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RELATION BETWEEN SUMMER TYPHOON FREQUENCY ANOMALIES IN WEST PACIFIC AND ENSO EVENTS AND THE ANOMALOUS ATMOSPHERIC CIRCULATION CHARACTERISTICS

ZHOU Xue-ming (周学鸣), WEI Ying-zhi (魏应植), WU Chen-feng (吴陈锋)

(Xiamen Meteorological Bureau, Xiamen 361012 China)

ABSTRACT: By using data of serially numbered typhoons in northwestern Pacific and NOAA OLR data and NCEP/NCAR reanalysis data of wind field, based on the statistics and study of the relationship between the calendar years with more (or fewer) summer typhoons and ENSO events, we compared the composites of OLR eigenvectors and tropical summer wind fields during El Niño and La Niño events with more or fewer than normal summer typhoons, respectively. The results show that, in summer, without remarkable systematic anomalies of Mascarene High and Australia High in South Hemisphere, the anomaly of Walker circulation will dominate and follow the rule of ENSO impacts to atmospheric circulation and typhoon frequency. Otherwise, when systematic anomalies of Australia High appear during the El Niño events, circulation anomalies in the South Hemisphere will dominate, and many more typhoons will occur. In 1999, which is a special year of La Niña events, northward and eastward monsoon was induced by the stronger Mascarene High, and fewer typhoons arose. The typhoon source are regions where weak vertical wind shear, warm pool in western Pacific and the area with monsoon troughs are overlapping with each other. Finally, this paper analyzes and compares the source locations and ranges of more (fewer) typhoons in the events of El Niño and La Niño, respectively.

Key words: typhoon frequency; ENSO events; atmospheric circulation anomalies

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1 INTRODUCTION

June – September in summer are the months when typhoons, including tropical storm, severe tropical storm and typhoon (hereafter the same), in West Pacific, including South China Sea, have the most frequent genesis in a year. The frequency of typhoons has obvious interannual variation, which mainly depends on the change of atmospheric circulation affecting the generation of typhoons. There have been many researches on the SST, atmospheric condition and physical processes of typhoon genesis. In the composite theory about typhoon genesis, Li[1] points out that the West Pacific typhoon genesis relates closely to the sustaining intensity of cross-equatorial flows excited by the movement of cold air on Southern Hemisphere. Tao et al.[2] and Li[3] think that the genesis and frequency of West Pacific typhoons relate to the onset of tropical westerly and the easterly flow south of the subtropical high. Chen et al.[4] present 6 conditions for typhoon genesis such as small vertical wind shear in the troposphere and cyclonic circulation of longitudinal trade wind with horizontal shear, etc. The summer cross equatorial flow, summer monsoon westerly, subtropical high and trade wind easterly on its south side and monsoon trough, or intertropical convergence zone ITCZ, are all the parts of East Asian summer monsoon circulation system. The genesis and variability of East Asian monsoon was described by He et al.[5]. East Asian summer monsoon circulation anomalies will result in the frequency anomalies of the typhoon generating or landing from West Pacific. Sun et al.[6] analyze and point out that the frequency of Northwest Pacific tropical cyclones in strong summer monsoon years is relatively large but relatively small in weak summer monsoon years, which tends to be normal later. Many researches have shown that the most important factor affecting the summer monsoon circulation anomalies is SST. Different SST anomalies in different sea areas result in different influences on

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Biography: ZHOU Xue-ming (1957-), male, native from Hebei Province, M.S., senior engineer, mainly undertaking weather forecast and climate prediction.
E-mail: zhoujin@public.xm.fj.cn

atmospheric circulation and make climate become abnormal. Li et al.[7], He et al.[8] research on the relation between ENSO circulation that results from equatorial central and eastern Pacific SST anomalies and West Pacific typhoon frequency and put forward that the frequency of typhoons generating or landing from West Pacific in El Niño years is fewer than that in normal years, and obviously more in La Niña years. In recent years, with the diversification of satellite observation data and the improvement on ENSO monitoring and diagnosis technology, the research on the physical causation of the interannual variability of summer monsoon circulation and typhoon genesis (landfall) have been developing in depth.

