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Changes in the Characteristics of Typhoons Crossing the Island of Taiwan

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ABSTRACT

Twenty-two typhoons (1960–72) are examined to determine the effect of Taiwan on the intensity and movement of tropical cyclones crossing the island. The results show an average intensity (maximum surface wind) decrease of over 40% and a distinct northward deflection as the storms approach the island with a southward deflection after passage. Forecast rules for typhoons approaching or crossing Taiwan are presented.

1. Introduction

In previous publications (Brand and Gaya, 1971; Brand, 1973) statistical information was given on the geographical and seasonal variations of tropical cyclone intensity changes for the western North Pacific region. It was evident from these general studies that a detailed examination of tropical cyclones crossing island land masses such as the Philippines and Taiwan would provide information useful to the forecaster, since in many situations he has to forecast the movement and intensity of storms to the west of these land masses while they are still to the east of the islands.

Such a study was published previously for the Philippines (Brand and Blelloch, 1973) and our present purpose is to describe and quantify similarly the characteristics of typhoons that are affected by Taiwan. This information, in conjunction with conventional prediction techniques, should be a useful forecast aid to the tropical cyclone forecaster.

A map of the western North Pacific area and a

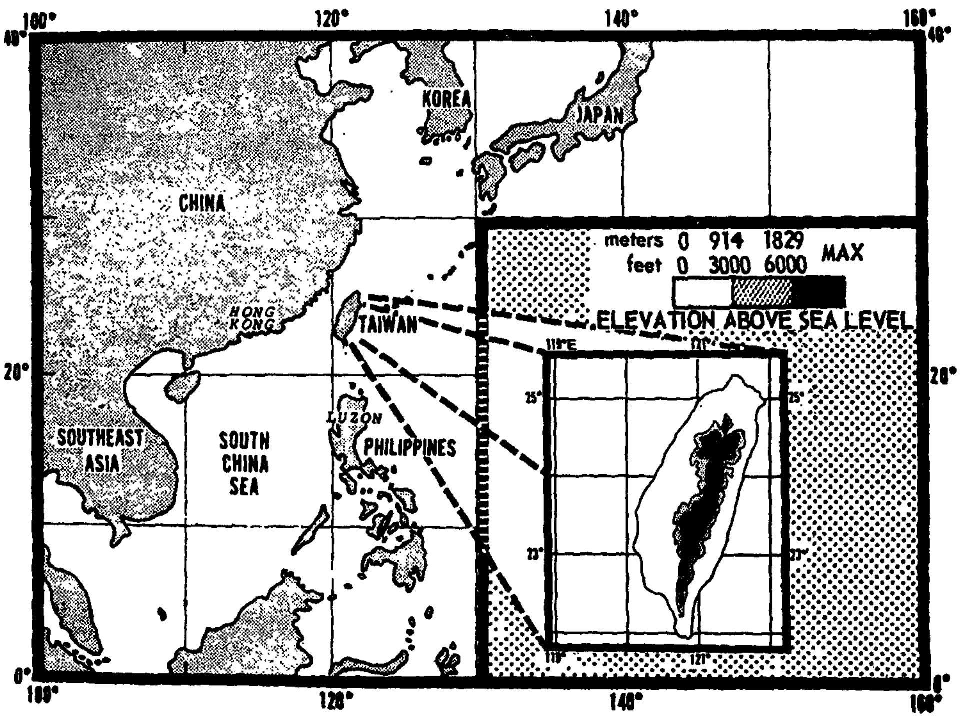


FIG. 1. The western North Pacific ocean with inset topographical map of Taiwan.

topographical map of the island of Taiwan are presented in Fig. 1.

2. Data sources

The data used for this study were extracted from the Annual Typhoon Reports published by the U. S. Fleet Weather Central/Joint Typhoon Warning Center, Guam, and from a history file of tropical storms and typhoons of the western North Pacific from 1945–71, compiled by the National Climatic Center (NCC) for and with the Navy Weather Research Facility (presently the Environmental Prediction Research Facility). The history file for the period 1945–71 contains 6-hr information on such storm characteristics as the location, movement, size, and intensity of tropical cyclonic circulations which, during their life cycle, reached tropical storm or typhoon intensity.

