Decadal Variation of Summer Rainfall in the Yangtze–Huaihe River Valley and Its Relationship to Atmospheric Circulation Anomalies over East Asia and Western North Pacific

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ABSTRACT

Decadal variations of summer rainfall during 1951 through 1990 are analyzed by using summer rainfall data of 160 stations in China. Four major patterns of decadal variations are identified. The decadal variations of summer rainfall showed northward shift in the eastern China from South China through the Yangtze–Huaihe River to North China. Summer rainfall in the Yangtze–Huaihe River valley underwent two obvious decadal transitions during the 40 years: one from rainy period to drought period in the end of the 1950's, the other from drought period to rainy period in the late 1970's.

Correspondingly, the atmospheric circulation over East Asia through the western North Pacific showed two similar obvious transitions. The East Asian / Pacific (EAP) pattern switched from high index to low index in the end of the 1950's and from low index to high index in the late 1970's, respectively. Hence, summer rainfall in the Yangtze–Huaihe River valley is closely associated with the EAP pattern not only in the interannual variation but also in the decadal variation.

Key words: Summer rainfall, Decadal variation, EAP pattern

I. INTRODUCTION

In recent decade, there have been worldwide attention and researches (Folland et al., 1986; Farmer, 1986; Entekhabi and Nicholson, 1987; Nicholson, 1983) on the persistent drought in the Sahara region because of its severeness and its great influence on economy. Researches have also been made on the persistent drought in North China (Huang and Zhang, 1990; Huang et al., 1992; Chen and Wu, 1994; Zhang, 1993) which bears similar feature to that in the Sahara region (Huang and Zhang, 1990; Yan et al., 1990). The flood and drought in the Yangtze–Huaihe River valley exert great influence on agriculture, industry and economy in China and have also been investigated (Chen,1993; Huang, 1993). However, these investigations are mainly on the interannual variation of summer rainfall.

Recently, Huang et al. (1992) analyzed the variability of summer drought and flood in China during 1951–1990 and investigated the possible causes of the transition of summer rainfall in the Yangtze–Huaihe River valley from drought period to rainy period in the late 1970's. They tried to link the decadal variation of summer rainfall in China to the anomalous warming in the equatorial central and eastern Pacific Ocean and the decrease of the heat content in the western North Pacific warm pool in the 1980's. On the basis of climatic division of precipitation in the eastern China, Chen and Wu (1994) analyzed the long–term variations of drought and flood in various climatic regions during 1951–1990. Yatagai and Yasunari (1994) documented the trends and decadal–scale fluctuations of surface air temperature and precipitation over China and Mongolia during 1951–1990. Nitta and Hu (1997) addressed the summer climate variability in China and its association with the 500 hPa height and the tropical convection in interannual and decadal time scales.

In this paper, we intend to make further researches on the decadal variation of summer rainfall in the eastern China. We will focus on the spatial–temporal characteristics of summer rainfall changes. Investigations will be made on the possible association between the rainfall and the atmospheric circulation anomalies over East Asia and the western North Pacific specifically on the decadal time scales.

The summer rainfall data of 160 stations extend from 1951 through 1990. The monthly mean 500 hPa geopotential heights of the Northern Hemisphere are from 1946 through 1993 north of 20°N by 5° latitude and 5° longitude. The rainfall data are provided by National Meteorology Center of China. The 500 hPa geopotential height data are from National Meteorological Center of USA.

II. DECADAL VARIATION OF SUMMER RAINFALL IN THE EASTERN CHINA DURING 1951–1990

According to seasonal and interannual variations of precipitation in the rainy season, Chen and Wu (1994) divided the eastern China into 21 climatic regions (Fig. 1). They discussed the long–term trends of summer drought and flood in these regions during 1951–1990. Based on the examination of similarities and differences in the transitions of summer rainfall anomalies among different regions, they identified four major patterns of long–term variation of summer drought and flood in the eastern China. These four patterns are North China pattern (NC), Northeast China pattern (NE), the Yangtze–Huaihe River pattern (YH) and south of the Yangtze River pattern (SC). The locations of the four patterns are indicated by the heavy–dotted lines on Fig. 1. The North China pattern includes the Huanghe–Huaihe Plain (6), Hebei Plain (7), Great Bend of the Huanghe River (21), east Loess Plateau (17) and the lower reaches of the Huanghe River (8) regions. The Northeast China pattern includes Northeast China Plain (11), Da Hinggan Mountains (12) and Sanjiang–Changbai Mountains (13). The Yangtze–Huaihe River pattern includes the upper (15), middle (3) and lower reaches of the (4) Yangtze River, the Yangtze–Huaihe Plain (5) and Qingling–Daba Mountains (16). Nanling Mountains (2) and Guizhou Plateau (14) belong to south of the Yangtze River pattern. Those regions in the same pattern show similar long–term drought and flood transitions, while those in different patterns display different transition times in the transitions.

