REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: NAVENVPREDRSCHFAC Technical Paper No. 3-76
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): An Evaluation of the Harbor of Cebu, Republic of the Philippines, as a Typhoon Haven
5. TYPE OF REPORT & PERIOD COVERED
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): B. K. Hassell
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Environmental Prediction Research Facility, Monterey, CA 93940
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AIR TASK: A370-370G/076C/6W0S33-0000 NEPRF WU: 055:3-2
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Air Systems Command, Department of the Navy, Washington, D.C. 20361
12. REPORT DATE: May 1976
13. NUMBER OF PAGES: 74
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Tropical Cyclone
Typhoon
Typhoon Haven
Cebu City
Cebu Harbor
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study is an evaluation of Cebu Harbor as a typhoon haven. Characteristics of the harbor discussed include facilities available, wind and wave action, storm surge and the topographical effects on winds prior to and during passage of tropical cyclones. Problems to be considered if remaining in port and possible evasion procedures for ships sailing from the port are examined.

20. Abstract (continued)

The tracks of tropical cyclones from 1947-1974 for the western North Pacific were analyzed to determine the probability of threat to Cebu Harbor. Observations by the author and information obtained in conversations with port and harbor authorities were utilized in reaching conclusions.

In general, the results indicate that Cebu Harbor is not a safe haven. Under threatening conditions, all fleet units capable of evasion at sea should sortie at the earliest possible moment.

NAVENVPREDRSCHFAC
Technical Paper No. 3-76

AN EVALUATION OF THE HARBOR OF CEBU, REPUBLIC OF THE PHILIPPINES, AS A TYPHOON HAVEN

by

B. K. HASSELL

MAY 1976

NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
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AN (1) AD-A027 533
FG (2) 040200
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CA (5) NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
MONTEREY CALIF
TI (6) An Evaluation of the Harbor of Cebu, Republic of the
Philippines, as a Typhoon Haven.
TC (8) (U)
DN (9) Technical paper,
AU (10) Hassell,B. K.
RD (11) May 1976
PG (12) 74p
RS (14) NEPRF-Technical Paper-3-76
PJ (16) A370-370G/076-C/6W0533-0000
RC (20) Unclassified report
DE (23) *Typhoons, *Tropical cyclones, Surface navigation,
Philippines, Paths, Tracks, Safety, Evasion,
Assessment, Storms, Sea states, Sea traffic
DC (24) (U)
ID (25) *Cebu Harbor, Evaluation
IC (26) (U)
AB (27) The report is an evaluation of Cebu Harbor as a typhoon
haven. Characteristics of the harbor discussed include
facilities available, wind and wave action, storm surge
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considered if remaining in port and possible evasion
procedures for ships sailing from the port are examined.
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FOREWORD

COMSEVENTHFLT has requested that twenty-two western North Pacific and Indian Ocean ports be evaluated as typhoon havens. CNO tasked COMNAVWEASERV with the preparation of these evaluations, and in response to a request from COMNAVWEASERV, COMNAVAIRSYSCOM tasked NAVENVPREDRSCHFAC with the development of these studies, incorporating the assistance of the Naval Postgraduate School through theses projects.

The present study of Cebu Harbor represents another step in the overall task, the final goal of which is a comprehensive typhoon havens handbook containing condensed studies for the twenty-two designated ports in the western Pacific/Indian Ocean. This particular analysis was prepared as a Master of Science thesis in Meteorology by LCDR B. K. Hassell, USN, at the Naval Postgraduate School.

The assistance of the Naval Weather Service Detachment, Asheville, and the Naval Weather Service Environmental Detachment, Cubi Point, in providing data, reports and comments is gratefully acknowledged.

R.C. Sherar
Captain, U.S. Navy
Commanding Officer
Naval Environmental Prediction
Research Facility

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ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of the following individuals of the Naval Environmental Prediction Research Facility: Mr. S. Brand for his helpful suggestions and guidance throughout the writing effort, Mr. J. W. Blelloch for his help in compiling and reducing data, Mr. M. Clark for his graphical assistance, and Mrs. W. Carlisle for her expert typing of the final manuscript.

LCDR J. M. Wright, Jr., Officer in Charge, Naval Weather Service Environmental Detachment, Naval Air Station, Cubi Point, R.P., is acknowledged for his invaluable assistance in performing liaison with officials in Cebu City. In addition, the assistance of the Naval Weather Service Detachment, Asheville, in providing data is gratefully acknowledged.

Special thanks to Major A. Paulin, PAF, Squadron Commander, 566th Operations Squadron, Mactan Airbase, R.P., for opening the proper channels in Cebu for the author. Mr. C. Canastra, Jr., Mactan International Airport, Mactan, R.P., is gratefully acknowledged for the personal effort and time contributed to the author in pursuit of personal interviews and data. Mr. A. Tantoco, Coordinator, Weather Station, Cebu Airport, Cebu, R.P., A. Mabasa, Chief Meteorologist, Aviation Weather Station, Pagasa, Mactan Airport, R.P. and CAPT Pablo J. Pido, PN (ret.) Chief Pilot of Cebu, are acknowledged for the time and effort spent in advance screening and preparation of data, as well as sharing the benefit of their many years of experience.

The guidance and assistance received under the direction of the thesis advisor, Dr. G. J. Haltiner, Chairman, Department of Meteorology, Naval Postgraduate School (NPS), is gratefully acknowledged.

1. INTRODUCTION

Severe tropical cyclones, also known as typhoons or hurricanes, are one of the most destructive weather phenomena a ship may encounter whether it be in port or at sea. When faced with an approaching tropical cyclone, a timely decision regarding the necessity and method of evasion must be reached. Basically, the question is: should the ship remain in port, evade at sea, or if at sea, should it seek the shelter offered by the harbor? This study will examine Cebu Harbor, Republic of the Philippines.

In general it is an oversimplification to label a harbor as merely good or bad. Consequently, an attempt is made here to present enough information about the harbor to aid a commanding officer in reaching a sound decision with respect to his ship. The decision process obviously does not depend on the expected weather conditions alone, but must include ship characteristics, and very importantly, the characteristics of the harbor. The latter include: surrounding topography for natural shelter provided, wind and wave action, bottom holding quality, port congestion, support facilities (normal and emergency) available to individual type commands, and particular problems ships may or may not encounter during storm conditions.

2. TROPICAL CYCLONES

2.1 DEVELOPMENT

The primary region of tropical cyclone development lies between latitudes 25N and 25S, except very near the equator. The area between the latitudes 5N to 20N and from 170E longitude to the Philippine Islands produces more intense tropical cyclones than any other region in the world. It is in this area that the water temperature is always above 26°C (78.8°F) and empirical data indicates that warm water such as this is a necessary condition for the development and intensification of tropical cyclones. These warm ocean waters over which the tropical cyclones travel provide the energy required for the growth and sustenance of the storm (Palmen and Newton, 1969).

2.2 WIND CIRCULATION

In the Northern Hemisphere the wind circulation associated with tropical cyclones is counterclockwise around the eye. Figure 1 depicts the wind pattern around the eye of a large, intense 150 kt typhoon. Note that the more intense winds are located in the right semicircle of the circulation. For this reason the right side of a tropical cyclone is known as the "dangerous semicircle."

The highest winds associated with tropical cyclones have never been accurately measured; however, based on data from past storms, tropical cyclone winds may attain speeds in excess of 200 kt. The following classification system concerning the intensity of tropical cyclones has been established by international agreement:

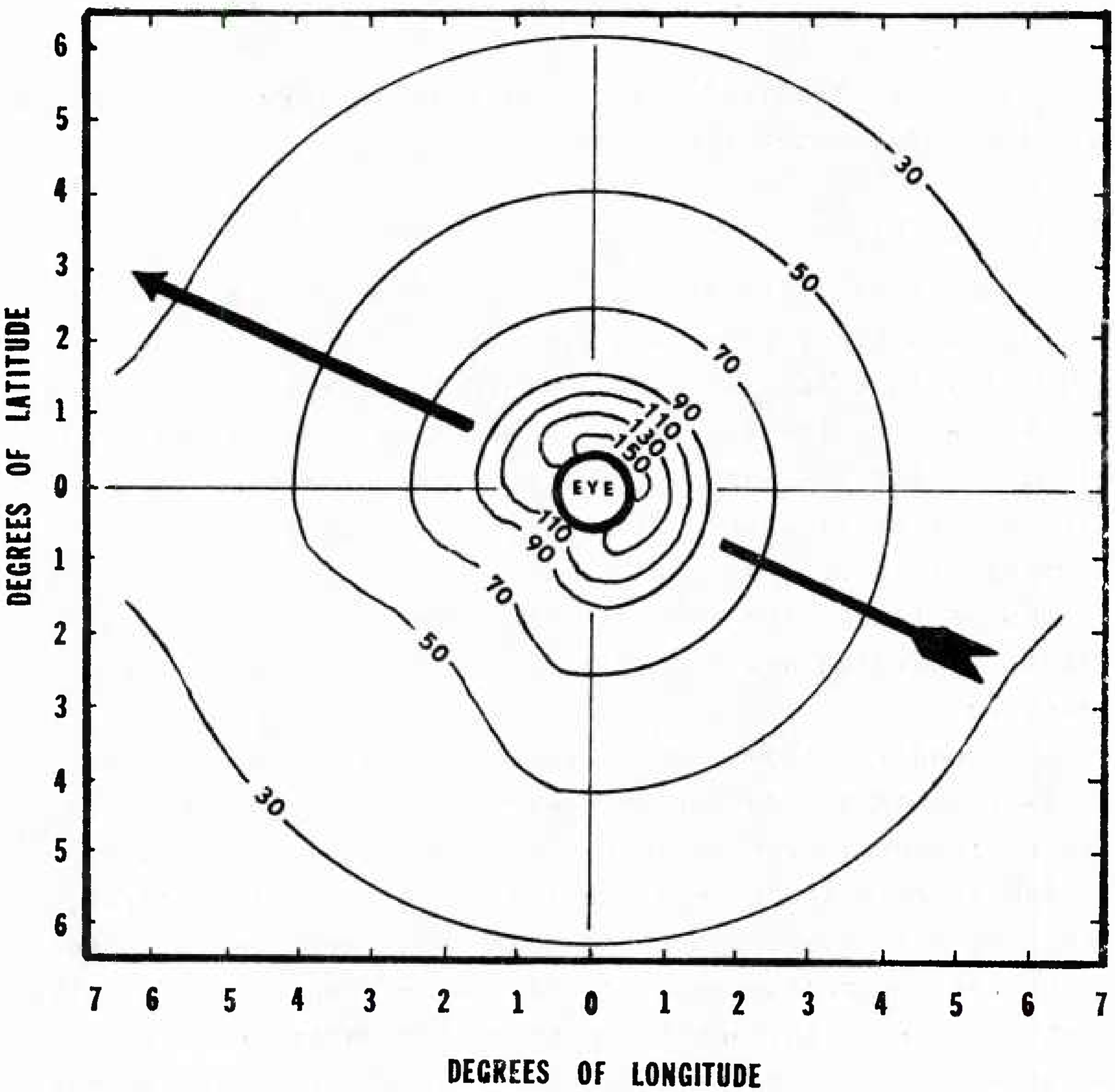

Figure 1. Distribution of surface wind speeds (in knots) around a large, intense typhoon in the Northern Hemisphere over open water. The arrow indicates direction of movement (after Harding and Kotsch, 1965).

Tropical Depression:	Maximum sustained winds no greater than 33 kt
Tropical Storm:	Maximum sustained winds in the range 34-63 kt
Typhoon:	Maximum sustained winds in excess of 63 kt

The term tropical cyclone as used in this study includes all the above categories.

2.3 MOVEMENT

The subject of tropical cyclone movement is very complicated since speed and direction of movement are primarily functions of wind and pressure patterns from the sea surface to the top of the atmosphere. In the initial stages of its development, the movement of a tropical cyclone is particularly difficult to forecast since the forecaster is dealing with an ill-defined circulation. This should be taken into account when warnings or formation alerts regarding newly developed tropical cyclones are received.

Appendix A shows the tracks of all typhoons for the June-December period for the years 1946 through 1969. In these figures it can be seen that individual cyclones may follow erratic and widely varying tracks but, in general, they begin in the tropics and move west-northwest. In some cases the movement eventually becomes northward and finally northeastward. This shifting of direction is known as recurvature. Burroughs and Brand (1972) found that approximately 40% of WESTPAC tropical storms and typhoons recurved.

Prior to recurvature, tropical cyclones generally move at speeds from 8 to 12 kt; however, after recurvature they may accelerate and reach speeds 2-3 times the speed at the point of recurvature within 48 hours. (This acceleration varies with the time of year.) During the recurvature process the tropical cyclone is moving farther from the tropics. In doing so, it comes into contact with cooler surface waters and air from extratropical regions is drawn into its circulation. These two factors usually result in the ultimate weakening and/or dissipation of the tropical cyclone.

2.4 SEA STATES AROUND TROPICAL CYCLONES

It is important to realize that sea conditions affecting ship movement will extend well beyond the wind field associated with a tropical cyclone, and a miscalculation concerning sea conditions could result in a destructive rendezvous with the storm. The extent of the sea state generated by a tropical storm is primarily a function of storm size, duration and intensity. Figure 2 shows the combined sea height[1] associated with 21 WESTPAC tropical storms and typhoons (based on 173 analyses for the year 1971) plotted as a function of distance from the storm center and storm intensity (Brand, et al., 1973). There is a large variation in the sea state with storm intensity. A tropical storm (winds 34-63 kt) could produce 12 ft seas 217 n mi from the storm center, while an intense typhoon (winds ≥100 kt) could produce 12 ft seas 454 n mi from the center. The distances given are mean distances since the isopleths

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[1]The combined sea height is defined as the square root of the sum of the squares of "significant" sea and swell height. Sea is wind waves, and swell consists of wind generated waves which have advanced into regions of weaker or calm winds. "Significant" will be defined here as the average height of the highest one third of the waves observed over a specified time.

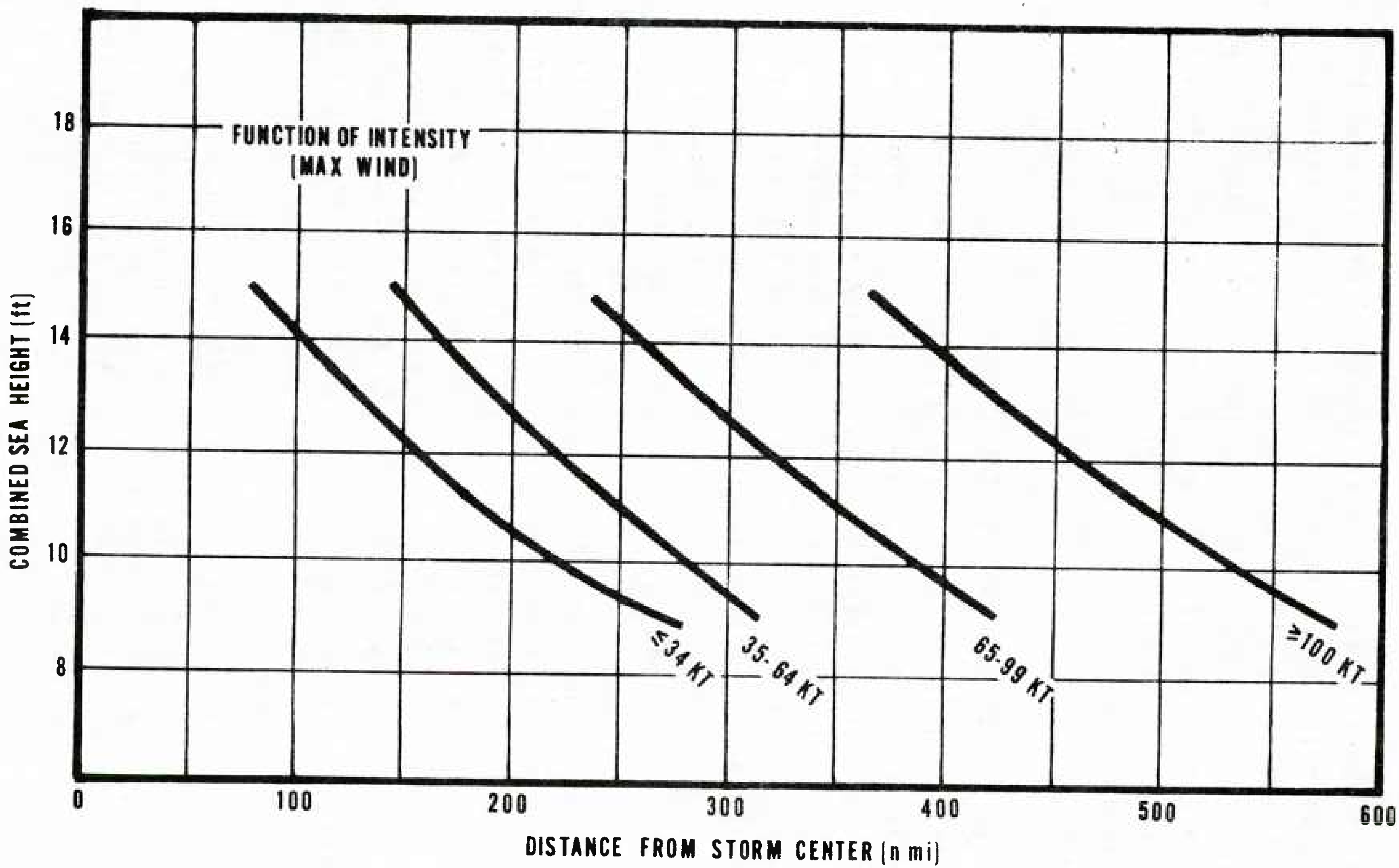

Figure 2. Combined sea height plotted against distance from storm center and given as a function of storm intensity (Brand, et al., 1973).

of combined sea height are not symmetric about the storm center. Brand, _et al_. (1973) found that the actual wave heights are at least partially dependent on the direction in which the storm is moving. For example, Figure 3 shows the average combined 9-15 ft sea height isopleths for tropical cyclones moving between 240° and 360°. It is based on 81 sea state analyses between 240°-300° and 66 analyses between 301°-360°. These analyses were for tropical cyclones that occurred during 1971. Notice that the greatest area of higher seas (9-15 ft range) exists to the rear and toward the right semicircle of the tropical cyclone. It should be noted that Figure 3 is applicable only to the WESTPAC area east of the Philippine Islands. A cursory study of South China Sea tropical cyclones indicates that the sea states associated with those storms are approximately 20% less than those for the above area (Brand, _et al_., 1973).

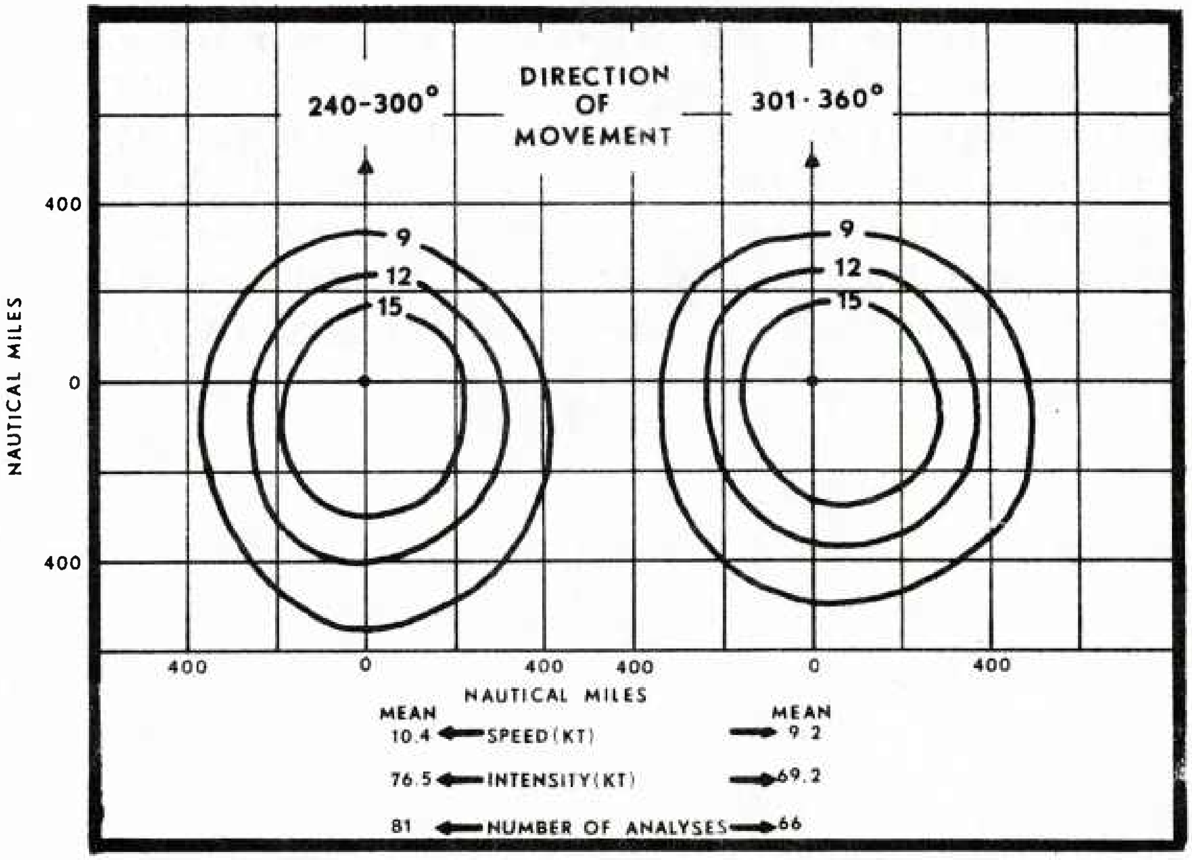

Figure 3. Combined sea-height isopleths (9-15 ft) for tropical cyclones heading between 240°-360° (after Brand, et al., 1973).

