Characters of Precipitation Change in Heilongjiang from 2000 to 2020

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Abstract. Analyzing the precipitation in Heilongjiang Province, the result shows that the zonal difference of precipitation in Heilongjiang province is significant and the annual distribution of precipitation in Heilongjiang Province is very uneven. Generally, the precipitation in the east of Heilongjiang is better than that in the west. Through M-K trend test, it is found that during the period of 2000–2020 the annual precipitation in Heilongjiang Province generally showed a rising trend. And the precipitation in Heilongjiang Province increased steadily after 2002, while the abrupt point when the rainfall began to increase significantly was 2015.

Keywords: Precipitation change; Mann-Kendall (M-K) test; trend analysis; Heilongjiang Province.

1. Introduction
The increasing trend of global warming is striking since twentieth century, and the Intergovernmental Panel on Climate Change (IPCC)’s Fifth Assessment (AR5) in 2014 pointed out that global averaged temperature experienced a warming of 0.85(0.65 to 1.06) °C from 1880 to 2012. Global temperature rise would affect the entire water cycle process, resulting in changes in precipitation distribution, surface runoff and flood frequency. There are studyd[1, 2] showed that the warming of global temperature causes the summer monsoon in East Asia to strengthen, and make the boundary of summer monsoon move northward, leading to the increase of precipitation in northern China.

Water resource is an important factor that affects the coordinated development of ecological environment and social economy and precipitation is the main source of water supply, and the change of precipitation is one of the main factors of the uneven spatial and temporal distribution of water resources, and also it is an important part of water resources evaluation study. At present, on the basis of long-term meteorological observation data, there have been many research results on the variation of rainfall trend in regions and basins in China.

Chengcaocao[3] analyzed the annual and seasonal rainfall in the Jinghe River basin from 1961 to 2004, and the results showed that the seasonal rainfall in the upper, middle and lower reaches of the Jinghe River basin changed obviously, but the rainfall increased or decreased little during 1981-2004 and 1961-1980. Yangzhaoming et al[4] analyzed the change of rainy season precipitation in northeastern Qinghai-Tibet Plateau from 1961 to 2017, the results showed that the rainy season precipitation in arid area of northeastern Qinghai-Tibet Plateau increased from 1961 to 2017, while the precipitation in semi-arid and sub-humid areas increased extremely. Extreme storms are now occurring with increasing
frequency, in order to alleviate the water resources crisis, to understand and grasp the characteristics of water cycle in the basin, we need to analyze the character of the annual changes in precipitation.

2. Study area and methods

2.1. Study area and data

Heilongjiang Province is located in the hinterland of Northeast Asia and northeast China, ranging from 121°11′ to 135°05′ E, and 43°26′ to 53°33′N, and it is covering 473,000 square kilometers. The terrain of Heilongjiang province is generally high in northwest, north and southeast, and low in northeast and southwest, which is composed of mountains, platforms, plains and water surface. It stretches across four major water systems: the Heilongjiang River, Wusuli River, Songhua River and Suifen River, and it is categorized as a sub-frigid zone and temperate continental monsoon climate.

Most area of the Heilongjiang basin belongs to the continental climate, and only the area from the east of the Greater Khingan Range to Khabarovsky are affected by the Marine monsoon. [5]The annual average temperature in the upper reaches of Heilongjiang basin is below zero, and the temperature changes dramatically, with the annual temperature difference reaching about 80℃. In winter it is controlled by the cold air from Siberia, and the time that the temperature is below to zero would last about 6 months. In Summer, it is wet and rainy affected by the warm humid air which comes from the Pacific Ocean.

The daily, monthly, and yearly precipitation data used in this research is comes from the National Meteorological Information Center, China and the CPC Global Unified Precipitation data provided by the NOAA, USA.

![Figure 1. Overview of the study area](image-url)
2.2. Method of analyzing the change in precipitation
Sorting out the monthly precipitation in the thirteen cities in Heilongjiang and the whole Heilongjiang Province and analyze the averaged seasonal precipitation situation in Heilongjiang. Calculating the annual averaged precipitation of thirteen cities in Heilongjiang and annual total averaged precipitation in Heilongjiang, and test the statistical significance by precipitation tendency rate and Mann-Kendall (M-K) test, a non-parametric trend-detection study method.

