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Analysis of Changing Trend of Summer Precipitation in North China

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Abstract Based on the reanalysis data of the National Center for Environmental Prediction (NCEP) and the precipitation dataset of the U. S. Climate Prediction Center (CPC), the changing trend of summer precipitation in North China (35° – 40° N, 110° – 125° E) during 1979 – 2020 was studied. By calculating the monthly climatic precipitation in North China, it is found that precipitation was mainly distributed from June to August, so the trend of precipitation in North China from June to August was mainly analyzed. Firstly, the five-point moving average of regional mean precipitation in North China from June to August during 1979 – 2020 was conducted. It is found that the fitting curve of the five-point sliding average was basically consistent with the changing trend of regional precipitation, and it showed a certain upward trend. Secondly, the cumulative anomaly of regional average summer precipitation in North China showed a significant upward trend after 2005, which was similar to the moving average result, indicating that the precipitation in the later period increased compared with the earlier period. The changing trend of summer precipitation in North China in the past 42 years was analyzed, and the results show that precipitation showed a significant increasing trend in most areas of North China, so that regional average precipitation also tended to increase significantly. By comparing the precipitation in the past five years (2016 – 2020) and the last 36 years (1979 – 2015), it is found that the increase of summer precipitation in North China was more obvious, so the reasons for the increase in precipitation were further analyzed. Since the occurrence of precipitation requires favorable thermal dynamic conditions, the one-dimensional linear regression of water vapor content at 850 hPa and meridional wind speed was conduced, and it is found that the two variables tended to increase obviously, which was consistent with the increasing trend of precipitation. Seen from both the results of regional average and the spatial distribution of trends, the lower atmospheric water vapor content and wind speed showed a significant positive trend, which led to the increase of summer precipitation. Therefore, it can be concluded that there was a certain changing trend of summer precipitation in North China in the past 42 years, which can provide certain reference for the future forecast of summer precipitation in North China.

Key words North China; Summer precipitation; Trend analysis

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In recent years, a global problem, which is mainly characterized by global warming, has been caused by climate change. In the fourth report of IPCC[1], global temperature increased by (0.74 ± 0.18) ℃ from 1906 to 2005, and especially after 1980, the worldwide warming rate accelerated significantly, which is very likely to be caused by large-scale emissions of greenhouse gases. At the same time, due to the water cycle caused by global warming, a series of problems such as redistribution of global precipitation, frequent occurrence of extreme weather, and melting of glaciers and frozen soil have appeared, causing changes in the characteristics of water resources, which have attracted the attention of the academic community[2].

North China is located in the north of China, to the north of the Qinling Mountains and Huaihe River, east of Qinghai – Tibet Plateau and Greater Hinggan Mountains, and south of Inner Mongolia Plateau. It borders the Bohai Sea and the Yellow Sea in the east and Inner Mongolia in the north and northeast. North China covers central Inner Mongolia, Tianjin City, Beijing City, Shanxi Province, Hebei Province, and is an important part of China. In addition, North China has a temperate monsoon climate, and there is high temperature and more precipitation in summer[3]. Due to its geographical location, any meteorological disaster in North China will cause huge losses to China. Hence, North China has become an important area in the field of meteorology. Precipitation is an important indicator in addition to climate types. Precipitation in North China is characterized by rainfall concentration and strong regional feature, and summer precipitation accounts for more than 60% of annual precipitation[4 – 5].

North China is a famous main grain production area in China, and weather factors have a great impact on the growth and yield of grain, of which summer precipitation is the main influencing factor[6]. With the global warming, the shortage of water resources and other problems gradually appear. North China has a semi-humid and semi-arid continental monsoon climate, and its precipitation distribution is extremely uneven, with significant seasonal and annual variations[7 – 8]. Since the 1960s, precipitation in this region has continued to be less, decreasing until the 1980s, thereby resulting in long-term water shortage in this region; the per capita water volume is the lowest among the major river basins in China, only accounting for 1/6 of the national average[9]. Therefore, it is very necessary to conduct in-depth research on the changing trends and influencing factors of summer precipitation in North China[10]. In this paper, based on the reanalysis data of the National Center for Environmental Prediction (NCEP) and the

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precipitation dataset of the U. S. Climate Prediction Center (CPC), the changing trend of summer precipitation in North China from 1979 to 2020 was studied.

1 Data and methods

1.1 General situation of the study area North China (35° – 40° N, 110° – 125° E) has a temperate monsoon climate, with high temperature and more precipitation in summer, which has a significant impact on the national economy and people's production and life. North China is a vast region with complex and diverse landform and different characteristics of precipitation change[11 – 12].

