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A Diagnostic Analysis of Winter Atmospheric Circulation during the 1982–1983 ENSO Event

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ABSTRACT

In this paper, the winter atmospheric circulation, the convection along the equator and their variations of 1982 and 1983 are investigated. It is suggested that there was a well organized three dimensional structure of anomalies of the atmospheric circulations during 1982 winter which may be related to the variations of the convection in the equatorial region.

I. INTRODUCTION

In the last decade, the El Nino / Southern Oscillation (for short as ENSO) phenomenon became a hot topic in both meteorological and oceanographical researches. The main reason is that the ENSO events involve the significant sign of interannual climate changes (Trenberth, 1984) and the studies of ENSO events may be a promising approach to understand the causes of interannual climate changes and to improve the long–range forecasting.

1982–1983 ENSO event was the strongest one in this century, which brought about severe anomalies of weather and climate in the globe and caused a huge economic damage (World Climate Data Programme, 1984). The ENSO events have drawn more attention of scientists in the world. A significant progress has been made in this field. Many studies have carried out the investigation of the influences of ENSO events on the atmospheric circulations, weather and climate all over the world (Wright, 1977; Wyrtki, 1974; Fu, et al., 1978; Rasmusson et al., 1983; Quinn et al., 1983; Pittock, 1975; Pan, et al., 1983; Li, 1985; Zhang, et al., 1984; Fu, 1985, etc.)

In order to understand the physical mechanism of anomalous SST affecting the weather and climate during ENSO events, we should have a good comprehension of atmospheric circulation in association with the anomalous climate. Bjerknes (1966, 1969) made the pioneer studies in this field. He pointed out that the anomalous warming of SST in the eastern equatorial Pacific could enhance the local Hadley circulation which transports much of momentum to middle latitudes and strengthens the westerlies. It is the Hadley circulation that connects the SST anomalies in the equatorial region to the intensification of westerlies in middle latitudes. He called it "teleconnection" (1966). In the other work (1969), Bjerknes brought on an idea of "Walker circulation" —the east–west circulation in the equatorial plane, which could be used to explain the Southern Oscillation and links the changes of air pressure over the Pacific Ocean to the variation of SST in the eastern equatorial Pacific. Since then, El Nino and Southern Oscillation have been studied as a whole which was known as El Nino / Southern Oscillation (ENSO). The Walker circulation was confirmed by observation (Newell, et al., 1974). Fu, et al. (1979) calculated the east–west circulation along the equator in the Dec. of 1972 and found that the Walker circulation disappeared during the ENSO event. Pan and

Oort (1983) analysed a global 15–year set of data and concluded that the Walker circulation was weak and the local Hadley circulation in central and eastern Pacific was strong during the warm episodes. Tourre, et al. (1984) showed a schematic picture of Walker circulation of the 1982–1983 winter, based on the computation of upper and lower tropospheric divergent winds. And Tourre analysed the 30°S–30°N averaged east–west circulation during this period in his another paper (1987).

Many authors (e.g. Bjerknes, 1969; Pan and Oort, 1983, etc.) pointed out that during ENSO developing, the northern Pacific subtropical high increases in its strength. Wallace and Gutzler (1981) made a correlation analysis based on a 15–year set of geopotential height data at 500 hPa and revealed some correlation patterns in the Northern Hemisphere winter, one of which was called Pacific North America pattern (for short as PNA pattern). The SST anomalies in the equatorial region could stimulate the developing of this pattern which makes the influence of SST in equatorial region spread to middle and high latitudes. Hoskins and Karoly (1981) established a theory, known as "the great circle theory", or the theory of Rossby wave train, for explanation of this pattern. Blackmon et al. (1982) and Shukla and Wallace (1983) believed that this pattern is the responses of stationary Rossby wave to the anomalous heat source in the equatorial Pacific. Shukla and Wallace (1983) showed a schematic illustration of the geopotential height pattern and wind anomalies at lower and upper troposphere during an warm SST episode in the equatorial Pacific.

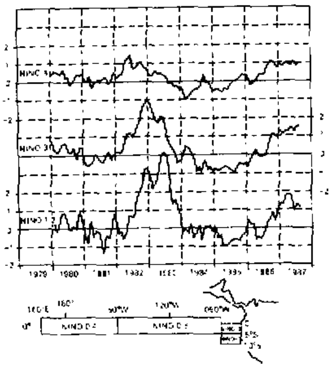

Fig.1. Variation of SST anomalous index in the equatorial Pacific * * Nino 1+2 is average value for Nino 1+Nino 2.

