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IMPACT OF ENSO ON THE PRECIPITATION OVER CHINA IN WINTER HALF-YEARS

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Abstract: In this paper, the impact of ENSO on the precipitation over China in the winter half-year is investigated diagnostically. The results show that positive precipitation anomalies with statistical significance appear over southern China in El Niño episodes, which are caused by the enhanced warm and humid southwesterlies along the East Asian coast in the lower troposphere. The enhanced southwesterlies transport more water vapor to southern China, and the convergence of water vapor over southern China increases the precipitable water and specific humidity. In La Niña episodes, although atmospheric elements change reversely, they are not statistically significant as those in El Niño periods. The possible physical mechanism of the different impact of ENSO cycle on the precipitation over southern China is investigated by analyzing the intraseasonal oscillations (ISOs) in El Niño and La Niña winter half-years, respectively. By comparing the characteristics of ISOs in El Niño and La Niña, a physical mechanism is proposed to explain the different responses of the precipitation over China to ENSO in the winter half-year. In El Niño episodes, over western North Pacific (WNP) and South China Sea (SCS) the ISOs are inactive and exert little effect on water vapor transport and convergence, inducing positive precipitation anomalies with statistical significance over southern China in El Niño episodes. In La Niña episodes, however, the ISOs are active, which weaken the interannual variation signals of ENSO over WNP and southern China and lead to the insignificance of the interannual signals related to ENSO. Therefore, the different responses of precipitation over China to ENSO in the winter half-year are possibly caused by the difference of intraseasonal oscillations over WNP and SCS between El Niño and La Niña.

Key words: precipitation over China; ENSO; intraseasonal oscillation; winter half-year

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1 INTRODUCTION

The ENSO cycle is considered the most important interannual variation signal in the tropical Pacific. When ENSO occurs in this region, it causes severe climate anomalies in many regions of the world (Rasmusson and Wallace[1]). ENSO has large impacts on the monsoon systems in East Asia (Fu[2]; Huang and Wu[3]; Wang et al.[4]). The summer monsoon and precipitation anomalies in East Asia are closely related to the different phases of ENSO cycle (Zhang et al.[5]; Huang et al.[6]; Wu et al.[7]). The interannual variations of East Asia winter monsoon (EAWM) tend to be opposite in the warm and cold phases of ENSO cycle. The EAWM becomes weaker during El Niño periods but stronger during La Niña periods (Li[8]; Tao and Zhang[9]; Chen[10]; Zhou and Wu[11]).

The precipitation of EAWM is related to different phases of ENSO cycle closely. The impacts of El Niño and La Niña events on the precipitation over China have been investigated by many researchers. Jin and Tao [12] pointed out that positive precipitation anomalies occur in the southern regions of Yangtze River during El Niño episodes, but the characteristics of precipitation anomalies are unclear during La Niña episodes in China. Zhang et al.[5, 13] found that positive precipitation anomalies with statistical significance appear over southern China in El Niño episodes, and the impacts of El Niño on EAWM are statistically significant in winter but the impacts of La Niña on EAWM are not. Chen[10] and Ni et al.[14] argued that the impacts of El Niño and La Niña on the EAWM are approximately reversed, and the impacts of La Niña on the EAWM are weaker than those of El Niño.

As mentioned above, previous studies found that there is significant relationship between ENSO signals and the precipitation over China during El Niño episodes in winter, but the relationship is insignificant during La Niña episodes. However, it is still unknown why El Niño and La Niña episodes respond differently. Zhang [15], Huang et al.[16], Zhu et al.[17] and Gu et al.[18] pointed out that the precipitation in East Asia is closely related to atmospheric water vapor transport. Wen and Zhang [19] showed that remarkable Intraseasonal Oscillations (ISOs) exist in tropical western North Pacific

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(WNP) and South China Sea (SCS) with predominant periods in 30-60 d and 10-20 d, respectively. Therefore, in this study, we will investigate the impacts of ENSO cycle on the precipitation over China and its mechanism by analyzing the characteristics of water vapor transport and the ISOs. The differences of ISOs between El Niño and La Niña episodes are diagnosed by analyzing oscillations of 20-70 d and 10-20 d, respectively.

2 DATA AND METHODOLOGY

The datasets used in the present study consist of (1) the daily mean reanalysis datasets on a 2.5°×2.5° grid obtained from NCEP/NCAR (Kalnay et al.[20]), (2) the monthly mean sea surface temperature (SST) data on a 2°×2° grid obtained from NOAA/ERSST (Smith and Reynolds[21]), (3) the outgoing long wave radiation (OLR) data on a 2.5° ×2.5° grid obtained from NOAA/AVHRR (Liebmanm and Smith[22]), and (4) the daily and monthly precipitation data of 740 stations across China provided by the National Meteorological Information Center (NMIC) of China Meteorological Administration (CMA). The valid precipitation data are from 488 stations for which no missing data exist. All datasets used in this study cover the period 1979-2010.

In this study, southern China refers to the region from 18°-27.5°N, 105°-120°E, which covers the areas of Guangdong, Guangxi, Hainan, Fujian, southern parts of Hunan and Jiangxi. There are 72 observational stations in the region. A winter half-year is taken to be the period from November to April. The SST anomaly (SSTA) averaged over the Niño 3 region of 150°-90°W and 5°S-5°N is taken as an ENSO index in the winter half-year. We define an El Niño episode to be the period when the Niño 3 SSTA averaged in the winter half-year is greater than 0.5℃, and La Niña episode less than -0.5℃. Based on our definition, there are six El Niño episodes (1982/83, 1986/87, 1991/92, 1997/98, 2002/03, 2009/10) and eight La Niña episodes (1984/85, 1985/86, 1988/89, 1995/96, 1998/99, 1999/2000, 2005/06, 2007/08) during the winter half-years of 1979-2010, respectively.