According to summer rainfall deviation percentage of climatic regions in the same pattern, we calculated summer rainfall deviation percentages for the four patterns. Fig. 2 gives the ten–year running means of weighted summer rainfall deviation percentage of the four patterns. The arrows on the figures show the reference times of climatic jump of summer rainfall and values above the arrows show the jump coefficients (Yamamoto et al., 1986) with respect to pre– and post–jump 5 years. The jump coefficients are calculated using the following formula:

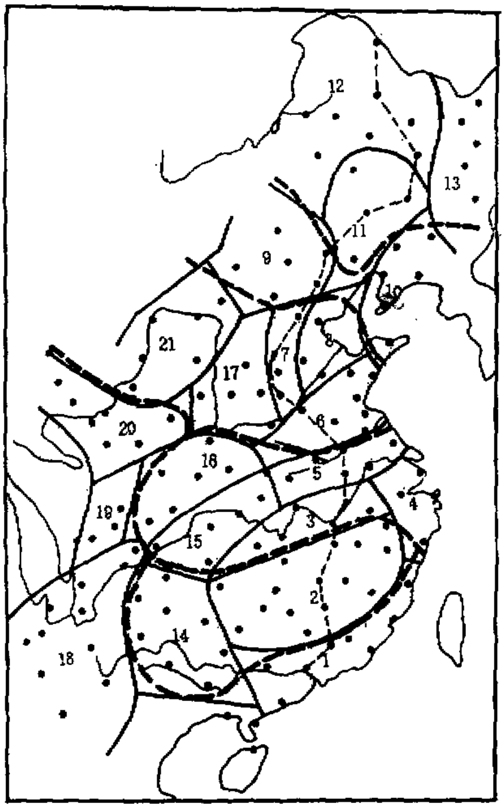

Fig. 1. Climatic regions derived from precipitation records in summer half year in the eastern China: 1) South China 2) Nanling Mountains 3) the middle reaches of the Yangtze River 4) the lower reaches of the Yangtze River 5) Yangtze–Huaihe Plain 6) Huanghe–Huaihe Plain 7) Hebei Plain 8) the lower reaches of the Huanghe River 9) North Hebei Mountains 10) East Liaoning–East Shandong Peninsulas 11) Northeast China Plain 12) Da Hinggan Mountains 13) Sanjiang–Changbai Mountains 14) Guizhou Plateau 15) the upper reaches of the Yangtze River 16) Qingling–Daba Mountains 17) Eastern Loess Plateau 18) Yunnan–Sichuan 19) Western Sichuan 20) Western Loess Plateau 21) Great Bend of the Huanghe River. Dotted points are the positions of 140 stations. For details, refer to Chen and Wu (1994). Dashed line is a north–south section used in Fig. 3. Heavy–dashed line indicates the locations of the four patterns.

$$J_y = \frac{|M_1 - M_2|}{\sigma_1 + \sigma_2} ,$$

where M_1 and M_2 are 5–year means before and after the jump, σ_1 and σ_2 are standard deviation during the pre– and post–jump 5 years. The reference time of climatic jump is determined when the jump coefficient reaches a local maximum value over 1.0. It indicates the approximate time when the most abrupt climate change takes place. Features of decadal variations of summer rainfall in the four patterns can be summarized as follows.

