Temperature Characteristics and Temperature Estimation with Different Return Periods in Huailai County

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Abstract Huailai County in Zhangjiakou was taken as the research area. Based on daily temperature data from 1992 to 2021, various methods were used to analyze the characteristics of extreme temperature changes in the region and estimate extreme temperature values for different return periods. The results showed that from 1992 to 2021, both the annual average maximum and minimum temperatures in Huailai County exhibited a slight downward trend, with continuous low temperatures from 2010 to 2012; the annual average extreme maximum temperature slightly decreased, reaching a peak in 2010, with July being the concentrated period of extreme high temperatures; the extreme minimum temperature "continuously cooled down", with multiple occurrences of low temperatures in the past decade and a decrease in the number of high temperature days. The estimation of return periods based on the Gumbel distribution indicates that the temperature values for different return periods vary between the highest and lowest temperature months, and the longer the return period, the more significant the extreme temperature values and the larger the standard deviation. The research can provide a basis for local agricultural development.

Key words Extreme temperature; Variation characteristics; Return period

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In recent years, the trend of global warming has significantly intensified. According to the 2023 report by the World Meteorological Organization (WMO), the global average temperature has risen by approximately 1.2 ℃ compared to pre-industrial levels over the past decade (2014 – 2023), with a significant increase in both frequency and intensity of extreme weather events such as extremely high temperature and heavy precipitation[1]. In recent years, extreme weather events have occurred frequently[2], and the frequent occurrence of extreme heat weather events continued to intensify. This has led to meteorological disasters and their secondary or derivative hazards, posing severe threats to the safety of public life and property and the sustained development of public health, ecological environment, and agriculture[3 – 5]. Many scholars have conducted research on the characteristics and impacts of extreme temperatures. Xu Junchang *et al.*[6] analyzed the recurrence period of extreme temperatures in Shaanxi Province; Zhou Chengxia[7] studied the correlation between extreme temperature distribution and altitude in Guizhou Province; Li Bozhen *et al.*[8] revealed the cyclical characteristics of temperature changes in Jiangxi Province; Wang Hua *et al.*[9] revealed the cyclical characteristics of temperature changes in Jiangxi Province. It can be seen that research on temperature return period in China has been conducted in multiple regions.

Huailai County, Zhangjiakou City, Hebei Province, belongs to a temperate continental monsoon climate, characterized by distinct four seasons, sufficient sunshine, simultaneous rain and heat, and large temperature differences between day and night. It is an important agricultural production area in the Beijing – Tianjin – Hebei region, and has become a famous grape and wine production area in China due to its abundant grape production. Due to grape cultivation and wine making, there are specific temperature requirements[10 – 11], and other locally grown agricultural products such as *Malus spectabilis*, corns, potatoes, *etc.* are generally sensitive to extreme temperatures. However, systematic research on extreme temperatures with different return periods in Huailai is relatively scarce. In this paper, Huailai County was taken as the object, and the characteristics of extreme temperatures and the return periods of high and low temperature extremes in the region were systematically analyzed. It aimed to provide a basis for agricultural disaster prevention, variety improvement, and planting optimization, and ensure the sustainable development of characteristic agricultural products.

1 Data and methods

1.1 Data sources and methods In this paper, daily temperature data in Huailai County National Station from 1992 to 2021 was selected. The data has undergone strict quality control and auditing to ensure accuracy and reliability. Four season division: spring (March to May), summer (June to August), autumn (September to November), and winter (December to next February).

When calculating extreme meteorological parameters, Mann – Kendall (MK) was used to detect sudden changes and validate trend results (this non parametric test method is not limited by data distribution and can effectively identify sequence trends). The widely used Gumbel probability distribution (extreme value type I) was used for fitting and calculating the highest and lowest temperatures with different return periods (Gumbel distribution is based on extreme value theory and can effectively describe the probability characteristics of extreme events, widely used in the

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field of meteorological extreme value analysis).