1.2 Data sources Precipitation data was mainly from the data set of CPC Global Unified Gauge – Based Analysis of Daily Precipitation. The data of variables for the spatio-temporal evolution analysis of large-scale environmental field was the reanalysis data of the National Center for Environmental Prediction (NCEP) of the United States, and the horizontal grid spacing was 2.5° × 2.5°; the analysis fields mainly included water vapor and wind fields at 850 hPa[13]. All of the above data covered the period of 1979 – 2020.

1.3 Research methods

1.3.1 Analysis of climate state. The monthly average of climate state means calculating the average of a certain climate indicator by using the average method. An average can reflect the central tendency of data. In this paper, the climate state analysis of precipitation will be mainly analyzed, and the average can be calculated as follows:

$$x = \frac{x_1 + x_2 + \cdots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n}$$

1.3.2 Analysis of standard deviation. Standard deviation refers to the arithmetic square root of variance, reflecting the degree of dispersion between individuals in a group. The ratio of standard deviation to expected value is standard deviation rate. By measuring the degree of distribution, it is found that it is a non-negative value, and has the same unit as the measurement data. Its formula is as follows:

$$SD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

In the formula, μ is average ($\bar{x}$).

1.3.3 Moving average. For a group of data (the number is n), moving average refers to the average of multiple consecutive m ($m < n$) data. That is, from all n values, adjacent m values are taken to conduct arithmetic average operation[14], so as to facilitate real-time processing of non-stationary data. The formula is as follows:

$$f_k = \frac{1}{m}\sum_{i=0}^{m-1})y_{k+i}, \ k = 1, 2, 3, \cdots, n - m + 1$$

In the formula, m is the sliding length; y is the precipitation in year $k + i$[15].

1.3.4 Cumulative anomaly. Cumulative anomaly is often used to judge the changing trend of meteorological elements such as temperature and precipitation[16], and the formula is:

$$\hat{x}_i = \sum_{i=1}^{t}(x_i - \bar{x}), \ i = 1, 2, 3, \cdots, t$$

In the formula, x is the mean of precipitation (℃); t is the time (a). If the curve of cumulative anomaly shows an upward trend, anomaly value increases. If there is a downward trend, anomaly value decreases[15].

1.4 Data analysis process In this experiment, precipitation data was mainly from the data set of CPC Global Unified Gauge – Based Analysis of Daily Precipitation and NCEP/NCAR reanalysis data, and climate state analysis, standard deviation analysis, trend analysis, moving average, cumulative anomaly and research methods were used. In addition, NCL (NCAR Command Language) was used. This language is convenient and concise, and is suitable for meteorological language for drawing. The data analysis and graph drawing in this paper were conducted by NCL.

2 Results and analysis

2.1 Characteristics of precipitation climatic state First, the monthly average of precipitation data from 1979 to 2020 was obtained (Fig. 1). It can be seen that the precipitation in North China was concentrated in June, July and August. In addition, due to the vast territory of China and the monsoon climate along coastal areas, the months with more precipitation would be correspondingly earlier than summer with the decrease of latitude, so the data in the figure is also consistent with the objective reality[17 – 18]. Next, the variation characteristics of precipitation in North China (35° – 40° N, 110° – 125° E) from June to August during 1979 – 2020 were mainly studied.

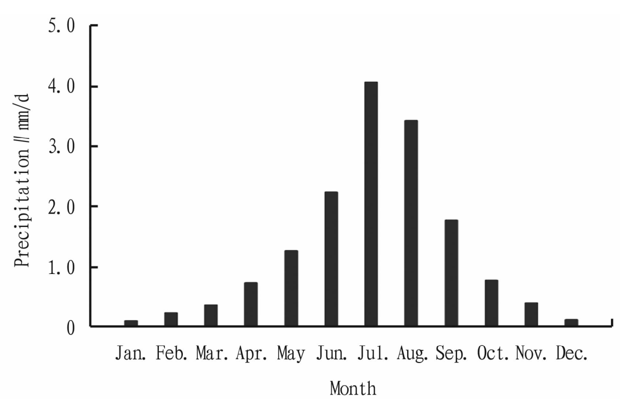


Fig. 1 Monthly variation of precipitation in North China from 1979 to 2020

After June, July and August were determined as the study period, the climate field and standard deviation field of precipitation in North China from 1979 to 2020 were plotted (Fig. 2 and Fig. 3). As can be seen from Fig. 2, North China is in the monsoon region, so its average precipitation was lower than that in eastern China and higher than that in western China, about 2 – 4 mm/d, and the precipitation in the country gradually decreased from south to north. As shown in Fig. 3, compared with the middle and lower reaches of the Yangtze River basin in China, the standard deviation of precipitation in North China was smaller, with the range of

6 – 8 mm/d.