In this study the typhoons from 1960–72 were examined. During the 13-yr period there were 25 typhoons which hit Taiwan;[1] of this number, one recurved over the island and two crossed from west to east. The remaining 22 westward crossing typhoons (all eventually hitting the Asian mainland) were studied in the time from 48 hr prior to hitting Taiwan to 12 hr after leaving the island. The parameters examined were position (from fix[2] and best track[3] data), intensity (maximum surface wind), and speed and direction of movement.

TABLE 1. Typhoons (1960–1972) which crossed Taiwan on a general westerly heading and subsequently struck the Asiatic mainland. Typhoons are separated by month in which storm crossed the island. No crossings occurred in the months not shown.

May	July	August	September	November
Betty 1961	Shirley 1960	Trix 1960	Pamela 1961	Gilda 1967
	Elsie 1961	Elaine 1960	Sally 1961	
	Kate 1962	June 1961	Amy 1962	
	Wendy 1963	Lorna 1961	Elsie 1969	
	Harriet 1965	Opel 1962	Agnes 1971	
	Clara 1967	Mary 1965	Bess 1971	
	Nadine 1971	Nora 1967		

3. Discussion of results

Table 1 provides a list of the typhoons investigated in this study, separated by month of crossing the

[1] In the context of this paper, a typhoon is defined as a tropical cyclonic circulation which reached typhoon intensity at some stage in its life cycle. This intensity was not necessarily achieved during that part of the circulation existence considered in this paper.

[2] The determination of the position of a tropical cyclone at a precise time, generally by reconnaissance aircraft penetration of the center or by airborne, land, or ship radar or satellite photographs.

[3] A post-analysis track incorporating all available data.

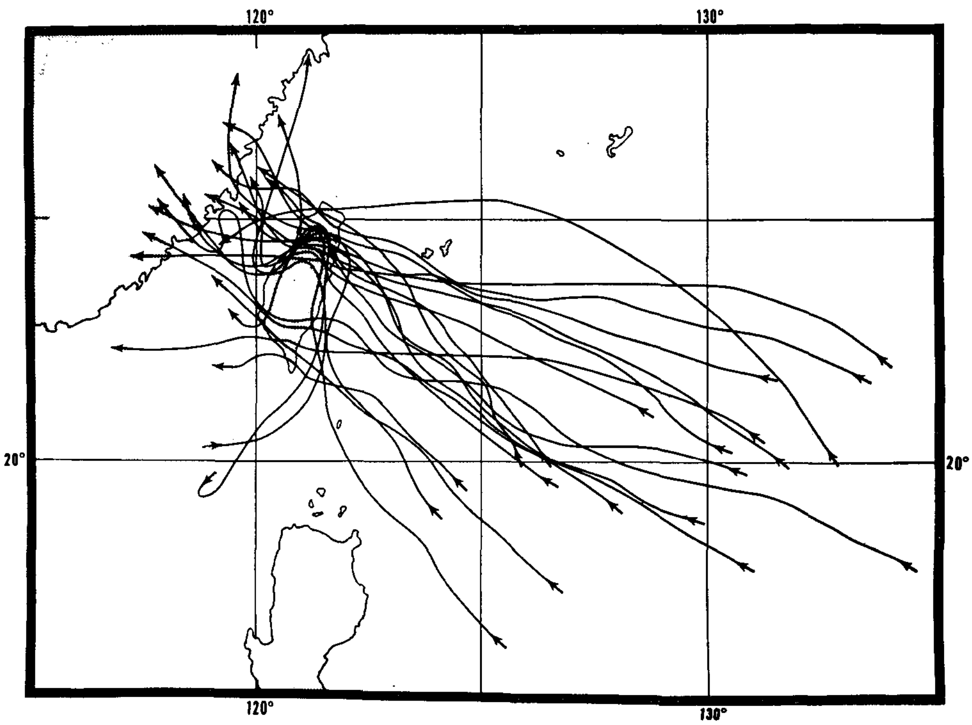


FIG. 2. Track segments for centers of 22 typhoons for the time frame 48 hr prior to hitting Taiwan to 12 hr after leaving the island.