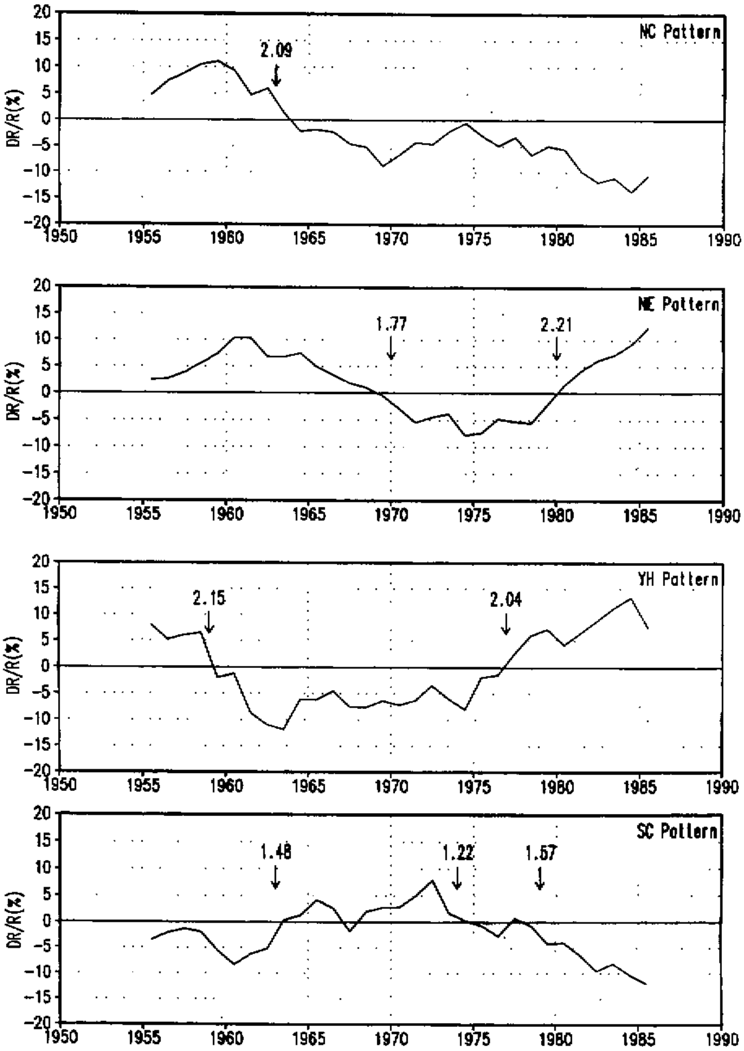

Fig. 2. Ten-year running means of summer rainfall deviation percentage of the four drought-flood patterns. Arrows show reference times of climatic jump of summer rainfall and values above the arrows are jump coefficients with respect to pre- and post-jump 5 years.

In the North China pattern, summer rainfall was in rainy period in the 1950's. An obvious transition from rainy period to drought period occurred in the mid-1960's. Afterwards, drought period has been persisting though drought was somewhat weakened in the mid-1970's. These results are consistent with earlier analyses (Huamg and Zhang, 1990; Huang et al., 1992).

In the Northeast China pattern, summer rainfall was in rainy period during the 1950's through the mid-1960's. There happened an obvious transition in the late 1960's from rainy period to drought period. In the 1970's, it was in drought period. Another obvious transition occurred in the end of the 1970's from drought to rainy period. In the 1980's, it was in rainy period. Therefore, during recent 40 years, there are two obvious transitions in summer rainfall of the Northeast China pattern. The transition from rainy to drought period was somewhat later than that of the North China pattern.

In the Yangtze–Huaihe River pattern, there have been two obvious transitions during the 40 years. In the 1950's, summer rainfall was in rainy period. The first transition occurred in the end of the 1950's from rainy to drought period. Summer rainfall was in the drought period during the 1960's through the mid–1970's. The second transition was in the late 1970's from drought to rainy period. In the 1980's, summer rainfall was obviously in rainy period.

In the south of the Yangtze River pattern, in the 1950's, summer rainfall was in drought period. It transited to rainy period in the early 1960's. The rainy period persisted until the mid–1970's and then switched back to drought period. In the 1980's, summer rainfall was in drought period.

So, the transition from rainy to drought period in the eastern China was earlier in the south and later in the north. It occurred in the end of the 1950's in the Yangtze–Huaihe River pattern, in the mid–1960's in the North China pattern, in the late 1960's in the Northeast China pattern. In fact, south of the Yangtze River pattern also underwent a transition from rainy to drought period in the early 1950's. The transition from drought to rainy period was in the early 1960's in the south of the Yangtze River pattern, in the late 1970's in the Yangtze–Huaihe River pattern, in the end of the 1970's in the Northeast China pattern, while drought period is maintained in the North China pattern.

