

# The Characteristics of Precipitation During the Flood Seasons in Heilongjiang Province Over the Past 53 Years

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## Abstract

Based on monthly precipitation data from May to September 1970-2022 from 80 weather stations, methods such as the IDW space interpolation method, Mann-Kendall test, cumulative anomaly method, and wavelet analysis were used to analyze the rainfall trends, periodicity, and mutation characteristics of precipitation during the flood season. The results show: (1) In recent 53 years, the average flood precipitation amount is 459.2 mm, with the most at 784.1 mm (in 2016) and the least at 317.6 mm (in 2007). The flood precipitation has shown a slight trend of increasing at a rate of 2.5 mm/a. (2) The precipitation in flood season reflects obvious intergenerational variation characteristics, mainly in a "W" variation trend, with the average flood precipitation in each decade showing 2000s < 1970s < 1980s < multi-annual average < 1990s < 2010s. (3) The mid part of the province in Yichun, north of Hegang and the middle of Harbin had the highest flood rainfall, the lowest was in the Great Khingan Mountains, the Songnen Plain, and the Sanjiang Plain. The spatial distribution from west to east was characterized by a "low-high-low" distribution. (4) There were three time scales, 54, 17, and 6 years, with the first period, the most intense one, being the first primary period. The main cycle of precipitation in flood season is 34a, the sub-cycles are 12a and 4a. (5) The cumulative distance showed a "decline - fluctuate - rise" trend. The flood season precipitation had an abrupt change in 2011 and showed a change from less to more, post-mutation 2012-2022 compared to pre-mutation 1970-2011, the mean increase was 142.5 mm.

## Keywords

Precipitation in the flood season, rainfall trends, mutation characteristics, wavelet analysis, mutation analysis

## 1. Introduction

According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [1], human activities are the main driving force of climate system change. The global surface temperature during 2011-2020 was about 1.09°C higher than that during 1850-1900 [2], with greenhouse gases contributing about 1.5°C of warming and other human activities, such as anthropogenic aerosols, contributing about 0.4°C of cooling. As the global climate continues to warm, the water vapor content in the atmosphere increases and the speed of the water cycle increases [3], leading to the obvious increase in the intensity and frequency of meteorological disasters such as drought and flood [4]. Extreme weather disasters come one after another - heavy precipitation, widespread drought, and prolonged high temperatures, which have exacerbated the instability of water resources

and the contradiction between supply and demand [5]. As an important point in the water cycle, precipitation is the direct or indirect replenishment source of various water bodies, and its long-term evolution has a decisive influence on regional water resources [6]. The change in precipitation pattern and water cycle process intensifies the complexity of water resources change, resulting in increased uncertainty of precipitation and its spatio-temporal distribution [7]. Flood season is the precipitation concentration period in a year, and it is also the peak period of disastrous weather such as strong convection and heavy precipitation [8]. Abnormal precipitation in flood season is very likely to cause droughts, floods, and other natural disasters [9]. Quantitative analysis of precipitation variation in flood season has important practical significance for industrial and agricultural production, water data management, ecological environment, flood control, and drought resistance.

Current studies have shown that the middle and high latitudes in the Northern Hemisphere are most obviously affected by global warming [10], which is manifested by increasing precipitation and extreme heavy precipitation events [11]. Heilongjiang, which is a typical "climate-vulnerable area" [12] and one of the regions prone to climate disasters [13], is located in the middle and high latitudes, spanning about 10 latitudes and longitudes [14]. Main characteristics of meteorological disasters in Heilongjiang [15]: (1) Frequency. It shows that there are disasters almost every year, among which flood and drought disasters are the most frequent. (2) Regional. In spring, there are often droughts in the west and floods in the east. In summer, there are many floods along the river banks, many waterlogging in the lowlands, and much hail in the middle region. (3) Seasonality. Spring is prone to drought; summer and autumn are prone to waterlogging. (4) Continuity. Some disasters can occur in successive seasons or years. In 1956-1957, 1964-1965, and 1971-1972, there were cold damage and waterlogging. (5) Periodicity. Affected by quasi-periodic changes in climate, meteorological disasters have obvious phases. For example, from 1954 to 1965, the main meteorological disasters were low-temperature and waterlogging. From 1966 to 1976, it was mainly low temperature and drought. The period from 1977 to 1989 was mainly high temperature and drought. From 1990 to 1994, it was mainly high temperature and rainy.

Heilongjiang, as one of the country's important grain production bases [16], has ranked first in the country for many consecutive years in terms of grain output, commodity volume, and export volume, playing a pivotal role in national grain production [17]. The main flood season in Heilongjiang is the key period for the growth and development of grain crops. In 1998, the mainstream basins of the Nenjiang River and Songhua River were hit by heavy rain in summer, which caused the worst flood in 150 years, which greatly affected the grain yield and caused scholars to pay attention to and study the precipitation characteristics in Northeast China. There have been studies on the characteristics of flood season precipitation in Heilongjiang. For example, it is pointed out that the flood season precipitation in Heilongjiang accounts for 65% of the annual precipitation [18]. Some studies have found that the flood season average precipitation in Heilongjiang (1981-2010) showed a general trend of more precipitation in the south and less precipitation in the north, more precipitation in the east, and less precipitation in the west [19]. The extreme precipitation threshold was unevenly distributed, high in the west and low in the east, and showed a decreasing trend from the middle to the north and south. Someone studied the obvious abnormal precipitation in the main flood season (June-August) of 2013 in Heilongjiang [20], and showed that there were many rainy days, large-scale continuous heavy precipitation was intensive and occurred early, which led to rare floods in history and regional flood disasters, to result in the total loss of rice and corn output up to  $3.97 \times 10^9$  kg. Some people analyzed that the average accumulated precipitation in flood season (May-September) was 430.0 mm and high precipitation area was concentrated in the eastern and southern Songnen Plain and the southern Lesser Khingan Mountains by using hourly precipitation data of Heilongjiang from 1961 to 2014 [21]. Someone studied summer (June-August) precipitation in Heilongjiang in the past 55 years (1961-2015), and found that the spatial distribution of precipitation was the highest in the central Lesser Khingan Mountains and the western Zhangguangcai Mountains, above 360 mm, and the lowest in the Sanjiang Plain and Songnen Plain, between 300 and 320 mm [22].

