Activities of Low–Frequency Waves in the Tropical Atmosphere and ENSO①

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ABSTRACT

ENSO, particularly the occurrence of ENSO is still an important research object in climatic variation. Using the ECMWF data, the relationship between ENSO and the activities of low–frequency waves in the tropical atmosphere is analyzed in this paper. It is shown that the occurrence of ENSO is closely related to the intraseasonal oscillation and the quasi–stationary waves (the period > 90 days) in the tropical atmosphere.

Associated with the occurrence of El Nino event, the kinetic energy of low–frequency waves has obvious variation: the kinetic energy of atmospheric intraseasonal (30–60 days) oscillation (ISO) decreases abruptly and the kinetic energy of quasi–stationary waves increases abruptly. Moreover, the ISO and quasi–stationary waves propagate eastward clearly corresponding to El Nino; but they clearly propagate westward in La Nina cases.

Key words: Intraseasonal oscillation, El Nino / Southern Oscillation, Quasi–stationary wave

I. INTRODUCTION

The ENSO (*El Nino / Southern Oscillation*) has been paid much attention in atmospheric sciences, because it is always associated with the climatic disaster in great scope in the world (Rasmusson and Wallace, 1983; Philander, 1985; Ropelewski and Halpert, 1987). The occurrence mechanism of ENSO is even regarded as a result of air–sea interaction but not yet be understood very well. As we know, ENSO is a stronger sign of climate variation for interannual time scale. The intraseasonal oscillation in the tropical atmosphere has also been studied regarding as the representation or mechanism of monthly–seasonal climatic variation (Li, 1993; Madden and Julian, 1994).

How about the relationship between ENSO and the low–frequency oscillation in the tropical atmosphere? Especially, the ENSO and low–frequency oscillation are usually regarded as climate systems with different time scales. Based on some analyses of OLR data, a conjecture was put forward and it was thought that the intraseasonal oscillation in the tropical atmosphere can excite El Nino event through increasing amplitude and decreasing frequency by the air–sea interaction (Lau and Peng, 1986). Then, the interaction between El Nino event and the ISO in the tropical atmosphere was advanced at first in 1994, based on some results of the data analyses and numerical simulation experiments in GCM (Li and Zhou, 1994).

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In present paper, the relationship between the occurrence of ENSO and low-frequency waves (the ISO and quasi-stationary waves) in the tropical atmosphere is studied. From the results in this paper, we will get deeper understanding to the mechanism of ENSO.

In order to study the activities of low-frequency waves in the tropical atmosphere, the initialized, grided datasets in ECMWF from 1980 to 1992 are used. According to the previous studies in relation to intraseasonal oscillation in the atmosphere, we processed the daily data at 850 and 200 hPa levels on a $5° \times 5°$ grid by using the 30-60 day band-pass filter to obtain intraseasonal oscillation and the low-pass (period> 90-day) filter to obtain the quasi-stationary waves.

II. KINETIC ENERGY VARIATION OF TROPICAL ISO AND EL NINO

The kinetic energy is an important physical quantity in the atmospheric system. Its variations can express some activity features of the atmospheric system. The analysis of the kinetic energies in ECMWF data shows that the ISO in the tropical atmosphere, especially over the equatorial western Pacific, has prominent characteristic of interannual variation and it is closely related to El Nino event. For example, the time evolution of the square zonal wind (u^2) at 200 hPa associated with 30-60 day oscillation over the equatorial western Pacific (10°S-10°N, 110°E-180°E) is shown in Fig.1 and it is clear that there is anomalous strengthening of kinetic energy of tropical ISO prior to the occurrences of 1982 / 83 El Nino and 1986 / 87 El Nino events. This indicates that the occurrence of El Nino event is closely related to the anomaly of tropical ISO and it also proves the conjecture on the tropical ISO exciting El Nino event.

In Fig.2, the evolutions of zonal mean kinetic energy at 200 hPa for tropical ISO associated with the occurrence of El Nino events in 1982 and 1986 are shown. It is clear that the kinetic energy of tropical ISO decreases abruptly associated with the occurrence of El Nino events (June-July, 1982 and 1986).

The kinetic energy of tropical ISO is particularly strengthened prior to the occurrence of El Nino, but it abruptly decreases corresponding to the occurrence of El Nino event. This not only means the close relationship between the tropical ISO and El Nino but also the tropical ISO system loses a lot of energy accompanying with the occurrence of El Nino. It should be studied that where does the kinetic energy of tropical ISO go away?

