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TYPHOON ACTIVITY IN NORTHWEST PACIFIC IN RELATION WITH EL NIÑO AND LA NIÑA EVENTS*

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ABSTRACT: Statistic and typical-year composition methods are used to study the northwest Pacific typhoon activities in relation with the El Niño and La Niña events. The result indicates that the typhoon tends to be inactive in the El Niño years and active in the La Niña years and it is also dependent on the onset and ending time and intensity of the events and areas of genesis of typhoons. With statistic features of the frequency of typhoon activity in the El Niño and La Niña years and the time-lag correlation between the frequency and sea surface temperature (SST), useful information is provided for the prediction of typhoon occurrence. In addition, the singular values disassemble (SVD) method is applied to study the correlation between the geopotential field and SST field. The result shows that the air-sea coupling in the El Niño years is unfavorable for the typhoon to develop, which take place with a smaller number. Opposite situations are found with the La Niña years.

Key words: typhoon; El Niño and La Niña events; singular values disassemble

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Ⅰ. INTRODUCTION

Anomalous typhoon activity is closely linked with the changes in large-scale circulation in the tropics. The El Niño event is such an effective signal for the general circulation and climatic anomalies that it certainly poses influences on the frequency of occurrence, intensity and geographic location of the typhoon. Since the 1980's, numerous research has been carried out in the respect. Analyzing the correlation between the SST in the equatorial eastern Pacific and northwestern Pacific typhoons, Pan (1980 and 1982), Li (1985 and 1987), Dong (1988) and Dong and Qi (1990) point out that the typhoon is getting more (less) active in the El Niño (La Niña) years in addition to quantitative accounts of the typhoons over the northwestern Pacific in relation to the El Niño influence. Chen and Yao (1989) make fresh attempts to study the relationship between the El Niño (La Niña) years and the genesis location and intensity of the typhoon. They have largely unified opinions on the relationship between the El Niño event and the typhoon activity, but the complicated association of typhoon activity in the northwestern Pacific with the event remains an issue to focus on. Gray (1984) conducts a systematic survey on the behavior of tropical cyclones across the globe by analyzing the hurricane in the Atlantic and presenting statistics of typhoon occurrence in the northwestern Pacific for comparison. He indicates that the typhoon in the latter region is not significantly fewer in the El Niño year as compared to the year before or after it and the effects of the El Niño event is rather on where the ty-

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phoon is generated. Similar conclusions are drawn in the work of Ramage and Hori (1981), Chan (1985) and Wei (1987). As it goes in the 1990's, strong El Niño events have taken place in a succession to accumulate more observational facts. For an extensive study of the influence of the El Niño and La Niña events on the typhoon activity in the northwestern Pacific, we will discuss the influence of the El Niño and La Niña events on the frequency of typhoon occurrence and landfall and location of genesis and storm intensity corresponding to variations of starting and ending seasons and intensity for the former in 1951 ~ 1996. The statistic results so obtained are helpful for short-term climatic predictions of typhoon occurrence frequency. The SVD method is also used here to correlate mean geopotential field at 500 hPa in summer (June through August) to simultaneous values of Pacific SST distribution. The aim is to address possible effects of air-sea coupling in the El Niño and La Niña years on anomalous typhoon activity.

The relevant data for 1884 through 1948 are taken from the *Track Chart of Some Statistics of Hurricanes* by Gao Youxi et al (1957) and those for 1949 through 1996 are abstracted from the *Typhoon Yearly Book* compiled and edited by the China Meteorological Administration. The sample includes tropical storm. The El Niño and La Niña events from 1884 to 1950 are sampled from the *El Niño and Anti- El Niño events in 1854 ~ 1987* by Zang and Wang (1991) and the data between 1951 and 1996 are from the ENSO Monitoring Group, National Climate Center (ENSO M.G., 1989). There are 21 El Niño years and 22 La Niña years between 1884 and 1950. There are 15 El Niño years respectively in 1951, 1953, 1957, 1963, 1965, 1972, 1976 ~ 1977, 1982 ~ 1983, 1987, 1991, 1993 and 1994, and 11 La Niña years, respectively in 1955, 1964, 1967 ~ 1968, 1970 ~ 1971, 1985 and 1988 ~ 1989, between 1951 and 1996. The data of Pacific SST, 500 hPa geopotential field and sea level pressure are taken from the National Climate Center and the OLR data from NOAA, the United States.

