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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study evaluates the Numazu Operating Area and Kagoshima Harbor as possible typhoon havens. Characteristics of the areas under tropical cyclone conditions, including climatology, topographical effects on the wind, and wave action at each location are discussed. Problem areas to be considered if remaining in the operating area/harbor and

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suggested evasion procedures for ships are examined.

The tracks of tropical cyclones from 1947-1974 for the western North Pacific were analyzed to assess the threat posed to each area by a tropical cyclone. Results show that neither area is an entirely safe haven. The Numazu Operating Area could be a haven under certain specified conditions but only as a last resort. Kagoshima Harbor should never be considered a typhoon haven.

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**NAVENVPREDRSCHFAC
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AN EVALUATION OF THE NUMAZU OPERATING AREA AND KAGOSHIMA HARBOR, JAPAN AS TYPHOON HAVENS

by

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DECEMBER 1975

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CONTENTS

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1. INTRODUCTION

Severe tropical cyclones (typhoons and hurricanes) are among the most destructive weather phenomena a ship may encounter whether the ship be in port or at sea. When faced with an approaching typhoon, 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 a harbor?

An attempt is made to answer this question regarding the Japanese port of Kagoshima and the Numazu Operating Area. The intent is to provide an aid to the commander in his decision making process.

In general, it is an oversimplification to label a harbor as merely good or bad. Consequently, an attempt is made to present enough information about the harbor/operating area to aid a commanding officer in reaching a sound decision with respect to his ship. The decision should not be based on the expected weather conditions alone, but also on the ship itself, as well as the characteristics of the harbor/operating area. These characteristics include, but are not limited to, natural shelter provided, port congestion, support facilities (normal and emergency) available, and alternatives for evasion of the storm.

2. TROPICAL CYCLONES

2.1 LIFE CYCLE

An informative and convenient method to view the typhoon is to look at its evolution from a weak tropical disturbance to its dissipating stage. The evolution from a tropical disturbance to a mature typhoon and subsequent weakening and dissipation is usually a slow process but it can at times be very rapid. Several of the terms used to describe the life cycle are as follows (adapted from Crutcher and Quayle, 1974):

1. Tropical Cyclone

A tropical cyclone is a cyclone originating over the tropical ocean. Weather fronts are not associated with the tropical cyclone as with temperate latitude cyclones and most of its energy is derived from an intricate system which, to a large extent, is dependent upon the sea-surface temperature (SST). Tropical cyclones rarely are generated when the SST is less than 26°C. In the Northern Hemisphere the wind rotates counterclockwise around the warm center core of low pressure. Official, consecutively numbered warnings are disseminated by the Fleet Weather Central/Joint Typhoon Warning Center, Guam (FWC/JTWC) on tropical cyclones in the western Pacific at approximately six-hour intervals.

2. Tropical Disturbance

A tropical disturbance, the formative stage from which a typhoon may develop, is a weak low pressure area characterized by below normal pressure, above normal cloudiness, shower activity and weak cyclonic wind flow. The disturbance forms in the low latitudes over a warm sea surface. The fall of barometric pressure is generally a slow, gradual process to about 1000 millibars (mb). The strongest winds occur to the north of the developing vortex in the Northern Hemisphere.

3. Tropical Depression

The term "tropical depression" defines the situation when there is a closed circulation (a closed isobar generally locates the center of the depression) and the maximum sustained wind speed[1] is below 34 kt, although gusts may exceed 34 kt.

4. Tropical Storm

If a tropical cyclone has maximum sustained winds of 34 to 63 kt, it is termed a tropical storm and is assigned a name by the FWC/JTWC. Not all tropical depressions reach this stage.

Assuming that the cyclone intensifies, the center pressure falls rapidly below 1000 mb and the winds form a tight band around the center. Cloud and rain patterns develop into narrow organized bands, spiraling inward toward the center.

5. Typhoon

A tropical cyclone in the western North Pacific with maximum sustained winds of 64 kt or greater is called a typhoon. The tropical cyclone is considered immature as long as the barometric pressure is falling and the speed of the gusty winds increase. In an immature stage, the typhoon strength winds may exist within a relatively small area.

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[1] The maximum winds referred to usually occur near the center and near the eye wall. However, strong winds will usually extend a considerable distance outward from the center, particularly in the dangerous semicircle. In this connection, sustained wind is defined as the average wind over a specified time period. The wind will be stronger in gusts, and peak gusts may be 50% higher than the sustained wind.

When the central surface pressure stops falling, and the sustained wind speed regime stabilizes, the mature stage is reached; however the size of the storm may continue to increase for a number of days. The circulation of a large, mature typhoon can be over 1000 n mi in diameter, with winds exceeding 64 kt in a region 150 n mi in diameter.

The right side (relative to the track of the cyclone) of a tropical cyclone in the Northern Hemisphere is known as the "dangerous semicircle," while the left side is known as the "navigable semicircle" (navigable does not imply that a ship can maneuver without difficulty and the left side is still extremely dangerous). Figure 1 gives an overall view of the wind pattern around the eye of a Northern Hemisphere, 150-kt typhoon. Note the relationship between the wind intensity and the direction of movement in the right semicircle relative to the direction of motion.

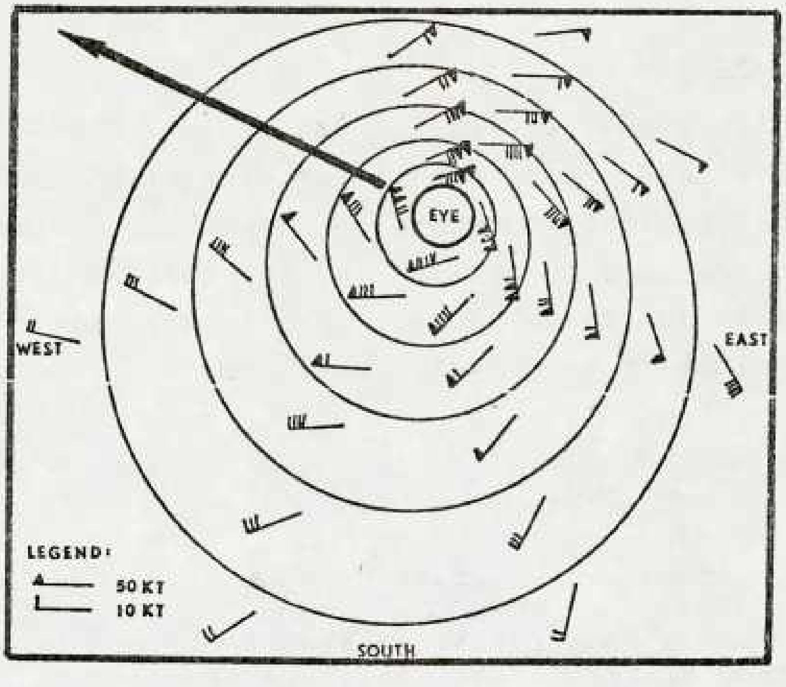

Figure 1. Distribution of surface wind speeds (kt) around a 150-kt typhoon in the Northern Hemisphere over open water. The arrow indicates direction of movement (after Harding and Kotsch, 1965).

6. Dissipation Stage

Dissipation occurs when the maximum wind speed declines steadily along with a rising central barometric pressure.

2.2 TROPICAL CYCLONE MOVEMENT

Individual tropical cyclones (the term tropical cyclone is inclusive of tropical depressions, tropical storms, and typhoons) may follow irregular and widely differing tracks. In general they begin in the tropics and usually move west to west-northwest. Some cyclones move from the tropical latitudes to the temperate latitudes, their northwest movement becoming northward and finally northeastward. This change in direction through north to the northeast is known as "recurvature."

In a study of 586 western North Pacific tropical storms and typhoons which occurred during the months of May-December, 1945-1969, Burroughs and Brand (1972) found that 236 (40%) of them recurved. The majority of typhoons which are a matter of concern to Japan are the recurvers. The above value of 40% is derived from Table 1. Note the change in the percent that recurve for each month. Appendix A shows the mean monthly and part monthly tracks of all typhoons in the western North Pacific for the June-October period.

Prior to recurvature tropical cyclones typically move at speeds from 8 to 14 kt. After recurvature, they may accelerate within a period of 48 hours to speeds 2-3 times that at the point of recurvature (Burroughs and Brand, 1972). This acceleration is mainly due to the system entering the belt of prevailing westerly winds, and varies with the time of year.

As a tropical cyclone moves into temperate latitudes, it comes into contact with cooler surface waters and cooler air is drawn into its circulation. These factors hasten its weakening and dissipation.

Table 1. Recurving tropical storms and typhoons versus total number of tropical storms and typhoons separated by monthly periods for the period 1945-1969 (Burroughs and Brand, 1972).

Period	Recurving Tropical Storms & Typhoons 1945-1969	Total Tropical Storms & Typhoons 1945-1969	Percent That Recurve
May	14	24	58%
June	14	40	35
July	17	88	20
August	39	113	35
September	53	123	43
October	52	94	55
November	34	70	48
December	13	34	38
May-December	236	586	40%

2.3 SEA STATE AROUND TROPICAL CYCLONES

Wind is the driving force which generates the waves and produces the state of the sea. Swell, which affects ship movement, extends well beyond the wind field associated with a tropical cyclone. A miscalculation or imprudent decision concerning sea conditions may lead to a destructive rendezvous with a storm. Though the tropical cyclone's maximum wind and wind distribution relative to the center can be described with fair accuracy, a forecast of the sea state is more difficult. The character of the sea state is primarily a function of storm size, duration and intensity and storm path.

Figure 2 shows the combined sea height[2] associated with 21 tropical storms and typhoons to the east of the Philippines (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 (wind category 34-63 kt) can produce 12-ft seas approximately 200 n mi from the storm center, while an intense typhoon (wind category $\geq$ 100 kt) can produce 12-ft seas approximately 450 n mi from the center. The distances given are mean distances since the isopleths 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 sea-height pattern (9-15 ft range) for recurved storms moving on headings between 001° and 090° and is based on 24 sea-state analyses for tropical storms and typhoons that occurred during 1971. Note that the greatest area of higher seas (9-15 ft range) exists to the rear and toward the right (dangerous) semicircle of the storm.

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

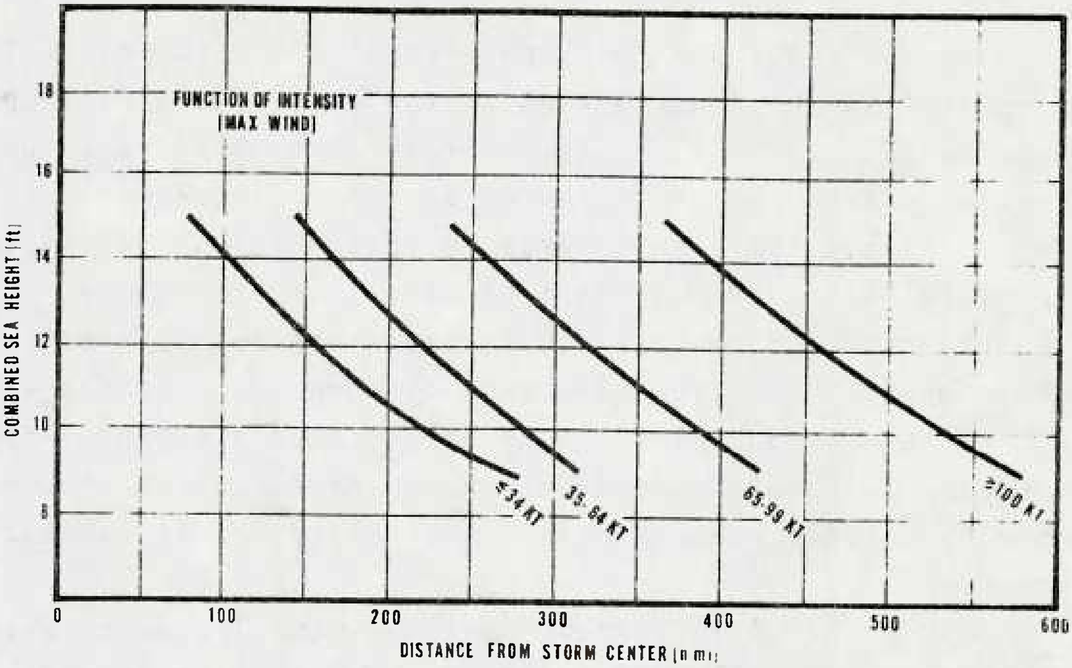

Figure 2. The combined sea height (9-15 ft range) around 21 tropical storms and typhoon (based on 173 analyses for the year 1971) plotted against distance from storm center and given as a function of intensity (Brand, _et al_., 1973).

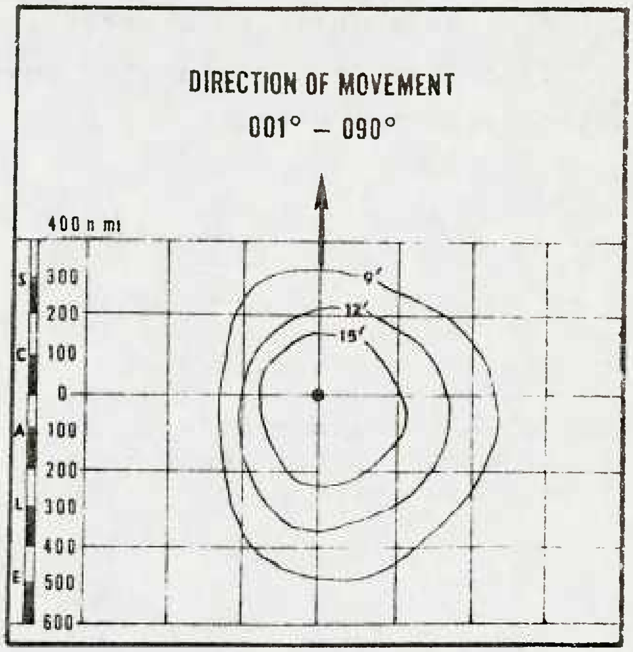

Figure 3. Combined sea-height isopleths (9-15 ft) based on 24 analyses of tropical storms and typhoons heading between 001°-090°. The mean speed of movement for these 24 analyses was 12.1 kt, and the mean intensity was 64.6 kt (after Brand, _et al_., 1973).

2.4 INTENSITY

In an examination of 66 recurving typhoons (1957-1968), Riehl (1971) found that most typhoons reach their maximum intensity at, or just prior to, the point of recurvature (see Table 2). Since the mean latitude of recurvature in the western Pacific is approximately 23°N, most typhoons are decreasing in intensity as they are approaching Japan.

Table 2. Point of reaching typhoon maximum intensity for 66 cases of recurving typhoons based on 12-hourly observations (1957-1968) (after Riehl, 1971).

	Number of cases
Maximum intensity occurred <u>within</u> 12 hours of recurvature	43
Maximum intensity occurred one day or more <u>before</u> recurvature	22
Maximum intensity occurred one day or more <u>after</u> recurvature	1
Total	66

3. JAPAN

3.1 JAPANESE ISLANDS

Japan is an island nation in the western part of the North Pacific Ocean off the eastern coast of the Asiatic mainland, consisting of a chain of islands extending in an arc from northeast to southwest. The northeastern tip of the chain is at 46°N, 143°E and the southernmost point is at 26°N, 131°E. The four main islands of Japan from north to south are Hokkaido, Honshu, Shikoku, and Kyushu. Hundreds of smaller islands lie off the coasts of the main ones. Figure 4 shows the position of Japan relative to the surrounding land and water masses.

3.2 HONSHU

Honshu is the largest of the main Japanese Islands. The Numazu Operating Area in south central Honshu is used routinely by the U.S. Navy. Additionally, commercial shipping firms utilize three small harbors in the area.

The island of Honshu is one of the most rugged of land areas. The mountains in the north central area average 5,000 ft to 10,000 ft in height and are often called the Japanese Alps. Northern Honshu is less mountainous. Figure 5 depicts the predominant topographic features of central Honshu. The mountainous terrain of central Honshu has a distinct influence on the weather in the Numazu Operating Area.

A detailed description of the coasts and harbors of Honshu can be found in the Sailing Directions (Enroute) for Japan, H.O. Pub. Number 156.

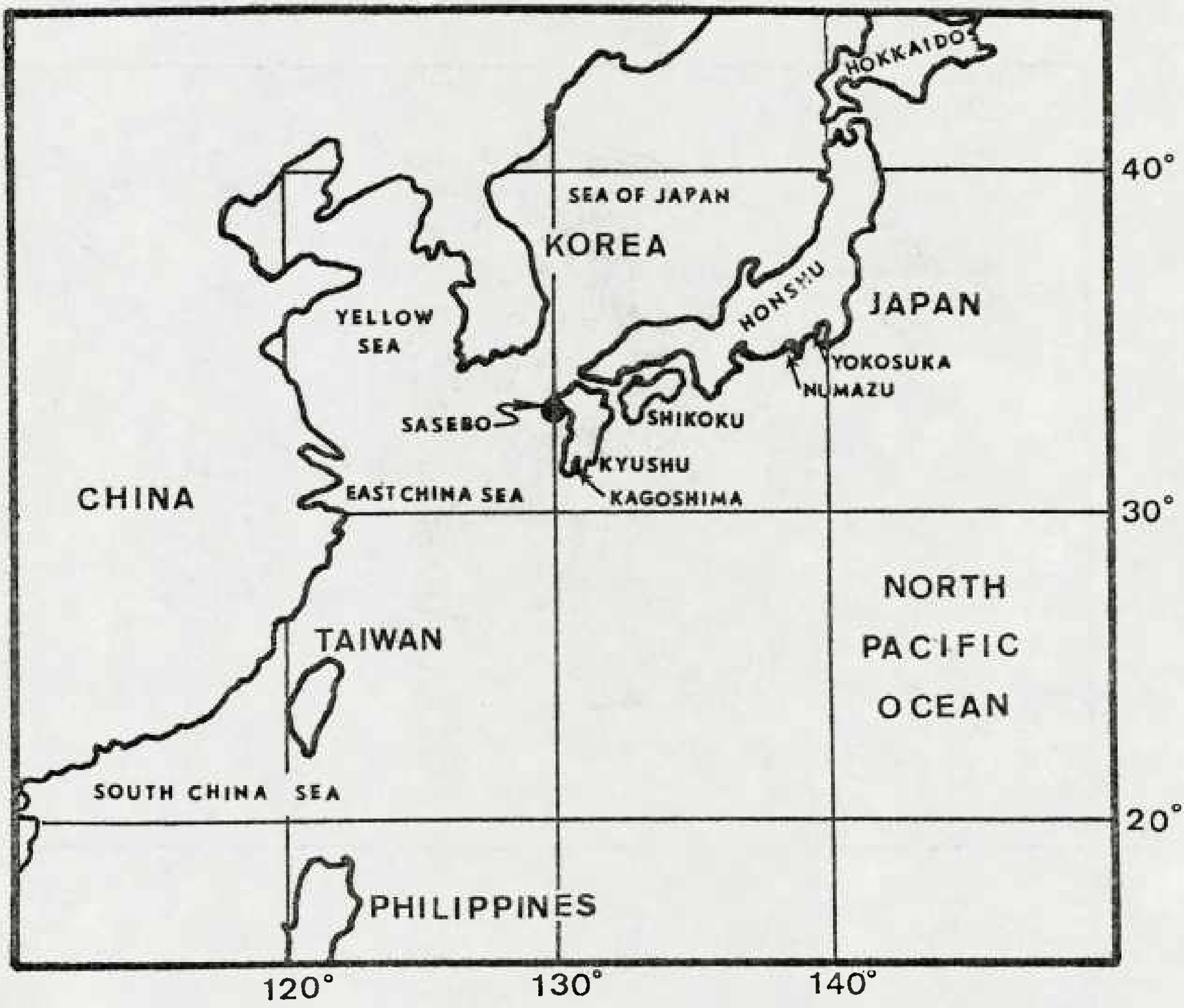

Figure 4. Map of western North Pacific Ocean, showing the main Japanese Islands.

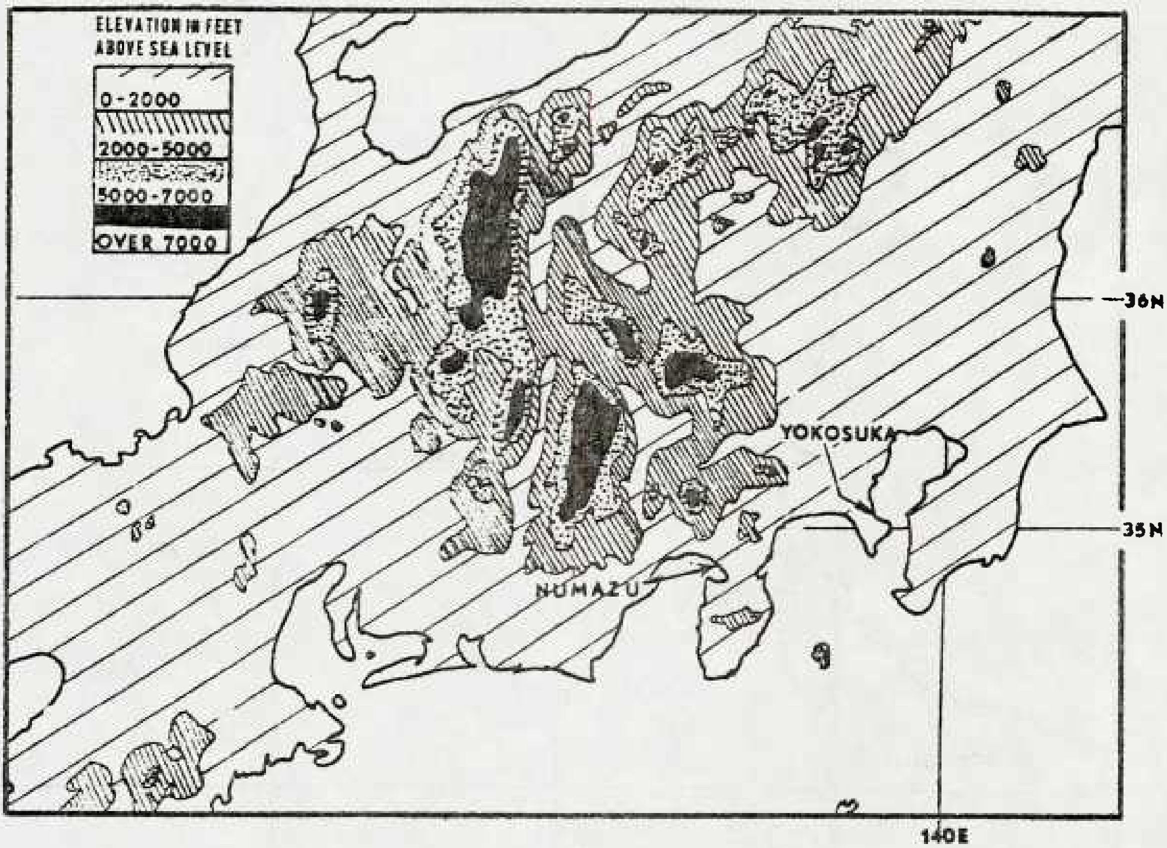

Figure 5. Topographical map of central Honshu in vicinity of the Numazu Operating Area.

4. NUMAZU OPERATING AREA -- GENERAL DESCRIPTION

4.1 LOCATION AND TOPOGRAPHY

The terrain around Suruga Bay is generally rugged and mountainous. The dominant topographic feature in the area is Fujiyama (12,395 ft), the highest mountain in Japan. This extinct volcano rises from the northern shore of the bay to its peak, 12 n mi away. Along the eastern and western coasts, the mountains rise abruptly to heights in excess of 4000 ft and 6000 ft, respectively. These ridges lie generally in a north-south orientation with a "saddle" between them and Fujiyama. Figure 6 shows the topographic features of this region.

The Numazu Operating Area takes its name from the city of Numazu, which is located at 35°05'N, 138°52'E at the northwestern side of the Izu Peninsula on the northeast shore of Suruga Bay. The harbors of Shimizu and Tagonoura are also located, respectively, on the western and northern shore of Suruga Bay. Figure 7 locates some pertinent features. Suruga Bay penetrates the southern coast of Honshu in a north-northeasterly direction for a distance of approximately 35 n mi. Numerous ships of various sizes transit the bay enroute to the harbors mentioned.[3]

Suruga Bay itself is characterized by extreme depths. At its entrance, the depth is in excess of 8000 ft. An exception is in the south central region of the bay where the bottom rises up to within 100 ft of the surface. Along the northern shore the bottom drops off to over 100 fathoms within a mile of the coast. Figures 7 and 8 reflect hydrographical features of Suruga Bay.

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[3] Shimizu is a major container ship port for central Honshu; Tagonoura is a small exporting industrial city; and Numazu is a local port for small (less than 500 tons) fishing and rock gathering boats.

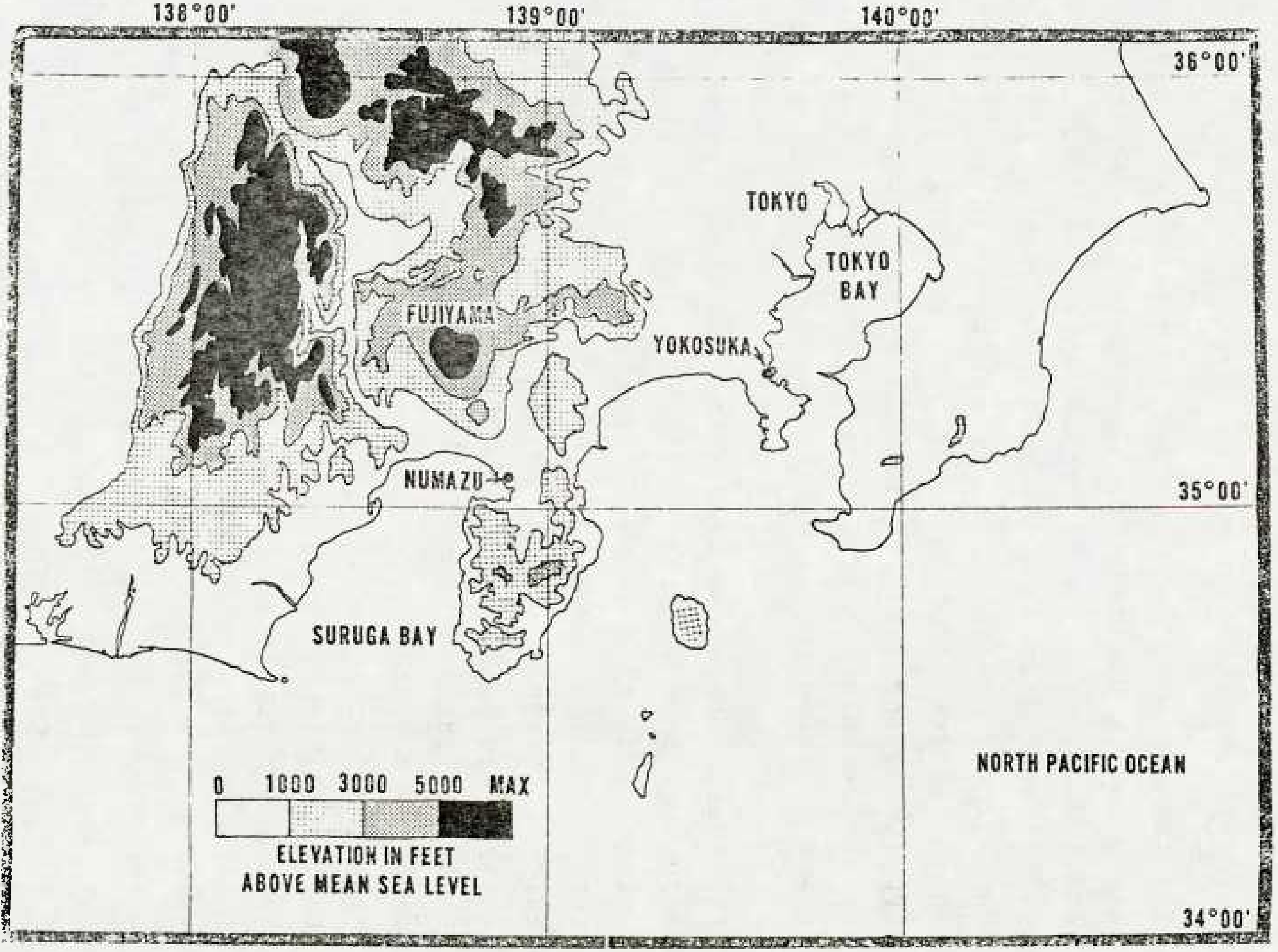

Figure 6. Geographical and topographical depiction of south central Honshu featuring Suruga Bay, Tokyo Bay, and surrounding features.

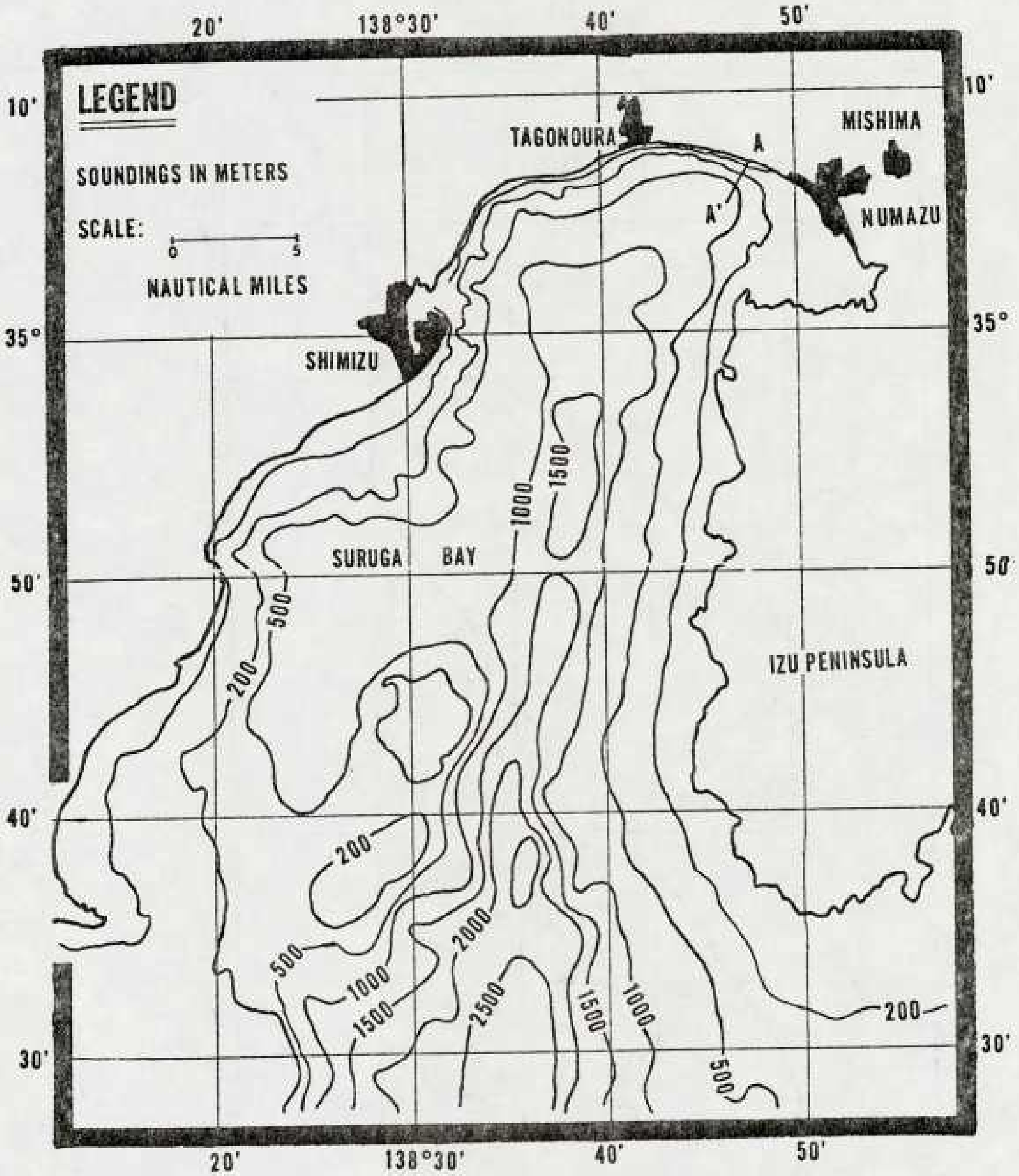

Figure 7. Geographical depiction of Suruga Bay featuring bathymetry of the Bay (see Figure 8 for cross sectional depiction of A-A').

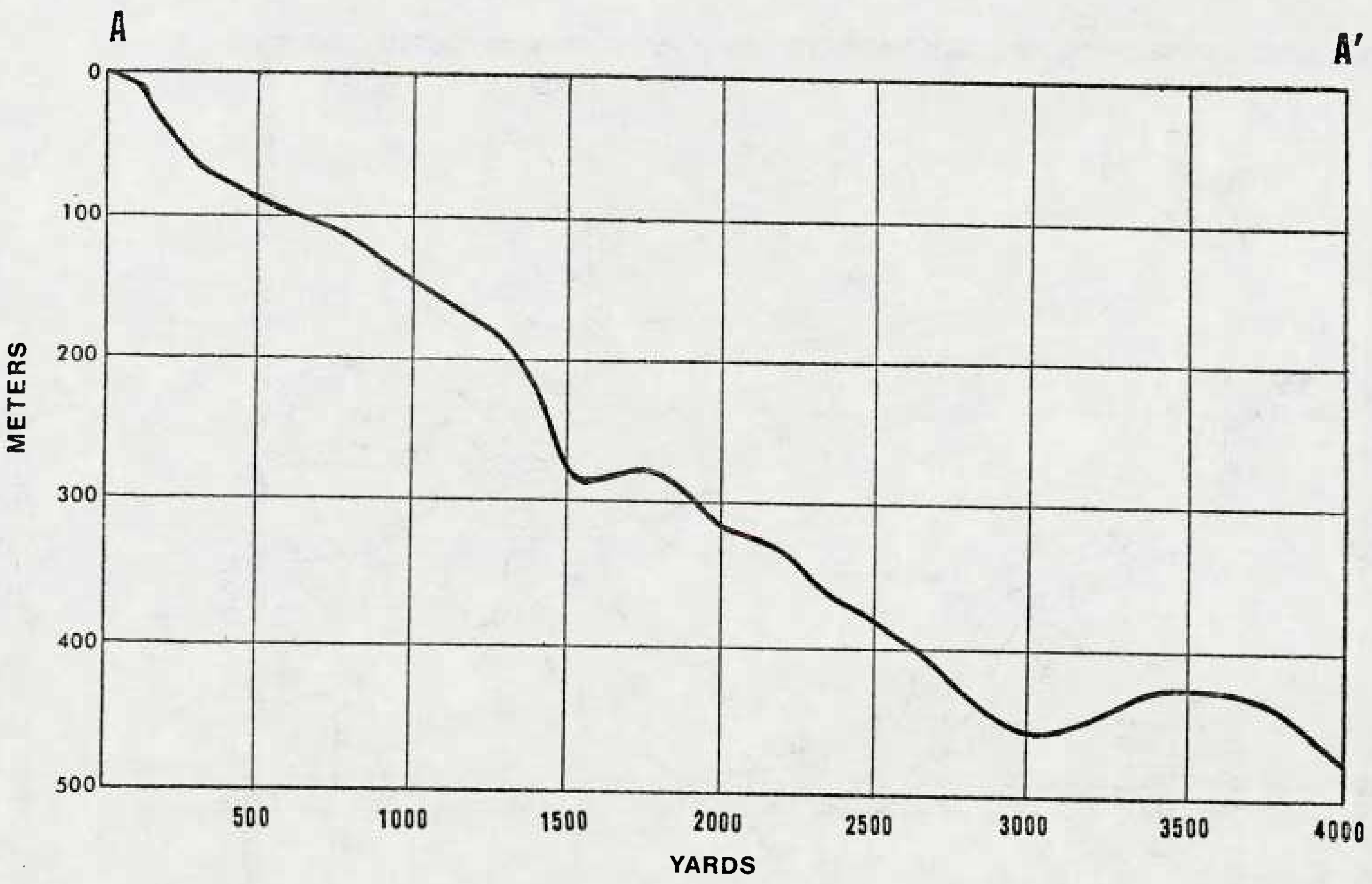

Figure 8. Cross sectional representation of A-A' (see Figure 7) depiction of bottom depths bearing 200° from 35°07'N, 138°48.5'E.

5. TROPICAL CYCLONES AFFECTING THE NUMAZU OPERATING AREA

5.1 CLIMATOLOGY

Tropical cyclones which affect the Numazu Operating Area generally form in an area bounded by the latitudes 5°N and 30°N and the longitudes 120°E and 165°E. The latitudinal boundaries shift poleward during the summer months and then equatorward in winter in response to the seasonal location of the southern boundary of the prevailing easterlies.

In the genesis area mentioned above, typhoons have occurred in all months but, with rare exceptions, those affecting the main Japanese Islands are confined to the period May to November. Late summer and early autumn are the likeliest seasons. Size and intensity of the storms vary widely. The majority of those that pose a "threat" to the area (any tropical cyclone approaching within 180 n mi of Numazu is defined as a "threat" for the purpose of this study) occur during the months June-October. Figure 9 gives the frequency distribution of threat occurrences by 5-day periods. This summary of 84 tropical cyclones is based on data for the 28-year period, June-October 1947-1974. Note that the maximum number occur during August and September.[4]

Figure 10 displays the "threat" of tropical cyclones according to the octant from which they approached the 180 n mi radius threat area. The circled numbers indicate the total that approached from an individual octant. The figure count for an octant of approach includes both recurving and

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[4] A total of 89 tropical cyclones passed within 180 n mi of the Numazu Operating Area during the May-November period for the years 1947-1974. Eighty-four (94%) of these tropical cyclones passed within 180 n mi during the 5 months, June-October, and the remaining 5 passed in the months May and November.

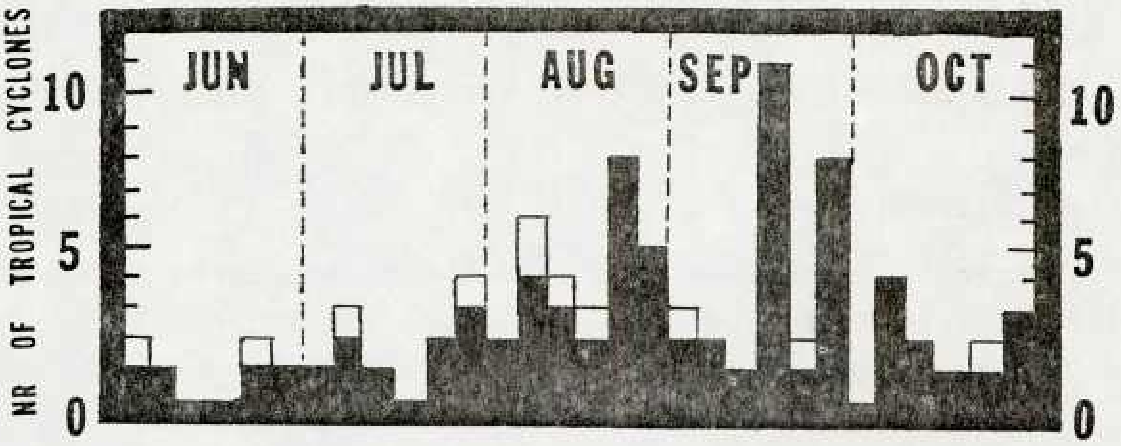

Figure 9. Frequency of tropical cyclones that passed within 180 n mi of the Numazu Operating Area. Subtotals are based on 5-day periods for tropical cyclones that occurred during 1947-1974. Shaded area indicates recurving tropical cyclones per 5-day period (that is, had a northeasterly direction of movement at CPA).

