Characteristics of Two General Circulation Patterns During Floods over the Changjiang-Huaihe River Valley*

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ABSTRACT

Characteristics of the atmospheric general circulation during the catastrophic floods over the Changjiang-Huaihe River Valley (CHRV) are investigated. There are two precipitation patterns over China in the CHRV flood years: the CHRV flood-whole country-wet (P1) pattern and the CHRV flood-south (north) side-dry (P2) pattern. The circulation analysis results show that there are obvious differences between the NH 500-hPa geopotential height fields of P1 and P2 precipitation patterns. The establishment of East Asia-Atlantic (EAA) correlation chain (the South China Sea (SCS) high−the Meiyu trough−the Okhotsk Sea high over East Asia) is a critical condition for excessive summer precipitation over the CHRV, while the European blocking high plays an important role in determining the precipitation pattern over China in the CHRV flood years. Besides, the relation between the EAA correlation chain and the sea surface temperature anomaly (SSTA) in the North Pacific is also studied.

Key words: flood, circulation characteristics, blocking high, sea surface temperature

1. Introduction

The flood/drought in the Huaihe River Valley has long been focused by meteorologists in China. Zhu (1979) studied the catastrophic floods happened in July 1931, Tu and Niu (1950) investigated the floods over the Changjiang River Valley in July 1931 and the severe droughts in Central China in July 1934 using the Northern Hemispheric sea level pressure, Chen (1957) analyzed the 1954 inundation over the Changjiang River Valley, Tao and Xu (1960) detailedly investigated the 1959, 1961, and 1954 persistent drought and flood phenomena in the Changjiang-Huaihe River Valley (CHRV), and Xu (1979) researched the characteristics of the monthly sea level pressure fields in the summer CHRV flood/drought periods; and all those studies pointed out that there existed particular patterns of atmospheric general circulations in the Northern Hemisphere during the severe summer CHRV drought/flood periods, and those patterns were relatively stable. Under the circumstances of those circulation patterns, surface fronts, cyclone tracks, and main rain belts showed such a relative concentration trend, so that they could be clearly seen on monthly or seasonally 500-hPa height anomaly maps. Lin and Yu (1993) and Lin and Zhang (2000) further analyzed the exceptional floods over the CHRV in July-August of 1991 and 1998, and it was found that in the CHRV exceptional flood years the summer precipitation distribution over China showed large differences, i.e., the CHRV flood-whole country-wet (P1) pattern and the CHRV flood-south (north) side-dry (P2) pattern.

In regard to summer precipitation patterns in China, Wang and Zhao (1979) performed the EOF decomposition of the 508-yr dry/wet grade time series from 25 stations, and results show that the EOF1 denotes the same sign patterns (i.e., wet or dry weather over the whole China), the EOF2 represents opposite sign patterns (i.e., wet in the southern China, but dry in the northern China, and vice versa), and the FOF3 displays meridional patterns of "−+−" (wet in the CHRV, and dry to its south and north sides) or "+−+" (dry in the CHRV, and wet to its south and

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north sides). Basing on the temporal coefficients of the first three EOFs, they partitioned the 500-yr precipitation over China into five patterns, and among them, Pattern 1 was divided into two sub-patterns: Patterns 1a (wet in whole China) and 1b (wet in the CHRV and dry to its south and north sides) after further analyzing the 500-yr wet/dry maps and the spatial distribution features of the first three EOFs. Later on, Xu and Zhang (1983) similarly conducted the EOF decomposition of the 510-yr wet/dry grade time series from 100 stations, and according to the size of the temporal coefficients of the first three EOFs partitioned with the 510-yr precipitation into six patterns, wherein Wang's Patterns 1a and 1b became an independent pattern, respectively. On the basis of above studies, Yu and Lin (1989) found that the pattern-partitioning using the EOF has limitations, in particular when the temporal coefficients of the first three EOFs were used as criteria for pattern-partitioning. When the temporal coefficient of the EOF3 was the largest, the actual precipitation pattern might not be a pattern of "$-+-$" or "$+-+$" due to differences in the variance contributions of the first three eigenvectors. We also performed a similar EOF decomposition using the same data, took the EOF decomposition as a method of filtering, and partitioned with 510-yr wet/dry grade fitting maps (instead of actual grade maps) by the first three EOFs into six precipitation patterns. Ye et al. (1997) also discovered the limitation of the EOF pattern-partitioning, and partitioned the 524 wet/dry grades over the eastern China into six wet/dry patterns by using the REOF (rotating EOF) decomposition and considering the six regional features, wherein the names of Patterns 1a (wet over whole China) and 1b (wet in the CHRV, and dry to its south and north sides) were directly cited from Wang and Zhao (1979), but were actually independent patterns. Xu and Zhang (1983), Yu and Lin (1989), and Ye et al. (1997) all partitioned the summer precipitation into six patterns, whose Chinese specifications were almost same, but denoted with a different symbol, for example, Patterns 1$-$6 (Xu and Zhang, 1983; Yu and Lin, 1989) and Patterns 1a, 1b, 2, 3, 4, and 5 (Ye et al., 1997; Wang and Zhao, 1979). There are relatively large differences in their partitioning results due to different partitioning methods.

