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A METHOD OF ESTIMATING TYPHOON CENTRAL WIND BASED ON SEA LEVEL PRESSURE OF THE TYPHOON YEARBOOK OF CHINA

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Abstract: Based on the Typhoon Yearbook data (1980－2000), some wind-pressure fitting relationships were established for different typhoon intensity at the different latitudes of the western North Pacific. As shown in validations with the 2001-2005 data, the relationships (namely, those between minimum sea level pressure (SLP) and maximum sustained wind near a typhoon center) are stable. They may be applied to correct the overestimated typhoon wind speeds in earlier years (1950－1979). Statistical analysis showed that the stronger the typhoon, the more stable this wind-pressure relationship is. Moreover, it is more stable at the lower latitude belt (10°N－30°N). On the basis of this result, a methodology of correcting typhoon's wind speeds and frequency in these years was put forward, and the climatological series were reconstructed of yearly total typhoon frequencies over the western North Pacific in 1950-1979 and indices were determined of destructive power of typhoons in the offshore regions of China.

Key words: typhoon; western North Pacific; wind-pressure relationship

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1 INTRODUCTION

Before satellite and remote sensing techniques were used in meteorological observations, the western North Pacific typhoon surveillance depended mainly upon military planes from a US base at Guam and ships[1, 2]. In early years, the plane sounding collected a lot of reliable measurements of typhoon central minimum pressures without corresponding wind data. How to establish a steady and reliable linkage between the tropical cyclone near-center maximum wind speeds and the central lowest pressures that can be used as a transitional function between the wind speeds and pressures is one of the focuses for meteorologists worldwide, especially for those working at the Joint Typhoon Warning Center (JTWC). For typhoons over the western North Pacific, Takahashi[3, 4] earlier obtained an empirical expression on the basis of ship and island observations. Fletcher [5, 6] and Fujita [7] constructed their own fitting formulae and applied them to the JTWC operations. A empirical expression was also given by Atkinson and Holliday and is still in use [7]. These results showed that the typhoon's wind-pressure relationship has experienced multiple changes for improvement. In addition, using 700-hPa aircraft routine observations from the mid 1950s, some scientists set up a relationship between the typhoon's central minimum SLP and 700-hPa geopotential height [8-11]. However, the JTWC workers also recognized that these early empirical expressions overestimate the typhoon central wind speeds. Thus the Fujita's wind-pressure equation[12] was put into use in 1973. Subsequently, the Atkinson – Holliday expression was developed and is now in use [2, 13, 14].

From the 1960s to 1970s, typhoon data greatly increased with improved surface and upper-air observation networks as well as increased airplane and ship weather reports. Since the fitting expression derived by Atkinson and Holliday (hereafter AH) is based on the 25-year data from 1947 to 1971 and fails to reflect some regional features of the typhoon wind-pressure relationships, the accuracy and applicability of the AH wind-pressure relationship are

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not so high. Yan and Fan[13] performed some latitude and seasonal improvements of the AH expression by means of 1975-1985 aircraft observations in the Typhoon Yearbook. For reducing the overestimated typhoon central winds in the 1950s and 1960s[15、17、18], Chen considered an effect of latitude on the AH wind-pressure relationship with the 1970-1986 data from the yearbook and then corrected the wind speeds in the 1950s and 1960s[15]. However, the existing wind-pressure expressions do not take into account both the intensity and latitudes of typhoons.

As a result, although ongoing studies are correcting the JTWC overestimated wind speeds prior to the mid 1970s by using the AH correction method, it is now possible to build more suitable wind-pressure models for different latitudes and intensity because of a great increase of typhoon observation data. Moreover, because there are differences among various data sets, it is also necessary to establish a better wind-pressure model for the records in the Typhoon Yearbook complied by the Shanghai Typhoon Institute and to correct the overestimated wind speeds.

2 DATA AND METHODS

The 1949-2005 optimal typhoon track data come from the compilation of the Shanghai Typhoon Institute of China Meteorological Administration (to be called CMA_SHI hereafter).

The mean relative error (E) and absolute error (D) are calculated as follows:

$$E = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\hat{x}_i - x_i}{x_i}\right)^2}$$

$$D = \frac{1}{n}\sum_{i=1}^{n}\left|\hat{x}_i - x_i\right|$$

in which $\hat{x}_i$ signifies the fitted value and x_i the measurement. Moreover, the AH wind-pressure empirical model takes the following form

$$v_{\max} = 6.7(1010 - p_c)^{0.644},$$

in which $v_{\max}$ is the 1-minute maximum sustained wind (unit: knots) near the center of a tropical cyclone (TC); p_c is the lowest SLP (unit: hPa) in the center.