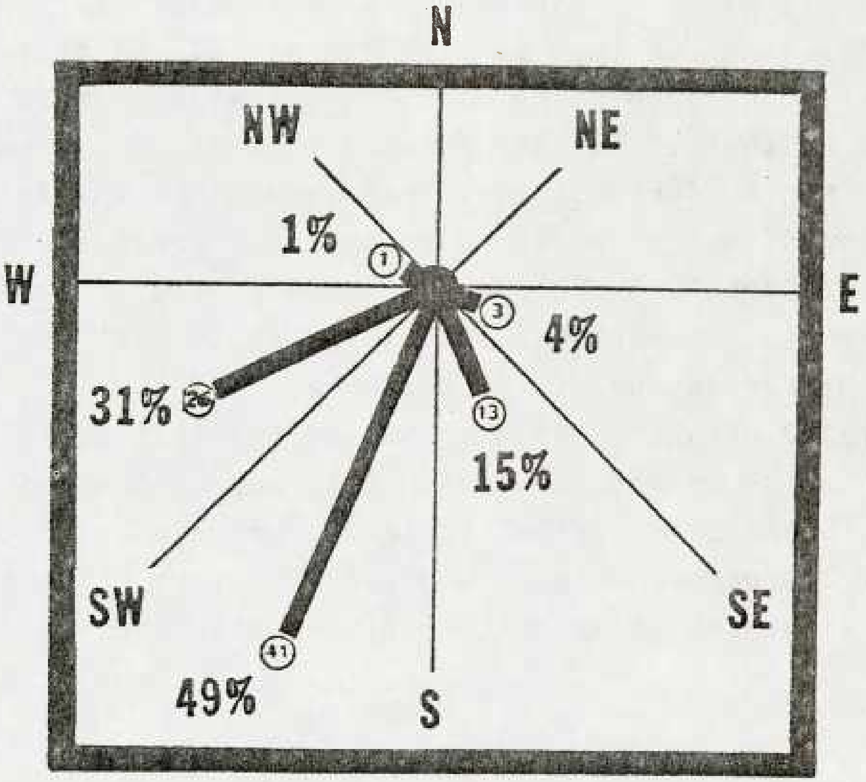

Figure 10. Directions from which tropical cyclones entered threat area during the period 1947-1974. Numbers circled indicate the number of tropical cyclones that entered from each octant. This is expressed as a percentage adjacent to the circled number.

non-recurving tropical cyclones. (See Section 2.2 for description of recurving tropical cyclones.) The adjacent numbers express this as a percentage. It is evident that a majority of these approach from the southwestern quadrant. A more detailed inspection of the sample of 84 tracks reveals that 11 (13%) did not recurve before passing the Closest Point of Approach (CPA) to the Numazu Operating Area.

Table 3 indicates that of the 84 tropical cyclones that posed a "threat" to the Numazu Operating Area during the years 1947-1974, 46% passed to the east of Numazu, 42% passed to the west and 12% passed in the immediate vicinity (within 20 n mi) of the area. The apparent majority of the "threat" tropical cyclones passing to the west or in the immediate vicinity implies that the Numazu Operating Area is placed quite often in the right or "dangerous" semicircle where the winds and seas are more intense.

Table 3. "Threat" tropical cyclone passage relative to Numazu (1947-1974).

Track relative to Numazu	JUN	JUL	AUG	SEP	OCT	TOTAL
Passed east of Numazu	3	3	13	12	8	39
Passed west of Numazu	2	7	12	11	3	35
Passed in the immediate vicinity of Numazu	1	1	3	4	1	10

Figures 11 through 15 represent an analysis of the estimated "threat" probability for any tropical cyclone as it approaches the Numazu Operating Area. The solid lines represent the probability of a system within an isoline coming within 180 n mi of the Numazu Operating Area. The dashed lines represent the approximate time in days for a system to reach Numazu based on typical speeds of movement of tropical cyclones

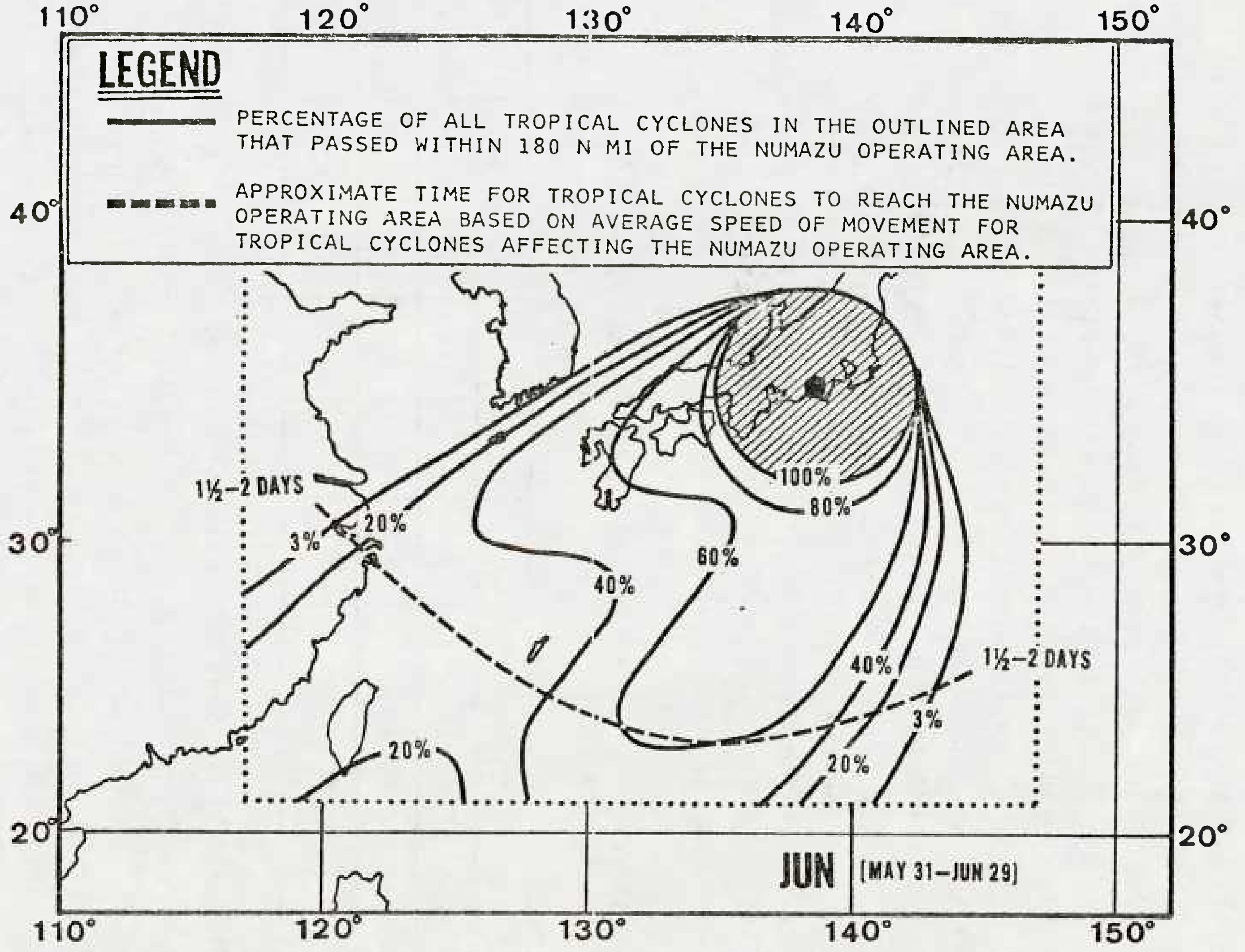

Figure 11. Percentage of tropical cyclones that passed within 180 n mi of Numazu for the month of June (based on data from 1947-1974).

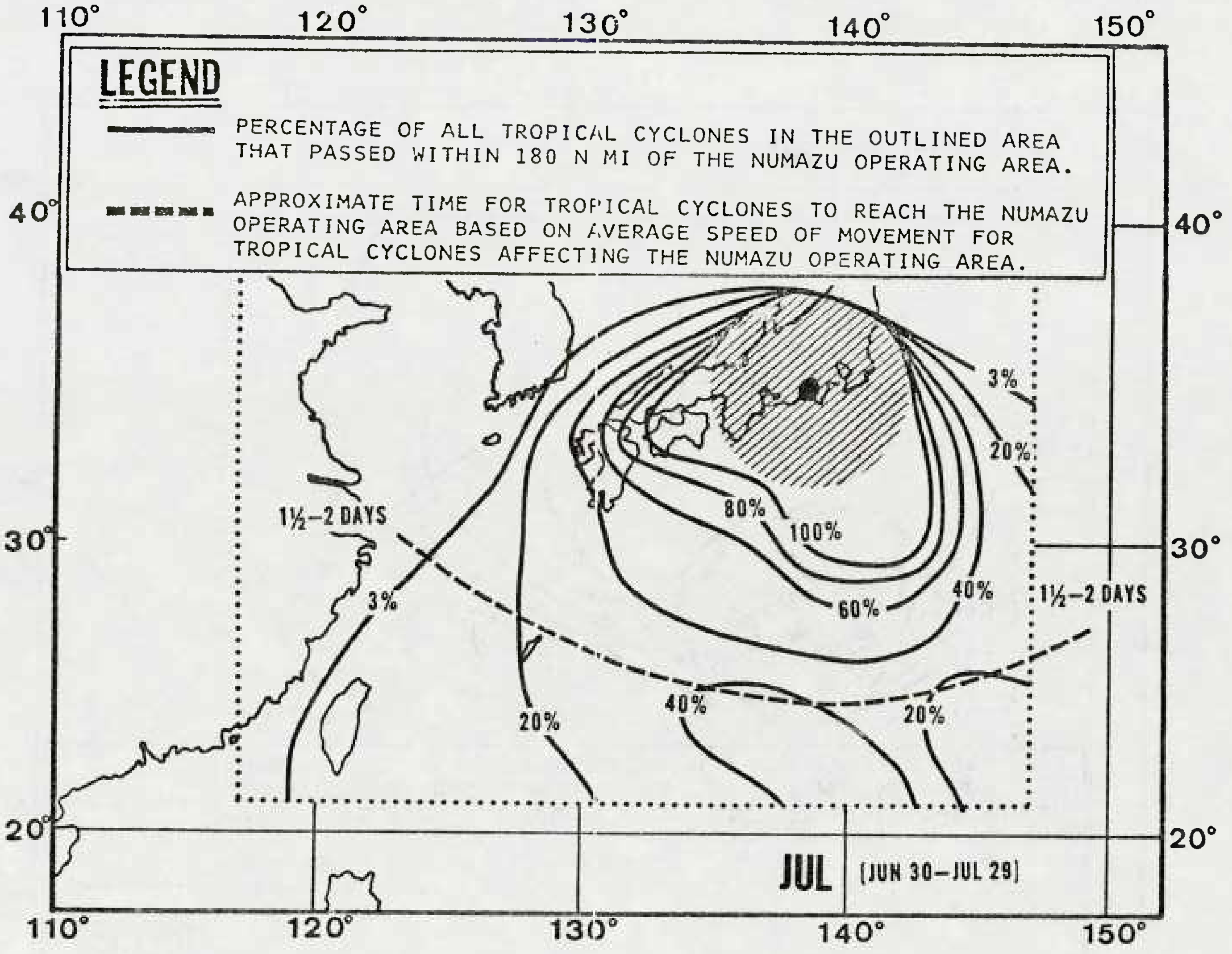

Figure 12. Percentage of tropical cyclones that passed within 180 n mi of Numazu for the month of July (based on data from 1947-1974).

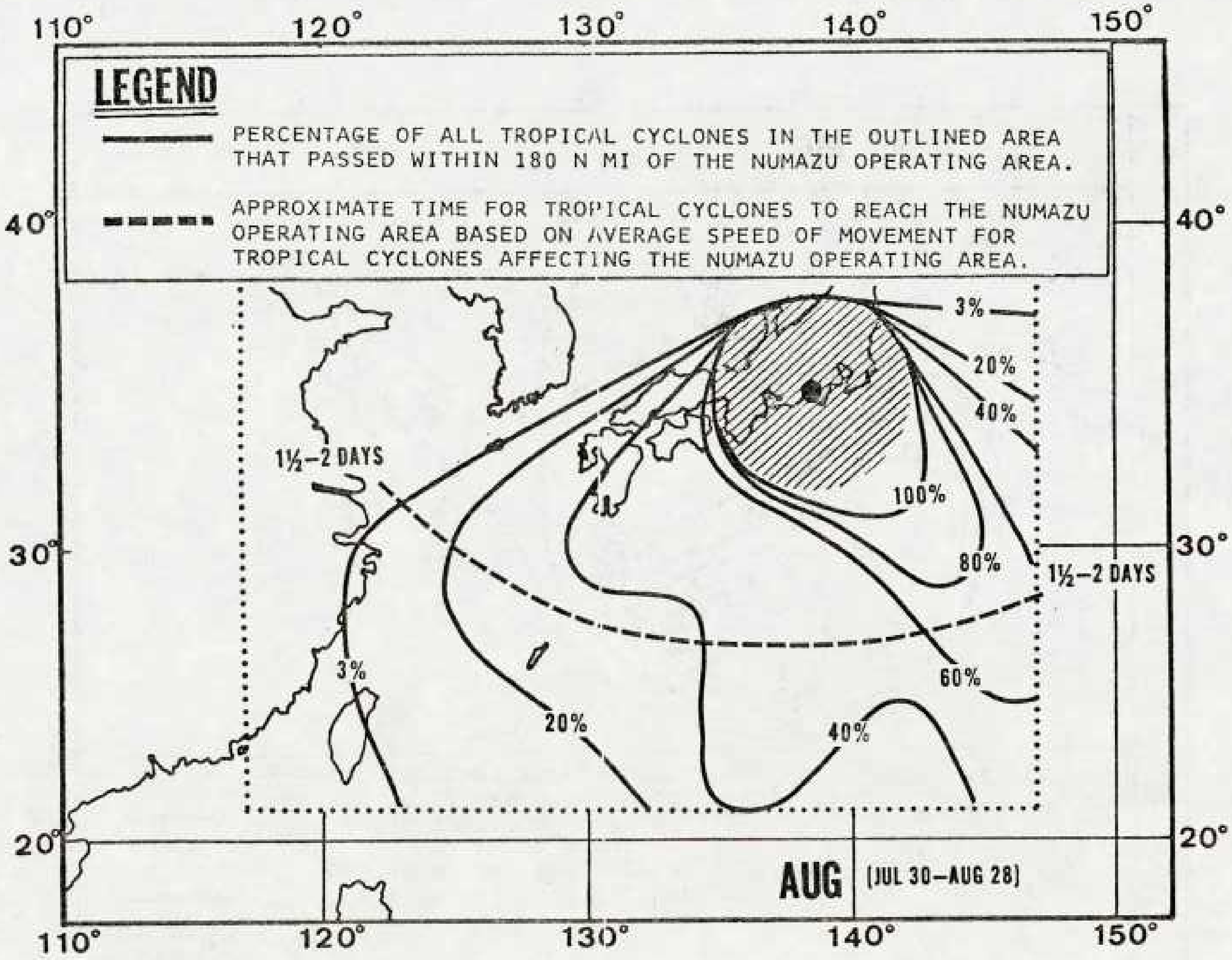

Figure 13. Percentage of tropical cyclones that passed within 180 n mi of Numazu for the month of August (based on data from 1947-1974).

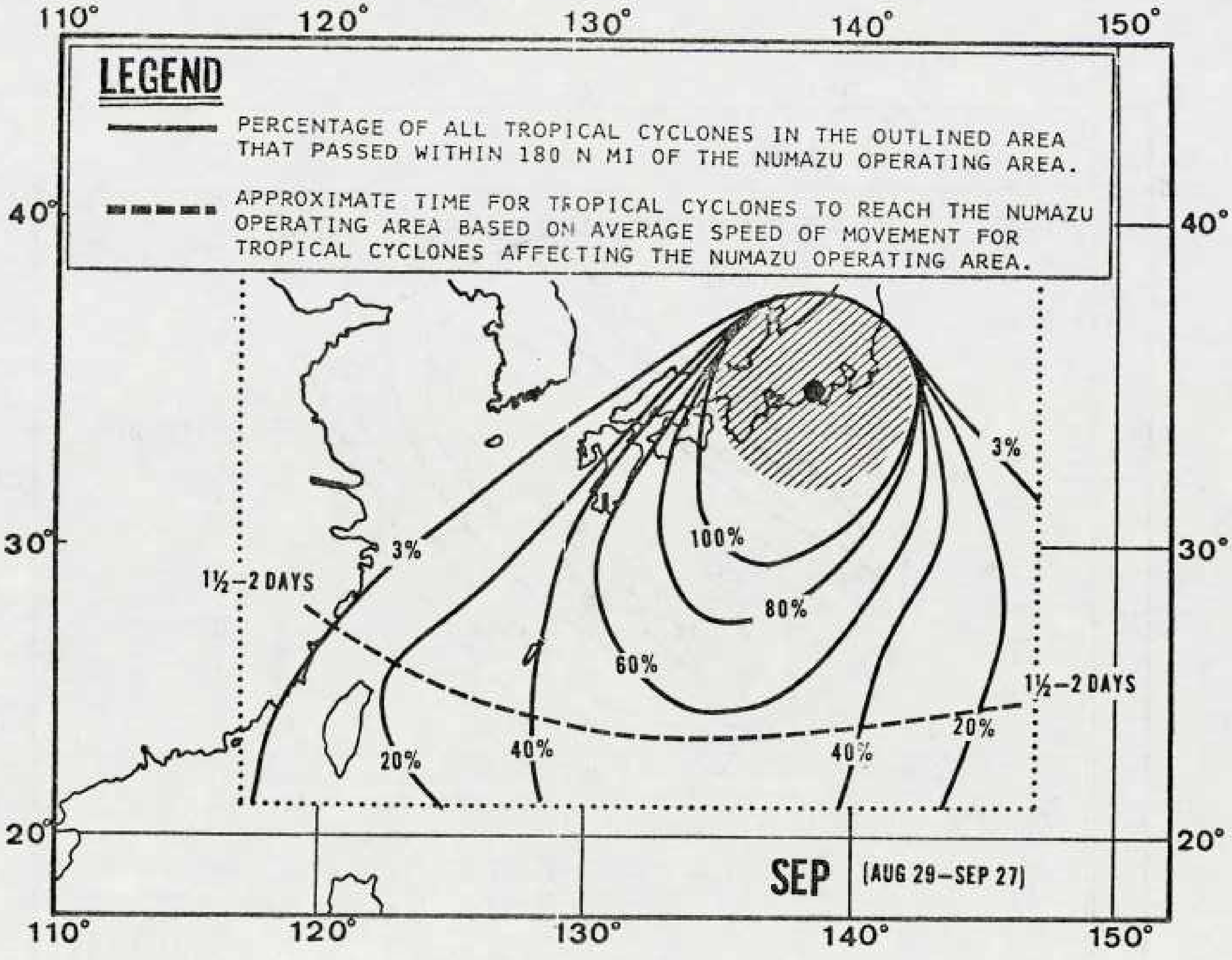

Figure 14. Percentage of tropical cyclones that passed within 180 n mi of Numazu for the month of September (based on data from 1947-1974).

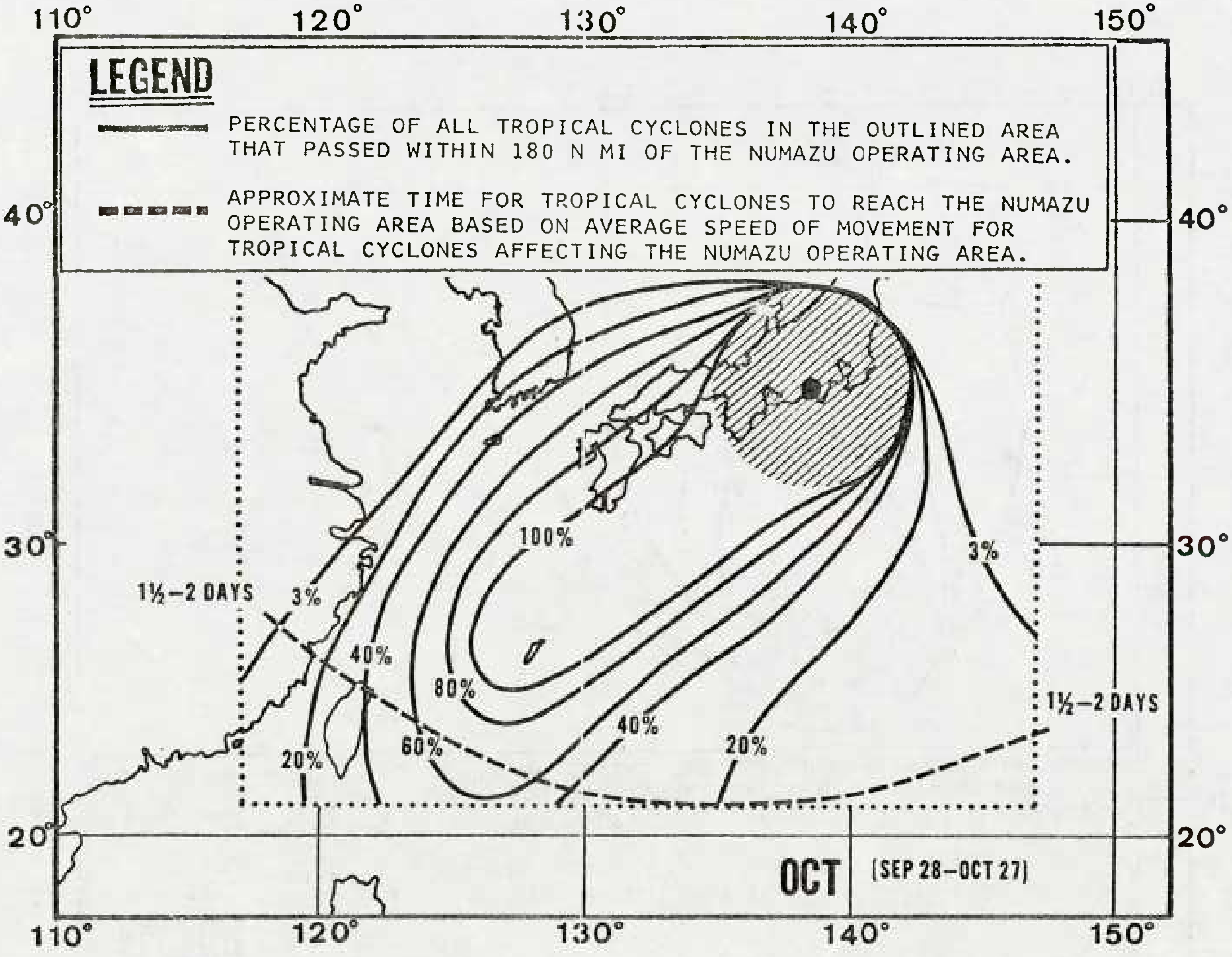

Figure 15. Percentage of tropical cyclones that passed within 180 n mi of Numazu for the month of October (based on data from 1947-1974).

affecting Numazu (Table 4). For example, in Figure 11, a tropical cyclone located at 27°N, 140°E has a 60% probability of passing within 180 n mi of the Numazu Operating Area and it will reach Numazu in about one day.

Table 4. Average tropical cyclone speed of movement (kt) per 5-degree latitude band for tropical cyclones affecting the Numazu Operating Area for June-October.

LATITUDE BAND	JUN	JUL	AUG	SEP	OCT	AVERAGE
30 - 35 N	23	15	13	20	28	19.8
25 - 30	17	12	11	14	21	15.0
20 - 25	13	10	11	11	13	11.6
15 - 20	10	10	10	11	12	10.6

The speeds in Table 4 were arrived at by considering that as tropical cyclones recurve, their forward speed characteristically, but not always, slows during the recurvature period. It should be expected that the system will subsequently accelerate rapidly toward the north or northeast. Speeds of 20 to 30 kt are common and speeds as great as 50 kt have been observed (Somervell and Jarrell, 1970).

5.2 WIND AND TOPOGRAPHICAL EFFECTS

A total of 50 tropical cyclones passed within 180 n mi of the Numazu Operating Area in the 19 year period 1956-1974 during the months June-October, or about 2.6 per year.[5] Table 5 groups the 50 tropical cyclones by strong ($\geq$ 22 kt) and gale force ($\geq$ 34 kt) wind intensities (based on hourly

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[5] From Chin (1972) for years 1956-1970 and from Annual Typhoon Reports for years 1971-1974 (FWC/JTWC, 1971-1974).

wind data) that they produced at Mishima.[6] Tropical cyclone activity within 180 n mi of the Numazu Operating Area is at a maximum during the months of August and September and these individual monthly values are also shown.

Table 5. Extent to which tropical cyclones affected the Numazu Operating Area during the period June-October, 1956-1974 and for the individual months of August and September.

	JUN-OCT	AUG	SEP
Number of tropical cyclones that passed within 180 n mi of the Numazu Operating Area	50	20	16
Number of tropical cyclones resulting in strong ($\geq$ 22 kt) winds in the Numazu Operating Area	39 (78%)	14 (70%)	15 (94%)
Number of tropical cyclones resulting in gale force ($\geq$ 34 kt) winds in the Numazu Operating Area	25 (50%)	10 (50%)	10 (63%)

It can be discerned from Table 5 that 25 (50%) of the total 50 tropical cyclones for the period June-October (1947-1974) resulted in winds of 34 kt or greater at Mishima. However, note that of the 16 tropical cyclones in September, 10 (63%) of these resulted in winds of 34 kt or greater.

The observation station at Mishima is located approximately 3 n mi northeast of the city of Numazu. The wind instrument is located on top of the station in a residential section of the city. There is no appreciable difference in the elevation of the station and that of Numazu, both being located in a flat coastal plain lying between the mountainous

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[6] Data provided by the Japanese Meteorological Agency weather station located at Mishima, 3 n mi inland from the Numazu Harbor (see Figure 7).

ridge running south into the Izu Penninsula and Fujiyama to the northwest. The observed wind is fairly representative of that at the Numazu Harbor where the observation station had been previously located. However, during the period 1964-1973, the highest recorded wind gust in Numazu was 97 kt on 25 September 1966 while at Mishima the wind gust was recorded at 82 kt (also the highest recorded during the period). This southeasterly gust was attributed to Typhoon Ida which passed 30 n mi to the west of Numazu on 25 September 1966. During this particular typhoon, sustained winds were recorded in excess of 34 kt for 5 hours.

Winds in Suruga Bay are greatly influenced by the surrounding topography and geographical features of the bay itself. The extent of this influence is dictated by the direction of approach of the storm and the passage relative to the Numazu Operating Area. From an analysis of the tropical cyclone tracks in Figures 16 through 20, it is apparent that tropical cyclones that result in gale force winds or greater at Mishima can pass to the east or west of Mishima or in some instances the center of the storm passes over the immediate area. The basic difference between the passages is the direction of the resulting winds in the area.

If the tropical cyclone passes to the west of the Numazu Operating Area, the winds will be predominantly from the southwest. For a passage to the west, the storm must necessarily cross the mountain ranges of Honshu (see Figures 5 and 6). An example of this was Typhoon Vera (September 1959) which had a CPA of 110 n mi to the northwest of Mishima The typhoon pounded the area with gusts of 68 kt from the southwest and sustained gale force winds for a 7-hour period.

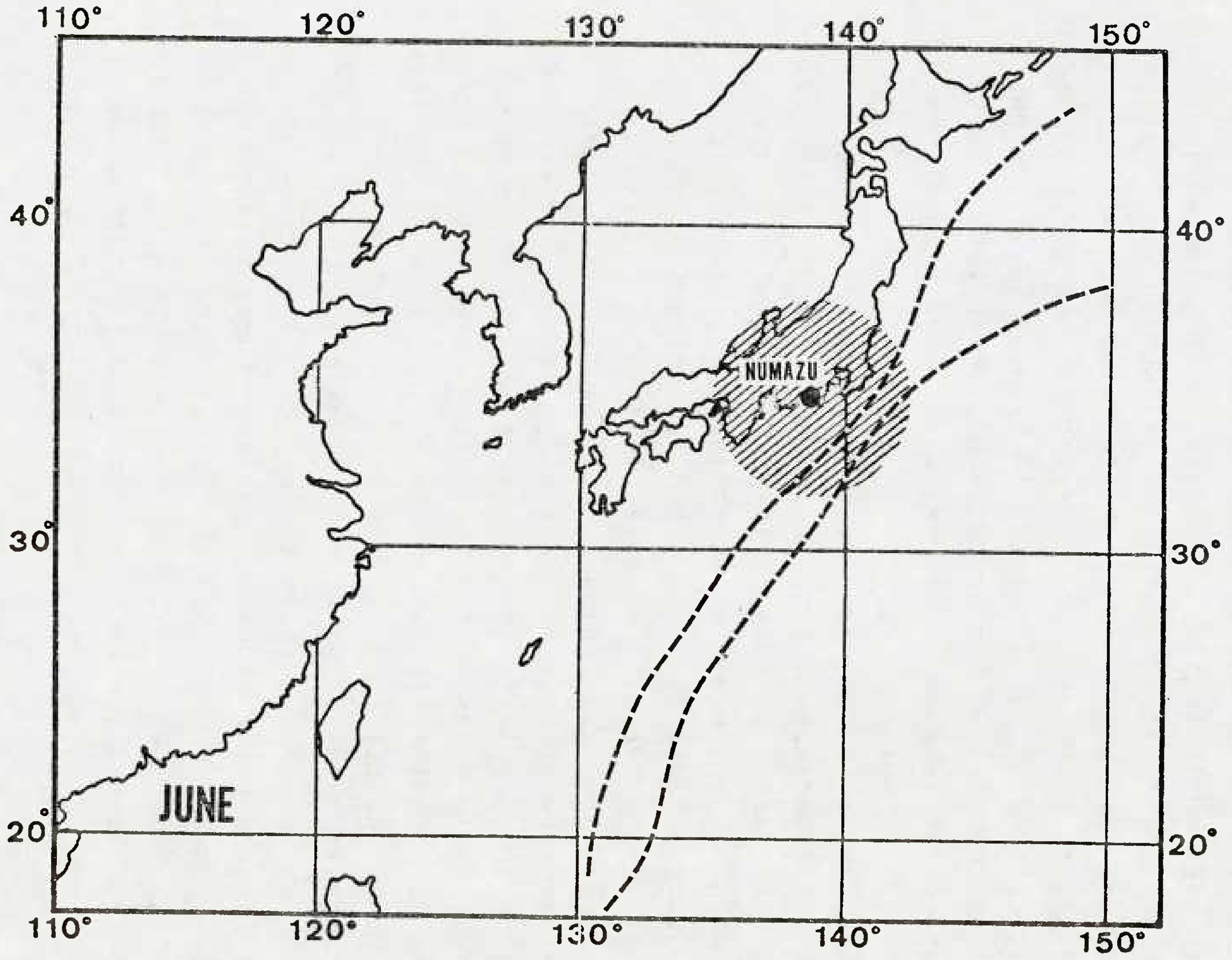

Figure 16. Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for June. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds ≥ 34 kt at Mishima.

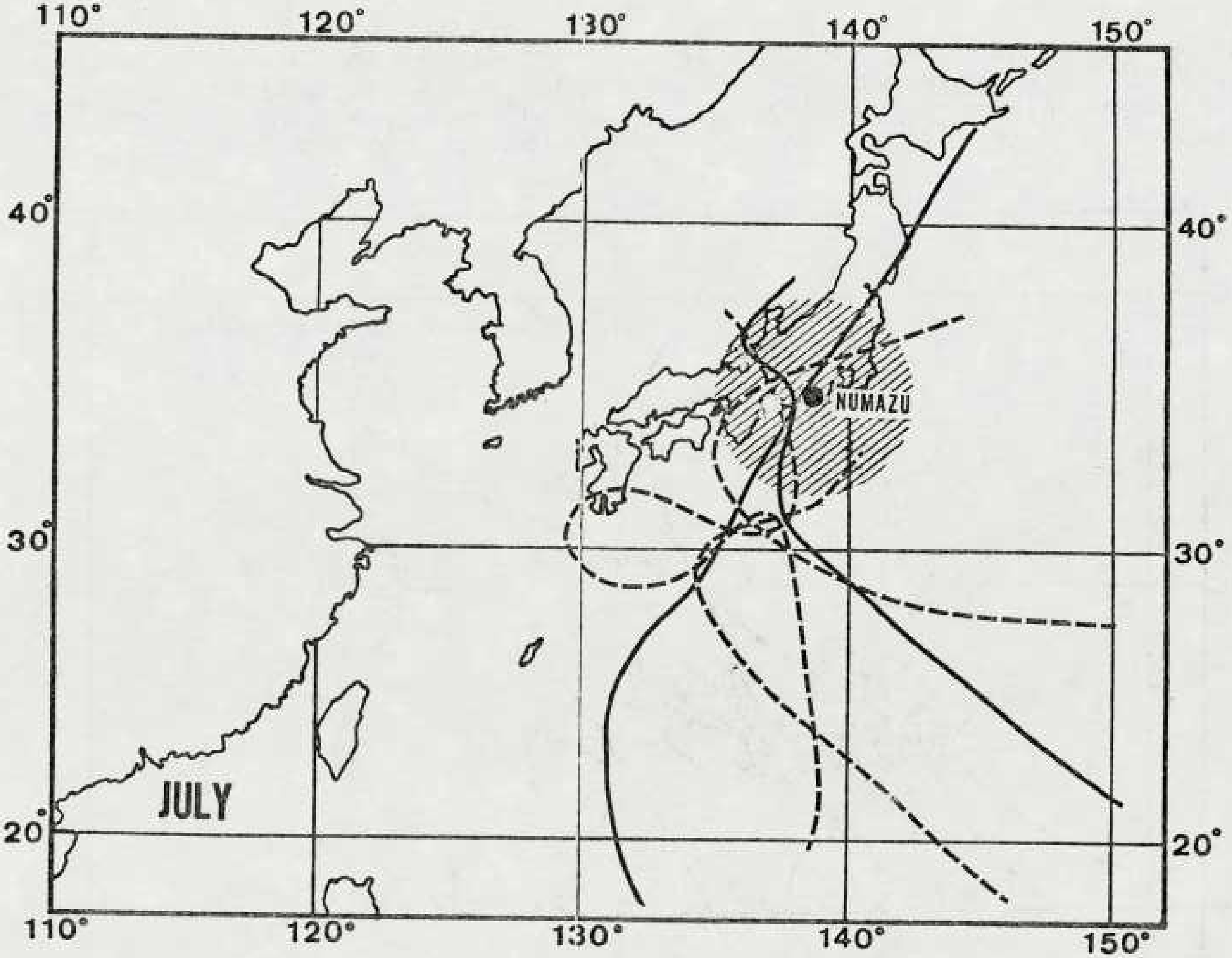

Figure 17. Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for July. Solid lines indicate tracks of tropical cyclones that produced winds $\geq$ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds $\geq$ 34 kt at Mishima.

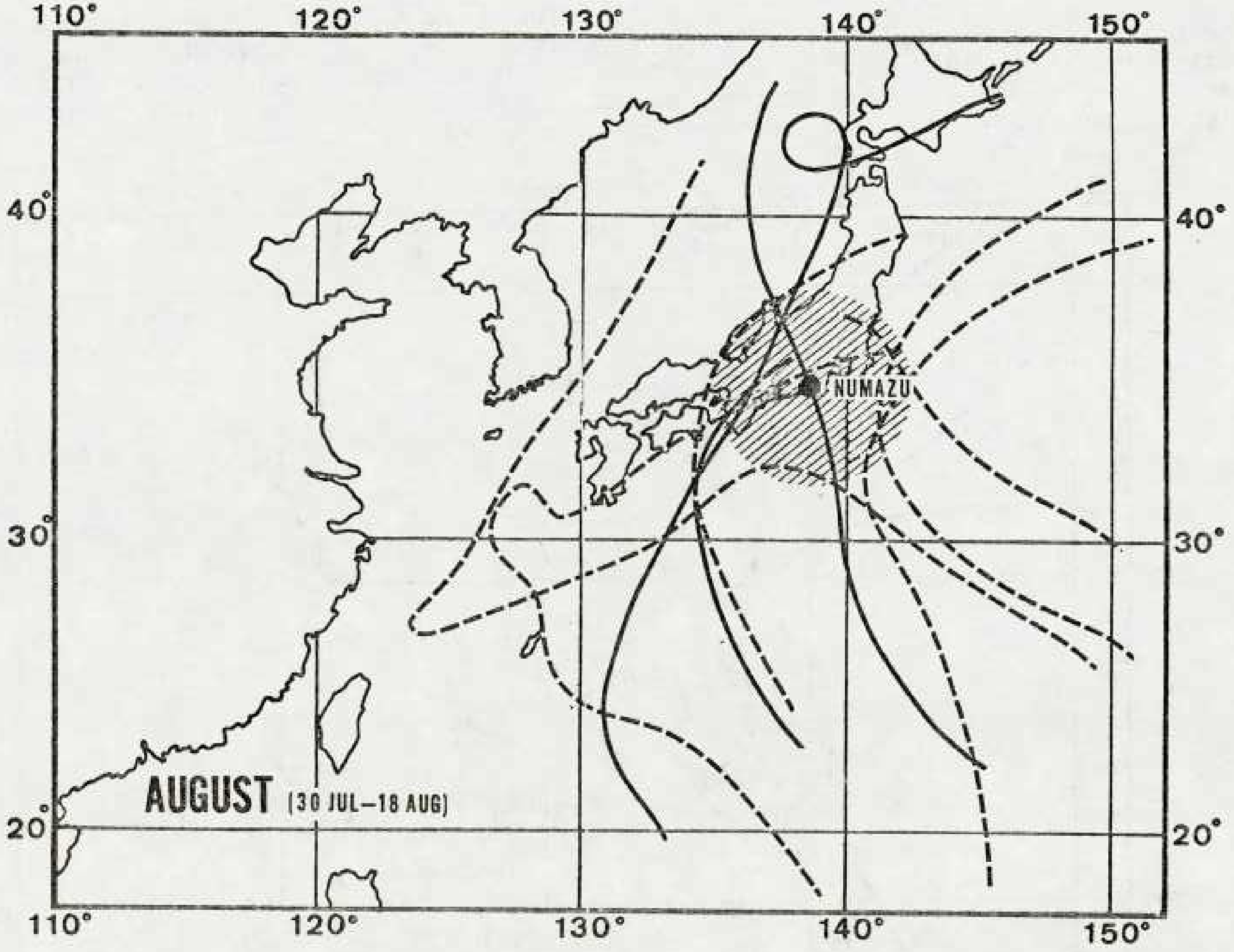

Figure 18(a). Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for 30 July-18 August. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds ≥ 34 kt at Mishima.

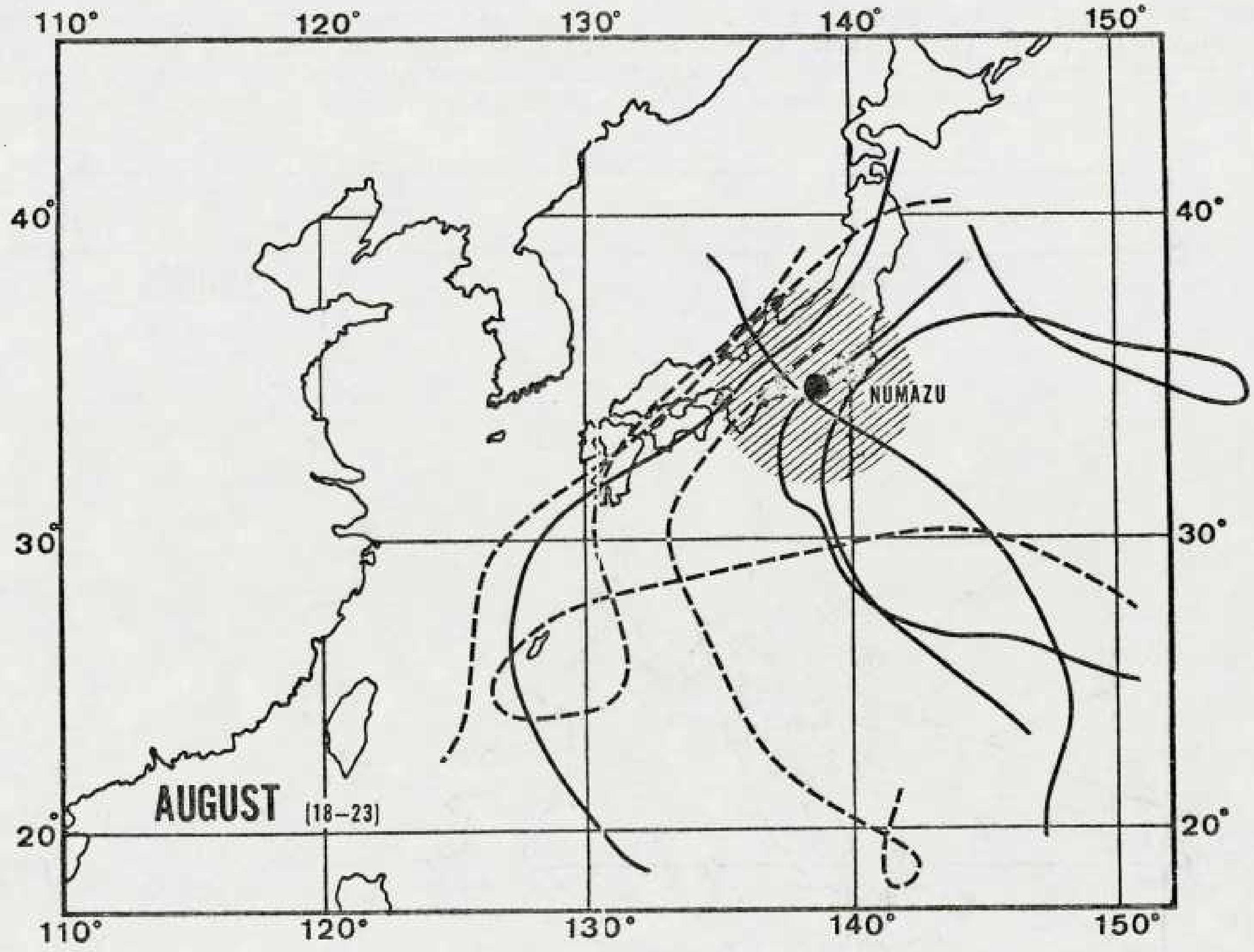

Figure 18(b). Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for 18-23 August. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds ≥ 34 kt at Mishima.