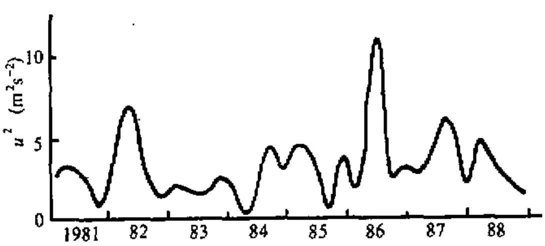

Fig.1. Temporal variation of the square zonal wind (u^2) at 200 hPa for 30-60 day oscillation over the equatorial western Pacific (10°S-10°N, 110°E-180°E).

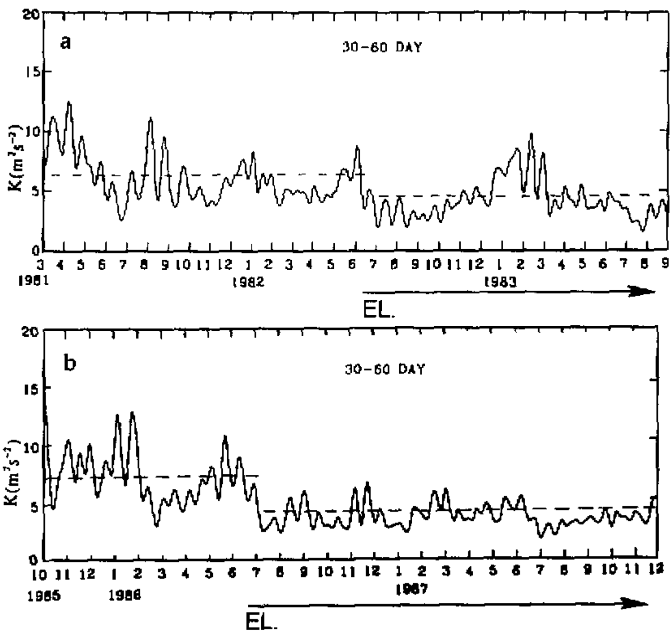

Fig.2. Temporal variations of zonal mean kinetic energy at 200 hPa for tropical (10°S–10°N) ISO associated with the occurrence of El Nino events in 1982 and 1986.

III. KINETIC ENERGY VARIATION OF QUASI–STATIONARY WAVES IN THE TROPICAL ATMOSPHERE

As we know, the climate variation has multiple time–scale feature. Some studies have shown that the ENSO and QBO are very stronger low–frequency signs to the variation of tropical atmosphere, and the ENSO is related with QBO. Therefore except for the ISO, we should simply regard the atmospheric system, which has the variation period >90–day, as the quasi–stationary waves. These waves are not stationary, but they move (propagate) very slowly. Then, the action of this quasi–stationary wave is analyzed. In Fig.3, the evolutions of zonal mean kinetic energy at 200 hPa for the quasi–stationary waves in the tropical atmosphere associated with the occurrence of El Nino events in 1982 and 1986 are shown. Contrary to the ISO, we can see the kinetic energy of the quasi–stationary waves abruptly increases accompanying with the occurrence of El Nino events. This at least means that the quasi–stationary waves in the tropical atmosphere are enhanced corresponding to the occurrence of El Nino event.

At the same time to the occurrence of El Nino event, the obvious decrease of kinetic energy for the tropical ISO and the increase of kinetic energy for the quasi–stationary waves express their close relationship. In a certain sense, it can be also suggested that some kinetic energy of tropical ISO is transferred to the tropical quasi–stationary system, so that the El Nino event is excited through the air–sea interaction. This is a possible way the tropical ISO

