ON WESTERLY WIND BURSTS IN EQUATORIAL WESTERN PACIFIC BEFORE AND DURING THE ONSET AND INITIAL DEVELOPMENT PHASES OF ENSO

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ABSTRACT

By means of NCEP/NCAR reanalysis dataset, the origins of westerly wind anomalies at low level over equatorial western Pacific Ocean before and during the onset and initial development phase of ENSO are explored. Evidences show that westerly anomalies in the equatorial western Pacific (110—180°E) are characterized by two remarkable enhancements in the spring and summer of the year when El Nino emerges. The enhancements are not only, to some extent, due to the eastward propagation of low-level westerlies in equatorial Indian Ocean, but also predominantly resulting from the intense convergence of the meridional wind from both hemispheres. The latitudinal convergence leads to the local intensification of zonal pressure gradient so as to cause the reinforcement and bursts of westerly wind over warm pool. Besides, by virtue of the effect of earth rotation, the northeasterlies (southeasterlies) from the Northern (Southern) Hemisphere turn into northwesterlies (southwesterlies) progressively in the near-equatorial zone, which directly strengthens the westerly velocity. Comparing the contributions of the meridional wind from both hemispheres to westerly wind bursts, it seems that southeasterlies from the Southern Hemisphere are much stronger and more stable than northwesterlies of Northern Hemisphere. It is evident that the southeasterlies to the east of Australia originate from the southern mid- and high latitudes and are in close association with the Southern Oscillation.

Key words: westerly wind bursts, ENSO, meridional wind anomalies

I. INTRODUCTION

Many previous studies have found that the occurrence of El Nino is closely associated with the tropical westerly wind anomalies. Wyrtki (1975) defined westerly wind bursts as the abrupt enhancements of westerlies in equatorial western Pacific Ocean, and considered El Nino as the response of ocean to the expansion/contraction between the westerly and trade wind. Rasmusson and Carpenter (1982) demonstrated the existence of westerlies during the previous winter and spring prior to the onset of El Nino, and presumed it is the related Kelvin wave propagating eastward that leads to the warming of sea surface temperature in central and eastern equatorial Pacific. Recently, Ding (1998), using the dataset of TOGA-COARE IOP, substantially elaborated the features of wind field in

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equatorial Pacific during IOP period. and drew the conclusion that the large-scale stable strong westerly wind is an essential condition for the occurrence and maintenance of El Nino events. All the work suggested that the westerly anomalies in western Pacific serve as triggers to the onset of warm events. Therefore. explorations for the formation of westerly wind bursts will be very helpful for successfully predicting ENSO.

The origins of westerly wind bursts have been investigated by the foreign and domestic meteorologists. Keen (1982) believed that the pair of cyclones across the equator are responsible for the westerlies in western Pacific. while Barnett (1984) showed that both the anomalous lower level wind and sea surface pressure arise first in equatorial Indian Ocean before the onset of El Nino and then shift into tropical Pacific. Besides. the eastward propagation of 30 — 60-day low frequency oscillation in Indian Ocean was suggested to play an important role in the westerly anomalies and El Nino (Lau and Chan (1986; 1988).

Other studies stressed the close relationship between El Nino and the anomalous atmosphere circulation over regions away from the tropics. Li (1988) emphasized the positive role of strong East Asian winter monsoon on exciting the active tropical convection and related Kelvin wave as well as 30—60-day oscillation. which are considered to be significant to the occurrence of ENSO. Both Reiter (1978) and Krishnamurti (personal communication) have noted the meridional wind anomalies in tropical Pacific Ocean previous to the onset of ENSO. but they ignored its possible linkage with the westerly wind anomalies. In the equator region. it is the pressure gradient force that dominates the flow of air. The cold surge originating from mid-latitudes will increase the pressure gradient over western Pacific Ocean and then cause the westerly wind bursts (Chu 1988; Chu and Frederick 1990). Chen (1998. Academic Report) also demonstrated the similar mechanism of meridional wind from the Southern Hemisphere. In addition. Fu and Huang (1997) reported that the propagation of westerly wind from mid-latitudes to equatorial area is another source of tropical westerly wind anomalies in western Pacific.

As a fact. all those ways mentioned above maybe exist. but are there any other candidates responsible for the westerly wind bursts? Furthermore. which is the most robust one among those candidates or whether the dominant factor is different for the regions in different longitudes along the equatorial Pacific? All these fundamental problems are still unclear at present. The purpose of this paper. therefore. is to examine the lower-level wind anomalies before and during the onset of El Nino/La Nina with the focus on the source of equatorial westerly wind so as to reveal some precursors for ENSO prediction.

II. DATA

NCEP/NCAR reanalysis dataset is used in this study, involving the elements of zonal and meridional wind and geopotential height. The daily grid wind dataset spans the period January 1979 to August 1998. and the 40-a monthly dataset is available from 1958 through 1997.

The global SST dataset gets from Wisconsin University for the interval of 1958 to 1981. and the data from January 1982 to August 1998 are from Optimal Interpolation SST field of NCEP with the resolution of 1°×1°.

Nino 3 Index series was downloaded from the Internet site of NOAA spanning from January 1951 to August 1998.

