A STUDY ON THE VARIATIONS OF ANNUAL FREQUENCY FOR TROPICAL CYCLONE IN NORTHWEST PACIFIC DURING THE LAST HUNDRED YEARS

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ABSTRACT

In this paper, a study on the variation of annual frequency of tropical cyclone (TC) and its relation with SST, Southern Oscillation index, sunspot relative number and number of days for specific circulation patterns was made by using 1884-1988 data of annual frequency for Northwest Pacific TC occurrence, which had been corrected to tendencies. Preliminary results indicated that in the variation of annual TC frequency there exist obvious periods of 21, 31, 15 and 6 years and sustaining periods lasting 12 years in average. Well-defined processes of inflexion were observed in 1931, 1959 and 1977 over the past hundred years. The results also suggested insignificant statistic tendency of annual TC frequency increasing (decreasing) in winter / spring (summer / autumn)in the El Nino years. When the stratosphere was in the zonally westerly phase, the northern zonal circulation would abnormally develop and solar activity would enhance to favour the generation and development of TC.

Key words: tropical cyclone, El Nino, environmental variable

I. INTRODUCTION

Zhang (1958) has studied the interannual variation of typhoon frequency over Western Pacific by using the data during 1900-1950 and found that the relations between the long-term variation of typhoon frequency, atmosphere circulation pattern and solar activity are closely related. Xue (1977) prolonged the data of typhoon to 1974 and obtained the same result. In recent years, studies by Pan (1982), Li (1987) and Dong (1988) on the relations between the interannual change of typhoon number, sea surface temperature in equatorial eastern Pacific as well as the El Nino phenomena pointed out that the typhoon numbers are lower than normal during the period of El Nino year for a positive anomaly SST, but in the La Nina years for a negative anomaly SST the typhoon numbers are above the normal. In contrast, the studies from Ramage (1981), Gray (1984), Zhang (1990) and others believed that the relations between them are quite weak.

In this study, by using the data of tropical cyclone occurring in west of 180°E and to the north of equatorial Pacific, the relationship between interannual variation of tropical cyclone numbers and some environmental variables have been examined. It is expected that some of the climate backgrounds for long-range prediction of TC frequency will be given.

II. DATA AND HANDLING METHOD

1. *Data*

The data of annual frequency used in this study for tropical cyclone in Northwest Pacific comes from National Hurricane Center (NHC, NOAA) for the years 1884-1978 and from National Meteorological Center of China (NMCC) for the years 1979-1988.

Here, the tropical depression (the wind velocity of center is less than 17.5 m/s), tropical storm and severe tropical storm (the wind velocity of center is 17.5-32.8 m/s) and typhoon (the wind velocity of center is greater than 32.9 m/s) are all called tropical cyclone in Northwest Pacific.

Southern oscillation index (SOI) for data-set 1884-1988 used in this study are sorted out by Shi (1993) according to definition of CAC (U. S. A.). By the inserting methods we got seasonal average SOI data-set beginning with the year 1857. The data of sea surface temperature in equatorial east Pacific (0-10°S, 180—90°W) is calculated from global grid data in adopted monthly reports on average value of SST received from WMO by NMC of China. The number of days of WCE circulation pattern in the northern hemisphere comes from literature (Girs, 1976) for the years 1882-1972 and from National Climatic Center of China for the years 1973-1988. Data of sunspot relative numbers for the years before 1978 comes from "Basic Data of Magstorm Inventory and Heliogeophysics" and data for the years after 1979 comes from Spatial Environment Service Center (SESC, U. S. A.).

2. *Handling method*

There is a false rising trend in the variation of annual frequency for tropical cyclone because of rare observation stations and poor observing methods previously. By using cubic splines, a trend fitting annual frequency variation for tropical cyclone has been made in this study before studying the variation.

