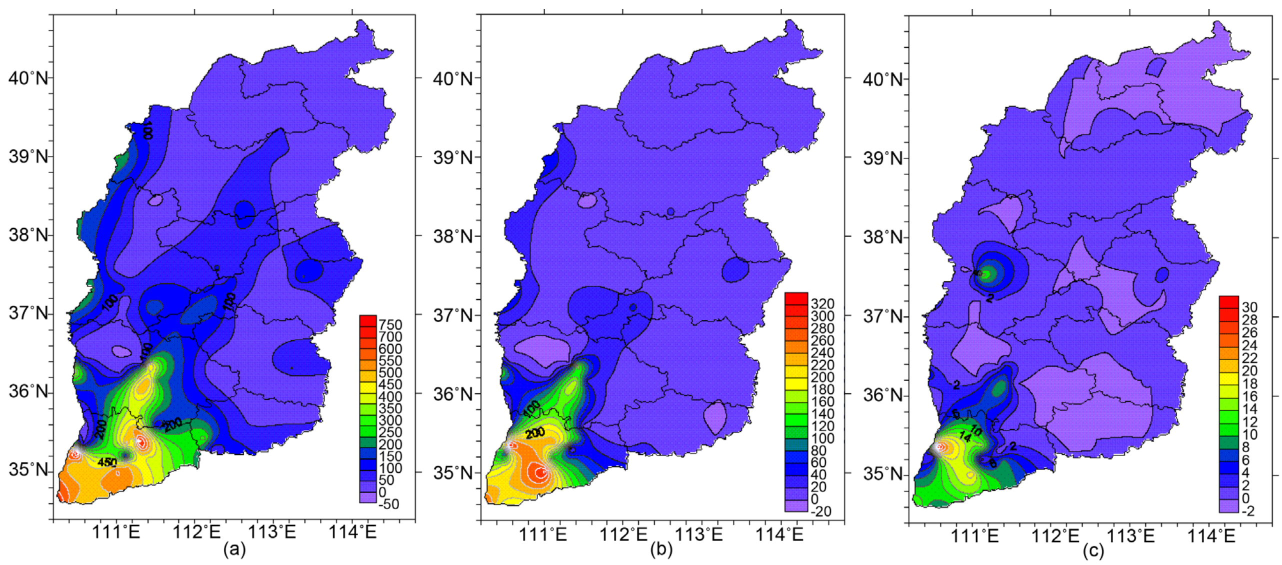


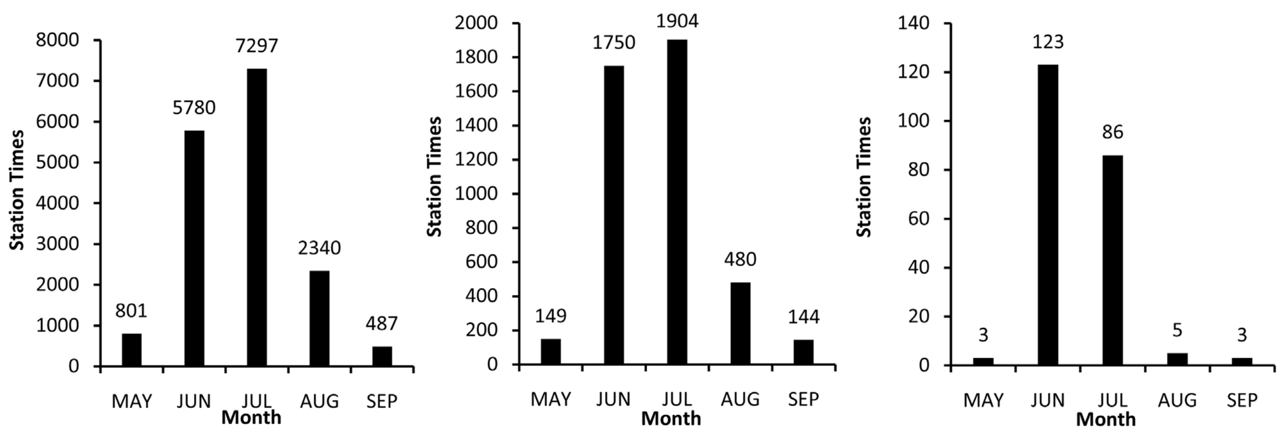
Figure 1. Spatial distribution of cumulative high temperature days in Shanxi Province from 1981 to 2010 ((a), (b), and (c) are cumulative high temperature days of ≥35˚C, ≥37˚C, and ≥40˚C, respectively).

Linfen are more than 7 days, and the maximum of 30 days in Lushan. The probability of high temperature above 40˚C in other counties and cities in the province is very small, and the high temperature area of ≥40˚C is mainly concentrated in Yuncheng and Linfen areas Figure 1(c)).