3 PRECIPITATION OVER CHINA IN EL NIÑO AND LA NIÑA EPISODES

The time evolution of Niño 3 SSTA and normalized precipitation over southern China in the winter half-years during 1979-2010 are shown in Fig.1. The correlation coefficient between them is 0.68, exceeding the 99% significance level. It can be seen in Fig.1 that the precipitation over southern China is much more than normal in El Niño episodes. Positive anomalies of the precipitation over southern China are in the periods of stronger El Niño episodes, such as 1982/83, 1991/92, 1997/98, with an exceptional case in 2002/03. For the La Niña episodes, however, most of the precipitation anomalies do not show the negative anomalies. Two cases have positive anomalies (1984/85, 1999/2000), another two cases are near the normal state (1988/89, 2005/06), and yet another four cases have negative anomalies (1985/86, 1995/96, 1998/99, 2007/08). Therefore, the statistical significance of positive correlations between ENSO and the rainfall over southern China is mainly contributed by their correlations in El Niño episodes, and the relationship is not obvious in La Niña episodes.

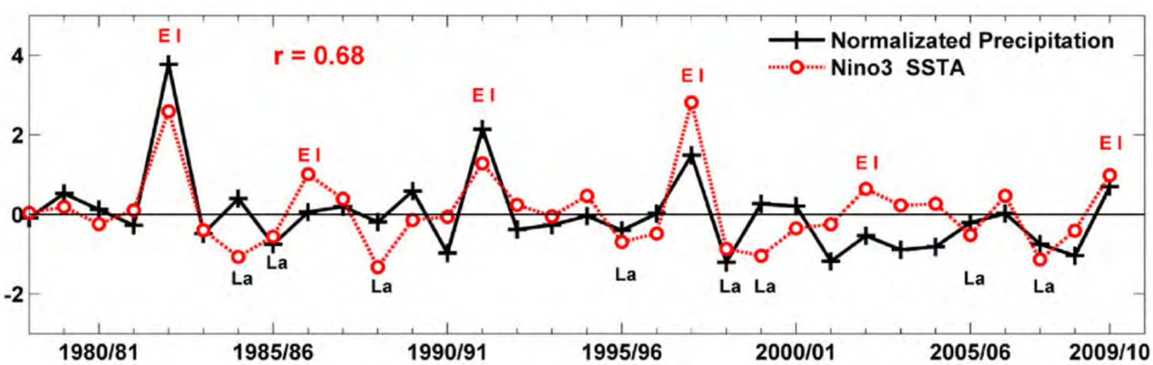

Figure 1. Time evolution of Niño 3 SSTA (dotted line, unit: ℃) and normalized precipitation over southern China (solid line) in winter half-years during 1979-2010.

In order to investigate into the precipitation distribution in El Niño and La Niña episodes in China, we make the composites of the precipitation anomalies for the 488 stations in China in the winter half-years of El Niño and La Niña episodes, respectively (Fig.2). It is obvious that the positive precipitation anomalies mainly appear over the regions to the south of the Yangtze River over southern China in El Niño episodes (Fig.2a). The center of precipitation anomalies is located in the eastern Pearl River Delta of southern China, and the maximum of precipitation anomalies is greater than 50 mm/month. The result of a Student *t*-test shows that the statistical significance of composite precipitation anomalies over southern China exceeds the 95% level in El Niño episodes. Fig.2b shows the composite of precipitation anomalies in La Niña episodes. It can be seen that weak negative precipitation anomalies also appear over the regions of southern China, and the minimum of precipitation anomalies is around -10 mm/month. The result of the t-test shows that the statistical significance of composite of the negative precipitation anomalies over southern China does not exceed the 95% level in La Niña episodes, indicating that the negative precipitation anomalies are not statistically significant.

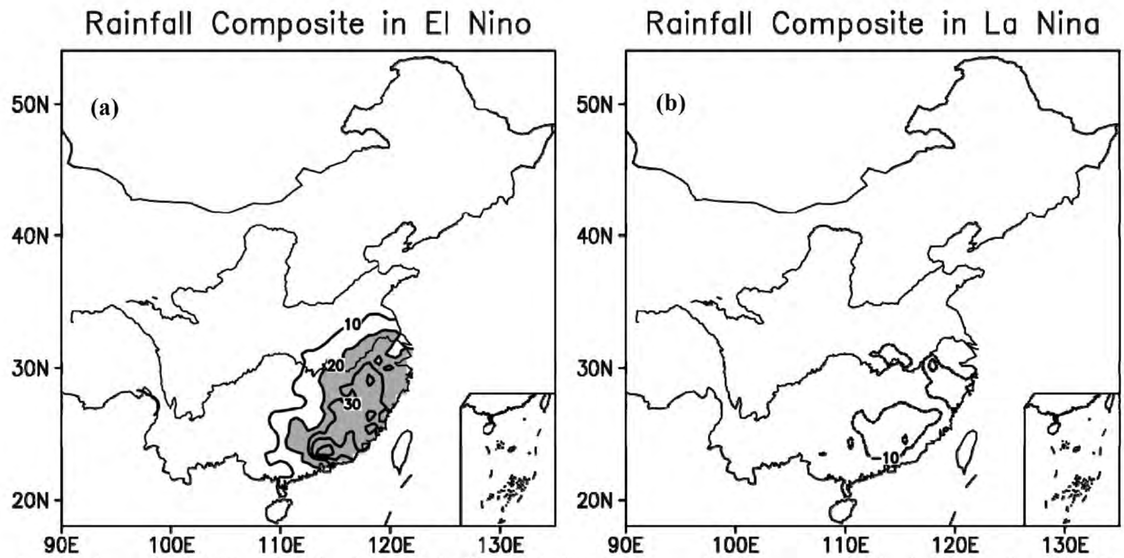

Figure 2. Composites of rainfall anomalies for (a) El Niño and (b) La Niña episodes, respectively (unit: mm/month). Shadings are the areas with statistical significance exceeding the 95% level.

