Origin of the TBO–Interaction between Anomalous East–Asian Winter Monsoon and ENSO Cycle①

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ABSTRACT

Based on the data analyses by using NCEP / NCAR reanalysis data and other data (OLR, precipitation and temperature), it is shown that the tropospheric circulation and climate in East Asia and the northwestern Pacific region have the evident quasi–biennial oscillation (TBO) feature. It is also shown that anomalous East Asian winter monsoon can impact the atmospheric circulation and climate variations in the following summer, particularly in East Asian region; there is clear interaction between anomalous East Asian winter monsoon and ENSO cycle. The continuous strong (weak) East Asian winter monsoon can excite El Niño (La Niña) through the air–sea interaction, the El Niño (La Niña) event can lead the East Asian winter monsoon to be weak (strong) through the teleconnections or remote responses. The strong or weak winter monsoon and ENSO cycle are linked each other. It can be suggested that interaction between anomalous East Asian winter monsoon and ENSO cycle is a fundamental origin of the TBO.

Key words: Origin, Tropospheric biennial oscillation (TBO), Interaction, Anomalous East Asian winter monsoon, ENSO cycle

1. Introduction

The QBO, a quasi–periodic (about 26 months) variation of the wind field in the equatorial lower stratosphere was found and this kind of quasi–periodic variation in the temperature, tropopause height and O_3 content is further detected during the 1960s (Read, 1961; Read and Rogers, 1962; Tucker and Hopwood, 1968; Augell and Korshover, 1968). Then, the dynamic mechanism of the QBO was advanced as the upward–propagating planetary wave theory (Lindzin and Holton, 1968; Holton and Lindzin, 1972), and the influences of the QBO on the atmospheric circulation and climate were investigated (Mukherjee et al., 1985; Gray, 1984; Li and Long, 1992).

In recent years the phenomena of the quasi–biennial variation of the tropospheric circulation and climate are revealed, it was called the tropospheric (quasi–) biennial oscillation (TBO). Some studies have indicated that the TBO might result from the influence of the QBO in the stratosphere, including the influences of the QBO on the tropical cyclone, summer rainfall and subtropical high activity (Gray et al., 1992; Chan, 1995; Li and Long, 1997; Elsner

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et al., 1999). At the same time, the TBO is also regarded as a phenomenon associated with the sea surface temperature anomaly (or ENSO) and the monsoon system (Shen and Lau, 1995; Tomita and Yasunari, 1996; Meehl, 1997).

In general, the period of ENSO is unsteady, but 2–7 years can be its quasi–period. Some studies have indicated that the biennial oscillation is one of important modes of the ENSO, for example, it has been shown that the tropical sea water temperature has quasi–biennial oscillation (Kawamura, 1988); the ENSO has 18–36 months and 36–120 months two major modes (Lau and Sheu, 1988; Lau and Yang, 1996); the SOI has biennial mode, 1 year cycle and low–frequency mode (Rasmusson, Wang and Ropelewski, 1990; Ropelewski, Halpert and Wang, 1992). It was also showed that there are two peaks in the power spectrum analysis of SSTA in Nino 3 region, one is 2–3 years period and another is 3–7 years period (Mu and Li, 1999), they are all above the 99% significance. If we regard the SSTA peak in period 2–7 years as the ENSO signal, the calculation showed that the 2–3 years mode is about 35% of total ENSO signal. Therefore, the biennal oscillation is important in the ENSO cycle.

Through the data analyses, it is indicated in this paper that the origin of the TBO is the interaction between anomalous East Asian winter monsoon and ENSO cycle.

