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A DIAGNOSTIC ANALYSIS OF 1997/1998 ENSO EPISODE AND ROLE OF INTRA-SEASONAL OSCILLATION IN TROPICAL ATMOSPHERE

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ABSTRACT: On the basis of comparison of 1982/1983 strong ENSO processes, key characteristics such as rapid development, immense intensity and abrupt retreat are revealed with regard to the warm episode in 1997/1998, features governing the intraseasonal oscillation for the tropical Indian Ocean and the western Pacific during its onset and evolution of the ocean and atmosphere for the process are diagnostically studied in detail.

Key words: 1997/1998 warm episode; SST; intraseasonal oscillation

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1 INTRODUCTION

Considerable differences do exist in intensity and pattern of ENSO processes and the genesis and development of ENSO episodes do not agree with each other, though sharing much in common during the evolution. Compared with previous ENSO episodes, the 1997/1998 one is marked by fierce upcoming, rapid development, immense intensity and abrupt ending, among other less significant features. Detailed diagnostic study on the evolution of the ocean and atmosphere over the course of 1997/1998 ENSO episode will therefore have important scientific significance for the understanding and forecasting of ENSO mechanisms. In view of the large intensity in both 1982/1983 and 1997/1998 episodes, the current work, with the former episode as the basis for comparison, conducts a diagnostic study of the genesis, development and decay of the latter and isolates the role of the intraseasonal atmospheric oscillations of the tropical Indian Ocean and the tropical western Pacific for the formation of the ENSO episode in question.

2 DATA AND METHODS OF ANALYSIS

The technique of wavelet analysis and Murakami method[2] are used in the current study of the intraseasonal oscillation. It is mainly used to detect how the convection varies over the equatorial Indian Ocean and the western Pacific on the scale of 2 weeks ~ 90 days, and with good reflection of the oscillatory characteristics on various temporal scales. Concrete procedures of performing the wavelet analysis are shown in [3] and the wavelet function used in the current work is as follows:

$$F(t) = (1 - t^2)\exp(\frac{-t^2}{2})$$

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which is known as Marr wavelet or the Mexican hat.

In addition, for further study of the relation between the intraseasonal variations of the low-level zonal winds in the western Pacific and ENSO, the monthly standardized anomalies of 850-hPa zonal wind averaged over the region 5°N ~ 5°S, 135°E ~ 180° have been calculated. It is one of the important indexes used in ENSO diagnosis for the monitoring of trade winds in the western Pacific[2].

The Murakami method[2] is then used to derive the intraseasonal variation in the low-level wind field $C_i'^*$, which is written as

$$C_i'^* = C_i' - \overline{C_i'}$$

C_i' is the standardized anomalies of the 850-hPa zonal wind in the *ith* month. Applying moving average to remove non-intraseasonal changes gives that

$$\overline{C_i'} = 0.25C_{i-1}' + 0.5C_i' + 0.25C_{i+1}'$$

The SST and OLR data used in the study come from the National Center for Environmental Prediction, USA and the wind fields are abstracted from the reanalysis data of NCEP / NCAR.

3 MAJOR FEATURES OF 1997 / 1998 ENSO EPISODE

ENSO is the product of interaction between the ocean and atmosphere, which is reflected in the variation of many of its indexes. To reveal the oceanic and atmospheric characteristics, we conduct a diagnostic study of the ENSO event in 1997/1998.

3.1 *Characteristics of sea surface temperature in the equatorial Pacific*

As shown in Fig.1, anomalously warm SSTs started moving from west of the dateline to the east before the spring 1997. The SSTs in the coast of South America responded by rapid shift from cold to warm temperatures in early 1997. By the end of spring, extensive warming of SSTs took place in the equatorial Pacific east of the dateline, initiating the onset of the warm ENSO episode immediately. The SSTs anomalies from June 1997 to May 1998 were 2°C ~ 5°C abnormally higher and reached the peak in winter. In late spring and early summer of 1998, it became warmer rapidly in the equatorial western Pacific and cooler unexpectedly in the central Pacific and western part of the eastern Pacific, putting an end to the anomalous warming episode in vast areas of the equatorial central and eastern Pacific.

