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NEW DEFINITION FOR NORTH HUAIHE RIVER RAINY SEASON AND ATMOSPHERIC CIRCULATION CHARACTERISTICS IN PRECIPITATION ANOMALY YEARS

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Abstract: In this article, a new definition for the North Huaihe River rainy season (NHRS) is presented using summer daily precipitation in East China and subtropical high ridge axis at 500 hPa. By calculating the annual precipitation amounts in the NHRS and Meiyu of the Yangtze-Huaihe Rivers basin (YHMY) from 1961 to 2009, the dates of precipitation beginning and ending as well as the duration of the two rainy seasons in the 49 years are analyzed. Atmospheric circulation characteristics in positive and negative precipitation anomaly years during the NHRS are also studied. Results are shown as follows. (1) The new definition for the NHRS is much easier to use. It involves only two meteorological factors, making its application more practical. It can also distinguish two rainy periods of the NHRS more objectively. (2) The average duration of the NHRS is similar to that of the YHMY, except that its average dates of beginning and ending are about one week later than those of the YHMY. The average precipitation of the NHRS is slightly less than that of the YHMY, and the yearly precipitation variation of the two rainy seasons are similar to each other with no obvious increasing or decreasing trend in the 49 years, but with distinguished decadal and inter-annual variations. (3) In positive precipitation anomaly years, the South Asian high moves more northward and more eastward, the western Pacific subtropical high is located more northward and westward, and the summer monsoon is stronger than normal, resulting in the convergence of the warm and moist southwesterly airflow from the west side of the subtropical high and the cold air from the north side of the northeast trough in North Huaihe River basin.

Key words: North Huaihe rainy season; Mei Yu; atmospheric circulation characteristics

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1 INTRODUCTION

The Huaihe and Yangtze rivers flow from west to east in China. As a result, Shandong, Anhui, and Jiangsu provinces are geographically separated by the two rivers into three regions, namely, the North Huaihe River area, Yangtze-Huaihe Valley area, and Southern Yangtze River area, respectively. In these areas of large population and complex terrains, extreme meteorological events such as floods and draughts often cause serious disasters. In each early summer, accompanied by the seasonal adjustment of atmospheric circulation, especially after the seasonal northward jump of the subtropical high over the western Pacific, the East Asian monsoon strengthens and moves northward, the annually first raining season over South China, Mei-Yu over the Yangtze River Basin, and the rainy season over North China occur one after another in East China. In mid-June, the rainband reaches the Yangtze River Basin and is called Yangtze-Huaihe Meiyu (YHMY)[1-3]. When the rainband approaches North China in mid- and late-July, it is called North China rainy season. The main area of the YHMY in East China is located in southern Huaihe River, while most of Shandong province belongs to the North China rainy season. Accordingly, when the Meiyu in south Huaihe River area occurs, usually no persistent rainfall appears to the north of Huaihe River. With the northward jump of the subtropical high in the western Pacific, the

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main rain belt moves further northward, when the rainy season is in the north of Huaihe River. After a period of stagnation, the subtropical high moves with its ridge axis across 28ºN, while the rain belt continues to move northward into North China to initiate the North China rainy season. Therefore, the northern area of the Huaihe River is regarded as a transition zone between the areas affected by the YHMY and North China rainy season. Since the strength of monsoon varies from year to year, the strength and the beginning date of persistent rainfall also differ. As a result, rainfall distribution in northern Huaihe River exhibits different features compared with the other regions. Therefore, the rainy season that occurs in North Huaihe area is an independent rainy season, different from the traditional YHMY and North China rainy season. There is limited research on how to define the North Huaihe River rainy season (NHRS). Jiangsu Meteorological Observatory has defined YHMY and NHRS as two relatively independent rainy seasons based on the variation of atmospheric circulation as well as local meteorological features[4, 5]. However, the definition is relatively complex and is affected by many factors that are difficult to be determined, thus it is not convenient to be applied in actual forecast and climate diagnostics.

