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INTERDECADAL TRANSITIONS AND TWO EXCEPTIONAL YEARS OF JUNE PRECIPITATION OVER SOUTH CHINA

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Abstract: An analysis of high-resolution precipitation data for 1978–2006 indicates that the precipitation over southern China in June experienced a low-value period in 1980–1989 and a high-value period in 1992–2001. It also reveals that exceptional heavy (light) precipitation occurred in June 2005 (2004) since 1951. For these variations on both interdecadal and interannual timescales, fairly uniform anomalies of precipitation appeared over Vietnam, southern China, and southeastern China. Corresponding to positive (negative) precipitation anomalies, anomalous southeasterly (northwesterly) flow at 850 hPa reached Vietnam and anomalous southwesterly (northeasterly) flow expanded to the coastal regions of southern and southeastern China. Precedent to the positive (negative) precipitation anomalies during 1992–2001 (1980–1989), positive (negative) anomalies of sea surface temperature appeared over the extratropical northwestern Pacific in the winter and spring seasons, associated with a strong (weak) extension of the warm Kuroshio Current that affects the coastal region of eastern China. The above-normal precipitation in June 2005 was associated with the pseudo-ENSO event in the previous winter, and the below-normal precipitation in June 2004 was associated with negative anomalies of sea surface temperature over the equatorial central Pacific and positive anomalies over the equatorial western and eastern Pacific.

Key words: Southern China; June precipitation; anomalies of atmospheric circulation and sea surface temperature; interdecadal and interannual timescales

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1 INTRODUCTION

In the part of China that is east of the Tibet-Qinghai Plateau, summer climate is subject to the East Asian monsoons. After the onset of summer monsoon in mid-May in the South China Sea, monsoon precipitation advances to the south of China first, then to the Yangtze River in the end of June, and then further north in July to the Huaihe River, Yellow River and the northernmost region at the northwestern tip the country[1, 2]. Therefore, the annually first rainy season (hereafter “rainy season”) for the south of China (usually taking place in April to June) is the first phase of the annual northward seasonal shift of rain bands in China. As shown in the statistics, June is the month that receives the most rainfall in the general rainy season—usually from April to September—for the south of China[3], with a multi-month mean greater than 250 mm. Since the 1990s, hard rain and floods have been frequent in the rainy season and June is the month that witnesses several of the main floods, e.g. in 1994, 1998 and 2005. Therefore, further study on the temporal and spatial distributions of precipitation in Junes in the south of China holds significant implication to understanding the precipitation there during the rainy season.

Hard rain and floods during the rainy season have been drawing extensive attention. With analyses of the variations of droughts and floods and their tendencies, Lin et al.[4] and Deng et al.[5] pointed out the presence of multiple periods that alternate dry and wet spells in the south of China. As shown in studies, considerable differences exist in circulation systems that form dry and wet spans on the monthly and seasonal scales in this part of the country. Having studied the interannual variation of the subtropical high in the western Pacific and its effect on the precipitation in the south of China, Liang et al.[6] pointed out that a northward (southward) located subtropical high is corresponding to less (more)

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rainfall in this region. Another important feature of a more-rain year there is the presence of an anomalous low pressure in the south of China and an anti-cyclonic circulation over waters east of the Philippines, which is favorable for the transfer of warm and moist airflow from the ocean to this region[5, 7]. As indicated in diagnostic analyses with cases of floods there, anomalous monsoon jet streams and their interactions with mid-latitude synoptic systems are important characteristics of hard rains that lead to floods in the south of China[8-10]. Besides, precipitation anomalies were also investigated oceanographically for their causes in recent years. Dividing the western North Pacific into eight portions, Xie et al.[11] studied the relationships between the variation of precipitation in the rainy season in Guangdong and sea surface temperature (SST) in these portions of the ocean. They noted that the effects of SST on the precipitation for the annually first and second rainy season are different depending on the time of the year and the portion of the ocean. As a key region that affects the global climate, the warm pool in the western Pacific and waters around it are playing equally important roles in the atmospheric circulation and precipitation during the rainy season[5-7].