In order to give a more detailed demonstration of spatial–temporal characteristics of decadal variation of summer rainfall in the eastern China, we analyzed the decadal variation in 21 climatic regions. The results show that the transition from rainy to drought period occurred in 1959–1961 in the regions of the Yangtze–Huaihe River pattern, in 1963–1964 in those regions of North China pattern and in 1967–1970 in those of Northeast China pattern. Summer rainfall switched from drought period to rainy period in 1957 in South China, in 1958 in Southwest China, in 1963–1964 in the regions of south of the Yangtze River pattern, in 1972, 1977–1978 and 1982 in the regions of the Yangtze–Huaihe River pattern, in 1979–1981 and 1985 in those of Northeast China pattern. Shown in Fig. 3 is a north–south section of summer rainfall deviation percentage subjected to 10–year running mean. From the progress of zero deviation isolines, the transition from rainy period to drought period began in the Yangtze River valley, shifted northward and reached North China in the mid–1960's. In Northeast China, similar transition happened earlier in the north part and later in the south part, though the transition was slightly later than that in North China. The transition from drought to rainy period began to the south of the Yangtze River. It progressed northward as well. It reached the Yangtze–Huaihe River in the 1970's and then showed little fluctuation in the 1980's. Northeast China also switched to rainy period, but drought period persisted in North China. In the 1970's, South China first entered into drought period and there is some indication that the drought region also showed northward progress. So, the decadal variation of summer rainfall seems to have two sources, one is from south and progresses northward to North China, the other begins in Northeast China and progresses southward. However, the progress is far from gradual nature. Both gradual and jump feature can be noticed.

According to the long–term variation of summer rainfall in the four patterns, in the 1950's, summer rainfall was mainly above–normal in the eastern China except for part of

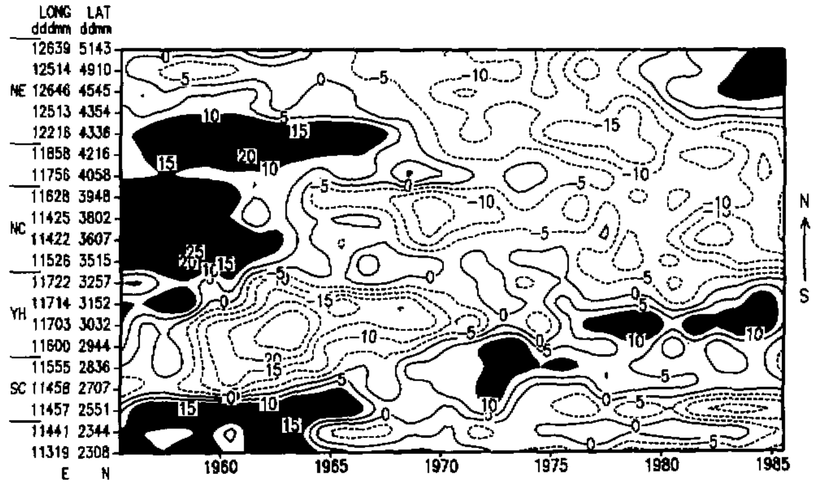

Fig. 3. North–south section of summer rainfall deviation percentage subjected to ten–year running means. Contour interval is 5%. Values over 10% are shaded. The location of the section is indicated in Fig. 1. The number columns on the left indicate the longitude and latitude of the stations. The patterns for the stations are also indicated.

South China. In the 1960's, the summer rainfall anomaly was below–normal in the Yangtze–Huaihe River valley. Summer rainfall in North China transited from above–normal to below–normal, while Northeast China was mainly in the above–normal period. So, the summer rainfall anomaly distribution in the eastern China was in above–normal, below–normal and above–normal pattern from south to north in the 1960's and the below–normal region gradually extended northward. In the late 1970's, to the south of the Yangtze River, the summer rainfall anomaly transited from above–normal to below–normal, while it transited from below–normal to above–normal in the Yangtze–Huaihe River valley, and it was below–normal in Northeast China. So, the summer rainfall anomaly distribution in the eastern China was mainly in below–normal, above–normal and below–normal pattern from south to north. In the 1980's, summer rainfall was below–normal to the south of the Yangtze River and in North China, while it was above–normal in the Yangtze–Huaihe River valley and in Northeast China. So, the summer rainfall anomaly distribution in the eastern China was in below–normal, above–normal, below–normal and above–normal pattern from south to north with two above–normal zones and two below–normal zones, respectively.

