ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 21, NO. 5, 2004, 699–707

A Possible Linkage in the Interdecadal Variability of Rainfall over North China and the Sahel

REN Baohua*[1,2] (任保华), LU Riyu[2] (陆日宇), and XIAO Ziniu[3] (肖子牛)

[1] *School of Earth and Space Sciences, University of Science and Technology of China, Hefei* 230026

[2] *State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

[3] *Meteorological Institute of Yunnan Province, Kunming* 650032

(Received 6 January 2004; revised 12 March 2004)

ABSTRACT

The instrumental records of precipitation, including some historical documentary evidence, show that the rainfall in North China during the rainy season (July and August) exhibits an interdecadal variability similar to the Sahelian rainfall. Both these areas exhibited a weak interdecadal rainfall variability prior to the 1950s, and experienced a long-lasting drought since the 1960s, with two rainfall decreasing transitions, one around the year 1965 and another in the late 1970s. NCEP/NCAR reanalysis data are used to analyze the associated changes in atmospheric circulation during the second decrease transition. The changes of local atmospheric circulation at the end of the 1970s, at both lower and upper levels, contribute to the less precipitation in North China and the Sahel.

Key words: North China, the Sahel, rainfall, interdecadal variability

1. Introduction

The capital city of China, Beijing, and other large cities, such as Tianjin and Shijiazhuang are all located in North China (roughly the region 35°–40°N, 110°–125°E), a region with a very large population. In the past several decades, the rainfall decreased remarkably in North China. Nevertheless, the amount of water demanded by agriculture and industry and the population at large has increased. These two trends have made the deficiency of water resources in North China become a serious problem, not only for China but also potentially for the world grain market due to the large population in North China. Therefore, it is necessary to understand the background and reasons for the low-frequency variability of North China rainfall.

North China is located in the central part of eastern China and at the north edge of the East Asian summer monsoon (EASM) region. Generally speaking, the rain belt moves poleward in eastern China during summer, which is the rainy season in eastern China. It appears at the southeastern coastal zones of China in May, and at the Yangtze River Basin, which is approximately along 30°N in the scope of eastern China, in June and July. In the middle of July, usually, the rain belt shifts poleward to North China and stays at there for about three weeks before returning southward. North China is the most northward region in China where the clear influences of the EASM can reach.

It is well known that the EASM is a major source of rainfall in eastern China (Tao and Chen, 1987). The summer rainfall shows a considerable decrease in North China, corresponding to rapid weakness of the EASM there. The EASM, which is characterized by south winds at lower levels in eastern China, transports a large amount of water vapor from the Tropics into eastern China.

The understanding of the mechanisms for the variability of North China rainfall is much poorer relative to that of the Yangtze River basin in China. The climate in the Yangtze River basin, which is located south of North China, is influenced more dominantly by the EASM. The rainfall in North China, however, is influenced by the mid-latitudinal disturbances as well

*E-mail: ren@ustc.edu.cn

as the EASM, and thus it is a tough task to understand well the mechanism for the variability of North China rainfall.

The North China rainfall in the rainy season has a great variability on the interannual timescale, partly due to the variability of the EASM on the same timescale (Shi and Zhu, 1996). Zhao and Song (1999) presented that the atmospheric circulation over the Eurasian continent and the western Pacific subtropical high are associated with the interannual variability of North China rainfall. Wang and Li (1990) suggested that ENSO is associated with the precipitation fluctuation over the semiarid region in China, the main part of which is located west of North China with a small part overlapped.

Besides the interannual variability, interdecadal variability is also clearly detected in North China rainfall (Dai et al., 2004; Huang et al., 1999; Lu, 1999; Yan et al., 1990; Yatagai and Yasunari, 1994; Zhu and Wang, 2001). In fact, the interdecadal variability has been somewhat well documented, although their mechanisms basically remain unclear. There were two significant decreases in summer rainfall in North China, one around the year 1965 and another in the late 1970s (Yan et al., 1990; Huang et al., 1999; Chen, 1999). The reasons for the climatic jumps, especially for the decrease of North China rainfall in the late 1970s, however, are still not well known. Lu (2002, 2003) suggested that the physical mechanisms for the interannual and interdecadal variations of North China rainfall may be different and can be separately investigated. Furthermore, several studies showed that in summer the North China rainfall is related to the rainfall in India (Guo and Wang, 1988; Kripalani and Singh, 1993; Zhang et al., 1999; Kripalani and Kulkarni, 2001).

The Sahel lies on the southern flanks of the Sahara, and receives the bulk of its rainfall during July to September. The low annual precipitation in this area ranges approximately from 100 to 600 mm, and is one of the drought-vulnerable regions of the world, similar to North China to some extent. The Sahel experienced persistent drought from the late 1960s, with very brief recovery in some years. A great effort has been made to explain this persistent drought with global or regional SST variations (Folland et al., 1986; Shinoda and Kawamura, 1994; Rowell et al., 1995; Rowell, 2001; Camberlin et al., 2001; among many others). These studies showed that the SST variations are responsible for most of the variability of seasonal rainfall over tropical North Africa. In addition, the land-surface forcing may also contribute to decadal variability of the Sahelian rainfall (Charney, 1975; Xue and Shukla, 1993).

Yan et al. (1990, 1991) and Ji and Song (2001) investigated the Northern Hemispheric summer climatic jump and atmospheric circulation changes around 1965, and found that the changes in climate (rainfall and temperature) and circulation exhibit a southwest-to-northeast zonal structure in geographical distribution. However, they did not focus on the linkage in the low-frequency rainfall variability between North China and the Sahel. In particular, they did not mention the rainfall decrease in the late 1970s at all. The purpose of this study is to investigate the linkage in the interdecadal rainfall variability between North China and the Sahel and the associated circulation change before and after the late 1970s, when the accurate observational data are available.

