Appendix B

Characteristics of Tropical Cyclones Affecting the Philippine Islands (Shoemaker 1991)

Using a powerful desktop computer and computerized data bases available at the Naval Oceanography Command Center/Joint Typhoon Warning Center (NAVOCEANCOMCEN/JTWC), Shoemaker (1991) presents a climatology of tropical cyclones (TCs) approaching or crossing the Philippine Islands.

The data base for examining TC intensity, direction and speed includes all six-hourly best track positions from 45 years (1945–1989). However due to the lack of satellite coverage the earlier portion of the record identified fewer weak TCs and lowered the number of TCs which hit the PI by more than one per year (20%). Therefore the climatology section is based on **20 years (1970–1989)** to preclude lowering the numbers of weaker systems.

The September-November period has the maximum potential for TCs to hit the Philippine Islands. The average time over land is 11 hours north of 14.5°contrasted to 20 hours south of 14.5°.

The average latitude of landfall has an annual cycle, similar to the monsoon trough, with a latitude maximum during August (~15.5°N) and a latitude minimum during February (~9.0°N).

TCs of intensity >65 knots just prior to landfall reach peak intensity 6 to 12 hours prior to landfall whereas storms 65 knots or less prior to landfall peak only 0 to 6 hours before landfall. TCs of typhoon intensity generally weaken as they cross the PI, but TCs with intensity less than 50 knots at landfall do not weaken significantly. The amount of weakening is proportional to intensity, and weakening is less for TCs south of 14.5°.

The average speed in the 12 hours prior to landfall for TCs hitting the PI south of 14.5°N is 13.3 knots with a standard deviation of 4.2 knots. North of 14.5°N, the average speed is 11.8 knots with a standard deviation of 3.2 knots. Accordingly, the average time over land is 20 hours south of 14.5°N, but only 11 hours north of 14.5°N (due to the narrow E-W dimension of Luzon).

TCs moving faster than 15 knots tend to slow down after making landfall; however, TCs moving 15 knots or less experience little velocity change.

The mean direction of motion just before first landfall is west-northwestward; only two storms in 45 years have **first** hit the PI with an eastward velocity component, (i.e., coming **from** the South China Sea), and both were weak systems.

TCs moving south of west tend to turn more westward after landfall; however, TCs moving west-northwestward show little change in direction. TCs moving more north than west (320°–360°) tend to recurve before hitting the Philippine Islands (Shoemaker 1991).

ANNUAL CLIMATOLOGY(1970–1989)

The Philippine Islands (0° to 20°N, 118° to 128°E) are hit by an average of **6.5 TCs per year**. Only three TCs struck the PI during two of the 20 years; whereas, the maximum occurred in two years when 12 TCs struck the PI. With a standard deviation of 2.6, **approximately 70% of the time between 4 and 9 TCs strike annually**.

The average intensity at landfall ("just before landfall") for TCs striking the PI is **66.9 knots**. With a standard deviation of 34.4 knots, **approximately 70% of the TCs have an intensity between 30 and 100 knots**. 10% have ≥120 knots intensity. During the 20-year period, seven (7) super typhoons (≥130knots) struck the PI (see Fig. B.1).

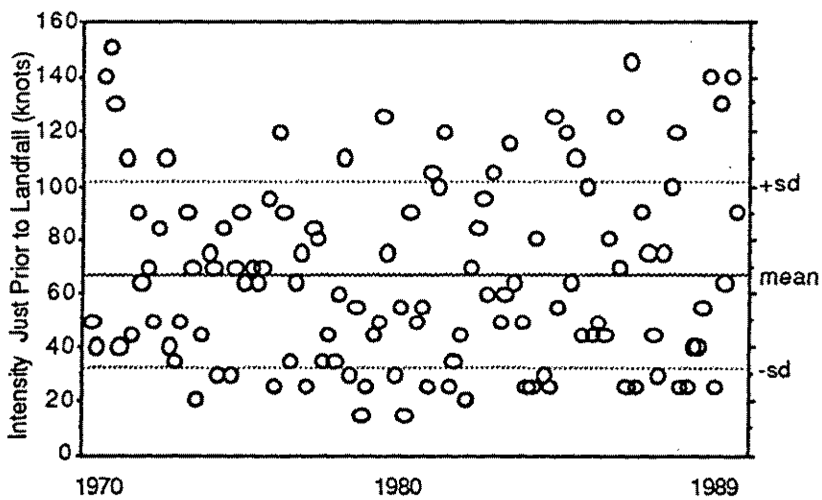


Figure B.1: Average Intensity of TCs Hitting the PI (adapted from Shoemaker (1991)).

TCs that miss the PI (but are located for at least 24 hours in the latitude/longitude box defined above) are significant because they still threaten the PI, causing preparations to be made and impacting operations. The average number of TCs which miss the PI is 4.0 with a standard deviation of 1.6 (see Fig. B.2).

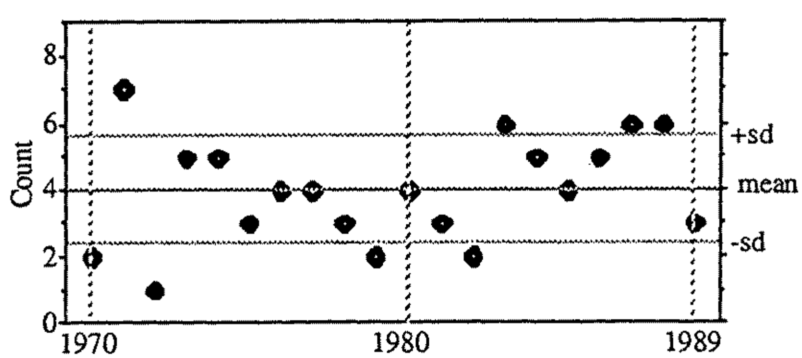


Figure B.2: Annual Climatology of TCs in the Area of Interest but Missing the PI (adapted from Shoemaker (1991)).

