Spatial and Temporal Distribution Characteristics of Precipitation in Different Seasons in Heilongjiang Province from 1954 to 2013

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Abstract. This paper intends to provide data as reference basis for Heilongjiang Provinces' optimization of precipitation forecast and the resource allocation. The precipitation characteristics of Heilongjiang Province from 1954-2013 (60 years) were studied by Mann-Kendall rank order correlation test, mutation test, linear trend analysis, and Kriging interpolation combined with GIS analysis. The results show that the overall trend of precipitation in Heilongjiang Province from 1954 to 2013 was decreasing, but the results of segmental analysis show that the trend has been increasing since 1980, and the spatial distribution was characterized by high in the east and low in the west, with the precipitation center in the middle; the seasonal average precipitation gradually increased from east to west, and the precipitation was mainly concentrated in summer, accounting for 63.47% of the year. The annual precipitation was mainly light rainfall, but the difference with the medium rain was not large, both about 35%.

1. Introduction

1.1 Overview of the study area

Heilongjiang Province is the province with the highest latitude and the easternmost longitude in China, from 121°11′E in the west to 135°05′E in the east, from 43°26′N in the south to 53°33′N in the north, spanning 14 longitudes from east to west, 10 latitudes and 2 heat belts from north to south; 14 longitudes and 3 humid zones from east to west. It covers an area of 473,000 square kilometers (including the Jiagedaqi and Songling districts). [1]

The topography of Heilongjiang Province is characterized by "five mountains, one water, one grass and three fields". As for the terrain features, it is generally high in the northwest, north and southeast, and low in the northeast and southwest, consisting mainly of mountains, terraces, plains and water. The northwestern and northern part of the country is adjacent to the Outer Xing'an Mountains, etc. The northwestern part is the Daxing'an Mountains running from the northeast to southwest, the northern part is the northwest-southeast trending Xiaoxing'an Mountains, and the southeastern part is the northeast-southwest trending Zhang Guangcai Mountains, Laoye Mountains, and Wanda Mountains. In the northeast is the Sanjiang Plain (including the Xingkai Lake Plain), and in the west is the Songnun Plain.

Most of the mountainous areas in Heilongjiang Province are between 300-1000 meters above sea level, covering about 58% of the total area of the province; the tablelands are between 200-350 meters above sea level, covering about 14% of the total area of the province; the plains are between 50-200 meters above sea level, covering about 28% of the total area of the province. [2]

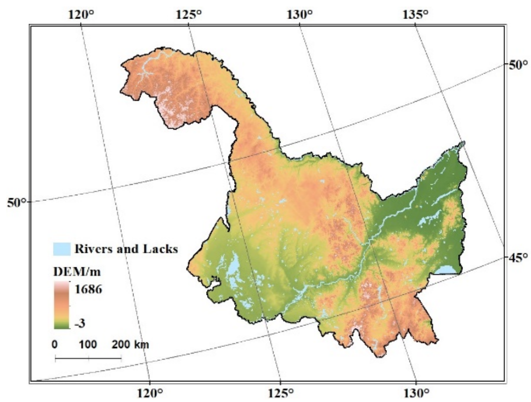


Figure 1. Map of the study area

Heilongjiang province has a cold-temperate and temperate continental monsoon climate. From south to north, the province can be divided into mesothermal and cold temperate zones according to temperature indicators. From east to west, it can be divided into humid, semi-humid and semi-arid zones according to the dryness index. The main characteristics of the province's climate are low temperature and drought in spring, warm and rainy in summer, easy to flood and early frost in autumn, cold and long winter, short frost-free period, and large regional differences in climate. The precipitation in Heilongjiang Province shows obvious monsoonal characteristics. In summer, under the influence of the southeast monsoon, precipitation is abundant, and in winter, under the control of dry and cold northwest winds, it is dry with little rain. [2]

A lot of studies have found that the natural environmental changes caused by climate change have an impact on the human living environment; meanwhile, since 1990, the trend of precipitation has increased significantly, mainly distributed in the northeast, and there was an interdecadal precipitation cycle of about 30 years in Heilongjiang Province, and the trend of decreasing precipitation was not obvious. [9]

2. Data and Methods

2.1 Data sources

In this paper, the daily precipitation data of 14 national meteorological stations in Heilongjiang Province for a total of 60 years from 1954 to 2013 were used. The precipitation data set used for 1954-2014 is based on the "Corrected Monthly Data File (A0/A1/A) Base Data Set for 1951-2010 Chinese National Ground Station Data" archived by the Ground-based Meteorological Data Construction Project. The location of each station is shown in Figure 2.