So far, the three–dimensional structure of general circulation anomalies, including meridional circulation, east–west circulation and horizonal circulation anomalies during ENSO events has not been very clear. In this study, we use more complete data of wind and tropical convection to investigate the winter atmospheric circulation in December of 1982 and 1983 over the tropical Pacific and discuss the possible mechanism by which the SST anomalies and convection in the tropics affect the atmospheric circulation. The change of SST anomalies in the equatorial Pacific (see Fig.1) shows that this warming event reached its highest peak in Dec. of 1982 and returned to near the normal in Dec. of 1983. Therefore the atmospheric circulation in Dec. of 1982 could represent the winter circulation during the ENSO event and the circulation in Dec. of 1983 could be a normal one. By comparing their differences, we study the influences of the ENSO event on the winter atmospheric circulations.

II. DATA

The wind data set used in present study is the objectively analysed wind from the European Center for Medium Range Weather Forecasts (ECMWF), which is of seven layers in the vertical (i.e. 100 hPa, 200 hPa, 300 hPa, 500 hPa, 700 hPa, 850 hPa and 1000 hPa) and once a day (12 GMT). The wind data set includes the horizontal speed components u, v and vertical speed w. The data of convection are adopted from ≪ Atlas of High Reflective Clouds for the Global Tropics: 1971–1983≫ (Carcia,1985). The high reflective clouds (for short as HRC) were derived from images of satellites and defined as the Type C in Fig. 2. In contrast to the HRC, the OLR (Outgoing Longwave Radiation) data, another widely used indicator of large–scale convection over tropics, also includes the nonconvective clouds (as Type A and D in Fig.2). So the HRC is a better index than the OLR in describing the convections. The original HRC data(Carcia, 1985) are the daily frequency of occurrence of HRCs at grides(1 × 1) in a month (Unit: days / month). In this paper, the equatorial HRCs are averaged in the latitudes of 5°S–5°N.

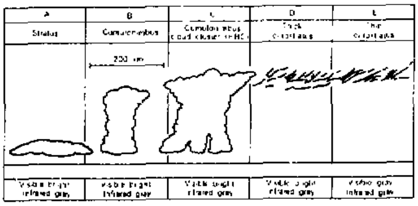

Fig.2. The types of cloud in the tropics.

III. THE VARIATION OF EQUATORIAL CONVECTION

The convection in the equatorial region is important for the air–sea exchange of energy and internal transformation and transportation of atmospheric energy. The variation of intensity and position of the convection area in the equatorial Pacific is a major characteristic associated with the ENSO phenomenon (Fu, et al., 1986). According to the average state for 13 years from 1971 to 1983 (the diagram omitted), the most active convection area in the equatorial region is located in the area of 90°E–170°E, whose eastern border is consistent with the climatological isotherm of 28.5℃ of SST. The distribution of the equatorial convection in Dec. of 1983 is shown in Fig.3b, which generally agrees with the climatological one. The active convection area is over 70°E–180°E and there was almost nonconvection over 180°E–70°W. The average value of HRC around the global tropics is 2.3 days / month. In Dec. of 1982, accompanying the eastward shifting and extending of the equatorial warm pool (the 28.5 isotherm of SST reached 125°W (Fu, et al., 1986)), the active convection migrated and extended eastward(see Fig.3a). As compared with the situation in 1983, it is of three noticeable changes: a) an active convection was in the region from 170°E to 130°W, the maximum HRC up to 7.4 days / month; b) the convection in western equatorial Pacific became less active; c) as a whole, the global equatorial convection strengthened, the average HRC up to 3.0 days / month. The difference between these two months (1982 minus 1983, shown as Fig.3c) shows this feature more clearly, i.e. the equatorial convection intensifies in the central and eastern Pacific and weakens in the western Pacific. The migration of active convection area is the reflection of SST changes and concerns with the variation of atmospheric circulations. We will analyse the local meridional circulation, the east–west circulation along the equator and the horizontal circulation at lower and upper levels of troposphere in the next three sections.