1.2 Common extreme value analysis methods for meteorological parameters with return period Gumbel type type of fitting curve:

$$F(x) = \exp(-\exp(-a(x-u)))\ (a>0,\ -\infty<u<\infty)$$

where a is scale parameter of distribution; u is location parameter of distribution. When the return period is R (with a probability of $1/R$):

$$x_R = u - \frac{1}{a}\ln[\ln(\frac{R}{R-1})]$$

2 Results and analysis

2.1 Average highest and lowest temperatures From 1992 to 2021, the average annual maximum temperature in Huailai County was 16.6 ℃, with a fluctuation range of 15.0 – 17.7 ℃, reaching its peak in 2007. From the trend of change, there was a slight downward trend and intermediate fluctuation. The average maximum temperature from January to July has increased overall, reaching its highest point in July (with an average of 30.7 ℃) and its lowest point in January (−0.9 ℃). The average maximum temperature from August to December has decreased overall, dropping to about 0.6 ℃ in December (Fig.1).

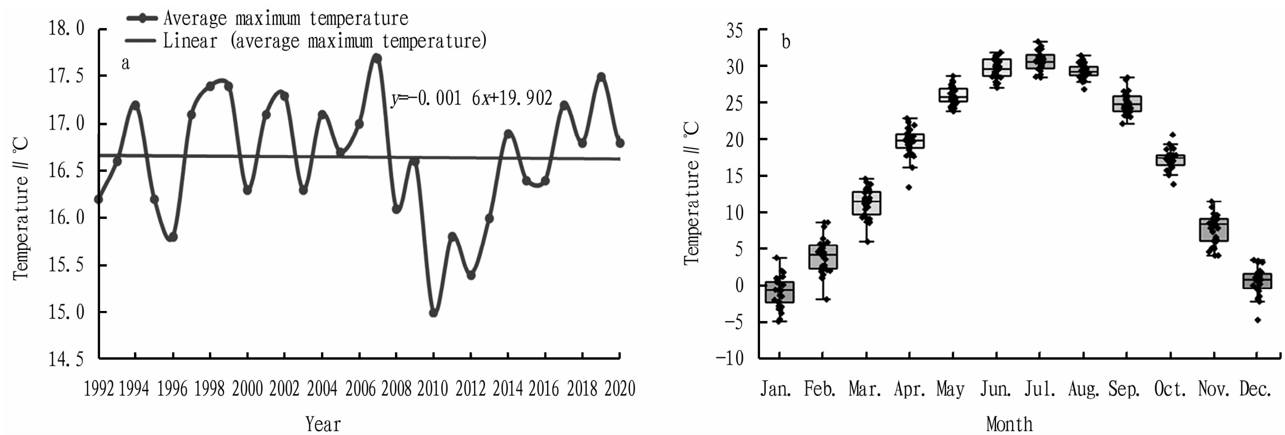

Fig.1 Interannual (a) and intra-annual variations (b) of the average maximum temperature from 1992 to 2021

The average annual minimum temperature from 1992 to 2021 was 5.0 ℃, with a fluctuation range of 3.8 to 5.9 ℃. The temperature remained low from 2010 to 2012, and reached a 30-year low in 2012. Overall, there was a slight downward trend, but temperature was higher in some years. The temperature in the region was the lowest in January and the highest in July. The temperature changed relatively smoothly in spring and autumn (Fig.2).