3. THE PHILIPPINE ISLANDS IN RELATION TO TROPICAL CYCLONES

3.1 GEOGRAPHICAL LOCATION

Figure 4 shows the geographical location of the Philippine Islands in the western North Pacific Ocean. The Philippines constitute the largest island group, in terms of numbers, of the Malay Archipelago. They comprise approximately 7100 islands and islets, of which Luzon is the largest, covering an area of approximately 115,600 square miles.

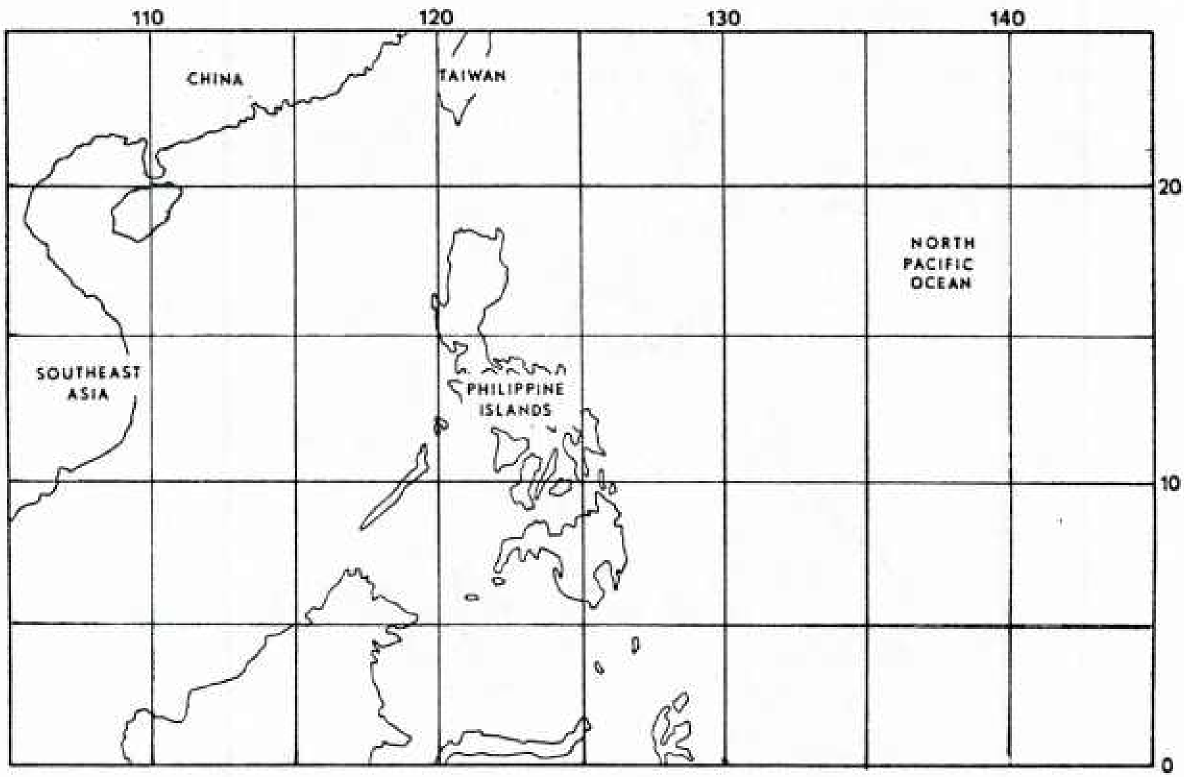

Figure 4. Map of the western North Pacific Ocean showing the positions of major land masses.

3.2 EFFECT OF PHILIPPINE ISLANDS ON TROPICAL CYCLONES

The degree of land influence on a tropical cyclone is a function of the area and topography over which the storm is passing. Figure 5 depicts the topography of the Philippine Islands. It can be seen that the terrain of the Philippine Islands varies a great deal, ranging from extensive mountainous regions on Luzon and Mindanao to a sea-land mix in the central Philippine Islands.

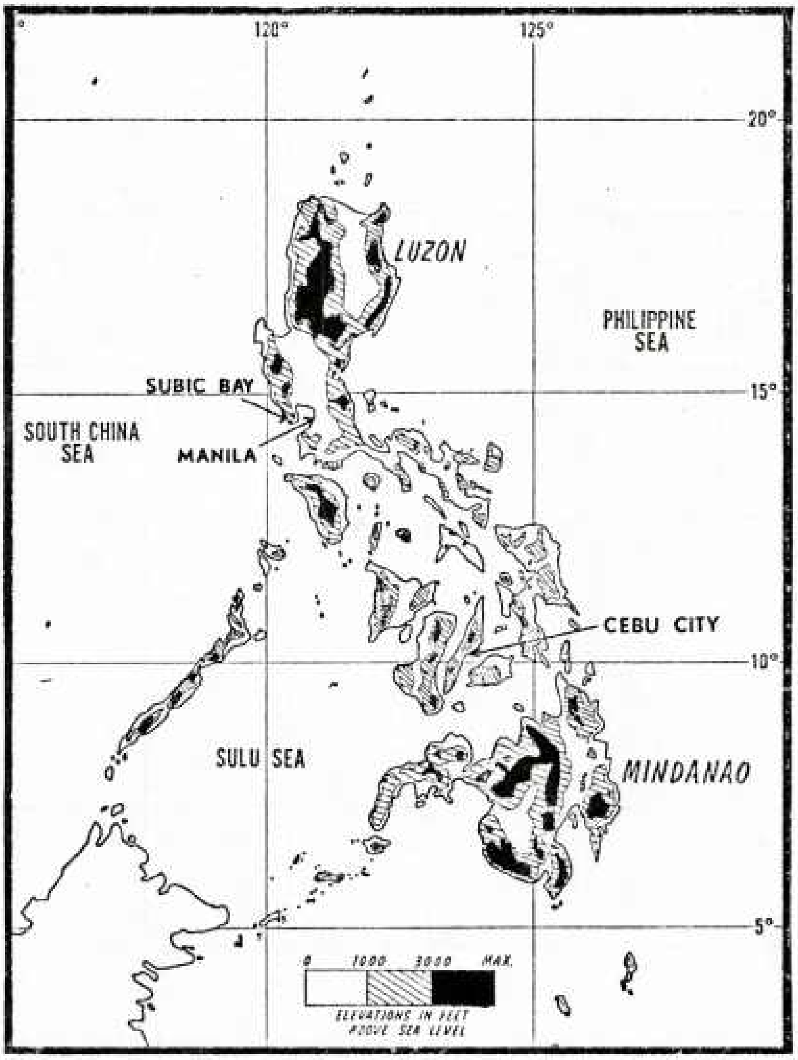

Figure 5. Topographical map of the Philippine Islands showing the location of Cebu City.

Brand and Blelloch (1972) showed that the intensity, speed, and circulation size of typhoons can be greatly influenced by the Philippine Islands. Two of these parameter changes are depicted in Figures 6a and 6b. The typhoons used in this study were divided into two categories: intense typhoons, or those having an initial average intensity $\geq$90 kt in the 24 hr period prior to crossing the Philippines, and weak typhoons, or those having an average initial intensity $\leq$90 kt in the 24 hr period prior to crossing the Philippines. The intensity of intense typhoons decreased 45-50 percent in maximum sustained wind, while the weak typhoons decreased in intensity only 10-15 percent. The speed of intense typhoons shows little decrease, while weaker typhoons, which move faster, show a marked decrease in speed (see Figure 6b). The circulation size of all typhoons considered decreased by an average of 17% in areal extent when crossing the Philippines.

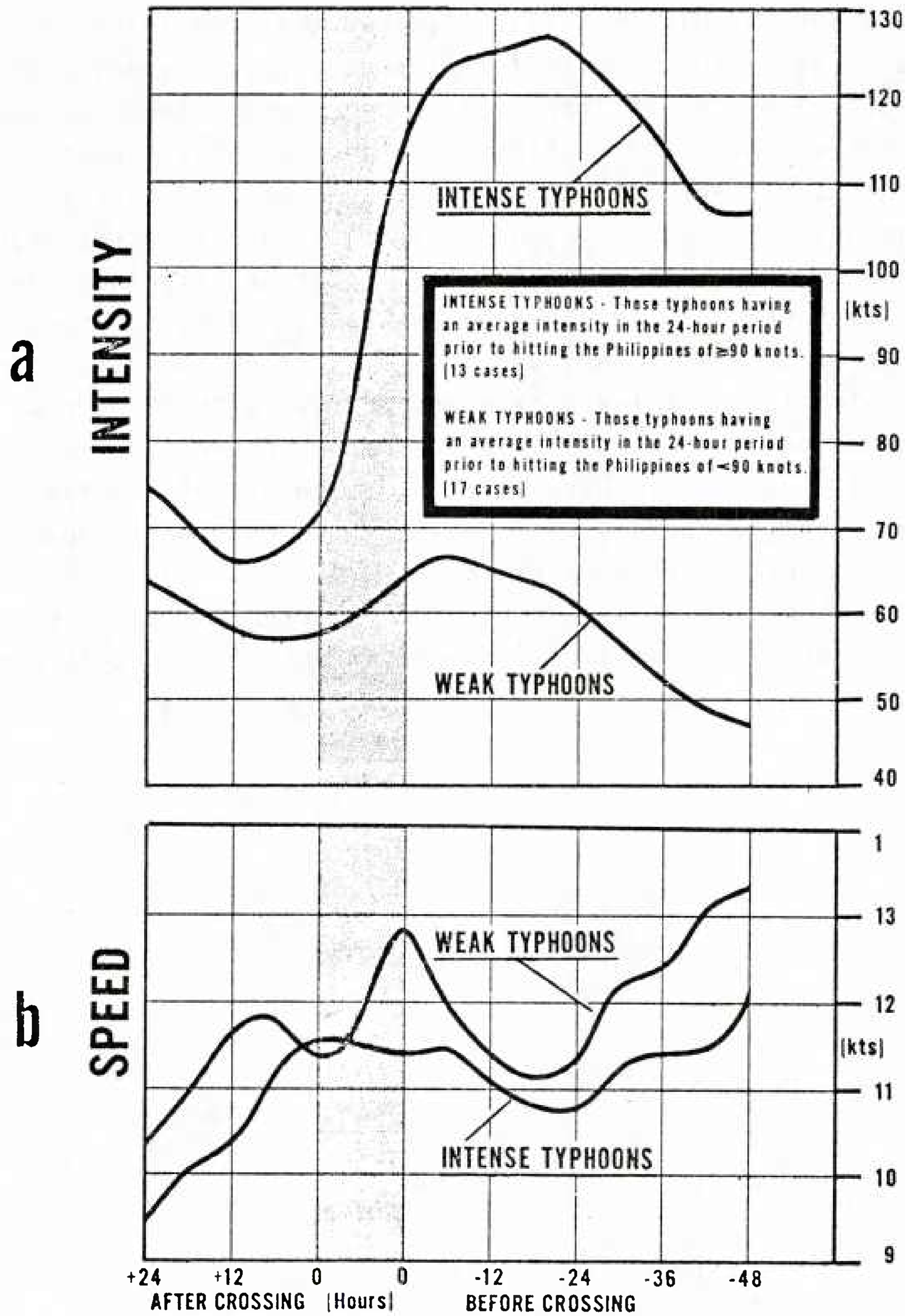

Figure 6. Average intensity (a) and speed (b) profiles for intense and weak typhoons crossing the Philippines (Brand and Blelloch, 1972).

4. CEBU

4.1 GEOGRAPHICAL LOCATION

Figures 5 and 7 show the geographical location of Cebu City on the island of Cebu. Cebu City, the capitol of the province of the same name, is the second largest city in the Archipelago and is a port of entry. Figure 8 shows Cebu Harbor, one of the finest in the Philippines, formed by the strait between Cebu and Mactan Island, centered about 10°20'N and 123°55'E.

4.2 CEBU HARBOR

Limits of the harbor (Figure 8) are defined by a line extending from Bantolinao Point on the northern tip of Mactan Island, due north to the mainland of the island of Cebu and a line extending from Lauis Ledge on the southwestern tip of Mactan Island to Lipata Point on Cebu. Pilotage is compulsory within the harbor limits.

Cebu Harbor can be entered from the south. The northeast channel is narrow and heavily congested, having a least navigable width of 150 yards and a controlling depth of 26 feet. A bridge connects Mactan Island to the mainland with vertical clearance of 89 feet (Figure 8).

U.S. Navy ships are generally assigned anchorage in the south anchorage zone[2] located in the outer harbor (Figure 8). All vessels drawing more than 8 feet are advised to anchor within the limits of the south anchorage zone.

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[2]Refer to H.O. Pub. No. 91, Sailing Directions for the Philippine Islands, Vol. II, Sec 5A-8 for a more detailed description of Cebu Harbor.

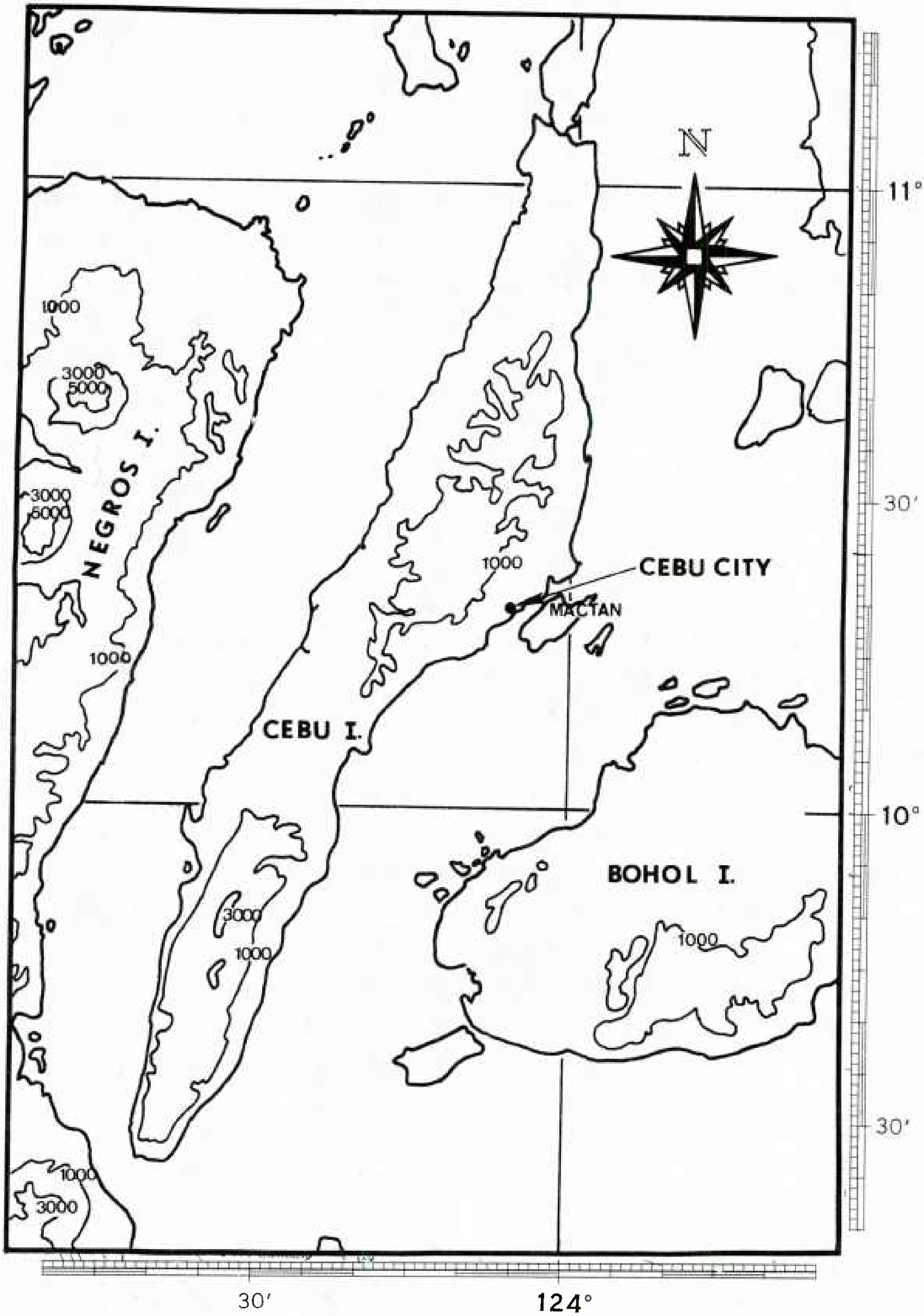

Figure 7. Area map showing location of Cebu City and topographical features of the surrounding terrain (feet).

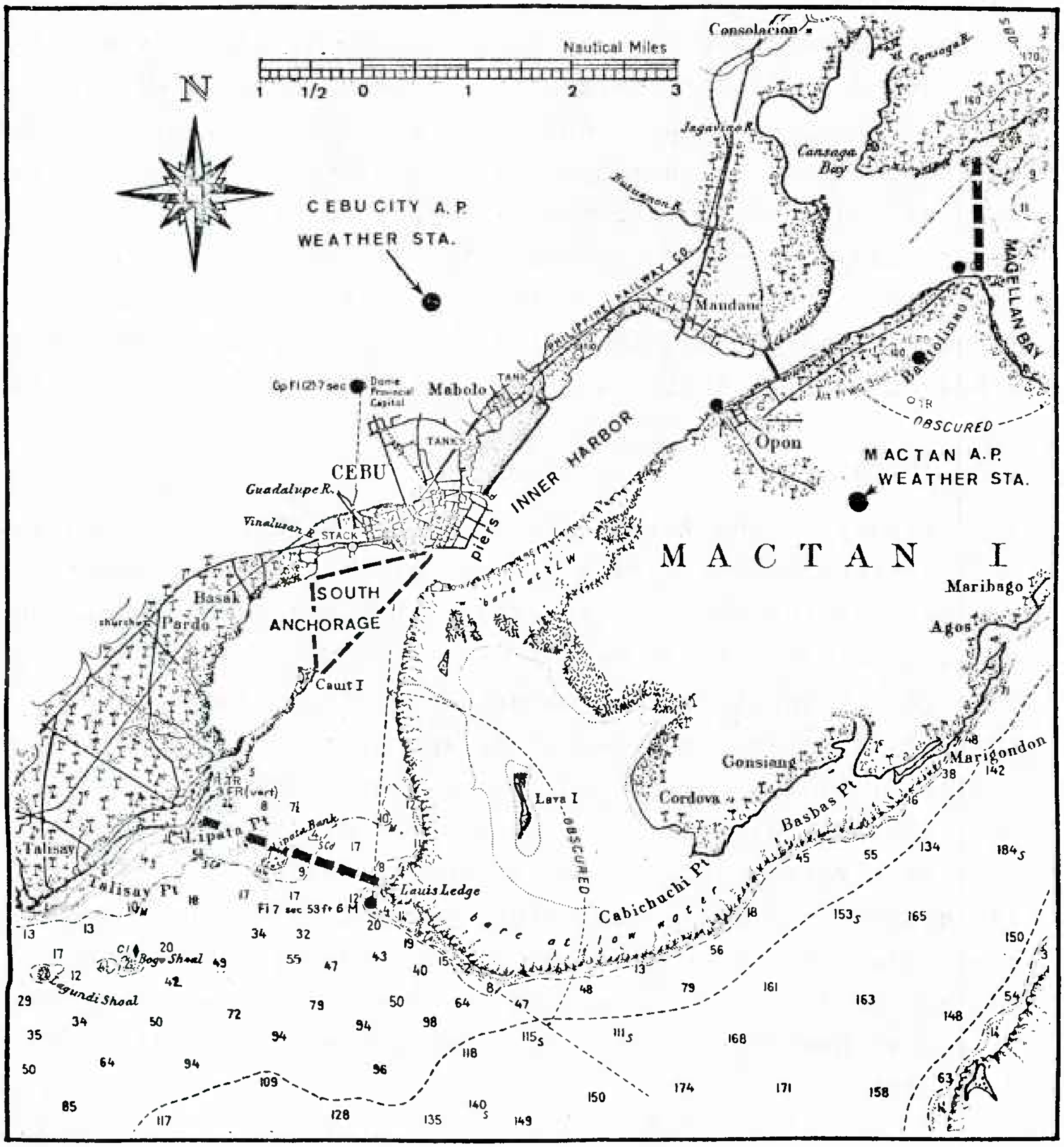

Figure 8. Cebu Harbor showing the outer limits (▬▬), the inner harbor, south anchorage (--) and location of Cebu and Mactan Weather Stations. Soundings in fathoms (H.O. Pub. 91, 1956).

The inner harbor is used only by inter-island vessels and is not recommended for usage by U.S. Navy ships at any time. The following information was received firsthand from Capt. Pablo J. Pido, PN (ret), Chief Pilot of Cebu, with over 40 years experience in Cebu Harbor: Cebu Harbor should not be considered as a storm haven for U.S. Navy ships. Within the inner harbor, holding is not good, and maneuvering is restricted during ebb tide or during storm conditions. As an additional word of caution, maneuvering has also been found to be restricted with winds greater than 12 knots. The south anchorage area was reported to be restrictive to maneuvering, to have a mud bottom, to be inadequately protected from high winds out of the south, and is not equipped with typhoon buoys.

