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Analysis on the Characteristics of High-Temperature Heat Wave Weather in Jilin Province from 1961 to 2018

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Abstract: In this study, meteorological data from 47 stations in Jilin Province during June to August from 1961 to 2018 are examined. The data includes daily maximum temperature, wind speed, and relative humidity. The analysis focuses on the change patterns of daily maximum temperature (Tmax), perceived temperature (ATmax), and high temperature heat waves (3d ≥ 35°C). The impact of meteorological factors on daily maximum perceived temperature is assessed using gray correlation degree and partial correlation coefficient. The researchresultsshow that from 1961 to 2018, the average values of Tmax from June to August of each meteorological station in Jilin Province were 25.6℃, 27.5℃ and 26.6℃ respectively, and the average climatic inclination rates were 0.192, 0.134 and 0.153℃ $(10a)^{-1}$ respectively; the average values of ATmax were 26.6℃, 30.2℃ and 29.3℃ respectively, and the average climatic inclination rates were 0.339, 0.238 and 0.234℃$(10a)^{-1}$. From June to August, the average numbers of days with the maximum air temperature ≥35℃ of each station were 0.29, 0.26 and 0.10 dof^{-1}, and the overall average is 0.64 dd $^{-1}$, with the maximum in June, the secondary in July and the minimum in August. The increase rate of the number of days with the maximum air temperature ≥35℃ from June to August was 0.132d second^{-1}. The maximum number of days with high temperature occurred in the western part of Jilin Province, and the minimum occurred in the central and southern part. The average number of times of high-temperature heat waves at each station was 0.041 per year, and the increase rate of heat waves was 0.012 times$(10a)^{-1}$. The high-value areas were mainly distributed in the west of Jilin Province, and basically no high-temperature heat waves occurred in the central and southern regions. Analysis of the grey correlation coefficient shows that the maximum somatosensory temperature is most closely related to the maximum air temperature, followed by relative humidity, and wind speed is the least relewant.

1. Introduction

The high-temperature heat wave usually refers to the high-temperature weather process above 35℃ that lasts for many days, within which the long duration makes people, animals and plants no longer adapted to the environment [1,2]. Under the background of global warming, the frequency and the intensity of high-temperature weather are both increasing, causing huge impact and rising risk of harm [3~6]. The increase in the frequency and intensity of high-temperature weather will trigger a series of natural disasters [7, 8], and even cause much faster increase in casualties than all other extreme weather events [9]. In 2014, high temperature red warnings appeared in many places in North China, and 2019 was the year of second high temperature since meteorological records [10]. In recent years, all parts of China have also been severely threatened by high-temperature heat waves. High-temperature heat waves have become one of the worst meteorological disasters in Ningbo in summer. During the study period, the average frequency of their occurrence is 2.85 times per year, resulting in 7,356 patients suffering from heatstroke [11]. Wuhan can quantitatively express the excess mortality rate of summer population, and extreme high temperature has the greatest impact on the excess mortality [12]. In summer of 2013, Zhejiang Province experienced the most severe weather with high temperature and little rainfall since 1951, and the daily maximum air temperature of all stations over the province was basically above 38℃ [13]. The frequent occurrence of high-temperature heat waves has caused serious consequences to people's life and health, economic and social development and regional ecological environment [14~18].