In order to study the mechanism of the precipitation difference over southern China between El Niño and La Niña episodes, we will compare the differences of atmospheric water vapor transport and corresponding atmospheric elements as well as the differences of ISOs between El Niño and La Niña episodes in the following two sections.

4 WATER VAPOR TRANSPORT OVER EAST ASIA IN EL NIÑO AND LA NIÑA EPISODES

Figure 3 shows the 850-hPa water vapor flux and its divergence in the composites of six El Niño and eight La Niña episodes during 1979-2010, respectively. It can be seen that a prominent anomalous anticyclone of water vapor flux is formed over the areas of western North Pacific (WNP) and South China Sea (SCS) during El Niño episodes (Fig.3a). For La Niña episodes, however, a relatively weaker anomalous cyclone of water vapor flux is formed over WNP and SCS. Furthermore, a divergence center of negative anomalies is located over southern China in El Niño episodes, implying a strong convergence of water vapor over southern China. For the La Niña episodes, on the other hand, the minor positive anomalies of divergence imply that the divergence of water vapor is weak over southern China.

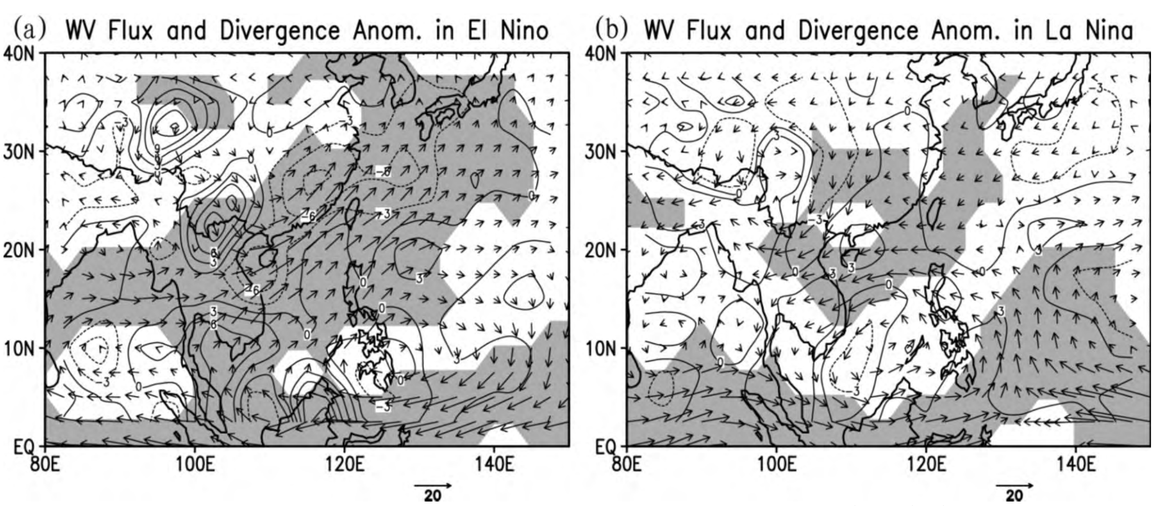

Figure 3. Same as Fig.2, but for anomalies of atmospheric water vapor flux (vectors; unit: g·cm^{-1}·hPa^{-1}·s^{-1}) and its divergence (contour, unit: 10^{-6}g·cm^{-2}·hPa^{-1}·s^{-1}) in (a) El Niño and (b) La Niña episodes. Shadings are the areas with statistical significance exceeding the 95% level.

It was preciously shown that the anomalous anticyclone (cyclone) over WNP results from the convective cooling (heating) anomalies over tropical western Pacific in El Niño (La Niña) episodes (Wang et al.[4]; Zhang et al.[5]; Wu et al.[7]; Chang et al.[23]). Significant anomalous southwesterlies extending from SCS to southern China are caused by an anomalous anticyclone in the lower troposphere in El Niño episodes. The enhanced southwesterlies transport large amount of water vapor to southern China and the water vapor converges there. All of these are the main causes for the increasing of precipitation in the El Niño winter half-years over southern China. For La Niña episodes, however, the weak anomalous northeasterlies caused by the anomalous cyclone appear over the north of SCS and southern China. The weakened water vapor transport and the divergence of water vapor lead to the decreasing of precipitation in La Niña winter half-years over southern China.

Figure 4 shows the composites of the atmospheric precipitable water anomalies and specific humidity anomalies. It is clear that positive precipitable water and specific humidity anomalies extend from the southeastern coast of China and southern China to WNP to the south of Japan in El Niño episodes (Fig.4a), and the center of positive anomalies is located in the area of Pearl River Delta of southern China. The negative anomalies of precipitable water and specific humidity appear in the areas south of SCS and west of WNP. The distributions of positive anomalies of precipitable water and specific humidity are similar to the composites of precipitation anomalies in El Niño episodes. Fig.4b shows the composites of atmospheric precipitable water and specific humidity anomalies in La Niña episodes. The negative anomalies of precipitable water and specific humidity have similar distributions to those of the composites of precipitation anomalies in La Niña episodes.