With the lengthening of observational records, more and more facts have shown that extreme climate events become more frequent under the background of climate change and enormous differences exist in the response of regional climate to climate warming on the global scale[12, 13]. A significant climate shift took place around 1976 in China, and precipitation increased significantly in the basin of the Yangtze River while decreasing substantially in the north of China and basin of the Yellow River to result in droughts in the summers from 1977 to 2000 (Zhou al.[14]). As what our research discovers recently, precipitation has been on an increasing trend across the whole Southeast Asia since 1978[13]. By contrast, it remains unclear in which direction precipitation tends to vary and how it behaves on the interdecadal scale in the south of China and other parts of Southeast Asia. In addition to that, a drought that was the most severe for the past 50 years occurred in June 2004 while floods that were rarely seen in the same period of time happened in June 2005[16]. The appearance of droughts and floods in two consecutive years have shown that extreme interannual climatic events, whose possible intriguing mechanisms have yet to be identified, become more dramatic in this part of China. In this work, the same day-to-day rainfall dataset used in Yao et al.[13]—covering the period from 1978 to 2006 and at a gridpoint interval of 0.5°×0.5°—is used first to identify interannual and interdecadal transitions of the June precipitation in the south of China and relationships with precipitation anomalies in neighboring Southeast Asia regions and then to study possible atmospheric circulation anomalies and oceanic forcing.

2 DATA AND METHODS

Apart from the dataset described in the last section, which covers the area (5–60°N，65–155°E), this work also uses the reanalysis of humidity, temperature, pressure and wind from National Centers for Environmental Protection/National Center for Atmospheric Research (NCEP/NCAR, USA)[18] and ERSST data from NOAA[19], and monthly rainfall (1951–2006) from 13 observation sites in the south of China[20]. Based on an analysis of the interannual and interdecadal averages for Junes and variations of the hard rain, this work selects one decade with the smallest average and one decade with the largest average as well as the years of 2004 and 2005, and studies the anomalous distributions of average rainfall, hard rain, 850 hPa winds, geopotential heights and SST fields by using composite and comparison methods.

3 DECADAL AND EXTREME INTERANNUAL VARIATIONS OF JUNE PRECIPITATION IN SOUTH OF CHINA

As shown in our analysis, precipitation is this region underwent an interdecadal change in 1991 to 1992 in which summertime precipitation shifts from being decadal less to decadal more[13, 21]. Figure 1 gives the variation of year-to-year rainfall anomalies in Junes of 1951–2006. As shown in Figure 1a, 2005 is the year with the most June rainfall, 226.15 mm more than the average (272.39 mm), while 2004 is the year with the least June rainfall, 128.16 mm less than the average. Besides, the precipitation varies on the decadal scale as well. Its interannual variability is larger in one decade than the other. For instance, it is larger in the 1950s and 1990s than other decades. In some decades, a year of increasing annual rainfall is followed by a year of decreasing annual rainfall, e.g., there was less rain in 1967 but more rain in 1968.

To give quantitative description of the decadal variation of rainfall, Figure 1b presents the variation of rainfall anomalies in Junes that has been processed with 10-year moving average since 1951. For the June rainfall, the late-1950s is negatively anomalous, the 1960s to mid-1970s is positively anomalous, the 1980s is negatively anomalous, and the 1990s is positively anomalous again. Relatively speaking, the interdecadal less and more precipitation that happened in the 1980s, 1990s and time beyond are the most significant since 1951. Next, Asian precipitation datasets with high spatial and temporal resolution will be used to conduct intensive study on how precipitation varies over this period of time. First, our focus is on the distribution of the regions with large rainfall variabilities in the southeast part of Asia. Figure 2 gives the distribution of standard deviations of rainfall in Junes of 1978–2006. Standard deviations larger than 50 mm are distributed south of the Tibet-Qinghai Plateau and areas east of the plateau and south of the Yellow River, and centers of mean square deviations larger than 100 mm are concentrated in four regions: the south of China (Pearl River basin), area in and around the lower reach of Yangtze (referred to the lower reach of Yangtze hereafter), coastal regions of Bangladesh south of the plateau and eastern Indochina Peninsula west of the South China Sea.

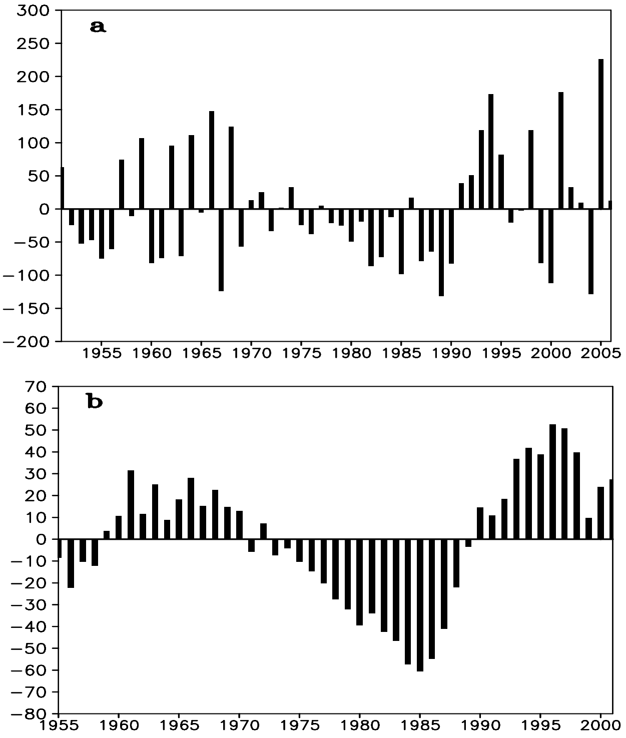


Figure 1. (a) Variation of year-to-year rainfall anomalies in Junes of 1951–2006 from 13 of the observation sites in the south of China (as indicated with circular points in Figure 2); (b) Variation of rainfall anomalies in Junes that has been processed with 10-year moving average since 1951. Units: mm. The abscissa is for the year.

