Intensity of Recurved Typhoons

HERBERT RIEHL

Dept. of Atmospheric Science, Colorado State University, Fort Collins 80521

(Manuscript received 10 January 1972, in revised form 22 February 1972)

ABSTRACT

The maximum wind speed obtained by reconnaissance aircraft in recurved typhoons is examined for 66 cases from 1957 to 1968 for 2–3 days after recurvature from a westward to an eastward component of motion. The maximum wind decreases at a variable rate as the storms move out of the tropics, but a fairly uniform behavior is found if the maximum speed at any given time after recurvature is normalized to a percentage of the highest speed attained during the life of a typhoon.

For latitude increments in position of up to about 8 deg in 48–72 hr a linear relation gives results within fairly narrow limits. For longer displacements a logarithmic relation is indicated. The latter is compared with the variation of maximum wind speed in steady-state storms with latitude. It appears that a large fraction of the decrease in intensity after recurvature can be ascribed to the latitude effect itself but that an additional smaller term possibly related to decreasing ocean and air temperatures is present.

1. Introduction

In addition to track, the intensity of hurricanes and typhoons is a critical forecast parameter. The change of intensity, as given by the maximum wind speed determined by reconnaissance aircraft, is examined in this paper for a large sample of recurving typhoons in the western Pacific ocean for time intervals of 48–72 hr.

The information used in the study—typhoon location, size, minimum pressure and maximum wind—was extracted from a computer printout of typhoon data covering the period 1945–68 produced by the U. S. Armed Forces. In the earlier years of this 24-year period, reports of maximum wind were in many instances very irregular from one observation time to the next. Although samples of such irregularity are also found in later years, they are less frequent, suggesting improvement in wind-measuring equipment, notably Doppler radar. Because of these irregularities, only data from the period 1957–68 was used. Maximum wind turned out to be the most tractable indicator, and it alone will be considered.

In accord with the intent of this study, each tropical cyclone must have met the following criteria to be included: 1) it had to attain typhoon force at some time; 2) it had to have a history of at least 3 days; 3) it had to have reached at least 30N, as recorded in the printout; 4) it had to have an initial westward component of motion and attained typhoon intensity in the tropics; and 5) it had to remain over the open ocean and not cross land such as Taiwan or the Chinese mainland (this limited consideration mainly to typhoons remaining east of 125E).

2. Statistics of recurving typhoons

A large sample of 66 typhoons, or nearly one-third of all typhoons between 1957 and 1968, satisfied the preceding criteria. They exhibited certain common characteristics with regard to intensity changes. In 43 cases the maximum wind reported for a given typhoon occurred within 12 hr of the time of recurvature (Table 1). It must, however, be noted that the exact place of recurvature is probably not known closer than to the nearest 12 hr; different sources of storm-track data disagree to this extent. Table 1 also shows that in 22 cases maximum typhoon intensity took place one day or more (rarely two days) before the time of recurvature. Only once did the maximum wind speed of a recurving typhoon occur as much as one day after recurvature.[1] We may conclude that virtually all typhoons reached their peak intensity at, or a little

TABLE 1. Relation between typhoon maximum intensity and typhoon recurvature for 66 cases of recurving typhoons (1957–68).

	Number
Maximum intensity occurred within 12 hr of recurvature	43
Maximum intensity occurred one day or more before recurvature	22
Maximum intensity occurred one day after recurvature	1
Total	66

[1] The few cases with slow intensification on long tracks, from the southwest, mostly early and late in the typhoon season, are not included. These may have had at least partial characteristics of polar front cyclones.

TABLE 2. Some characteristics of recurving typhoons (66 cases, 1957–68).

Month	Recurvature Latitude (°N) Mean	Max.	Min.	Wind speed (kt) Mean	Max.	Min.	Number of storms
June–July	25	33	19	125	170	80	6
August	29	34	24	105	140	70	10
September	26	30	22	125	170	90	18
October	24	31	17	120	150	75	19
November–May	20	25	14	125	150	100	13

before, the point of recurvature and subsequently decreased at some variable rate.