In section 2, the data used in this study are described. In section 3, the variability of North China rainfall, particularly on the interdecadal timescale, is examined. The interdecadal variability of North China rainfall is compared with that of Sahelian rainfall in section 4. In section 5, the associated atmospheric circulation changes are analyzed. Conclusions and discussion are presented in the final section.

2. Data

The monthly total precipitation data at 160 stations in China from 1951 to 2001, compiled by the China Meteorological Administration, are used in this study. Seventeen of these stations located in the region (34°–41°N, 111°–122°E) are used to calculate the North China rainfall, i.e., the rainfall in North China means the precipitation averaged over these seventeen stations. The summer rainfall variability exhibits a consistency in the selected region (Weng et al., 1999).

To investigate the rainfall variation in a long time period, we also use a monthly precipitation dataset for global land areas from 1900 to 1998, gridded at 2.5° latitude by 3.75° longitude resolution, constructed by Dr. Hulme at the Climatic Research Unit, University of East Anglia, UK (Hulme, 1992; Hulme et al., 1998). In addition, we also use a seasonal precipitation dataset of 35 stations in China from 1880 to 2000, constructed by the Department of Atmospheric Science, Peking University, China (Ye et al., 1998; Wang et al., 2000). This dataset is for seasonal mean, and the summer season is June, July, and August. The data are based on both instrument observations and historical documentary evidence before 1951, and based only on instrument observations after 1951. During the period 1900-1950, the historical documentary evidence occupies 31.0% of the construction.

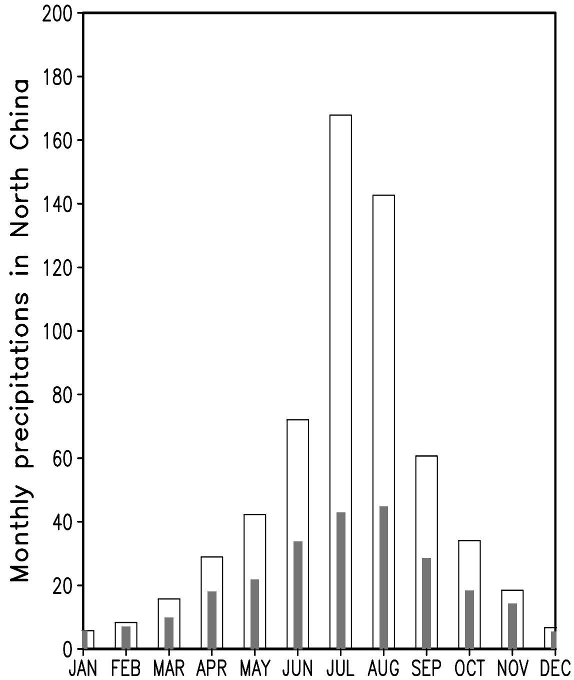

Fig. 1. Monthly total precipitation (white) and its year-to-year standard deviation (grey) in each month in North China, averaged over 17 observation stations in the region (34°–41°N, 111°–122°E). Units: mm.

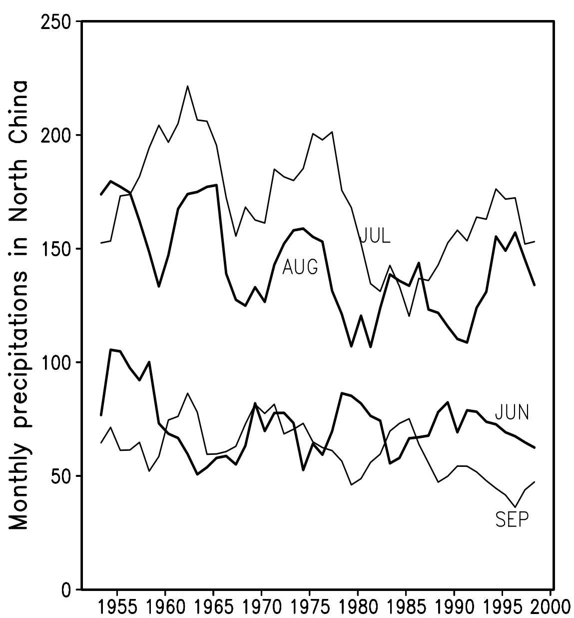

Fig. 2. Five-year running mean of monthly total precipitation in North China. Lines for June and August are thick, and lines for July and September are thin. Units: mm.

The National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data are used. The reanalysis data were expected to be devoid of any artificial climate jumps due to the use of different data assimilations, as the analysis system and the model remained unchanged throughout the analysis period (Kalnay et al., 1996). However, recently, it was indicated that the NCEP/NCAR reanalysis data have a problem in encoding surface and mean sea level pressure into the assimilation system for the period 1948–1967 (Yang et al., 2002). The summer rainfall in North China is closely related to lower-level circulation. Therefore, in this study, only the 33-year (1968 to 2000) reanalysis data are used.

3. Variations of rainfall in North China

Figure 1 shows the monthly total precipitation and year-to-year standard deviations of each month in North China. The rainfall is largely concentrated in July and August. This fact suggests the existence of a rainy season in North China, although the precipitation is not very large. The rainfall in North China exhibits a feature different from the mei-yu, which is the rainy season in the Yangtze River Basin in eastern China and it generally starts in June and ends in July. Unlike the mei-yu, the rainy season in North China starts in July and ends in August. The standard deviation is also largest in July and August.