Figure 3 presents the variations of the anomalies of overall rainfall and those of hard rain and above for the Junes of 1978–2006. They are generally similar to the anomalies made with data from observation sites (figure omitted). For the multi-year overall rainfall, Figure 3a gives a multi-year monthly mean rainfall of m=265.04 mm, 7.35 mm less than the average determined with the site data, an increasing overall rainfall at a rate of 3.29 mm per year (α=3.29 mm/year), and a tendency coefficient of r=0.3875 which passes the 0.05 significance test. Figure 3b shows that the multi-year monthly rainfall is m=67.87 mm for the level above hard rain and an increasing trend for rainfall above hard rain at 1.32 mm per year (α=1.32 mm/year) with a tendency coefficient of r=0.3377, which passes the 0.1 significance test. The number of hard rain is also on the rise (figure omitted). Using the data from observation sites, Ding et al.[22] studied the persistent hard rain that took place in the Junes of 1958–2000 in the south of China with the conclusion that there has been more of this type of rain since the 1990s, which is consistent with the result above. Figure 1b gives the decadal differences of rainfall for two decades. Extreme interannual differences are also clearly shown between 2004 and 2005 (Figure 3). Next, comparisons and analyses will be given of the decadal rainfall for the two decades (1980–1989 and 1992–2000) and of the extreme interannual rainfall for 2004 and 2005.

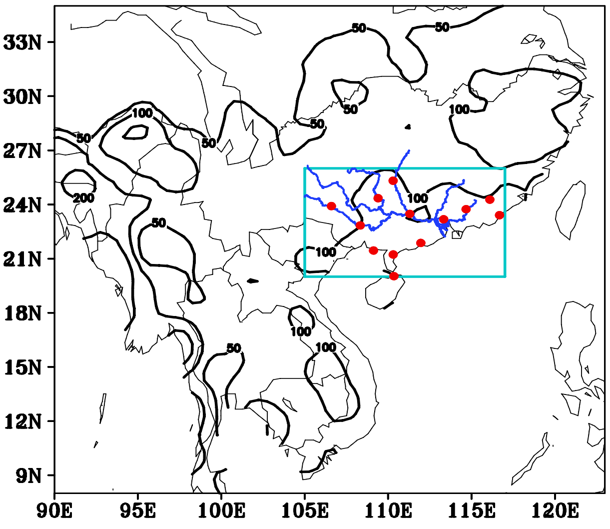
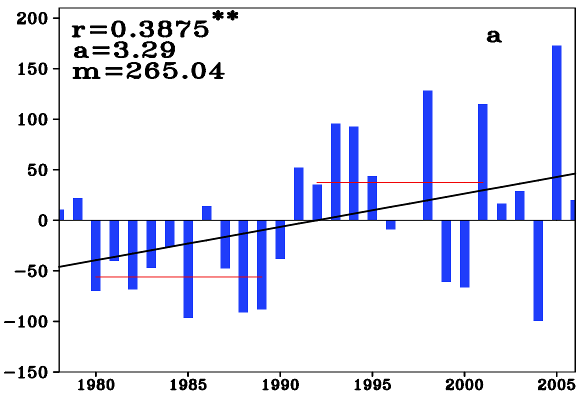


Figure 2. Standard deviations of June rainfall in the Asian region from 1978 to 2006 (mm). The box is the basin of Pearl River in the south of China (20–27°N, 105–117°E), in which the circular points indicate the locations of the 13 observation sites.