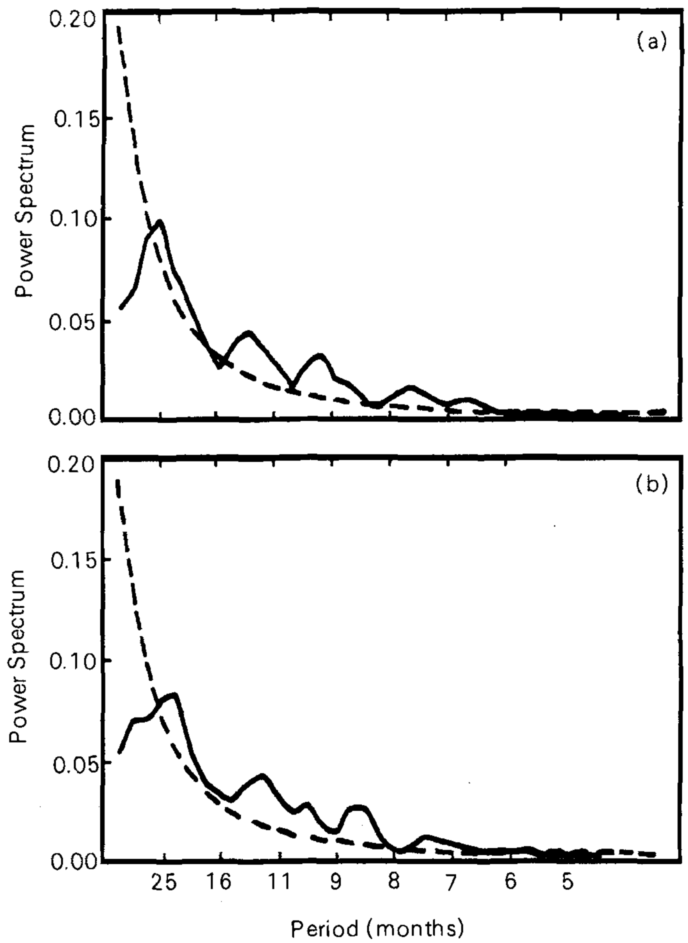

Fig. 1. The power spectra of monthly precipitation in the middle and lower reaches of the Yangtze River (a) and South China (b). The dashed line denotes 95% significance level.

2. Quasi–biennial variations of the circulation and climate in the northwestern Pacific and East Asian region

The quasi–biennial variation of monthly precipitation in eastern China has been studied and shown (Huang, 1988). In fact, the quasi–biennial variation of monthly precipitation is more evident in the Yangtze River and South China regions. The power spectra of monthly precipitation in the middle and lower reaches of the Yangtze River and South China for the period 1951–1980 are shown in Fig. 1, respectively. Obviously, there are clear quasi–biennial (25–27 months) spectral peaks in the precipitation over the above–mentioned areas. The surface air temperature also showed similar quasi–biennial variation as well as the precipitation in the above areas (figure omitted).

As we know, the subtropical high is an important system for the weather and climate variation in the northwestern Pacific and East Asia, particularly in summer. Generally, the intensity and variability of the subtropical high over the northwestern Pacific can be

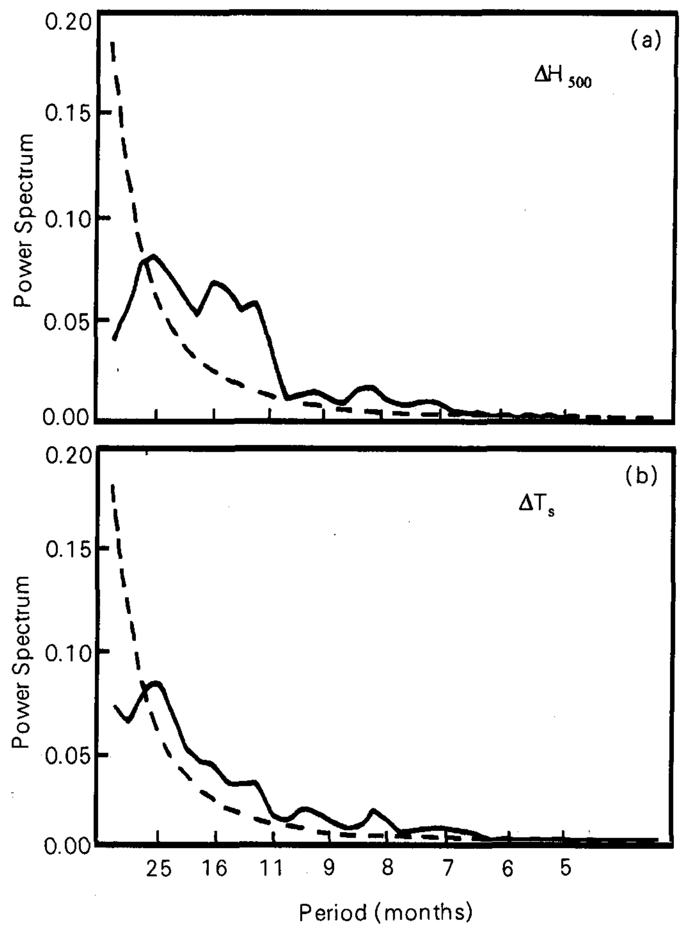

Fig. 2. The power spectra of the geopotential height variation at 500 hPa in the northwestern Pacific (20°–30°N, 120°–150°E) region (a) and surface temperature variation in the middle and lower reaches of the Yangtze River (b).

represented by using the geopotential height anomalies at 500 hPa in (20°–30°N, 120°–150°E) region. The power spectrum of the intensity variation for the subtropical high over the northwestern Pacific is shown in Fig. 2a. The 26 months spectrum peak is evident. Therefore, the intensity of the subtropical high over the northwestern Pacific has the quasi–biennial variation. Also, the latitude location of the ridge line of the subtropical high, which is another important feature showing the subtropical high activities, has similar quasi–biennial variation (figure omitted). The surface temperature variation in the middle and lower reaches of the Yangtze River also showed the feature of the quasi–biennial oscillation (Fig. 2b).

