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Climatological Characteristics of the Moisture Budget and Their Anomalies over the Joining Area of Asia and the Indian-Pacific Ocean

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ABSTRACT

The climatological characteristics of the moisture budget over the joining area of Asia and the Indian-Pacific Ocean (AIPO) and its adjacent regions as well as their anomalies have been estimated in this study. The main results are as follows.

In the winter, the northeasterly moisture transport covers the extensive areas at the lower latitudes of the AIPO. The westerly and northerly moisture transport is the major source and the South Indian Ocean (SIO) is the moisture sink. In the summer, influenced by the southwesterly monsoonal wind, the cross-equatorial southwesterly moisture transport across Somali originating from the SIO is transported through the Arabian Sea (AS), the Bay of Bengal (BOB), and the South China Sea (SCS) to eastern China. The AIPO is controlled by the southwesterly moisture transport.

The net moisture influx over the AIPO has obvious interannual and interdecadal variations. From the mid- or late 1970s, the influxes over the SIO, the AS, the northern part of the western North Pacific (NWNP), and North China (NC) as well as South China (SC) begin to decrease abruptly, while those over Northeast China (NEC) and the Yangtze River-Huaihe River basins (YHRB) have increased remarkably. As a whole, the net moisture influxes over the BOB and the southern part of the western North Pacific (SWNP) in the recent 50 years take on a linear increasing trend. However, the transition timing for these two regions is different with the former being at the mid- or late 1980s and the latter occurring earlier, approximately at the early stage of the 1970s.

The anomalous moisture source associated with the precipitation anomalies is different from the normal conditions of the summer precipitation. For the drought or flood years or the years of El Niño and its following years, the anomalous moisture transport originating from the western North Pacific (WNP) is the vital source of the anomalous precipitation over eastern China, which is greatly related with the variation of the subtropical Pacific high.

Key words: the joining area of Asia and the Indian-Pacific Ocean, moisture transport and budget, climatological characteristics, anomalies

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1. Introduction

The joining area of Asia and the Indian-Pacific Ocean (AIPO) generally includes the East Indian Ocean (EIO) and the West North Pacific (WNP), whose northern part connects with the Asian continent and the southern part meets with the Australian land mass. The huge warm pool with the highest temperatures in the world exists over this area, where the convection is the strongest, the water vapor content is most abundant and the air-sea interaction is extremely vehement. In the summer, the moisture transportation belt originating from the WNP converges with that coming from Somali through the North Indian

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Ocean (NIO), and then flows to the Asian continent, which directly influences the drought/flood disasters in China (Wu et al., 2006). As such, quantitatively estimating the climatological features of the moisture budgets over the Indian Ocean (IO), the South China Sea (SCS), and the WNP, and the impact of their anomalies on the precipitation patterns in China has become one of the important contents of the "973 Program" [namely, Ocean-Atmosphere Interaction over the Joining Area of Asia and the Indian-Pacific Ocean (AIPO) and Its Impact on the Short-Term Climate Variation in China].

China is located in the Asian monsoon area. The moisture accompanied with the monsoon flow plays a significant role in the moisture balance over the monsoonal regions. Therefore, research on the relationship between the moisture transport and monsoonal precipitation has been of great concern (Xu, 1958; Xie and Dai, 1959; Ding, 1994; Zhou et al., 2008b). The other important aspect of the monsoonal precipitation is concerned with the moisture source. Up to now, there have been many views on the moisture source of the precipitation in the summer of eastern China. Some works emphasized the importance of the moisture from the Bay of Bengal (BOB) and the SCS (Tao and Chen, 1987; He and Murakami, 1983; Chen, 1994; Ding, 1994; Tao and Chen, 1994; Ninomiya, 1999); others thought that the anomalous moisture can be ultimately traced back to the tropical WNP (Simmonds et al., 1999; Zhou and Yu, 2005); in addition, the SCS, the tropical WNP, and the BOB were all considered as the main moisture sources. The westerly moisture from the middle latitudes (though weak) was also regarded as one of the moisture sources of the precipitation in northern China (Huang et al., 1998; Tian et al., 2004).

By far, people still have not acquired a unanimous cognition on the moisture source of the precipitation in eastern China, which is mainly due to the difference of the research objective, region, and period for the investigation. Some works addressed the moisture transport in the climatological condition; others focused on the anomalous conditions. Furthermore, the majority of the previous works confined to eastern China or some certain region, or utilized shorter-length datasets, and only aimed at some typical years. Some results thereby may have a limitation to a degree. The precipitation anomalies in the drought/flood years are directly related with the anomalous moisture transport. Hence, the investigation in this aspect is of crucial significance. In this study, a comparative longer-record reanalysis and observation dataset are used to quantitatively estimate the climatological features of the moisture budget over the AIPO and its adjacent regions as well as their anomalies. The problem on the moisture source, which resulted in the precipitation anomalies in the summer over eastern China, is stressed in the present study. Moreover, the relative contributions for the precipitation anomalies by the IO and the WNP are compared and investigated in detail. The outline of the paper is as follows: section 2 introduces the data and methodology and section 3 describes the climatological features of the moisture transport and budget. Anomalies of the moisture budget and their impact on the precipitation in the summer throughout China are presented in section 4, including inter-decadal and inter-annual variations. Concluding remarks are given in section 5.

2. Data and methodology

The data used in this study consists of the monthly reanalysis (1958–2001) from the European Center of Meteorological Weather Forecast (ECMWF), and the precipitation observation data (1951–2006) at 743 stations of China. In order to make the precipitation data match the reanalysis data, the period from 1958 to 2001 is chosen when processing the composite analysis. Due to the fact that the moisture in the atmosphere is mainly confined in the lower levels of the troposphere, the surface pressure $P_{\rm s}$ is used to remove the impact of topography on the estimation of the whole layer when performing vertical integration, namely excluding the spurious moisture.

3. Climatological features of the moisture transport and budget

The intraseasonal variations of the moisture transport over the AIPO have been investigated in many researches (Tian et al., 2002; Ding and Sun, 2002; Zhou et al., 2005; Qiao and Lin, 2006; Liu et al., 2006) and many similarities have been obtained, which can be briefly summarized as follows. In the winter, the northeasterly moisture transport covers the lower latitude areas of the AIPO (such as the AS, the BOB, and the SCS), which turns into northwesterly/westerly moisture when crossing the equator. Consequently, the moisture is transferred into the SIO and the Australian monsoon region (Fig. 1a). In the summer, the southeasterly moisture transport covers the Australian monsoon region and the SIO in the lower latitude areas. It turns into southwesterly moisture and transfers plenty of moisture to the SCS and eastern China through the AS and the BOB. Moreover, the moisture transport is much stronger than that in the winter (Fig. 1b). The moisture transport over the WNP is an obvious independent system, where the