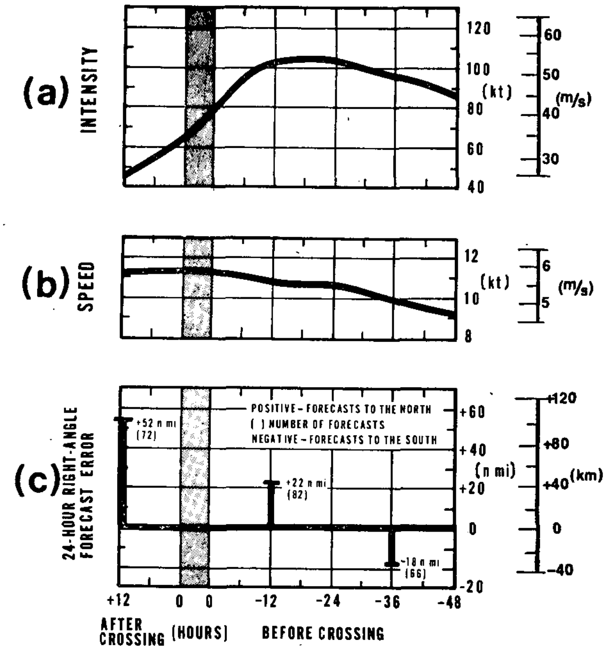


FIG. 3. Average intensity (a) and speed (b) profiles for 22 typhoons crossing Taiwan from 48 hr prior to hitting Taiwan to 12 hr after leaving the island. The shaded area represents Taiwan. The average 24-hr right-angle forecast errors (from Joint Typhoon Warning Center, Guam, best track) are presented in section (c) of the figure.

island. Twenty of the 22 typhoons crossed in the months of July, August, and September.

The track segments for the 22 typhoons can be seen in Fig. 2. If the 6-hr values of intensity and speed during this before-and-after period are averaged, an average intensity and speed profile for the 22 typhoons crossing Taiwan can be compiled. This is shown in Fig. 3. The shaded area represents Taiwan; to the right is before crossing and to the left, after crossing.[4] The intensity profile (Fig. 3a) shows an average increase in intensity during the period 48 to 24 hr prior to hitting Taiwan. The intensity then levels off until 12 hr prior to landfall and then decreases throughout the remainder of the period examined. From 6 hr prior to hitting the island to 6 hr after leaving, the intensity decreases from 95 to 56 kt (41% decrease).

The average time the storms exist over the Taiwan Strait prior to landfall on the China coast is 12.75 hr. Thus, the +12-hr value of intensity reflects the influence of the Asiatic mainland; it should also be mentioned that only one of the 22 cases existed over the waters to the west of Taiwan less than 6 hr. In general, the subject typhoons never regain an opportunity to intensify, unlike the typhoons crossing the Philippines and entering the South China Sea (Brand and Blelloch, 1973).

[4] The average time the center position of the 22 typhoons existed over the island was approximately 5.5 hr with a standard deviation of 2.8 hr.