The annual mean latitude of landfall is 13.9°N. The standard deviation of 2.7° places the center in the area which is most likely to affect Manila as well as Subic Bay.

MONTHLY CLIMATOLOGY(1970–1989)

Figure B.3 shows the distribution of PI tropical cyclones by month (darkest shade ≡ super typhoon). The lack of February TCs corresponds to the peak of the northeast monsoon when TCs are sheared apart before reaching the PI. The relative minimum in August occurs when the southwest monsoon trough is farthest north and the TCs form on the trough too far north to impact the PI (Atkinson 1971).

The annual distribution is bi-modal, coinciding with the monsoon transition seasons of June–July and October–November. TCs forming close to the islands impact at tropical depression or tropical storm intensity, while those forming farther east in the Philippine Sea are likely to impact at typhoon intensity. In December the number of recurvers and sheared systems increase, and fewer TCs hit the PI.

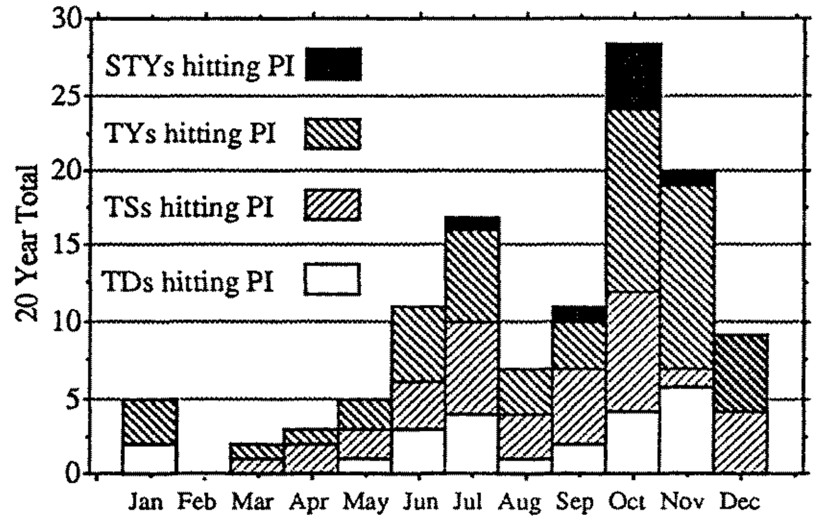


Figure B.3: TCs Hitting the PI during the 20 Years 1970–1989 (adapted from Shoemaker (1991)).

Figure B.4 reveals that while June TCs have the weakest average intensity, November (during the peak season) has the highest average intensity. March with only two TCs, one intense (105 knots) and one moderate (60 knots), ranks surprisingly high. Standard deviations are in the 20 to 30 knot range.

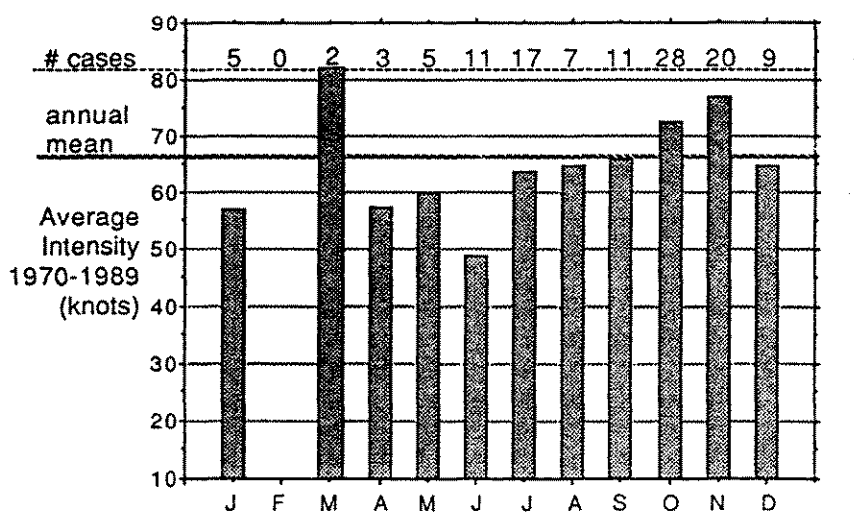


Figure B.4: Monthly Climatology of Intensity for TCs Hitting the PI (adapted from Shoemaker (1991)).

Figure B.5 shows the latitude of landfall following a cycle similar to the monsoon trough cycle, with a latitude maximum occurring during August and a minimum during February (Shoemaker 1991).

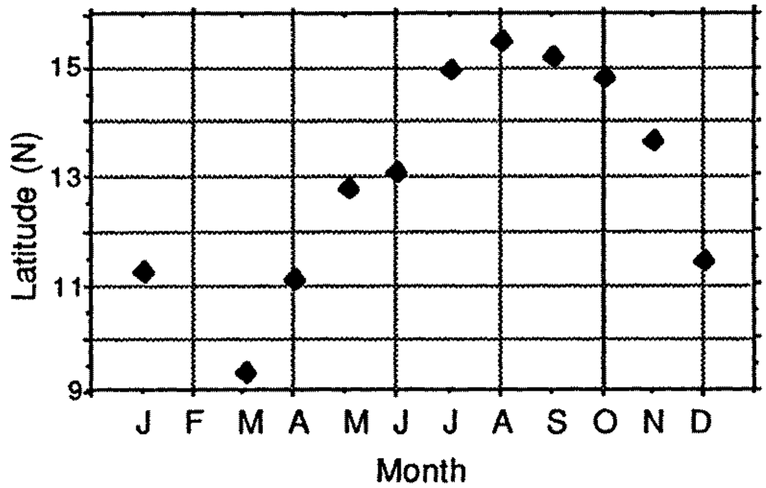


Figure B.5: Monthly Climatology of Landfall Latitude of TCs hitting PI (adapted from Shoemaker (1991)).