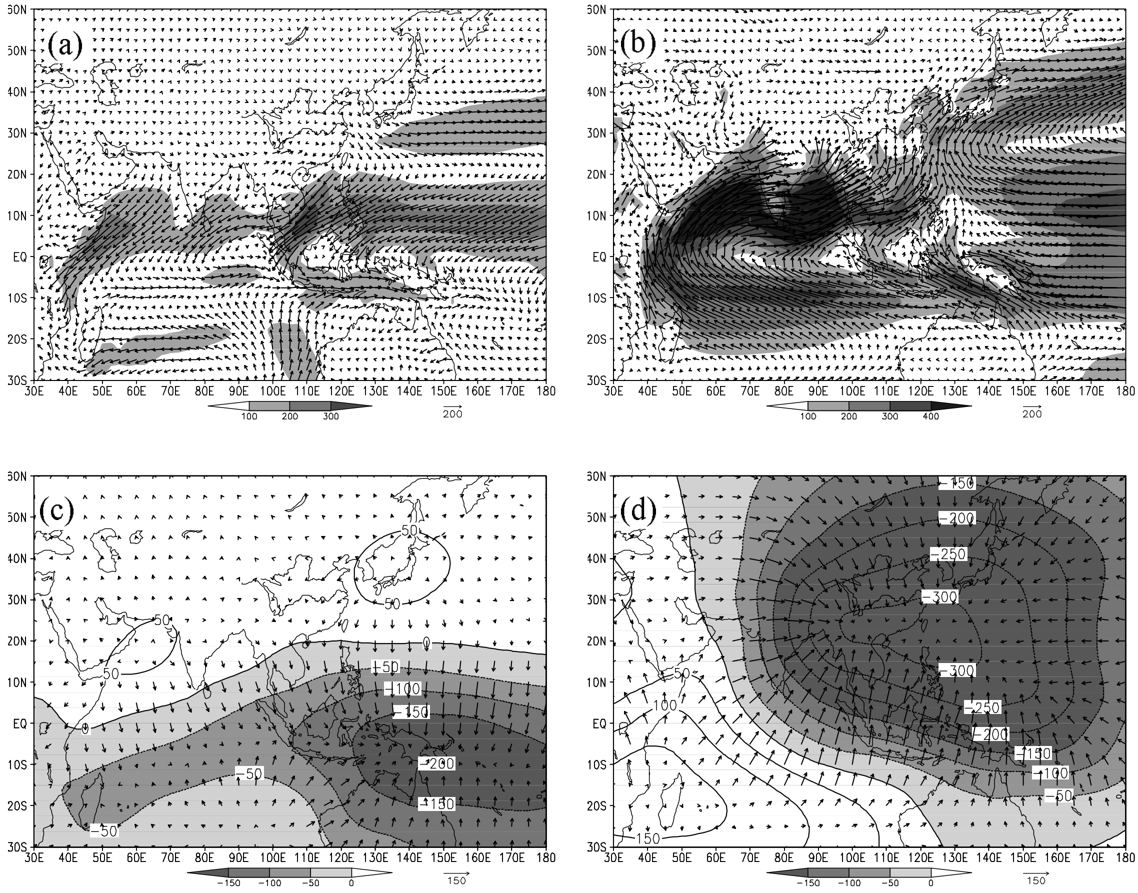

Fig. 1. The climatological mean vertical integrated moisture flux transport over the AIPO (a, b; units：kg m^{-1} s^{-1}) and the moisture potential function values as well as the divergence vectors (c, d; units: 10^6 kg s^{-1}). Solid lines refer to the moisture potential function values and the vectors are the components of the divergence. (a, c) winter, (b, d) summer.

stronger easterly moisture transport dominates the southern part of the WNP (SWNP), while the weaker southwesterly moisture transport dominates over the northern part of the WNP (NWNP). Although the magnitude of the moisture divergent flux is very small in the global moisture transport, it is generally considered as a key indicator of the moisture sources and sinks. As show in Fig. 1c, the center of the moisture convergence is located at the areas from Indonesia to the South Pacific (SP) and the AIPO is under the moisture divergence flow (Fig. 1c). In the summer, the center of the moisture convergence moves northward and locates in the ocean to the east of the Philippines with the value above 300×10^6 kg s^{-1}. It is demonstrated that the tropical oceans, such as the AS, the IO, and the WNP may play a vital role in maintaining the high moisture sinks of the East Asian monsoon region (Fig. 1d).

The regional moisture budget mainly reflects the moisture source and sink, which is determined by the sum of the moisture flux across each boundary. Thus, the climatological features of the moisture budget of the sub-regions in the AIPO domain are quantitatively estimated to establish a complete physical image in the climatological condition. In order to carry out a systematic analysis from the extensive range, the AIPO and its adjacent regions are divided into 10 sub-regions: the AS (0°–22.5°N, 40°–80°E); the BOB (0°–22.5°N, 80°–100°E); the SCS (0°–22.5°N, 100°–120°E); the SIO (30°S–0°N, 40°–120°E); the SWNP (0°–22.5°N, 120°–160°E); the NWNP (22.5°–45°N, 120°–160°E); South China (22.5°–27°N, 100°–120°E); the Yangtze River-Huaihe River Basins (YHRB) (27°–35°N, 100°–120°E); North China (NC) (35°–42°N, 100°–120°E)； and Northeast China (NEC) (42°–54°N, 120°–135°E). Here, the positive and negative values represent the net moisture influx and efflux, respectively. Figure 2 shows the schematic maps of the moisture budget anomalies for these sub-regions in the winter and summer, respec-

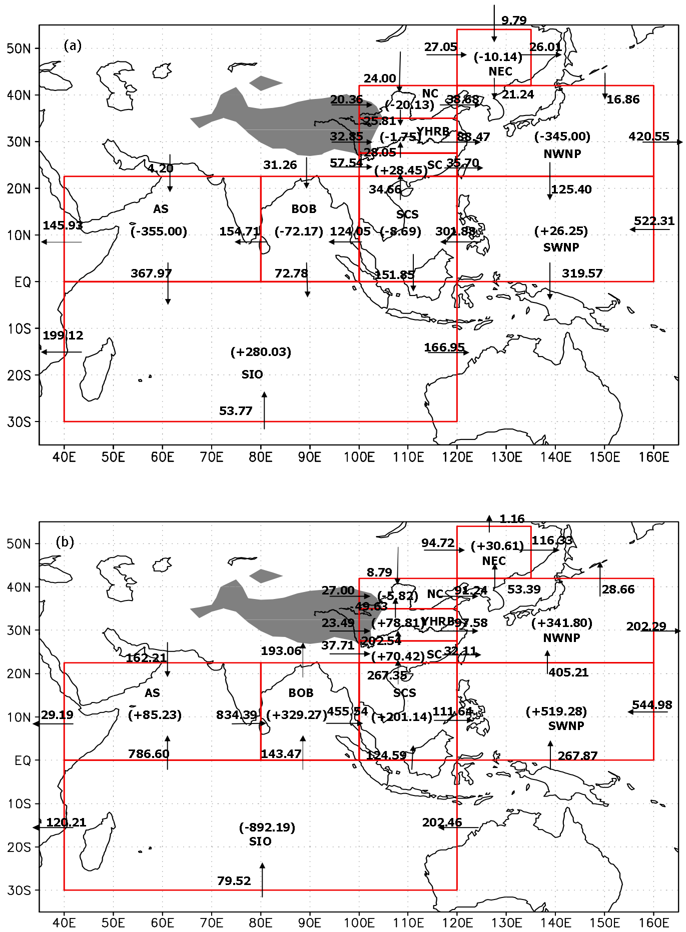

Fig. 2. Schematic maps of the climatological mean moisture budget for the sub-regions over the AIPO in the (a) winter and (b) summer, respectively (units: 10^6 kg s^{-1}). The shaded area refers to the Tibetan Plateau. The positive and negative values represent net moisture influx and efflux, respectively.