Large intensity is the common feature of the ENSO events in 1997 / 1998 and 1982 / 1983. They both took place in late spring and were featured by significant seasonal dependence. The onsets of warm events were all preceded by warming in the equatorial central Pacific. During the anomalous warming, the peaks occurred in winter and there were double peak periods in the equatorial eastern Pacific. It is thought to be associated with the effect of equatorial wave systems intrigued by anomalous wind stress moving eastward[5].

It is noted that the 1997 / 1998 ENSO episode has much to be different from the previous one. Before the onset, anomalous warming was found in the equatorial central Pacific and along South America coast. The SSTA in the NINO3 region had been growing by the month in the direction of positive anomalies ever since December 1996, when ENSO was still in the cold phase. It accounts

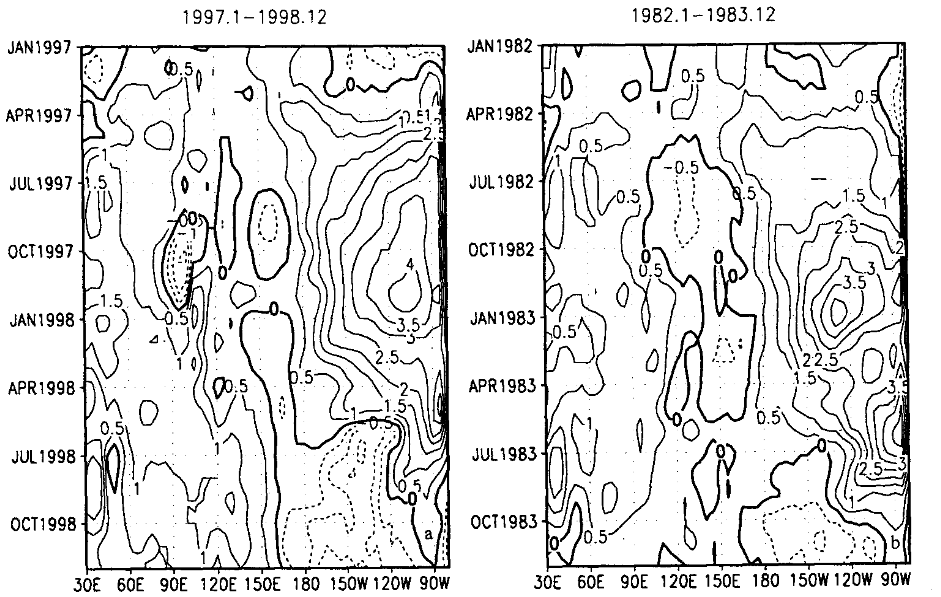

Fig.1 Time-longitude cross-sections of SST anomalies for the equatorial Pacific during ENSO episodes in 1997/1998 (a) and 1982/1983 (b).

for relatively short duration (13 months) of the episode. Nonetheless, the peak index for SSTA in NINO3 was as high as 3.9°C, being more anomalous than that of 1982 / 1983 which was 3.6°C. Another point standing out in the latter episode was the unexpected cooling in waters from 160°W to 120 °W in the equatorial eastern Pacific and 1°C ~ 2°C lower in the anomalies of SSTs in contrast to 2°C ~ 3°C higher in that along the coast of South America. It is known from the structure of SSTs distribution over the tropical Pacific that the sea surface is anomalously warmer in the equatorial western Pacific during the ending phase of the warm episode of ENSO in 1997 / 1998.

3.2 *Characteristics of tropical atmosphere*

The Southern Oscillations (SO) is an important atmospheric index for describing the evolution of ENSO. The SOI was in an anomalously positive period prior to February 1997, consistent with the preceding cold phase of ENSO. The pressure rose afterwards over west of the tropical Pacific but weakened over east of it with lowered SOI anomalies. The SOI was consistently lower by more than 1.0 from May 1997 to April 1998 and reached the minimum of –3.4 in the ending phase of the warm episode, being next to the process in 1982 / 1983 in terms of anomalies. The atmospheric characteristics as a warm event rapidly disappeared after May 1998 when the SOI made a sudden shift to the side of anomalously positive index (Tab.1).