INTENSITY CHANGES(1945–1989)

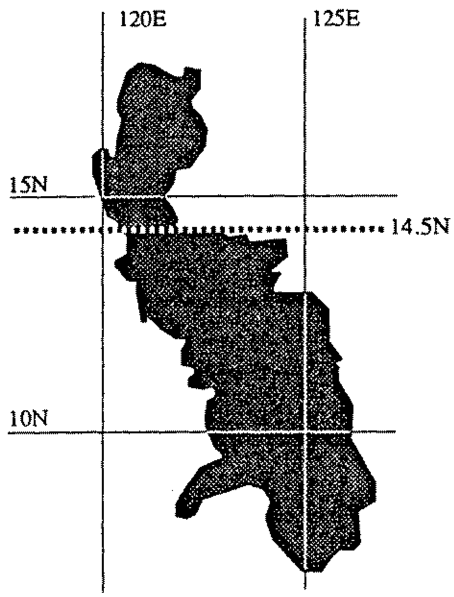


Figure B.6: The Philippines separated by 14.5°N. Transition time was based on entering and exiting the gray area (adapted from Shoemaker 1991)).

Intensity change statistics utilize the entire 45-year data set and will contain tropical depressions and tropical storms, as well as typhoons. As depicted at left in Fig. B.6, the Philippine Islands are divided into two regions—south and north of 14.5°N. The area encompassed by the island is about twice as wide **south** of 14.5°N, where there are smaller islands. The northern region, primarily *narrow* northern Luzon, consists of many mountains, while only a **smaller** portion of the southern region includes Mindanao with its mountainous terrain.

Tropical Depressions (25–30 kt) do not present a wind threat, but can still cause heavy rainfall. Tropical depressions actually tend to increase slightly in intensity while transiting the Philippines (see Table B.1). This increase, despite the frictional effects of land, may occur since tropical depressions have normally formed just east of the islands and are responding to the dynamics increasing their intensity to a tropical storm.

Tropical Storms (35–62 kt) are subdivided into weak (35–45 kt) and strong (50–60 kt) tropical storms. While both weaken slightly, strong tropical storms weaken more than the weak ones (Table B.1).

Typhoons are subdivided into weak (65-80 kt), moderate (85–100 kt) and strong (≥100 kt). As reported in earlier studies, the more intense the typhoon, the larger the intensity decrease while transiting the islands (Table B.1).

Note that the standard deviations shown in Table B.1 indicate that the most variability occurs with moderate typhoons. Possibly some have peaked before landfall, while others intensify. Variability may also be due to the speed of transition, since slower-moving typhoons experience land effects longer. Further stratification is included in Tables B.2–B.3.

Table B.1: Intensity Change for Tropical Cyclones Crossing the Philippines (Intensity, Change and Std. Dev. in Knots)(adapted from Shoemaker (1991)).

	South of 14.5°			North of 14.5°		
Intensity at Landfall	Intensity Change	Std Dev	# of Cases	Intensity Change	Std Dev	# of Cases
25 - 30	5.8	11.3	19	3.0	7.5	10
35 - 45	-2.5	9.6	22	-2.0	11.4	10
50 - 60	-5.8	9.7	18	-6.7	9.9	15
65 - 80	-17.5	13.3	18	-13.5	12.5	26
85 - 100	-20.3	26.4	15	-25.0	25.8	21
> 100	-49.4	16.6	16	-43.5	19.3	23

Tables B.2 through B.3 provide a stratification by **intensity trend** prior to landfall. Tropical cyclones that weaken in the 12 hours prior to landfall show less variability in their intensity change than those that are intensifying.

Tropical cyclones are also stratified by **time over land** in Tables B.2 through B.3. Note that for moderate typhoons (85–100 kt) the faster the system moves, the less variable (smaller standard deviations) the expected intensity change (Shoemaker 1991).

Table B.2: Intensity Change for Tropical Cyclones Which Were (a) Weakening (b) Strengthening Prior to Landfall (South of 14.5°N)(Intensity in Knots) (adapted from Shoemaker (1991)).

(a)

Crossing Time	6 - 12 hours			18 - 24 hours			30 - 36 hours		
Intensity	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count
25-30	-5.0	n/a	1	n/a	n/a	0	n/a	n/a	0
35-45	n/a	n/a	0	-10.0	0	2	n/a	n/a	0
50-60	n/a	n/a	0	n/a	n/a	0	n/a	n/a	0
65-80	-26.7	2.8	3	-12.5	31.8	2	-15.0	n/a	1
85-100	-12.5	10.6	2	-10.0	n/a	1	-22.5	53.0	2
> 100	-45	n/a	1	-42.5	9.5	4	-80.0	n/a	1

(b)

Crossing Time	6 - 12 hours			18 - 24 hours			30 - 36 hours		
Intensity	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count
25-30	5.0	14.1	6	6.7	8.2	6	-10.0	n/a	1
35-45	2.5	5	4	0.0	10.5	10	-5.0	5.0	3
50-60	-1.0	6.5	5	-5.0	10.0	10	-15.0	7.1	2
65-80	-13.3	10.4	3	-15.6	13.2	8	n/a	n/a	0
85-100	22.5	3.5	2	-36.2	13.2	4	-17.5	10.6	2
> 100	-39.0	17.8	5	-65.7	4.8	4	-45.0	n/a	1

Table B.3: Intensity Change for Tropical Cyclones Which Were (a) Weakening (b) Strengthening Prior to Landfall (North of 14.5°N)(Intensity in Knots) (adapted from Shoemaker (1991)).