Despite the fact that the summer rainfall in North China decreases abruptly around 1965 (Yan et al., 1990) and at the end of the 1970s (e.g., Huang et al., 1999), the decrease transitions do not happen in the rainfall for each month. The decrease transitions are mainly concentrated in the July and August rainfall, showing no appreciable decrease in the monthly rainfall of June and September (Fig. 2). Both July and August precipitation values decrease 60–80 mm at each major transition, and increase 30–50 mm afterwards. The August rainfall exhibits low-frequency variations similar to the July rainfall, except for two short periods: the middle 1980s and late 1950s.

Due to the large amounts and standard deviation and significant low-frequency oscillation of the July and August (JA) rainfall, in this study we concentrate on JA rainfall rather than summer (June–August) rainfall. Figure 3 shows the JA precipitation variations in North China. To separate the low-frequency variation from the interannual component, we used a 5-yr running mean. An 11-yr running mean was also performed and showed a considerably similar result. On the low-frequency timescale, the JA rainfall decreases abruptly around 1965 and repeats a decrease with a similar range at the end of the 1970s after a slight increase in the 1970s. In the middle 1990s, the rainfall increases after the long dry period of the whole

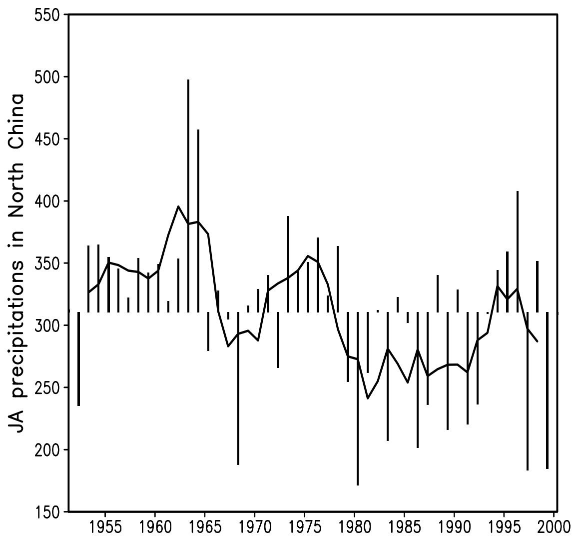

Fig. 3. The precipitation variations in North China during the rainy season (July and August, JA) from 1951 to 2001. The bars are for JA precipitation in each year, and the line is for the five-year running mean. Each bar rises or falls from the 1951–2001 climatology. Units: mm.

1980s. Due to the lack of reliable circulation data prior to 1968, in this study, we investigate the circulation difference before and after the end of the 1970s and the possible mechanism responsible for this difference.

4. Comparison with the Sahelian rainfall

Yan et al. (1990, 1991) found that around 1965, the changes in climate (rainfall and temperature) and circulation exhibit a southwest-to-northeast zonal structure in geographical distribution, and linked the rainfall decrease in North China with that in the Sahel. In this section, we compare the low-frequency rainfall variability in North China and that in the Sahel, using a longer period of rainfall data.

Figure 4 illustrates the time series of the JA rainfall variations in the Sahel and in North China, respectively. The area defined as the Sahel encompasses 11.25°–18.75°N, 16.875°W–35.625°E, being identical to that of Rowell (2001). The JA Sahelian rainfall (Fig. 4a) exhibits weak low-frequency variability prior to the 1950s, and becomes heavy during the 1950's. After the 1950s, the Sahel experiences a long-running drought, with short periods of steady states around the early 1970s and around 1990. The JA Sahelian rainfall shows a roughly similar feature of low-frequency variability with the July-August-September (JAS) Sahelian rainfall (e.g., Rowell et al., 1995), despite the exclusion of the month of September from the JA grouping.

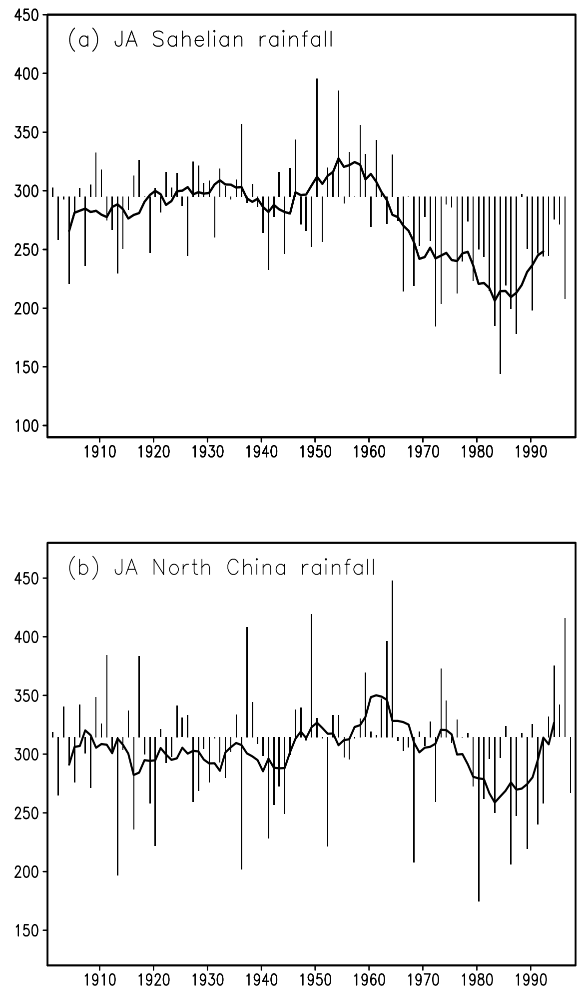

Fig. 4. The JA precipitation variations in the Sahel (a) and in North China (b) from 1900 to 1998, according to the monthly precipitation dataset for global land areas, constructed by Hulme. The bars are for JA precipitation in each year, and the line is for the five-year running mean. Each bar rises or falls from the 1941–70 climatology. Units: mm.