II. RELATIONSHIP BETWEEN THE EVENTS AND TYPHOON GENERATION IN NORTHWEST PACIFIC

1. *Climatic background of typhoon occurrence*

Fig.1 plots the year-to-year evolution of typhoon generation with (■) and (o) denoting the years of the El Niño La Niña events. Due to different coverage and thresholds applied for the statistics of typhoons over periods before and after the founding of the People's Republic of China, the multi-year average of named typhoon is 20 (west of 150°E) between 1884 and 1948

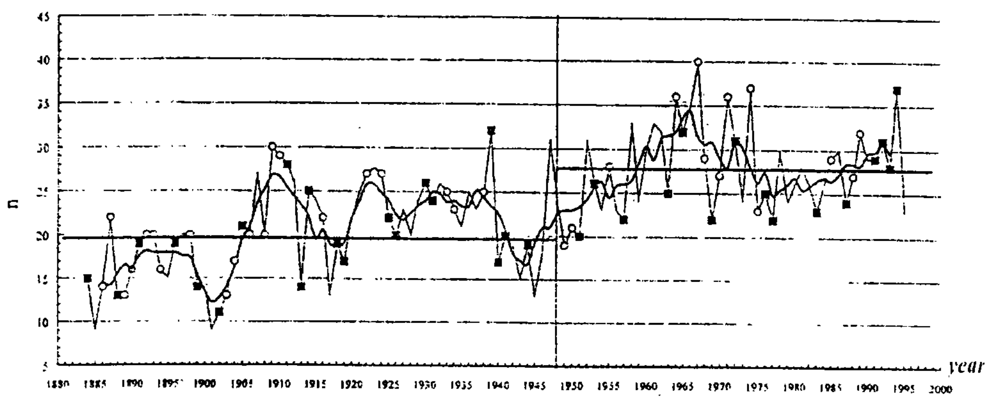

Fig.1 Year-to-year evolution curves of named northwestern Pacific typhoons. The thick solid line is the 5-year running mean and thin solid line the annual occurrence of typhoon

and 28 (west of 180°) between 1949 and 1996. It is seen from the figure that the typhoon is inactive in most of the El Niño years and active in La Niña years. The difference is considerably large after 1949, with 7 landed typhoons per year on average.

In the period from 1884 to 1948, there are on average 6.9 (7.3) and 19.4 (20.9) typhoons that made landfall and were generated in an El Niño (La Niña) year. In the period from 1949 to 1996, the yearly average is 6.2 (8.0) for typhoons that made landfall in the El Niño (La Niña) years out of 26.4 (31.3) named typhoons. In other words, there are two (five) more landed (named) typhoons in the La Niña years than in the El Niño years on a yearly basis. It is suggested that there are generally fewer (more) typhoons that are landed and named in the El Niño (La Niña) years.

There are 15 (11) El Niño (La Niña) years between 1951 and 1996. The significance of the difference in typhoon generation between the El Niño and La Niña years is judged using the χ^2 test. The method follows that $\chi^2 = d^2/n$ where $d=(C-D)-(A-B)$, n is the total number of years, A, B, C and D are the number of years in which there anomalously more or fewer occurrence of typhoons in the El Niño and La Niña years. When the degree of freedom is unity, the confidence of 90% is $\chi^2 = 2.71$ and that of 95% is $\chi^2 = 3.84$.