Table 2, on the left, shows the seasonal variation in the latitude of typhoon recurvature, moving north and south with the general circulation, well known from many previous climatologies. The range of the latitude of recurvature is very large in each month, indicating the variable influence of the synoptic situation on specific storms. The tabulation on the right of Table 2 is of interest in that the mean wind speed of a recurving typhoon is approximately 125 kt [2] in all months except August when typhoons tend to be somewhat weaker.

The data also show that typhoons that recurved during the off-season (November–May), and that survived as far as 30N after recurvature as typhoons, had maximum winds of at least 100 kt at some time during their existence.

3. Decrease of typhoon intensity

The data show a wide difference in the decrease of typhoon wind speed with latitude. One may normalize these differences with respect to the strongest intensity attained by the typhoons. Consider, for instance, the case of typhoon Kit in June 1966 presented in Table 3. The velocity during and after recurvature has been normalized by expressing it as a percentage of the maximum wind speed at 1200 GMT 26 June. Typhoon Kit reached its westernmost position at 0000 GMT 26 June; its wind speed at that time was also 170 kt. Thus, the maximum winds of typhoon Kit persisted 12 hr beyond the time of reaching the westernmost point of its track.

TABLE 3. Velocity of typhoon Kit (1966) during and after curvature.

Date	Time (GMT)	Latitude (°N)	Wind speed (kt)	Percent of strongest maximum wind	Heading
25 June	1200	16	120	71	330°
26 June	1200	22	170 (max)	100	020°
27 June	1200	28	120	71	035°
28 June	1200	36	65	38	040°

[2] It should be mentioned that some doubt has been expressed concerning the reliability even of Doppler winds at 130 kt and higher.

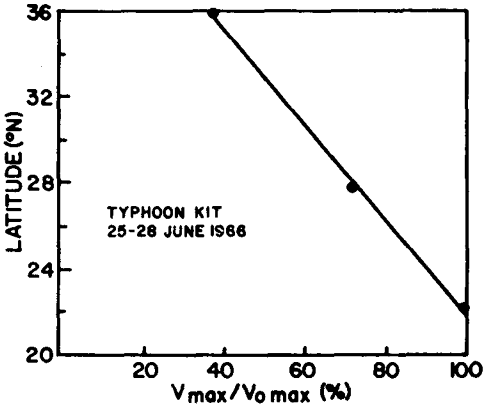

FIG. 1. The maximum wind (V_{max}), at a given time, of recurving typhoon Kit, expressed as a percentage of the strongest maximum wind ($V_{0\ max}$) at recurvature, against latitude (from Table 3).

When the wind speed changes during recurvature of each typhoon[3] were normalized in the manner just illustrated, the relation between maximum wind speed and latitude could generally be represented by a straight line on log paper or, in many cases, even on linear graph paper as illustrated for typhoon Kit in Fig. 1.

The variation in the slope of the curves of the individual storms fell within a relatively narrow range for most storms, especially for those storms whose tracks did not extend more than 8°–10° of latitude after recurvature. The curves for these storms are well represented by the straight line approximation

$$V_{max}/V_{0\ max}=100-b(\Phi-\Phi_r), \qquad (1)$$

where V_{max} is the maximum wind speed at a given time in the typhoon, $V_{0\ max}$ the highest maximum wind speed recorded during the life of the typhoon, Φ the present

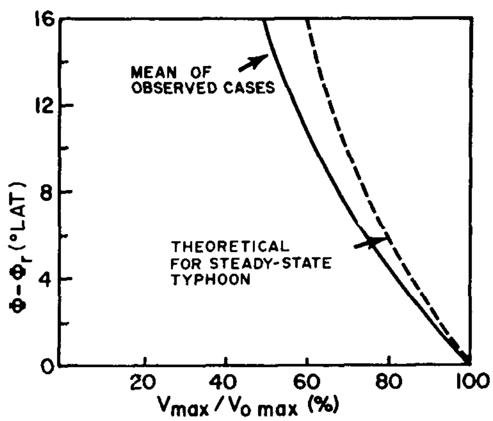

FIG. 2. The maximum wind, at a given time, of recurving typhoons, expressed as a percentage of the strongest maximum wind, against latitude (solid). See text for a discussion of the theoretical relation for steady state typhoons (dashed).