Since the Hulme rainfall data are box data, when we use the Hulme rainfall data it is impossible to represent North China by the identical region that we used to represent North China in the preceding section. The region for North China for the Hulme rainfall data encompasses 33.75°–41.25°N, 110.625°–121.875°E, and is a little larger than the previously used one. The North China rainfall (Fig. 4b) also exhibits weak low-frequency variability prior to the 1950s. It becomes heavy around the 1960s. The North China rainfall decreases around 1965 and around the late 1970s with a slight increase in the early 1970s. Similar to the Sahelian rainfall, the North China rainfall also increases around 1990. The North China rainfall shows a generally similar low-frequency variability with the Sahelian rainfall, despite the lower values in the middle 1950s.

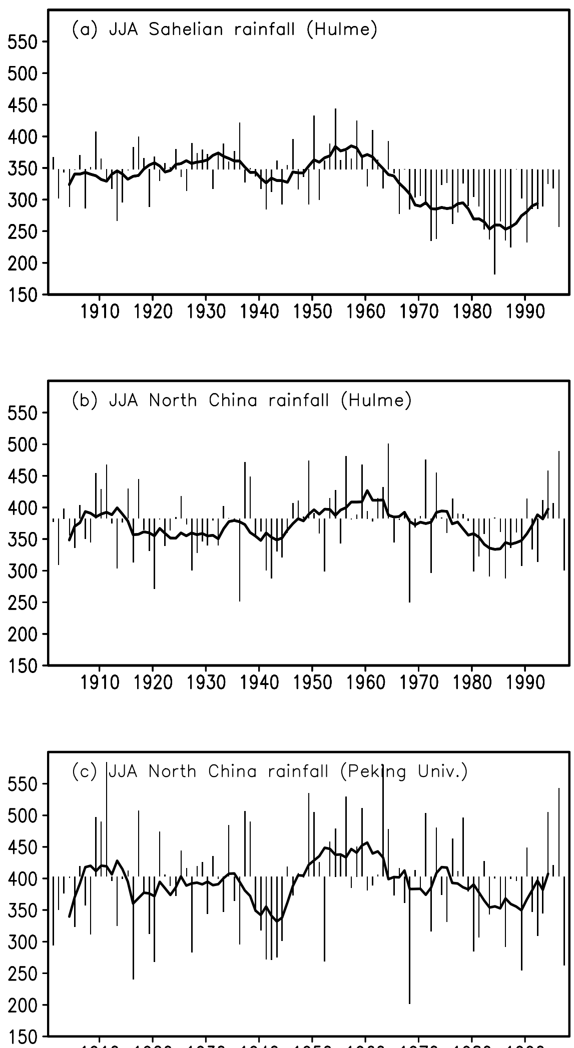

Fig. 5. The JJA precipitation variations in the Sahel (a) and in North China (b and c) from 1900 to 1998. (a) and (b) are obtained according to the monthly precipitation dataset for global land areas, constructed by Hulme (c) is according to the seasonal precipitation dataset at 35 stations in China, constructed by Peking University. The bars are for JJA precipitation in each year, and the line is for the five-year running mean. Each bar rises or falls from the 1941–70 climatology. Units: mm.

Figure 3, which is obtained by gauge observation in China, shows that the rainfall is heavy in the 1950s in North China, though it is slightly lower than in the early 1960s. This is not consistent with the result shown by Fig. 4, which is obtained by the Hulme rainfall data. This inconsistency may be due to several reasons. Among these reasons, the following two might be important. First, the difference in domain for North China causes different time series. Particularly, a box (2.5° latitude by 3.75° longitude) for the Hulme rainfall dataset is not adequately small, compared with the region of North China. There are 9 boxes in the region of North China, and one more/less box might cause a significant difference in the time series of North China rainfall. Second, the methods for weighted average are different. For the gauge observation data in China, we used equal weights to calculate the rainfall average in North China. On the other hand, the Thiessen weighted values were used to compute the grid-box means in the Hulme rainfall dataset. The different weighting methods, however, may not produce a significant difference in rainfall variability, since the 17 stations that are used to represent North China are roughly uniformly spaced.

The rainfall variability was examined again using a different dataset. The Department of Atmospheric Science, Peking University, China, constructed a long-time seasonal precipitation dataset. The dataset includes the precipitation data at 35 stations in China from 1880 to 2000. Among these 35 stations, six stations located in North China are Taiyuan (37.9°N, 112.5°E), Zhengzhou (34.3°N, 113.6°E), Beijing (39.5°N, 116.3°E), Jinan (36.7°N, 117.0°E), Xuzhou (34.3°N, 117.6°E), and Yantai (37.5°N, 121.4°E). These six stations are roughly uniformly spaced and are all included among the 17 stations that have been used to represent North China in the preceding and present sections.