Generally, the meridional wind in the northwestern Pacific region (20°–35°N, 120°–150°E) and surface air temperature in eastern China can represent the activity of East Asian winter monsoon. The data analyses showed clearly the quasi–biennial variation features for the above parameters. In Fig. 3, the temporal variation and wavelet (Mexican hat) analyses of meridional wind anomaly at the surface averaged in (20°–35°N, 120°–150°E) region with the COADS during 1950–1993 are shown. It can be seen in both temporal variation and the wavelet analysis results that a quasi–biennial fluctuation is clear. The surface temperature in eastern China has similar quasi–biennial fluctuation, as shown in Fig. 2b.

It can be still shown from the wavelet analysis results that the quasi–biennial variation is stronger during the periods 1965–1975, 1981–1993 and before 1954. This means the TBO may have the interdecadal variation feature.

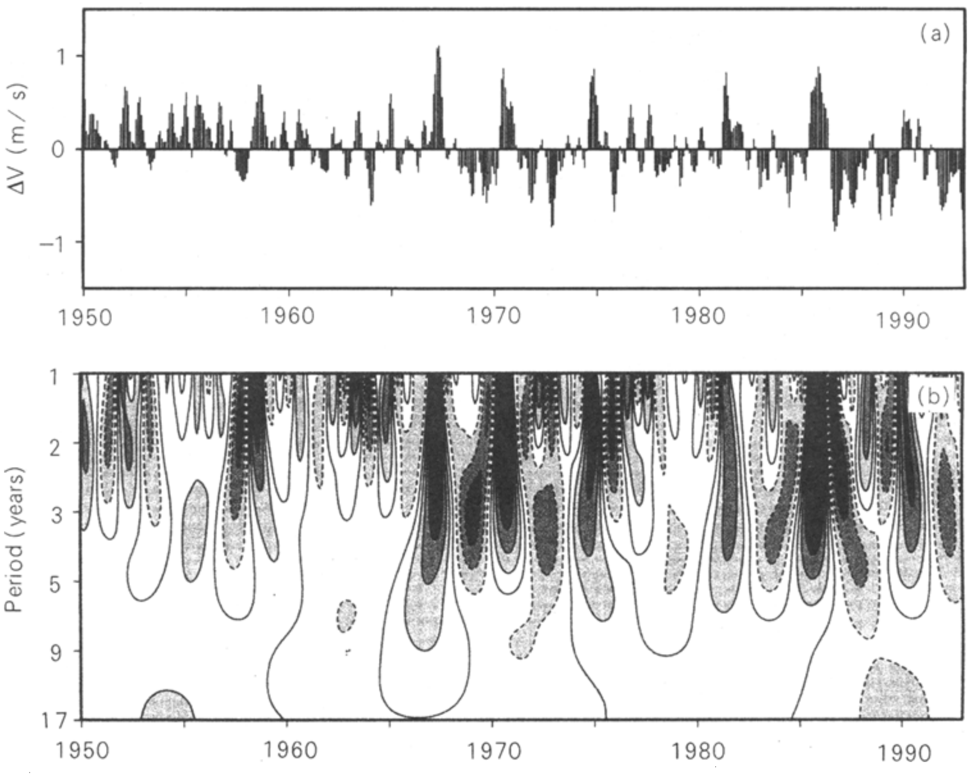

Fig. 3. Temporal variation of meridional wind anomalies in (20°–35°N, 120°–150°E) region (a) and its wavelet analysis results (b).

3. Interaction between anomalous East Asian winter monsoon and ENSO cycle

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 (Li, 1989; 1990; 1996). In this paper, we just give out 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.