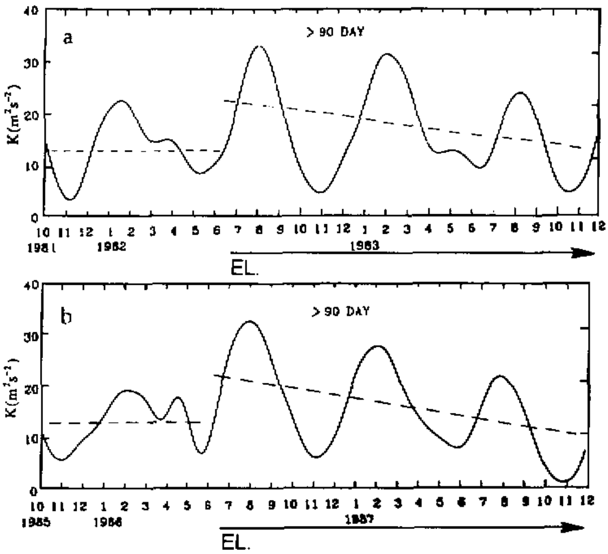

Fig.3.Temporal variations of zonal mean kinetic energy at 200 hPa for tropical quasi-stationary system associated with the occurrence of El Nino events in 1982 and 1986.

(anomaly) excites El Nino event; and the very low-frequency atmospheric waves are advantageous to the coupled air-sea interaction to excite El Nino event.

In the present paper, some results in data analyses are only shown. The dynamical study is given in another paper and it is indicated that exciting effect of the intensity of tropical ISO on the ENSO is mainly interannual anomalies of tropical ISO, which are caused by anomalous winter monsoon in East Asia.

IV. PROPAGATION OF ISO IN THE TROPICAL ATMOSPHERE AND ENSO

In a study on the ISO in the tropical atmosphere based on analyzing OLR data (Knutson, 1986), through careful comparison, it can be shown that the ISO propagates clearly eastward along the equator prior to the occurrence of warm events during the warm event period (1976, 1980 and 1982). The ECMWF data analyses also show that the El Nino event is accompanied by the eastward propagation of tropical ISO. Fig.4 is time-longitudinal sections of zonal wind at 850 hPa for 30-60 day oscillation in the tropics (10°N-10°S). In 1982 , the ISO propagates eastward systematically from March to October (Fig.4a); the systematic eastward propagation of tropical ISO is more obvious in 1986 (Fig.4b); also in 1991, the tropical ISO propagates eastward after middle of April (Fig.4c). It is very interesting that these systematic eastward propagations of tropical ISO link up closely with the westerly anomalies over the equatorial Pacific in 1982, 1986 and 1991 (figures omitted).

Oppositely, in 1988 La Nina case, the tropical ISO propagates westward very clearly during May-October(Fig.5a). As we know , in 1990 spring, there are obvious positive anomalies

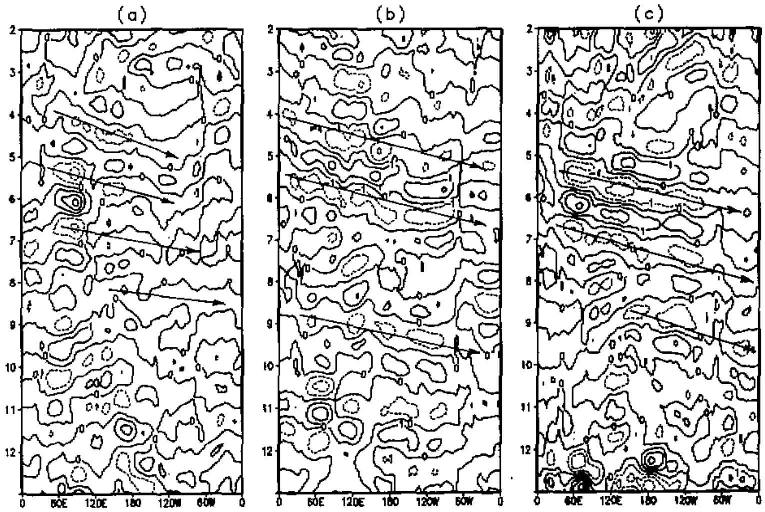

Fig.4. Time-longitudinal section of the ISO for zonal wind at 850 hPa in the tropics (10°S–10°N). Figures a, b and c represent 1982, 1986 and 1991, respectively. The interval is 1 m / s, shaded area represents the westerlies.

of SST in Nino3 and Nino4, but El Nino event did not occur. For this undeveloped El Nino case, the propagations of tropical ISO are confessed during the summertime, there is no systematic eastward propagation of tropical ISO (Fig.5b); and corresponding to this westward propagation of tropical ISO, there are clear easterly anomalies or westward propagation of westerly anomalies over the equatorial Pacific (figure omitted).