Many achievements have been made on the research of high-temperature heat waves: [19] studied and analyzed the spatio-temporal characteristics of high-temperature days and frequency and comprehensive index of heat waves in China. The nationwide severe high-temperature heat wave events began to spread to the whole country from the middle and lower reaches of Yangtze River plain in early July. [20] predicted based on the CMIP6 model that South China and Central China will face greater risk of heat waves in the future. [21] analyzed the occurrence frequency, duration, intensity and other characteristics of three grades of high-temperature heat waves in North China. The results showed that the cumulative times of high-temperature heat waves, mild and moderate heat waves in North China are increasing overall. At present, the high-temperature weather in China mainly occurs in South China and Southwest China. There are few studies on high temperature in Northeast China, but some achievements have been made [22~23]. Jilin Province is located in the central part of Northeast China. In the environment of global warming, the high temperature in summer also poses a threat to economic agriculture and human health. Therefore, based on the data of daily maximum air temperature, wind speed and relative humidity from June to August of 1961 to 2018 (high-temperature weather in Jilin Province mainly occurs in June to August) and analysis on the variation characteristics of daily maximum air temperature, daily maximum somatosensory temperature and high-temperature heat waves (continuous 3d≥35℃) in Jilin Province, the results of the study will help to further understand the regional characteristics of high-temperature weather in Jilin, and provide scientific support and guarantee for early warning and prediction of high-temperature disasters in Jilin region.

2. Materials and Methods

2.1. Study Area

Jilin Province is located between 122-131 degrees east longitude and 41-46 degrees north latitude, covering 187,400 square kilometers, accounting for 2% area of the country. Located in the central part of northeast China, it is adjacent to Heilongjiang Province in the north, Liaoning Province in the south, Inner Mongolia Autonomous Region in the west, Russia in the east, and Tumen River and Yalu River in the southeast. Its terrain is high in the southeast and low in the northwest, with plains lying in the midwest. Jilin Province has a temperate monsoon climate, with hot and rainy summers and cold and dry winters, distinguished by the obvious continental nature. From June to August, the average temperature is 21.1℃, the average precipitation is 130.8mm, and the average sunshine duration is 7.3h.

2.2. Data

This study selected data from 47 meteorological stations in Jilin Province (Figure 1) from June to August, a total of 58 years from 1961 to 2018, such as daily maximum air temperature, wind speed, and relative humidity. The data are from Jilin Provincial Information Center. To ensure its integrity and reliability, all data shall be checked and corrected.

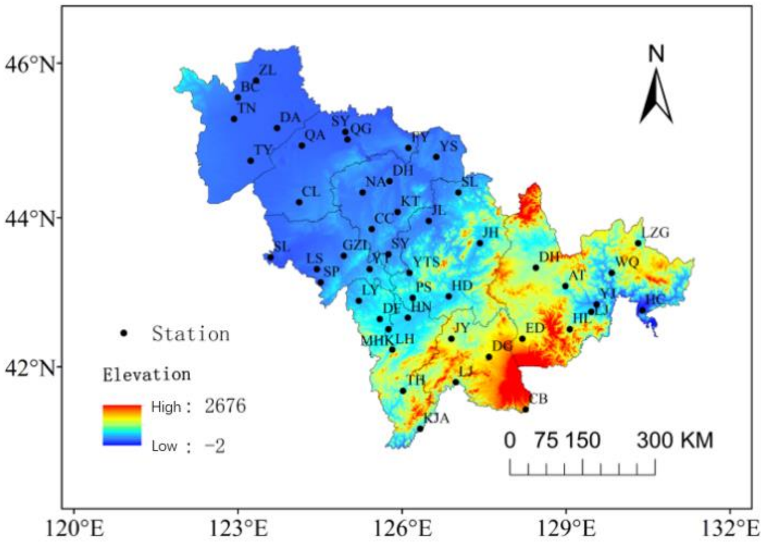

Figure 1: Distribution of 47 meteorological observation stations in Jilin Province

2.3. Methods

2.3.1. Somatosensory temperature

Somatosensory temperature refers to the body temperature index felt by human, which is converted to equivalent temperature. Considering the somatosensory temperature index of the comprehensive influence of temperature, humidity and wind speed, the formula proposed by [24] is introduced:

$$T_{ap} = 1.04T + 0.2e - 0.65V - 2.7 \quad (1)$$

$$e = 6.11 \times 10^{7.5T/(237.3+T)} \times RH \quad (2)$$

In the formula (1) - formula (2), T_{ap} is the daily maximum somatosensory temperature (℃); e is the water vapor pressure (hPa); T is the daily maximum air temperature (℃); V is the wind speed (m•s^{-1}); RH is the relative humidity (%).