From the 2003 and 1991 CHRV floods, we select from 10 CHRV flood years (the mean precipitation anomaly over 42 representative stations is greater than 20%), partitions them into two categories: one with floods in the CHRV and less precipitation to its south and north sides; and the other with floods in the CHRV and more precipitation over the whole country. We analyze the climatic background of the 10 flood years, and then discuss the circulation characteristics of the two category floods.

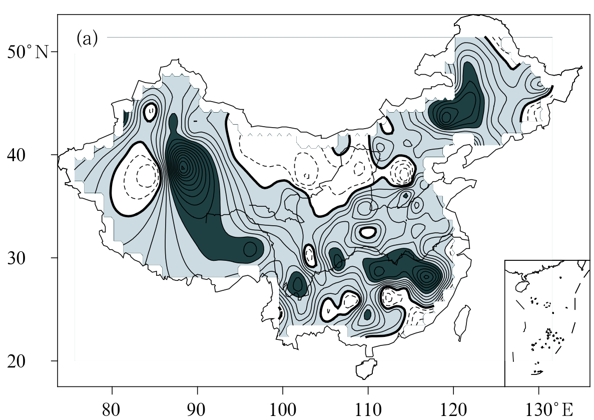
2. Climatic background and the whole country precipitation pattern during the CHRV exceptional floods

Precipitation in the rainy season (JJA) of 1998 was obviously more than normal over most areas in China, and the precipitation distribution belongs to Pattern P1. The main positive rain anomaly centers lay in the Changjiang River Valley, and along the west of Northeast China$-$the east of Inner Mongolia area, and the exceptional floods occurred over the whole Changjiang River Valley. The rainfall of JJA varied within 700-900 mm in the north of southern Jiangsu, Anhui and northern Zhejiang, the southwest of Hubei, Chongqing, and the east and southwest of Sichuan, and exceeded 1000 mm in some areas. The unprecedentedly exceptional floods devastated the Nenjiang and Songhua River Basins, and the rainfall of JJA was doubled in comparison with normal years. Besides, the severe floods also occurred in the southwest of the Pearl River and the Minjiang River Basin. The wide range, high peak water levels, and long durations of the floods were unprecedented (Fig.1a). According to the statistical record up to 22 August 1998, floods attacked 22 provinces to different extent, resulting in a hit area of 21.2×10^7 hm^2, a disastrous area of 13.1×10^7 hm^2, a population of 0.223 billion affected, the death of 3004 persons (1320 persons in the Changjiang River Basin), 4.97 million houses destroyed, and a total direct loss of 166.6 billion RMB yuan. Similarly disastrous precipitation and floods also occurred in 1954 (figure omitted; Chen, 1957), and the summer rainfall was generally much more than normal in the whole country except Xinjiang and the north of Northeast China. The major rainbelt lay over the CHRV, and the summer rainfall was 50% more than normal in Zhengzhou, Nanjing, Hefei, Hangzhou, Jiujiang, Yichang, Nanchang, Changsha, etc., and 100% more in Anqing, Tunxi, Hankou, Yueyang, and Changde, leading to the grave losses of life and economy.

The precipitation in the rainy season (JJA) of 2003 was obviously more than normal in the area between the Changjiang and Huanghe Rivers, and the excessive rain area with a 50% anomaly was mainly concentrated in the CHRV, where an exceptional inundation since 1991 occurred, and meanwhile the severe droughts appeared in northern as well as southern China due to deficit rainfall (Fig.1b). The major precipitation centers lay in Shandong, Jiangsu, Anhui, Hubei, Henan Provinces, etc., especially at Xingpu, Qingjiang, Xuzhou, Bengbu, Fuyang, Zhengzhou, Nanjing, Hefei Stations, etc., and the precipitation was 50% more than normal, leading to severe floods. On the contrary, the precipitation was deficit in the south of North China and Northwest China, especially at Fujin, Jixi, Tongliao, Yanji, Yingkou, Dalian, Chifeng, Chengde, Zhangjiakou, Shanba, Beijing, Shijiazhuang Stations as well as Zhangye, Dunhuang, Qiemo, Wusu, etc., where the precipitation was 20% less than normal, resulting in droughts. In southern China, the severe drought in a wide range mainly occurred in Shanghai, Zhejiang, Jiangxi, Fujian, Hunan, Guangdong, Guangxi, etc., especially at Hangzhou, Ningbo, Ji'an, Changsha, Rongjiang Stations, etc., the precipitation was 50% less than normal, leading to the severest droughts in recent years. Yu and Lin (1989) partitioned the summer precipitation distributions into six patterns, i.e., whole country-wet pattern, whole country-dry pattern, south-wet-north-dry pattern, south-dry-north-wet pattern, CHRV-wet-south (north)-dry pattern, and CHRV-dry-south (north)-wet pattern. The precipitation in the summer of 2003 is a typical CHRV-wet-south (north)-dry pattern.

