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A Study on Extreme Temperature and Climate Events in Zhejiang Region of East China

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Abstract

The extreme high temperature anomaly (EHTA) events in a region are one of the most important climatic parameters to make climate assessment of the trend of regional climate change. The diagnosis and analysis of the EHTA event in Zhejiang Province in East China in 2022 show that the event has set the rarest record in this region in the past 71 years from both time and space perspectives. The results of Mann-Kendall trend analysis showed that the mean annual high temperature days in Zhejiang Province had a sudden change. The sudden change occurred around 2004, and the trend was rising after the sudden change.

Keywords

Extreme High Temperature Anomaly, Mann Kendall Test, Climate Assessment, Climate Change

1. Introduction

The death toll caused by EHTA disasters is much higher than that caused by both tornadoes and floods. Due to the increasing trend of extreme hot weather events in recent ten years, many meteorologists pay attention to the evaluation of climate anomalies of extreme hot weather events in a certain region [1]-[12]. Many of these scholars estimated the trend based on Ordinary Least Squares (OLS) linear regression method. T test method is used to judge the statistical significance of the trend, and some other people use F test method to judge the statistical significance. In this paper, we try to use Mann-Kendall trend analysis method. In 2022, there were EHTA events in many parts of the world, and many records were broken in meteorological statistics. In addition, meteorologists are no longer satisfied with using statistical data of conventional meteorological observation to characterize the characteristics of extreme heat wave weather events, but from the connotation of heat wave, namely from the span of time and space to characterize the fact of heat wave, to analyze the mechanism and trend of heat wave generation. This paper studies the temporal and spatial characteristics of the 2022 anomalous high temperature event in Zhejiang, East China.

2. Data and Methods

2.1. Data

In this paper, the data of high temperature were obtained from 66 national meteorological observation stations in Zhejiang Province, and the average annual values of meteorological elements were taken from 1991 to 2022. In the ranking of meteorological elements, the single station value is taken from the data since the establishment of the station, and the regional (or provincial) average value is taken from 1951. The high temperature strength evaluation is based on the national and industry standards and relevant business regulations of the department.

2.2. Methods

2.2.1. The Definition of a Day That the Hot Wave Weather Occurs in the Region

A day that heat wave occurs is determined when more than 33 stations in the region have high temperature (maximum daily temperature ≥ 35˚C).

2.2.2. The Comprehensive Intensity of the Heat Wave Occurs at a Single Station

$$\mathrm{SI}=\sum_{j=1}^{3} I_j \times T_j \tag{1}$$

Formula (1) was used to calculate the comprehensive intensity index of high temperature weather at a single station. Where, SI represents the comprehensive intensity index of high temperature weather at a single station; I_j represents the classification of high temperature intensity (daily maximum temperature) at a single station, and the values 1, 2 and 3 correspond to three temperature intervals [35˚C, 37˚C), [37˚C, 40˚C) and [40˚C, +∞) respectively; T_j represents the number of high temperature days corresponding to I_j.

2.2.3. The Evaluation of Regional High Temperature Weather Processes

Formula (1) was used to calculate the SI value of each station during all regional high temperature weather processes in Zhejiang Province from 1951 to 2020. The percentile method was used to divide SI to determine the value interval of each grade of SI, and thus the comprehensive intensity grade value G_k of a single station in high temperature weather was determined. According to the classification method of regional high temperature weather process given in literature, formula (2) is used to calculate the regional high temperature weather process grade.

$$\mathrm{RI} = \sum\nolimits_{k=1}^{5} G_k \times W_k \tag{2}$$

where, RI represents the grade index of regional high temperature weather process; G_k represents the comprehensive intensity grade of high temperature weather in a single station within the region; W_k indicates the ratio of the number of G_K to the total number of stations in the region

2.2.4. Mann-Kendall Trend Analysis Test

(1) Construct an order column for time series x with sample size n:

$$s_k = \sum_{i=1}^{k} r_i \quad (k = 2,3,\cdots,n) \tag{3}$$

where, when $x_i > x_j$, $r_i = 1$; when $x_i \le x_j$, $r_i = 0$ ($j = 1,2,\cdots,n$)

Statistical quantity UF_k is defined under the assumption of random independence of time series.

$$UF_k = \frac{s_k - E(s_k)}{\sqrt{\mathrm{var}(s_k)}} \quad (k = 1,2,\cdots,n) \tag{4}$$

where $UF_1 = 0$; both $E(s_k)$ and $\mathrm{var}(s_k)$ are the mean and variance of cumulative quantity s_k respectively.