Figure 2(a) shows the cumulative daily number of high temperature ≥35˚C for each month from 1981 to 2010. Figure 2(a) shows that: ≥35˚C high temperature first appeared in May, the latest appeared in September, June-August is 35˚C high temperature weather, the most in July, followed by June. Figure 2(b) is the cumulative daily number of high temperature ≥37˚C for each month from 1981 to 2010. Figure 2(b) shows that: ≥37˚C high temperature first appeared in May, the latest appeared in September, June-August is 37˚C high temperature weather, which is the most in July, followed by June. Figure 2(c) shows the cumulative daily number of high temperature ≥40˚C for each month from 1981 to 2010. Figure 2(c) shows that: ≥40˚C high temperature first appeared in May, the latest appeared in September, June to July is 40˚C high temperature weather, the most in June, followed by July.

Figure 3 shows that from 1981 to 2010, the amplitude of the high-temperature day station above 35˚C was very large. In 1997, the high-temperature day station above 35˚C was the most, and in 1984, the high-temperature day station above 35˚C had only 84 stations. From 1981 to 2010, the daily temperature stations above 35˚C showed an overall upward trend. Especially in 1997, 2001, 2002 and 2005, the high temperature stations ≥35˚C reached 1573, 1108, 1190, 1212 stations respectively; on June 22 and 23, 2005, the number of high temperature stations ≥35˚C reached 107 stations and 105 stations, that is, the province is high temperature weather; from 1997-2010, the amplitude of the high temperature day station change is larger than that of 1981-1996, indicating that the number of high temperature days is increasing in the past 20 years, and the range of high temperature is increasing.

Figure 4 shows that from 1981 to 2010, the interannual variation of high



(a) (b) (c)

Figure 2. High temperature daily station distribution in 1981-2010 ((a), (b), and (c) are for high temperature ≥35˚C, ≥37˚C and ≥40˚C, respectively).

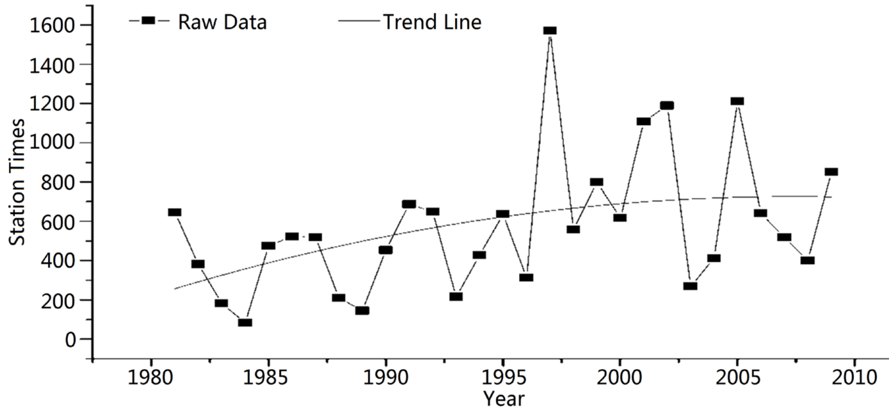


Figure 3. Interannual distribution of high temperature daily stations ≥35˚C from 1981 to 2010.

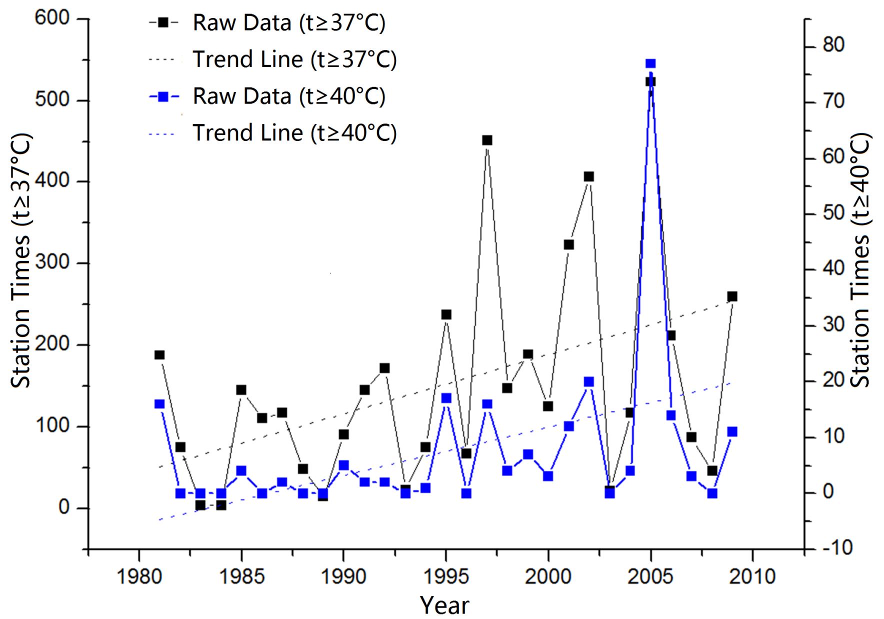


Figure 4. Interannual distribution of high temperature daily stations ≥37˚C and ≥40˚C from 1981 to 2010.