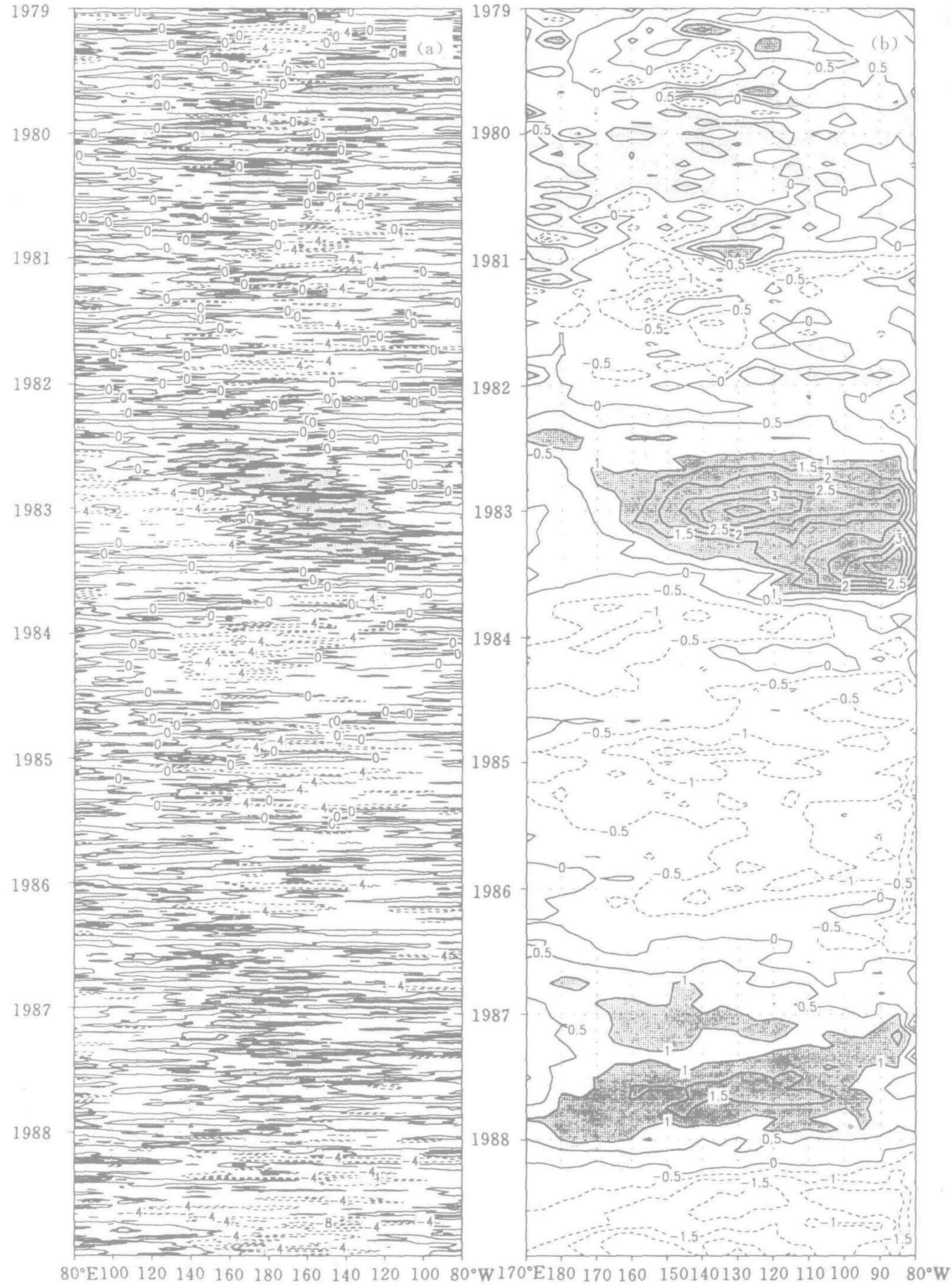
III. EVOLUTION OF ZONAL WIND ANOMALIES

Figure 1 shows the time-longitude cross section of 1979 — 1998 pentad mean zonal wind anomalies and monthly SSTA within 5°S—5°N along the equator. It is evident that. before six El Nino events of the recent 20 years. the westerly wind anomalies at 850 hPa unexceptionably move eastward along the equator. even for the 1979/1980 ENSO event in which the warm event was not fully development.

However. not just does the anomalous westerly wind appear before El Nino. As shown in Fig. 1. there are many cases that westerly anomalies are observed over equatorial 100—140°E region without El Nino followed later. and even some of them are followed by La Nina events. for instance. the boreal winter and spring of 1980/1981. 1984/1985. 1988/1989. That means SSTA in central and eastern equatorial Pacific will not necessarily rise several months later when the westerly anomalies emerge in western Pacific. The onset of warm events depends on the fact whether the westerly wind in spring amplifies and shifts into the eastern Pacific in the following summer. In the summer of El Nino year. such as 1982. 1986. 1991. 1994. 1997. this phenomenon took place and hereby El Nino developed into the mature phase in winter later.

Among the recent six El Nino events described above. the SSTA of 1982/1983 and 1997/1998 not only has center more eastward in equatorial Pacific than the others. but also are considered as the two strongest warm events since the reliable monitoring on SSTA was available. For this difference. a possible explanation lies in the fact that westerly anomalies accompanied with these two cases were very intense and reached to as far as 120°W in equatorial Pacific. For the other four cases. however. the weaker westerlies stayed in the central basin and did not expand farther eastward. This indicates that both the intensity and location of westerly anomalies are fundamental to the warming amplitude and place of El Nino. In addition. the pentad-mean dataset clearly reveals the noticeable discontinuity of westerly wind bursts. in other words. the equatorial westerly anomalies before the onset of El Nino are remarked by pulse variation and usually composed of several severe westerly wind bursts. To be noted particularly. the out-bursts or enhancements of westerlies often are confined chiefly over western Pacific. taking on a noticeable localization. so it is named as local enhancement of westerlies.

In order to identify the time and place of local enhancement of westerly wind. the composite of anomalous atmosphere circulation is made for the El Nino and La Nina events in the period of 1958 to 1997 respectively. The year when Nino 3 index changes from the negative value to the positive and reaches up to 0. 5C is defined as the onset year of El Nino. and the year with the opposite conditions is the onset year of La Nina. Based on the definition. the El Nino years are chosen as follows: 1963. 1965. 1968. 1972. 1982. 1986. 1991. 1994. 1997. and La Nina years are 1961. 1964. 1967. 1970. 1971. 1973. 1975. 1984. 1988. All of the composites in this paper are made on the base of those years. Figure 2 depicts the monthly evolution of the regional wind anomaly (5°N—5°S) over three


(a)
(b)
1979
1980
1981
1982
1983
1984
1985
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1987
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80°E100 120 140 160 180 160 140 120 100 80°W
170°E180 170 160 150140130 120 110 100 90 80°W