In the case of x_1, x_2, … When x_k is independent of each other and has the same continuous distribution, it can be calculated by the following formula

$$E(s_k) = \frac{n(n-1)}{4}; \mathrm{var}(s_k) = \frac{n(n-1)(2n+5)}{72} \tag{5}$$

In this case, UF_k is the standard normal distribution.

3. Results

3.1. The Total Number of Days with Hot Wave Weather

As showed in chapter 2.2.1, one day with hot wave weather is defined as the day when half or more than 33 stations in Zhejiang have high temperature (maximum daily temperature ≥ 35˚C). Figure 1 shows us that the average number of high temperature days in Zhejiang throughout the year is 25.5. From 1951 to 1971, it fluctuated around the perennial value, with a maximum of 38.6 days (in 1953) and a minimum of 10.9 days (in 1954). The period from 1972 to 2002 was the low value area, the least in 1982 was 6.2 days, followed by in 1999 (6.5 days). 2003 and beyond is the high value area. In 2022, the average number of high temperature days in our province reached 53 days, 27.5 days more than the usual number, which broke the record of the largest number (43 days in 2013). The number of annual high temperature days in Hangzhou and other 53 national meteorological stations broke the record.

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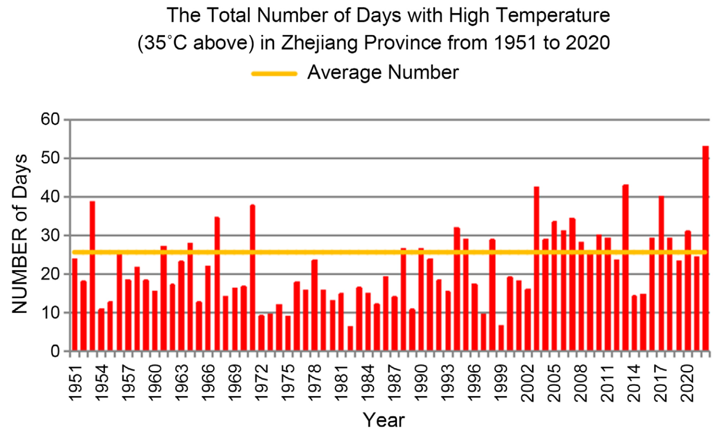


Figure 1. The total number of days with hot wave weather.

3.2. The Percentage of Coverage of Days with Hot Heat Wave Weather

With the calculation method of SI (see chapter 2.2.2) and RI (see chapter 2.2.3), we can obtain Figure 2 and Figure 3.

The high temperature of 35.2˚C appeared on April 12 in Zhuji, which was the 7th earliest in history (the high temperature appeared on March 14, 1988, which was the earliest since 1951). On June 6-7, there was a dispersed high temperature; The end of high temperature was late. From September 30 to October 4, there were regional high temperature weather processes, which was the latest in history. October 5 saw the end of high temperature completely, and the end of high temperature was the third late in history (high temperature occurred in Yeosu on October 11, 2017 and 2019, which was tied for the latest). Five large-scale regional high temperature processes occurred during the period, which occurred from June 23 to 29 (lasting 7 days), July 3 to 17 (lasting 15 days), July 20 to August 27 (lasting 39 days), August 29 to 30 (lasting 2 days) and September 30 to October 4 (lasting 5 days). However, the large-scale regional sustained high temperature weather process occurred from June 23 to August 30, which consisted of four regional high temperature weather processes with short intervals.

3.3. High Temperature Days Distribution in Zhejiang Province

From the analysis of high temperature extremes, there are only two maximum centers of high temperature in Zhejiang (1951-2020), respectively in Lishui (43.2˚C); Xinchang (44.1˚C) and Fenghua (43.5˚C) junction area. In 2022, 20 stations broke the record for extreme maximum temperature, and a new extreme temperature center appeared in Sanmen (43.1˚C) on the new high temperature extreme temperature distribution map.

3.4. Evaluation of High Temperature Strength Classification

From the perspective of climate state, the occurrence of hot heat wave in summer is a normal phenomenon, but the duration length, intensity and scope of the hot heat wave event in 2022 have reached the extreme abnormal degree, which is behind the deep-seated climate scale reasons. This section examines whether heat waves are related to climate change trends. Traditional method estimated the climate trend based on Ordinary Least Squares (OLS) linear regression method. Here we estimate the climate trend by using Mann-Kendall Method.