temperature daily stations above 37˚C and above 40˚C is very large. In 2005, the high temperature stations above 37˚C were as many as 523 stations, and the high temperature stations above 40˚C. The number of times was 77 stations; in 1983 and 1984, there were only 4 stations (1 day) for high temperature days above 37˚C; there were no high temperature days above 40˚C for 11 years in 30 years. Between 1981 and 2010, the high temperature days of 37˚C and 40˚C increased.

A high temperature weather above 35˚C occurs for more than 3 consecutive days (including 3 days) at a station, which is marked as a continuous high temperature weather process. Through statistical analysis, from 1981 to 2010, there were 1859 high-temperature processes in the province that lasted for more than 3 days, and 206 high-temperature processes lasted for more than 7 days. Figure 5 shows that the longest duration of the high temperature process reaches 11

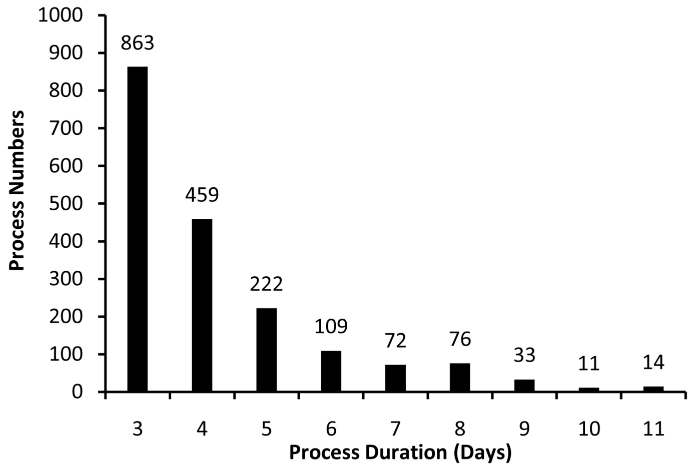


Figure 5. Quantitative distribution of duration (days) of ≥35˚C high temperature process from 1981 to 2010.

days, the number of processes reaches 14 times, the highest temperature process lasts for 3 days, up to 863 times, and the high temperature process lasts for more than 3 - 5 days. The persistent high temperature is mainly found in Linfen and Yuncheng.

Figure 6 shows that the continuous high-temperature process occurred in June and August, accounting for 95.05% of the total number of times. 1981-1996 was the era of continuous high-temperature processes, and 1997-2010 was the age of persistent high-temperature processes. The continuous high temperature process of more than 9 days concentrated in 1997, indicating that after the 1990s, not only the number of high temperature days increased, but also the duration, intensity and range of high temperature increased.

Based on the statistical analysis and census analysis of the 500 hPa high-altitude circulation situation occurring in the extreme maximum temperature from June to September, the two circulation situations of the western Pacific subtropical high when extreme extreme temperatures occur are summarized:

Sub-high latitude type: when the western Pacific subtropical high is lifted northward and reaches the eastern part of the northwestern region, the 5880 gpm line covers a large area, and the northwestern region is controlled by the east to the northeast of the northeast. The northern part of China will have hot and cold weather. The characteristics of this situation are: the latitudinal circulation in the middle and high latitudes of Europe and Asia, the cold air in the north is not easy to go south, and the front area is generally located at 44˚N - 51˚N.

Sub-high meridional type: when the western Pacific subtropical high is extended to the northwest of the northwestern region, the East Asian trough strongly deepens the formation of a relatively stable two-slot-ridge type in the middle and high latitudes of Asia, making it difficult for the western Pacific subtropical high to retreat. Under its control, there will be hot and cold weather in the east of the northwestern region to the west of the Bohai Bay. For the