Mann-Kendall test was proposed by H. B. Mann and Mann-Kendall originally, and then was developed by many other people to an improved integrated calculating formula. In such a trend-detection method, the sample does not required to follow some specific distributions, and the test would not be disturbed by outliers, so M-K test is suitable for ordinal variables and categorical variables.[6]

For a time series \(X=X_1, X_2, \ldots, X_n\), define a test statistic \(S\):

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i)
\]  

(1)

\(\text{Sign}(x_i-x_k)\) is a signum function, and

\[
\text{sign}(x_j - x_i) = \text{sign}(R_j - R_i) = \begin{cases} 
1 & x_j < x_i \\
0 & x_j = x_i \\
-1 & x_j > x_i 
\end{cases}
\]

(2)

\(S\) would follow normal distribution, and the mean and variance of \(S\) is given by the eq.(3) and eq.(4), under the assumption that the data are independent and identically distributed.

\[
E(S) = 0
\]  

(3)

\[
V(S) = n(n-1)(2n+5)/18
\]  

(4)

For M-K statistic \(Z\), it can be calculated as follow:

\[
Z = \begin{cases} 
(S-1)/\sqrt{V(S)} & S > 0 \\
0 & S = 0 \\
(S+1)/\sqrt{V(S)} & S < 0 
\end{cases}
\]

(5)

For a given significance level \(\alpha\), if the absolute value of \(Z\) is greater than or equal to \(Z_{1-\alpha/2}\), then the null hypothesis is unacceptable, which means that at the significance level of \(\alpha\) there is a significant increasing or declining trend in the time series. When the statistic \(Z\) is greater than 0, there is an increasing trend, when the statistic \(Z\) is less than 0, there is a declining trend, and when \(|Z|\) is greater than or equal to 1.28, 1.64, and 2.32, it means that the trend passed the test of significance of 90%, 95% and 99%.

Supposing a hydro-logical series \(x_1, x_2, \ldots, x_n\), define a statistic variable \(S_k\):

\[
s_k = \sum_{i=1}^{k} r_i, \quad k = 2, 3, \ldots, n
\]

(6)

Where

\[
r_i = \begin{cases} 
+1, & x_i > x_j \\
0, & x_i \leq x_j, \quad j = 1, 2, \ldots, i 
\end{cases}
\]

(7)

Apparently, \(S_k\) is the cumulative number of \(x_i\) that is greater than \(x_j\) (\(i \leq j\)).

Defining a statistic \(UF\) under the assumption that that the time series is randomly independent:
UF_k = \left[ \frac{s_k - E(S_k)}{\sqrt{\text{var}(S_k)}} \right], \quad k = 1, 2, L, n \quad (8)

Where UF_1=0, E(S_k) and \text{var}(S_k) is the mean and variance of the cumulative number S_k. When x_1, x_2, ... x_n is independent of each other and has the same continuous distribution, they can be calculated by the following eq:

\begin{align*}
    E(s_k) &= \frac{n(n+1)}{4} \\
    \text{var}(s_k) &= \frac{n(n-1)(2n+5)}{72}
\end{align*} \quad (9)

UF follows the standard normal distribution and, for a given significance level \( \alpha \), if \(|UF_i| > U_\alpha \), it indicates that there is an obvious trend change in the series.

Repeating the above process in the reverse order of time series X: x_n, x_{n-1}, ..., x_1 to calculate UB, and make UB_k=-UF_k (k = n, n-1, ..., 1), UB_1=0. draw the sequence of statistics UB_k, UF_k, \( u_\alpha \) in a graph, if the value of UF_k or UB_k is greater than 0, it indicates that the sequence has an upward trend; if the value is less than 0, it indicates that the sequence has a downward trend. When they exceed the critical line, it indicates a significant upward or downward trend. The range beyond the critical boundary is defined as the time zone where the mutation occurs. If the UF_k and UB_k curves intersect, and the intersection point is between the critical boundary, then the corresponding moment at the intersection point is the time when the abrupt change begins.