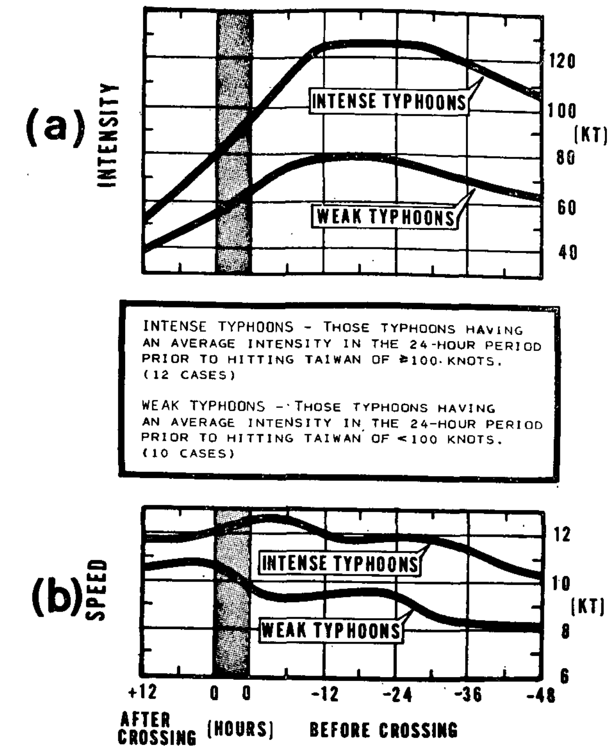


FIG. 4. Average intensity (a) and speed (b) profiles for 12 intense typhoons (having an average intensity of ≥ 100 kt in the 24-hr period prior to landfall on Taiwan) and 10 weak typhoons (having an average intensity of <100 kt in the 24-hr period prior to landfall on Taiwan).

The average speed of movement profile (Fig. 3b) shows an increase in speed during the period from -48 hr to -24 hr, then a leveling off in speed of movement just prior to a slight acceleration near the island.

Another parameter examined was the movement variations of storms crossing Taiwan. This was done indirectly by examining 24-hr right-angle forecast errors; that is, the forecast error to the right or left of the best track.

Since the 24-hr forecast is heavily dependent on persistence and synoptic-scale steering, forecast errors may be related to factors not usually considered in the normal forecast. For example, Fig. 3c shows that the average right-angle forecast error for the 66 available forecasts in the 48- to 24-hr period, prior to hitting Taiwan, is 18 n mi (33 km) to the south of the best track. This could possibly be due to the storms veering more toward the northwest after following a general east-to-west track. In the 24 hr prior to hitting the island the forecasts are 22 n mi (41 km) to the north as the storms continue toward Taiwan and do not continue veering in a recurving situation.[5] The exceedingly

[5] It should be pointed out that the mean latitude of recurvature of typhoons (24N) is approximately the same latitude of that of Taiwan (Burroughs and Brand, 1972).

large right-angle forecast error to the north of Taiwan after leaving the island [+52 n mi (96 km)] reflects the southerly movement of the storms as they leave the influence of the island. This can be seen dramatically in the detailed tracks shown by Fig. 2. Figure 2 also shows a northward deflection for some of the storms beginning approximately 120 n mi (222 km) from Taiwan. Additionally, many of the storms exhibit a deflection to the north and then south as they move around the mountain range.

The question then arises as to whether the effect of Taiwan is the same for both intense and weak typhoons. If those typhoons having an initial average intensity of ≥ 100 kt in the 24-hr period prior to hitting Taiwan are separated from those typhoons having an average initial intensity < 100 kt, some interesting comparisons can be made. For example, as seen in Fig. 4a, intense typhoons are considerably affected by Taiwan, showing an average decrease in maximum wind from 115 kt to 65 kt (45% decrease) from 6 hr prior to hitting Taiwan to 6 hr after leaving. Weak typhoons decrease in maximum wind from 75 kt to 45 kt (40% decrease) in this time period. Notice that both intense and weak typhoons start to decrease in intensity about 12 hr prior to hitting the island.

The speed of movement profiles (Fig. 4b) show the intense typhoons to be the faster moving systems. Note the increase in speed as the weak typhoons cross the island, while the intense typhoons show a slight decrease.