Only the summer (June, July, and August; JJA) precipitation data are available from the dataset by the Department of Atmospheric Science, Peking University, China. Therefore, we have to compare the JJA, rather than JA, rainfall variations in North China and in the Sahel. Figure 5 shows the JJA rainfall variations in the Sahel and in North China. The North China rainfall variations, both obtained by the Hulme dataset and by averaging over the above-mentioned six stations, are given in Fig. 5. A comparison between Fig. 5a and Fig. 4a, and that between Fig. 5b and Fig. 4b, all indicate that the June rainfall does not influence much the interdecadal variability of summer rainfall in the Sahel and in North China. This is also shown by a comparison between Fig. 5c and Fig. 3 for the period of 1951–1998. Thus, the low-frequency variability of JJA rainfall can be regarded as that of JA rainfall.

The low-frequency variation of North China rainfall obtained by the long-time gauge dataset exhibits less rainfall in the early 1940s and more rainfall in the 1950s (Fig. 5c) compared with that obtained by the Hulme dataset (Fig. 5b). Thus, the North China rainfall obtained by the long-time gauge dataset shows a more similar interdecadal variability to the Sahelian

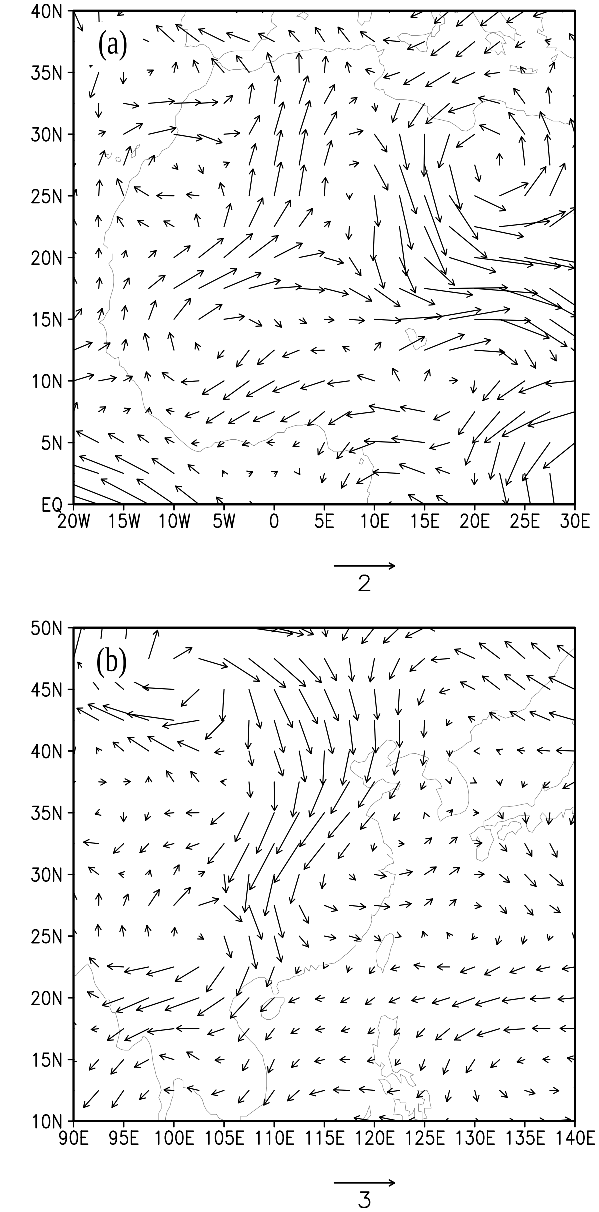

Fig. 6. July–August mean 850-hPa horizontal wind differences between the dry period (from 1979 to 2000) and the normal period (from 1968 to 1978). (a) over North Africa; (b) over North China. The vector scales are shown below each panel.

rainfall.

5. Associated atmospheric circulation

In the preceding two sections, it has been shown that the JA rainfall both in North China and in the Sahel exhibits a similar low-frequency variability, with major decreasing transitions around 1965 and at the end of the 1970s, respectively. In this section, we investigate the atmospheric circulations associated with the second decreasing transition of rainfall, around which the reliable reanalysis data are available.

Figure 6 shows the JA mean 850 hPa horizontal wind differences before and after the end of the 1970s, i.e., the 1979–2000 mean minus the 1968–1978 mean. Although the North China rainfall shows an increasing tendency in the middle 1990s, it decreases again in the late 1990s. On the other hand, we found that the circulations in the middle 1990s are very similar to those in the 1980s, at least in the scope of this study (not shown here, but partly shown in Figs. 7 and 9). Therefore, in this study we consider the rainfall decrease in the middle 1990s as part of the interannual variation and include the middle 1990s in the dry period.

Around the late 1970s, the wind changes show an anticyclonic anomaly over tropical North Africa. Associated with this anticyclonic anomaly, there is a westerly anomaly along 15°–20°N, and an easterly anomaly around 5°N. This feature of lower-level circulation anomaly is very similar to that related to the Sahelian drought (Shinoda and Kawamura, 1994; Fontaine et al., 1995; Camberlin et al., 2001).