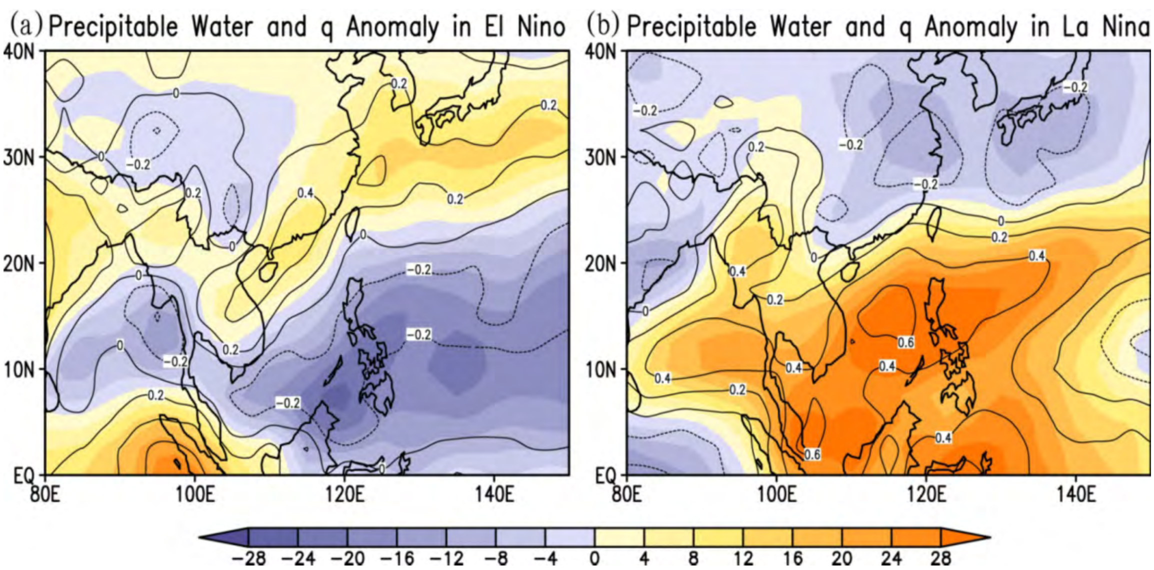

Figure 4. Same as Fig.2, but for anomalies of precipitable water (shadings; unit: kg·m^{-2}) and specific humidity (contour; unit: g·kg^{-1}) in (a) El Niño and (b) La Niña episodes.

It is known from the above analyses that the enhanced water vapor transport to southern China by the southwesterlies and the convergence of water vapor over southern China increase the precipitable water and specific humidity of the atmosphere, which are conducive to the increasing of precipitation over southern China in El Niño episodes. In La Niña episodes, however, the weak negative anomalies of precipitable water and specific humidity over southern China are caused by the weakened water vapor transport and its divergence.

We further diagnose the means of the anomalies of meridional wind, zonal wind, specific humidity and meridional water vapor transport over southern China (110°-120°E, 15°-25°N) in El Niño and La Niña episodes, respectively. The results show that the means of the anomalies of meridional wind, zonal wind, specific humidity and meridional water vapor transport in El Niño episodes have remarkable differences from the neutral years. The statistical significances of these atmospheric elements exceed the 95% level as checked by the Student *t*-test. In contrast, in La Niña episodes, the means of the anomalies of meridional wind, zonal wind, specific humidity and meridional water vapor transport do not have significant differences from the neutral years, and their statistical significances are less than the 95% level. Only the anomalies of zonal wind are statistically significant exceeding the 95% level. All of these results show the different impact of El Niño and La Niña on the precipitation over southern China in the winter half-years.

5 FEATURES OF ISOS DURING EL NIÑO AND LA NIÑA EPISODES

5.1 *OLR and their variance anomalies*

As mentioned previously, the precipitation and other atmospheric elements do not present obviously opposite features during El Niño episodes as those in La Niña episodes. The atmospheric elements mentioned above have significant positive anomalies over southern China in El Niño episodes, but the negative anomalies of them are not statistically significant in La Niña episodes. What is the physical mechanism leading to the insignificant negative anomalies in La Niña episodes? Lau and Chang[24] found that the interannual variations of EAWM is not only related with the ENSO cycle but also affected by the ISOs in the tropics. OLR is a good proxy in representing the convection activities in the tropics. Fig. 5 shows the composites of OLR anomalies and their variances during El Niño and La Niña episodes, respectively. In El Niño episodes (Fig.5a) positive OLR anomalies appear over WNP and SCS and negative anomalies over the equatorial central Pacific. In La Niña episodes (Fig.5b), however, the distribution of OLR anomalies is basically reversed compared with that in La Niña episodes. The negative OLR anomalies appear over WNP and SCS and positive OLR anomalies over the equatorial central Pacific. The distributions of OLR anomalies show that the tropical convection activity is inactive over tropical WNP in El Niño episodes but active in La Niña episodes.

Furthermore, we analyze the amplitude of daily OLR variations during El Niño and La Niña episodes, respectively. The variances of daily OLR variations are computed by using the daily OLR dataset of six El Niño episodes and eight La Niña episodes. The negative anomalies of daily OLR variance appear over WNP and SCS in El Niño episodes (Fig.5c). Besides, the anomalies of daily OLR variance are positive in La Niña episodes (Fig.5d). The results show that the convection activities are inactive in El Niño episodes because of