Though with fewer landed and named typhoons in most of the El Niño years and more in the La Niña years, Tab.1 shows that the value of χ^2 test does not exceed the requirement of 0.10 confidence. It is then drawn that the reliability is not high enough for the effects of the El Niño and La Niña years on the activity of the typhoon. It is thought to have possible relation with other features of the events. Next, we are going to discuss the influence of the El Niño and La Niña

Tab. 1 χ^2 test of tropical cyclone occurrence in the El Niño and La Niña years

	El Niño years / a, χ^2		La Niña years / a, χ^2	
	More (A)	Fewer (B)	More (C)	Fewer (D)
Landed typhoon	6, 1.38	9, 1.38	7, 1.38	4, 1.38
Named typhoon	6, 2.46	9, 2.46	8, 2.46	3, 2.46

events on the typhoon activity according to the definition and division set by the ENSO Monitoring Group, China Meteorological Administration with regard to the starting and ending seasons and intensity of the events from 1951 to 1996.

2. *Relationship between the starting and ending seasons of El Niño and La Niña events and typhoon occurrence*

Tab.2 gives the positive anomalies of typhoon occurrence in the El Niño and La Niña years with various seasons of starting and ending. It is seen in the table that

(1)There is insignificant relationship between the occurrence of typhoons and the El Niño and La Niña events that start in spring, though it may be possible that there will be more severe typhoons in the current year and landed typhoons in the subsequent year. There is not much difference between the El Niño year and the La Niña year starting from summer — in the current years of El Niño and La Niña events the named typhoons tend to be less, while in the subsequent year after the El Niño (La Niña) there tend to be more landed (named) typhoons. In the year that follows an autumn-starting El Niño (La Niña) year, fewer (more) typhoons will be generated.

Tab. 2 Positive anomalies of typhoon occurrence in the El Niño and La Niña years with varied seasons of starting and ending. C.Yr. and S.Yr. stand for current and subsequent year for the event, respectively

			Landed typhoons		Named typhoons		Severe typhoons	
			C.Yr.	S.Yr.	C.Yr.	S.Yr.	C.Yr.	S.Yr
Starting season of El Niño event / a	Spring	6		5/6			6/6	
	Summer	4	1/4	3/4	1/4		1/4	3/4
	Autumn	3	0/3	0/3		0/3		
Starting season of La Niña event / a	Spring	2					2/2	
	Summer	4	1/4		1/4	4/4		
	Autumn	2		2/2	0/2	2/2		
Ending season of El Niño event / a	Before summer	8	6/8	8/8			6/8	7/8
	Summer & after	5						
Ending season of La Niña event / a	Before summer	2		0/2	0/2	0/2		0/2
	Summer & after	6	5/6		5/6		6/6	5/6

(2)There will be more typhoons that make landfall and acquire a severe intensity in the current and subsequent years with the El Niño event ending before summer; the typhoon tends to less active in the subsequent year with the La Niña event ending before summer but more active in the current year with the La Niña event ending in and after summer.

It is shown in the statistics that the effects on the typhoon occurrence are relatively large in the years with the El Niño and La Niña events starting in autumn and ending before summer.

3. *Relationship between the intensity of El Niño and La Niña events and typhoon occurrence*

Tab.3 is the statistics of typhoon occurrence in the El Niño and La Niña years with different intensity.

Tab. 3 Average frequency of named and landed typhoons in El Niño and La Niña years with varied intensity. P.Yr., C.Yr., and S.Yr. are respectively for the preceding, current and subsequent year for the event

	Landed typhoons			Named typhoons		
	P.Yr.	C.Yr.	S.Yr.	P.Yr.	C.Yr.	S.Yr.
Strong El Niño years	7.6	5.4	7.4	28.8	25.8	28.2
Weak El Niño years	6.8	7.0	7.0	27.4	27.0	28.8
Strong La Niña years	6.3	7.0	8.3	23.7	30.7	26.0
Weak La Niña years	6.3	8.5	8.0	25.3	30.8	30.0

(1)There are fewer named and landed typhoons than the average over years in a strong El Niño year and much fewer than in the years before and after it. The number in a weak El Niño year is a little smaller than the normal year.