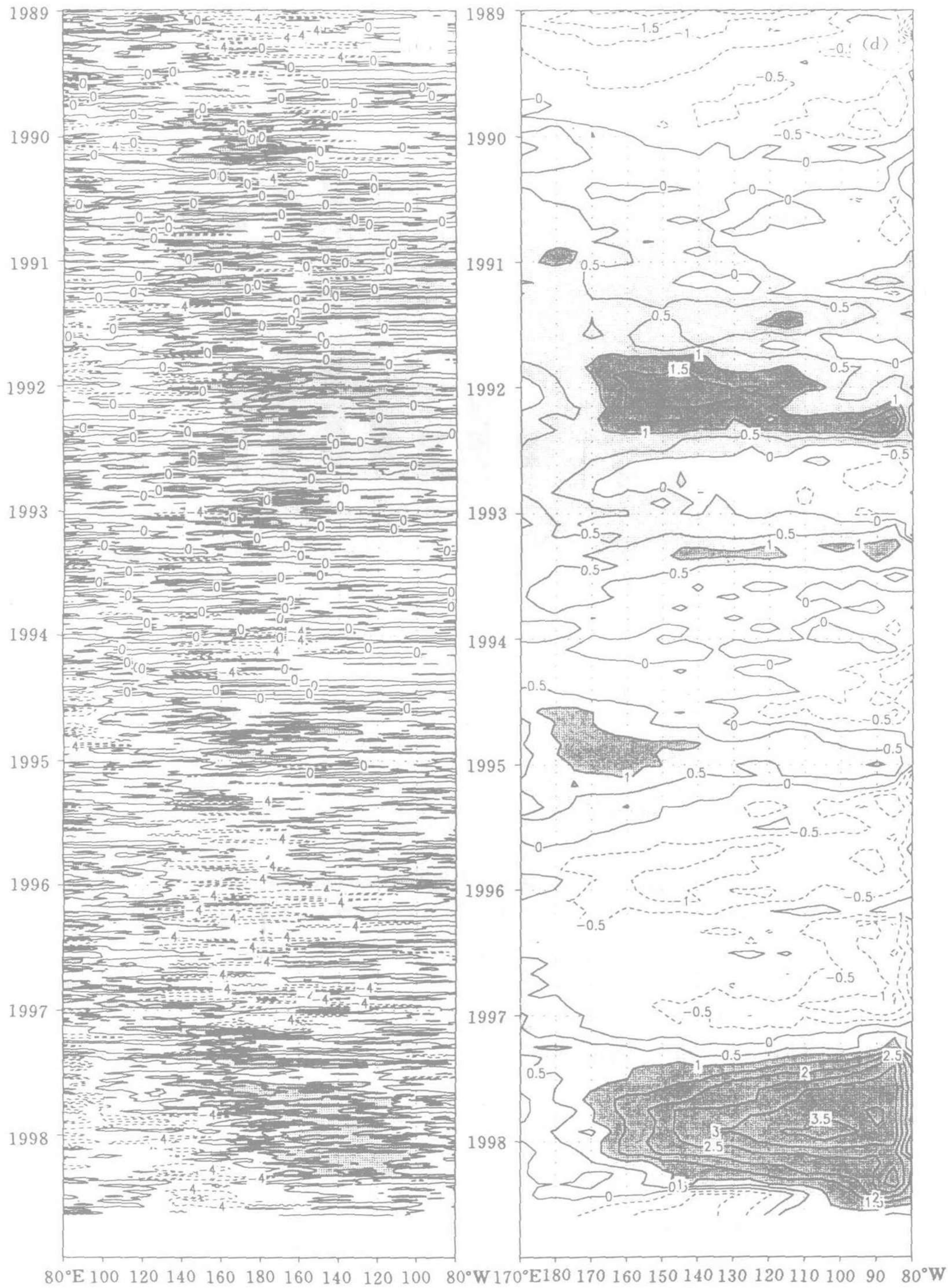

Fig. 1. The time-longitude cross section of pentad mean zonal wind anomalies (a, c) and monthly SSTA (b, d) within 5°S—5°N along the equator.

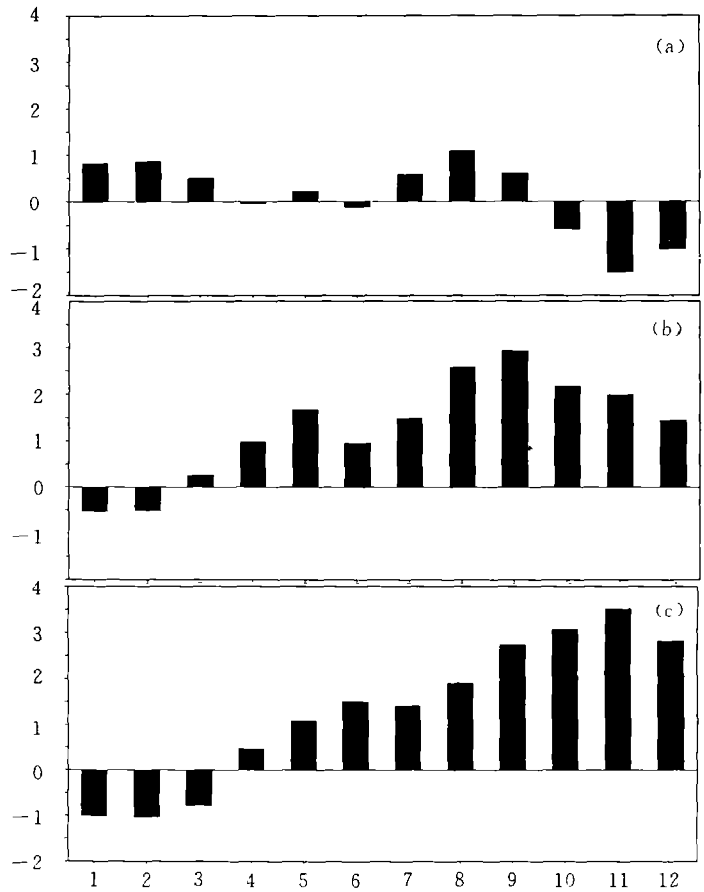

Fig. 2. Monthly evolutions of the regional mean wind anomaly in the onset year of El Nino. (a) 5°S—5°N, 100—140°E; (b) 5°S—5°N, 140—180°E; (c) 5°S—5°N, 180°E—120°W.

adjoining domains along the equatorial Pacific in the onset year of El Nino. The change of wind anomalies with time is different for different regions. Over region of 100—140°E, westerly anomalies maintain from the January to March in El Nino year and decrease in spring, and rise again in summer and then reduce to easterly anomalies in the following autumn and winter. Within 140—180°E, there are two reinforcement processes of westerly anomalies happening in May and August respectively. For 180°E — 140°W region, anomalous westerly wind replaces the normally easterly winds in April and then increases progressively with time.