The sea level pressure field is closely linked with the wind field in the tropical Pacific area. Examining the anomalies chart of 850-hPa zonal winds, we find much larger SST gradient on the eastern and western sides of the equatorial Pacific, the positive SOI in the anomalies, dominance of a pair of anticyclonic anomalous circulation off the equator over the eastern Pacific and easterly anomalies over the equatorial eastern Pacific, for the 1996 ~ 1997 winter[6]. In the spring of 1997, the equatorial western Pacific was controlled by strong westerly anomalies while warm water appeared in the equatorial eastern Pacific and rapidly developed. At times beyond the summer, the westerly anomalies spread to almost the entire equatorial Pacific, which was also drawn in the prime session of the warm episode. Afterwards, the center of the low-level westerly anomalies

Tab.1 Indexes of SSTA in NINO3, SOI and COI during the warm episodes 1997/1998 and 1982/1983

month	SSTSA／℃ 5 °N～5 °S,150～90 °W	SOI	COI	month	SSTSA／℃ 5 °N～5 °S,150～90 °W	SOI	COI
1997.2	-0.3	1.6	1.2	1982.2	0.2	0.6	0.4
1997.3	0.2	-1.1	-0.6	1982.3	0.2	0.1	0.7
1997.4	0.4	-0.9	-0.5	1982.4	0.4	0.7	0.4
1997.5	1.4	-1.8	-2.2	1982.5	1.0	1.0	0.4
1997.6	2.1	-2.0	-2.8	1982.6	1.3	1.6	-0.4
1997.7	2.7	-1.0	-1.5	1982.7	1.1	1.6	-2.2
1997.8	3.1	-2.1	-2.9	1982.8	1.4	2.1	-2.5
1997.9	3.3	-1.6	-2.9	1982.9	2.0	2.4	-2.7
1997.10	3.5	-1.9	-2.5	1982.10	2.6	1.9	-2.8
1997.11	3.8	-1.4	-2.2	1982.11	2.9	2.4	-3.0
1997.12	3.9	-1.3	-2.0	1982.12	3.5	1.9	-3.0
1998.1	3.6	-3.3	-3.4	1983.1	3.6	3.6	-2.7
1982.2	2.7	-2.7	-3.2	1983.2	2.8	3.9	-2.9
1998.3	2.3	-3.4	-2.2	1983.3	2.3	2.7	-2.5
1998.4	1.8	-1.9	-1.2	1983.4	1.9	0.7	-2.1
1998.5	1.4	0.1	-0.4	1983.5	2.3	0.8	-1.1
1998.6	-0.2	0.7	0.7	1983.6	2.1	1.0	-1.3

swiftly moved east over the equatorial Pacific and intensified. The westerly anomalies disappeared suddenly in May 1998 without any signs and cool water increased the coverage rapidly, neutralizing the conditions for the warm event to exist. The warm ENSO episode lasted to May 1998 and normal state of the atmosphere and ocean was restored in June, a judgement made from comprehensive study of the variation of SST in the equatorial parts of central and eastern Pacific.

During the warm event, the changes in the wind field are differently reflected with regions of the tropics. The highest record of westerly anomalies appeared as early as in March 1997 over the equatorial western Pacific region while the persistent westerly anomalies did not come until June over the central and eastern Pacific, a lag of about 2 ~ 3 months. In November 1997, drastic changes took place in the strong westerly anomalies in the equatorial western Pacific, which became easterly anomalies while the westerly was vigorously prevalent over the equatorial central and eastern Pacific.

The two warm episodes have much in common in low-level wind anomalies field over the equatorial Pacific Ocean. 1) The onset of both events was related with strong anomalous westerly in the equatorial western Pacific. 2) The westerly anomalies showed a tendency of eastward expansion and movement over the evolution of the events. 3) Easterly anomalies appeared west of the region of westerly anomalies with the strengthening of warm events after summer and developed eastward with the east-going of the westerly anomalies. It is interesting to note that the warming was also at the maximum about 2 months after that of the ocean in eastern Pacific, which is consistent to the centers of strong westerly anomalies east of the dateline in autumn and equatorial eastern Pacific in summer (Fig.2). It shows that the low-level equatorial wind field is indeed of important precursory for the prediction of ENSO.

The difference between the 1997 / 1998 and 1982 / 1983 warm events in terms of low-level equatorial wind field lies in the fact that the intensity of westerly anomalies is much stronger, and the easterly anomalies to the west are also more anomalous. Extra difference includes a much earlier ending of strong westerly anomalies, and thus leading to an earlier ending season, for the 1997 / 1998 episode.