2.3.2. Climate inclination rate

In order to study the long-term variation trend of daily maximum air temperature and somatosensory temperature in Jilin Province, the climatic inclination rate [25] is selected as the evaluation index. When calculating the variation trend, the least square method is adopted to calculate the linear regression coefficient a between samples Xt and time t. 10 times the linear regression coefficient a (i. e. 10 years) is taken as the climate inclination rate. The linear equation can be expressed as:

$$Xt = at + b(t = 1, 2, ..., n) \quad (3)$$

2.3.3. High-temperature heat wave

In China, the daily temperature of 35℃ or higher is used as a criterion for determining a high temperature day. High-temperature heat wave is a hot summer weather process that continues to be hot for a period of time and makes the human body feel extremely uncomfortable [26]. According to the regulations of China Meteorological Administration, "the maximum daily temperature is higher than or equal to 35℃ for more than 3 consecutive days" can be regarded as a high temperature heat wave event. This topic studies the high-temperature heat wave events in Jilin Province from June to August based on the above criteria.

2.3.4. Grey correlation degree

The study of the correlation between daily maximum somatosensory temperature and daily maximum air temperature, relative humidity and wind speed [27] is generally described by grey correlation method. The correlation coefficient (ξ_i) is calculated as follows:

$$\xi_i(k) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \rho \times \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \times \max_i \max_k |x_0(k) - x_i(k)|} \tag{4}$$

In formula (4), $x_0(k)$ is the comparison series, $x_i(k)$ is the reference series, the value of ρ is 0.5, and the value of ξ_i is between 0 and 1. The correlation coefficient is calculated after the data is homogenized.

3. Results and Analysis

3.1. Variation Characteristics of Daily Maximum Air Temperature

Figure 2 shows the average daily maximum air temperature and the multi-year climatic inclination rates in Jilin Province from 1961 to 2018. In June, the annual average daily maximum air temperature of each station ranged from 22.4℃ to 27.6℃, with an average value of 25.6℃. The overall trend was decreasing from northwest to southeast. The high-value areas were mainly distributed in the northwest of Jilin (including Baicheng, Taonan, Zhenlai, Tongyu, Qian'an and Shuangliao, etc.), and the low-value areas were mainly distributed in the southeast mountainous area of Jilin (including Hunchun, Donggang, Changbai and Jingyu). The climatic inclination rates of the daily maximum air temperature of each station ranged from 0.024-0.599℃·$(10a)^{-1}$, with an average value of 0.192℃·(10a-1). Only the climate inclination rates at Luozigou and Changbai stations were more than 0.3℃• $(10a)^{-1}$, while at the other stations were all less than 0.3℃• $(10a)^{-1}$. The high value areas of the daily maximum climatic inclination rate were distributed in Changbai, Luozigou, Liuhe, Liaoyuan, Songyuan and other places, while the low value areas were distributed in Yanji, Jilin, Erdao, Changchun and other places. The climatic inclination rates at all sites were positive, indicating an increasing trend of daily maximum temperature during the study.

In July, the annual average daily maximum air temperature of each station ranged from 25.2℃ to 29.2℃, with an average value of 27.5℃. As a whole, the trend decreased from northwest to southeast. The high-value areas were mainly distributed in the northwest of Jilin (including Taonan, Tongyu and other places) and Ji'an area in the south of Tonghua. The low-value areas were mainly distributed in the mountainous area of southeast Jilin (including Dunhua, Donggang, Changbai and Hunchun). The climatic inclination rates of the daily maximum air temperature of each station ranged from 0.006 to 0.529℃· $(10a)^{-1}$, with an average of 0.134℃·$(10a)^{-1}$. Only at Changbai Station, the climatic inclination rate was more than 0.3℃• (10a)$^{-1}$, while at the other stations were all lower than 0.3℃• (10a-1). The high value areas of climatic inclination rates of daily maximum air temperature were distributed in the areas of the low average value of daily maximum air temperature, such as Changbai, Luozigou, Hunchun and Dunhua, etc.; the low value areas were distributed in Da'an, Dehui, Erdao and Shuangliao. The climatic inclination rates of all stations were positive, indicating that the daily maximum temperature was increasing during the study period.

