Vol.19 No.4 JOURNAL OF TROPICAL METEOROLOGY December 2013

Article ID: 1006-8775(2013) 04-0375-13

RELATIONSHIP BETWEEN WINTERTIME THERMAL CONTRAST OVER THE ASIAN CONTINENT AND THE CLIMATE IN CHINA

LIANG Hong-li (梁红丽)[1], YAN Hong-ming (晏红明)[2], XU Yan-yan (许彦艳)[1], DUAN Wei (段 玮)[3]

(1. Yunnan Meteorological Observatory, Kunming 650034 China; 2. Climate Center of Yunnan, Kunming 650034 China; 3. Meteorological Science Institute of Yunnan, Kunming 650034 China)

Abstract: Recent studies indicated that except for the land-sea thermal contrast, there also existed the land-land thermal contrast. The composite analysis and *t*-test method are used to further study the local thermal contrast variation over the Asian continent, and to discuss the association of seasonal variation of land thermal state with circulation over East Asia, the early summer and summer monsoon activity, and the precipitation anomaly in China in the decadal scale. Results show that the positive meridional temperature anomaly transports downward from upper tropospheric layers in middle-high latitudes north of 25°N in the positive years. In the zonal direction, the Tibetan Plateau heating in the successive spring acts as a force to influence the atmosphere, leading to the rapid temperature warming over eastern Chinese continent, which could increase the land-sea thermal contrast with the negative SSTA. Accordingly, the monsoon activity in early summer over East Asian establishes earlier and the summer monsoon intensity becomes stronger. The early summer precipitation is more-than-normal over the Yangtze River, and the summer precipitation is more-than-normal over the north China and the southwest China. The situation is contrary in the negative years.

Key words: land-sea thermal contrast; *t*-test method; Asian continent; monsoon activity; circulation; precipitation anomaly

CLC number: P461.2 **Document code:** A

1 INTRODUCTION

The land-sea thermal contrast resulting from land-sea distribution plays an important role in the conversion of monsoon circulation[1, 2]. Many works have investigated the effects of meridional land-sea thermal contrast over East Asia on the formation of the tropical monsoon[3, 4], especially the thermal and dynamic influence of the Tibet Plateau. Zhang et al.[5] and Qian et al.[6] were the first people to discuss the effects of zonal land-sea thermal contrast on summer monsoon. Recently, Qi et al.[7] analyzed the seasonal characteristics of zonal land-sea thermal contrast between East Asian continent and the western Pacific, and suggested that thermal contrast's seasonal cycle resulting from solar radiation was the most possible reason for independent existence of subtropical East Asian monsoon. He et al.[8] further proposed that the foundation of tropical summer monsoon was mainly dependent on the variation of meridional land-sea thermal contrast, and subtropical monsoon was more dependent on the reversion of zonal land-sea thermal contrast over East Asia, meanwhile he claimed that seasonal transition of zonal land-sea thermal contrast between the Asian continent and western Pacific was important to both East Asian subtropical and tropical summer monsoons.

Sea surface temperature anomaly (SSTA) in the tropical ocean, a main energy region, is an important factor in climate change. El Nino-southern oscillation (ENSO) in the tropical ocean is one of the strongest signals of interannual climate anomaly, and many researches have focused on its variation and impact since 1980[9-12]. In the last decade, dipole-like SSTA in tropical Indian Ocean and its effect on climate has been widely studied and become a hot issue in meteorological studies[13-20]. As another factor, thermal anomaly in land is also of the same importance to monsoon formation and climate change[21-24]. Tang et al.[25] investigated the relationship between surface temperature and summer precipitation in China, and the results showed that the variation of surface temperature in winter is closely related to the precipitation in the following summer.

Received 2012-10-19; **Revised** 2013-09-05; **Accepted** 2013-10-15

Foundation item: Natural Science Fund projects of China (40675045, 41065004); NSFC-Yunnan Joint Foundation (U0833602); National Public Benefit Research Foundation of China (GYHY201206017)

Biography: LIANG Hong-li, professor, primarily undertaking research on synoptics and climate.

Corresponding author: LIANG Hong-li, e-mail: lhl1678@163.com

Cheng et al.[26] claimed that the variation of strength and location of the subtropical high over western Pacific is related with not only the SST but also surface temperature in the Asian continent. Tian et al.[27] proposed that the surface temperature in Tibet Plateau is closely related with the variation of rain belt location in China, especially in May. The Asian continent is the largest land and its thermodynamic property has great diversity in different areas. Based on the NCEP/NCAR reanalysis data from 1948 to 2000, Yan et al.[28] noticed that the decadal variation of surface temperature over Eastern Asia and Southern Asia is much different and there are also evident decadal characteristics with the variation of monsoon circulation, 500 hPa height field, and air temperature from low to high level.

To deeply understand the characteristics of regional thermal contrast over the Asian continent and their impact on monsoon and climate, we further analyzed, based on the NCEP/NCAR reanalysis data from 1950 to 2008, the seasonal variation of meridional and zonal land thermal contrast in different thermodynamic anomaly years, and its relationship with the thermal contrast in meridional and zonal vertical circulation during the early summer and summer in East Asia, monsoon activity, precipitation during early summer and flood seasons in China.

2 DATA AND METHODS

The data used in the work are (1) the NCEP/NCAR 2.5°×2.5° monthly reanalysis from 1950 to 2008, including air temperature, vertical velocity and horizontal wind, and (2) surface temperature and precipitation of 160 stations in China. Because early summer is a key season of monsoon transition, the early/late onset of monsoon has a close relationship to the rainfall variation during the annually first rain season in Southern China and precipitation in the beginning stage of Yunnan's rainy season. The monthly mean from December to the following February represents the winter, the monthly mean from March to April represents the spring, May represents the early summer, and the monthly mean from June to August represents the summer. The climatological mean takes a 30-year average from 1961 to 1990.

To express the difference between extreme and general climatic years, the *t*-test method is used[29]. Set m the general year and n the extreme year, and the means of a particular meteorological element are denoted by $\overline{x^c}$ and $\overline{x^a}$ respectively, $t=\dfrac{\overline{x^c}-\overline{x^a}}{s(\frac{1}{n}+\frac{1}{m})^{\frac{1}{2}}}$ obeys the *t*-distribution and the degree of freedom is $n+m-2$, the unbiased estimator of difference variance is s^2, $s^2=\dfrac{\sum_{i=1}^{n}(x_i^c-\overline{x^c})^2+\sum_{i=1}^{m}(x_i^a-\overline{x^a})^2}{n+m-2}$, where x_i^c and x_i^a denote the elements in general and extreme years respectively.

3 THERMAL CONTRAST OVER THE ASIAN CONTINENT IN WINTER AND ATMOSPHERIC CIRCULATION ANOMALIES

The EOF analysis method is used to analyze winter surface temperature over Eurasia, and the results show that its spatial distribution has two principal modes; the first mode (with a total variance contribution of 47%) reflects, to a certain extent, the thermal difference over the North and South Eurasia, and the second mode (with a total variance contribution of 15%) indicates that the surface temperature over Northeast and South Asia has significantly opposite variation. It is closely connected with South and East Asian monsoon on the decadal scale. In this paper, we further discussed the variation characteristics of surface temperature over Northeast and South Asia and the relationship with atmospheric circulation changes.

3.1 *Characteristics of wintertime thermal contrast over the Asian continent*

Following Yan et al.[28], we defined a thermal contrast index with surface temperature difference between South Asia (15–30°N, 75–100°E) and Northeast Asia (30–50°N, 100–130°E). Fig. 1a presents the variation and 11-year running means of the thermal contrast index for the winters in South-Northeast Asia from 1950/1951 to 2007/2008. We can see that thermal difference is relatively large and the surface temperature over South Asia is 3.5℃ higher than that of Northeast Asia in 1952/1953, 1954/1955, and 1956/1957. However, it is 2.0℃ lower than that of Northeast Asia in 1991/1992, 1992/1993, 1994/1995, 1996/1997, and 2006/2007.

