PAPER

Relationship between East Asian winter monsoon, warm pool situation and ENSO cycle

LI Chongyin & MU Mingquan

LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

Abstract Based on the observational data analyses and numerical simulations with the air-sea coupled model (CGCM), a new perspective on the occurrence mechanism of ENSO is advanced in this paper. The continuous strong (weak) East Asian winter monsoon will lead to continuous westerly (easterly) wind anomalies over the equatorial western Pacific region. The anomalous equatorial westerly (easterly) winds can cause eastward propagation of the subsurface ocean temperature anomalies (SOTA) in the warm pool region, the positive (negative) SOTA have been in the warm pool region for quite a long time. The eastward propagating of positive (negative) SOTA along the thermocline will lead to positive (negative) SSTA in the equatorial eastern Pacific and the occurrence of El Niño (La Niña) event. After the occurrence of ENSO, the winter monsoon in East Asia will be weak (strong) due to the influence of El Niño (La Niña).

Keywords: East Asian winter monsoon, warm pool in the western Pacific, subsurface ocean temperature (SOT), ENSO cycle.

ENSO has been paid much attention in the world because it can always cause serious climate anomalies and disasters in vast areas. Previous studies have attributed ENSO to the interaction between the atmosphere and ocean in the tropical Pacific region[1,2]. In relation to the mechanism of El Niño (ENSO), even though the oceanic relaxation theory[3], the unstable oceanic waves theory[4—6] and the delayed action oscillation theory[7—9] have been advanced, the origin of ENSO has not been understood very well.

Moreover, putting stress on atmospheric anomaly in the air-sea interaction, our research indicated that the abnormal strong winter monsoon in East Asia plays an important role in exciting the El Niño event[10,11]. The data analyses and numerical simulations in a CGCM have shown that strong (weak) winter monsoon in East Asia can excite El Niño (La Niña) through the produced westerly (easterly) wind anomalies and strong (weak) convection in the equatorial western Pacific region, as important physical processes to excite ENSO, the former will lead to warm (cold) oceanic Kelvin waves and the latter will lead to strong (weak) intraseasonal oscillation[12,13].

In this paper, we will indicate that there are clear interactions between East Asian Winter Monsoon (EWM), Warm Pool Situation (WPS) and ENSO, the EWM-WPS-ENSO seems to be a large climate system. According to this system and its evolution, the ENSO mechanism will be understood better.

The NCEP/NCAR reanalysis data, the Joint Environmental Data Analysis Center (JEDAC) data and the COADS data were mainly used in this study.

1 Interaction between abnormal East Asian winter monsoon and ENSO

The relationship of ENSO with the anomalies of East Asian winter monsoon has been indicated in a series of studies and their interactions are also evident[10,11,14]. In this paper, we just give some composite results for the El Niño and La Niña events in order to show the interactions between ENSO and abnormal East Asian winter monsoon.

As we know, the activity of East Asian winter monsoon can be represented by using some meteorological elements in the East Asia region, such as the sea level pressure, surface air temperature, surface wind and geopotential height at 500 hPa. For continuous strong East Asian winter monsoon, there are usually strong surface cold high system in the Siberia-Mongolia region, deepening trough at 500 hPa in East Asia, strong northerly wind and low surface air temperature in eastern China and the northwestern Pacific region. Conversely, the above systems will be in opposite situations for continuous weak East Asian winter monsoon. Fig. 1 shows the interaction between abnormal East Asian winter monsoon and El Niño. Fig. 1(a), (d) can represent the activity of winter monsoon in East Asia, fig. 1(e),

(f) represent the zonal wind anomaly over the equatorial western Pacific and the El Niño event (SSTA in Niño 3). It is very evident that the El Niño (composited) event outbreaks in spring, the westerly wind anomalies over the equatorial western Pacific are about 2—3 months earlier than El Niño outbreak, and

