Article ID: 1006-8775(2002) 02-0191-10

ON THE INTERACTIONS BETWEEN ENSO AND THE ASIAN MONSOON ON THE SCALE OF QUASI-BIENNIAL OSCILLATION

ZOU Li (**邹 力**) [1] , ZHU Hong-wei (**朱红伟**) [1], WU Ai-ming (**吴爱民**) [2], NI Yun-qi(**倪允琪**) [3]

(1. *Meteorological Institute*, *China PLA University of Science & Technology*, *Nanjing* 211101; 2. *Oceanology Institute of Chinese Academy of Sciences*, *Qingdao* 266071; 3. *Chinese Academy of Meteorological Sciences*, *Beijing* 100081 *China*)

ABSTRACT: A diagnostic analysis is performed of the quasi-biennial oscillations during the ENSO cycle and the results are based to study the interactions between ENSO and the Asian monsoons. It shows that the Asian monsoons have significant influence on the ENSO cycle on the quasi-biennial scale. Materialized through the onset and southward progression of the winter monsoon, the influence appears in the tropical western Pacific to excite severe convection and to further affect the ENSO cycle. The phenomenon is not only reflected in the quasi-biennial mode but the annual variation of the Asian winter monsoon in reality.

Key words: quasi-biennial oscillations; ENSO; monsoon; composite analysis

CLC number: P732 **Document code:** A

1 INTRODUCTION

ENSO is an annual oscillation phenomenon on the global scale in which a single warm (cold) episode takes place at intervals between 2 and 9 years, having a wide spectral band. Moreover, as shown in spectral analysis, tropical variables, such as SST, sea level pressure, zonal winds and amount of precipitation, are marked by two significant peaks, with the primary oscillation at 3 ~ 6 years and the secondary at quasi-biennial (QBO) [1, 2]. As noted in Barnett[3] and Ropelewski[4] et al., the quasi-biennial oscillation is part of the ENSO evolution that mainly situates over the Indian and Pacific Oceans. In this work, variance contribution by the wind, OLR and SSTA fields and their distribution are also studied (figure omitted), indicating the presence of significant quasi-biennial oscillation in the region of East Asian monsoon in addition to the Indian and Pacific Oceans.

Since the 1990's, the relationships between the ENSO phenomenon and monsoons have been widely watched. As early as in 1983, Rusmusson and Carpenter find that the ENSO relates well with the summer monsoon in Asia. Shukla[5, 6] discovers that the drought years of India link with the warm phase of ENSO while the flood years with the cold phase. Zou et al[7].have shown that variations of varying degrees or with even opposite features have taken place in every member of the summer monsoon systems in the Asian region. In order to have more understanding of the cycling mechanism of ENSO and cause of formation for the annual changes of Asian monsoons, the work devotes itself to detailed analysis and investigation of the interactions between ENSO and the monsoon on the quasi-biennial scale.

2 DATA AND METHODS OF ANALYSIS

Received date: 2001-02-28; **revised date:** 2002-07-28

Foundation item: Natural Science Foundation of China (49906003)

Biography: ZOU li (1962 –), male, native from Changzhou City of Jiangsu Province, associate professor, Ph.D., mainly undertaking the study of climatological dynamics.

2.1 *Data*

Monthly mean gridpoint data are used in the work, which include the global wind field (ECMWF), the global sea surface temperature (National Climate Center of the China Meteorological Administration) and the OLR in the tropical regions. The wind field takes the levels of 300 hPa (Jan. 1980 ~ Dec. 1994) and 850 hPa (Jan. 1975 ~ Dec. 1994), representing the upper and lower levels of the troposphere, respectively. The SST data covers a period from Jan. 1962 to Dec. 1994 while the OLR data covers a period from Jan. 1975 to Dec. 1991, with the year 1978 absent.

A new time series is constructed by seeking the anomalies of every month from the data above. In this way, changes from season to season have generally been eliminated to make it possible for the data to better respond to changes in the annual course.

2.2 *Composite methods*

Following the time-longitude profile of the QBO component along the equator (figure omitted), it is determined that a semi-period of QBO oscillation is made up of five phases over the ENSO cycle. Phase 1 is that of cold water and Phase 5 of warm water, for the QBO component of the SSTA. The division from Phase 1 to Phase 5 is conducted in the following ways. The month in which the negative component center of the QBO appears is taken as Phase 1, the month in which the positive component center of the QBO appears as Phase 5, the month in which the QBO component turns from negative to positive as Phase 3, the month that lies between the month of Phase 1 and that of Phase 2 as Phase 2 and the month that lies between the month of Phase 3 and that of Phase 5 as Phase 4. In view of the relatively short data length (especially of wind fields and OLR data) and the symmetric temporal distribution of QBO as a Class-One wave, the other half of the QBO cycle is made to change sign in actual computation to compose with the half cycle described above. The number of samples to be composed is doubled. Tab.1 gives the dates for the 8 phases over the biennial variation.