During the past 58 years, the thermal variation over South and Northeast Asia exhibits significant interdecadal features. The index is positive in 1950/1951–1971/1972, but negative in 1972/1973–2007/2008. The analysis with discrete power spectrum verifies that its most significant periodic variation is in the decadal scale with a remarkable period of 14.7-year (Fig. 1b). Following the observation, Mu et al.[30] pointed out that the atmospheric circulation variation has distinct interdecadal characteristics, manifesting quasi-periodical oscillations of both 10–20 years and more than 30 years. The periodic variation is generally consistent with that of thermal difference over Eurasia.

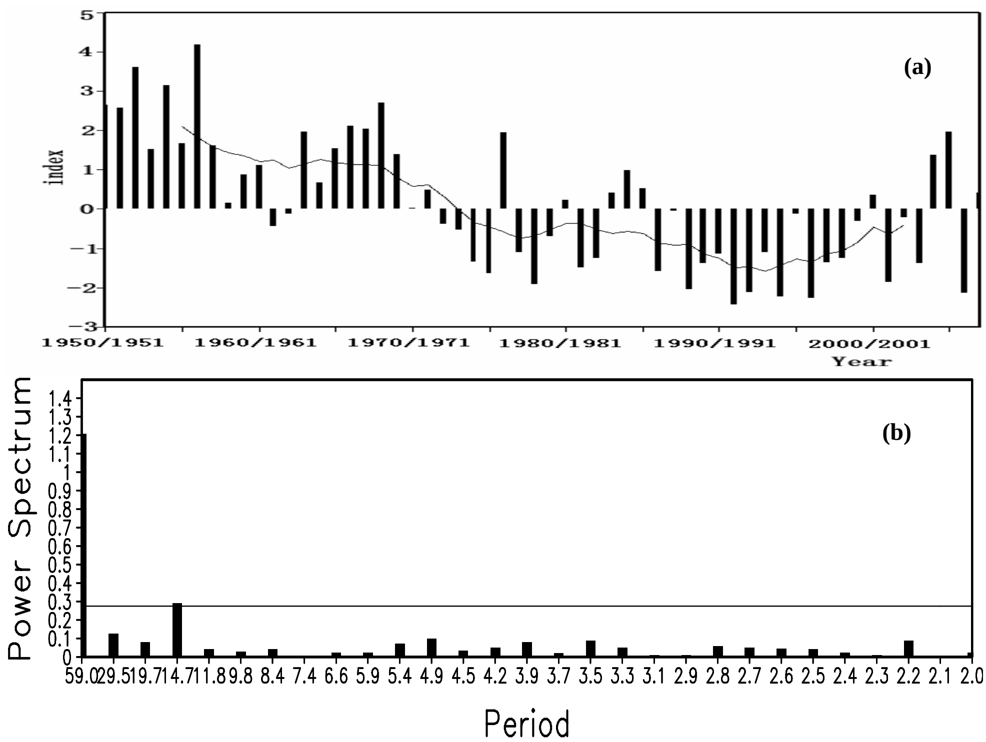


Figure 1. (a) Histogram and curve of 11-year running means of disperse power spectrum and (b) winter thermal contrast index in the Asian continent from 1950/1951 to 2007/2008.

3.2 *Characteristics of wintertime circulation in the years of positive and negative index*

When the East Asian winter monsoon builds up, the cold air intrudes southward with the northeast gale extending to the lower latitude. In general, the anomalous variations of meridional wind at 850 hPa can explain the strong northerly associated with cold air bursting from higher latitudes[3]. Fig. 2a and 2b show the composite of winter wind anomaly at 850 hPa and *t*-test distributions in positive and negative categories. The changes in the wind field are quite different in the two categories. Precisely, the evident northerly is prevailing over the coastal area of East Asian mainland in the positive years, and then it flows through Indochina Peninsula (IP) to extend southward to the northeastern Bay of Bengal (BOB). The difference of wind variation is significant in Hunan, Hubei and northeastern BOB. There is abnormal anticyclonic circulation over the Mongolia and the northern BOB, whereas the anomalous cyclonic circulation is over the South China Sea (SCS). Contrarily, the middle-lower Yangtze valley is occupied by an abnormal cyclonic circulation in the negative years and there is anomalous southerly to the north that does not pass the significance test. Simultaneously a significant cyclonic anomaly appears over the northern BOB.

The winter monsoon onset process is characterized by cold air advancing from north to south resulting in both strengthened northerly and decreased temperature. Therefore, the anomaly of land surface temperature also can describe the strength of winter monsoon. It can be mutually verified by comparing the observation from stations (Fig. 3a and 3b) with NCEP/NCAR reanalysis (Fig. 3c and 3d) datasets. The anomalous surface temperature distribution of 160 stations indicates that the difference of interdecadal variation of winter temperature is significant over the Chinese mainland. In the positive group, the temperature anomaly over the Chinese mainland is negative except the southwestern region, and a significance level of more than 95% is in parts of Inner Mongolia, Great Bend of Yellow River, Northeastern and Northwestern China, where the anomalous temperature is distinctly lower (Fig. 3a). In the negative group, the temperature anomaly is positive over most of Chinese mainland with a significance level of greater than 95% in most areas. Especially, the centers of abnormal temperature with the significance level greater than 99% are situated in parts of the middle-lower Yangtze basin, Northeastern and Northern China, coast of Southern China and Southwestern China (Fig. 3b). In addition, the composite results obtained from reanalysis datasets (Fig. 3c and 3d) demonstrate that, in the positive category, the surface temperature anomaly is significantly negative over Eastern China and positive over South Asia. In the negative group, however, the surface temperature anomaly is positive in the eastern part of East Asia but negative in South Asia. The surface temperature anomaly is significant to the north of Yangtse River. The composite, based on the two kinds of datasets, could produce similar results, confirming the consistent spatial structure and interdecadal characteristics of surface temperature anomaly in the positive and negative categories.

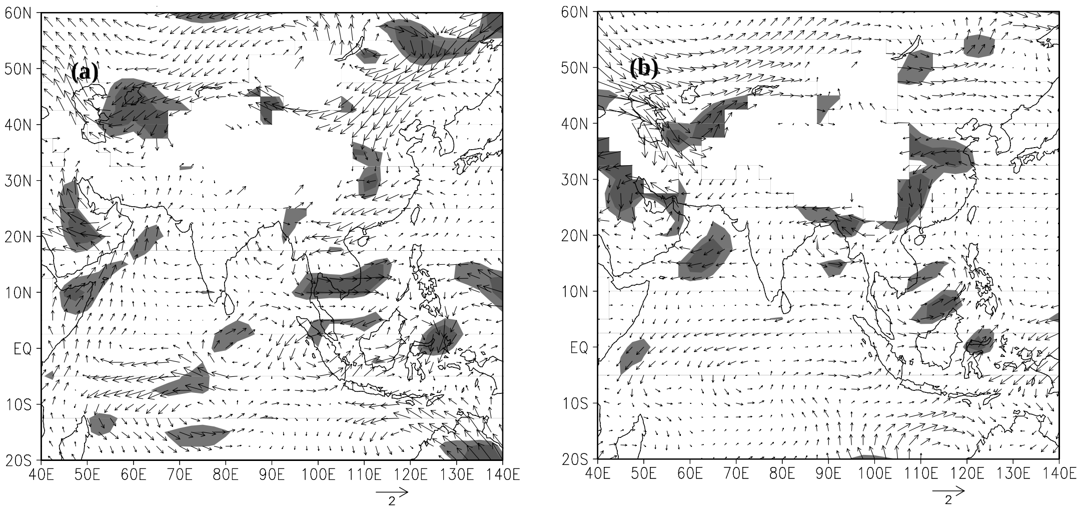


Figure 2. (a) Positive and (b) negative index years of composite winter wind anomalies at 850 hPa (units: m/s) and significant areas of *t*-test (shading stands for significance level, light shade: α=0.05, dark shade: α=0.01).