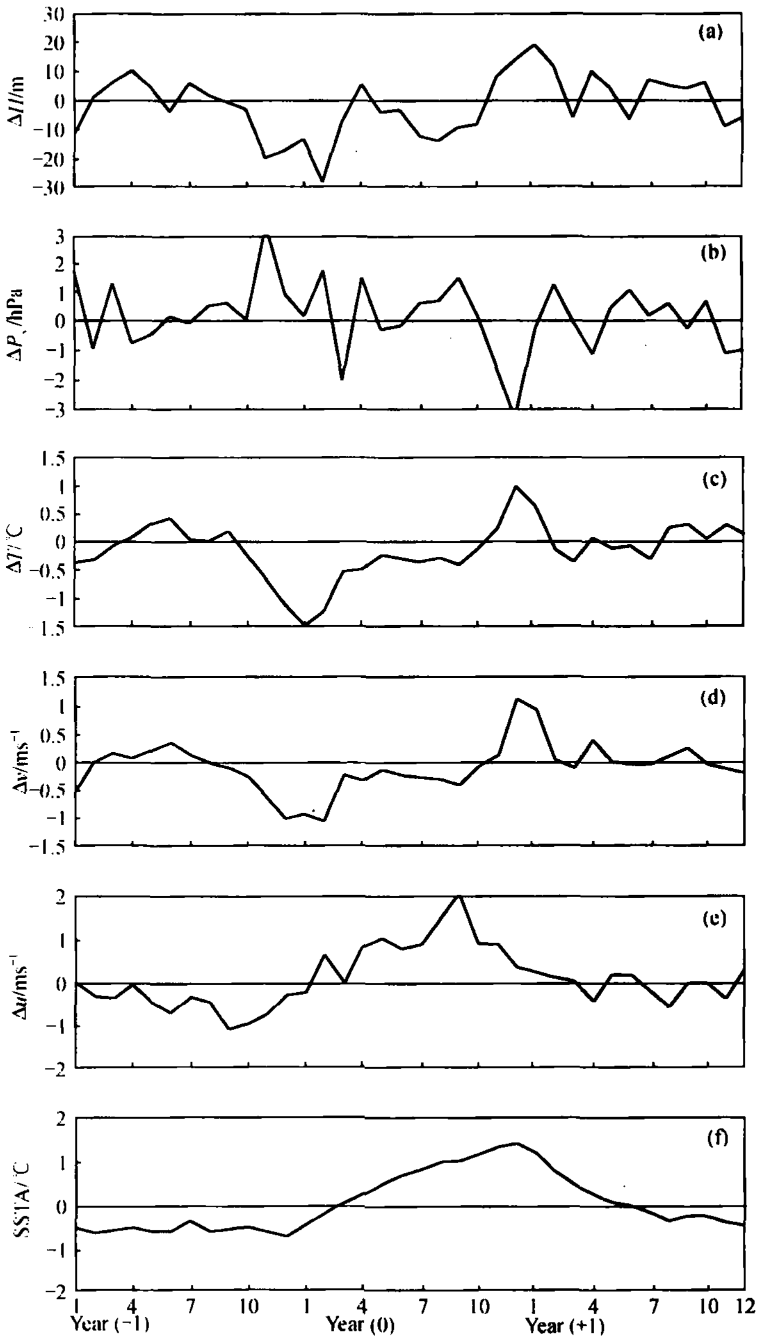

Fig. 1. The relationship between abnormal East Asian winter monsoon and El Niño. Geopotential high anomalies at 500 hPa (gm) in (30°—40°N, 100°—130°E) region (a), sea level pressure anomalies (hPa) in (35°—50°N, 80°—110°E) region (b), surface air temperature anomalies (°C) in (30°—40°N, 120°—130°E) region (c), meridional wind anomalies (m/s) in (25°—35°N, 120°—130°E) region (d), zonal wind anomalies (m/s) over the equatorial western Pacific (e) and the SSTA in Niño 3 region (f) for composite El Niño case.

there was strong winter monsoon in East Asia during the wintertime prior to the El Niño outbreak. This means that strong winter monsoon plays an important role in exciting the El Niño event through producing westerly wind anomalies over the equatorial western Pacific. It is also clear that there is weak winter monsoon in East Asia during the wintertime after the El Niño outbreak. This suggested that the El Niño event should reduce the winter monsoon in East Asia.