It is apparent that westerly wind anomalies in western Pacific Ocean strengthen significantly in the spring and summer of El Nino onset year. Due to the fact that the equatorial westerly anomalies within 140 — 180°E are much stronger than its both side regions, so we identify this area as the key domain for the twice reinforcements of westerly wind anomalies in spring and summer.

IV. ORIGIN SOURCES OF WESTERLY WIND ANOMALIES

Because of the well-known relationship between westerly wind and SSTA in the central and eastern Pacific, our study focuses on the cause and mechanism of westerly wind anomalies. In term of 1979—1995 850 hPa pentad mean wind, the lagged correlation is computed between the global zonal, meridional wind and the regional zonal wind indexes averaged over the boxes within 5°S—5°N and 100—120°E, 120—140°E, 140—160°E and 160 — 180°E. The global wind anomalies lead the regional ones from 0 to 2 months. Thereby the distribution of correlation vector is obtained by taking the correlation coefficients between global u and v components with the regional u indexes as the zonal and meridional components of the vector respectively.

Figure 3 denotes the case that the leading time is 2 months (0—1 month omitted). In the shaded areas at least one coefficient of the vector passes the confidence level of 95%. No matter for the simultaneous or lagged cases, the distributions of correlation vectors for the regions to the west of equatorial 140°E are quite distinct from that to the east of 140°E.

To the west of 140°E, before the emergence over the maritime continent, the anomalous westerlies in equatorial Indian Ocean travel eastward for 1—2 months earlier. Meanwhile, the trade wind enhances considerably and meets the westerly wind in western Pacific. It is noted that the convergence of meridional wind is not so conspicuous as the zonal wind. Thus we believe the westerly anomalies shifting eastward in Indian Ocean are an important source for the far western Pacific.

However, for the equatorial basin to the east of 140°E, 2 months earlier than the appearance of westerly wind, the reduced trade wind and anomalous easterly wind are observed in eastern Pacific and Indian Oceans respectively, which indicates little contribution from Indian Ocean to the local westerly anomalies. On the other hand, the strong southeasterly and northeasterly from both mid-latitudes converge over warm pool, producing the local eastward pressure gradient which drives the westerly wind bursts into central and eastern Pacific. Furthermore, under the influence of earth rotation, the easterly components from both hemispheres turn into westerly and contribute to the amplification of westerlies more directly.

What should be noted is that the northeasterly anomalies in Figs. 3c and 3d come from central northern Pacific rather than the usual breakout region of East Asian cold wave. Besides, based on this investigation, there are few evidences for the propagation of westerly anomalies beyond the tropics into the equatorial western Pacific.

In summary, the causes of westerly wind anomalies are significantly different over the regions of the two sides of 140°E. To its left, the eastward movements of westerly anomalies from equatorial Indian Ocean are an important source, at the same time, the convergence of meridional wind along the eastern coasts of East Asia and Australia also contributes to the westerly anomalies. In contrast, to the local reinforcement of westerly wind in equatorial 140—180°E, the contribution of meridional wind convergence is much more remarkable than that of zonal propagation from Indian Ocean. Throughout the tropical Pacific, the propagation of westerly anomalies beyond the tropics to the equator is not pronounced.