At the same time, there are clear northerly changes in eastern China with a maximum center over North China. As the most northward region in China where the clear influences of the EASM can reach, North China obtains water vapour transported from the Tropics by lower-level southerlies. Therefore, the nor-

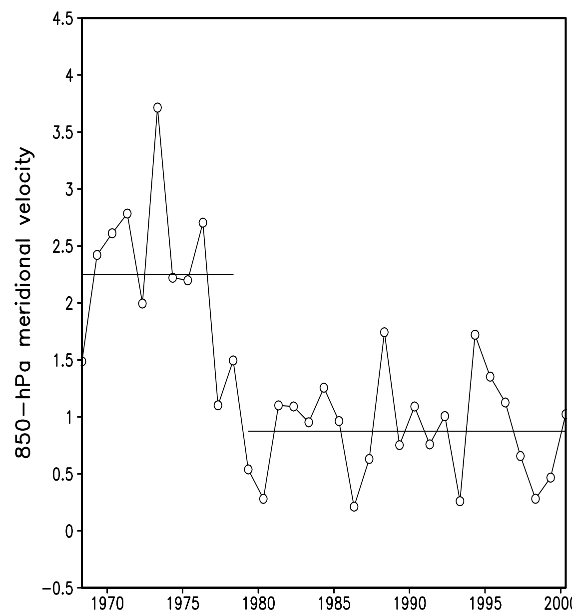

Fig. 7. Variations of the 850-hPa meridional velocity averaged over the region (110°–120°E, 30°–50°N). Units: m s^{-1}. The two bars indicate the averaged values during the wet and dry periods, respectively.

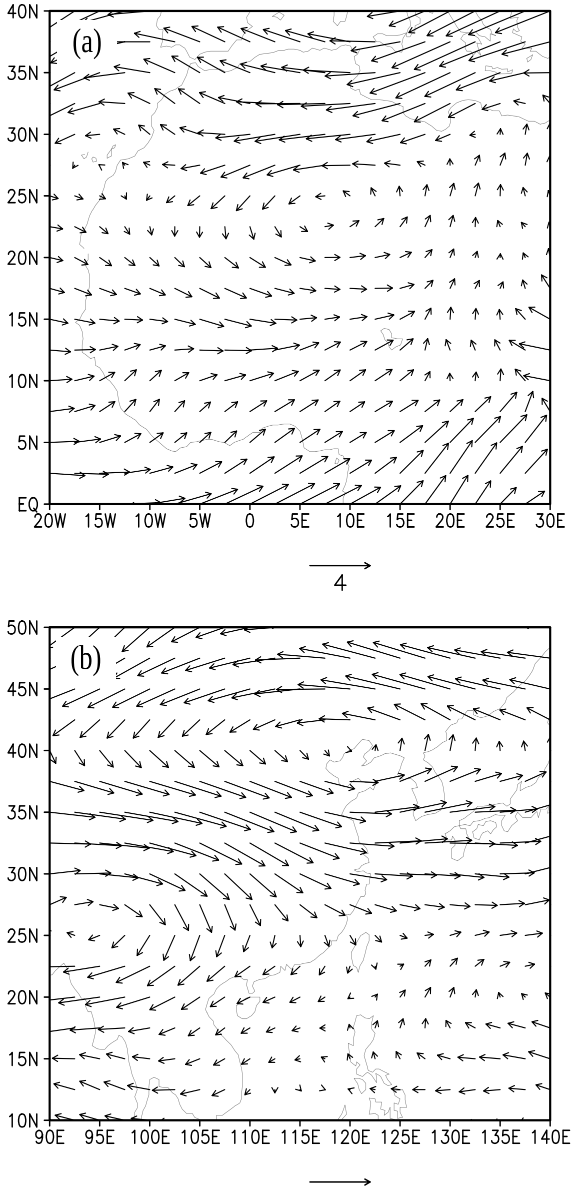

Fig. 8. Same as Fig. 6, but for 200 hPa.

therly changes diminish the climatological southerlies in eastern China, and result in less flux of water vapor poleward into North China, where the precipitable water is generally much less than in the Yangtze River basin and is a crucial condition for rainfall. The 850 hPa southerly over North China exhibits remarkable decreases in the late 1970s (Fig. 7). The southerly averaged over North China is more than 2 m s^{-1} before the late 1970s, whereas it decreases considerably afterwards, to approximately 0.8 m s^{-1}.

At the end of the 1970s, the upper-level circulation also experienced significant changes over both North

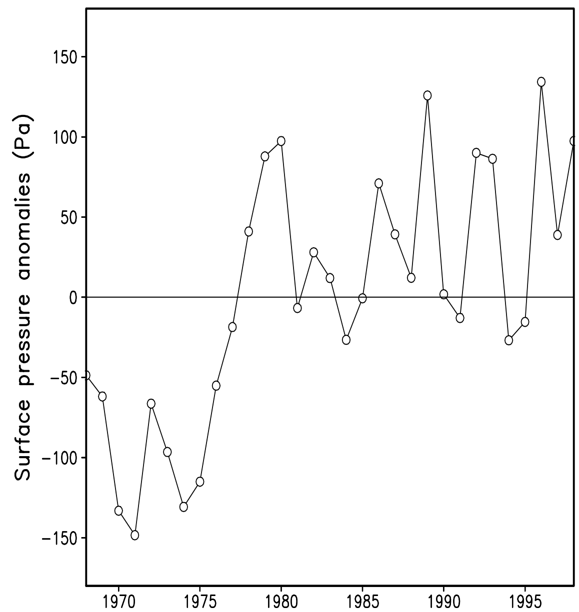

Fig. 9. Surface pressure anomalies from 1968 to 1998 averaged over (60°–120°E, 30°–60°N). Units: Pa.

Africa and North China. Figure 8a shows that there is a cyclonic circulation change over North Africa. This circulation change indicates that the 200 hPa tropical easterly jet (TEJ) located at about 7°N becomes weakened after the late 1970s, and is related to the Sahelian rainfall change, since a weaker TEJ is associated with the Sahelian drought (Fontaine et al., 1995; Camberlin et al., 2001). Over North China, there is also a cyclonic circulation change in upper levels at the end of the 1970s (Fig. 8b). This circulation change indicates that the East Asian upper-level westerly jet (EAJ), which is located at 40°N in July and August, shifts southward after the end of the 1970s. A southward-shifted EAJ is associated with a southward-shifted lower-level subtropical anticyclone over the western North Pacific, and thus prevents the poleward shift of the EASM rainband into North China. Therefore, the cyclonic circulation change is also related to the drought from the end of the 1970s in North China.