Besides, when analyzing the climate tendency rate of precipitation, calculating the linear regression coefficient between meteorological element value and time, if the tendency rate is greater than 0, it means that the precipitation tends to increase, if the tendency rate is less than 0, it means there is a declining trend.

3. Results

3.1. Multi-year average precipitation characteristic

It can be seen from table 1 that the zonal difference of precipitation in Heilongjiang province is significant. The multi-year average precipitation in the northern Heilongjiang such as the Greater Khingan Range is 457.2mm, while the multi-year average precipitation in the southern Heilongjiang such as Harbin is 622.4mm. The average precipitation in Heilongjiang Province is almost the same as that in the central region, which is 554.0mm. And the precipitation in the east of Heilongjiang is better than that in the west, which is also can be seen in the Isohyet map of Heilongjiang Province (Figure 2).

| Region                  | Precipitation | Region                  | Precipitation |
|-------------------------|---------------|-------------------------|---------------|
| Heilongjiang province   | 554.0         | Daqing                 | 468.0         |
| Qitahei                 | 546.9         | Mudanjiang             | 606.7         |
| Yichun                  | 648.7         | Suihua                 | 555.0         |
| Jiamusi                 | 558.8         | Jixi                   | 544.7         |
| Shuangyashan            | 556.6         | Hegang                 | 587.4         |
| Harbin                  | 622.4         | Heihe                  | 555.9         |
| Greater Khingan Range   | 457.2         | Qiqihar                | 493.0         |
Figure 2. Isohyet map of Heilongjiang Province

3.2. Seasonal precipitation distribution characteristic
As can be seen from the table, the annual distribution of precipitation in Heilongjiang Province is very uneven. The precipitation is mainly concentrated in summer, accounting for about 60% of the whole year, while the precipitation in spring and autumn accounts for about 20% of the whole year, and that in winter accounts even more less. The percentages in the table 2 refer to the ratio of the precipitation in a particular season in an area to the annual precipitation in this area. In spring, the percentages of precipitation in the southern part of Heilongjiang is about 20%, while that in the northern part is about 16%. Meanwhile, in summer, the southern part receives about 5% more precipitation than the northern part. The seasonal distribution of precipitation in Shuangyashan, Jixi and Mudanjiang are not consistent with the general situation of precipitation in Heilongjiang Province. These three regions have less precipitation in summer and more precipitation in spring and autumn, and these three regions are all located in the eastern part of Heilongjiang Province.
Table 2. The distribution of seasonal precipitation in Heilongjiang Province

| Region                | Spring Precipitation | Summer Precipitation | Autumn Precipitation | Winter Precipitation |
|-----------------------|----------------------|----------------------|----------------------|----------------------|
|                       | Precipitation | Percentage | Precipitation | Percentage | Precipitation | Percentage | Precipitation | Percentage |
| Qitaihe               | 107.6          | 19.68%      | 318.2          | 58.18%      | 99.8          | 18.24%      | 21.3          | 3.90%      |
| Yichun                | 108.4          | 16.72%      | 401.7          | 61.93%      | 112.9         | 17.41%      | 25.6          | 3.94%      |
| Jiamusi               | 106.1          | 18.98%      | 316.7          | 56.68%      | 109.1         | 19.53%      | 26.9          | 4.81%      |
| Shuangyashan          | 111.8          | 20.09%      | 308.6          | 55.44%      | 110.4         | 19.84%      | 25.8          | 4.63%      |
| Harbin                | 107.4          | 17.25%      | 384.3          | 61.75%      | 107.2         | 17.23%      | 23.5          | 3.77%      |
| Greater Khingan Range | 74.4           | 16.26%      | 279.1          | 61.05%      | 86.9          | 19.00%      | 16.9          | 3.69%      |
| Daqing                | 69.2           | 14.79%      | 312.2          | 66.70%      | 74.1          | 15.83%      | 12.5          | 2.68%      |
| Mudanjiang            | 118.6          | 19.55%      | 351.9          | 58.00%      | 111.5         | 18.37%      | 24.7          | 4.08%      |
| Suihua                | 83.8           | 15.10%      | 364.8          | 65.73%      | 88.9          | 16.03%      | 17.4          | 3.14%      |
| Jixi                  | 113.0          | 20.75%      | 292.9          | 53.77%      | 110.4         | 20.27%      | 28.4          | 5.21%      |
| Hegang                | 110.4          | 18.79%      | 351.6          | 59.85%      | 102.2         | 17.40%      | 23.3          | 3.96%      |
| Heihe                 | 88.0           | 15.82%      | 349.3          | 62.83%      | 98.3          | 17.68%      | 20.4          | 3.67%      |
| Qiqihar               | 69.4           | 14.08%      | 329.1          | 66.75%      | 81.2          | 16.47%      | 13.3          | 2.70%      |
| Heilongjiang Province | 97.5           | 17.53%      | 335.4          | 60.67%      | 99.5          | 17.95%      | 21.5          | 3.86%      |