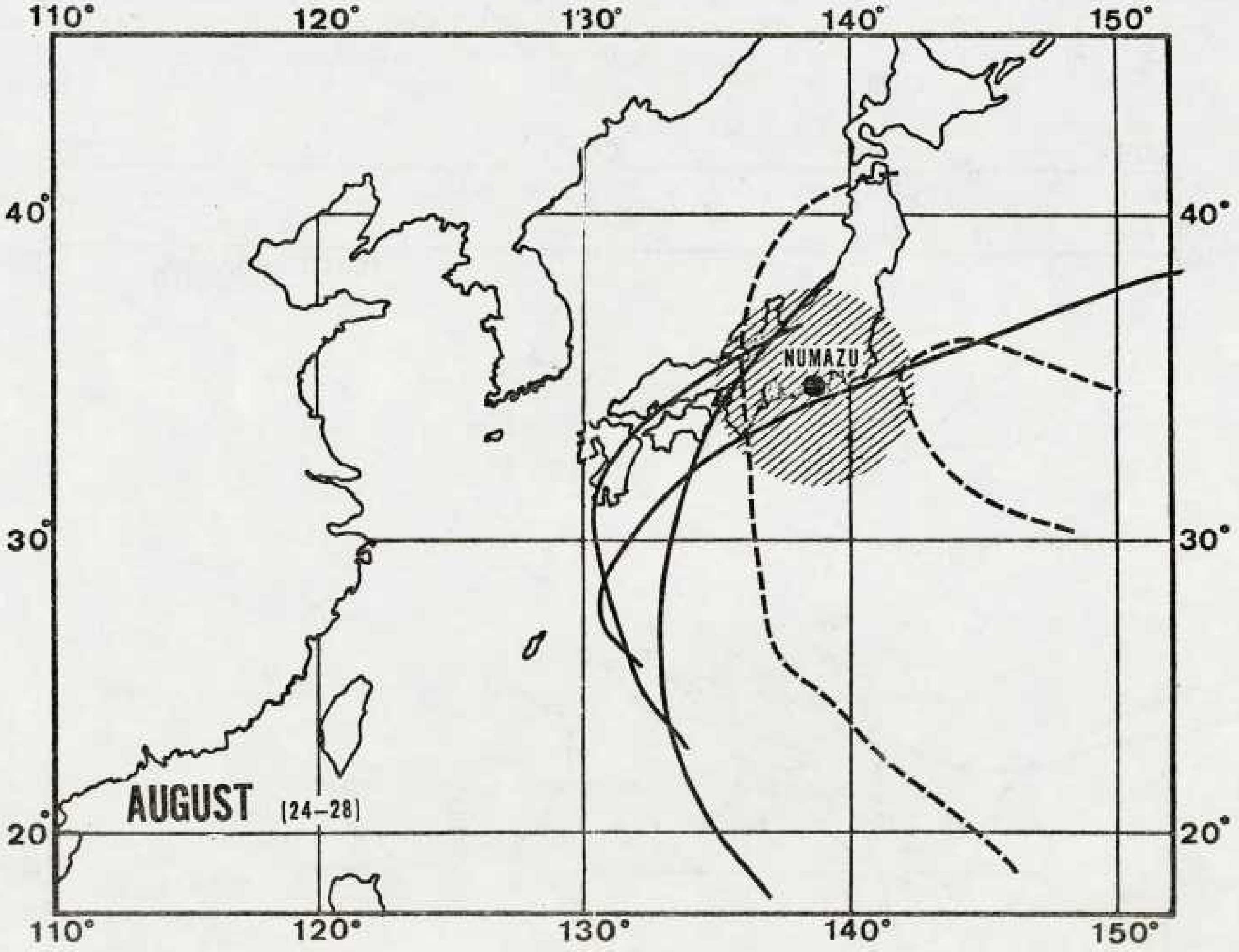

Figure 18(c). Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for 24-28 August. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds ≥ 34 kt at Mishima.

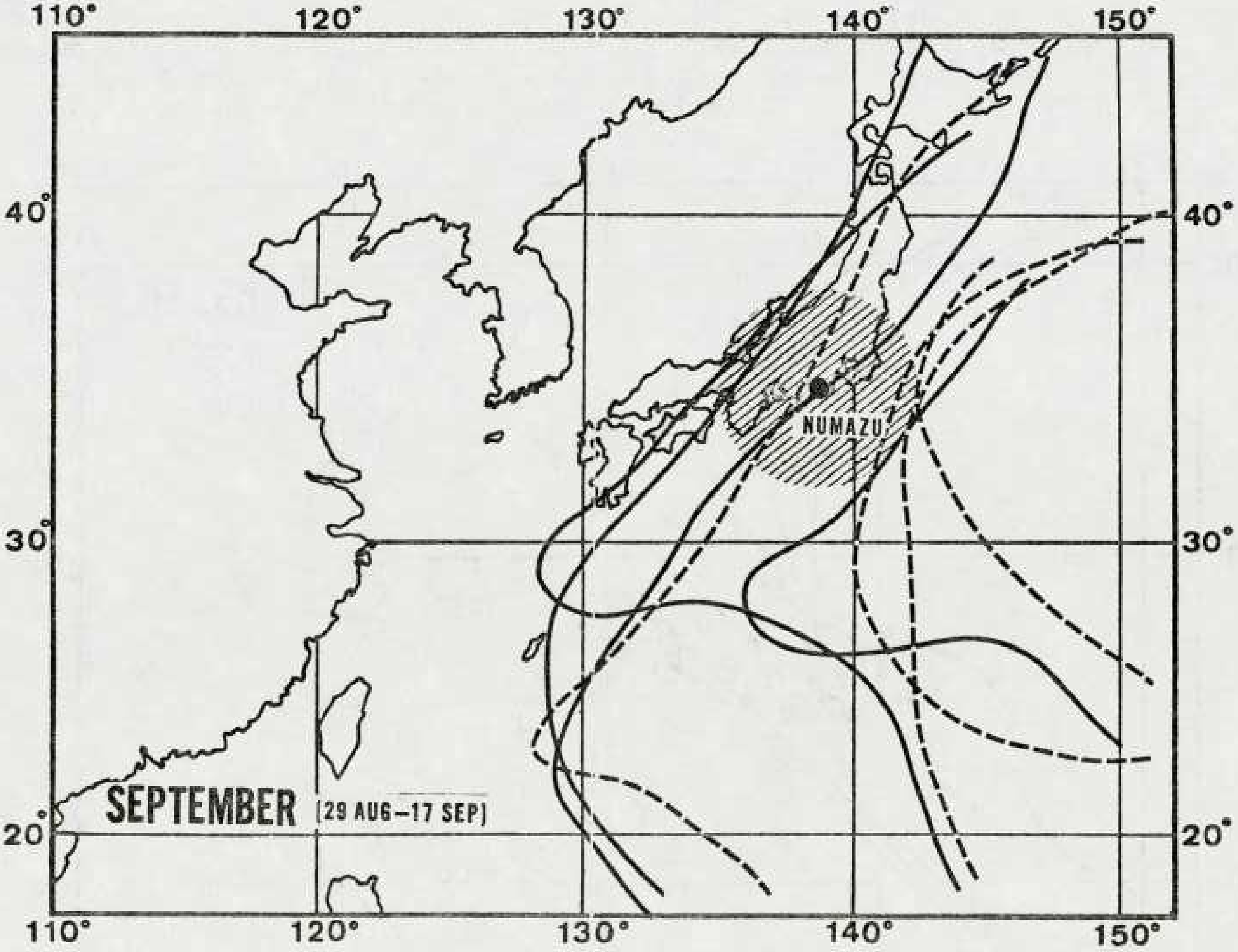

Figure 19(a). Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for 29 August-17 September. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds ≥ 34 kt at Mishima.

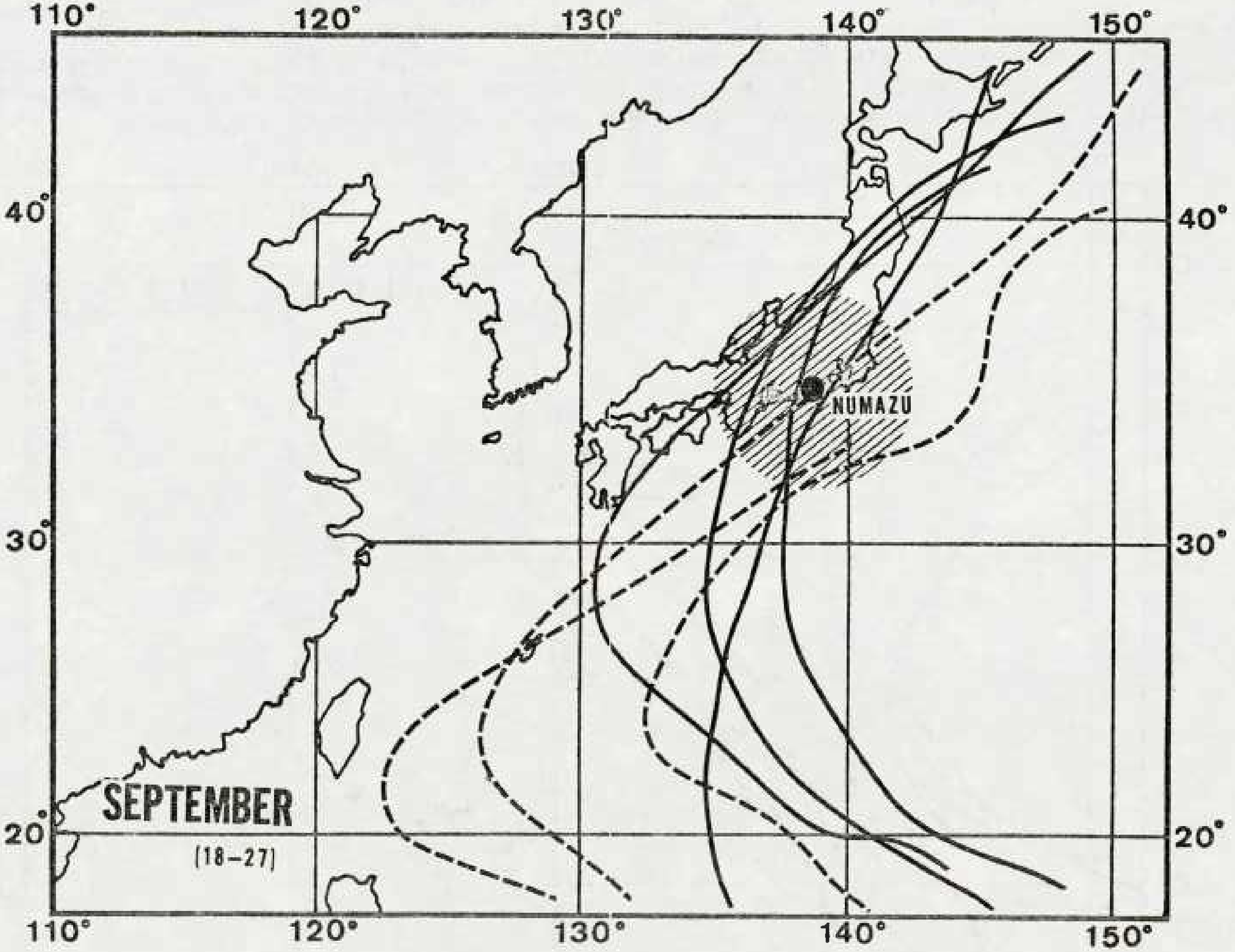

Figure 19(b). Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for 18-27 September. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds ≥ 34 kt at Mishima.

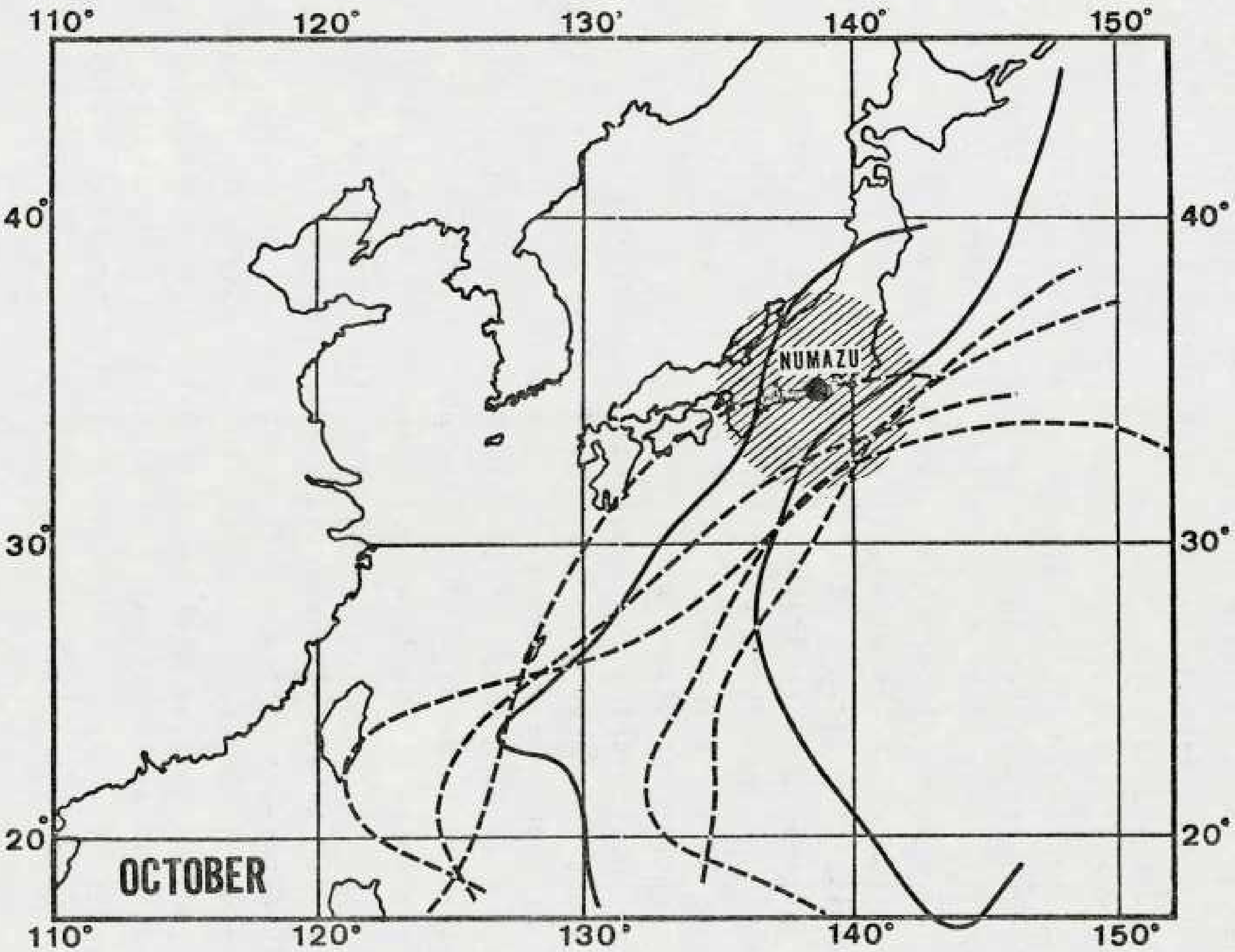

Figure 20. Tracks of tropical cyclones approaching within 180 n mi of the Numazu Operating Area during the 19-year period 1956-1974 for October. Solid lines indicate tracks of tropical cyclones that produced winds $\geq$ 34 kt at Mishima. Dashed lines indicate tropical cyclones passing within 180 n mi of the Numazu Operating Area but not producing winds $\geq$ 34 kt at Mishima.

If the tropical cyclone passes to the east of Mishima, the path will generally be over water and the winds will be primarily northeasterly. An example of this was Typhoon Ida (September 1958) which had a CPA of 30 n mi to the southeast of Mishima. As a result, the area experienced gusts of 64 kt from the north-northeast.

Occasionally, a tropical cyclone will pass in the vicinity of Suruga Bay. In the 28 year period (1947-1974), ten tropical cyclones tracked in such a manner with 7 of them bringing gale force winds to the area. Under such circumstances there is no discernable pattern of a prevailing direction from which the strongest winds originate. Nor is the proximity of a storm's center indicative of force. Of the 10 tropical cyclones tracked, the maximum wind gust recorded ranged from 20 kt to 85 kt..

Figure 21 shows the position of "threat" tropical cyclone centers when strong winds ($\geq$ 22 kt) were first and last recorded at Mishima. A number of storms gave Mishima $\geq$ 22 kt winds when they were 300 n mi from the city with a predominant number of occurrences to the south and east of the Numazu Operating Area. Note also that strong winds were still being generated by a few storms when the storm centers were as far north as the island of Hokkaido. Figure 22 shows tropical cyclone center positions when gale force ($\geq$ 34 kt) winds were first and last recorded at Mishima. It can be ascertained from this figure that winds $\geq$ 34 kt generally do not begin until the storm is about 180 n mi away. Notice the preponderance of storms that generate gale force winds are south-southeast and northwest from Mishima and that those storm centers that track to the northwest of the area produce gale force winds of longer duration.

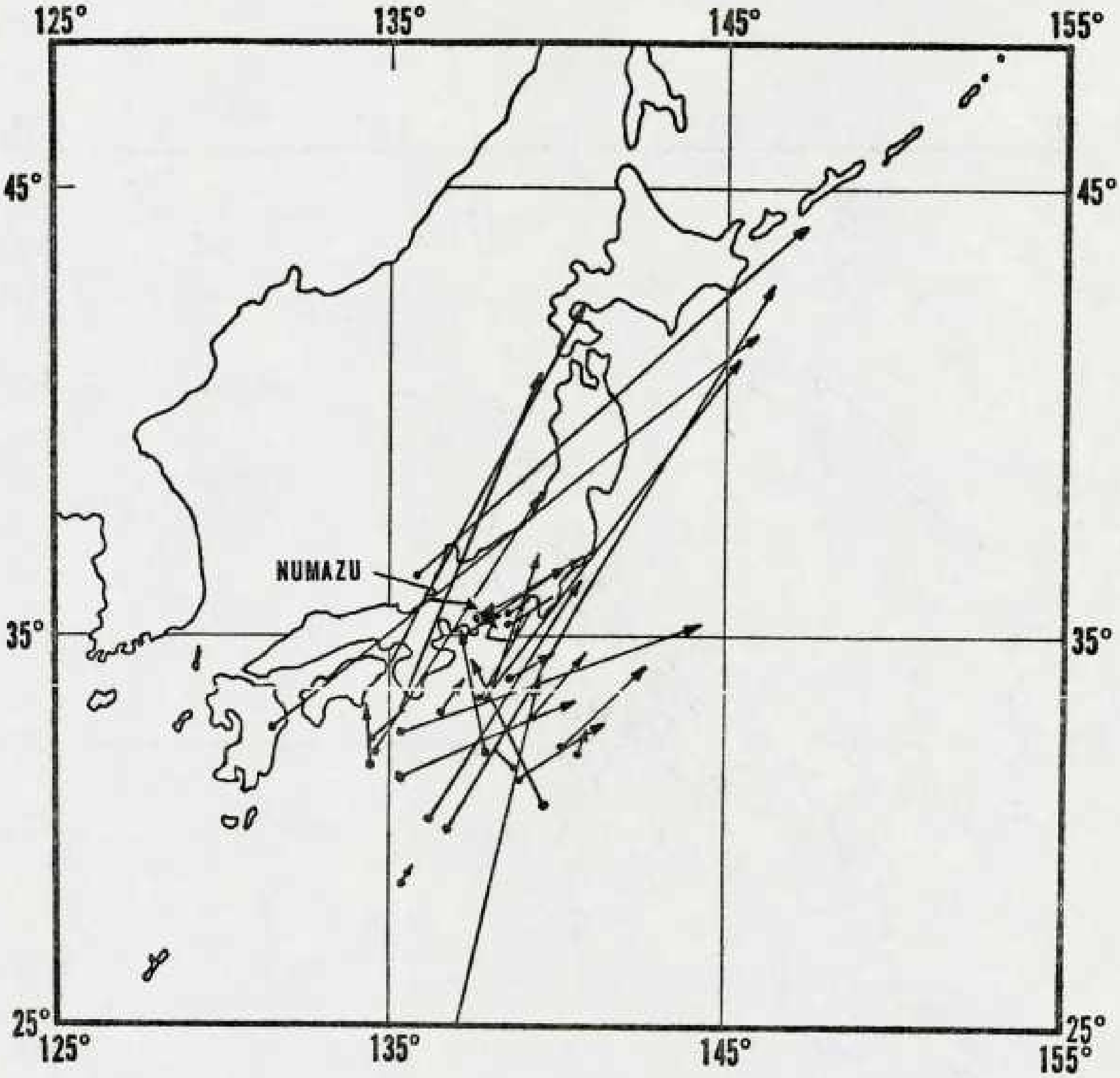

Figure 21. Positions of 39 tropical cyclone centers when winds ≥ 22 kt first and last occurred at Mishima (based on hourly data for the months June-October during the years 1956-1974).

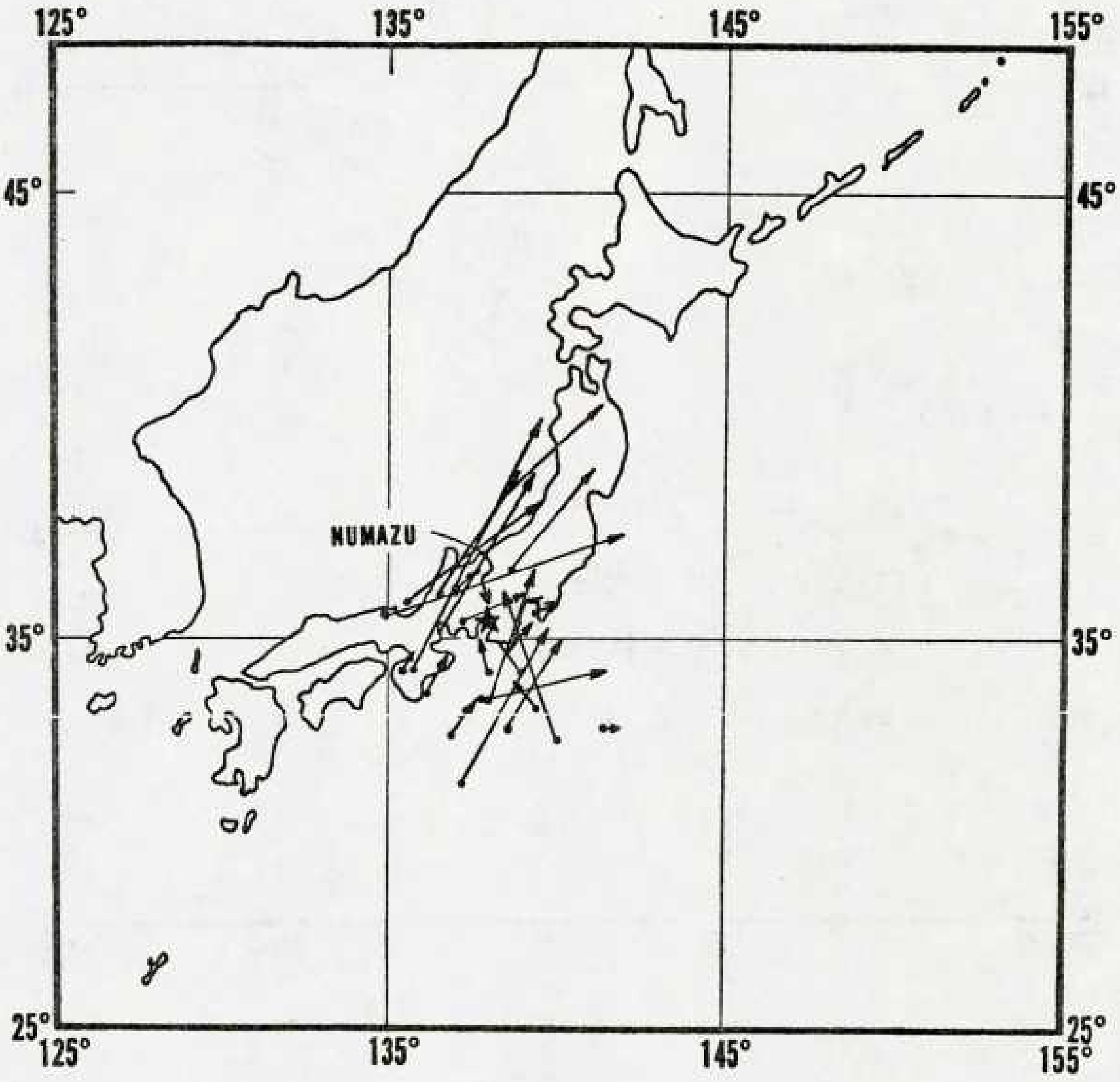

Figure 22. Positions of 25 tropical cyclone centers when winds ≥ 34 kt first and last occurred at Mishima (based on hourly data for the months June-October during the years 1956-1974.

5.3 WIND AND SWELL WAVE ACTION

The combination of the extreme depth and geographical orientation of Suruga Bay makes the area susceptable to extreme wave action -- often on short notice. Because of the depth of the bay (see Figures 7 and 8) wave activity in the open areas of the bay is to be considered similar to that of the open ocean (under certain circumstances). Incoming wind and swell wave energy does not begin to come under the shoaling effect until it reaches the extreme northern reaches of the bay.

The northeast-southwest geographical orientation of Suruga Bay makes it extremely vulnerable to the wind and wave condition of the ocean and provides an unimpeded region for winds from the southwest quadrant to flow. The Numazu Operating Area is located in the northern reaches of the bay in extremely deep water and fully exposed to the aforementioned southwesterly flow of wind. The result is that the operating area is placed at the focal point of a considerable amount of incoming wave energy -- produced both locally and at great distances.

The beach along the northern side of the bay can be considered steep and is composed of pea gravel. From Figure 8 it can be seen that the bottom profile drops off rapidly to over 100 fathoms in less than 1 n mi. The Japanese government has built a massive sea wall (approximately 50 ft. high) that stretches along the entire northern coast of Suruga Bay and on the southwestern flank of the Numazu Harbor.

Maximum wave action generated by winds will occur when tropical cyclones pass to the west of the Numazu Operating Area. The resultant winds from the southwestern quadrant will flow unimpeded the entire length of the Suruga Bay, and depending on the size of the storm and the area over which the generating wind blows (fetch), produce wave heights typically associated with such winds encountered in the open ocean.

For tropical cyclones passing to the east, as approximately 46% have done in the 28-year period 1947-1974, the effects of wind produced waves will be lessened by the northeasterly flow of winds interacting with the mountains of the Izu Peninsula. Under such circumstances however, wind waves generated over the shorter fetch will be of the high frequency type -- usually steep with a short time interval between successive crests.

Swell waves are characterized by long, smooth undulations of the sea surface. These waves result from storms located at great distances from the coast and the time between successive crests may be quite large. Such waves seldom, if ever, break in deep water as in Suruga Bay and unless very high usually do not affect small craft operations while they are operating in the deep water. They do, of course, cause rolling and pitching of large vessels. However, swell waves are important in that upon reaching shallow water the wave height increases markedly, perhaps by a factor of two or more. Thus when they reach a depth shallow enough to break, they can give rise to immense surf which may cause damage or destruction to small craft or harbor installations.

Since Suruga Bay opens to the southwest, it is exposed to swells arising from the tropical cyclone generating area in the lower latitudes. These swells with their incumbent high energy approach the coast at high speeds and in the case of a large offshore disturbance such as a typhoon, the swell will ordinarily arrive before the disturbance. This situation could hamper a ship's efforts in attempting to reach a typhoon haven ahead of the storm.

The two types of waves, wind and swell waves, usually exist simultaneously at any time in the open waters of Suruga Bay. Often times the swell are completely obscured by the wind waves generated by local wind conditions. It is only near the shoreline in the Numazu Operating Area, where the swell begins to peak to greater heights, is the observer made aware of their presence. In this area, where critical wave conditions result from swell generated by storms occurring at considerable distances, local wind conditions may be of little value in determining significant wave and surf characterictics. A consideration of the orientation of isobars on a weather map will reflect large scale wind patterns and permit an estimate of the extent of the generation area and, consequently, the length of the fetch and the direction of wave propagation.

Table 6 is an example of Fleet Numerical Weather Central's Wave Refraction/Surf Prediction based on the bottom topography of the Numazu Operating Area, direction of the incoming wave energy, and the period of the wave. The result is a "surf coefficient" that is dependent on the angle of incidence of the wave energy ray with respect to the beach. This surf coefficient is the equivalent to the ratio of the shallow water wave height and the deep water wave height. With this coefficient, an observer located in the deeper water of the operating area can estimate the height of waves passing his location and apply the surf coefficient to determine the height of the surf at the beach. For example, if a wave from the southwest with a height estimated to be 5 ft high in the deeper water and a period (measured crest to crest) of 10 sec, the surf height would range from 5 ft to 10 ft with an average of 7 ft. It should be noted that independent studies have found that the average period of typhoon generated waves is approximately 8-12 sec.

Table 6. "Surf Coefficients" determined by wave period and direction of wave energy. Resultant coefficients reflect the range of the coefficients with the average in parenthesis.

Direction of Wave Energy	Wave Period (crest to crest) sec.									
	6	8	10	12	14	16	18	20	22	24
SOUTH	1.1-2.5 (1.3)	1.1-2.7 (1.5)	1.1-2.0 (1.5)	1.0-2.1 (1.5)	1.2-2.5 (1.6)	1.3-2.4 (1.8)	1.4-3.3 (2.1)	1.5-3.1 (2.1)	1.0-4.1 (2.2)	1.0-5.1 (2.4)
SOUTHWEST	0.9-1.7 (1.3)	1.0-2.0 (1.3)	1.0-2.0 (1.4)	1.2-2.2 (1.6)	1.1-2.5 (1.7)	1.3-2.6 (1.9)	1.4-2.5 (1.9)	1.5-2.9 (2.1)	1.4-3.0 (2.1)	1.5-3.0 (2.1)

Because of its geographical configuration, the above indicates that surf conditions near Numazu may be affected by distant storms that pass to the south or southwest, even though they may pose no threat to the Numazu Operating Area or show tendency of recurving. The swell generated by these and other storms travel at speeds (kt) of three times their crest-to-crest period. (That is, a swell with a period of 12 sec will progress outward from the generating area at 36 kt.) Eventually the "family" of swell separates with the longer period swell outdistancing the shorter periods. Decay rates of swell energy varies according to the size of the generating area and strength of the wind over the fetch. Typical tropical cyclones of typhoon intensity can generate sufficient energy such that swell from these storms can be felt at distances of 800-1000 n mi from the center of the generating area. Thus, a typhoon hitting Taiwan can result in high surf at Numazu.

5.4 STORM SURGE AND TIDES

Storm surges result when a tropical cyclone crosses a coastline. They are caused by an interaction between wind stress on the water, the sharp drop in atmospheric pressure, and the shallowness of the harbor or bay.

Ships operating in Suruga Bay should not normally notice such a surge due to the extreme depths of the bay. More evident would be the wind generated waves and swells originating from the tropical cyclone system itself.

Tidal ranges near the Numazu Harbor area are quite small -- less than 2 ft for maximum ranges. Therefore, any surge associated with a tropical cyclone would tend to have a significant effect close to the harbor entrance where the water depth becomes shallower (approximately 45 fathoms).

6. PREPARATION FOR HEAVY WEATHER IN THE NUMAZU OPERATING AREA

6.1 EVASION RATIONALE

The responsibility for overall coordination of action to be taken by naval activities in the Numazu Operating Area has been assigned to Commander, Fleet Activities, Yokosuka.[7] The Naval Weather Service Facility, Yokosuka issues the local wind warnings.

The commander must recognize the inherent dangers that exist when exposed to the possibility of hazardous weather while operating in the Numazu Operating Area. By proper utilization of the meteorological products of the Naval Weather Service Command, especially the FWC/JTWC Tropical Cyclone Warnings, and a basic understanding of weather, the commander will be able to act in the best interest of his unit and to complete his mission when the unfavorable weather subsides. The following time table (in conjunction with Figures 23-27) has been set up to aid in these actions. The orientation of the threat axis in Figures 23-27 was arrived at by considering the general direction from which the tropical cyclones approached to within 180 n mi of the Numazu Operating Area as determined in Figures 11-15. The time in days to reach the Numazu Operating Area was based on average speeds of movement of tropical cyclones affecting Numazu (Table 4).

1. An existing tropical cyclone moves into or development takes place in area "A" with long range forecast movement toward the Numazu Operating Area (recall that about 40% of all tropical storms and typhoons recurve):

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[7] Storm/typhoon doctrine and coordination procedures for naval forces operating in the COMNAVFORJAPAN area of responsibility has been established by COMNAVFORJAPAN INST 3140.1 series.

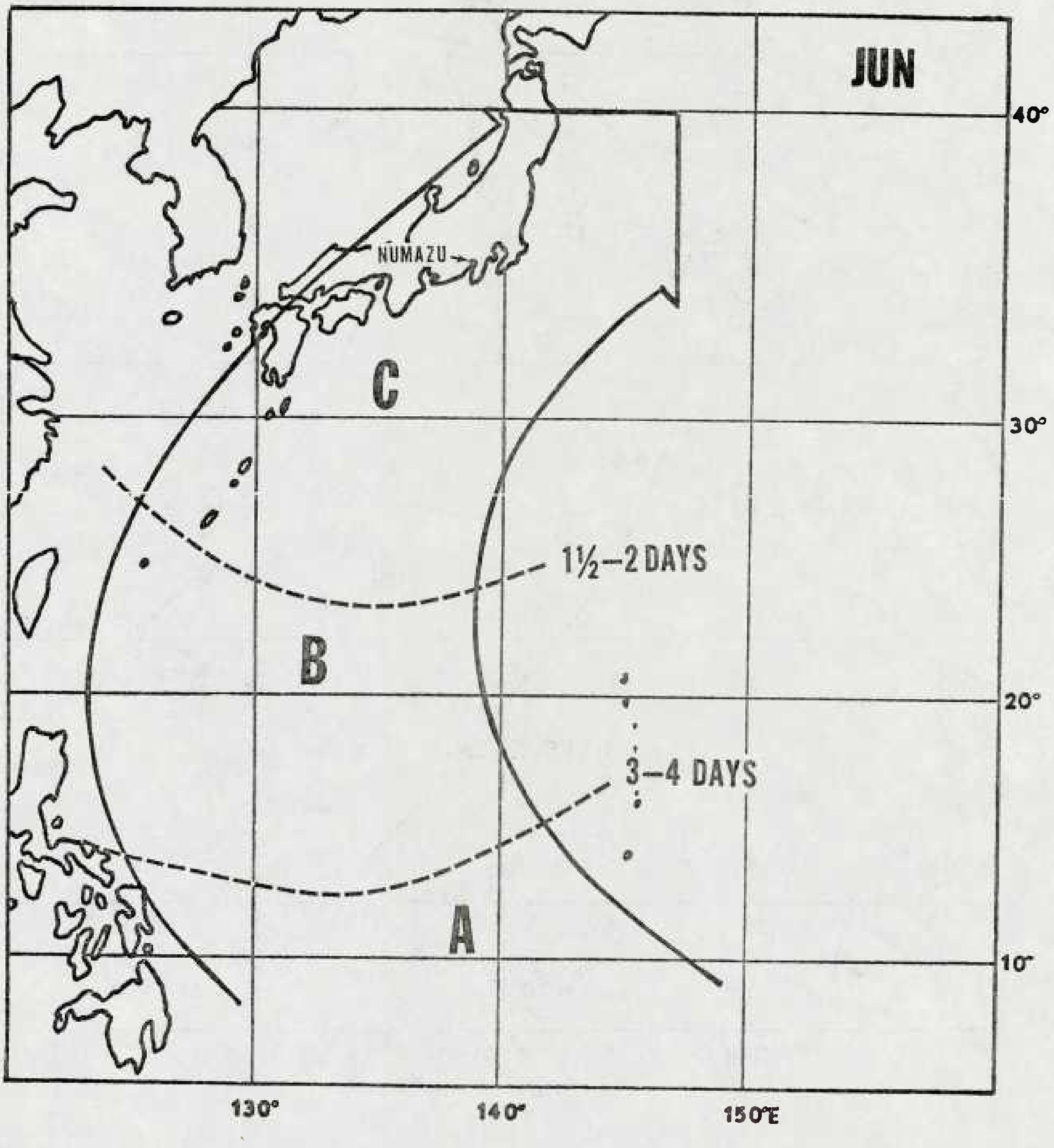

Figure 23. Tropical cyclone threat axis for the Numazu Operating Area for the month of June. Approach times to Numazu are based on the average speed of movements for tropical cyclones affecting Numazu.

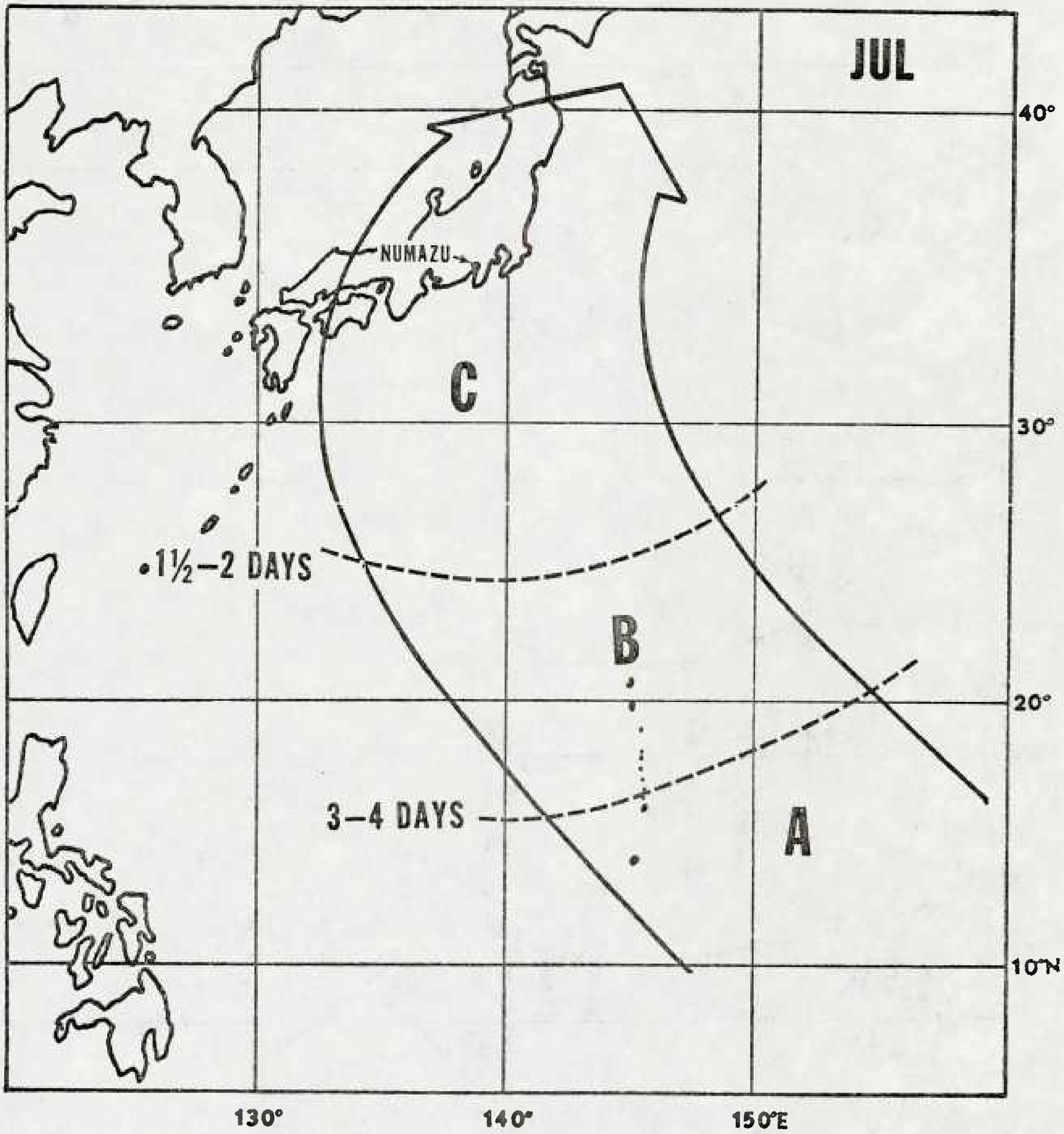

Figure 24. Tropical cyclone threat axis for the Numazu Operating Area for the month of July. Approach times to Numazu are based on the average speed of movements for tropical cyclones affecting Numazu.