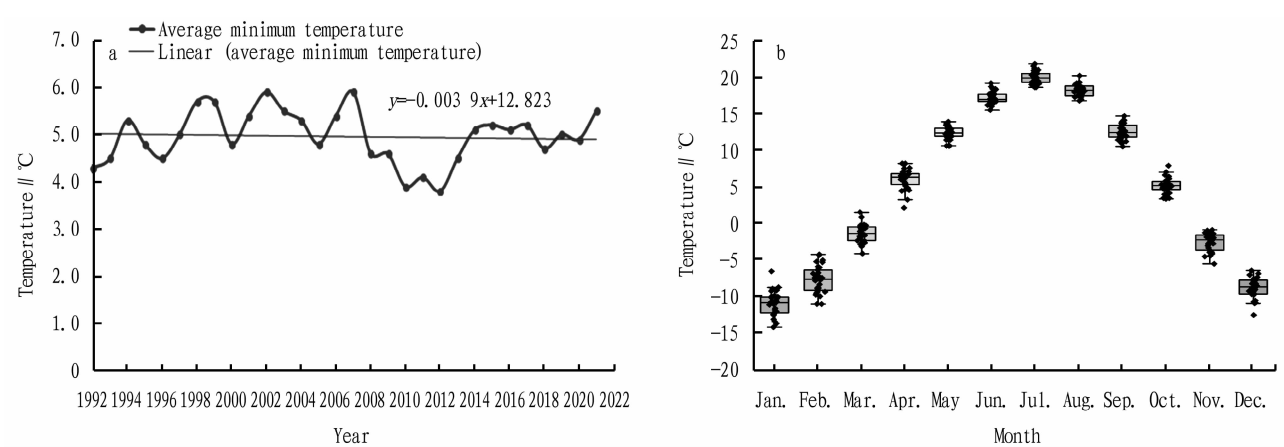

Fig.2 Interannual (a) and intra-annual variations (b) of the average minimum temperature from 1992 to 2021

2.2 Extreme temperatures The annual average extreme maximum temperature in Huailai County from 1992 to 2021 was 37.0 ℃, with a fluctuation range of 34.2 to 41.7 ℃. In 2010, it reached 41.7 ℃ (the most extreme year in 30 years, the only year exceeding 40 ℃). From the trend of change, there was a slight downward trend, and a "mid-term fluctuation" existed in the middle, with extremely high temperature exceeding 39 ℃ in some years (Fig.3). From 1992 to 2021, the extremely high temperature in summer generally ranged from 34.0 to 41.7 ℃, with an average extreme maximum temperature of 36.1 ℃ in July and a lower extreme high temperature in January.

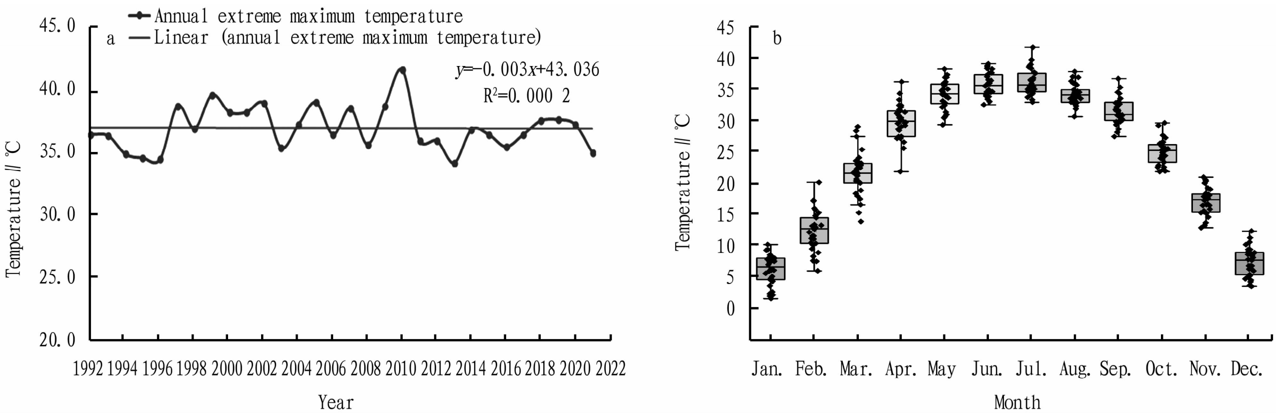

Fig. 3 Interannual (a) and intra-annual variations (b) of extreme maximum temperature from 1992 to 2021

From 1992 to 2021, the annual average extreme minimum temperature in Huailai County was −18.4 ℃, with a fluctuation range of −24.3 to −14.7 ℃, showing an overall trend of "continuous cooling". From 2010 to 2021, there were multiple instances of lower extreme low temperature, with 2021 being nearly 6 ℃ lower than the average, possibly due to the frequent occurrence of extreme weather events under global climate change[12]. The seasonal characteristics were obvious. The extremely low temperature in January was the most significant, with an average value of −17.46 ℃. In January 2021, it set a record of −24.3 ℃. In summer, it was usually between 5 and 18.5 ℃, and may be abnormally lower in some years. Spring and autumn are transitional seasons, with significant differences in temperature extremes. The temperature range in spring was wide, with the highest temperature reaching above zero and the lowest temperature being extremely low. The upper limit of extremely low temperature in September was 8 ℃. After October, the temperature dropped sharply, and the extremely low temperature dropped below freezing point, significantly deepening the chill (Fig. 4).