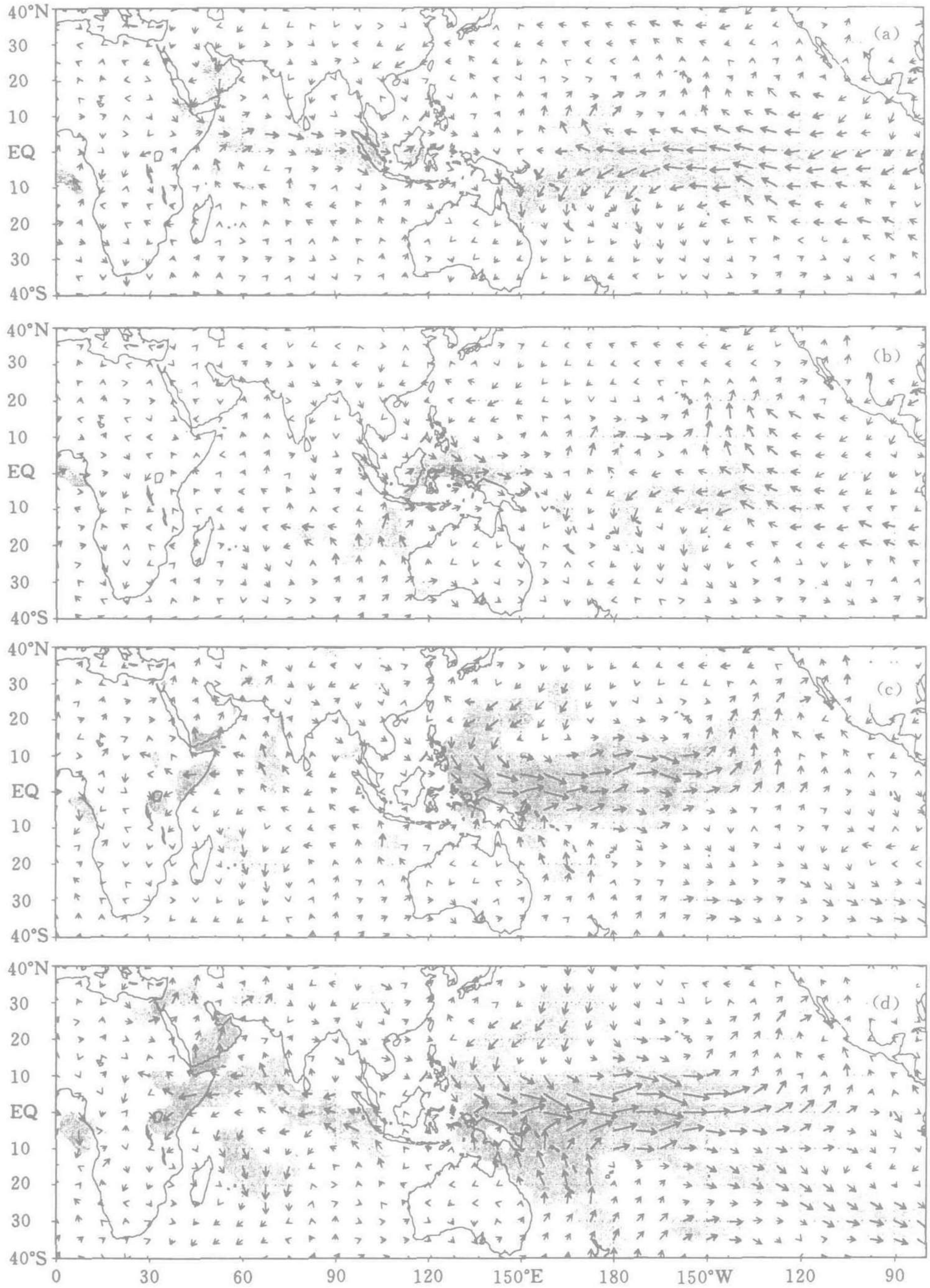

Fig. 3 Lagged-correlation vectors between regional mean 850 hPa zonal wind indexes and zonal and meridional wind fields. The indexes lag by 2 months, and the shaded regions indicate that at least one correlation coefficient passes the confidence level of 95%. The domains of zonal wind indexes: (a) 5°S—5°N, 100—120°E; (b) 5°S—5°N, 120—140°E; (c) 5°S—5°N, 140—160°E; and (d) 5°S—5°N, 160—180°E.

V. *COMPARISON* OF RELATIVE IMPORTANCE OF MERIDIONAL WIND FROM BOTH HEMISPHERES

As described above, there is an increase of westerly velocity within 5°S—5°N, 140—180°E before and during the onset of El Nino respectively, which mainly depends on the convergence of meridional wind from mid-latitudes of both hemispheres. A further study is needed to explore the evolution of meridional wind so as to improve our understanding of its relation with the westerly wind bursts over warm pool.

For the purpose of identifying the relative contribution between the Northern and Southern Hemispheric meridional winds, the composite evolutions of wind anomalies are compared in Fig. 4 from the previous (—1) to the current (0) and to the followng (+1) year of the onset of El Nino year.

As shown in Fig. 4a, within the band of 2. 5°S to 20°S, there are totally two remarkable southerly wind centers in equatorial eastern Indian Ocean (90—110°E) and western Pacific (150—170°E), the west one maintaining from the previous (—1) October to April of the following (+1) year, the stronger one in Pacific lasting from the current (0) April to July of the following (+1) year. More interestingly, both centers intensify suddenly in April and July of the current (0) year, which agrees well with the time of westerly wind enhancements in western Pacific.

Figure 4b indicates the evolution of meridional wind from the Northern Hemisphere. Along the longitude 100 — 140°E of East Asian coast, the enhanced northerly wind anomalies are found both in boreal winter before the onset of El Nino, which means a strong winter monsoon happening in April and July of the current (0) year of El Nino.

However, the meridional wind anomalies of Northern Hemisphere, being weaker than its counterpart of Southern Hemisphere before the onset of El Nino, travel eastward with time. For details, its center is located around 100°E in January of the current (0) year, and moves to 140°E and 170°E three and seven months later respectively, finally reaches to the eastern Pacific and then disappears in the January of the following (+1) year. The same process is not true for the meridional wind anomalies of Southern Hemispher, which are more stable in intensity and location over southern Pacific to the east of Australia.

Figure 4c is the difference between Figs. 4a and 4b, demonstrating the evolution of meridional convergence along the equator. It is easy to see the enhancement of convergence in equatorial Indian Ocean from as early as the late summer through early autumn of the previous (—1) year and also its later reduction and eastward movement. In the following boreal winter, due to the intense northerlies from the Northern Hemisphere, the reduced convergence gets strong again around the western maritime continent and then decreases and shifts eastward continuously. The similar condition happens around 140 — 160°E in April of the current (0) year. Finally, the convergence reaches to its maximum in the current (0) July and persists around 150—170°E until the mature phase of El Nino. In total, the whole life of eastward propagating meridional convergence along the equator experiences four enhancements and then reduction processes from the previous to following year of El Nino. In consonance with the evolution of meridional convergence, as shown in Fig. 4d, the anomalous westerlies are also marked by the similar four processes in vigor in