The relationship between abnormal East Asian winter monsoon and La Niña is similar to that in fig. 1 (figure omitted). It is also evident that the La Niña event outbreaks in spring, the easterly wind anomalies over the equatorial western Pacific are about 2—3 months earlier than La Niña outbreak, and there was weak winter monsoon in East Asia during the wintertime prior to the La Niña outbreak. This means that weak winter monsoon plays an important role in exciting the La Niña event through producing easterly wind anomalies over the equatorial western Pacific. Moreover, during the wintertime after the La Niña outbreak, there is strong winter monsoon in East Asia. This can suggest that the La Niña event should enhance winter monsoon in East Asia.

In order to show the exciting effect of abnormal East Asian winter monsoon on occurrence of ENSO, some numerical simulations are completed with a CGCM, which was developed in the Institute of Atmospheric Physics, CAS. The atmospheric component is two-level GCM formulated in the σ-coordinate with the resolution of 4° in latitude and 5° in longitude[15]. The oceanic component is a free surface tropical Pacific Ocean general circulation model with resolution of 1° in latitude and 2° in longitude and 14 unequal layers in the vertical with flat-bottom (4 000 m), of which the domain is 121°E—69°W and 30°S—30°N[16]. In order to control the "climate drift" in the coupled system, the linear statistical correlation is used in the model integration[17].

The numerical simulations in the CGCM showed some similar results to those in the data analyses, abnormal strong (weak) East Asian winter monsoon in the wintertime will lead to positive (negative) SSTA in the equatorial eastern Pacific as El Niño (La Niña) like pattern. Since the space is limited, the simulated SSTA in Niño 1+2 and in Niño 3 caused by abnormal strong East Asian winter monsoon,

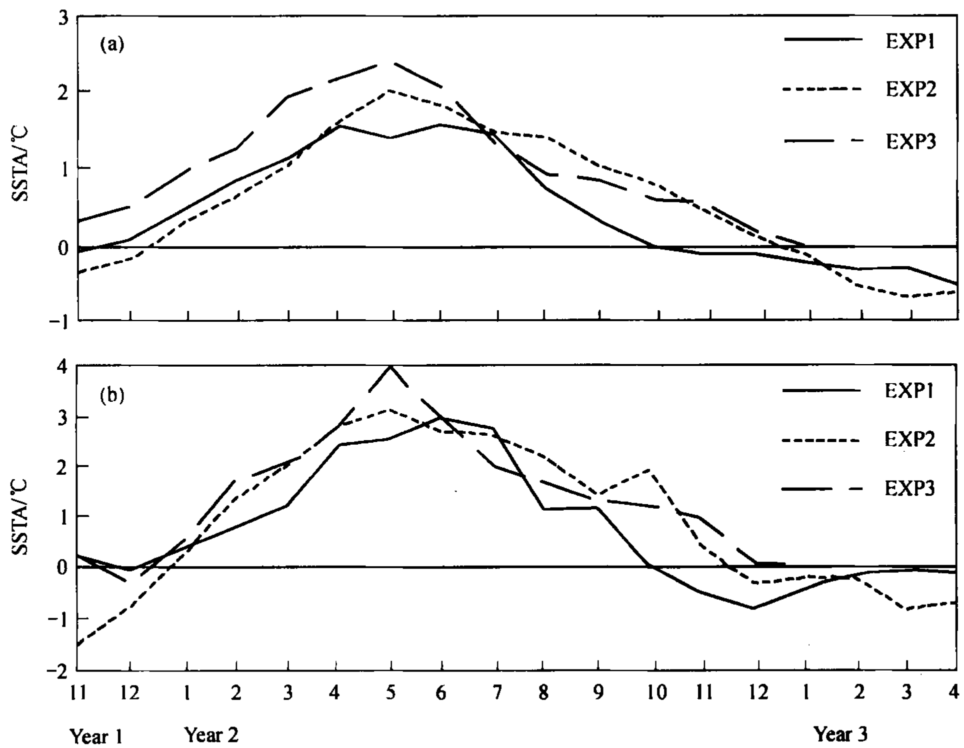

Fig. 2. Temporal variations of the simulated SSTA in Niño 1+2 (a) and Niño 3 (b) regions caused by the anomalous strong winter monsoon in East Asia. Three lines represent the results for different initial fields.