tively. It can be noticed that in the winter, the net moisture influx over every sub-region to the north of the equator (except SC and the SWNP) is obviously convergent with the negative values, among which the divergence over the NWNP is the strongest and the value of the net moisture efflux is about 350×10^6 kg s^{-1}. In the meantime, the SIO is the biggest moisture convergent area. Consequently, there is no doubt that the SIO becomes the most prominent moisture sink for the AIPO and its adjacent regions. Therefore, the westerly and northerly moisture transport, especially the westerly moisture transport, seems of great importance in the winter and thereby become the moisture provider for the AIPO. In the summer, influenced by the southwesterly wind, the western and southern boundaries of the BOB and the SCS consistently turn into the westerly and southerly moisture transport. The net moisture influx of the sub-regions to the north of the equator almost becomes positive, which indicates these regions are the moisture convergent areas. At the same time, the moisture efflux over the SIO is the strongest with the peak value of 890×10^6 kg s^{-1}. Opposite to the situation in the winter, the SIO becomes the biggest moisture source for the AIPO and its adjacent regions. Simultaneously, the net moisture influx over the SWNP is the strongest and its value reaches 520×10^6 kg s^{-1}. Although the moisture transportation from the middle latitudes does really contribute somewhat to the moisture budget over eastern China, it is much less related to the westerly moisture from the BOB. It is clearly found that the SIO is the major moisture supplier for the AIPO and the adjacent areas, while in the winter the moisture sources are mainly related with the westerly moisture transportation from the high and middle latitudes.

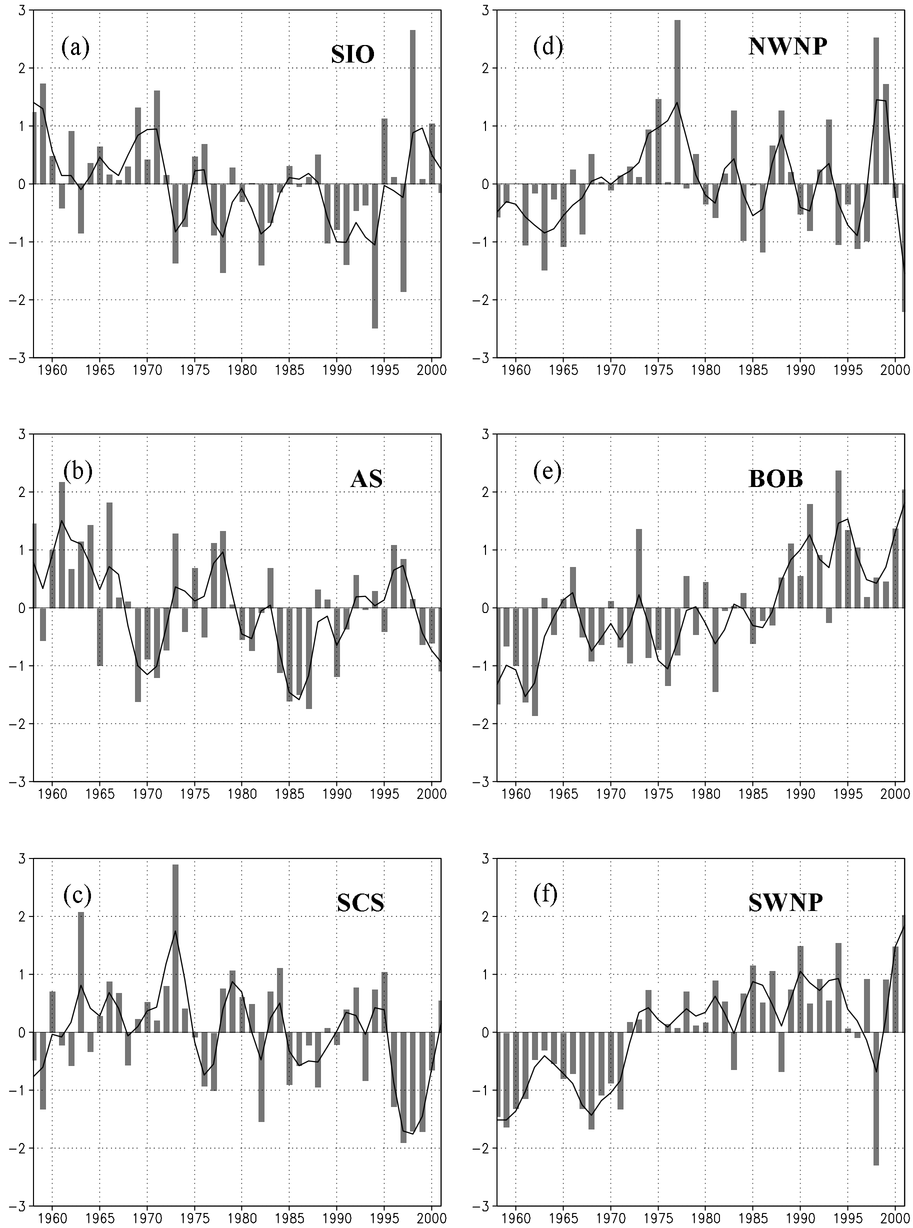

Fig. 3. Time series of the normalized net moisture budget anomalies in the summer for the ocean regions over the AIPO and its adjacent areas (units: 10^6 kg s^{-1}, the solid line refers to the 9 year running mean). (a) the SIO, (b) the AS, (c) the SCS, (d) the NWNP, (e) the BOB, and (f) the SWNP.