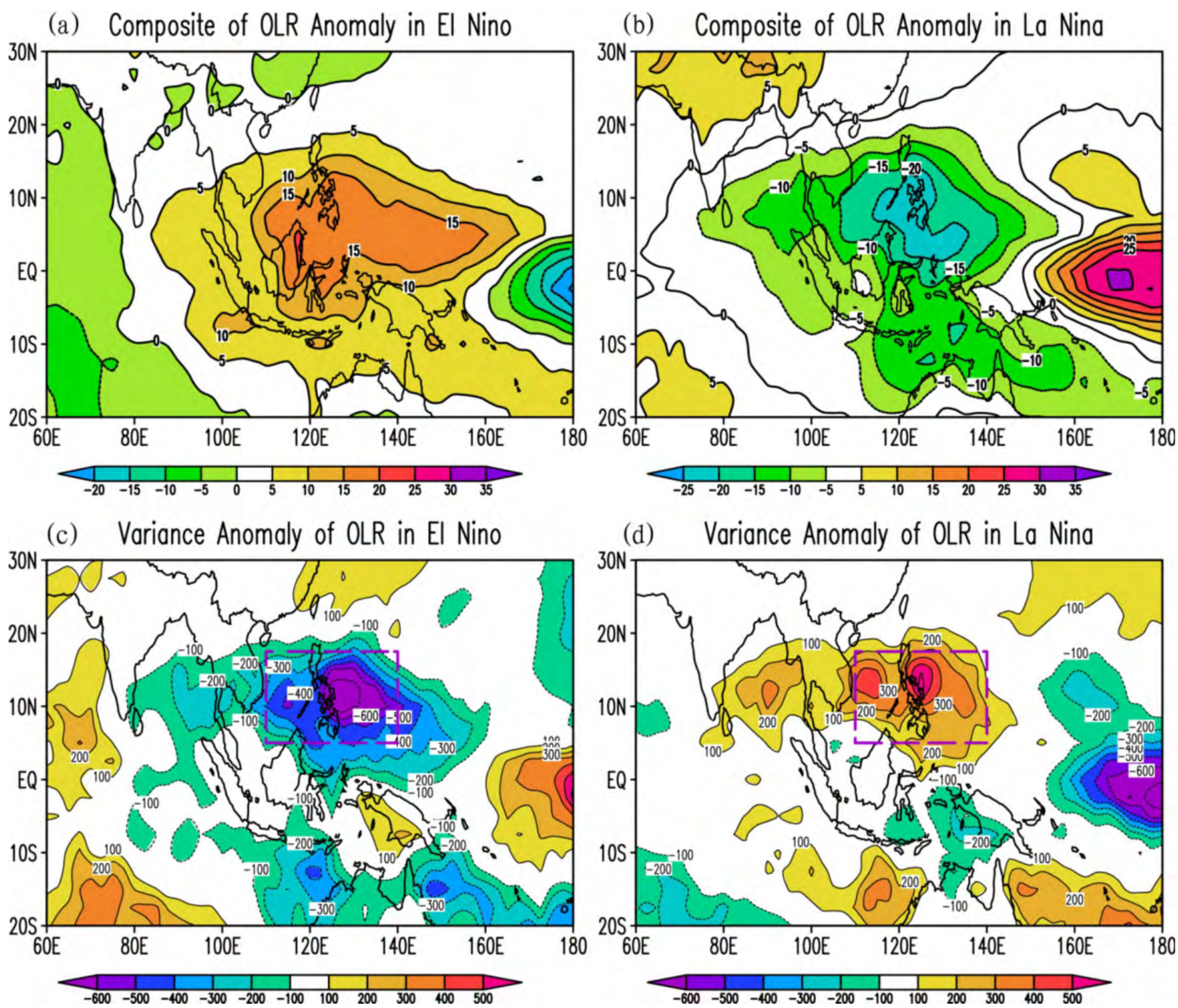

Figure 5. OLR (unit: W·m^{-2}) and their variance (unit: W^2·m^{-4}) anomalies in El Niño and La Niña episodes. (a) OLR anomalies in El Niño. (b) OLR anomalies in La Niña. (c) OLR variance anomalies in El Niño. (d) OLR variance anomalies in La Niña.

the small OLR variance over WNP and SCS but active in La Niña episodes because of the big OLR variance.

5.2 *Activity of ISOs*

In the tropical zone, the activity of ISOs corresponds well to the heat condition of ocean (Huang and Wu[3]; Li[26]) and is stimulated by the convection. Many studies showed that ISOs can explain important percentage in the variance of daily variation except the 7-d timescale disturbance (Ren and Huang [27-28]). The daily meridional and zonal winds of 850 hPa are filtered on the timescale of 10- to 20- d and 20- to 70- d, respectively, by using the band-pass filter method of Lanczos (Duchon[29]). Then, the perturbation kinetic energy (PKE) is computed with the filtered data. Fig.6 shows the distribution of 10- to 20- d and 20- to 70- d PKE anomalies averaged in 5°-17.5°N in El Niño and La Niña episodes, respectively. It can be seen that the PKE anomalies of 10- to 20- d and 20- to 70- d in El Niño episodes present opposite characteristics to that in La Niña episodes over WNP and SCS. The strong negative anomalies of 850-hPa PKE show that the activities of ISOs are inactive over WNP and SCS in El Niño episodes, but the strong positive anomalies imply that the ISOs activities are active over this region in La Niña episodes.