which is represented by using positive anomalies of the surface pressure (maximum +14 hPa) and negative anomalies of surface air temperature (maximum – 4℃) in the Siberia-Mongolia region in the period of November—April, are just given in this paper. It is clearly shown in fig. 2 that abnormal strong East Asia winter monsoon can excite positive SSTA in the equatorial eastern Pacific like El Niño, through air-sea coupled interaction. Moreover, similar to the observation results, it can be shown that the westerly wind anomalies and enhanced intraseasonal oscillation over the equatorial central-western Pacific caused by strong East Asian winter monsoon play an important role in occurrence of El Niño (figure omitted). In the above simulations, the anomalies of East Asian winter monsoon were just in the period of November—April, which were shorter than those observated. If the anomalies continued into summer as shown in fig. 1, the simulated result will be much similar to the observation, which showed the maximum of SSTA in November.

2 Occurrence of ENSO and subsurface ocean temperature anomaly in the warm pool region

The strongest El Niño event in this century outbroke in summer of 1997. But the observation showed that there were obviously positive anomalies of subsurface ocean temperature (SOT) in the warm pool region before the occurrence of El Niño, the anomaly of SOT began in the autumn of 1996. The eastward propagation of positive anomalies of SOT from the equatorial western Pacific to the equatorial eastern Pacific and expanding to the sea surface can be regarded as the origin of the El Niño event. When the El Niño event was onset, there were negative anomalies of SOT in the warm pool, then, the negative anomalies of SOT propagated eastwards from the warm pool region to the equatorial eastern Pacific along the thermocline and excited the La Niña in 1998.

In relation to the evolution of SOT anomalies in the equatorial Pacific in the 1997—1998 ENSO period, most of us have found it in *Climate Diagnostics Bulletin* published in USA, it is not necessary to show that again. But it can be suggested that the 1997—1998 ENSO is closely related to the anomalies of SOT in the warm pool region and the eastward propagation of the anomalous SOT.

In fact, the important role of the subsurface ocean temperature anomalies in the warm pool region in the occurrence of ENSO was not only shown in the 1997—1998 ENSO, but also in most of the historical events. As we know, the SSTA in Niño 3 can represent the ENSO process very well, and the anomaly of SOT during 100—200 m layer in (10°S—10°N, 140°E—180°) region can represent thermal regime of subsurface in the warm pool. In order to investigate the relationship between ENSO and anomaly of SOT in the warm pool region, the temporal variations of the SSTA in Niño 3 and the SOTA