4. Anomalies of the moisture budget and their impact on the precipitation in the summer in China

4.1 *Interdecadal variations*

Figure 3 presents the time series of the normalized summer moisture budget anomalies over the sub-regions in the AIPO and its adjacent areas. It is found that the net moisture fluxes over these sub-regions have their own obvious interannual and interdecadal variations, respectively. From the mid- or late 1970s, the net moisture influxes over the SIO, the AS, the SCS, and the NWNP start to decrease abruptly and their values are basically below normal. After the year 1995 or so, the net influx over the SCS decreases more dramatically than the former phase and the values are all below normal. To be mentioned, before the abrupt change at the mid- or late 1970s, there are two stage changes for the NWNP and the AS, namely before and

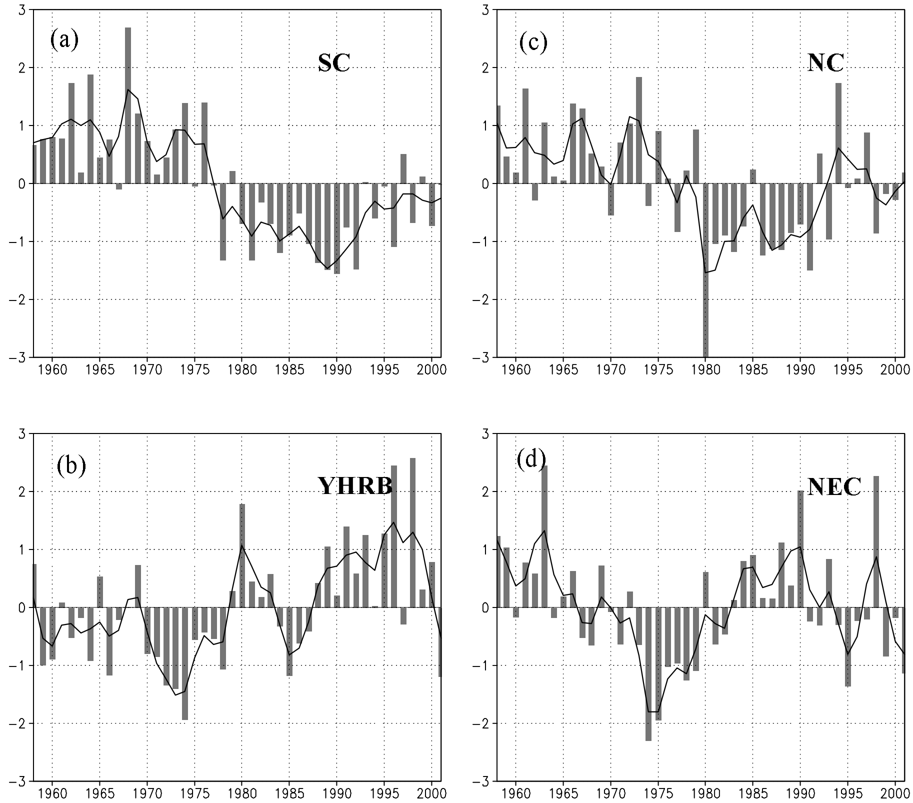

Fig. 4. Same as Fig. 3, but for the regions over eastern China. (a) SC, (b) YHRB , (c) NC, and (d) NEC.

after the year 1970, however the variations over these two regions are reverse. As a whole, the net moisture influxes over the BOB and the SWNP in the recent 50 years take on a linear increasing trend. However, the transition timing for these two regions is different. The former is at the mid- or late 1980s and the latter seems earlier, about at the early stage of the 1970s. Figure 4 shows the time series of the normalized summer moisture budget anomalies for the four regions over eastern China. It can also be observed that at the mid- or late 1970s, the net moisture influxes over SC, the YHRB, and NC simultaneously change. Then, the net moisture influxes in SC and NC abruptly become negative and their values are obviously less than the first stage. While that over the YHRB obviously surpasses the normal value, especially during the last ten years of the twentieth century, the amplitude enhances greatly. Also, a short-term decrease of the net moisture influx occurs from 1984 to 1987. The turning points of the net moisture influxes over these four regions are basically before or after the year 1975, found through using the Man-Kendall statistical test (Figure not shown). For NEC, the change is relatively more complicated. Before the year 1970, the net moisture influx was evidently a bit more. After that, it turns into negative anomalies and then decreases dramatically. Whereas from 1983 to 1993, the net moisture influx over this region is slightly more but the intensity is not that strong. After 1993, the trend is not significant. Change of the net moisture influx is closely related with that of the precipitation. Here, only the interdecadal variations of the net moisture influxes and precipitation over SC, the YHRB, and NC are taken into account. Compared with the variations of precipitation (Fig. 5), the stage change of the net moisture influx over eastern China corresponds to the variation of the precipitation pattern in the summer in the recent 50 years, namely from the drought (in the southern region of eastern China)-flood (in the northern area of eastern China) pattern to the adverse pattern which frequently appears in the recent 20 years. From the end of the 1970s, the main precipitation belt moves from NC, to the YHRB and South China, which leads to a 20-year drought that occurred over NC, thus ultimately changing the precipitation pattern in the summer in China (Zhai et al., 1999; Xu, 2001; Ding and Sun, 2003). From Figs. 5c and 5d, it can be seen that before the end of the 1970s, the location of the subtropical Pacific high is anomalously farther north. The anomalous southerly moisture transport from the