Tab.1 Dates corresponding to 8 phases in the quasi-biennial variation

phase	Date (year/month)					
1	75.12	82.1	84.1	86.4	88.12	91.1
2	76.3	82.4	84.4	86.9	89.3	91.4
3	76.7	82.7	84.7	87.2	89.6	91.7
4	76.9	82.10	84.11	87.6	89.9	91.10
5	76.12	83.1	85.2	87.10	90.1	92.1
6	77.4	83.4	85.4	88.2	90.4	92.3
7	77.7	83.7	85.8	88.6	90.7	92.6
8	77.11	83.10	85.11	88.9	90.10	92.10

It is shown in the table that the dates for Phases 1 and 5 generally occur in the boreal winter while those for Phases 3 and 7 in the boreal summer.

It must be pointed out that limited data length has resulted in unequal number of samples for every quantity of physics composed, though posing no obvious effects on the results composed, as shown in comparisons specially made to check. It is also demonstrated that the composed results can apply generally.

3 CHARACTERISTICS OF QBO COMPONENTS IN THE AIR-SEA COUPLING SYSTEM

3.1 *Flow fields*

As shown in composite results of the 5 phases in the first half cycle of the QBO component of the wind fields at higher and lower tropospheric levels, in Phase 1 at the lower level of 850 hPa (Fig.1), there is separately a cyclonic anomalous circulation in the subtropical regions of the Northern and Southern Hemispheres in the western Pacific, an anticyclonic anomalous circulation in the subtropical regions of both hemispheres in the eastern Pacific, but with the circulation extending westward far into the central and western Pacific. The anomalous

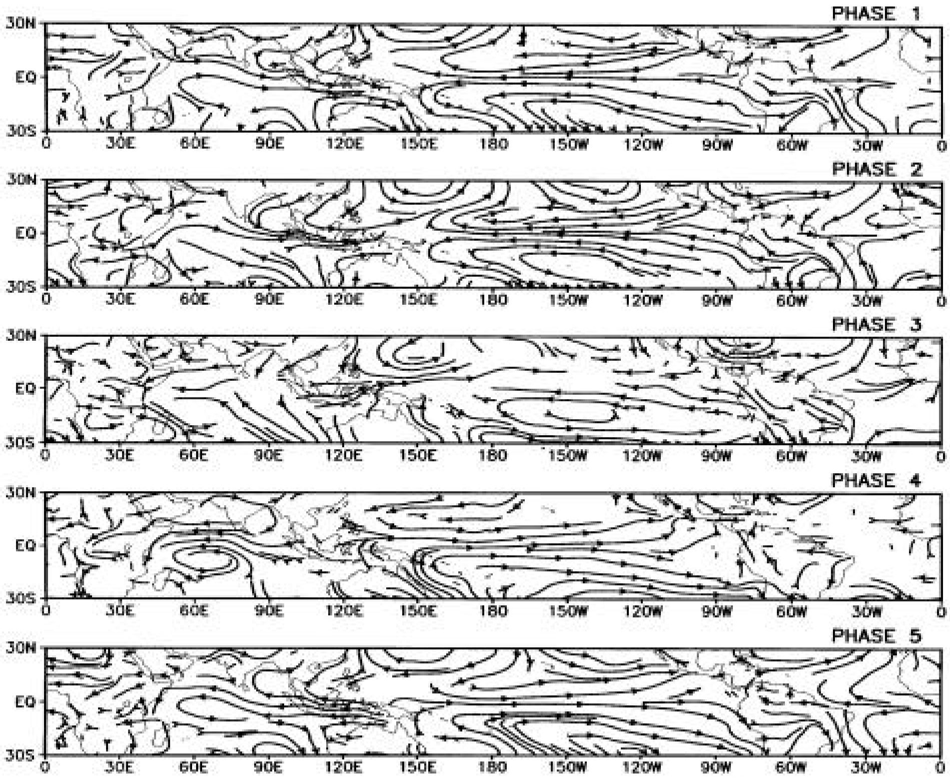

Fig.1 Composite results of the first 5 phases in the first half cycle of QBO component of the tropical 850 hPa wind field anomaly.