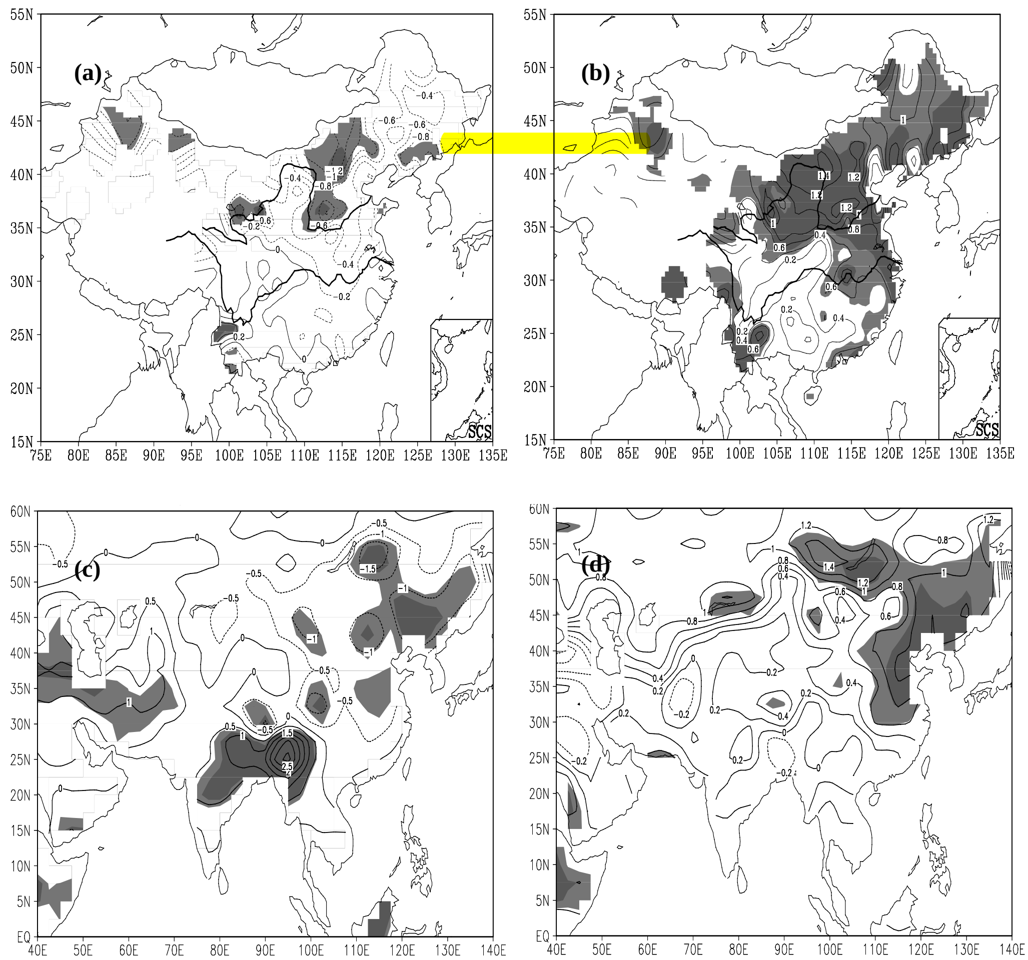


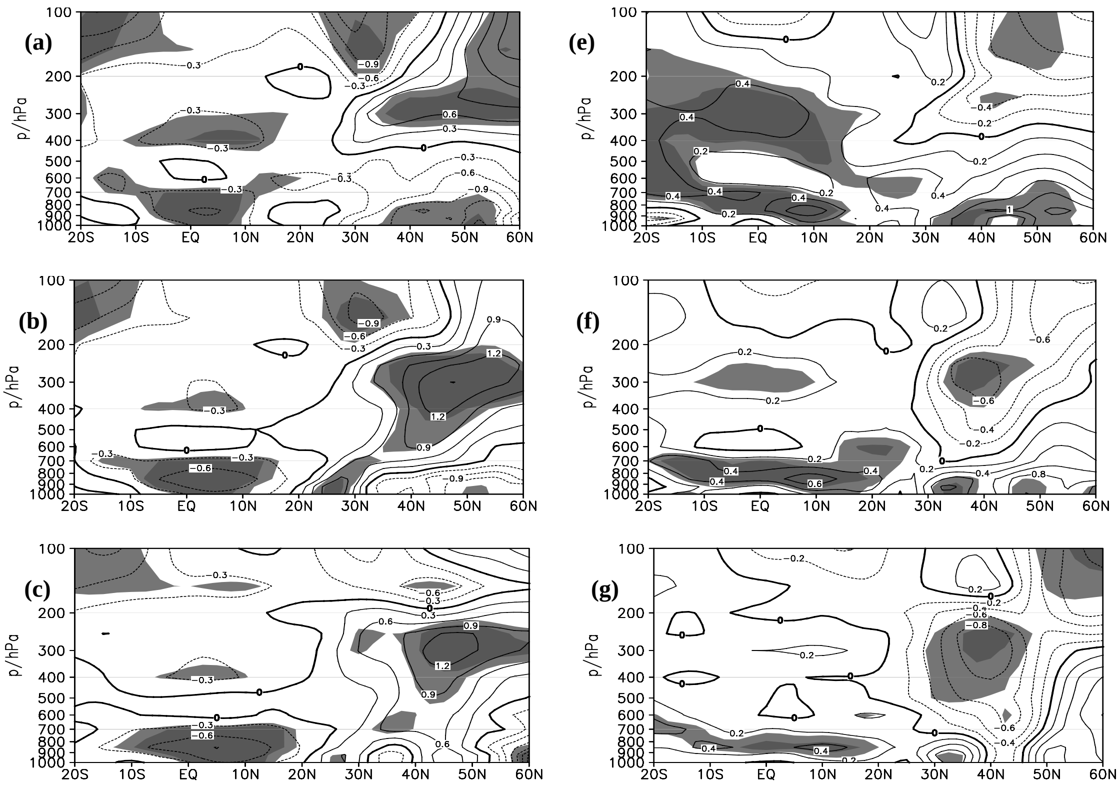
Figure 3. Composite fields of positive and negative index years of winter surface temperature anomaly (units:℃) made with records from 160 stations in China (a, b) and NCEP/NCAR reanalysis data (c, d) and significant areas of *t*-test (other captions as in Fig. 2).

4 RELATIONSHIPS OF LOCAL THERMAL CONTRAST CHANGES WITH THE MERIDIONAL AND ZONAL CIRCULATION

As seasonal variation of land-sea thermal contrast is one of the important factors influencing the monsoon onset, the relationships of the variation of local thermal contrast with the meridional and zonal circulation will be further discussed in this section.

4.1 *Anomalies of thermal contrast*

In East Asia, the variation of meridional land-sea thermal contrast plays a crucial role in monsoon circulation. Fig. 4 shows the 110–115°E averaged pressure-latitude cross section of air temperature anomalies in winter, the following spring, early summer and summer, respectively. In the positive group, the significant anomalies of air temperature are positive in the middle and high latitudes to the north of 25°N in the upper troposphere, but negative on middle and lower levels (35–55°N). In this period, air temperature anomalies are negative over the tropical ocean, and the meridional land-sea thermal difference in the lower troposphere is not noticeable in winter (Fig. 4a). In spring, a negative anomaly area shrinks in the middle and high latitudes of lower troposphere, and the positive anomalies of air temperature occur near 30°N. The air temperature anomalies are positive at the middle and high latitudes of mid- and upper-troposphere and gradually extend toward lower latitudes on the lower level, but they are significantly negative in the tropical marine area (Fig. 4b). In early summer, the air temperature anomalies are positive below 200 hPa over the East Asian continent but negative above it, and the tropical marine area is controlled by negative anomalies (Fig. 4c). In summer, positive anomalies are enhanced significantly in the middle and high latitudes of East Asia, accompanied by the maximum of about 2.0°C, and the significant area expands, implying that the thermal effect is stronger than that of the previous period. In the middle and low latitudes, the air temperature anomalies still remain negative (Fig. 4d). In a word, in the positive category, the air temperature changes from cold to warm in the East Asian continent from winter to summer, and the positive anomalies of air temperature expand downward from the upper troposphere to the area north of 25°N, but they always maintain negative in the tropical marine area. The seasonal variation of land thermal effect is evidently stronger than that of the ocean. In summer, the meridional land-sea thermal contrast is enhanced to favor the strengthening of East Asian monsoons.