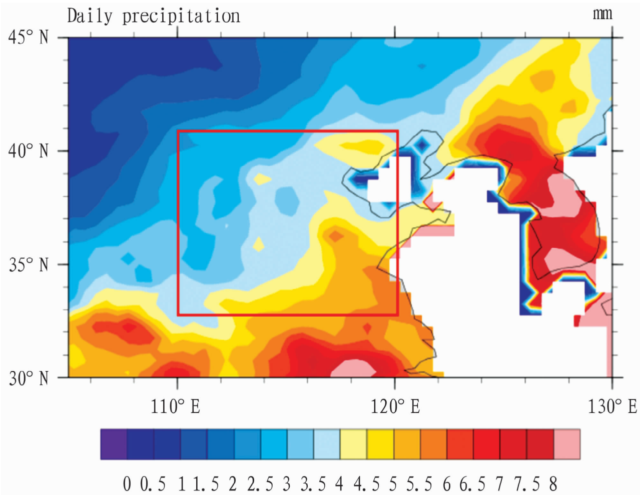


Fig. 2 Climate field of precipitation in North China during June – August from 1979 to 2020 (unit: mm/d)

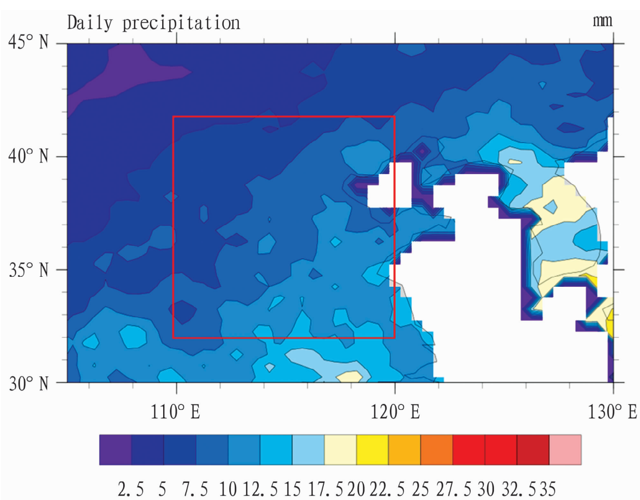


Fig. 3 Standard deviation field of precipitation in North China during June – August from 1979 to 2020 (unit: mm/d)

2.2 Analysis of moving average In order to eliminate the occasional variation factors of summer precipitation in North China from 1979 to 2020, five-point moving average was calculated for regional precipitation from June to August during 1979 – 2020 to find out the changing trend of precipitation. Seen from Fig. 4, the precipitation in North China had a downward trend from 1979 to the middle 1980s, and began to increase again from 1985 to 1990, with a greater variability than that in the previous shrinking stage. After an increase from 1985 to 1990, it declined from the middle 1990s to the early 21st century. However, the precipitation was basically 4.0 – 5.0 mm from 2000 to 2020. The trend change was not significant, and there was a slight rebound. After the five-point moving average was obtained, the new fitting curve was basically consistent with the trend of the changing trend of regional precipitation, and it showed an increasing trend on the whole.

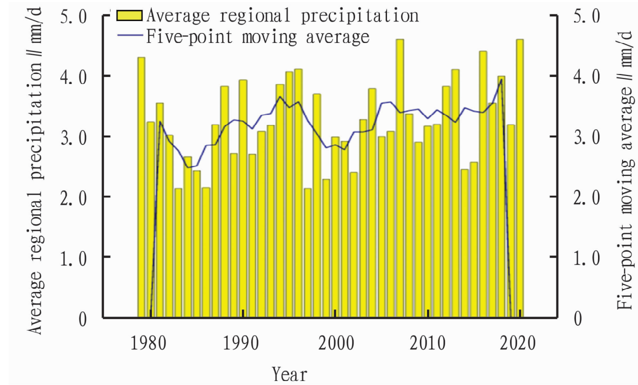


Fig. 4 Variation in the moving average of regional precipitation from June to August during 1979 – 2020