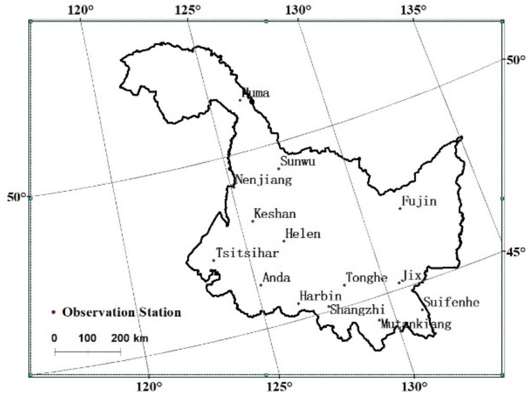


Figure 2. Site Distribution Diagram

2.2 Research Methodology

In this paper, the spatial and temporal characteristics of daily precipitation data of 14 stations in Heilongjiang Province for 60 years were analyzed by Mann-Kendall rank correlation test, mutation test and kriging interpolation method.

According to the classification method of Zhang Baokun[3], which is often used to classify the four seasons in China currently, the four seasons are divided by the " Pentad Average Temperature ", with March to May as spring, June to August as summer, September to November as autumn, and December to February as winter. Firstly, the total amount of rainfall and rainy days in different seasons were calculated for 14 stations in Heilongjiang Province from 1954 to 2013, and then the trend of rainfall and rainy days in different seasons was calculated by the one-dimensional linear trend method, and the trend was analyzed by M-K analysis, and the time series was tested for abrupt changes, and finally the spatial distribution of precipitation data was analyzed by GIS.

2.2.1 Temporal analysis methods

In this paper, the Mann-Kendall rank order correlation test and the mutation test will be used to analyze the temporal characteristics of rainfall at each measuring station and each level as follows.

(1) Mann-Kendall rank correlation test method [4]

The MK trend test can be used to obtain the trend of the time series. This method is a non-parametric test recognized and recommended by WMO, and its basic principle is roughly as follows.

For any time series Xt (t=1, 2, 3..., n) to be analyzed, n is the length of the series to be examined, and the statistic S can be defined.

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn(X_j-X_k) \qquad (1)$$

where X_j and X_k are the values of the time series studied under the corresponding years; n is the length of the time series to be tested; $sgn(X_j-X_k)$ is the sign of the function.

When $X_j>X_k$, $sgn(X_j-X_k)=1$; when $X_j=X_k$, $sgn(X_j-X_k)=0$; when $X_j<X_k$, $sgn(X_j-X_k)=-1$.

When n ≥ 10, the statistical parameter S approximately obeys the normal distribution, and its corresponding expectation and variance are:

$$\begin{cases} E(S)=0 \\ Var(S)=n(n-1)(2n+5)/18 \end{cases} \qquad (2)$$

Subsequently, the standardized test statistic can be constructed according to equation (3):

$$\begin{cases} Z=\dfrac{S-1}{\sqrt{Var(S)}}, & S>0 \\ Z=0, & S=0 \\ Z=\dfrac{S+1}{\sqrt{Var(S)}}, & S<0 \end{cases} \qquad (3)$$

Z is a parameter that obeys the standard normal distribution. When the obtained Z value is greater than zero, the time series has an upward trend; when the obtained Z value is less than zero, the time series has a downward trend. For a given significance level a, when |Z|>=Z1-a/2, it indicates that there is a significant upward or downward trend in the time series to be examined.