III. RELATIONSHIP OF DECADAL VARIATION OF SUMMER RAINFALL IN THE YANGTZE–HUAIHE RIVER VALLEY TO ATMOSPHERIC CIRCULATION ANOMALY OVER EAST ASIA AND THE WESTERN NORTH PACIFIC

Researches have shown that there exists close association between atmospheric circulation anomaly over East Asia and the western North Pacific and the interannual variation of summer rainfall in the Yangtze–Huaihe River valley (Huang, 1992; Wu and Chen, 1994). Fig. 4 shows the distribution of simultaneous correlation between the summer rainfall in the

Yangtze–Huaihe River valley (YH pattern) and the 500 hPa height of the Northern Hemisphere. Alternatively positive, negative and positive correlations along East Asian coast are very obvious, indicative of East Asian / Pacific (EAP) pattern of correlation distribution. When 500 hPa height is higher over the subtropical western North Pacific and South China Sea, lower over middle latitudes of East Asia and higher west of the Okhotsk Sea, i.e., when the atmospheric circulation anomaly of EAP pattern develops, summer rainfall is above–normal in the Yangtze–Huaihe River valley, and vice versa.

On the other hand, it has been shown that there are two obvious decadal transitions of summer rainfall in the Yangtze–Huaihe River valley, one is in the end of the 1950's from rainy period to drought period, the other is in the late 1970's from drought period to rainy period. A problem is whether there are corresponding decadal transitions in atmospheric circulation, i.e., if there is any relationship in the decadal variation between the summer rainfall in the Yangtze–Huaihe River valley and atmospheric circulation over East Asia and the western North Pacific. To address this problem, we calculate the EAP pattern index. The index is defined as follows:

$$\text{EAP pattern index} = Z^*_{500}(20N,120E) - Z^*_{500}(40N,135E) + Z^*_{500}(55N,145-150E) ,$$

where Z^*_{500} is the standardized 500 hPa height anomaly. Fig. 5 shows the EAP pattern index subjected to 10–year running means. By comparing Fig. 5 with Fig. 2, it is evident that the decadal variation of the EAP pattern index has a very good correspondence to that of summer rainfall in the Yangtze–Huaihe River valley. During the 40 years, the EAP pattern also shows two obvious transitions which correspond to those of summer rainfall. In the end of the 1950's, the EAP pattern transited from high index to low index period, while in the late 1970's, it transited from low index back to high index period.

For further illustration of the good relation of the decadal transition between the rainfall and the atmospheric circulation, singular value decomposition (SVD) is employed to the summer rainfall and the 500 hPa geopotential height subjected to 9–year running mean. SVD is an effective statistical tool to identify coupled patterns between two different fields (Bretherton et al., 1992; Wallace et al., 1992). It is a method in some sense similar to EOF method but using the cross–variance matrix between the two different fields instead of the auto–variance matrix of only one field. Two sets of singular vectors (corresponding to eigen vectors in EOF) are generated with each one for one field. Similarly, two sets of expansion coefficients (or temporal amplitudes) are obtained by projecting the singular vectors onto the

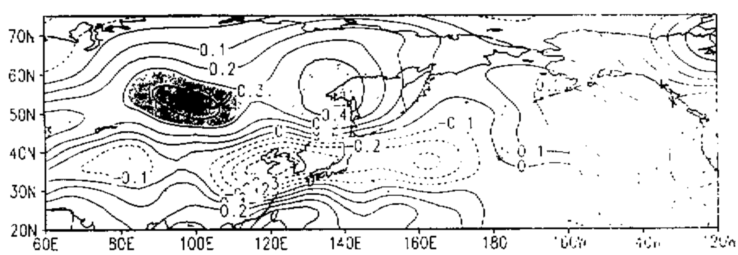

Fig. 4. Simultaneous correlation between summer rainfall in the Yangtze–Huaihe River valley (YH pattern) and 500 hPa geopotential height during 1951 through 1990. Correlation contour interval is 0.10. Shaded regions are over 95% significance level.

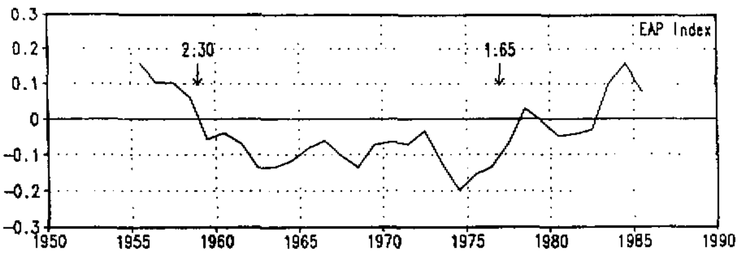

Fig. 5. EAP pattern index subjected to ten–year running means. Arrows show reference time of climate jump, the values above arrows are jump coefficients with respect to pre– and post–jump 5 years. Refer to the text for the definition of the EAP pattern index.

corresponding fields respectively. Two types of correlation fields can be obtained: homogeneous correlation and heterogeneous correlation. The former represents the correlation distribution between the expansion coefficient of one field with the same field. The latter reflects the correlation distribution between the expansion coefficient of one field with the other field. There are several measures of the strength of the relationship between the spatial pattern of the two fields. Squared covariance fraction (SCF) is the percentage of squared covariance explained by a pair of patterns (for each SVD mode). It indicates the relative importance of that SVD mode in the relationship between the two fields. Correlation coefficient measures how strongly the pair of patterns is related to each other.