By using data of serially numbered typhoons in West Pacific from 1951 to 2003 provided by National Climate Center, the satellite-observed OLR data (2.5 °×2.5 ° grid) in 1974-2003 and wind field reanalysis data (2.5 °×2.5 ° grid) in 1951-2003 from NOAA, NCEP/NCAR, Based on the statistics and study of the relationship between the calendar years with more (or fewer) summer typhoons in West Pacific typhoon, we compared the composites of OLR eigenvectors and atmospheric characteristics during El Niño and La Niña years with more or fewer than normal summer typhoons, respectively, and further unveiled the rules and physical causation of different types of tropical summer monsoon circulation anomalies and summer typhoon frequency anomalies in West Pacific during ENSO events, which can offer basis for short-term climate prediction. The summers with more or fewer typhoons can be described by abnormality C:

$$C=\frac{Y-Y_P}{d_Y},Y_P=\frac{1}{n}\sum_{i=1}^{n}Y_i,d_Y=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Y_i-Y_P)^2}$$

In the formula, Y is the serial number of typhoon in a certain year, Y_P is the climatologically averaged value of the serial numbers of typhoons, and δ_Y is the standard deviation. In the 53 years from 1951 to 2003, there were 788 serially numbered typhoons during July to September. The climatologically average annual frequency was 14.7 typhoons, and standard deviation is 3.3 typhoons. For definition, if $C\geqslant1$, it means that the typhoon frequency is relatively more than normal years (11 years in all); if $C\leqslant-1$, it means that the typhoon frequency is relatively fewer than normal years (8 years in all).

2 STATISTICAL RELATION BETWEEN SUMMER WEST PACIFIC TYPHOON FREQUENCY ANOMALIES AND ENSO EVENT

ENSO is the outcome of large-scale air sea interaction. El Niño and La Niña events are the abnormal reflection of changing SST when the ENSO cycle is in the warm and cold phases. Li et al.[9] define the ENSO event using abnormal SST variation in the equatorial central, eastern Pacific (Niño 4 and Niño 3 regions) as indices. Wang et al.[10] use the SST and SOI indices for Niño 3 and Niño C regions to determine ENSO events at seasonal scale. The two indexes mentioned above will be used in this paper to determine the ENSO event, and the corresponding relation is isolated between summers (July-September) with fewer typhoons in West Pacific ($C\leqslant-1$) and those with more typhoons ($C\geqslant1$) and ENSO events.

It is shown in Tab.1 and Tab.2 that, within 11 calendar years with more summer typhoons than normal years, 4 years are with warm events, six years with cold events and one year with non-ENSO event. Within the 8 calendar years with fewer typhoons then normal years, 7 years are with warm events and one year with cold event, which is similar to the conclusions of many researches[7-8] that in El Niño years, typhoon frequency in West Pacific is generally fewer than in normal years while in La Niña year it is much more, being consistent with general statistical characteristics and physical principles. But they cannot be applied to air-sea interactions without modification. It can be found in the statistics mentioned above that the years with fewer typhoons generally occur during El Niño but the years with fewer typhoons usually occur during La Niña. It is not the case contrarily. There are quite a few years with more typhoons during the course of El Niño but some isolated years (1999) with fewer typhoons showing up during the course of La Niña. There is also a non-ENSO event year with more typhoons, i.e. 1960. It is also found in the table that, strong or relatively strong ENSO events, more of which are El Niño events, occurred frequently within 1980 – 1990, which shows that tropical sea and atmosphere interacted most dramatically in this anomalous period. During 1950's – 1970's, ENSO events mainly broke out in Eastern Pacific, but mainly in central Pacific after 1980's. All summer typhoon frequency anomalies may happen in the ascending period of SST trend in central and eastern Pacific during ENSO events, which also shows that SST may have persistent influence on atmospheric circulation. After analyzing the simultaneous and lagging correlation between SSTA and the monthly mean geopotential height fields at 500 hPa, Chen et al.[11] put forward that the correlation between SSTA in the Niño zones and the atmospheric circulation over tropical region can maintain for 3 – 5 months. So even 1-5 months (the ending period) after the termination of ENSO events, West Pacific tropical summer monsoon circulation and typhoon frequency are still affected by SST.