3 A SCHEME FOR CORRECTING CMA_SHI WINDS

3.1 *The wind- pressure fitted expression*

Following the traditional AH model, our empirical equation takes the form of

$$v_{\max} = a(1010 - p_c)^b,$$

in which $v_{\max}$ signifies the 2-minute maximum sustained wind (unit: knots) near the TC center and p_c is the lowest SLP (unit: hPa) in the center.

Based on a 20-year (1980－2000) CMA_SHI observed data with an interval of 6 h, we built the wind-pressure equations for TC, tropical storm (TS), and typhoon (hereafter TY) at latitudes 0°－10°N, 10°N－20°N, 20°N－30°N, 30°N－40°N, 40°N－50°N, over the western North Pacific, with the coefficients *a* and *b* of the equations shown in Table 1. Then the 2001-2005 observations were used to test the reliability of these fitting equations. Table 1 also shows the mean relative error (E) and the mean absolute error (D) (shown in section 2) for the newly constructed wind-pressure fitting equation (E_New) and the AH equation (E_A-H).

Table 1 shows that our fitting equations can better reflect the typhoon wind-pressure relationships for different intensity and regions, with E generally below 10% and D generally below 2 m/s. Moreover, for the 2001-2005 data used to validate the fitting model, our equations also show a good fitting result. For TS and TY, most of their E and D values are smaller than those in 1980－2000, which indicates higher applicability and steadiness of the new model.

It is also seen from Table 1 that the fitted result of the new model is better with the increase of the typhoon intensity, i.e., the stronger the typhoon, the better the result. For instance, the E (D) in the maximum TY wind is below 7% (1.5－2.2 m/s) for 1980－2000 and 3.7%－5.7% (<1.5 m/s in most cases) for 2001－2005.

Comparing the results at the different latitude belts shown in Table 1, our fitted result is seen to be better at 10°N－20°N and 20°N－30°N (where the low-pressure system appears more frequently) than at other latitudes. This might be attributed to a more stable wind-pressure relationship when there is a larger sample of typhoons at one latitude belt. Meanwhile, the fitted result of TY is better at lower latitude belts, which differs from the cases of TS and TC. Therefore, the wind-pressure expression should be amended for different latitudes and typhoon strengths.

Compared to the AH expression, the new model is seen to have smaller E and D and can more accurately fit the maximum wind speed from SLP. This further exhibits the necessity of improving the AH expression.

Table 1 Coefficients (*a* and *b*) of wind-pressure equation, errors (E and D), and sample number (SN) for TC, TS, and TY at different latitudes of the western North Pacific.

period(type)	Latitude / °N	E_New		E(%)		D (m/s)		SN
		a	b	E_New	E_A-H	E_New	E_A-H	
1981－2000 (TC)	0－10	10.8	0.120	10.2	24.1	1.2	2.6	693
	10－20	10.3	0.142	9.7	20.1	1.1	21	2719
	20－30	11.4	0.089	10.1	25.9	1.2	2.7	1248
	30－40	11.0	0.104	9.7	22.6	1.1	2.4	498
	40－50	10.3	0.123	9.2	37.6	1.0	4.0	189
2001－2005 (TC))	0－10			10.1	22.1	1.3	2.5	172
	10－20			9.1	20.1	1.1	2.3	559
	20－30			10.2	22.7	1.2	2.3	197
	30－40			9.2	21.5	1.1	2.5	70
	40－50			9.8	24.6	1.2	2.6	49
1981－2000 (TS)	0－10	6.4	0.434	9.6	12.2	1.7	2.2	440
	10－20	6.2	0.442	8.8	11.4	1.6	2.0	3357
	20－30	5.8	0.457	9.1	11.2	1.6	2.0	1980
	30－40	6.8	0.400	10.5	14.4	1.9	2.4	988
	40－50	7.9	0.329	11.3	22.6	2.1	3.8	264
2001－2005 (TS)	0－10			7.0	7.1	1.2	1.3	134
	10－20			8.6	8.3	1.5	1.3	633
	20－30			8.7	9.2	1.4	1.5	478
	30－40			10.2	12.5	1.8	2.0	265
	40－50			12.1	27.5	2.2	4.4	45
1981－2000 (TY)	0－10	3.9	0.6	6.7	7.4	2.2	2.6	115
	10－20	4.8	0.546	6.6	8.2	2.2	2.6	2093
	20－30	4.5	0.561	6.2	7.5	1.9	2.4	1932
	30－40	8.3	0.392	5.5	8.5	1.5	2.4	312
2001－2005 (TY)	0－10			5.7	6.6	1.4	1.8	29
	10－20			4.0	4.5	1.3	1.5	503
	20－30			3.7	4.3	1.1	1.4	699
	30－40			5.2	4.7	1.6	1.4	121

