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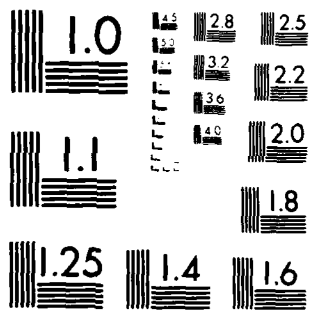

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28 Jun 84

From: Commanding Officer, Naval Environmental Prediction Research Facility, Monterey

Subj: FORWARDING OF CHANGE 2 TO NAVENVPREDRSCHFAC TR 82-03

Ref: (a) CINCLANTFLT ltr 3100/FF1-2/N37A ser 2374 of 13 April 1982
(b) NEPRF transmittal sheet 5600 ser 171 of 25 May 1982
(c) NEPRF ltr 5600 ser 191 of 17 May 1983

Encl: (1) Change 2 to NAVENVPREDRSCHFAC Technical Report TR 82-03, Hurricane Havens Handbook for the North Atlantic Ocean

1. Enclosure (1) is forwarded to all holders of the basic volume of TR 82-03 as specified in the distributions of references (a), (b) and (c). Instructions for entering the change pages and additional sections of Change 2 into the basic volume are provided as part of enclosure (1).

2. The basic volume of TR 82-03 was distributed to units of the U.S. Atlantic Fleet by reference (a) and to additional NAVENVPREDRSCHFAC addressees by reference (b). Change 1 to TR 82-03 was distributed to all holders of the basic volume by reference (c).

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Pages/Sections	Action
DD 1473 of Change 2	Replace present DD 1473
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Section IX, Newport, RI, of Change 2 (with tab)	Replace present tab and slipsheet
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Tropical Meteorology
Warnings
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This handbook is a ready reference decision-making aid for commanding officers and other personnel responsible for the safety of ships facing a hurricane threat. Guidance on assessing a hurricane threat and choosing appropriate countermeasures at specific North Atlantic Ocean (and Gulf of Mexico) ports is provided in the port evaluations in Sections II-XXIII. The handbook is *not* directed only to ships at these ports, however, and the general guidance in Section I will assist ships at other ports or at sea.

Block 18, Supplementary Notes, continued.

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(1) Advance draft copies of Sections II, III, IV, V, and VII provided to CINCLANTFLT for review between 20 May and 8 September 1981.

(2) Basic volume containing Sections I-XI (less Newport, RI, Sec. IX) published in June 1982.

(3) Change One containing additional port evaluations, Sections XII-XVII, published in June 1983.

(4) Change Two containing additional port evaluations, Sections XVIII-XXIII plus IX (Newport, RI), published in July 1984.

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FOREWORD

Following the publication by the Naval Environmental Prediction Research Facility (NEPRF) in 1976 of the Typhoon Havens Handbook for the Western Pacific and Indian Oceans, the Commander SECOND Fleet and the Commander-in-Chief U.S. Atlantic Fleet stated a requirement for certain ports of the North Atlantic - including the Gulf of Mexico and Caribbean Sea - to be similarly evaluated as hurricane havens.

The aim of the Hurricane Havens Handbook for the North Atlantic Ocean is to provide a ready-reference, decision-making aid to commanding officers or other individuals who are responsible for the safety of ships faced with a hurricane threat. It provides guidelines for making decisions in regard to evasion or remaining in port or, for ships already at sea, the seeking of shelter in port.

The development of this Handbook is a long-term and continuing project; evaluations of other ports will be published for future inclusion in the Handbook. Every effort has been made to cover most contingencies to be expected under threatened or actual hurricane conditions in the ports presented. However, the ultimate test of its value will be conducted by decision makers at threatened ports in the future. Users are therefore urged to offer comments and criticisms on the Handbook's practical utility as soon as any shortcomings become evident.

WILLIAM G. SCHRAMM
Captain, U.S. Navy
Commanding Officer

ACKNOWLEDGMENTS

The undertaking of a large study such as this one requires assistance and cooperation at many levels. The authors would like to thank the numerous Naval Oceanography Command activities, local port and harbor officials, U.S. Army, Navy, Coast Guard and National Oceanic and Atmospheric Administration personnel for contributing significant time and effort and for providing data, reports and constructive comments. All the above contributors are gratefully acknowledged as is the assistance of CDR F. K. Martin and CAPT C. M. Zucker of the CINCLANTFLT Staff. CAPT W. G. Schramm, Commanding Officer of the Naval Environmental Prediction Research Facility (NEPRF), initiated the Hurricane Havens Project and provided support, encouragement and the opportunity to undertake such an effort which he felt was needed by the Fleet. The authors also wish to thank Mr. Stephen Bishop for his editorial services and Ms. Winona Carlisle for her manuscript typing.

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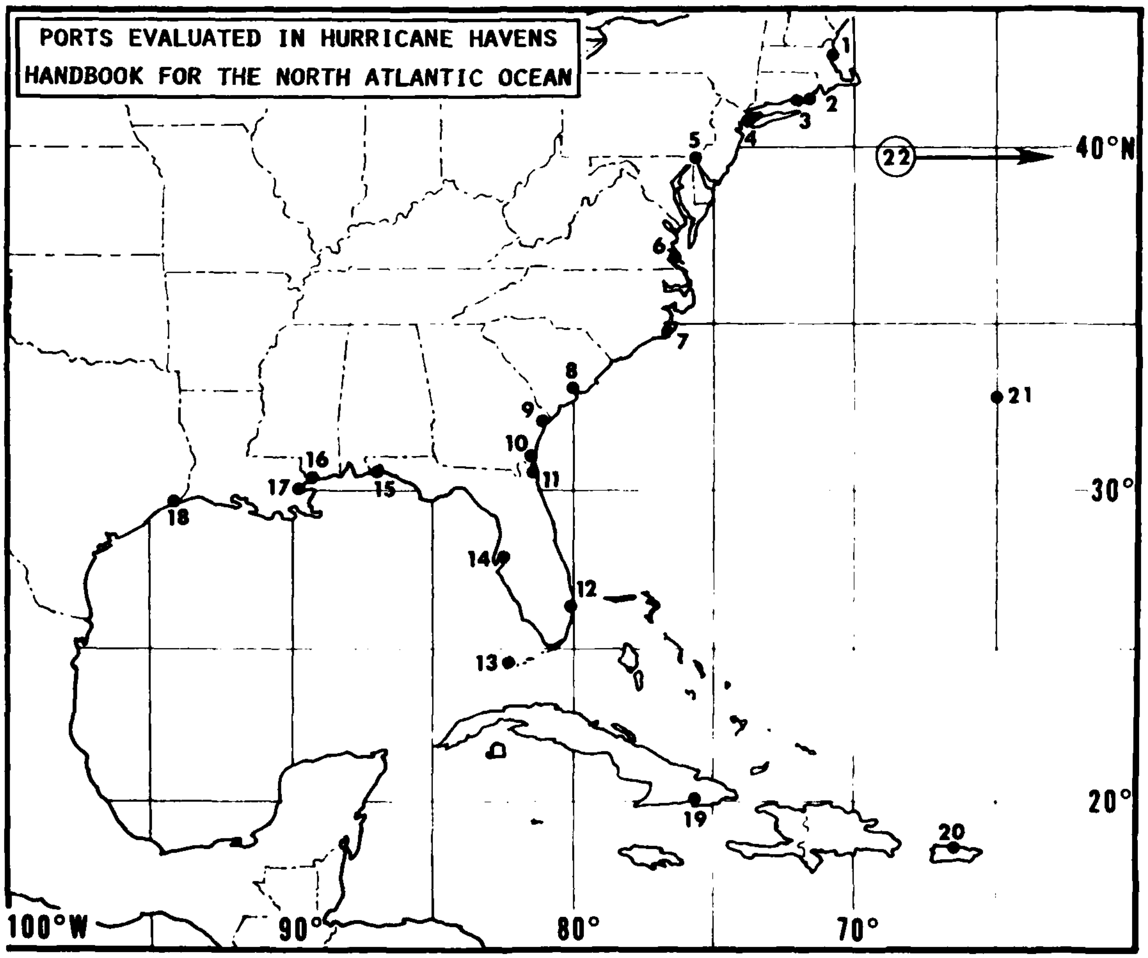
INTRODUCTION

CAUTION: None of the deepwater harbors evaluated in this Handbook have the exceptional qualities needed to safeguard ocean-going vessels from damage in a worst-case direct hurricane strike.

This Handbook provides guidance for assessing a hurricane threat's circumstances and likely impact on the given port to support decision-makers' reasonable choice between either remaining in port or evading at sea. This choice is based on informed compromise between a harbor's protective qualities, and the possibility that a sortie will prove to have been unnecessary.

The general guidance provided in Section I of this Handbook will be of value not only to vessels located at evaluated ports, but also to decision-makers aboard vessels threatened by hurricanes at non-evaluated ports or in transit in the North Atlantic Ocean and Gulf of Mexico.



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IX. NEWPORT,RI

IX: CONTENTS

IX. NEWPORT, RHODE ISLAND

SUMMARY

The port of Newport is located inside Narragansett Bay, which has deep water anchorages within its confines. Although these anchorages are not well sheltered from winds, they have proven hurricane haven properties for ships able to steam at anchor.