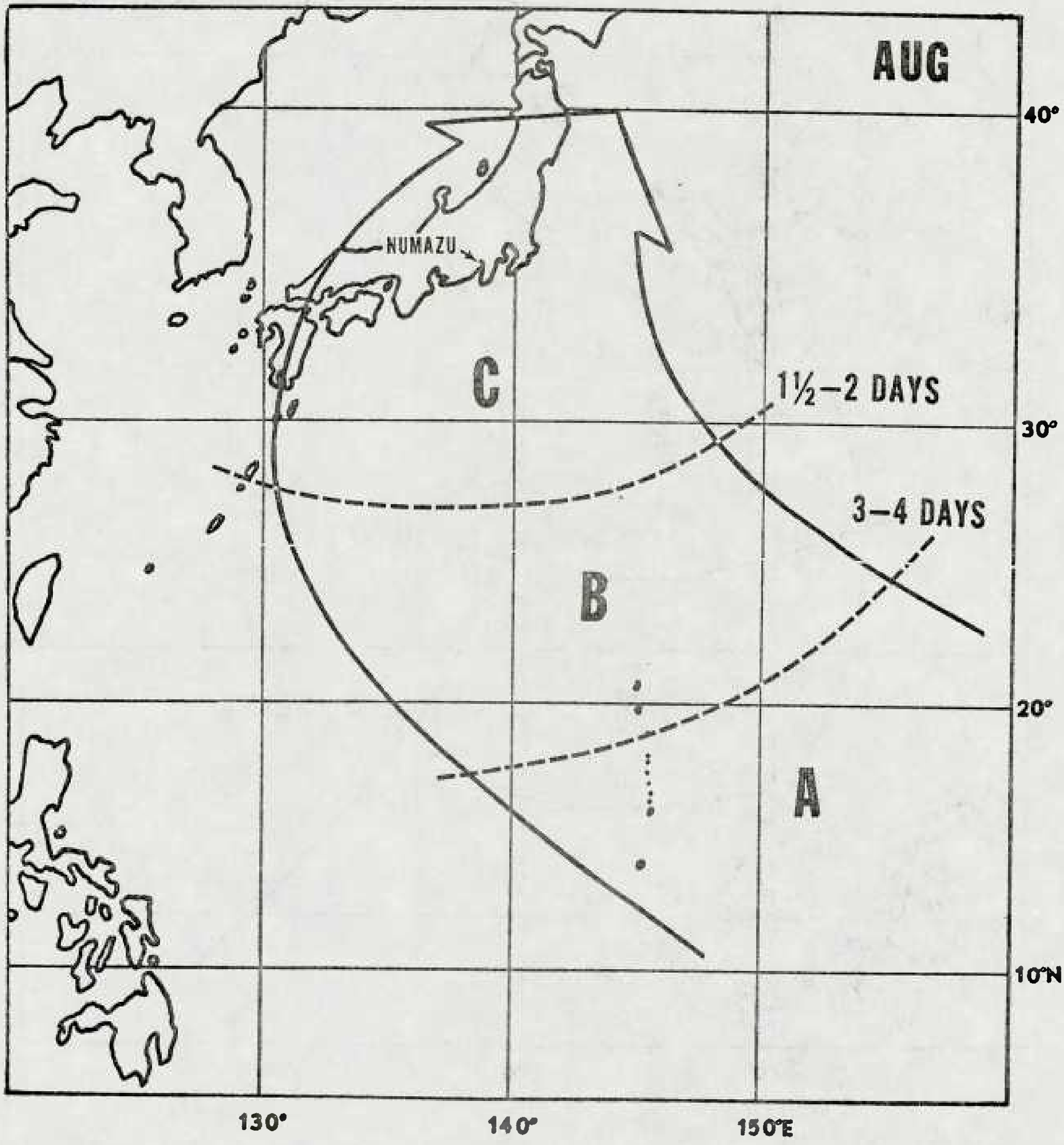

Figure 25. Tropical cyclone threat axis for the Numazu Operating Area for the month of August. Approach times to Numazu are based on the average speed of movements for tropical cyclones affecting Numazu.

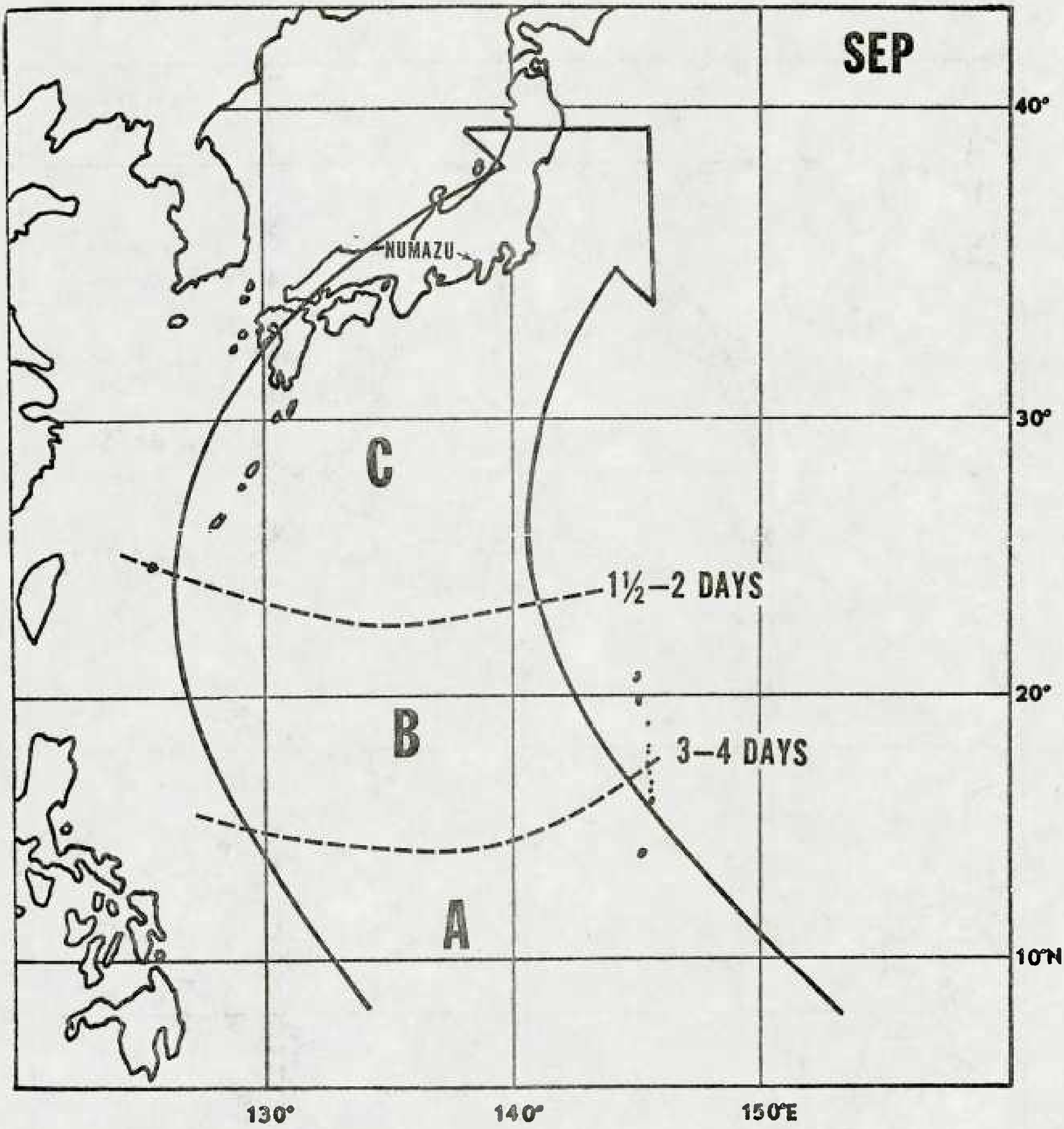

Figure 26. Tropical cyclone threat axis for the Numazu Operating Area for the month of September. Approach times to Numazu are based on the average speed of movements for tropical cyclones affecting Numazu.

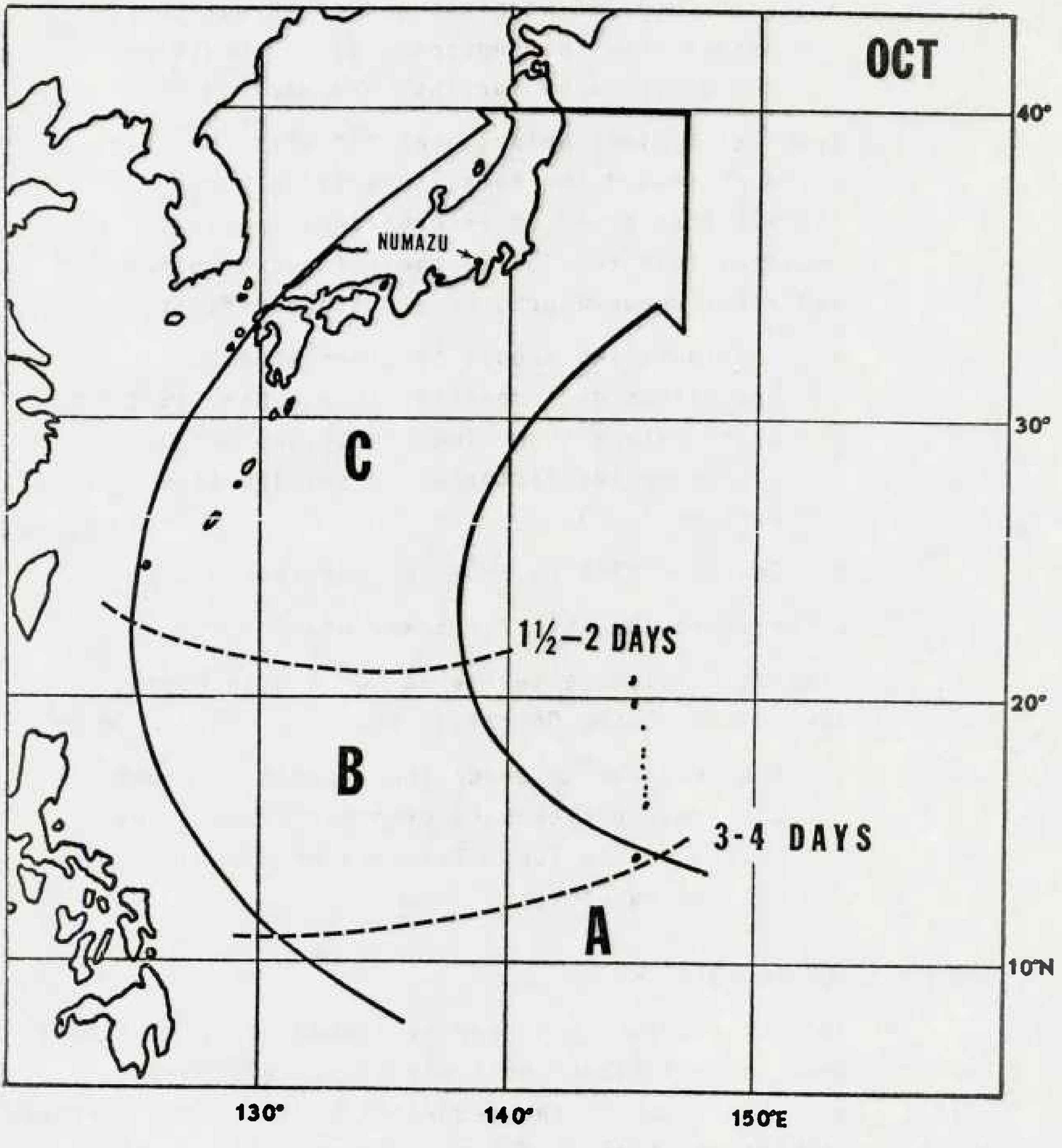

Figure 27. Tropical cyclone threat axis for the Numazu Operating Area for the month of October. Approach times to Numazu are based on the average speed of movements for tropical cyclones affecting Numazu.

    a. Review material condition of ship.

    b. Plot FWC/JTWC warnings and construct the danger area (see Appendix B). Reconstruct the danger area for each new warning.

2. Tropical cyclone enters area "B" with forecast movement toward the Numazu Operating Area (recall that prior to recurvature, tropical cyclones tend to slow in their forward motion and after recurvature, accelerate rapidly):

    a. Consideration should be given to ceasing operations and departing Suruga Bay. Sea state rather than wind conditions may be the governing factor at this stage (see Section 2.3.)

    b. Continue plot of FWC/JTWC warnings.

    c. Prepare the ship for heavy weather.

3. Tropical cyclone enters area "C" and is moving toward the Numazu Operating Area:

    a. The decision to evade the typhoon by departing the area for Yokosuka or other known typhoon havens in the Tokyo Bay area or evasion at sea must be made.

6.2 EVASION TO YOKOSUKA

The port of Yokosuka has been evaluated as an excellent typhoon haven for all sizes and types of vessels (Graff, 1975). In general, due to the geographical location, surrounding topographical features and harbor construction, the hazardous effects of wind and sea from a typhoon are greatly reduced. However, if crowded conditions exist within the port, which would reduce availability of pierside facilities, a Commanding Officer may elect to evade the typhoon at sea or anchor in Tokyo Bay.

6.3 EVASION IN TOKYO BAY

Japanese Maritime Self Defense Force ships in the past have anchored in Tateyama Bay for typhoon passage to the east of Tokyo Bay. They also make use of Kisarazu Harbor (see Figure 28).

Merchant vessels have, at times, depending on the direction of the tropical storm or typhoon CPA, anchored in the following areas:[8]

(1) Tropical cyclone passage to the east or south of Tokyo Bay: anchor in Chiba Harbor or Kisarazu Harbor.

(2) Tropical cyclone passage to the west or north of Tokyo Bay: anchor in Kaneda Bay.

Vessels carrying a dangerous cargo must anchor as directed by the Japanese Maritime Safety Office.

Ships requiring a pilot to transit the Uraga Suido Traffice Route may be unable to secure pilot services if winds are greater than about 35 kt because pilots embark and debark from small motor launches.

6.4 EVASION AT SEA

The widely held doctrine of evasion at sea rather than remaining in port for the single purpose of minimizing typhoon related damage is not generally recommended if the ship can reach Yokosuka. However, if putting to sea is desirous, each tropical storm or typhoon must be considered as differing from those preceding it. The accompanying weather situation must be fully understood. To establish one technique or rule to avoid the danger area is not practical.

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[8] See Defense Mapping Agency Hydrographic Center charts H.O. 97151 and H.O. 97143.

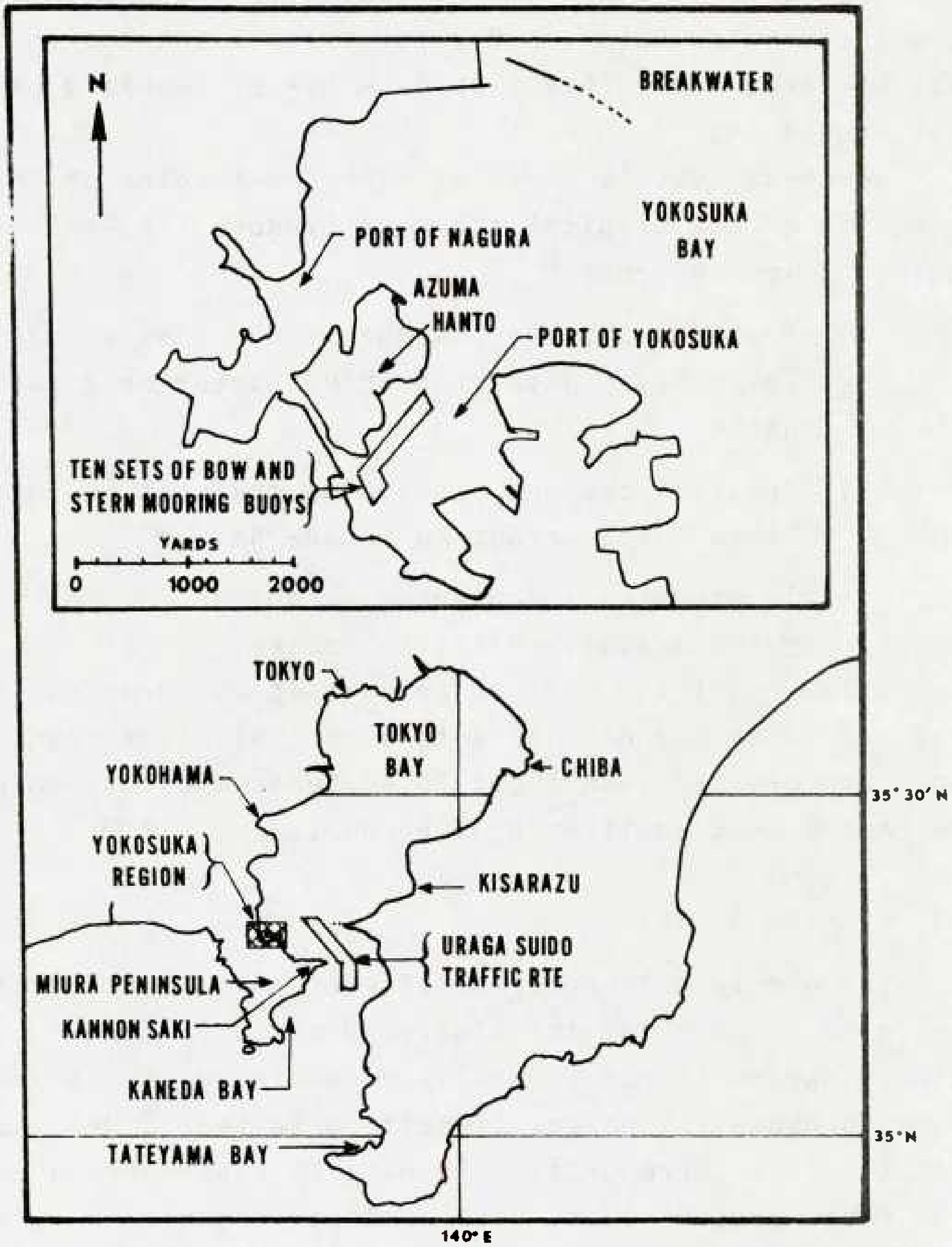

Figure 28. Tokyo Bay and the surrounding land area. The hatched area (Yokosuka region) is enlarged at top of the figure.

In general, the effects of sea/swell generated by a tropical cyclone may reduce the speed of advance (SOA), thereby increasing the time required to reach the open sea (see Appendix C). If a ship is caught in the sea/swell pattern ahead of a tropical cyclone, in particular an intense tropical storm or typhoon, the SOA may be reduced to the point that the ship will be unable to maneuver to clear the danger area (see Appendix C).

If the typhoon is forecast to follow a recurving track, with a CPA to the east of Numazu, then a course downsea/downwind, in the left or navigable semicircle may be advisable.

Any course to the north along the east coast of Honshu (north of Tokyo Bay) is considered unwise. The possibility of being overrun exists if the storm accelerates and/or turns suddenly to the north. The average speed of advance in the higher latitudes (30°-40°N) of tropical cyclones is about 25 kt; however, they have been tracked as fast as 50 kt. Typhoon wind intensities tend to decrease as the system moves into the northern latitudes but, nevertheless, can be quite destructive.

Remaining in the northern regions of Suruga Bay and riding out the storm should only be considered if the certainty of the typhoon's passage well to the east of the area can be ascertained. Some degree of protection may be offered by the mountains along the eastern side of the bay protecting the area from the northeasterly flow around the cyclone's center. Additionally, the sea state will not be as destructive because the fetch will not be as great for the northeasterly wind as it would be for a southwesterly wind.

7. CONCLUSIONS (NUMAZU OPERATING AREA)

The conclusion reached in this study is that Suruga Bay, including the Numazu Operating Area should not be considered a "safe" typhoon haven for ships operating in the area or transiting the south central coast of Honshu. The primary factors in reaching this conclusion are:

(1) The openness of the bay to the effects of the ocean--especially in the southwestern quadrant.

(2) The lack of any suitable sheltered area for a ship to lie to or anchor in.

(3) Wind and swell wave action can be as devastating in the Suruga Bay area as on the open ocean if these effects are being felt from the south-southwest.

Some protection from northeasterly winds (associated with a tropical cyclone passing to the east) may be found by keeping close to the Izu Peninsula (eastern) side of the bay. This should reduce the effects of the wind and wind generated waves because of the shorter fetch the winds would blow over. In spite of the deep water in Suruga Bay, caution should be exercised when operating close to land as visibility may be reduced and radar reception hindered by the effects of a tropical cyclone passing close by. Also the confused sea state with accompanying wind may set up unpredictable local currents.

Additionally, it has been concluded that surf conditions in the Numazu Operating Area may be unsafe for small craft operation for a number of days after a tropical cyclone passes CPA because of the slow decay rate of swells associated with such a storm. This conclusion can also be applied to tropical cyclones, especially typhoons, that pass well to the south of the 180 n mi threat circle used in this study.

To avoid the effects of tropical cyclones that pose a threat to the Numazu Operating Area, evasion to the Yokosuka/Tokyo Bay area is highly recommended.

8. KYUSHU

Kyushu is the third largest and the southernmost island in Japan. The island is characterized by its ruggedness as depicted in Figure 29. The Kyushu Mountains that lie in a north-south orientation traverse the central region of the island.

A detailed study of the coast and harbors of Kyushu is included in H. O. Publication 156, Sailing Directions (Enroute) for Japan. Specific remarks concerning navigation aides and coastal features may be found in this publication.

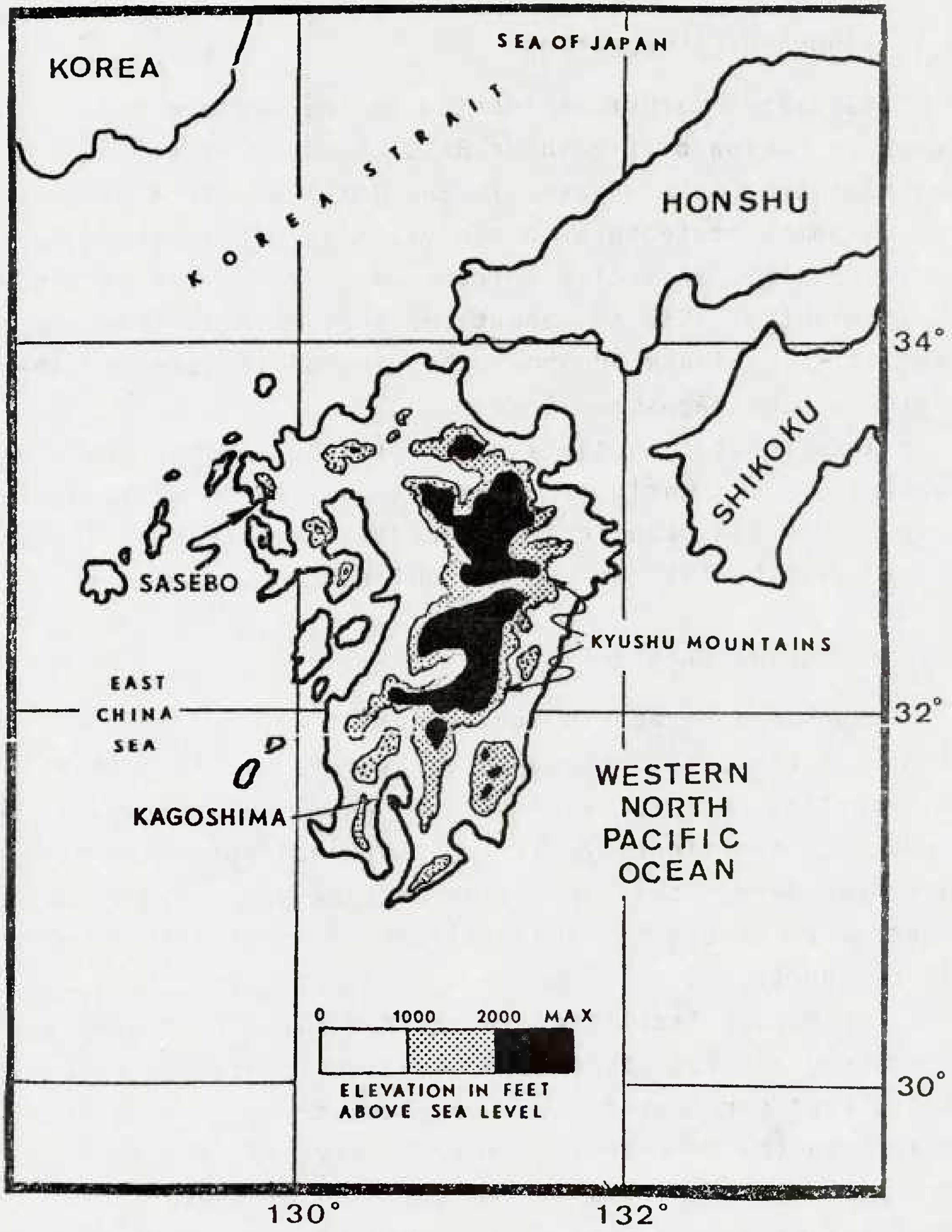

Figure 29. Kyushu topography.

9. KAGOSHIMA--GENERAL DESCRIPTION

9.1 GEOGRAPHICAL LOCATION

Kagoshima Harbor is located on the western side in the northern region of Kagoshima Bay. The bay itself cuts into the southern tip of Kyushu Island for a distance of 45 n mi.

A dominant feature in the vicinity of Kagoshima Harbor is Sakurajima, an active volcano which rises out of the bay to a height of 3655 ft, about two n mi from the harbor facilities. Figure 30 shows the general features of the region around Kagoshima Bay.

Also located in the vicinity is the largest crude oil terminal in the world at Kiire, 14 n mi south of Kagoshima City. This man made facility handles in excess of 500 vessels a year with berths for 500,000 DWT tankers.

9.2 KAGOSHIMA HARBOR

Kagoshima Harbor is located at 31° 35'N, 130° 34'E and is one of the principal ports in Kyushu. It is primarily an exporting port for agricultural and light industrial products. Additionally, it is a terminal point for auto/ passenger ferry boats operating between Japan and Okinawa. On occasion, the U.S. Navy utilizes the port city as a liberty port.

The harbor facilities in the Kagoshima port area consist of numerous "ports" that have been constructed to provide specialized services for various industries. These ports stretch southward from the central city area for approximately 10 n mi. Figure 31 depicts some of these "ports" servicing Kagoshima City. It should be noted that as newer facilities are built or planned, they will be designed to

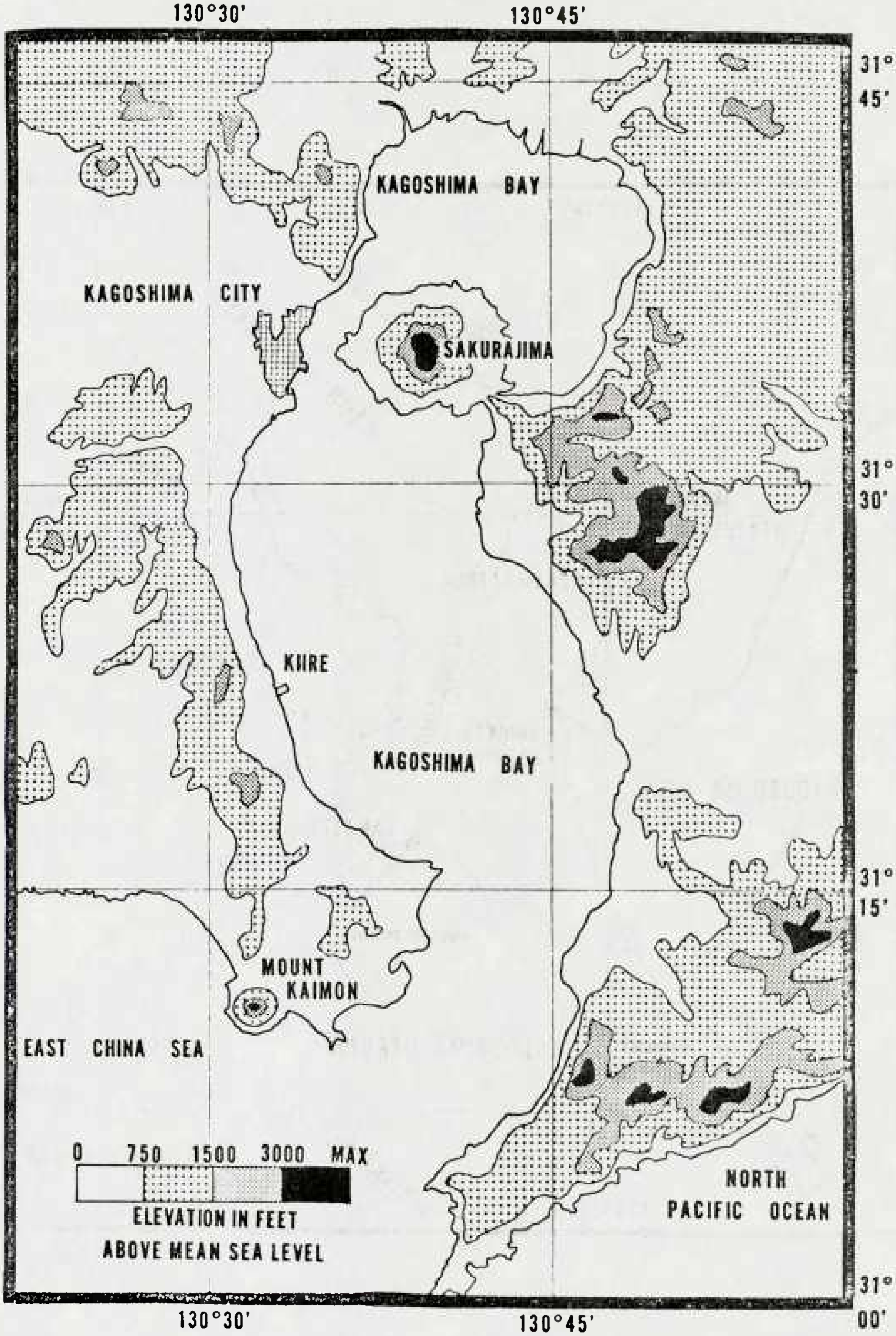

Figure 30. Geographical and topographical features of Kagoshima Bay and the surrounding vicinity.

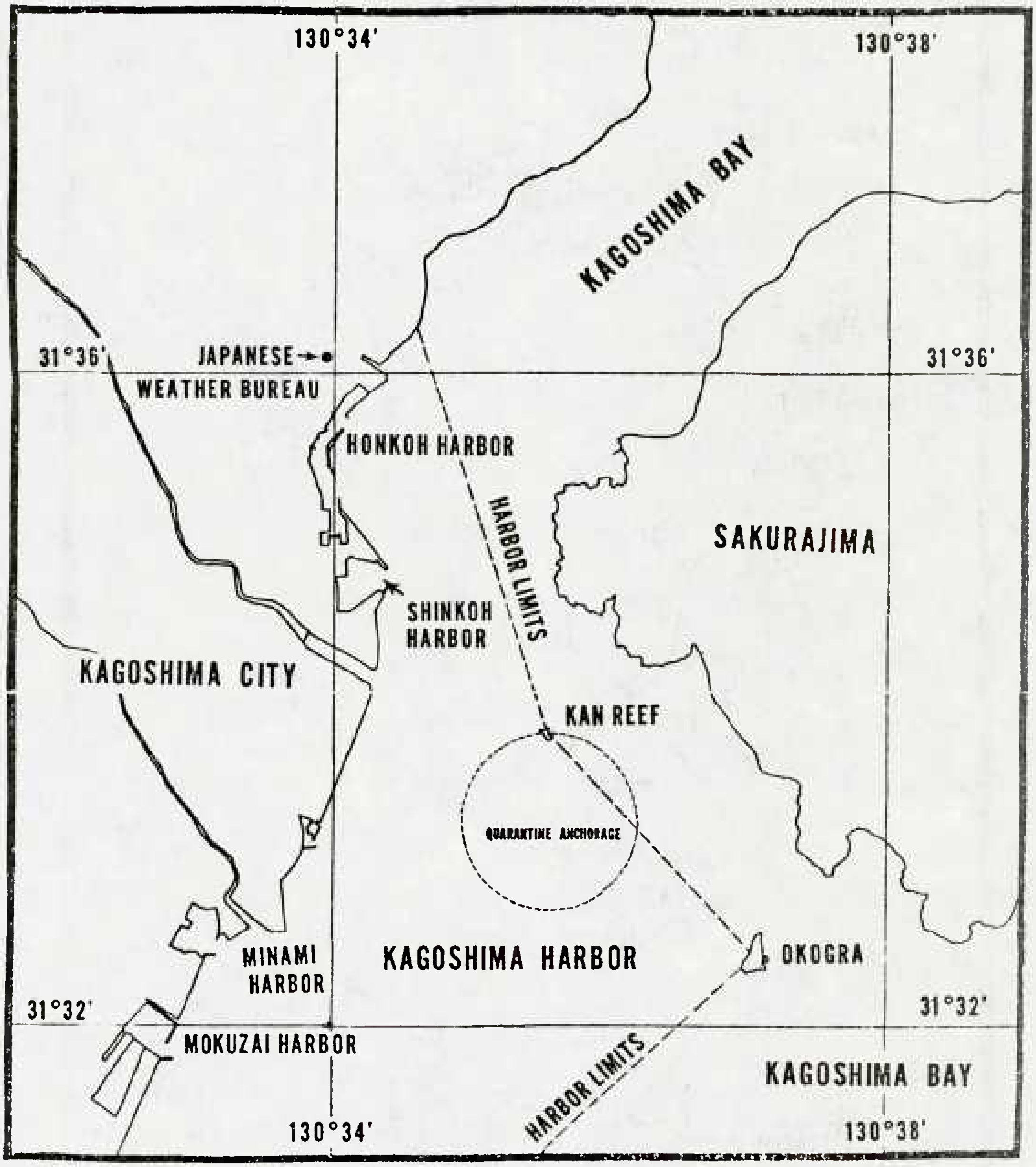

Figure 31. Kagoshima Harbor and surrounding geographic features.

accomodate the larger vessels that are currently being built. For example, at the newer port at Taniyama No. 2 (not shown), the south berth is approximately 4300 ft long with a design depth of 43 ft., while at an older port, Shinkoh Harbor further to the north, the longest berth is approximately 850 ft with a limiting depth of about 25 ft.

Currents in the harbor area flow at a speed of about 2 kt when the tide is setting south in the area between Kagoshima City and Sakurajima. These currents result from rising and ebbing tides and are not considered hazardous to navigation. There is no known record of a tsunami ("tidal wave") affecting the harbor.

The outer harbor has numerous anchorages with poor holding strength (fine to coarse sand and shale). There are no safe typhoon anchorages in the area. (Refer to Port Directories of U.S. Pacific Fleet and Military Sealift Command for details on additional port and harbor facilities.)

9.3 TOPOGRAPHY

Kagoshima Bay is a large bay opening to the extreme southern tip of Kyushu. At its widest point, at about 31° 20'N, it is 12.5 n mi wide. The north-south distance is approximately 45 n mi. Except for Sukurajima, there are no other significant topographic features breaking the expanse of the bay itself. Figure 30 shows the topographic features of Kagoshima Bay and its surroundings.

Sukurajima, an active volcano, is situated in the northern reaches of the bay. During the last significant eruption, it connected itself with the eastern shore of the bay. Current activity is limited to releasing considerable amounts of smoke and ash. It should be noted that this volcano and others on the island of Kyushu from time to time "rumble" as a reminder of their activeness. While Sukurajima does offer the harbor and anchorage protection from winds and rough seas generated by local weather conditions, it can also compound the adverse effects of heavy weather when the area comes under the influence of a tropical cyclone or other storms of equal size or intensity. Sakurajima and the mountains on the western side of the bay present a significant topographical feature that could influence northeasterly winds and produce a localized funneling and strengthening of the winds affecting the harbor area.

A mountain ridge that rises to 4080 ft lies along the eastern side of the bay. To the west of Kagoshima Bay is the aforementioned mountain ridge rising to nearly 2000 ft that gradually becomes rolling foothills and low lying areas to the south with Mount Kaimon rising from the southern tip of Kyushu at the western entrance to the bay.

10. TROPICAL CYCLONES AFFECTING KAGOSHIMA

10.1 CLIMATOLOGY

Climatology indicates that the island of Kyushu has been affected by tropical cyclones from April through December. The majority, however, that pose a threat to Kagoshima (any tropical cyclone approaching within 180 n mi of Kagoshima Harbor is defined as a "threat" for the purpose of this study) occur during the months of June-October. Figure 32 gives the frequency distribution during the months of "threat" occurrences by 5-day periods. This summary is based on data for the 28-year period, 1947-1974. Note that the maximum number occur during August and September.[9]

Figure 33 depicts on an 8-point compass, the "threat" tropical cyclones according to the octant from which they approached Kagoshima. The circled numbers indicate the total that approached from an individual octant. The count for an octant of approach includes both recurving and non-recurving tropical cyclones. (See Section 2.2 for description of recurving tropical cyclones.) Note that a majority of these approach from the south-southeast and south-southwestern octants. A more detailed inspection of the 85 tracks revealed that 20 (22%) did not recurve prior to passing the closest point of approach to Kagoshima.

Table 7 indicates that of the 85 tropical cyclones that posed a threat to Kagoshima during the years 1947-1974 (June-October), 53% passed to the east of Kagoshima, 36% passed to the west and 11% passed in the immediate vicinity

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[9] A total of 90 tropical cyclones passed within 180 n mi of Kagoshima during the May-November period for the years 1947-1974. 85 (94%) of these tropical cyclones passed within 180 n mi during the 5 months June-October, and the remaining 5 passed in the months of May and November.

of the port. The fact that the majority of the "threat" tropical cyclones pass to the east, implies that Kagoshima is placed more often in the left or "navigable" semicircle where the wind and seas are less intense.

Table 7. "Threat" tropical cyclone passage relative to Kagoshima (1947-1974).

Track Relative to Kagoshima	JUN	JUL	AUG	SEP	OCT	TOTAL
Passed east of Kagoshima	5	10	10	15	5	45
Passed west of Kagoshima	7	7	13	3	1	31
Passed in the immediate vicinity of Kagoshima	0	0	6	3	0	9

Figures 34 to 38 represent an analysis of the estimated probability for any tropical cyclone approaching within 180 n mi of Kagoshima. The solid lines represent the probability of coming within 180 n mi of Kagoshima for any storm location. The dashed lines represent the approximate time in days for a system to reach Kagoshima, computed from typical speeds of movement for tropical cyclones affecting Kagoshima (Table 8). For example, in Figure 34, a tropical cyclone located at 21°N, 130°E has a 20% probability of passing within 180 n mi of Kagoshima and it will reach Kagoshima in about 1 1/2-2 days.