3.2 *Correcting the yearly typhoon frequency*

The fitted results using the new model demonstrate the stable relationships between the central SLP and maximum wind speed for mature tropical cyclones. For the overestimated wind speeds in the 1950s-1960s CMA_SHI data, the v_{max} values can be calculated from the typhoon central SLP values on the basis of wind-pressure equations and may be used to replace the observed values.

According to the typhoon operational regulations of China, when the 2-minute maximum sustained wind near a tropical low-pressure center exceeds 17.2 m/s, it is called TS. Following the new wind-pressure relationships shown in section 3.1 and considering the practical conditions (that is to say, the 18 m/s wind is used as the criterion of TS), the tropical low-pressure system with a 998-hPa value may be defined as TS (see Table 2).

According to the above criterion, when the lowest pressure in the lifespan of a typhoon is below 998 hPa in the CMA_SHI dataset, the tropical low-pressure system is called TS. Figure 1a shows the yearly TS frequencies over the western North Pacific (at 0°－90°N, 100°E－180°E) in 1980－2005 on the basis of the SLP (998 hPa) or wind (18 m/s) criterion. In this figure, the yearly TS frequency from the pressure criterion is close to that from the wind criterion during

1980 – 2005, in which their frequency difference is ≤ 1 in 19 years (accounting for 73% of the 26-year total), with the error of 1 during 1980 – 2005. Therefore, for the overestimated winds in the 1950s and 1960s[1,16-18], we use the 998-hPa criterion to replace the 18 m/s wind criterion, obtaining the temporal evolution of the TS frequency over the western North Pacific in the 55 years from 1950 to 2005 (as shown in Fig. 1b). It is seen from Fig. 1b that TS occurred more frequently in the mid 1960s than in the mid 1970s. Moreover, there is also a relatively high-frequency period of TS in the mid 1990s while there is a relatively low-frequency period from the late 1990s to the early 21st century. Overall, the TS over the western North Pacific showed a decreasing trend in the recent 56 years.

Similarly, when the maximum wind of 32.7 m/s is used as a criterion of TY, the associated TY SLP is 975 hPa, based on our wind-pressure equations and the practical work. Figure 2a shows the yearly TY frequencies over the western North Pacific in 1980 – 2005 on the basis of the 975-hPa SLP or 32.7 m/s wind criterion during 1980 – 2005.

It is seen from Fig. 2 that the TY frequency from the pressure criterion, according to our wind-pressure equations, is quite consistent with that from the wind criterion during 1980 – 2005, with an error of the TY frequency less than 1 for 90% of the years and a mean error of 0.7 during 1980 – 2005. Similarly, the TY frequency series can be constructed from the 975-hPa SLP criterion during 1950 – 1979.

Figure 2 shows the TY frequencies over the western North Pacific based on the wind or pressure criterion from the CMA_SHI data and based on the corrected JTWC data sets[2,14,16]. The TY frequency from the wind criterion of the corrected JTWC wind data (for the overestimated wind speed) before 1973 is approximately taken as an observed value[16]. In Fig. 3, the TY frequency based on the pressure criterion of the CMA_SHI data is closer to the observed before the 1970s and there is no significant difference between them. The TY frequency based on the wind criterion of the CMA_SHI has a significant difference from the observation, with their mean difference (variance) significant at the 0.1% (5%) confidence level of the ***t*** (F) test. These results show that the overestimated winds in the 1950s-1960s CMA_SHI data can be better corrected by using the CMA_SHI SLP based on our wind-pressure equations to reduce the statistical error in an effective way.