2.3 Analysis of cumulative anomaly From the above analysis, it can be seen that the inter-annual variation of summer precipitation in North China had phased characteristics. Cumulative anomaly was used to clearly study the interannual variation of precipitation (Fig. 5). According to the data analysis, the average of regional precipitation in the past 42 years was about 3.28 mm/d. From 1979 to the middle 1980s, cumulative anomaly showed a downward trend, indicating that precipitation was less than the average. From the middle 1980s to the middle 1990s, anomaly began to increase, and precipitation increased. After an increase from the middle 1980s to 1990, there was an overall decrease from 1995 to 2005, and precipitation became smaller. However, from 2005 to 2020, anomaly began to increase again, and the changing rate was smaller than that in the previous decreasing stage; precipitation rose, but the changing rate was smaller than that in the previous reduction stage.

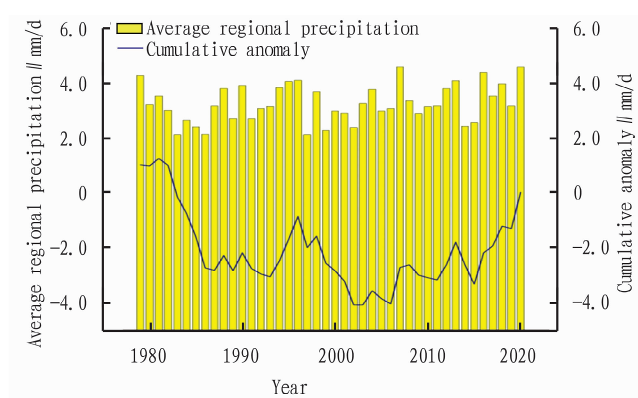


Fig. 5 Variation in the cumulative anomaly of regional precipitation from June to August during 1979 – 2020

2.4 Analysis of precipitation trend In order to observe the changing trend of regional precipitation from June to August in North China, the changing curve of regional precipitation from 1979 to 2020 was drawn (Fig. 6). As can be seen from Fig. 6, regional precipitation in North China from June to August ranged from 2.0 to 4.5 mm in the past 42 years, showing an upward trend, and its regression coefficient R was 0.143 5, indicating that the upward trend and correlation were not obvious. Therefore, summer precipitation in North China had an overall upward trend in the past 42 years. However, precipitation in North China had a downward trend from 1979 to 1985. After 1985, precipitation began to increase again, and the growth rate was greater than that of the previous years. After an increase from 1985 to 1990, there was an overall decline from 1995 to 2005, and then there was an increase in precipitation during 2005 – 2020.

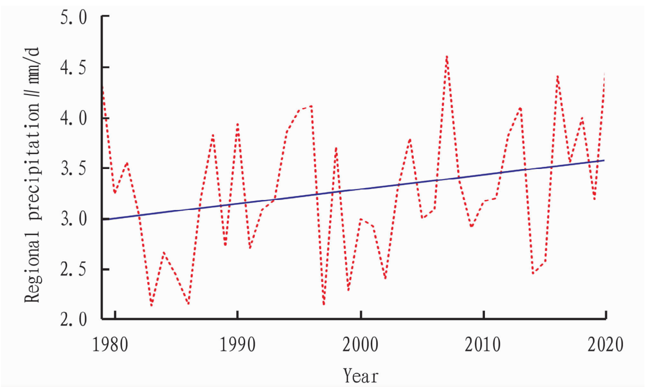


Fig. 6 Annual changes of regional precipitation from June to August during 1979 – 2020

The horizontal distribution of precipitation trend from June to August during 1979 – 2020 was analyzed. When the trend value was greater than 0, precipitation showed an increasing trend; on the contrary, when the trend value was less than 0, precipitation had a decreasing trend. As shown in Fig. 7, there was an increasing trend in most areas of North China, which was consistent with the result of regional average. The precipitation in the southeast had a very obvious increasing trend, with an increase of 4 mm/(d · a). The precipitation in the north and southwest also had a decreasing trend, but the area was small.