The basic principle of cubic spline function is to insert M-1 knots of splines into the data series of annual TC frequency and introduce a new knot to both ends of the series respectively, then function $f(x)$ is divided into M polynomials, i. e. $f_1(x)$, $f_2(x)$, ……, $f_M(x)$, where

$$f_i(x) = \sum_{s=0}^{3} V_{is} T_{is}(x) \qquad i = 1, 2, \cdots\cdots, M,$$

where $T_{is}(x)$ is the first kind of Chebyshev's ploynomial, the restricted condition is that $f_i(x)$ and its second order derivative are all continuing on M-1 knots. V_{is} can be determined by using least square fitting. And then the polynomials $f_i(x)$ obtained are just cubic splines. A smoothed fitting curve for TC's annual frequency series could be obtained by using the method mentioned above (Fig. 1) . The points on the curve are cor-

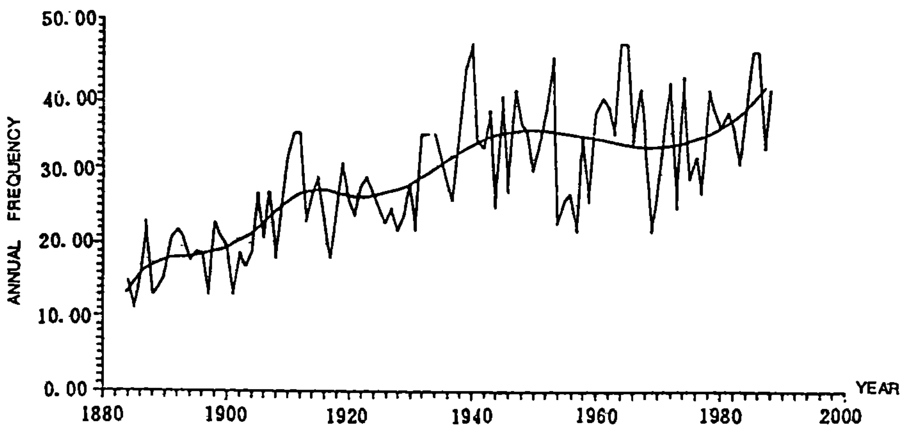

Fig. 1. Annual frequency of tropical cyclone in Northwest Pacific during 1884-1988. and its fitting curve (the smooth line).

responding to the trend values, which are subtracted for particular years from original TC annual freqency, plus average value for the years 1949-1988, then TC frequency that has been reduced could be obtained. To take the data series as basic data, power spectrum analysis, cumulative anomaly, abrupt change analysis and correlation analysis will be done.

II. INTERANNUAL CHANGE OF FREQUENCY FOR TROPICAL CYCLONES

1. *Climatic Characteristics*

The average of frequency for tropical cyclones during the years 1884 through 1988 ($\overline{F}$) is 35. 5. The largest number (49) was found in 1949, the smallest number (22) was found in 1957 and 1969, the mean square deviation (σ) is 5. 7. The frequency of tropical cyclones could be divided into three levels, normal, negative anomaly and positive anomaly based on a standard value of 0. 5σ. The climatic probability for tropical cyclone frequency in the past 105 years are listed in Table 1. From Table 1, we can see that anomalous years for tropical cyclone frequency accounted for 70%. The normal years took up no more than 30%.

Table 1. Probability for annual frequency of tropical cyclone in different standard.

Levels	Standard	Climate probability (%)
Positive anomaly	$(\overline{F}+0.5\sigma) \leqslant F$	36
Normal	$(\overline{F}-0.5\sigma) < F < (\overline{F}+0.5\sigma)$	29
Negative anomaly	$F \leqslant (\overline{F}-0.5\sigma)$	35

2. *Period characteristics*

The feature of power spectrum characteristics are shown in Fig. 2, which is calculated from the data for 105 years' TC frequencies during the years 1884 through 1988, taking a maximum lag as long as one third of this time series. The smooth curve in Fig. 2 is for the confidence limit of 95%. From Fig. 2, we can see that maximum spectra over