Tab.1 Relation between years with fewer West Pacific typhoons in July – September ($C \leqslant -1$) and ENSO events

Year	Number of coded typhoons	ENSO event	SST trend	SST Intensity	Onset Type
1951	7	Warm Event	Ascending period	Weak	E
1953	11	Warm Event	Ascending period	Very weak	E
1957	10	Warm Event	Ascending period	Strong	E
1983	10	Warm Event	Descending period	Very strong	C
1986	11	Warm Event	Ascending period	Very strong	C
1998	8	Warm Event	Ending period	Very strong	E
2003	10	Warm Event	Ending period	Weak	C
1999	10	Cold Event	Descending period	Strong	C

Tab.2 Relation between years with more West Pacific typhoons in July – September ($C \geqslant 1$) and ENSO events

Year	Number of coded typhoons	ENSO Event	SST trend	SST intensity	Onset Type
1958	18	Warm Event	Ending period	Strong	E
1965	18	Warm Event	Ascending period	Medium	E
1966	23	Warm Event	Ending period	Medium	E
1994	25	Warm Event	Ascending period	Weak	C
1962	18	Cold Event	Descending period	Very weak	E
1964	20	Cold Event	Descending period	Medium	E
1967	26	Cold Event	Descending period	Weak	E
1971	18	Cold Event	Ascending period	Strong	E
1974	19	Cold Event	Descending period	Strong	C
1989	18	Cold Event	Ending period	Strong	E
1960	19	None			

In order to explore the circulation difference in years with more or fewer typhoons during El Niño and La Niña and try to find the physical reasons and rules of such differences, we synthesized, compared and analyzed the El Niño years with fewer typhoons (1951, 1953, 1957, 1983, 1986, 1998 and 2003, seven years in all), La Niña years with more typhoons (1962, 1964, 1967, 1971, 1974 and 1989, six years in all) and El Niño years with fewer years (1958, 1965, 1966 and 1994, 4 years in all). At the same time, we compared and analyzed the special La Niña years with fewer typhoons (1999). However, because 1960, which is a non-ENSO event year with more typhoons, was affected by other main factors and mainly resulted from the fact that West Pacific subtropical high was stronger than normal years and located more southward, it will be discussed in another paper.

3 ANALYSIS OF ATMOSPHERIC CIRCULATION ANOMALIES WITH TYPHOON FREQUENCY ANOMALIES IN THE COURSE OF EL NIÑO AND LA NIÑA

Ding, et al.[12] point out that lower-level monsoon troughs or (ITCZ) are much different in seasons with more typhoons from those with fewer typhoons. The analysis of Chen, et al.[13] also points out that the location of monsoon trough affects the genesis of typhoon obviously. According to the statistics, most Northwest Pacific typhoons develop from the perturbation in intertropical convergence zone, and most typhoons occurred in a zone within 10°N – 15°N. However, in the South China Sea, most typhoons occur near 17°N. There are three places in Northwest Pacific where many typhoons form, which are located over the South China Sea, east of the Philippines and near Mariana Islands[14]).

Fig.1 shows the climatologically averaged (1971–2000) streamline, wind speed and monsoon trough at 850 hPa in summer (July – September). It can be seen from the figure that, within the latitude range of 10 – 20°N, the monsoon trough is located from the South China Sea to West Pacific at 150 °E, reaching 160 °E at 1000 hPa. Monsoon trough is mostly located over the extensive Pacific Ocean warm pool. The warm ocean surface, active convection activity and corresponding flow divergent zone east of the South Asia high anticyclone at higher levels are very advantageous to the genesis and development of typhoons. So the annual variation of monsoon trough's location and intensity are closely related to typhoon frequency. It is also shown in the figure that the main circulation systems, which affect summer monsoon circulation and monsoon trough anomalies, include the monsoon westerly that forms from cross-equatorial flows originating over the Southern Indian Ocean Mascarene High and Australia High, east trade wind on the south side of the Pacific subtropical high and the Walker and Hadley circulation that are produced under the force of heat source. So when the influence of El Niño and La Niña on summer monsoon circulation and monsoon trough anomalies are studied, we shall pay attention to the anomalous activities of cross-equatorial flow from Mascarene High and Australia High on Southern Hemisphere, and the effect of the relationship between them on the annual variation of the location, intensity of monsoon trough and typhoon frequency.