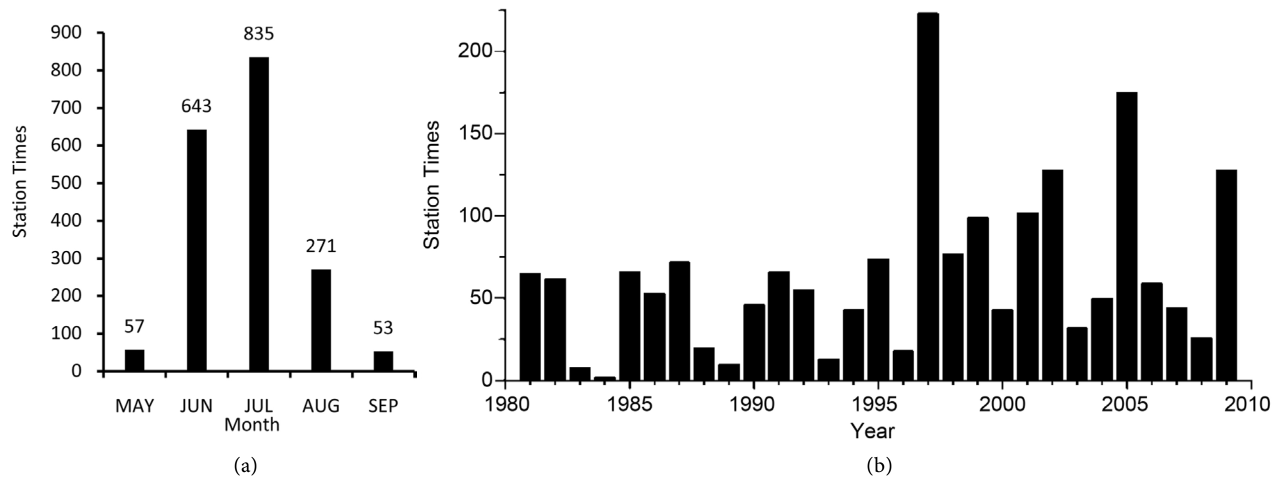


Figure 6. Continuous high temperature process ((a) by month; (b) by year).

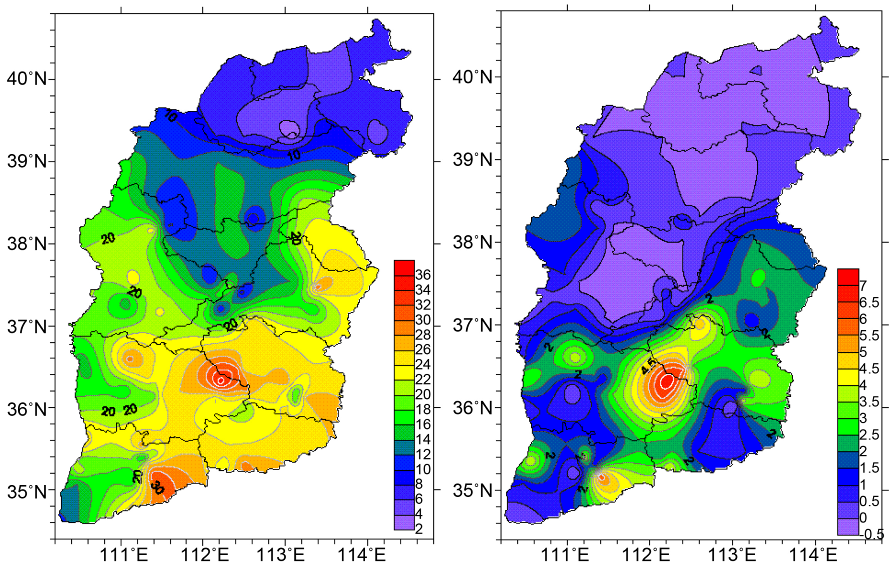
Qinghai-Tibet high pressure, which belongs to the subtropical high, its formation and eastward movement on the eastern side of the Qinghai-Tibet Plateau is another influence system that causes the high temperature weather in Shanxi in the summer.

In summary, the 500 hPa circulation situation affecting high temperature in Shanxi mainly includes subtropical high latitude, subtropical high meridional and continental high pressure control type, sweltering weather when subtropical high control, and dry (clear) heat when continental high pressure control the weather.

3.2. Temporal and Spatial Distribution and Circulation Features of Rainstorm Days

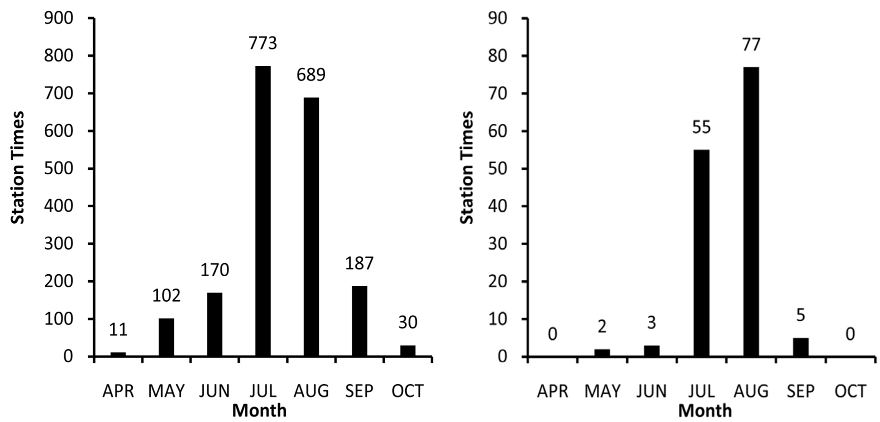
The rainstorm specified in the meteorology refers to the precipitation with a cumulative precipitation of ≥50.0 mm at 24 h on a certain station (20 - 20 pm, Beijing time). According to its precipitation intensity, it is divided into three grades, that is, 24 h cumulative precipitation is 50.0 mm - 99.9 mm for heavy rain; 100.0 mm - 249.9 mm for heavy rain; 250 mm or more is extraordinarily heavy rain.