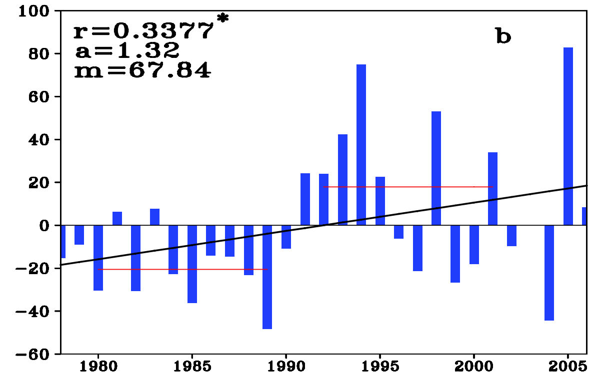
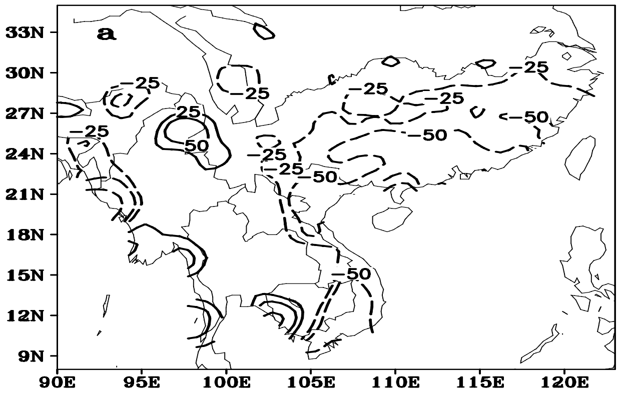


Figure 3. Anomalies of overall rainfall (a, mm), rainfall from hard rain or above (b, mm) and their tendency coefficients *r* and regression coefficients *a* (mm/year) for the south of China in the Junes of 1978–2006. The abscissa is for the year.

4 SPATIAL DISTRIBUTION OF ANOMALOUS PRECIPITATION IN THE SOUTH OF CHINA

First, we look at the distribution of two decadal rainfall anomalies. Figures 4a and 4b show the anomalous distribution of rainfall for 1980–1989 and 1992–2000 relative to the period 1978–2006. It is shown that consistent anomalous distribution is seen in the coastal area of southeast China and the eastern coast of Indochina Peninsula that are connected through negative (positive) anomalous rainfall centers in the south of China. With less rainfall, there is a negative anomalous center of 50 mm; with more rainfall, there is a positive anomalous center of 50 mm. Another positive anomalous center of 50 to 100 mm also exists in the lower reach of the Yangtze River. The two decadal distributions of hard rain are also similar to those of the overall rainfall described above (figure omitted).



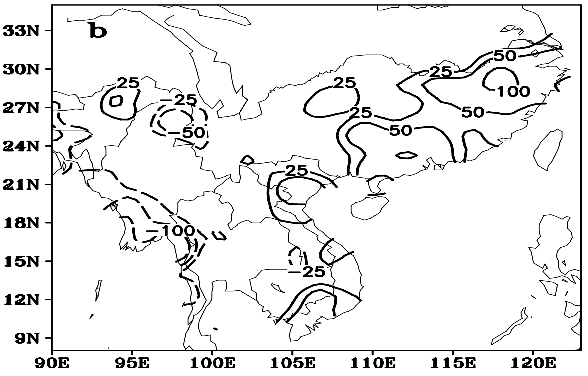


Figure 4. Anomalies of rainfall for the first decade 1980–1989 (a) and the second decade 1992–2000 (b) relative to the rainfall for 1978–2006. Units: mm.

Then, we examine the distribution of anomalies of precipitation for 2004 and 2005 relative to those for 1978–2006 (Figure 5). In 2004, an east-west stripe of negative precipitation anomalies is formed from Burma to the lower reach of the Yangtze River, which is in contrast with positive precipitation anomalies through the central Indochina Peninsula. The negatively anomalous precipitation (more than 100 mm) in the south of China is connected with that for the southeastern coast of China. In 2005, positively anomalous precipitation is present from southern Burma to the south of China while negatively anomalous precipitation is seen from Bangladesh to the Yangtze River. From the distribution of the anomalous precipitation for June 2005 minus that for June 2004 (as shown in Figure 5c), we noted that positively anomalous precipitation extends from Burma all the way eastward to the southwest and south of China and southeastern coast of China while negative anomalies are distributed over central Indochina Peninsula and from Bangladesh to the Yangtze River. In terms of distribution, rainfall differences (Figure 5d) for levels higher than hard rain—determined by subtracting the 2005 amount from the 2004 amount—are also similar to the rainfall anomalies described above.

Comparisons and analyses of Figures 4 and 5 demonstrate that the two decadal and extreme interannual variations are marked by transitions from being less to being more, and the transitions are consistent with those of the southeast of China and part of the Indochina Peninsula. What is different is that the former variation is distributed over the northwestern coast of South China Sea, south of China and lower reach of the Yangtze River while the latter variation is distributed in a consistently anomalous manner that centers on the south of China and connects with Burma and southeast coast of China in a near east-west orientation.