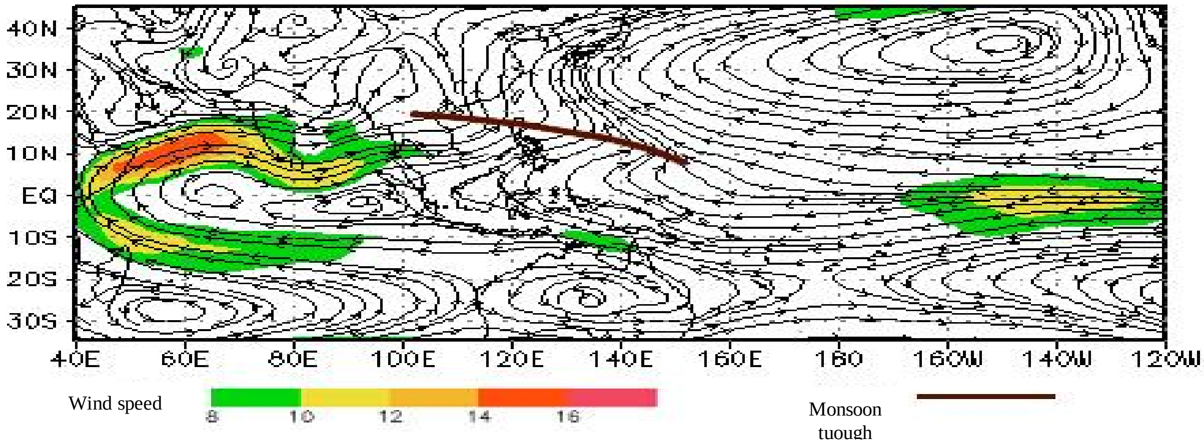

Fig.1 Climatologically averaged (1971 – 2000) streamline, wind speed (m/s) and monsoon trough at 850 hPa in summer (July –September).

3.1 Anomalous atmospheric characteristics in El Niño years with fewer typhoons and La Niña years with more typhoons

El Niño and La Niña events are strong signals affecting the atmospheric circulation and climate anomaly. The basic fact, which presents a decrease of typhoon activities in El Niño years and an increase in La Niña years, has been confirmed. In order to bring its basic principles to light, the El Niño years with fewer typhoons (7 years in all) and La Niña years with more typhoons (6 years in all) are synthesized, compared and analyzed in Tab.1 and Tab.2 in order to find out the physical causation of anomalous atmospheric circulation.

It is shown in Fig.2 that, in El Niño years with fewer typhoons, there exists an anomalous anti-Walker circulation between 140°E and 140°W. The ascending branch is located within 170°E – 140°W and the sinking branch is located within 140 – 170°E. There also exists a circulation cell west of 140°E. The sinking branch is located west of 120°E. The circulation bias on lower level (850 hPa) in summer between El Niño years with fewer typhoons and normal years is illustrated in Fig.3. The Mascarene High and Australia High on Southern Hemisphere have no obvious systematic anomalies. Because Walker circulation is weakened, west wind is strengthened near the equator in the West Pacific and on the side of Southern Hemisphere and anomalous west wind advances to 180°E. The convection ascending zone progresses from the warm pool in the West Pacific to the Dateline. An anomalous equatorial westerly is superimposed over the equatorial buffer zone, and an anomalous easterly over 5 – 20°N weakens the summer tropical westerly or changes it into an easterly, so tropical monsoon westerly moves southward and becomes weaker, ITCZ moves southward and is inactive, the convection and horizontal shear of the main source regions of West Pacific is weakened, which are all disadvantageous to the genesis of typhoons.

It can be seen in the figure of meridional vertical anomalous circulation averaged over 110 – 150 °E in El Niño years with fewer typhoons (figure omitted) that, there exists a positive anomalous circulation cell

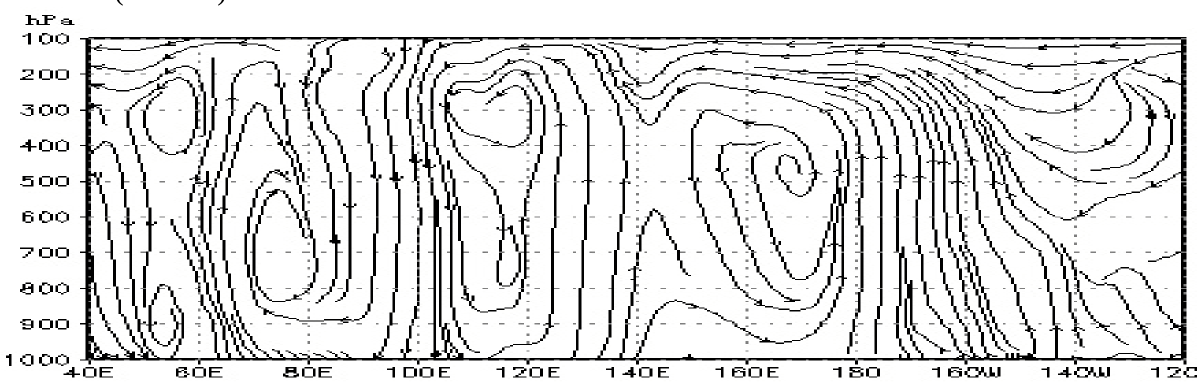

Fig 2 Zonal anomalous circulation section along equator (5 °S – 5 °N) in summer (July – September) of El Niño years with fewer typhoons.