In the event of a hurricane threat to the port of Newport, the following are recommended:

(1) Destroyers, frigates and smaller vessels should sortie to designated anchorages within Narragansett Bay when Hurricane Condition IV is set.

(2) Large auxiliaries and disabled warships (only) should berth singly outboard of deep-draft camels at Pier 2 in Coddington Cove.

(3) Only visiting aircraft carriers and submarines are considered to be suitable candidates for evasion at sea; they should sortie when or before Hurricane Condition II is set.

(4) If other warships are forced to evade at sea because hurricane berths are not available in Narragansett Bay, they should sortie to anchorages in Buzzards Bay.

The ports of southern New England are particularly prone to massive flooding on those relatively rare occasions when a hurricane accelerates along a northerly track to make landfall in the area. The more customary track is northeasterly, which directs storms toward Cape Cod or even further to the east. These hurricanes that adopt a northerly track usually are poorly forecast; this fact, together with their high speed of advance, makes evasion at sea particularly dangerous and subject to many false starts.

This hurricane haven evaluation was prepared by LT CDR R.J.B. Turpin, RN, Royal Navy Exchange Officer at NAVENVPREDRSCHFAC 1980-82.

1. GEOGRAPHIC LOCATIONS AND TOPOGRAPHY

Newport is located near the mouth of a broad glacial inlet, Narragansett Bay, on the north shore of Rhode Island Sound (Figure IX-1). The inset in the figure shows Newport's location on the southern New England coast 30 n mi east of New London. The port itself is at the southwestern tip of Aquidneck Island, which is the largest of the numerous islands and peninsulas (known locally as "necks") that rise out of the broad glacial bay.

The elevations of these Narragansett Bay islands and peninsulas, as well as much of the surrounding mainland to the east and west, reach to 100-200 ft above sea level (Figure IX-1). The northern shores of the bay, however, are mainly low-lying salt marshes and alluvial plains associated with the two main rivers that empty into the bay: the Providence to the northwest and the Taunton to the northeast. (Much of the densely populated area surrounding the port of Providence is of this marsh and plain character, and as a result the town itself has experienced massive flooding from the exceptionally high tides associated with hurricane strikes.)

2. APPROACHES TO NARRAGANSETT BAY AND DREDGED CHANNELS

Most ocean-going traffic into Narragansett Bay enters via the central channel denoted East Passage in Figure IX-1. The landfall mark is Brenton Reef Light, which is approximately 2 n mi to the south-southwest of the mouth of East Passage. The submarine contours shown in Figure IX-2 establish East Passage as a deep, natural channel into the bay as far north as Prudence Island. Further to the north, commercial traffic (consisting mostly of ocean-going oil tankers) must gain access to the port of Providence or the port of Fall River via dredged channels along the Providence and Taunton Rivers, respectively. An additional dredged channel from East Passage running northwestward to Quonset Point provides access for naval vessels to anchorages in West Passage to the south of Quonset Point. West Passage is frequently utilized by lighter draft vessels and tows, especially those bound for the Graduate School of Oceanography Pier and piers at Quonset/Davisville.

The project depth for the channel to Providence is 40 ft, and remaining channels have a project depth of 35 ft. Silting at the port of Providence and at other points along the channel, however, currently restricts the maximum draft of vessels handled at the port to 35 ft; it is likely that the other channels mentioned above will have suffered similarly. This mounting restriction on the depth of dredged channels stems from a total embargo on dredging in the Narragansett Bay area that has been in effect since 1971.

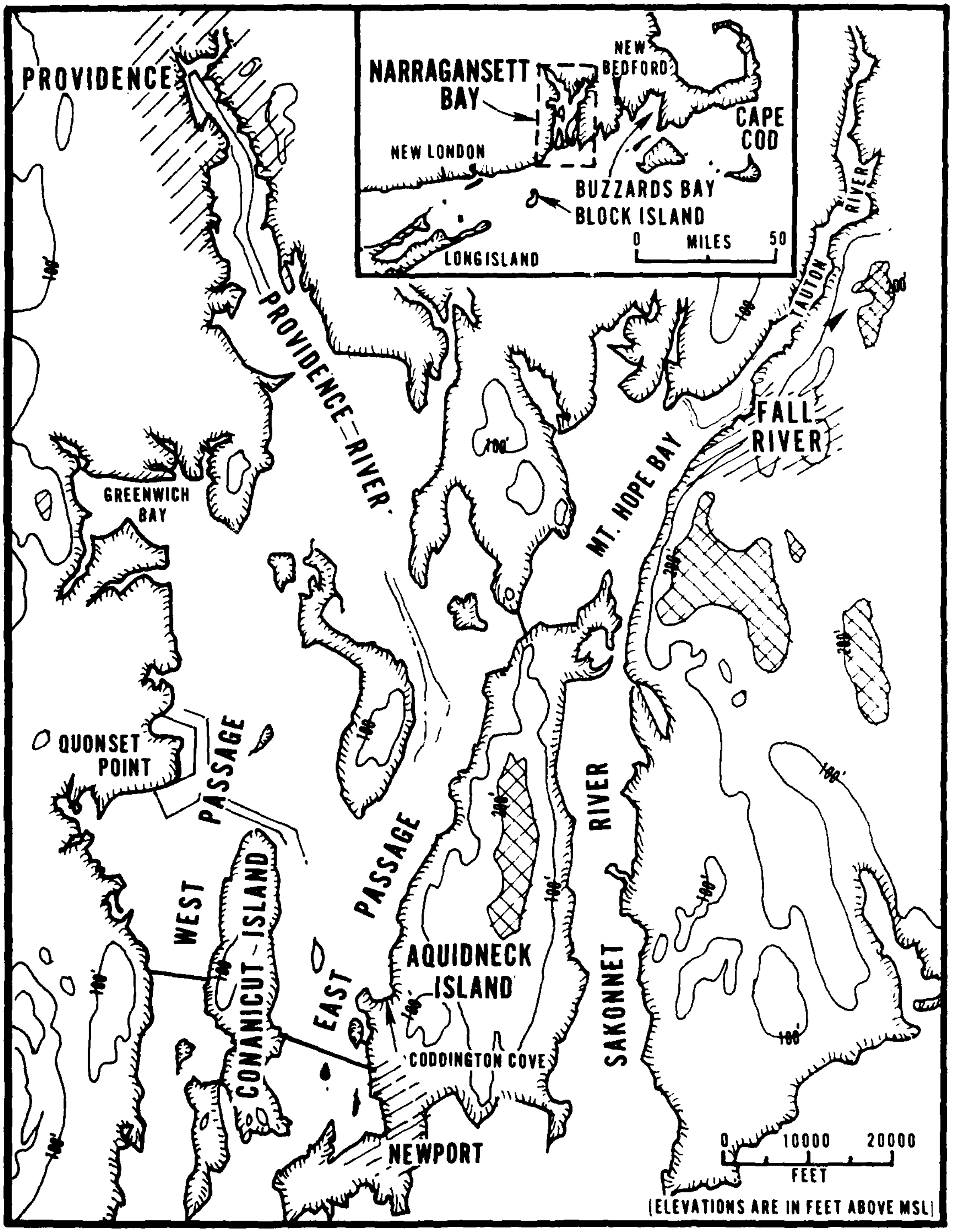

Figure IX-1. Narragansett Bay area showing surrounding topography and the three principal dredged channels.