The summer precipitation in 1991 distributed anomalously over China (figure omitted), similar to that in 2003 (Fig.1a), and was also a typical CHRV-wet-south (north)-dry pattern. The excessive rain area was concentrated in Jiangsu, Anhui, the south of Shandong, etc., where the distinct inundation areas with a positive precipitation anomaly more than 50% or even 100% occurred; however, the precipitation was deficit in Shanxi, Inner Mongolia, Gansu, etc., especially at Taiyuan, Linfen, Yulin, Zhongning, Wuwei, Dunhuang Stations, etc., where the precipitation was more than 50% less than normal, and in southern China the deficit rain areas were concentrated in Jiangxi, Fujian Provinces, etc., where the remarkably drought with a rainfall of 50% less than normal occurred.

It is obvious that there existed two precipitation patterns in the CHRV flood years: one is the CHRV



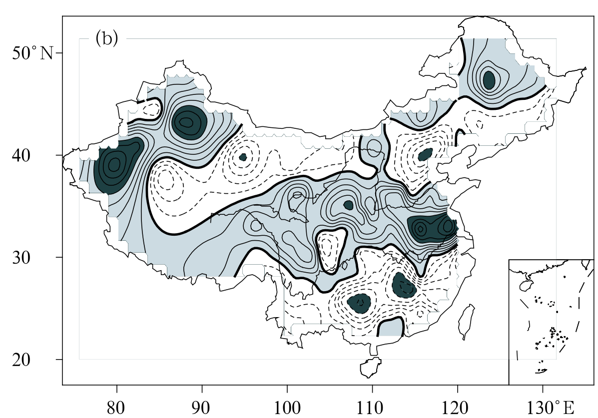


Fig.1. Percentages of the rainy season (JJA) precipitation anomaly in 1998 (a) and 2003 (b). Contours are drawn every 10%, with solid/dashed lines denoting positive/negative anomalies, and thick solid lines zero contours; a black area represents a flood or drought area with a precipitation anomaly of more than 50%.

flood-whole country-wet pattern (P1), and the other is the CHRV flood-south (north)-dry pattern (P2). Since 1951, 1954, 1956, 1969, 1980, 1983, 1989, l99l, 1996, 1998, and 2003 are CHRV flood years, among which the summer precipitation showed a P1 pattern in 1954, 1996, and 1998, and a P2 pattern in the other years.

Lin and Zhang (1998) used the mean percentages of precipitation anomaly over 42 stations, including Xuzhou, Bengbu, Nanjing, Hefei, Shanghai, Jiujiang, Yichang, Chongqing, Chengdu, Neijiang, etc. to represent the precipitation of the CHRV, and analyzed its interannual variation (Fig.2). It is seen from the figure that the interdecadal change is very clear. The positive precipitation anomaly dominated before 1957, which is an excessive rain period of the CHRV, with an averaged anomaly of 14.0%; afterwards, the negative anomaly dominated from 1958 to 1979, which is a deficit rain period, with an averaged anomaly of −10.5%; the later 1980 was again an excessive rain period, with an averaged anomaly of 8.1%. Such an interdecadal change in precipitation over the CHRV is in agreement with the climatic abrupt changes discussed by Lin (1998). Lin (1998) pointed out that the mid-1950s and from the last 1970s to the early 1980s are two abrupt change points, and between them there is a stable variation period of climate. It can be observed from Fig.2 that the negative anomaly dominated over the CHRV 1958-1979, which was a deficit period, and before and after this period the precipitation amounts were excessive. The precipitation amounts over the CHRV in the above selected 10 excessive rain years were averagely above 20% more than normal except 1969. Other nine excessive rain years occurred in the two interdecadal excessive rain periods, suggesting that the excessive rain period provided a favorable climatic background for the occurrence of exceptional floods over the CHRV.

3. Circulation characteristics during the CHRV floods

The composite of the summer precipitation anomaly for CHRV-wet-south (north)-dry (P2) pattern was performed over the seven CHRV flood years of 1956, 1969, 1980, 1983, 1989, 1991, and 2003 (Fig.3a). The distributive characteristics of P2 are that the major excessive rain belt lies between the Huanghe River and the Changjiang River, with positive anomalies of above 50% over the CHRV and negative anomalies in the CHRV's south and north sides. It is similar to the P2 in Fig.1b. The composite of corresponding 500-hPa heights as shown in Fig.3c indicates that the circulation over the mid-high latitudes of Europe-Asia maintains one trough-one ridge situation: a deep trough lies over the Ural mountains; the Okhotsk blocking high develops anomalously, and its west limit extends to the vicinity of the Baikal Lake; a Meiyu trough lies