(a)

Crossing Time	6 hours			12 hours			18 hours		
Intensity	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count
25-30	-10.0	n/a	1	n/a	n/a	0	n/a	n/a	0
35-45	-5.0	n/a	1	n/a	n/a	0	n/a	n/a	0
50-60	-10.0	5.0	3	n/a	n/a	0	n/a	n/a	0
65-80	-16.7	30.5	3	-10.0	7.1	2	-30.0	n/a	1
85-100	-23.3	11.5	3	-10.0	9.1	4	-25.0	30	3
> 100	-43.3	10.3	6	-45.0	n/a	1	-75.0	n/a	1

(b)

Crossing Time	6 hours			12 hours			18 hours		
Intensity	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count	Ins Chg	Std Dev	Count
25-30	0.0	0.0	2	4.0	6.5	5	n/a	n/a	0
35-45	-5.0	7.1	2	-0.7	13.3	7	n/a	n/a	0
50-60	-11.2	6.3	4	-5.0	10.0	4	7.5	17.6	2
65-80	-16.7	5.2	6	-10.5	10.6	11	-15.0	n/a	1
85-100	-26.7	2.9	3	-26.7	13.7	6	60.0	n/a	1
> 100	-37.9	27.5	7	-44.2	16.9	6	-30.0	n/a	1

DIRECTION CHANGES

Using a small data base, Brand and Blelloch (1972) reported that TCs crossing the Philippine Islands tend to move more northward just after landfall, followed by a westward shift after exiting into the South China Sea. In Shoemaker's study, a larger data base is used to examine direction changes of TCs.

Figure B.7 shows the direction of movement of **all** TCs at the time of landfall. Additionally, direction of movement during six-hourly increments, for 48-hours before and 48-hours after landfall, is presented. The average direction of movement at landfall is found to be toward the northwest (283°). However, in contrast to the earlier study (Brand and Blelloch 1972), the TCs are found to move slightly more northwards after exiting into the South China Sea. The increased length of the error bars following landfall indicates the greater variability of the direction of movement following landfall (see Fig. B.7).

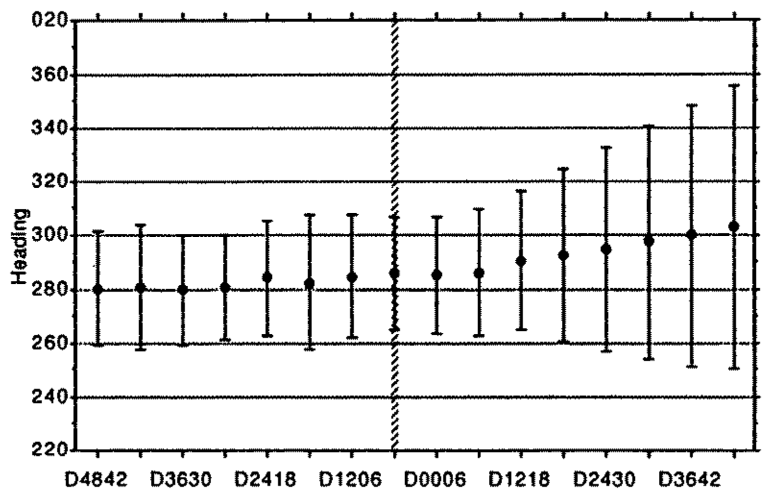


Figure B.7: Average Direction of Movement prior to and after Landfall in the Philippines. Error bars represent one standard deviation. The horizontal axis is in six hourly increments prior to and after landfall (dashed vertical line) (adapted from Showmaker (1991)).

Figures B.8 through B.11 stratify the TCs that cross the Philippines by the direction of movement and by intensity, just prior to landfall.

- Weak TCs moving toward the west-southwest generally travel more westward 48 hours prior to landfall, and after landfall. More intense TCs moving toward the west-southwest have a greater tendency, than the weaker TCs, to turn toward the northwest (see Figs. B.8(a) and (b)).
- More intense TCs moving toward the west have less directional variability and tend to turn more toward the northwest than do weaker TCs (see Figs. B.9(a) and (b)).
- TCs moving toward the west-northwest exhibit less directional variability. In the late calendar year, the winter monsoon, with low level flow from the northeast can shear a system apart and force a more southward movement—thus the large standard deviation after exiting into the South China Sea (see Figs. B.10(a) and (b)).
- TCs moving northwestward exhibit great variability in direction after landfall indicating that many recurve—especially the stronger TCs. Northwestward moving TCs tend to move more westward after landfall (while crossing the PI), then resume their northwestward movement—again, especially the stronger TCs (see Figs. B.11(a) and (b) (Shoemaker 1991).

(a)

(b)

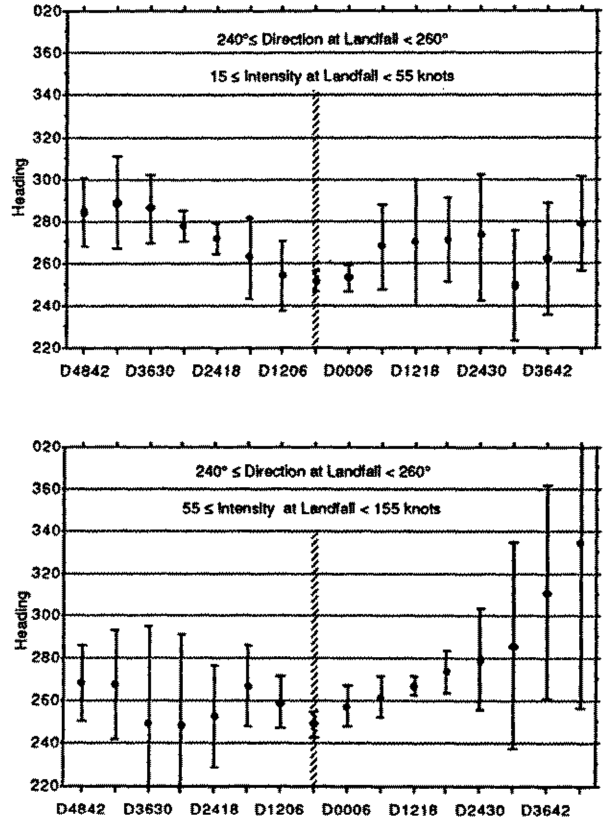


Figure B.8: Average Direction of Movement of Weaker (a) and More Intense (b) TCs Moving **West-southwest** at Landfall. Error bars represent one standard deviation (adapted from Shoemaker (1991)).