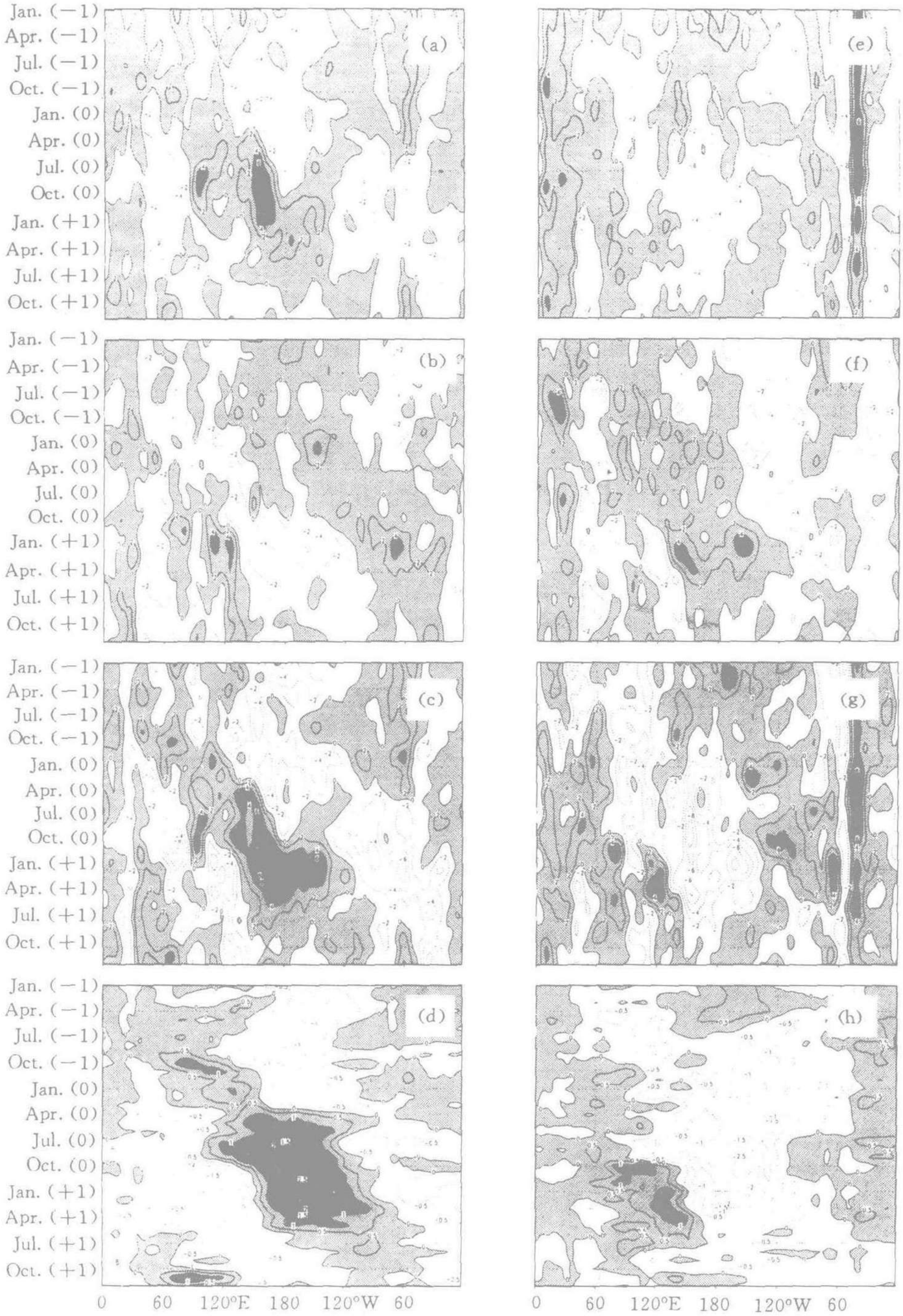

Fig. 4. The composite time-longitude cross sections of wind anomalies from the previous (−1) to the current (0) and to the following (+1) year of the onset of El Nino year. (a), (e): the sum of v within 2.5−20°S; (b), (f): the sum of v within 2.5−20°N; (c), (g): the difference between v within 2.5−20°S and 2.5−20°N; (d), (h): regional mean zonal wind within 10°S−10°N; (a)−(d) are the cases of El Nino, and (e)−(h) are the cases of La Nina.

the previous (— 1) autumn, winter and the current (0) spring and summer with its location shifting eastward by the order of time. Therefore, the anomalous westerlies over western Pacific mainly originate from the convergence of meridional wind and the movements of the analogue in Indian Ocean. Between these two sources, the former one is more pronounced, particularly over the tropical region to the east of 140°E, which is responsible for the two enhancements of westerlies in spring and summer of the onset year of El Nino. On the basis of evolution of meridional wind anomalies from both hemispheres, it seems that Southern Hemispheric one is more important than the Northern one.

The above-described conclusion is also true for the case of La Nina, only with the opposite anomalies in comparison to El Nino. Figure 4e demonstrates that the northerly anomalies become quite stable around 160°E in tropical southern Pacific since January of the onset year of La Nina. It strengthens three months later. For the case of Northern

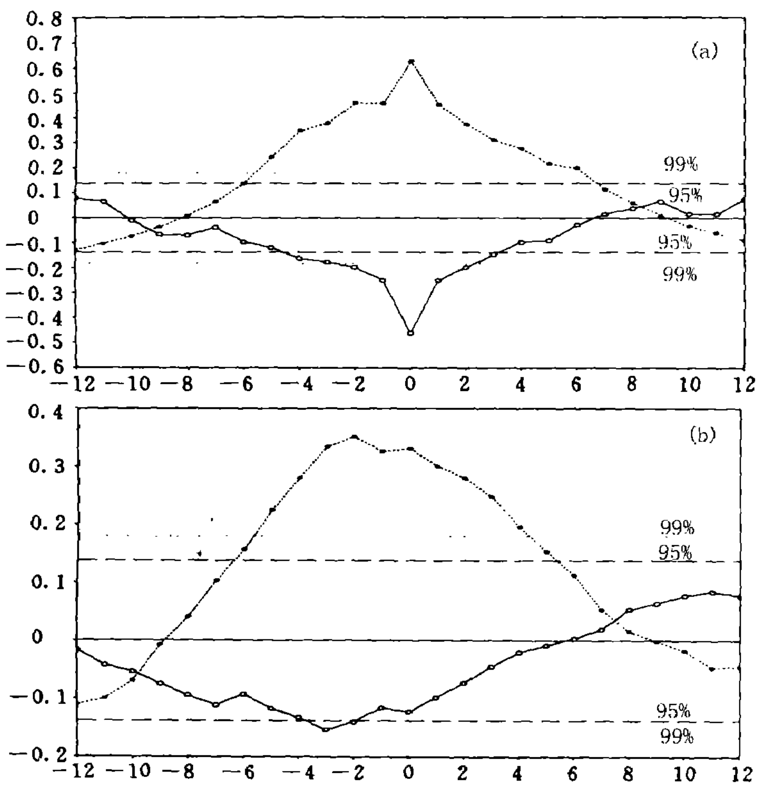

Fig. 5. The cross-correlation between meridional wind of both hemispheres and Nino 3 index, 850 hPa zonal wind respectively. The horizontal coordinate denotes the leading (positive) or lagging (negative) month of meridional wind. The long dashed and dotted lines stand for the confidence level of 95% and 99%. (a) Solid line: correlation of v (0 — 20°N, 120 — 160°E) and u (5°S — 5°N, 140 — 180°E); dashed line: correlation of v (0 — 20°S, 130 — 170°E) and u (5°S — 5°N, 160°E — 160°W); (b) same as (a), but for the correlation of meridional wind and Nino 3 index.