(2) Mutation test method [5]

For the time series of multi-year average precipitation, the cumulative number of samples in which $X_j>X_k(1 \le j \le i)$ is satisfied is defined as the sequence r_i, and S_k is defined as:

$$S_k=\sum_{i=1}^{k} P_i\ (k=2,3,\dots,n) \qquad (4)$$

$$E(S_k)=\frac{K(K+1)}{4} \qquad (5)$$

$$Var(S_k)=\frac{K(K-1)(2K+5)}{72} \qquad (6)$$

$$U_{FK}=\frac{S_k-E(S_k)}{\sqrt{Var(S_k)}}(k=1,2,,\dots,n) \qquad (7)$$

Where $U_{F1}=0$, $U_{BK}=-U_{FK}$, $K=n$, $n-1$. At the significance level of 0.05, $U_{0.05}=\pm1.96$, after which the two curves indicated by U_{BK}、U_{FK} and the two straight lines indicated by $U_{0.05}$ are plotted on the same graph. If there is an intersection point of the curves and the intersection point lies between the critical lines, the moment corresponding to the intersection point is the time when the mutation starts.

(3) Univariate linear trend method [6]

For multi-year folded maps of rainfall and rain days of different seasons and intensities for each region, a univariate linear trend line needs to be obtained to determine a clearer trend with deviations in the range of rainfall estimates.

The trend line $y = ax + b$ is calculated by:

$$a = \frac{\sum_{i=1}^{m}(x^i - \bar{x})(y^i - \bar{y})}{\sum_{i=1}^{m}(x^i - \bar{x})^2} \quad (8)$$

$$b = \bar{y} - a\bar{x} \quad (9)$$

The above is the calculation method of a and b, where $\bar{x}$ and $\bar{y}$ are the sample mean values.

2.2.2 Spatial analysis method

In this paper, the GIS-based kriging interpolation method[6] and principal component analysis were used to spatially analyze the precipitation data of Heilongjiang Province, and the related methods and principles are as follows.

Kriging method is more common in statistics and is commonly used in GIS spatial analysis, which can use Kriging interpolation for data processing, and its basic idea can be expressed by the following formula.

$$\widehat{z_o} = \sum_{i=0}^{n} \lambda_i z_i \quad (10)$$

where $\widehat{z_o}$ is the point (x_o, y_o) estimate, i.e., $z_o = z(x_o, y_o)$. λ_i is the weight coefficient, which needs to satisfy $min_{\lambda_i} Var(\widehat{z_o} - z_o)$ and also the unbiased estimation condition $E(\widehat{z_o} - z_o) = 0$.

3. Results Analysis

3.1 Time distribution of precipitation

Through the analysis of 60 years of precipitation data from 14 stations in Heilongjiang Province, the average precipitation is 527.7 mm, the average number of days of precipitation is 110 d, the average daily rainfall is, the average annual precipitation of small, medium, large and heavy rainfall and the number of days of different levels of precipitation and their respective proportions are listed in Table 1. below. the rainfall and the number of days of rainfall in different seasons are listed in Table

Table 1. Precipitation-Related Data by Class

	Multi-year average precipitation (*mm*)	Proportion (*%*)	Multi-year average number of precipitation days (*d*)	Proportion (*%*)
Overall	527.69		110	
Light rain	197.58	37.44	94	85.45
Moderate rain	182.06	34.50	12	10.91
Heavy rain	108.57	20.57	3	2.73
Torrential rain	39.48	7.48	1	0.91

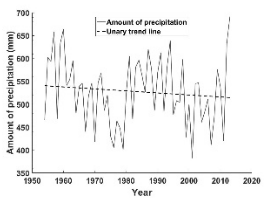
Table 2. Precipitation-Related Data by Season

	Multi-year average precipitation (*mm*)	Proportion (*%*)	Multi-year average number of precipitation days (*d*)	Proportion (*%*)
Overall	527.69		110	
Spring	78.43	14.86	24	21.82
Summer	334.93	63.47	43	39.03
Fall	98.27	18.62	25	22.73
Winter	16.06	3.04	18	16.36

3.1.1 Overall precipitation data analysis

By processing the precipitation amounts and precipitation days in different regions in different seasons, the fluctuation lines and the one-dimensional trend lines of the overall and the average precipitation amounts of rainfall, rainfall days, and rain days (hereafter referred to as average precipitation) in the 60 years of the study population are obtained in Figure 4.1.