Although there are lots of studies on the relationship between the YHMY and North China rainy season, little research has been done on the temporal-spatial distribution of the NHRS[6-9]. This study provides a new definition for the NHRS, based on which, the variation characteristics of relationship between NHRS and YHMY in recent years are investigated. The periods as well as the precipitation features of the two rainy seasons are also analyzed. Moreover, the atmospheric circulations for the positive and negative precipitation anomaly years are compared. In this paper, section 2 describes the data and methods, Section 3 describes the definitions and basic features of NHRS, and section 4 analyzes the atmospheric circulation characteristics of NHRS.

2 DATA AND METHODS

The summer daily rainfall data from 1961 to 2009 at 278 meteorological observation stations in East China, including Shandong, Jiangsu, Zhejiang, and Anhui provinces, and Shanghai Metropolis, are used in this study. The daily averages of the NCEP/NCAR reanalysis dataset at 2.5º×2.5º resolution are used in the analysis of atmospheric circulation. Common statistic functions are used in this article[10]. The North Huaihe River area mentioned in this article is the northern part of the Huaihe River in Anhui and Jiangsu provinces. All of the calculations for the YHMY are based on the definition of Jiangsu Meteorological Observatory[4]. The region of the YHMY is defined as the region to the south of the Huaihe River in both Jiangsu and Anhui provinces, as well as Zhejiang province and Shanghai.

3 DEFINITIONS OF NORTH HUAIHE RAINY SEASON(NHRS) AND ITS BASIC FEATURES

3.1 *Definitions of NHRS*

Atmospheric circulation and precipitation are main meteorological factors used for defining NHRS. In this study, the location of daily subtropical high ridge axis on 500 hPa in the western Pacific from June to July is selected as an atmospheric circulation factor. The basic idea of the new definition is as follows. As the subtropical high ridge moves northward so that continuous precipitation takes place for no less than 3 days, the NHRS starts. After that, when the subtropical high ridge keeps moving to a further north place without continuous precipitation, the NHRS ends. Such a rainy period is defined as the North Huaihe River rainy season. The NHRS region is located from 33ºN to 37ºN, including middle and south Shandong, north Anhui, and north Jiangsu.

Since June, the day when the daily 500 hPa subtropical high ridge axis shifts to north of 22ºN around 120ºE is defined as the initial circulation day. If significant precipitation appears on the initial circulation day and there is no precipitation during the previous days, the beginning day will start on the initial circulation day. If there is no precipitation on the initial circulation day, the beginning day will be the first day of the continuous precipitation after the initial circulation day. If significant precipitation appears on the initial circulation day and there is continuous precipitation a few days before, the beginning day will be the first day of the precipitation.

The definition of ending day of the NHRS: The terminating circulation day is defined as the day when the daily subtropical high ridge axis on 500 hPa is north of 28ºN along 120ºE. If there is no precipitation on this day, the day with the last precipitation will be the ending day. If significant precipitation appears on the terminating circulation day and there is no precipitation the next day, the terminating circulation day will be the ending day, or the day with the last precipitation before the terminating circulation day will be the ending day of the NHRS.

Using the new definition, the beginning and ending days of NHRS from 1961 to 2009 are obtained and the days in the rainy season can be divided accurately in every year. Results show that the day of initial circulation is close to the day of large-scale precipitation in NHRS, within three days in most years, except for 1966. For the ending day, the day of the terminating circulation and the day of NHRS ending differ in less than three days generally. For the ending situation, there are 12 years when the subtropical high ridge moves southward of 28ºN and remains stagnant for a few days and large-scale persistent rainfall appears once again. Of the 12 years, there are 10 years when the interval between the two continuous rainfall events is no more than three days. Thus the two periods are combined into one and the ending day of NHRS is defined as the last day when the rainfall ends in the second period. Moreover, as the intervals between the two continuous rainfall periods are quite long in 1988 and 1994, they are treated as two separate periods of NHRS. In 1988, the first period of NHRS is from 28 June to 4 July and the second period from 12 to 16 July. In 1994, the first period of NHRS is from 21 June to 1 July and the second from 12 to 18 July.