4.3 TOPOGRAPHY

Figures 5 and 7 indicate that Cebu Harbor is generally well protected from direct passage of most major tropical cyclones by the general topography of the island group. In close proximity, it is well screened from the southwest through northwest by the topography of the island of Cebu that rises rapidly to elevations approaching 3,000 feet some 7 miles inland. Farther southward, mountains rise steeply to 1,000 feet within 1 mile to 3 miles of the shore. Immediately adjacent, Mactan Island is less than 100 feet, and generally 8 to 10 feet high, thereby offering minimal protection from high winds of an easterly origin. Some protection from this direction, however, is afforded by the island of Bohol to the southeast with elevations rising to 3,000 feet.

4.4 HARBOR FACILITIES

For a detailed description of harbor facilities available in Cebu, the reader is referred to CINCPACFLTINST 3128.6, PACFLEET Port Directory, section III-5 or Publication 91, Sailing Directions for the Philippine Island, Vol. II, Sec. SA-17.

5. TROPICAL CYCLONES AFFECTING CEBU HARBOR

5.1 CLIMATOLOGY

For the purposes of this study, any tropical cyclone approaching within 180 n mi of Cebu City is considered a threat to the port. It is recognized that a few tropical cyclones which did not approach within 180 n mi may have affected Cebu. However, a reasonable criterion had to be chosen that would limit the size of the data sample.

Although tropical cyclones occur throughout the year, the majority of those which threaten the harbor of Cebu occur in the months of June through December. Figure 9 depicts the monthly summary of tropical cyclone occurrences based on data for the 28 years, 1947-1974. Of the 69 tropical cyclones that threatened Cebu in this 28-year period (more than 2 threats per year), the peak threat periods exist in October, November and December, but a consistent threat exists throughout the total June-December period.

Figure 10 displays the above storms as a function of the compass octant from which they approached Cebu. The numbers indicate the number of storms approaching from that octant, while the numbers in parentheses indicate the percentage of storms approaching Cebu from that octant. It is evident that the majority of storms generally approach Cebu from the east, and primarily from the east-northeast.

Figures 11 to 17 are analyses of tropical cyclones passing within 180 n mi of Cebu. The solid lines represent the "percent threat" for any storm location. The dashed lines represent approximate approach times to Cebu based on an approach speed of 8-12 kt. For example, in Figure 11, a storm located at 135E and 10N has approximately a 60% probability of passing within 180 n mi of Cebu and will reach Cebu in less than 3 days if its speed remains between 8-12 kt.

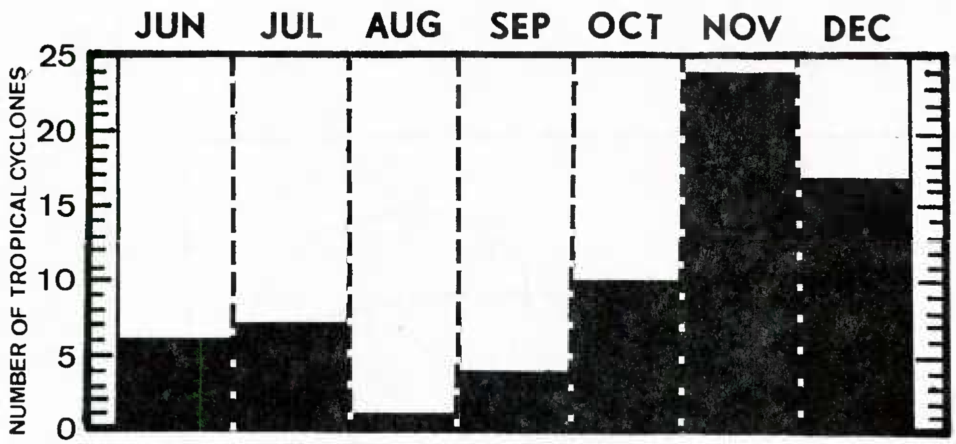

Figure 9. Frequency distribution of the number of tropical cyclones that passed within 180 n mi of Cebu (June-December, 1947-1974).

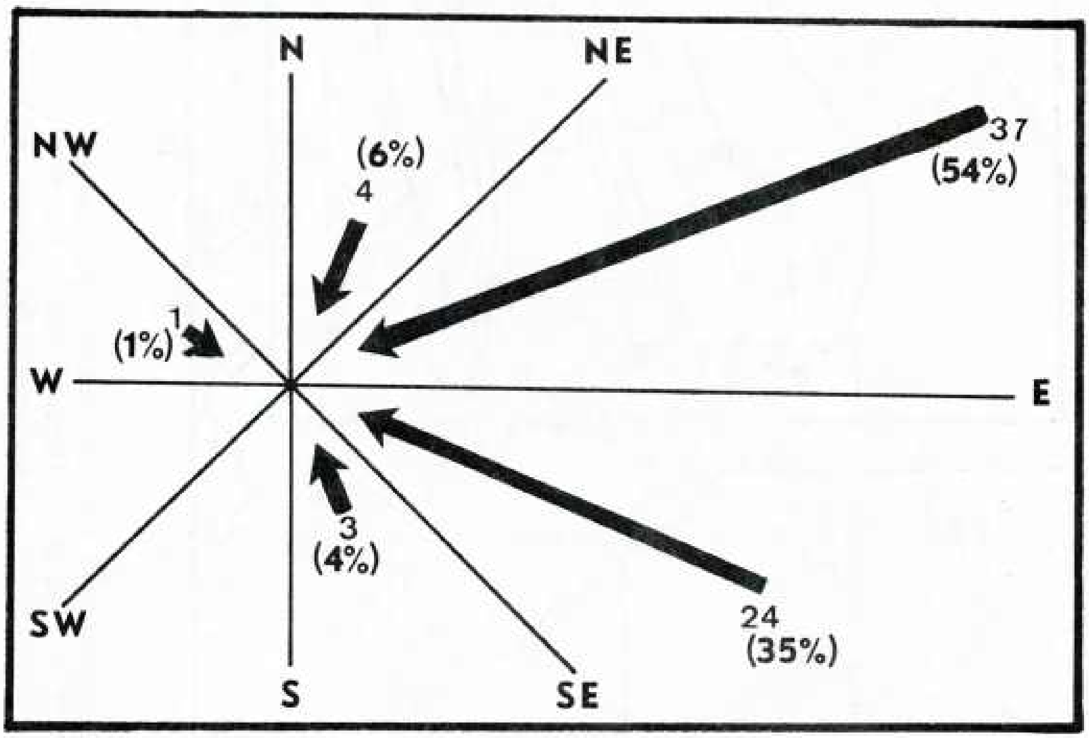

Figure 10. Direction of approach to Cebu of the tropical cyclones (June-December, 1947-1974) which passed within 180 n mi. Open numbers indicate the number that approached from each octant. The numbers in parentheses are the percentage of the total sample (69) that approached from that octant.

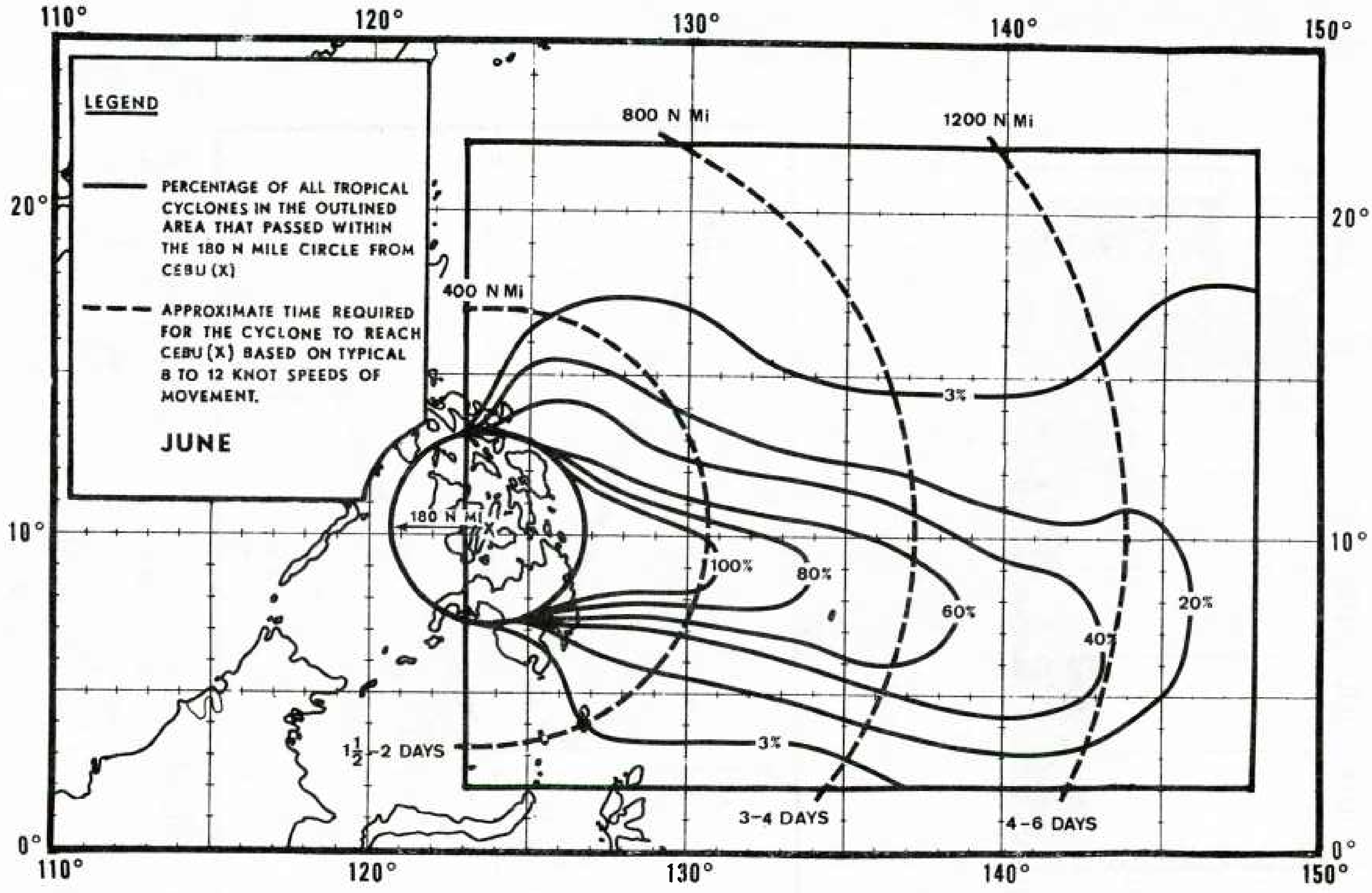

Figure 11. Percentage of tropical cyclones that passed within 180 n mi of Cebu (X) for the month of June. (Based on data from Chin (1972) for the years 1947-1970 and Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).)

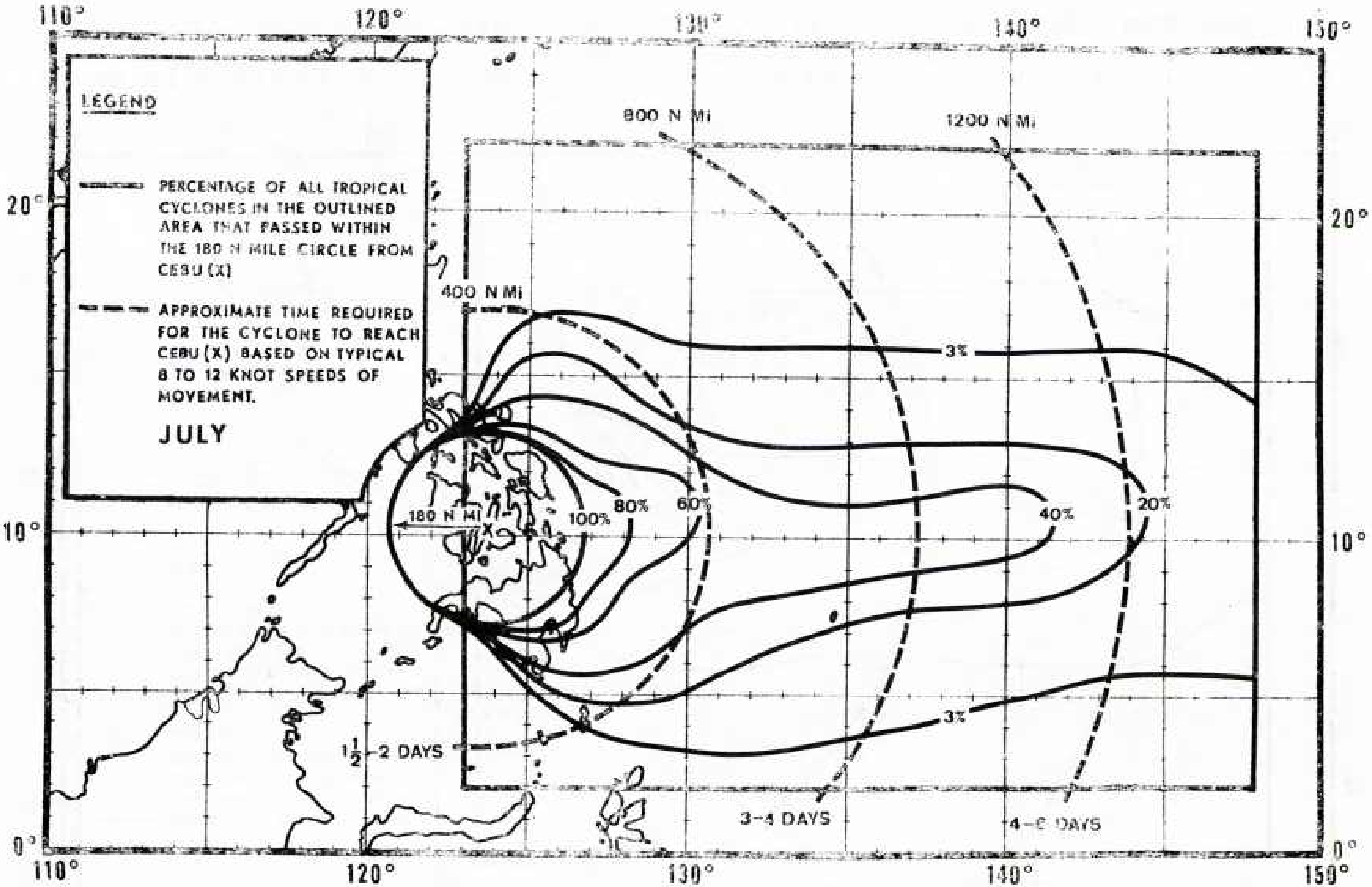

Figure 12. Percentage of tropical cyclones that passed within 180 n mi of Cebu (X) for the month of July. (Based on data from Chin (1972) for the years 1947-1970 and Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).)

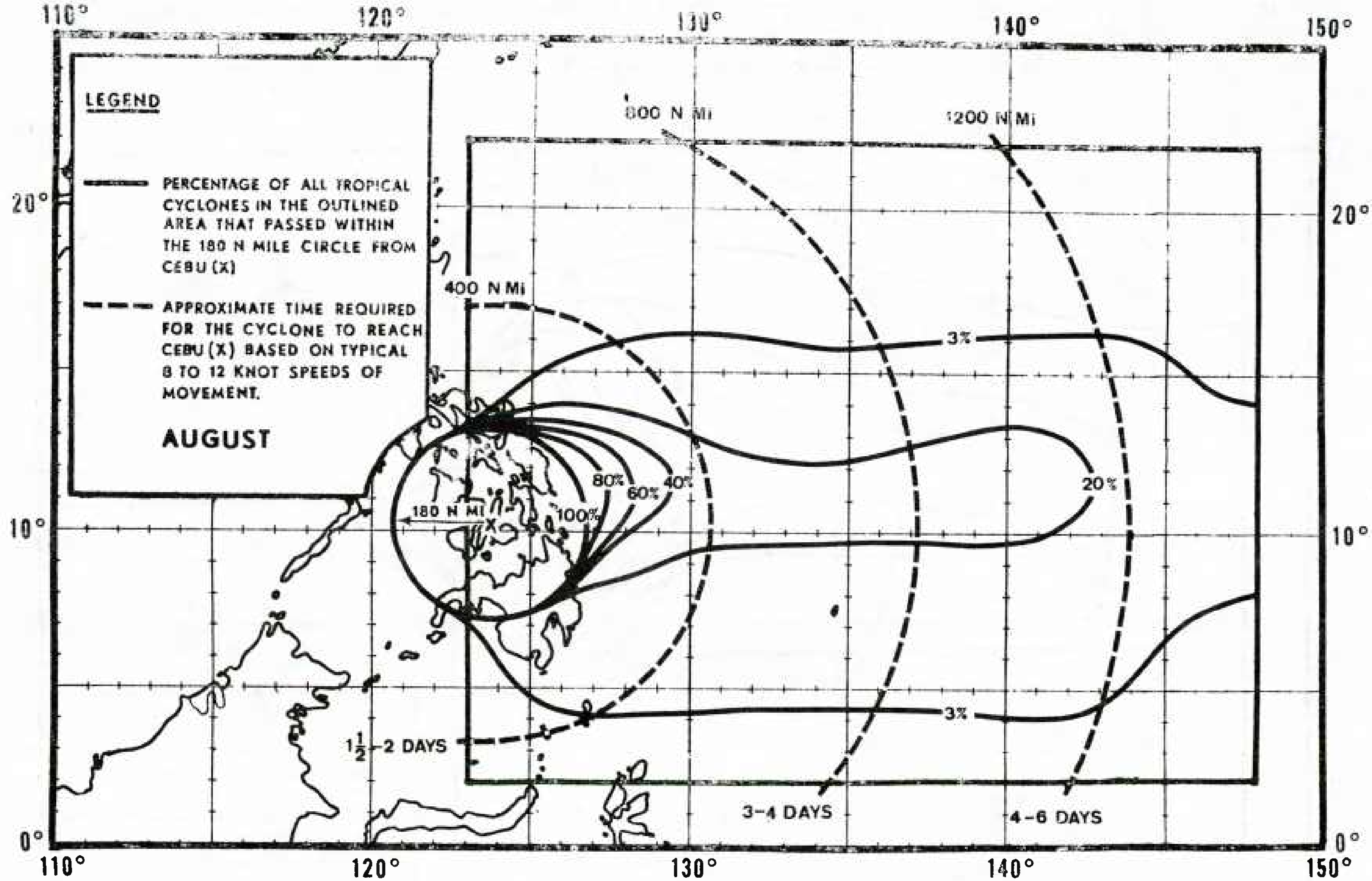

Figure 13. Percentage of tropical cyclones that passed within 180 n mi of Cebu (X) for the month of August. (Based on data from Chin (1972) for the years 1947-1970 and Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).)

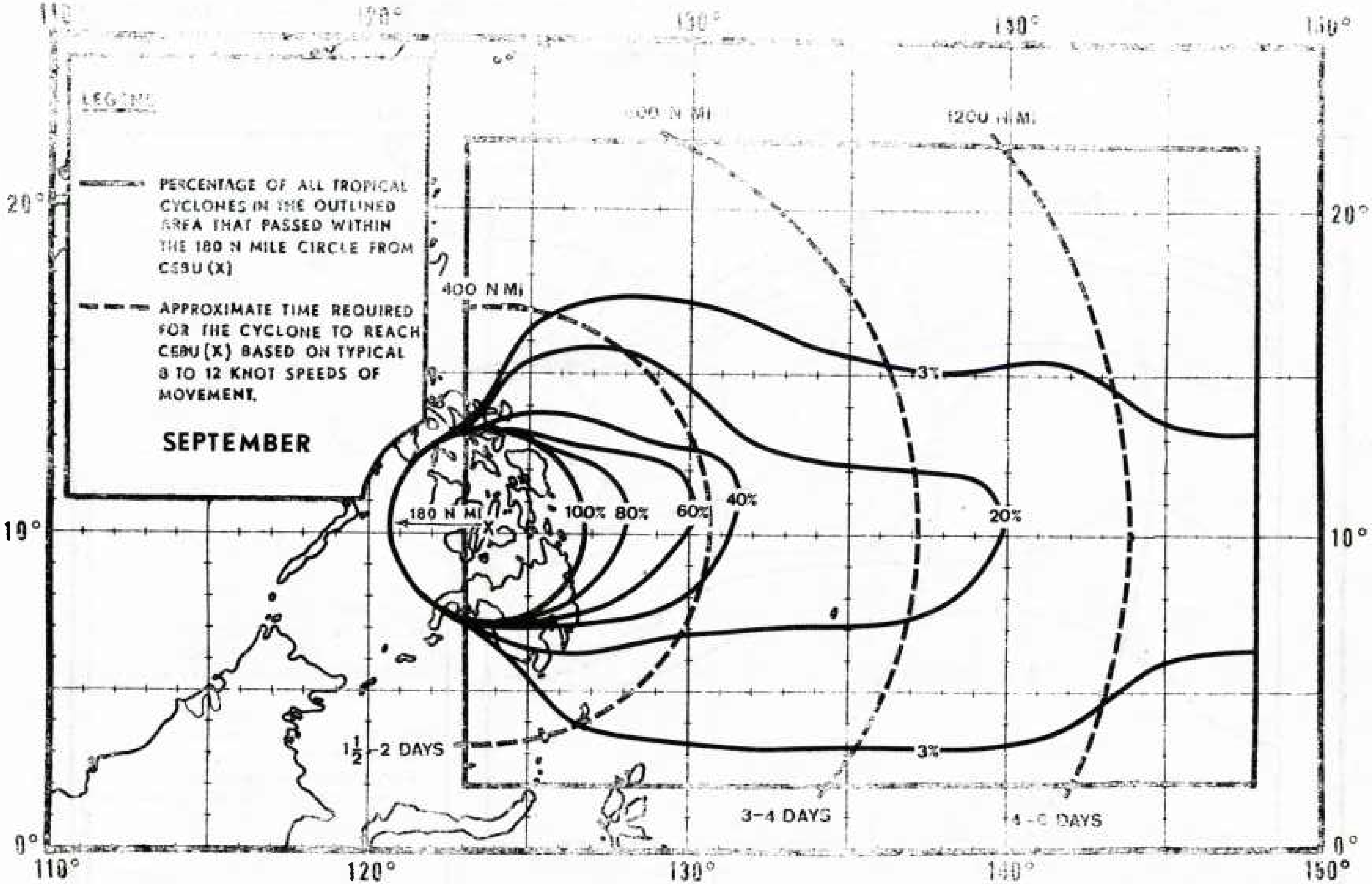

Figure 14. Percentage of tropical cyclones that passed within 180 n mi of Cebu (X) for the month of September. (Based on data from Chin (1972) for the years 1947-1970 and Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).)