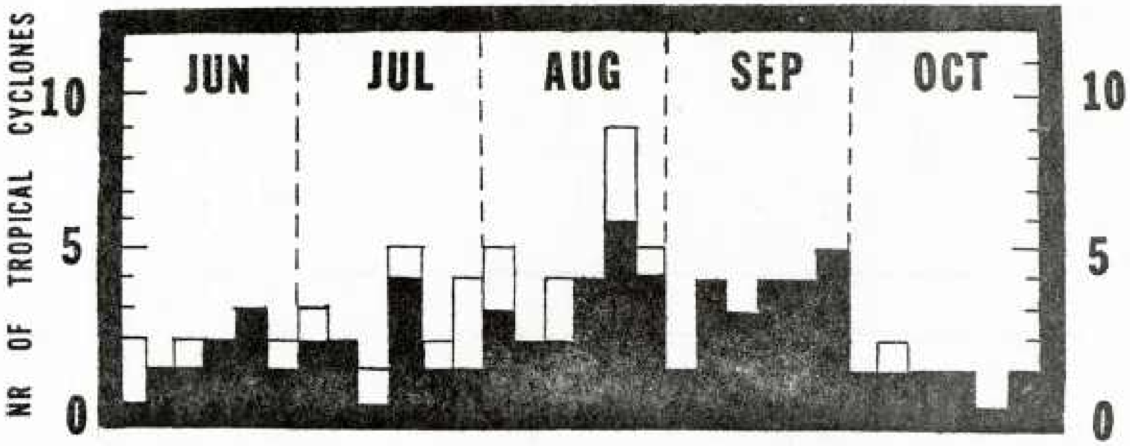

Figure 32. Frequency of tropical cyclones that passed within 180 n mi of Kagoshima. Subtotals are based on 5-day periods for tropical cyclones that occurred during 1947-1974. Shaded area indicates recurving tropical cyclones per 5-day period (that is, had a northeasterly direction of motion at CPA).

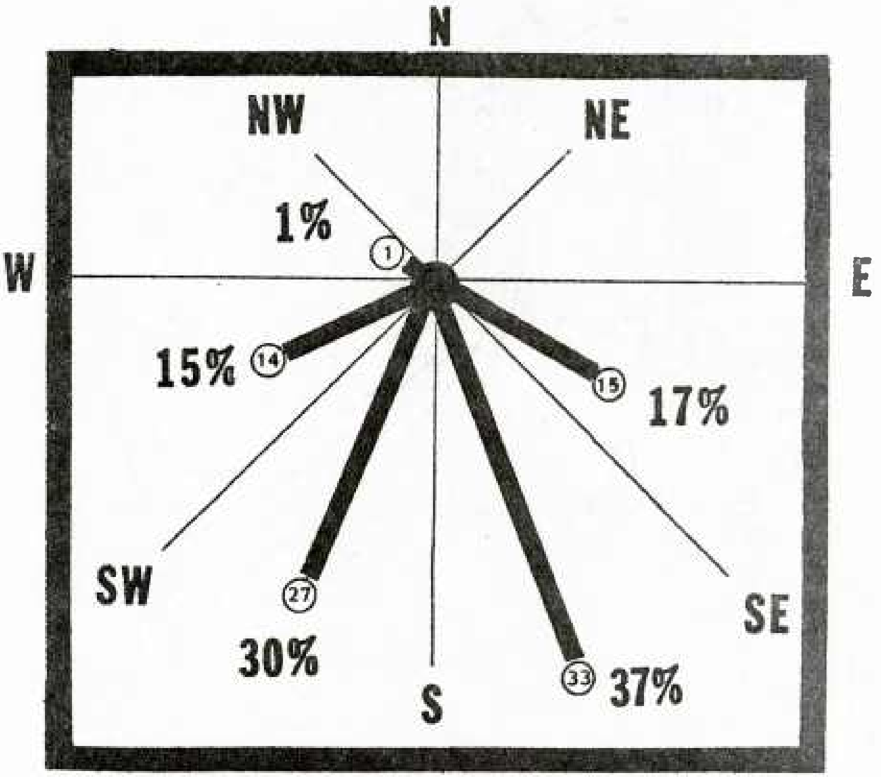

Figure 33. Directions from which tropical cyclones entered threat area (a 180 n mi radius circle centered at Kagoshima) during the period May-November, 1947-1974. Numbers circled indicate the number of tropical cyclones that entered from each octant. This is expressed as a percentage adjacent to the circled number.

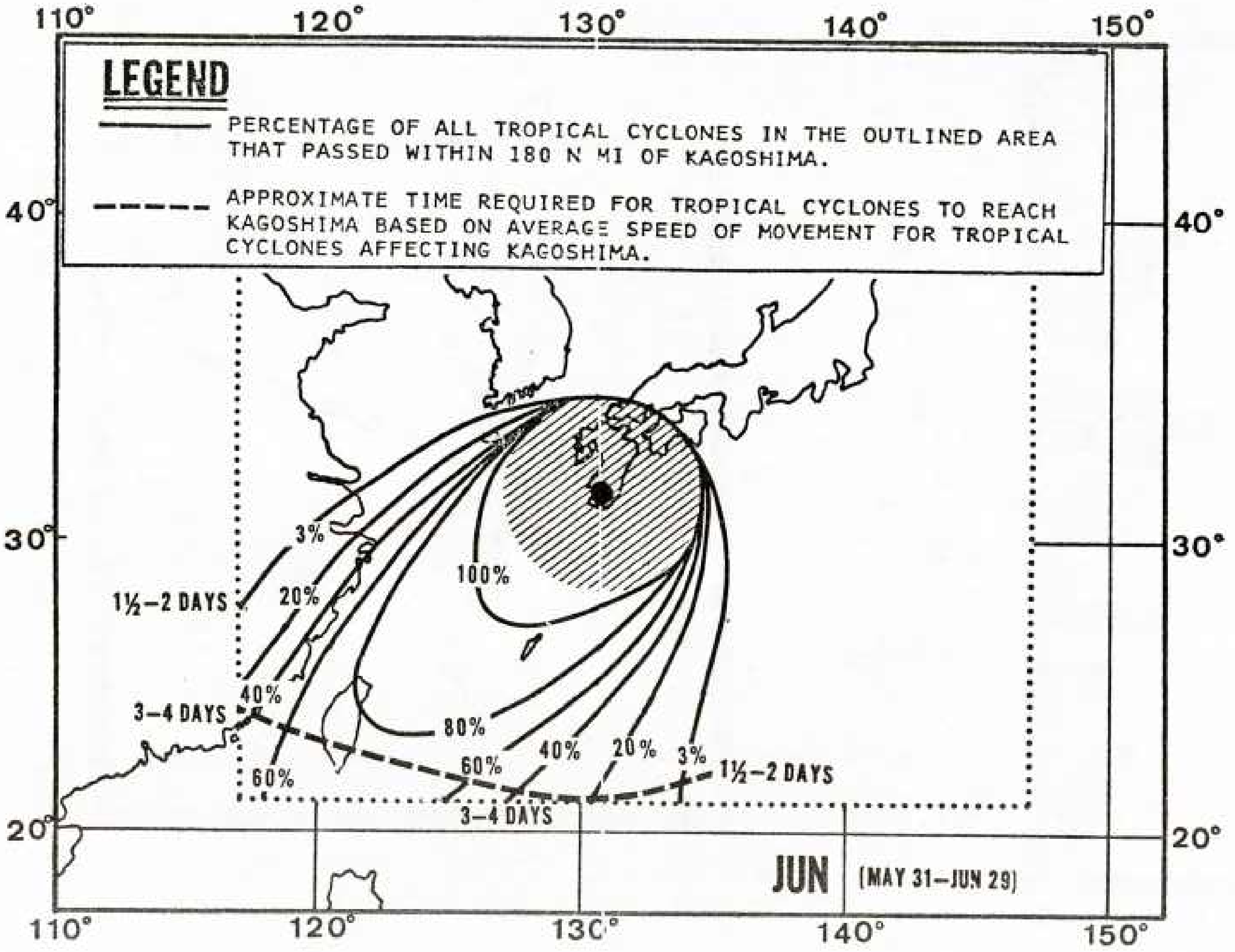

Figure 34. Percentage of tropical cyclones that passed within 180 n mi of Kagoshima for the month of June (based on data from 1947-1974.

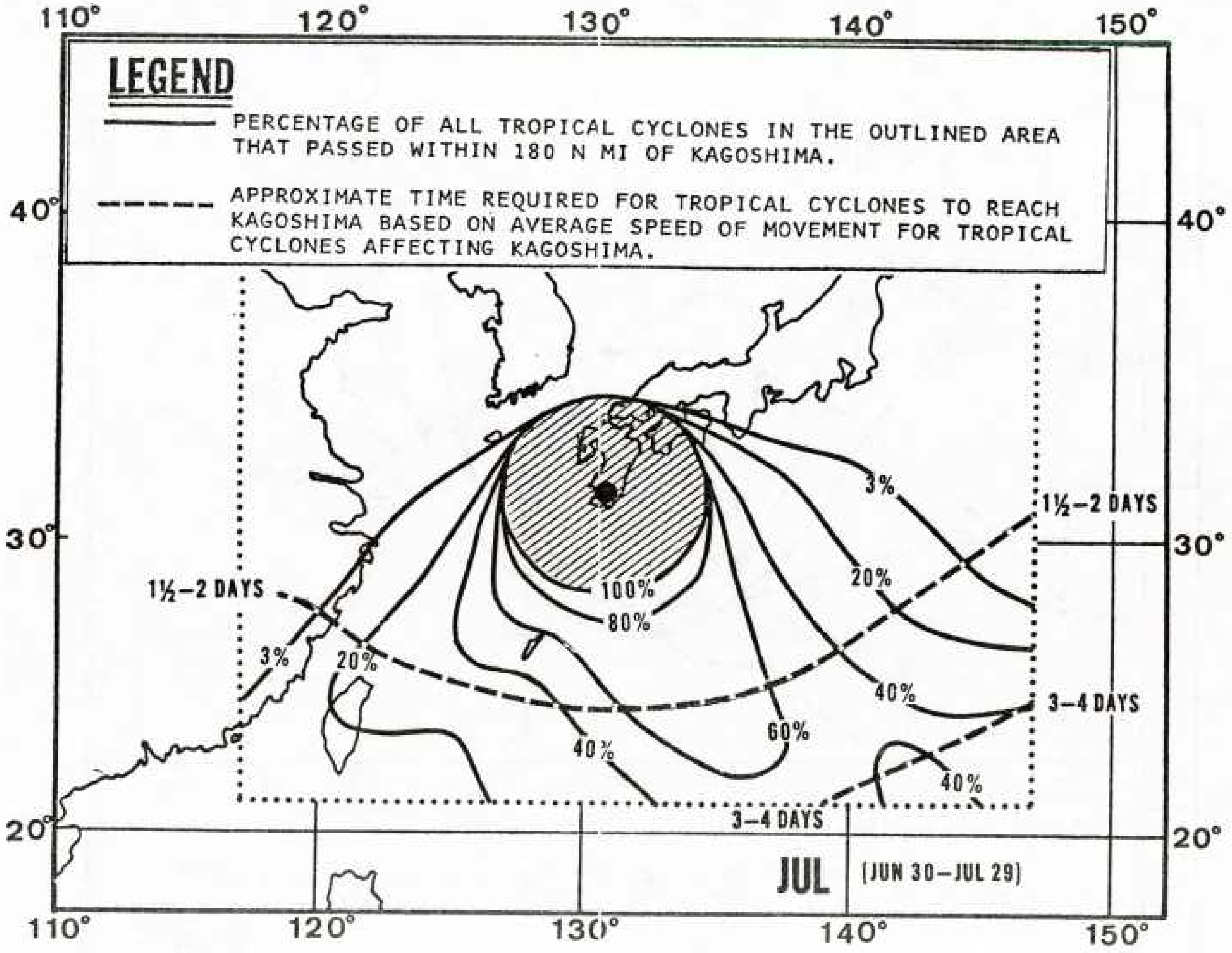

Figure 35. Percentage of tropical cyclones that passed within 180 n mi of Kagoshima for the month of July (based on data from 1947-1974).

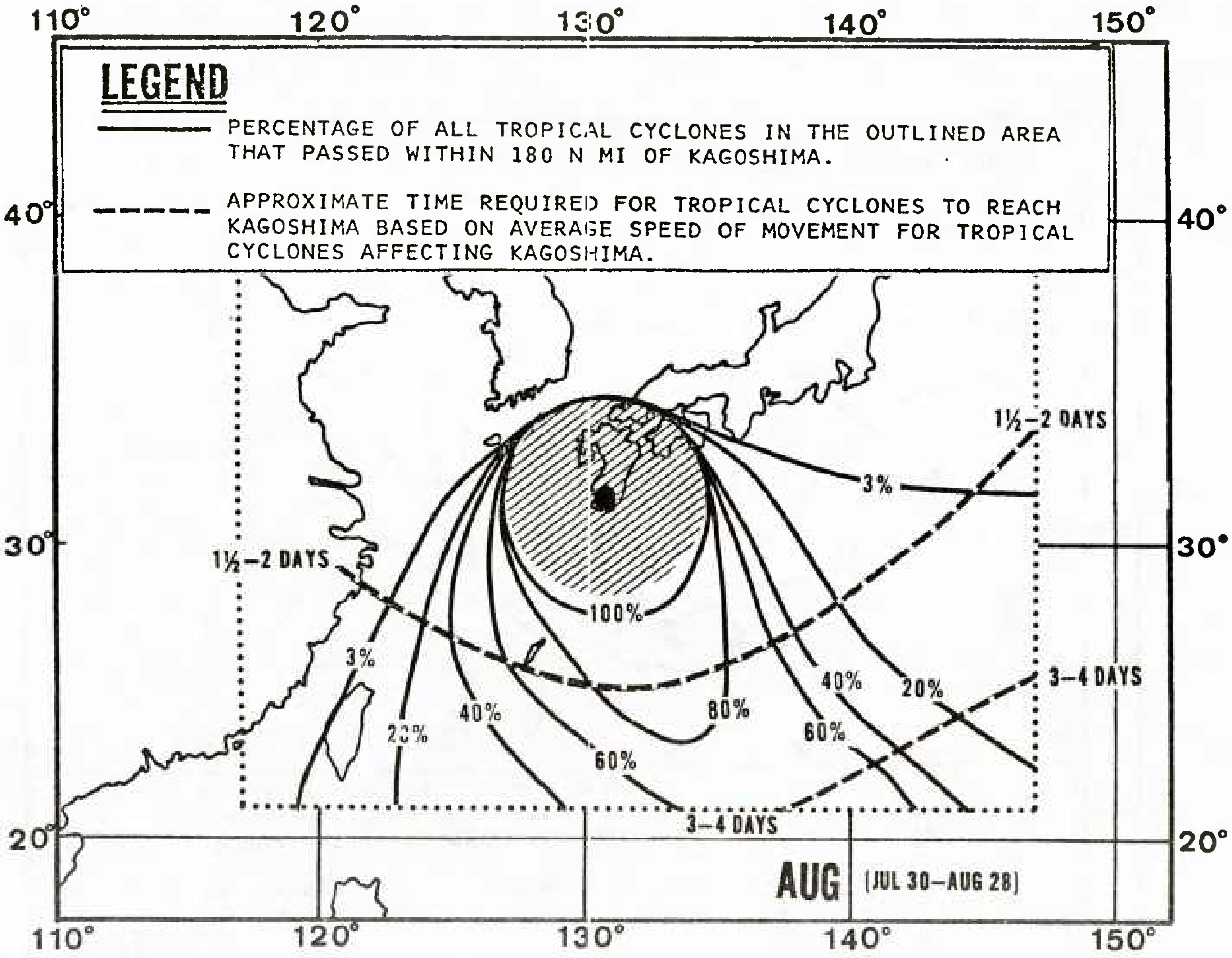

Figure 36. Percentage of tropical cyclones that passed within 180 n mi of Kagoshima for the month of August (based on data from 1947-1974).

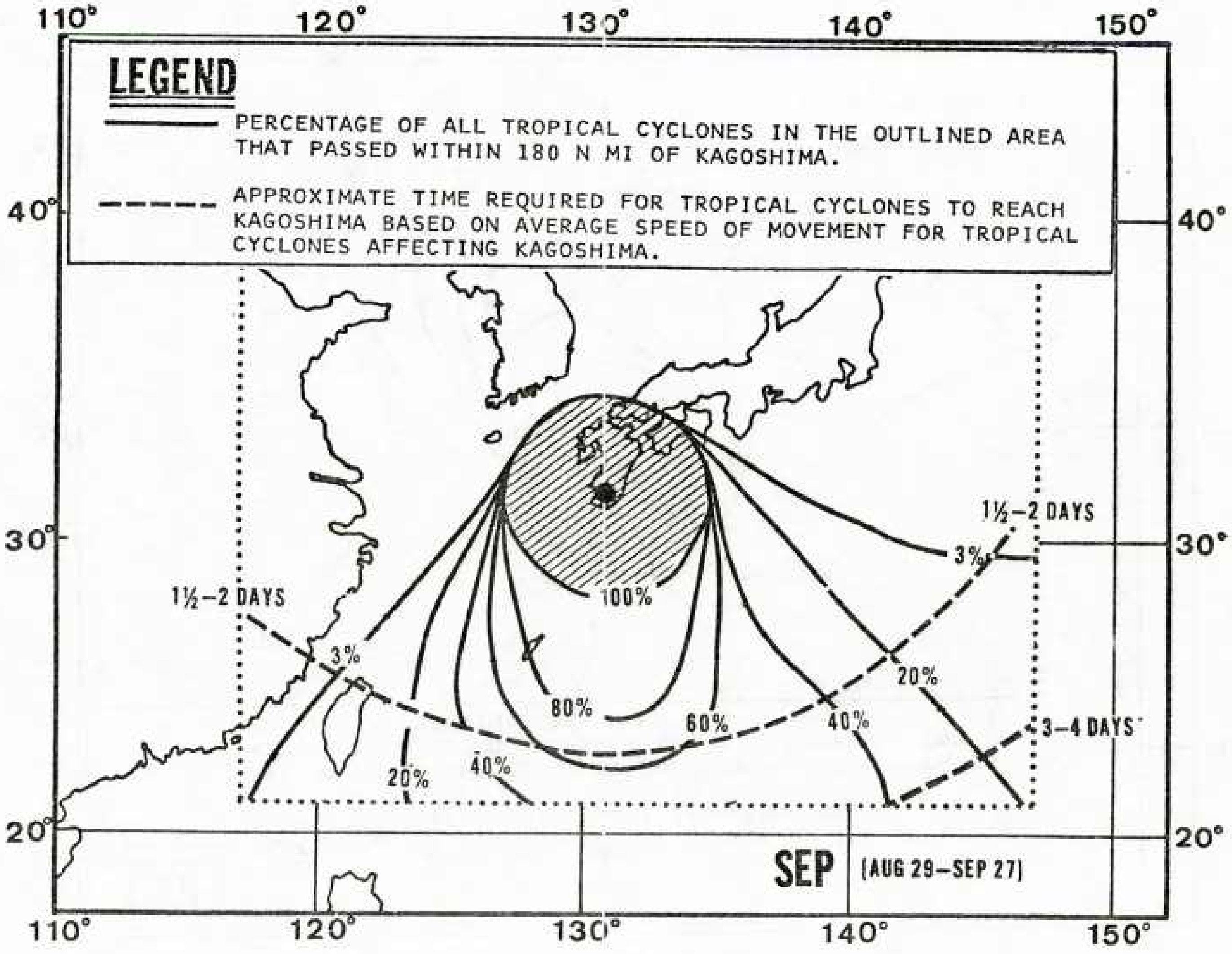

Figure 37. Percentage of tropical cyclones that passed within 180 n mi of Kagoshima for the month of September (based on data from 1947-1974.

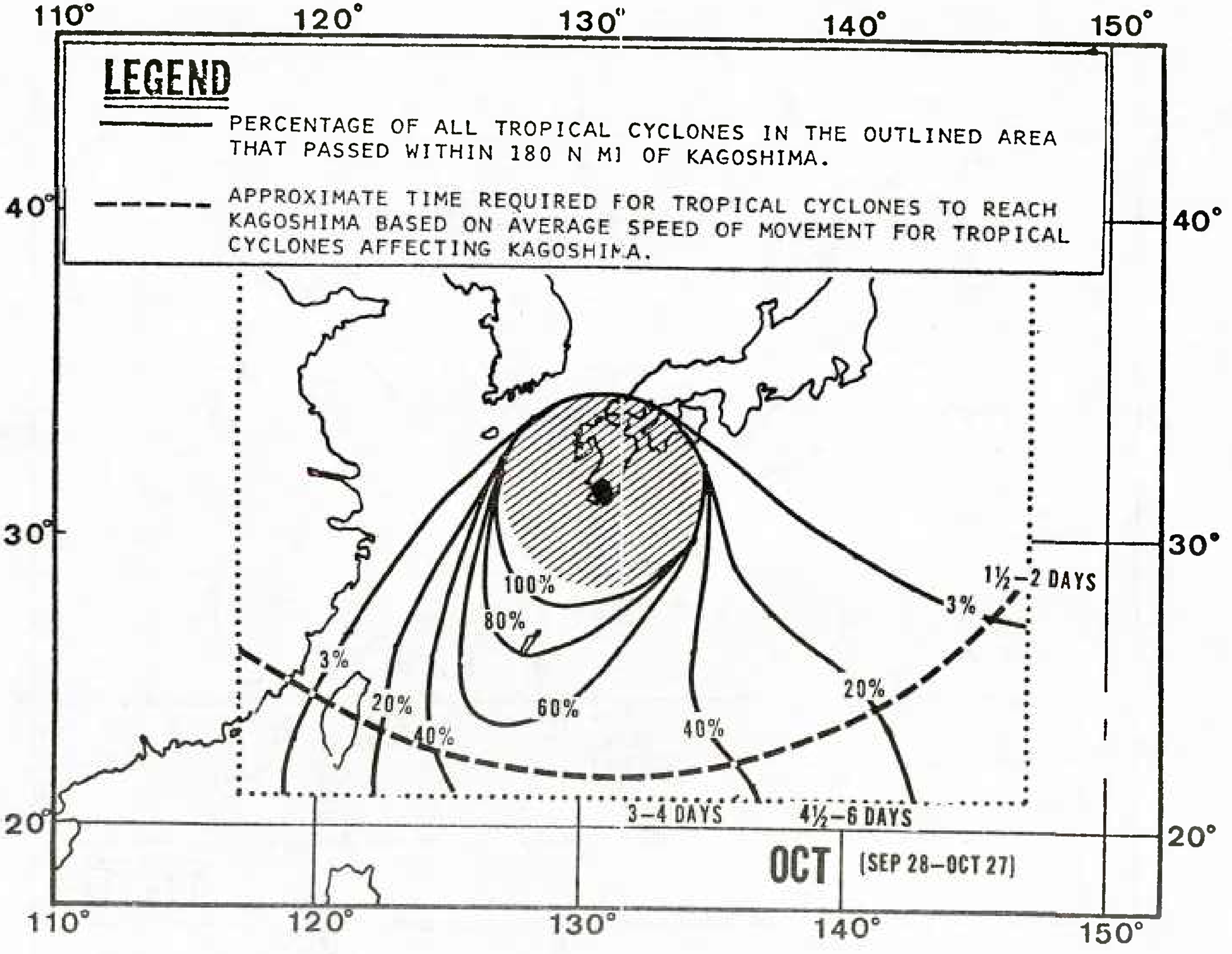

Figure 38. Percentage of tropical cyclones that passed within 180 n mi of Kagoshima for the month of October (based on data from 1947-1974).

Table 8. Average tropical cyclone speed of movement (kt) per 5-degree latitude band for tropical cyclones affecting Kagoshima for June-October.

LATITUDE BAND	JUN	JUL	AUG	SEP	OCT	AVERAGE
30-35N	25	13	13	18	18	17.4
25-30	18	12	10	14	15	13.8
20-25	11	11	10	12	13	11.4
15-20	10	10	10	11	11	10.4

Note the significant shift in direction from which tropical cyclones approach the Kagoshima area (Figures 34-38). In June the "threat" is generally from the southwest whereas, in July and August it is more to the south and southeast, then becomes more southerly in September, and then south to southwesterly in October.

10.2 WIND AND TOPOGRAPHIC EFFECT

A total of 54 tropical cyclones approached within 180 n mi of Kagoshima in the 19 year period 1956-1974 during the months June-October[10], or about 3.1 a year. Table 9 groups the tropical cyclones by strong (≥ 22 kt) and gale force (≥ 34 kt) wind intensities (based on hourly wind data) that they produced at Kagoshima[11]. Tropical cyclone activity in the Kagoshima area is maximal during the months of August and September and these individual monthly values are also shown.

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[10] From Chin (1972) for years 1956-1970 and from Annual Typhoon Reports for years 1971-1974 (FWC/JTWC, Guam, 1971-1974).

[11] Data provided by the Japanese Meteorological Agency weather station located at Kagoshima.

Table 9. Extent to which tropical cyclones affected the Kagoshima area during the period June-October, 1956-1974, and for the individual months of August and September.

	JUN-OCT	AUG	SEP
Number of tropical cyclones that passed within 180 n mi of Kagoshima	54	22	13
Number of tropical cyclones resulting in strong ($\geq$ 22 kt) winds at Kagoshima	43 (80%)	16 (73%)	10 (77%)
Number of tropical cyclones resulting in gale force ($\geq$ 34 kt) winds at Kagoshima	21 (39%)	10 (45%)	4 (31%)

It can be discerned from Table 9 that 21 (39%) of the total 54 tropical cyclones for the period June-October (1956-1974) resulted in winds of 34 kt or greater at Kagoshima. However, of 22 tropical cyclones tracked in August, 10 (45%) resulted in winds of 34 kt or greater.

An observation station for the Japanese Meteorological Agency is located in the downtown area of Kagoshima near the harbor facilities (see Figure 31). The wind instrument is located on top of the station in such a manner as to be unobstructed from any nearby buildings or trees. During the period 1947-1974, the highest recorded wind gust in Kagoshima was 100 kt on 29 September 1955. This easterly gust was attributed to Typhoon Louise which passed 30 n mi to the west of Kagoshima on 29 September 1955. The duration of gale force winds (excess of 33 kt) was 5 hours during this storm.

Winds in Kagoshima Bay are significantly influenced by the surrounding topography and the geographical features of the bay itself. The extent of this influence is dependent on the direction of approach of the storm and the passage relative to the Kagoshima area. Figures 39 through 43 depict the tracks of the threat tropical cyclones during the 19-year period 1956-1974 (June-October). Those resulting in gale force winds in Kagoshima are indicated by a solid line. Tropical cyclone tracks that resulted in winds less than 34 kt are depicted by dashed lines. From an analysis of the tropical cyclone tracks of Figures 39-43 it is apparent that tropical cyclones that result in gale force winds at Kagoshima can pass to the east or west of Kagoshima or in some instances the center of the storm passes over the immediate area. The basic difference in effect is the direction and strength of the resultant wind in the area.

If the tropical cyclone passes to the east of Kagoshima, the path will generally be over water and the winds will be primarily northeasterly. While there will be some interaction with the Kyushu Mountains (see Figure 29) to decrease the intensity of the winds, local topography becomes significant in its effect on northeasterly winds. The mountains on the northwestern side of the bay that rise to nearly 2000 ft and Sakurajima which rises to 3655 ft tend to direct and funnel winds from the northeastern quadrant into the narrow region of the Kagoshima Harbor area as can be seen in Figures 30 and 31. An example of this was Typhoon Helen which had a CPA of 40 n mi to the east-southeast of Kagoshima on 24 September 1966. During this particular typhoon, wind gusts were recorded up to 78 kt from the northeast.

In the case of tropical cyclones passing to the west of Kagoshima, the path is also over water in its approach to the area, thus retaining much of its strength before

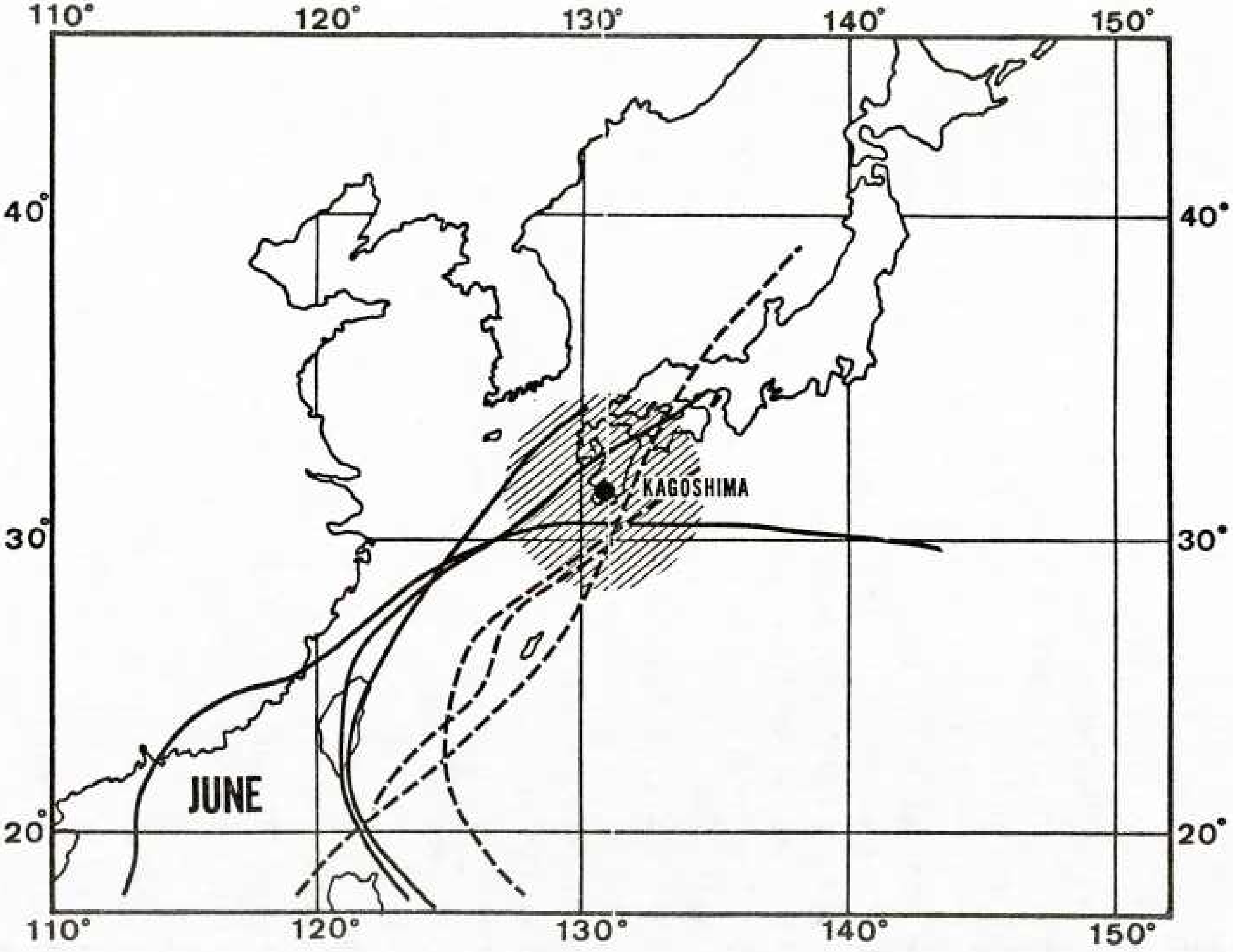

Figure 39. Tracks of tropical cyclones approaching within 180 n mi of Kagoshima during the 19-year period 1956-1974 for June. Solid lines indicate tracks of tropical cyclones that produced winds $\geq$ 34 kt at Kagoshima. Dashed lines indicate tropical cyclones passing within 180 n mi of Kagoshima but not producing winds $\geq$ 34 kt at Kagoshima.

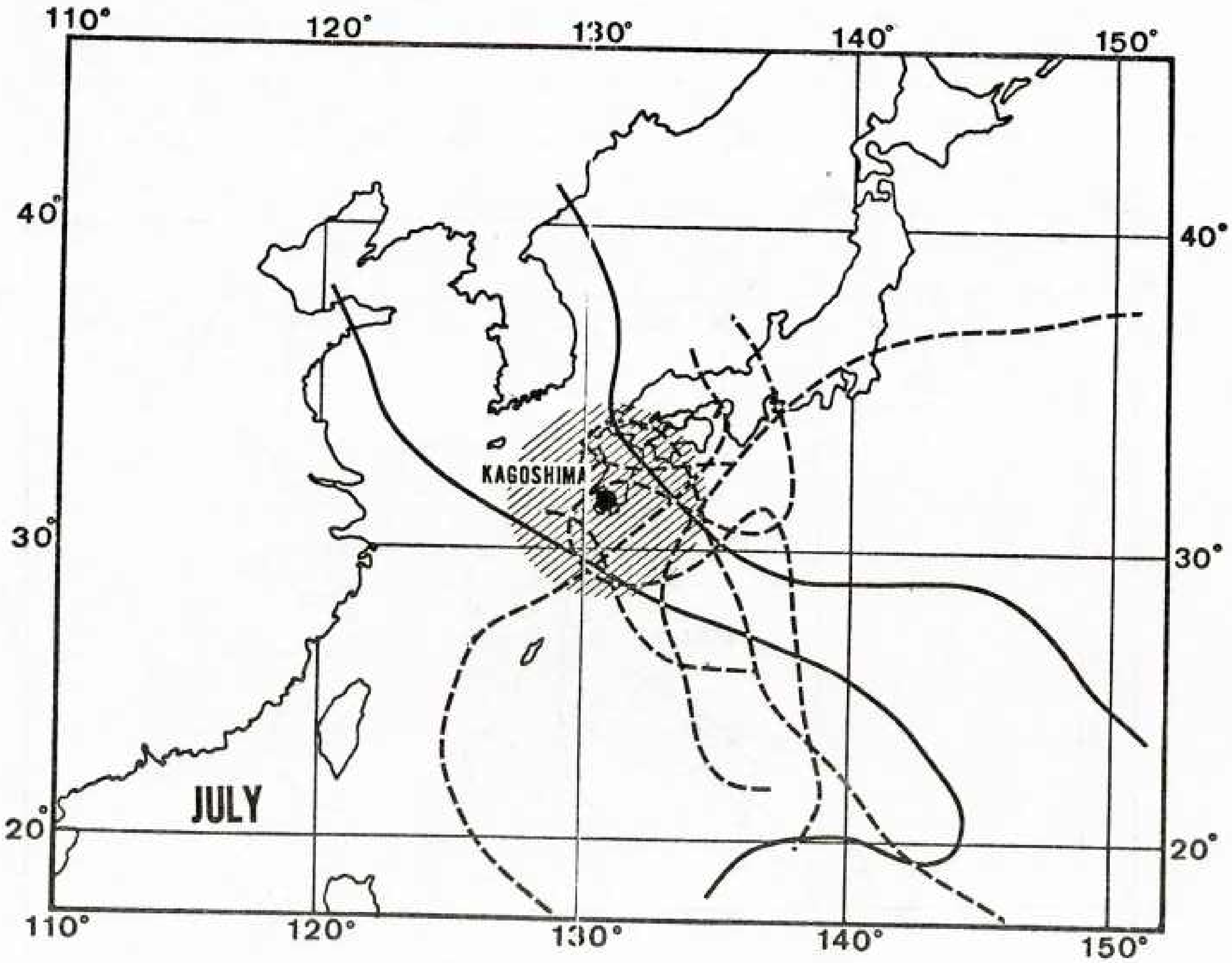

Figure 40. Tracks of tropical cyclones approaching within 180 n mi of Kagoshima during the 19-year period 1956-1974 for July. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Kagoshima. Dashed lines indicate tropical cyclones passing within 180 n mi of Kagoshima but not producing winds ≥ 34 kt at Kagoshima.

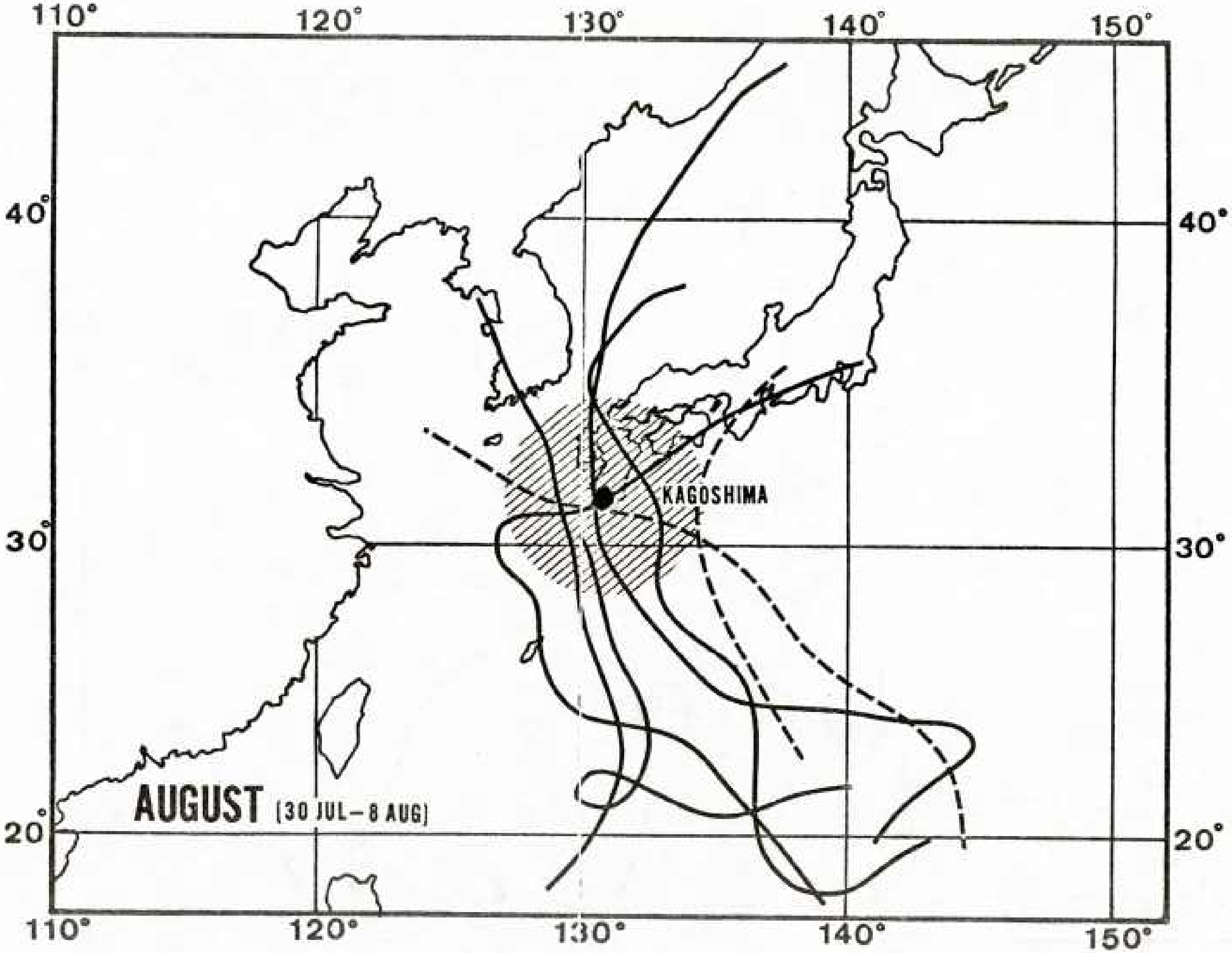

Figure 41(a). Tracks of tropical cyclones approaching within 180 n mi of Kagoshima during the 19-year period 1956-1974 for 30 July-8 August. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Kagoshima. Dashed lines indicate tropical cyclones passing within 180 n mi of Kagoshima but not producing winds ≥ 34 kt at Kagoshima.