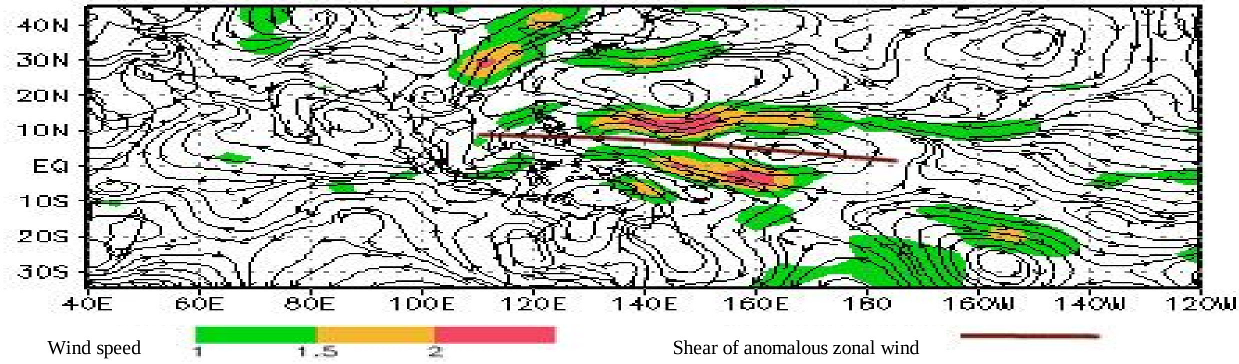

Fig 3 Steam field and wind speed anomaly on 850 hPa in summer (July – September) in El Niño years with fewer typhoons.

along the same direction of Hadley circulation. Its sinking branch is located over 10 – 25 °N, and its ascending branch is located over 0 ° – 10 °S. Corresponding to the southward West Pacific subtropical high and ITCZ, such weak summer monsoon characteristics are disadvantageous to the genesis of typhoons [6].

Contrary to El Niño years with fewer typhoons, SST of equatorial eastern Pacific in La Niña years with more typhoons is colder than normal years (most of them brake out in the eastern Pacific), there exists a positive Walker anomalous circulation, the sinking branch of which is located over 150 – 90 °W, and the ascending branch of which is located over 150 °W – 110 °E (figure omitted). It is known that because Walker circulation is strengthened in La Niña years with more typhoons, the equatorial Eastern Pacific easterly becomes stronger than normal years (figure omitted). There exist anomalous easterly stronger than 4 m/s over 130 – 150 °W. The anomalous easterly advanced to 150 °E. The West Pacific tropical monsoon westerly is much more northward. The anomalous westerly is located at 10 – 20 °N, and advances to 180° and then turns around. The West Pacific subtropical high is more northward. ITCZ is northward and strengthens.

Fig.4 illustrates the OLR difference in summers of El Niño years with fewer typhoons and La Niña years with more typhoons, which also shows that the convection activity（ITCZ）in the El Niño years with fewer typhoons is more southward but more northward in the La Niña years with more typhoons. Weak vertical wind shear is one of the important conditions for typhoon genesis. Fig.5 and Fig.6 show the *U* component difference at 200 hPa and 850 hPa in summers of El Niño years with fewer typhoons and La Niña years with more typhoons. The difference between them resides in that the weak velocity vertical shear zones (-8 m/s$\leqslant U_{200}-U_{850}\leqslant$8 m/s, the same hereinafter) adjacent and south of 10 °N in El Niño years are east of those in La Niña years. The monsoon trough in El Niño years with fewer years is southward (close to or south of 10 °N), the weak velocity vertical shear zones are east of 140 °E, so the South China Sea and western part of West Pacific are unfavorable to typhoon genesis. The areas favorable to typhoon genesis are limited to the eastern part of West Pacific. The area east of 160 °E deviates from the warm pool. So in El Niño years with fewer typhoons the typhoon source regions are smaller. The monsoon trough in La