In August, the annual average daily maximum air temperature of each station ranged from 24.5℃ to 28.4℃, with an average value of 26.6℃. The overall trend was decreasing from northwest to southeast. The high-value areas were mainly distributed in the northwest of Jilin (including Baicheng, Zhenlai, Taonan and Tongyu) and Ji'an area in the south of Tonghua. The low-value areas were mainly distributed in Donggang, Changbai and Dunhua. The climatic inclination rates of the daily maximum air temperature of each station ranged from 0.012 to 0.472℃·(10a)$^{-1}$, with an average of 0.153℃·(10a)$^{-1}$. Only at Changbai Station, the climatic inclination rate was higher than 0.3℃• (10a)$^{-1}$, while at the other stations were all lower than 0.3℃• (10a)$^{-1}$. The high value areas of daily maximum air temperature inclination rates were distributed in Changbai, Luozigou, Hunchun, Baicheng and Songyuan, etc., while the low value areas were distributed in Yanji, Yantong mountain, Erdao and Ji'an. The climatic inclination rates of all stations were positive, indicating that the daily maximum temperature is increasing during the study period.

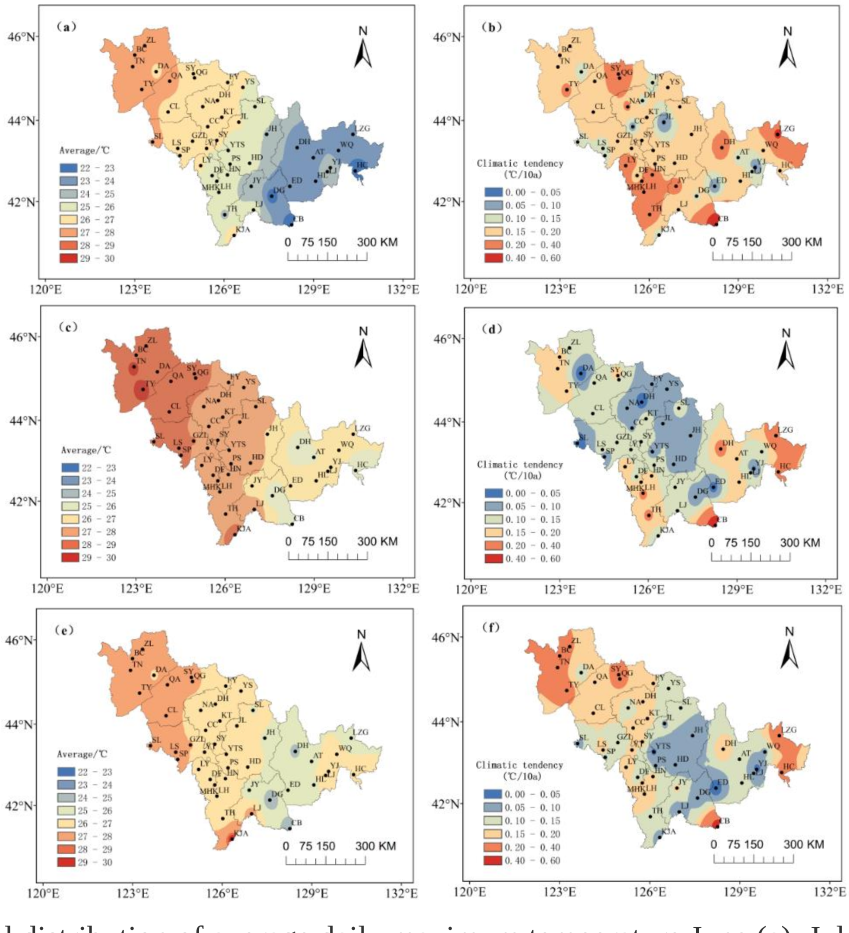

Figure 2: Spatial distribution of average daily maximum temperature June (a), July (c), August (e) and climate trend rate June (b), July (d), August (f) in Jilin Province from June to August 1961-2018