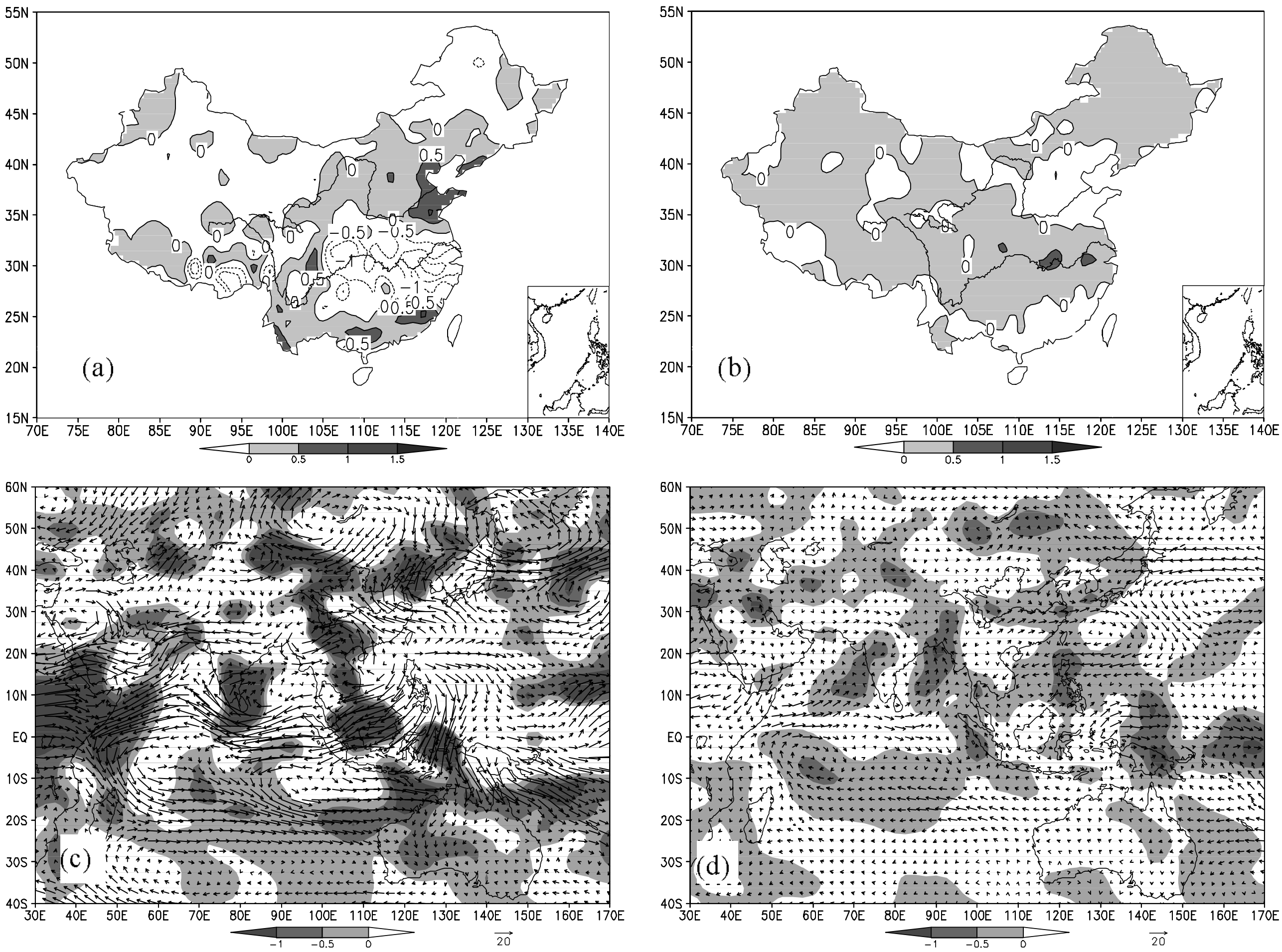

Fig. 5. The distributions of the summer precipitation anomalies (a, b; units: mm d^{-1}) over eastern China and the moisture flux transport anomalies (c, d; units: kg m^{-1} s^{-1}) over the AIPO and its adjacent areas for the periods (a, c) 1958–1978 and (b, d) 1979–2000. In (c) and (d), the shaded areas denote the moisture flux convergent regions.

Huaihe River to NC is dramatic, which converges with the dry/cold moisture in NC, thus making NC a convergent area with a high value. This corresponds to the greater amount of precipitation in NC (Zhou et al., 2008a; Ma et al., 2008). After the end of the 1970s, the location of the subtropical high is anomalously southerly and this kind of southerly moisture transport weakens. Meanwhile, the southwesterly moisture transport at the western flank of the subtropical high is anomalously violent and its front only reaches to the YHRB, not to NC. So, the YHRB is affected by the warm and humid southerly monsoon flow. Based on the above analysis, the interdecadal change of the net moisture influx and precipitation over eastern China actually reflects the weakening stage of the East Asian monsoon, and the interdecadal variations of the location and intensity of the subtropical high (Wang, 2001; Wang et al., 2003a). Comparing the change of these two stages, there is no doubt that the anomalous moisture source of the greater precipitation in NC at the former stage is from the mid-latitude WNP, while that in the YHRB at the latter stage is related with the anomalous moisture transport from the low latitude WNP.

4.2 *Interannual variations*

In the light of the above-mentioned analysis and the previous researches, the cross-equatorial southwesterly monsoonal moisture flow is the most important supplier for the precipitation in the summer in China. However, is this anomalous moisture transport a key factor for the anomalies of the precipitation in the summer in China? How about the contributions by other moisture sources? In the next section, these problems will be deeply discussed through the comparative analysis of the typical cases. It will be favorable for discovering the crucial moisture source, thus favoring further understanding of the mechanism of the formation for the drought/flood pattern in the summer over eastern China and improving the short-term climate prediction.

4.2.1 *Comparative analysis of the typical drought/flood years over the middle and lower reaches of the Yangtze River Basin*

The precipitation in the summer in China has remarkable interannual variations, however this kind of yearly oscillation is not concurrent throughout the whole country. The YHRB is one of the precipitation concentrated regions and also the region where the flood disasters frequently occur. Therefore, discussing the features of the moisture transport and budget over this region has been a hot issue (Xie et al., 2002; Ding and Hu, 2003; Zhuo et al., 2006; Zhu et al., 2007; Shi et al., 2008; Jiang et al., 2008). Different from the previous studies, the qualitative and quantitative analysis of the anomalous moisture source for the precipitation anomalies over the YHRB is comprehensively carried out to perfect the previous results.

In order to choose the drought/flood years conveniently and make the discussion brief, only the middle and lower reaches of the Yangtze River Basin (YRB) is adopted to analyze the difference of the moisture budget over the AIPO and its adjacent areas during the drought/flood years over this region. According to the time series of the normalized summer precipitation anomalies over this region, it is displayed that the interannual variation is very prominent with two-year oscillations, namely positive years and negative years appear alternately (figures not shown). About seven flood years (1954, 1969, 1980, 1983, 1996, 1998, and 1999) and seven drought years (1959, 1961, 1966, 1967, 1972, 1978, and 1985) are obtained based on the standard values. Figure 6 is the composite distributions of the precipitation anomalies in the summer between drought and flood years for this region and the vertically integrated moisture transport flux anomalies as well as their differences. In the flood years, the precipitation anomalies over eastern China take on a negative-positive-negative pattern, with the distinct positive precipitation anomalies over the middle and lower reaches of the YRB as well as the regions to the south (Fig. 6a). At the same time, the anomalous anticyclonic moisture transport exists over the region from the SCS to the WNP (Fig. 6d), whereas the anomalous cyclonic moisture transport appears over the region from NC to the WNP. The remarkably anomalous southwesterly moisture from the WNP through the SCS and the BOB converges with the anomalous northwesterly moisture transport over the middle and lower reaches of the YRB and the region to the south of it, thus leading to much more precipitation over these regions. This anticyclonic-cyclonic anomalous moisture transport pattern in the flood years coincides with the newly researched results (Zhu et al., 2007; Shi et al., 2008). From the composite schematic map of the moisture budget anomalies in the flood years (Fig. 7a), it can be clearly noted that about three branches of anomalous moisture transports (northerly, westerly, and southerly) import over eastern China (except NEC), among which the anomalous southerly moisture transport originating from the WNP through the SCS and SC to the YHRB are two times the northerly moisture from the high latitudes. Although a small part of the anomalous westerly moisture inflow over eastern China comes from the BOB, the value is much lower. Moreover, its moisture source can be tracked up to the SWNP, independent of the AS and the SIO. On the contrary, the composite precipitation pattern in the drought years is completely different form that in the flood years (Fig. 6b). The pattern has the positive-negative-positive distribution. The YRB and the region to the south of it are replaced by significantly negative precipitation anomalies. The cyclonic anomalous moisture transport occurs over the region from the SCS to the WNP. To the north of it is an anticyclonic anomalous moisture transport (Fig. 6e), which suggests the location of the subtropical high is a bit further north than that in the drought years. Thereby, the very powerful and anomalous easterly moisture transport occurs over the Indo-china Peninsula (ICP) with the axes at 10°N. The middle and lower reaches of the YRB and the region to the south of it are controlled by the dominantly anomalous northeasterly and southeasterly descending moisture flow and the moisture influx is evidently less, thus resulting in significantly less precipitation over these regions. Compared with the composite schematic map of the moisture budget anomalies (Fig. 7b), the anomalous moisture importing over eastern China mainly comes from the anomalous easterly moisture originating from the NWNP. The anomalous southerly moisture transport across the northern boundary of the SCS into SC is much weaker, only 1/7 times that in the flood years or so, which is just used to maintain the precipitation there. Also, the YRHB continually feeds the anomalous southerly moisture toward NC. It is just the above-mentioned reason that leads to the negative influx over the YRHB. From their difference distributions (Figs. 6c, 6f), it can be more fairly demonstrated that when the western subtropical Pacific high (WSPH) locates farther south, more precipitation is markedly over the middle and lower reaches of the YHRB and the region to the south of it, otherwise,