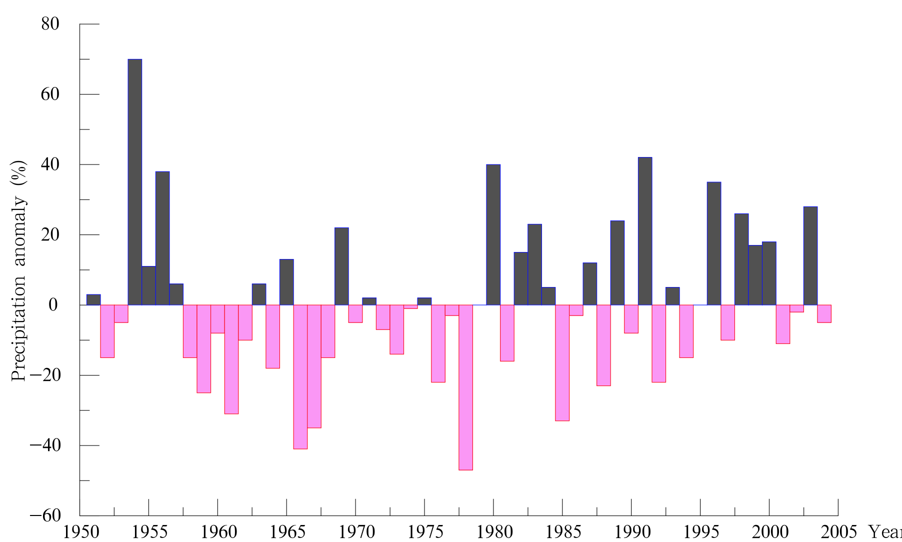


Fig.2. Interannual variation of rainy season (JJA) precipitation anomalies over the CHRV.