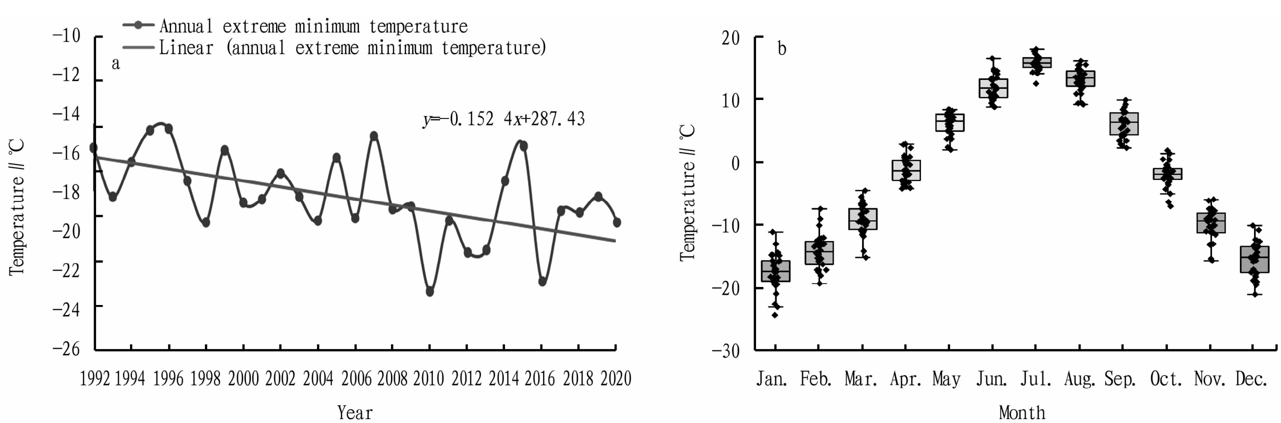

Fig. 4 Interannual (a) and intra-annual variations (b) of extreme minimum temperature from 1992 to 2021

2.3 High-temperature and low-temperature days From 1992 to 2021, Huailai County had an average of 5.9 d with the highest temperature ≥ 35 ℃ per year. In the 30 years, there were a total of 177 high temperature days, including 17 d with temperature ≥ 38 ℃ and only 1 d with temperature ≥ 40 ℃. The average minimum temperature was showing a slow downward trend, but with significant interannual fluctuations and not a continuous decline. There were a total of 8 years with ≥ 10 high temperature days, mainly concentrated between 1997 and 2009 (Fig. 5).

2.4 Estimation of extreme temperature return period The monthly average maximum temperature for different return periods was calculated, and the characteristics of average maximum temperature in the month with the highest temperature from 1992 to 2021 were analyzed. The average maximum temperature in the month with the highest temperature in Huailai Meteorological

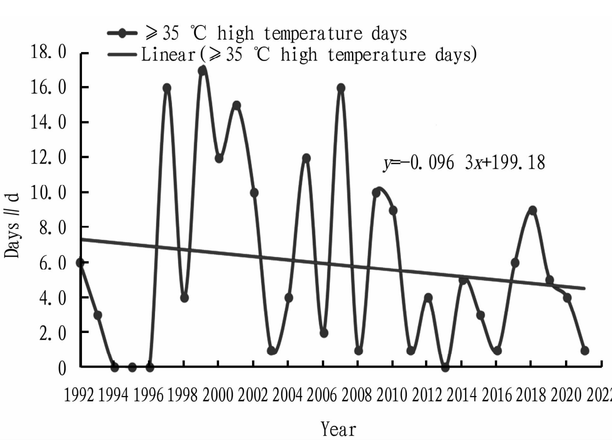

Fig. 5 Interannual variation of ≥ 35 ℃ high temperature days from 1992 to 2021

Station over the years was 30.9 ℃. In 1997, it reached a peak of 33.3 ℃, and it was a valley of 28.5 ℃ in 1995 (Fig. 6). From the trend of change, the temperature showed a decreasing trend during this period, but did not pass the significance test (0.05). Further validation of the trend results by Mann – Kendall (MK) showed no significant trend changes or abrupt changes, indicating a stable climate state (Fig. 7).