3.2 *The NHRS from the new and previous definitions*

The NHRS from the new and previous definitions are compared in Table 1. It shows that the average dates of beginning day and ending day as well as average duration are similar using different definitions. For the beginning day, the two definitions are on the same date for 23 years; the new definition is earlier for 16 years and later for the other 10 years. For the ending day, the two definitions are on the same date for 25 years; the new definition is earlier for 15 years and later for 9 years. From the above comparison, the new definition can reproduce the general characteristics of the previous definition while showing significant differences in inter-annual changes. Compared with the previous definition, the new one has several advantages in practical application. First, the previous definition involves many factors such as daily averaged air pressure, relative humidity, average temperature, extreme maximum temperature, precipitation, and ridge line of the subtropical high, among others, and yet only very few meteorological factors are used in the new definition. Thus, the new definition provides a much easier way to estimate the beginning and ending days. Second, the previous definition covers a smaller area in the north of Jiangsu province, while the new definition covers a much larger area, from the Huaihe River to South Shandong province. Third, two periods of NHRS can be easily classified by the new definition.

Table 1. Basic characteristics of NHRS and YHMY.

	average beginning day	average ending day	average duration (day)	years less than 15 days	years between 16 and 30 days	years more than 31 days	days (of the shortest year)	days (of the longest year)
NHRS (previous)	26 June	15 July	20	17	25	7	3 (1964)	37 (2004)
NHRS (new)	25 June	16 July	22	11	27	11	4 (1978)	42 (1980)
YHMY	18 June	10 July	24	11	24	14	3 (1978)	45 (1982)

3.3 *Basic characteristics of NHRS*

Table 1 shows the average beginning day in NHRS is 25 June. It is still regarded as normal as it is within 5 to 6 days of the average date. In the case that the NHRS starts on or before 20 June, it is defined as an early NHRS year, and similarly a late NHRS year is defined when the NHRS begins later than 1 July. From the definition, there are 10 early NHRS years, in which the earliest beginning day is 7 June, 1989, and there are nine late NHRS years, in which the latest beginning day is 17 July, 1974.

The average ending day of NHRS is 16 July. The early NHRS ending year is one in which rainfall ends on or before 9 July, and nine years are so defined, with the earliest ending day being 27 June. Moreover, the late NHRS ending year should have an ending day that appears on or after 23 July, and there are 10 such years, with the latest ending day being 14 August in 1974. Since 1961, there were only two years that the NHRS ended in August.

The average precipitation of NHRS is 182 mm in the 49 years. If we define the year in which the precipitation is 50% more than the annual average as a typical positive anomaly year, and the year in which the precipitation is 50% less than the annual average as a representative negative anomaly year, there are eight positive anomaly years (including 1970, 1971, 1974, 1980, 1990, 1996, 2003, and 2007), and nine negative anomaly years (including 1964, 1966, 1978, 1981, 1997, 1998, 1999, 2001, and 2002).

3.4 *Comparative analysis between NHRS and YHMY*

3.4.1 Comparative analysis on beginning day and ending day

The average beginning and ending days of NHRS are about one week later than those of YHMY (Table 1). Their average durations are similar, but the NHRS is two days shorter that that of the YHMY.

Figure 1a shows the difference of beginning days between NHRS and YHMY over the 49 years. It can be seen that the NHRS begins later than the YHMY in most years; only in a few years do the two rainy seasons begin on the same day. Before the 1980s, the difference in the starting day is less than 10 days. During the 1980s and 1990s, the difference is generally more than 10 days. Since 2000, the difference begins to decrease, and the rainy seasons are on the same day in many years. For the difference of ending days (Figure 1b), in most years, the NHRS ends later than the YHMY, by as many as 10 days, especially from the late 1960s to the 1970s, as well as from the mid-1980s to mid-1990s. However, since the late 1990s, the difference decreases obviously; there are only a few years with a much later ending day in the NHRS, and there are seven years when it ends earlier than the YHMY.