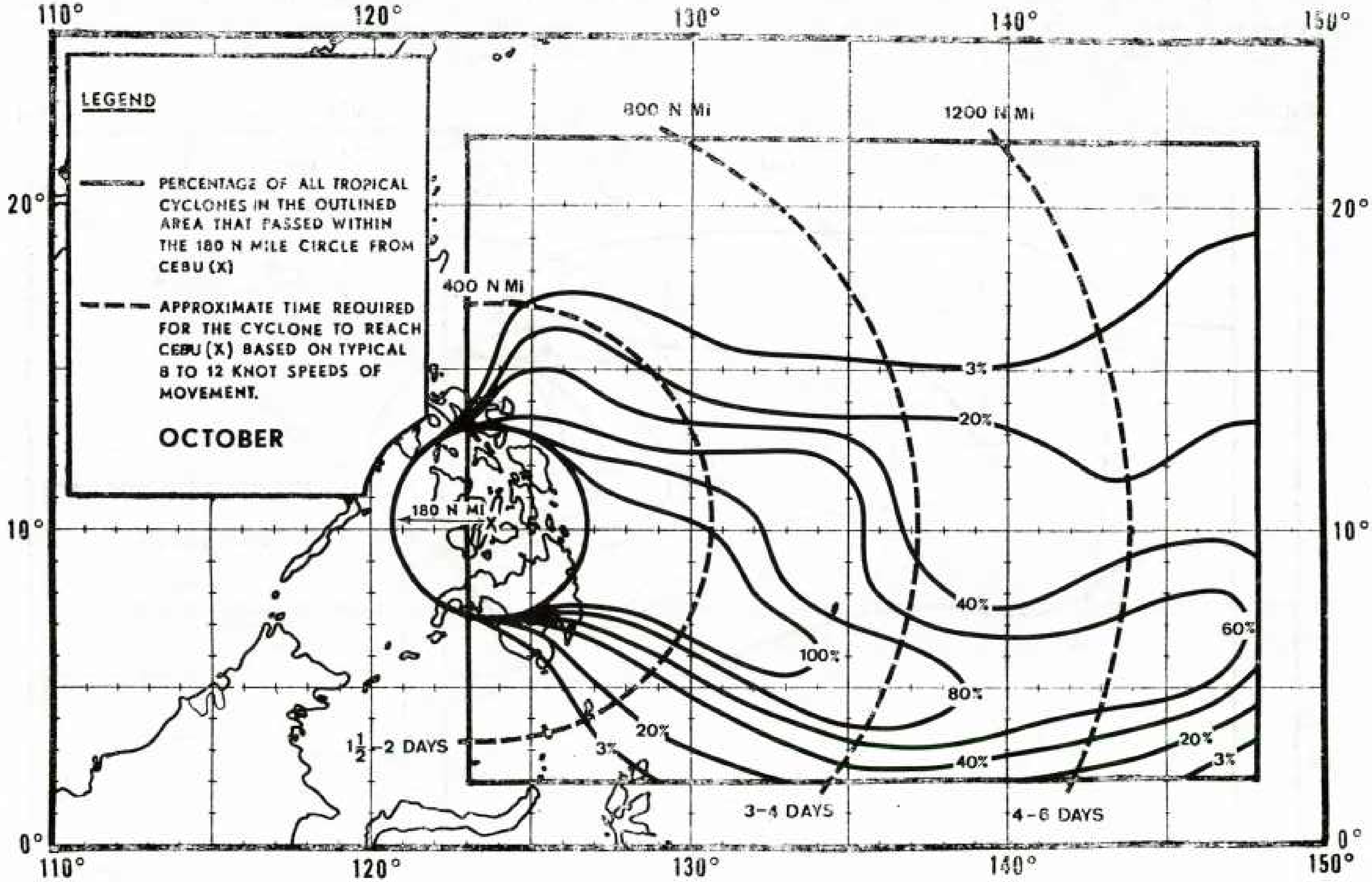

Figure 15. Percentage of tropical cyclones that passed within 180 n mi of Cebu (X) for the month of October. (Based on data from Chin (1972) for the years 1947-1970 and Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).)

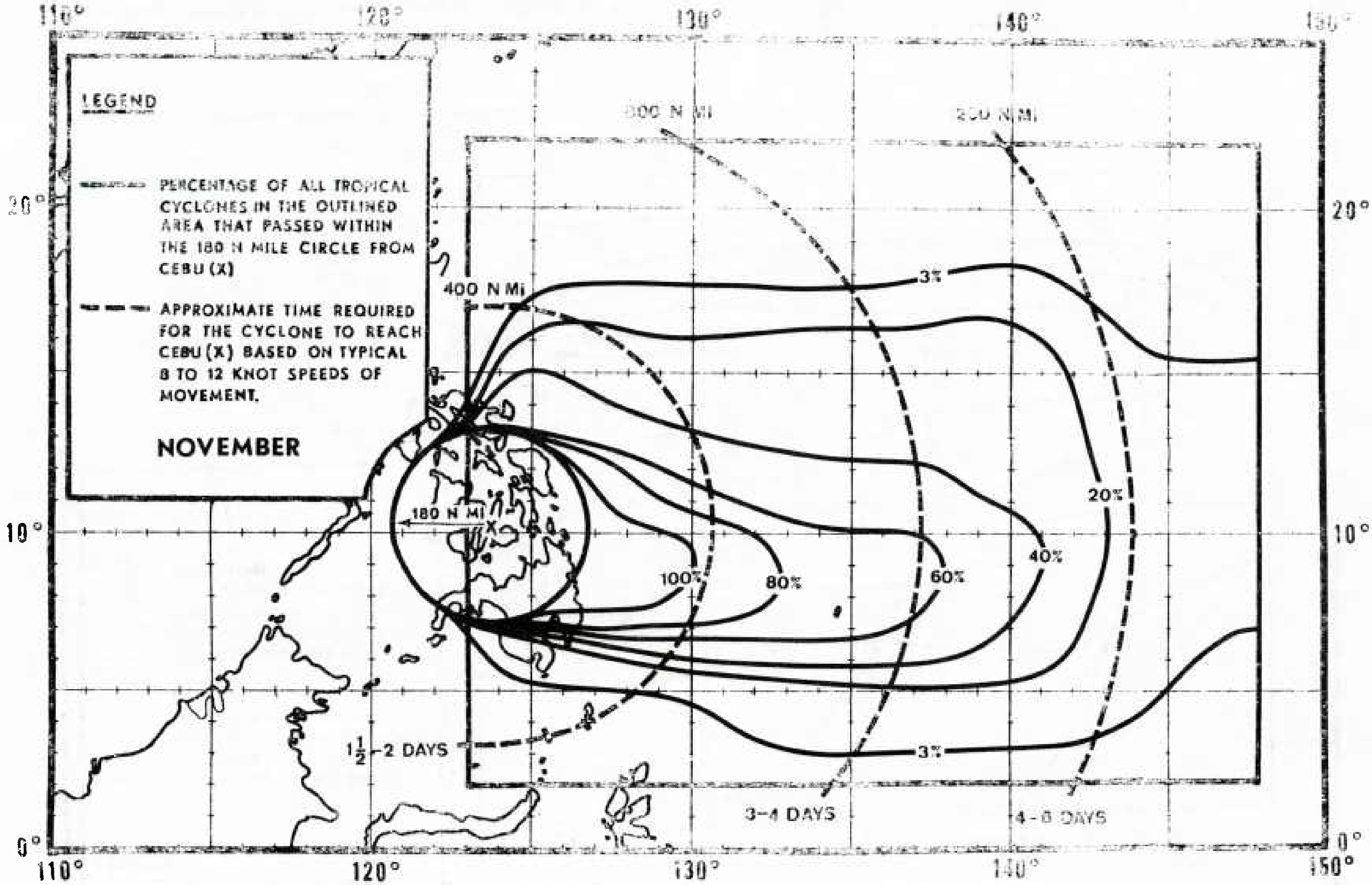

Figure 16. Percentage of tropical cyclones that passed within 180 n mi of Cebu (X) for the month of November. (Based on data from Chin (1972) for the years 1947-1970 and Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).)

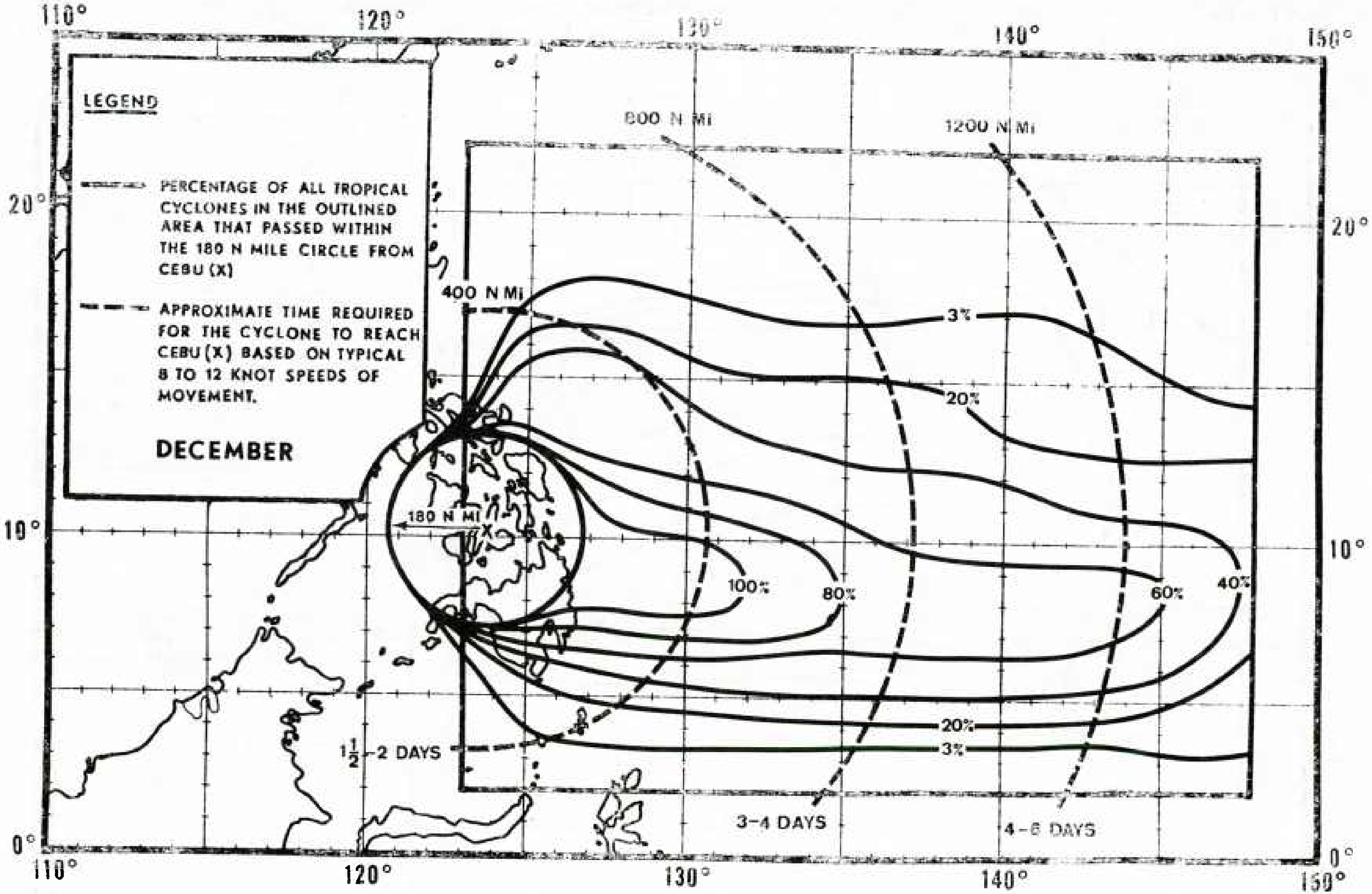

Figure 17. Percentage of tropical cyclones that passed within 180 n mi of Cebu (X) for the month of December. (Based on data from Chin (1972) for the years 1947-1970 and Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).)

5.2 WIND AND TOPOGRAPHICAL EFFECTS

In the 20-year period from 1955-1974, during the months June-December, a total of 45 tropical cyclones approached within 180 n mi of Cebu, which is more than two tropical cyclones per year.[3] Approximately 82% of this sample had their closest point of approach (CPA) to the north of Cebu, while 18% passed to the south. The largest number of tropical cyclones to threaten Cebu in any single year was 5 in both 1971 and 1972. Table 1 groups the above 45 tropical cyclones according to the wind intensity that they produced at Cebu. Of the 45 tropical cyclones concerned, 13% resulted in strong winds ($\geq$22 kt) and only 7% resulted in gale force winds ($\geq$34 kt). These results are based on hourly wind data.

Table 1. Extent to which tropical cyclones affected Cebu during the period June-December, 1955-1974, based on hourly wind data.

Number of tropical cyclones that passed within 180 n mi of Cebu	45
Number of tropical cyclones resulting in strong ($\geq$22 kt) winds at Cebu	6
Number of tropical cyclones resulting in gale force ($\geq$34 kt) winds at Cebu	3

The approximate locations of Cebu City Airport weather station and Mactan Airport weather station are shown in Figure 8. Wind data for years 1955-1974 are continuous with hourly data recorded at Cebu City Airport until 1972, when recording of hourly data was transferred to Mactan Airport and Cebu City commenced synoptic reports only. The data are

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[3]From Chin (1972) for years 1955-1970 and from Annual Typhoon Reports for the years 1971-1974 (U.S. FWC/JTWC, 1971-1974).

considered representative of the winds in Cebu Harbor in most situations. Note that the above wind data are reduced from hourly wind observations. Although records of winds greater than 33 knots were noted on only three occasions during the 1955-1974 period, several instances of significantly higher winds which occurred between reporting times were noted in the remarks of both the Cebu City Airport weather station and Mactan Airport weather station. An example of this occurrence for the above period was a recording of 50-kt gusts at Cebu City Airport with the passage of Typhoon Lucy in November 1962. For records available at Cebu City Airport weather station from 1949, the highest official recording for all times was a sustained wind of 85 knots as a result of Typhoon Amy at 0030 local time on 10 December 1951.

A description of Typhoon Amy[4] is presented in Appendix D as an example of the danger if caught in Cebu Harbor during the rare occurrence of close passage of a severe typhoon to Cebu City.

Figure 18 depicts the tracks of tropical cyclones that occurred during the months of June through December, for the period 1955-1974, which resulted in winds greater than or equal to 22 knots at Cebu. From this figure and a comparison with the percent threat diagrams presented previously (Figures 11-17), it is evident that tropical cyclones approaching from the east represent the primary threat to Cebu.

In Figure 19 the arrows showing tropical cyclone movement give the positions of tropical cyclone centers when the wind first and last exceeded 21 kt at Cebu. Figure 20 shows the position of tropical cyclone centers when the wind first and last exceeded 33 kt. In all instances, the onset

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[4]From "Tropical Cyclones of 1951," Republic of the Philippines, Department of Commerce and Industry, 1951.

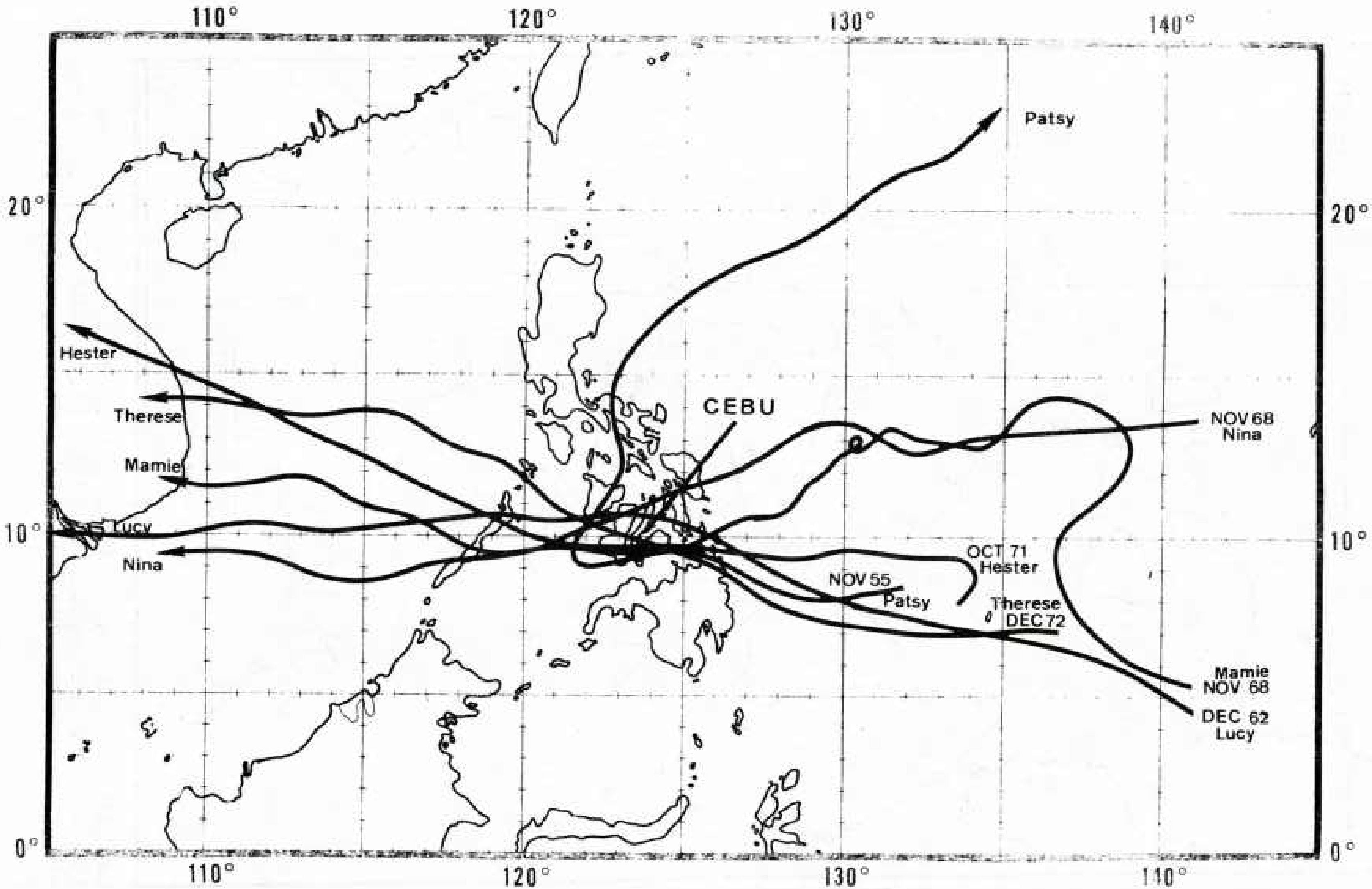

Figure 18. Tracks of tropical cyclones associated with strong winds ($\geq$22 kt) at Cebu for the months of June-December, 1955-1974. Of these tropical cyclones, Hester, Mamie, and Nina resulted in gale force or greater winds at Cebu.