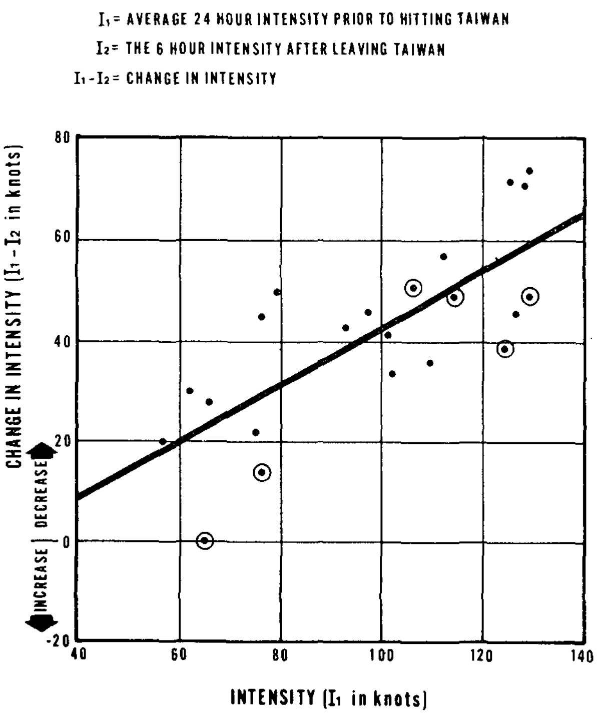


FIG. 5. Average intensity of typhoons 24 hr prior to hitting Taiwan (I_1) versus the change in intensity ($I_1 - I_2$), where I_2 is the intensity 6 hr after leaving Taiwan. The circled values are for those typhoons whose centers crossed just the southern or northern tips of the island.

TABLE 2. The effect of crossing Taiwan on tropical cyclones of different intensity and vertical extent (Based on Hsu, 1960).

Tropical cyclone category	Intensity (maximum wind)		Approximate vertical extent	Effect of Taiwan on tropical cyclone
I	<50 kt	or	<10,000 ft (3 km)	Tropical cyclone will dissipate.
II	50–100 kt	or	20,000 ft (6 km)	Secondary lows will form and may take over circulation. The tropical cyclone may appear to jump forward.
III	>100 kt	or	>35,000 ft (10.7 km)	Tropical cyclone will follow a continuous track even though secondary lows may form.

Another manner in which to examine the effect of Taiwan on typhoon intensity is to plot the average intensity of the storm approaching the island versus the change in storm intensity that occurred while traversing the island. This can be seen in Fig. 5, which is a plot of the average 24-hr intensity prior to hitting Taiwan (I_1), versus the change in intensity ($I_1 - I_2$), where I_2 is the intensity 6 hr after leaving the island.[6] The distribution has a correlation coefficient of 0.75 and the computed regression line based on the distribution could be of use to the forecaster. For example, Fig. 5 shows that if the maximum wind in a typhoon averages 120 kt in the 24-hr period prior to hitting the island, then the intensity 6 hr after leaving Taiwan will be approximately 55 kt less. Those typhoons which crossed the southern or northern tips of the island are shown as circled values and seem, in general, to indicate a smaller decrease in intensity than the other values in the distribution. Note there were no storms that showed an increase in intensity.

In order to examine the effect of those storms passing near, but not actually crossing Taiwan, a cursory study was made of those east-west moving typhoons whose centers came within 60 n mi (111 km) of Taiwan. The average 24-hr intensity prior to the time when the storms were at their closest point of approach to Taiwan was compared with the intensity value 6 hr after closest approach. Of the seven typhoons found fitting the above criteria, five experienced little or no change in intensity and the other two decreased in intensity, but well below the regression relationship as indicated in Fig. 5.

4. Some additional considerations

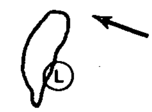
The results presented here show that the intensity and the speed and direction of movement of typhoons are significantly influenced by Taiwan. Primary causes include the reduction of heat and moisture supplied by

[6] See footnote 1.

a. If a typhoon heads westerly or northwesterly toward Taiwan and a secondary low forms on the western side of the island (near Taichung -24°09'N, 120°41'E) and intensifies, the typhoon will not recurve.

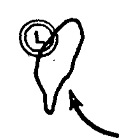
b. If a typhoon heads westerly or northwesterly toward the southern tip of Taiwan or just south of the island and a series of secondary lows or a trough forms on the western side of the island, there will be little or no recurvature.

c. If a typhoon heads westerly or northwesterly toward the northern tip of Taiwan and a secondary low forms near the southeast edge of the island (near Taitung-22°45'N, 121°09'E), the typhoon will pass north, or just hit the northern tip of the island.