Hemisphere (Fig. 4f). from the previous to the following year of La Nina. the prevailing southerlies travel from eastern Indian Ocean to central Pacific Ocean, which means that the meridional divergence is dominant over equatorial western Pacific throughout the most lifetime of La Nina. What differs from the condition of El Nino in Fig. 4h is that the anomalous easterly comes from both equatorial Indian Ocean and eastern Pacific Ocean. with the latter source being stronger to some extent, while none of the equatorial westerly anomalies propagates from eastern Pacific.

The cross-correlation among Nino 3 index. zonal and meridional winds of both hemispheres are shown in Fig. 5 to distinguish the relative role of meridional wind from different hemispheres to westerly anomalies. The correlation between meridional wind of Southern Hemisphere and westerlies in equatorial western Pacific. denoted by the dash line in Fig. 5a. is significantly positive at the confidence level of 95% in such a way that the lagged time is up to 6 months. Its simultaneous correlation is most pronounced. and then the second peak emerges when meridional wind anomalies lead zonal wind anomalies by two months. For the same lagged time. the coefficient when meridional wind anomalies lead the zonal one in time. taking the example of 2 months. is higher than that in the opposite case. It suggests that the contribution of meridional convergence to the westerlies enhancement takes place earlier than the possible feedback of westerlies on the meridional wind. In comparison. the relationship between the Northern Hemispheric meridional wind and equatorial westerlies is less robust, its cross-coefficient passing the confidence level of 95% only within 2 months. Figure 5b denotes the similar correlation between meridional wind of both hemispheres and Nino 3 index. At the confidence level of 95%, meridional wind anomalies either in Southern or Northern Hemispheres will contribute to the SSTA of eastern Pacific, but the role of anomalies in Southern one is much more noticeable than that from the other hemisphere.

Briefly. the anomalous westerlies in equatorial western Pacific are not only dependent on the propagation of westerlies from Indian Ocean. but also to a larger extent. on the convergence of meridional wind from both hemispheres. particularly on the contribution of southeasterlies over southern Pacific to the east of Australia.

VI. ANALYSIS OF REASON FOR THE OCCURRENCE OF MERIDIONAL WINDS IN SOUTHERN HEMISPHERE

Owing to the control of geostrophic approximation in middle and high latitudes. the meridional wind anomalies should be associated with the anomalies of pressure. Figures 6 and 7 show the composite of 1000 hPa pressure anomalies and simultaneous 850 hPa wind departures in April and July of the onset year of El Nino. To be seen clearly. before and during the onset of El Nino. there is a large-scale geopotential height anomaly below normal travelling northward and eastward from the northern Antarctic Continent. which reaches to central southern Pacific. Meanwhile. the opposite anomalies shift eastward from Indian Ocean and persist over Australia. Thus the pattern of Southern Oscillation with the negative SOI index comes into being in southern Pacific. Naturally. over the region to the east of Australia. the southerlies are aroused to adapt to the eastward pressure gradient between the two large-scale pressure anomalies in southern mid-

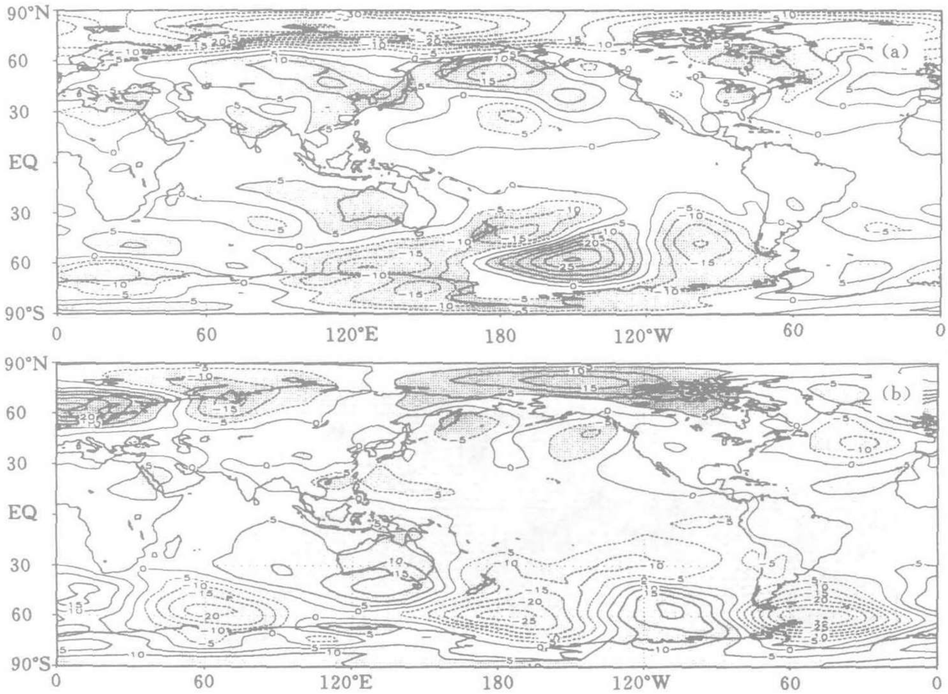

Fig. 6. The composite of 1000 hPa pressure anomalies in April (a) and July (b) of the onset year of El Nino. The shaded regions indicate the anomalies above 50 gpm.

latitudes, the twice enhancements of pressure gradient in April and July causing the two peaks of southerlies. Surprisingly, this pattern is considerably stable and stagnant until the following December. The similar pattern, with a weaker intensity and its stimulated meridional wind anomalies, is also found from January to March (figures omitted) in northern mid-latitudes, decreasing further more in the following several months. As expected, the drive of meridional flow from northern mid-latitudes to low latitudes becomes weaker.