(2)There are more named and landed typhoons than the average over years in a weak La

Niña year and much more than the average in the years before and after it. The number in a strong La Niña year is a little smaller than the normal year.

(3)There is no significant relationship between moderate El Niño and La Niña years and the occurrence of the typhoon.

As shown in the results above, the effects on the occurrence of the typhoon are significant in a strong El Niño year and a weak La Niña year.

4. *Differences of typhoon occurrence in east and west Pacific between El Niño and La Niña years*

The influence of the El Niño and La Niña events on the typhoon occurrence is also related with the geographic location in which the typhoon is generated. In 1951 ~ 1996, there are 25.8 and 2.3 typhoons generated on average in western and eastern Pacific. The statistics shows that the there are 23.1 named typhoons in a El Niño year in the western Pacific (<160°E), about 3 fewer than the normal year. The positive anomaly occurs at a frequency of 1/4. On the other hand. there are 3.3 named typhoons in the eastern Pacific (≥160°E), about 1 more than the normal year. The positive anomaly occurs at a frequency of 2/3. For the La Niña year, however, there are 28.7 named typhoons in the western Pacific, about 3 more than the normal year. The positive anomaly occurs at a frequency of 3/4. There are 2.8 named typhoons in the eastern Pacific, a little more than the average.

As shown in the χ^2 test (Table omitted) for the significance of difference in typhoon occurrence in both eastern and western Pacific in the El Niño and La Niña years, the χ^2 value exceeds the threshold of 0.05 confidence in the El Niño year. It suggests that the argument is reliable that the typhoon is less active in the western Pacific but more active in the eastern Pacific in the El Niño year and it is active in both parts of the Pacific Ocean in the La Niña year, having little difference between them.

5. *Differences of typhoon intensity and location between El Niño and La Niña years*

Apart from the occurrence of the typhoon, the El Niño and La Niña events also pose influence on its geographic location and intensity (Chen and Yao, 1989). From the analysis of average latitude and longitude at formation, mean lowest pressure and maximum wind velocity around the eye (Figure omitted), it is known that the mean geographic location of the named typhoon is more to the south and east but the central pressure is weaker and the wind stronger in a El Niño year than in a La Niña year. In other words, there are fewer typhoons generated with stronger intensity and more southward and eastward location than the average in an El Niño year. The opposite is prevailing in a La Niña year.

III. INFLUENCE OF INTERANNUAL VARIATION OF ENVIRONMENTAL FIELD ON TYPHOON ACTIVITY

The SST in the equatorial eastern Pacific is one of the important elements depicting the El Niño and La Niña events while the air-sea interaction influences the environmental field in which the typhoon generates and develops. We have studied the correlation between the characteristic quantities of the SST in the region and the subtropical high in the West Pacific and the occurrence of typhoon. The simultaneous correlation coefficient is obtained between the landed typhoon and the SST in Niño3 region (–0.29), area of the subtropical high (0.40) and its position of the ridge (0.72). The values are –0.47, 0.38 and 0.77 between the named typhoon and the latter three factors, respectively. The degree of confidence is all above 0.001 for the coefficients. Generally, the SST is low in the equatorial eastern Pacific and the subtropical high is more northward and stronger corresponding to more activity of the typhoon. The westward point to which the subtropical high extends is in opposition correlation with the occurrence of the typhoon, but the significance is low for the degree of confidence.

To indicate the correlation between the interannual variation of the SST field and the typhoon occurrence, we have performed a 12-month running smooth for the SST in the Niño3 region and the occurrence of the typhoon. It is found that the same inverse phase exists with the interannual variation of the new series group. The time lag between them suggests that a low-frequency oscillation is present correlating the typhoon occurrence to the SST in tropical areas.