At present, there is little research on the variation characteristics of precipitation in Heilongjiang during flood season. Heilongjiang is taken as the research object in this paper. Based on the monthly precipitation data of flood season (May-September) from 1970 to 2022, this paper uses the IDW spatial interpolation method, complex Morlet wavelet change method, Mann-Kendall test method, and other methods to study and analyze the interdenial spatiotemporal variation characteristics, periodic variation rules, multi-time scale variation characteristics and abrupt change characteristics of flood season precipitation. It is helpful to analyze the evolution process of flood season precipitation in Heilongjiang, and further analyze the change characteristics of regional water resources, to provide data reference for the signs of humidification and warming in Northeast China, to provide a theoretical basis for forecasting, guiding the work of drought prevention and control, meteorological disaster prevention and reduction, and to provide scientific and technological support for better flood season meteorological service.

## 2. Data and methods

### 2.1 Data Selection

At present, there are 84 ground meteorological observation stations in Heilongjiang, all of which have been built into automatic meteorological stations. The data are derived from monthly precipitation data of the Heilongjiang Meteorological Data Center

from May to September 1970 to 2022. If the number of missing years in the annual data of a single station accounted for  $\geq 5$  in all 53 years (1970-2022), this station would not be selected. According to this method, data from 80 ground observation stations in the province were selected for research, and the distribution is shown in Fig. 1.

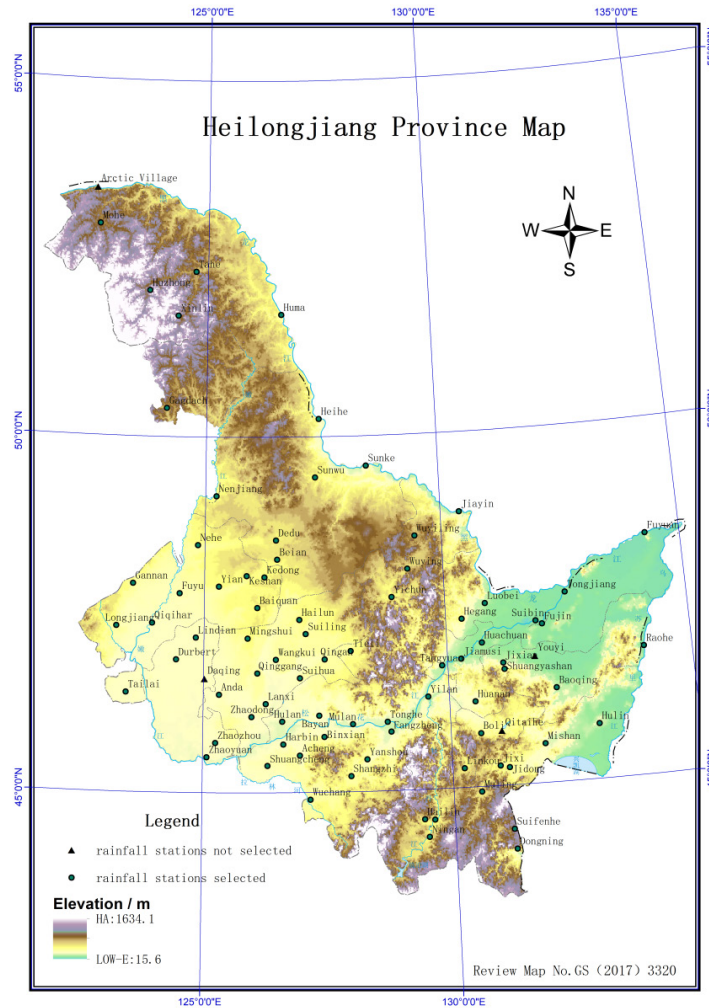


Figure 1. Geomorphology and meteorological stations of Heilongjiang Province.

## 2.2 Analysis Method

(1) Wavelet analysis introduces the window function based on Fourier transform. Wavelet analysis is very effective in obtaining the adjustment rule of a complex time series and diagnosing the internal hierarchy of time series changes. It has the advantage of multi-resolution and is very effective in resolving the evolution characteristics of time series at different scales.

In the wavelet change, wavelet functions, which are the more commonly used, are Mexican Hat wavelet, Daubechies wavelet, Morlet wavelet, and so on. Wavelet change can realize time-frequency localization of time series, which is a time-frequency local transformation. It can effectively extract information from the sequence, obtain a scale-time function, and carry out multiscale refinement analysis of the function through functions such as scaling and shifting. Wavelet coefficient:

$$W_f(a, b) = |a|^{-\frac{1}{2}} \sum_{k=1}^n f(k) e^{ikt} e^{-t^2/2} \tag{Eq.1}$$

In the formula:  $a$  is the scale factor, reflecting the period length of the wavelet;  $b$  is the time factor, reflecting the translation in time.

Wavelet square difference analysis is an important content of wavelet analysis. The wavelet square difference chart reflects the distribution of wave energy with time scale and can determine the relative intensity of disturbance at various scales in a time

series. The scale at the corresponding peak value is called the main time scale, which is used to reflect the main period of the time series. Complex Morlet wavelet, as a complex wavelet, has more advantages than the real wavelet in application. It eliminates the oscillation of the numerical mode in the transformation process of the real wavelet, and the mode and phase can be separated from the wavelet coefficient. Given its advantages, this paper selects the complex Morlet wavelet function to carry on the continuous wavelet transform to the flood season precipitation series. The main data processing and wavelet transform are realized in MATLAB.