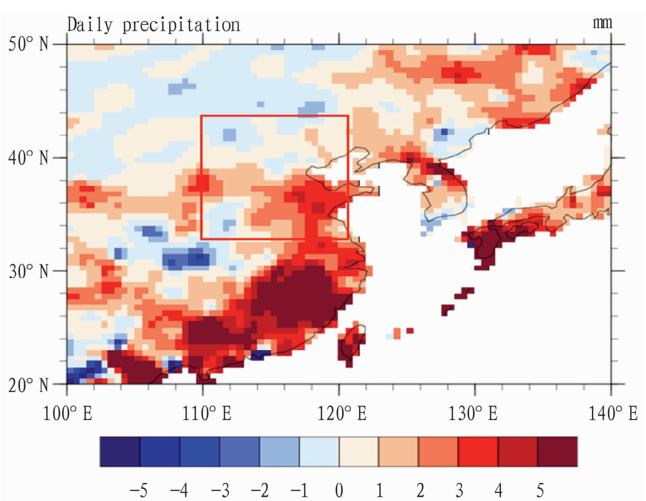
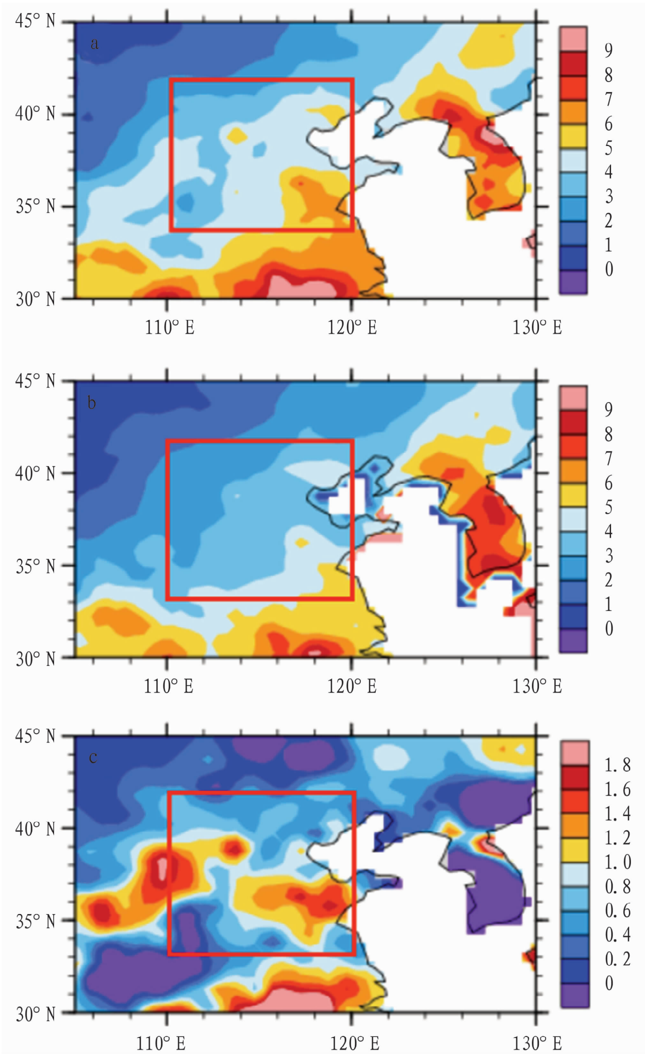


Fig. 7 Horizontal distribution of precipitation trend from June to August during 1979 – 2020 (unit: mm/(d · a))

2.5 Causes of changes in precipitation In order to better explore the variation trend of summer precipitation in North China, the difference between the mean climatic state of precipitation during 1979 – 2015 (Fig. 8a) and 2016 – 2020 (Fig. 8b) was calculated. From Fig. 8, it can be seen that average precipitation was 3 – 5 mm/d from 1979 to 2015 and 3 – 7 mm/d from 2016 to 2020, with an increase of about 0.8 – 1.4 mm/d. That is, summer precipitation in North China tended to increase from 1979 to 2020.