In **Figure 4** it given significance level of 0.05, a critical threshold value = 1.96. The results showed that the mutation of average annual high temperature days in Zhejiang Province began around 2004, and the trend after the mutation was on the rise.

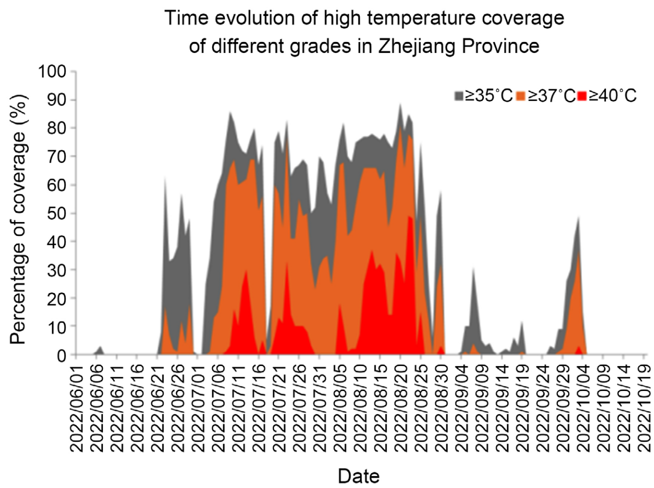
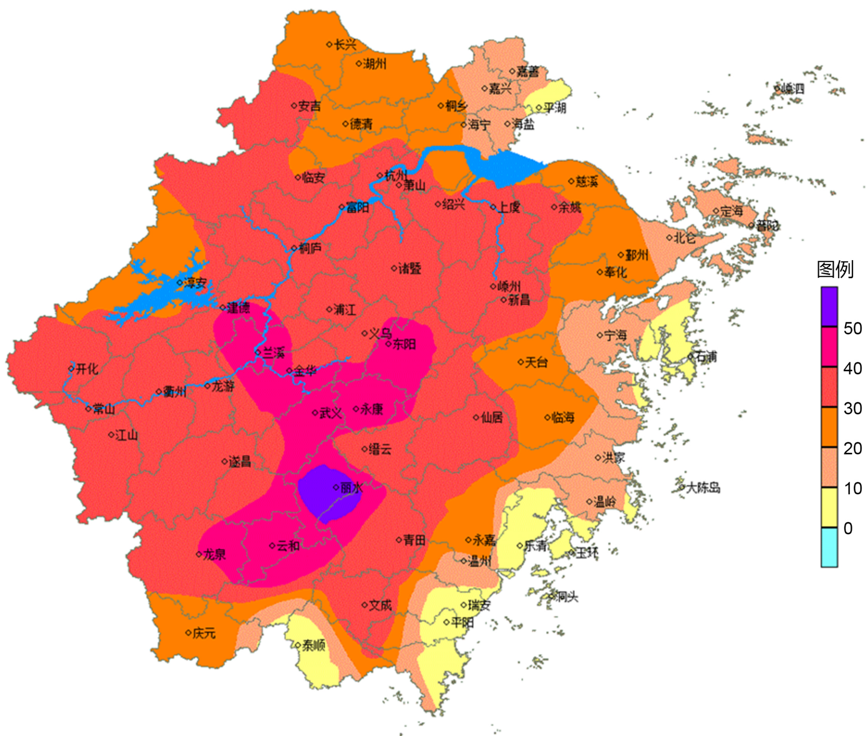
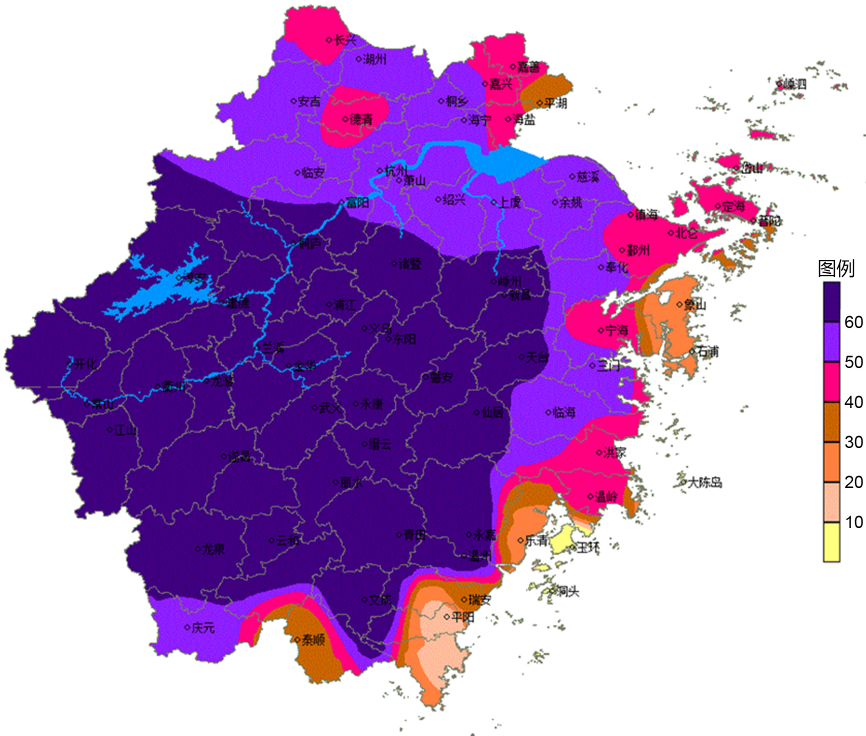