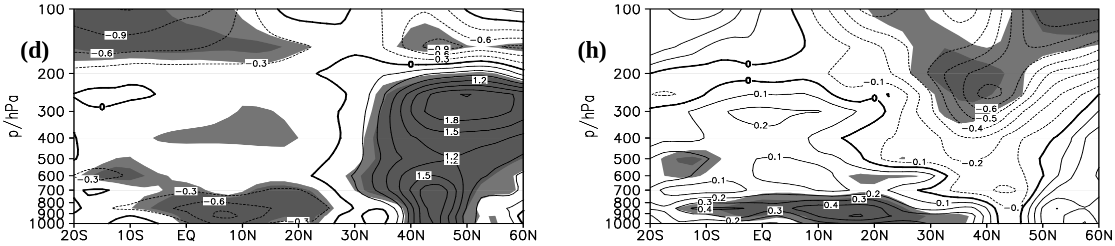
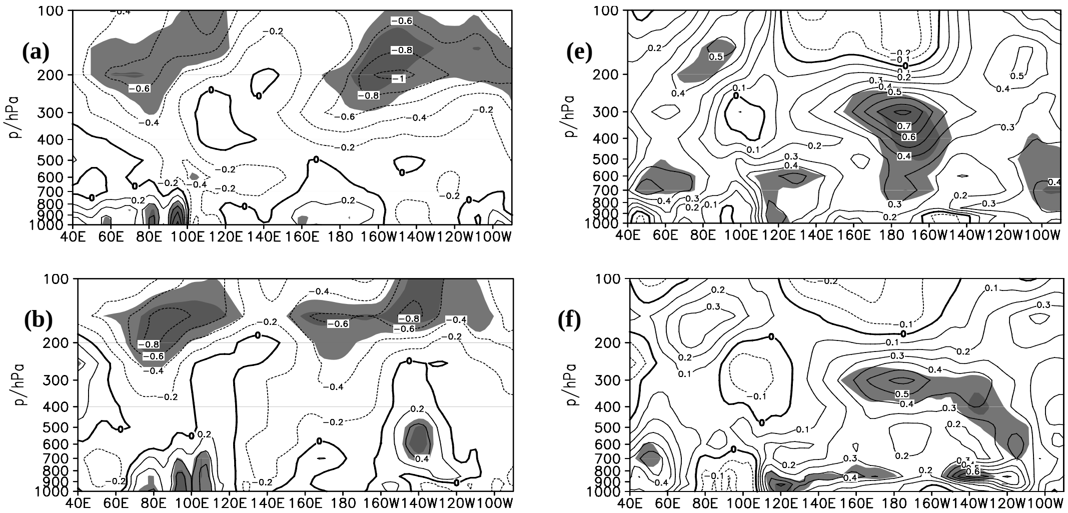


Figure 4. Positive (a–d) and negative (e–h) index years of height-latitude section composite fields of temperature anomaly in 110–115 °E from winter to the successive summer (℃, from top to bottom), and significant areas of *t*-test (other captions as in Fig. 2).

In the negative category, the air temperature anomalies are mainly negative in winter in the upper troposphere to the north of 25°N, but positive on middle and low levels. On the tropical marine area they are positive in the lower troposphere with significance greater than 99% (Fig. 4e). From spring to summer the negative anomaly area in the upper troposphere at middle and high latitudes gradually extends to the lower levels, which is occupied by positive anomaly in winter. However, they always maintain positive over the tropical ocean (Fig. 4f–4h). It was found that the air temperature anomalies change from warm to cold on the East Asian continent from winter to summer, while they always maintain positive on the tropical ocean. Generally, the air blows from the ocean to the land on lower levels in summer because of the warmer land and colder ocean. Thus such seasonal variation will decrease the land-sea thermal contrast to weaken the East Asian monsoon circulation.

Moreover, the zonal land-sea thermal contrast is also very important for the variation of monsoon circulation[3, 8]. Here the characteristics of changes in zonal thermal contrast at 20–35°N are presented in Fig. 5. Considering the topography of Tibetan Plateau, we focus on the thermal characteristics of the mid- and upper-troposphere. In the positive and negative categories, the decadal variation of air temperature anomalies is different from winter to summer, leading to the different feature of zonal land-sea thermal contrast. In the positive category, the anomalies are both negative in the mid-upper troposphere in winter (Fig. 5a). In spring, the positive anomaly begins to appear on middle and low levels over the eastern Tibetan Plateau and gradually extends upward and westward with seasonal transition (Fig. 5b). In early summer and summer, the air temperature anomaly is all positive on middle and upper levels from the East Asian continent to Tibetan Plateau to increase the temperature, whereas most areas in the middle and upper troposphere over the ocean is still occupied by negative anomaly at the same latitude (Fig. 5c and 5d). In the positive category, the anomaly of land-sea thermal contrast in the middle and upper troposphere facilitates the air to flow from the ocean to land. Meanwhile it will lead the low-level air to flow from land to the ocean.



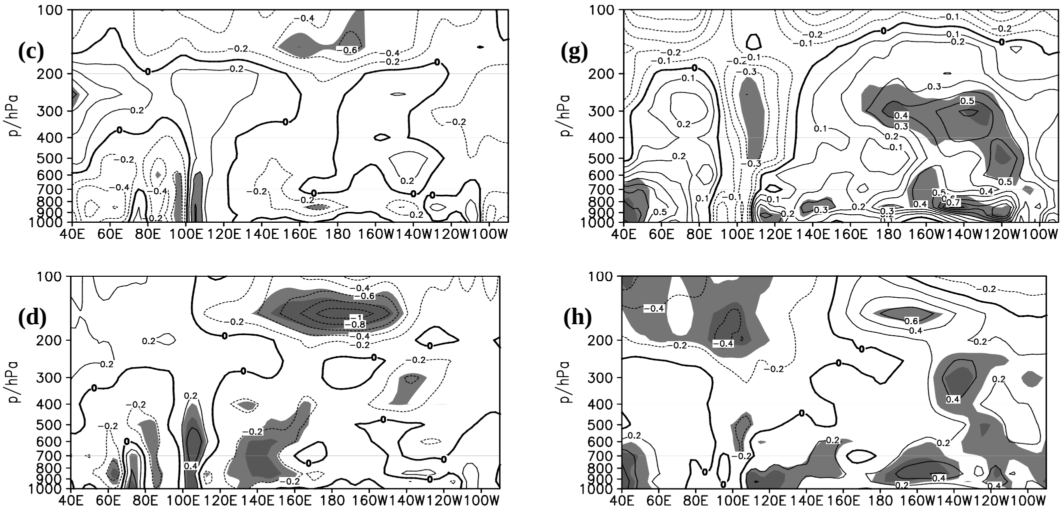


Figure 5. Same as Fig. 4 but along 20–35°N.

In the negative group, the anomaly of zonal thermal contrast in the middle and upper troposphere is generally opposite. In winter, the air temperature anomaly is positive in the middle and upper troposphere from Tibetan Plateau to the East Asian continent (Fig. 5e). During the seasonal transition from winter to summer, the anomalously positive areas are replaced by the negative ones, which gradually extend upward from the low level over eastern Tibetan Plateau (Fig. 5f and 5g). In summer, the air temperature anomaly is negative over most of the continent in the middle and upper troposphere (Fig. 5h). However, the air temperature anomaly in the ocean is not obvious from lower to upper levels, especially in the middle troposphere, but it is both significantly positive from winter to summer. The abnormal variation of land-sea thermal contrast on the middle and upper levels favors air flow to move from land to the ocean, but it helps low-level air flow from the ocean to land.

The results mentioned above show that the seasonal variation of thermal condition on the Asian continent is always apparent, whereas the variation above the ocean is relatively weak with significant continuity. As a result, to discuss the reason for the anomaly of monsoon variation, it is desirable to examine the variation of land thermal contrast.