The changes in the wind fields of the upper tropospheric levels are more or less opposite to those in lower levels. During the mature phase of ENSO, the pattern with a pair of anomalous anticyclonic flow appeared either side of the equatorial Pacific[6]. It increases the intensity of jet streams in the middle latitudes and the easterly anomalies over the equatorial eastern Pacific while

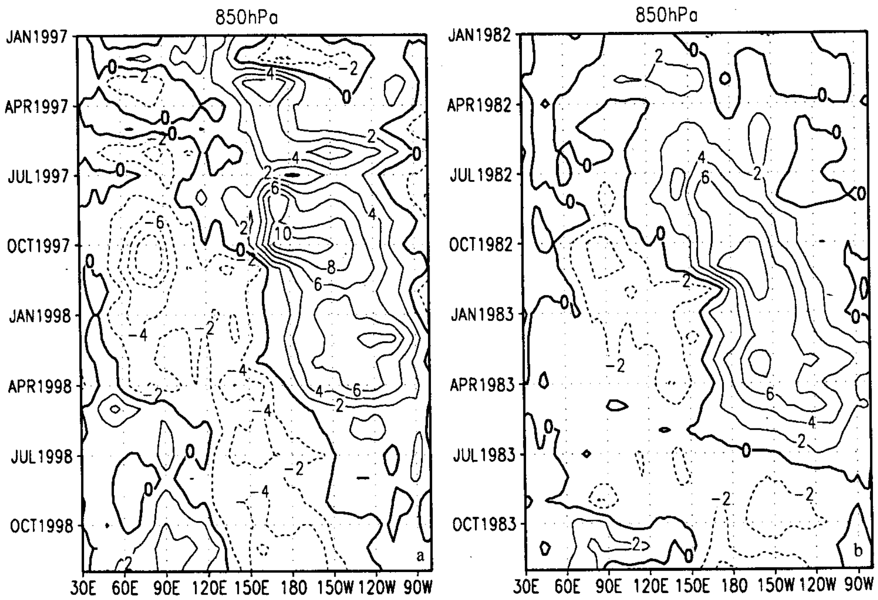

Fig.2 Same as Fig.1 but for zonal wind anomalies in the lower troposphere (850 hPa) over the equatorial Indian Ocean and western Pacific.

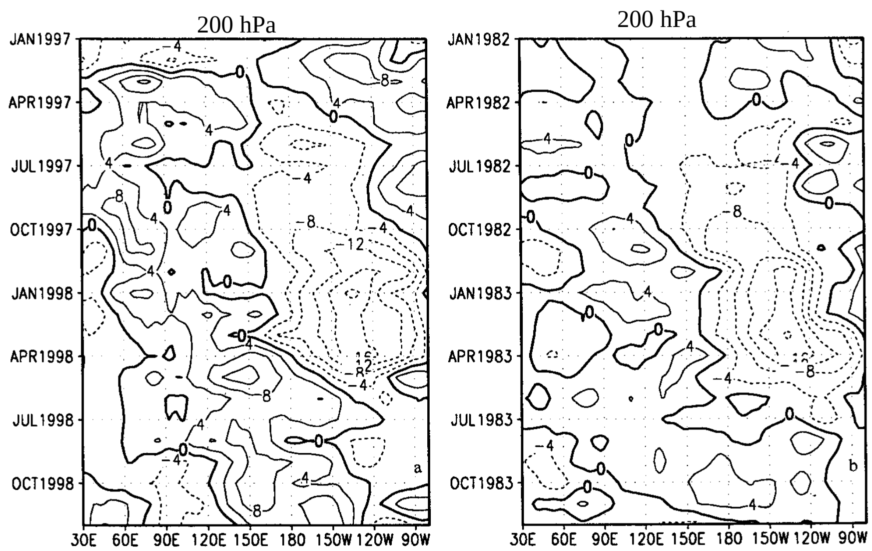

Fig.3 Same as Fig.2 but for 200 hPa.

decreasing the Walker circulation. Strong easterly anomalies (Fig.3a) were evident at 200 hPa over the equatorial eastern Pacific in the period from June 1997 to May 1998. In June 1982 ~ June 1983, the easterly anomalies were also significant (Fig.3b). During the two strong warm events, easterly anomalies appeared in the mature phase and the following one month or two, but the westerly anomalies were much larger over the central Pacific in 1998 than in 1983.