3.2. Variation Characteristics of Daily Maximum Somatosensory Temperature

Figure 3 shows the average daily maximum somatosensory temperature and the multi-year climatic tendency rate in Jilin Province from 1961 to 2018. In June, the daily maximum somatosensory temperature of each station ranged from 23.3℃ to 29.1℃, with an average value of 26.6℃; the daily maximum somatosensory temperature in the northwest was higher than that in the middleeast. The high value areas were distributed in the northwest and the south part of Tonghua, while the low value areas were distributed in the southeast mountains (Donggang, Changbai and Hunchun, etc.). The climatic inclination rates of daily maximum somatosensory temperature of each station ranged from 0.055 to 0.712℃·$(10a)^{-1}$ with an average of 0.339℃·$(10a)^{-1}$. The climatic inclination rates at all stations were positive, indicating that the daily maximum somatosensory temperature was increasing during the study period, .among which were 4 stations where the daily maximum somatosensory temperature inclination rates were above 0.5 ℃·$(10a)^{-1}$, namely Changbai, Luozigou, Liaoyuan and Songyuan; and the low value areas were distributed in the southeast, such as Erdao and Yanji.

In July, the daily maximum somatosensory temperature of each station ranged from 27.3℃ to 32.9℃, with an average value of 30.2℃. The daily maximum somatosensory temperature decreased from northwest to southeast. Among them, there were 16 stations with daily maximum somatosensory temperature < 30℃, while the daily maximum somatosensory temperatures of other stations were all above 30℃. The maximum value appeared in Ji'an, which is 32.9℃. High value areas were distributed in the northwest and the south part of Tonghua, while low value areas were distributed in the southeast mountains (Donggang, Changbai, Hunchun and Dunhua, etc.). The climatic inclination rates of the daily maximum somatosensory temperatures at each station ranged from 0.029 to 0.605℃·$(10a)^{-1}$ with an average of 0.238℃·$(10a)^{-1}$. The climatic inclination rates at all stations were positive, indicating that the daily maximum somatosensory temperature was increasing during the study period. Among them, there were 3 stations with daily maximum somatosensory temperature inclination rate >0.4℃• (10a)-1, which were Changbai, Hunchun and Luozigou; The low value area were distributed in the south-central part.

In August, the daily maximum somatosensory temperatureof each station ranged from 26.6℃ to 32.5℃, with an average value of 29.3℃. Among them, there were 8 stations where daily maximum somatosensory temperatures were above 30℃, while those of the other stations were all below 30℃. The maximum value appeared in Ji'an, which was 32.5℃. The high-value areas were distributed in the western region, the south of Tonghua and the southeast of Yanbian, while the low-value regions were distributed in the middle-east region (Donggang, Changbai and Dunhua, etc.). The climatic inclination rates of the daily maximum somatosensory temperature of each station varied from 0.049 to 0.523 ℃ $(10a)^{-1}$, with an average of 0.234℃• $(10a)^{-1}$.The climatic inclination rates of all stations were positive, indicating that the daily maximum somatosensory temperatures were increasing during the study period. Among them, there were 2 stations with daily maximum somatosensory temperature inclination rate >0.4℃• $(10a)^{-1}$, which were Changbai and Luozigou. The low value areas were distributed in the south-central part.