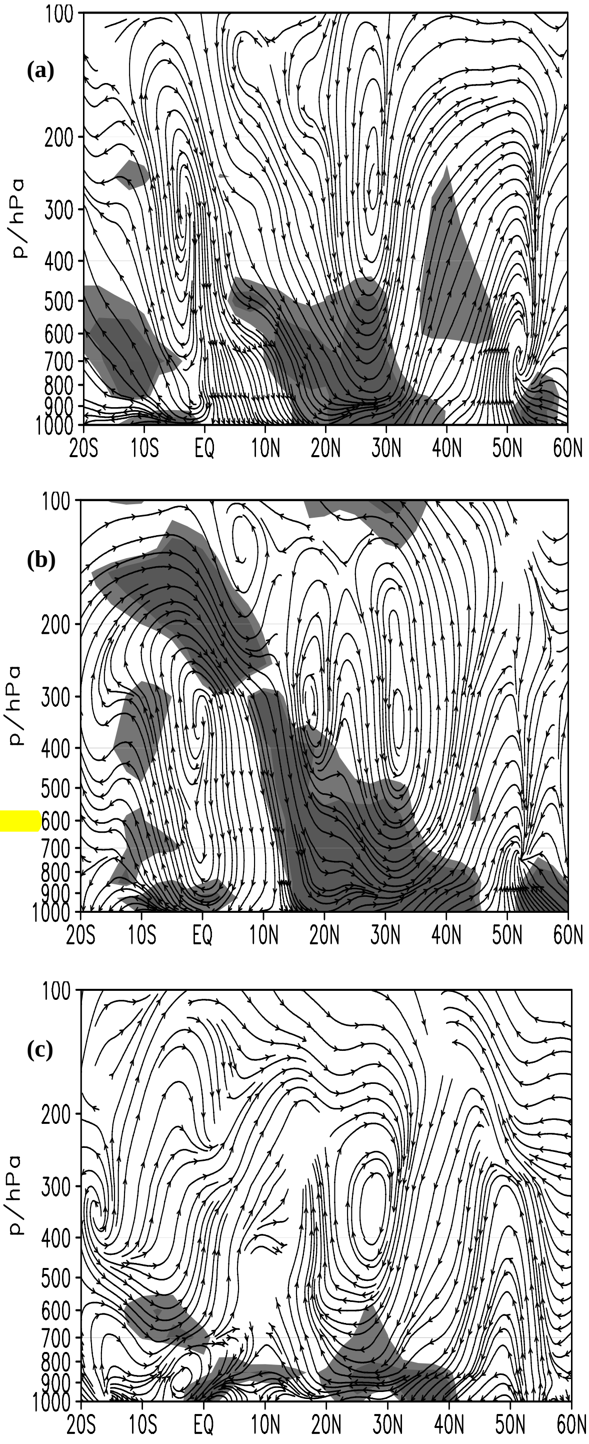
4.2 *Abnormal vertical circulation*

The difference of meridional and zonal thermal variation can affect the circulation anomaly. Based on the above analysis, the meridional and zonal land-sea thermal contrast variations are distinctly different between the positive and the negative category. Fig. 6a to 6d provide the 110–115°E averaged pressure-latitude cross section of vertical circulation anomaly fields (with the vertical velocity enlarged 100 times) in the successive early summer and summer in the positive and negative categories. It can be seen that an anticlockwise circulation is near 20–30°N in the troposphere with its center near 250 hPa in early summer in the positive category. There is southerly anomaly on the lower level but northerly anomaly on the upper level. Note that the southerly anomaly is more significant (Fig. 6a). In summer, the anticlockwise circulation center near 20–30°N moves northward to 32°N, and there is also anomalous anticlockwise circulation in the upper troposphere near 15–23°N. Meanwhile, the south wind anomaly strengthens obviously near 15–45°N on middle and lower levels with an extended area of 99% significance (Fig. 6b). In the negative group, the changes in abnormal vertical circulation are just contrary. In summer, the anomalous clockwise circulation is near 20–30°N with the center located at 300 hPa. In the mid-lower troposphere, there is significant anomalous northerly flowing from the middle and higher latitudes to the equator (Fig. 6c). The anomalous clockwise circulation of 20–30°N moves to 32°N and the cyclone center ascends to 200 hPa, while the abnormal lower northerly strengthens and flows from the middle latitude to the equator. Besides, the significance of northerly anomaly along 30–42°N is more than 99% (Fig. 6d). Since the seasonal variation of monsoon circulation mainly manifests as abnormal change in the wind field on the upper and lower levels, the variation characteristics of abnormal circulation shows that the abnormal circulation could advance the East Asian summer monsoon onset and lead to stronger summer monsoon activity in early summer and summer of positive index years. The situation is contrary in the negative category.

By comparing Fig. 4 with Fig. 6, we know that the abnormal variation of meridional thermal difference on the upper and lower levels is consistent with the vertical circulation. The heating increments of middle and high latitudes in East Asia are remarkable in early summer and summer of the positive index years. The positive anomaly is significant from the lower to upper levels, but the lower thermal variation over the tropical marine area is not obvious. Instead, the area is dominated by a negative temperature anomaly from winter to summer. In early summer and summer, this abnormal variation of meridional thermal difference further strengthens the land-sea thermal contrast to enhance the summer monsoon. Contrarily, this variation in the negative index years decreases the thermal contrast to weaken the summer monsoon.

Likewise, we further discuss the abnormal variations of zonal circulation on the upper and lower levels. Fig. 7 shows the pressure-longitude section of anomalously vertical circulation along 20–35°N (the vertical velocity is enlarged by 100 times) in the successive early summer and summer of positive and negative index years, respectively. With the abnormal variation of thermal difference on the upper and lower levels, the vertical circulation also presents different variation. The anomalous anticlockwise circulation is located over the eastern Tibetan Plateau with the center at 400–300 hPa near 106°E in the successive early summer of positive index years. There is anomalous upper-level easterly but abnormal lower-level westerly with the significance more than 95% from 85°E to 120°E (Fig. 7a) in the middle and lower troposphere. In summer, with the temperature further increasing over eastern Chinese mainland (Fig. 5d), the center of anomalous circulation moves eastward to 116°E, and the significance exceeds 95% on both the upper and lower levels (Fig. 7b). However, the anomaly variation is contrary in the negative index years. There is anomalous clockwise circulation situated above the eastern Tibetan Plateau with its center at 500–400 hPa near 105°E in the successive early summer, accompanied by the upper westerly and lower easterly anomalies. Note that the significance is more than 95% from 80°E to 107°E on the middle and lower levels (Fig. 7c). Subsequently, the temperature in summer over eastern Chinese mainland further decreases (Fig. 5h) to cause the center of anomalous circulation to move westward, with the anomalous westerly wind appearing on the upper level, and the significance is more than 95% on the middle and low levels (Fig. 7d).

As shown in the characteristics of anomalous zonal circulation, in the successive early summers of positive/negative index years, there is anomalous anticlockwise (clockwise) circulation over the eastern Tibetan Plateau, and it moves eastward (westward) in summer, and there is anomalous easterly (westerly) at the upper level, but anomalous westerly (easterly) at the lower level. The circulation in positive (negative) index years could advance (postpone) the establishment of the East Asian monsoon in early summer, subsequently strengthening (weakening) the intensity of summer monsoon.



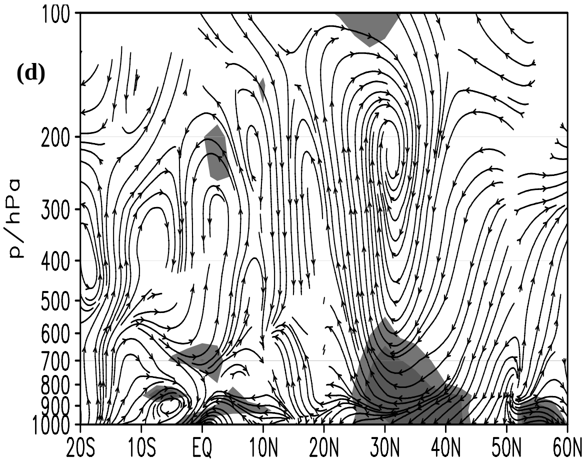
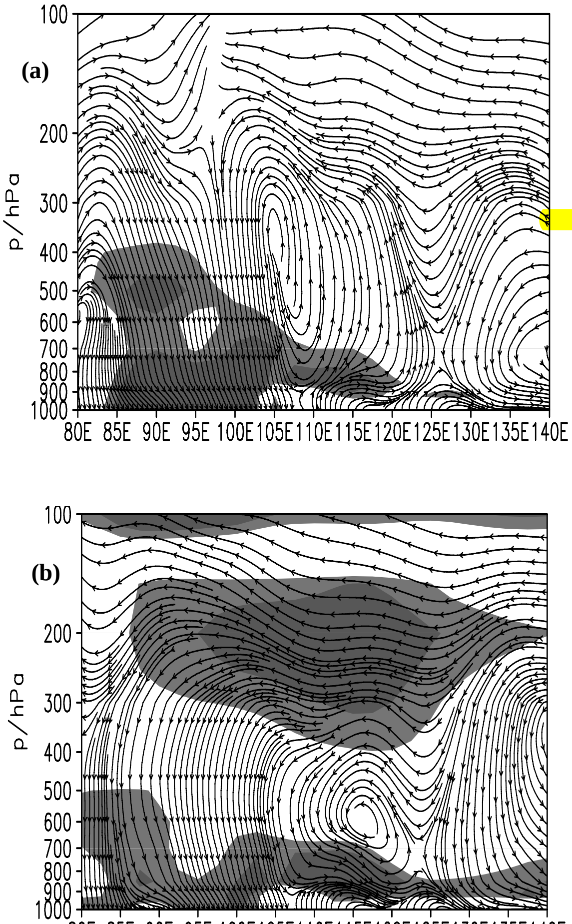