circulation is relatively weak in regions outside the Pacific Ocean. A convergence center is active over the equatorial western Pacific and the easterly anomalies prevail over the entire equatorial region of central and eastern Pacific. From Phase 2 to Phase 4, however, convergence and divergence systems along the equator are moving eastward and the cyclonic anomalous circulation center over the northwestern Pacific even travels towards the equator in its eastward-migrating course. The intensity of Phase 3 is relatively weak and the anomalous circulation strengthens in Phase 4. The anomalous circulation of Phase 5 is completely opposite with that of Phase 1. At the higher level of 300 hPa (figure omitted), good corresponding relationships are found with the lower level. In Phase 1, there is a cyclonic anomalous circulation over the tropics on both sides of the equator in the central and eastern Pacific. There is a small and weak anti-cyclonic anomalous circulation over the tropics on both sides of the equator from the Atlantic to the African continent. There is cyclonic anomalous circulation to the north of the equator in the Indian Ocean, which is small in scale and weak in intensity, decreasing much to the south of the equator. On both sides of the equator from the Malaysian islands to the western Pacific, there is an anti-cyclonic anomalous circulation, with the centers locating polewards. From the analysis, then, we know that two convergence centers are at 100°E and 90°W and two divergence centers are at 60°E and 165°E, featuring a zonal twin-wave distribution. The centers in the equatorial Pacific are better defined and westerly anomalies appear in the equatorial central and eastern Pacific. From Phase 2 to Phase 4, the anomalous circulation remains of zonal twin-wave distribution, with the centers corresponding with lower-level systems and moving eastward. By Phase 5, the distribution of the anomalous circulation is entirely opposite to that for Phase 1 so that the westerly anomalies that have been active over the equatorial central and eastern Pacific changes to easterly anomalies.

It is then clear that the anomalies of the zonal wind in the Pacific region propagates eastwards along the equator, together with the movement of centers of convergence and divergence. Associated velocity potential and divergence wind (Fig.2, which gives graphics on the 850-hPa level) are also good indicators of such eastward propagation. It is noted that during the first semi-cycle, the anomalous circulation in the subtropical regions of the northwestern Pacific and south Pacific is moving equatorward while going eastward, which is also proved by the time-latitude cross-section (Fig.3) of the QBO component at 850 hPa in the region of East Asia. It shows that there is linkage of flow fields between the tropics and subtropics, or, the Asian monsoons on the biennial scale may have important influence on the ENSO cycle.

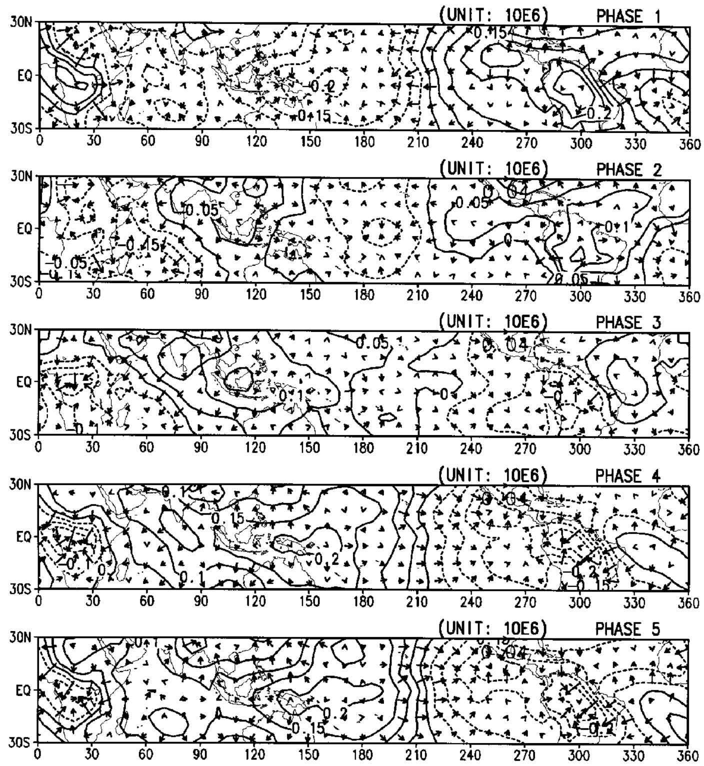

Fig.2 Same as Fig.1 but of the anomalies of velocity potential and divergent wind.