(2) Mann-Kendall mutation analysis (abbreviation M-K method) is a non-parametric statistical test method, which can not only detect the trend of sequence change but also test the mutation point. On the premise that the climate series is stationary, the MK method constructs an order column for the time series  $X$  with  $n$  sample sizes:

$$d_i = \sum_{i=1}^k r_i (2 \leq k \leq n) \tag{Eq.2}$$

The mean value  $E$  and variance  $Var$  of  $d_i$  are respectively:

$$E(d_k) = \frac{k(k-1)}{4} \tag{Eq.3}$$

$$Var(d_k) = \frac{k(k-1)(2k+5)}{72} \tag{Eq.4}$$

Assume that the time series is randomly independent and define statistics

$$UF_k = \frac{d_k - E(d_k)}{\sqrt{Var(d_k)}}, (k = 2, \dots, n) \tag{Eq.5}$$

$$UB_k = -UF_k, k = 1, 2, \dots, n \tag{Eq.6}$$

$UF_1 = 0, UB_n = 0$ , a given level of significance of  $\alpha = 0.01$ , namely  $U_{0.01} = \pm 2.58$  mm, if  $|UF_k| > U_\alpha$  formula has an obvious trend of increase or decrease. All  $UF_k$  form a curve  $UF$ , the time series is arranged in reverse order, and the same method is referenced to the inverse sequence to obtain the sequence  $UB$ . The statistics curves  $UF, UB$ , and  $\pm 2.58$  lines were plotted on the same graph. If  $UF > 0$ , the sequence shows an upward trend. If  $UF < 0$ , the sequence shows a downward trend. When they exceed the critical line, it indicates that the trend of change is significant, and the range beyond the critical line is determined as the time region of mutation. If  $UF$  and  $UB$  intersect at the critical boundary, then the time corresponding to the intersection is likely to be the mutation onset time and is statistically significant. If there is no significant change trend, the intersection point of two curves is outside the critical boundary or there is more than one intersection point, it cannot be determined whether it is a mutation point. The authenticity of mutation points should be verified by other tests to enhance the reliability of mutation analysis results. The advantage of the M-K method is that it is easy to calculate, the time of mutation can be defined, the mutation region can be indicated, and it is not disturbed by a few outliers.

(3) The cumulative anomaly method is a method to judge the trend of climate series intuitively. For climate variable  $x$ , the corresponding cumulative anomaly at a certain time can be expressed as:

$$\hat{x}_t = \sum_{i=1}^t (x_i - \bar{x}), t = 1, 2, \dots, n \tag{Eq.7}$$

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \tag{Eq.8}$$

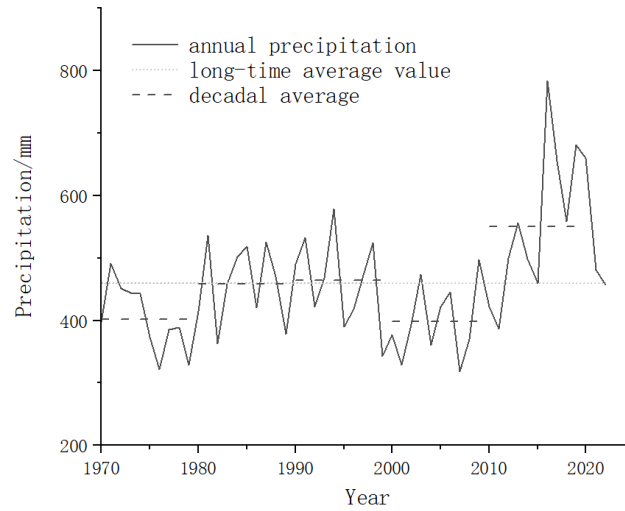
The cumulative anomaly value of  $n$  moments can be plotted to analyze the changing trend of the sequence, and its turning point can be used to judge the mutation process of the sequence.

### 3. Results and analysis

#### 3.1 The characteristics of temporal and spatial variation

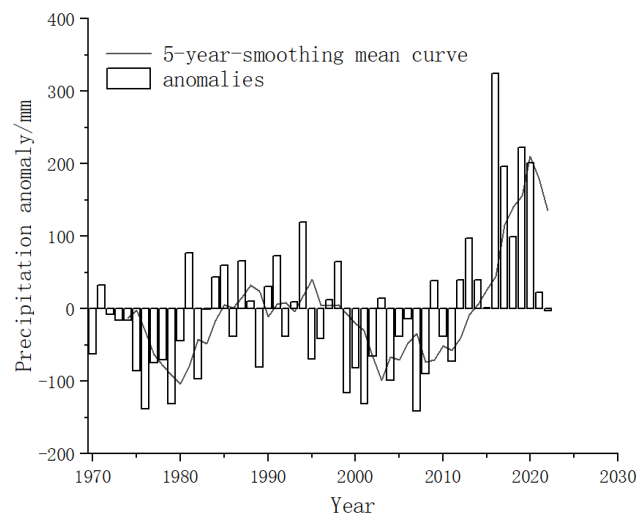
From 1970 to 2022, the lowest accumulated precipitation in flood season in Heilongjiang was 147.4 mm in 2021 in Shuangyashan, and the highest was 1343.7 mm in 2016 in Hegang. This can be shown in Fig. 2, the average precipitation in flood season of the whole province in 53 years was about 459.2 mm, showing a slightly rising trend with an increasing rate of about 2.5 mm/a,

and the interannual amplitude changes were not stable. The highest peak value was 784.1 mm in 2016, the second highest value was 681.4 mm in 2019, the trough value was 317.6 mm in 2007, and the second trough value was 321.5 mm in 1976.