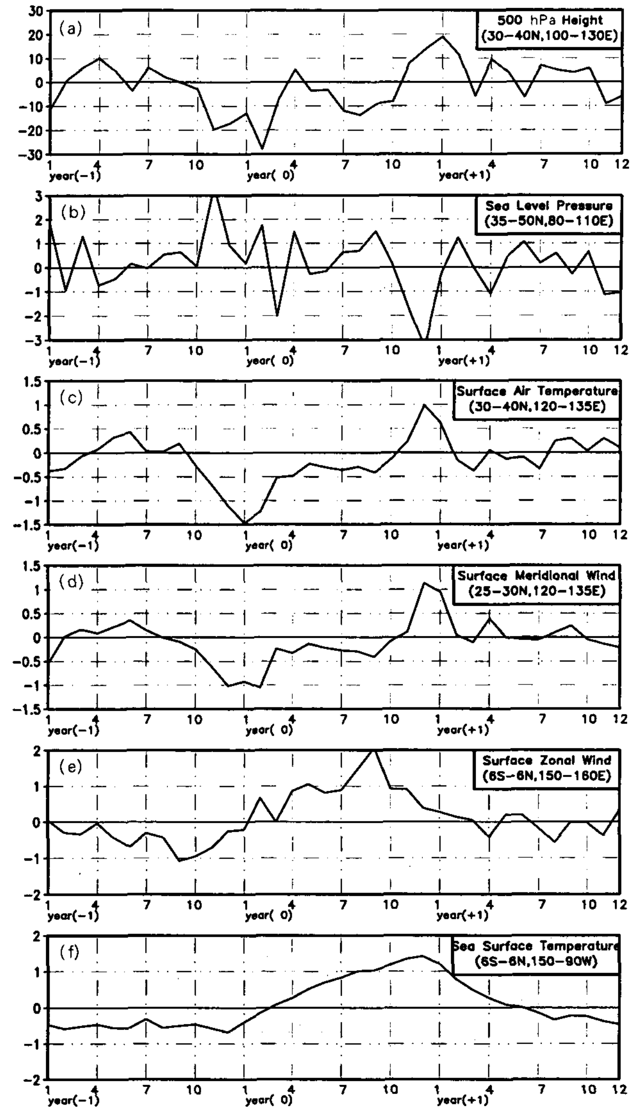

Fig. 4. The relationship between abnormal East–Asian winter monsoon and El Niño. The geopotential height anomalies at 500 hPa in the region (30°–40°N, 100°–130°E) (a), the surface pressure anomalies in the region (35°–50°N, 80°–110°E) (b), the surface air temperature anomalies in the region (30°–40°N, 120°–135°E) (c), the meridional wind anomalies in the region (25°–30°N, 120°–135°E), the zonal wind anomalies over the equatorial western Pacific region (6°S–6°N, 150°–160°E) (c) and the SSTA in the Nino 3 region (f) for composite El Niño case. The (–1), (0) and (+1) represent last year, present year and following year for the occurrence of El Niño, respectively.

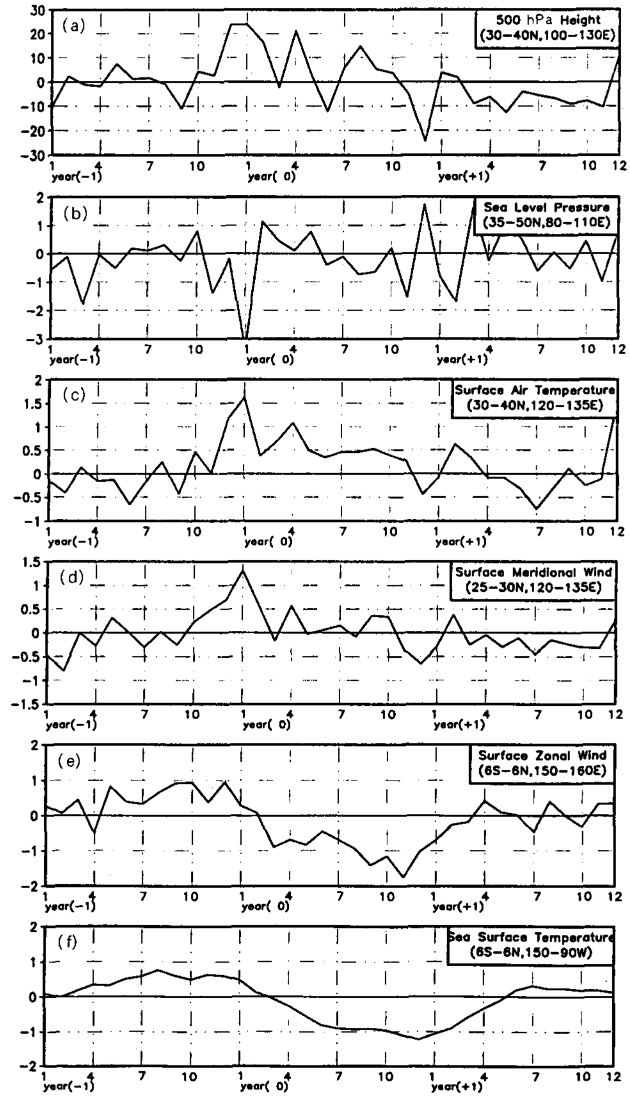

Fig. 5. Same as Fig. 1, but for composite La Niña case.