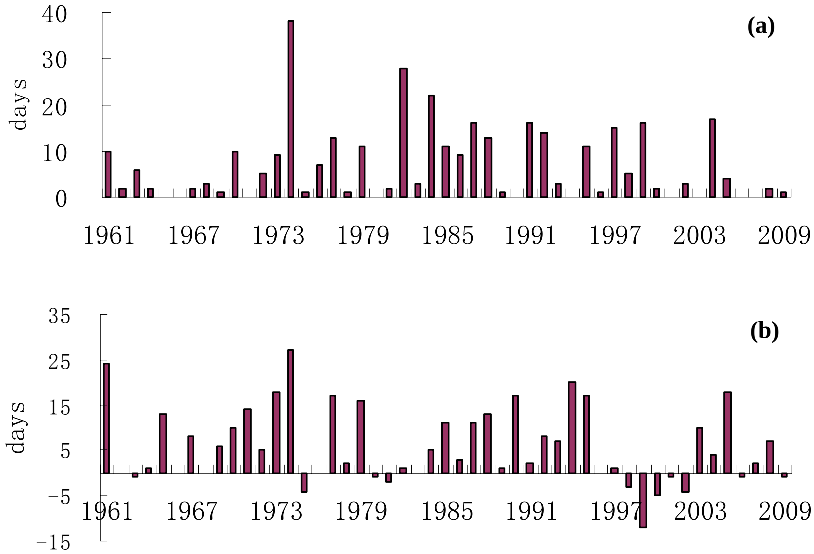


Figure 1. Difference in days between NHRS and YHMY: a: the beginning day, and b: the ending day.

3.4.2 COMPARATIVE ANALYSIS ON PRECIPITATION BETWEEN NHRS AND YHMY

Figure 2 illustrates the annual precipitation of all observation stations over the respective region in the two rainy seasons. The main characteristics are summarized as follows. (1) The overall variations of the two rainy seasons are similar, and the average precipitation of YHMY is a little more than that of NHRS. (2) The precipitation in the two rainy seasons shows no obvious trend of decrease or increase, but has obvious inter-annual and decadal variability during the 49 years. In the 1960s and 1970s, the precipitation was relatively low in most years. In the 1980s and 1990s, YHMY showed anomalously more precipitation while NHRS was normal. Since 2000, the precipitation in YHMY was essentially normal while that in NHRS increased. (3) During the positive anomaly years of YHMY, the NHRS precipitation was essentially normal, while in the positive anomaly years of NHRS, the precipitation in YHMY was more than normal in most years.

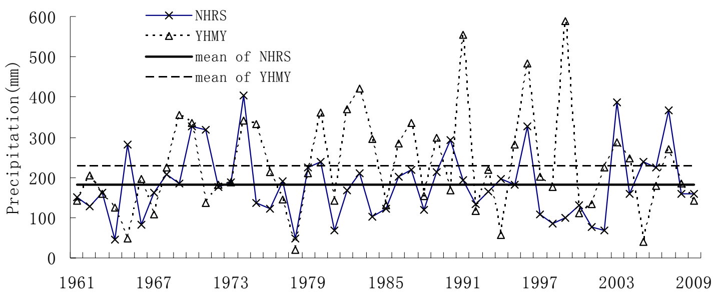


Figure 2. Accumulated precipitation during the two rainy seasons for the years 1961-2009.