Figure 6. Positive (a–d) and negative (e–h) index years of latitude-height section composite fields of anomalous vertical circulation along 110–115^{o}E in the successive early summer and summer and significant areas of *t*-test (other captions as in Fig. 2).



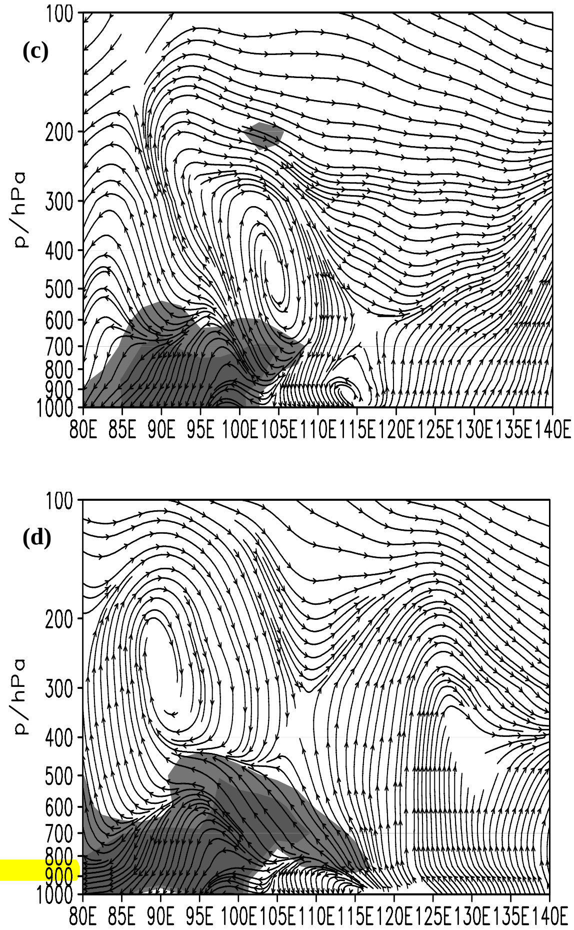


Figure 7. Same as Fig.6 but for the thermal contrast index and along 20–35°N.

5 RELATIONSHIP OF WINTERTIME THERMAL CONTRAST OVER THE ASIAN CONTINENT WITH PRECIPITATION IN CHINA

The ascending motion is dominant between 27.5–35ºN over the eastern Asia in climatology[3], and the subtropical summer monsoon prevails in this region. The abnormal variation of thermal difference and circulation over this region must have effect on the precipitation over Yangtze River and Yangtze-Huaihe valley. As analyzed above, the characteristics of thermal and circulation over Eastern Asia are distinctly different in positive and negative index years. To assess the influence of thermal contrast on precipitation, the variation features of precipitation in China will be investigated for corresponding years.

5.1 *Relationship with early summer precipitation in China*

The early summer is the key season for monsoon transition, because the summer monsoon onset is directly related to the start of precipitation and rainy season over South China. For example, at the beginning of early summer rainfall over South China (early April to late May), it is the frontal precipitation, which is comparatively stable and the rain amount is not very large. During the late period (late May to the middle ten days of June), the precipitation increases evidently due to the arrival of summer monsoon and the rainfall is featured by the monsoon precipitation[3]. The rain season of Yunnan generally begins in the middle ten days of May and the precipitation in May is closely associated with monsoon transition in early summer. Therefore, it is important to discuss the relationship between the seasonal transition of circulation and the precipitation for investigating the cause of precipitation anomaly.

Figure 8 presents the 850 hPa anomalous wind and precipitation anomaly of 160 stations in China in the successive early summers of positive and negative index years, respectively. Evidently, there is remarkable south wind anomaly in East Asia continent in the positive index years, and the significance is more than 99%, implying the earlier establishment and stronger intensity of early summer monsoon in East Asia. It helps increase the early summer precipitation over southern China, consistent with the anomalous thermal field as well as the variation of vertical circulation in the meridional and zonal direction. It is noteworthy that the Somali cross-equatorial flow passes through the coast of East Africa and southern Arabian Sea to converge with an anomalous cross-equatorial flow near the eastern equator over the BOB, and then the merged flow crosses the IP to the East Asian continent. It indicates that the enhancement of early summer monsoon over East Asia is closely related with the Somali cross-equatorial flow and the cross-equatorial flow near the equatorial BOB between 90–100°E (Fig. 8a). Simultaneously, there are positive rainfall anomalies over the Yangtze River basin, Guizhou and southern Yunnan, and the significance in parts of Hunan, Jiangxi and Guizhou is more than 95%. Thus the precipitation in early summer is more than normal (Fig. 8c). Meanwhile, in the successive early summers of negative index years, there is evident anomalous northerly over the East Asian continent with the significance exceeding 99%, demonstrating the postponed and weakened early summer monsoon over East Asia. The rainfall anomaly goes against the climate-mean early summer precipitation over South China. At this moment, the anomalous northerly in the east of East Asia is divided into two branches when moving southwards. One of them flows through the South China Sea and then eastward to the equatorial western Pacific. The other one goes through the IP, BOB and eastern Indian Ocean to the equator (Fig. 8c). However, less-than-normal precipitation is over most of South China in early summer but does not pass the significance test (Fig. 8d).

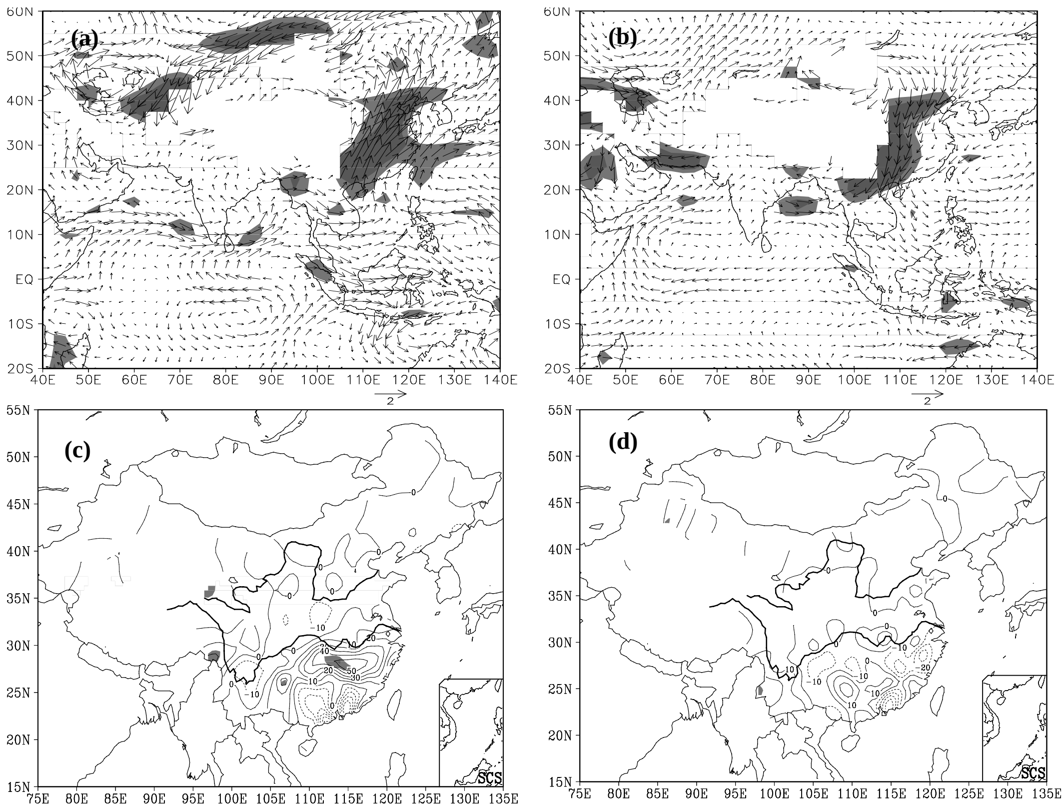


Figure 8. Anomalous wind field at 850 hPa (m/s) in the successive early summer of positive (a) and negative (b) index years and precipitation anomaly of 160 stations in China (c for a and d for b, mm) and *t*-test of significance (other captions as in Fig. 2).