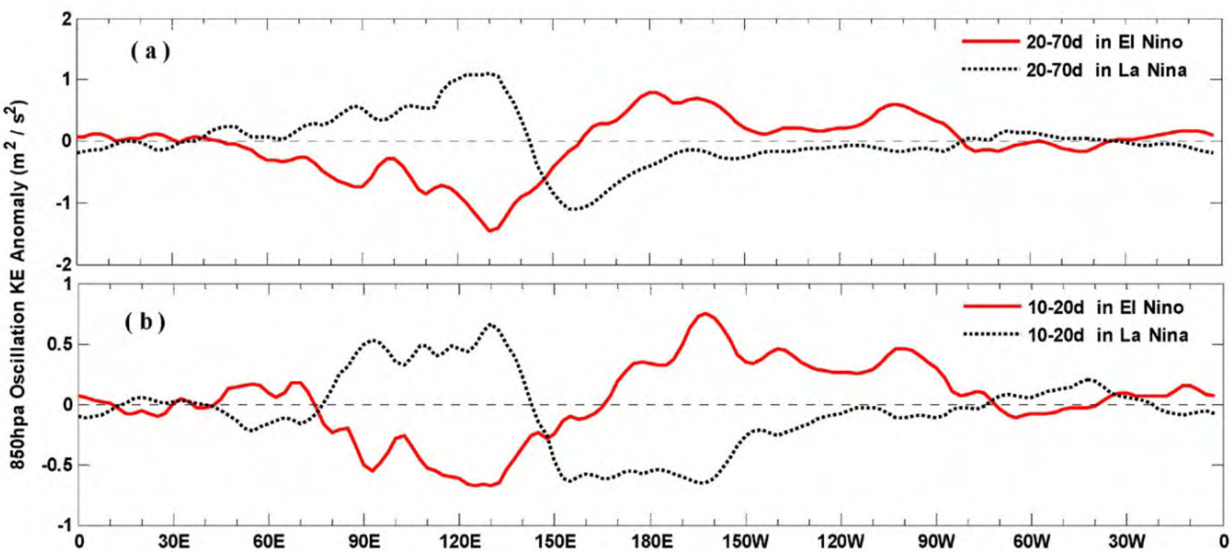

Figure 6. Anomalies of 850-hPa PKE in El Niño(solid line) and La Niña (dashed line) episodes (unit: $m^2 \cdot s^{-2}$) for (a) 20- to 70- d and (b) 10- to 20- d periods.

In addition, we compute the variances of 10- to 20- d and 20- to 70- d oscillations by using filtered daily OLR on the timescale of 10- to 20- d and 20- to 70- d. Fig.7 shows the variance anomalies of 20- to 70- d oscillation in El Niño and La Niña episodes, respectively. It can be seen that in El Niño episodes the 20- to 70- d oscillation of convection is weak because of the negative variance anomalies over WNP and SCS (Fig. 7a), but in La Niña episodes the 20- to 70- d oscillation of convection is strong because of the positive variance anomalies over the region (Fig.7b). Fig.7c and 7d are the variance anomalies of 10- to 20- d oscillation in the El Niño and La Niña episodes, respectively. It is found that they have similar features with the 20- to 70- d oscillation. In El Niño episodes, the 10- to 20- d oscillation of convection is weak because of the negative variance anomalies over WNP and SCS. In addition, in La Niña episodes the 10- to 20- d oscillation of convection is strong because of the positive variance anomalies over the WNP and SCS.

It can be seen that the 850-hPa PKE and ISOs are weaker in El Niño episodes than those in La Niña episodes. Additionally, comparisons of Fig.5 with Fig.7 show that the areas of active (inactive) convection basically coincide with those of strong (weak) ISOs (the frame areas in Figs.5 and 7). These results show that the variation of tropical convection activities has close relation with their strength on the intraseasonal timescale.

6 ROLE OF ISOS IN THE PRECIPITATION DIFFERENCE BETWEEN EL NIÑO AND LA NIÑA EPISODES

For the purpose of analyzing the variation characteristics of 850-hPa circulation over WNP and SCS on the intraseasonal timescale during La Niña episodes, the region of maximum OLR variance anomalies over WNP and SCS (110°-140°E, 5°-17.5°N) is chosen as the reference region. The cases of ISOs are picked out when the band-pass filtered value of OLR data in the reference region are more or less than a standard deviation. Therefore, 33 cases of 20- to 70- d oscillations and 66 cases of 10- to 20- d oscillations are picked out in the eight La Niña episodes. We define that the minimum