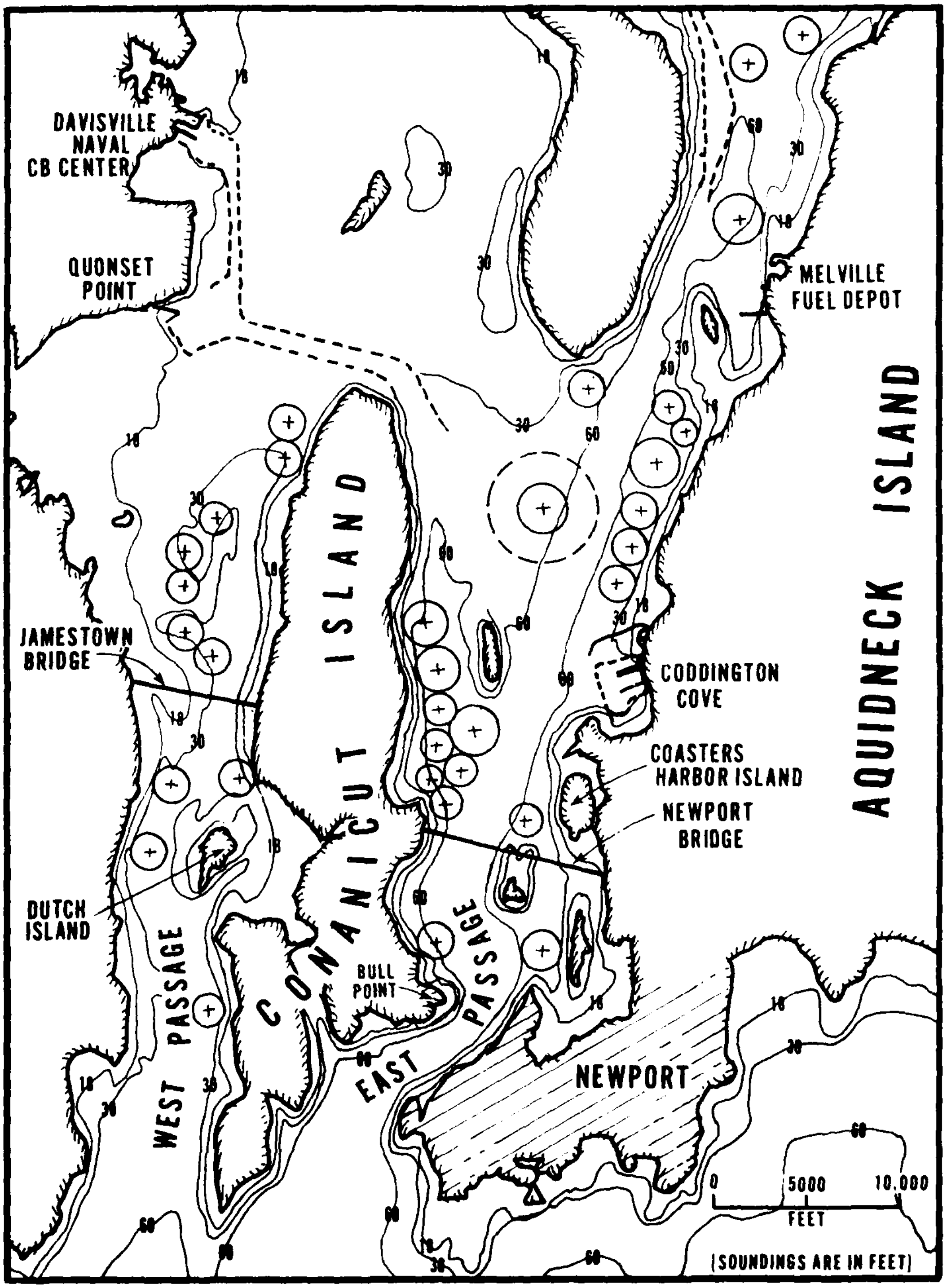

Figure IX-2. Lower Narragansett Bay showing submarine contours and locations of designated anchorages.

The embargo was the result of a successful legal suit brought against the Army Corps of Engineers to prevent any further dumping of polluted dredging spoils at Brenton Reef, 5 n mi south of the East Passage entry to the Bay. This embargo will persist until alternative sites for disposal of dredging spoil can be agreed upon (Olsen, Robadue and Lee, 1981).

3. THE HARBORS AND THEIR FACILITIES

3.1 NAVAL BERTHS

In 1973 the Navy controlled 31 miles of shoreline and 6,000 acres of shorefront property within Narragansett Bay, concentrated in two areas. The Naval Air Station and the Construction Battalions occupied an area on the western shore of the Bay, northward from Quonset Point, that was linked to the main fairway of East Passage by a dredged channel (Figure IX-2). On the eastern shore of the East Passage the Navy also occupied a six-mile stretch between Newport and the Melville Fuel Depot. The U.S. Atlantic Fleet Cruiser-Destroyer Force was home-ported at Coddington Cove.

In 1974 the Rhode Island Port Authority and Economic Development Corporation was established to oversee the redevelopment of ex-Navy holdings, leaving the mainstay of the Navy presence centering on the Naval War College on Coasters Harbor Island and the Naval Education and Training Center at Coddington Point on the southern tip of Coddington Cove.

Commander, Naval Surface Group Four occupies deep water berths on the north side of Pier 2 (Naval Education and Training Center (NETC) currently controls the south side of this pier), which is of modern robust construction with steel piling and concrete capping (Figure IX-3). The State Port Authority currently controls and Derektor Shipyard leases Pier 1. Shallow draft craft and the four Naval Education and Training Center yard patrol craft are berthed at the Stillwater Basin to the north of Pier 2. COMNAVSURFGRU FOUR plans to occupy deep-water berths on the south side of Pier 2 on completion of pier improvements in FY 85.

Visiting deep-draft vessels under Military Sealift Command occasionally may berth for short periods to discharge or load stores at Davisville (north of Quonset Point in Figure IX-2) by arrangement with the State Port Authority. Most of the traffic from these piers is now concerned with offshore oil and gas drilling operations. The large pier at Quonset Point, which formerly provided berthing for aircraft carriers, is a concrete-capped wood piling structure in a poor state of repair; it probably will not be used by visiting naval vessels in the foreseeable future. The Melville Fuel Depot (Figure IX-4) is only rarely used by U.S. Navy ships.

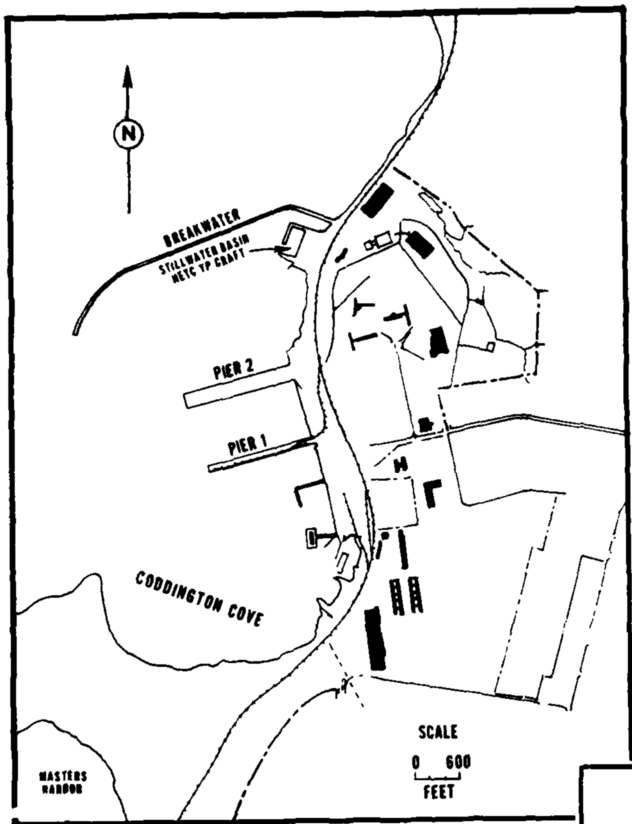

Figure IX-3. Coddington Cove area. The Naval Surface Group occupies the north side of Pier 2.

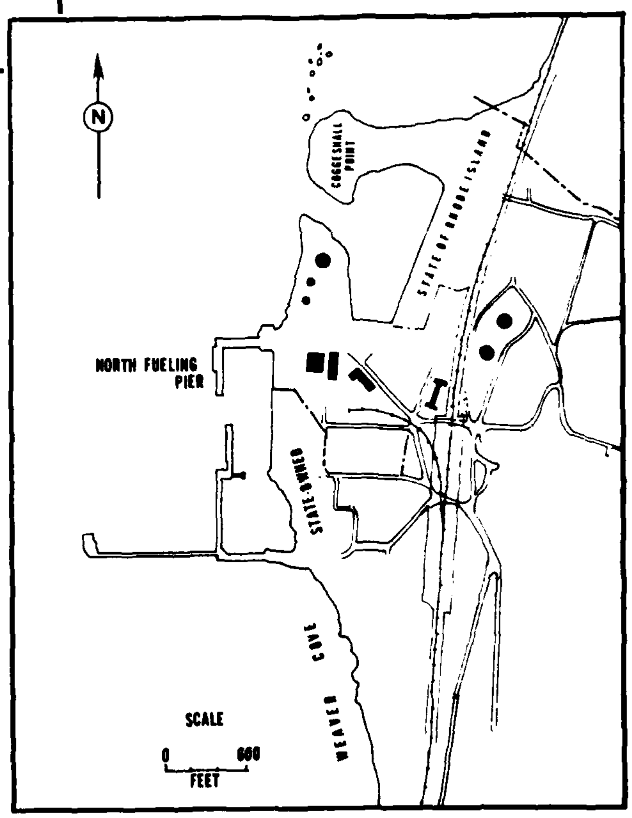

Figure IX-4. Melville Fuel Depot.

3.2 COMMERCIAL BERTHS

The berthing facilities for commercial traffic at Providence and Fall River have a higher occupancy rate and are prone to serious inundation if a hurricane strikes near Narragansett Bay. A detailed description of these commercial facilities is unnecessary, but the likely behavior of commercial vessels at these ports in case of a hurricane threat is discussed in Para. 6.3.

3.3 SMALL CRAFT

Recreational boating has increased in Narragansett Bay since 1960, when the last major hurricane threat occurred in the area. It was estimated that 13,000 craft were berthed at a total of 109 marinas in the area in 1979. From the Navy's viewpoint, this implies a massive quantity of flotsam if a major hurricane strikes.

3.4 REFERENCES AND CHARTS

The reader is referred to the following publications for details of the harbor and its facilities:

DMA Hydrographic/Topographic Center, 1980, Publication 940, Chapter 16, Fleet Guide Narragansett Bay.

U.S. Department of Commerce, 1979, Chart 13221, Narragansett Bay.