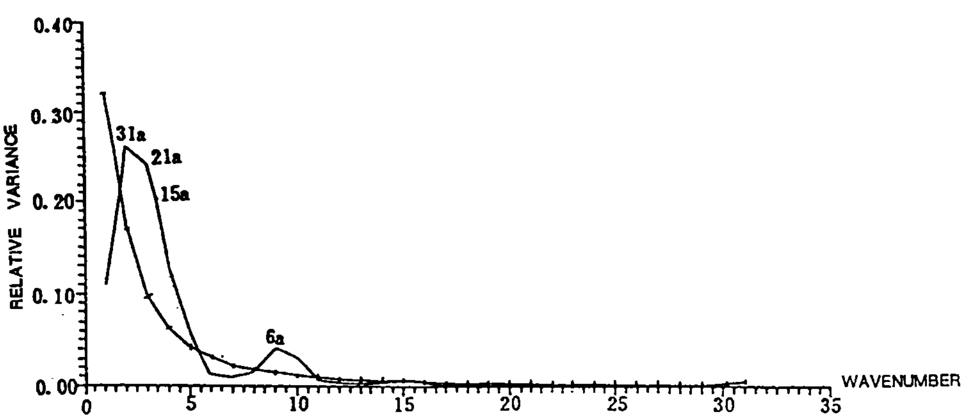

Fig. 2. Power spectrum for annual frequency of tropical cyclones in Northwest Pacific (the smoothing curve is 0. 95 confidence limit).

the confidence limit are found in 31, 21, 15, 6 years respectively. Among them, the period of 21 years is a significant one, which is in response to solar activities of 22-year period. The period of 31 years may be corresponding to ENSO events of 20th century, a period of 20-30 years. However the physical description for 15-and 6-year periods can hardly be given. A 15-year period for mean water discharge was found along the Yangtze River in Hankou by one of the authors. In calculating the changes of total number of TC in Western Pacific, during the years 1949-1973, a 6-year period can also be found in total number of lower-activity years for tropical cyclones, which is usually relative to an extreme value (max. and min.) for the sunspot in the years (Zhang, 1975)

3. *Analyzing of climate phase*

Fig. 3 shows the accumulated anomalies for annual frequency of tropical cyclones during 1884-1988. By using the signal-noise ratio methods from Yamamoto. R, the significant level of average value for any two neighbouring sub-series has been tested. We took the sub-series at ten years and signal-noise ratio $\geqslant 0.4$ as a turning year. Then we have 7 turning years, 1904, 1912, 1931, 1943, 1959, 1968 and 1977 (see Fig. 3).

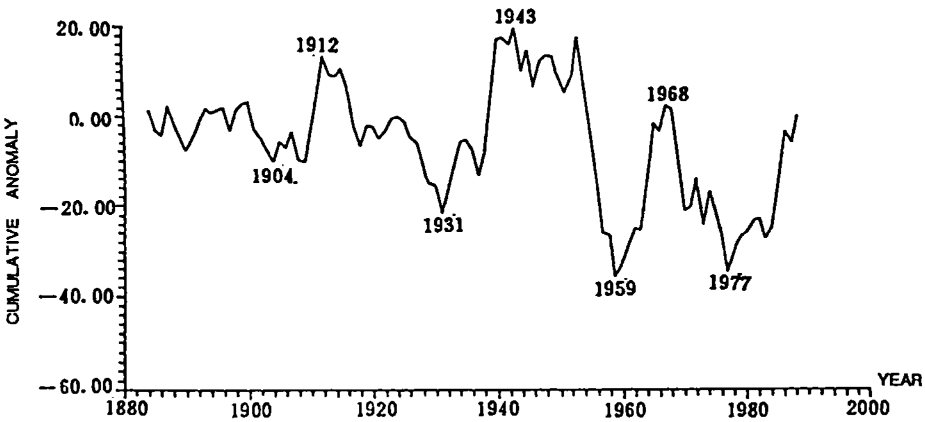

Fig. 3. Accumulated anomalies for annual frequency of tropical cyclone in Northwest Pacific. during 1884-1988 (Inflexion years are indicated).