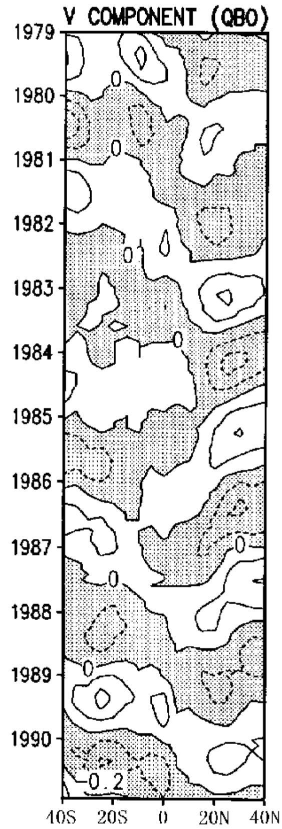

Fig.3 Time-latitude cross section of the QBO component of meridional wind anomaly at 850 hPa in East Asia (zonally averaged along 115～130°E).

3.2 *Tropical SSTA*

For the SSTA, high-value areas of the QBO component are mainly distributed in the equatorial central and eastern Pacific (figure omitted), with signs being the opposite to those to either side of it and the western Pacific but the same with those in the Indian Ocean. In association with the coupling response to the QBO component propagating eastwards at lower troposphere, the ocean reacts by having changes in the SSTA, i.e. the easterly (westerly) wind anomalies are corresponding to low (high) SST in the equatorial Pacific.

4 VARIATIONS OF ASIAN MONSOONS ON THE QUASI-BIENNIAL SCALE

Inspired by the foregoing section, we are now ready to study the quasi-biennial variation. The composite charts used in this section are the same as those in the preceding section except with different coverage.

Fig.4 shows the composite results of the 5 phases in the first semi-cycle of the QBO component of the wind field anomalies in the Asian monsoon region (only Phases 1, 3 and 5 are given). For Phase 1 at the higher level of 300 hPa, there is a cyclonic anomalous circulation east of Japan and an anti-cyclonic anomalous circulation over mainland China. At the lower level of 850 hPa, however, a cyclonic anomalous circulation east of Japan is affecting the eastern region of China by its northerly wind to the west. From Tab.1, we know that Phase 1 is primarily in the boreal winter. It is then concluded that the 300-hPa East Asian Trough is associated with cyclonic anomalous circulation, indicating strong trough activity that favors the southward progression of low-level cold air masses. In fact, the northerly winds are indeed stronger than normal at 850 hPa on the coasts of East Asia. It is why we could observe strong winter monsoon (of the quasi-biennial mode) in East Asia on both high and low levels for Phase 1. Phase 2 is more or less in the time of boreal spring. No significant changes are found for the 300-hPa level but the 850-hPa cyclonic anomalous circulation moves southward east of Japan, displacing from 35° for Phase 1 to 30°N. Phase 3 is generally the time of boreal summer. At 300 hPa, the cyclonic anomalous circulation weakens sharply east of Japan and splits into two cells, one over the Sea of Japan and the other over the northwestern Pacific (160°E, 30°N). Virtually being what

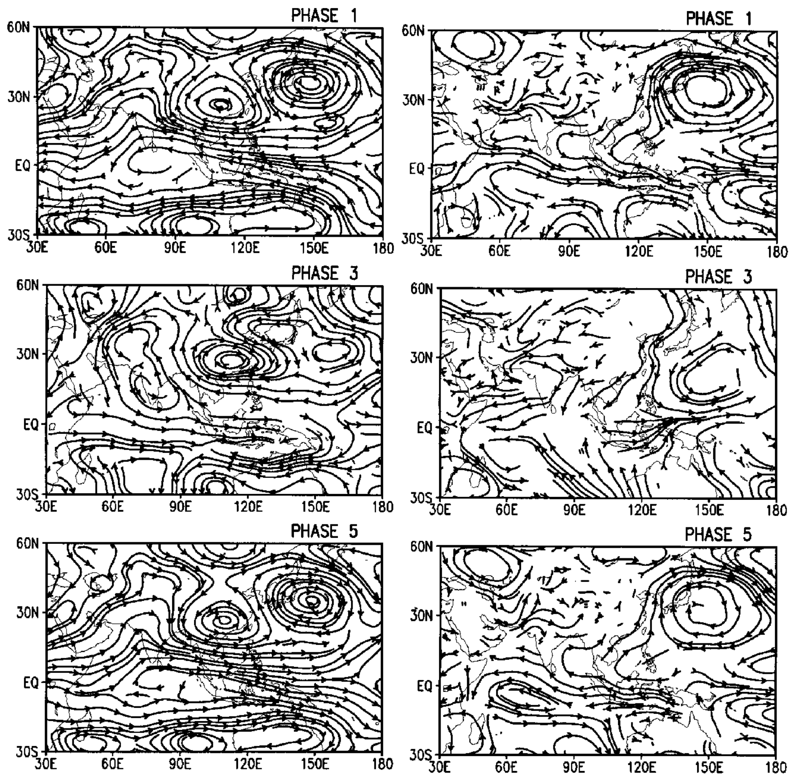

Fig.4 QBO composition of Phase 1, 3, 5 for the flow field anomaly over East Asia, at 300-hPa (left column) and 850 hPa (right column).

