Study on multi-time scale variation rule of rainfall during flood season in Jilin Province in recent 65 years

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Abstract. A total of 65-year rainfall data collected from 30 meteorological stations in Jilin Province during 1951 to 2015 was analysed by sliding average method, anomaly analysis method and Mann-Kendall mutation test, combined with MapInfo, ArcGIS software and R language drawing tool. The interdecadal, interannual and annual variation characteristics of rainfall in flood season in Jilin Province were used to reveal the multi-time scale characteristics of rainfall variation and the periodic variation and mutation points of rainfall sequences at different time scales. The results show that: 1) the interdecadal and interannual rainfall in Jilin Province shows a trend of fluctuating downward, especially in the 21st century, the decline in rainfall is more significant, and the sudden change points of annual precipitation occur in 1983 and 1992; 2) the monthly rainfall in flood season shows a significant downward trend, all but a small decline in June; 3) the rainfall during the flood season is mainly concentrated in July and August, accounting for 65% of the total rainfall during the flood season. The average proportion in September is the lowest, only 13%. In addition, the proportion of rainfall in June in the whole flood season has an increasing trend, that is, the rainfall in flood season is ahead of schedule; 4) the average rainfall intensity of each month in flood season shows an upward trend, and the decreasing rate of rainfall days is greater than that of rainfall.

1. Introduction

Jilin Province, located in the central part of Northeast China, is an important commodity grain base in China. 80% of annual rainfall is concentrated in summer, and the regional difference of precipitation is very obvious, which leads to natural disasters such as drought, floods and so on. The losses caused by meteorological disasters are obviously increased, threatening the lives and property of the broad masses of the people, and causing great damage to economic, social development and ecological environment. In recent years, scholars have done a lot of research on the characteristics of rainfall in Jilin Province [1-5]. However, previous studies mainly focused on the annual rainfall in Jilin Province, or only analysed the intergenerational and interannual rainfall. Some achievements have been made with little reference to the rainy season rainfall and multi-scale changes. Based on the 65-year rainfall data of 30 meteorological stations in Jilin Province, this paper uses sliding average method, Mann-Kendall mutation test [6-9] and anomaly analysis method [10,11], and combines Matlab [12], ArcGIS software and R language drawing tool [13,14] to diagnose and analyse the characteristics and rules of time series variation of rainfall in river basins [15], and reveals the structure of precipitation and the law of abnormal changes in different time scales, and analyses the periodic characteristics and
abrupt points of precipitation, which provides scientific basis for precipitation forecast, deployment of disaster prevention and mitigation and tackling climate change in Jilin Province.

2. Data sources and research methods
Rainfall data of meteorological stations in Jilin Province mainly come from China Meteorological Science Data Sharing Service Network (http://www.cma.gov.cn/), which includes 30 meteorological stations such as Qian’an, Tongyu, and so on. The spatial distribution of meteorological stations is shown in figure 1. The longest statistical time of rainfall data lasts for 65 years from 1951 to 2015. In this study, the multi-time scale analysis of rainfall series is carried out for the rainy season from June to September. The characteristics of inter-annual and inter-generational rainfall in flood season are analysed by anomaly analysis and moving average method, and the trend of time variation of rainfall, daily rainfall and intensity in each month of flood season is analysed by moving average method. The Mann-Kendall mutation test is used to analyse the rainfall in flood season.

3. Results and analysis
3.1. Analysis of interannual and intergenerational characteristics of rainfall in flood season

3.1.1. Analysis of interannual and intergenerational rainfall anomalies. Using anomaly analysis method and moving average method, the characteristics of annual rainfall in Jilin Province from 1951 to 2015 are analysed. From table 1 and figure 2, it can be seen that the rainfall anomaly in 1950s was 47 mm, the percentage of rainfall anomaly was 10.56%, and the amount of rainfall was too much. In the 1960s, rainfall anomaly was 39mm, and the percentage of rainfall anomaly was 8.91%, slightly lower than that in the 1950s. In the 1970s, the rainfall anomaly was negative for the first time, and the percentage of rainfall anomaly was -3.84%. In the middle and late 1980s and 1990s, the rainfall anomaly was positive, with the percentage of anomaly being 5.61% and 2.35%, respectively. In the 20th century, the anomaly value was negative, and rainfall decreased significantly. Among the 16a from 2000 to 2015, 12a was negative anomaly, and only 4a was positive anomaly, with abnormally low rainfall. During the study period, the maximum annual rainfall during flood season was 816mm, which occurred in 2010, and the minimum was 227 mm, which occurred in 2014. It can be seen that in the decade of the 20th century, the rainfall fluctuated greatly.
Table 1. Rainfall anomaly from 1951 to 2015.

| Years | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s |
|-------|-------|-------|-------|-------|-------|-------|-------|
| Anomaly (mm) | 47    | 39    | -17   | 25    | 10    | -41   | -63   |
| Percentage of anomaly (%) | 10.56 | 8.91  | -3.84 | 5.61  | 2.35  | -9.32 | -14.26 |

Note: 2010s refers to the average of 2010~2015

Figure 2. Annual flood season rainfall anomaly in Jilin Province.