(a)

(b)

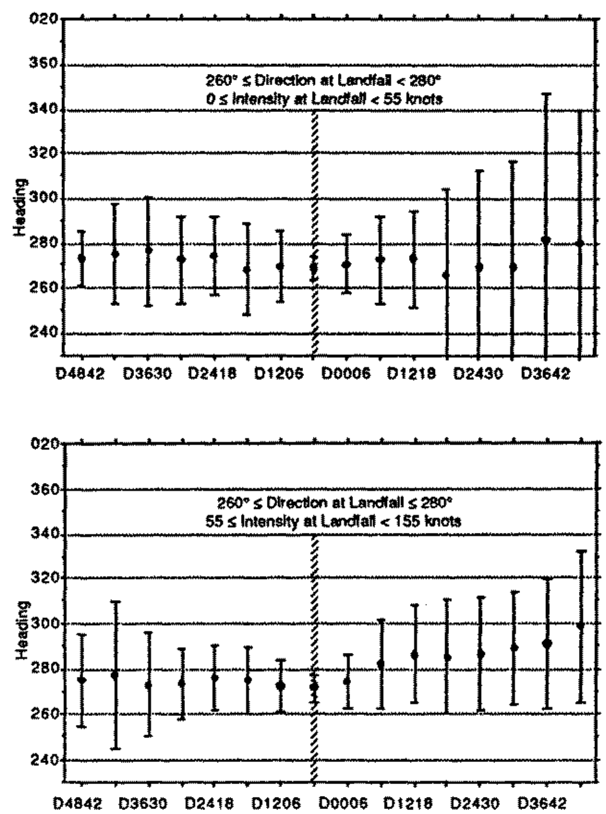


Figure B.9: Same as Fig. B.8 except for TCs Moving **Westward** (adapted from Shoemaker (1991)).

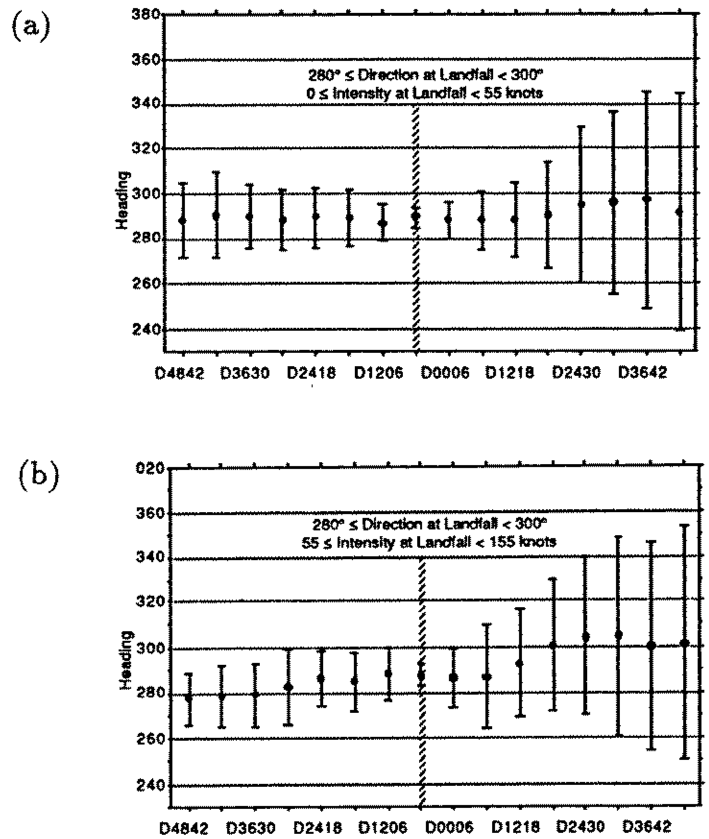


Figure B.10: Average Direction of Movement of Weaker (a) and More Intense (b) TCs Moving **West-northwest** at Landfall. Error bars represent one standard deviation (adapted from Shoemaker (1991)).

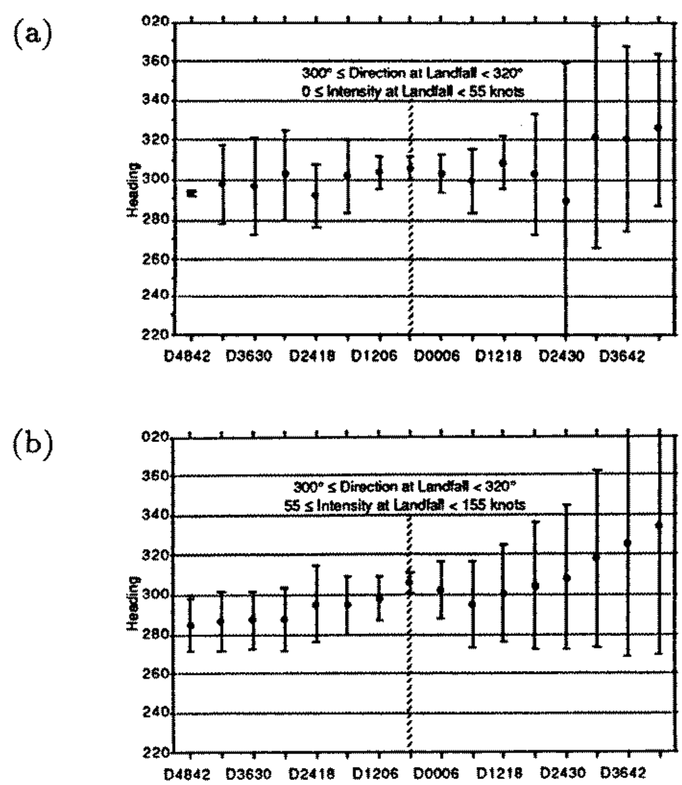


Figure B.11: Same as Fig. B.10 except for TCs Moving **Northwestward** (adapted from Shoemaker (1991)).

SPEED

The forecasting of the speed of movement of TCs approaching the Philippine Islands affects setting of Conditions of Readiness (CORs), as well as the time of onset and cessation of damaging winds.