5.2 *Relationship with summer precipitation in China*

Summer is the major rainy season in Northern Hemisphere, including most of China. Here we are mainly concerned with the effect of abnormal variation of monsoon circulation on the summer precipitation.

The anomalous winds at 850 hPa in the successive summer of positive and negative index years are shown in Fig. 9a and 9b. In the positive category, the anomalous southerly over the East Asia continent is sustained from early summer to summer, and the significance exceeds 99%. The summer monsoon is stronger over East Asia, consistent with the anomalous thermal field and meridional and zonal variations of vertical circulation. Meanwhile, the significance of anomalous easterly over the eastern equatorial Indian Ocean is more than 95%. And it is divided into two branches while moving to the north. One that is located over the southern Indian peninsula turns to the BOB, IP and South China Sea, and it is related to the southerly anomaly over the eastern part of East Asia. The other one goes through the BOB, IP and South China Sea to the East Asian continent. The results indicate that the strength of East Asia and South Asia monsoon is closely related to the anomalous easterly over the eastern equatorial Indian Ocean (Fig. 9a). Based on the anomalous precipitation (Fig. 9c), the summer rainfall is more than normal over North China, the east of South China and the most of Southwest China, whereas it is less than normal over Yangtze River basin without passing the significance test. In the successive summer of negative index years, the anomalous northerly over the East Asia in the early summer is sustained to the summer, and the significance is more than 99%. The intensity of summer monsoon is weaker over East Asia. Besides, the anomalous northerly over the East Asian continent is divided into two branches at this time. One flows to the South China Sea and the other passes through the IP, BOB and Indian subcontinent to the Arabian Sea and Indian Ocean, producing weaker Indian monsoon (Fig. 9b). In the negative index years, the rainfall variation indicates that the precipitation is more than normal over the Yangtze-Huaihe valley and the most of South China. It is less than normal over the North Asia and parts of Southwest China, corresponding to the less precipitation (Fig. 9d).

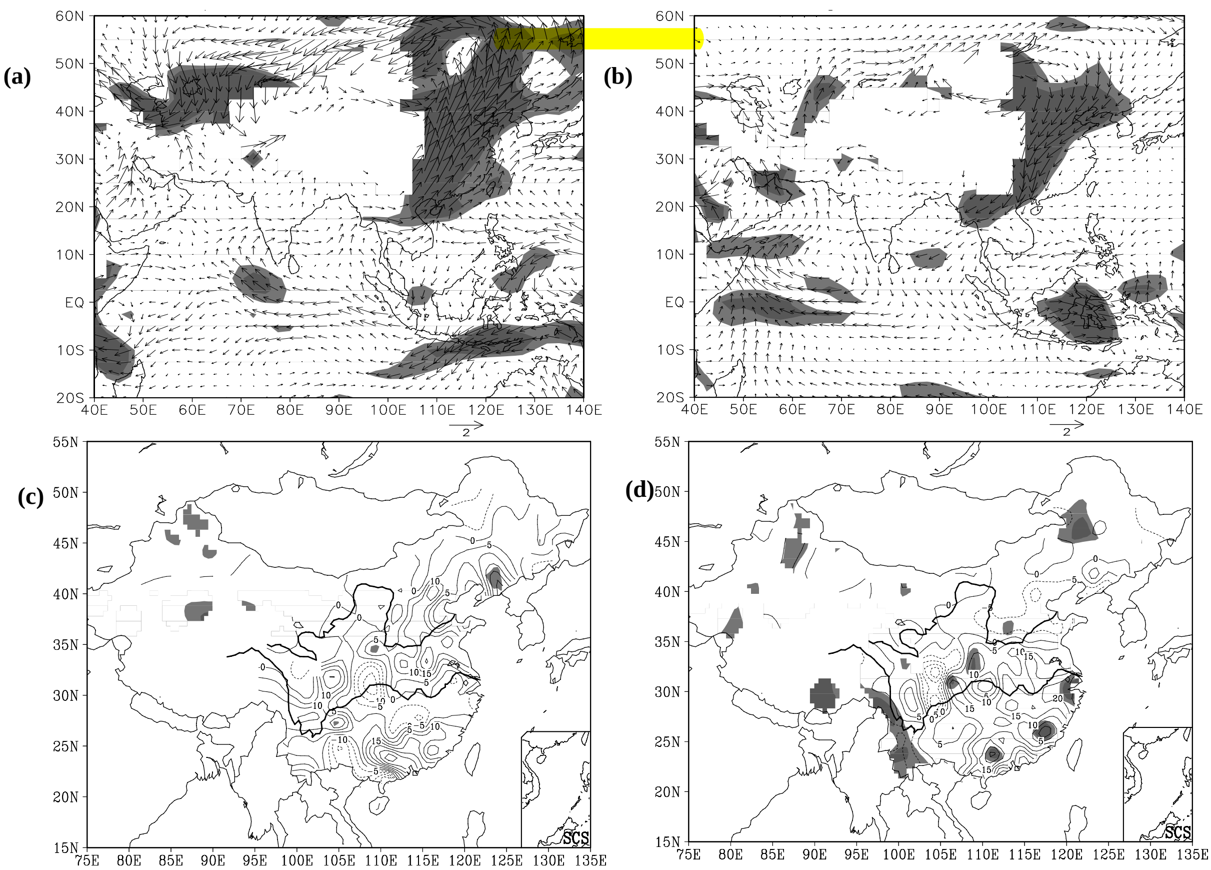


Figure 9. Same as in Fig. 8 but for the successive summer of the positive and negative index years.

6 CONCLUSIONS AND DISCUSSION

The variation characteristics of thermal difference over the Asian continent have been analyzed by the composite and *t*-test methods, and their relationship with land-sea thermal contrast, atmospheric circulation, precipitation anomaly over China in early summer and summer are further investigated. The main results obtained from this work are as follows:

(1) The variation of thermal contrast over the South and Northeast Asia is featured by marked interdecadal variability, which is closely associated with the decadal anomaly of winter atmospheric circulation.

(2) The variations of meridional and zonal thermal difference are significantly different on the upper and lower levels in various thermal difference years. In the meridional direction, the warm temperature anomaly over the East Asia continent changes to cold from winter to summer of the positive index years. There is warm anomaly of air temperature in the upper troposphere at middle and high latitudes to the north of 25°N, whereas a cold anomaly maintains over the tropical marine area. Since the thermal response of land is more significant than that of the ocean, the meridional land-sea thermal difference is very large in summer, facilitating the intensification of East Asia summer monsoon. Oppositely, in the negative index years, the different thermal variation between land and sea decreases the land-sea thermal contrast to weaken the summer monsoon. Furthermore, in the zonal direction, Tibetan Plateau affects the atmosphere as an anomalous heat/cold source in the successive spring of positive/negative index years, and the air temperature warms/cools rapidly over the eastern Tibetan Plateau, but keeps cold/warm over the Western Pacific in spring and summer. As a result, it could strengthen/weaken the intensity of East Asian summer monsoon.