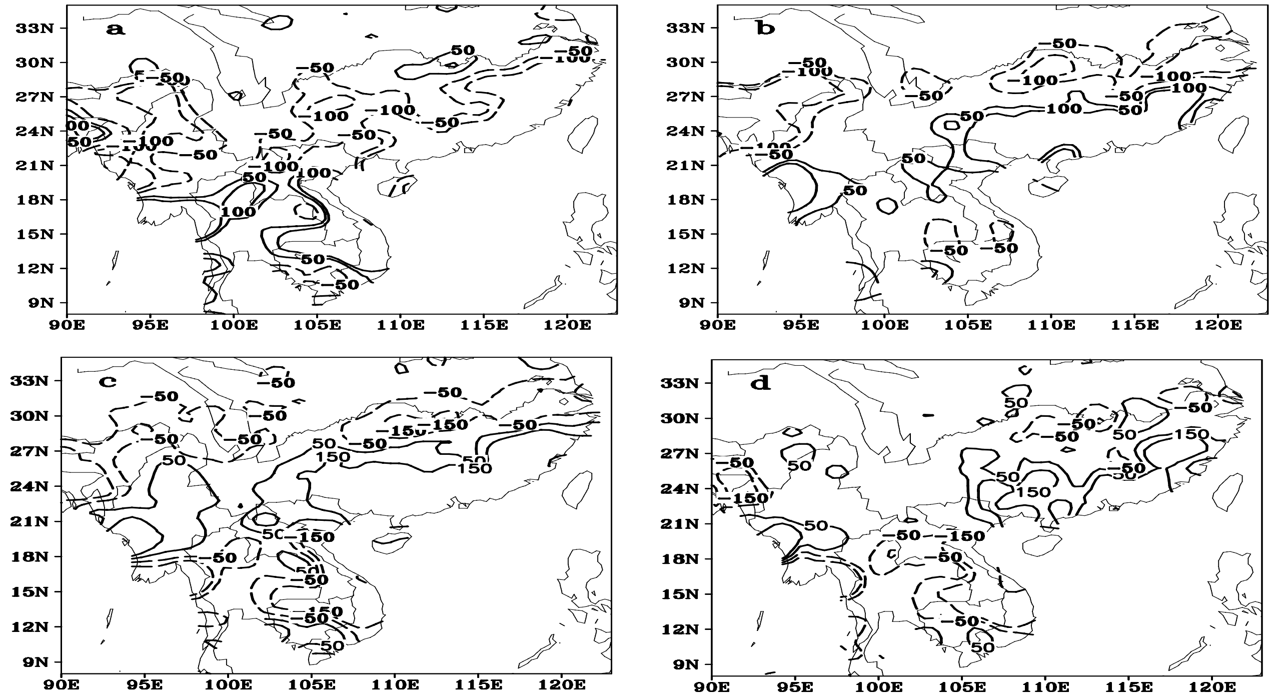


Figure 5. Distributions of anomalies of rainfall of 2004 (a) and 2005 (b) relative to those of 1978–2006, rainfall differences between 2004 and 2005 (c) and rainfall differences for precipitation above the level of hard rain by subtracting the 2005 amount from the 2004 amount (d). Unit: mm.

5 CIRCULATION ANOMALIES AND SST FORCING

Summer monsoon precipitation in the south of China is directly linked with 850 hPa circulation. Figure 6 gives the 850 hPa anomalies of wind and geopotential height fields for the two decades relative to the time 1978–2006. For the first decade, there is an anomalous cyclonic circulation and negative geopotential height anomalies from waters south of Japan to the South China Sea, and there is a northeast and north airflow over the southeast coast of China, south of China and Indochina Peninsula. Because of this airflow, decadal precipitation is anomalously less over the rim around South China Sea (i.e. the south and southeast of China) and eastern Indochina Peninsula. In contrast, for the latter decade, there is an anomalous anti-cyclonic circulation and a positive center of anomalous geopotential heights in Hainan province and waters east of it. Due to the effect of an anomalous south and southwest airflow in the western rim of South China Sea and south of China, precipitation is anomalously more in the latter decade. With the onset of monsoon in the South China Sea in May, the subtropical high retreats from the sea to move to the waters east of the Philippines while the high's extended ridgeline is over northern Hainan. A relatively weak subtropical high averaged for the Junes of the first decade is accompanied with less rainfall while a relatively strong subtropical high averaged for the Junes of the second decade is associated with more rainfall, in the south of China.

Figure 7 gives the 850 hPa circulation anomalies for the Junes of 2004 and 2005. In June 2004, the southeast coast of China and south of China were in the control of a northerly anomalous airflow. In June 2005, northern South China Sea was dominated by a southwesterly flow while the south of China was with an anomalous cyclonic circulation. These anomalous circulation and airflows could be the best footnotes for the extreme anomalies of the precipitation in the south of China in the Junes of 2004 and 2005.