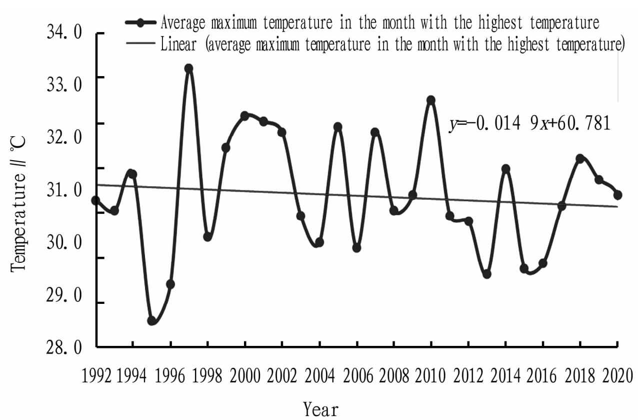

Fig. 6 Interannual variation of average maximum temperature in the month with the highest temperature at Huailai Meteorological Station over the years

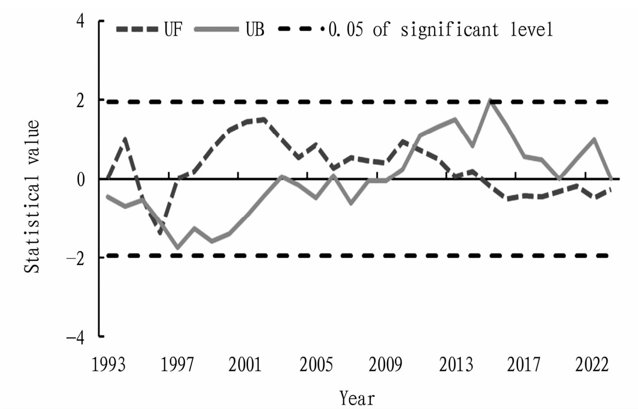

Fig. 7 Statistics of sudden change test of average maximum temperature in the month with the highest temperature at Huailai Meteorological Station

In this paper, the Gumbel distribution was used to estimate the return interval of average maximum temperature in the month with the highest temperature at the Huailai Meteorological Station: the estimated value for a 50-year return period was 33.9 ℃ (0.505 of standard deviation), which meant that extremely high temperature at this level may occur on average every 50 years; the estimated value for a 100-year return period was 34.6 ℃ (0.614 of standard deviation), which was higher in intensity and greater in uncertainty compared to the high temperature with a 50-year return period (Table 1).

The standard deviation reflects the uncertainty range of the calculated value. As the return period prolongs, both the calculated value and the standard deviation increase, indicating that the longer the return period, the lower the probability of extremely high temperature occurrence, and the higher the calculated uncertainty. By calculating the frequency distribution parameters of the monthly average maximum temperature with different return periods at the Huailai Meteorological Station, it can be seen that the mean under the Gumbel distribution was 30.74 ℃ (reflecting the long-term average level), and the coefficient of variation *Cv* was 0.04 (measuring the degree of dispersion). This indicated that although the monthly average maximum temperature in the region fluctuated, the overall dispersion was relatively small, and the data was relatively concentrated.

Table 1 Monthly average maximum temperature with different return periods at the Huailai Meteorological Station ℃

Return period // a	Gumbel	Standard deviation | σ |
10	32.3	0.248
30	33.4	0.426
50	33.9	0.505
60	34.1	0.534
100	34.6	0.614

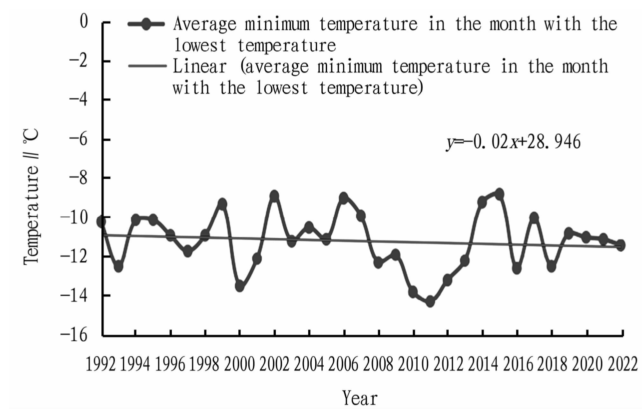

Fig. 8 Variation of average minimum temperature in the month with the lowest temperature at the Huailai Meteorological Station over the years