U.S. Department of Commerce, 1979, Chart 13223, Narragansett Bay

4. HEAVY WEATHER FACILITIES AND HURRICANE ANCHORAGES

4.1 TUG AVAILABILITY

In the absence of engineering problems, units of the Destroyer Squadron would be expected to reberth as necessary under their own power. Disabled units or larger visiting naval vessels including Military Sealift Command ships are required to report their requirements for tug assistance as early as possible in case of a hurricane threat or forecast of heavy weather, so that Navy contracted tugs based at Providence, RI (see inset, Figure IX-1) can be ordered to sail before weather seriously deteriorates outside Narragansett Bay (SOPA NARRABAY, 1983).

As of 1983, a maximum of four tugs were available from this source. The services of tugs based at the commercial ports of New Bedford and Fall River are likely to be heavily over-subscribed during a hurricane threat by large tankers, many of which are likely to sortie under these circumstances.

4.2 HURRICANE BERTHS AND ANCHORAGES

Storm surge data given in Para. 5 indicate that the deep-draft berthing facilities employed by Navy units at Coddington Cove are likely to be inundated by hurricane-induced exceptional tides once in every 30 to 50 years. In fact, the same is true of all but the more recently constructed tanker berths at the commercial ports to the north of Narragansett Bay. Pier 2 in Coddington Cove is of robust construction, however, and if special regard is given to the rigging of lines and outboard anchors, the inundation threat does not preclude safeguarding immobilized vessels at this pier.

Vessels capable of moving under their own power should relinquish their berths at Pier 2 during a hurricane threat, especially when this eliminates any "nesting" of vessels in these berths, and steam to designated anchorages within Narragansett Bay (Figure IX-2). These anchorages embody all those designated in Chart 13223 and in SOPA NARRABAY OPORDER 1-YR, 1983, but not all of them are equally secure. Specific guidance is given in Para. 6.2.

Six of the East Passage anchorages have mooring buoys which, as of 1983, had not been surveyed since 1972 and may therefore be less secure than a pair of ships anchors. Until these moorings can be declared safe or alternatively can be moved, they effectively mark fouled anchorages. Such mooring buoys are a legacy of 22 Navy Narragansett moorings listed in SOPA (Admin) NARRABAY OPLAN 4-74, 1974, and a program of survey was in progress as of 1983.

4.3 HURRICANE PLANS AND PREPARATION

The heavy weather plan for Navy afloat units in Narragansett Bay is contained in SOPA NARRABAY OPERATION ORDER 1-YR issued by the Commander Surface Group FOUR in 1983. The plan contains an exceptionally well-researched account of both hurricane- and winter storm-caused heavy weather in the Narragansett Bay area. Its findings and recommended plan of action are fully supported by the specific analysis of the local hurricane threat in Para. 5 of this study. Some supplementary guidance on the security of anchorages in the East and West Passages, as affected by both the natural environment and the likely behavior of the enlarged commercial tanker traffic in the Bay area, is provided in Para. 6.

The Sortie and Inshore Anchorage Plan for the Narragansett Bay Area (NARRABAY OPLAN 4-74) does not address the heavy weather threat.

5. TROPICAL CYCLONES AFFECTING NARRAGANSETT BAY

5.1 CLIMATOLOGY - AVERAGE BEHAVIOR

For the purposes of this study, any tropical cyclone approaching within 180 n mi of Newport is considered a threat. Analyses of tropical cyclone track data (Neumann et al., 1980) have shown that the tropical cyclone climatology for New London, CT,* which is located only 30 n mi west of Newport, is applicable also to the Newport area. The broad features of the tropical cyclone threat can be summarized as follows, with average and percentage figures in parentheses ( ) showing the corresponding data for New London:

(1) Although tropical cyclones have occurred in the North Atlantic during all months of the year, the tropical cyclone threat season at Newport occurs during the period June-November.

(2) An average of 0.9 (0.8) tropical cyclones per year pass within 180 n mi of Newport, but only 0.34 (0.35) per year are of hurricane intensity.

(3) Of all tropical cyclones threatening Newport between 1886 and 1979, 85% (86%) occurred in the months of August through October.

(4) The occurrence of tropical cyclones of hurricane intensity (winds $\geq$ 64 kt when within 180 n mi of Newport) has a marked peak during August and September with 85% (85%) occurring during those months.

(5) The major threat direction from which tropical cyclones approach Newport, determined at 180 n mi radius, is from the south and southwest. This quadrant accounts for 86% (88%) of all tropical cyclones approaching within 180 n mi of Newport.

The reader is referred to Figures VIII-5 and VIII-6 in Section VIII of this Handbook for graphic displays of the corresponding data for New London, CT.

5.2 CLIMATOLOGY - VARIABILITY

The qualitative aspects of the tropical cyclone described in the remainder of Para. 4.1 of Section VIII, New London, CT, are equally applicable to Newport. (Figures and text referenced hereafter with the designation VIII- are located in the Handbook section on New London

Particular attention is directed to the exceptionally destructive New England hurricanes typified by the four storm tracks shown in Figure VIII-7. These also were the most destructive hurricanes for Newport over the period for which detailed records are available. Storms such as these distinguish themselves not only in their destructive power but also in their exceptional speeds of advance, once they have passed to the north of Cape Hatteras.

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*See Section VIII of this Handbook.

This dangerous minority reduces the value of the climatological average data given in Figures VIII-8 through VIII-11, when these are used to estimate the timing of an approaching threat. For example, Figure VIII-11 indicates that a September storm near 27N/74W should reach Newport in 3 or 4 days, whereas the infamous September 1938 hurricane is believed to have covered this distance in only 30 hours (see Figure VIII-7).

In retrospect, the meteorological influences supporting occurrence of the exceptionally dangerous high-speed New England hurricane are now understood in principle. It is far more difficult, however, to quantify these factors in a real-time forecasting situation to yield an accurate prediction of landfall location and time. The speed of advance of all tropical cyclones threatening New England is significantly higher than for areas south of Cape Hatteras even when the "exceptional" storms are disregarded.

As explained in Para. 1.1 of Section I (General Guidance) of this Handbook, this character of the New England tropical cyclone threat -- being marked by a combination of fast moving storms and large forecast errors -- poses an even greater dilemma when the choices are to stay in port or to sortie and attempt to evade damage at sea. Under these storm circumstances, which reduce the chances of making a safe evasion at sea, there is a far greater incentive for ships occupying New England ports to seek secure berths or anchorages in harbor.

5.3 WINDS AND TOPOGRAPHICAL EFFECTS

The main reaches of open water in Narragansett Bay are oriented north-south, so the Navy berths and anchorages shown in Figure IX-2 are most exposed to winds from these directions. The bay islands and peninsulas rise gently to elevations of 100-200 ft (see Figure IX-1), and can be expected to produce a mild funneling of winds from these directions.

The four most destructive hurricanes of this century at Newport occurred in 1938, 1944, 1954 (CAROL) and 1960 (DONNA). They all approached at high speeds from the SSW and made their landfall close to the west of Newport (see Figure VIII-7 in Section VIII). This produced the worst combination of events for the naval berths and anchorages in the East and West Passages of Narragansett Bay: alignment of the strongest southerly winds in the circulation of these storms with the least sheltered direction for these berths and anchorages.

Complete hourly wind records for this period are available for Block Island, which lies in a well-exposed position approximately 15 n mi offshore to the SSW of Narragansett Bay (i.e., along the track towards Narragansett Bay for the four most destructive hurricanes). The maximum sustained winds recorded at Block Island exceeded hurricane force (64 kt) by a large margin during the passage of each of the four storms: 1938 - 80 kt; 1944 - 72 kt; 1954 (CAROL) - 79 kt; and 1960 (DONNA) - 71 kt.

Hourly wind records for the Naval Air Station at Quonset Point (see Figure IX-2) for the period 1944-73 provide an accurate measure of conditions at the anchorage in West Passage for the last three of these destructive hurricanes. The maximum winds recorded by an anemometer on a 70-ft mast during passage of the three storms were 1944 - 62 kt; 1954 (CAROL) - 65 kt; and 1960 (DONNA) - 48 kt.

The most pessimistic estimate of winds over the West Passage anchorage at the 33-ft standard anemometer height, obtained by disregarding the possibility of additional topographic shelter at low levels and applying minimum surface friction (Shellard, 1967), provides the following results: 1944 - 56 kt; 1954 (CAROL) - 59 kt; and 1960 (DONNA) - 43 kt. On the basis of these figures, it is unlikely that the maximum sustained winds in West Passage exceeded 60 kt during the passage of the 1938 hurricane or any other hurricanes of this century. Earlier subjective records imply that hurricanes of the 1938 intensity occur less frequently than once in 100 years (National Weather Service, 1969).

In assessing the degree of shelter in West Passage and similar sounds within Narragansett Bay, it can be concluded that sustained winds are extremely unlikely to reach hurricane force during a hurricane strike even in the least sheltered directions and then, only for a brief period (as wind directions in the tight, cyclonic circulation of a fast-moving hurricane change rapidly). The modest 20-30 kt reduction in wind speed, which has been demonstrated for the least sheltered direction at West Passage (relative to wind speeds at the exposed location of Block Island), implies a 50% reduction in the physical force acting on the hulls of ships at this anchorage. The general and naval anchorages in East Passage and the alongside berths in Coddington Cove are somewhat better sheltered.