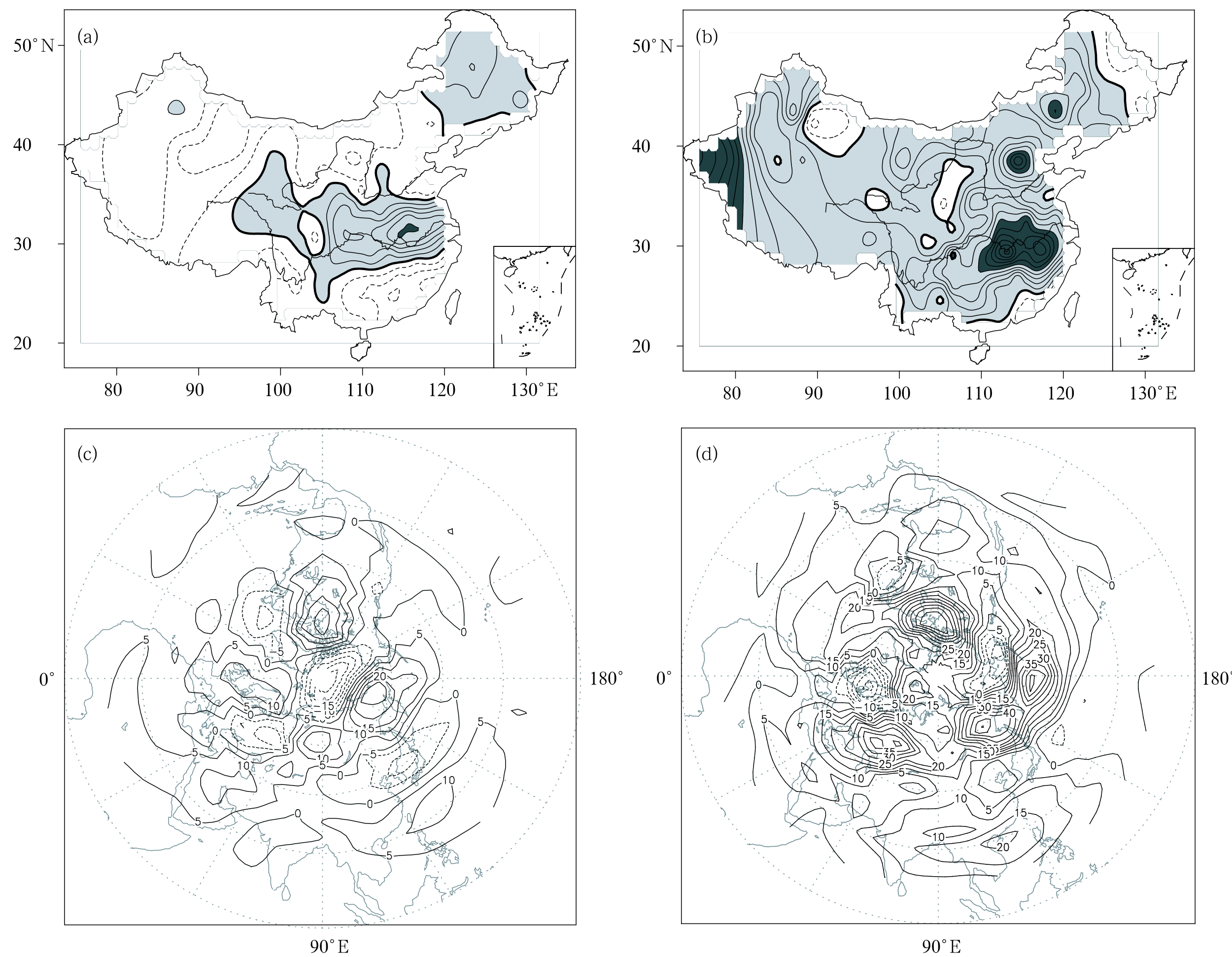


Fig.3. Composite patterns of precipitation (a, b) and corresponding 500-hPa height (c, d) anomalies for the CHRV flood years of P2 (i.e., more precipitation in the CHRV and less in its north and south sides) and P1 (i.e., more precipitation in the whole China). The percent contours of precipitation anomaly in (a) and (b) are drawn every 10% with solid (dashed) lines denoting positive (negative) anomalies, positive anomaly areas are shaded, and flood areas with a precipitation anomaly more than 50% are blackened; and the 500-hPa height contours in (c) and (d) are drawn every 5 gpm with solid (dashed) lines denoting positive (negative) anomalies.

over Japan; the mergence of strong SCS high with the western Pacific subtropical high results in a strong positive anomaly area over the SCS region; the surface front zone lies near the CHRV, and the cold air from the Ural trough invades into China along a NW path, the warm/humid air enters China along the southwest flow on the west and northwest sides of the western Pacific subtropical high, and the cold and warm flows meet together over the CHRV, forming the excessive precipitation. Owing to the mightiness of the Okhotsk Sea high, and the strengthening in intensity and southward shift in position of the subtropical high, the precipitation in the south and north sides of the CHRV is less than normal.

Correspondingly, the composite of the summer precipitation anomaly for P1 over the three CHRV flood years, i.e., 1954, 1996, and 1998, is given in Fig.3b, wherefrom it can be seen that the summer precipitation is excessive in most areas of China and the major rain belt still concentrates between the Huanghe River and the Changjiang River, with the precipitation in the flood area 50% more than normal in the CHRV. Figures 3a and b clearly show that the strength and width of the major rain belt are stronger and wider in P1 (Fig.3b) than P2 pattern (Fig.3a). The composite of corresponding 500-hPa heights of P1 is given in Fig.3d, wherefrom it can be observed that the circulation over the mid-high latitudes of Europe-Asia maintains the "double-blocking" pattern of two ridges-one trough, with two blocking highs respectively over the European region and the Okhotsk Sea region, and a relatively lower trough over the Ural mountains. Over the subtropical Pacific is a large stretch of negative height anomaly area, the subtropical high is weaker, and lies to south of normal position; the SCS high is strong; and the mid-latitude region is a relatively lower area. Warm/humid air flow enters China along a path of India-Bay of Bengal west of the SCS high, and cold air advances southwards along the Ural trough and enters the mid-latitudes along the south branch westerly south of the European blocking high. Because of the weakness of the subtropical high, the cold and warm airs meet in a broad zone over the CHRV, resulting in floods in the CHRV and abundant precipitation over almost whole China.

Comparison of Fig.3a with Fig.3b shows a common 500-hPa circulation feature of P1 and P2 precipitation patterns in the CHRV flood years that six positive and negative anomaly areas are distributed alternatively along the SCS−the Japanese Sea−the Okhotsk Sea−the North Pole−the Atlantic Ocean area, which is the major circulation character of the CHRV floods, and is also well in agreement with the research result of Yu and Lin (1989). The major differences of the 500-hPa circulations for P2 and P1 precipitation patterns are: (1) over the Eurasian mid-high latitudes in Fig.3c, there is only the Okhotsk Sea high, i.e., the "east-blocking" pattern, but in Fig.3d there are the European and Okhotsk Sea highs, i.e., the "double-blocking" pattern; (2) the subtropical high is stronger in Fig.3c, but weaker in Fig.3d; (3) the SCS high is stronger and lies east of normal position in Fig.3c, but it is weaker and lies west of normal position in Fig.3d; and (4) over the middle latitudes in Fig.3c, there is a Meiyu trough near the Japanese Sea, but in Fig.3d there is a broad negative anomaly area, especially in the mid-latitude of the western Pacific. Those circulation differences result in the obvious differences in the origins, propagating paths, and meeting areas of warm and cold airs, thus leading to the CHRV flood-whole country-wet (P1) precipitation pattern and the CHRV flood-south (north) side-dry (P2) pattern. The European and Okhotsk's "double blocking" is a necessary condition for P1 precipitation pattern, which is consistent with the result of the diagnostic analysis in strong/weak monsoons (Lin, 1987), while the strength of the SCS high is an indicator with which the P1 CHRV flood can be distinguished from the P2 CHRV flood.