From the spatial distribution of the average number of occurrences of heavy rains in the province (Figure 7), the spatial distribution of the number of rainstorm days in Shanxi has the distribution characteristics of the northern heavy rain "south and north less", and the east is more than the west, and the mountains are more than the basin. Figure 7(a) shows that: in most of Linfen, the middle and south of Changzhi, the total number of ≥50 mm rainstorm days in Jincheng and Yuncheng East stations is more than 22 days, the Jinzhong area is generally 14 - 18 days, and the Datong area in the north is the least number of rainstorms. In the area, the cumulative number of rainstorm days ≥50 mm is below 12 days. Figure 7(b) shows that in the eastern part of Linfen, the total number of heavy rainstorms of ≥100 mm in the southwestern part of Changzhi



(a) (b)

Figure 7. Spatial distribution of rainstorm days in Shanxi Province from 1981 to 2010 ((a) ≥50 mm, (b) ≥100 mm).



(a) (b)

Figure 8. Distribution of the cumulative monthly rainstorm days in Shanxi Province from 1981 to 2010 ((a) ≥50 mm, (b) ≥100 mm).

and the eastern part of Yuncheng is more than 2.5 days, and the Jinzhong area is generally on the 1st, while the Datong area in the north is the area with the least number of heavy rains, accumulating ≥100 mm. The number of heavy rain days is below 0.5 days. The spatial distribution of the occurrence of the above-mentioned rainstorms in Shanxi is closely related to the terrain of Shanxi, that is, the rainstorm-prone areas are mainly distributed in the windward slope area of the mountain range, and the southeastern part of the Taihang Mountains is a high-incidence area.

Figure 8(a) shows that there will be ≥50 mm rainstorms in the whole province from April to October, but mainly in the flood season (May-September), accounting for 97.91% of the rainstorm days, and the number of heavy rains in

April and October. Less than 0.56% and 1.52%. The main flood season (July-August) is the most concentrated period of heavy rain in Shanxi Province. The cumulative number of rainstorm days in the two months reached 773 and 689 respectively, and the number of heavy rains was much higher than other months. Figure 8(b) shows that there will be ≥100 mm heavy rain in the province from May to September. The main flood season (July-August) is the most concentrated period of heavy rain in Shanxi Province. The cumulative number of heavy rainstorm days in the two months is about 55 and 77 respectively. The number of heavy rains occurred much higher than other months, accounting for 92.96% of the heavy rainy days. Further statistical analysis shows that the end of July and the beginning of August are the main high-incidence periods of heavy rain in Shanxi Province, which is consistent with the characteristics of most of the heavy rains in the entire North China region from late July to early August, that is, most scholars call the "Late-July-early-August".

Figure 9(a) shows that from 1981 to 2010, the amplitude of the ≥50 mm rainstorm day station was very large. In 1988, the maximum number of rainstorm days above 50 mm was 119 stations. In 1986 and 2008, the rainy days above 50 mm only had 29 stations. Station times; from 1981 to 2010, the overall number of rainstorm days above 50 mm showed a steady trend. Especially from 2000 to 2006, the peak change of the rainstorm days showed an upward trend, indicating that the number of rainstorm days increased in the past 10 years, and the range of heavy rains increased. Figure 9(b) shows that from 1981 to 2010, the amplitude of the ≥100 mm rainstorm day was very large. In 1981 and 2003, the maximum number of heavy rains on the 100 mm or more was 16 stations, and the 7-year heavy rainy day was only 100 mm. 0; From 1981 to 2010, the overall number of heavy rain days above 100 mm showed an upward trend. It shows that the number of heavy rain days in the past 10 years is increasing, and the growth rate of heavy rains is faster than the growth of rainstorm days.