it has been over the mainland part of China, the anti-cyclonic anomalous circulation becomes a favorable condition for the extension of the eastern edge of the South Asia high (a continental anti-cyclone) into the Pacific Ocean. At 850 hPa, the cyclone east of Japan continues its southward movement, shifting from 30°N for Phase 2 to 25°N so that the northerly airflow on the northwestern edge of the circulation fitly affects the coastal areas of East Asia. In contrast, a weak anti-cyclonic anomalous circulation appears over the northeastern part of China. It is then known that the 300-hPa South Asia high is located eastward with weak easterly to the south while the easterly south of the western Pacific intensifies remarkably. The 850-hPa subtropical high is weaker than normal, i.e. the subtropical monsoon is weaker than normal, which graphically manifests as the strengthening of northerly winds on the East Asia coasts. It is interesting to note that it is the sustained southward advancement of the cyclonic anomalous circulation over the northwestern Pacific that keeps pushing the westerly anomalies of the equatorial western Pacific to the east. It is just one of the main characteristics associating with the generation of the El Niño event. We can see that the circulation at both higher and lower levels of the troposphere all reflects weak summer monsoon (of the quasi-biennial mode) in the East Asian region. Phase 4 appears in the time of boreal autumn. At 300 hPa, an anti-cyclonic anomalous circulation appears east of Japan while a cyclonic anomalous circulation occurs over southern China. The situation has been altered fundamentally as compared to the first three phases. At 850 hPa, the cyclonic anomalous circulation over the northwestern Pacific continues its southward progression till 15°N while expanding eastwards. It has become a strip-shaped anomalous circulation, with the equatorial westerly anomalies to the south expanding to the whole region of central and western Pacific. Phase 5 is around the boreal winter. It is a time when the anomalous circulation at both higher and lower levels is just the opposite to that in Phase 1—presenting a pattern in which the East Asian winter monsoon (of the quasi-biennial mode) is weak. It must be pointed out that the subtropical summer monsoon has been increasing until the following summer (in Phase 7 that is just opposite to Phase 3). At the same time, the easterly anomalies are strengthening and extending eastward in the equatorial western Pacific. It is one of the characteristics associated with the onset of the La Niña event. The evolution goes on and on in loops to form a quasi-biennial oscillation.

To further verify the significance of the quasi-biennial oscillations in the East Asia monsoons, a power spectral study is carried out (Fig.5) of the mean longitudinal wind anomalies on the coasts of the region (115°E ~ 135°E, 20°N ~ 45°N). The result shows that there are three primary peak values above the level of red noise, being 80, 26 and 4 months in periodicity, respectively. It is statistically meaningful to have anomalous signals of the longitudinal winds that are quasi-biennial in periodicity.

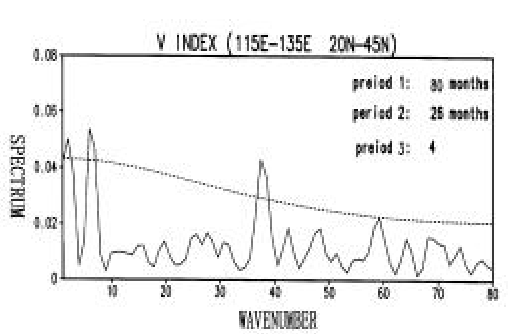

Fig.5 Power spectrum-yielded distribution of longitudinal wind anomaly on the coast of East Asia(115°E～135°E, 20°N～45°N).

The following points can be induced from the analysis above: Firstly, quasi-biennial variations are found in both winter and summer monsoons, especially so in the region of East Asia. In other words, the quasi-biennial mode works by having the first year of strong winter (summer) monsoon but the second year of weak winter (summer) monsoon, in East Asia. Secondly, close linkage is also found between the winter monsoon and summer monsoon in East Asia. It can be interpreted that the quasi-biennial mode associates strong (weak) winter monsoon with weak (strong) summer, in

East Asia, showing that they are negatively correlated. Thirdly, the variation is immediately connected between monsoon in East Asia and the westerly anomalies in the equatorial western Pacific, in the quasi-biennial mode. It is the southward progression of the anomalous circulation over the northwestern Pacific that may be one of the major processes in which the Asian monsoons are directly linked with ENSO.