As found in our general survey, definite lagging relationships are found between preceding (wintertime) SST anomalies in North Pacific and 850 hPa circulation in Junes of south of China. For the winters in the first decade, negative SST anomalies exist over Asian coasts off North Pacific and mid-latitude northwestern Pacific (Figure 8a). These SST anomalies are going northeastward from northern South China Sea, East China Sea and waters east of Japan, a well-known extension zone for the Kuroshio Current. It suggests that the precipitation is relatively less and so is that above the hard rain level in the Junes of the south of China in the decade when this current is relatively weak over the waters east of China and northwestern Pacific. For the latter decade (Figure 8b), the wintertime temperature is relatively high in this part of the ocean, i.e. an enhanced Kuroshio Current is favorable for more precipitation in the Junes of south of China. The differences between the two decades in the winter SST (Figure 9c) show the features more clearly. Such anomalous structures of SST are still evident in the spring (MAM), suggesting that the intensity of wintertime Kuroshio Current could be used as an indicator for the June rainfall in the south of China.

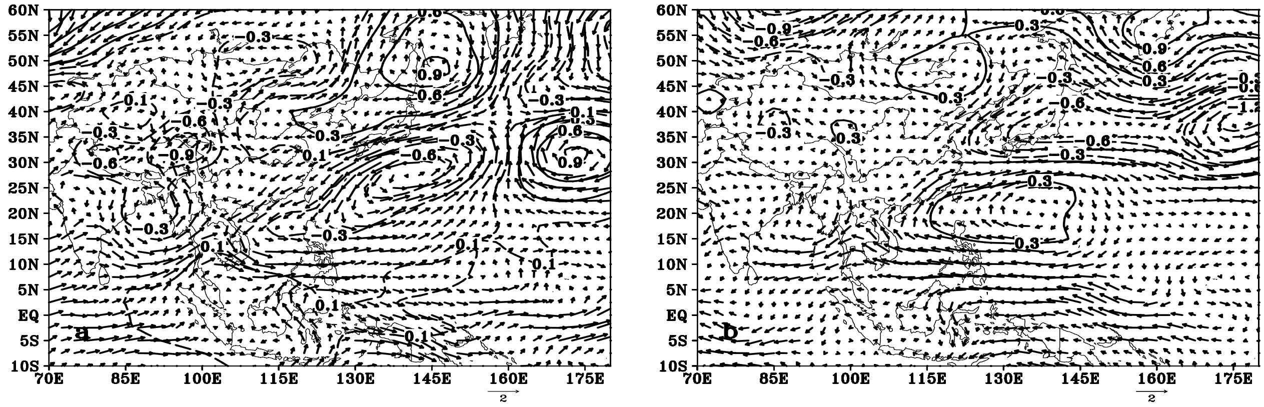


Figure 6. Anomalies of 850 hPa wind field (m/s) and geopotential height field (geopotential meter) for the first decade (a) and second decade (b) relative to the time 1978–2006.

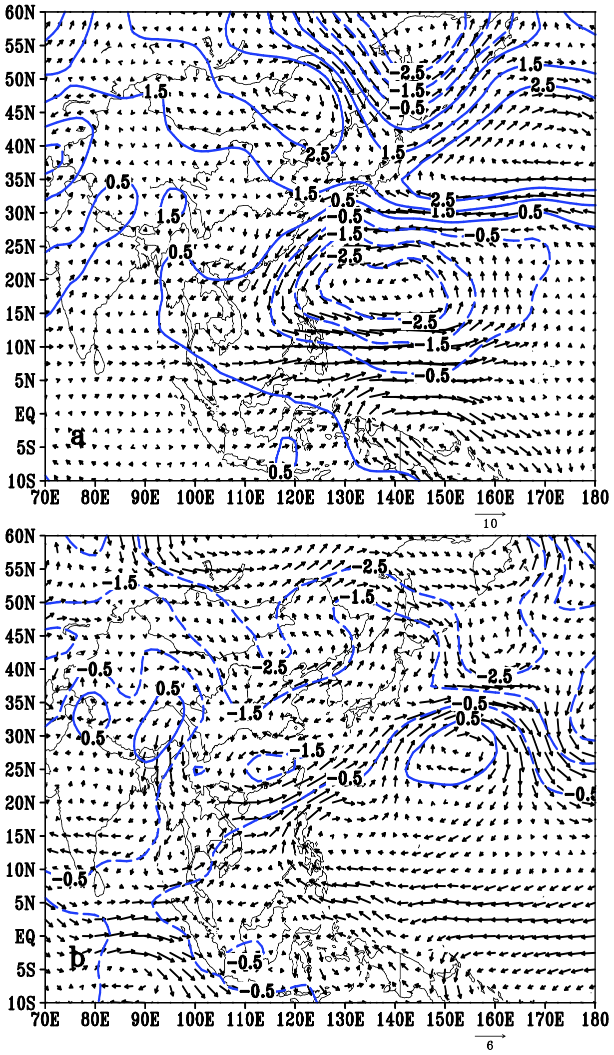


Figure 7. 850 hPa wind field (m/s) and geopotential height field (geopotential meter) anomalies for the Junes of 2004 (a) and 2005 (b) relative to the Junes of 1978–2006.