Yu and Lin (1993) defined the EAA index in the study on the relation between EAA correlation chain and flood season precipitation in China. The averaged anomalies of the 500-hPa heights at the 8 grid points (20°-25°N, 110°-140°E), at the 12 grid points (55°-70°N, 130°-150°E), and at the 8 grid points (35°-40°N, 120°-140°E) over summer (JJA), are used to represent the intensities (G_1, G_2, and D) of the SCS and Okhotsk Sea highs, and Meiyu trough, respectively, and G_1, G_2, and D are normalized to minimize the effect of latitude, and then the EAA index is defined by EAA=$(G_1+G_2\text{-}2D)/4$. Obviously, it is a measurement of the intensities of the East Asian summer monsoon and the cold air from the mid-high latitudes. It can be seen from the contemporaneous correlation field of rainy season EAA index and 500-hPa heights (Fig.4b) that six positive and negative correlation areas are distributed alternatively along a line of the SCS−the Okhotsk Sea−the Atlantic, and are called the EAA correlation chain since five out of the six are significant at a confidence level more than 0.05. The East Asian segment of the EAA correlation chain is also called the East Asian teleconnection pattern, whose three correlation area locations are just those of G_1, G_2, and D, i.e., the Okhotsk Sea high, the Meiyu trough, and the SCS high, respectively. It is known from comparison of Figs.3a and b with Fig.4 that the EAA correlation chain is the dominating circulation pattern responsible for the CHRV floods.

Figure 4a gives the contemporaneous correlation of the EAA index with summer precipitation in China. A positive correlation zone significant at above 5% confidence level lies over the CHRV, with a negative correlation zone in its south and north sides, respectively. The positive correlation coefficients at Qingjiang, Bengbu, Fuyang, Xinyang, Dongtai, Nanjing, Hefei Stations, etc., are all greater than 0.60, and correspondingly the magnitudes of negative correlation coefficients at Baotou, Shanba, Yinchuan, Ji'an, Ganzhou Stations, etc., are all greater than 0.45. Comparison between Fig.4a and Fig.1 shows that the contemporaneous correlation of the EAA index with summer precipitation is able to well explain the circulation characteristics of the 1991 and 2003 CHRV floods.

The EAA correlation chain is one of major structures of summer (JJA) circulations. The EOF expansion of the Northern Hemispheric summer 500-hPa height from 1951 to 2004 was performed, and the variances of first three eigenvectors account for 21%, 11%, and 9% of the total variance, respectively. The major positive and negative anomalies in the second mode (figure omitted) are concentrated on the line of the East Asia−the north pole region−the Atlantic Ocean, which is very similar to the EAA wavetrain in the study on atmospheric 3-5-yr cycle (Lin, 1990). It is seen from the simultaneous temporal correlation fields of the time coefficient of the second EOF with the Northern Hemispheric summer 500-hPa height anomaly fields (figure omitted) that the six positive and negative correlation areas significant at above 5% confidence level are distributed alternatively along the line of the East Asia−the North Pole−the Atlantic, and their locations are very close to those of the six correlation areas in Fig.4b. The EAA correlation chain may be associated with the West Pacific pattern (WP) and the East Atlantic pattern (EA) suggested by Wallace and Gutzler (1981), and its variance accounts for 11% of the total, therefore the EAA correlation chain is one of major structures of the NH summer 500-hPa circulations.

4. Relationship between EAA correlation chain and sea surface temperature in the North Pacific

Figure 5 displays the contemporaneous correlation of summer EAA index with the sea surface temperature in the North Pacific. The positive and negative correlation areas significant at above 5% confidence level are mainly concentrated in the western Pacific, and correspond to those of the SCS high and the Meiyu trough in Fig.4b, respectively. The positive correlation area locates at 15°-25°N, 120°-140°E, where the principal axis of the Kuroshio Current lies. This suggests that when the Kuroshio Current transfers warmer water into the area, the warm water piles up, results in a strong positive sea surface temperature anomaly (SSTA), and the EAA index increases, and vice versa. The negative correlation area lies at

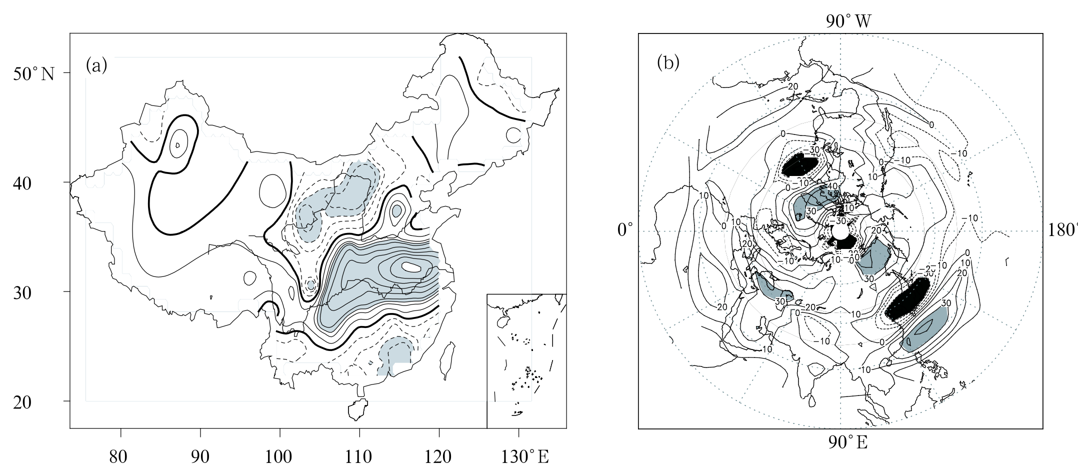


Fig.4. Contemporaneous correlation of rainy season (JJA) EAA index with precipitation (a) and 500-hPa height (b). The contour of correlation coefficient is drawn every 0.10, with solid (dashed) lines denoting positive (negative) correlation, and the correlations significant at a confidence level more than 0.05 are shaded.