It is well known, the activity of East–Asian winter monsoon can be represented by using some meteorological elements in the East Asian region, such as the surface 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–Mongolin region, deepening trough at 500 hPa in East Asia, strong northerly wind and lower surface air temperature in the eastern China and northwestern Pacific region. The opposite situation occurs for continuous weak East Asia winter monsoon. In Fig. 4, the interaction between abnormal East Asian winter monsoon and El Niño can be shown by the composite for 9 El Niño events (the period 1950–1990). Figure 4a–d all can represent the activity of winter monsoon in East Asia; Figures 4e and 4f represent the zonal wind anomaly over the equatorial western Pacific and the El Niño event (SSTA in Niño3). It is evident that the El Niño (composite) event outbreaks in spring; the westerly wind anomalies over the equatorial western Pacific are about 2–3 months earlier than the El Niño outbreak; and 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 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 suggests 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 shown in Fig. 5, in which the representative elements are all the same as those in Fig. 4 but for the composite of 7 La Niña events (the period 1950–1990). 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 the 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 La Niña event through producing easterly wind anomalies over the equatorial western Pacific. Moreover, during the wintertime after the

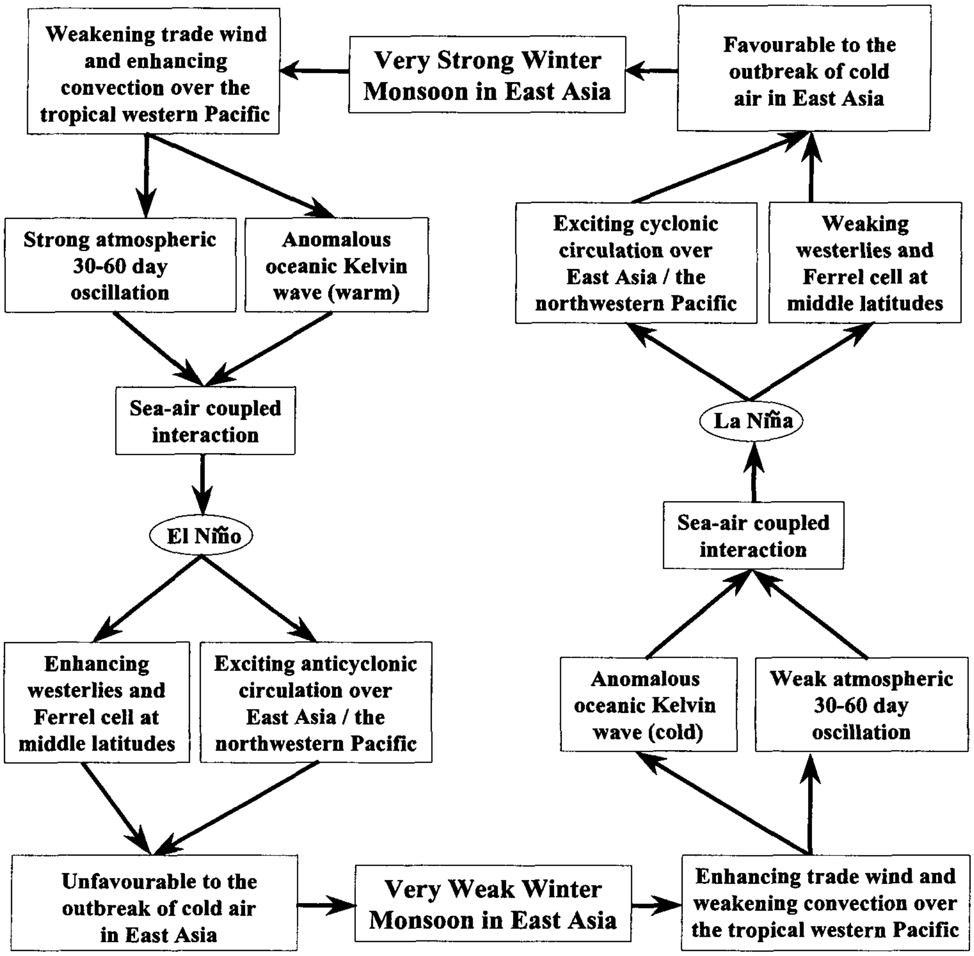

Fig. 6. Schematic diagram of the interactions between anomalous winter monsoon in East Asia and ENSO cycle.

La Niña outbreak, there is strong winter monsoon in East Asia as shown in Fig. 5. This can suggest that the La Niña event should enhance the winter monsoon in East Asia.

According to the above analysis results and the previous conclusion studying interaction processes between each other, we can suggest a schematic diagram to represent the interactions between anomalous East–Asian winter monsoon and ENSO cycle as shown in Fig. 6. It is very clear that the strong–weak winter monsoon variation in East Asia is closely linked to the ENSO cycle. The strong winter monsoon in East Asia will excite the El Niño event through the air–sea interaction, then, the El Niño event will lead East Asian winter monsoon to be weak through teleconnection. The weak East Asian winter monsoon will excite La Niña through the air–sea interaction, then the La Niña will lead East–Asian winter monsoon to be strong through teleconnection (atmospheric remote responses). Figure 6 not only shows the mechanism of quasi–biennial component in the ENSO cycle but also the origin of the TBO.