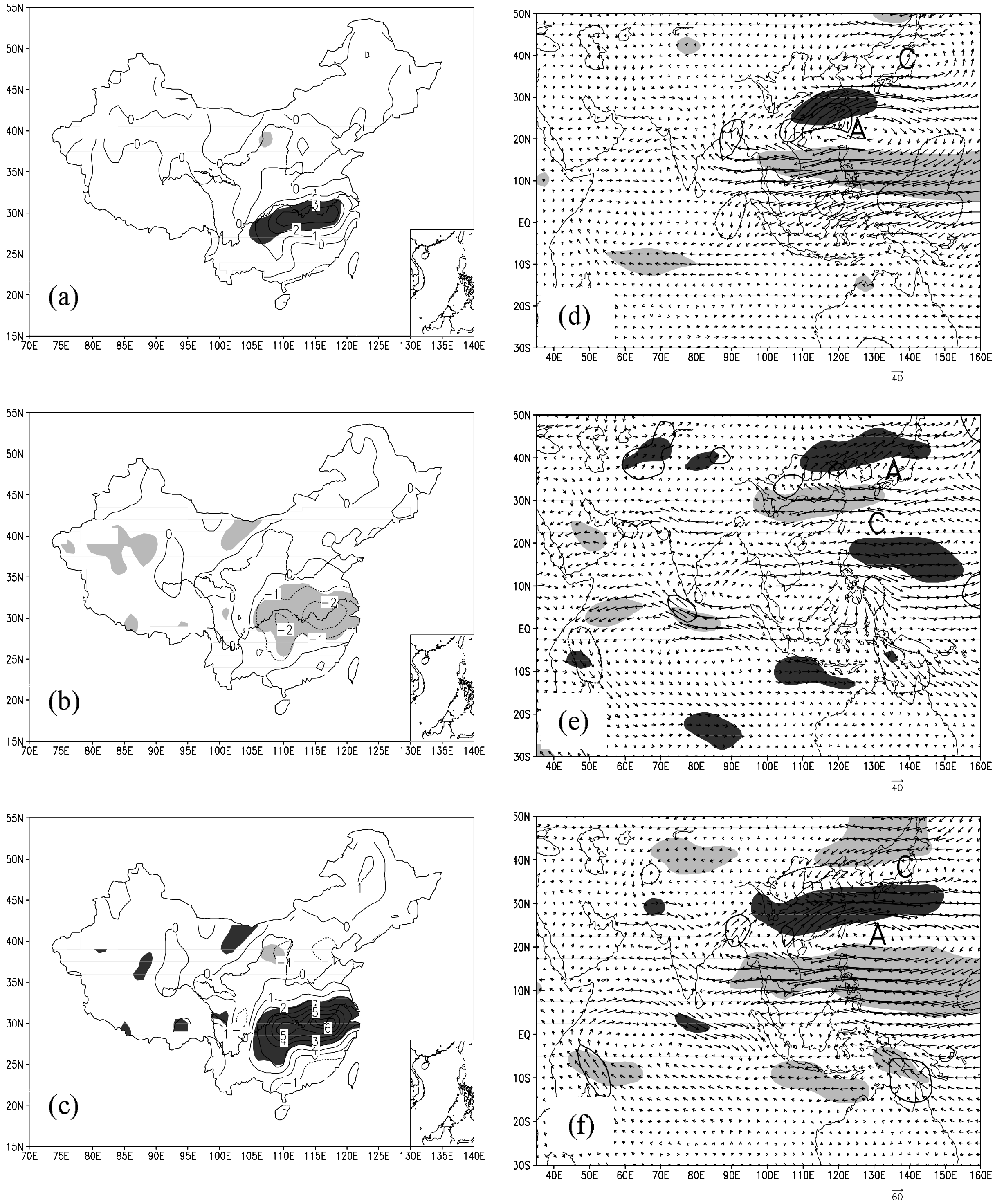

Fig. 6. Composite distributions of precipitation anomalies in the summer in China and the vertical integrated moisture transport flux anomalies (units: kg m^{-1} s^{-1}) as well as their differences between the flood and drought years for the middle and lower reaches of the YRB (units: mm d^{-1}). The shaded areas are significant at the confidence level of 95% using a t-test. On the left column, the isolines denote the precipitation anomalies; on the right column, the vectors denote the moisture flux transport anomalies and the isolines denote that the longitudal wind is significant. (a, d) the flood years, (b, e) the drought years, and (c, f) the flood years minus the drought years.