Therefore, the occurrence of ENSO is not only closely related to the anomalies of intensity of tropical ISO but also related to the propagation of tropical ISO, especially during the summertime. The systematic eastward propagation of tropical ISO, corresponding to westerly anomalies over the equatorial pacific, is advantageous to excite El Nino; The westward propagation of tropical ISO, corresponding to easterly anomalies over the equatorial Pacific, is favorable to excite La Nina.

V. PROPAGATION OF QUASI-STATIONARY WAVES IN THE TROPICAL ATMOSPHERE AND ENSO

As we know, the westerly anomaly is regarded as an important mechanism to excite El Nino event. Above analyses still show that the propagation of tropical ISO is closely related to the ENSO, the systematic eastward (westward) propagation of tropical ISO is correlative with the occurrence of El Nino (La Nina). Following analyses will more clearly show the close relationship between the propagation of quasi-stationary waves in the tropical atmosphere and ENSO.

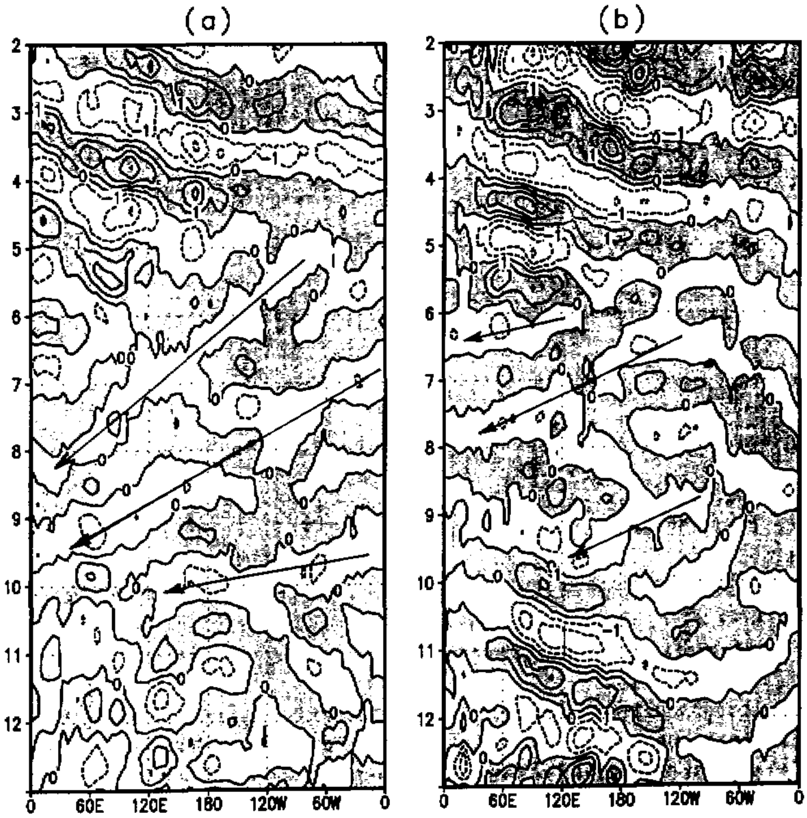

Fig.5. Time-longitudinal sections of the ISO for zonal wind at 850 hPa in the tropics (10°S–10°N). Figures a and b represent 1988 and 1990, respectively. The interval is ± 1 m / s, shaded area represents the westerlies.

In Fig.6, the time-longitudinal section of the quasi-stationary waves (T > 90-day) for zonal wind at 850 hPa in the tropics (10°S–10°N) is given. It is very clearly shown that the quasi-stationary system propagates eastward obviously accompanying with the occurrence of El Nino event in 1982 and 1986; but it propagates westward corresponding to the cold water events of the equatorial eastern Pacific in 1985 and 1988.

In order to express more clearly the propagation feature of the quasi-stationary waves in the tropical atmosphere corresponding to the warm events and cold cases, respectively, the time-longitudinal sections of zonal wind at 850 hPa associated with the quasi-stationary waves are shown in Fig.7 for 1982, 1986 and 1991 El Nino events and in Fig.8 for 1985 and 1988 cold water (La Nina) cases. Obviously, comparing Fig.7 with Fig.8, the eastward propagation of the quasi-stationary waves in El Nino cases and the westward propagation of the quasi-stationary waves in La Nina cases are all particularly shown. It is still very interesting shown associated with the anomalies of equatorial trade wind that there are clear westerly anomalies in the equatorial western Pacific and eastward expanding associated with the