Fig.2 gives the time-lag correlation between the occurrence of the typhoon and the SST with the 12-month smoothing. The ordinate to the left is the correlation coefficient and the one to the right the correlation probability. When $|R| \geq 0.30$, the degree of confidence exceeds 0.001. The abscissa is the time lag by month and the positive value means that the typhoon is lagging behind elements like the SST.

Fig.2a shows that for the frequency of named typhoons, the maximum negative correlation (–0.40) appears 2 months after corresponding changes in the SST and the maximum positive correlation (+0.40) 19 to 21 months later. For the landed typhoon, however, the former value appears 1 month after the SST change in the equatorial eastern Pacific (–0.35) while the latter one 25 ~ 26 months later (+0.44). The correlation probability appears at largely the same time as the correlation coefficient.

The interactions between the atmosphere and ocean also result in similar time-lag correlation

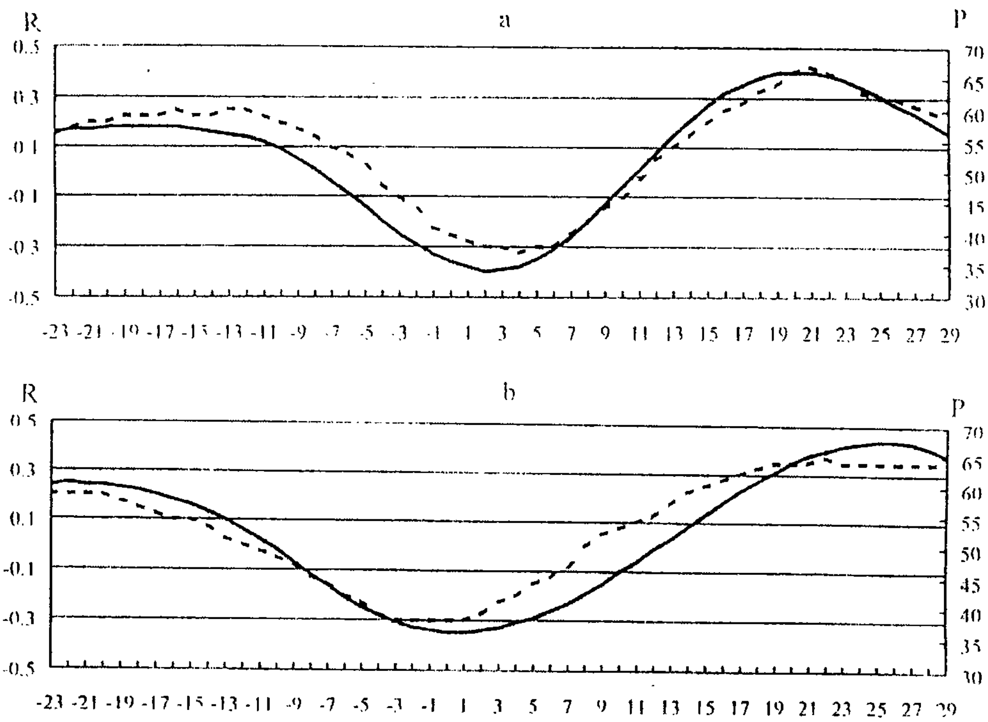

Fig.2 Time-lag coefficient (solid line) and probability (dashed line) for the correlation between the SST in the equatorial eastern Pacific and named typhoons (a) and landed typhoons (b) from 1951 to 1996. The response of the typhoon is from 30 months earlier than the SST to 30 months later than the SST

between the occurrence of typhoons and the subtropical high in earlier periods (Figure omitted). The maximum positive correlation (+0.43) of the occurrence of landed typhoons appears 18 ~ 19 months after the changes in the area index of the subtropical high in the northwestern Pacific and the maximum negative one (–0.33) appears 23 ~ 24 months after the change in the most western point of the ridge.