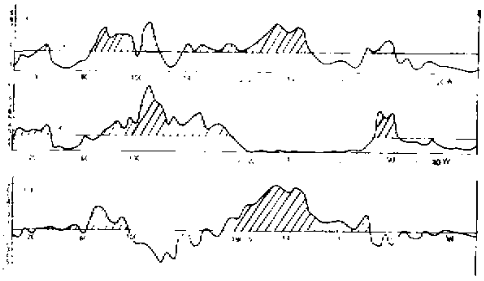

Fig.3 The distribution of convection along the global tropics. a) Dec., 1982, b) Dec., 1983 and c) 1982 minus 1983.

IV. LOCAL MEAN MERIDIONAL CIRCULATIONS

Bjerknes (1966) deduced that the local Hadley circulation in the eastern Pacific strengthened during ENSO events. Fu, et al. (1979) computed the observed data along 150°W and confirmed this result. According to the variation in the characteristics of convection area discussed in the last section, we now analyse the local mean meridional circulation in the central Pacific (160°E–150°W), the western Pacific (110°E–160°E) and the eastern Pacific (150°W–100°W), respectively.

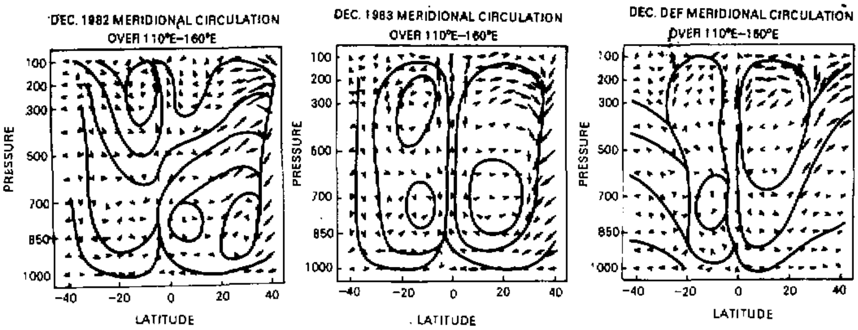

Fig.4. The local mean meridional circulation in the western Pacific, a) Dec. of 1982, b) Dec. of 1983 and c) the difference between a) and b).

Fig.4b shows the local mean meridional circulation Dec. of 1983 in the western Pacific, representative of normal condition. The ascending branch sites its centre at about 5°S. There is a strong Hadley cell in both the Southern Hemisphere and the Northern Hemisphere. These are the strong direct circulation which results from the active convection in the equatorial western Pacific. In Dec. of 1982 (see Fig.4a), the Hadley circulation in this region weakened significantly, and the Hadley cells shrank to lower levels in the Northern Hemisphere while it split up into upper cell and lower one in the Southern Hemisphere. But there was no descending flow near the equator and, of course, no anti–Hadley circulation formed. In fact, the sea surface temperature near the equator was still higher and the convection was still more active near the equator than that in the rest region. So it is impossible to induce an anti–Hadley circulation. From the differences between these two months (1983 minus 1982), it could be found that there was a strong anti–Hadley reinfored cell at upper levels and lower levels respectively in the Southern Hemisphere (see Fig. 4c). This shows clearly the influence of the weakening of convection in Dec. of 1982 in the equatorial western Pacific on the local meridional circulation.

On the contrary of the variation of meridional circulation in the western Pacific, the winter Hadley circulations in the central Pacific were obviously intensified within the ENSO event (as seen by comparing Fig. 5a with Fig. 5b). In Dec. of 1982 (Fig.5a), there was a strong Hadley cell in the Southern Hemisphere and a Hadley double–cell in the Northern Hemisphere which was also very strong. The descending flow at the lower and middle latitude (near the 30°N or S) was prosperous. Bjerknes (1966) inferred that this enhanced descending flow transports the west–wind momentum from upper levels to lower levels at lower and middle latitudes where the westerlies and subtropical high strengthened significantly. From the difference between these two months(Fig.5c), it is more apparent that the Hadley circulation both in the Northern Hemisphere and Southern Hemisphere were intensified.