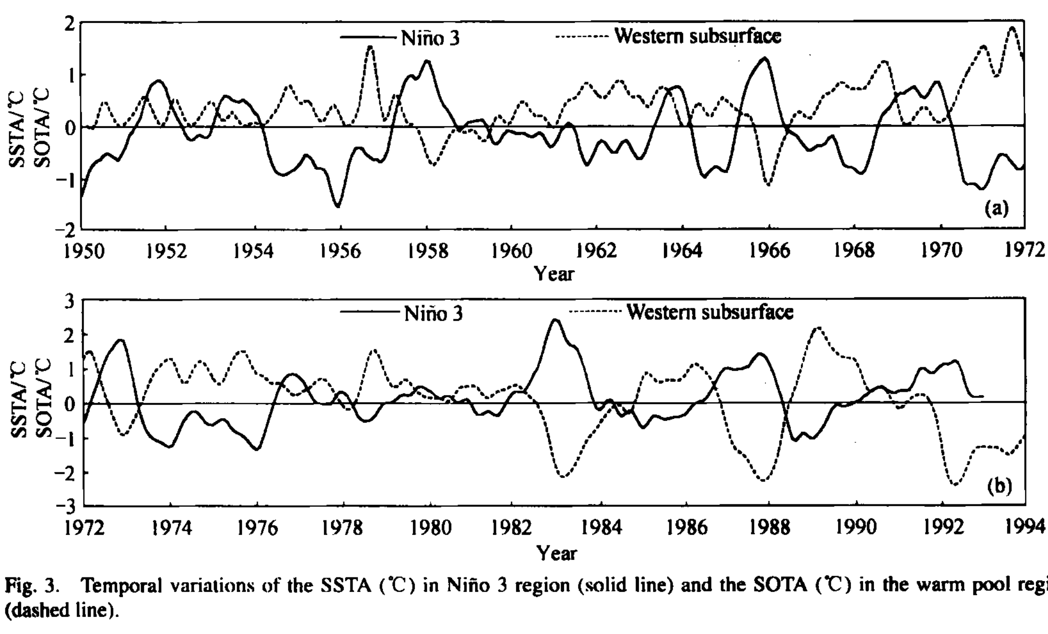

Fig. 3. Temporal variations of the SSTA (℃) in Niño 3 region (solid line) and the SOTA (℃) in the warm pool region (dashed line).

in warm pool are given in fig. 3, in which the SOTA and SSTA are computed by using the Joint Environmental Data Analysis Center (JEDAC) data and the COADS data, respectively. It is very clear that the positive anomalies of the SOT always exist in the warm pool region prior to the occurrence of El Niño event, but after the onset of El Niño, the SOTA in the warm pool region are out-of-phase to the SSTA in Niño 3. Moreover, it is also shown that the subsurface warming in the warm pool region leads to the onset of El Niño event for half to two years.

By analyzing each El Niño event, it can be shown that the eastward propagation of positive anomalies of the SOT is directly related to the occurrence of El Niño event, when positive anomalies of the SOT propagated into the equatorial eastern Pacific (from the warm pool region), the positive anomalies of SST will occur since the thermocline is gradually raised in the equatorial eastern Pacific. In other words, the positive SOTA in the warm pool region and its eastward propagation into the equatorial eastern Pacific can be regarded as an important origin of the El Niño occurrence. In fig. 4, the time-longitude sections of SOTA in the equatorial Pacific are given for composited El Niño cases and La Niña cases, respectively. The data of SOTA are respectively adopted in different depths, such as 160—120 m in the equatorial western Pacific, 120—60 m in the equatorial centre Pacific and 60—40 m in the equatorial eastern Pacific, because the thermocline is deeper and thicker in the equatorial western Pacific than that in the equatorial eastern Pacific. It is also evident that there were obviously positive (negative) anomalies of SOT in the warm pool region for quite a long time prior to the El Niño (La Niña) event, when the positive (negative) SOTA propagated eastwards into the equatorial eastern Pacific (east of 160°—150°W) along the thermocline, the El Niño (La Niña) will outbreak.