Brand and Blelloch (1972), using a small sample of 30 typhoons (only), observed that these typhoons slowed until 18 hours prior to landfall, accelerated until landfall and then slowed while exiting into the South China Sea. Speed of movement differences, for typhoons averaging 12 knots at landfall, were less than two knots. Shoemaker (1991), using a much larger data base, reexamines TCs speed, presenting a detailed stratification and standard deviation statistics.

In Figure B.12, the TCs moving **westward** or **west-northwestward** (260° – 300°) during the six hours prior to landfall are presented. Six-hourly speeds are computed using adjacent best track positions.

In Figs. B.13–B.16, the TCs are stratified into categories of tropical depressions, tropical storms, typhoons ≤100 knots and typhoons >100 knots. These categories are further subdivided by speed of movement (slow, moderate and rapid). A further stratification across 14.5°N had no effect and was not presented.

Results reveal a slight tendency for systems to move gradually faster until landfall, with an increased tendency for TCs with a larger speed at landfall. TCs tend to slow down after landfall and during exit into the South China Sea. Individual TC speed differences may be caused by synoptic factors, since most speed differences lie within one standard deviation of the mean.

In the following figures, categories were omitted when the sample size was one or less (Shoemaker 1991).

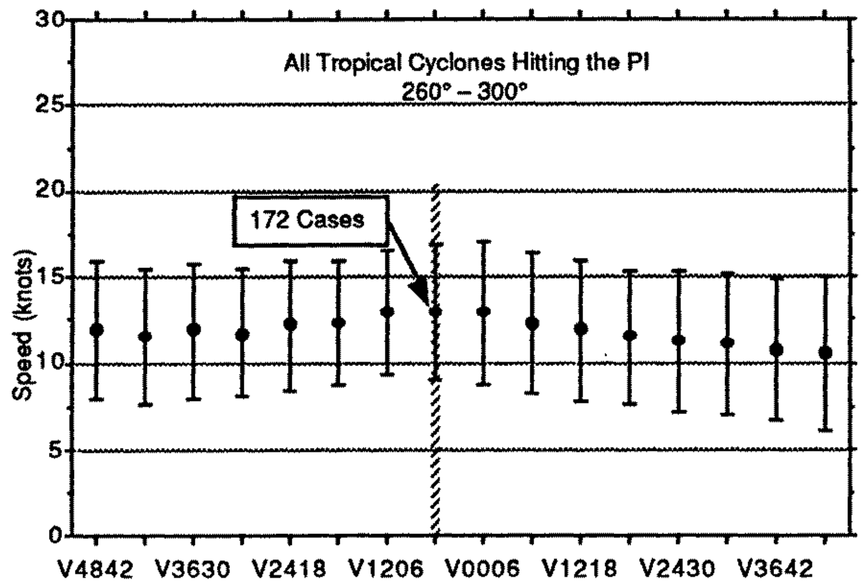
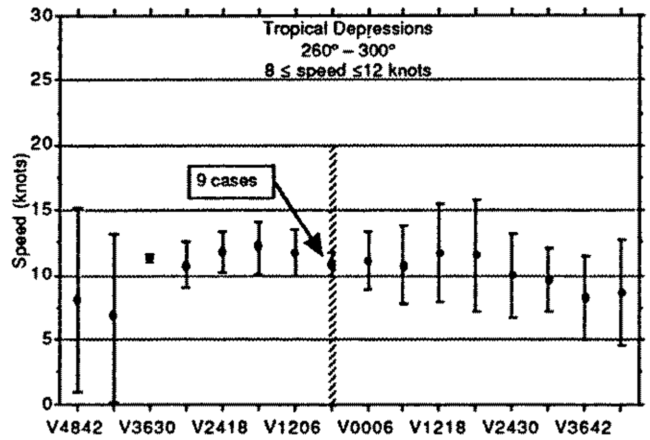
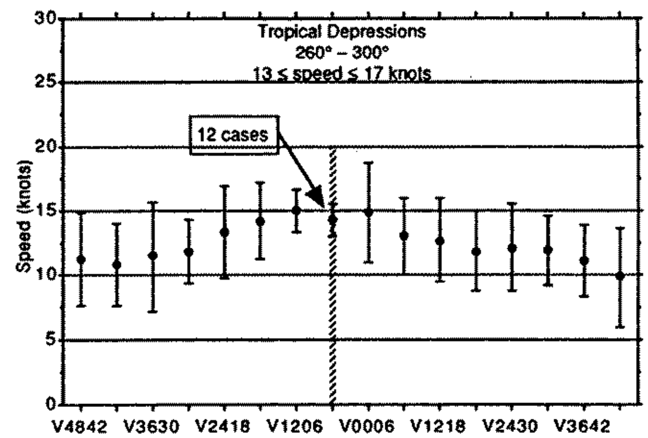


Figure B.12: Six Hourly Average Speed for **All** Tropical Cyclones moving Westward or West-northwestward in the Six Hours prior to Landfall. Error bars indicate one standard deviation. The dashed vertical line represents landfall (adapted from Shoemaker (1991)).

(a)



(b)



(c)

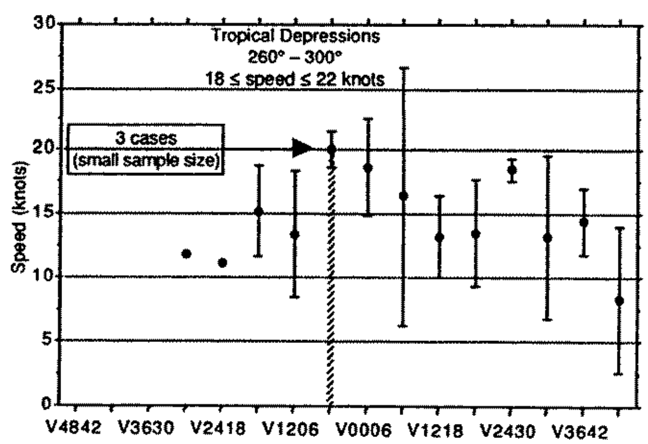


Figure B.13: Six Hourly Average Speed for Tropical Depressions (Intensity 25–30 knots) Moving at (a) 8 to 12 knots (b) 13 to 17 knots and (c) 18 to 22 knots Prior to Landfall. Error bars represent one standard deviation. Note the small sample size and large standard deviations in (c) (adapted from Shoemaker (1991)).