Many of the commercial berths at Providence and Fall River employ old wooden pilings sunk into soft mud. These would not withstand the stresses applied by a berthed vessel during a severe hurricane strike.

5.4 WAVE ACTION

Open ocean swell generated by tropical cyclones must enter the navigable waters of Narragansett Bay either through the convoluted southern reaches of East Passage -- whereupon most of its energy is absorbed on the seaward shores of Conanicut Island -- or through the more direct reach of West Passage south of Dutch Island (see Figure IX-2). None of the anchorages in East Passage will feel the effects of this swell, but the two anchorages to the west of Dutch Island in West Passage may be affected by swell approaching from due south. Effects of swell conditions generated by southerly gales and storms have been felt as far north as the former aircraft carrier pier at Quonset.

Wave action generated within Narragansett Bay is severely limited by short fetch for most wind directions. However, winds from between north and west act on a relatively long stretch of water starting in Greenwich Bay and cause wave action to build progressively towards Coddington Cove. Strong northwesterly winds have caused ships berthed at Coddington Cove to surge as much as 8 ft (Annex B, SOPA NARRABAY, 1983). The stone breakwater to the north of Coddington Cove (Figure IX-3) is effective in reducing the effects of strong, persistent northeasterly winds created by regular winter storms and the transient northeasterly winds produced by the rarer tropical cyclones.

Wave action generated within Narragansett Bay will create minimal problems for ships at anchor, if the scope of chain employed is set to give the best riding conditions (Annex B, SOPA NARRABAY, 1983).

5.5 STORM TIDES AND CURRENTS

5.5.1 Storm Tides

In the league table of exceptionally high tides from 1931 to 1975 (U.S. Army Corps of Engineers, 1979), three of the top four places are occupied by three of the 20th Century hurricanes previously mentioned. Fourth place is occupied by the winter storm of November 1963:

Date	Cause	Water Level at Newport (above MSL)
21 Sep 1938	Hurricane	10.8 ft
31 Aug 1954	Hurricane (CAROL)	9.8 ft
14 Sep 1944	Hurricane	6.6 ft
30 Nov 1963	Winter Storm	6.0 ft

The 1938 hurricane and Hurricane CAROL (1954) arrived at astronomical high tide. The 1944 hurricane arrived at low tide as did Hurricane DONNA (1960). The mean astronomical tidal range at Newport is approximately 4 ft; therefore, had the 1944 hurricane and DONNA arrived at high tide, all four of this century's destructive hurricanes would have headed the league table with high water levels about 10 ft above mean sea level - i.e., 4 ft above any of the more regular winter storms. This would have put the naval piers at Coddington Cove under water on four occasions between 1938 and 1960, or once every 5 1/2 years.

Statistical studies by the Army Corps of Engineers suggest that the coincidence of high astronomical tide with a hurricane strike sufficiently severe to flood the Navy piers, is once every 50 years. On one occasion when flooding was threatened (Hurricane EDNA, 1954), two tenders with a destroyer alongside each, rode out the storm successfully at Pier 1 by interposing deep-draft camels between the inboard vessels and the flooded pier (Annex A, SOPA NARRABAY, 1979). Mooring lines would have required constant attention.

Impacts of storm tides at the commercial ports to the north of Narragansett Bay have been devastating. High water levels recorded at Providence during the passage of the two worst 20th Century hurricanes were 6-7 ft higher than those cited previously for Newport. Levels at Fall River were approximately 4 ft higher than at Newport (U.S. Army Corps of Engineers, 1980).

Eyewitness accounts at Providence recall two events produced by Hurricane CAROL (1954). First, at the Mobil wharf on the east side of the river, the entire wharf area was flooded; oil pipes to the tank farm were filled with seawater to prevent their floating away, and an empty tanker moored at the wharf took on seawater ballast sufficient for her to rest securely on the bottom of the river (Seifert, 1981). Second, a small 15,000 barrel tanker at the Sun Oil Company wharf on the west side of the river came ashore while still secured to her mooring bollards. She escaped damage and was deposited back in the river under the action of her strained mooring lines (Sun Oil Company, 1981).

Soon after Hurricane CAROL (1954), local interests requested protection of Providence and Narragansett Bay against hurricane tidal flooding. Four barriers were proposed after three years of work (McAleer and Townsend, 1958): one across the Providence River to the north of the port at Fox Point in Providence City, and three at the seaward entrances to Narragansett Bay. Only the Fox Point barrier was built, leaving all the deep water berthing facilities in the Bay area susceptible to storm tides.

5.5.2 Storm Effects on Tidal Currents

Average tidal currents produced by the regular astronomical tides reach maximum speeds at choke points in the East and West Passages to Narragansett Bay of 1.1 kt during the flood and 1.4 kt during the ebb. The principal choke points are either side of Dutch Island in West Passage and off Bull Point in East Passage (Figure IX-2). Average maxima in the main anchorage areas of West and East Passages are 0.9 kt during the flood and 1.0 kt during the ebb.

The augmentation of these currents due to hurricane tidal effects is not symmetrical. As the hurricane approaches, an augmented flood current of up to twice the normal rate may flow, but the augmented ebb current may reach rates of 4 or 5 times the normal. This rapid drainage of tidal sounds, which occurs *after the hurricane has passed*, imposes an additional force on ships moored or anchored in the tideway. Such exceptional currents can also lead to the sudden shoaling of dredged channels. The force of the storm tide drainage current is thought to have been the main cause of mooring lines parting in 1960 at Morehead City, NC (see Para. 3.2.4 in Section VII), and sudden shoaling of dredged channels by storm tides is evident at ports in Georgia and Florida (see Para. 4.5 in Section VI).

Exceptional tidal currents will reduce the utility of the three anchorages in West Passage adjacent to Dutch Island, especially those to the west of Dutch Island where problems are likely to be compounded by reduced shelter and some penetration of deep ocean swell at the approach phase of a hurricane threat. Furthermore, the possibility of some storm-induced shoaling of the dredged channel between East Passage and Quonset Point could hamper the departure of deeper-draft vessels that may anchor off Quonset Point in an emergency.

6. THE DECISION TO EVADE AT SEA OR REMAIN IN PORT

6.1 EVASION RATIONALE

SOPA NARRABAY OPORDER 1-YR (1983) provides specific instructions to Navy ships for dealing with heavy weather. The findings of this study concur with the rationale expressed in the OPORDER, but minor refinements are proposed in Paras. 6.2 and 6.3 of this Section.

The OPORDER's basic rationale requires that -- if a hurricane is forecast to make landfall anywhere between New York and Cape Cod -- all destroyers, frigates and minesweepers should take up assigned anchorages within Narragansett Bay, and tenders and auxiliaries should moor singly outboard of deep-draft camels at available pier berths in Coddington Cove, with instruction to sortie to emergency anchorages if such berths become untenable. Only aircraft carriers and submarines are considered to be candidates for taking evasive action at sea.

Annex C of the OPORDER requires preparations for ship movements to be carried out at Hurricane Condition IV (72 hours from a possible hurricane strike in New England). In view of the nature of the New England hurricane threat (see Para. 5.2) these advance preparations are well justified. They are based on a past record of destroyers' suffering damage in attempting to evade a fast-moving New England hurricane at sea, and on the recognition of the limited accuracy of forecast tracks for these storms. Coupled with these considerations are three recent instances of warships (including one aircraft carrier) successfully riding out a hurricane strike while anchored in the Narragansett Bay area (see Annex A, SOPA NARRABAY, 1983).

6.2 NARRAGANSETT BAY ANCHORAGES

Paragraph 5.3 provides firm evidence of shelter in the West Passage anchorage. Shelter in the East Passage anchorage is expected to be at least as effective. Nevertheless, ships using these anchorages should be prepared for full power steaming at anchor. Specific limitations outlined in Para. 5.3 and 5.4 are summarized as follows (see Charts 13221 and 13223):

(1) The security of anchorages in the West Passage to the south of Jamestown Bridge is impaired by ocean swell penetration and reduced wind shelter, and to the west of Dutch Island by the possibility of strong storm tide drainage currents.

(2) Deeper-draft vessels unable to use the designated anchorages in West Passage may anchor in an emergency off Quonset Point. These vessels should be aware of the possibility of sudden shoaling of the dredged channels from East Passage to Quonset Point after a hurricane strike.

(3) General anchorage 'B' to the north of Coddington Cove in East Passage will be more heavily subscribed-to by laden tankers as commercial traffic increases in the bay. Increased risk of collision, with hampered vessels in particular, is implied at this anchorage, especially at those anchor berths to the north of Melville Fuel Depot (Figure IX-4).

(4) Naval anchorage 'A' to the west of Coddington Cove is a valuable deep-water anchorage which is well clear of the fairway in the north. Some difficulty may arise from fouling with chains from old 'M' moorings. Local pilots recall some ships dragging at anchor south of Newport Bridge, which raises doubts on the holding qualities in this part of the anchorage.

(5) The spacing of designated anchorages in West Passage to the north of Jamestown Bridge provides scant allowance for dragging anchor, even presuming that destroyers or frigates occupying this anchorage in the event of a hurricane strike, would steam at anchor to reduce forces on their cables. Because of the special dangers of such vessels attempting to evade at sea, consideration may be given to controlled de-restriction of Navy-controlled prohibited areas to enlarge the anchorages available to destroyers. Deep water sufficiently remote from submarine cables to the west of Prudence Island is a possible candidate.