The years 1884-1988 can be divided into 8 climate phases for more and less (see Table 2) occurrence of TC. In order to test the difference of significant level among phases, the t-test for average value of the phases has been made.

$$t = \frac{|\bar{X}_1 - \bar{X}_2|}{\sqrt{\frac{\sigma_{x_1}^2}{n_2} + \frac{\sigma_{x_2}^2}{n_1}}},$$

where $\bar{X}_1$、$\bar{X}_2$ are the average values in the neighboring phase 1 and phase 2, $\sigma_{x_1}$and σ_{x_2} are mean square deviation for the neighboring phases and n_1、n_2 are the number of years for phase 1 and phase 2 respectively. If t-value is larger than t_α, a given confidence level for freedom $n_1 + n_2 - 2$, it means the difference under this confidence level in the particular tested phases is significant. From Table 2, all confidence level reached to 0. 01, except a value for 0.05 between phase 1 and phase 2 and for 0.02 between phase 7 and phase 8. It indicated that phase 1 and phase 8 are located in the beginning and end of the data with a poor confidence level. If phases 1 and 8 can be neglected, then the average persistent period of TC frequency for the phases is 12 years. Among them, the average persistent period for positive anomaly of TC frequency is 9.7 years and those for negative is 14.7 years.

Table 2. Statistical features at various periods for annual frequency of tropical cyclone in Northwest Pacific during 1884-1988.

Number	Phase	Number of years	Average	Mean square deviation	Positive anomaly%	Negative anomaly%	t-value	Confidence level
1	1884—1904	21	34.9	3.37	48	52	2.17	0.05
2	1905—1912	8	38.4	4.97	63	37	3.01	0.01
3	1913—1931	19	33.5	3.31	26	74	3.44	0.01
4	1932—1943	12	38.8	5.27	75	25	2.92	0.01
5	1944—1959	16	31.9	6.78	37	63	3.00	0.01
6	1960—1968	9	39.5	4.57	100	0	2.92	0.01
7	1969—1977	9	31.3	7.08	33	67	2.76	0.02
8	1978—1988	11	38.5	4.51	55	45		

From Table 2, we can see that the maximum signal-noise ratio were found in 1931, 1959 and 1977 (0.67, 0.53 and 0.57 respectively). The increasing of TC number after 1931 coincides with sudden weakening of a W-type circulation (1932) and a warmer climate period in Shanghai in 1931 (Zhang 1992); the increasing of TC number after 1959 is probably corresponding to climate changes in the summer of 1960's over Northern Hemisphere; the increasing of TC number after 1977 is relative to a warming process around 1978, which is one of the three sudden warming periods in the recent hundred years (around 1896, 1926 and 1978 respectively)①. So the transition year for interannual change of TC number in Northwest Pacific are relative to the years for sudden changing of zonal circulation and global climate warming.

Ⅳ. THE RELATIONSHIP BETWEEN TC FREQUENCY AND SOME ENVIRONMENTAL FACTORS

1. *The relationship between TC frequency and ENSO event*

Shi's ② studies show that based on calculating of the anomalous SST in equatorial eastern Pacific (0-10°S, 180-90°W), the El Nino events could be divided into two patterns, the first pattern with an anomaly 0.5°C found in spring, marked with E, the second has an anomaly of 0.5°C but in the summer or autumn, marked with E^*. The two patterns of La Nina events have been given which are described by A and A^*. Those two patterns of El Nino and La Nina years for 1884-1988 are shown in Table 3.

① Ye Jinlin. A study on global sudden warmig in recent 100 years (1992). Peking University.
② Shi Wei, ENSO system and climate change (1993). Peking University.

Table 3. Distribution of El Nino and La Nina events.