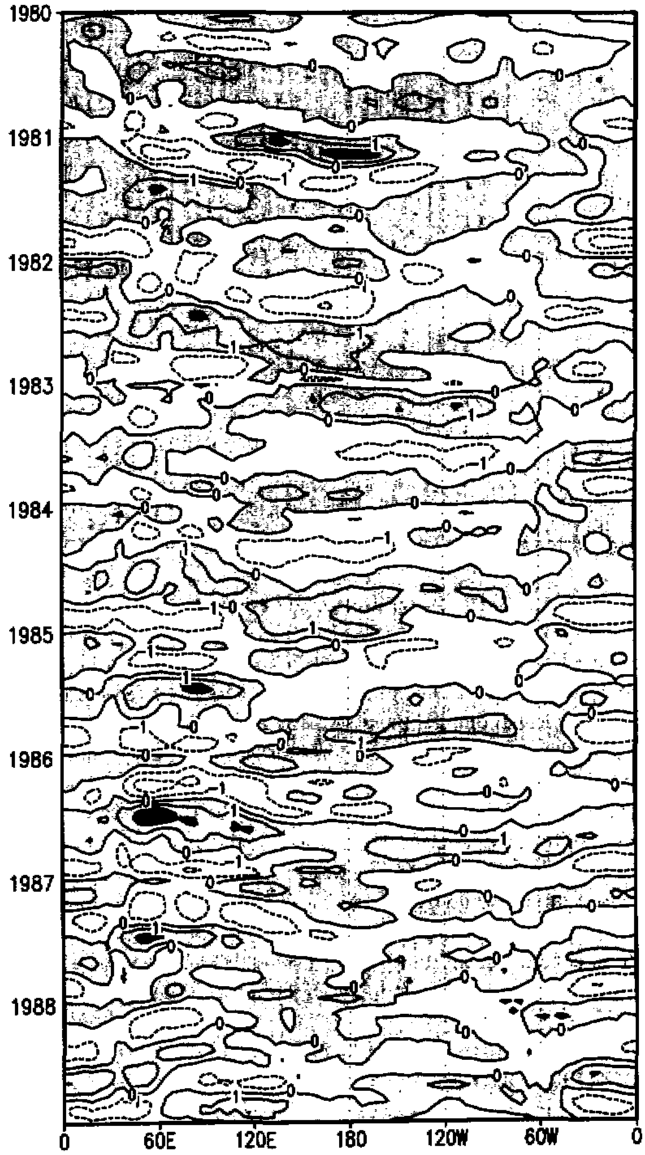

Fig.6. Time-longitudinal section of quasi-stationary waves (T > 90-day) for zonal wind at 850 hPa in the tropics (10°S–10°N) in 1980–1988. The interval is ± 1 m / s, shaded area represents westerlies.

eastward propagation of the quasi-stationary waves, but there are easterly anomalies associated with westward propagation of the quasi-stationary waves (figure omitted).

We can regard the situation in 1990 as a special case to discuss it, because there are obvious positive SSTA in Nino3 and Nino4 regions in 1990 spring, but El Nino event did not

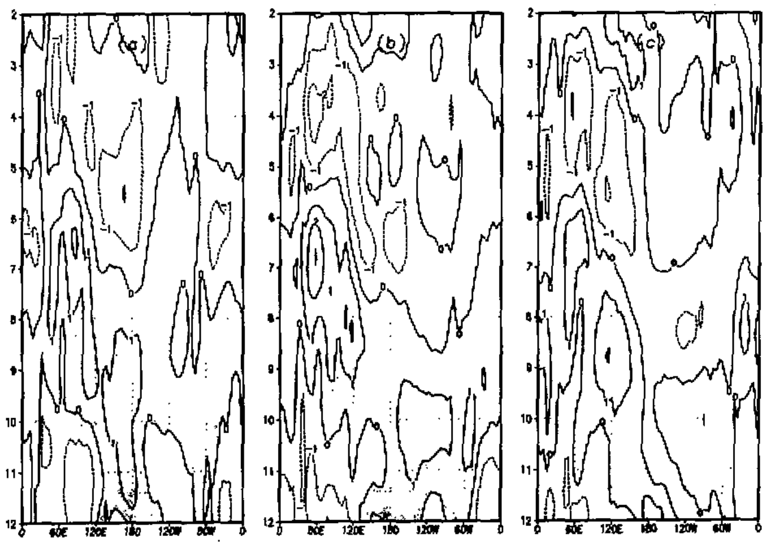

Fig.7. Same as Fig.6, but only for 1982, 1986 and 1991 El Nino events.