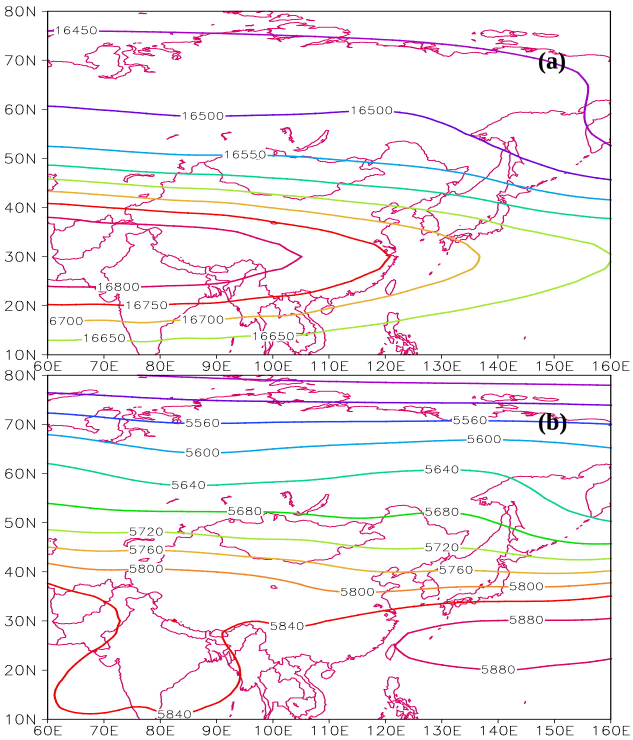
4 ATMOSPHERIC CIRCULATION CHARACTERISTICS OF NHRS

Numerous investigations indicated that the northward movement of the summer rain belt of East

China is determined by many factors, such as the movement of the westerlies and easterlies in Asia, the activity of East Asian summer monsoon, and the subtropical high, as well as the circulation of blocking highs[11-13]. The characteristics of normal years' atmospheric circulations are analyzed in this section. In addition, the differences of atmospheric circulation in typical positive anomaly years and negative anomaly years are also analyzed.

4.1 *Average atmospheric circulation characteristics of NHRS*

Figure 3 illustrates the average atmospheric circulation characteristics of NHRS in the 49 years. It shows that the mainland China is controlled by the South Asian high at the geopotential height of 100 hPa. The geopotential height field at 500 hPa indicates that the western Pacific subtropical high is zonally distributed with its ridge axis located around 23–24ºN. A stable trough over India contributes to the southwesterly wind in East China. Over the mid- and high-latitudes, two blocking highs occupy the area east of Urals Mountains, and Lake Baikal to Sea of Okhotsk, respectively; a stable trough exists in Northeast China, transferring the cold air southward from the north of the trough. In the 850 hPa wind field, there is a stable southwesterly airflow controlling East China carrying the warm and moist air to the North Huaihe River region. When the warm southwesterly airflow meets the northern cold air, precipitation occurs and persists in the North Huaihe River area.



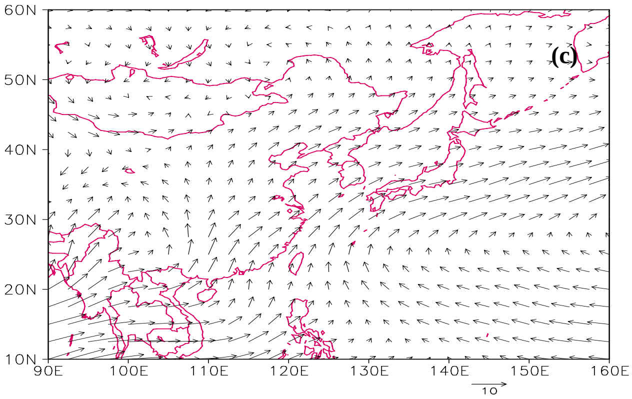


Figure 3. Averaged atmospheric circulation characteristic during the NHRS: (a) 100 hPa height (gpm), (b) 500 hPa height (gpm), and (c) 850 hPa wind field (m s^{-1}).