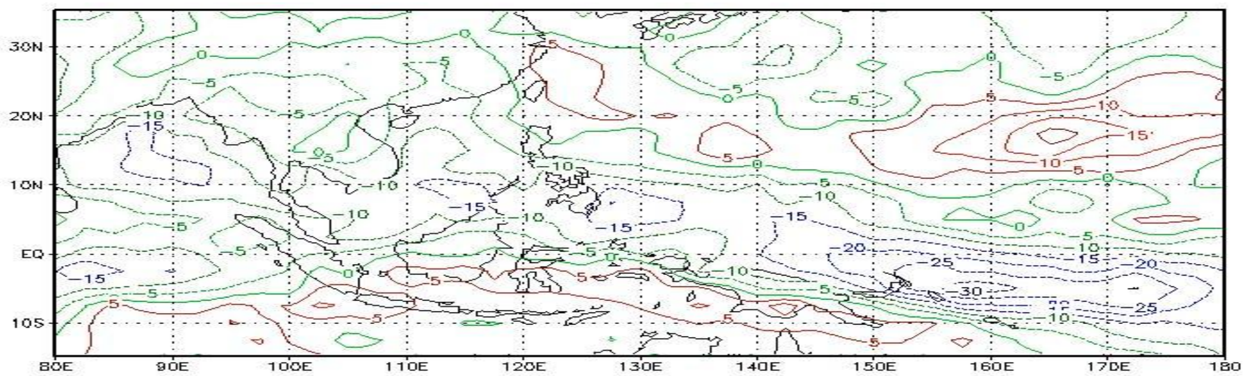

Fig.4 OLR difference in summer (July – September) of El Niño years with fewer typhoons and La Niña years with more typhoons (Unit: W/M^2).

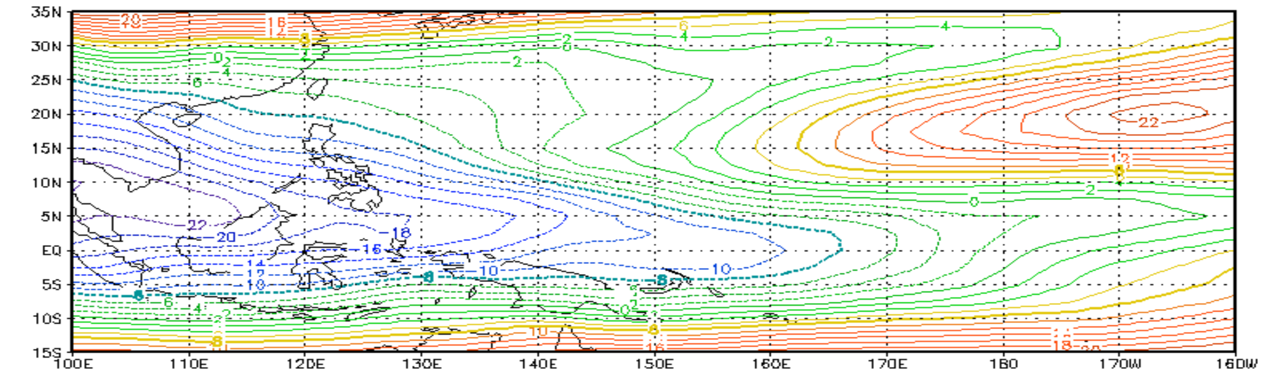

Fig.5 *U* component difference at 200 hPa and 850 hPa in summer (July~September) of El Niño years with fewer

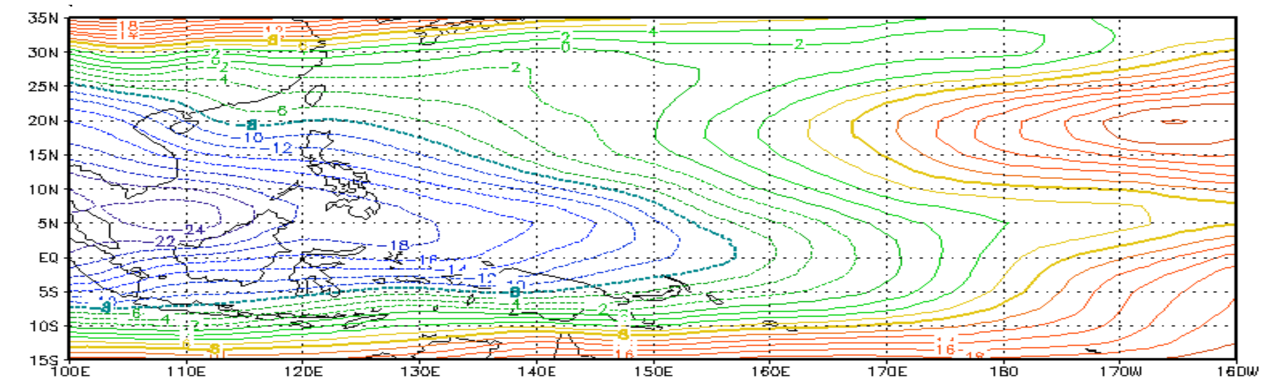

Fig.6 *U* component difference at 200 hPa and 850 hPa in summer (July-September) of La Niña years with more typhoons.