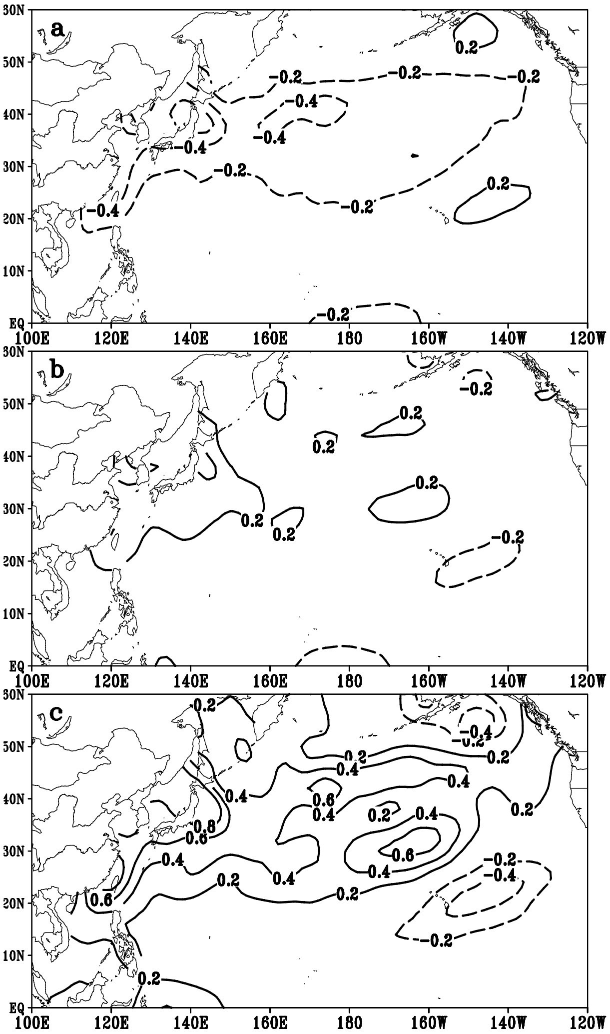


Figure 8. SST anomalies (°C) of winters (DJF) for the first decade (a) and the second decade (b) relative to the time 1978–2006 and SST differences (°C) between the first and second decade (c, units: °C).

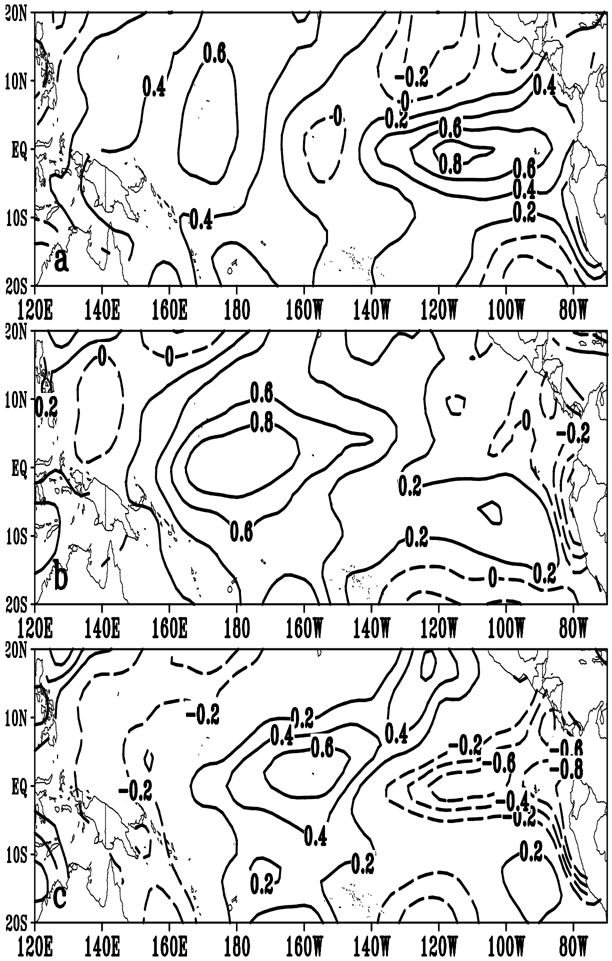


Figure 9. SST of the equatorial Pacific for the winter (DJF) of 2004 (a) and 2005 (b) relative to that of 1978–2006 (°C) and SST differences between the winter of 2004 and 2005 (c, units: °C).