The first SVD mode has an SCF of about 61% and correlation of −0.93. It reveals consistent relation between the summer rainfall and the 500 hPa geopotential height (Fig. 6). The heterogeneous correlation pattern of rainfall displays above–normal deviation along the Yangtze and Huaihe River, below–normal deviation to the north and south. The 500 hPa height pattern is very like the negative phase of EAP pattern along the East Asian coast. Their temporal amplitudes are remarkably out–of–phase. More importantly, they capture the two decadal phase transitions and clearly correspond well to each other.

In order to further demonstrate above association in the decadal variation, differences between the 5–year mean 500 hPa heights before and after the two transitions are calculated and examined with t–test. From Fig. 7, it can be seen that the difference of 500 hPa height corresponding to the first transition shows distribution of negative, positive and negative pattern along East Asian coast with negative difference over the subtropical western North Pacific, positive difference over middle latitudes of East Asia and negative difference over Kamchatka Peninsula. So, the difference distribution is in negative phase of the EAP pattern and it is basically opposite to the 5–year mean 500 hPa height deviation prior to the transition and similar to that after the transition. This demonstrates that corresponding to the transition of the summer rainfall in the Yangtze–Huaihe River valley in the end of the 1950's, the 500 hPa height deviation transited from positive to negative over the subtropical western North Pacific, from negative to positive over middle latitudes of East Asia and from positive to negative over Kamchatka Peninsula. Consequently, the EAP pattern transited from high index to low index. The differences of the 500 hPa height in the above regions all reach 95% significance level according to t–test.