[3] Because of the additional requirement that the typhoon track extend at least two full days beyond the period of maximum intensity without striking land, the sample size for the following decreased from 66 to 61 cases.

latitude (degrees), Φ_r the latitude of recurvature,[4] and b the slope of the straight line. The slope for all cases averages 3.8 with a standard deviation of 0.9; two-thirds of the slopes fell within one standard deviation.

For storms with tracks extending beyond 8°–10° latitude after recurvature, the relation generally tends to be of the form

$$V_{\max}/V_{0\,\max}=1/(1+\alpha y), \qquad (2)$$

where $y=\Phi-\Phi_r$ is measured in degrees of latitude, and α is a constant to be determined. On long latitudinal tracks it is worth while to make this refinement over Eq. (1). Fig. 2 shows the mean $V_{\max}/V_{0\,\max}$ curve for all storms with tracks extending up to 16° latitude beyond recurvature. For this distribution α equals 0.056.

Riehl (1963) showed, at a given time for a steady-state typhoon, that the following relationship is valid:

$$V_{\max}=\text{constant}/f, \qquad (3)$$

where f is the Coriolis parameter and the constant is determined from the tangential wind speed at a chosen radial distance from the center. Of course, this relation does not refer to successive states of an individual storm since variations with time are not examined. It may be of interest, however, to compare the above relation with the mean curve shown in Fig. 2 keeping in mind, of course, that only a select sample of typhoon tracks is being considered. Given Eq. (3), then

$$V_{0\,\max}=\text{constant}/f_0, \qquad (4)$$

and, therefore,

$$V_{\max}/V_{0\,\max}=f_0/f. \qquad (5)$$

One can approximate the Coriolis parameter f at a given latitude by

$$f=f_0+\beta y, \qquad (6)$$

where f_0 is the value of the Coriolis parameter at some fixed latitude, β is the change of Coriolis parameter with latitude (df/dy), and y the distance going north from the latitude of f_0. Substituting (6) into (5), we have

$$V_{\max}/V_{0\,\max}=1/[1+(\beta/f_0)y]. \qquad (7)$$

This relation may now be compared with Eq. 2. Choosing 20° as the latitude of f_0, $\beta/f_0=0.4\times10^{-8}$ cm^{-1}. The curve corresponding to (7) with this value is shown in Fig. 2. It resembles the observed distribution well but gives a somewhat slower velocity decrease with latitude; the discrepancy is slightly larger if the mean latitude of recurvature (Table 2) is used.

While there are reservations, just mentioned, in comparing the two curves in Fig. 2, it is probably valid to say that a large fraction of the decrease in central intensity with latitude is due to the change in Coriolis parameter and a smaller fraction due to other factors. In an attempt to analyze the latter, sea-surface temperature charts were examined. These showed that recurving typhoons move nearly at right angles to the sea-surface isotherms in nearly all months. In contrast, storms that do not recurve and that maintain a northwest track move over more nearly constant ocean temperatures. This might help to account for the slower variation in wind speed with latitude usually shown by these storms.

From general knowledge of tropical storm structure and mechanics it would be expected that the minimum sea-level pressure increases with lowering sea-surface temperature. No doubt such a relation is broadly valid; however, it is difficult to put a number on it. The typhoon statistics shows numerous cases where the maximum wind of typhoons decreased to 35–50 kt, while central pressures were still as low as 970–980 mb. This and other aspects of the subject must be investigated further before a complete explanation of the $V_{\max}$ vs latitude relationship in Fig. 2 can be offered.

It is hoped that the foregoing information will give the forecaster at least a first approximation concerning the decrease in typhoon intensity to be expected during two or more days following typhoon recurvature. An estimate should be made only for at least a full 48-hr interval. Fig. 2 does not indicate changes over shorter time intervals reliably; some storms decrease very rapidly at first and then quite slowly while in other cases the opposite occurs. No obvious reason is seen why the general scheme should not be applicable over oceans other than the Pacific.

Acknowledgments. This research was begun in association with the former U. S. Navy Weather Research Facility and completed under a research contract between NOAA and Colorado State University.

[4] Except in those cases where the maximum wind occurred before recurvature: then Φ_r is the latitude at which the storm attained its highest maximum wind speed.

REFERENCE

Riehl, H., 1963: Some relations between wind and thermal structure of steady state hurricanes. *J. Atmos. Sci.*, **20**, 276–287.