6.3 COMMERCIAL BERTHS AT PROVIDENCE AND FALL RIVER

The impact of a hurricane strike on these commercial ports has been devastating in the past, largely as a result of the effects of massive storm tides which are considerably higher at Providence than at Newport (Para. 5.5.1). Many of the berths at both Providence and Fall River comprise wooden pilings sunk into the soft river bed, and these would scarcely resist the stresses imposed by a berthed vessel during a hurricane strike. The consensus at the commercial ports is that most tankers would sortie from their berths in the event of a hurricane threat if they were loaded or could take on ballast. The preferred option for them would be to seek deep-water anchorage in Narragansett Bay. This implies increasing demand on the general anchorages to the north of Coddington Cove in East Passage (Figure IX-2).

Light tankers that are unable to take on ballast would probably remain in alongside berths. The newer tanker berths of robust steel and concrete construction on the east bank of the Providence River would be capable of holding berthed tankers during a hurricane strike, given that normal hurricane berthing precautions had been observed. Such precautions should include the use of anchors set outboard of the vessel to hold it off the berth. Towing vessels have been used to hold lightly laden ships alongside in strong winds, but experience at the Mobil Wharf during Hurricane CAROL's strike (1954) shows that ballasting down at the berth is an effective tactic under these conditions. The later, south berth at the Mobil Wharf with its robust concrete dolphins rising well above storm tide levels, is a good example of facilities designed with hurricane wind and tidal effects in mind.

6.4 EVASION AT SEA

The case for warships sortieing from Narragansett Bay to evade at sea is difficult to justify, given the special problems of evading a fast moving, poorly forecast New England hurricane and the existence of proven (though only partly sheltered) hurricane anchorages in the bay area.

The special facility which submarines and high speed fixed-wing aircraft carriers have for successfully evading tropical storms at sea, set these vessels apart from other classes of warship. Annex F, SOPA NARRABAY OPORDER 1-YR, 1983 provides details of the Sortie Plan in which a firm commitment is made to sortie aircraft carriers in the event of a hurricane threat. It is recommended that large auxiliaries be sortied only under the same circumstances as destroyers or smaller vessels, i.e., the non-availability of buoys or anchorages.

Timing of the order to sortie from any New England port carries special problems created by the enormous variation in the speed of advance of New England hurricanes. Average hurricane transit time from the latitude of Charleston, SC to New England is 48 hr, but may be considerably less, as in the cases of these four storms: 21 Sep 1;938 - 14 hr; 15 Sep 1944 - 20 hr; CAROL 1954 - 22 hr; and DONNA 1960 - 14 hr (Neumann et al., 1980).

All forecasting techniques possess a degree of bias towards average behavior, so will usually underestimate the time of arrival of a more destructive, exceptionally fast-moving hurricane. It is considered, therefore, that the commitment in Annex F, SOPA NARRABAY OPORDER 1-YR, to order sortie at Hurricane Condition I, places too much reliance on forecast accuracy and may not permit surface units to gain sufficient sea room before they are hampered by rising winds and sea state.

Forecast errors are approximately proportional to forecast period (see Figures I-3 and I-4 in Section I, General Guidance). Thus the best compromise in balancing penalties in this dilemma is considered to be a firm commitment to make the sortie decision at Hurricane Condition II and accept the improved prospects of successful evasion as adequate compensation for the inevitable higher frequency of unjustified sorties.

The navigational tactics employed by sortieing units will be governed by the particular forecast behavior of the threatening hurricane. The following general guidelines can be employed:

(1) Tropical cyclones near the Bahamas that are forecast to curve northward towards Cape Hatteras are the most serious threat to New England ports. Twenty-four hour forecast errors could embrace landfall anywhere between New York and Cape Cod, or even passage of the storm east of Cape Cod. Attempts by surface units to steam S or SSW from New England to stay in the 'navigable' semicircle are highly dangerous and best speed should be made ESE or SE to gain sea room outside Cape Hatteras - Cape Cod embayment as early as possible. Submarines should make best speed SSE to safe submergence depths.

(2) Tropical cyclones north of 27°N and east of 70°W have a very low probability of making landfall in New England.

(3) Tropical cyclones originating in the Gulf of Mexico or West Caribbean Sea have a high probability of passing within 180 n mi of Newport, but unless they enter the main basin of the Atlantic near Florida or Georgia, they are likely to be significantly weakened by an overland transit and therefore cease to pose a serious threat to New England.

If non-availability of suitable hurricane berths forces sortie action upon such vessels as destroyers, large auxiliaries or large amphibious ships -- which are not as able as aircraft carriers and submarines to counter the threat from fast-moving hurricanes -- they may be better advised to heave to or even steam at anchor in coastal waters sheltered from the heavy ocean swell, rather than risk storm damage in the open ocean.

The nearest suitable anchorage from storm-augmented ocean and tidal currents is Buzzards Bay (see Figure IX-1), a location favored by local pilots (Fisher, 1981). Smaller vessels should seek shelter in the upper reaches of Buzzards Bay towards the entrance to the Cap Cod canal. Draft limitations will restrict larger Navy vessels to the western end of the Bay (SOPA (Admin) NARRABAY OPLAN 4-74, 1974). Vineyard Sound to the south of Buzzards Bay is not recommended for this purpose. Long Island Sound to the west of Narragansett Bay has been employed by merchant vessels during a hurricane strike according to Port Authorities at New London, CT (Paras. 5.1 and 5.2 of Section VIII).

6.5 RETURNING TO HARBOR

Unless otherwise directed, all sortied Navy units may return to Newport without signal (Annex F, SOPA NARRABAY OPORDER 1-YR, 1983). Special caution will be required after a severe hurricane strike that may have left obstructions in channels and may have displaced channel markers. Alongside services may well be disrupted by the flooding associated with storm surge.

6.6 RUNNING FOR SHELTER

The few sheltered berths within Narragansett Bay are likely to be over-subscribed if there is a hurricane threat to southern New England. However, Annex A of SOPA NARRABAY OPORDER 1-YR, 1983, provides for the reservation of one or two anchorages close to the harbor entrance for unexpected arrivals.

6.7 ADVICE TO SMALL CRAFT

Flooding associated with hurricane-induced high tides is the principal threat to small craft in the area. They should be hoisted and secured ashore above projected flood levels whenever possible. The majority of small craft marinas are prone to flooding in the event of high storm tides (Olsen, Bobadue and Lee, 1981) and craft that cannot be brought ashore are best safeguarded at anchor in sheltered creeks and inlets rather than in their alongside marina berths. Small Navy craft within the Stillwater Basin would be best safeguarded if lines could be tended during the flood.

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XVIII. SAVANNAH,GA

XVIII: CONTENTS

XVIII. SAVANNAH, GEORGIA

SUMMARY

This study concludes that Savannah Harbor offers few of the characteristics of a haven during hurricane-force winds. When winds over 50 kt are expected, all ships should evade at sea or, if at sea, seek shelter elsewhere. In less severe tropical storm conditions (winds 34-50 kt), some moorings at the Georgia Ports Authority terminals may be adequate. Small vessels, fishing boats and sailing craft, and those ships disabled by maintenance should stay fast or seek shelter upriver. There are no designated hurricane anchorages in the Savannah Harbor.

Historically, the tropical cyclones that have caused widespread damage in the area have approached from the east or southeast. Several tropical cyclones, however, that have crossed Florida from the Gulf of Mexico and then tracked through or offshore of Georgia have generated winds of 50-60 kt in Savannah Harbor. The topography of the surrounding area is almost flat and near sea level, thus the harbor provides limited shelter from the wind. There is a threat of storm surge propagating up the Savannah River into the main harbor area.

It is recommended that ships take action as described above at an early stage because of problems involved in scheduling sorties during ebb tide conditions and the necessity to gain sufficient clearance for safe maneuvering room.

This hurricane haven evaluation was prepared by J.F. Sanders and J.D. Jarrell of Science Applications, Inc. (SAI), of Monterey, CA 93940.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Savannah, the second largest city and the chief port of Georgia, is situated on the southern bank of the Savannah River approximately 13 n mi from the Atlantic Ocean (Figure XVIII-1). The area surrounding Savannah proper is characterized by flat terrain with extensive marsh land. The city is built atop a bluff of low elevation. Maximum elevations of approximately 11-13 ft are generally reached within 0.3-1.1 statute miles to the south and west of the Georgia Ports Authority Ocean Terminal. The surrounding terrain and barrier islands provide little protection to the harbor area, except for cases where the winds are from the south.

The bathymetry along the Savannah coast is characterized by shallow shoals and banks out to 3-7 n mi offshore. Due to the gentle relief of the continental shelf, depths increase gradually and may be only 50 ft 7-10 n mi offshore. The gentle slope of the shelf is a characteristic which promotes the generation of storm surge under proper conditions. A deepwater channel is maintained across the bar through Tybee Roads to Savannah's waterfront terminals. Several landmarks and prominent features mark the various approaches to the ocean jetties.