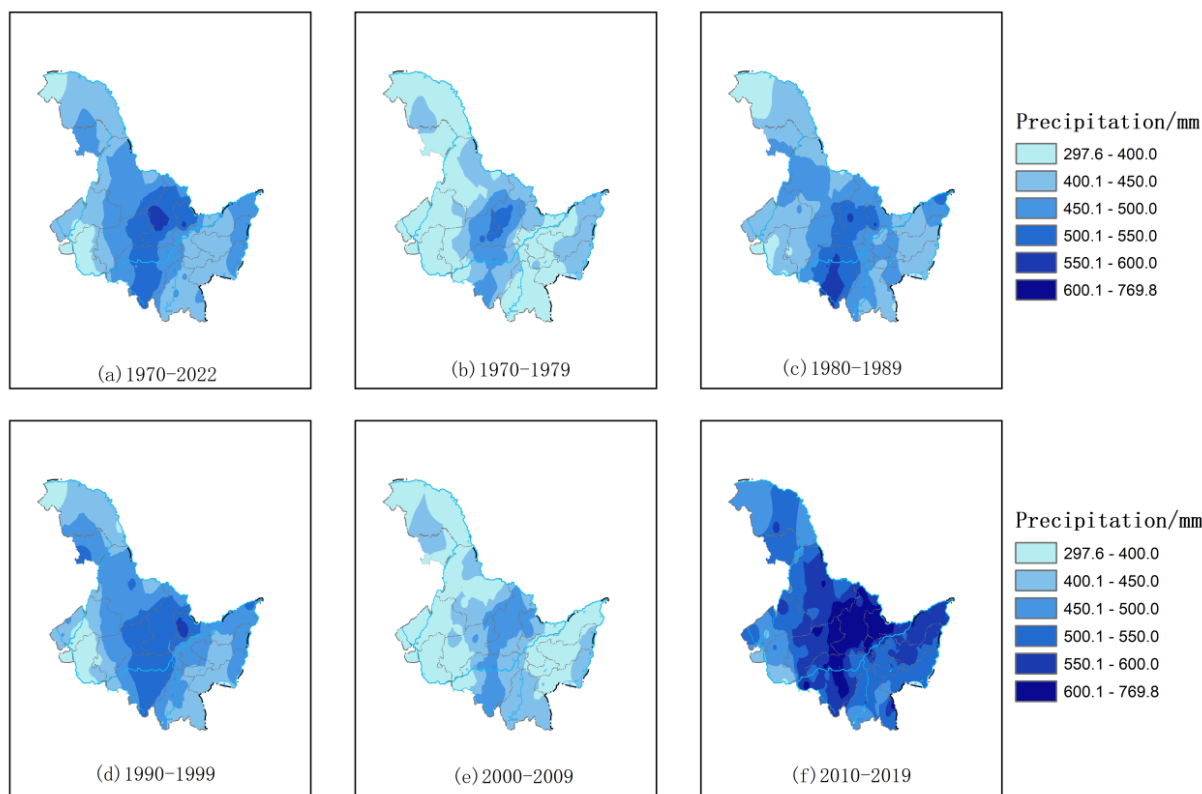


**Figure 2. The change curve of annual precipitation during flood season in Heilongjiang from 1970 to 2022.**

The sliding mean curve of 5 years generally presents a "W"-shaped trend (Fig. 3), and the anomalous values show that precipitation in individual years has a large variation and has obvious interdecadal variation characteristics as a whole. In the 1970s, the average total precipitation in flood season in Heilongjiang showed a low precipitation trend, and the average precipitation was 402.3 mm from the average value of -56.9 mm. From the 1970s to the 1980s, the flood season precipitation showed an increasing trend, with an average increase of 56.4 mm in ten years. In the 1980s, the average precipitation in the flood season of the whole region was 458.7 mm. In the 1990s, the average precipitation of flood season in the whole region was 463.7 mm. In the 1980s and 1990s, the average precipitation of flood season was relatively high, and both were close to the anomaly value. From the 1980s to the 1990s, the anomaly showed an "M"-shaped variation trend, while the precipitation fluctuated up and down between different years. The average precipitation in flood season in the 2000s was the lowest at 398.4 mm, which was lower than the normal value of -60.8 mm. During the 1990s and 2000s, the decrease was 65.3 mm. In the flood season in the 2010s, the average precipitation was 550.2 mm, which was 91 mm higher than the normal value. In the flood season between the 2000s and 2010s, the precipitation increased significantly, increasing 151.8 mm in decades.