occur. Why did not El Nino event occur in 1990? Corresponding to positive SSTA in Nino3 and Nino4 in 1990 spring, there are westerly anomalies in the equatorial western Pacific (Fig.9a). But these westerly anomalies propagated westward and disappeared quite quickly, it is different from that the westerly anomalies continuously exist in the equatorial western Pacific region and expand eastward in 1982 and 1986. In Fig.9b, the time–longitudinal section of the quasi–stationary waves for zonal wind at 850 hPa in the tropics (10°S–10°N) is shown. To compare Fig.9b with Fig.7, it can be clearly shown that the quasi–stationary waves propagate westward in 1990 which is different from eastward propagation in 1982, 1986 and 1991.

Therefore based on above analyses, we can suggest that the propagation of quasi–stationary waves in the tropical atmosphere is very important to drive continuous westerly anomalies in the equatorial Pacific and excite ENSO. The systematic eastward (westward) propagation of quasi–stationary waves in the tropical atmosphere is favorable to excite El Nino (La Nina).

VI. CONCLUDING REMARKS

The role of low–frequency waves (intraseasonal oscillation and quasi–stationary waves) in the tropical atmosphere to excite ENSO is indicated by using data analyses in this paper. The results can be summarized as follows:

1). There are abnormal increases of kinetic energy of tropical ISO prior to the occurrence of El Nino, especially over the equatorial western Pacific; the abrupt decrease of kinetic energy of tropical ISO and abrupt increase of kinetic energy of quasi–stationary waves (including ENSO mode) are related to the occurrence of El Nino events, these mean that tropical ISO will transfer the energy to the quasi–stationary system in the tropical atmosphere. In other

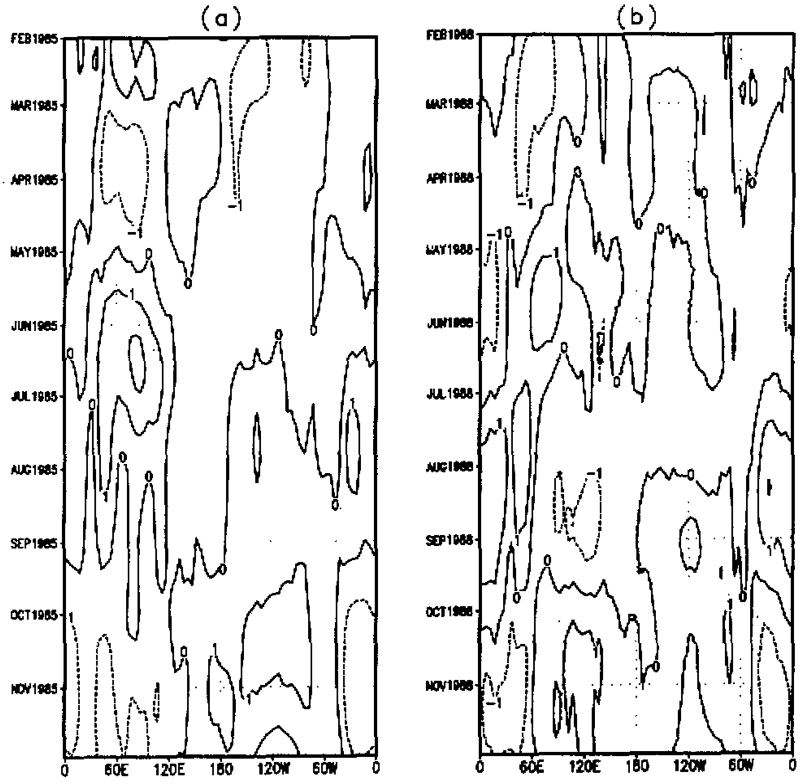

Fig.8. Same as Fig.6, but only for 1985 and 1988 La Nina cases.

words, stronger anomaly of tropical ISO plays an important role in exciting El Nino event through the energy transfer and the air–sea interaction. Some studies in relation to the air–sea interaction also showed that the interaction is more advantageous when the modes in the atmosphere and the ocean have closer frequency. The energy transfer from intraseasonal oscillation (low–frequency) to the quasi–stationary waves (more low–frequency) in the atmosphere will enhance the very low–frequency mode in the atmosphere and the air–sea interaction for exciting El Nino event.