Over the past 50 years, the following changes have been noted for the SST in the equatorial Pacific. First, the location of warming shifted from Niño3 (90–150°W, 5°S–5°N) westward to Niño3, 4 (90–170°W, 5°S–5°N), while the warming concentrates in Niño4 (150°W–150°E, 5°S–5°N) since the 21st century. Second, a pseudo-ENSO episode occurred in the winter 2004–2005, in which warming took place in Niño4 and equatorial western Pacific while cooling happened in the equatorial eastern and western parts of the Pacific[23]. Signals began emerging in 2003, 2005 and early 2007 that pointed to SST anomalies on the quasi-2-year scale in the sub-surface layer of the equatorial central and eastern Pacific, or a pseudo-ENSO episode (Qian et al.[2]). For the three of the warmest winters in 2003, 2005 and 2007 in the equatorial central Pacific, floods occurred in the Huaihe River basin in the summers of these years, i.e., summer precipitation is relatively more. For colder water that occurred in 2002, 2004 and 2006 in the equatorial central and eastern Pacific, summer precipitation is normal or relatively less in this basin. Figures 9a and 9b give the SST anomalies in the equatorial Pacific for the winter of 2004/2005 (DJF) relative to those of the time 1978–2006. It is now clear that 2004 is the year when warming took place in the equatorial western and eastern Pacific with slight cooling in the equatorial central Pacific while 2005 is the year when warming happened in the equatorial central and eastern Pacific, i.e. a pseudo-ENSO episode occurred. It is shown in the differences of wintertime SST between 2004 and 2005 (Figure 9c) that the positive SST anomalies in the equatorial central Pacific are in sharp contrast to the negative ones in the equatorial western Pacific and eastern Pacific, as shown in the modes of anomalous SST distribution along the equatorial Pacific during the pseudo-ENSO episode. The distribution of SST anomalies described above for the equatorial Pacific during the winter can also explain the amount of anomalous rainfall in the Junes of 2004 and 2005 in the south of China.

6 CONCLUDING REMARKS

(1) In the monsoon region of East Asia, June is the month when precipitation from the regional monsoon concentrates in the south of China, though the rainfall is marked with significant interdecadal and interannual variations. 1980–1989 is the time of less decadal precipitation while 1992–2001 is the period of more decadal precipitation, in the south of China. 2004 is the year with extremely less rainfall while 2005 is the year with extremely more rainfall, in the south of China over the period 1951–2006.

(2) Centered on the decadal precipitation anomalies in the south of China, consistent distributions of June precipitation anomalies exist from Vietnam, which is in the western section of the rim around South China Sea, to the south and southeast of China. An opposite spatial distribution of June precipitation is found in 2004 and 2005; precipitation—with the center in the south of China—is anomalously less for June 2004 in the southeast coast of China, south of China and Burma while it is just the opposite in June 2005.

(3) For either the interdecadal or interannual scale, anomalous southeasterly (northwesterly) winds for positive (negative) precipitation anomalies reached Vietnam while anomalous southwesterly (northeasterly) winds arrived at the coast of south and southeast China. Such anomalous 850 hPa circulation can well explain the effect of moisture transported from the ocean on the south of China and nearby areas.

(4) In the winter and spring prior to the positive (negative) decadal precipitation anomalies, SST anomalies appeared in the western North Pacific, as

relatively strong (weak) Kuroshio Current affected the coast of eastern China. In June 2005, positive precipitation anomalies in the south of China appeared in response to a pseudo-ENSO episode in the preceding winter over the equatorial central Pacific. By contrast, in June 2004, negative precipitation anomalies in this part of China reacted to the negative anomalies in the equatorial central Pacific and positive anomalies at the eastern and western end of the equatorial Pacific.

In the current work, a set of high-intensity rainfall dataset was used that covered the south of China and its surrounding areas including the Indochina Peninsula. This work not only studied the anomalous distribution of decadal and extreme interannual precipitation in the south of China, but also revealed the simultaneous relationships between the June precipitation in the south of China and circulation anomalies and the lagging relationships between the former and SST anomalies. The responsible mechanisms need to be studied further. It is noteworthy that since the end of the 1970s, the south of China precipitation has been extremely less and then more on the decadal scale over a time from 1951 up to the present while the extreme interannual rainfall was less in 2004 and more in 2005. Does it suggest that both the extreme decadal and interannual climatic anomalies are increasing in the annually first rainy season in the south of China? It deserves more intensive study.

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