Niña years with more typhoons is more northward (15 – 20 °N), which corresponds to the weak velocity vertical shear zone and wider warm pool over 115 – 170 °E and forms a circulation configuration for typhoons that develop from very favorable SST conditions and low-pressure perturbation. The source region of typhoon genesis is wide.

3.2 Anomalous atmospheric characteristics in El Niño years with more and fewer typhoons

It can be seen in Tab.1 and Tab.2 that most years with fewer typhoons (except 1999) relate to El Niño events. The summer monsoon circulation system is mainly affected by Walker circulation anomaly, which makes ITCZ southward, the genesis source region of typhoons eastward and with smaller range. But not all the El Niño years have fewer typhoons and there are quite few of them belonging to those with more typhoons, which shows that atmospheric circulation anomalies are not only affected by a single factor. The interactions between the sea and air and the atmospheric circulation on Southern Hemisphere and that on Northern Hemisphere are relatively complex. So when the high-pressure circulation on Southern Hemisphere has no systematic anomaly, the influence of Walker circulation anomaly resulting from long-range central-eastern Pacific SST warm event will dominate, which will cause anomalies in summer monsoon over West Pacific and decrease the number of typhoons. However, if the high-pressure circulation on Southern Hemisphere has systematic anomalies, the joint influence and action of the high-pressure circulation and El Niño event walker circulation shall be considered, the former of which mainly increases the number of typhoons.

It is known by comparing the anomalous circulation at 850 hPa in summers of El Niño years with more typhoons (figure omitted) with El Niño years with fewer typhoons that there exist different configurations of tropical summer monsoon circulation. In EL Niño years with more typhoons, Australia High circulation is enhanced systematically, the anomalous southeast flows in the northeast part of which reaches 85 °E, 105 °E and 145 °E respectively, then gets across the equator, and produces relatively strong anomalous monsoon westerly over 0 – 15 °N, gets across the Dateline and converges with anomalous easterly on the east side and produces the maximum ascending flow. However, in El Niño years with fewer typhoons, Australia High has no major systematic anomalies. The monsoon westerly is weaker and more southward. It

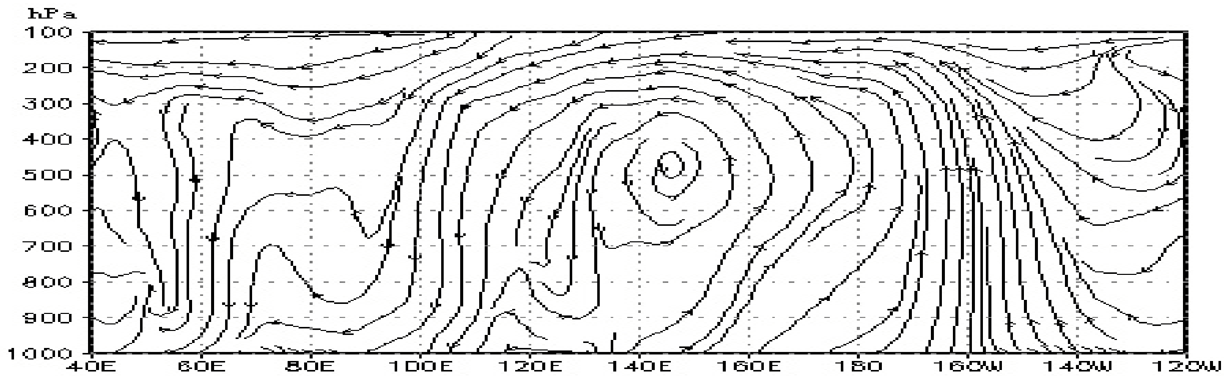

Fig.7 Anomalous circulation latitude section along the equator(5 °S–5 °N) in summer (July–September) of El Niño years with more typhoons.

converges with the easterly at a location 10 longitudes more to the west. It can be seen from what is mentioned above that, the monsoon trough in El Niño years with more typhoons is deeper than in normal years. On the contrary, the intensity of monsoon trough in years with fewer typhoons is relatively weak. In the summers of El Niño years with more typhoons, the anomalous anti-Walker circulation is larger than that in years with fewer typhoons (Fig.7). The centers are located at the place 30 latitudes to the west of those in normal years, which is just in accordance to the fact that Australia High circulation is stronger than in normal years. The Equatorial high (buffer zone) and the westerly north of the equator enhance. The strong convection zone is more northward. The more northward ITCZ corresponds with a wider, weaker vertical wind shear (figure omitted). Both the formation mechanism of typhoons and the size of source regions of typhoon genesis are all favorable to the increase of typhoon frequency.