Pattern 1	E	1884	1888	1891	1902	1940	1951	1953	1957	1965	1972	
	A	1892	1898	1908	1916	1922	1938					
Pattern 2	E*	1896	1899	1904	1911	1913	1918	1925	1930	1944	1963	1968
		1976	1982	1986								
	A*	1886	1889	1903	1924	1933	1949	1954	1964	1970	1988	

Statistic analyzing of frequency for TC anomaly has been made for two patterns succeeding ENSO events. The relationship between the first pattern and current year's TC frequency and that between the second pattern and the next year's TC frequency are also discussed. The results show that there is not any reasonable relations statistically for weak activities of TC in EL Nino years or the strengthening activities of TC in La Nina years (see Table 4). If the differnt patterns are not to be concerned with, we can

Table 4. Annual frequency anomaly of tropical cyclone during the El Nino and La Nina years.

	E	A	E*	A*	E+E*	A+A*
More (times)	5	3	4	4	9	7
Fewer (times)	3	2	8	4	11	6
X^2	0. 08		0. 80		0..03	

calculate the relation for the data of next year's TC frequency only, a little better relationship between El Nino, La Nina and TC frequency for next years could be expected (see Table 5), that means the negative anomaly of TC frequency would occur frequently rather than those for positive in El Nino next years and the positive anomaly of TC frequency could be found little more than those for negative in La Nina the following years. But its confidence level is not high, closing to 0. 10($X^2_{0.10}=2.17$) only. It indicates that there are not any significant relations between TC' s frequency in Northwest Pacific and ENSO events.

Table 5. Annual frequency anomaly of TC after the EL Nino and La Nina years.

	E	A	E*	A*	E+E*	A+A*
More (times)	2	3	4	4	6	7
Fewer (times)	5	1	8	4	13	5
X^2	2. 27		0. 80		2. 61	

In order to study the relations of TC and ENSO mentioned above, the correlation of TC frequency and SST for current and preceding years at 5× 5 latitude and longitude boxes in the area 120°E-80°W, 10 °S-50°N have been calculated. The results indicate that negative correlation was found physically in the west of 180 °E, i. e. , the higher SST we get then the lower TC frequencies could be found (Figure omited). But the value of negative correlation is quite small. The correlation of TC frequency with average SST in the eastern equatorial Pacific area (0-10° S, 180°-90°W) and the correlation of seasonal average of SOI with TC frequency are also calculated (see Table 6). The results indicated that correlation coefficient of TC frequency with SST in the equatorial eastern Pacific area is negative from preceding summer to current summer. It turns to the positive value in autumn. The negative correlation indicate that when SST increases then TC frequency will be decreased, but it turns to increase beginning with the autumn in the eastern Pacific. It is very interesting that if we divide QBO phases, which are calculated from zonal wind at 30 hPa in the equatorial stratosphere area, into these two parts, i.e., eastern wind phases (n=21 year / times) and western wind phases (n=18 year / times), to calculate the correlation of these two parts, then higher correlation coefficient could be found in all of the seasons. It is also found that negative correlation observed in current winter and spring for eastern wind phase turns to positive in summer and autumn. All the negative correlation is observed from spring to autumn for western wind phases.

Table 6. The correlation coefficient of TC frequency with SST in equatorial eastern Pacific and with SOI.

Correlation with	Winter	Spring	Summer	Autumn
preceding year's SST	0.31	0.17	−0.08	−0.18
current year's SST	−0.20	−0.17	−0.11	0.05
SST for current year's eastern wind phase	−0.38	−0.10	0.17	0.30
SST for current year's western wind phase	0.03	−0.21	−0.35	−0.22
preceding year's SOI	0.01	0.01	−0.05	−0.05
current year's SOI	0.08	−0.07	−0.13	−0.14
SOI for current year's eastern wind phase	0.19	0.09	−0.12	−0.25
SOI for current year's western wind phase	0.06	−0.01	−0.07	−0.08

A higher correlation coefficient of TC frequency with SOI can be seen obviously for eastern wind phase (Table 6). The positive correlation occured in winter and spring, the negative in summer and autumn. So the number of TC will be increased when SOI is positive, which is relative to La Nina events. The number of TC will be decreased when SOI is negative, which is relative to El Nino events. In general, since SOI is an opposite phase with SST and ENSO is usually relative to east wind phases, TC frequency would have a decreasing tendency in ENSO years in winter and spring only. It will be increased in ENSO year's summer and autumn, especially in autumn. The higher correlation of TC frequency with SST occuring in winter eastern wind phase (with the correlation coefficient −0.38) means that SST in winter would be a potential indicator for current year's TC activities in the eastern wind phases. So if no particular season is considered and the relations are considered in terms of the year only, the correlation will not be significant.