The group of graphs reflects the fluctuation and trend analysis of precipitation, number of precipitation days, and rain days precipitation data in Heilongjiang Province from 1954 to 2013, and the overall summary is shown in Table 3.



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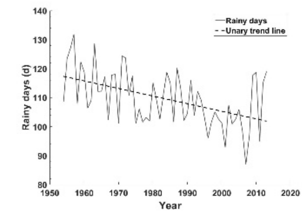

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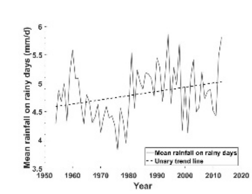

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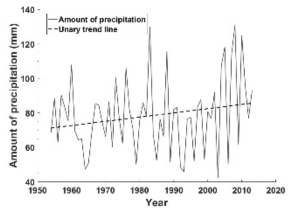

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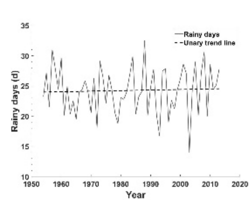

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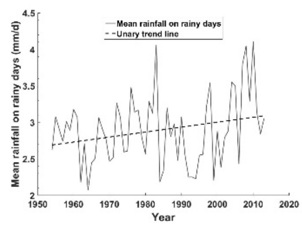

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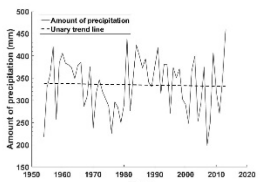

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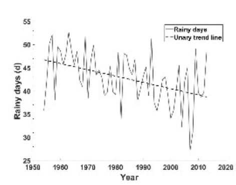

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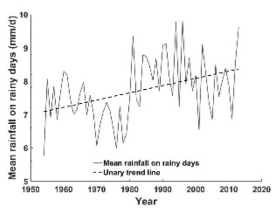

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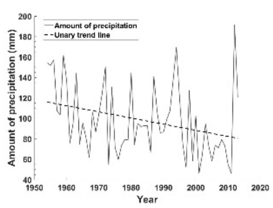

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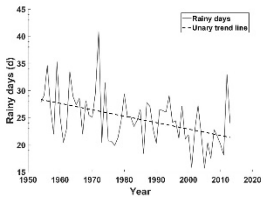

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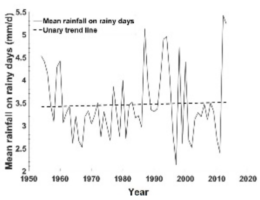

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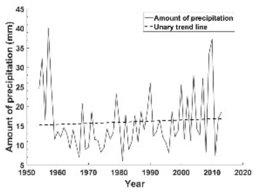

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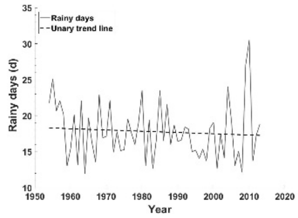

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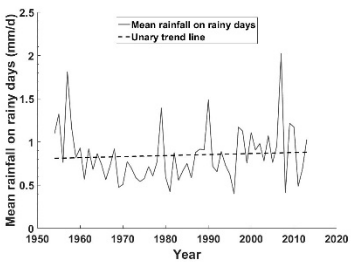

(o)

(where a~c are total precipitation, total precipitation days, and average precipitation on total rain days, d~f are spring precipitation, spring precipitation days, and average precipitation on spring rain days, g~i are summer precipitation, summer precipitation days, and average precipitation on summer rain days, j~l are autumn precipitation, autumn precipitation days, and average precipitation on autumn rain days, and m~o are winter precipitation, winter precipitation days, and average precipitation on winter rain days. (Average precipitation.)