Remembering that Australia is governing climatologically by cold highs in July, the mid-winter of Southern Hemisphere, we infer that Australia winter monsoon must be reasonably above normal based on the fact (Fig. 6) that the positive geopotential height anomalies are located over Australia while the reversal is over central southern Pacific. In Fig. 7, the southeasterlies to the east of Australia originate from the high latitudes or polar region with three southerly anomaly centers arranged over the south end of Africa, Australia and South America one by one. This pattern suggests that there are cold air transferred from high latitudes into middle latitudes in the Southern Hemisphere. Among these centers, both the African and South American one are suspended around 30°S and each is divided into two sub-streams flowing to both sides. There is one sub-stream from the African and South American center respectively combining into the southerlies to the south of Australia, and then flow to low latitudes and equatorial areas along 150—170°E. This is why the southerlies to the south of Australia are stronger than its two sides. It is well known that the transportation of cold air from high latitudes to low latitudes is

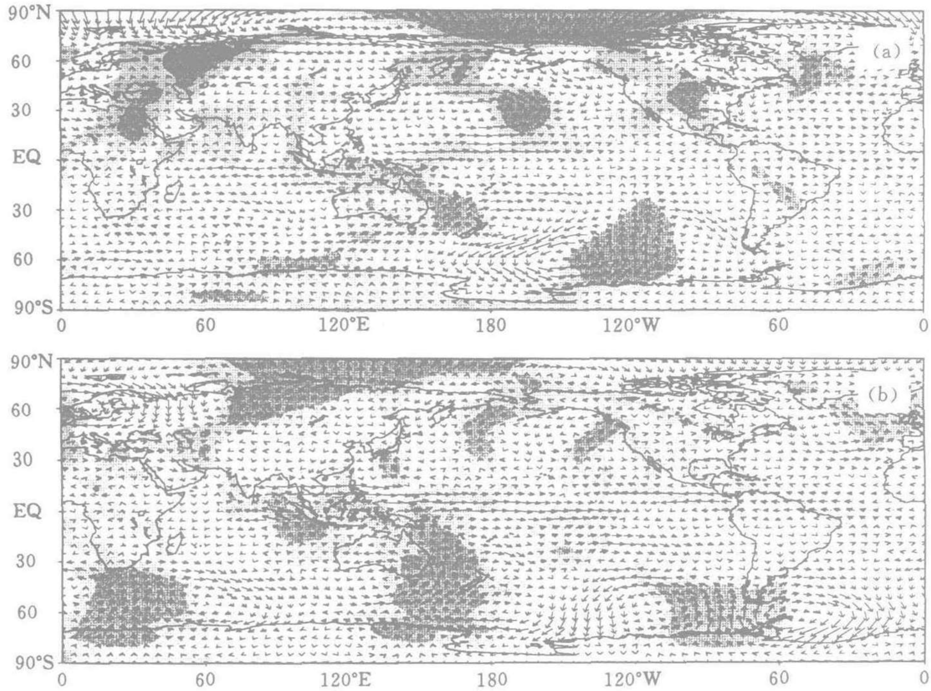

Fig. 7. Same as Fig. 6. but for 850 hPa wind anomalies. The shaded regions indicate the southerly anomalies.

marked by the outbreaks of cold waves, so the related enhancement of equatorial westerlies takes on the form of pulses. Perhaps this is the explanation for the intermittent enhancements of westerly wind shown in the pentad mean cross-section (Fig. 1).

Figures 8 and 9 demonstrate that the pattern of pressure and wind fields before and during the onset of La Nina is reverse to that of El Nino. In April. the positive anomalies of geopotential height travel from South Pole to mid-latitudes and then persist over central southern Pacific, concurrently, the opposite anomalies move from southern Indian Ocean to Australia. Consequently. a westward pressure gradient is set up and also for the associated northerlies. In contrast. there is no such noticeable pressure gradient between East Asian and western Pacific. The stable and intense northerlies lying to the east of Australia. as shown in Fig. 9. will be convenient for the depression of pressure in equatorial western Pacific and the westward extension of easterly over eastern Pacific Ocean. Similarly, there are three northerlies centering on the south end of South Africa. Australia and South America. their velocities being larger than that of the southerlies in the Northern Hemisphere.

The above study confirms that the characteristics of pressure and wind before and during the onset of El Nino/La Nina do stand for two reverse extreme states of global air-sea interactions. The mechanism of its formation is the next goal of researches in future.

VII. CONCLUSIONS AND DISCUSSION

Based on the composite analysis of low-level wind field before and during the onset of El Nino/La Nina, we can draw the conclusion as follows.

Two local enhancements of westerlies in equatorial western Pacific happen in April and July of the onset year of El Nino within the longitudinal range of 140—180°E.

The enhancements of westerlies in western Pacific not only result from the eastward propagation of westerlies from equatorial Indian Ocean, but also to a larger extent, from the convergence of both hemispheric meridional flows which lead to the rise of zonal pressure gradient and then cause the westerly wind bursts. In addition, under the control of earth rotation, the northeasterlies (southeasterlies) from mid-latitudes of Northern (Southern) Hemisphere turn into northwesterlies (southwesterlies) in tropics, which directly strengthens the westerly wind anomalies in western Pacific.

The comparison between the roles of meridional wind in Southern and Northern Hemispheres in the development of equatorial westerlies over western Pacific suggests that the contribution from the Southern Hemisphere is more stable in locations and stronger than its northern counterpart. The meridional wind in the Southern Hemisphere originates from high latitudes and even from South Pole region, being the result of anomalous pressure field in southern mid-latitudes.

The above-described features of wind and pressure fields are also true for cold events, but with the reverse pattern. In respect to the variations of zonal wind along equator, all of the westerlies travel from western to eastern Pacific throughout the whole life of El Nino, while for La Nina events, the easterly shifts from both sides into the central Pacific. The flow from eastern Pacific seems more remarkable than that from the other side.

As compared with the previous studies, our results focus on the contribution of meridional wind from mid-latitudes of Southern Hemisphere rather than that of Northern Hemisphere. It is due to the fact that the zonal pressure gradient associated with Southern Oscillation in southern mid-latitudes is much stronger and maintains for a longer period. As a consequence, the related meridional wind anomalies are more severe and stable in the Southern Hemisphere than that of Northern Hemisphere.

To be emphasized, the anomalous meridional wind in western Pacific does not just occur in the respective winter of each hemisphere and then disappear in other seasons. Actually, the southeasterlies to the east of Australia emerge as earlier as March in the onset year and last until the mature phase of El Nino. It is also true for the pressure anomalies and for the anomalies of Northern Hemisphere. In this sense, the anomalous East Asian and Australian winter monsoons are not necessarily the fundamental reason for the development of meridional wind anomalies in both hemispheres. On the contrary, the winter monsoon anomalies are just the special reflections of meridional wind in specified locations and time. The major reason responsible for meridional wind anomalies has been found in relation with the large-scale propagation of pressure field in interannual time-scale, which will be discussed in another paper later.

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