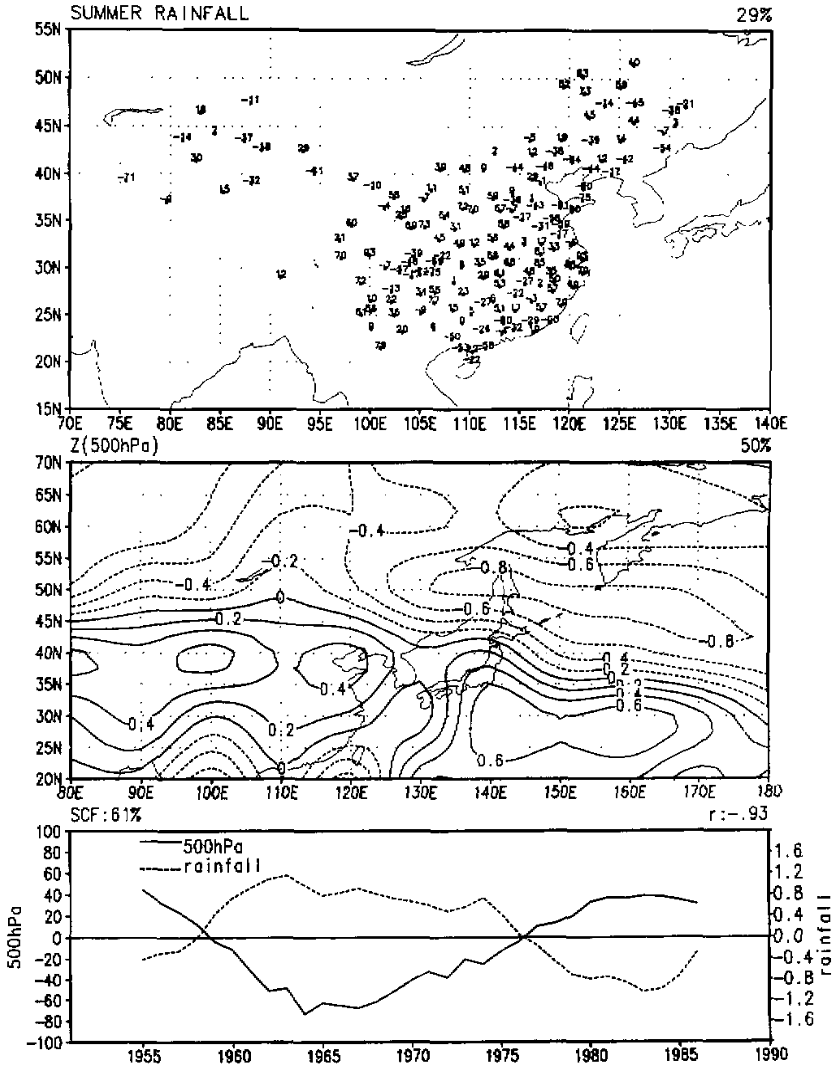

Fig. 6. Heterogeneous correlation patterns for the first SVD mode of observed 500 hPa height (middle panel) and rainfall (upper panel) in summer after 9–year running mean. The corresponding temporal amplitudes are shown in the lower panel with the solid line for 500 hPa (scaled on the left) and the dashed line for rainfall (scaled on the right). SCF is squared covariance fraction accounted for by the first SVD mode. r is the correlation coefficient of the temporal amplitudes. The values on the top–right of pattern fields are fractional variances accounted for by respective pattern.

Corresponding to the transition of the summer rainfall in the late 1970's, the difference distribution is obviously in the EAP pattern with positive difference over the subtropical

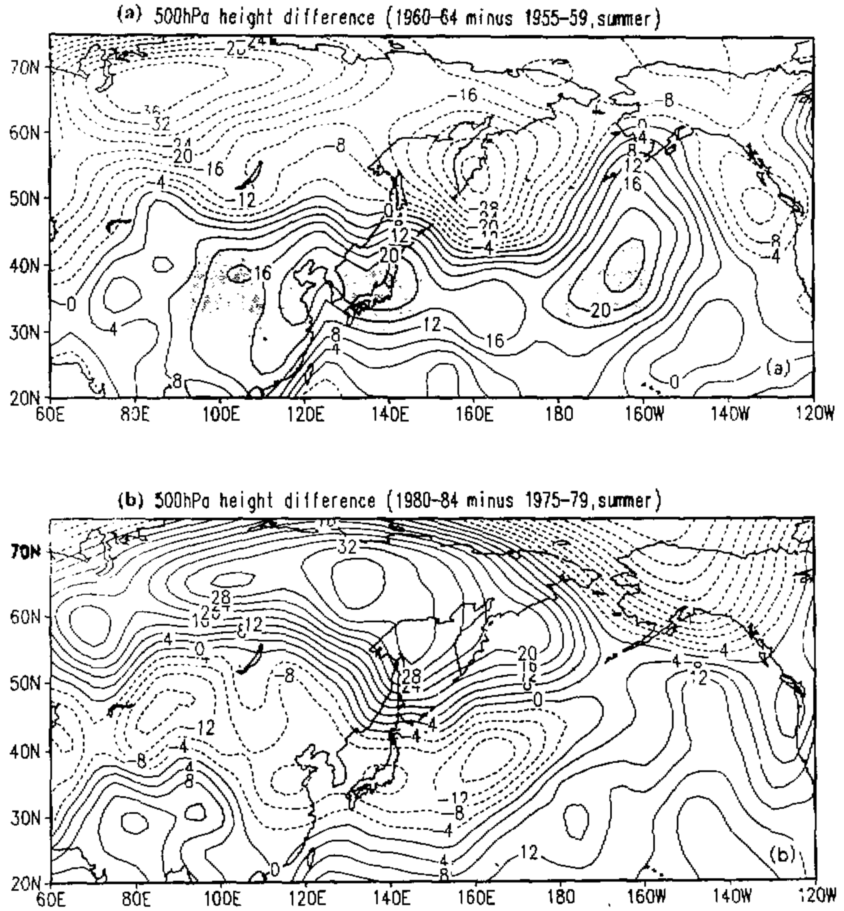

Fig. 7. Difference of 5–year mean 500 hPa height (a) 1960–64 minus 1955–59 and (b) 1980–84 minus 1975–79. Shading indicates regions over 95% significance level according to t–test.

western North Pacific, negative difference over middle latitudes of East Asia and positive difference over the northwest of the Okhotsk Sea. Such a difference distribution is basically opposite to the 5–year mean 500 hPa height deviation prior to the transition and similar to that after the transition. Hence, the 500 hPa height deviation transited from negative to positive over the subtropical western North Pacific, from positive to negative over middle latitudes of East Asia and from negative to positive over the Okhotsk through East Siberia. It indicates that the EAP pattern transited from low index to high index. According to t–test, though the difference over middle latitudes is somewhat weak, the differences in the other two regions are over 95% significance level.