**Figure 3. The flood precipitation anomalies and their 5-year smooth lines in Heilongjiang from 1970 to 2022.**



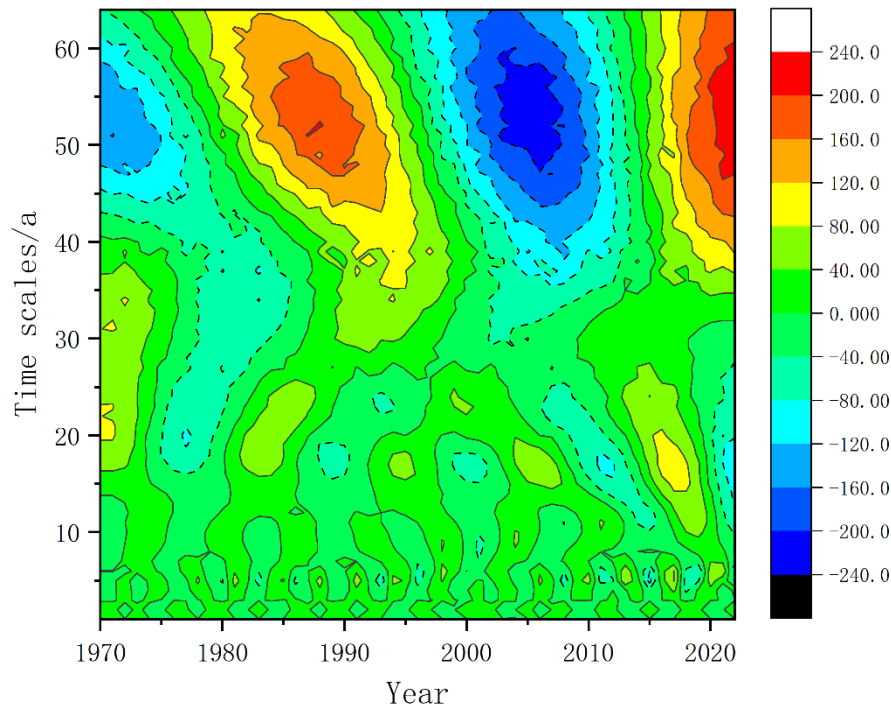
**Figure 4. Spatial distribution of inter-decadal flood precipitation in Heilongjiang.**

Fig. 4 shows that the average precipitation in flood seasons from 1970 to 2022 ranges from 366.4 to 575.6 mm, and the average precipitation in flood seasons of each decade ranges from 307.6 to 512.1 mm in the 1970s. The 1980s were 373.3~589.1 mm; The 1990s were 371.7~586.8 mm; the 2000s were 297.6 to 488.3 mm; The value of 2010s ranges from 387.6 mm to 769.8 mm. The average precipitation in flood season was low in the 1970s, a little different in the 1980s and 1990s, the lowest in the 2000s, and the highest in the 2010s. The precipitation in flood season is high in the middle part of Heilongjiang, but low in the western and eastern parts, showing a "low-high-low" distribution from west to east. The high precipitation is concentrated in Yichun, the north of Hegang, and the middle of Harbin, and the average precipitation in flood season was more than 500 mm in 53 years. The flood season precipitation in the Greater Khingan Mountains, Sanjiang Plain, and Songnen Plain was low in each period. Because the Sanjiang Plain and Songnen Plain are low and flat, they are greatly affected by river floods. According to the statistics from 1978 to 2000, the disaster area caused by rainstorms and floods accounted for 29.1% of the total disaster area on average, and the direct economic losses and direct agricultural losses accounted for 48% and 36% of the total losses respectively.

The spatial distribution chart can directly show the intergenerational evolution process of each region. In the last 53 years, there were only 6 stations with average precipitation below 400 mm, less than 1% of the total research stations, which were mainly concentrated in Qiqihar, Daqing, and the Greater Khingan Mountains. Precipitation was low in the 1970s and 2000s, and 43 stations had average precipitation of less than 400 mm in flood season, accounting for 54% of the total research stations and more than half of the regions. In the 2000s, the average precipitation in flood season did not exceed 500 mm at most, while in the 1970s, the average precipitation in flood season exceeded 500 mm in four places: Yichun Yichun (512.1 mm), Yichun Wuying (505.2 mm), Suihua Qingan (504.2 mm), and Yichun Tieli (503.8 mm). Precipitation in the 1980s and 1990s was similar. There were 8 and 10 sites with average precipitation of less than 400 mm in flood season, accounting for about 1% of the total research sites, mainly in the Greater Khingan Mountains and Daqing. The maximum average precipitation of flood season is below 600 mm in the 1980s and 1990s. The average precipitation of flood season in the 1980s was over 550 mm mainly in the Haerbin and Yichun. The average precipitation of flood season in the 1990s exceeded 550 mm mainly in the north of Hegang. In the 1990s, the region that the average precipitation in flood season was more than that in the 1980s. In the 2010s flood season, Daqing Zhaoyuan was the only station whose precipitation of less than 400 mm, and 14 stations with precipitation of more than 600 mm, accounting for 18%, mainly distributed in Yichun, Hegang and the middle of Harbin.

### 3.2 The characteristics of periodic change

The real number of the wavelet coefficient is positive, indicating that the precipitation is high, and it is drawn by a solid line. When it is negative, it means low precipitation, which is drawn by a dotted line. The amount of the central value can reflect the intensity of the oscillation. The magnitude of the wavelet modulus represents the periodicity of the corresponding period of a certain scale. The larger the modulus is, the more significant the periodicity is, and vice versa. The modulus of the wavelet coefficient represents the energy density, and the contour map of the modulus shows the distribution of periodic changes of various time scales in the time domain. The larger the mode value of the wavelet coefficient, the more obvious the periodicity of the corresponding period and scale.



**Figure 5. Real part contour map of wavelet transform coefficients.**

According to the wavelet analysis of flood season precipitation in the recent 53 years, it can be seen from Fig. 5 that the multi-time scale cycle characteristics of the evolution process exist obviously in the 47-56 years, 17-23 years, and 4-10 years three scale cycle variation rules. On the 47-56 years characteristic time scale, there are two quasi-periodic oscillations with less - more alternations; on the 17-23 years characteristic time scale, there are five quasi-periodic oscillations with more - fewer alternations; on the 4-10 year characteristic time scale, there are nine quasi-oscillations with more - less alternations. The period of the above three scales is relatively stable in the analysis period of nearly 53 years. The wavelet coefficients at the scale of 47-56 years have a large modulus and strong oscillation energy, and the period changes are the most obvious, with a whole region. It is followed by the characteristic scale energy in the period of 17-23 years. 1985-2004 is the weakest period of the energy in this time scale. On the whole, the change cycle is stable, showing the whole region. The energy intensity and periodicity distribution at the 4-10 year scale are weak, and the change period is obviously local, mainly distributed in two periods from 1977 to 1999 and from 2005 to 2022.