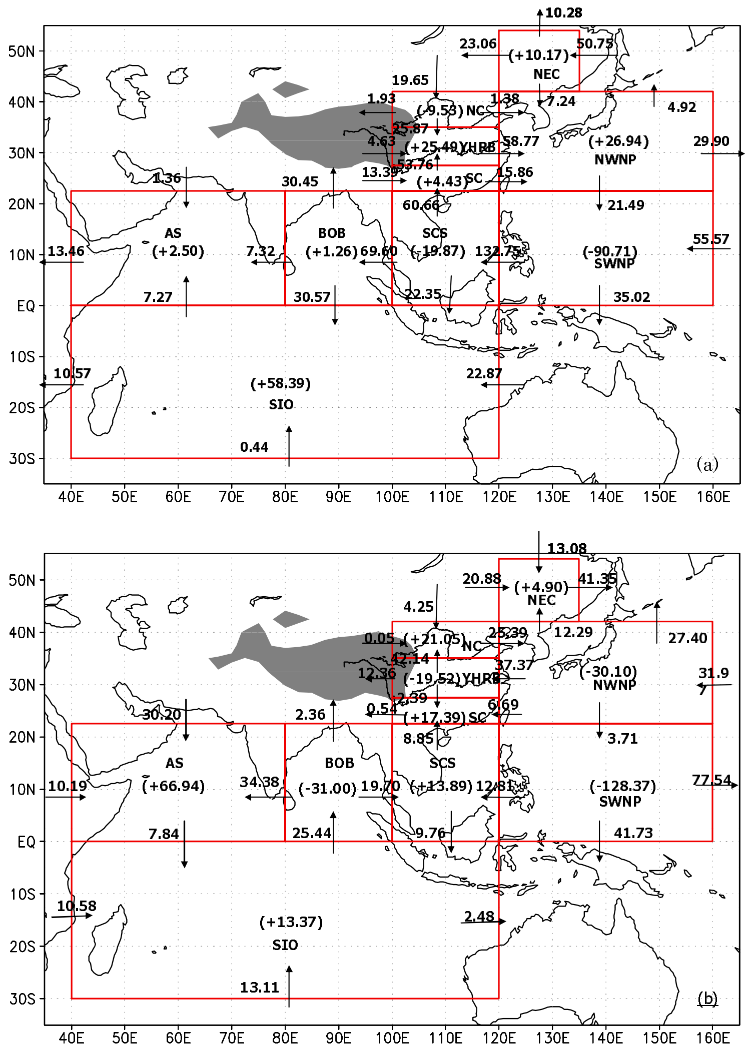

Fig. 7. Composite schematic maps of the moisture budget anomalies in the summer between the flood and drought years for the middle and lower reaches of the YRB (units: 10^6 kg s^{-1}). The shaded area refers to the Tibetan Plateau. (a) the flood years, (b) the drought years.

there is less precipitation. To sum up, whether the drought or flood years, the anomalous moisture transport originating from the WNP is the major supplier for the anomalous precipitation over eastern China, which is greatly related with the variation of the WSPH. When the WSPH is located farther north, the anomalous easterly moisture transport from the WNP in the middle latitudes is the provider for the greater precipitation in NC; otherwise, the anomalous southwesterly moisture at the western flank of the WSPH is the major source for the precipitation anomalies over the YRHB. The above results clearly illuminate again that the WSPH has a deciding influence on the distribution of precipitation in the summer over eastern China (Wu et al., 2002; Shi et al., 2008).

4.2.2 *Analysis of the years and following years of the El Niño events*

El Niño as one of the strongest interannual climate signals, has remarkable impacts on China's climate (Liu and Ding, 1995; Yao and Li, 1995). Because the tropical oceans are the vital moisture sources for the summer precipitation in China, their interannual variations are necessarily affected by El Niño events. At the present, the studies in this aspect are still scarce, which will be stressed in the following section.

In the light of previous works (Gong and Wang, 1999; Zhai et al., 2003; Wang et al., 2003b), about twelve significant warm episodes (1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1987, 1991, 1994, and 1997) occurred in the recent 50 years. We took the

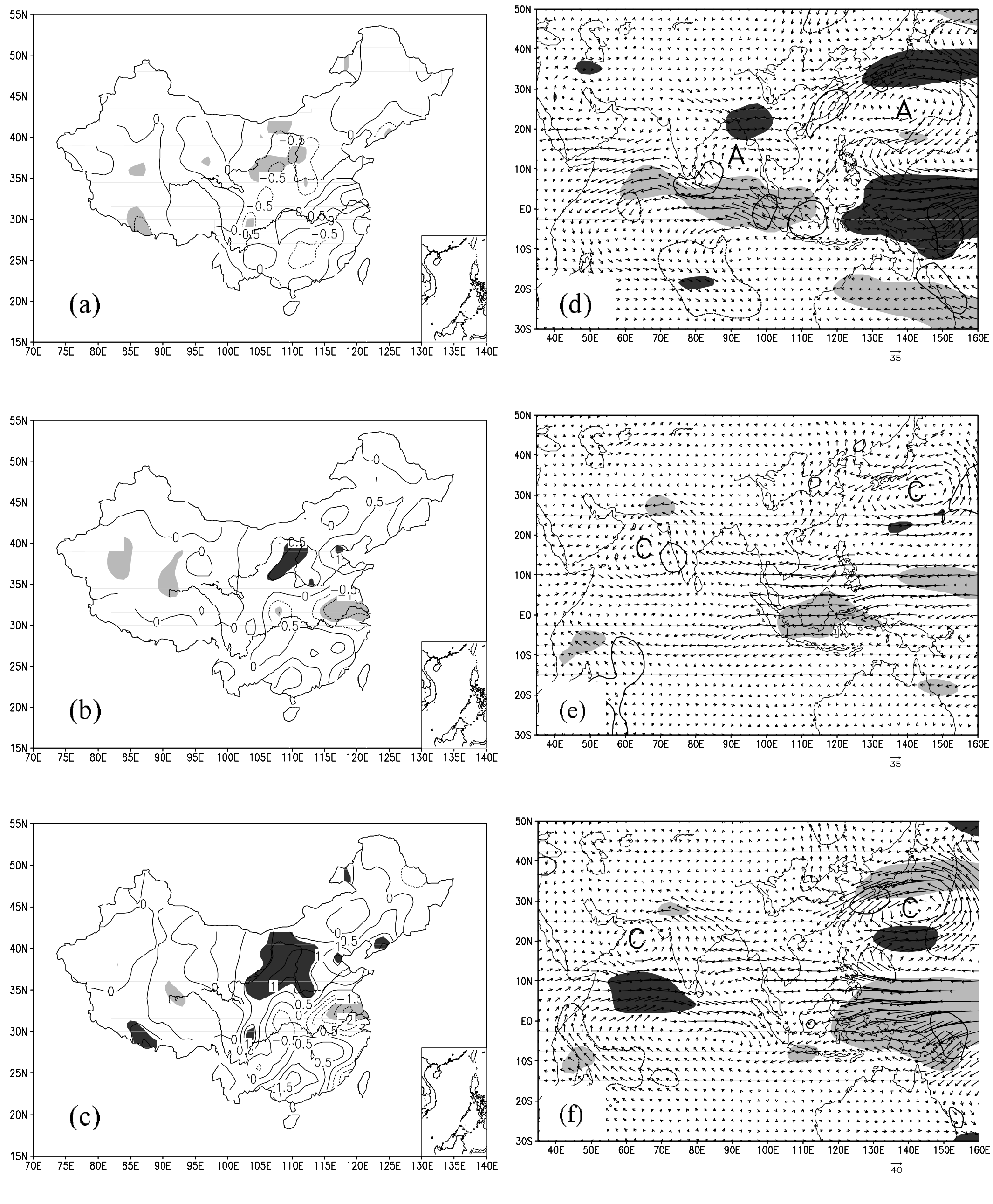

Fig. 8. Same as Fig. 6, but for the years of El Niño events and the following years. (a,d) the years of El Niño, (b,e) the following years, and (c,f) the following years minus the years of El Niño.