The surface pressure also shows a significant change at the end of the 1970s (Fig. 9). The surface pressure increases remarkably over the eastern Eurasian continent in the late 1970s, and the positive anomalies basically persist throughout the 1980s and 1990s. There appears to be an anticyclonic anomaly over the eastern Eurasian continent, especially over China. Such an anticyclonic anomaly over China appears also in Fig. 6b. We have also examined the variations of geopotential heights at 850 hPa, and obtained a very similar pattern (not shown). Note that there are many mountains higher than the level of 850 hPa in the Eurasian continent between the latitudes of 30°N and 50°N. Thus the data at 850 hPa are somewhat artificial at the high regions. However, there are not many high and huge mountains in eastern China, and thus the data, including all of the surface pressure and wind flows and geopotential heights at 850 hPa, are adequately accurate in eastern China. Therefore, the above results are reliable for the discussion on the circulations in eastern China.

The weakening of the 850-hPa southerly flows over eastern China, associated with the anticyclonic anomaly over China, can be used to explain the decreasing transition in the North China rainfall in the late 1970s. However, the reason for the existence of the anticyclonic anomaly is still unknown. Wang (2001) also found the transition in the late 1970s and showed that the Asian and African summer monsoon circulation becomes weaker after this transition.

6. Conclusions and discussion

In this study, the interdecadal variations of rainfall in North China are examined and compared with those in the Sahel by using the Hulme dataset, a gauge observation dataset, and a gauge observation and historical document merged dataset in China. In North China, the rainfall in July and August is much greater than in other months, and exhibits a significant interdecadal oscillation. Therefore, in this study we concentrate on JA rainfall, rather than summer (June–August) rainfall.

A 5-year running mean depicts well the interdecadal variability and shows that the North China rainfall experiences two decrease transitions: one around 1965 and another at the end of the 1970s. Both the North China rainfall and Sahelian rainfall show a great interdecadal variability after 1950. For almost a century (1900–1998), the rainfall in North China exhibits a low-frequency variability similar to the Sahelian rainfall. In particular, these two remote regions both experienced a persistent drought in the last three decades.

The 33-year (1968 to 2000) NCEP/NCAR reanalysis data are utilized to analyze the associated changes in atmospheric circulation. The data period covers the decreasing transition of North China rainfall at the end of the 1970s. Corresponding to this transition, a northerly anomaly and an anticyclonic anomaly appear at lower levels over eastern China and over North Africa, respectively. At upper levels, corresponding to the transition, there are cyclonic anomalies over North China and North Africa, respectively. These circulation features at both upper and lower levels are related to the decrease in precipitation in North China and the Sahel.

The present study fails to give the reasons for the linkage in the interdecadal variability of rainfall in the Sahel and North China, due to the absence of long-period datasets, especially the circulation data. On the other hand, current numerical models have some ability to capture the interdecadal variability of the Sahelian rainfall, but no ability to reproduce the rainfall variability in North China.

The North China rainfall shows a more significant interannual variability than the Sahelian rainfall, suggesting the existence of other contributors to the variability of the North China rainfall in addition to the Sahelian rainfall. However, these contributors may play a minor role or counteract each other on the low-frequency timescales, and thus the North China rainfall shows a similar low-frequency variability with the Sahelian rainfall.

Acknowledgments. This study was supported by the project KZCX3-SW-218, Program for Knowledge Innovation Program, Chinese Academy of Sciences, and by the project 2003D0014Z in Yunnan Province, and LASG, Institute of Atmospheric Sciences, Chinese Acadeny of Sciences. The historical monthly precipitation dataset (gu23wld0098.dat, version 1.0) for global land areas used in this study was constructed and supplied by Dr. Mike Hulme at the Climatic Research Unit, University of East Anglia, Norwich, UK. The comments of two anonymous reviewers were valuable in revising the manuscript.

REFERENCES

Camberlin, P., S. Janicot, and I. Poccard, 2001: Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. *International Journal of Climatology*, **21**, 973–1005.

Charney, J. G., 1975: Dynamics of deserts and drought in the Sahel. *Quart. J. Roy. Meteor. Soc.*, **101**, 193–202.

Chen Lieting, 1999: Regional features of interannual and interdecadal variations in summer precipitation anomalies over North China. *Plateau Meteorology*, **18**, 477–485. (in Chinese)

Dai Xingang, Wang Ping, and Chou Jifan, 2004: The multiscale characteristics of the rainy season rainfall and interdecadal decading of summer monsoon in North China. *Chinese Science Bulletin*, **49**, 2730–2734.

Folland, C. K., T. N. Palmer, and D. E. Parker, 1986: Sahel rainfall and worldwide sea temperatures, 1901–85. *Nature*, **320**, 602–607.

Fontaine, B., S. Janicot, and V. Moron, 1995: Rainfall anomaly patterns and wind field signals over West Africa in August (1958–89). *J. Climate*, **8**, 1503–1510.