The appearance of the maximum inverse correlation of the typhoon occurrence 1 ~ 2 months after the SST change and of the maximum positive correlation 19 ~ 25 months after it are in general consistence with Pan (1980) and Dong et al. (1990). It is suggested that the time-lag correlation is stable and has some value of reference for long-term forecasting of the typhoon occurrence.

IV. ANALYSIS OF ENVIRONMENTAL FIELD IN EL NIÑO AND LA NIÑA YEARS AFFECTING TYPHOON ACTIVITY

The results above show that the activity of the typhoon in the northwestern Pacific is closely related with the El Niño and La Niña events. The anomalous distribution of 500 hPa geopotential height, SST in the Pacific and OLR in the prime season (from July to September) of the events have clearly indicated the difference of the generation environment of the typhoon between the El Niño and La Niña years.

On the composite chart of the 500 hPa geopotential anomalies (Figure omitted) from July to September in the El Niño year, a positive-negative-positive anomalous distribution is present north-south from the west Pacific to the Asian continent. The pattern of a positive anomaly south of 30°N indicates that the subtropical high and the ITCZ are more southward than the average year which results in frequent activity of cold air from the middle latitudes. The anomalous pattern of large-scale upper-air circulation is unfavorable for the development of the typhoon. The anomalous field in the La Niña year is in opposite phase with that in the El Niño year — the subtropical high is more northward, being favorable for the development of the typhoon because of a changed circulation pattern in the upper air and a more active and northward-going ITCZ.

Fig.3 gives the composite chart of the OLR anomalous field in July ~ September in the El Niño year (a) and the La Niña year (b). The positive anomalies appear west of 160°E between

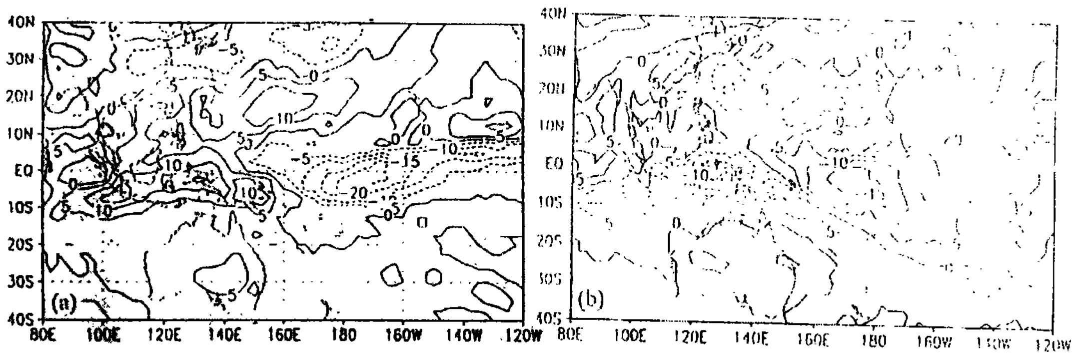

Fig.3. Composite anomalous field of OLR in July~September in the El Niño year (a) and the La Niña year (b)

10°S and 25°E in the El Niño years (1982, 1983, 1987 and 1993) and the negative anomalies east of 160°E near the Equator. Specifically, the anomalous center of $-20 W/m^{-2}$ is found near 180°, suggesting that convection has weakened in one of main source areas in the west Pacific in the El Niño years. The ascending region of the convection has shifted eastward from the warm pool in the west Pacific to the areas near the Dateline and the Walker cell has weakened to lead to inactive and more southward ITCZ, being unfavorable for the generation of the typhoon. In the La Niña years (1981, 1985 and 1989), however, a distribution is shown with the inverse phase against that in the El Niño years regarding the field of anomalies (Fig.3b). It is a sign that convection enhances greatly in the equatorial west Pacific and the ITCZ becomes active during the La Niña years, providing a circulation favorable for the typhoon.