Figure 3. Fluctuation line of each data item

Table 3. Summary of the trends of precipitation, precipitation days, and rainy day precipitation in Heilongjiang region by season

	precipitation		Number of precipitation days		Precipitation on rainy days	
	Trend	Number (mm/a)	Trend	Number (d/a)	Trend	Number $(mm/(d \cdot a))$
Overall	Down	-0.44	Down	-0.26	Up	0.0074
Spring	Up	0.24	Up	0.01	Up	0.0068
Summer	Down	-0.11	Down	-0.14	Up	0.0217
Autumn	Down	-0.60	Down	-0.12	Up	0.0017
Winter	Up	0.03	Down	-0.02	Up	0.0012

The overall data fluctuation trends obtained in the table in the corresponding time series are consistent with those obtained in Chen Jing's "Spatial and temporal variation characteristics of precipitation in Heilongjiang Province, 1971-2018" [9], which were analyzed as upward trends, as shown in the segmental trend analysis in 4.1.2; the trend of summer precipitation is consistent with the trend obtained from the analysis of Zhang Hongling's "Climatic characteristics of summer precipitation in Heilongjiang Province" [10], all of which are decreasing trends. The specific values of changes included in the trends vary slightly depending on the study site, region and method.

3.1.2 Multi-year average precipitation segmentation analysis

With Figure 3.a in 4.1.1 for the overall precipitation trend in Heilongjiang Province for 60 years, a quadratic trend fit (Figure 3) can be made based on its situation, and it can be roughly judged from the whole that 1954-1970 is the first stage with a decreasing trend, 1971-2000 is the second stage with a stable trend, and 2001-2013 is the third stage with an increasing trend.

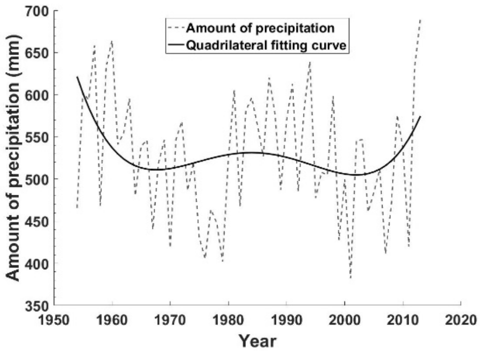

Figure 4. Quadratic trend fitting

In the following, Mann-Kendall trend analysis is carried out for 60 years of total precipitation in Heilongjiang Province. the M-K trend test method, with certain confidence level of significance test, reflects the time-varying characteristics of local precipitation, and the results are shown in the following table.

Table 4. Results of MK trend analysis for 1954-1970

Item	value
Z-value	-0.62
Trend	Down
Reliability	73.24%

Table 5. Results of MK trend analysis from 1971-2000

Item	value
Z-value	-0.11
Trend	Down
Reliability	54.38%

Table 6. Results of MK trend analysis, 2001-2013

Item	value
Z-value	0.69
Trend	Up
Reliability	75.15%

From Tables 4, 5, and 6, it can be seen that the average precipitation from 1954 to 1970 shows a slight downward trend with a significance level of 73.24%; the average precipitation from 1971 to 2000 shows a downward trend

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with a significance level of 54.38%, which has a low confidence level and can be regarded as a stable trend; the average precipitation from 2001 to 2013 shows a slight upward trend with a significance level of 75.15%. The overall average precipitation from 2001 to 2013 showed a slight upward trend with a significance level of 75.15%.

It can be clearly found that 1954-1970, 1971-2000 and 2001-2013 show decreasing (-6.37mm/a), slightly increasing (1.59mm/a) and increasing (11.81mm/a) trends respectively.

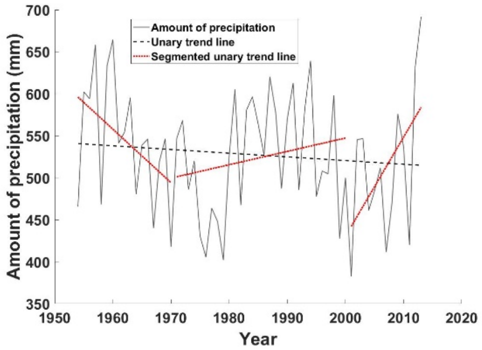


Figure 5. Segmented trend line

Based on the results of the above analysis, it can be inferred that the last 10-20 years should be in a cycle of rising precipitation, and this result can provide some guidance for hydrological forecasting, i.e., the precipitation in Heilongjiang Province may show an upward trend before the next inflection point.