Convection activities were also anomalous in the tropical Pacific during the warm event. Before the spring of 1997, the center of strong convection was over the equatorial western Pacific and convection was suppressed around the dateline. With the eastward advancement of the westerly anomalies at low levels, the convection significantly weakened in the equatorial western Pacific but greatly enhanced in the equatorial east-central Pacific from the spring of 1997. Sometime around late spring and early summer 1998, convection anomalies disappeared unexpectedly in the equatorial eastern Pacific that had been anomalously strong but maintained a weak state in the equatorial western Pacific. Accessing with the convection oscillation index (COI) developed recently[6], the anomalies were far beyond 1982 / 1983, suggesting that convection was significantly suppressed in the equatorial western Pacific during 1997 / 1998 ENSO in contrast to anomalous strengthening over the equatorial central and eastern Pacific. It is obviously the consequence of weakened Walker cell in the anomalous distribution.

4 INTRASEASONAL OSCILLATION OF TROPICAL ATMOSPHERE

What are the main background and mechanisms behind the abrupt onset and rapid development of the 1997 / 1998 ENSO event? Previous studies suggested that the intraseasonal oscillation was one of the factors that may trigger the ENSO event[8, 9]. Studying the characteristics of ENSO in 1993, Ding and Sumi[10] argued that the 30-60 day low-frequency oscillation was vitally important for frequent occurrence and strengthening of low-level westerly. Then, how did the intraseasonal oscillation behave during the onset of the 1997 / 1998 ENSO? What is its role in the event?

The wavelet transformation has been performed of the OLR data over the equatorial Indian Ocean and the western Pacific. The results (Fig.4) indicated that the intraseasonal oscillation, which was 30-90-day in period, was anomalously active in the equatorial Indian Ocean just before the onset of the warm event from the autumn of 1996 to early 1997. The analysis also reveals a lengthening period and enlarging amplitude in the oscillation. In the meantime, a generally opposite and weak intraseasonal oscillation is shown to be over the equatorial western Pacific. It was specially active at the end of 1996 and the spring of 1997. With the lengthening of the intraseasonal oscillation and its eastward propagation over the equatorial Indian Ocean, it showed that the negative phase over the western Pacific shortened rapidly but prolonged after summer to have positive-phase amplitude in prominent position. Convection was then rapidly suppressed over the equatorial western Pacific while the SST got warming enormously in the equatorial central and eastern Pacific Ocean, leading to abrupt onset of warm ENSO event that developed vigorously.

As shown in the comparison between Fig.4b and Fig.5, two strong intraseasonal oscillations in the western Pacific late 1996 and early 1997 were responded by obvious eastward propagation of positive anomalous centers of the subsurface sea temperature in the equatorial Pacific. It was in fact the reflection of Kelvin wave transportation. It enabled the adjustment of distribution of subsurface sea temperature in the equatorial Pacific Ocean to cause anomalous warming in the eastern part. It appears likely that the linkage between the strong intraseasonal oscillation and the Kelvin wave is related with the sudden onset of low-level westerly.

It is shown that the warm event in 1982 / 1983 warm event was also related with strong intraseasonal oscillation over the Indian Ocean and western Pacific (Fig.6). A distinct 20-80-day oscillation took place in the equatorial Indian Ocean in the summer and autumn of 1981. Before the onset of warm event in the end of 1981 and the spring of 1982, another strong intraseasonal oscillation took place in the western Pacific where a convection-weakened pattern gradually came into