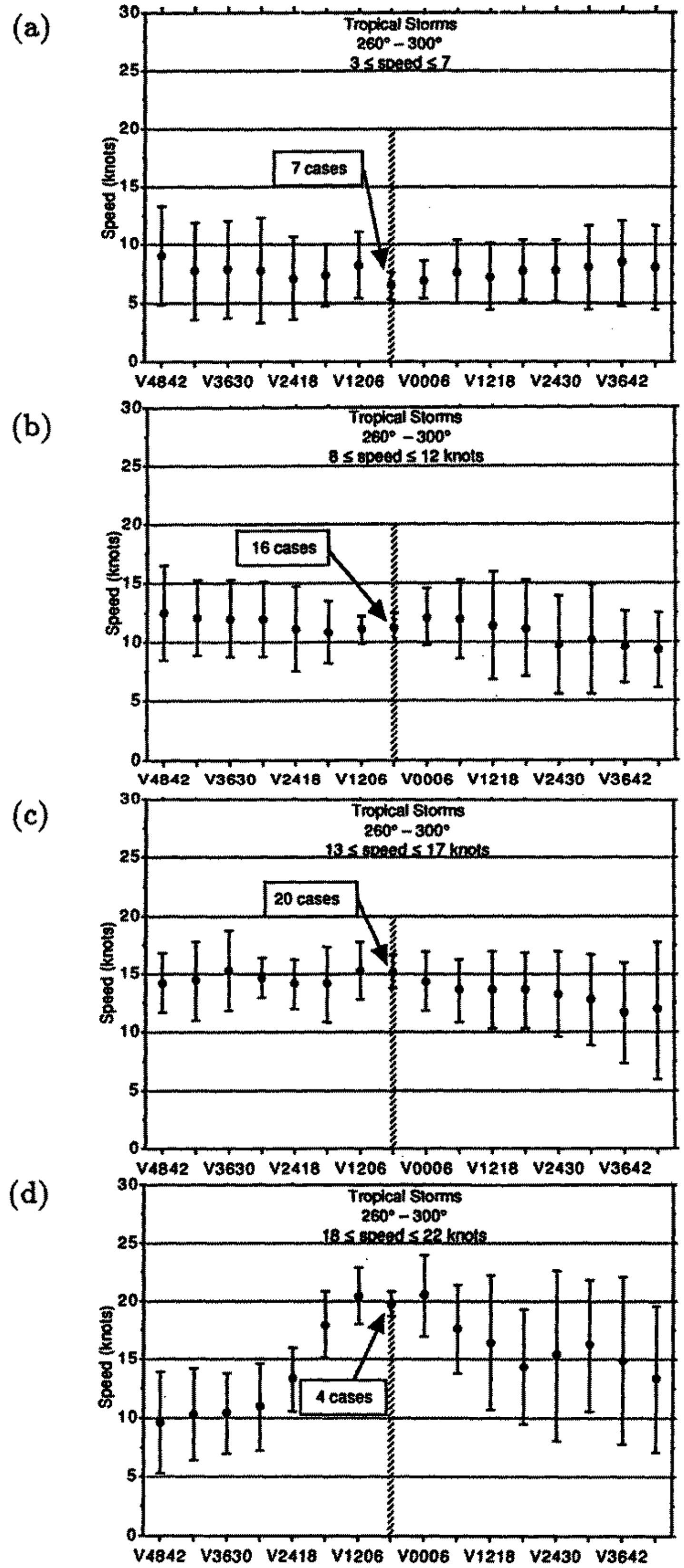


Figure B.14: Six Hourly Average Speed for Tropical Storms (Intensity 35–60 knots) Moving at (a) 3 to 7 knots (b) 8 to 12 knots (c) 13 to 17 knots and (d) 18 to 22 knots Prior to Landfall. Error bars represent one standard deviation. Again, note the small sample size in the most rapidly moving tropical storms in (d) (adapted from Shoemaker (1991)).