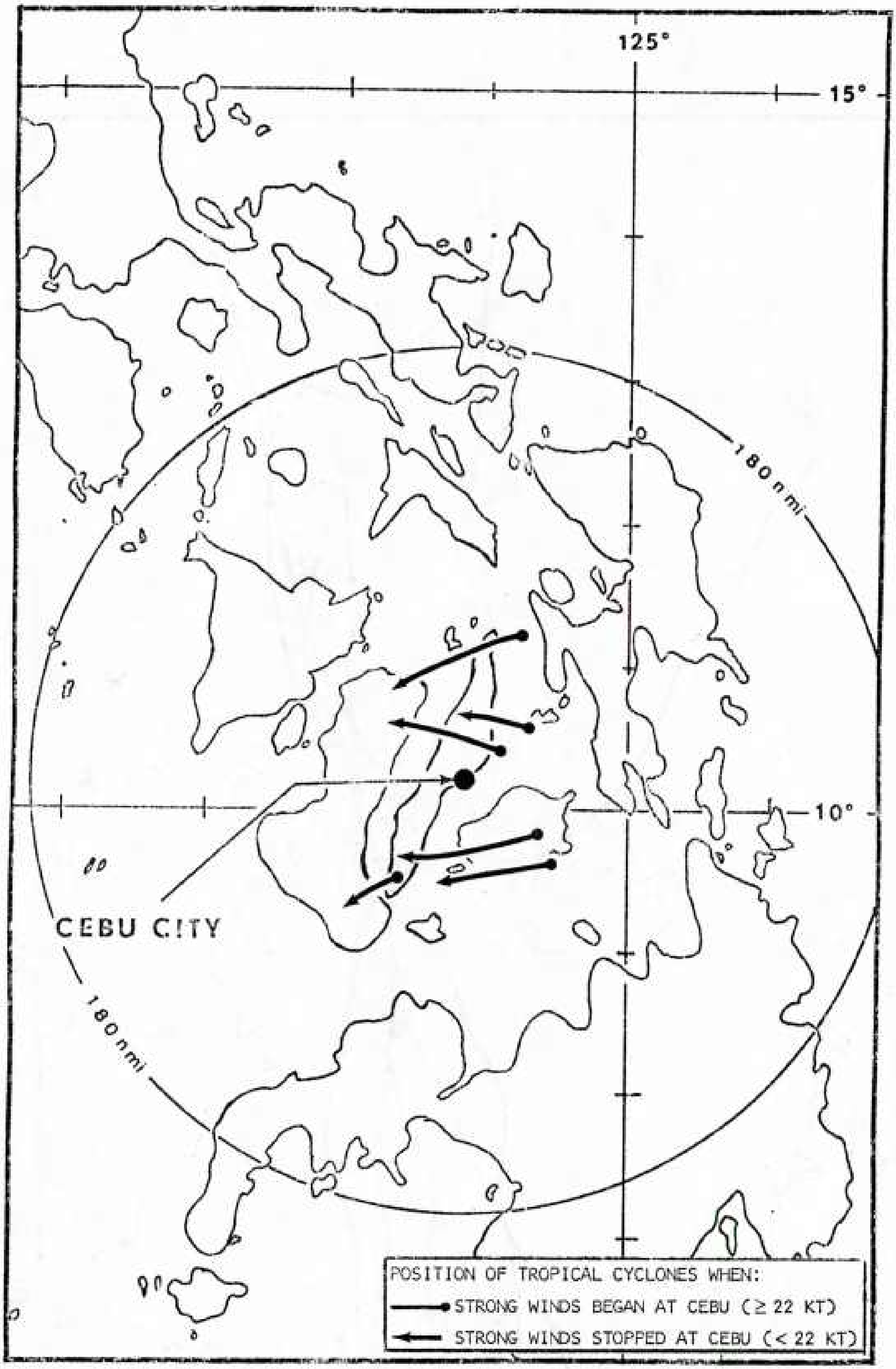

Figure 19. Position of tropical cyclone centers when winds greater than or equal to 22 kt first and last occurred at Cebu. (Based on June-December data from 1955-1974.)

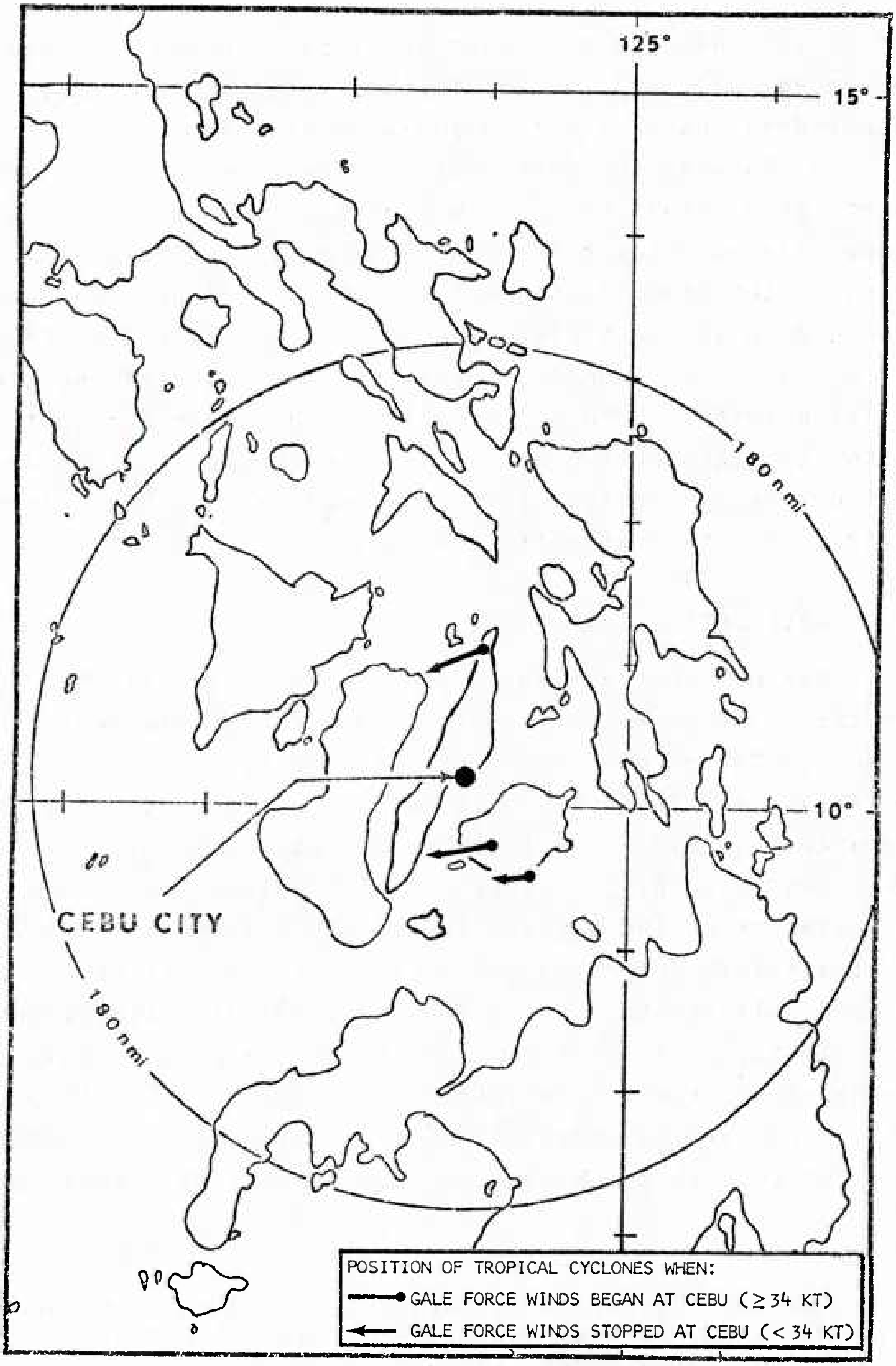

Figure 20. Positions of tropical cyclone centers when ≥ 34 kt winds first and last occurred at Cebu. (Based on June-December data from years 1955-1974.)

of 22 kt winds did not occur until the tropical cyclones had advanced well into the Philippines (west of 125° east longitude) and were within 100 n mi of Cebu.

A study of the above period also revealed that strong winds as a result of a close tropical cyclone passage were generally restricted to winds from a sector, northeast clockwise to the south-southwest. Tropical cyclones that have managed to approach close enough to severely effect Cebu City (i.e., sustained winds or gusts over 50 kt) have had close passage (within 50 n mi) equally to the north and south. Also, the sample of occurrences is much too small to draw definitive conclusions as to the most severe threat to Cebu City in terms of direction of passage.

5.3 WAVE ACTION

Maximum wave action is associated with a typhoon passing to the south or west since this places Cebu Harbor in the right or "dangerous" semicircle of the typhoon. The greater relative wind in this area generates waves which tend to be more destructive. The interior of Cebu Harbor is relatively well protected by the geography of the area, the southwest orientation of the bay and the nearby hydrography. Any waves that actually enter the bay must be as a result of refraction around islands surrounding Cebu from all directions, and are of little significance. Although the author found no evidence of direct observations recorded at Cebu City, a highly simplified computation[5] indicates that just outside the entrance to the harbor maximum heights of approximately

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[5]Based on Forecasting Curves for Shallow Water Waves from U.S. Army Coastal Engineering Research Center, 1973: "Shore Protection Manual (Volume I)."

6.5 feet can be obtained with winds of 50 kt and about 8 feet can be obtained with typhoon intensity ($\geq$64 kt) winds.

5.4 STORM SURGE AND TIDES

Conversations with harbor authorities in Cebu City revealed no evidence of significant storm surge within the harbor of Cebu. Tidal currents in the harbor are reported variable and generally weak.[6] However, conversations with harbor officials revealed normal tidal currents of 3 to a high of 7 kt that can attain values greater than 7 kt as a result of a close typhoon passage. Due to restricted maneuvering room in the harbor, U.S. ships would find maneuvering difficult if not impractical during the stronger tides resulting from a close passage of a typhoon. In addition, maneuvering within the inner harbor is restricted during normal ebb tide.

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[6] U.S. Naval Oceanographic Office, H.O. Pub. No. 91 places a maximum velocity of 1 to 2 kt for the harbor. Although unverified by direct measurements, the author suspects this is a low estimate.

6. PREPARATION FOR HEAVY WEATHER

6.1 TROPICAL CYCLONE WARNINGS

Tropical cyclone warnings, including 24-, 48-, and 72-hr forecasts, are issued by the Fleet Weather Central/ Joint Typhoon Warning Center (FWC/JTWC) located on Guam. When the existence of a tropical depression has been established and the decision to designate it has been made, it is numbered serially and that number is continued throughout its life cycle irrespective of changes in classification. In order to maximize the use of available reconnaissance platforms in multiple storm situations, a variable warning time may be used. Warnings will be issued within 2 hours of 0000Z, 0600Z, 1200Z and 1800Z with the constraint that two consecutive warnings may not be more than 7 hours apart.

Even with sophisticated modern techniques for locating and monitoring tropical cyclones, the present state of the art does not permit perfect predictions of storm movements. Many variables exist which can alter the path of a typhoon; hence, every typhoon should be treated with the utmost respect. COMSEVENTHFLT OPORD 201-(YR), Annex H, describes the procedures and techniques to be used when plotting the FWC/JTWC typhoon warning track positions. Figure 21 demonstrates the method to obtain the "danger area" utilizing the 135 n mi average 24-hr forecast position error. The 135 n mi value is used in order to expand the radius of 30-kt winds (given in the warning) by the average forecast error. Note the radius of the 30-kt winds is usually greater on the right side of the storm track -- the dangerous semicircle. In this example, the radius to the 30-kt isotach is 200 n mi to the north and 150 n mi to the south. The 24-hr forecast predicts the radius to expand to 225 n mi to the north and 175 n mi to the south. Adding the average 24-hr forecast position error to

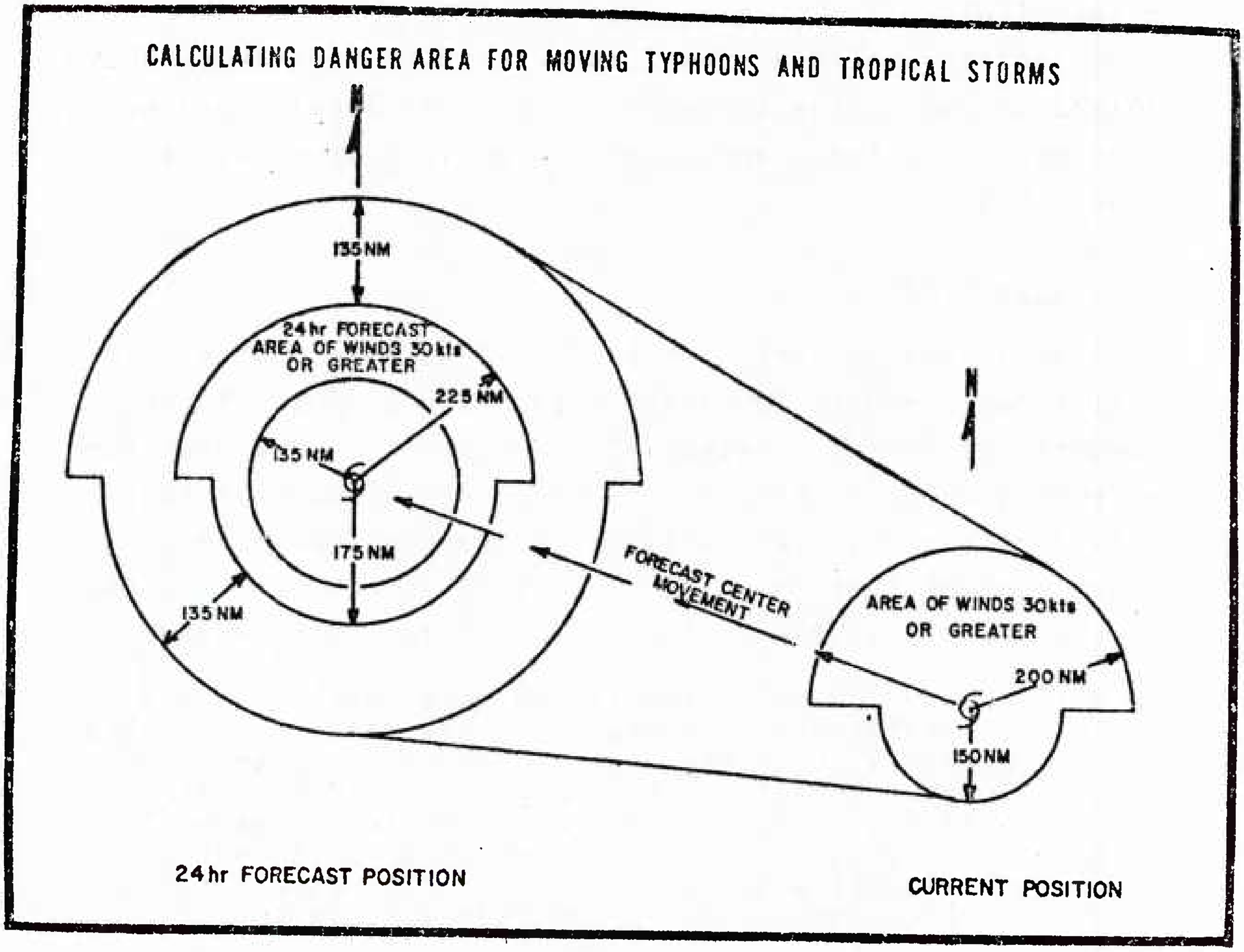

Figure 21. Method of calculating the danger area for moving typhoons and tropical storms (from Commander, Seventh Fleet, OPORD 201-YR).

the above figures will show a 24-hr danger area extending 360 n mi to the north and 310 n mi to the south. The 48- and 72-hr forecast positions given in the FWC/JTWC warning provide a planning forecast, but must also be adjusted to consider a 275 n mi and 400 n mi average forecast error, respectively.

Section 6 of Appendix I to Annex W of COMNAVPHIL OPORD 201-72 discusses the criteria for setting local heavy weather readiness conditions and is reprinted in this study as Appendix B.

6.2 REMAINING IN PORT

Remaining in port when the means to evade a storm is available is a decision that is contrary to most of the traditional rules of seamanship. However, if the decision to remain in port is made, it should not be made without considering every available fact concerning the impending storm and the port in which the vessel is berthed. In the case of Cebu City the following points should be noted:

(1) Securing to a pier in the inner harbor is not recommended as maneuvering is restricted during normal ebb tide, with winds greater than approximately 12 kt, and during tides greater than 7 kt (associated with tropical cyclones). (Only piers 1 and 2 are used for ocean going vessels[7] and use of these by USN vessels is recommended only for emergency measures.)

(2) Anchoring (south anchorage) should be completed prior to the onset of 20-kt winds as maneuvering is severely restricted.

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[7] U.S. Naval Oceanographic Office, H.O. Pub. No. 91, Sec. 5A-17.

(3) Once the decision to remain in port has been made, any reversal in plans would be extremely dangerous. Cebu City is a relatively sheltered harbor so any wave and wind actions experienced inside the bay would be much more severe outside the entrance to the bay and in the open sea.

(4) Evasion from the harbor can only be accomplished via the southwest exit.

(5) The holding action of the mud bottom is considered by harbor officials to be minimal for typhoon conditions and there is danger of breaking loose in heavy weather.

(6) There is danger of other ships breaking loose.

6.3 EVASION

Evasion is the recommended course of action when threatened by a tropical cyclone. When evasion is contemplated, the importance of correctly assessing the threat posed by the storm and acting quickly so as to retain flexibility cannot be overemphasized. The following time table in conjunction with Figure 22 has been set up for this purpose:

1. There is an existing tropical cyclone, or potential development in Area C, with forecast movement toward Cebu City:

    a. Review the material condition of the ship; sailing within 2-4 days is a distinct possibility.

    b. Reconsider all maintenance activities scheduled to exceed 48 hours.

2. A tropical cyclone has entered Area B with forecast movement toward Cebu City:

    a. Operational plans should be made in the event sortie is ordered.

    b. Reconsider all maintenance activities scheduled to exceed 24 hours.

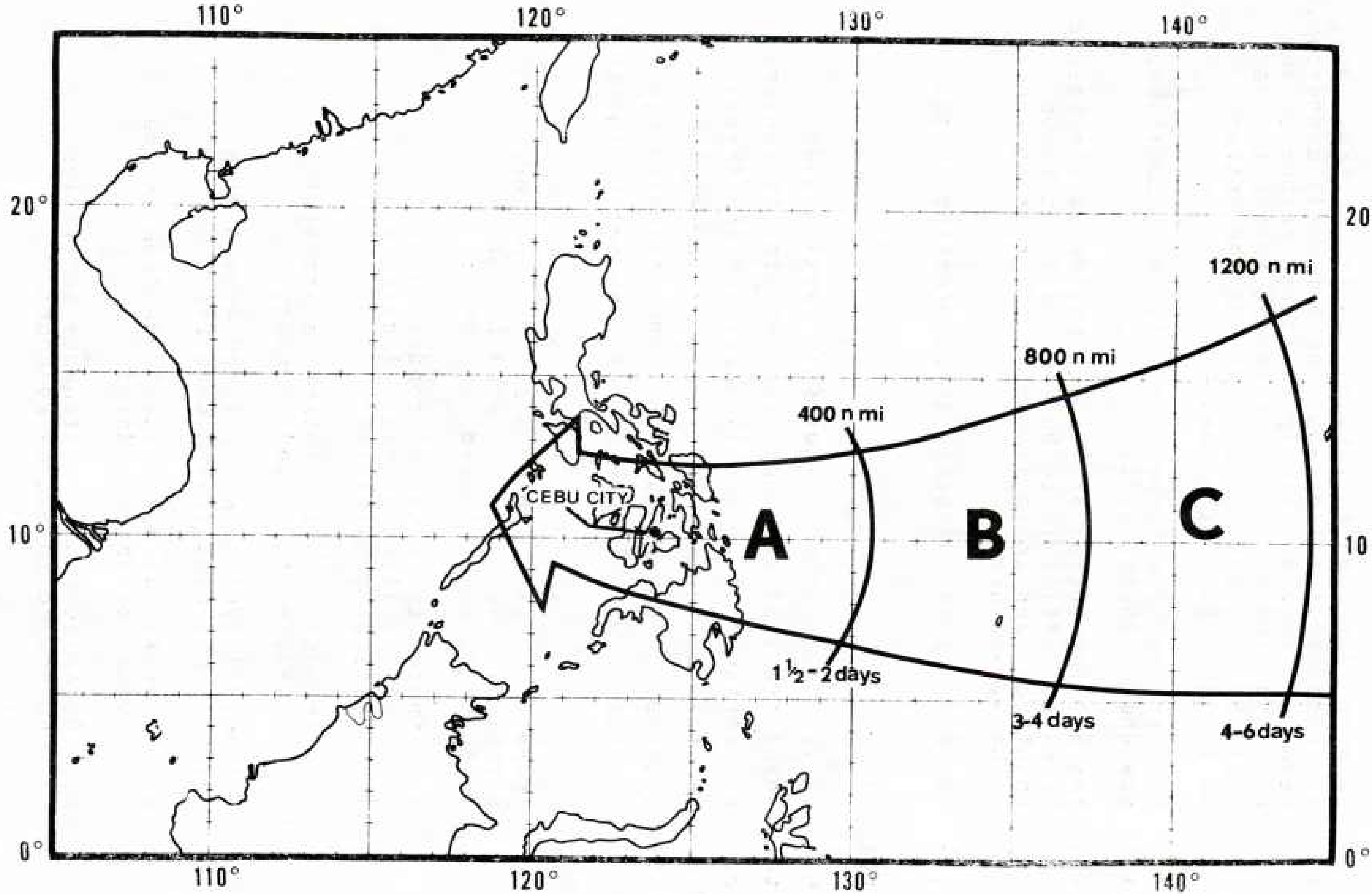

Figure 22. Tropical cyclone threat axis for Cebu City. Distances and approach times are measured from Cebu City based on an 8-12 kt speed of movement.

3. A tropical cyclone has entered Area A with forecast movement toward Cebu City:

    a. Execute evasion plans made in previous steps.

Whatever evasion decision is made, the following general comments should be considered:

1. When departing Cebu City, ample time should be given to combat the heavy sea condition likely to be encountered at the entrance to the harbor.

2. Crossing ahead of a typhoon should be accomplished well in advance. Heavy swells may be encountered ahead of an advancing typhoon long before the occurrence of strong winds. Such swells may decrease a ship's maneuverability and speed of advance, preventing avoidance of the typhoon track.[8]

3. At certain times of the year, particularly in the peak typhoon season, the possibility exists that two or more tropical storms will be present at one time. This will greatly complicate any evasion planning and execution.