Similarly, an inverse distribution is also shown on the composite chart of anomalous SST field in July ~ September in both the El Niño year and the La Niña year (Figure omitted). In the El Niño year, the anomalous field is positive in the east and negative in the west for the tropics in north Pacific so that the underlying surface in the source region becomes unfavorable for the development of the typhoon. The conditions of the SST field changes to be favorable for the genesis and development of the typhoon in the La Niña year. It is obvious that it agrees well with the preceding conclusion that a sharp difference exists in the occurrence of the typhoon between the east and west part of the Pacific Ocean.

V. SINGULAR VALUE DISASSEMBLE OF 500 hPa GEOPOTENTIAL AND SST FIELDS IN SUMMER

To reveal the effects of air-sea coupling on the typhoon occurrence in the El Niño and La Niña year, the SVD method is used to study the correlation between 500 hPa geopotential field and SST and its possible effects on the typhoon. Fig.4 (Zu, He and Jin, 1998) gives the first pair of coupling modes between the mean 500 hPa geopotential height and SVD in the Pacific SST in

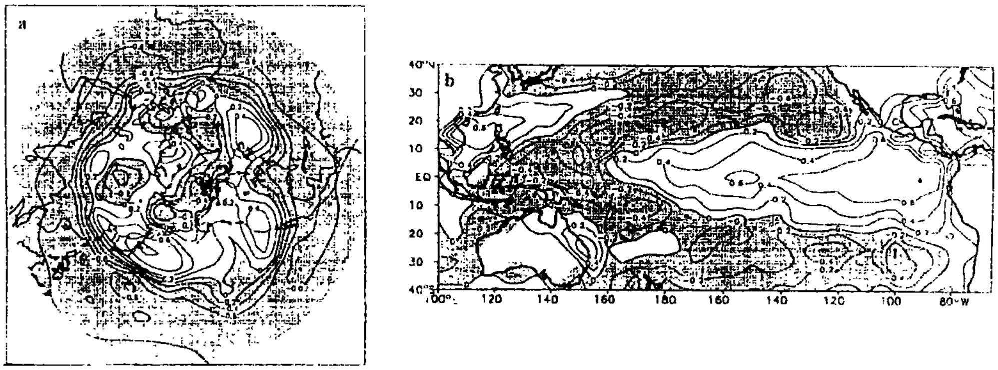

Fig.4 Anomalous 500 hPa geopotential height in summer and the first pair of coupling SVD modes in summer. a. Left singular vector. b. right singular vector [Ordinate of (b) in degree of latitude]

summer (June ~ August). The SVD vector field to the left (right) is the first mode in the characteristic fields of the 500-hPa geopotential height (SSTA). They have a common interpretive variance of 45% and a correlation coefficient of 0.91, taking up 30% and 17% of the variance of the primary fields, respectively. Analyzing the vector fields (Fig.4a) reveals that the mid- and higher-latitude regions in East Asia are marked by large-scale positive correlative centers for the 500-hPa geopotential field and the Pacific SST, with the greatest correlation coefficient being 0.8. In the area between 100°E and 180° at 30°N, there is a dense concentration of isoplethic coefficient lines at the conjunction dividing the north and south, which is the transitional zone from the positive to the negative correlation. A south to north distribution of negative-positive-negative correlation from East Asia to the west Pacific is present. It is found in Fig.5 (Zu, He and Jin, 1998) that as the time coefficient drops to a valley in the left singular vector field the anomalies are high in the north but low in the south in the corresponding geopotential field when the westerly becomes active with the axis shifted southward. The pattern is accompanied by a usually southward location of the subtropical high in west Pacific that keeps the ITCZ in more southward latitudes to favor no development of the typhoon. From the field of the right singular vector (Fig.4b), we know that there is a significant positive correlation between the 500-hPa geopotential field and the anomalous SST in the central and east Pacific, with the highest coefficient being 0.6 that varies in negative correlation with the SST east of the Philippines. When the time coefficient climbs to the peak for the right singular vector, there appears a SST field in the equatorial area that is low in the west but high in the east. In other words, the SST takes the form of normal El Niño distribution by having positive anomalies in the cool water pool of the Equator. As the typhoon mainly originates from a negative SST region, the pattern is obviously an unfavorable condition for the development of the typhoon.