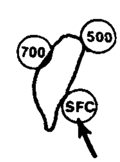


d. If a typhoon heads northwesterly toward Taiwan in a northerly curving trajectory (or a typhoon heads north in close proximity to the east coast of Taiwan), and a secondary low appears on the west coast of Taiwan and moves slowly northward and weakens, the typhoon will not cross Taiwan. These typhoons would in general be the more intense typhoons (Category III).
Note: These secondary lows can at times extend up to the 700-mb level and this could mislead the forecaster in thinking the typhoon has crossed the island.

e. If a typhoon heads northwesterly toward Taiwan in a northerly curving trajectory (or a typhoon heads north in close proximity to the east coast of Taiwan), and a secondary low appears on the west coast of Taiwan and intensifies, the secondary low will take over the typhoon circulation. These typhoons would in general be the less intense typhoons (Category II).
Note: The closer to the mountain range the primary typhoon lies, the better are the chances for a secondary low to take over the circulation.



f. If a typhoon is heading north-northwesterly toward Taiwan and the vertical axis tilt of the cyclonic circulation breaks into two segments (the lower to the northwest and the upper to the northeast), the typhoon is in the process of recurvature. If a constant vertical tilt exists, the typhoon will head in that direction.



g. If a typhoon is heading northerly toward the southern tip of Taiwan, the typhoon will tend to move toward the east side of the island.

FIG. 6. Forecast rules for tropical cyclones approaching or crossing Taiwan.

the ocean and the frictional effects of the land mass itself as it disrupts the balance of forces of the typhoon circulation. In addition, the steering current in which the typhoon circulation is embedded is probably significantly influenced by the mountain range which extends north-south for about 140 n mi (260 km) with terrain above 6000 ft (1.8 km), and with many peaks extending over 10,000 ft (3 km).

The mountainous terrain of Taiwan also produces a meteorological phenomenon peculiar to extensive mountain barriers; that is, the induced low. These lows or a trough are produced dynamically as the flow passes over the mountain barrier or by the horizontal wind shear resulting from the wind flow about the corners of the island.

Hsu (1960) and Li (1963) indicate that the area of formation, the increase and decrease of intensity, and the movement variations of these induced lows have a definitive relationship with the primary typhoon. These relationships can at times be used as an aid in forecasting the typhoon movement and intensity changes.

The effect of crossing Taiwan on tropical cyclones of different intensities and different vertical extent of circulations have been summarized (Hsu, 1960) and can be seen in Table 2.

Tropical cyclones with a maximum sustained wind of less than 50 kt, or with a vertical extent less than 10,000 ft (3 km) (Category I), will tend to dissipate over the island. Those storms between 50–100 kt, or with vertical extent of circulation about 20,000 ft (6 km) (Category II), will tend to produce secondary induced lows that may take over the circulation. These storms may appear to "jump forward" or accelerate rapidly through the island (see speed of movement profile for weak typhoons, Fig. 4b). Those exceeding 100 kt, or with vertical extent of circulation above 35,000 ft (10.7 km) (Category III), will follow a continuous track even though secondary lows will form.

Based on many of the ideas presented by Hsu (1960) and Li (1963), Fig. 6 presents a paraphrased series of forecast "rules" (derived from detailed synoptic analyses of some 25 tropical cyclone situations from 1952–62) for tropical cyclones approaching or crossing Taiwan which are applicable if there are no significant changes in the steering current. The synoptics of each individual situation should, of course, be taken into consideration by the forecaster if observational information is available. For example, cooler air if near the tropical cyclone may enter the circulation of the storm and decrease its intensity. Or, at times, surges in the northeast monsoon may increase the low-level cyclonic shear in the region of the low-level trough, if present, and this presents an excellent path for tropical cyclones.

In the later months of the typhoon season the ocean becomes a factor since sea-surface temperatures near Taiwan decrease more rapidly than those in the Philippine Sea region to the southeast. The thermal structure parameters, other than sea-surface temperature, are also very important in that they determine how much warm water is available for the energy of the storm (Brand, 1971).

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