2. THE HARBOR, APPROACHES AND FACILITIES

The harbor includes the lower 21 statute miles of the Savannah River. The principal waterfront facilities are located along the southern bank of the river adjacent to the city and on Hutchinson Island, which is opposite the city proper (see Figure XVIII-1). The route of the Atlantic Intracoastal Waterway crosses the Savannah River approximately 9 statute miles below the primary port area.

2.1 APPROACHES

Savannah Light is on piles in 50 ft of water, approximately 10 miles east-southeast of the jetties. Tybee Light stands near the entrance of the river on the south side. A Coast Guard station and radio beacon are at this light. With an approach from the north, three water tanks on Hilton Head Island, South Carolina are readily visible and, with a seaward approach from the east, red lights atop three radio towers on Oatland Island and three 200-ft-high tanks on Elba Island (about nine miles above the entrance) can be seen.*

A dredged channel 40 ft deep at mean low water (MLW) and 600 ft wide is maintained for about 7.0 miles from the sea buoy (Tybee Lighted Whistle Buoy T, 31°58.3'N, 80°44.0'W) to the jetties. From this point, channel depths are maintained at 38 ft MLW as the width decreases to 500 ft, then later to 400 ft.

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*Coast Pilot 4.

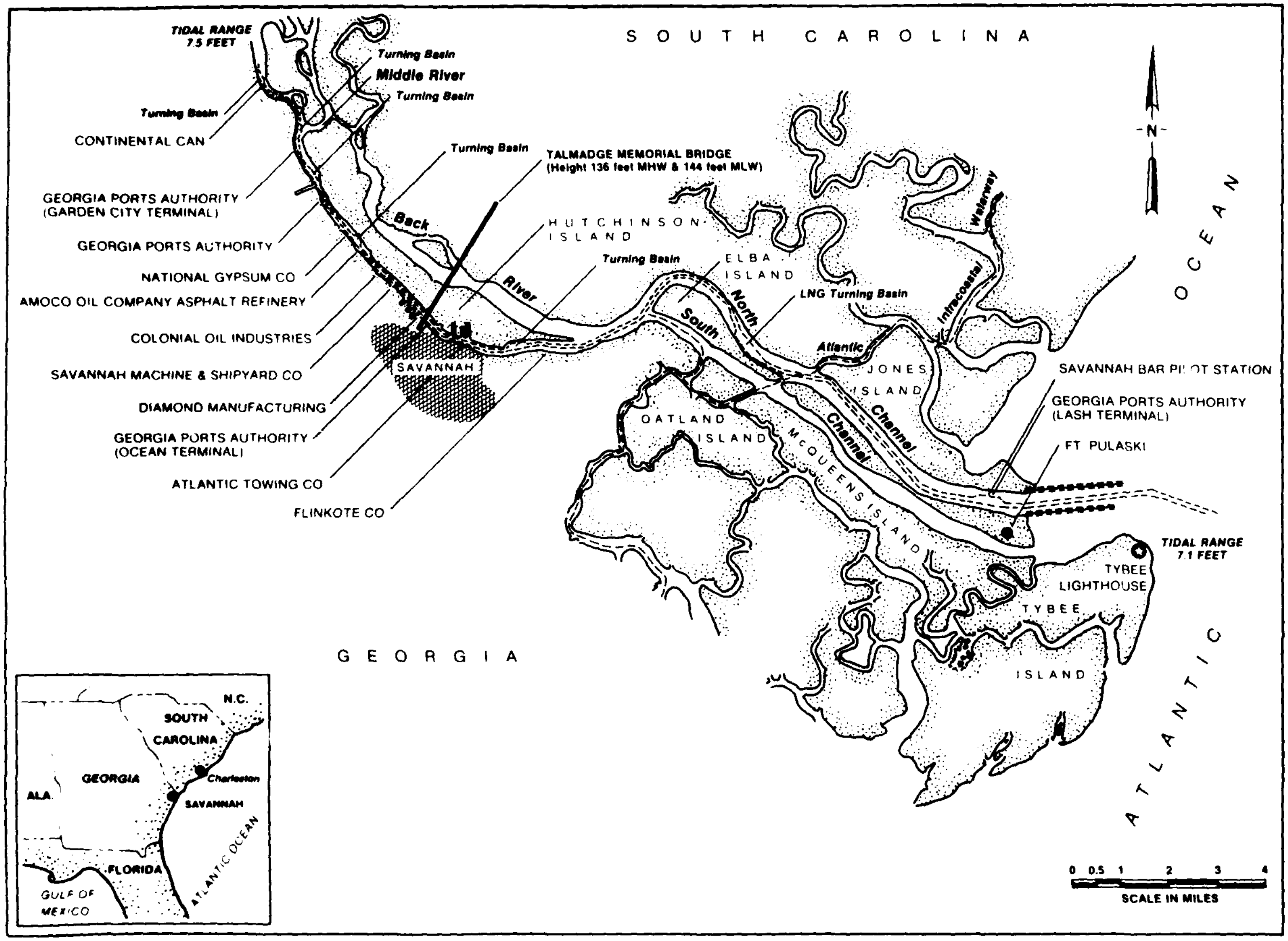

Figure XVIII-1. Locator map of Savannah harbor and vicinity.

In addition to the channel, there are several turning basins maintained within the river. Pilotage is available on a 24-hr basis with pilots boarding from the pilot boats near the sea buoy.

2.2 ANCHORAGES

Most vessels anchor to the north or northwest of the sea buoy. Depths range from 19 to 45 ft with good holding ground. There is no anchorage in Savannah River except in an emergency. The river areas are exposed to the wind and would offer no protection from debris during a storm.

2.3 BERTHS

A total of 51 piers, wharves and docks are described in the Corps of Engineers, Port Series No. 14 report for the Port of Savannah. Many of these wharves are multiple purpose although several are designed to handle only specialized cargo, e.g., sugar, fuel, gypsum and timber products. The Georgia Ports Authority terminals are a major site for the transhipment of containerized cargo second only to Baltimore of ports along the Atlantic.

Navy use of Savannah's port facilities has been minimal. The facilities used for docking are the Georgia Ports Authority's Ocean and Garden City terminals. The port facilities used for repairs are Diamond Manufacturing Company and Savannah Machine and Shipyard Company. Navy use of the port may increase in the future if Rapid Deployment Force vessels are based there.

2.3.1 Ocean Terminal

The Georgia Ports Authority Ocean Terminal is located on the right descending bank of the Savannah River. Berths 1 and 2 are about 200 ft below the Eugene Talmadge Memorial Bridge, while berths 10-20 are located above the bridge.

The height of the bridge could be an important variable for a Navy vessel needing to sortie before a tropical cyclone strikes. The bridge stands 136 ft above the river during mean high water and 144 ft during mean low water, and an advancing storm might induce surge that could reduce this clearance. A sortie at ebb tide would be extremely difficult because the strong outbound current makes maintaining steerageway difficult around the turns.

There are variations in construction methods, alongside depths and deck heights among the available berths at Ocean Terminal. Berths 1 and 2, which have been used by the N.S. SAVANNAH and passenger cruise vessels, have a solid-filled concrete bulkhead with a timber relieving platform supported by timber piling. The alongside depth is 30 ft and the deck height is 14 ft, both MLW. The wharf has a 22-ft apron and the bulkhead is fronted by timber fenders.

By contrast, berths 12 to 20 have concrete-decked wharves and prestressed concrete piling. Alongside depths for berths 10 to 20 range from 30 to 34 ft MLW and deck heights are generally 15 ft MLW. Aprons are as much as 57 ft in width. Berths 10A and 10B have concrete-decked wharves on concrete and timber piles. The alongside depth is 30 ft MLW and the deck is 13 ft MLW. Maximum apron width is 23 ft.

Note that the numbering system for the wharves at Ocean Terminal is not entirely consecutive. The numbers 3 to 9, inclusive, and 11 are not used.

2.3.2 <u>Garden City Terminal</u>

The Garden City Terminal of the Georgia Ports Authority extends along the right side of the Savannah River from 2.4 to 3.7 miles above the Talmadge Bridge. Berths 51-60 are constructed of concrete, and berths 51-57 have a steel sheet pile bulkhead with solid fill. Alongside depths range from 37 to 40 ft and deck height is 15 ft relative to MLW.

Berths 50A and 50B are timber pile, timber-decked offshore wharves with an alongside depth of 34 ft and deck height of 12.5 ft MLW. Berth 61 also has an offshore wharf, a 38-ft depth alongside, and a 15-ft MLW deck height. This berth is constructed of prestressed concrete with concrete-capped breasting dolphins.

2.3.3. <u>Other Berthing for Navy Vessels</u>

Seven other berths in the Savannah Harbor have been constructed well enough and with an adequate water depth alongside to handle smaller Navy vessels. These include the berths of Diamond Manufacturing Company and Savannah Machine and Shipyard Company, the two major marine repair facilities in the harbor. The remaining well-constructed berths are Continental Can, Flintkote Wharf, National Gypsum, American Oil and Colonial Oil Industries. Each of these seven berths, except for the Flintkote Company Wharf, is located above the Talmadge Bridge.