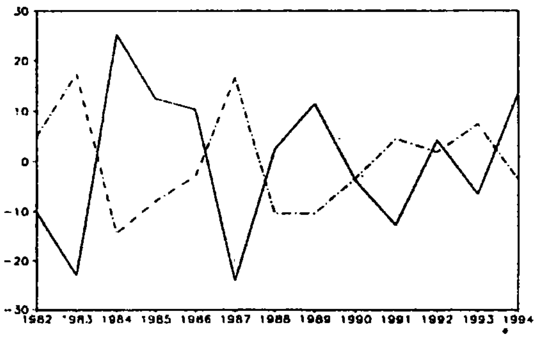

Fig.5 Time coefficients of the first-pair of coupling modes of the SVD with the coefficients of the left (right) singular vector indicated by the solid (dashed) line (Ordinate: time coefficient)

As shown in the time coefficients corresponding to the first pair of coupling modes in the SVD analysis (Fig.5), they are in opposite phase each other for the left and right singular vectors. The peak years (1983, 1987, 1991 and 1993) of the time coefficient in the right singular vector are corresponding to the El Niño year and the valley years of that in the left singular vector are consistent with the years when the subtropical high is more southward in summer. For the four years, except for 1991 when the named typhoons are close the average and 1993 when both named and landed typhoons appear as frequently as in the normal year, both types of typhoons are less than the average year.

It is clear in the preceding correlation analysis that the typhoon activity in the northwest Pacific is linked with the El Niño year and the La Niña year by altering the environmental conditions for the typhoon through air-sea coupling, affecting the its activity eventually.

Ⅵ. CONCLUSIONS

a. Compared to the multi-year mean, the typhoon in a El Niño year is generated with a smaller frequency in the northwestern Pacific in a more eastward and southward location with a lower central pressure and stronger winds near the eye while there is a more frequent occurrence of the typhoon that is located more westward and northward in weaker intensity.

b. The influence of the El Niño year and La Niña events on the typhoon activity is dependent on the intensity and starting and ending season of the former and the geographic location of the typhoon formation. There are not many strong typhoons named or landed in a strong El Niño year while there are more in the La Niña year. The typhoon is frequent (infrequent) when the El Niño (La Niña) event starts in autumn in the previous year while it is increased (decreased) when the El Niño (La Niña) event starts before summer in the previous year. The typhoon is less (more) active in west (east) Pacific in the El Niño year and it is active in both parts of the Pacific Ocean in the La Niña year.

c. An inverse relationship exists between the typhoon occurrence and the interannual variation of the SST in the equatorial eastern Pacific. For the rising stage of the SST, there is smaller occurrence of the typhoon and otherwise is true. The maximum of positive correlation in the typhoon occurrence usually appears 19 ~ 25 months after the change in SST. Information is then provided for the short-term prediction of the typhoon using statistic features of the relation between the El Niño and La Niña events and the typhoon activity and relevant time-lag correlation.

d. As shown in the analysis with the SVD method of the correlation between the 500-hPa geopotential field and the SST field in the Pacific Ocean, the SST is anomalous warm in the central and eastern Pacific region in the El Niño year. The resulted air-sea coupling has caused much changes in the general circulation in the tropical and subtropical areas so that the subtropical high is shifted southward, the convection in west Pacific weakened and the ITCZ made less active, unfavorable for the development of the typhoon. Consequently, the occurrence is smaller in the El Niño year. On the contrary, the changes in the environmental field in the La Niña year are favorable for the genesis and development of the typhoon.

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