2. *The relationship of TC frequency with atmosphere circulation and solar activities*

Zhang (1958) has studied annual changes of TC frequency for western Pacific area by using the data 1900-1954. A synchronous phase for an anomalously integrated curve of typhoon's frequency with an anomalous curve of annual frequency of westerlies in Pacific area was found. An asynchronous phase with meridional circulation pattern (M) also occured. In this study, the relationship between TC frequency with zonal circulation pattern (W), meridional circulation pattern(C, E)and annual average sunspot number is calculated for 1884-1986 (Table 7). It is found that the correlation coefficient of TC frequency with those for sunspot are small, only over 0.10 ($\Upsilon=0.16$). If we divide

Table 7. The correlation coefficient of TC frequency with daily numbers of circulation pattern and with sunspot number.

	W	C	E	Number of sunspot
All phase	0.09	−0.10	−0.07	−0.17
Eastern wind phase	−0.08	−0.06	0.11	−0.09
Western wind phase	0.33	−0.07	−0.25	−0.46

QBO at 30 hPa into eastern and western wind phases, to calculate correlation coefficient respectively, then correlation of TC frequency with sunspot and with circulation pattern in Northern Hemisphere will be increased in western wind phase. Among them the correlation coefficient of TC frequency with sunspot reach to −0.46 with a confidence level of 0.05. But it is very weak in the eastern wind phases. The weakening of solar activities and development of zonal circulation will bring about the generation and developing of TC in western wind phases. It is understood that during the period of developing for zonal circulation, polar cyclones in the mid-troposphere would be contracted to the north, westerlies and sub-tropical high in the Pacific will move to the north, then will cause ITCZ to push to the north and to warm tropical ocean for TC generation and developing in the high temperature ocean area. However, as a disturbing factor, effect of solar activities on pressure system and weather condition in the troposphere must be realized by changing atmospheric circulation firstly. When solar activities are increasing, meridional circulation will be strengthened, zonal circulation be weakened; or when solar activities are decreasing, meridional circulation weakened and zonal circulation strengthened. So based on weather long range changes, the weakening of solar activity will lead to development for zonal circulation and TC generation. If we consider the western wind phase only, then an obvious relation will occur. It is indicated that the changing of wind phases in equatorial stratospheric atmosphere would be partly leading to an adjusted process onto the solar troposphere circulation system (Gray W. M., 1984).

V. CONCLUSIONS

a. The annual TC frequency not only has the periods with 21, 31, 15 and 6 years but also has a phase variation with persistence of 12 years in average.

b. During the year 1884-1988, the annual TC frequency have three remarkable turning points—1931, 1959 and 1977, which may be related to the intensity changes of zonal circulation in Northern Hemisphere from strong to weak and the years of abrupt increasing of global temperature.

c. The annual TC frequency has a decreasing tendency for winter-spring season during the El Nino year, but for the summer-autumn season it has an increasing tendency, especially during the period when zonal wind takes an easterly phase in equatorial stratosphere. During La Nina years, the relation between them is reversed. However these correlation coefficients are quite weak that the statistical significance test can hardly be passed.

d. The annual TC frequency relationship is positively correlated with the days of zonal circulation pattern (the zonal type W) over Northern Hemisphere and positively correlated with the sunspot relative number, especially during the period when the equatorial stratospheric zonal wind takes a westerly phase. During the period of the easterly phase the correlation would be weakened.

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