The wavelet square difference reflects the energy distribution of the wave with the scale, and the relative intensity of various scale disturbances in a time series can be determined. The scale corresponding to the peak value is called the main time scale of the series. There are three obvious peaks of precipitation in flood season, among which the first peak is a 54-year scale, and its oscillation is the strongest, which is the first main cycle. However, due to the short time domain of the whole study, it is not enough to form a complete peak. The second peak appears at the 17-year scale, which is the second main cycle. The third peak appears at the 6-year scale, which is the third main cycle. According to the results given by wavelet square difference, the evolution process of the wavelet coefficients of three principal periods over time is plotted, as shown in Fig. 6. The trend chart of the main cycle can be used to analyze the characteristics of periodic changes in different time scales. On the characteristic

time scale of 54 years, there are few experienced periodic changes, but in general, it can be seen that there are about 1.5 change cycles, and the average change cycle is about 34 years. On the 17-year observation scale, the average period of change is about 12 years, and about 4.5 alternate periods have been experienced. On the 6-year characteristic time scale, the average change period is about 4 years, with about 13 cycles of change.

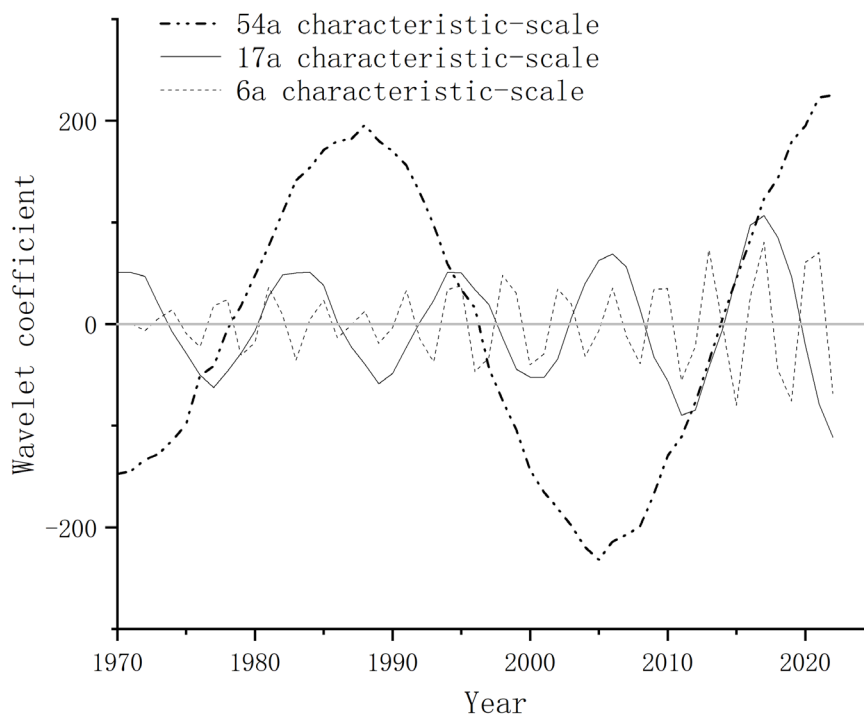


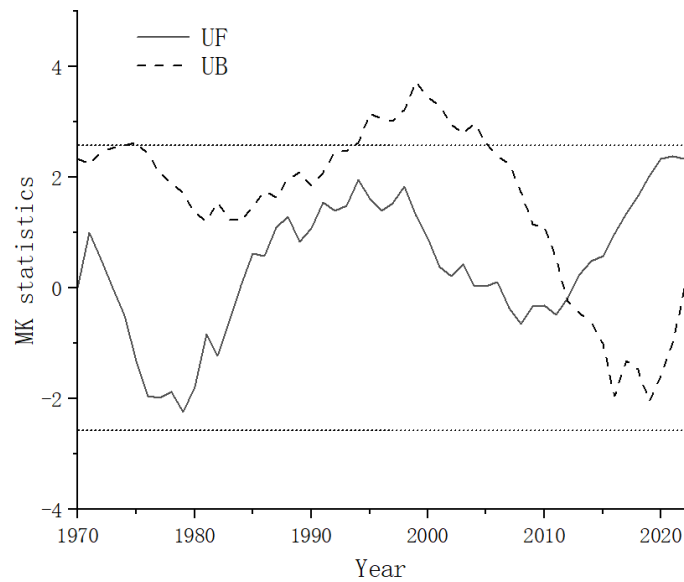
Figure 6. The wavelet transform coefficients under different time scales of flood precipitation anomaly series.