4. A looping tropical cyclone can cause a false sense of security as evading ships attempt to return. A looping storm after initial passage can regenerate and cause as high or higher winds/seas upon its return.

6.4 EVASION TECHNIQUES

The final decisions involving evasion of tropical cyclones rest with the commanding officer of the vessel involved. One of the more successful Pacific Ocean evasion tactics involves running downwind and downsea relative to the typhoon in order to reach a latitude south of the storm

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[8]See Appendix C for discussions and examples of the extent to which sea state and wind speed reduce the speed of advance of a vessel.

and in the navigable semicircle. The success of this method depends upon almost continuous reconnaissance coverage and a relatively slow movement and gradual expansion of the initially small area affected by severe winds which is characteristic of typhoons at low latitudes (Somervell and Jarrell, 1970).

Due to the confined nature of the harbor (the restriction to use the southwest exit only) and the difficulty experienced in maneuvering a ship in strong winds, the ship should be ready to get underway before the storm approaches within 400 n mi (see Figure 22). If this general rule is followed, there will be more than ample time to clear restricted waters and evade before adverse weather can affect the sortie route. (Appendix C discusses the extent to which wind and sea state reduces speed of advance.)

For a ship in or near Cebu City evasion to the southwest is a particularly sound tactic due to the harbor's close proximity to the equator. Typhoons rarely pass to the south of Cebu below 10°N and have never passed below 5°N (refer to Appendix A).

The following evasion techniques for the more common threat situations (any tropical cyclone expected to have a CPA within 180 n mi) are suggested:

1. Tropical cyclone forecast to pass north of Cebu City:

   a. Evasion should be to the southwest since units are already in the navigable semicircle and will remain there.

2. Tropical cyclone forecast to pass east of Cebu City:

   a. Evasion should be to the southwest since an eastward passing tropical cyclone may have already started recurvature and a westward heading will keep the ship in the navigable semicircle.

3. Tropical cyclone forecast to pass south of Cebu City:

   a. Evasion should be to the southwest. This decision should be made as early as possible in order to avoid meeting the storm.

It should be noted that some tropical cyclones do generate in the South China Sea each year. However, their normal tracks are to the west and/or north and no case of threat to the Cebu City area was noted in this study (refer to Appendix A).

In all cases careful monitoring of the storm should be conducted to permit the utilization of the proper evasion technique in the event of a sudden change in storm track.

7. CONCLUSIONS

H.O. Pub. No. 91, Sailing Directions for the Philippine Islands, describes Cebu City as an ideal harbor with safe anchorages and protected from winds from all sides. However, interviews with harbor officials revealed that extensive damage has occurred within the confines of the harbor as a direct result of close passages of typhoons. Harbor officials cited the passage of Typhoon Amy which produced sustained winds up to 85 kt on 10 December 1951, resulting in the destruction of seven inter-island vessels. Also cited were instances where larger vessels (none larger than U.S. Destroyer class) dragged anchor in the outer harbor under much lighter winds. Other key factors that make Cebu City less than desirable as a typhoon haven are:

1. Maneuvering is severely restricted within the harbor. (Use of the inner harbor is not recommended and is restricted during winds above approximately 12 kt, during ebb tide or during the event of tropical-cyclone-associated tides.)
2. The threat of other vessels adrift in the confined harbor.
3. The likely absence of sheltered berths for U.S. ships within the inner harbor due to overcrowding by inter-island vessels.

After considering the above facts and the many discussions with experienced personnel at Cebu City, it is the conclusion of this study that, although Cebu City does afford relatively good shelter in the majority of typhoon passages, it should not be considered an "unqualified" typhoon haven. Larger combatants (cruiser, etc) would find the size and obstructions severely restrictive. The cost in terms of time and money of evasion would be small since the evasion routes are short and relatively direct. Smaller craft, given ample warning time, should also be able to evade into the navigable semicircle. If ample warning time is not given, or the means to evade does not exist, only limited, relatively safe anchorage is present for a limited number of small vessels. Since inter-island vessels occupy virtually all the inner harbor berths and anchorages suitable for U.S. craft, assignment will likely be made to south anchorage.

APPENDIX A

MONTHLY TYPHOON TRACKS FOR YEARS 1946-1969

Figures A-1 through A-11 show monthly and half-monthly (June-December) tracks of western North Pacific tropical cyclones (1946-1969) which were at one time of typhoon intensity. The tropical cyclones have been placed into monthly categories according to the median date of their existence (from Gray, 1970).