(3) The abnormal variation of thermal difference in the meridional and zonal direction affects the circulation and the rainfall anomaly. In the meridional direction, anticlockwise/clockwise anomalous circulation in the troposphere is at 20–30°N in the successive early summer of positive/negative index years. It moves northward in summer, forming anomalous upper northerly/southerly and lower southerly/northerly. In the zonal direction, there is anticlockwise/clockwise anomalous circulation over the eastern Tibetan Plateau in the successive early summer of positive/negative index years. It moves eastward/westward in summer, corresponding to the anomalous easterly/southerly on the upper level and anomalous southerly/ easterly on the lower level. It can advance/postpone the onset of early summer monsoon over East Asia, and enhance/weaken the intensity of summer monsoon. Accordingly, the early summer precipitation in the Yangtze River basin is more/less than normal in the early summer of positive/negative index years, while the summer precipitation over North China is more/less than normal, and the summer rainfall over the Yangtze River basin is less/more than normal.

Meanwhile, it is shown that in the meridional direction the temperature over the East Asian continent changes from cold/warm to warm/cold during the seasonal transition from winter to summer of positive/negative index years. The positive/negative anomaly of air temperature transmits downward from the upper troposphere at middle and high latitudes to the north of 25°N, and it can affect the meridional land-sea contrast and monsoon activity. Then what is the mechanism for such downward transport of air temperature anomaly? Is it related to sudden stratospheric warming in winter and early spring? These two questions are worth studying in the future.

REFERENCES:

[1] WEBSTER P J. The elementary monsoon [C]. FEIN J S, STEPHENS P L, Monsoons. New York: John Wiley & Sons, Inc., 1987: 3-32.

[2] YOUNG J A. Physics of monsoons: the current view [C]. FEIN J S, STEPHENS P L, Monsoons. New York: John Wiley & Sons, Inc., 1987: 211-243.

[3] CHENG Long-xun, ZHU Jiang-geng, LUO Hui-bang, et al. East Asian monsoon [M]. Beijing: China Meteorological Press, 1991: 1-362.

[4] HUANG R H, ZHOU L T, CHEN W. The progress of recent studies on the variability of the East Asian monsoon and their cause [J]. Adv. Atmos. Sci., 2003, 20(1): 55-69.

[5] ZHANG Yan, QIAN Yong-fu. Thermal effect of surface heat source over the Tibetan Plateau on the onset of Asian summer monsoon [J]. J. Nanjing Inst. Meteor., 2002, 25(3): 298-305.

[6] QIAN Yong-fu, JIANG Jing, ZHANG Yan, et al. The earliest onset area of the tropical Asian summer monsoon and its mechanisms [J]. Acta Meteor. Sinica, 2004, 62(2): 129-139.

[7] QI Li, HE Jing-hai, ZHANG Zhu-qiang, et al. Zonal land-sea thermal contrast seasonal transition and East Asian subtropical monsoon circulation [J]. Chin. Sci. Bull., 2007, 52(24): 2895-2899.

[8] HE Jin-hai, QI Li, WEI Jin, et al. Reinvestigations on the East Asian subtropical monsoon and tropical Monsoon [J]. Chin. J. Atmos. Sci., 2007, 31(6): 1257-1265.

[9] LI Chong-ying. Frequent movement of strong East Asia trough and El Nino occurrence [J]. Sci. China (Ser. B), 1988, (6): 667-674.

[10] LI Chong-yin, MU Ming-quan. El Nino occurrence and sub-surface ocean temperature anomalies in the Pacific warm pool [J]. Chin. J. Atmos. Sci., 1999, 23(5): 513-521.

[11] LI Chong-yin, MU Ming-quan. The relationship with East Asian winter monsoon, warm pool status and ENSO cycle [J]. Chin. Sci. Bull., 2000, 45: 678-685.

[12] LONG Zhen-xia, LI Chong-yin. A numerical study of the summer climatic response in East Asia to positive SSTA with different duration in equatorial eastern Pacific [J]. Chin. J. Atmos. Sci., 1999, 23(2): 161-176.

[13] CHAO Ji-ping, YUAN Shao-yu, CAI Yi. Large-scale air-sea interaction in the tropical Indian Ocean [J]. Acta Meteor. Sinica, 2003, 61(2): 251-255.

[14] CHEN Lie-ting. Zonal anomaly of sea surface temperature in the tropical Indo-Pacific Ocean and its effect on summer

Asia monsoon [J]. Chin. J. Atmos. Sci., 1988, 12 (Spec. Iss.): 142-148.
[15] DENG Ai-jun, TAO Shi-yan, CHEN Lie-ting. The temporal and spatial distributions of Indian Ocean SST and it's relationships with China rainfall [J]. Chin. J. Atmos. Sci., 1989, 13(4): 393-399.
[16] LI Chong-yin, MU Ming-quan. The Dipole in the equatorial Indian Ocean and its impacts on climate [J]. Chin. J. Atmos. Sci., 2001, 25(4): 433-443.
[17] WU Guo-xiong, LIU Ping, LIU Yi-min, et al. Impacts of the sea surface temperature anomaly in the Indian Ocean on the subtropical anticyclone over the western Pacific—Two-stage thermal adaptation in the atmosphere[J], Acta Meteor. Sinica, 2000, 58(5): 513-522.
[18] XIAO Zi-niu, SUN Ji-hua, LI Chong-yin. Influence of the Indian Ocean SSTA on Asian climate during an ENSO period [J]. Chin. J. Atmos. Sci., 2000, 24(4): 461-469.
[19] XIAO Zi-niu, YAN Hong-ming, LI Chong-yin. The relationship between Indian ocean ssta dipole index and the precipitation and temperature over China [J]. J. Trop. Meteor. 2002, 18(4): 335-341.
[20] XIAO Zi-niu, YAN Hong-ming. A numerical simulation of the Indian Ocean SSTA influence on the early summer precipitation of the southern China during an El Nio Year [J]. Chin. J. Atmos. Sci., 2001, 25(2): 173-183.
[21] WANG Yue-nan, HE Jin-hai, JIANG Ai-jun. A study on the climate features of the summer persistence high temperature concentration in Jiangsu province [J]. J. Trop. Meteor., 2009, 25(1): 97-102.
[22] ZHU Xiao-feng, QIAN Yong-fu, NING Liang, et al. An analysis on the climatic features of the rainfall of rain storms in the rainy season in the lower reaches of Yangtze River [J]. J. Trop. Meteor., 2008, 24(2): 136-146.
[23] YE Dian-xiu, ZOU Xu-kai, ZHANG Qiang, et al. An analysis of climatic characteristics of high temperature in the three Gorges area [J]. J. Trop. Meteor., 2008, 24(2): 200-204.
[24] WANG Yong-mei, REN Fu-min, LI Wei-jing, et al. Climatic characteristics of typhoon precipitation over China [J]. J. Trop. Meteor., 2008, 24(3): 233-238.
[25] TANG Mao-chang, ZHANG Jiang, WANG Jin-xiang. A primary method for predicting rainfall amount of flood season by winter's soil temperature [J]. Plateau Meteor., 1987, 6(2): 150-160.
[26] CHEN Yue-juan, ZHANG Hong, ZHOU Ren-jun, et al. Relationship between the ground surface temperature in Asia and the intensity and location of subtropical high in the Western Pacific [J]. Chin. J. Atmos. Sci., 2001, 25(4): 515-522.
[27] TIAN Yong-li, CAO Jie. Study on effect of Asian surface air temperature anomaly on position of rainy belt in Chinese flood season [J]. Plateau Meteor., 2004, 23(3): 339-343.
[28] YAN Hong-ming, QI Ming-hui, XIAO Zi-niu, et al. The influence of wintertime thermal contrast over the Asian continent on Asian monsoon [J]. Chin. J. Atmos. Sci., 2005, 29(4): 549-564.
[29] HUAN Jia-you. Statistic analysis and forecast methods in meteorology [M]. Beijing: China Meteorological Press, 2000: 19-21.
[30] MU Ming-quan, LI Chong-yin. Interdecadal variations of atmospheric circulation. I: Observational analyses [J]. Clim. Environ. Res., 2000, 5(3): 233-241.

Citation: LIANG Hong-li, YAN Hong-ming, XU Yan-yan et al. Relationship between wintertime thermal contrast over the Asian continent and the climate in China. *J. Trop. Meteor.*, 2013, 19(4): 375-387.