3.1.3 Mutation test

Subsequently, the total precipitation in Heilongjiang from 1954 to 2013 was tested for mutation, and a clearer trend of annual precipitation variation was obtained. See Figure 6 for details.

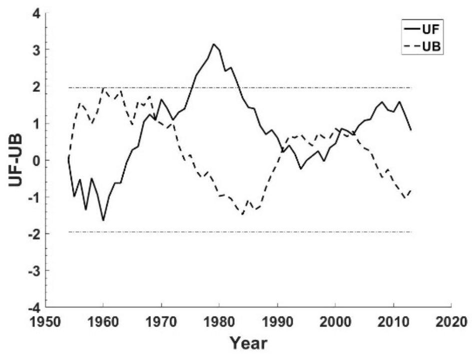


Figure 6. UF-UB

From the figure, we can see that the U_{FK} and U_{FB} lines intersect in 1954, 1969, 1991, 2001, and 2003. The figure shows that mutations that were not obvious in 1991 and 2001, and mutations that occurred in 1954, 1969, and 2003 were relatively obvious (since the mutations in 2001 and 2003 were very close to each other, they can be considered as the same mutation position when analyzed in segments).

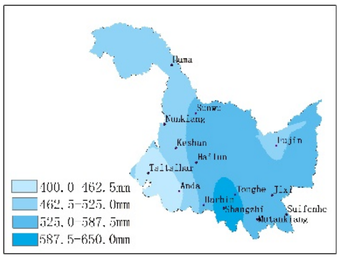
The more obvious mutation points 1954, 1969 and 2003 were very close to the nodes 1954, 1971 and 2001 in the segmentation analysis in 4.1.2, and it can be determined that the segmentation in 4.1.2 is reliable. And it can be seen in Fig. 6 that the U_{FK} and U_{FB} lines start to approach $U_{0.05}$ since 2001, which indicates that the trend of precipitation change (upward) in Heilongjiang Province has become more and more obvious since the 21st century, and this conclusion is consistent with the results of the analysis obtained in 4.1.2, that is, the precipitation in Heilongjiang Province may show an upward trend since the 21st century. The analysis of the mutation situation and the trend since the 21st century is the same as the results of Chen Jing's analysis in "Characteristics of spatial and temporal variation of precipitation in Heilongjiang Province, 1971-2018" [9] in several places.

3.2 Spatial Distribution of Precipitation

Based on the temporal analysis of the data, the distribution of precipitation characteristics by season can also be visualized using the data from each measuring station. The spatial distribution of different data was plotted by analyzing the spatial characteristics of 60 years of precipitation data from 14 stations in Heilongjiang province, combined with kriging interpolation, and the results are as follows.

3.2.1 Precipitation distribution

The total precipitation in Heilongjiang Province over the past 60 years and the distribution of precipitation in all seasons are shown in Figure 7.



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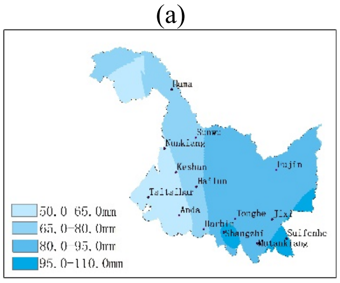

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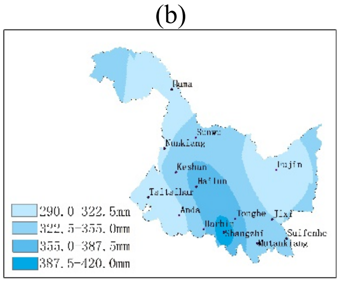

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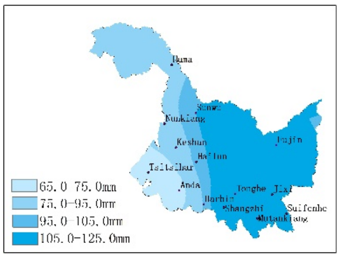

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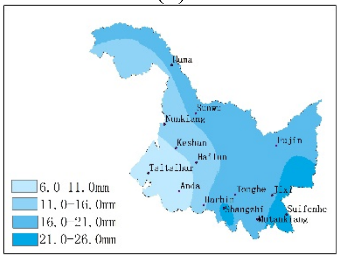


(e)

(Where a is total precipitation, b is spring precipitation, c is summer precipitation, d is fall precipitation, and e is winter precipitation.)