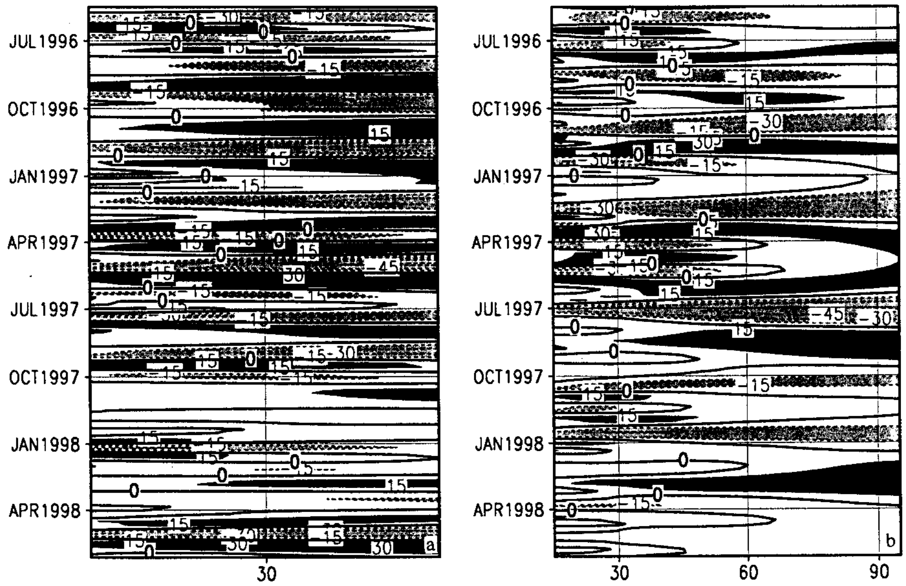

Fig.4 Transformation of OLR wavelets in the equatorial Indian Ocean (5 °S～5 °N，60°E～90 °E) （a) and the equatorial western Pacific （5 °S～5 °N，120°E～150 °E）(b) in June 1996～June 1998.

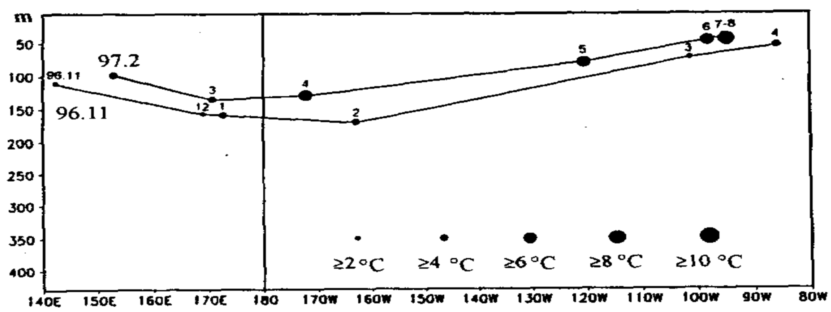

Fig.5 Schematic diagram of variation of SSTA centers in sub-surface layers of the equatorial Pacific before the onset of the 1997/1998 warm episode.

being corresponding to the warm event.

The changes in convection are closely related with the wind field. The propagation prior to the ENSO onset of significant intraseasonal oscillation towards the Pacific Ocean from the Indian Ocean is reflected on the anomalies fields at 850 hPa (Fig.2 and 3). Beginning from spring 1997, strong low-frequency oscillation appeared over the western Pacific. Consequently, a westerly anomalous area rapidly and steadily established over the equatorial western Pacific, causing the sudden onset of the warm event.

For further discussion of the effects of intraseasonal oscillation over the western Pacific on the onset of warm events, the current work studies the intraseasonal variation of 850-hPa zonal winds in the western Pacific and SST variation in the equatorial eastern Pacific (Fig.7).

As shown in Fig.7, in the time leading up to the ENSO events in 1982 / 1983, 1986 / 1987, 1991 / 1992 and 1997 / 1998, the intraseasonal oscillation intensified significantly in the westerly wind over the equatorial western Pacific, with the one in 1997 / 1998 the most intense. The low-frequency oscillation was much decreased in intensity in the ending phase of ENSO. It must be observed that the intraseasonal oscillation in early 1985 was only next to that in early 1997 but it was still within the cold event period in 1984 / 1985. It is therefore concluded that the strong low-frequency oscillation may be one of the factors to set off the warm event, though it may not necessarily result in its occurrence.