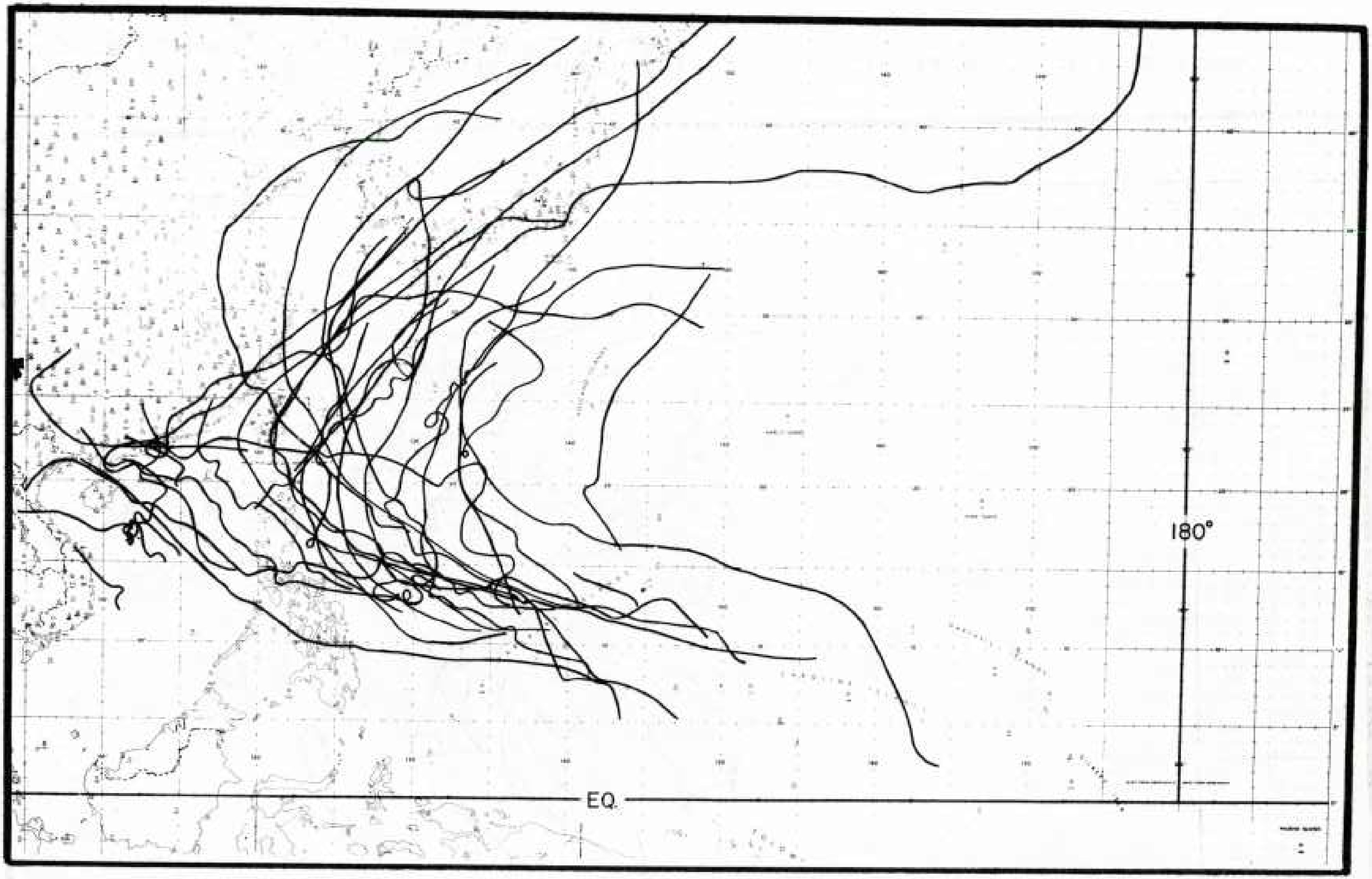


Figure A-1. June tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

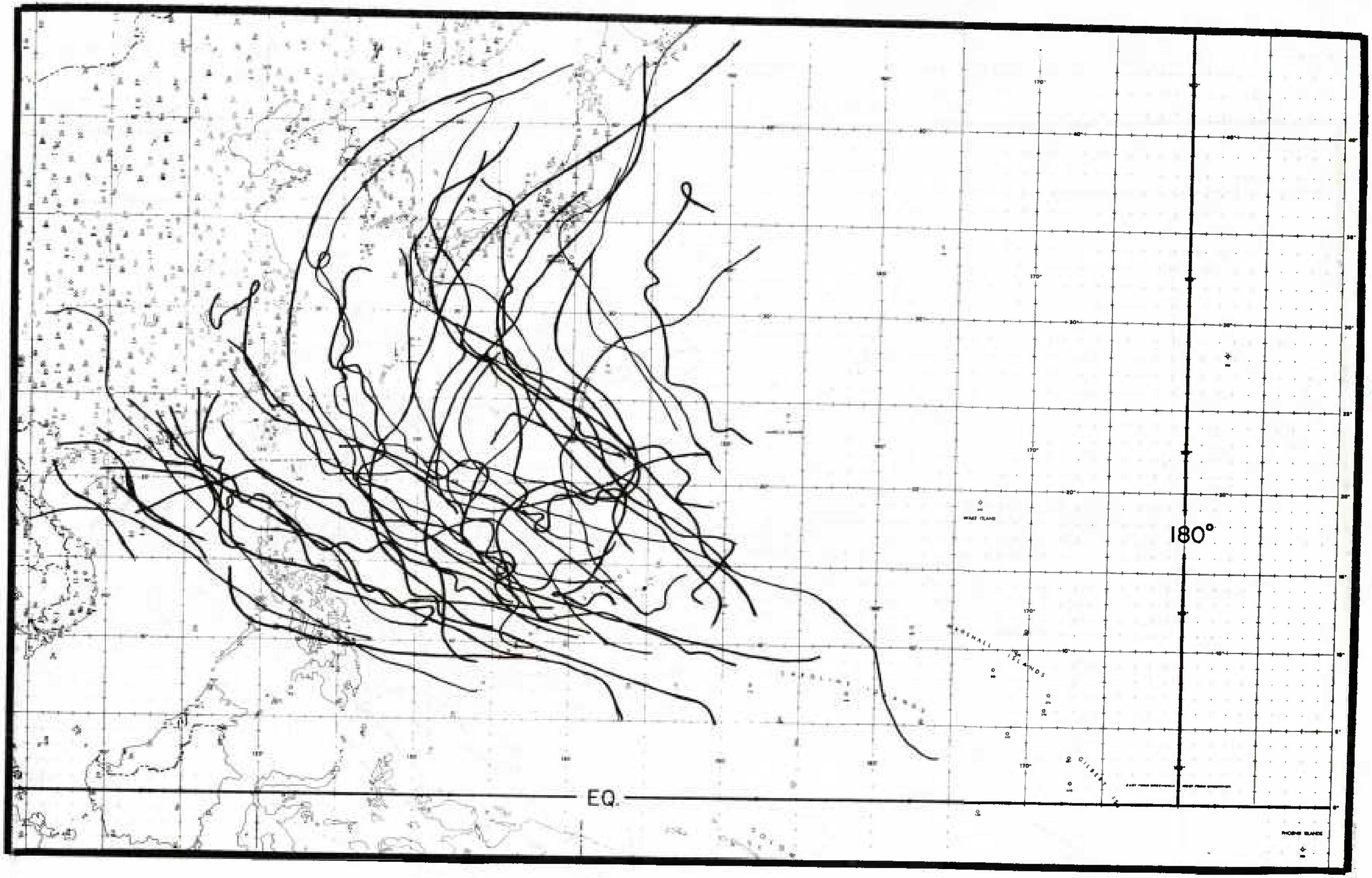


Figure A-2. July (First Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

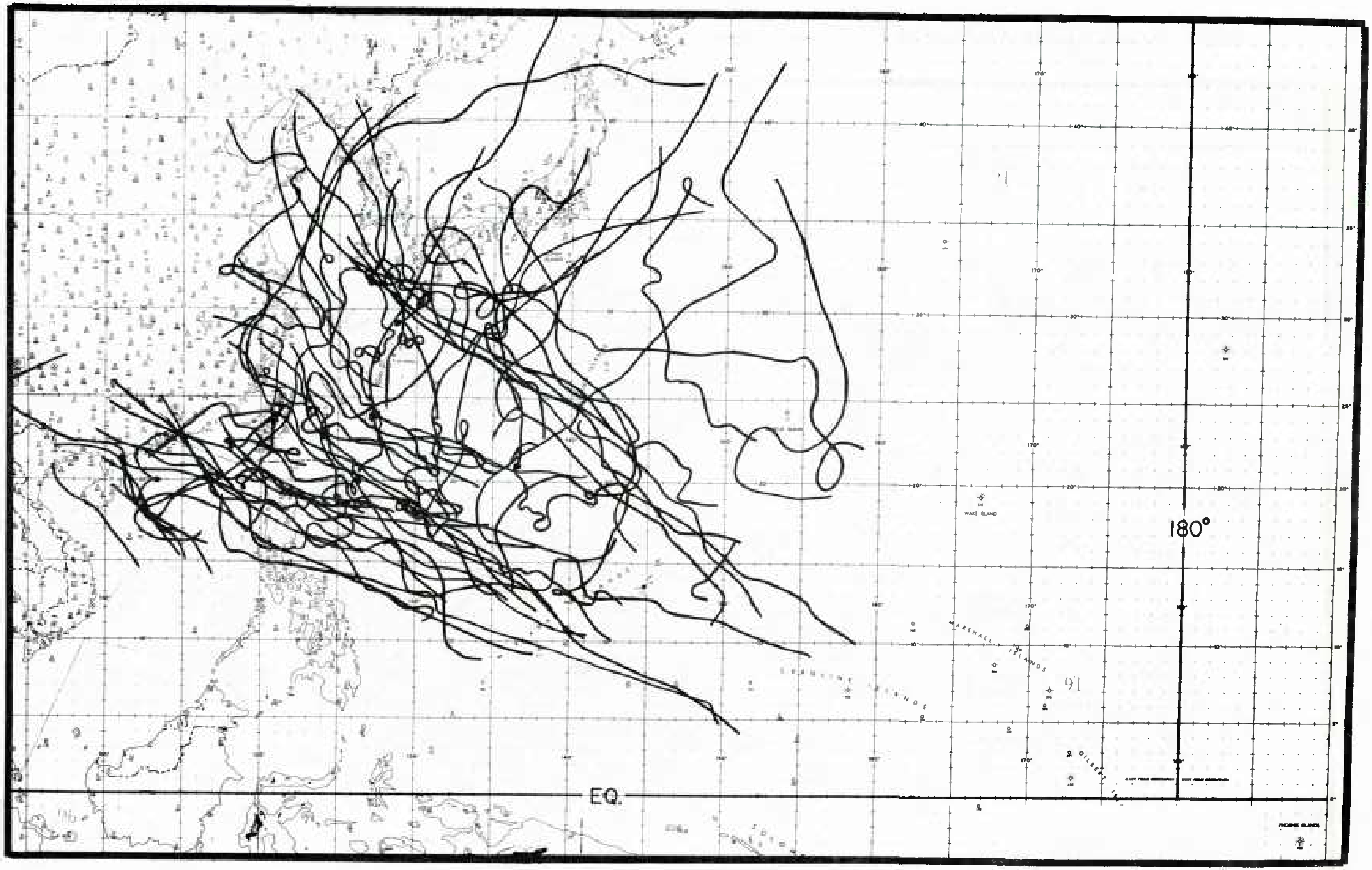


Figure A-3. July (Second Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

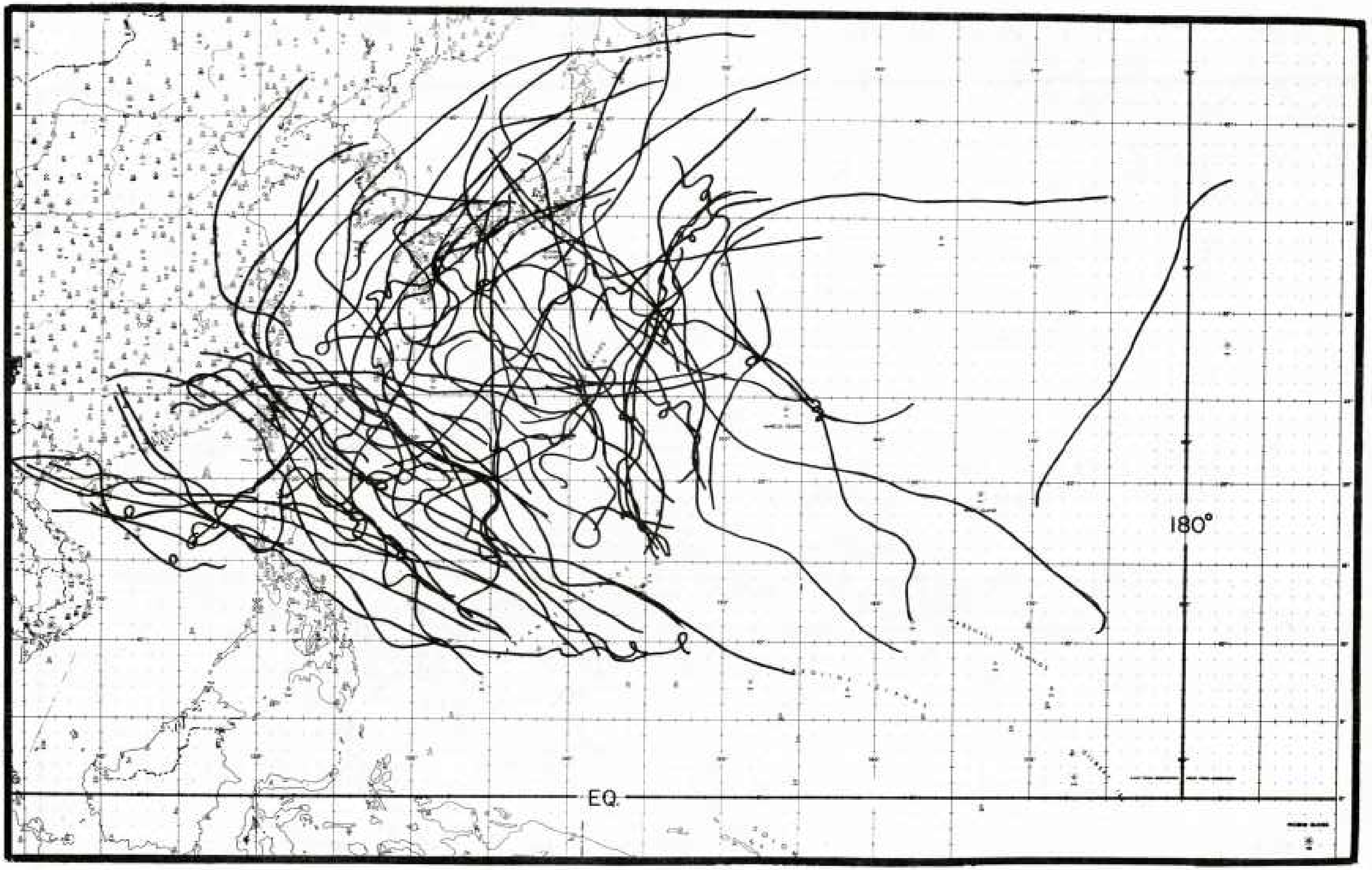


Figure A-4. August (First Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

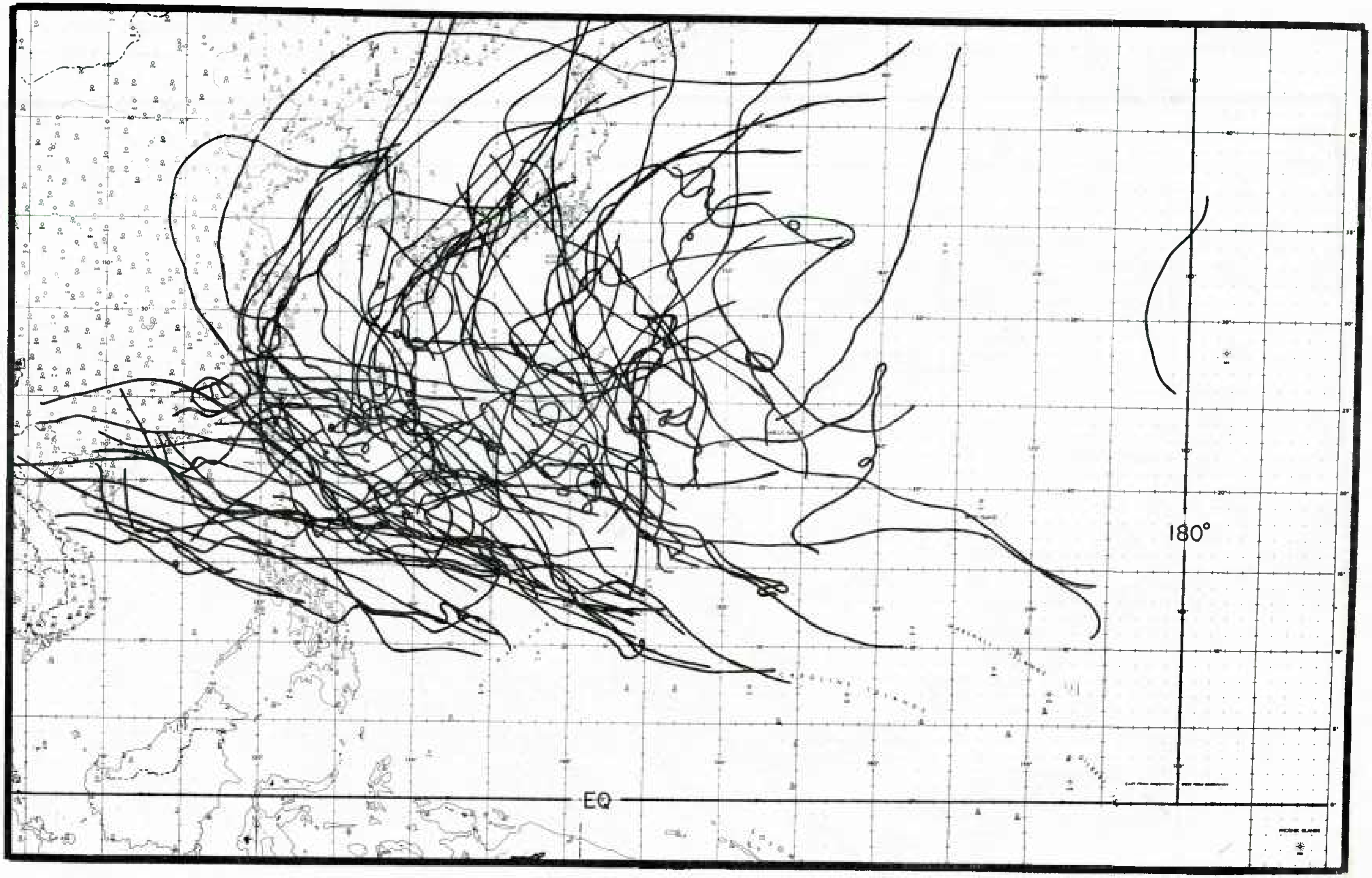


Figure A-5. August (Second Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

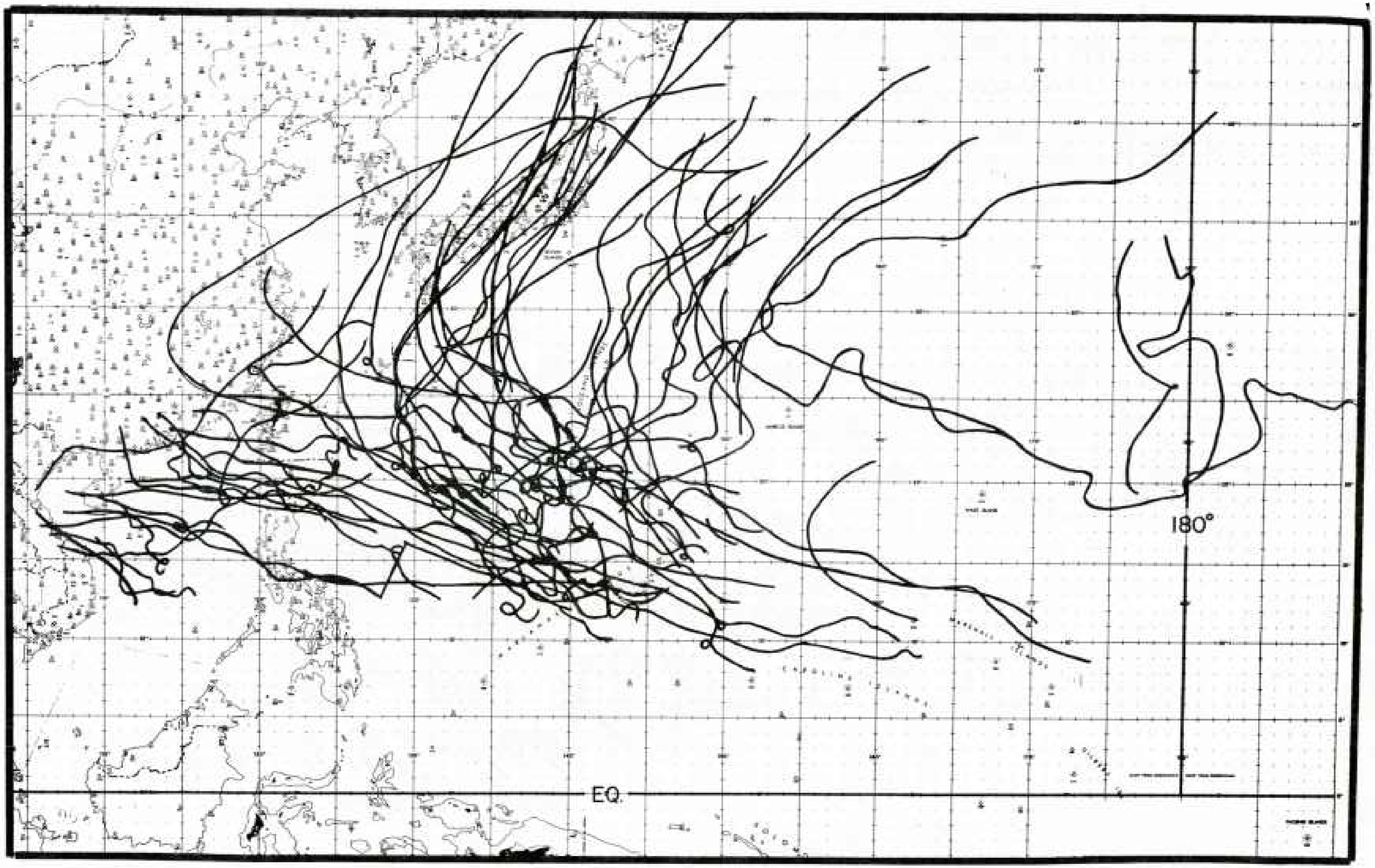


Figure A-6. September (First Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

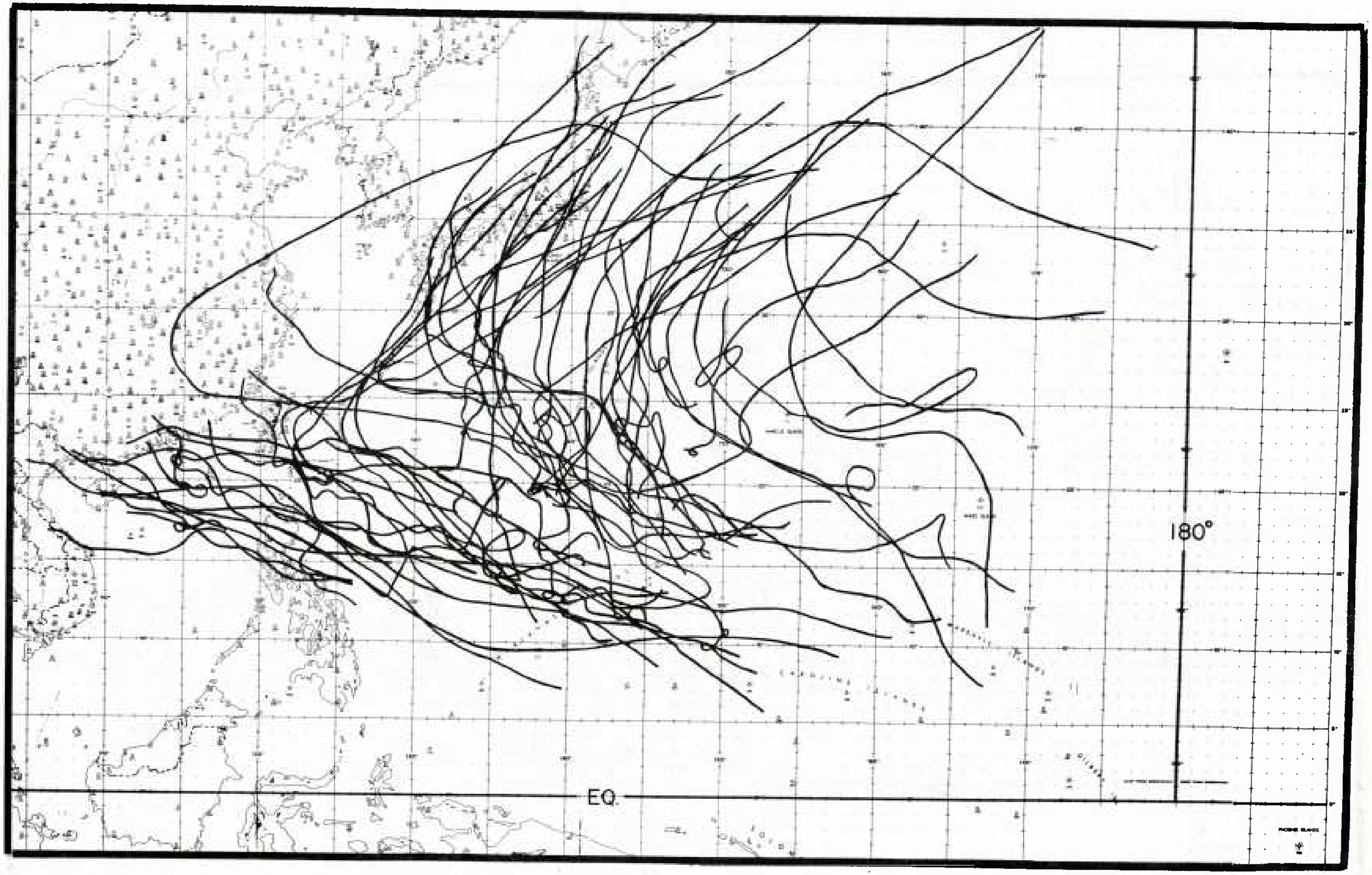


Figure A-7. September (Second Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

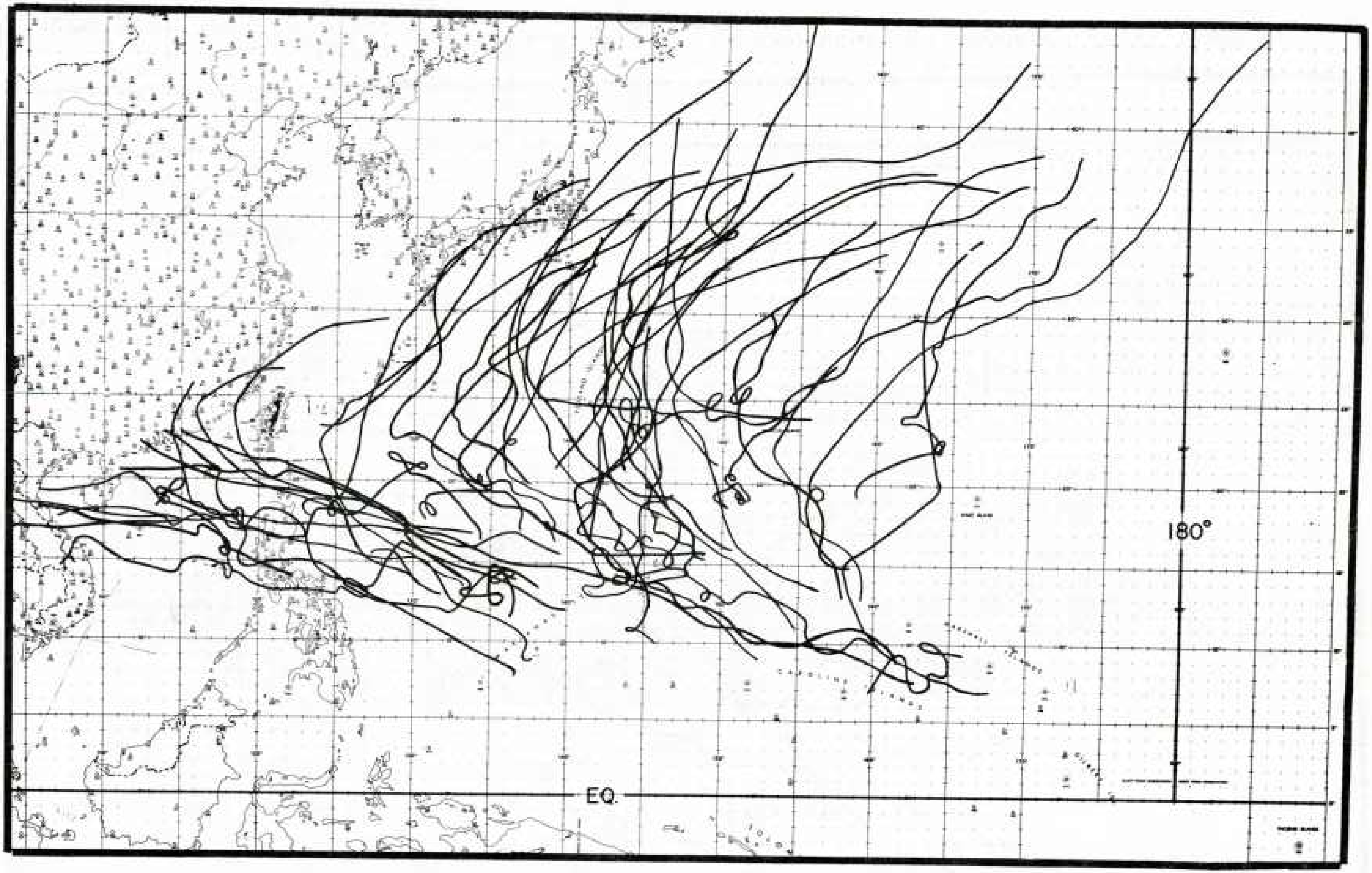


Figure A-8. October (First Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

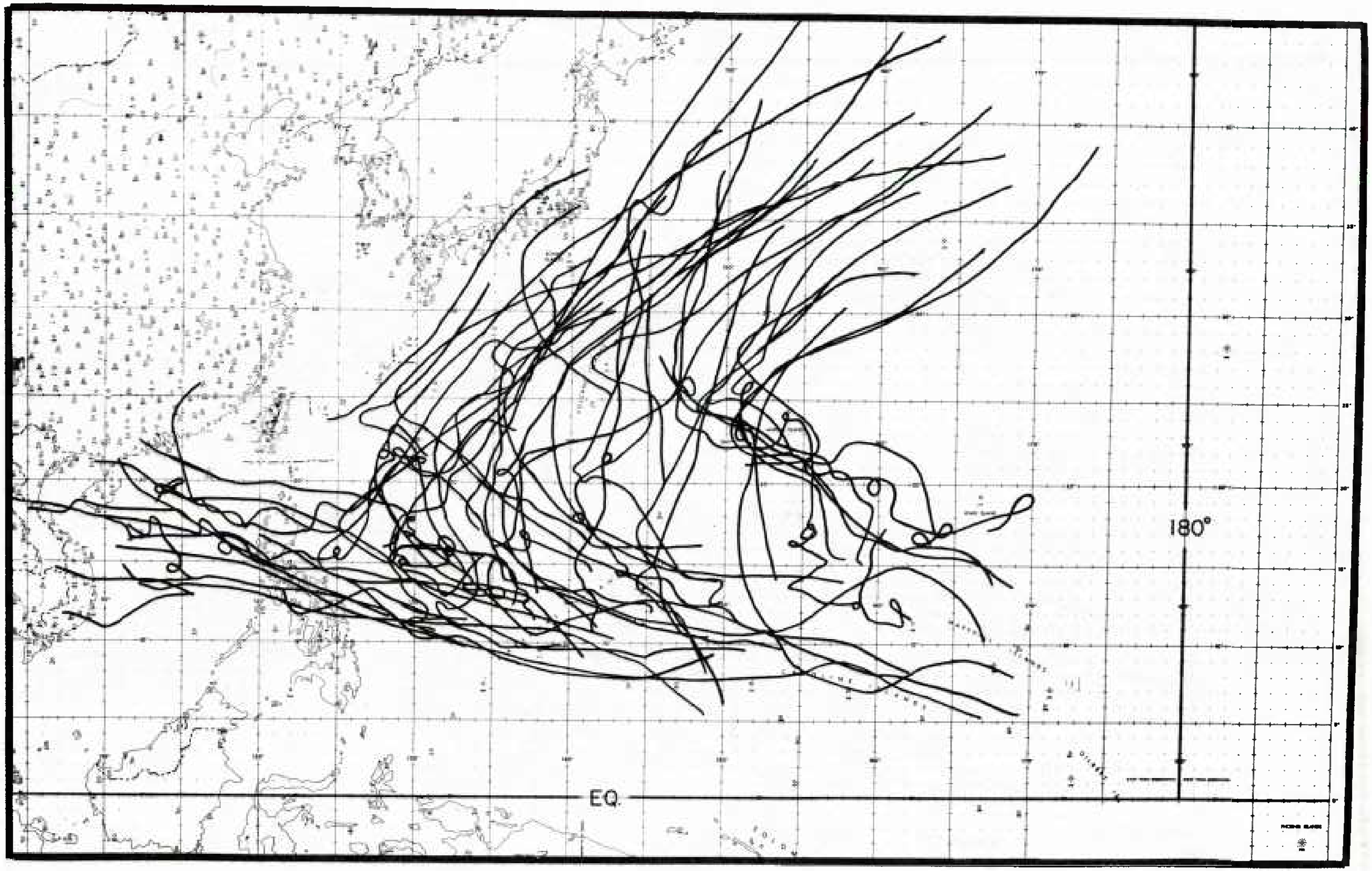


Figure A-9. October (Second Half) tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