Figure 7. Spatial Distribution of Precipitation

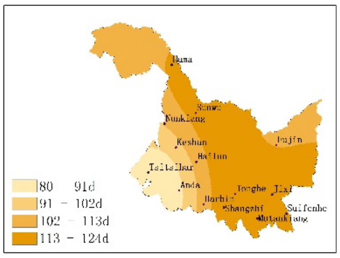
Overall, the annual precipitation in most areas was in the range of 462.5-587.5 mm. The central, eastern, northeastern, and southeastern parts of Heilongjiang Province were rich in rainfall compared to the rest of the region, and the annual precipitation is higher. The precipitation characteristics in spring, summer, autumn and winter basically conformed to the feature that precipitation in the east was greater than that in the west. Except for summer, the annual precipitation was characterized by a clear east-high and west-low distribution, and in summer it decreased from Harbin and Shangzhi to the rest of the province as the rainfall center. It can also be seen from the figure that the rainfall centers for the year as a whole and for all seasons were in the Shangzhi area, followed by the eastern part of Heilongjiang Province; while Huma, Nengjiang, Qiqihar, and Anda were within the lowest precipitation or sub-minimum areas almost all year round, i.e., the western part of Heilongjiang Province. The obtained interpolation results of the overall spatial distribution of precipitation are very close to the results of Kriging interpolation analysis in "Comparison of GIS-based spatial interpolation analysis of multi-year average precipitation in Heilongjiang Province" [8] by Luo Li. After analyzing various interpolation methods in this paper, the result is that the kriging model interpolation is more effective for the study of precipitation distribution in Heilongjiang province.

The spatial precipitation distribution may be due to the fact that the southeastern part of Heilongjiang Province is closer to the coastline and more susceptible to the monsoon climate, with obvious temperate continental monsoon climate characteristics; the western part is higher in elevation than the eastern part and farther from the ocean, so it is not easy to produce the same amount of precipitation as the eastern part in the process of water vapor transport and circulation. Therefore, the distribution of precipitation from east to west is gradually decreasing.

In terms of temporal distribution, the precipitation in Heilongjiang Province was seasonally distributed from high to low in summer, autumn, spring and winter, with obvious monsoonal characteristics. The temporal precipitation distribution was caused by the monsoon. Due to thermal reasons, the summer airflow mainly coemes from the high pressure ocean, which carries more moisture; the winter airflow mainly comes from the high pressure Siberian continent, which is drier. Therefore, the time distribution characteristics of more rain in summer and less rain in winter are formed.

3.2.2 Distribution of precipitation days

The total number of precipitation days in Heilongjiang Province over the past 60 years and the distribution of the number of precipitation days in each season are shown in Figure 8.



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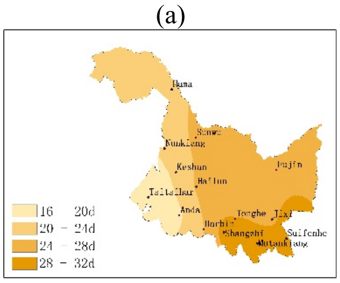
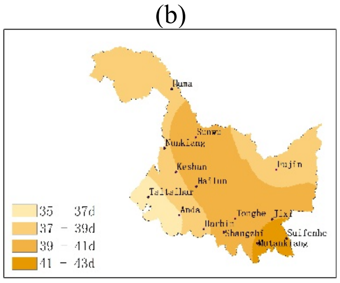
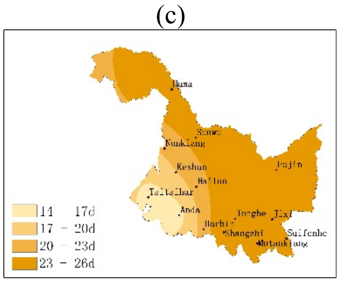