4.2 *Comparison of the concurrent atmospheric circulation characteristics of NHRS precipitation in positive and negative anomaly years*

In order to analyze circulation differences in typical positive and negative anomaly years of NHRS, composite analysis is performed to obtain concurrent atmospheric circulation. The duration of NHRS varies widely from year to year, and the number of days from the beginning day to the ending day differs by more than two months. Therefore, for the convenience of comparison, we define the same period from 15 June to 30 July. The two days are calculated by the average beginning day of early NHRS beginning year and the average ending day of late NHRS ending year.

It is known from the figures of 100 hPa geopotential height and anomalies field (not shown) that the whole South Asia is controlled by the South Asian high in both positive and negative anomaly years. In the positive anomaly years, there are obvious negative anomalies in the region north of 20ºN while there are positive anomalies south of 20ºN. However, the negative anomaly years show an opposite situation, with obvious positive anomalies north of 25ºN and negative anomalies south 25ºN. Figure 4a shows the difference between the positive and negative years (all the differences are defined by the positive year minus the negative year). There are obvious negative anomalies north of 25ºN and positive anomalies south of 25ºN. The results above suggest that in positive years, the location of South Asian high might be more northward and eastward than its normal location, and reversed situation occurs in negative precipitation anomaly years.

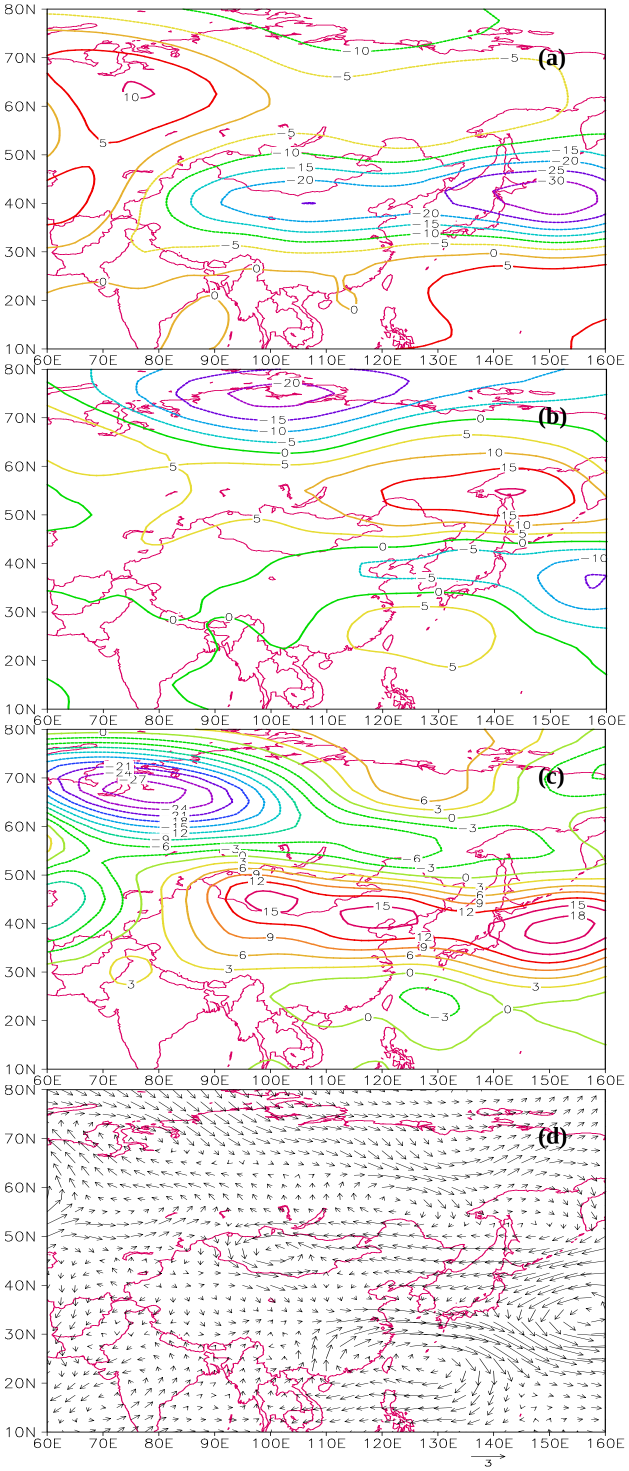


Figure 4. Concurrent atmospheric circulation characteristics of NHRS. (a): positive minus negative anomaly years at 100 hPa (gpm); (b): positive anomaly at 500 hPa; (c): negative anomaly at 500 hPa (gpm); (d): positive minus negative anomaly years at 850 hPa (m s^{-1}).