3.3. Interannual Variation of Precipitation

Analyzing the interannual variation trend of Precipitation in Heilongjiang province by mk nonparametric trend test, it is found that the precipitation in Heilongjiang Province generally showed a rising trend. Except for Harbin city and the Greater Khingan Range, the MK trend test of precipitation in every area all passed the test at confidence level a 99%, and the Z values of mk test of the precipitation in Harbin and the Greater Khingan Range were all greater than 1.64.

The precipitation tendency rate in Heilongjiang province is high, which is 129.96mm/10a. Among these areas, Jiamusi, Shuangyashan, Hegang and Yichun, which are located in the northeast of Heilongjiang Province, have the most significant increasing trend of precipitation, while the Greater Khingan Range and Qiqihar, which are located in the east, have relatively small increasing trend of precipitation. In this regard, mk trend test and precipitation trend rate are consistent.

It can be seen from the test curve that the precipitation in Heilongjiang Province increased steadily after 2002, and the abrupt point when the rainfall began to increase significantly was 2015.

The increase of precipitation in Heilongjiang Province is related to global warming, and the global temperature change mainly affects the distribution of precipitation in China through the strength of summer monsoon. The warming of global temperature leads to the strengthening of summer monsoon in East Asia, which means the difference in temperature between sea and land would be enlarged, and the boundary of summer monsoon would extend northward and inland, leading to the increase of precipitation in Heilongjiang Province in northern China.

Table 3. Annual coefficients of Mann-Kendall and tendency of precipitation

| Region                             | M-K | tendency rate | Region                             | M-K | tendency rate |
|------------------------------------|-----|---------------|------------------------------------|-----|---------------|
| Qitaihe                            | 2.99| 157.63        | Mudanjiang                         | 3.23| 129.59        |
| Yichun                             | 3.59| 166.18        | Suihua                             | 2.75| 125.46        |
| Jiamusi                            | 4.08| 178.85        | Jixi                               | 2.93| 137.41        |
| Shuangyashan                       | 3.71| 179.79        | Hegang                             | 3.65| 214.52        |
| Haerbin                            | 2.20| 130.03        | Heihe                              | 2.87| 130.26        |
| The Greater Khingan Range          | 2.08| 53.40         | Qiqihar                            | 2.69| 123.83        |
| Daqing                             | 3.11| 123.14        | whole Heilongjiang Province        | 3.53| 129.96        |
4. Conclusion

The zonal difference of precipitation in Heilongjiang province is significant and the annual distribution of precipitation in Heilongjiang Province is very uneven, generally, the precipitation in the east of Heilongjiang is better than that in the west. Seasonally, the precipitation is mainly concentrated in summer, accounting for about 60% of the whole year, while the precipitation in spring and autumn accounts for about 20% of the whole year. During the period of 2000--2020 the annual precipitation in Heilongjiang Province generally showed a rising trend. And the precipitation in Heilongjiang Province increased steadily after 2002, while the abrupt point when the rainfall began to increase significantly was 2015.

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