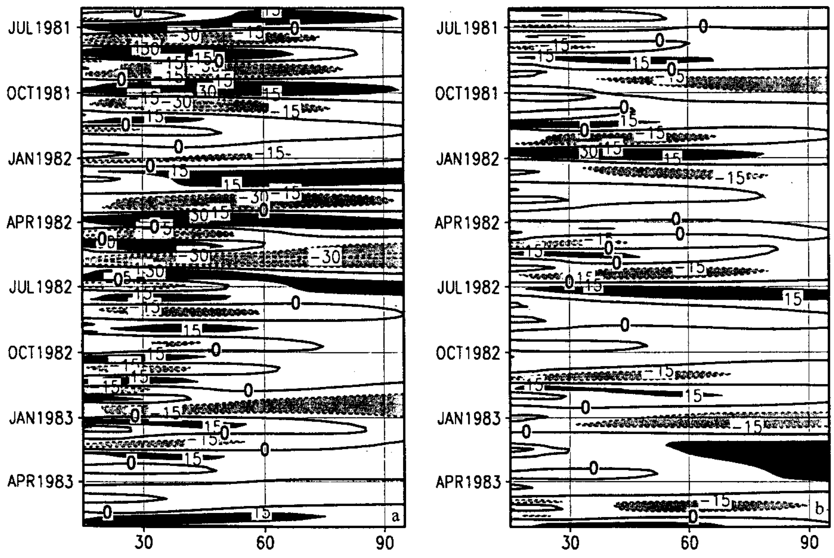

Fig.6 Same as Fig.4 but for May 1981～June 1983.

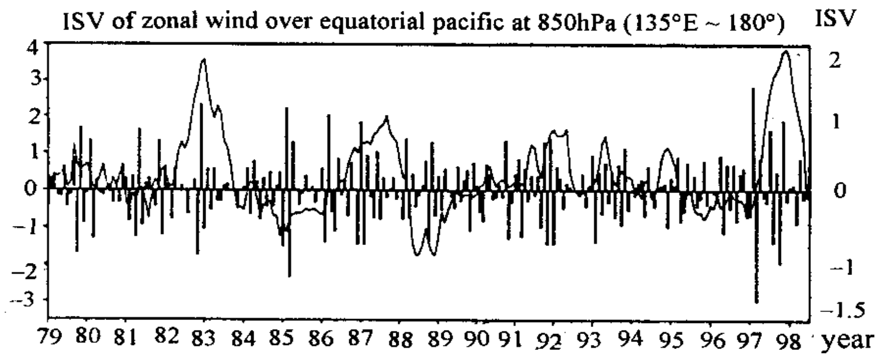

Fig.7 Evolution of intraseasonal variation of 850-hPa zonal winds in the equatorial western Pacific (5 °N～5 °S, 135 °E～180 °)in January 1979 ~ April 1998. The black columns stand for amplitudes of intraseasonal variation. Variation from month to month reflects the magnitude of the intraseasonal variability.

5 CONCLUDING REMARKS

a. The 1997 / 1998 warm episode developed during the course of seasonal warming in the spring over the equatorial eastern Pacific but decayed abruptly over the seasonal cooling after spring. The warm event formed rapidly in late spring of 1997. During the onset and development period it set up a number of records in observation concerning such monitoring indices of the SST, zonal wind and convection activities in the equatorial Pacific Ocean.

b. The process of ENSO mainly depends on the thermal and thermodynamic structures of subsurface ocean layers and changes of low-level wind fields over the equatorial Pacific Ocean. The onset, development, maturation and termination of warm events are all related with the changes of wind fields over the equator. The anomalies in the zonal wind field at the low levels over the western Pacific have precursory significance for the prediction of warm events.

c. During the onset of the strongest warm event in the 20th century, the low-level westerly wind in the equatorial western Pacific showed the strongest intraseasonal oscillation in record. It propagated to the east over the equatorial Indian Ocean to facilitate the rapid formation and anomalous development of its counterpart over the equatorial western Pacific and the lengthening of the oscillatory period. Due to incessant intensification and stabilization, the westerly anomalies caused the 1997 / 1998 warm event to come to a rapid onset and development. On the other hand, the intraseasonal oscillation experienced two processes of intensification over the equatorial western Pacific and it may lead to the outburst of low-level westerly wind and the onset of two well-defined propagations of the Kelvin wave such that the subsurface sea temperature in the equatorial Pacific was quickly redistributed in structure, resulting in the sudden onset of the warm event.

d. It must be pointed out that the mechanism directly responsible for the generation, development and decay of ENSO events is by no mean simple. They are related with some abrupt processes as well as some slowly varying and regular ones. It shows that it is still hard to predict how the ENSO event starts and develops and no significant improvements can be expected relative to the prediction of ENSO unless it is monitored and diagnostically studied with fuller understanding of its workings.

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