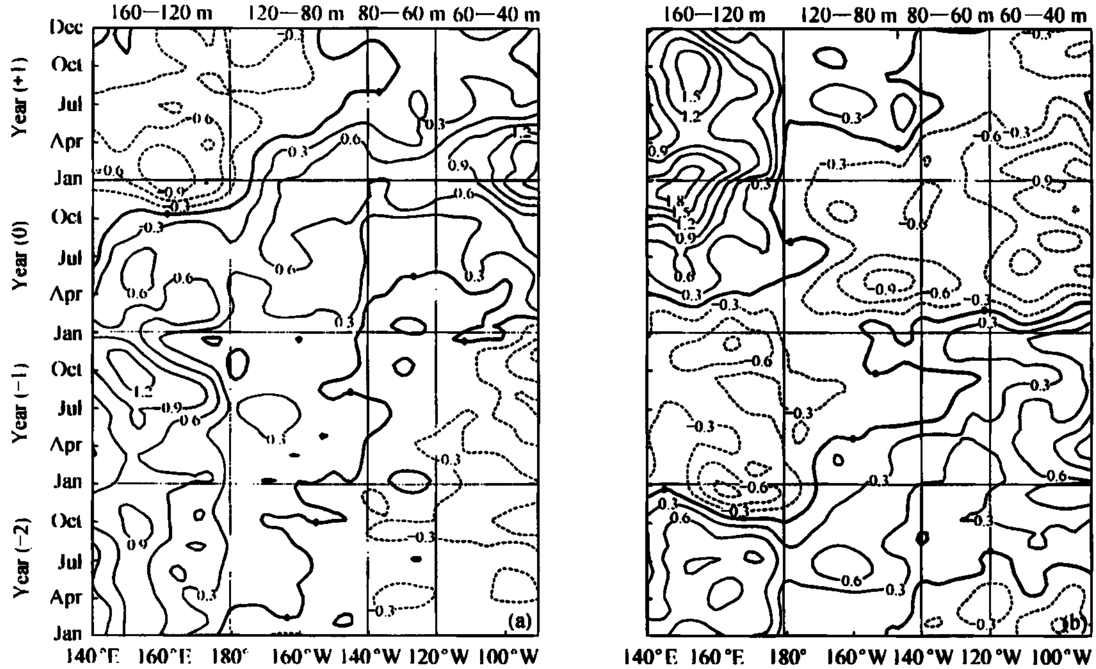

Fig. 4. Time-longitude sections of SOTA (°C) in the equatorial Pacific along the maximum variation layer (thermocline) of ocean temperature for composite El Niño case (a) and La Niña case (b).

In order to expose further the important role of SOTA in the warm pool region in exciting ENSO, the numerical simulation data in the CGCM (which has been introduced in the first section) are analyzed for the 61st—100th years integrations. During the 40 years (the 61st—100th), 13 simulated warm (El Niño) events and 12 simulated cold (La Niña) events are clearly shown, even though the intensity of SSTA is weaker than the observation. The temporal variations of the simulated SSTA in Niño 3 region and the SOTA in the warm pool region (6°S—6°N, 140°E—180°) are shown in fig. 5. It can be seen that there are obviously positive anomalies of SOT in the warm pool region prior to most of

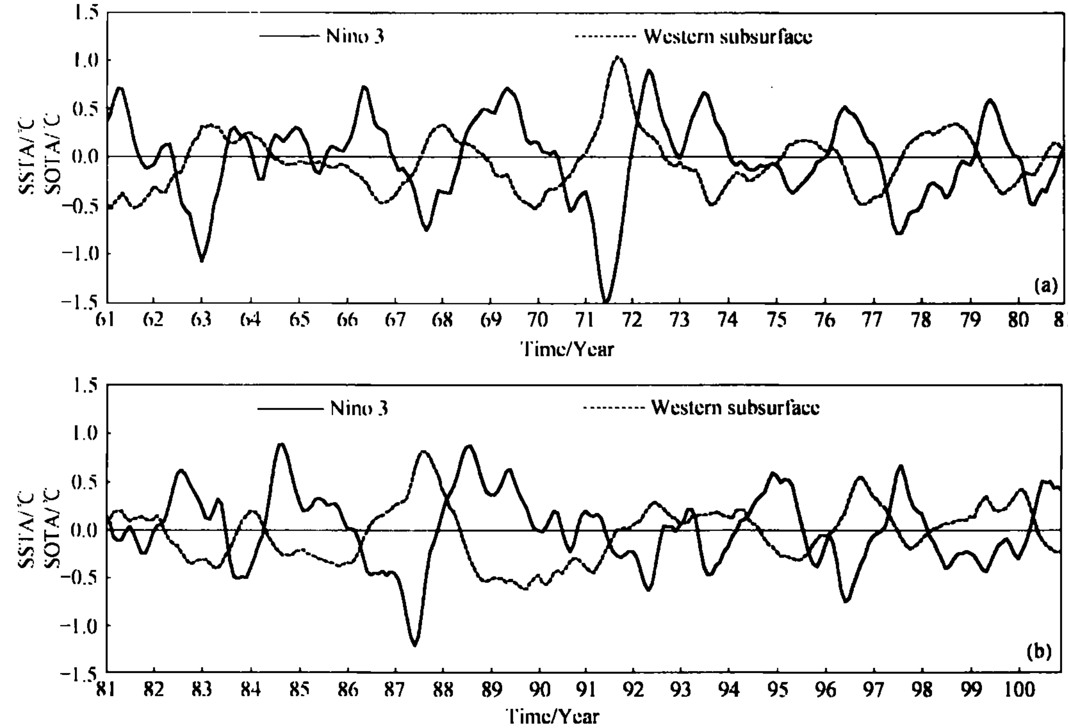

Fig. 5. Temporal variations of the simulated SSTA in Niño 3 region (solid line) and SOTA in the warm pool (6°S—6°S), 140°E—180°) region (dashed line).

the warm events and the SOTA in the warm pool region become negative after the appearance of warm events. On the contrary, the cold events are always corresponding to negative SOTA in the warm pool region in the earlier stage.