next year after the end of every El Niño event as the following year of the El Niño event. Then, the composite analysis is performed based on these twelve events. In the years of El Niño, less precipitation is characterized in northern China, whereas more is observed in the YRHB and the southeast costal areas. The significant negative values are found over the Hetao region of NC (figures not shown), which basically coincides with the conclusion by Zhang (1999). In the following years of El Niño, positive precipitation anomalies appear in most parts of China, but less precipitation anomalies are found over the region from the middle and lower reaches of the YRB to the Huaihe region. The positive anomalous precipitation in the Hetao region and the negative precipitation in the YHRB are statistically significant at the 0.05 confidence level by a t-test (figures not shown). It is displayed that in the year of El Niño, anomalous southerly moisture transport predominates over the regions from SC to the YHRB and the anomalous northerly moisture transport dominates over NC, which is greatly similar to the situation in the flood years of the middle and lower reaches of

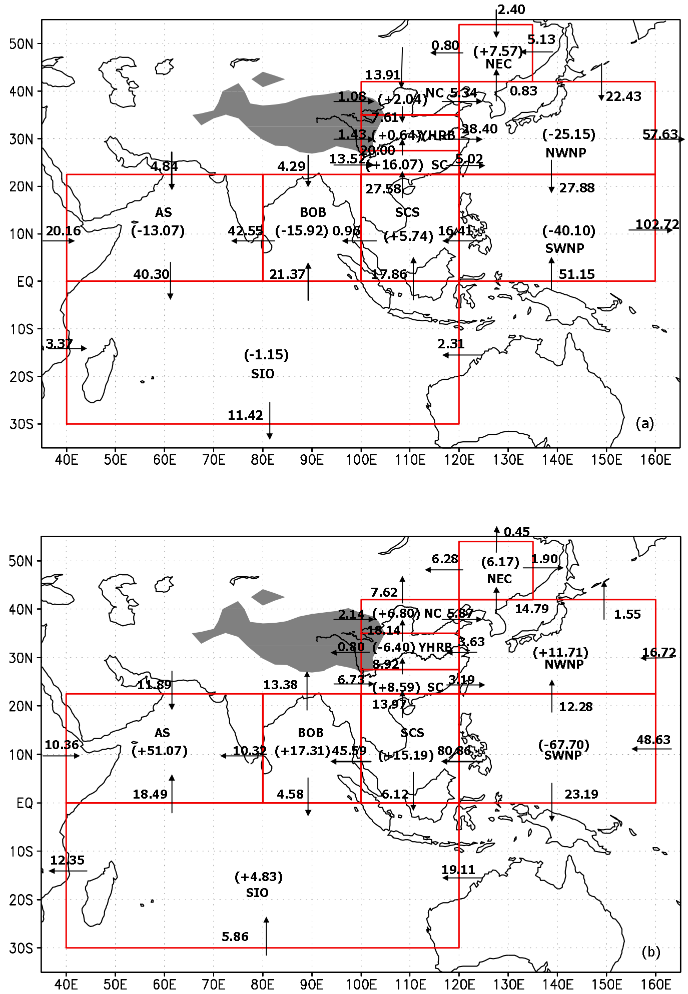

Fig. 9. Same as Fig. 7, but for the years of El Niño events and the following years. (a) the years of El Niño events, and (b) the following years.

the YRB, namely the anomalous southerly moisture originating from the WNP through the SCS and the anomalous northerly moisture convergence over the YHRB, thus leading to the anomalous convergence and greater precpitation there. To be noted is that the convergence in the years of El Niño is obviously weak and the location of the anomalous anticyclonic moisture transport over the WNP is farther north and east. So, the location of the major precipitation belt is also slightly north. It is also demonstrated that the directions of the anomalous moisture transport importing into eastern China are similar to those in the flood years of the middle and lower reaches of the YRB. However, the intensity of the anomalous moisture through the northern boundary of the SCS is obviously weaker. Therefore, it is suggested that in the years of El Niño, the anomalous moisture source that influences China is closely associated with the WNP. In the following year, the most sailent feature is that there exists an obvious anomalous anticyclonic moisture circulation over the Philippines Sea (Wang et al., 2000). The anomalous easterly moisture over the southern part of the subtropical Pacific high mostly separates into two branches. One branch transports westward through the SCS, the ICP, and the BOB, and the other turns into southwesterly moisture when it passes through the SCS, and then toward China. The anomalous southerly moisture extends from SC to NC, but it is not significant (figures not shown). Compared with Fig. 9b, there is no doubt that the anoumalous southerly moisture transport importing over eastern China through the northern boundary of the SCS is the main provider for the precpitation in the summer in China in the following years of El Niño. The anomalously more abundant net influx over the SCS is greatly related with the easterly moisture transport from the WNP. All in all, whether in the years of El Niño or the following years, the anoumalous sources that affect precipitation over eastern China are utimately originating from the WNP, and only its location and intensity change.

5. Conclusions

The climatological characteristics of the moisture budget over the joining area of Asia and the Indian-Pacific Ocean (AIPO) and its anomalies have been estimated in this study. The main results are as follows.

In the winter, the northeasterly moisture transport covers the extensive areas at the lower latitudes of the AIPO. The westerly and northerly moisture transport is the major source and the South Indian Ocean (SIO) is the moisture sink. In the summer, influenced by the southwesterly monsoonal wind, the cross-equatorial southwesterly moisture transport across Somali originating from the SIO is transported through the AS, the BOB, and the SCS to eastern China. The AIPO is controlled by the southwesterly moisture transport. On the contrary, in the winter, the SIO is the most striking moisture source for the Asian-Australian monsoon system.

The net moisture influx over the AIPO has obvious interannual and interdecadal variations. From the mid-or late 1970s, the influxes over the SIO, the AS, the northern part of the WNP, and NC as well as SC begin to decrease abruptly, while those over NEC and the YHRB have increased remarkably. As a whole, the net moisture influxes over the BOB and the SWNP in the recent 50 years take on a linear increasing trend. However, the transition timing for these two regions is different with the former being at the mid- or late 1980s and the latter occurring earlier, approximately at the early stage of the 1970s.

The anomalous moisture source associated with the precipitation anomalies is different from the normal conditions of the summer precipitation. For the drought or flood years over the middle and lower reaches of the YRB or the years of El Niño and its following years, the anomalous moisture transport originating from the WNP is the vital source of the anomalous precipitation over eastern China, which is greatly related with the variation of the subtropical Pacific high. When the WSPH is located farther north, the anomalous easterly moisture transport from the WNP in the middle latitudes is the supplier for more precipitation in NC; in contrast, the anomalous southwesterly moisture at the western flank of the WSPH is the major source for the precipitation anomalies over the YRHB. The above results clearly show again that the WSPH has a controlling influence on the distribution of precipitation in the summer over eastern China through the moisture flux.

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