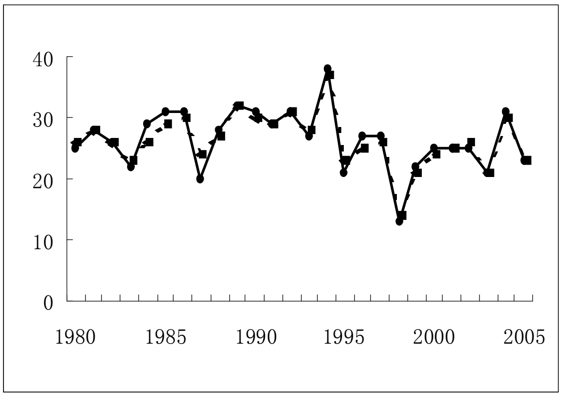
Similar to the correction of the typhoon frequency, we also correct the CMA_SHI wind speed based on the foregoing wind-pressure equations. Because of the poorer reliability of the wind data before 1973[16], the 998-hPa (975-hPa) value is applied as a criterion of TS (TY) before 1973. For the 1974-2005 period, the wind criterion is used, with 17.2 m/s (32.7 m/s) for TS (TY). When the relative error between the raw wind value and theoretical wind values exceeds 15%, it is defined that there is a significant difference between the observed and theoretical wind values. Figure 4 shows the number with this significant difference for the TS wind in the offshore regions of China and its ratio to the total number.

In Fig. 3, the number is larger in the 1950s and 1960s, indicating a larger difference between the calculated and observed TS wind values in the offshore regions of China. The number exceeds 100 and the ratio falls in 50% – 80% in most of the years (the 1950s – the 1960s), greatly larger than in the other periods. After the 1980s, the difference in the winds is smaller. Particularly since the late 1980s, the number (ratio) is smaller than 20 (10%), indicating that the TS wind-pressure relationship in the observed data is satisfied well after the 1980s. For the TY observation (Table 3), the ratio with a significant difference between the theoretical and observed TY winds is between 30% and 95% in the 1950s and 1960s. Since the mid 1970s, the number with a significant difference has reduced greatly. There is almost no difference in most of the years after 1990. This result also implies high consistency between the theoretical and observed wind values and good reliability of the new wind-pressure equations.

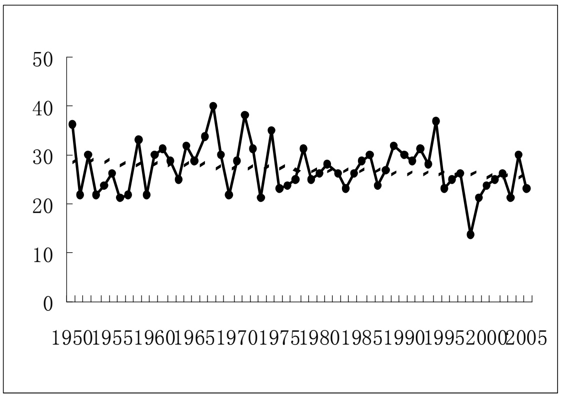
Figure 4 shows the temporal curves of the TS wind destructiveness[16] in the offshore regions of China during 1950 – 2005. It is seen from the figure that the destructiveness calculated from the corrected maximum winds greatly reduces in the 1950s and 1960s compared to that without the correction. There is almost no difference between the corrected and uncorrected destructiveness after the 1970s. As a result, the new wind-pressure equations can correct the overestimated winds in the Typhoon Yearbook for the 1950s and 1960s. The TS destruction index calculated from the corrected data shows that the TS damage was relatively weak before the 1970s, relatively strong in the 1980s and the early 1990s, relatively weak in the mid-late 1990s to the early 20th century, and relatively strong again in 2004 and 2005.

Table 2 v_{max} values corresponding to the central pressure in different latitude belts based on the E_New equations.

	997 hPa					998 hPa					999 hPa				
	0°N－10°N	10°N－20°N	20°N－30°N	30°N－40°N	40°N－50°N	0°－10°N	10°N－20°N	20°N－30°N	30°N－40°N	40°N－50°N	0°－10°N	10°N－20°N	20°N－30°N	30°N－40°N	40°N－50°N
v_{max} / m/s	**19.5**	**19.3**	**18.7**	**19.0**	**18.4**	**18.8**	**18.6**	**18.1**	**18.4**	**17.9**	**18.1**	**17.9**	**17.4**	**17.7**	**17.4**



(a)



(b)

Fig.1 Yearly total frequency of TS in the western North Pacific in which the solid and dotted lines are for the pressure and wind criteria, respectively. (a): 1980-2005; (b): 1950-2005.