3.3. Variation Characteristics of High Temperature-Heat Wave Weather

From June to August in Jilin Province from 1961 to 2018 the station with the most days≥35℃ was Taonan Station, with a total of 177d of high temperature days and an annual average of 3.05d, followed by Tongyu Station, with a total of 173d of high temperature days. The station of least days was Donggang Station, which is 0d. In June, July and August, the average numbers of days ≥35℃ for all stations were 0.29, 0.26, 0.10 d·a^{-1}, and the overall average was 0.64 d·a^{-1}. Except for Wang Qing, Helong, Linjiang, Ji'an and Changbai, the numbers of days verage of 3.05d, followed by Tongyu

Station, with than that in August in figure 4. From 1961 to 2018, the 5 stations with the total high temperature days >100d were Taonan (177d), Tongyu (173d), Baicheng (129d), Zhenlai (118d) and Qian'an (107d), all of which are located in the western part of Jilin Province; there were 8 stations with a total number of high temperature days ≤ 10d, mainly located in the central and southern region, namely Panshi (8d), Huinan (7d), Changbai (7d), Jiaohe (6d), Dunhua (2d), Jingyu (2d), Erdao (1d) and Donggang (0d). Spatial differences were significant in figure 5. During the study period, the number of days, T°C in each month showed an increasing trend in figure 6. Overall, the increasing trend of June and July was greater than that in August, with June > July > August, and the increase rate of daysd i°C from June to August is 0.132d $\cdot(10a)^{-1}$. Among them, the maximum number of high temperature days occurred in the western part of Jilin Province, and the minimum number of high temperature days occurred in the central and southern regions of Jilin Province.

From June to August, the annual average times of continuous 3d≥35°C at each station in Jilin Province was 0.041 times, with 0.018 times, 0.019 times, and 0.004 times in June , July, and August respectively. Among them, there were 2 stations ral and southern regions of Jilin Province. er of high tempeoth located in western Jilin; 18 stations had 0 times, mainly distributed in the central and southern region of Jilin Province. During the study period, the number of times of continuous 3dtim°Cin each month showed an increasing trend, and the increase rate was 0.012 times$\cdot(10a)^{-1}$ from June to August.

3.4. Correlation of Relative Humidity, Wind Speed and Daily Maximum Temperature with Daily Maximum Body Temperature

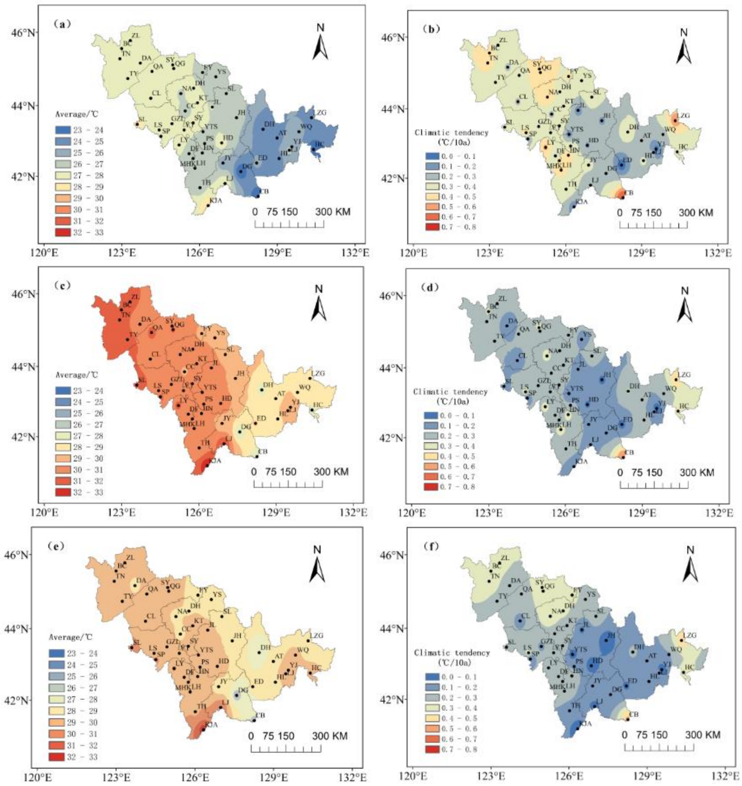

Figure 3: Spatial distribution of average daily maximum somatosensory temperature June (a), July (c), August (e) and climate trend rate June (b), July (d), August (f) in Jilin Province from June to August 1961-2018