5 PRELIMINARY ANALYSIS OF THE MECHANISM OF QUASI-BIENNIAL ASIAN MONSOONS AFFECTING ENSO

The Asian winter monsoon is closely related with the cold waves of air well known to us. Severe cold waves come with strong activity of winter monsoon. As suggested in observational data analysis and theoretic study[8], the winter half prior to the onset of El Niño event is a season witnessing frequent and strong activity of cold waves, which are accompanied by significant decrease of the easterly trade wind in the equatorial central and western Pacific Ocean (or, an increase of the westerly anomalies). The situation occurs due to frequent activity of the strong East Asia Trough (cold wave) in the winter half that keeps transporting the energy southeastward to the tropical central / western Pacific through dispersion with the planetary wavetrain, resulting in sustained reduction of the trade wind but enhancement of convection in the equatorial central and western Pacific. The continuing anomaly of the general circulation and eastward expansion over the region may eventually cause the appearance of the El Niño event.

As the OLR, the indicator of tropical convection, is important description of the anomalies of the tropical circulation, we start with the tropical OLR to study the effect of the quasi-biennial Asian monsoons on the ENSO cycle. From the spatial distribution composed by 8 phases (Fig.6, only four of them are given) of the full periods of the QBO component in the tropical OLR anomalies, we know the following points.

Phase 1 corresponds to the boreal winter with strong winter monsoon in East Asia. For the QBO component of OLR, there are two positive-value and two negative-value areas in the tropics.

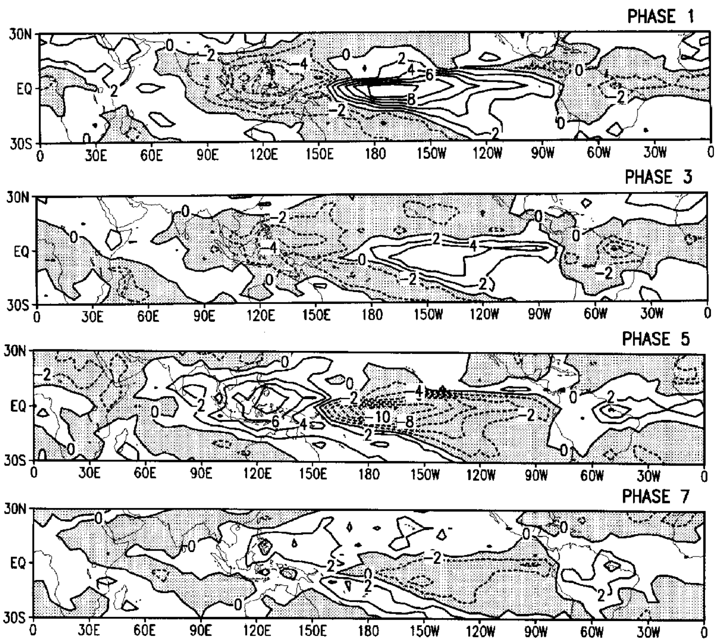

Fig.6 QBO composite phases for the OLR departure, Phases 1, 3, 5, 7.

The former area is in the central / western part of the Indian Ocean and the latter one in the tropical eastern Pacific and tropical western Pacific, all with large absolute values, an indication that convection is strong there. In addition, positive values are found in the tropical central / eastern Pacific while negative values in the tropical South America—Atlantic—western Africa. It is then known that the QBO component is also of double waves along the equator that features the presence of strong convection region in the tropical Pacific Ocean. Viewing the anomalous circulation in comparison (Phase 1 in Fig.1), we know that in areas where convection is enhanced in the tropical western Pacific the zonal airflow converges at low levels but diverges at high levels, but in areas where convection is weak in the tropical eastern Pacific the zonal airflow diverges at low levels but converges at high levels. In contrast, neither the convergence nor the divergence is significant for the zonal airflow over the equatorial Indian and Atlantic Oceans. It can then be concluded that strong winter East Asian monsoons are accompanied by enhanced westerly anomalies in the central / western Pacific, in addition to, indeed, enhanced convection in the tropical western Pacific.