Through the statistical analysis and census analysis of the 500 hPa high-altitude circulation situation during the May-September rainstorm process, it is concluded that the 500 hPa geopotential height field is distributed in the

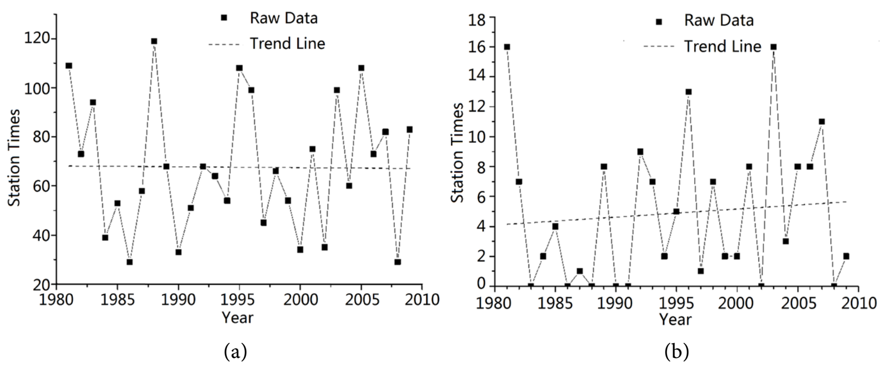


Figure 9. Interannual distribution of rainstorm days in Shanxi Province from 1981 to 2010 ((a) ≥50 mm; (b) ≥100 mm).

middle and high latitudes of the entire Eurasia region. Among them, two troughs are located in the east of the Ural Mountains and east of Baikal Lake. The two weak ridges are located in the west of Baikal and in the northeast of China to the Sea of Okhotsk. From Shanxi to the Jianghuai River Basin is an obvious high-altitude trough, the western Pacific subtropical high is a zonal band, 584 dagpm line extends to 80˚E, and the subtropical high ridge is located near 28˚N, with the westerly wind over Shanxi. The trough formed an obvious "east-high-west-low" situation. In the low latitudes, the Bay of Bengal is an obvious trough of low pressure. Under this circulation situation, it caused the occurrence of heavy rain in Shanxi.

3.3. Temporal and Spatial Distribution of Cold Wave Frequency and Circulation Characteristics

According to the "*Cold Air Rating*" in the "*National Standards of the People's Republic of China*" implemented on November 1, 2006, the daily minimum temperature drops by more than 8˚C for 24 h, or decreases by 10˚C for 48 h, and the daily minimum temperature is ≤4˚C, then cold air activity was identified as a "cold wave". The cold wave intensity is expressed by 24 h and 48 h cooling. It is prescribed that more than 2/3 of the stations have a cold wave, which is the province's cold wave process. More than 1/4 of the stations have a cold wave, which is the regional cold wave process. The station data used in this section selects the daily minimum temperature data of 109 stations from September of the year from 1981 to 2010 to the analysis of the temporal and spatial characteristics and trends of the cold wave.

Figure 10 shows that the most frequent occurrence of cold wave is Youyu, the cumulative number of cold waves reached 430 times, followed by the higher frequency of cold waves in the northwest of Guangling, Suzhou, Wuzhai and Kelan, the cumulative number of cold waves reached more than 300 times. These areas have higher altitudes, all above 1100 m above sea level. The cumulative cold wave frequency in some areas in the north and central part is more than 100 times. Due to the low altitude in most parts of the south and central part, the cumulative cold wave frequency is below 80 times. The frequency distribution of cold waves in Shanxi shows a trend of decreasing from north to south, and is greatly affected by the altitude of the terrain.

During the 30 years from 1981 to 2010, there were a total of 1542 cold waves in Shanxi Province. Among them, the province's cold wave (prescribed more than 2/3 sites, which is the province's cold wave process) 5 times, as shown in Table 1; Regional cold waves (prescribed as more than a quarter of sites, that is, regional cold wave process) occurred 85 times, and single station cold wave appeared 474 times.

Figure 11 shows the cumulative number of cold wave days and the monthly distribution of cold wave frequency in Shanxi Province from 1981 to 2010. Figure 11 shows that the cold wave in Shanxi Province mainly occurs from October to April, and there will be no in May. More cold waves occur, mainly in the