3.1.2. Analysis of rainfall variation in annual flood season. As shown in figure 3, the annual flood season rainfall in Jilin province showed a downward trend, and the rainfall trend rate was 21.80 mm/10a. The average annual rainfall was about 602 mm, with the highest annual rainfall of 816 mm (2010) and the lowest annual rainfall of 227 mm (2014). As can be seen from the 5a sliding average, the annual rainfall during the flood season from the 1950s to the early 1960s presented a stable trend, and the annual rainfall during the flood season from the late 1970s to the early 1980s had a significant upward trend, and the annual rainfall during the flood season from the 1980s to 2015 had a significant downward trend.

Figure 3. Trend of annual rainfall during flood season.

Figure 4. Abrupt change analysis of annual flood season rainfall.
3.1.3. Sudden change of rainfall in interannual flood season. The Mann-Kendall mutation test was used to analyse the annual rainfall mutation of 65a in Jilin province during the flood season. From figure 4, it can be seen that the rainfall during the flood season showed a fluctuating downward trend on the whole, and the downward trend was more and more obvious from 1964 to 1982. From 1977 to 1985, the rainfall from 2006 to 2012 decreased significantly. In the figure, UF and UB have more points of intersection, but the years with obvious abrupt changes are 1992 and 1983.

3.1.4. Analysis of rainfall days and rainfall intensity in inter-annual flood season. Figure 5 shows the variation trend of the number of rainy days in the whole time series. It can be seen from figure 5 that the average number of rainy days in the whole flood season was about 23 days, the maximum number of rainy days was close to 35 days, and the minimum number of rainy days was 15 days. The number of rainy days in flood season showed a fluctuating downward trend, and the rate of decline was 1.805/10a, that was, the number of days decreased by 1.805 every decade. Figure 6 shows the trend chart of the average rainfall intensity in flood season. It can be seen from the graph that the average rainfall intensity in flood season can be roughly divided into three stages in the whole time series. From 1950s to mid-1990s, the fluctuation process raised, from mid-1990s to 2008, the period of steady changed, and from 2008 to 2015, the period of sharp declined. The average rainfall intensity in the whole flood season showed a fluctuating upward trend, and the rising rate was (0.644 mm/day)/10a.

3.2. Analysis of annual variation characteristics of rainfall in flood season

3.2.1. Comparative analysis of monthly rainfall in flood season. Figure 7 shows the boxplot of rainfall in each month during the flood season, which generally shows a trend of increase and then decrease. The average rainfall in June, July, August and September is about 100 mm, 160 mm, 130 mm and 60 mm, respectively. The maximum rainfall is in June, and the minimum is in September, and there is no sudden change in rainfall in each month. The rainfall distribution in June and September was more even than that in July and August. The rainfall in flood season is concentrated in June and July, with the maximum rainfall in June and the minimum rainfall in September being about 280 mm and 50 mm respectively.

Figure 8 shows the variation trend of rainfall in each month during the flood season. It can be seen from that the rainfall in the four months presented different degrees of decreasing trends. The decline rate in June was 2.55 mm/10a, and the average rainfall decreased by 15 mm in 65 years. The maximum rainfall was about 170 mm and the minimum was about 35 mm. Compared with June, the variation of rainfall in July fluctuated greatly, with the decline rate of 7.04 mm/10a, and the average rainfall decreased by 46 mm, with the maximum rainfall of 270 mm and the minimum rainfall of 48 mm.
August was still relatively abundant, with a rate of decline of 6.62 mm/10a, with an average rainfall of 43 mm, the maximum rainfall was about 250 mm, the minimum was about 40 mm. Compared with June, July and August, and the fluctuation of rainfall in September was the largest, with a decline rate of 5.89 mm/10a. The maximum rainfall was 120 mm, and the minimum was 20 mm. As can be seen from the five-year moving average of the four months, since the beginning of the 20th century, each month presented a fluctuating downward trend and the rainfall decreased abnormally.

3.2.2. Analysis of the proportion of monthly rainfall in flood season to rainfall in flood season. The time series analysis of the proportion of rainfall in each month in the flood season is shown in figure 9. It can be seen that the rainfall in July and August accounted for 65% of the total rainfall in flood season, and the rainfall in flood season was mainly concentrated in July and August. June is the starting month of the whole flood season, with an average ratio of about 0.22. In 65 years, the highest proportion in June reached 0.37 (2009), and the lowest was only 0.08 (2010). It can be seen from the trend line that the proportion of rainfall in the flood season in June had an increasing trend, and the growth rate is 0.006/10a. Therefore, the rainfall in the flood season had an early trend, that was, the proportion concentrated in June was increasing year by year. In July, the proportion of rainfall accounted for a higher proportion in the flood season, with an average ratio of 0.35. The concentration of rain in the flood season started in July, with the highest proportion reaching 0.57 (1996) and the lowest being 0.19 (1954). The trend line shows that the July change is relatively stable. The average
The proportion in August reached 0.3. Compared with July, the rainfall shows a downward trend, but it was still abundant. The highest proportion in August reached 0.52 (1997) and the lowest was 0.09 (1991). The change in August was still stable. In June, July and August, most of the rainfall in the flood season was occupied. September is the end of the flood season, with an average ratio of only 0.13. The highest proportion was 0.22 (1954) and the lowest was only 0.03 (2002). It can be seen that the proportion of rainfall in the flood season in September has a decreasing trend, and the rate of decline is 0.007/10a, that is, the rainfall concentrated in September was decreasing year by year.