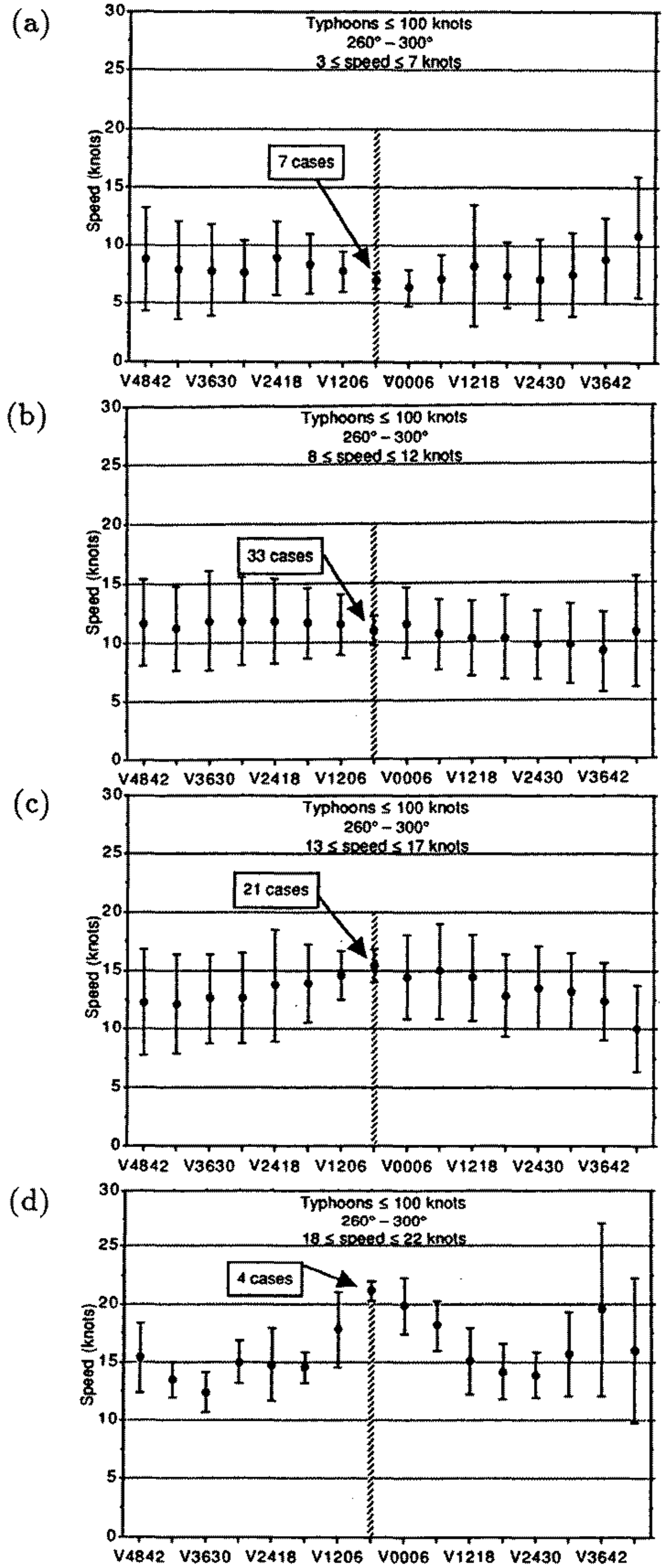


Figure B.15: Six Hourly Average Speed for Typhoons (Intensity ≤100 knots) Moving at (a) 3 to 7 knots (b) 8 to 12 knots (c) 13 to 17 knots and (d) 18 to 22 knots Prior to Landfall. Error bars represent one standard deviation. Again, note the small sample size in the very fast moving typhoons in (d) (adapted from Shoemaker (1991)).

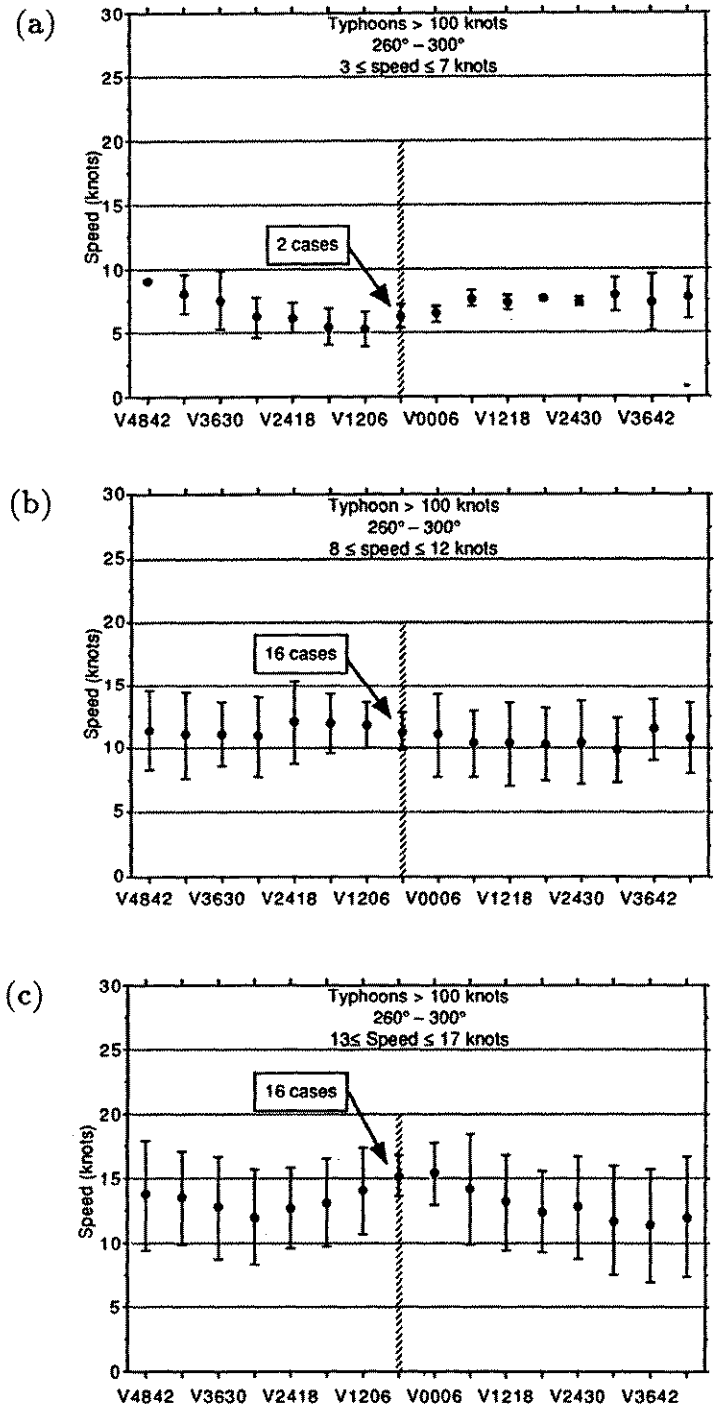


Figure B.16: Six Hourly Average Speed for Typhoons (Intensity >100 knots) Moving at (a) 3 to 7 knots (b) 8 to 12 knots and (c) 13 to 17 knots Prior to Landfall. Error bars represent one standard deviation. Note the small sample size in the slow moving strong typhoons in (a); no strong typhoons made landfall moving faster than 17 knots. Such speed are generally caused by a strong environmental wind envelope, which tends to shear the TCs apart vertically (adapted from Shoemaker (1991)).