The above-mentioned discussions have shown that the data analyses and numerical simulations in the CGCM indicated the same results: the occurrence of ENSO is closely related to the anomaly of SOT in the warm pool region, there are positive (negative) SOTA in the warm pool region prior to the El Niño (La Niña) event; the onset of ENSO is directly related with the eastward propagation of SOTA in the warm pool region, the eastward propagating of positive (negative) SOTA into the equatorial eastern Pacific and expanding to the sea surface will lead to the anomalies of SST in the equatorial eastern Pacific and the onset of El Niño (La Niña) event. After the occurrence of ENSO, the SSTA in Niño 3 and the SOTA in the warm pool region are in the opposite phase.

3 Important role of the westerly wind anomaly over the equatorial western Pacific

The above discussion clearly shows that the occurrence of ENSO is directly related to eastward propagation of the SOTA in the warm pool region. What is the factor to cause the eastward propagation of the SOTA? In fig. 6, the temporal variations of the composite SOTA in the warm pool region, westerly wind anomalies over the equatorial western Pacific (10°S—10°N, 120°—160°E), SOTA in the equatorial eastern Pacific (5°S—5°N, 170°—130°W) region and SSTA in Niño 3 region (5°S—5°N, 150°—90°W) are respectively shown for El Niño cases. Fig. 7(d) clearly shows the evolution of SSTA in Niño 3 region for the El Niño event; before the occurrence of positive SSTA in Niño 3, positive SOTA have propagated into the equatorial eastern Pacific as shown in fig. 6(c); but the westerly wind anomalies over the equatorial western Pacific occurred earlier (fig. 6(b)) and it can be regarded as a mechanism to cause eastward propagation of SOTA in the warm pool region; fig. 6(a) shows that before the occurrence of El Niño event (about 1 year), there were obviously positive SOTA in the warm pool region.

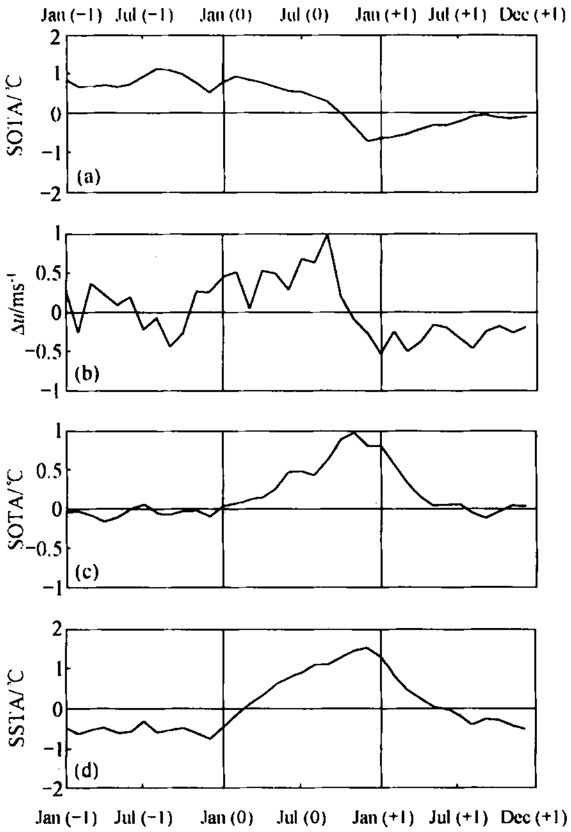

Fig. 6. The relationships between the SOTA in the warm pool region (a), zonal wind anomalies over the equatorial western Pacific (b), the SOTA in (5°S—5°N, 170°—130°W) region (c), which can represent the eastward propagation of SOTA from the warm pool region, and the SSTA in Niño 3 region (d) for the composite El Niño case.