According to above analyses, it follows that the summer rainfall in the Yangtze–Huaihe River valley is closely associated with the atmospheric circulation anomaly of EAP pattern not only in the interannual scale but also in the decadal scale. In the end of the 1950's, the EAP pattern transited from high index period to low index period in correspondence to the transition of summer rainfall in the Yangtze–Huaihe River valley from rainy period to drought period. In the late 1970's, the EAP pattern transited from low index period to high index period corresponding to the transition of the summer rainfall in the Yangtze–Huaihe River valley from drought period to rainy period.

IV. SUMMARY AND DISCUSSIONS

The spatial–temporal characteristics of the decadal variation of summer rainfall in the eastern China during recent 40 years are analyzed. Investigations are made on the association of the summer rainfall in the Yangtze–Huaihe valley with the atmospheric circulation over East Asia through the western North Pacific in the decadal scale. The main results are as follows:

1. The decadal variation of the summer rainfall in the eastern China during recent 40 years can be summarized as four major patterns: North China Pattern, Northeast China pattern, Yangtze–Huaihe River pattern and south of Yangtze River pattern.

2. The Summer rainfall of North China pattern underwent a transition from rainy period to drought period in mid–1960's. Northeast China pattern switched from rainy period to drought period in the late 1960's and back to rainy period in the end of the 1970's. Yangtze–Huaihe River pattern transited from rainy period to drought period in the end of the 1950's and switched back to rainy period in the late 1970's. South of Yangtze River pattern entered rainy period in the early 1960's and back into drought period in the mid–1970's.

3. The decadal variation of the summer rainfall in the eastern China shows the feature of northward progress from South China to North China.

4. The summer rainfall in the Yangtze–Huaihe River valley is closely associated with the atmospheric circulation over East Asia through the western North Pacific not only in the interannual variation but also in the decadal variation. The high and low index periods of the EAP pattern correspond to the rainy and drought periods of summer rainfall in the Yangtze–Huaihe River valley respectively and the transitions of the EAP pattern are well consistent with those of summer rainfall.

In recent decade, there has been world–wide interest on the decadal climate change in the late 1970's in both the tropical and North Pacific (Nitta and Yamada, 1989; Trenberth, 1990; Trenberth and Hurrell, 1994). Researches begin to address the reasons and plausible processes which may cause the change (Miller et al., 1994; Trenberth and Hurrell, 1994). Different viewpoints have been proposed about the possible mechanisms of the decadal variability (Latif and Barnett, 1994; Graham, 1994; Lau and Nath, 1994; Trenberth and Hurrell, 1994; Jacobs et al., 1994; Jin, 1997).

In the tropical Pacific Ocean, the SST is anomalously warm in the 1980's (Nitta and Yamada, 1989; Wang, 1995). An interesting problem is whether the warmer SST in the tropical Pacific Ocean is related to the above–normal summer rainfall on the Yangtze River region in the 1980's or they are different aspects of the decadal variability in the ocean–atmosphere–land system. Huang et al. (1992) attempted to link these two decadal variations and thought that the warmer SST may be a cause for the above–normal rainfall. However, it is not clear what are the plausible processes. Another problem is that the decadal summer rainfall transition also occurred in the late 1950's in the Yangtze River region. Is there corresponding change in the tropical Pacific SST?

The revealed decadal summer rainfall pattern and the 500 hPa height anomaly distribution are very similar to those in interannual time scale (Nitta, 1987; Huang and Li, 1987; Wu and Chen, 1996). The 500 hPa height anomaly pattern seems also present in intraseasonal fluctuations (Huang et al., 1993). There is the possibility that the decadal pattern in the 1980's may be due to more frequent occurrence of positive EAP pattern and less frequent negative EAP pattern. This may result in a decadal EAP pattern (in a residual sense) in the 1980's.

Whether the decadal pattern is due to the dominance of one phase of the interannual variation over the other or due to the pure decadal mode of the ocean–atmosphere–land system, the persistence of the pattern over one decade or longer apparently requires some specific mechanisms for its maintenance. The plausible candidates are lower boundary conditions such as snow cover, soil moisture, and SST. How the decadal anomalies in those lower boundary conditions are related to the maintenance of the atmospheric circulation anomaly patterns and in turn the rainfall anomaly patterns and what are the processes are interesting topics in the future study.

Another point raised in this paper is that the decadal summer rainfall anomaly displayed spatial progress in the eastern China. It remains to be examined whether the atmospheric circulation evolution displayed similar feature in decadal variation. This may be helpful to the understanding of the causes of the decadal variability through diagnosis of the evolution processes and plausible reasons.

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