Figure 2. Time evolution of high temperature coverage of different grades in Zhejiang province.



(a) Average Distribution



(b) Distribution in 2022

Figure 3. High Temperature days Distribution in Zhejiang Province (Unit: day).

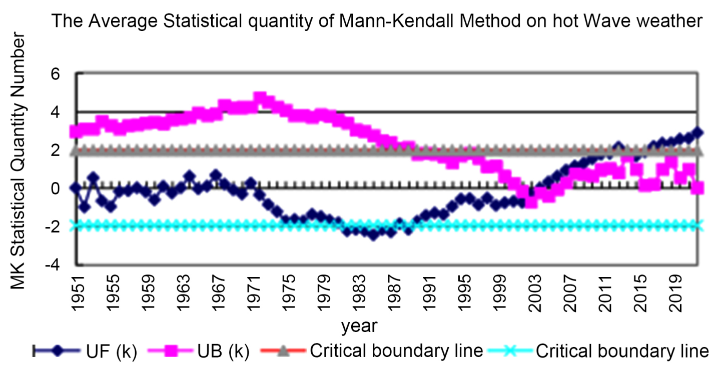


Figure 4. The Average Statistical Quantity of Mann-Kendall on hot Wave weather.

Also, the historical series of high temperature days of four national meteorological stations with long time series (Hangzhou, Quzhou, Hongjia and Wenzhou) were detected (omitted). The results show that the mutation time of these four stations appeared around 2003, 2013, 2007 and 2002, respectively.

The statistical analysis of the annual number of high temperature days in Zhejiang Province since 1951 shows that 6 of the 10 years with the highest number of high temperature days occurred after 2000, and the three years with the highest number were 2022, 2013 and 2003. According to the statistics of regional high temperature processes in Zhejiang from 1971 to 2022, 8 of the 10 strongest regional high temperature processes in Zhejiang occurred in the last 20 years.

The results further confirm the link between the unusually high temperatures in 2022 and climate change.

4. Discussion and Summary

4.1. Discussion

In the summer and autumn of 2022, the strongest high temperature event since 1951 occurred in Zhejiang Province. The high temperature appeared early and ended late. There were five regional high temperature weather processes, among which the sustained high temperature weather from June 23 to August 30 consisted of four regional high temperature processes with short intervals, and the latest regional high temperature process occurred from September 30 to October 4. The evaluation results show that the extreme high temperature events in 2022 have the characteristics of long duration, wide range, high intensity and high extremity. The comprehensive average high temperature intensity in the whole province is the strongest in history. The regional high temperature weather process lasting 39 days from July 20 to August 27 is exceptionally strong. It was tied with the regional high temperature process, which lasted 43 days from June 30 to August 11, 2003, as the strongest on record.

Was this extreme heat event just a fluke? Or is it the inevitable result of climate change trends? Will there be more extreme heat events in the future? It is very important to seek for the answers of all these academic problems.

4.2. Summary

The results of the temporal and spatial characteristics analysis showed that this extreme heat event is not an accidental event, and the result of Mann-Kendall trend analysis also showed that the mean annual high temperature days in Zhejiang Province had a sudden change. The sudden change occurred around 2004, and the trend was rising after the sudden change.

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Conflicts of Interest

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

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