4. The connection between East Asian winter monsoon and the circulations in the following summer

The studies have shown that there exists a good connection between anomalous East Asian winter monsoon and the circulation in the following summer. In general, summer floods in the central region of the eastern China corresponds mostly to a preceding weak East Asian winter monsoon; drought years are preceded by stronger East Asian winter monsoon (Sun and Sun, 1994). Case studies and numerical simulations have also indicated that a stronger (weaker) East Asian winter monsoon is associated with a weaker (stronger) East Asian summer monsoon (Chen and Sun, 1999; Ji et al., 1997). This section gives a composite study to illustrate the temporal teleconnection of circulation on an annual time scale. Three cases for both strong and weak East Asian winter monsoon are chosen respectively, based on a complex index considering the meridional circulation index, surface temperature of southeastern China and NE–component surface wind in the coastal region of East Asia.

As can be seen by comparing the composites of the two groups, the difference of anomalous wind fields in the lower troposphere between the strong and weak East Asian winter monsoon is remarkable. For the strong cases, strong northerly wind anomalies appear in the wide area ranging from eastern China to the Philippines. Noticeable is that not only the anomalous northerly winds appear over the tropical western Pacific, but there forms a cyclonic difference circulation to the east of the Philippines, i.e. the warm pool area. Consequently, it leads to a stronger convergence, hence, ascending current over the equatorial western Pacific. And for the weak cases, the direction of wind field anomaly is basically reverse.

Figures 7a and 7b are the composite maps of the wind anomalies winds at 850 hPa in summer corresponding to the strong and weak East Asian winter monsoon cases respectively. The wind vectors in the two figures are nearly opposite to each other. In Fig. 7a corresponding to stronger East Asian winter monsoon, an anomalous cyclonic stream field is located over the tropical western Pacific, there are anomalous westerly winds along the latitudes (EQ–10°N) over the longitudes (100°–160°E). Over eastern China, there are weaker northeasterly winds, and the summer monsoon is weaker. Corresponding to the weak winter monsoon case (Fig. 7b), there is an anticyclonic stream field over the tropical western Pacific and anomalous easterly winds along the latitudes (EQ–10°N). Also there are anomalous southwesterly winds over the eastern China, and the summer monsoon is stronger.