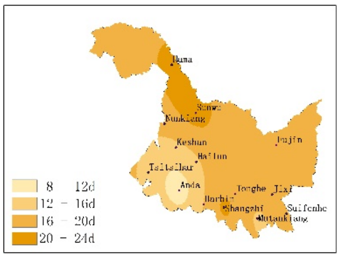
(b)



(c)



(d)



(e)

(Where a is the number of total precipitation days, b is the number of spring precipitation days, c is the number of summer precipitation days, d is the number of fall precipitation days, and e is the number of winter precipitation days.)

Figure 8. Spatial distribution of precipitation days

In general, the numbers of precipitation days in most of the whole Heilongjiang province were within a relatively close level, i.e., 102-124 days of average precipitation days in many years, and only some areas in the west, such as Keshan, Anda and Qiqihar, were significantly lower than the average number of rainfall days (110d/a).
Similar to the precipitation distribution characteristics, the characteristics of precipitation days in spring, summer, autumn and winter were also basically in line with the characteristics that the number of precipitation days in the east was greater than the number of precipitation days in the west. The regions with the largest number of precipitation days throughout the year include Shangzhi, Tonghe, Jixi, Mudanjiang, Suifenhe and Sunwu, which was also basically consistent with the regions with the largest amount of precipitation throughout the year. It is clear from the distribution map that the overall and all seasons of the year show generally more precipitation days on the east side than on the west side, basically divided by Nengjiang, Keshan, Hailun and Harbin. Meanwhile, the number of precipitation days in summer was significantly higher than that in the rest of the seasons, while the number of precipitation days in winter was the least. The reasons for the spatial and temporal distribution of precipitation days were the same as those for the corresponding distribution of precipitation (4.2.1).

4. Summary99999

The results show that the 60-year precipitation and precipitation days in Heilongjiang Province from 1954 to 2013 were generally high in the east and low in the west, and the precipitation center was located in the central part of Heilongjiang Province, with an average precipitation of 527.7 mm and 110 d in the study area. Overall annual precipitation decreased by 0.44mm per year, but there was an increasing trend since 1980, especially since the 21st century.
(1) The analysis of abrupt changes in precipitation in Heilongjiang from 1954 to 2013 shows that three significant abrupt changes occurred in 1954, 1969 and 2003, while two insignificant abrupt changes occurred in 1991 and 2001. The local interannual precipitation fluctuated very much, but there was an overall significant decreasing trend of -0.44 mm/a by the one dimensional linear trend analysis.
(2) There were differences in precipitation, days of precipitation, and rainy days of precipitation in Heilongjiang region in each season. Among them, the precipitation in spring and winter showed an increasing trend, but the increasing trend in winter was not obvious, and the precipitation in summer and autumn showed a decreasing trend; the number of precipitation days in spring and winter showed a non-significant increasing and non-significant decreasing trend, and in summer and autumn showed a decreasing trend; the rain-day precipitation in all seasons showed an increasing trend, among which the increasing trend in summer was the most significant, then it can be assumed that the intensity of rainfall in summer may have increased in the past 60 years, and may continue to rise.
(3) Precipitation in the Heilongjiang region was mainly light rain and moderate rain, with the sum of the two precipitation levels exceeding 70% and the sum of precipitation days exceeding 95%; at the same time, precipitation was mainly concentrated in summer, with summer precipitation accounting for 63.47% of the annual precipitation; precipitation centers were concentrated in the areas where Tonghe, Shangzhi, and Harbin were located, and precipitation in the entire Heilongjiang region was significantly influenced by the monsoon and topography, showing that precipitation and precipitation frequency (days) decreases from east to west.
This paper can only reflect the precipitation pattern of the study area to a certain extent because of the limited number of stations in the study area, especially in the spatial distribution, which may be different from the actual spatial distribution of precipitation and precipitation days, and the paper only summarized the precipitation pattern without exploring the underlying causes and mechanisms, which needs to be analyzed and studied in depth.

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