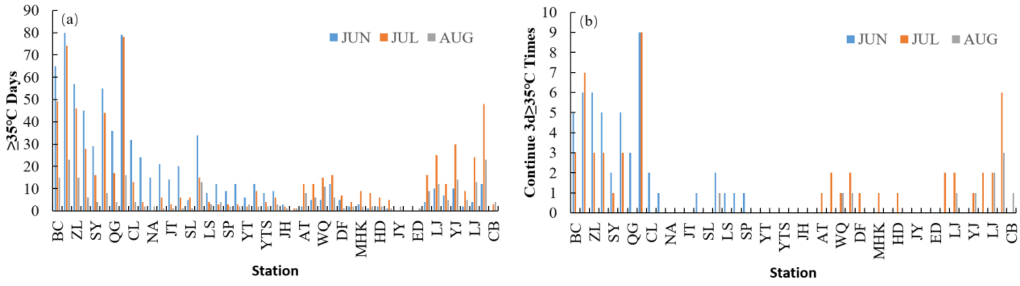

Figure 4: The number of high temperature (daily maximum temperature ≥ 35°C) days (a) and the number of high temperature heat waves (3d ≥ 35 ℃ in a row) (b) at each site in Jilin Province from June to August 1961 to 2018

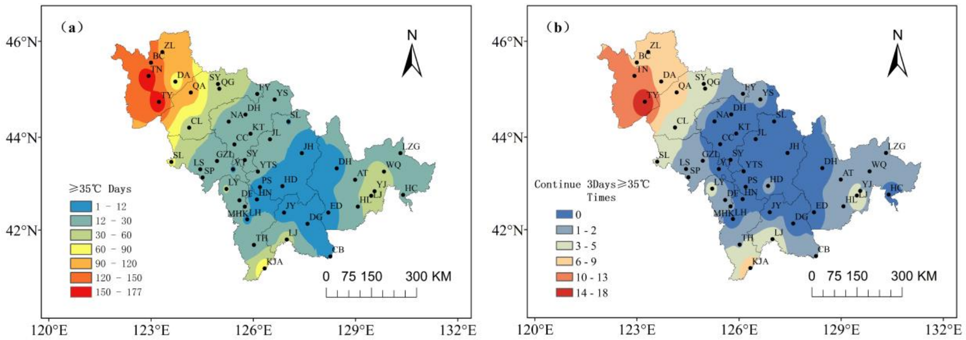

Figure 5: Spatial distribution of the number of high temperature (daily maximum temperature ≥ 35°C) days (a) and the number of high temperature heat waves (3d ≥ 35°C in a row) (b) at each site in Jilin Province from June to August 1961 to 2018

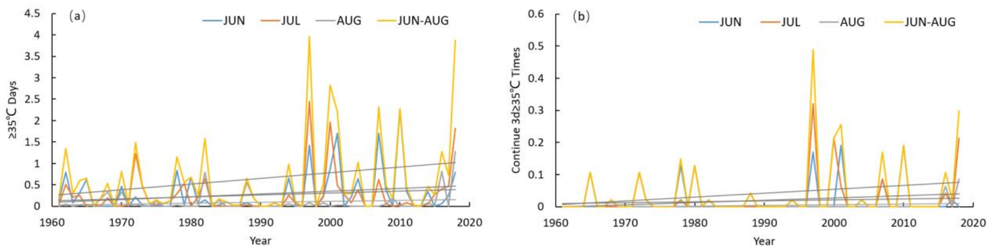

Figure 6: Inter-annual variation of the number of high temperature (daily maximum temperature ≥ 35°C) days (a) and the number of high temperature heat waves (3d ≥ 35°C in a row) (b) at each site in Jilin Province from June to August 1961 to 2018