Phase 3 corresponds to the boreal summer with weak summer monsoon in East Asia. The negative center over the tropical western Pacific and the positive center over the tropical central Pacific are moving eastwards, i.e. the areas of strong convection are traveling to the east. It is obvious that the westerly anomalies in the equatorial central / western Pacific (Fig.1, Phase 3) are expanding eastward while the trade wind is decreasing in the equatorial Pacific. At 850 hPa, the convergence area (Fig.3, Phase 3) has migrated to the region of equatorial central Pacific. It is a sufficient proof that the quasi-biennial mode sees weak East Asian summer monsoon in company with the prevalence and east-propagation of convection over the tropical central / western Pacific, the eastward extension of the equatorial westerly anomalies and the decrease of the equatorial Pacific trade wind. It then causes the on-going rise of SST in the equatorial central / eastern Pacific, thus being favorable for the onset of the El Niño event or the decadence of the La Niña event.

Phase 5 corresponds to the following boreal winter with weak winter monsoon in East Asia. The negative-value areas originally over the tropical central / western Pacific have now moved to the tropical central / eastern Pacific. By this time, positive-value areas have reappeared over the tropical western Pacific, i.e. strong convection is active again in the tropical central / eastern Pacific. During this phase, the whole equatorial central / eastern Pacific region has been completely dominated by the westerly anomalies (Phase 5 in Fig.1), with the SST the highest in the tropical central / eastern Pacific. It is then clear that weak winter monsoons in East Asia are closely related with weak convection in the tropical western Pacific, in the quasi-biennial mode.

Phase 7 corresponds to the following boreal summer with strong summer monsoon in East Asia. The negative-value areas over the tropical central / eastern Pacific are now moving to the east with the intensity reducing and the positive-value areas over the tropical western Pacific are expanding to the east, i.e. weak convection areas are moving eastwards. With this situation, easterly anomalies appear at low levels of the equatorial central / western Pacific that extend eastwards to restore and strengthen the trade wind in the equatorial Pacific. The QBO component of the SSTA in the equatorial eastern Pacific has now returned to normal. It shows that for the quasi-biennial mode the East Asian summer monsoons are stronger than average, and in company with weaker-than-average convection in the tropical central / western Pacific region and development to the east, the equatorial easterly anomalies expand eastwards, favorable for the decadence of the El Niño event (the onset of the La Niña event).

It must be pointed out that it is over the tropical western Pacific region that the negative (positive) areas of the QBO component of the OLR anomalies get rapidly strong and move eastwards. It shows that for the quasi-biennial mode, the strong (weak) winter monsoons in East Asia can indeed increase (decrease) the convection in the tropical central / western Pacific region. In other words, frequent strong cold waves of air propagate the energy to the southeast to strengthen the convection there. It displays as a negative area in the tropical central / western Pacific in the anomaly of OLR. Conversely, with weak winter monsoon in East Asia, energy is less that transports to the southeast and thus triggers less convection. It displays as a positive area in the tropical central / western Pacific in the anomaly of OLR.

The study above aims at possible effects the quasi-biennial Asian monsoons on the ENSO process, but such phenomena in their annual variations were indeed observed. Following Phases 1 (5) in Tab.1, composite analyses using the anomalous fields of wind speed without wave filtering (Fig.7) apparently point to the result of a strong (weak) circulation pattern for the Asian winter monsoon. For the three El Niño events beyond 1980 (1982/1983, 1986/1987 and 1991/1992), their preceding wintertime is that of 1982, 1986 and 1991, which just correspond to part of the years of the first case of composition for the Asian winter monsoon (which is stronger than usual). In the winter of the El Niño years (of the prime season), i.e. 1983, 1988 and 1992, the wintertime just corresponds to part of the years of the second case of composition for the Asian winter monsoon (which is weaker than usual). Having generally the same conclusion as previous work by other researchers, the current work contributes by showing more of the interactions between the quasi-biennial Asian winter monsoon and the ENSO cycle.