Guo Qiyun, and Wang Jiqin, 1988: A comparative study on summer monsoon rainfall in China and India. *Journal of Tropical Meteorology*, **4**, 53–60. (in Chinese)

Huang Ronghui, Xu Yuhong, and Zhou Liantong, 1999: The interdecadal variation of summer precipitations in China and the drought trend in North China. *Plateau Meteorology*, **18**, 465–476. (in Chinese)

Hulme, M., 1992: A 1951-80 global land precipitation climatology for the evaluation of General Circulation Models. *Climate Dyn.*, **7**, 57–72.

Hulme, M., T. J. Osborn, and T. C. Johns, 1998: Precipitation sensitivity to global warming: Comparison of observations with HadCM2 simulations. *Geophys. Res. Lett.*, **25**, 3379–3382.

Ji Jinjun, and Song Yan, 2001: The interdecadal abrupt change of the African-Asian summer monsoon in the 1960s. *Chinese J. Atmos. Sci.*, **25**, 200–208. (in Chinese)

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc.*, **77**, 437–471.

Kripalani, R. H., and S. V. Singh, 1993: Large-scale aspects of India-China summer monsoon rainfall. *Adv. Atmos. Sci.*, **10**, 71–84.

Kripalani, R. H., and A. Kulkarni, 2001: Monsoon rainfall variations and teleconnections over South and East Asia. *International Journal of Climatology*, **21**, 603–616.

Lu Riyu, 1999: Interdecadal variations of precipitations in various months of summer in North China. *Plateau Metoerology*, **18**, 509–519. (in Chinese)

Lu Riyu, 2002: Separation of interannual and interdecadal variations of rainfall in North China. *Chinese J. Atmos. Sci.*, **26**, 377–392.

Lu Riyu, 2003: Linear relationship between the interdecadal and interannual variabilities of North China rainfall in rainy season. *Chinese Science Bulletin*, **48**, 1040–1044.

Rowell, D. P., 2001: Teleconnections between the tropical Pacific and the Sahel. *Quart. J. Roy. Meteor. Soc.*, **127**, 1683–1706.

Rowell, D. P., C. K. Folland, K. Maskell, and M. N. Ward, 1995: Variability of summer rainfall over tropical North Africa (1906-92): Observations and modeling. *Quart. J. Roy. Meteor. Soc.*, **121**, 669–704.

Shi, N., and Q. Zhu, 1996: An abrupt change in the intensity of the East Asian summer monsoon index and its relationship with temperature and precipitation over East China. *International Journal of Climatology*, **16**, 757–764.

Shinoda, M., and R. Kawamura, 1994: Tropical rainbelt, circulation, and sea surface temperatures associated with the Sahelian rainfall trend. *J. Meteor. Soc. Japan*, **72**, 341–357.

Tao Shiyan, and Chen Longxun, 1987: A review of recent research on the East Asian summer monsoon in China. *Monsoon Meteorology*, C. P. Chang, and T. N. Krishnamuti, Eds., Oxford University Press, 60–92.

Wang Huijun, 2001: The weakening of the Asian monsoon circulation after the end of 1970's. *Adv. Atmos. Sci.*, **17**, 376–385.

Wang Shaowu, Gong Daoyi, Ye Jinlin, and Chen Zhenhua, 2000: Seasonal precipitation series of eastern China since 1880 and the variability. *Acta Geographica Sinica*, **55**, 281–293. (in Chinese)

Wang, W., and K. Li, 1990: Precipitation fluctuation over semiarid region in Northern China and the relationship with El Niño/Southern Oscillation. *J. Climate*, **3**, 769–783.

Weng, H., K.-M. Lau, and Y. Xue, 1999: Multi-scale summer rainfall variability over China and its long-term link to global sea surface temperature variability. *J. Meteor. Soc. Japan*, **77**, 845–857.

Xue, Y., and J. Shukla, 1993: The influence of land surface properties on Sahel climate. Part I: Desertification. *J. Climate*, **5**, 2232–2245.

Yan Zhongwei, Ji Jinjun, and Ye Duzheng, 1990: Northern Hemispheric summer climatic jump in the 1960's. I: Rainfall and temperature. *Science in China* (*Series B*), **33**, 1092–1101.

Yan Zhongwei, Ji Jinjun, and Ye Duzheng, 1991: Northern Hemispheric summer climatic jump in the 1960's. II: Sea level pressure and 500 hPa height. *Science in China* (*Series B*), **34**, 469–478.

Yang, S., K.-M. Lau, and K.-M. Kim, 2002: Variations of the East Asian jet stream and Asian-Pacific-American winter climate anomalies. *J. Climate*, **15**, 306–325.

Yatagai, A., and Yasunari T. 1994: Trends and decadal-scale fluctuations of surface air temperature and precipitation over China and Mongolia during the recent 40 year period (1951–1990). *J. Meteor. Soc. Japan*, **72**, 937–957.

Ye Jinlin, Chen Zhenhua, Gong Daoyi, and Wang Shaowu, 1998: Characteristics of seasonal precipitation anomalies in China for 1880-1996. *Quarterly Journal of Applied Meteorology*, **9**, 57–64. (in Chinese)

Zhang Renhe, A. Sumi, and M. Kimoto, 1999: A diagnostic study of the impact of El Niño on the precipitation in China. *Adv. Atmos. Sci.*, **16**, 229–241.

Zhao Shengrong, and Song Zhenshan, 1999: Floods and droughts in northern China and general circulation anomalies over middle and high latitude. *Plateau Meteorology*, **18**, 535–540. (in Chinese)

Zhu Jinhong, and Wang Shaowu, 2001: 80a-oscillation of summer rainfall over the east part of China and East-Asian summer monsoon. *Adv. Atmos. Sci.*, **17**, 1043–1051.