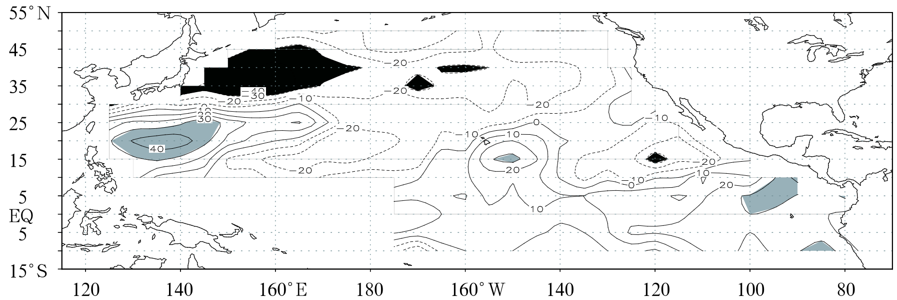


Fig.5. Contemporaneous correlation of rainy season (JJA) EAA index with the sea surface temperature in the North Pacific (the contour of correlation coefficient (magnified by 100) is drawn every 10, with solid (dashed) lines denoting positive (negative) correlation, and the correlations significant at a confidence level more than 10 are shaded).

35°-45°N, 140°-160°E, where the Tsushima Current meets the Kuroshio Current. This indicates that when the Tsushima Current is strong, its mixing with the Kuroshio results in a negative SSTA, and then the EAA index reduces; conversely, when the Tsushima Current is weak, its mixing with the Kuroshio Current results in a positive SSTA, and then the EAA index increases. This shows that the intensity change of the Kuroshio and Tsushima Currents is the major forcing for the formation of the EAA correlation chain.

Figures 6a and b exhibit the composites of the North Pacific SSTAs over the CHRV flood years of P2 and P1, respectively, and their common feature is that in the West Pacific there is a pair of positive and negative SSTA areas, whose locations match well with those of a pair of the positive and negative correlation areas significant at 5% in Fig.5. This proves that when the Kurosio Current is strong, with positive SSTAs between 15° and 25°N, and meanwhile the Tsushima Current is also strong, with negative SSTAs between 35° and 45°N, then it is easy for EAA correlation chain to occur at 500 hPa. Comparison of Figs.6a and b shows the following major differences: (1) Negative SSTAs dominate the North Pacific between 30° and 45°N in Fig.6b (corresponding to P1 pattern). According to the statistical study by Lin (1976), the positive (negative) SSTA corresponds to the positive (negative) 500-hPa height anomaly, respectively, but the 500-hPa height anomaly usually lies west of the SSTA. This means that in the CHRV flood years of P1 pattern, the Meiyu trough is a broad one, or it fluctuates violently and meridionally; while in the CHRV flood years of P2 pattern, it fluctuates slightly. (2) In the CHRV flood years of P2 (Fig.6a), the positive SSTA of the NW Pacific between 15° and 30°N extends northeastwards, forming an NE-SW positive SSTA belt; Correspondingly, an NE-SW positive 500-hPa height anomaly belt forms due to the mergence of the strengthened SCS high with the subtropical high, which is responsible for the occurrence of droughts in southern China. (3) In the CHRV flood years of P2 (Fig.6a), the positive SSTA pattern in the equatorial Pacific, especially in the equatorial East Pacific, is similar to the SSTA pattern of El Niño; while in the CHRV flood years of P1 (Fig.6b), the negative SSTAs dominate. Lin and Yu (1993) discussed the impact of El Niño events on summer precipitation in China, and pointed out that after the peak value of the sea surface temperature of East Pacific El Niño, summer precipitation is less than normal in the CHRV, but more in its both sides; and after the peak value of the sea surface temperature of central Pacific El Niño, summer precipitation is more than normal in the CHRV, but less in its both sides. In this paper, the CHRV flood years of P2 pattern were strictly selected according to the precipitation pattern−excessive precipitation in the CHRV and deficit precipitation in its both sides, and therefore would not be El Niño years. Therefore, the formation of the positive SSTA pattern in the equatorial East Pacific in Fig.6a is complicated, for example, the summer of 1969 was in the slowly declining period of sea surface temperature after the