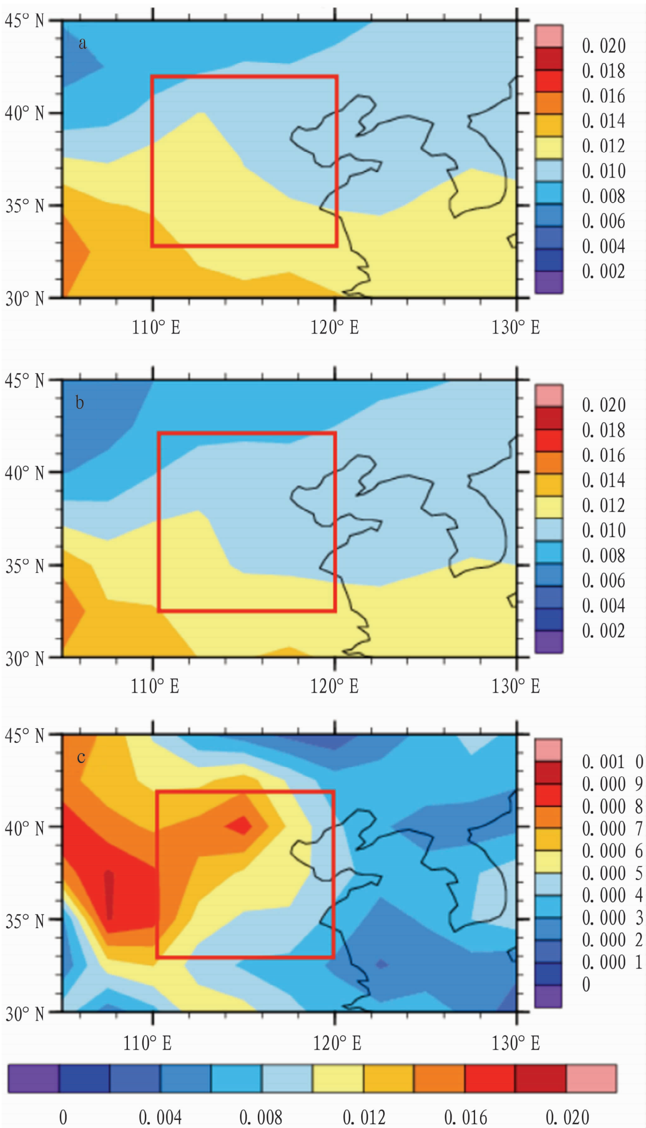
Note: a. 2016 – 2020; b. 1979 – 2015; c. Difference.

Fig. 8 Average precipitation in North China from June to August during 1979 – 2020 (unit: mm/d)

In order to further confirm the analysis of Fig. 8, the correlation between precipitation and water vapor content at 850 hPa was tested, and the results show that there was a strong correlation at the confidence interval of 95%.

The difference between average water vapor content at 850 hPa during 1979 – 2015 (Fig. 9a) and 2016 – 2020 (Fig. 9b) was calculated to study the change of water vapor content at 850 hPa. As can be seen from Fig. 9, the average water vapor content was 0.008 – 0.012 mm/d during 2016 – 2020 and 1979 – 2015. The difference between the two periods was about 0.000 9 – 0.000 3 mm/d, and water vapor content at 850 hPa in summer in

North China increased, which was consistent with the situation of precipitation.