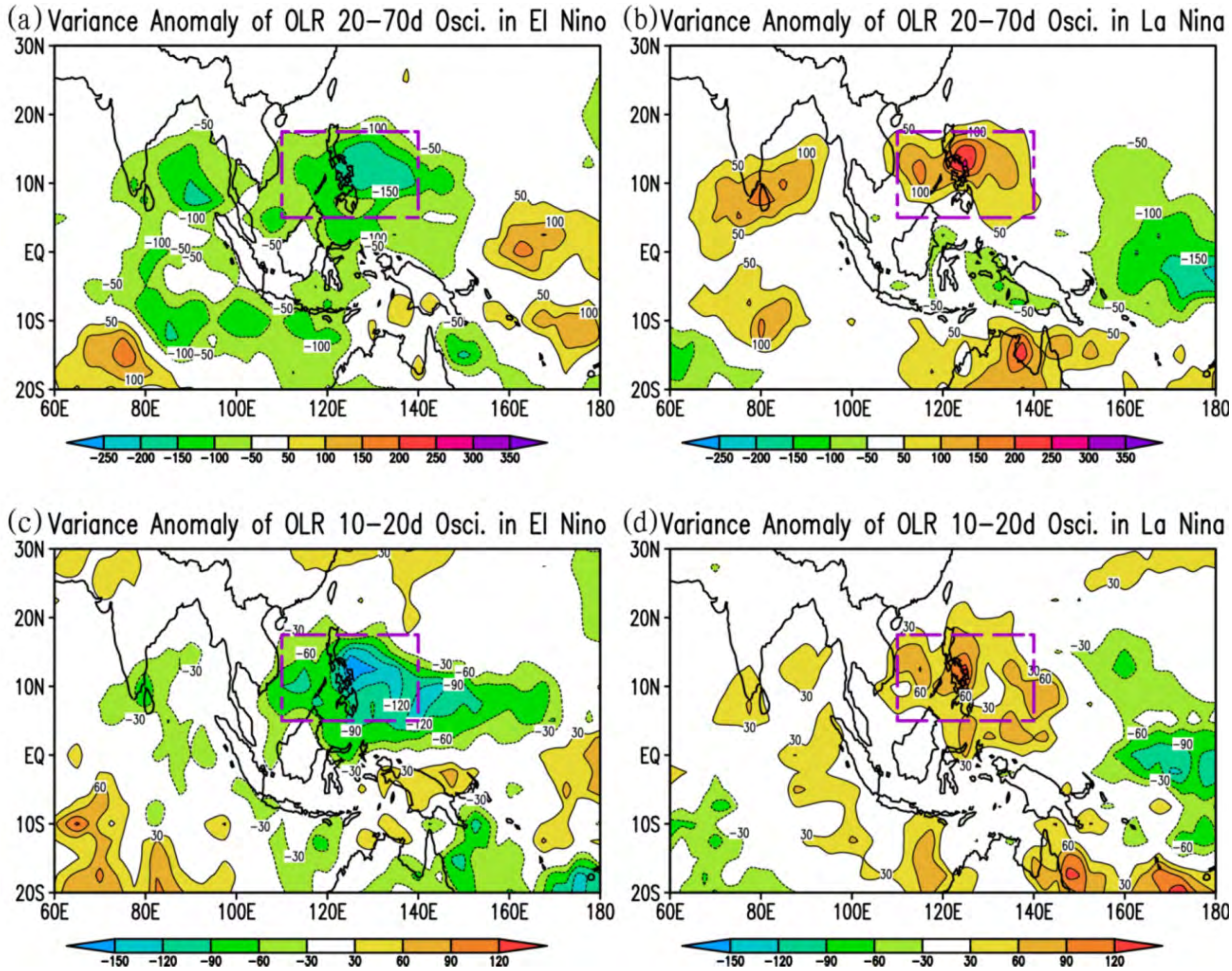

Figure 7. The variance anomalies of ISOs in the 20- to 70- d and 10- to 20- d periods in El Niño and La Niña episodes (unit: W^2·m^{-4}). (a) 20- to 70- d in El Niño. (b) 20- to 70- d in La Niña. (c) 10- to 20- d in El Niño. (d) 10- to 20- d in La Niña.

(maximum) anomalies of OLR filtered data are phase 1 (5) or phase wet (dry), which corresponds to the strongest (weakest) ISO phase of convection. Fig.8 shows the composites of the anomalous winds and OLR at two extreme ISO phases of maximum and minimum OLR anomalies during La Niña episodes.

From Fig.8 we can see that significant cyclone anomalies appear over WNP and SCS for the 20- to 70- d (Fig.8a) and 10- to 20- d (Fig.8c) oscillations during La Niña episodes in phase wet (phase 1). Besides, the center of cyclone anomalies coincides with the center of negative anomalous OLR, indicating that the convection activities are active. Meanwhile, the large northeasterly anomalies appear over southern China. For the phase dry (phase 5), however, opposite features can be observed compared with phase wet. Obvious anticyclone anomalies appear over WNP and SCS for the 20- to 70- d (Fig.8b) and 10- to 20- d (Fig.8d) oscillations. Besides, the center of anticyclone anomalies coincides with the center of positive anomalous OLR, which means the tropical convection activities are inactive. At the same time, obvious southwesterly anomalies appear over southern China.

Therefore, during La Niña episodes, the active ISOs over WNP and SCS result in the alternately changing of anomalous circulation of 850 hPa on the intraseasonal timescale. In other words, the cyclonic and anticyclonic anomalies appear alternately. The interannual variation signals related to ENSO are disturbed by intraseasonal variation signals over WNP and SCS, and the cyclone anomalies in La Niña episodes cannot keep steady because of the large signals of ISOs, which lead to the southerly and northerly anomalies periodically appearing over SCS and southern China on the intraseasonal timescale. For the El Niño episodes, however, the ISOs over WNP and SCS are inactive. As a result, the anticyclone anomalous circulation of 850 hPa can keep steady, and the southwesterly anomalies can be sustained over SCS and southern China in El Niño episodes.

By comparing the features of ISOs between El Niño and La Niña episodes, it can be seen that the activity of ISOs in La Niña episodes is quite different from that in El Niño episodes. In La Niña episodes, the variation of atmospheric circulation over the tropical western Pacific is mainly on the intraseasonal timescale