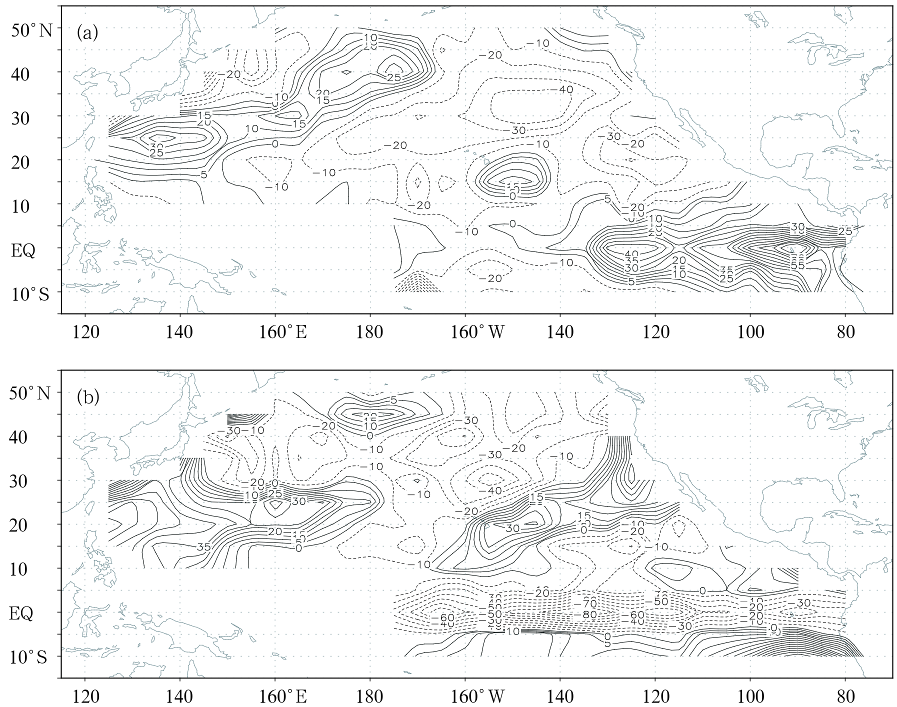


Fig.6. Composites of SSTAs in the North Pacific over the CHRV flood years for (a) P2 pattern and (b) P1 pattern. The contours are drawn every 10°C, and solid (dashed) lines denote positive (negative) anomalies.

peak value of El Niño, the summer of 2003 in the rising period of sea surface temperature before the formation of El Niño, and the summers of most years in the transition period of El Niño cycle. Likewise, the formation of the negative SSTA pattern in the equatorial East Pacific in Fig.6b is also complicated. It is known from the above discussions that when the Kurosio Current is strong, with positive SSTAs between 15° and 25°N, and meanwhile the Tsushima Current is also strong, with negative SSTAs between 35° and 45°N, then the EAA correlation chain frequently appears at 500 hPa, and floods often occur in the CHRV.

5. Conclusions

The following conclusions can be drawn from the above analyses:

(1) In the summer CHRV flood years, precipitation over China displayed two distinctive patterns: one is the CHRV flood-whole country-wet (P1) pattern; and the other is the CHRV flood-south (north) side-dry (P2) pattern. The summer precipitation of 1991 and 2003 can be classified into this pattern. The common feature of corresponding 500-hPa circulations of P1 and P2 patterns is the EAA correlation chain−the six anomaly areas with positive sign alternating with negative sign along the line of the SCS−the Okhotsk Sea−the north pole area−the Atlantic Ocean, and its East Asian part corresponds to the SCS high, the Meiyu trough, and the Okhotsk Sea high, respectively. This is the basic circulation pattern resulting in the CHRV floods. The fundamental circulation difference of P1 and P2 patterns is that in the CHRV flood years of P1 pattern two blocking highs lie over the European area and the Okhotsk Sea, respectively, in the mid-high latitudes of the Eurasian area, i.e., a "double-blocking" pattern, while in the CHRV years of P2 precipitation pattern, only one blocking high lies over the Okhotsk Sea, i.e., an "east-blocking" pattern.

(2) Based on the comprehensively statistical results of the onset date of the SCS monsoon and the establishment of the Okhotsk Sea high with summer precipitation patterns over China, the following relations are obtained: when the SCS monsoon bursts early, and meanwhile if there is no high over the Okhotsk Sea,

then the summer rain belt lies north of normal position, and the first and second category precipitation patterns frequently occur (6/6); otherwise the rain belt lies south of normal position, and the third category precipitation pattern usually takes place (3/4). When the SCS monsoon bursts late, and meanwhile if there is no high over the Okhotsk Sea, then the rain belt lies south of normal position, and the second and third category precipitation patterns take place (5/5); otherwise the rain belt lies north of normal position, and the first category precipitation pattern occurs (3/5).

(3) The genesis of the summer EAA correlation chain is associated with the forcing of the sea surface temperature of the North Pacific, especially of the Northwest Pacific. When the summer Kuroshio Current is stronger, with positive SSTA in the western Pacific between 15° and 30°N, and meanwhile the Tsushima is also stronger, with negative SSTA in the western Pacific between 35° and 45°N, the EAA correlation chain forms at the 500-hPa level.

(4) Except the above circulation features, the CHRV flood is also to some extent related with particular climatic background, and the CHRV floods frequently occur in the CHRV excessive rain period of interdecadal climatic changes.

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