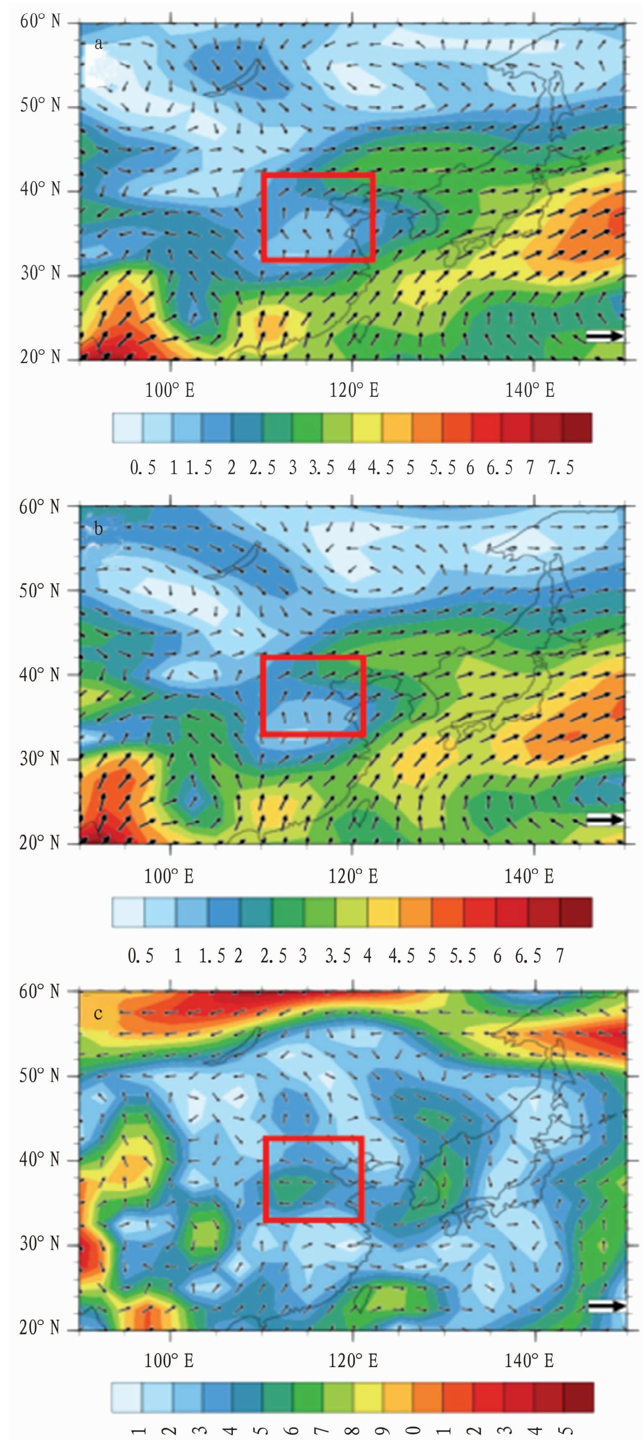


Note: a. 2016 – 2020; b. 1979 – 2015; c. Difference.

Fig. 9 Average water vapor content at 850 hPa in North China from June to August during 1979 – 2020 (unit: mm/d)

Similarly, the correlation between precipitation and wind speed at 850 hPa was tested. The calculation results show that the correlation was significant at the confidence interval of 95%.

Like water vapor content, wind speed was transformed. Seen from Fig. 10, average wind speed was 1.0 – 3.5 m/s from 2016 to 2020 and 0.5 – 3.5 m/s from 1979 to 2015. The difference between the two periods was about 0.1 – 0.6 m/s, and the average wind speed during 1979 – 2015 was higher than that during 2016 – 2020, and the wind direction had a tendency to the west. Thus, the wind speed at 850 hPa in summer in North China increased, which was consistent with the situation of precipitation.



Note: a. 2016 – 2020; b. 1979 – 2015; c. Difference.

Fig. 10 Average wind speed at 850 hPa in North China from June to August during 1979 – 2020 (unit: m/s)

To further confirm the analysis of Fig. 9, a line chart of water vapor content at 850 hPa during 1979 – 2020 was drawn (Fig. 11). As can be seen from Fig. 11, water vapor content at 850 hPa was 0.008 0 – 0.010 4 mm. Water vapor content at 850 hPa from June to August in North China from 1979 to 2020 showed a slight upward trend, but it was not significant, and its regression coeffi-

cient R was 6.398 55e − 06. From the middle 1970s to the middle 1980s, the precipitation in North China showed a downward trend, and the water vapor content at 850 hPa in the corresponding year also decreased. After 1985, the value continued to increase, and the variation rate was larger than that in the previous shrinking stage, which was related to the change of precipitation. After an increase from the middle 1980s to the early 1990s, it declined from the middle 1990s to 2010 on the whole, but rose again from 2010 to 2020, which was basically consistent with the change of precipitation.

In a word, the changes of precipitation in North China in the past 42 years were basically consistent with the changes of water vapor content at 850 hPa, and the confidence interval was 95%.

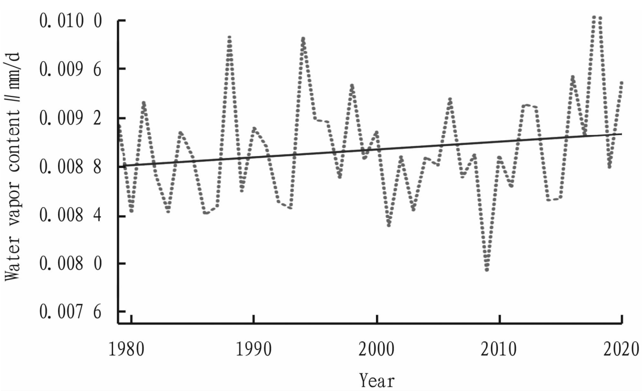


Fig. 11 Annual changes of average water vapor content at 850 hPa in North China from June to August during 1979 – 2020

A line chart of meridional wind at 850 hPa during 1979 – 2020 was drawn (Fig. 12). As can be seen from Fig. 12, wind speed at 850 hPa was 0.4 – 2.0 m/s. Meridional wind at 850 hPa from June to August in North China during 1979 – 2020 showed a slight upward trend on the whole, but it was not significant, and its regression coefficient *R* was 0.003 430 13.