### 3.3 Analysis of mutability

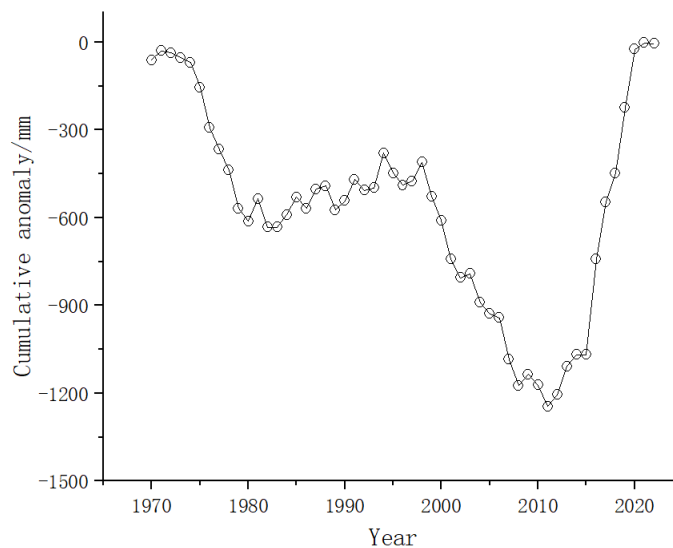
Abrupt climate change is an important phenomenon in climate change and an important factor to be considered in climate prediction and simulation. Abrupt climate change refers to the phenomenon that climate changes from one stable state (or stable and continuous trend of change) to another stable state by leaps and bounds. It is manifested as the sharp change of climate from one statistical feature to another in space and time. There are many methods to detect climate abrupt change. The most basic climate abrupt change includes mean abrupt change, variance abrupt change, seesaw abrupt change, and transition abrupt change. The actual abrupt change is usually a combination of these abrupt changes. In a general way, the test methods of mean mutation are more credible, commonly the Mann-Kendall method, sliding T-test, Cramer method, Yamamoto index method, wavelet analysis, and so on. The m-K method has the characteristics of a wide detection range, high quantization degree, and low humanness. It is the most obvious theoretical significance among the mutation detection methods that are widely used and have a strong theoretical basis. The m-K method also has some defects. When there are multiple mutation points in the same time series, only the most significant mutation point can be determined by this method, while mutation information at other times cannot be detected. Moreover, the M-K method cannot determine the mutation time of the mutation point at the end of the time series. Therefore, the M-K method and wavelet analysis method are used to study the trend of mean change and mutation time of each station.

According to the wavelet change characteristic scale chart, there are three abrupt points of precipitation in flood season on the 54a characteristic scale, and the abrupt properties change from dry to wet (1978) - from wet to dry (1996) - from dry to wet (2013). The characteristic scale was 17a, and ten alternating cycles of abundance and drought and nine mutation points were experienced. The results showed that abundance - dry - abundant - dry - abundant - dry - abundant - dry - abundant - dry - abundant - dry. On the 6-year characteristic scale, the number of abrupt precipitation points in flood season increased to twenty-eight. It can be shown from the above results that the mutation points are roughly consistent at different scales. With the thinning of scales, the mutation points increase, indicating that the region variation characteristics of precipitation can be reflected on a smaller scale in a more specific way. That is, the change in Heilongjiang flood season precipitation is volatile in a short period

but has an overall trend of change over a longer period.



**Figure 7. Mann-Kendall statistical analysis curve of flood precipitation in Heilongjiang from 1970 to 2022.**



**Figure 8. Accumulated anomaly for annual average precipitation in flood season in Heilongjiang from 1970 to 2022.**

M-K method (Fig. 7) and cumulative anomaly method (Fig. 8) were used to test the abrupt change of precipitation in flood season. When the given significance level is 0.01, the confidence interval is  $[-2.58, +2.58]$ . The intersection point of *UF* and *UB* in 2011 was within the confidence interval which is an obvious mutation. The *UF* curve changed from negative to positive, indicating that the precipitation change in the flood season in Heilongjiang before 2011 had shifted from a relatively low precipitation period to a relatively high precipitation period. However, the *UF* curve did not exceed the critical boundary, indicating that the trend was not significant.

The cumulative anomaly shows a trend of "down - fluctuation - down - rise". The cumulative anomalies before 2011 showed a downward trend, mainly negative anomalies. The cumulative anomalies after 2011 showed an upward trend, mainly positive anomalies. Before 2011, the average precipitation was 429.5 mm and decreased by 29.7 mm to the mean value. After 2011, the

average precipitation was 572.0 mm, a decrease of 112.8 mm from the mean value, and the flood season precipitation increased by 142.5 mm before and after the abrupt change.

#### 4. Conclusion

The average precipitation in flood season (May-September) of the whole province during 1970-2022 was about 459.2 mm, the peak value in 2016 was 784.1 mm, and the trough value in 2007 was 317.6 mm, showing a slight upward trend. The climatic trend rate is 2.5 mm/a.

The precipitation in flood season has the characteristics of interdecadal variation, showing a "W" shaped trend. The average precipitation in the flood season in the 1970s was low, ranging from 307.6 mm to 512.1 mm, with an average of 402.3 mm. The precipitation in the 1980s and 1990s was similar, but the 1980s was more than the 1970s. In the 1980s, the precipitation is 373.3~589.1 mm, with an average of 458.7 mm. The precipitation in the flood season in the 1990s was 371.7 ~ 586.8 mm, with an average of 463.7 mm. The precipitation in the flood season in the 2000s is the lowest, which is 297.6 ~ 488.3 mm, with an average of 398.4 mm. The flood season precipitation has increased significantly in the 2010s. The flood season precipitation ranges from 387.6 mm to 769.8 mm, and the average precipitation is 550.2 mm.

In terms of spatial distribution, the spatial distribution characteristics of flood season precipitation in Heilongjiang are high in the middle part and low in the east and west, showing a "low - high - low" distribution from west to east. The high-value areas are concentrated in the northern part of Yichun, Hegang, and the middle part of Harbin, and the average precipitation in the 53-year flood season is above 500 mm. The flood season precipitation in the Greater Khingan Mountains, Sanjiang Plain, and Songnen Plain is low.

In terms of periodic changes, the main cycles are the 54-year scale, 17-year scale, and 6-year scale, among which the 54-year scale is the strongest. Under different characteristic scales, the mean change period of the 54-year scale is 34 years, that of the 17-year scale is 12 years, and that of the 6-year scale is 4 years.

In terms of time mutation, the flood season precipitation series of the last 53 years in Heilongjiang had a sudden change in 2011, showing a changing trend from less to more. After the mutation occurred, the average precipitation in flood season during 2012-2022 increased by 142.5 mm compared with that during 1970-2011 before the mutation.