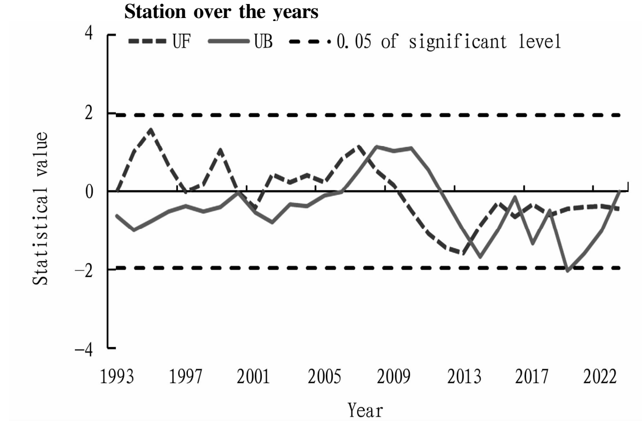

Fig. 9 Statistics of sudden change test of average minimum temperature in the month with the lowest temperature at the Huailai Meteorological Station

The average minimum temperature in the month with the lowest temperature at the Huailai Station from 1992 to 2021 was analyzed, with a cumulative value of −11.2 ℃. The time series showed fluctuating changes, reaching the highest in 2014 (−8.6 ℃) and the lowest in 2011 (−14.3 ℃) (Fig. 8). It reflected the interannual differences in winter temperatures. Trend analysis over the past 30 years showed that there has been no significant increase or decrease in temperature, overall stable, and not significantly affected by climate change. MK was used to further validate the trend results, and the results showed there was no abrupt changes observed during the study period, further verifying the stability of temperature (Fig. 9).

Gumbel distribution was used to calculate the monthly average minimum temperature with different return periods at the Huailai Station: the calculated value of the monthly average minimum temperature that occurred once every 50 years was −15.0 ℃ (0.599 of standard deviation), which meant that Huailai area may experience a low temperature weather with a monthly average minimum temperature of around −15.0 ℃ every 50 years on average; the estimated monthly average minimum temperature that occurred once every 100 years was −15.8 ℃ (0.727 of standard deviation). Compared to the situation that occurred once every 50 years, the extremely low temperature that occurred once every 100 years was lower, and the uncertainty has also increased.

As the return period increases, the calculated monthly average minimum temperature decreases, and the standard deviation increases, indicating that the longer the return period, the less likely extremely low temperature events will occur, but the higher the uncertainty of the calculation. In addition, the mean temperature was −11.19 ℃ (reflecting the average level) under the Gumbel distribution, and the coefficient of variation Cv was 0.13 (measuring the degree of dispersion). It indicated that although there were fluctuations, the overall dispersion was relatively small.

Table 2 Monthly average minimum temperature with different return periods at the Huailai Meteorological Station ℃

Return period//a	Gumbel	Standard deviation | σ |
10	−13.1	0.295
30	−14.4	0.505
50	−15.0	0.599
60	−15.2	0.632
100	−15.8	0.727

3 Conclusions

3.1 Basic characteristics of temperature Average temperature: the annual average maximum temperature for 30 years was 16.6 ℃, with an interannual fluctuation range of 15.0 – 17.7 ℃, showing a slight downward trend; the annual average minimum temperature was 5.0 ℃, with a fluctuation range of 3.8 – 5.9 ℃. The seasonal characteristics of temperature were obvious throughout the year, with an average maximum temperature of 30.7 ℃ in July and an average minimum temperature of −17.46 ℃ in January.

Extreme temperature: the average annual extreme maximum temperature was 37.0 ℃ (reaching 41.7 ℃ in 2010, the only year exceeding 40 ℃, with a high incidence in July); the average annual extreme minimum temperature was −18.4 ℃ (showing a significant trend of "continuous cooling", with multiple low temperatures in the past decade and a high incidence in January).

Days of high temperature: the cumulative days of high temperature ⩾ 35 ℃ in 30 years was 177 d, and the annual high temperature days showed a decreasing trend.