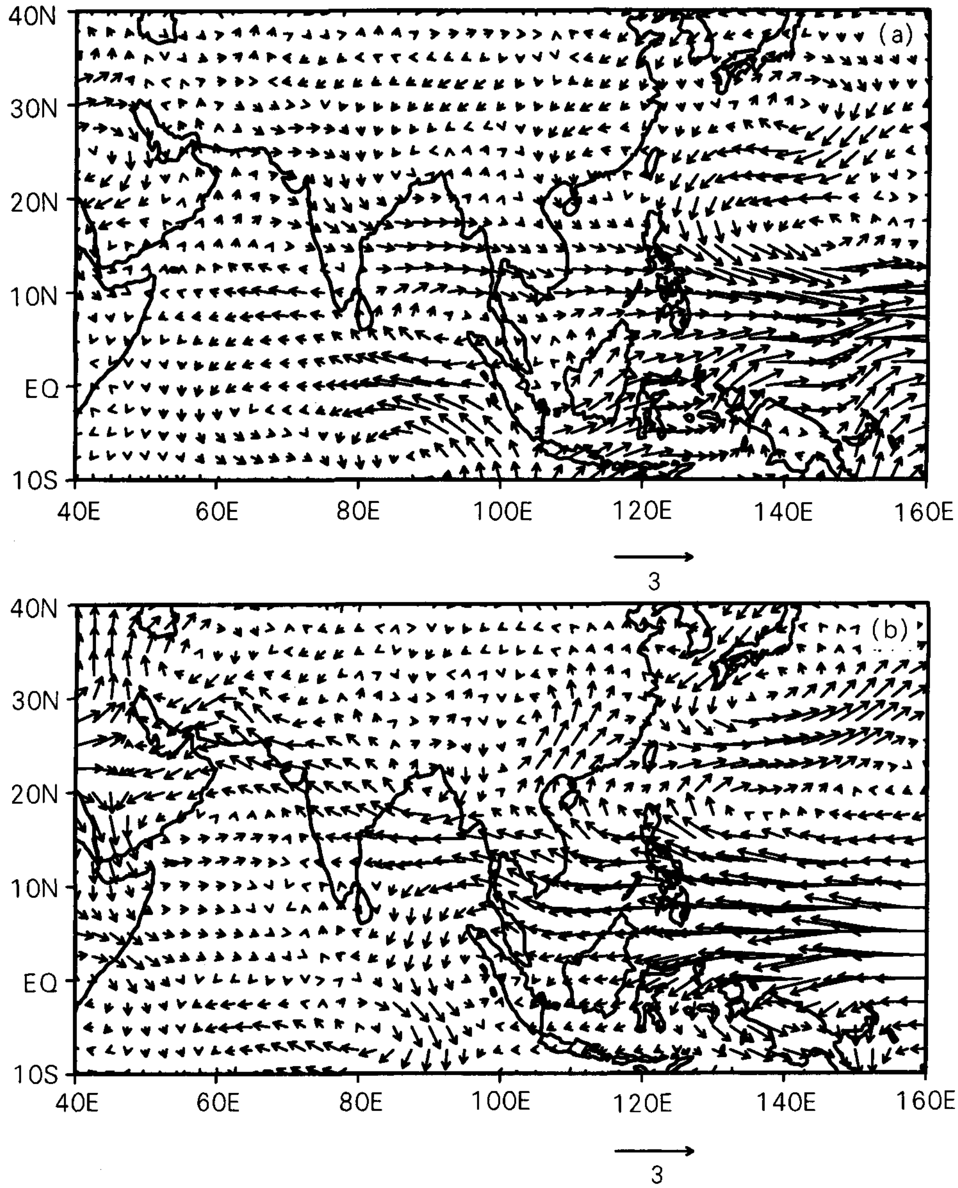

Fig. 7. Composite maps of the wind anomalies at 850 hPa in summer (JJA). (a) For strong East Asian winter monsoon cases (1962–1963, 1967–1968, 1975–1976, 1981–1982, 1985–1986, 1990–1991, 1996–1997), (b) for weak ones (1963–1964, 1972–1973, 1974–1975, 1982–1983, 1987–1988).

The strength of summer monsoon influences directly the precipitation near eastern China. Figure 8 shows the differences of total summer rainfall (JJA) between the strong and weak Asian winter monsoon respectively. A band of negative value is ranging along the Yangtze River valley implying deficient summer rainfall in the " Meiyu" area for the strong cases and more precipitation in the weak cases. This fact is in good agreement with the results given by Sun and Sun (1994) and Ji et al. (1997).

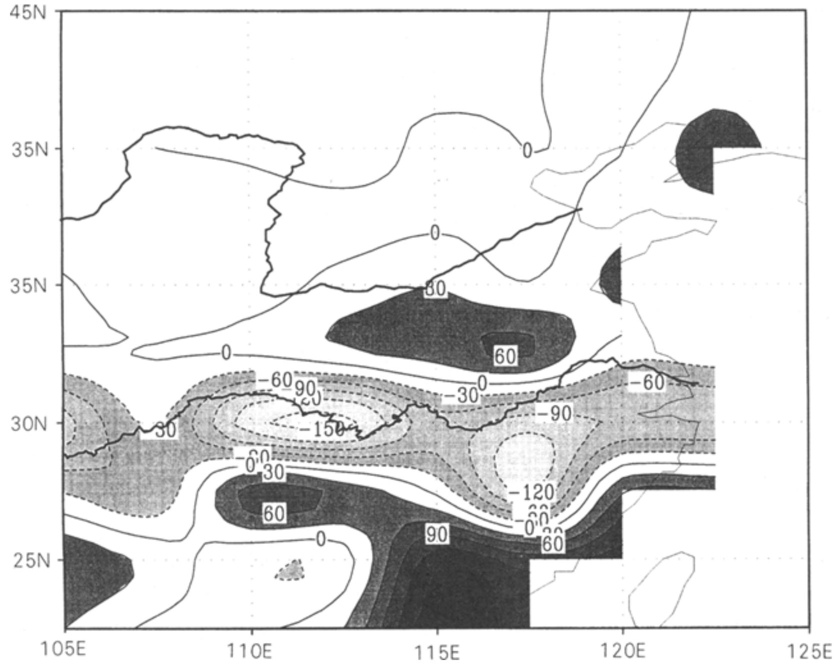

Fig. 8. The differences (mm / month) of summer rainfall between strong and weak winter monsoon.