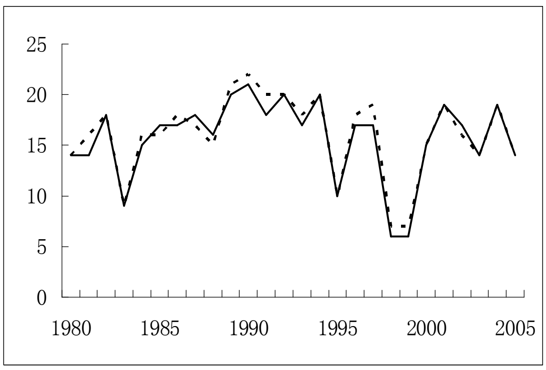


Fig.2 Yearly total frequency of TY in the western North Pacific in 1980-2005, in which the solid and dotted lines are for the pressure and wind criteria, respectively.

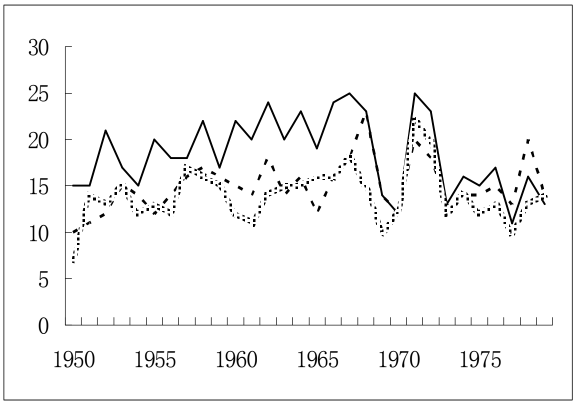


Fig.3 Yearly total TY frequencies over the western North Pacific in 1950-1979, in which the solid and grey lines are for the wind and pressure criterions of the CMA_SHI data, respectively, and the dotted line is for the corrected JTWC data. The abscissa stands for the frequency.

4 CONCLUSIONS

(1) Based on the 1980-2000 data of the Typhoon Yearbook compiled by the Shanghai Typhoon Institute, the wind-SLP fitting equations are established for TC, TS, and TY at the different latitudes of the western North Pacific, respectively. Tests using the 2001-2005 observations for these equations show their high steadiness and consistency.

(2) The typhoon wind-pressure relationships are dependent on the typhoon's latitude and intensity. The stronger the storm is, the steadier the relationships are. The relationships are quite steady at 10°N－20°N and 20°N－30°N where there are more frequent activities of the tropical cyclone.

(3) The new wind-pressure equations can be used to estimate the typhoon maximum sustained wind from SLP before the 1970s. The TS and TY frequencies and destructiveness calculated from SLP are possibly closer to the reality during the 1950s－1970s, which may

decrease the statistical errors due to the overestimated winds in this period. The typhoon destructiveness indices in the offshore regions of China depict that the destruction indices are relatively low before the 1970s, relatively strong from the 1980s to early 1990s, and then relatively low again from the mid-late 1990s to the early 20th century except in 2004 and 2005.