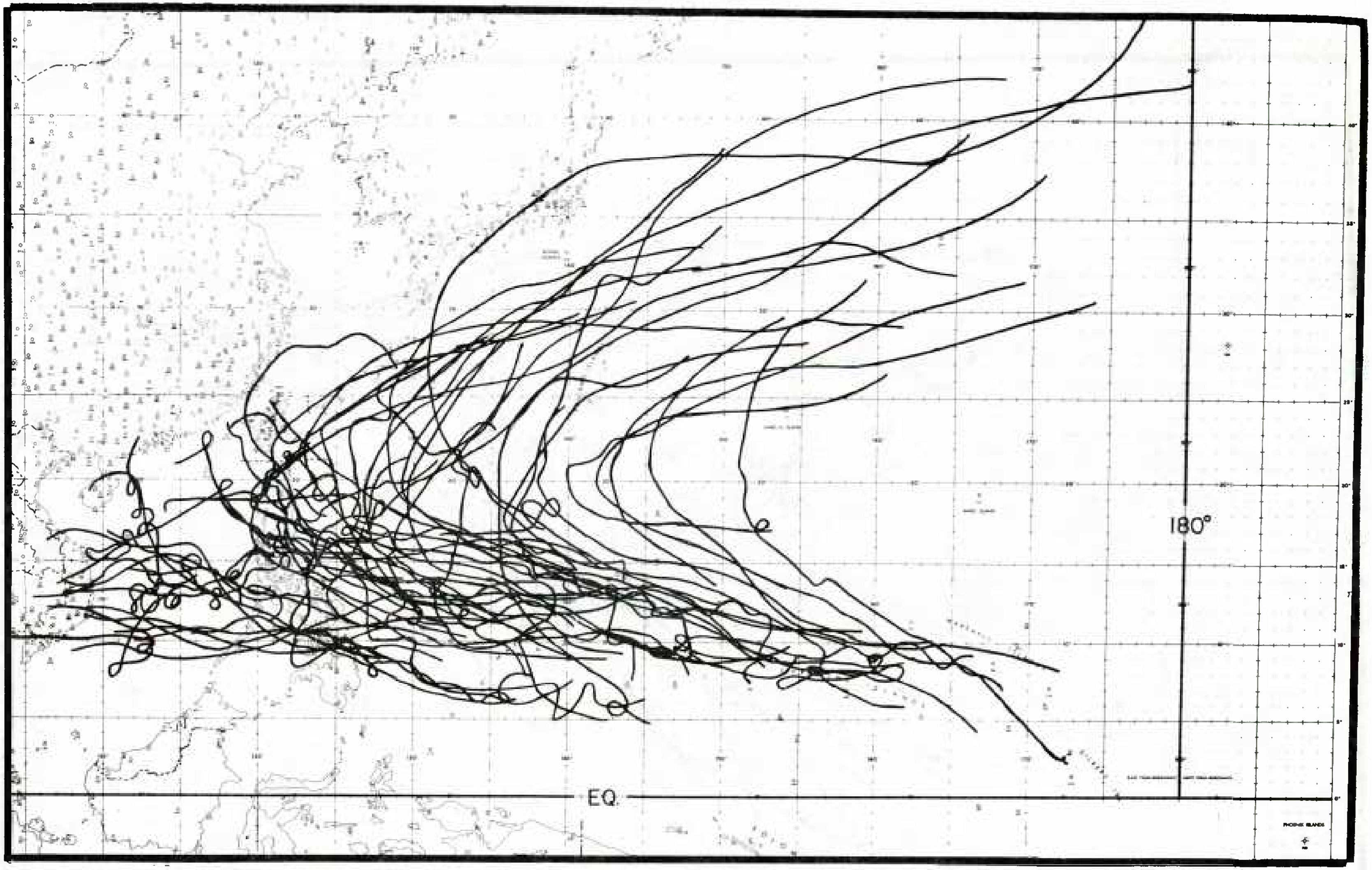


Figure A-10. November tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

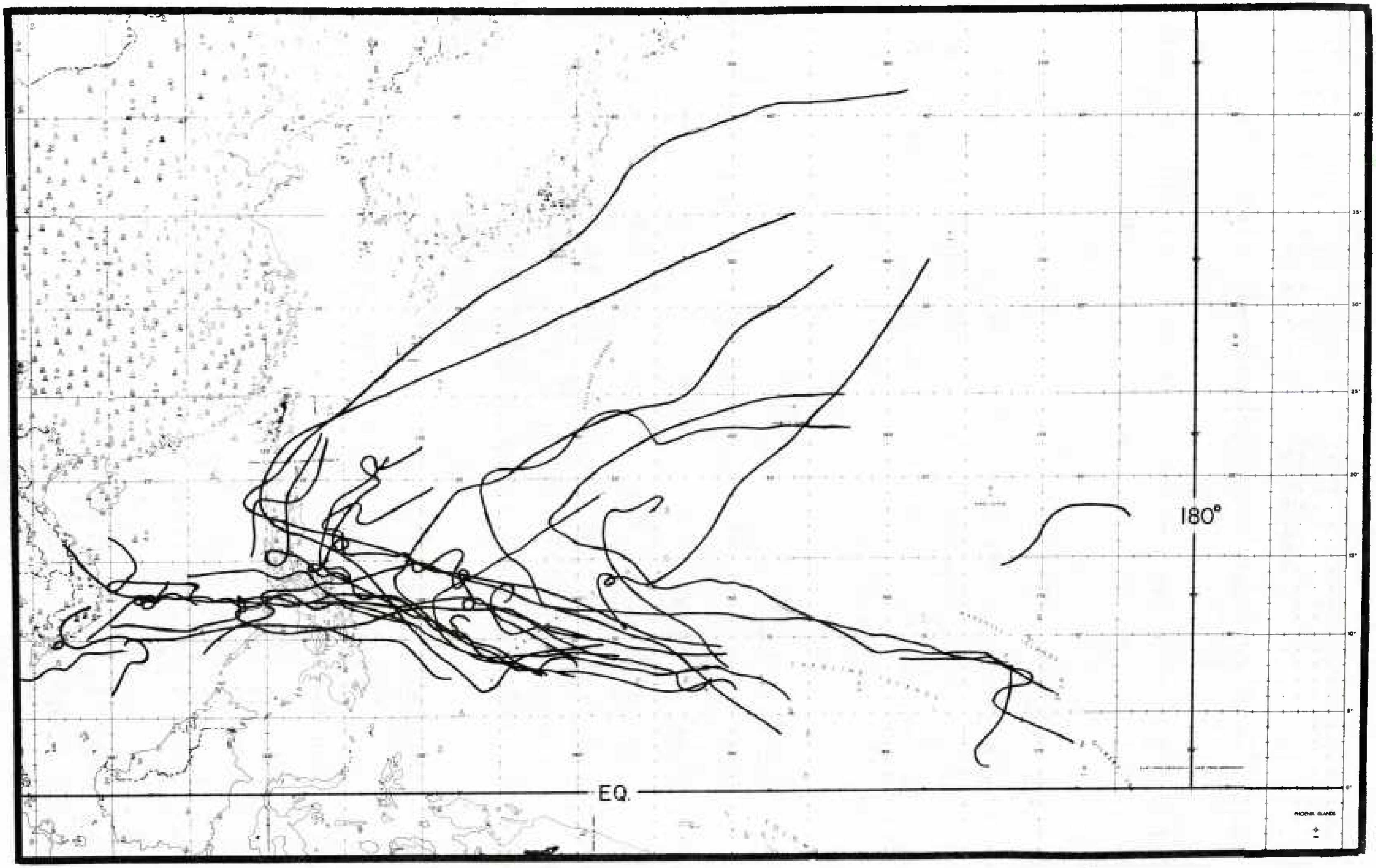


Figure A-11. December tracks of tropical cyclones which at some time were typhoons during the years 1946-1969.

APPENDIX B

HEAVY WEATHER PLAN FROM COMUSNAVPHIL OPORD 201-72

The following heavy weather plan is a reprint of Section 6 of Appendix I to Annex W to COMUSNAVPHIL OPORD 201-72.

6. Conditions of Readiness

When a typhoon or destructive storm approaches shore installations in the Philippine area, COMUSNAVPHIL will order appropriate conditions of readiness be set. The four (4) conditions of readiness and minimum action required for each are:

a. Condition IV

(1) Definition. Trend indicates a possible threat of destructive winds of force indicated within 72 hours.

(2) Minimum Action. Condition IV is the normal readiness condition in the COMUSNAVPHIL area of responsibility. All commands will continually review plans and bills and make preliminary plans for setting a higher condition or readiness.

b. Condition III

(1) Definition. Destructive winds of force indicated are possible within 48 hours.

(2) Minimum Action

(a) The minimum action will usually not interfere with normal routine and will consist of insuring that plans are completed and that personnel, power plants, and other facilities will be readily available, should conditions II or I be set.

(b) Ships capable of evading the typhoon or storm at sea take on fuel as necessary.

(c) Make preparations for securing small and yard craft and ships not capable of evasion at sea.

(d) Prepare preliminary aircraft evacuation plans based on characteristics and movements of the weather.

c. Condition II

(1) Definition. Destructive winds of force indicated are anticipated within 24 hours.

(2) Minimum Action

(a) All ships capable of evading typhoon or storm at sea or of shifting to a protected anchorage, prepare to get underway on four (4) hours notice.

(b) Ships in unsheltered harbors shall sortie as directed or as soon as practicable if proceeding singly when anticipated winds are considered a hazard.

(c) Ships in protected harbors may be ordered to sortie, may request to sortie, or may remain in port at their discretion if not ordered to sortie. Ships remaining in port shall be prepared to get underway on four (4) hours notice or as directed.

(d) Evacuate and/or secure aircraft at the discretion of the commander directly responsible.

(e) Secure small craft and ships not capable of evasion at sea.

(f) Be prepared to set Condition I on short notice.

d. Condition I

(1) Definition. Destructive winds of force indicated are anticipated within 12 hours.

(1) Minimum Action

(a) In unsheltered harbors, all ships capable of reaching the open sea in time to evade the typhoon, proceed to sea.

(b) Ships in sheltered harbors may put to sea or remain, at their discretion, unless ordered to sortie. Ships remaining in port complete all preparations for riding out the typhoon, shifting berths if required, readying ground tackle, ballasting to reduce wind area and increase stability, running additional mooring lines, and setting steaming watches and anchor details as necessary.

(c) Complete the securing of small craft and ships not capable of evading the typhoon at sea.

(d) Complete all measures for securing shore installations commensurate with the intensity of the forecast winds. Due regard shall be had for the vagaries of violent weather phenomena.

APPENDIX C

SHIP'S SPEED VS WIND AND SEA STATE

Figure C-1 represents the estimated resultant speed of advance of a ship in a given sea condition. The original relationships were based on data of speed versus sea state obtained from studies of many ships by James, 1957. They should not be regarded as truly representative of any particular ship (Nagle, 1972).

For example, from Figure C-1, for a ship making 15 kt encountering waves of 16 ft approaching from 030° (relative to the ship's heading) one can expect the speed of advance to be slowed to about 9 kt. Twenty-foot seas, under the same conditions, would result in a speed of advance of slightly less than 6 kt. However, it is emphasized that these figures are averages and the true values will vary somewhat from ship to ship.

Figure C-2 shows the engine speed required to offset selected wind velocities for various ship types (computed for normal loading conditions).

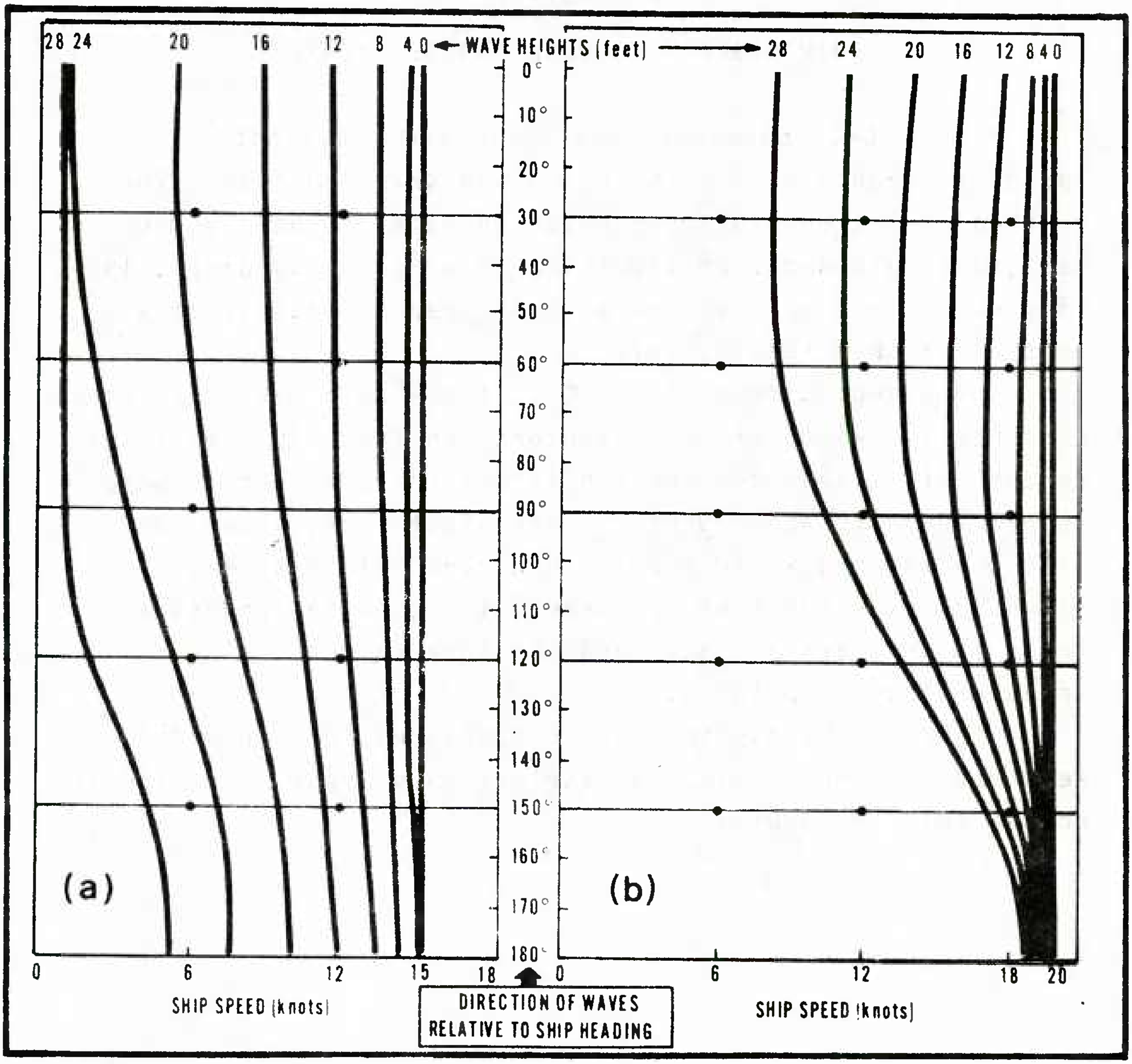
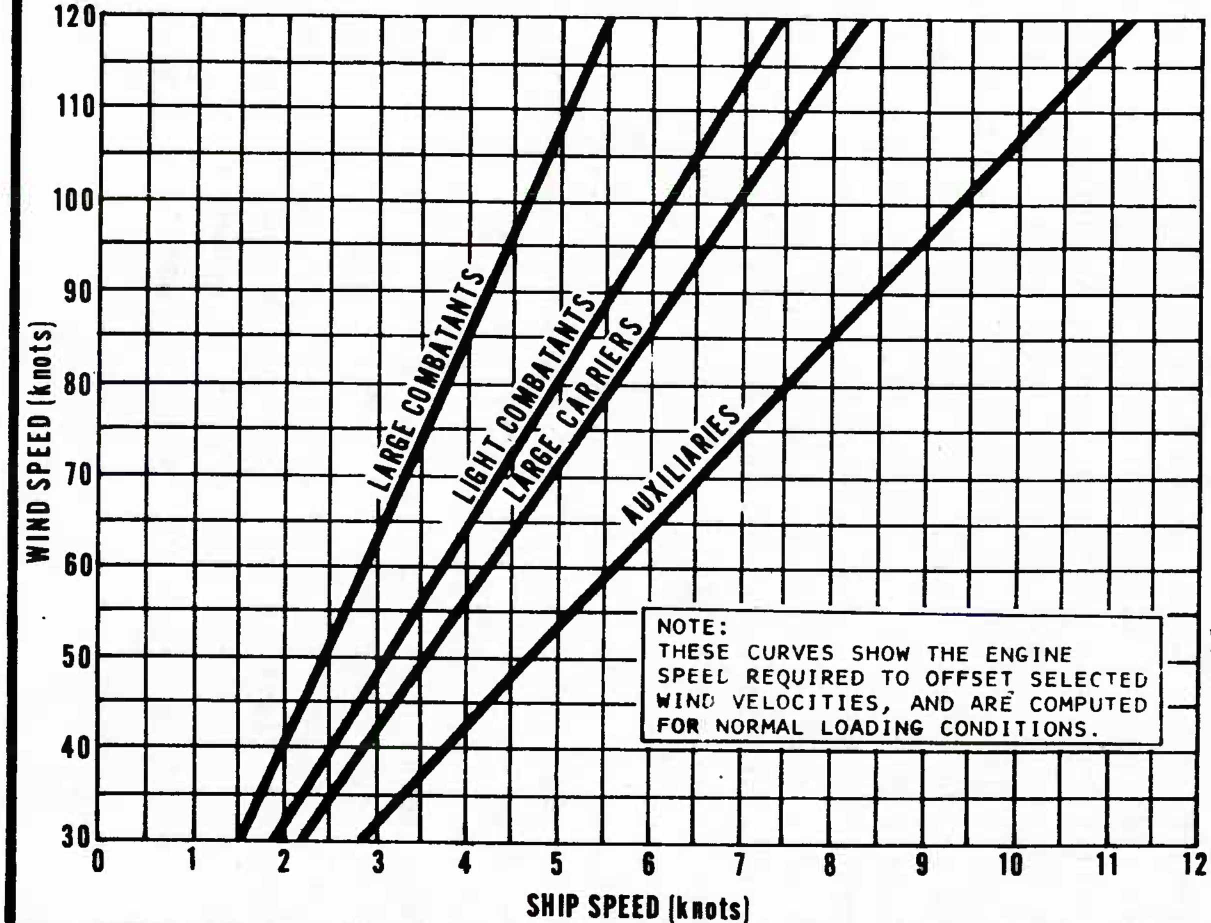


Figure C-1. Expected ship speed as a function of wave height and wave direction relative to ship's heading for a ship making 15 kt (a) and 20 kt (b) (from Nagle, 1972).



The curves shown were developed using the basic formula:

WIND LOAD = $R_w A V^2$

where R_w is equal to wind friction factor. (R_w is generally taken as 0.004.)

V is equal to wind velocity in knots
A is equal to projected area above the waterline in sq ft.

Three sets of calculations with varying R_w were used. The plotted values illustrated represent the mean of these values.

Figure C-2. Engine speed as a function of wind velocity for offsetting force of wind (from Crenshaw, 1965).

APPENDIX D

CASE STUDY - TYPHOON AMY
(30 November - 19 December 1951)

(From "Tropical Cyclones of 1951," Department of Commerce and Industry, Republic of the Philippines, 1951.)

"From a cyclonic circulation detected as early as November 30, this disturbance was able to develop within 58 hours into a typhoon of almost 100 miles per hour winds near the center. For almost two days thereafter, the maximum winds fluctuated to as low as 50 miles per hour. The general movement was west-northwest but the speed varied from 9 to as high as 28 miles per hour. In the morning of December 6th the typhoon started to move westward and like a tight-rope walker it traced in an unusual manner the 12°N latitude for more than 58 solid hours from a fast rate of 18 miles per hour at the beginning slowing down exhaustedly to about 4 miles per hour near the end of the period. Eastern Luzon and Visayas were already under its influence as early as December 6, as light rains began to fall along the eastern region of the Visayas and 35-40 miles per hour winds were felt" (See Figure D-1).

"On December 8, when its center was around 250 miles east of Catbalogan, the typhoon made a spectacular change in direction from the usual west-northwest manner to an unusual west-southwest fashion hitting the southern tip of Samar in the afternoon of December 9. Barely missing Cebu City, it, however, lashed that city with its 110 miles per hour winds and very heavy continuous rain. After passing 30 miles south-southeast of Bacolod it maintained its westward movement for 24 hours slowing down to about 3 miles per hour at a point 75 miles northeast of Puerto Princesa on the 11th.

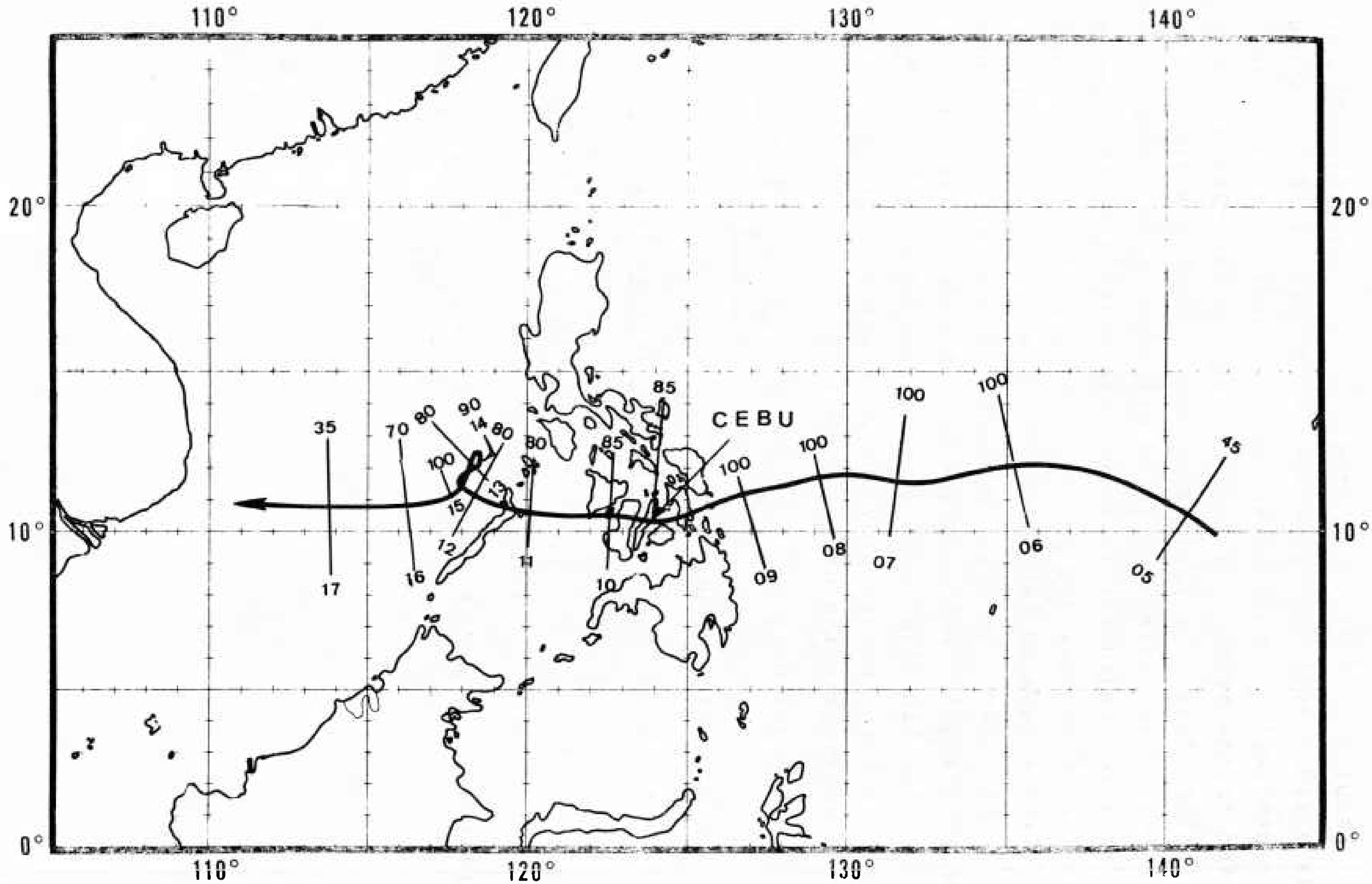


Figure D-1. Track of Typhoon Amy from 5 December 1951 to 17 December 1951. Wind intensity (knots) are shown above the track. Dates shown below the track are for 0000Z daily.

Peculiar and freak as it was in form and movement, it made a final performance before leaving our area by making a breath-taking counterclockwise loop during the 48-hour period beginning noon of December 12. After such a rigorous acrobatic stunt, the cyclone weakened and its maximum winds near the center were down to 40 miles per hour. However, it was able to regain its lost strength after a brief sojourn over the China Sea, and in the morning of the 15th, it was again sporting a maximum wind of 115 miles per hour at its northeast quadrar.t. Heading west-southwest at 7 miles per hour it gradually weakened and merged with a weak cyclonic circulation 250 miles east of the coast of French Indo-China, which was later absorbed by the anticyclonic flow over the region in the evening of the 19th."

MAXIMUM 24-HOUR RAINFALL: 20.40 in. at Camp 7 Minglanilla, Cebu on December 9.

MAXIMUM SUSTAINED WINDS:

Over land - - - 100 miles per hour at Cebu Airport Dec. 9.

Over water - - - 100 miles per hour from Dec. 5 2300Z up to the time it hit the archipelago.

MAXIMUM GUSTINESS OVER LAND: 130 miles per hour at Cebu Airport on Dec. 9.

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