3.2 Estimation of extreme temperature return period based on Gumbel probability distribution The monthly average highest temperature increased with the extension of return period: 32.3 ℃ once every 10 years, 33.4 ℃ once every 30 years, 33.9 ℃ once every 50 years, 34.1 ℃ once every 60 years, and 34.6 ℃ once every 100 years; the monthly average lowest temperature decreased with the extension of the recurrence period: −13.1 ℃ once every 10 years, −14.4 ℃ once every 30 years, −15.0 ℃ once every 50 years, −15.2 ℃ once every 60 years, and −15.8 ℃ once every 100 years.

The standard deviation increased with the extension of return period, indicating that the longer the time, the higher the uncertainty of the calculation. The coefficients of variation for extremely high and low temperatures were 0.04 and 0.13, respectively, with smaller interannual fluctuations in extremely high temperature. According to the MK test, there was no significant trend or sudden change point. The extreme temperature was generally stable, but the fluctuation increased.

In this paper, the seasonal and interannual variations of extreme temperatures in Huailai County, as well as the extreme values of return periods were clarified. It revealed the characteristics of extremely low temperature cooling and high temperature days reducing. It can provide a basis for local agricultural disaster prevention and reduction, variety improvement and planting optimization of characteristic agricultural products (such as grapes and *M. spectabilis*), and help promote sustainable development of regional agriculture.

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rious impact on meteorological detection environments to start construction without approval and permission. Meteorological stations need to maintain long-term stability. If urban development has already threatened the existing meteorological stations and after investigation, it is indeed necessary to relocate them, a comprehensive planning, scientific site selection, and reasonable layout should be carried out to determine the location of a new station with the consent of meteorological administrative departments at or above the provincial level, which is conducive to achieving the coordinated development of urban and rural construction and the protection of meteorological detection environments.

3.2 Investigating and dealing with all kinds of behaviors that damage meteorological detection environments in accordance with the law In light of the speed and trend of social and economic development in the new era, it is needed to further improve the collaboration and communication mechanism between meteorological departments and local governments, and jointly do a good job in the protection of meteorological detection environments and facilities. Meteorological, urban construction, planning, and land and resource departments should enhance daily communication, conscientiously perform their duties, carry out special inspections, and handle seriously any violations of the regulations on the protection of meteorological detection environments and facilities. If any unit or individual sets up obstacles within the protection range of meteorological detection environments, meteorological departments should promptly and strictly stop such behavior. If meteorological detection environments are seriously affected and damaged, the local government should be requested to carry out special law enforcement inspections, formulate solutions, investigate and deal with them in accordance with the law, and implement law enforcement penalties to units and individuals.

3.3 Strengthening the publicity of the protection work of meteorological detection environments Meteorological departments at all levels in Ulanqab City should adopt various forms of meteorological science popularization and publicity. On the basis of on-site explanations, setting up display stands, distributing publicity brochures and posting publicity posters, they should increase online publicity efforts, and use platforms such as wechat, Weibo official accounts, Douyin, Kuaishou and Wevideo to produce animations, videos and other popular science content, so as to publicize to the public the significance of protecting meteorological detection environments, enhance the public's awareness of the importance of protecting meteorological detection environments, and create a favorable atmosphere throughout society for jointly protecting meteorological detection environments. Meanwhile, meteorological departments at all levels should promptly disclose to the public the scope and standards for the protection of meteorological detection environments. Local governments should set up warning signs outside meteorological observation sites, clearly define the range of protected areas, prevent damage to meteorological detection environments and facilities.

4 Conclusion

To enhance the protection of meteorological detection environments in the new era and further raise the awareness and behavior of the whole society in participating in the protection of meteorological detection environments, the Ulanqab Meteorological Bureau should do a good job in the protection of meteorological detection environments, clarify that meteorological departments are the first person responsible for the protection of meteorological observation facilities and meteorological detection environments, increase the inspection of meteorological detection environments, and increase the number of installed cameras to ensure that there are no blind spots or dead zones in positioning. At the same time, it is necessary to enhance communication among departments, earnestly perform the functions of supervision and inspection, and ensure early detection, early reporting and early handling of problems existing in meteorological detection environments. Besides, it is needed to promote the comprehensive implementation of the protection of meteorological detection environments in accordance with the law, and give full play to the role of meteorological detection environments as the first line of defense in disaster prevention and mitigation.

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