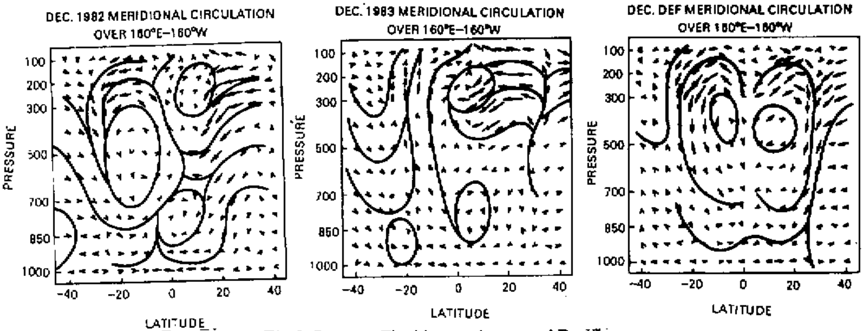

Fig.5. Same as Fig.4 but in the central Pacific.

The local mean meridional circulations in the eastern Pacific did not show any fundamental difference between these two months. In Dec. of 1983, there was a weak anti–Hadley cell near the equator. In Dec. of 1982, there was no closed cell of the anti–Hadley circulation near the equator and no Hadley circulation formed (diagram omitted). This is because that even though the SST in the equatorial eastern Pacific was anomalously warm, at that time, its absolute value was still low, and no systematic ascending movement was established.

In summary, the variations of local mean meridional circulation were quite different in different regions, during the winter when the ENSO event developed obviously. Due to the change of convection in equatorial region, the ascending flow weakened and maintained a weak Hadley circulation in the equatorial western Pacific, while an enhanced ascending flow and then a strong Hadley circulation were formed in the equatorial central Pacific, with no significant changes in the vertical movement and meridional circulation in the equatorial eastern Pacific.

V. THE EAST–WEST CIRCULATION ALONG THE EQUATOR

The east–west circulation along the equator in Dec. of 1983 is shown as Fig. 6b. There is a complete Walker circulation cell in the equatorial Pacific. Another strong circulation cell located in the area from the western Paicfic to Indian Ocean with an ascending branch in the east and a descending branch in the west. The other big cell consisted of the ascending in the Southern America continent and descending in the equatorial Atlantic. This situation well agrees with the results of Newell et al. (1974) and generally coincides with the schematic illustration of winter mean state obtained by Tourre et al. (see Fig 7a). It is also confirmed that it is reasonable to use the Dec. of 1983 as a representative of the normal winter.

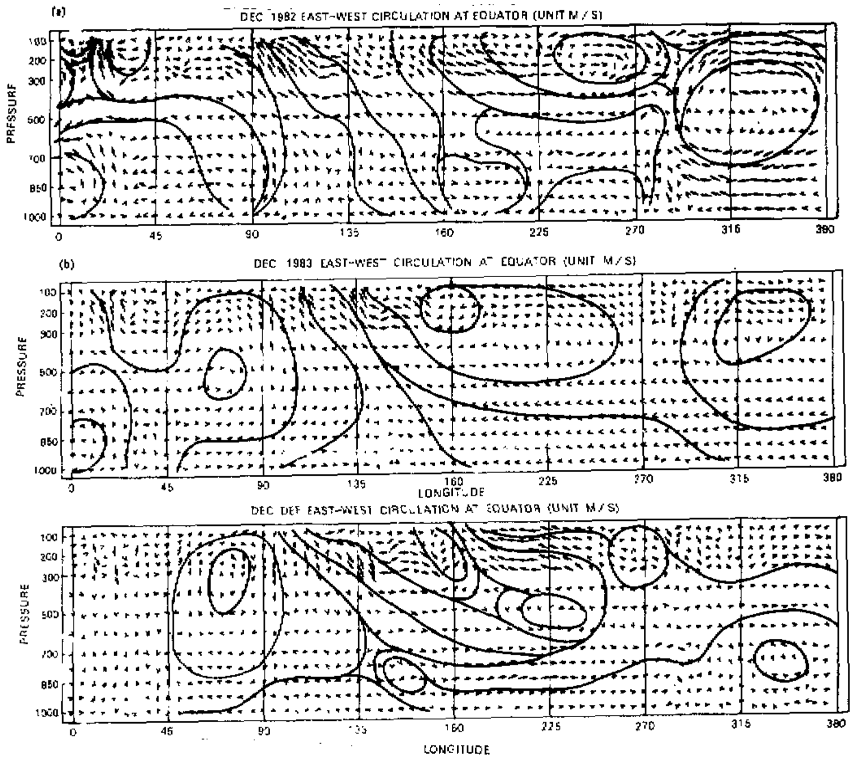

Fig.6. The east–west circulation along the equator (5°S–5°N averaged), a) in Dec. of 1982, b) in Dec. of 1983, and c) difference between a) and b).