3.3 Anomalous atmospheric circulation characteristics in the special year (1999) with fewer typhoons in the event of La Niña

Compared with other La Niña years, in 1999, the central, eastern Pacific near the equator was colder than normal years, which had characteristics such as large intensity and onset in central Pacific [15]. Positive walker anomaly circulation center was located at 140 °E (figure omitted), which is 70 longitudes more west of the location than the years with fewer typhoons in the event of La Niña. The ascending branch of Walker circulation is only located between 110 °E and 140 °E, and descending branch is located between 140 °E and 100 °W. It can be seen from the 850-hPa circulation anomaly in this summer (figure omitted) that, compared with La Niña year with more typhoons (Fig.4), there is much difference in atmospheric circulation characteristics, with the largest anomalous easterly wind near the equator moving to the place between 165 °E and 175 °E, which matched the character of onset of cold seawater in central Pacific. The anomalous eastern wind range reaches 17 °N, and advances west to 135 °E, which causes the source location of typhoon to be more westward with shrinking area. On the other hand, the systematic anomalies of Mascarene high on Southern Hemisphere are stronger (the maximum anomalous value of east wind near the equator reaches 4.5 m/s), which makes the equatorial buffer zone move northward. After the 10 – 20 °N monsoon west wind reaches the South China Sea, it does not turn to the mainland. Because the subtropical high is eastward, the monsoon west wind keeps advancing to the East China Sea before changing course, which results in a situation in which not only the converging of east and west winds is westward, but also their horizontal shear becomes weaker and fewer typhoons occur.

4 CONCLUSIONS

(1) The years with fewer typhoons in normal summers basically occur during El Niño and there are more typhoons during La Niña than in normal years. It shall not be true otherwise. The years from 1980 to 1990 were an abnormal period when the interaction between tropical sea and atmosphere is most violent. Most ENSO events brake out in central Pacific, with large intensity. And there are many years with more typhoons than in normal years.

(2) The frequency anomalies of summer typhoon usually happen in the ascending and descending periods of SST over the central, eastern Pacific in ENSO events, and can also occur in ending periods, which shows that SST may have lasting influence on atmospheric circulation.

(3) In summer, when Mascarene High and Australia High on Southern hemisphere have no systematic anomalies, the influence of Walker

circulation anomalies resulting from the cold and warm events of SST over Equatorial Central-Eastern Pacific dominates, which also follows the basic principle of the influence of ENSO event on atmospheric circulation and typhoon frequency: during El Niño, zonal Walker circulation is weakened, monsoon trough is southward and weakened, and typhoons become fewer than in normal years. During La Niña, zonal Walker circulation is strengthened, monsoon trough is northward and strengthened, and typhoons become more than in normal years.

(4) During El Niño, when Australia High circulation has systematical anomalies, the influence of the circulation anomaly on Southern Hemisphere dominates, because the stronger Australia High circulation anomaly can strengthen the equatorial high (buffer zone), cross-equatorial flow and west wind north of the equator and make monsoon trough northward and enhanced, and more typhoons occur on the contrary.

(5) Under general conditions, there are more typhoons in La Niña years than in normal years. But there are fewer typhoons in some special years, such as 1999, when the ascending branch of Walker circulation is westward, which is caused by large-scale westward advancing of the east wind resulting from the onset cold seawater, and the monsoon westerly resulting from the stronger Mascarene High anomalies on Southern Hemisphere is northward and eastward, the number of typhoons are fewer than in normal years.

(6) The typhoon sources are regions of weak vertical wind shear, warm pool in West Pacific and the area with monsoon troughs overlapped with each other. In the years with fewer typhoons in the events of El Niño, the source locations of typhoons are southward and eastward with small area. In the years with more typhoons in the events of La Niña and El Niño, the source locations of typhoons are northward with large area. In 1999, which is a special year with fewer typhoons in the events of La Niña, monsoon trough is weakened; convection activity is westward. The source location of typhoon is westward with small area.

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