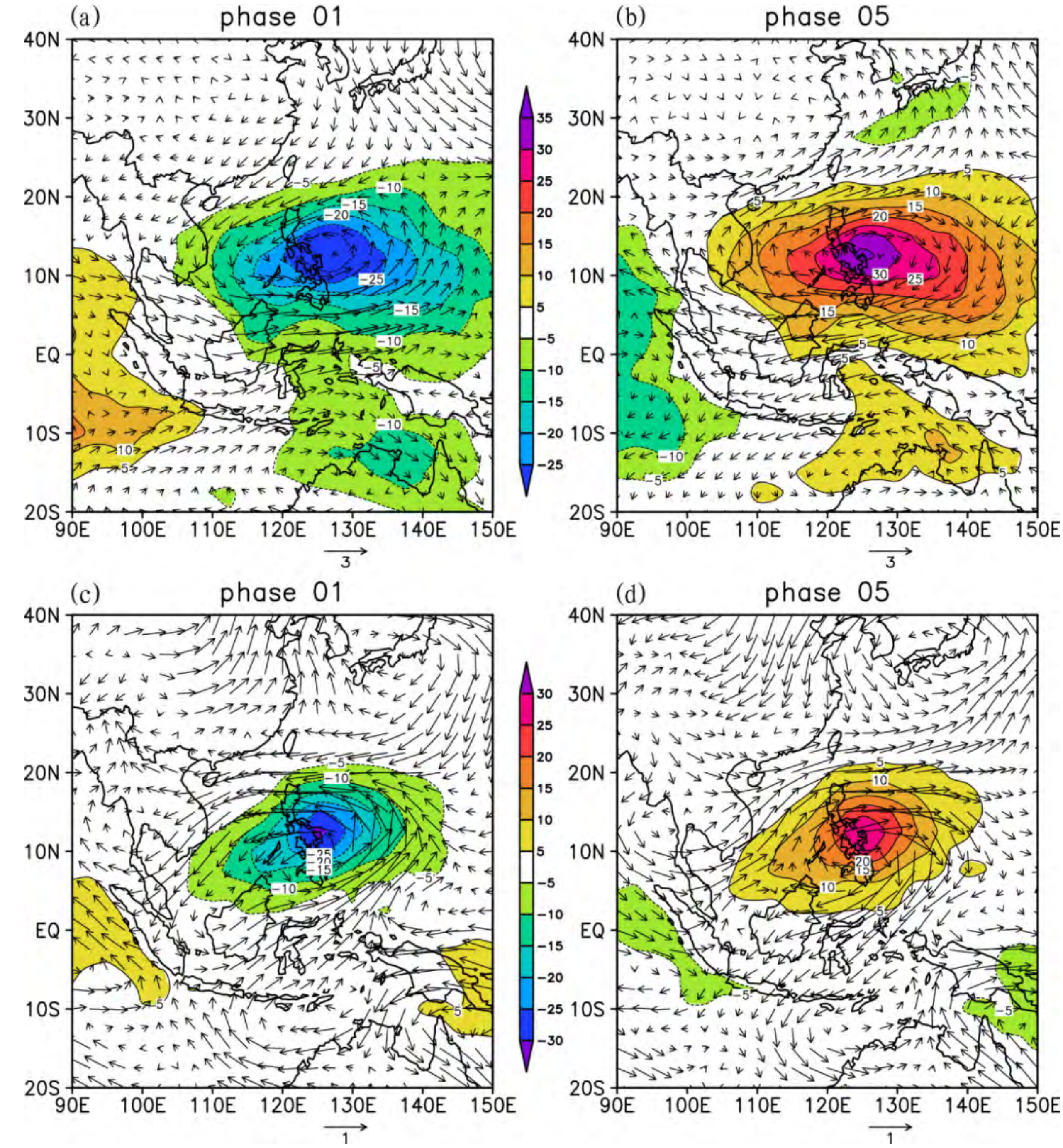

Figure 8. Composites of the 20- to 70- d and 10- to 20- d band-pass filtered anomalous wind at 850 hPa (vectors, unit: $m \cdot s^{-1}$) and OLR (contour and shadings, unit: $W \cdot m^{-2}$) at phase dry and phase wet. (a) phase wet of 20- to 70- d. (b) phase dry of 20- to 70- d. (c) phase wet of 10- to 20- d. (d) phase dry of 10- to 20- d.

because ISOs are dominant. The offset of intraseasonal variation signals will lead to weak signals in the winter half-year during La Niña episodes. Conversely, the signals of ISOs are weak during El Niño episodes and the signals of interannual variation related to ENSO are relatively strong. Therefore, obvious anticyclonic anomalies appear over WNP and SCS during El Niño episodes, which cause the positive anomalous precipitation in southern China.

In order to further confirm that the difference of ISOs over WNP and SCS between El Niño and La Niña episodes is a possible mechanism for the different precipitation over southern China, we pick out the winter half-years with strong and weak ISO activities which do not belong to El Niño and La Niña episodes according to the threshold of ± 0.5 standard deviation. There are four strong ISO years (1996/97, 2000/01, 2003/04, 2006/07) and seven weak ISO years (1979/80, 1980/81, 1981/82, 1983/84, 1990/91, 2001/02, 2004/05). The result of the *t*-test shows that the composite difference between the precipitation in strong (weak) ISO years and that in other years is not statistically significant. The results show that the precipitation over southern China in strong or weak ISOs years does not have significant anomalies in the winter half-years without El Niño or La Niña. The significant difference of precipitation over southern China only occurs in El Niño and La Niña episodes. In addition, the correlation coefficient between the precipitation over southern China and the ISO index is about -0.45, which is statistically significant exceeding the 95% level. After removing the linear dependence of ISO index to Niño 3 index, however, the correlation coefficient between the ISO index and precipitation over southern China reduced to -0.06, which is not statistically significant. These results also show that the impact of ISOs on the precipitation over southern China is mainly related to ENSO.

7 CONCLUSIONS

In the present study, the impact of ENSO on the precipitation over China in the winter half-years is investigated diagnostically. The main conclusions are as follows:

(1) It is found that strong positive precipitation anomalies appear over southern China in the El Niño winter half-years, but weak negative rainfall anomalies in the La Niña winter half-years. The amplitude of precipitation anomalies over southern China in the El Niño winter half-years is different from that in the La Niña winter half-years.

(2) In El Niño episodes, strong anticyclonic anomalies of water vapor flux over WNP and SCS cause positive anomalies of water vapor over southern China. Meanwhile, there are positive anomalies of the meridional wind, precipitable water, specific humidity, and water vapor transport over southern China with statistical significance. Their joint influences cause the positive anomalies of precipitation over southern China. For La Niña episodes, however, weak cyclonic anomalies of water vapor flux over WNP and SCS cause weak negative anomalies of water vapor over southern China. At the same time, there are weak negative anomalies of the meridional wind, precipitable water, specific humidity, and water vapor transport over southern China. Consequently, the negative anomalous precipitation over southern China is not statistically significant.

(3) The differences of ISOs signals over WNP and SCS between El Niño and La Niña episodes is the possible reason for the different precipitation over southern China. During El Niño episodes, the convection activities over the tropical western Pacific are weak and ISOs are inactive. The interannual variation signals of ENSO can be reflected in EAWM. The anticyclone anomalies over WNP and SCS can keep steady. Therefore, the positive anomalies of precipitation over southern China are statistically significant. For La Niña episodes, however, the convection activities over the tropical western Pacific are strong, and ISOs are very active. The cyclonic anomalies of water vapor flux over WNP and SCS cannot keep steady because of the strong oscillation on the intraseasonal timescale. Therefore, the interannual variation signals of ENSO are disturbed by the intraseasonal oscillation signals, leading to weak negative precipitation anomalies over southern China during La Niña episodes.

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