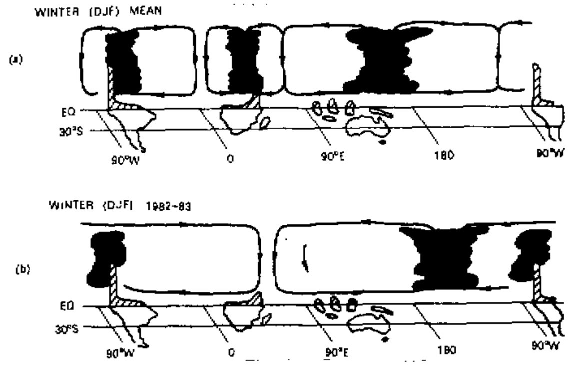

Fig.7. The schematic map of east–west circulation along the equator computed from divergent wind at lower and upper troposphere (Tourre, et.al., 1984).

It is surprising that the east–west circulation in Dec. of 1982 (see Fig. 6a) did not suffer an expectant alteration, i.e. no anti–Walker circulation appeared in the Pacific. As the eastward migrating and extending of the equatorial convection area, the centre of ascending branch moved to 170°E–130°W. This agrees with the changes of HRC (Fig.3a). And the descending branch of Walker circulation shrank to the area of 100°W–80°W. It made the Walker circulation recede eastward about 60 degrees of longitude and decrease in its intensity. These results are the same as the statistical results (Pan, et al., 1983). It should be pointed out that there was no systematic descending flow, neither the westerly wind at lower troposphere in the equatorial western Pacific, of course, nor the so–called anti–Walker circulation suggested by Tourre et al. (see Fig.7b). On the other hand, as the active convection area shifts from the western Pacific to the central Pacific, the westerly wind anomalies and the easterly wind anomalies appeared at lower levels and upper levels respectively, and an anti–Walker reinfored circulation (or anomalous circulation) was formed in the region where the Walker circulation occupies in normal winter. Fig. 6c is the difference of east–west circulation (1982 minus 1983). This picture can be regarded as the anomalies in the present study. The anti–Walker circulation made the real Walker circulation much weaker and shrunk eastward.

The calculated east–west circulation of Dec. of 1982 (Fig.6) differs from the Tourre's illustration. The main difference is in two aspects: a) Whether the easterly wind or the westerly wind prevails in lower troposphere to the west of the date line? b) Is there a systematic descending air flow in the equatorial western Pacific? The part of their difference can be tied to the fact that the Tourre's illustration is the winter (DJF) mean situation and our results are based upon the monthly mean data of Dec. of 1982. But the another winter (DJF) mean material published by Climate Analysis Center / NMC, NMS & NOAA (Phillip, 1983) shows that it was the easterly wind that prevailed at lower troposphere to the west of the date line in 1982–1983 winter. This supports our results and is contrary to the Tourre's schematic illustration. At the upper troposphere, the easterly wind dominated in the equatorial western and central Pacific. So there was a thick easterly wind in the troposphere. Of course, the anti–Walker circulation could not be formed. In Tourre's diagram, there is a one–to–one correspondence between the vertical movement structure and the divergence field of zonal wind direction. This one–to–one correspondence may neglect the effects of meridional mass circulation on vertical air flow. Many studies (e.g. Newell et al., 1973) have shown that the magnitude of meridional mass circulation is ten times greater than that of east–west circulation. Therefore, the divergence of zonal wind could not determine the vertical motion completely. Our computed results also support this viewpoint. As discussed above, the convection in the equatorial western Pacific, even through weakened, was still active and maintained the ascending air flow which was weaker than the normal winter. And no alternative ascending with descending took place, at least as was the case in Dec. of 1982 when additional SST anomaly was at peak.

VI. THE VARIATION OF HORIZONTAL CIRCULATION AT LOWER AND UPPER TROPOSPHERE

The variation of the horizontal circulation should keep pace with the change of vertical motion. In this section, we use 850 hPa and 200 hPa as the lower and upper levels of the troposphere to discuss the horizontal circulation. Since our main purpose is to understand the variation of horizontal circulation during the ENSO event, our attention is mainly paid to the difference (or anomalies) between these two winter months (1982 minus 1983).