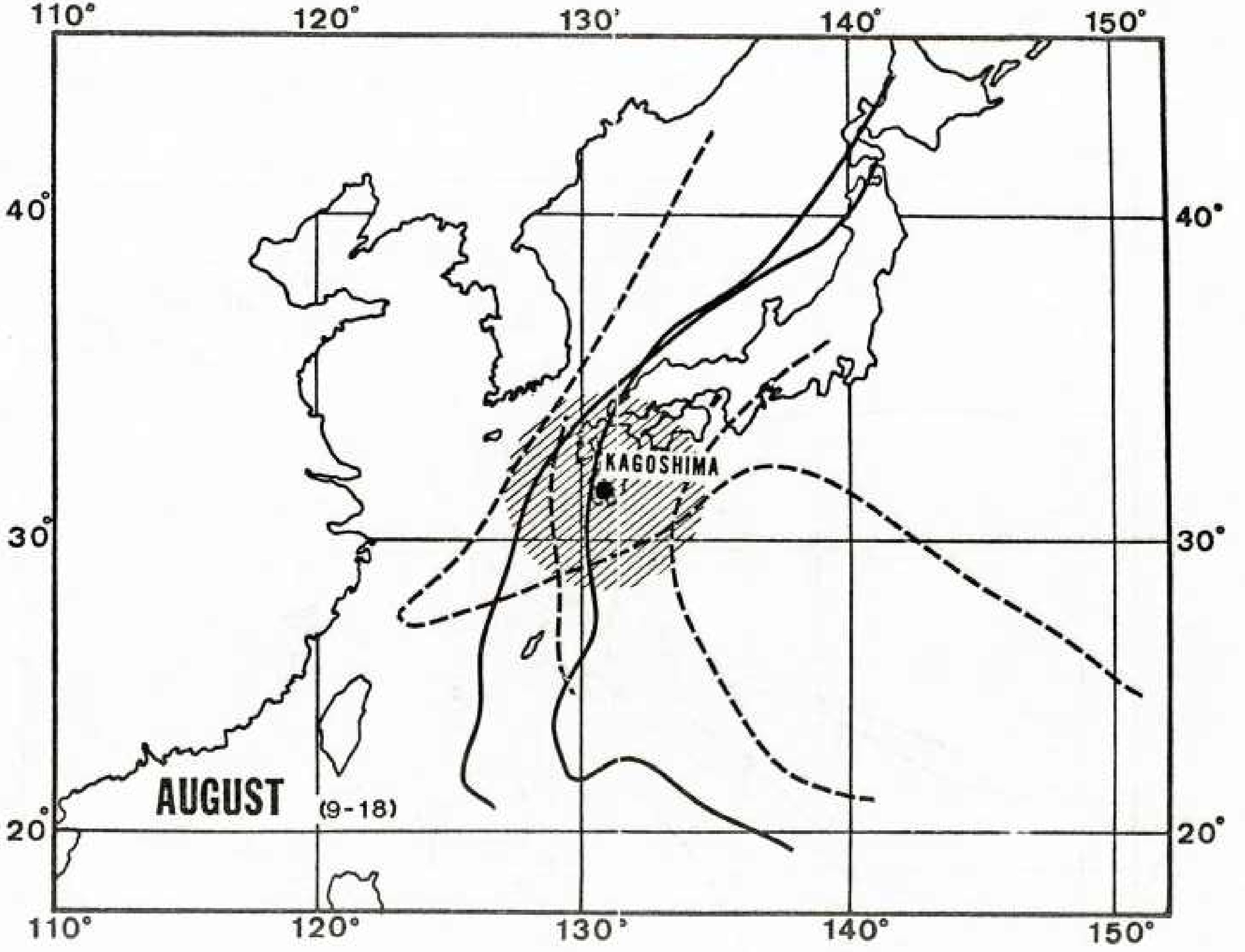

Figure 41(b). Tracks of tropical cyclones approaching within 180 n mi of Kagoshima during the 19-year period 1956-1974 for 9-18 August. Solid lines indicate tracks of tropical cyclones that produced winds $\geq$ 34 kt at Kagoshima. Dashed lines indicate tropical cyclones passing within 180 n mi of Kagoshima but not producing winds $\geq$ 34 kt at Kagoshima.

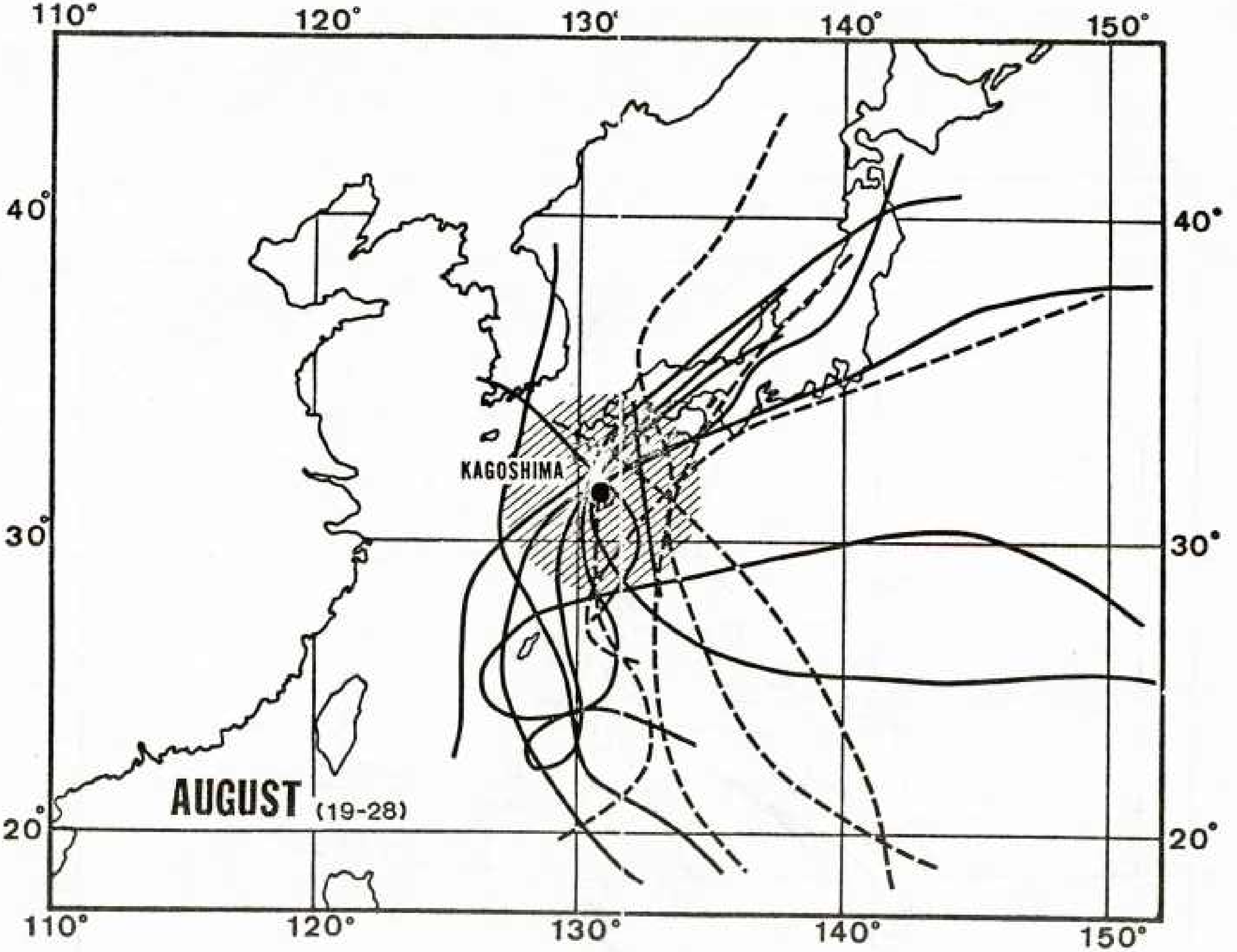

Figure 41(c). Tracks of tropical cyclones approaching within 180 n mi of Kagoshima during the 19-year period 1956-1974 for 19-28 August. Solid lines indicate tracks of tropical cyclones that produced winds ≥ 34 kt at Kagoshima. Dashed lines indicate tropical cyclones passing within 180 n mi of Kagoshima but not producing winds ≥ 34 kt at Kagoshima.

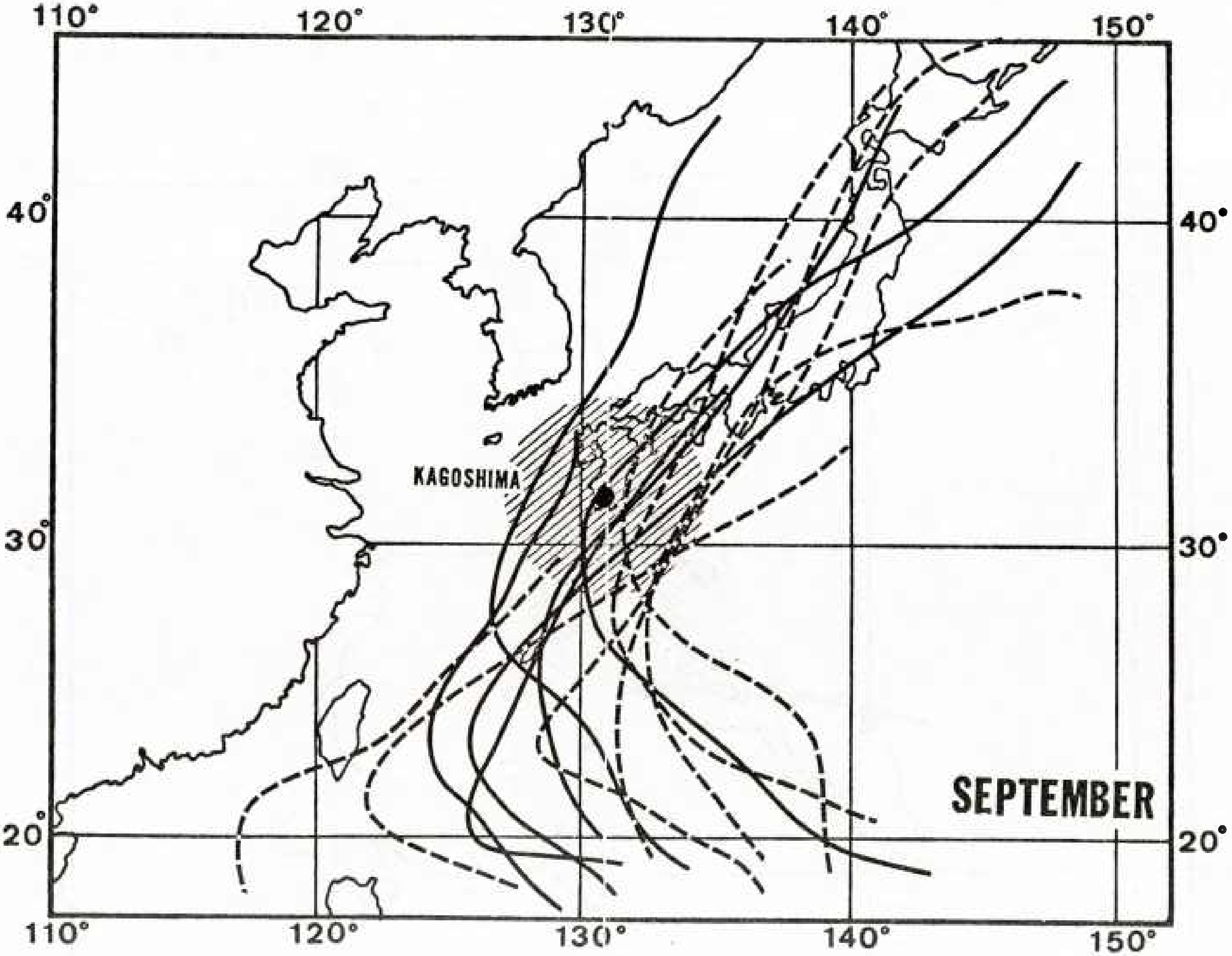

Figure 42. Tracks of tropical cyclones approaching within 180 n mi of Kagoshima during the 19-year period 1956-1974 for September. Solid lines indicate tracks of tropical cyclones that produced winds $\geq$ 34 kt at Kagoshima. Dashed lines indicate tropical cyclones passing within 180 n mi of Kagoshima but not producing winds $\geq$ 34 kt at Kagoshima.

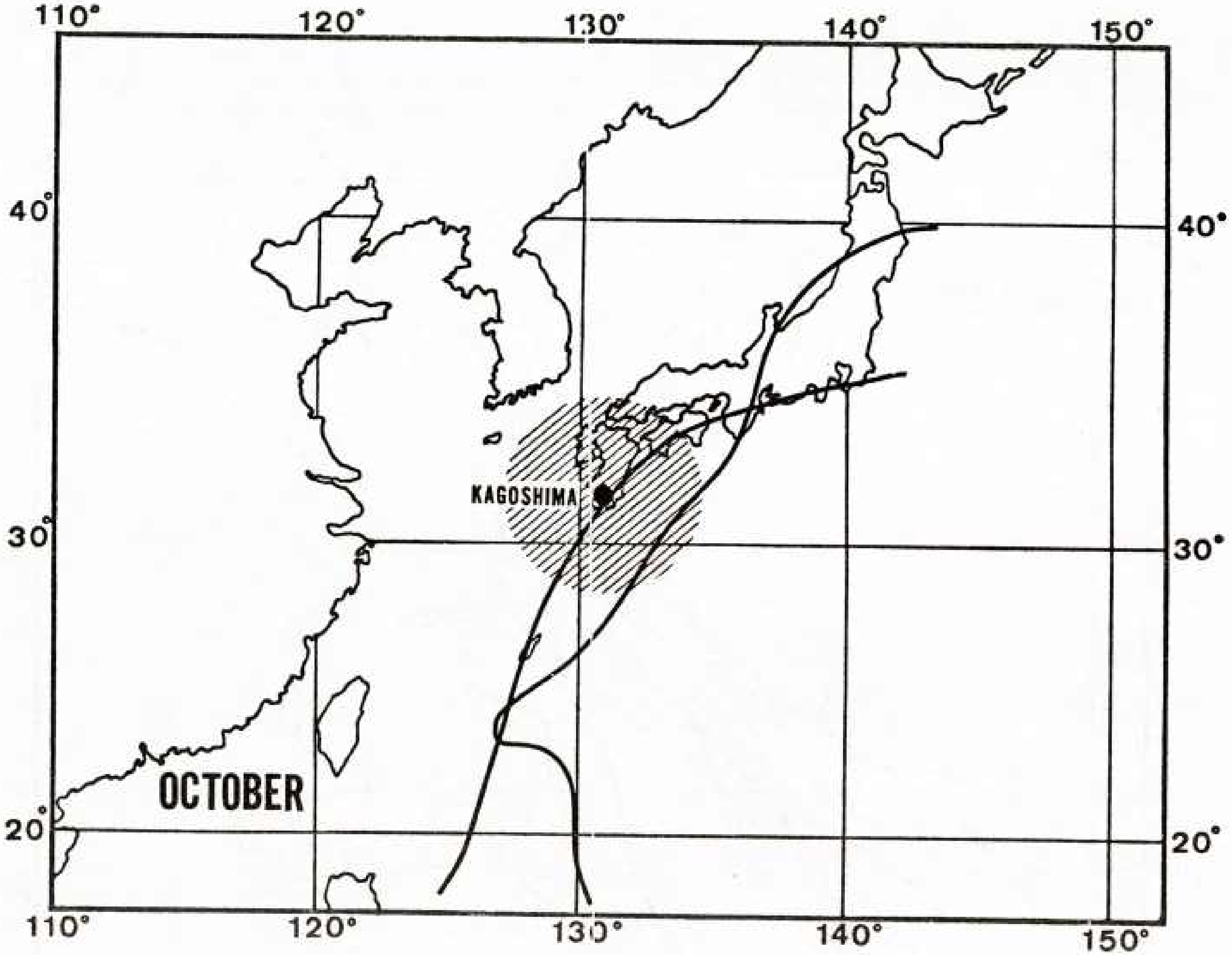

Figure 43. Tracks of tropical cyclones approaching within 180 n mi of Kagoshima during the 19-year period 1956-1974 for October. Solid lines indicate tracks of tropical cyclones that produced winds $\geq$ 34 kt at Kagoshima. Dashed lines indicate tropical cyclones passing within 180 n mi of Kagoshima but not producing winds $\geq$ 34 kt at Kagoshima.

striking Kyushu. From Figures 29 and 30 it is evident that the protection offered by surrounding topography is of little assistance in decreasing the intensity of the storm as it makes its first encounter with land. The long broad expanse of Kagoshima Bay allows practically uninterrupted flow from the southeastern quadrant. These factors, in addition to the bay being placed in the "dangerous" semicircle, as described in Section 2.1.5, makes a western passage extremely dangerous. An example of this case was Typhoon Babs which had a CPA of 150 n mi to the west-northwest of Kagoshima on 16 August 1956. Typhoon Babs produced wind gusts of up to 72 kt from the south-southeast.

Figures 44 through 46 show the average maximum wind gust associated with the tropical cyclones studied, and the direction from which it originated as recorded at Kagoshima during the period 1947-1974. An evaluation of these figures show that winds from tropical cyclones passing to the west come primarily from the southeasterly direction and tend to be more intense than those from tracks of storms passing to the east. In those cases, the winds may come from any direction but for the most part come from the northeast or northwest. Occasionally, a tropical cyclone will pass in the immediate vicinity of Kagoshima. In the period 1947-1974, ten such storms tracked in such a manner with all but one producing gale force winds or stronger. Under such circumstances, there is no discernible pattern as to prevailing direction from which the strongest winds originate. The proximity of the storm's center when passing in the immediate vicinity, however, is indicative of force. Of the 10 tropical cyclones studied, the average maximum wind gust was 58 kt.

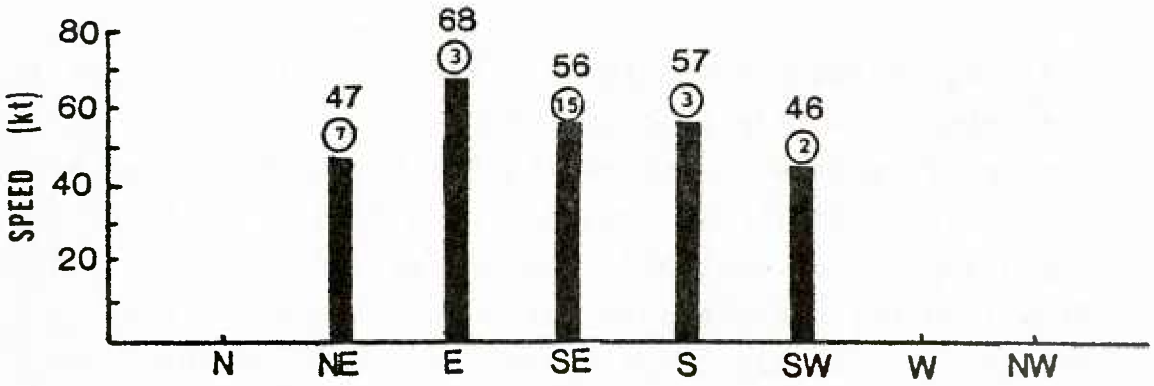

Figure 44. Average maximum wind gust and direction of winds originating from tropical cyclones passing within 180 n mi to the west of Kagoshima. (Numbers circled indicate total number of tropical cyclones producing winds from the direction indicated.)

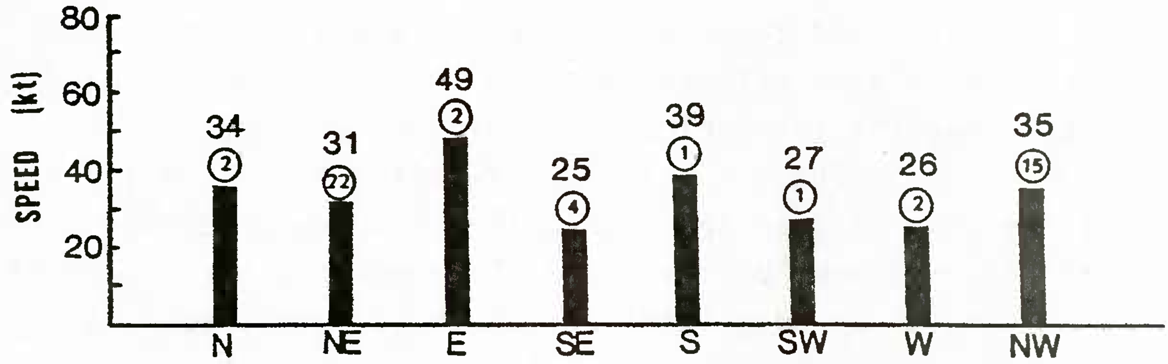

Figure 45. Average maximum wind gust and direction of winds originating from tropical cyclones passing within 180 n mi to the east of Kagoshima.

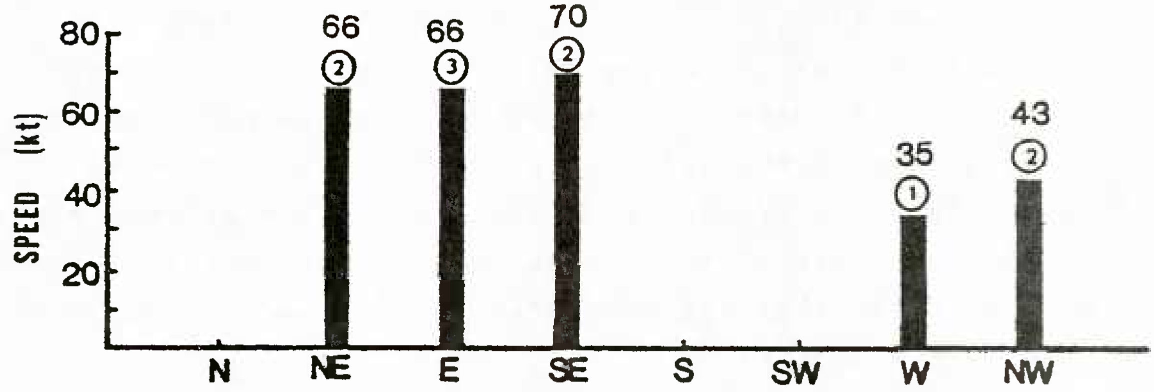

Figure 46. Average maximum wind gust and direction of winds originating from tropical cyclones passing in the immediate vicinity (within 20 n mi) of Kagoshima.

Figure 47 shows the position of "threat" tropical cyclone centers when strong winds ($\geq$ 22 kt) were first and last recorded at Kagoshima. A number of storms gave Kagoshima $\geq$ 22 kt winds when they were 300 n mi to the south of the city. Figure 48 shows tropical cyclone center positions when gale force ($\geq$ 34 kt) winds were first and last recorded at Kagoshima. It can be ascertained from this figure that winds $\geq$ 34 kt generally do not begin until the storm is about 180 n mi away. Notice the preponderance of storms that generate strong or gale force winds originate to the south and west of Kagoshima and that no gale force winds occurred when the storms moved north of 34°N.

The most severe threat to the harbor occurs when a tropical cyclone approaches from the southwest and passes west of Kagoshima within 50 n mi. In this case, winds will flow from the southeast unimpeded the entire length of Kagoshima Bay focusing on the narrow harbor area.

10.3 WAVE ACTION

The geographical location of Kagoshima Harbor is such that regardless of whether a tropical cyclone passes east or west of the port, ships anchored in the outer harbor area will experience considerable wave action. Tropical cyclones passing to the east will generate winds from the northeastern quadrant. In this area there is an unbroken fetch of 12 n mi in the northern portion of Kagoshima Bay. In a similar manner, the fetch to the south-southeast of the harbor is approximately 28 n mi over which winds generated by a tropical cyclone passing to the west can flow unimpeded.

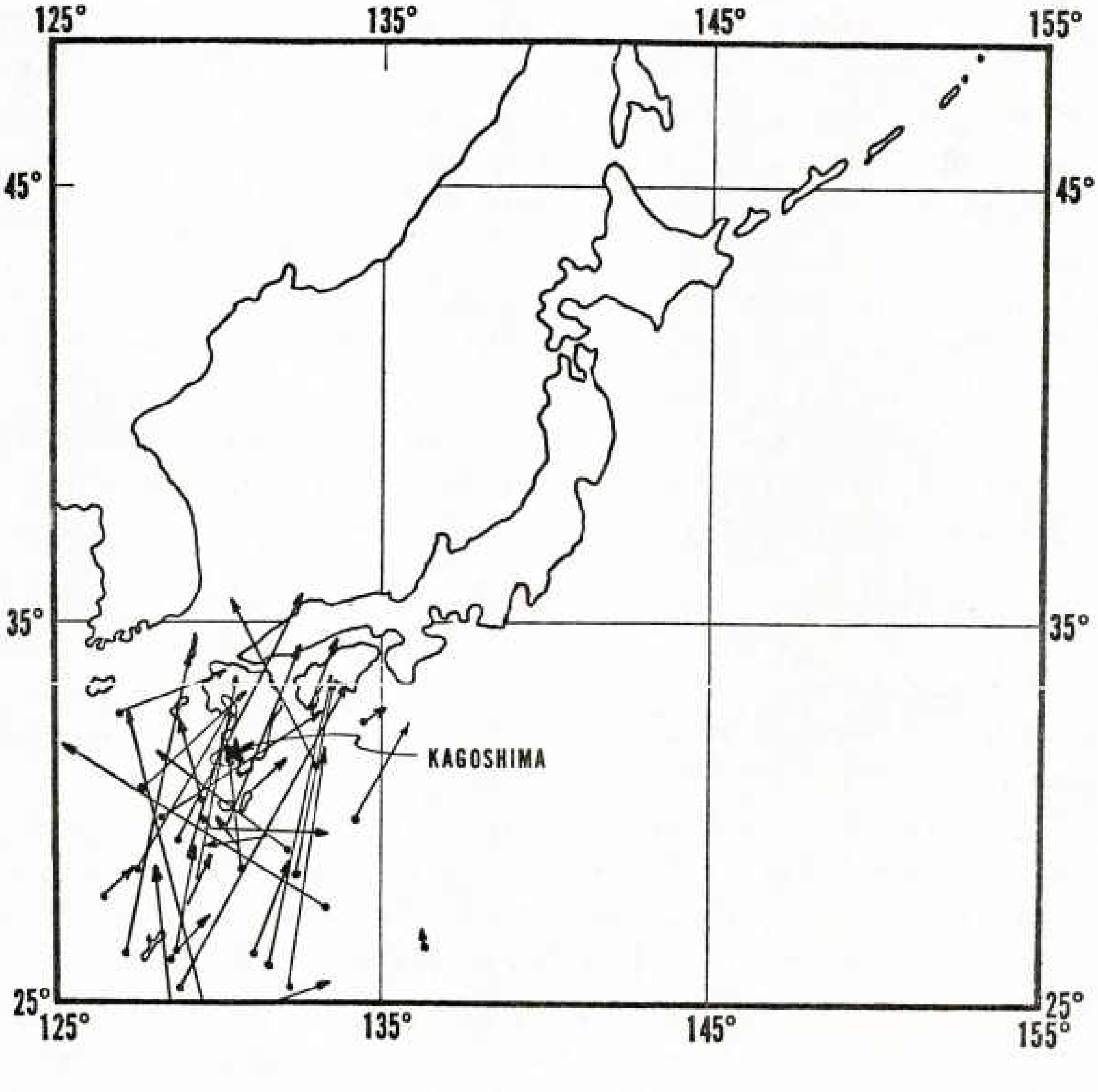

Figure 47. Positions of 43 tropical cyclone centers when winds ≥ 22 kt first and last occurred at Kagoshima (based on hourly data for the months June-October during the years 1956-1974).

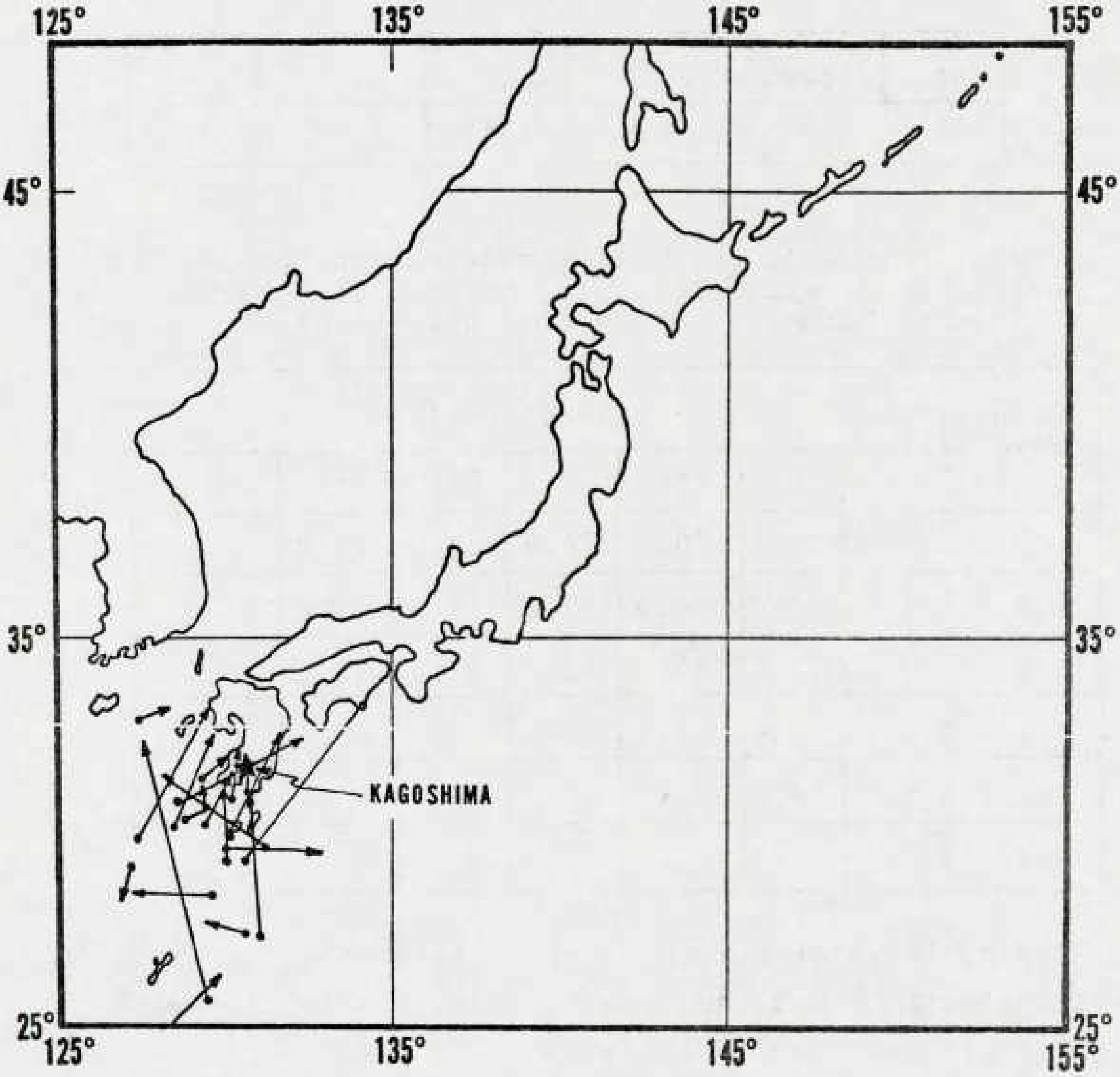

Figure 48. Positions of 21 tropical cyclone centers when winds ≥ 34 kt first and last occurred at Kagoshima (based on hourly wind data for the months June-October during the years 1956-1974).

Table 10 shows the wind speed required to generate various wave heights in Kagoshima Harbor based on the direction and length of fetch that the wind blows over.[12]

Table 10a. Fetch limits (n mi by direction from Kagoshima Harbor (Honkoh Harbor area).

NE	ENE	E	ESE	SE	SSE
12	3	1.8	1.5	10.2	28.2

Table 10b. Wind speed (kt) required to obtain indicated wave heights (m) at Kagoshima Harbor (Honkoh Harbor area) by wind direction.

Resultant Wave Height (m)	WIND DIRECTION					
	NE	ENE	E	ESE	SE	SSE
0 - 0.5	12.6	20.0	24.0	26.0	13.0	10.0
0.6 - 1.0	22.2	36.0	23.6	46.8	23.0	17.0
1.1 - 1.5	31.6	50.0	60.0	64.0	32.6	24.0
1.6 - 2.0	40.6	64.0	-	-	42.0	30.6
2.1 - 3.0	56.0	-	-	-	58.0	42.0
3.1 - 5.0	-	-	-	-	-	-

During the same period of study that produced Table 10, additional data shows the frequency distribution of wave height as can be seen in Table 11.

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[12] From a 10-year study of wind effects on Kagoshima Harbor (1960-1969) prepared by the Japanese Meteorological Agency for the Kagoshima Prefecture government. (Note: wave heights are in meters; wind speed in kt; and fetch in n mi.)

Table 11. Frequency of wave height occurences at Kagoshima Harbor occuring over the 10-year period 1960-1969 (from a Japanese Meteorological Agency study).

WAVE HEIGHT	TOTAL NUMBER	PERCENTAGE
0 - 0.5 M	3015	82.5
0.6 - 1.0	572	15.7
1.1 - 1.5	56	1.5
1.6 - 2.0	7	.2
2.1 - 3.0	3	.1
3.1 - 5.0	1	--
	3654	100.0

It should be noted that these tables reflect weather conditions that occured throughout the entire year for 10 complete years, and included 35 tropical cyclones.

Because of the configuration of the entrance to Kagoshima Bay, swell generated by the storm centers is effectively intercepted. Thus the sea state inside the bay and in the Kagoshima Harbor area is dependent solely on local wind conditions.

10.4 STORM SURGE

Storm surge may be defined as an abnormal rise of the sea along a shore as the result of the winds of a storm and the pressure drop. The piling up of water on a coast ahead of a tropical storm or typhoon is more apparent in the dangerous semicircle, the region of most intense winds. Kagoshima Harbor is in the dangerous semicircle when a tropical cyclone passes to the west of the area. The surge effect is most evident in the shallow waters of large inland bays that open to the south (Miyazaki, 1974).

Conversations with officials of the Kagoshima Harbor Office and Japanese Maritime Safety Agency indicate that the harbor area is not adversely affected by storm surges.

11. EVASION FROM KAGOSHIMA

11.1 EVASION RATIONALE

Because of the threat of high winds associated with tropical cyclones and the extremely poor holding quality of the bottom (sand and shale) in the anchorage, Kagoshima Harbor IS NOT CONSIDERED A SAFE TYPHOON HAVEN. Commanding Officers and Masters of vessels must recognize the inherent dangers that exist when exposed to hazardous weather and remaining at an anchorage which has known poor holding qualities.

(At the Nippon Oil Staging Terminal located at Kiire, all pumping from oil tankers is ceased when sustained winds reach 30 kt. When sustained winds reach gale force intensity, ship's masters are advised to leave the terminal and depart the area, preferably to the open sea.)[13]

Figures 49 through 53 show the tropical cyclone threat axis for Kagoshima from June-October. The area of the arrows represent approximately a 30% or greater probability of a tropical cyclone coming within 180 n mi of Kagoshima.

11.2 EVASION

In the southern part of Japan there are two areas that have been evaluated as typhoon havens--Sasebo in northwestern Kyushu (Rudolph, 1975), and the Kure/Iwakuni area in Hiroshima Bay (Manning, 1975). (Sasebo Harbor is considered an excellent haven but only for vessels smaller than aircraft carriers.)

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[13] Based on a conversation with the port captain at Kiire.

Since transit time, whether it be to another port or to sea, may be lengthy, evasion must commence early. To facilitate early action, the following time table (in conjunction with Figures 49-53) has been constructed.

1. An existing tropical cyclone moves into or development takes place in area "A" with forecast movement toward Kyushu:
    a. Review material condition of ship. Evasion may be desirable 2-4 days hence. Begin planning course of action to be taken in case of increasing threat.
    b. Reconsider any maintenance that would render the ship incapable of getting underway within 48 hours.
2. Tropical cyclone enters area "B" with forecast movement toward Kagoshima:
    a. Execute evasion plans made in previous steps. Evasion should be completed before storm enters area "C". If evasion is to be made to Sasebo, approximately one-half day's steaming time, the commanding officer may elect to delay execution of evasion plans accordingly.
3. Tropical cyclone enters area "C" moving toward Kagoshima:
    a. If evasion was not accomplished by this time, evasion from Kagoshima Bay is no longer recommended. If the decision to remain at anchor is made, ensure sufficient power is made available to counter high winds and seas by steaming to the anchor (see Appendix C).

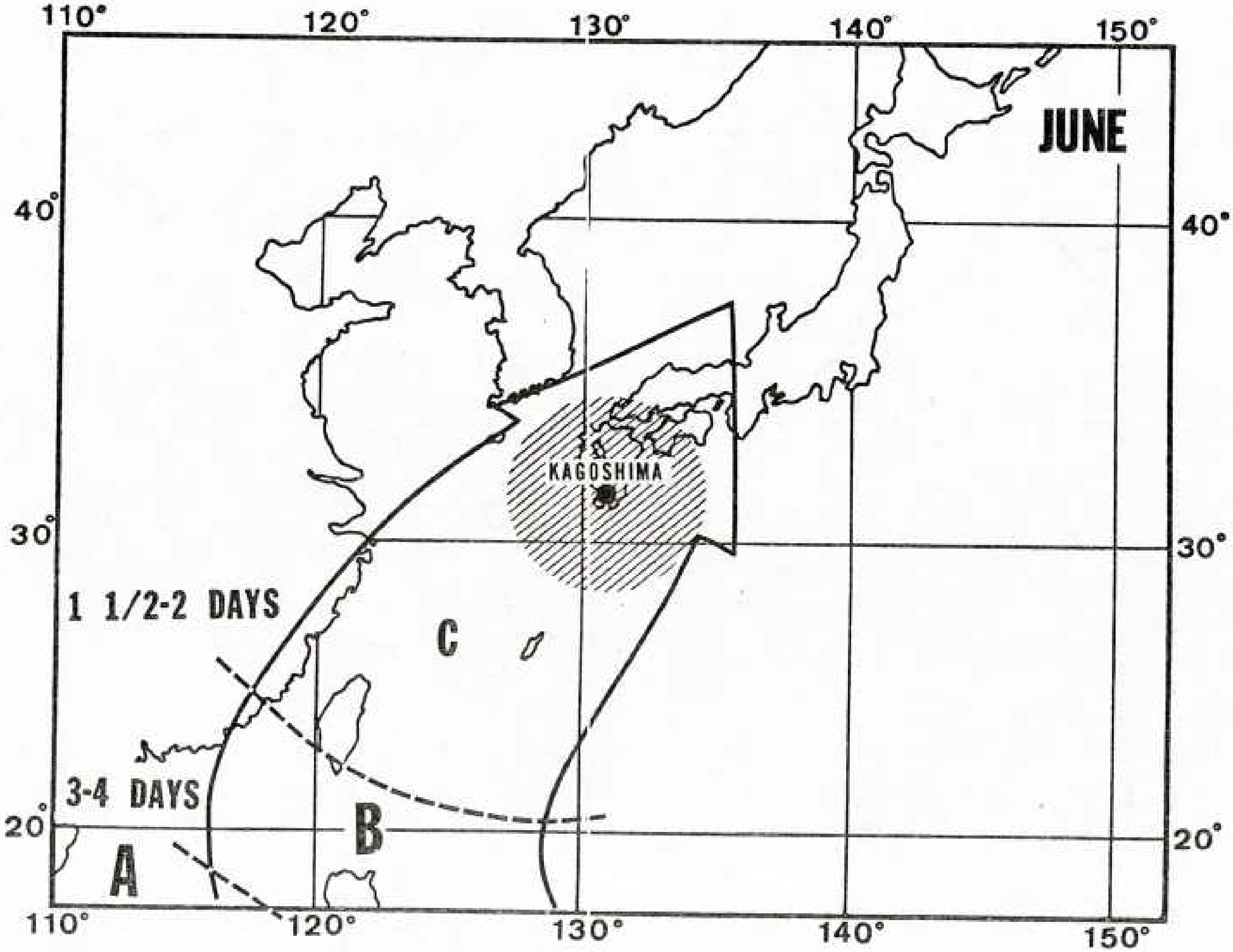

Figure 49. Tropical cyclone threat axis for Kagoshima for the month of June. Approach times to Kagoshima are based on typical speeds of movement for tropical cyclones affecting Kagoshima.