2). The propagation of tropical ISO is also related to the ENSO, and systematic eastward propagations of tropical ISO accompany with the occurrence of El Nino event, but the case in which the tropical ISO propagates westward is corresponding to the La Nina.

3). The propagation of quasi–stationary waves in the tropical atmosphere is more clearly related to the ENSO, the El Nino is always corresponding to systematic eastward propagation but the La Nina is accompanied with systematic westward propagation of quasi–stationary waves.

4). The systematic eastward propagation of low–frequency waves in the tropical atmosphere is always associated with the continuous westerly anomalies and eastward expanding over the equatorial Pacific. It is suggested that the systematic eastward propagation of tropical low–frequency waves plays an important role in driving westerly anomalies over the

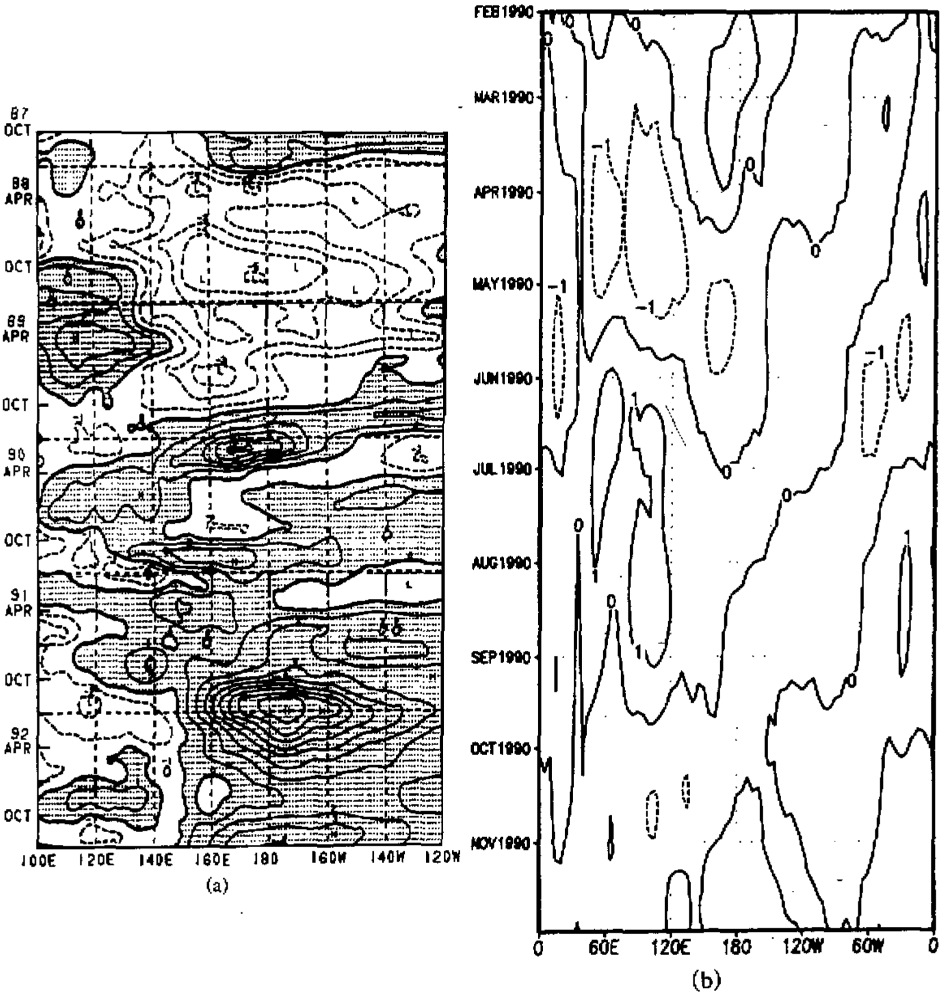

Fig.9. Time-longitudinal sections of zonal wind anomalies (a) and quasi-stationary waves for zonal wind (b) at 850 hPa in the tropics (10°S–10°N) in 1990.

equatorial Pacific and exciting El Nino event. Of course, it is necessaty to study the mechanism that the propagation of low-frequency waves in the tropical atmosphere may drive the anomalies of equatorial westerlies.

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