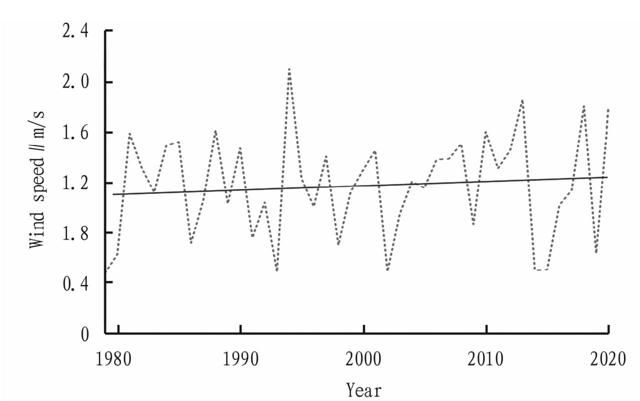


Fig. 12 Annual changes of meridional wind at 850 hPa in North China from June to August during 1979 – 2020

3 Conclusions and prospects

(1) The precipitation in North China is mainly concentrated from June to August under the combined effects of multiple factors such as monsoon, sea and land location.

(2) From 1979 to 2020, the summer precipitation trend in North China showed an upward trend on the whole.

(3) Summer precipitation in North China showed a gradual trend of decade change. From 1979 to 1985, the precipitation had a decreasing trend; from 1985 to 1995, the precipitation increased; after the increase from 1985 to 1990, precipitation decreased from 1995 to 2005 on the whole. However, from 2005 to 2020, it began to increase again, and the change rate was less than that in the previous reduction stage.

(4) From the analysis of changes in water vapor field and wind field at 850 hPa, it is found that the water vapor content and wind speed showed a slightly increasing trend, which provided a powerful thermal dynamic field for the occurrence of precipitation, so precipitation tended to increase.

There are still some shortcomings in this study. Some results are consistent with those of the predecessors, but there are also some differences. In this study, only the precipitation field, water vapor and wind fields at 850 hPa in summer were qualitatively discussed, but the influence on temperature field and height field was not further discussed. Since North China is a monsoon region, the effects of temperature, height and wind fields on precipitation need to be further studied. In addition, the selection and processing methods of data were relatively limited, which may have a certain impact on the calculation and analysis results. It will be more accurate and reliable to use precipitation data with higher temporal and spatial resolution to analyze climate characteristics of precipitation. Finally, it is hoped that in the future, the impact of global warming, south wind anomaly and other issues that are of more concern to all mankind on precipitation change in North China, as well as the impact of precipitation change in North China on agriculture, industry and human production and life will be comprehensively studied.

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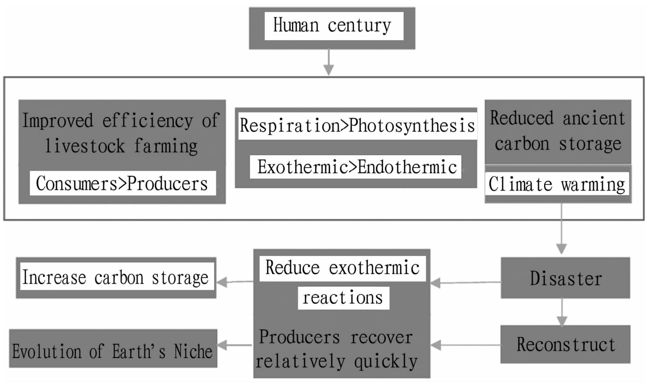

Fig. 2 Feedback mechanism of climate alternation between cold and warm

(2) Biomass is the main energy source of the Earth, and climate warming is not the result of an increase in atmospheric CO_2 concentration. In theory, carbon and heat are a twin relationship.

(3) Climate warming-extreme weather-disaster occurrence-reducing the factors of warming through basic principles, restoring the order of the Earth's climate, and scientifically understanding disasters are particularly important for human society.

The article describes three expressions of the causes of climate change through basic principles, and proposes the scientific issues of carbon heat homology, the reasons why CO_2 concentration lags behind temperature changes, the doubling effect of improving livestock breeding efficiency on climate change, and the important significance of scientific understanding of disasters for human adaptation to climate change. Overall, the feedback mechanism of climate has always been a global challenge, and the literature available for reference is disorganized. This requires starting from the basic principles and finding the key to the problem. If the basic principles are correct, it is not far from uncovering the essence of things. I am very grateful to Mr. Frank Wilchek for his inspiration in publishing the book *Fundamentals*. Although there is still a lot of work to be done in terms of CO_2, thermal energy, global energy cycling, and the causes of biological extinction, it is undoubtedly correct to think about climate change from the perspective of "fundamental principles".

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