From the geopotential high field at 500 hPa (not given), it shows that the high ridge line is located near 23ºN, with the western boundary of its 588 geopotential height at 123ºE in positive years. Nevertheless, the high ridge line lies near 22ºN, with its western boundary around 130ºE in negative years. Figure 4b illustrates the anomaly of positive years. In East Asia, from low to high latitudes there is a "+, –, +, –" anomaly wave train, indicating that the area south of Yangtze River is of positive anomaly, the North Huaihe River is of negative anomaly, Northeast China and the Sea of Okhotsk are of positive anomalies, and the North Polar area is of negative anomaly. The pattern is just the opposite in negative years, with a "–, +, –, +" anomaly wave train from the low to high latitudes. All of these indicate that the subtropical high is stronger and more westward and northward, and the blocking high of the Sea of Okhotsk and the northeast trough are stronger than normal, simultaneously.

From the figures of wind field at 850 hPa and anomalies (not shown), it is known that East China is covered by southwesterly wind in both positive and negative years. The anomaly filed in positive years reveals significant southwesterly airflow south of 34ºN and northerly airflow north 33ºN. In negative years, however, East China is occupied by northerly or easterly airflow. The difference (Figure 4d) shows strong southwesterly airflow south of 35ºN and weak northerly airflow north of 35ºN, indicating that the summer monsoon and southwesterly flow are intensive in positive years.

From the analysis above we can see that in positive years the South Asian high advances more northward and eastward while the western Pacific subtropical high moves more northward and westward, making the summer monsoon stronger than normal. The warm and moist southwesterly airflow from the west of the subtropical high converges with the cold air from north of the Northeast trough in the northern Huaihe River basin. The opposite atmospheric circulation characteristics appear in negative precipitation anomaly years.

5 CONCLUSIONS AND DISCUSSION

(1) The North Huaihe River rainy season (NHRS) is defined with a new definition in this study, using the subtropical high on 500 hPa and daily precipitation. In most years, the days of precipitation beginning and ending can be obtained clearly. This new definition uses only two meteorological factors, making its application convenient.

(2) The average duration of NHRS is about 22 days, which is close to that of YHMY. Both the beginning and ending days of NHRS are normally later than the YHMY's by about a week. In most years, NHRS begins later than YHMY. Moreover, the ending day of NHRS is later than the YHMY's in most years.

(3) The average precipitation of NHRS is a bit less than that of YHMY, and the overall variations of the two rainy seasons are very similar over the 49 years. No obvious increasing or decreasing trend is

found. However, significant inter-annual and decadal variations are revealed in the study.

(4) Analysis on atmospheric circulation characteristics in typical positive and negative precipitation anomaly years shows that in positive years the South Asian high advances more northward and eastward, while the western Pacific subtropical high moves more northward and westward, making the summer monsoon stronger than normal. The warm and moist southwesterly airflow from the west of the subtropical high converges with the cold air from north of the northeast trough in the North Huaihe River, in favor of NHRS's formation and duration.

Some relationship exists between the NHRS and YHMY in terms of rainy season's duration and rainfall intensity. The atmospheric circulation characteristics of NHRS in typical positive and negative anomaly years are probably consistent to the features of the rain pattern shifting northward in YHMY. But in some years, particularly when the subtropical high is active and oscillates widely from north to south, the characteristics of NHRS are quite complicated, even presenting two periods of rainy seasons in some years. These atmospheric circulation anomalies and air-sea interaction associated with NHRS need further investigation.

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