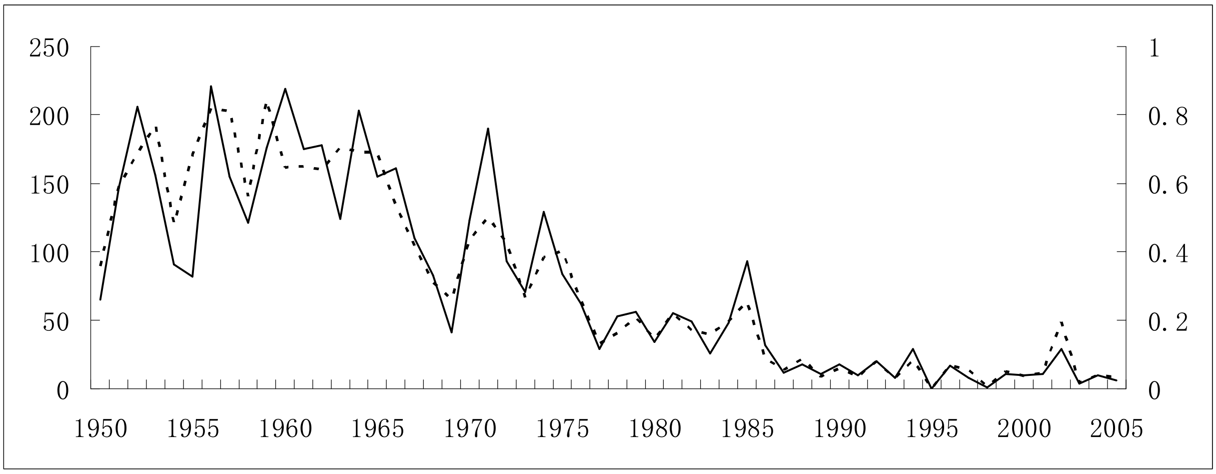


Fig.4 The number (the solid line) with a significant difference between the observed and theoretical TS winds in the offshore regions of China and its ratio (the dotted line) to the total number.

Table 3 The number of TY (N_TY) and the number with a significant difference between observed and theoretical v_{max} values (N_DC) in the offshore regions of China.

Year	N_DC	N_TY	Year	N_DC	N_TY	Year	N_DC	N_TY
1950	13	29	1969	17	74	1988	7	58
1951	52	73	1970	37	98	1989	2	125
1952	37	60	1971	46	114	1990	0	135
1953	63	75	1972	10	59	1991	0	137
1954	54	103	1973	13	80	1992	1	93
1955	40	55	1974	27	103	1993	1	70
1956	94	103	1975	4	58	1994	0	107
1957	63	73	1976	7	103	1995	0	39
1958	79	83	1977	7	75	1996	0	128
1959	84	92	1978	3	102	1997	0	85
1960	61	86	1979	18	105	1998	0	35
1961	57	71	1980	2	70	1999	0	61
1962	51	98	1981	5	63	2000	0	99
1963	51	75	1982	7	119	2001	0	85
1964	76	105	1983	9	82	2002	0	61
1965	65	75	1984	4	72	2003	0	106
1966	24	57	1985	8	114	2004	0	150
1967	28	74	1986	3	117	2005	0	106
1968	34	108	1987	1	115			

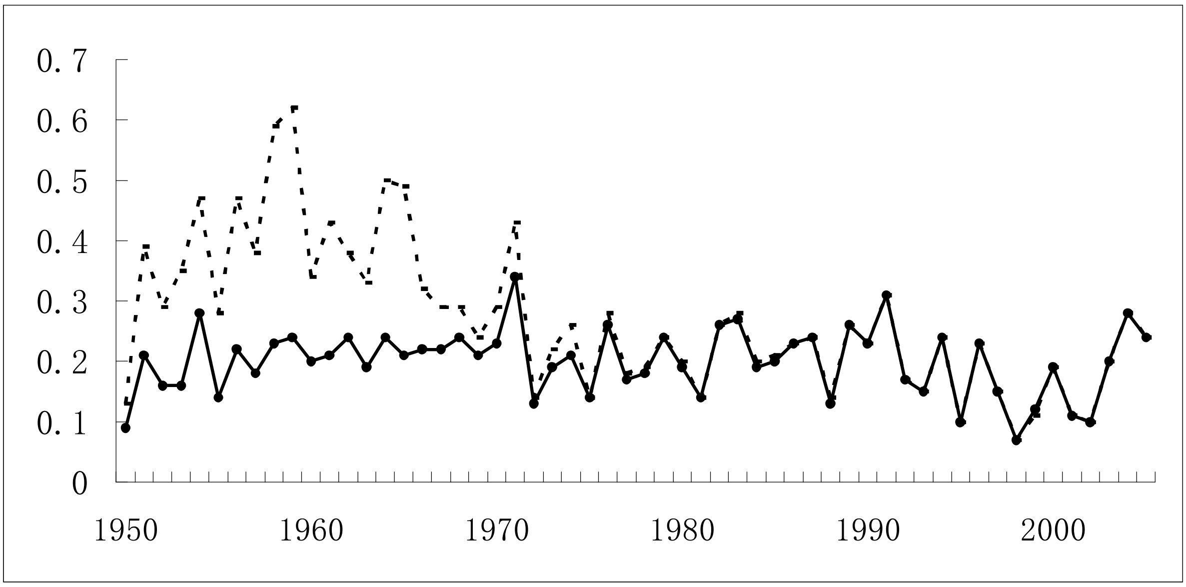


Fig.5 The TS destructiveness indices ($\times10^{12}$) in the offshore regions of China during 1950-2005, in which the solid (dotted) line indicates the corrected (uncorrected) wind data.

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