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#### References

- [1] Zhou, B. T. & Qian, J. (2021). Changes of weather and climate extremes in the IPCC AR6. *Climate Change Research*, 17(6): 713-718.
- [2] Li, X., Zhang, B., Ren, R., Li, L., & Simonovic, S. P. (2022). Spatio-temporal heterogeneity of climate warming in the Chinese Tianshan Mountainous Region. *Water*, 14(2): 199.
- [3] Allan, R. P., Barlow, M., Byrne, M. P., Cherchi, A., Douville, H., Fowler, H. J., Gan, T. Y., Pendergrass, A. G., Rosenfeld, D., Swann, A. L. S., Wilcox, L. J., & Zolina, O. (2020). Advances in understanding large—scale responses of the water cycle to climate change. *Analysis of the New York Academy of Sciences*, 1472(1): 49-75.
- [4] Agha Kouchak, A., Chiang, F., Huning, L. S., Love, C. A., Mallakpour, I., Mazdiyasn, O., Moftakhari, H., Papalexio, S. M., Ragno, E., & Sadegh, M. (2020). Climate extremes and compound hazards in a warming world. *Annual Review of Earth and Planetary Sciences*, 48: 519-548.
- [5] Sone, J. S., Araujo, T. F., Gesualdo, G. C., Ballarin, A. S., Carvalho, G. A., Oliveira, P. T. S., & Wendland, E. C. (2022). Water security in an uncertain future: Contrasting realities from an availability-demand perspective. *Water Resources Management*, 36(8): 2571-2587.
- [6] Cao, S., Cao, G., Wang, Z., Hou, Y., Wang, Y., & Kang, L. (2022). Isotopic hydrological links among precipitation, river water and groundwater in an alpine mountain basin, NE Qinghai—Tibet Plateau in warm seasons. *Environmental Earth Sciences*, 81(14): 366.
- [7] Yang, R. & Xing, B. (2022): Spatio-temporal variability in hydroclimate over the upper Yangtze River Basin, China. *Atmosphere*, 13(2): 317.
- [8] Su, C., Wu, X., Xie, S., & Qu, Y. (2022). The climatological characteristics of precipitation amount in the flood seasons of xinxing county from 1958 to 2019. *Guangdong Meteorology*, 44(05): 15-19.
- [9] Koycegiz, C., & Buyukyildiz, M. (2022). Investigation of spatiotemporal variability of some precipitation indices in Seyhan Basin, Turkey: monotonic and sub-trend analysis. *Natural Hazards*, 116: 2211-2244.

- [10] Sadeghi, M., Nguyen, P., Nacini, M.R., Hsu, K., Braithwaite, D., & Sorooshian, S. (2021). Persiann-Ccs-Cdr, a 3-hourly 0.04° global precipitation climate data record for heavy precipitation studies. *Scientific Data*, 8(1): 157.
- [11] Shi, S., & Liu, G. (2021). The latitudinal dependence in the trend of snow event to precipitation event ratio. *Scientific Reports*, 11(1): 18112.
- [12] Wu, L., Zhang, Y., Wang, L., Xie, W., Song, L., Zhang, H., Bi, H., Zheng, Y., Zhang, Y., Zhang, X., Li, Y., & Lv, Z. (2022). Analysis of 22-year drought characteristics in Heilongjiang Province based on temperature vegetation drought index. *Computational Intelligence and Neuroscience*, 1003243: 1-13.
- [13] Li, H., Xi, W., Zhang, L., & Zang, S. (2021). Snow-disaster risk Zoning and assessment in Heilongjiang Province. *Sustainability*, 13(24): 14010.
- [14] Wang, X., Luo, P., Zheng, Y., Duan, W., Wang, S., Zhu, W., Zhang, Y., & Nover, D. (2023). Drought disasters in China from 1991 to 2018: Analysis of spatiotemporal trends and characteristics. *Remote Sensing*, 15(6): 1708.
- [15] Xu, H., Zhang, L., & Jiang, L. (2014). Spatiotemporal distribution of main meteorological disasters in Heilongjiang Province during A. D. 612-2000. *Journal of Natural Disasters*, 23(3): 107-118.
- [16] Lv, D., Gao, H., & Zhang, Y. (2021). Rural economic development based on shift-share analysis in a developing country: a case study in Heilongjiang Province, China. *Sustainability*, 13(4): 1969.
- [17] Ji, Y., Wang, C., Zhao, Y., Wang, L., Mo, Z., Yu, Y., Wang, M., & Yan, P. (2022). Analysis of agricultural meteorological year in Heilongjiang Province in 2022. *Modern Agriculture*, (03): 6-7.
- [18] Zhang, J. & Li, Y. (2019). Study on characteristics and types of rainfall in flood season in Heilongjiang Province. *Journal of Natural Disasters*, 28(5): 229-336.
- [19] Zhao, N., Wang, S., & Han, B. (2022). Temporal and spatial characteristics of precipitation anomalies in flood season in Heilongjiang Province in 2019. *Heilongjiang Meteorology*, 39(04): 13-15.
- [20] Jiang, L., Chen, K., Liu, D., Lv, J., Wang, L., Gong, L., & Li, S. (2015). Analyses of abnormal rainfall and its influence on crop production during main flood season of Heilongjiang Province in 2013. *Meteorological Monthly*, 41(1): 105-112.
- [21] Zhang, H., Yin, C., Wei, L., Liu, H., & Zhu, H. (2016). Temporal and spatial variations of hourly precipitation in Heilongjiang Province in the flood season. *Journal of Glaciology and Geocryology*, 38(5): 1258-1263.
- [22] Liu, C., Xu, Y., Liu, H., Wang, B., & Wei, L. (2019). Spatial and temporal distribution characteristics of summer rainfall and rainstorm in Heilongjiang. *Chinese Agricultural Science Bulletin*, 35(13): 107-111.