The difference of horizontal circulation at the lower troposphere (see Fig.8a) is tightly linked with the changes of meridional circulation. With the weakening of the equatorial convection, the poleward divergent wind strengthened in the western Pacific while it was weakened in the central and eastern Pacific. The meridional anomalous flow, affected by the Coriolis force, formed a couple of anti-cyclonic anomalous cells which straddled on the equator west of 145°W, which have been mentioned by Shukla and Wallace (1983). There was the northeasterly anomalies in the tropical eastern and central Pacific and the westerly anomalies over the equator in the eastern Pacific. A couple of cyclonic anomalous centers could be identified between them. One of the cyclonic center was located in the northeastern Pacific, which stimulated the intertropical convergence zone and resulted in strong activities of typhoon (Sadler and Bernard, 1983) and rainy weather over there (WCDP, 1984). The other center was over the southeastern Pacific, which made the southern Pacific highly decrease in its strength and the Southern Oscillation Index (SOI) fall. It is significant in Fig.8a that the anomalous centers are almost symmetric to the equator. Partly due to the difference of the topography and the basic air flow between the two hemispheres, the anticyclonic center in the northern Pacific and the cyclonic center in the southeastern Pacific are stronger than their partners.

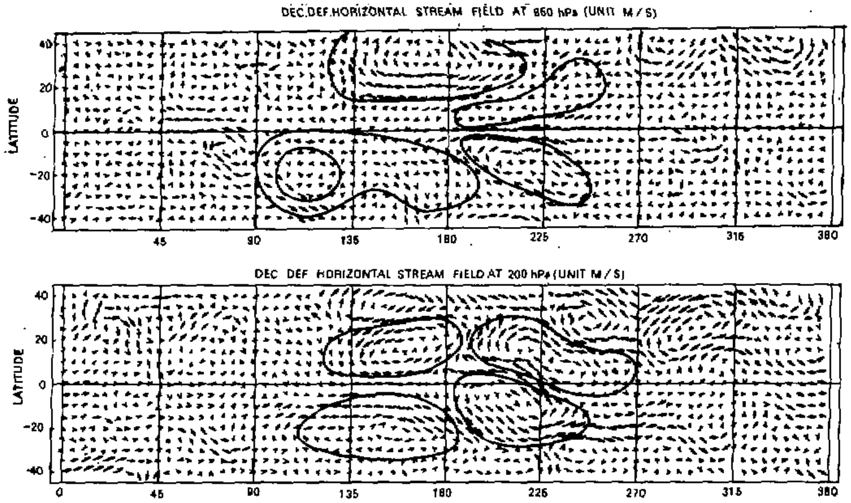

Fig.8. The difference of horizontal circulation between Dec. of 1982 and Dec. of 1983, a) at the lower troposphere (850 hPa), and b) at the upper troposphere (200 hPa).

In 1982—1983 winter, the anticyclonic anomalous circulation in the northern Pacific intensified the Western Pacific High which, at 500 hPa, increased by about 10—30 geopotential meters in the Eastern Hemisphere and whose ridge was about 5 degrees latitude north of the normal. These made the disturbances in westerlies and the cold air actions occur in an area further to the west and south respectively. On the other hand, too much westward extending of the western Pacific high (reached Indian Peninsula) blocked the channel transporting vapour from the Bay of Bengal to China. These circulation may be responsible for the severe cold and drought in southern China in Dec. of 1982 (Yan, et. al., 1983). The strengthening of anticyclonic circulation in central southern Pacific resulted in the higher pressure, less active ITCZ and the maintenance of extreme drough in Australia (WCDP, 1984).

The difference of horizontal flow field at upper levels is shown in Fig.8b. There are strong poleward divergent anomalous flows in the central Pacific, associated with the strengthening of Hadley circulation. Under affecting of Coriolis force, the divergent anomalous flows made up the anticyclonic anomalous circulation. The anomalous equatorward convergence flows in the western Pacific are linked with the weakening of local Hadley circulation. The westerly anomalies over the equator yield the cyclonic shear of wind anomalies, which resulted in a couple of cyclonic anomalous centres. All the systems mentioned above, the four anomalous centers at upper troposphere, the four centers at lower levels, and the variations of local mean meridional circulations and the variations of the east–west circulations have established a complete three–dimensional structure, which will be discussed further in the next section. The couple of anticyclonic anomalous centers had been described in some previous studies (e.g. Shukla and Wallace, 1983), while the couple of cyclonic anomalous centers at upper levels only less attention has been received. In fact, they could be identified in the 1982–1983 winter mean stream function anomaly field at 200 hPa.