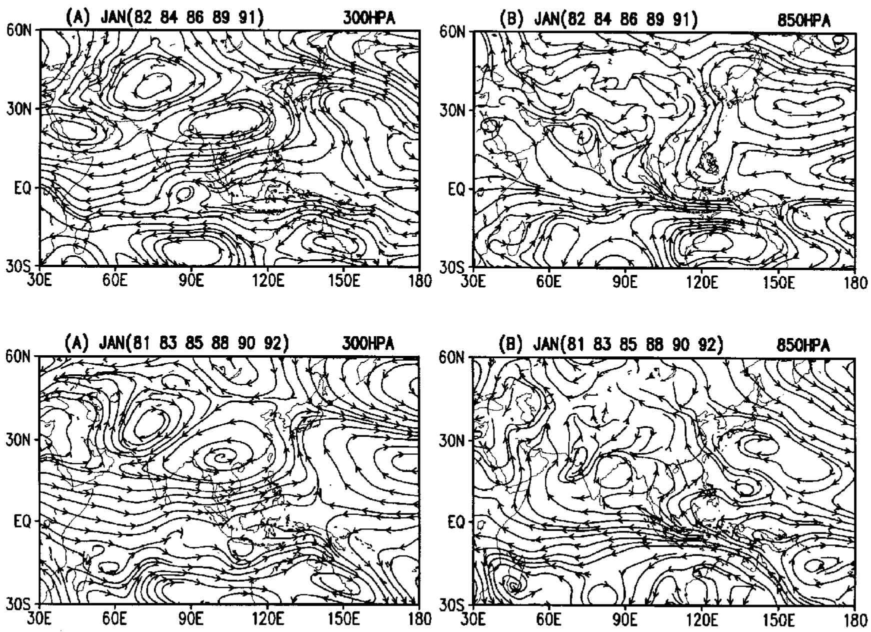

Fig.7 Composition for the flow field anomaly of winter. (A, upper) strong winter monsoon years at 300 hPa, (B, upper) strong winter monsoon years at 850 hPa, (A, lower) weak winter monsoon years at 300 hPa, (B, lower) weak winter monsoon years at 850 hPa.

It must be pointed out that there are no such characteristics in the annual variation of Asian summer monsoon, indicating that the quasi-biennial mode shows some patterns of variation between high and low intensity, but it is not outstanding on the quasi-biennial scale.

6 CONCLUDING REMARKS

a. Significant QBO exists in either the ENSO phenomenon or the Asian monsoon systems, particularly in the region of tropical Pacific. For example, the troposphere over the tropical Pacific is marked by significant QBO component of the zonal wind that propagates eastwards. In addition, the QBO component of the zonal wind in the lower troposphere over the northwestern Pacific is propagating from the mid-latitude East Asian monsoon region to the equatorial region, reflecting to some degree the effect of the East Asian monsoon system on the ENSO cycle.

b. The positive (negative) areas of the QBO component of the OLR anomalies are strengthened and moving eastwards over the tropical western Pacific. The region plays a key role for the East Asian monsoon to influence the ENSO cycle. The intensity of convection is related with the anomalies of the East Asian monsoons. When the monsoon strengthens (weakens), convection increases (decreases) over the tropical western Pacific, followed by a decrease (increase) in the summer monsoon in East Asia six months later, accompanied by the eastward expansion of the westerly (easterly) anomalies, resulting in the rise (fall) of SST in the equatorial central / eastern Pacific region, which is favorable for the onset (or decadence) of El Niño (La Niña).

c. The quasi-biennial variation pattern found in the winter monsoon of Asia is reflected not only in the quasi-biennial mode but well in the annual variation of the actual Asian winter monsoon.

Acknowledgements: Mr. CAO Chao-xiong, who works at the Guangzhou Institute of Tropical and Oceanic Meteorology, China Meteorological Administration, has translated the paper into English.

REFERENCES:

[1] LAU K M, SHEN P. Annual cycle, QBO, and southern oscillation in global precipitation [J]. *Journal of Geophysics Research*, 1988, **93**: 10975-10988.
[2] RUSMUSSON E M, WANG X, ROPELEWSKI C. The biennial component of ENSO variability [J]. *Journal of Marine Science*, 1990, **1**: 71-96.
[3] BARNETT T P. The interaction of multiple time scales in the tropical climate system [J]. *Journal of Climate*, 1991, **4**: 269-285.
[4] ROPELEWSKI C F, HALPERT M S, WANG X. Observed tropospheric biennial variability and its relationship to the southern oscillation [J]. *Journal of Climate*, 1992, **5**: 594-614.
[5] SHUKLA J. Long range forecasting of Indian monsoons[J]. *Science Age*, 1987(Nov), 21-23.
[6] SHUKLA J. Short term climate variability and prediction[A]. JAGER J, FERGUSON H J. Proceedings of the second world climate conference [C]. Cambridge University Press, 1991. 203-210.
[7] ZOU Li, NI Yun-qi. Impact of ENSO on the variability of the summer monsoon over Asia and the summer rainfall in China [J]. *Journal of Tropical Meteorology*, 1997, **13**: 306-314.
[8] LI Chong-yin. Frequent activity of strong East Asian Trough and the onset of El Niño [J]. *Scientia Sinica* (*Series B*), 1988, (6): 667-674.