Table 1: Grey correlation coefficient and partial correlation coefficient of daily maximum temperature, relative humidity, wind speed and daily maximum somatosensory temperature in Jilin

Month	Grey correlation coefficient			Partial correlation coefficient		
	daily maximum temperature	relative humidity	Wind speed	daily maximum temperature	relative humidity	Wind speed
JUN	0.9487	0.7041	0.6268	0.9792	-0.7106	-0.2846
JUL	0.9508	0.7191	0.5974	0.9718	-0.5189	-0.1149
AUG	0.9729	0.8557	0.7211	0.9790	-0.2688	-0.4384
JUN-AUG	0.9605	0.7974	0.6291	0.9737	-0.5338	-0.3469

During the study period, the daily maximum body temperature was most closely related to the daily maximum temperature, with a gray correlation coefficient of 0.9 or higher for all months, followed by relative humidity, with the lowest correlation for wind speed (Table 1). Daily maximum body temperature is positively correlated with daily maximum temperature, and negatively correlated with relative humidity and wind speed. The higher the daily maximum temperature, the lower the relative humidity and the lower the wind speed, the higher the daily maximum body temperature.

4. Conclusions

This study analyzed the spatial distribution characteristics of daily maximum temperature, daily maximum body temperature and high temperature heat wave based on daily maximum temperature, relative humidity and wind speed data from 47 stations in Jilin Province from June to August 1961-2018, and analyzed the influence of meteorological factors on daily maximum body temperature using gray correlation and partial correlation coefficients, and obtained the following conclusions:

(1) From 1961 to 2018, the average values of daily maximum temperatures in June to August at various stations in Jilin province were 25.6 ℃ (22.4-27.6 ℃), 27.5 ℃ (25.2-29.2 ℃) and 26.6 ℃ (24.5 -28.4℃), with an overall decreasing trend from northwest to southeast, the high value area is mainly distributed in the northwest of Jilin, and the low value area is mainly distributed in the southeastern mountainous region of Jilin; the mean values of climate tendency rate are 0.192, 0.134 and 0.153℃·$(10a)^{-1}$, respectively, and the climate tendency rate of all stations are positive, indicating that the daily maximum temperature during the study period is increasing. The average values of daily maximum body temperature in June to August at each station in Jilin Province were 26.6℃ (23.3-29.1℃), 30.2℃ (27.3-32.9℃) and 29.3℃ (26.6-32.5℃), respectively, and the daily maximum The mean values of climate tendency rate were 0.339, 0.238 and 0.234℃·$(10a)^{-1}$, respectively, and all stations had positive values, indicating an increasing trend of daily maximum body temperature during the study period. (2) During the study period, the average number of daily maximum temperature ≥35°C days at each site was 0.29, 0.26 and 0.10 d·a^{-1}, respectively, from June to August, with an overall average value of 0.64 d·a^{-1}, of which the maximum was in June, the second in July and the smallest in August. the rate of increase of ≥35°C days from June to August was 0.132 d·$(10a)^{-1}$, with the maximum number of high temperature days occurring in the western part of Jilin and the minimum number of high temperature days occurring in the south-central part of Jilin. (3) The annual number of high-temperature heat waves at each site was 0.041, and the rate of increase of heat waves was 0.012 times·$(10a)^{-1}$. The high value areas were mainly distributed in western Jilin, and there were basically no high-temperature heat waves in the south-central region. (4) During the study period, the daily maximum body temperature was most closely related to the daily maximum temperature, with the gray correlation coefficient reaching above 0.9 for all months, followed by relative humidity, and the lowest correlation for wind speed. The daily maximum body temperature was positively correlated with the daily maximum temperature, and negatively correlated with the relative humidity and wind speed.

Acknowledgments

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