VII. THE THREE–DIMENSIONAL STRUCTURE OF VARIATION OF ATMOSPHERIC CIRCULATION IN TROPICAL PACIFIC IN DEC. OF 1982

In Dec. of 1982, when the ENSO event was at the peak, the variations (or anomalies) of atmospheric circulation in the tropical Pacific were remarkable. We summarize the variations (which roughly equals the anomalies and are called anomalies) into a schematic illustration, (see Fig.9). As the equatorial warm pool extended and migrated eastward and the SST in offshore of southern America warmed up, the equatorial convection weakened in the western Pacific and strengthened in the central and eastern Pacific. Subsequently, the anomalous descending flow was forced in the equatorial western Pacific and the anomalous ascending flow in the equatorial central Pacific. At lower troposphere, there was an anomalous poleward flow in the western Pacific, and over the equator, there was a westerly anomaly east of 160°E and the easterly anomaly west of 160°E, all of which compensated for the anomalous descending flow in the equatorial western Pacific. For the same reason, there was the equatorward anomalous flow in the central Pacific. All the meridional compensatory anomalous flows, under the affecting of Coriolis force, constructed a couple of anomalous cyclones. In the eastern Pacific, the meridional anomalous flow, which had turned into the northeasterly (southeasterly) wind in the Northern (Southern) Hemisphere, and the westerly anomalous wind over the equator formed a strong cyclonic shear which resulted in a cyclonic anomaly on both sides of the equator. At the upper troposphere, the situation was contrary. There was an equatorward compensatory anomalous flow in the western Pacific and poleward anomalous flows in the central Pacific. The convergent point between the easterly anomalies and the westerly anomalies is at 170°E. The meridional anomalous flows, which had alternated their directions under the Coriolis force, and zonal anomalous flows over the equator formed a couple of anticyclonic anomalous centers in the central and eastern Pacific and a couple of cyclonic anomalous centers in the western Pacific. Meanwhile, the ascending anomalous motion was forced at the lower and middle latitudes of the western Pacific and the descending anomalous flow of the central Pacific. Thus, an anomalous anti–Hadley circulation developed in the western Pacific and an anomalous Hadley circulation formed in the central Pacific.

It is shown in Fig.9 that the anomalous descending flow in the western equatorial Pacific seems to have a dominant impact on the zonal anomalous winds, while the anomalous ascending flow in the central Pacific seems to have a remarkable influence on the meridional compensatory winds. There is a divergence of easterly and westerly anomalies below the anomalous descending flow as well as a convergence over it. The most strong meridional compensatory flow occurred in the central Pacific, which was associated with a couple of anticyclonic anomalous centers in lower and upper troposphere. There is no doubt that a couple of cyclonic anomalous centers existed in both upper and lower troposphere during the ENSO event. But its influence needs to be investigated further.

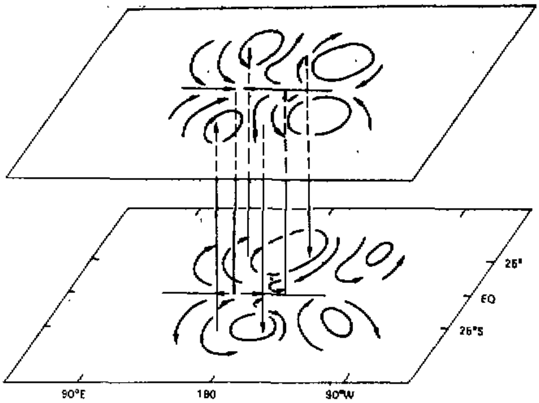

Fig. 9. The schematic three-dimensional structure of the winter atmospheric circulation anomalies during the ENSO event.

This paper discusses the 1982–1983 winter only. The influences on the summer circulation and the changing process of atmospheric circulation during the ENSO event will be studied in another paper.

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