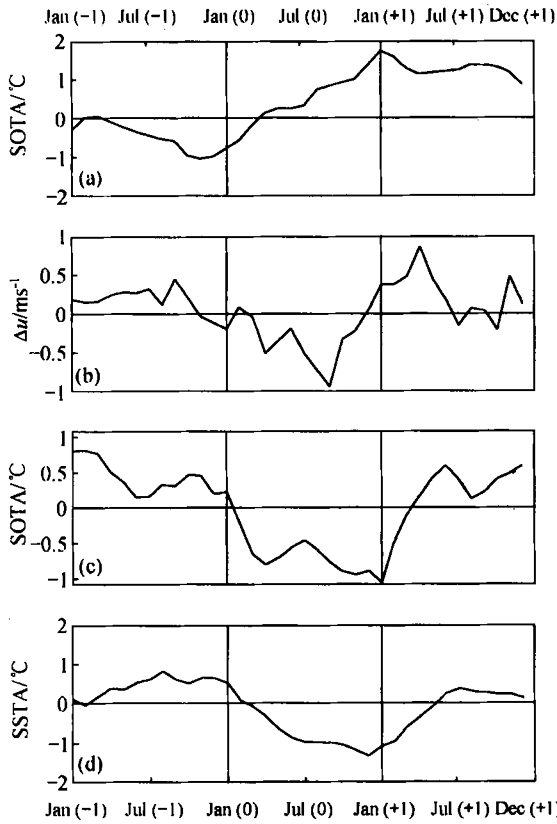

Fig. 7. Same as in fig. 6, but for composite La Niña case.

The similar evolution for La Niña cases is shown in fig. 7, negative SSTA in Niño 3 corresponds to early negative SOTA and the easterly wind anomalies over the equatorial western Pacific. In other words, the easterly wind anomalies over the equatorial western Pacific will lead to the eastward propagation of negative SOTA in the warm pool region, when negative SOTA propagated into the equatorial eastern Pacific, negative SSTA will appear in the equatorial eastern Pacific and La Niña will occur.

Based on figs. 6 and 7, it can be suggested that the westerly wind anomalies over the equatorial western Pacific play an important role in the eastward propagation of SOTA in the warm pool region and the occurrence of ENSO. The oceanic Kelvin wave may be a fundamental mechanism causing the eastward propagation of the SOTA in the warm pool region, because some studies have indicated that the westerly (easterly) wind anomalies over the equatorial western Pacific can excite anomalous oceanic warm (cold) Kelvin wave[18,19].

Figs. 1 and 2 clearly show that continued westerly (easterly) wind anomalies over the equatorial western Pacific are closely related to the strong (weak) winter monsoon in East Asia. Therefore, we can still say that the anomaly of zonal wind over the equatorial western Pacific, which is mainly caused by anomalous winter monsoon in East Asia, is an important mechanism to drive the eastward propagation of SOTA in the warm pool region and excite the ENSO.

4 Conclusion

Through the data analyses and numerical simulations with a CGCM, the new perspective associated to the occurrence of ENSO is advanced in this paper. It can be represented as follows:

The continued strong (weak) winter monsoon in East Asia will lead to continued westerly (easterly) wind anomalies over the equatorial western Pacific; then anomalous westerly (easterly) wind causes the eastward propagation of positive (negative) anomalies of SOT in the warm pool region, which have been there for quite a long time; the eastward propagating positive (negative) SOTA along the thermocline will lead to positive (negative) SSTA in the equatorial eastern Pacific and the occurrence of El Niño (La Niña) event. After the occurrence of ENSO, the winter monsoon in East Asia will be weaker (stronger) due to the influence of the El Niño (La Niña) event, as shown in previous studies.

Therefore, ENSO cycle is closely related to the SOTA in the warm pool region and the anomaly of winter monsoon in East Asia. There is a cycle evolution which showed the interactions between the East Asian winter monsoon, SOTA in the warm pool region and ENSO. Of course, two questions need to be investigated further: what is the mechanism to cause the anomaly of SOT in the warm pool region? How about the physical process, through which anomalous zonal wind over the equatorial western Pacific can lead to the eastward propagation of the anomalous SOT in the warm pool region?

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