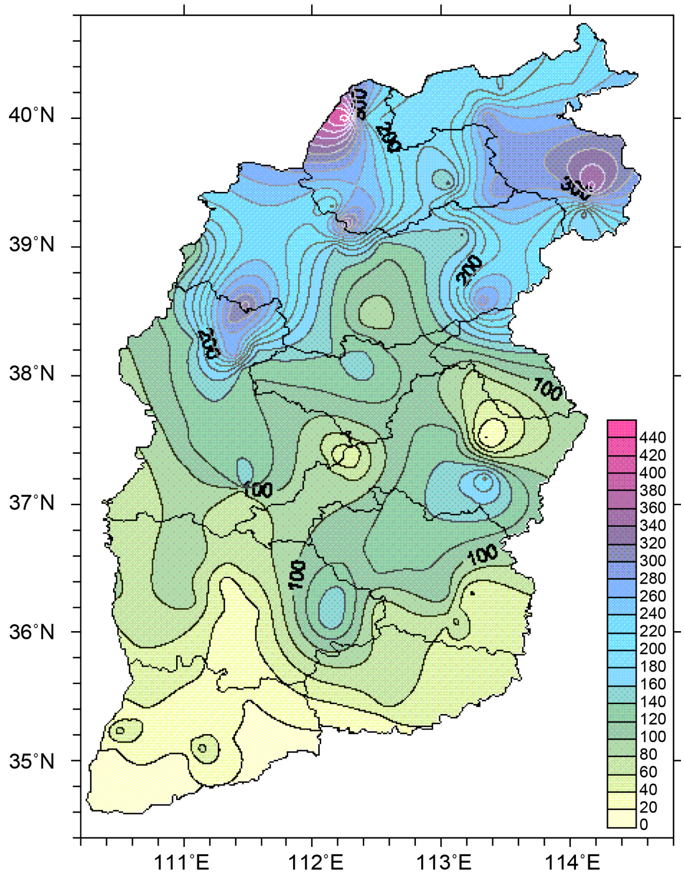


Figure 10. Spatial distribution of cumulative cold wave frequency in Shanxi Province from 1981 to 2010.

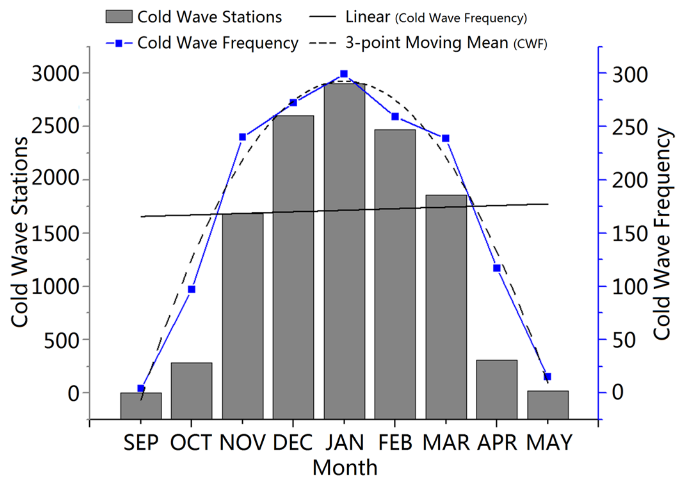


Figure 11. The cumulative number of cold wave days and the monthly distribution of cold waves in Shanxi Province from 1981 to 2010.

north, and in some parts of the north, there will be occasional cold waves in September. Due to the high altitude, Wutai Mountain has cold wave events in addition to the cold wave season (October to April), and sometimes in May and

Table 1. The whole-provincial-level cold wave process in Shanxi Province from 1981 to 2010.

Year	Month	Days	Number of stations
1988	1	21	88
1992	1	29	74
1994	1	16	97
1999	2	17	78
2000	1	11	75

September. This is due to the high altitude, low temperature and low temperature, which is easy to reach the cold wave standard. From the monthly distribution of cold wave frequency, the frequent cold wave months are from November to March, all of which are more than 230 times. The most frequent occurrence of cold wave is January, with a cumulative frequency of 299; the rest of the month is below 120, and the cold wave is the lowest in September. , only accumulated 4 times. From the distribution of the cold wave station for several months, the months with more cold wave stations are December, January and February, and the cumulative number of stations is above 2400 stations. The rest of the months are below 1900 stations, and the least in September. There are only 4 stops at the station. In November and March, there were more frequent cold waves and fewer cold wave stations, indicating that from December to February, it is prone to provincial and regional large-scale cold weather processes, and in November and March, it is prone to a single-station small-scale cold wave weather process.

Figure 12 is the annual distribution of the number of cold wave stations and the frequency of cold wave frequency in Shanxi Province from 1981 to 2010. Figure 12 shows that the amplitude of the cold wave is very large from 1981 to 2010, and the frequency of cold waves in 1984 and 1986 is up to 69 times. In 1981, the frequency of cold waves was only 26 times; from 1981 to 2010, the total number of cold waves in the province showed a decreasing trend. Especially from 1991 to 2001, the cumulative frequency of cold waves has increased significantly. In 1988, there were a total of 624 stations in the cold wave station. In 1981, there were at least 185 cold wave stations. The statistics showed that there was a positive correlation between the frequency of cold wave and the cold wave station, but the frequency of the cold wave was the highest. It is not the year when the cold wave station has the most time. The decreasing trend of the cold wave frequency is faster than the decreasing trend of the cold wave station. It shows that under the background of global warming, the frequency of cold wave is actually decreasing year by year, but the influence range of the cold wave process is increasing.