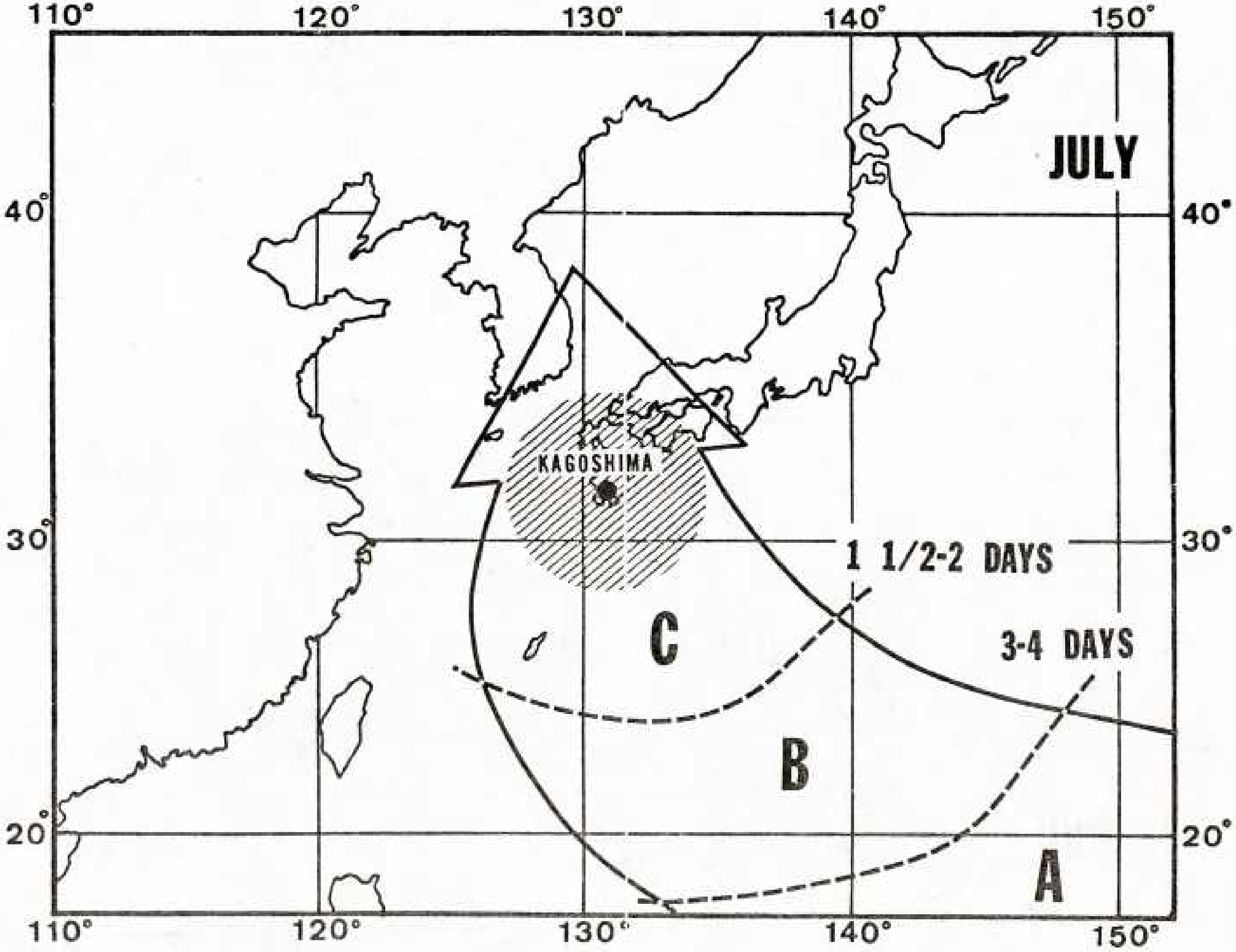

Figure 50. Tropical cyclone threat axis for Kagoshima for the month of July. Approach times to Kagoshima are based on typical speeds of movement for tropical cyclones affecting Kagoshima.

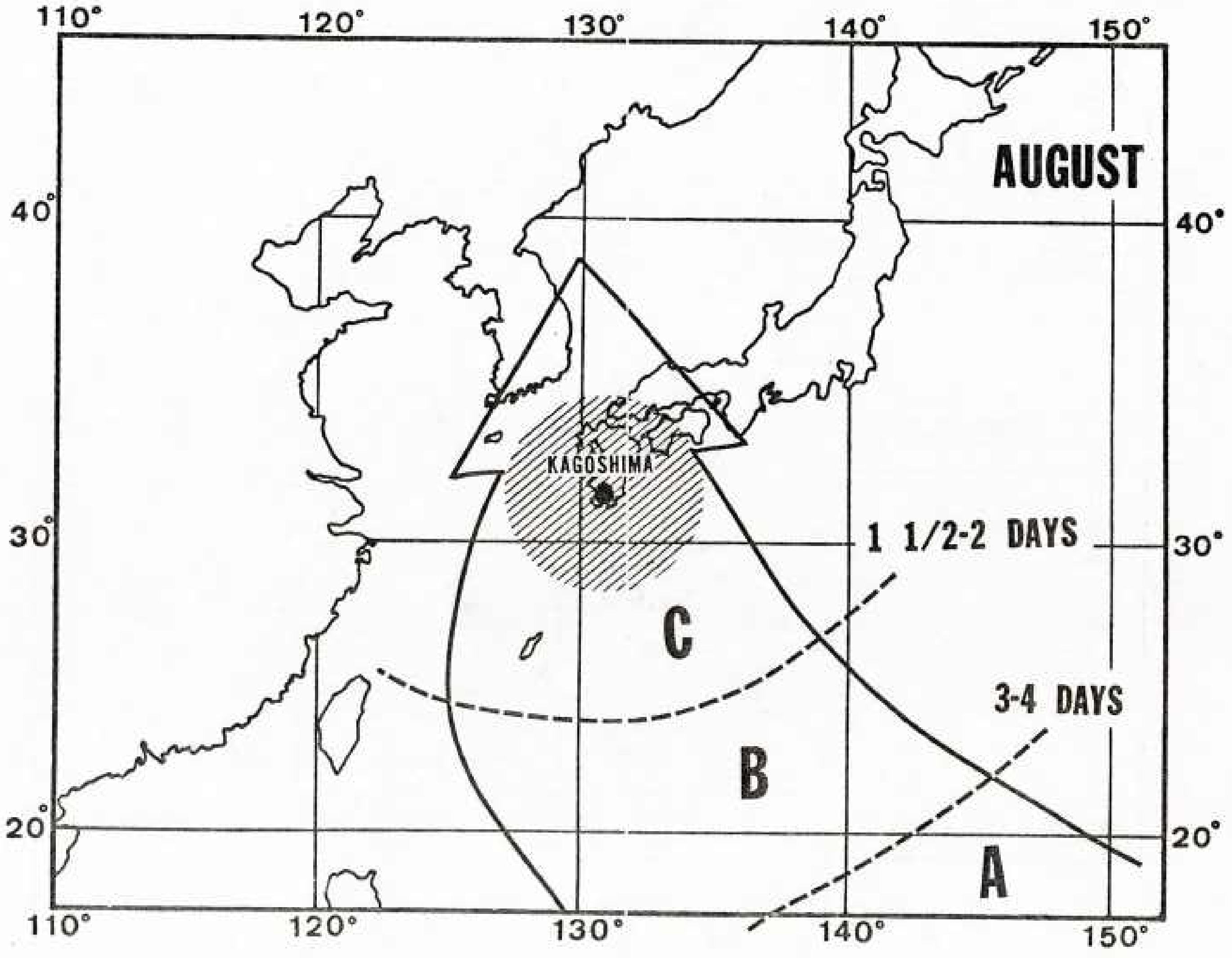

Figure 51. Tropical cyclone threat axis for Kagoshima for the month of August. Approach times to Kagoshima are based on typical speeds of movement for tropical cyclones affecting Kagoshima.

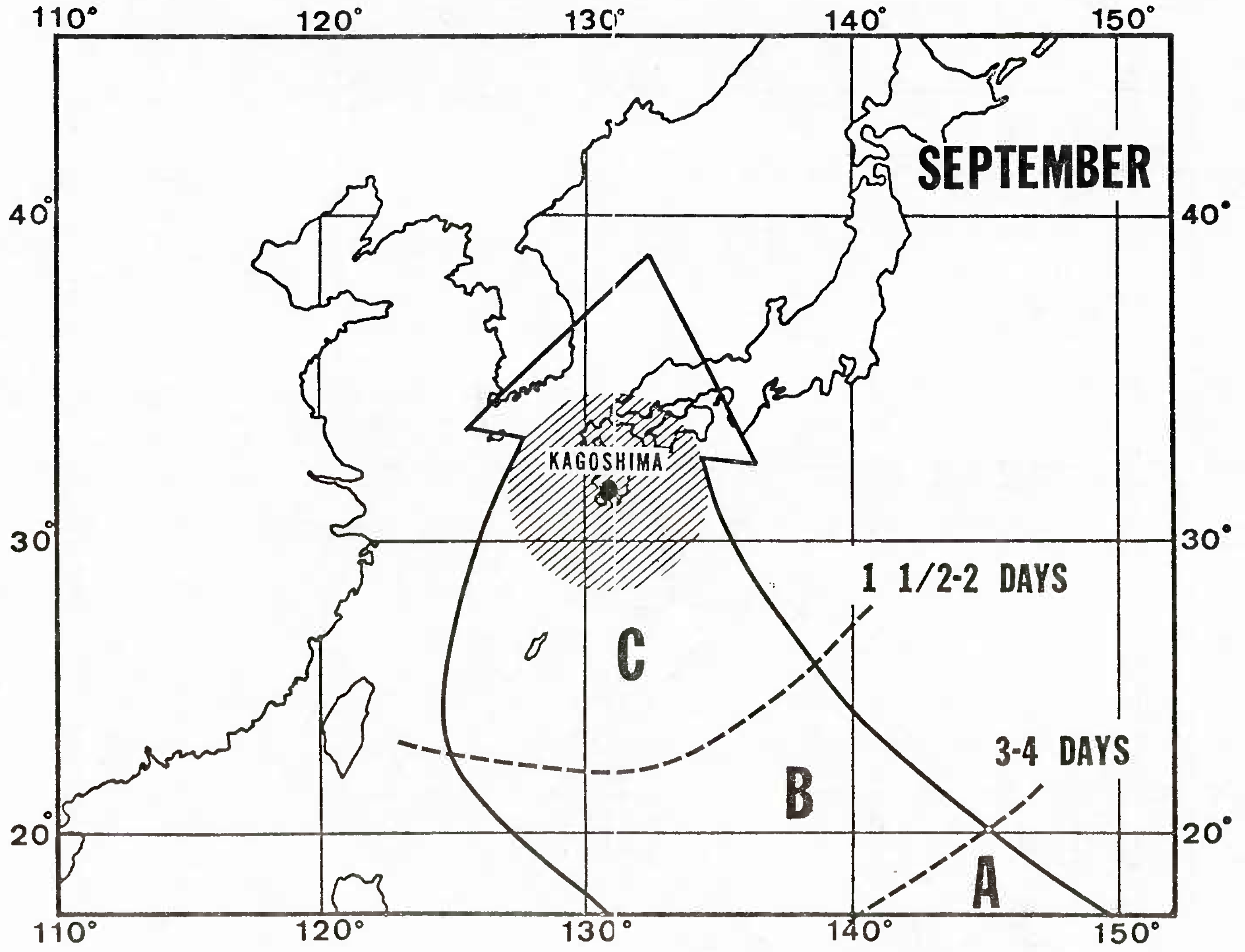

Figure 52. Tropical cyclone threat axis for Kagoshima for the month of September. Approach times to Kagoshima are based on typical speeds of movement for tropical cyclones affecting Kagoshima.

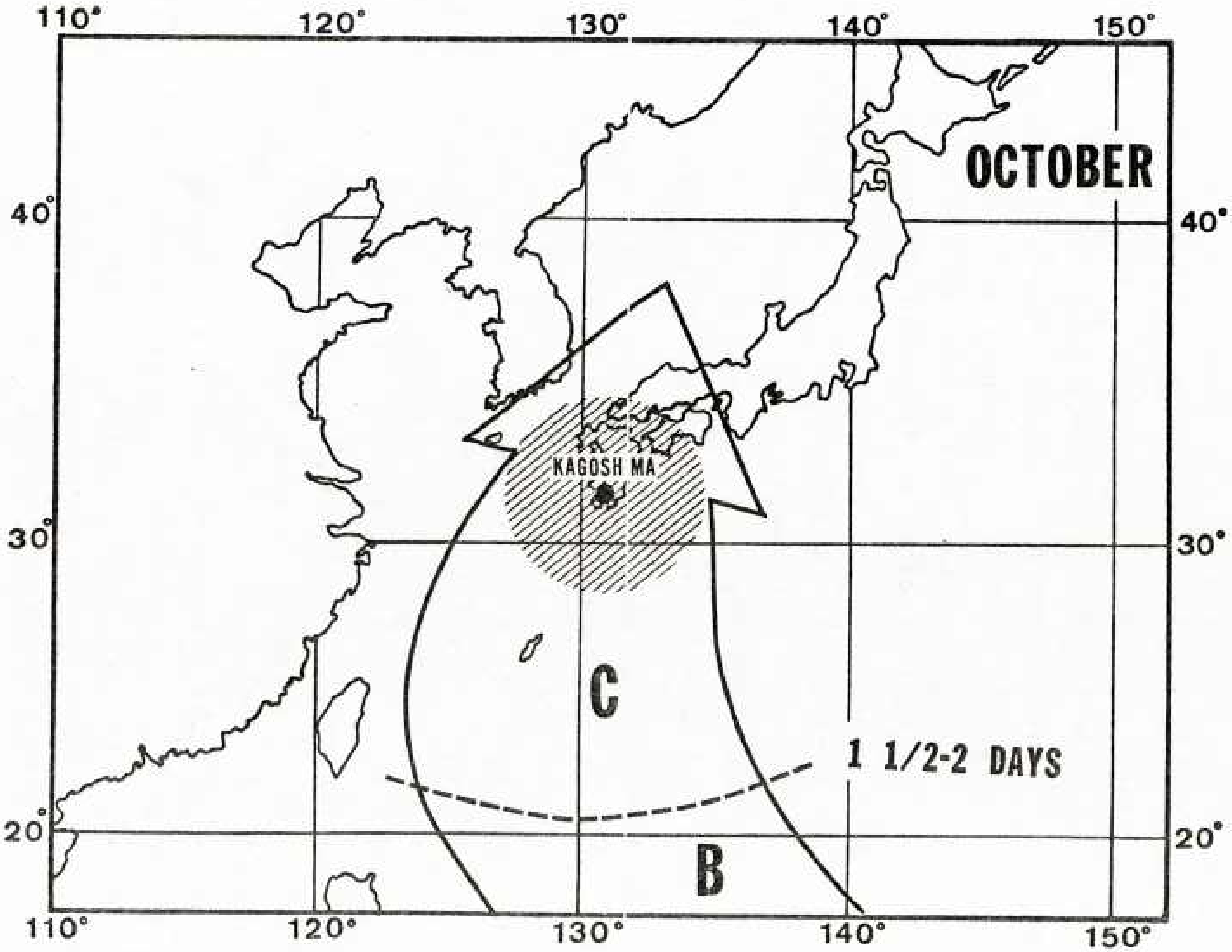

Figure 53. Tropical cyclone threat axis for Kagoshima for the month of October. Approach times to Kagoshima are based on typical speeds of movement for tropical cyclones affecting Kagoshima.

b. Another course of action would be to get way on the ship, and place the ship's head into the wind and sea (see Appendix C). Since Kagoshima Bay is large, and with few exceptions deep, the ship can be placed in various locations in the bay to reduce the fetch and thereby reduce the effects of wave action. Movement into the southwestern part of the bay would tend to offset the effects of southeasterly winds. It is not recommended that a ship be placed in the northern regions of Kagoshima Bay, north of Sakurajima, due to the restrictive nature of the area and the shallow water in the middle of this region. (It should be noted that of all the tropical cyclones studied, the longest duration of gale force winds at Kagoshima was 5 hours.)

Evasion routes at sea may be developed by the use of the warnings received from FWC/JTWC and Appendix A (the mean tropical cyclone tracks, track limits, and average speed of movements for the months June-October) in conjunction with Figures 49-53 (tropical cyclone threat axis and approach times to Kagoshima for the months June-October). In all cases, Optimum Track Ship Routing (OTSR) should be consulted as to the best evasion route. Ships whose ultimate destination is the eastern Pacific may want to consider evading to Yokosuka in south central Honshu (Graff, 1975).

In general, the effects of sea/swell generated by a tropical cyclone may reduce the speed of advance (SOA) thereby increasing the time required to reach the open sea (see Appendix C). If a ship is caught in the sea/swell pattern ahead of an intense tropical storm or typhoon, the SOA may be reduced to the point that the ship will be unable to maneuver to clear the danger area.

There are two basic evasion tactics. The most common among civilian shipping companies is to place the ship south of the tropical cyclone in the navigable semicircle. The other is to proceed north into the Yellow Sea or Sea of Japan.

In the latter case, the cooler surface water and cool air found at higher latitudes cause a weakening and ultimate dissipation of the tropical cyclone. Therefore, a ship should experience less difficulty in riding out a storm at these latitudes than if it steamed south to seek the navigable semicircle and encountered winds in excess of 80 kt enroute.

12. CONCLUSION

The conclusion reached in this study is that Kagoshima Harbor is not a safe harbor during the passage of an intense tropical cyclone. The key factors in reaching this conclusion were:

(1) The harbor provides little shelter from wind and seas due to the size and shape of Kagoshima Bay and surrounding land masses.

(2) Wave action induced by gale force winds can be quite dangerous.

(3) The holding action of the bottom in the harbor area is considered very poor under adverse weather conditions.

(4) The restricted nature of the anchorage itself would give a commanding officer little reaction time in the event the anchor began to drag.

This conclusion is in full agreement with the Kagoshima Harbor authorities and the Japanese Maritime Safety Agency concerning ships that are anchored.

It is recommended that commanding officers and masters of vessels take early evasion action commensurate within operational constraints. For U. S. Navy or contracted DOD vessels, it is recommended that Sasebo or Hiroshima Bay be given priority consideration as typhoon havens. If evasion to sea is more desirable, it is recommended that the ship be placed in the Yellow Sea or Sea of Japan where effects from the typhoon will be considerably lessened.

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APPENDIX A

The mean typhoon tracks, track limits and average speed of movements for the months of June through October are depicted in Figures A-1 to A-13. It must be realized that storms deviate from the mean tracks, but about 80 percent will fall within the track limits. The use of these tracks should be of particular benefit in long range (in excess of 48 hours) planning. The application of average tracks to the short range specific situation should be avoided (U.S. FWF Sangley Point, 1967).

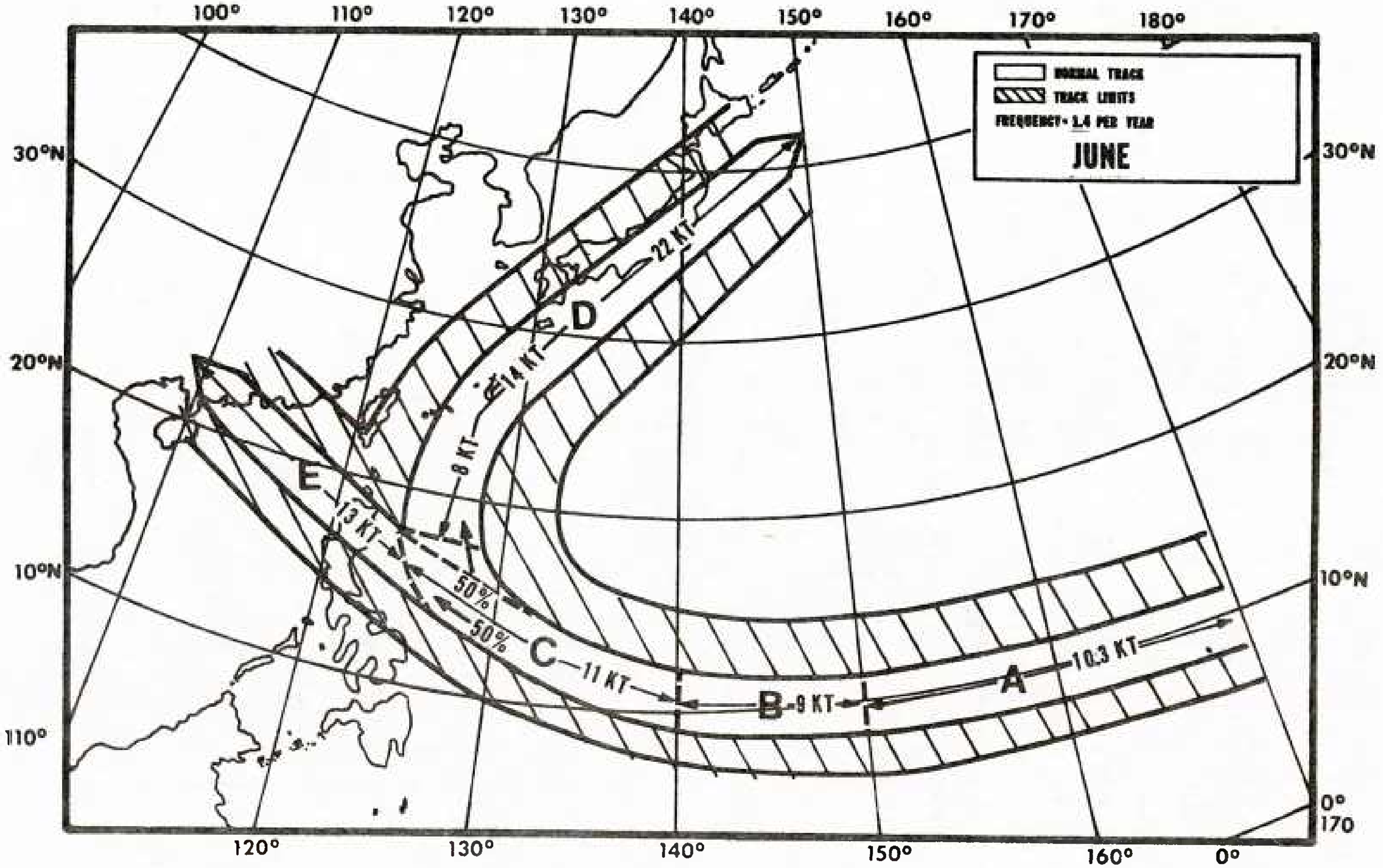


Figure A-1. Mean typhoon tracks for June. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

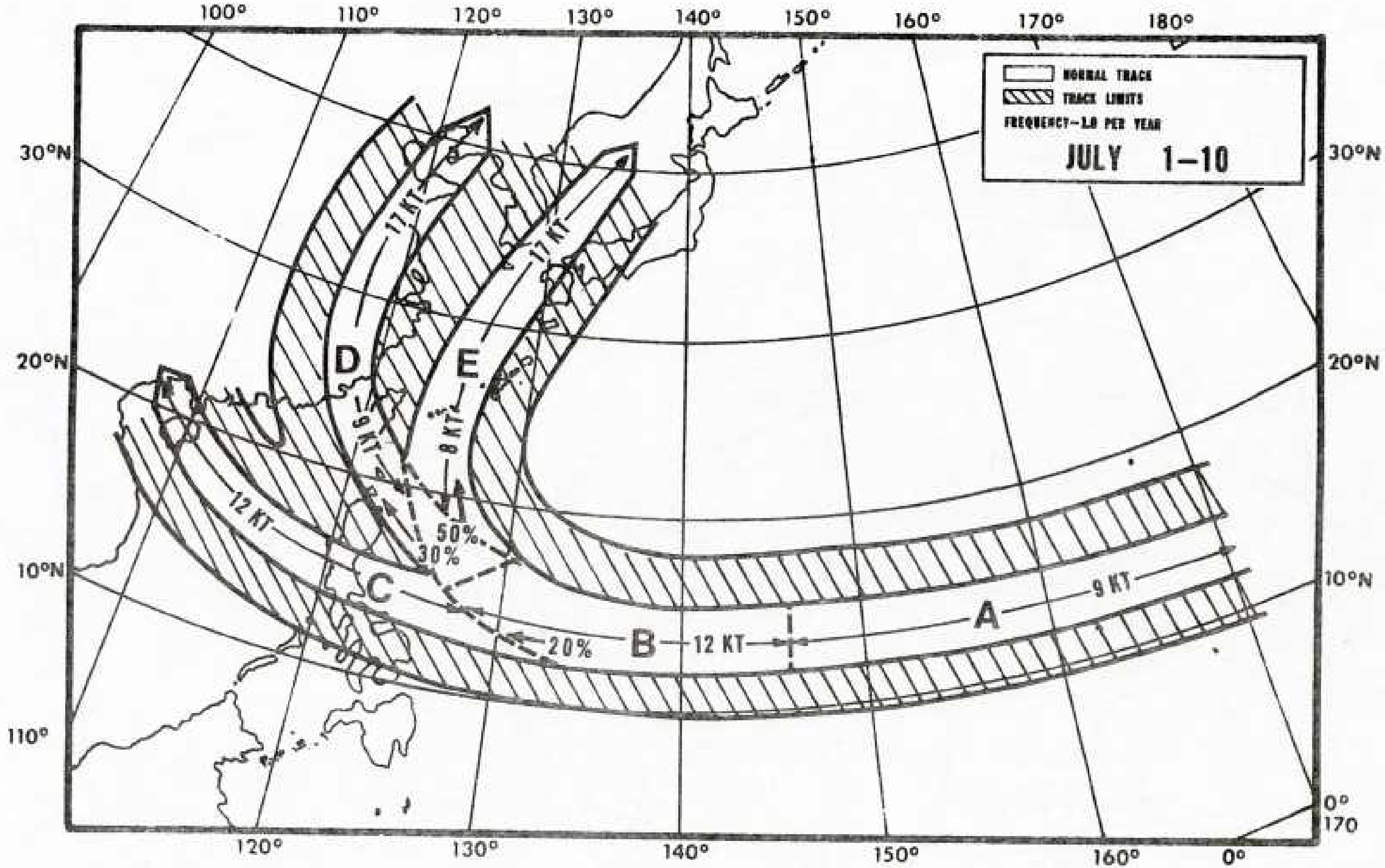


Figure A-2. Mean typhoon tracks for 1-10 July. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

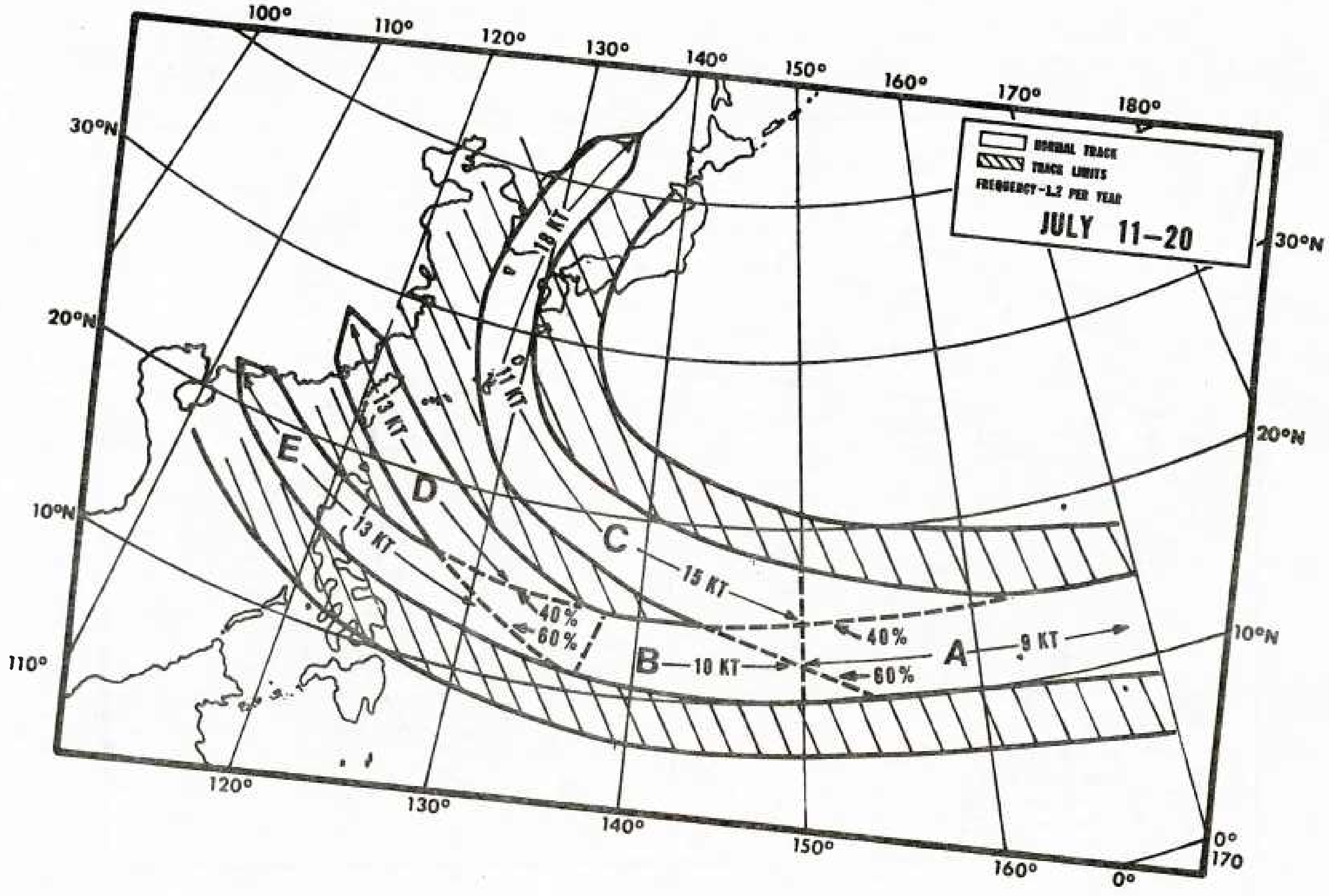


Figure A-3. Mean typhoon tracks for 11-20 July. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

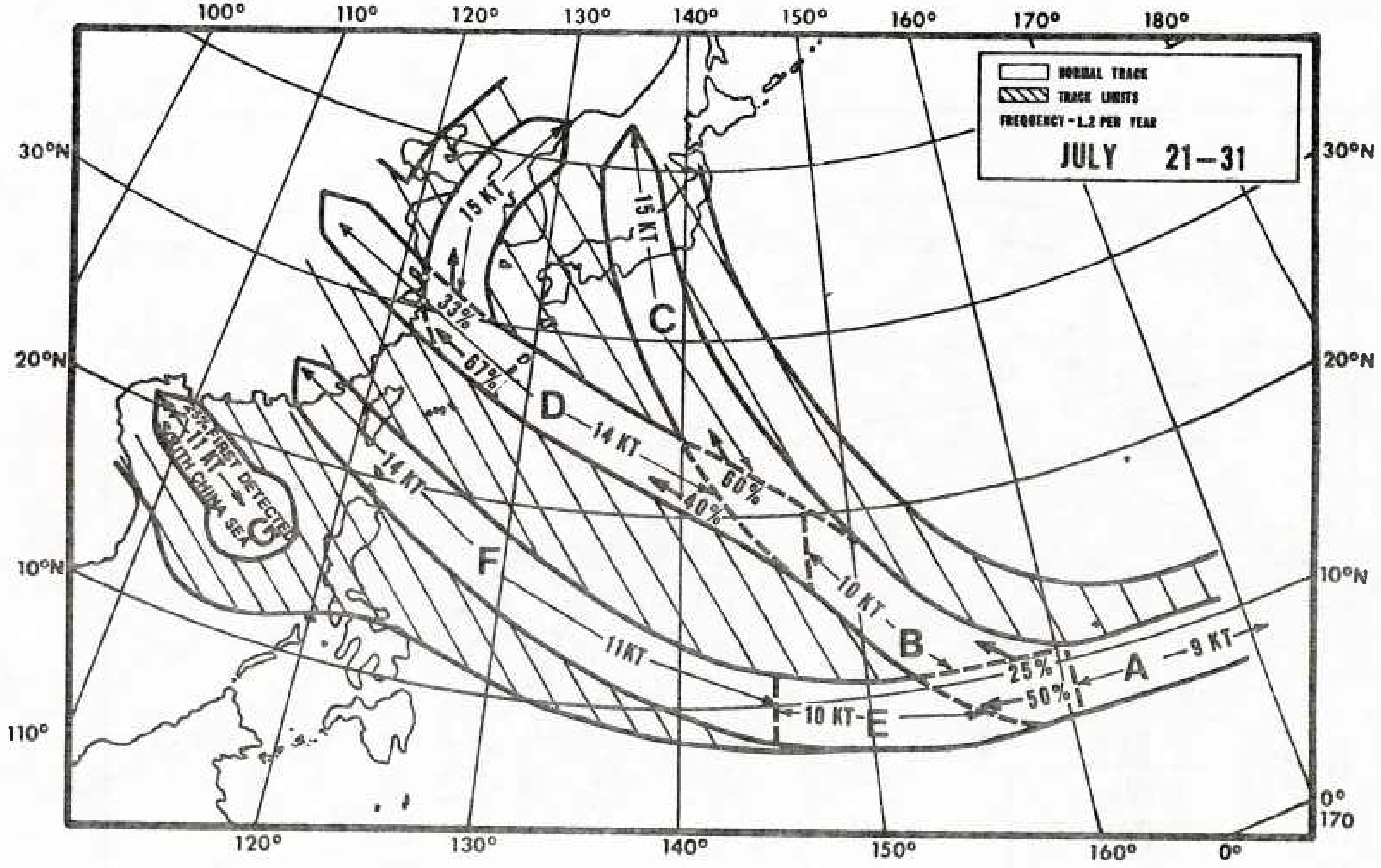


Figure A-4. Mean typhoon tracks for 21-31 July. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

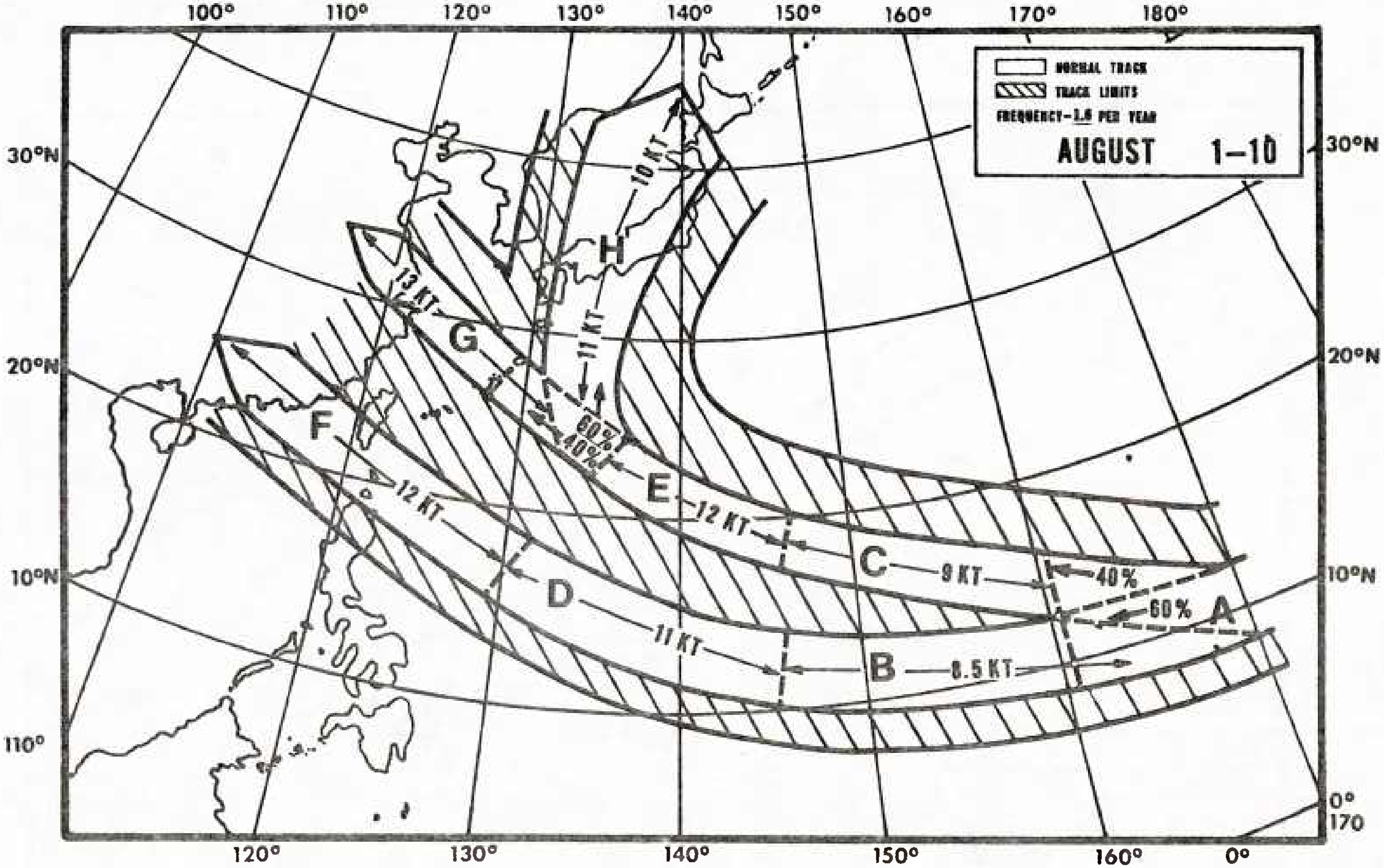


Figure A-5. Mean typhoon tracks for 1-10 August. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

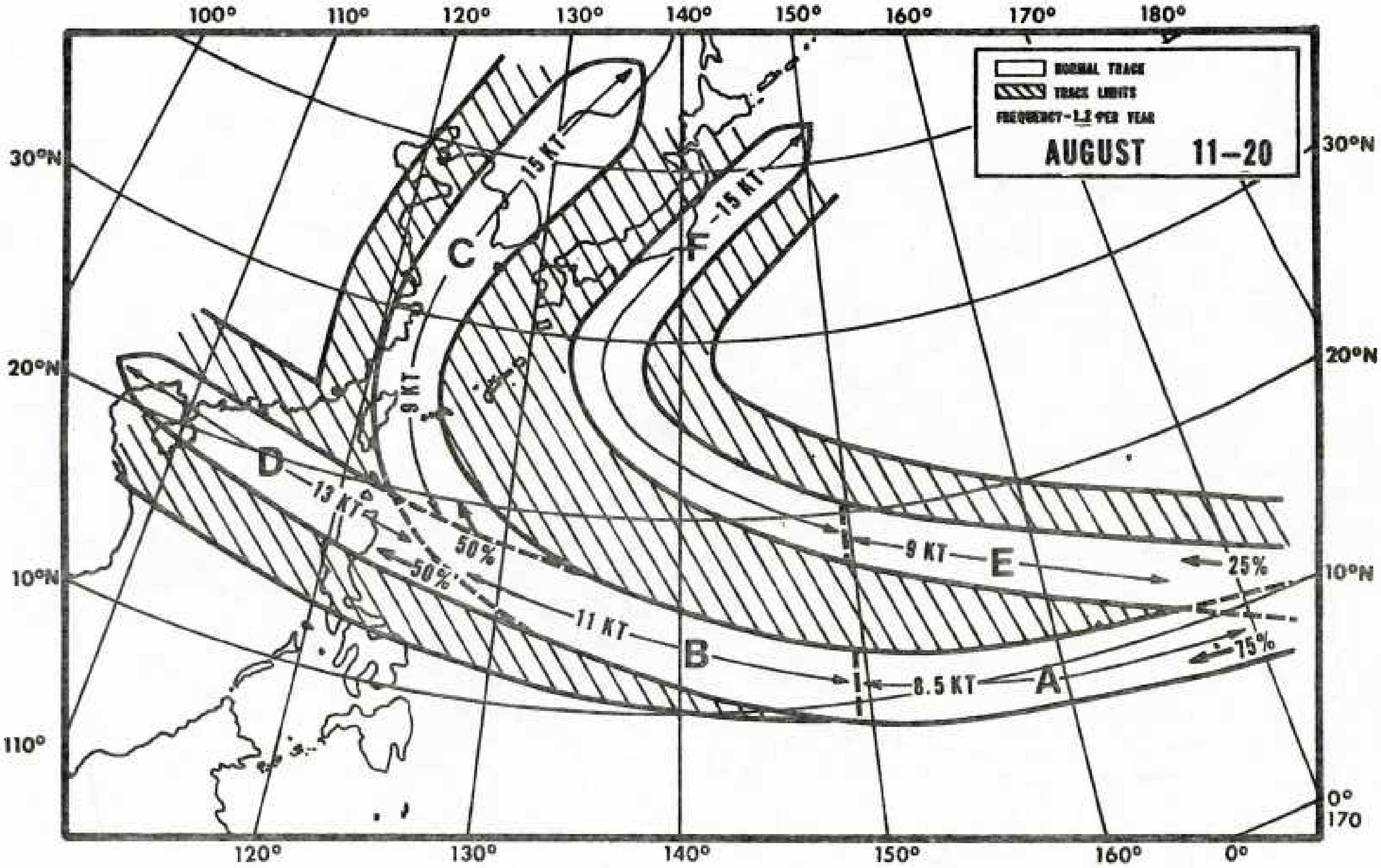


Figure A-6. Mean typhoon tracks for 11-20 August. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