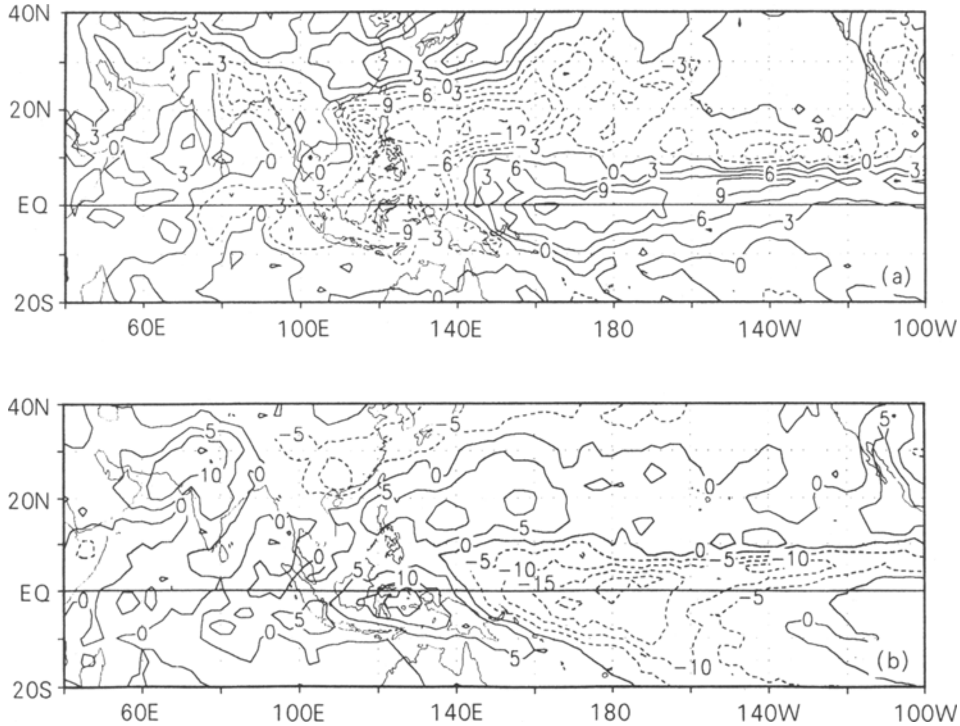

Fig. 9. Anomalous OLR (W/m^2) distributions in summer for strong (a) and weak (b) winter monsoon in East Asia.

The influence of anomalous East Asian winter monsoon on the following summer circulation can be seen in the monsoon area and the vast tropical region as well. Figure 9 is the corresponding composite of OLR distribution. As can be seen, the signs of OLR anomaly are reverse between strong and weak East Asian winter monsoon years, not only over the Asian monsoon region, but also over the central and eastern equatorial Pacific. This indicated that there is weaker convection over the central and eastern Pacific in summer following a stronger East Asian winter monsoon year; while for weaker one, the opposite is the case, ITCZ at that location being stronger. The drastic contrast of OLR distribution is in agreement with the flow anomalies in Fig. 7.

To summarize, the above results suggest that the anomalous East Asian winter monsoon and its impact bear a persistence of seasonal time scale, i.e. the anomalous East Asian winter monsoon could exert a pronounced impact on the following summer circulation and cliamte. The connection between them is quite apparent.

5. Conclusions

According to the above analysis results in this paper, the following conlusions could be drawn:

1) In the northwestern Pacific and East Asian area, particularly in the subtropics and tropical region, the quasi–biennial oscillations of atmospheric circulation and climate, i.e. the TBO, is very clear. We should pay more attention to the TBO in research and prediction of the climate.
2) The ENSO (El Niño–La Niña) cycle is closely related to strong or weak winter monsoon in East Asia, through the tropical air–sea interaction and atmospheric remote responses, there is well–marked interaction between the ENSO cycle and the anomalies of East–Asian winter monsoon. Moreover, the interaction between anomalous East–Asian winter monsoon and the ENSO cycle can be regarded as the mechanism of the TBO.
3) The anomalous East Asian winter monsoon could exert a pronounced impact on the following summer circulation and climate. The strong (weak) East Asian winter monsoon will lead the following summer monsoon to be weak (strong) in the East Asian region. Also the influences of anomalous East Asian winter monsoon on the following summer circulation can be seen over the equatorial Pacific region, including the wind fields and convection activities.

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TBO 的原因—异常东亚冬季风与 ENSO 循环的相互作用

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摘 要

基于对 NCEP / NCAR 再分析资料以及其他资料(OLR, 降水和气温等)的分析研究, 结果表明东亚和西北太平洋地区的对流层环流和气候变化都有明显的准两年振荡(TBO)特征。同时, 异常东亚冬季风可以影响次年夏季的大气环流和气候变化, 特别是在东亚地区; 而异常东亚冬季风和 ENSO 循环间又有明显相互作用: 持续的强(弱)东亚冬季风通过海—气相互作用可以激发 El Niño(La Niña), El Niño(La Niña)反过来又可通过遥相关或遥响应而导致东亚冬季风偏弱(强)。强或弱的冬季风和 ENSO 循环是相互衔接在一起的, 因此可以认为异常东亚冬季风与 ENSO 循环的相互作用是 TBO(对流层准两年振荡)的基本原因。

关键词: 原因, 对流层准两年振荡(TBO), 相互作用, 异常东亚冬季风, ENSO 循环