Through the study of the frequency sequence of the Shanxi cold wave from 1981 to 2010 and the monthly calculation of the 500 hPa sea level pressure field and the sea temperature field in the same period, it was found that the cold air from the Arctic Ocean, especially from Eastern Siberia, cooperated with Lake

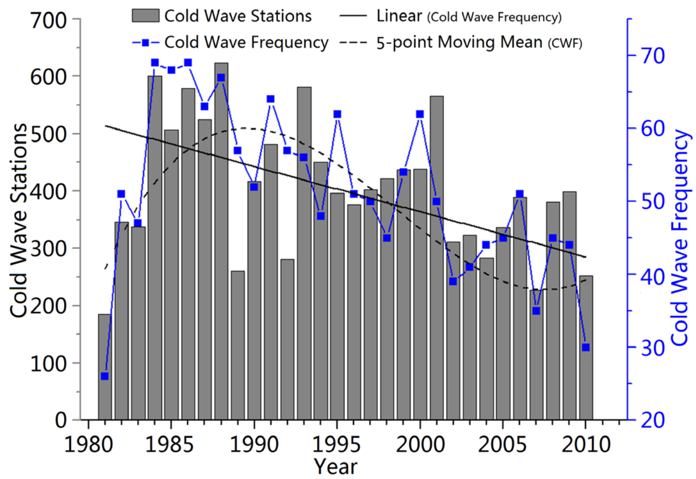


Figure 12. Interannual distribution of cumulative cold wave days and frequency of cold waves in Shanxi Province from 1981 to 2010.

Baikal and Its negative anomaly in the southeast will cause frequent cold surges in the later period, that is, the cold air from Eastern Siberia is one of the main sources of the cold wave in Shanxi. It can be seen that the characteristics of the 500 hPa correlation field are mostly characterized by high positive latitude anomalies and high negative anomalies at low latitudes, which often lead to more frequent occurrences of cold waves in the next year. Such circulation conditions are favorable for cold air from high latitudes. It brings cold weather to the south.

4. Conclusion and Discussions

By analyzing the daily maximum temperature of ≥35˚C, ≥37˚C and ≥40˚C in Shanxi 108 station from 1981 to 2010, it is concluded that the number of high temperature days decreases with the elevation of latitude, and the west is more than the east and the south is more than the north. The spatial distribution of the basin is more than that of the mountainous area; June-August is a frequent occurrence of high-temperature weather, and in July, high-temperature weather above 35˚C is more likely to occur. After entering the 1990s, the number of high temperature days has gradually increased, and the duration, intensity and range of high temperature have increased. The 500 hPa circulation situation affecting the high temperature in Shanxi mainly includes subtropical high latitude, subtropical high meridional and continental high pressure control type. The subtropical high control is sweltering weather, while the continental high pressure control is dry (clear) hot weather.

By analyzing the daily precipitation of ≥50 mm and ≥100 mm in Shanxi 108 station from 1981 to 2010, it is concluded that the spatial distribution of the number of rainstorm days in Shanxi is spatially distributed in the south and more than the west, and the east is more than the west, and the mountainous area is more than the basin; The flood season (July-August) is the most concentrated period of heavy rain in Shanxi Province. In the past 10 years, the number of rainstorm days has gradually increased, the range of heavy rains has increased and the intensity has increased. The circulation situation affecting the heavy rain in Shanxi is the 500 hPa geopotential height field. The middle and high latitudes of the Eurasian continent are distributed as "two troughs and two ridges", and the western Pacific subtropical high is distributed in a zonal band, forming a westerly trough over Shanxi, obviously the situation of "high-east-low-west". In the low latitudes, the Bay of Bengal is an obvious trough of low pressure. Under this circulation situation, it caused the occurrence of heavy rain in Shanxi.

Based on the analysis of the daily minimum temperature from September to May of Shanxi Province from 1981 to 2010, it is concluded that the frequency distribution of cold wave in Shanxi is decreasing from north to south, and it is greatly affected by the altitude of the terrain. The cold wave frequent month is from November to March, and from December to February, it is prone to provincial and regional large-scale cold weather processes. In November and March, it is prone to single-site Small range cold wave weather process. Under the background of global warming, the frequency of cold wave is decreasing year by year, but the range and intensity of the cold wave process are increasing. The characteristics of the 500 hPa correlation field in Shanxi cold wave weather are characterized by high altitude latitude and high altitude negative anomalies at low latitudes, which often lead to more frequent cold wave occurrences in the next year. Such circulation conditions are favorable for cold air from high latitudes. It brings cold weather to the south. The cold air from Eastern Siberia is one of the main sources of the cold wave in Shanxi.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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