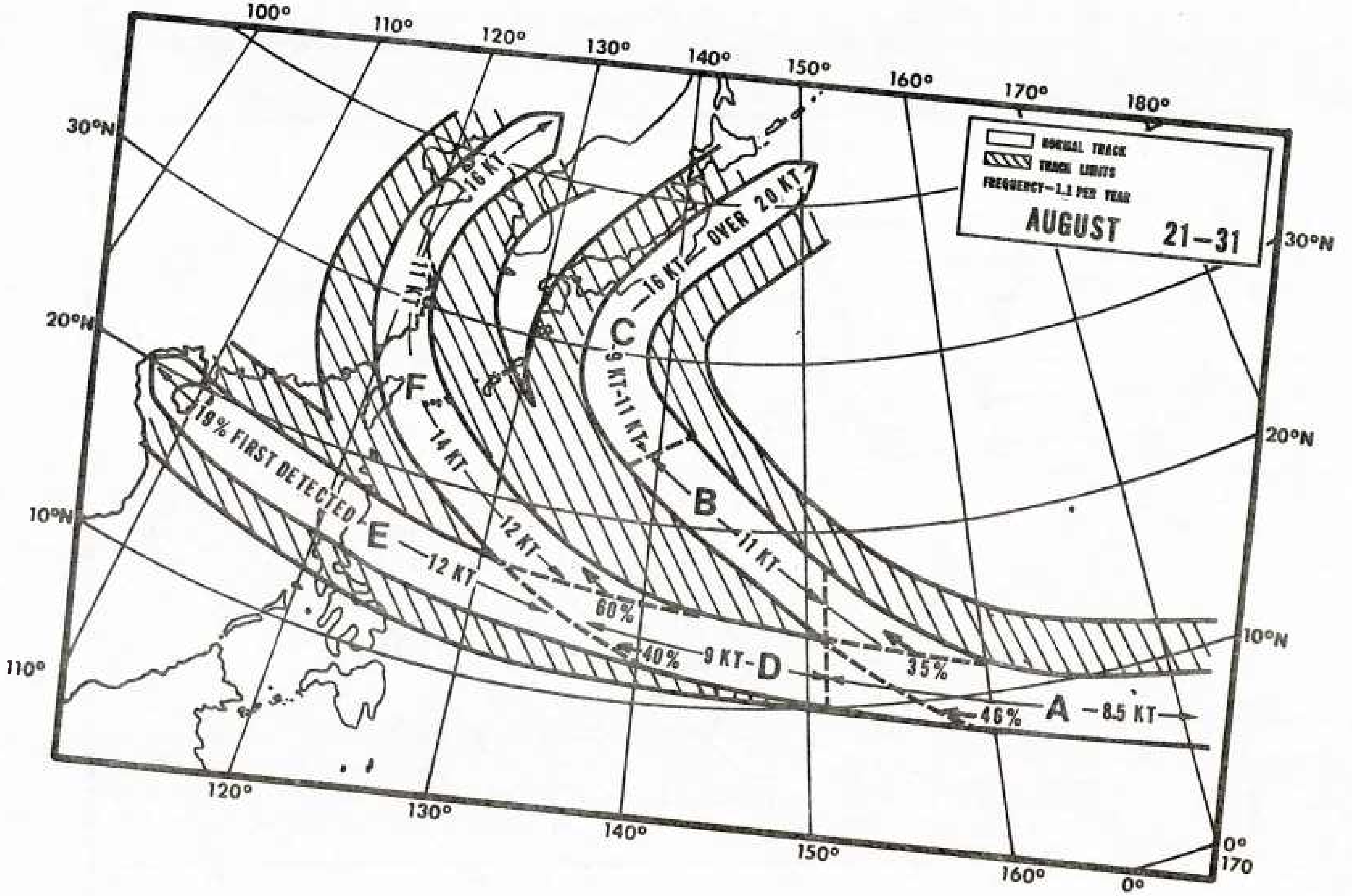


Figure A-7. Mean typhoon tracks for 21-31 August. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

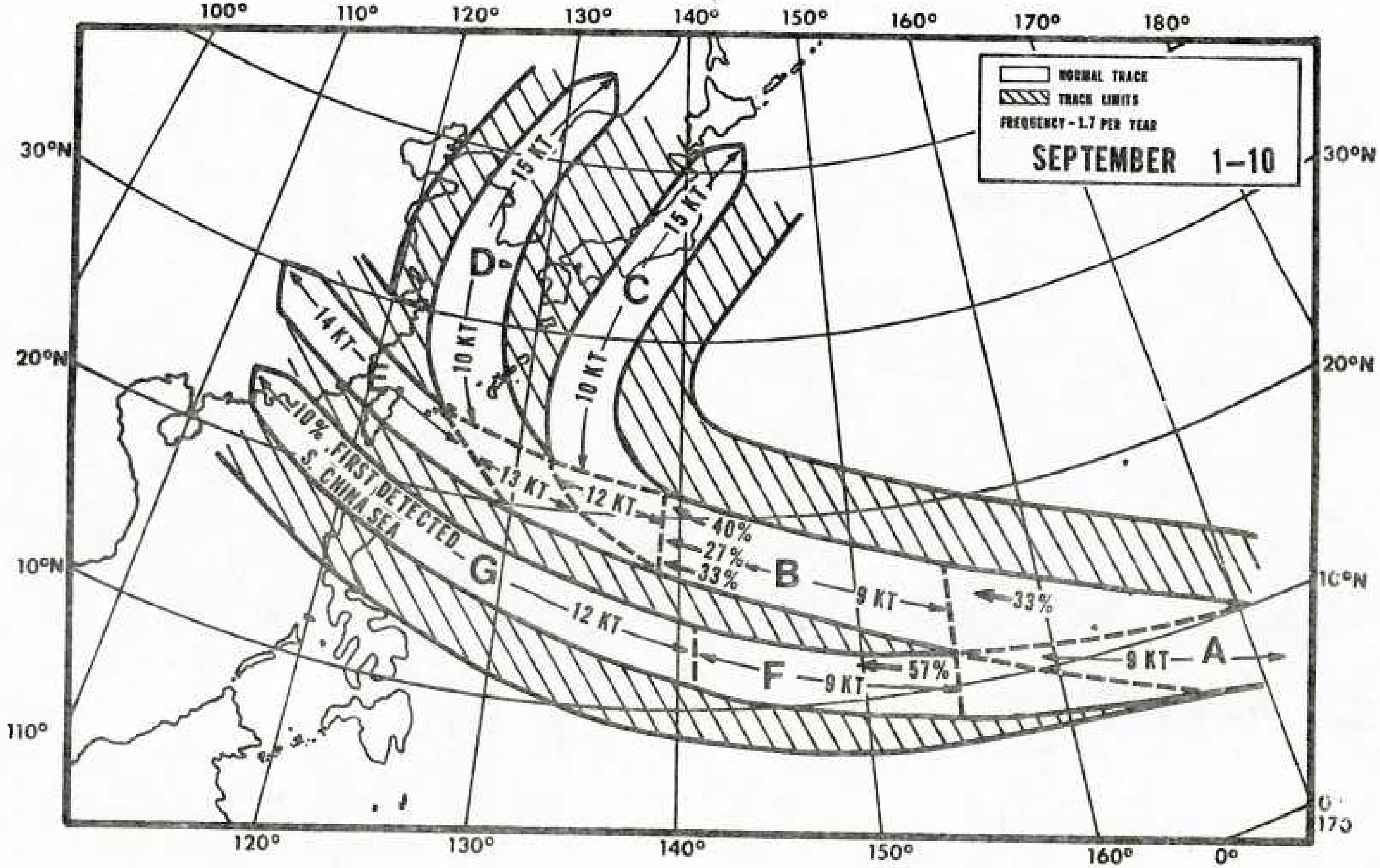


Figure A-8. Mean typhoon tracks for 1-10 September. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

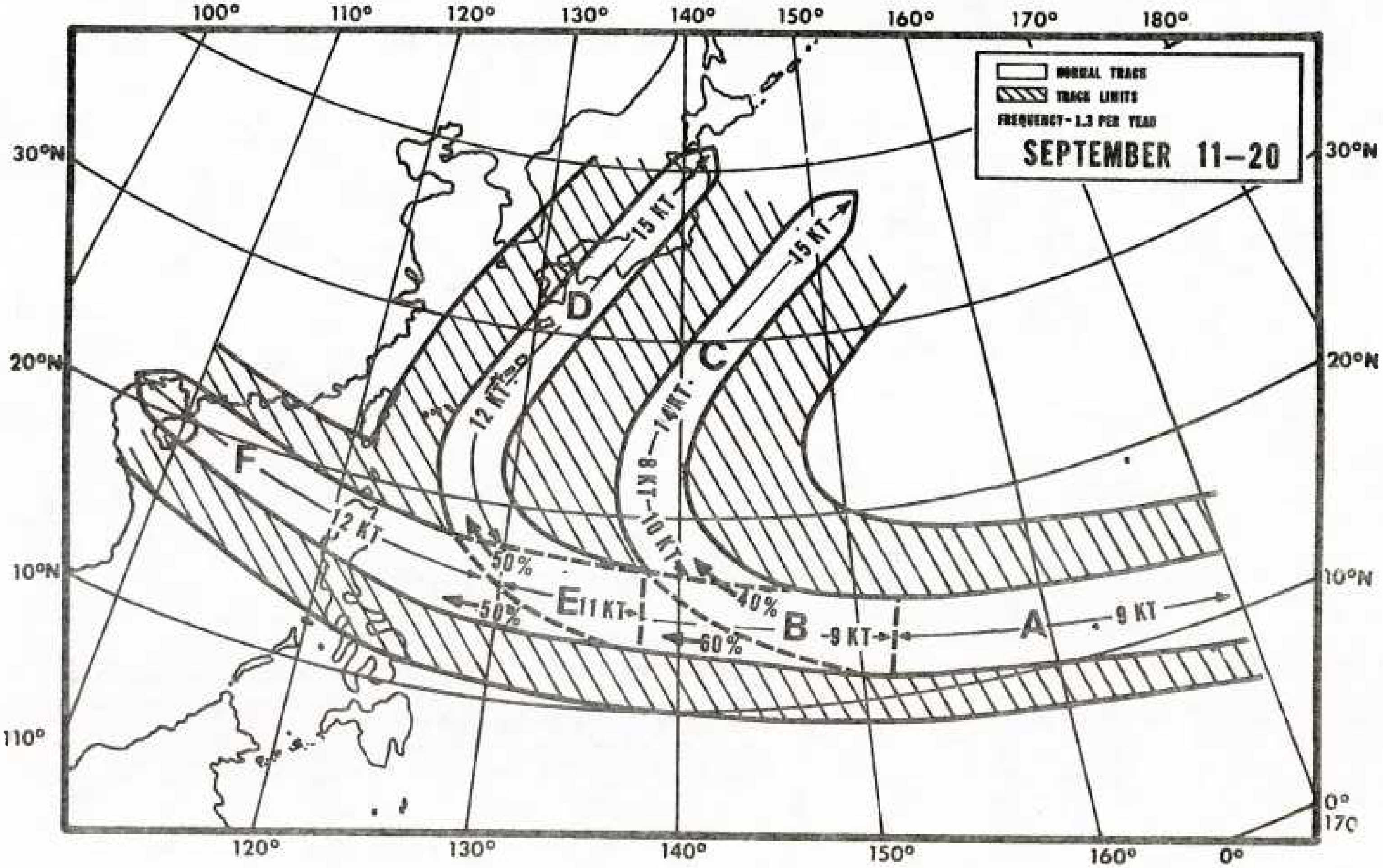


Figure A-9. Mean typhoon tracks for 11-20 September. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

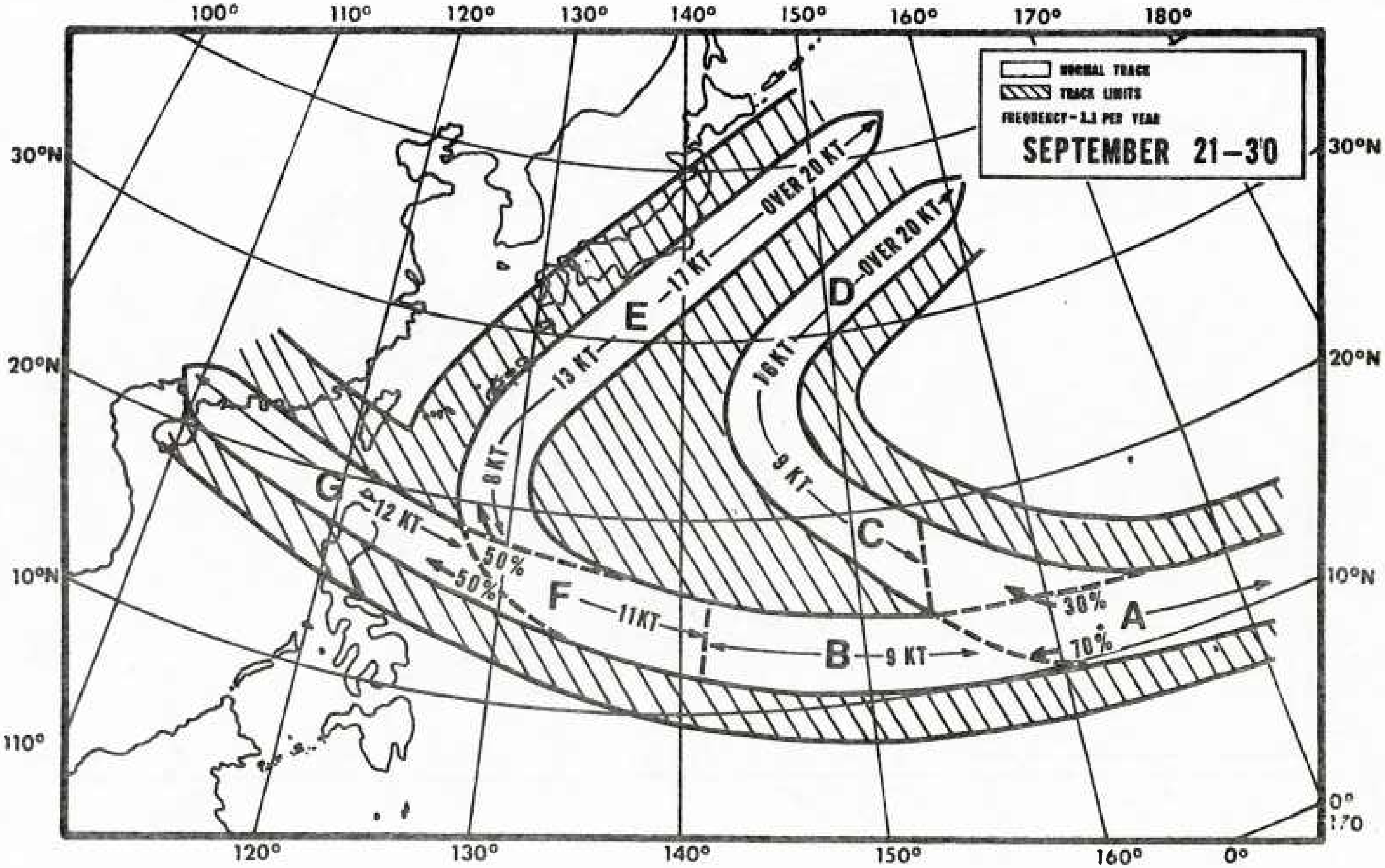


Figure A-10. Mean typhoon tracks for 21-30 September. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

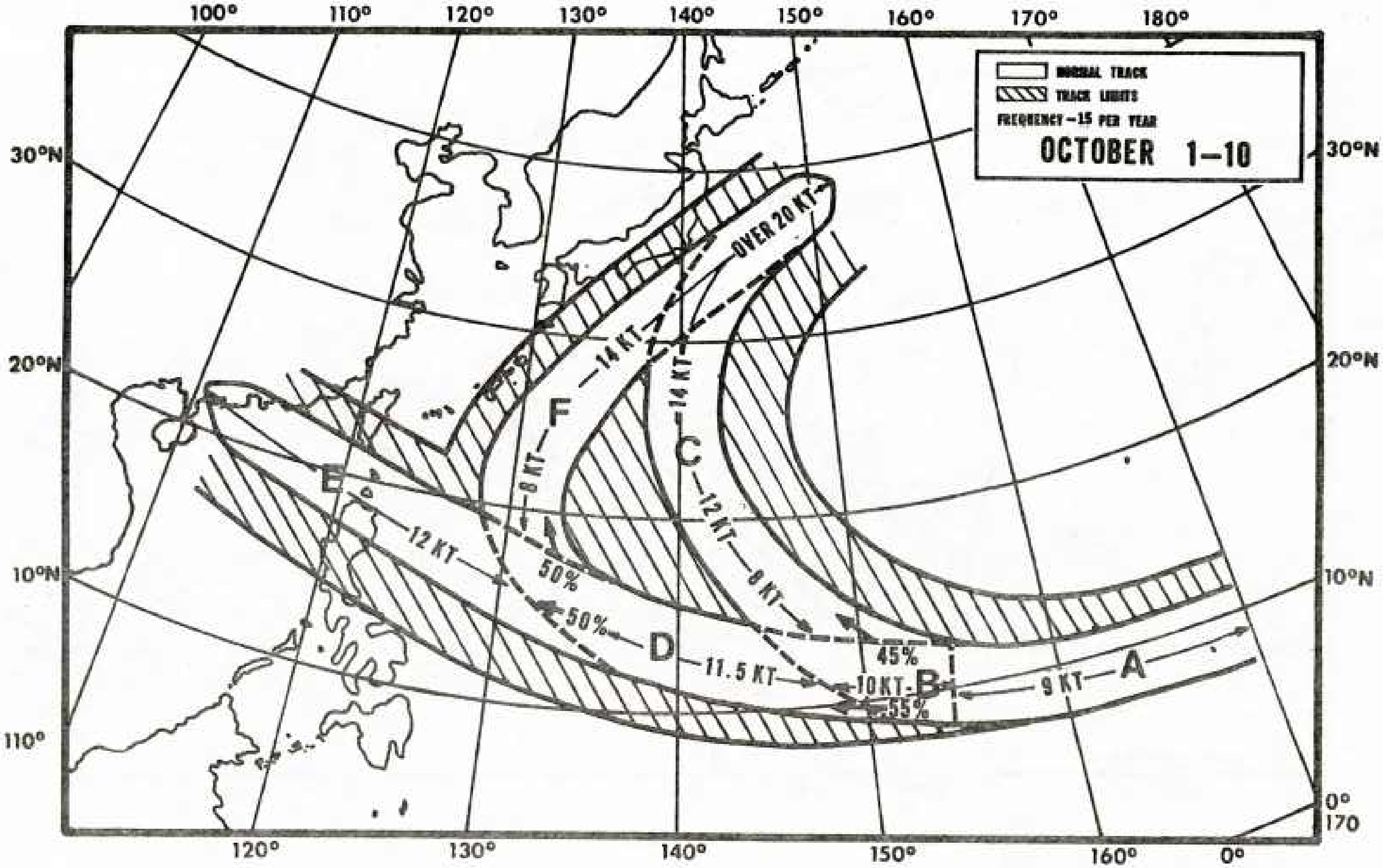


Figure A-11. Mean typhoon tracks for 1-10 October. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

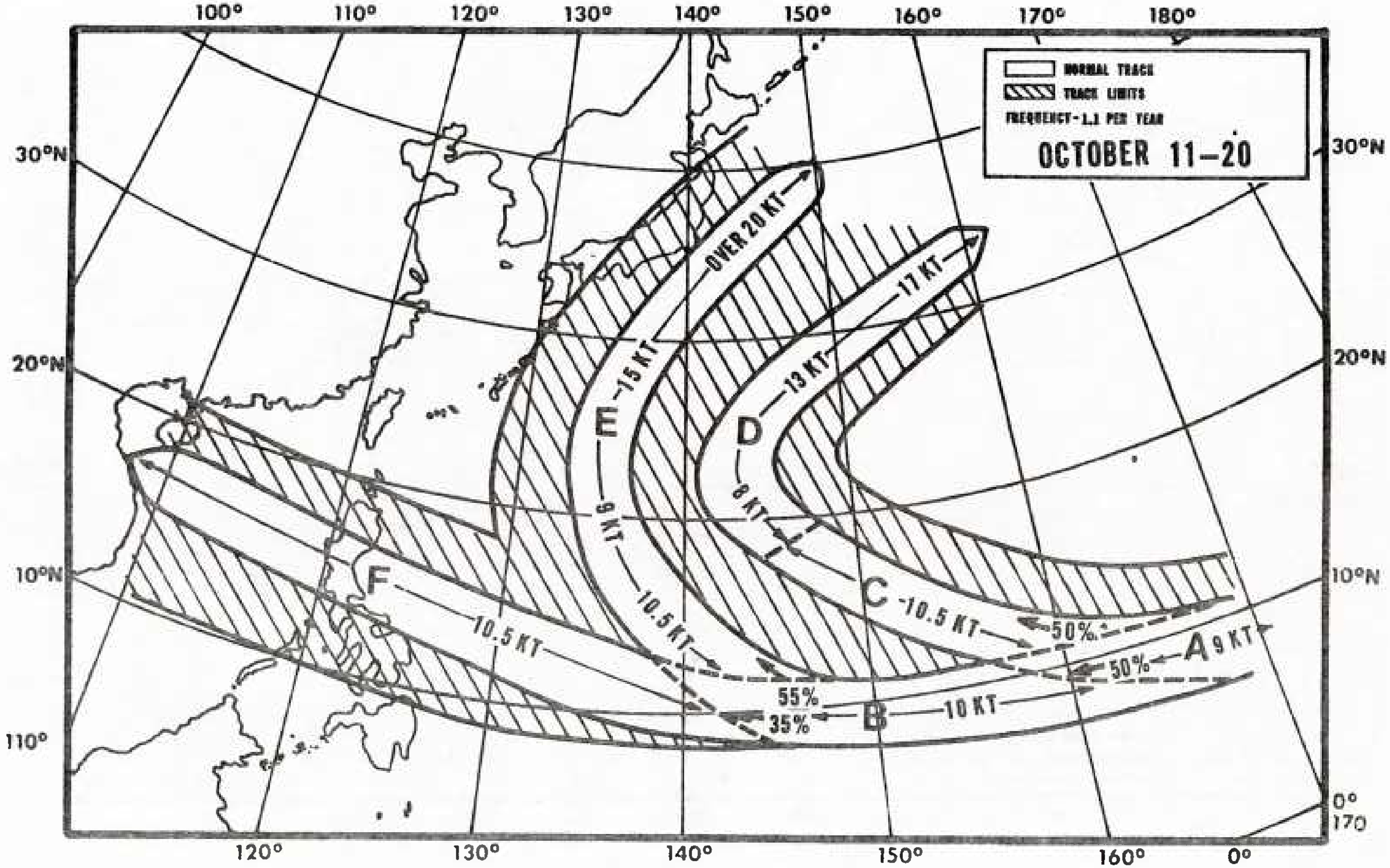


Figure A-12. Mean typhoon tracks for 11-20 October. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

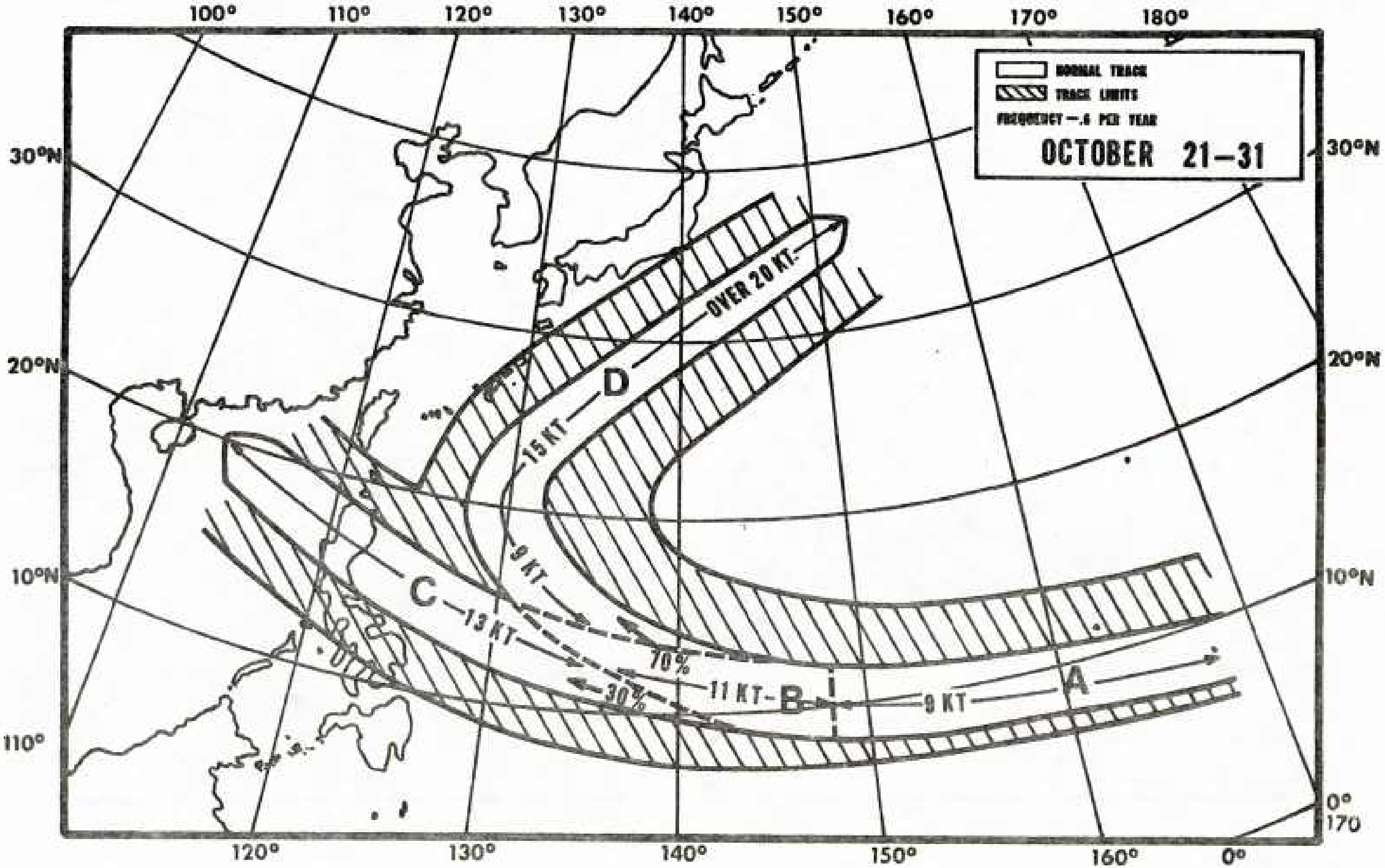


Figure A-13. Mean typhoon tracks for 21-31 October. Note that individual typhoon tracks may deviate 20% from the track limit. Average speed of movements are also given for the various track segments.

APPENDIX B

CALCULATING THE "DANGER AREA" (FROM CINCPACFLT OPORD 201-YR)

EXCERPTS FROM APPENDIX 1 (HEAVY WEATHER DOCTRINE) TO ANNEX H OF CINCPACFLT OPORD 201 (U)

(2) Calculating Danger Area. Although forecast accuracy is improving, the average Joint Typhoon Warning Center 24 hour typhoon forecast error, derived from statistics over past years, is about 135 miles. Tropical cyclone warnings issued by the Joint Typhoon Warning Center now contain 24 hour forecasts of peripheral winds greater than 50 knots and greater than 30 knots winds associated with a tropical cyclone. Should conditions of fetch and duration obtain, 30 knot winds are capable of producing a fully arisen sea with waves up to 28 feet. The nonexactness of center position reports and the fact that a system often follows an erratic track have led to the evolution of rules for avoiding the destructive winds (greater than 30 knots) in the circulation. Figure 1 is one scheme for avoiding the winds and seas associated with these systems.

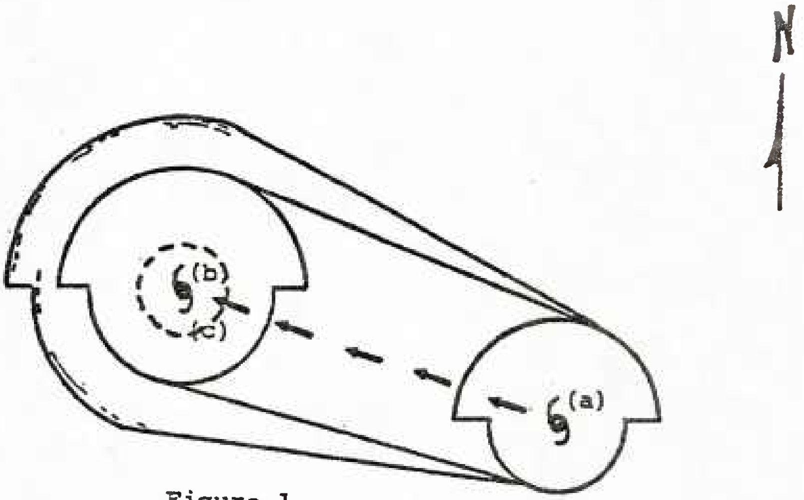


Figure 1

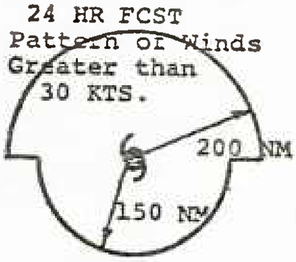


Figure 2

As each new warning is received:

(a) Mark the reported center position of the tropical cyclone and the extent of winds greater than 30 knots.

(b) Mark the 24 hour forecast center position of the cyclone.

(c) Draw a line from point (a) to point (b) indicating the forecast track.

(d) Using a radius of 135 miles draw a circle around the forecast center. This will enclose a locus area of possible 24 hour center positions.

(e) Extract the 24 hour forecast for winds greater than 30 knots. For example this might read, "RADIUS OF OVER 30 KT WIND: 24HRS VALID 021700Z 200 NM NORTH SEMICIRCLE 150 NM SOUTH SEMICIRCLE."

(f) Using a template or mechanical drawing compass lay off the locus of the limiting area of 24 hour forecast of winds greater than 30 knots (Fig. 2) by placing the center of the north-south oriented wind pattern along the perimeter of the 24 hour locus of possible center locations. A practical approximation would be simply to add 135 miles to the forecasted wind radii.

(g) Draw the envelope connecting the points of maximum extent of the 30 knot winds. The resultant enclosed area could very likely contain winds in excess of 30 knots within the next 24 hours. THE ENTIRE AREA IS TO BE AVOIDED.

(h) RECALCULATE THE DANGER AREA WITH EACH NEW WARNING RECEIVED.

(3) Estimating Danger Area.

(a) Locating the ship relative to the dangerous and navigable semicircles to initiate evasion procedures is a continuing problem. Revision and updating of the tropical cyclone system forecast movement may completely change the spatial relationship of the ship to tropical cyclone system center. When still well in advance of the circulation, carefully plotting each new warning, ships should maneuver to avoid adverse winds and seas. However, changing course and speed to cross the forecast track of a system in order to reach the navigable semicircle (Tab C) is considered extremely dangerous once the ship is located within the area of greater than 30 knots wind.

(b) In the event that the center position of a system is not available, the direction can be estimated as follows: "Face the wind. The bearing of the storm center is then 100 to 130 degrees to your right." Care should be taken not to use a wind direction during a squall, for the wind may be non-representative. Larger allowance in degrees should be made in the rear of a circulation then in the front.

(c) A ship equipped with radar which is capable of giving a return from precipitation may be able to use it to advantage if near the storm. Attenuation of the signal by precipitation may cause the scope picture to be deceptive. For this reason the established methods of maneuvering in the vicinity of a typhoon must not be ignored.

e. Riding Out a Typhoon. When impossible to avoid the typhoon associated 30 knot winds standard rules serve as a guide. These depend on the ship's estimated position with relation to the track of the typhoon. Position with respect to the typhoon circulation depicted ideally in Tab C can be estimated by plotting the ship's position with respect to the forecast track and danger area depicted in figure 1.

(1) When on Track of Typhoon. If the barometer continues to fall and the wind direction remains constant or veers clockwise slowly and increases in intensity, the ship is on or near the track of the typhoon. In this case, bring the wind to the starboard quarter, note the course, hold it and run for the "navigable" semicircle. As long as the wind direction remains constant or veers slowly, the ship is in the path of the storm. When the wind has backed, or shifted counterclockwise, 15 degrees, the ship is entering the "navigable" semicircle.

(2) When in Dangerous Semicircle. If the ship is in the dangerous semicircle, bring the wind on the starboard bow and hold it there. Make as much way as the condition of the sea will allow. While maintaining this course, watch the wind log carefully. If the wind veers (clock-wise), it indicates that you are in the dangerous semicircle, so keep changing the course to hold the wind on the starboard bow, and the typhoon will pass astern.

(3) When in the "Navigable" Semicircle. If it is estimated that the ship is in the "navigable" semicircle, bring the wind on the starboard quarter, note the course, and hold it. If the wind backs (counter-clockwise) it means that the ship is in the "navigable" semicircle. If this course is held, the typhoon will pass astern. However, if the wind starts to veer (clock-wise) it means that you are in dangerous semicircle rather than the "navigable" semicircle, and the course should be changed to follow the procedure described in subparagraph (2) above.

APPENDIX C

SHIPS SPEED VS. WIND AND SEA STATE CHARTS

Figures C-1(a) and C-1(b) represent 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(a), for a ship making 15 kt encountering waves of 16 ft approaching 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 condition, 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 slightly 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).

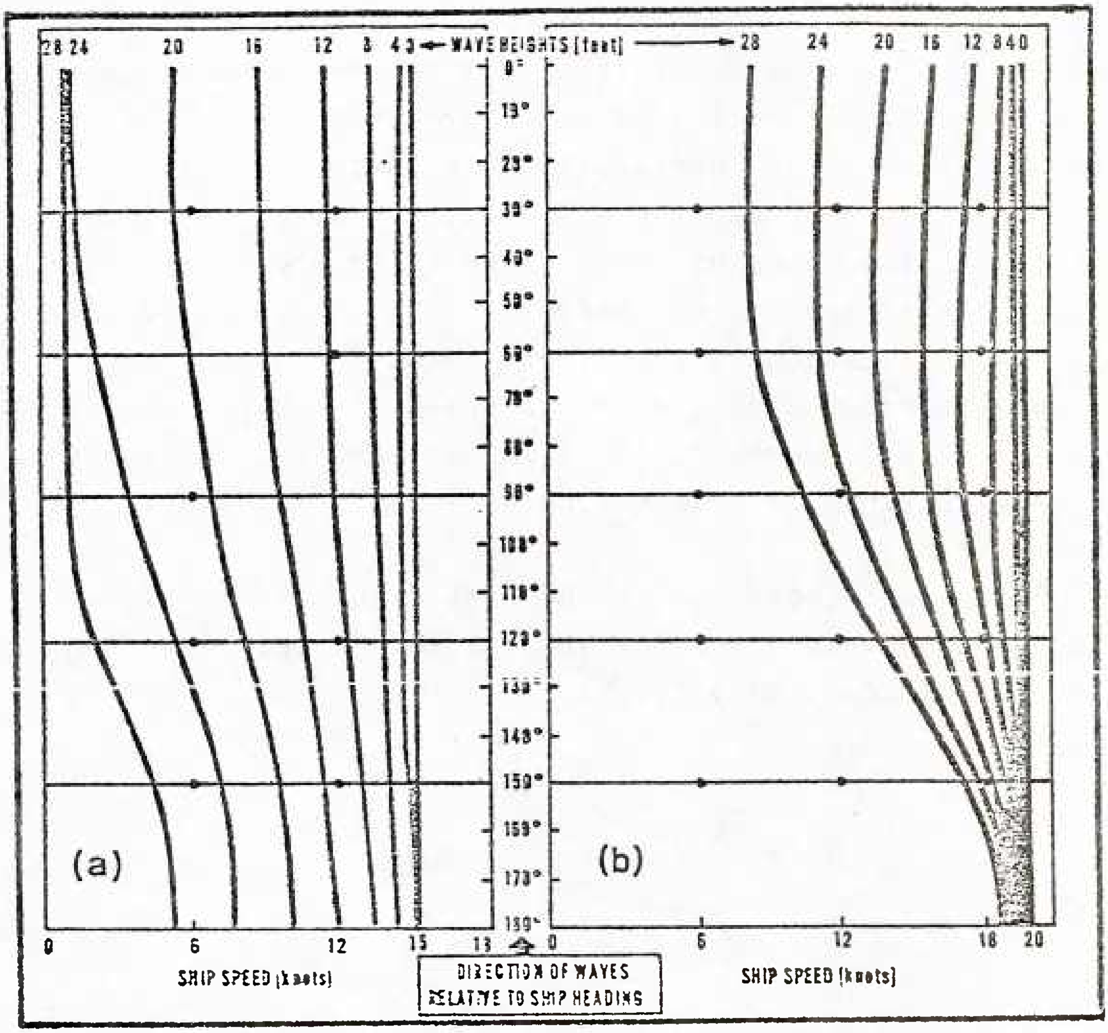
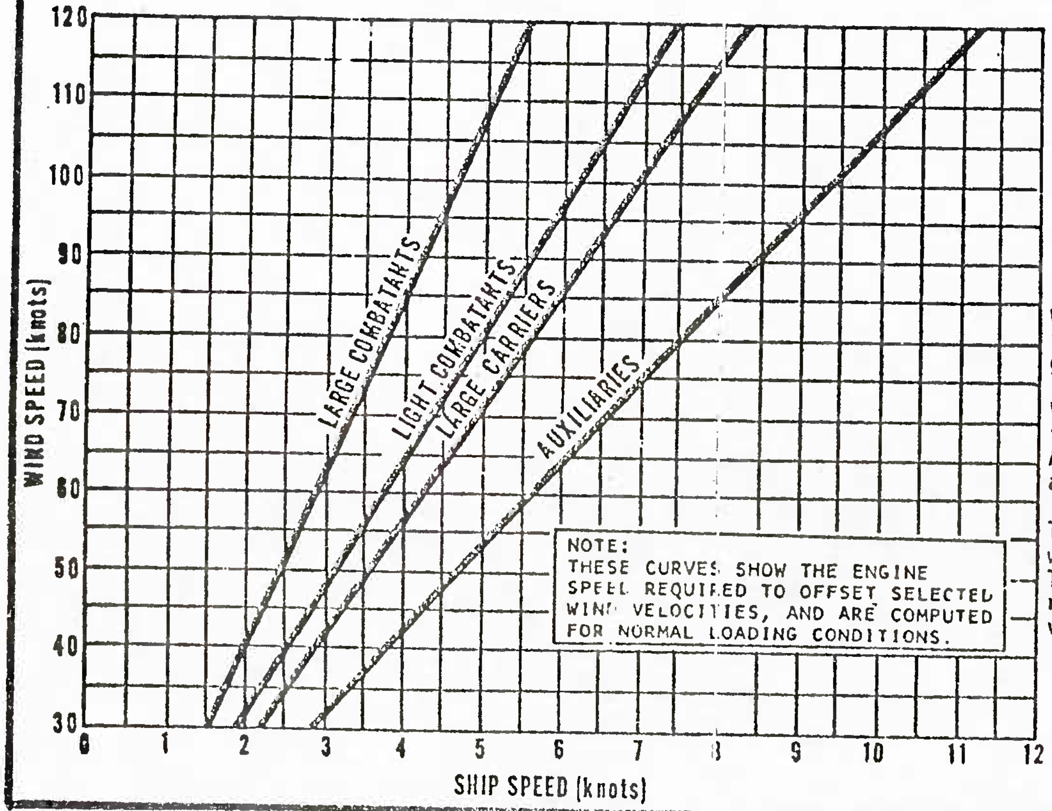


Figure C-1. Expected ship speed as a function of wave height and wave direction relative to ship's heading for (a) a ship making 15 kt and (b) a ship making 20 kt (from Nagle, 1972).



NOTE: THESE CURVES SHOW THE ENGINE SPEED REQUIRED TO OFFSET SELECTED WIND VELOCITIES, AND ARE COMPUTED FOR NORMAL LOADING CONDITIONS.

The curves shown were developed using the basic formula:

$$\text{WIND LOAD} = R_w A V^2$$

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 vs wind velocity for offsetting force of wind (from Crenshaw, 1965).

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