![Figure 9. Monthly change in proportions.](image)

![Figure 10. The change trend chart of the number of rainfall days in each month.](image)

3.2.3. Analysis of rainfall days in month in flood season. Figure 10 shows the changing trend of the number of rainfall days in each month. It can be seen that the number of rainfall days in each month presents a decreasing trend to varying degrees. The average number of rainfall days in the six parts
was about 7 days, the highest number of rainfall days reached 17 days (in 1951), the lowest number of rainfall days was less than 4 days, and the number of rainfall days was decreasing at a rate of 0.37/10a. The average number of rainfall days in July was about 6 days, the highest number of rainfall days reached 8 days, the lowest number of rainfall days was less than 4 days, and the decline rate of rainfall days was 0.314/10a. The average number of rainfall days in August was about 6 days, the highest number of rainfall days was close to 10 days, the lowest number of rainfall days was close to 4 days, and the decline rate of rainfall days was 0.437/10a. The average number of rainfall days in September was about 6 days, the highest number of rainfall days was close to 9 days, the lowest number of rainfall days was close to 2 days, and the decline rate of rainfall days was 0.685/10a.

3.2.4. Analysis of average rainfall intensity in each month. Figure 11 shows the variation trend of average rainfall intensity in each month. It can be seen that the average rainfall intensity in each month presents an upward trend of varying degrees. The highest average rainfall intensity in June was 23.70 mm/day (1986) and the lowest was 8.41 mm/day (1997), the variation trend of average rainfall intensity was (0.177 mm/day)/10a. The average rainfall intensity in July was the highest at 40.99 mm/day (2010), the lowest at 12.48 mm/day (2014), and the change trend of average rainfall intensity was (0.314 mm/day)/10a. The average rainfall intensity in August was the highest at 50 mm/day (1951), the lowest at 9.13 mm/day (1967), and the change trend of average rainfall intensity was (0.567 mm/day)/10a. The highest average rainfall intensity in September was 23.90 mm/day (1987) and the lowest was 4.76 mm/day (1966). The variation trend of average rainfall intensity was (0.379 mm/day)/10a. The biggest trend was in August and the smallest in June.

3.2.5. Abrupt change analysis of rainfall in each month. Figure 12 is the test chart of precipitation catastrophe in each month. It can be seen that the precipitation in June was mainly decreasing before 1976 and rising after 1976. However, because they were all within the critical value of significance, the trend of decrease and increase was not obvious and could be regarded as no catastrophe point. The precipitation in July showed a general downward trend, only from 1952 to 1953, and from 1963 to 1964, there was a short upward trend. The year of mutation was 1983. After 1983, the precipitation changed from fluctuation downward to fluctuation upward. Rainfall in August showed a short upward trend only in 1958 and 1969. From 1951 to 1958 and after 1969, there was a downward trend of fluctuations. Among them, from 1970 to 1980, from 1986 to 1992, the downward trend was increasing, but the downward and upward trend was not obvious. The obvious year of abrupt change in the series was 1968. After the abrupt change in 1968, the rainfall showed a downward trend. The
precipitation in September only increased from 1951 to 1965, but decreased after 1965. Among them, from 1965 to 1968, from 1975 to 1983, and from 1994 to 2015, the trend of decline was increasing. From 1982 to 1986, the change trend from 2003 to 2015 was remarkable. The intersection points of UF and UB is only 1997, but not the year of mutation.

![Figure 12. Monthly mutation test analysis.](image)

4. Conclusion

- The annual and interannual rainfall in Jilin Province shows a downward trend of fluctuation, especially in the 21st century. After 2008, the rainfall decreased sharply, and the sudden change point of annual precipitation occurs in 1983 and 1992.
- The precipitation in each month of the flood season showed a significant downward trend, except for the smaller downward trend in June, the other months had a more obvious downward trend. Among them, in the 65-year change, the average rainfall in June decreased by 15 mm, and the average rainfall in July, August and September decreased by 46 mm, 43 mm and 40 mm, respectively.
- Rainfall in flood season is mainly concentrated in July and August, accounting for 65% of the total rainfall in flood season, and the average proportion in September was the least, only 13%. The proportion of rainfall in June in the whole flood season had an increasing trend, namely, the rainfall in flood season was ahead of schedule.
- The average number of rainy days in each month of flood season showed a downward trend in varying degrees. The average rainfall intensity showed an upward trend, and the decreasing rate of rainfall days was greater than that of rainfall.

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