3. HEAVY WEATHER FACILITIES AND HURRICANE ANCHORAGES

3.1 HURRICANE PLANS AND PREPARATION

Tropical cyclone conditions of readiness are set for the Savannah area in accordance with COMNAVBASCHSN Disaster Preparedness Plan of 1 July 1977. Specific instructions to Navy ships for dealing with severe weather are laid down in SOPA (ADMIN) CHASINST 5400.1 series. A definition of Tropical Storm/ Hurricane Conditions I through IV is also given, together with the expected status of preparedness and action required to achieve each condition of readiness. Other sources of information on hazardous tropical cyclone weather and readiness action are: Fleet Guide, Pub. 940, Chapter 7; OPNAVINST 3140.24 series; and CINCLANTFLTINST 5400.2 series.

3.2 TUG AVAILABILITY

There is only one tug company providing service to the Savannah Harbor. The Atlantic Towing Company operates seven tugs and performs towing, docking, undocking and shifting services for vessels in Savannah Harbor and vicinity. The seven tugs are adequate for normal operations, but would be scarce during heavy weather conditions.

3.3 HURRICANE BERTHING

There are no berths in Savannah Harbor which are considered suitable for Navy use during a hurricane. The extensive marsh to the north, east and southeast of the harbor offer little protection against hurricane-force winds. In a normal day the tidal range is 7.8 ft at the upper end of the harbor and 6.9 ft at the lower end with current velocities averaging 5 kt or more. During a hurricane, storm surge could propagate up the channel, causing tides to rise several feet above normal, and displace vessels from their berths. Should a Navy vessel that is in port for repairs be unable to evade at sea, it may attain some safety by proper tie-down in a slip at the Ocean Terminal. There are constraints at the Ocean Terminal, since slips are limited in both length (940 ft) and beam width (106 ft).

The Coast Guard facility does not have berthing suitable for use during a hurricane. The Coast Guard moves their vessels to semi-protected places, such as the Middle River or Little Back River, whenever a tropical cyclone threatens.

3.4 HURRICANE ANCHORAGES

There are no designated hurricane anchorages in the Savannah Harbor. The soft bottom conditions, swift current and flat terrain surrounding the river channel make any attempt at river anchorage hazardous. For those ships able to hold anchor in the river during passage of a tropical cyclone, either storm debris or vessels torn loose from their moorings could create new hazards. Vessels have anchored offshore near the sea buoy to ride out storms, but here ships are completely exposed to heavy seas.

4. TROPICAL CYCLONES AFFECTING SAVANNAH

4.1 CLIMATOLOGY

For the purpose of this study, any tropical cyclone that approached within 180 n mi of Savannah is considered a threat. It is recognized that a few tropical cyclones that did not approach within 180 n mi may have affected Savannah in some way, so to some extent this criterion is arbitrary.

Track information on Atlantic tropical cyclones is available as far back as 1871*. Data for the 109-year period 1871-1979 are used for all but one of the climatological figures. The exception is the seasonal distribution of tropical cyclones and hurricanes (Figure XVIII-2); center or maximum wind information was not available for storms prior to 1899, so this distribution is based on 81 years of data (1899-1979).

Although tropical cyclones have occurred in the North Atlantic during all months of the year, most tropical cyclones threatening Savannah have occurred from June through November. Of the 116 tropical cyclones that threatened Savannah in the 81-year period (approximately 1.4 per year), 85 (73%) occurred in the months of August through October with the peak threat in September (see Figure XVIII-2). The occurrence of tropical cyclones of hurricane intensity (winds $\geq$64 kt when within 180 n mi of Savannah) also has a marked peak during these months, with 30 out of 36 (83 %) having occurred from August through October (1899-1979).

Figure XVIII-3 displays the tropical cyclones as a function of the compass octant from which they approached Savannah. The circled numbers indicate the number of cyclones that approached from that octant. The open numbers represent the same information as a percentage of the total. The majority of the tropical cyclones that affected Savannah approached from south and southwest. Hence, most of the storms had moved overland before reaching the Savannah area.

Tropical cyclones following an overland track tend to be considerably weaker than those that approach from directly off the ocean. When a tropical cyclone tracks onshore, it moves away from its primary source of heat energy (the ocean). The reduction in heat energy for the storm system, along with the increase in friction produced by the land surface, causes the storm to weaken in intensity. At Savannah only 25 of the tropical cyclones that affected the area during the years 1899-1979 produced winds of gale force or higher (Table XVIII-1).

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*Track information was obtained from the National Climatic Data Center, Asheville, NC.

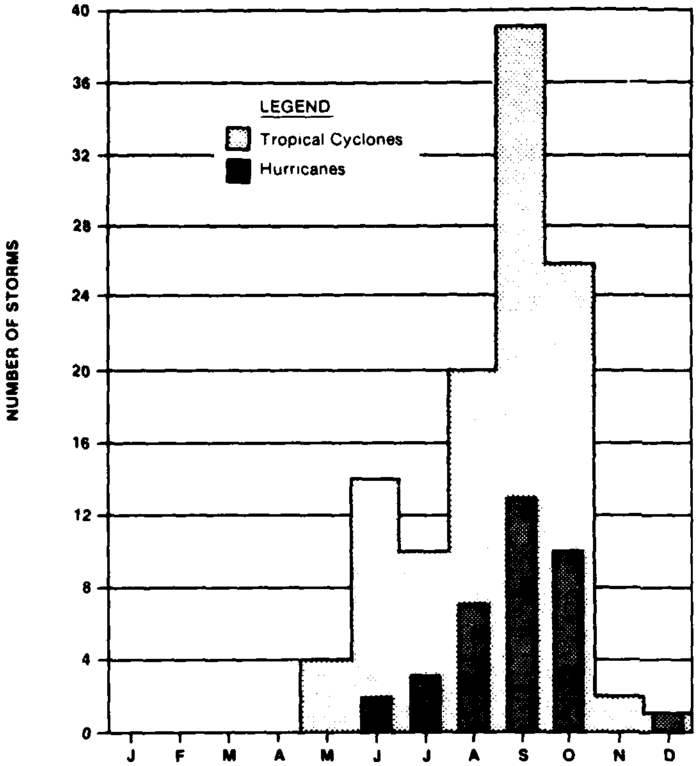

Figure XVIII-2. Monthly totals of tropical cyclones and hurricanes passing within 180 n mi of Savannah during the period 1899-1979. The area of light shading represents monthly totals of tropical cyclones while the dark shaded columns represent the monthly totals of hurricanes (winds ≥64 kt when within 180 n mi of Savannah).

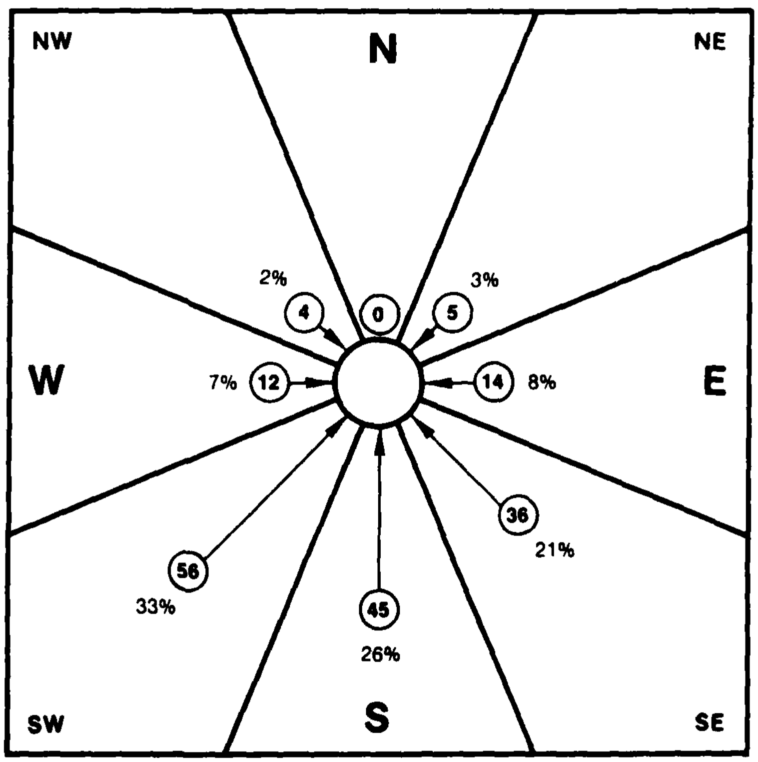

Figure XVIII-3. Directions of approach of tropical cyclones toward Savannah (1871-1979) which passed within 180 n mi. Circled number indicates the number of tropical cyclones that approached from that octant; the percent figure is the percentage of the total sample that approached from that octant.

Table XVIII-1. Observed winds of tropical cyclones that approached within 180 n mi of Savannah. Only 22 percent of the tropical cyclones affecting the area during the years 1899-1979 produced local wind speeds of gale force or higher.

Time Period	OBSERVED WIND MAXIMA			TOTAL
	<22 kt	22-33 kt	≥34 kt	
1899-1910	11	7	4	22
1911-1920	3	5	5	13
1921-1930	3	2	4	9
1931-1940	3	5	4	12
1941-1950	5	6	5	16
1951-1960	7	5	2	14
1961-1970	12	4	0	16
1971-1979	12	1	1	14
1899-1979	56	35	25	116

In addition, the Georgia coastline is situated at a latitude that corresponds with the mean latitude of the axis of the subtropical ridge, and the orientation of the coastline is parallel to the mean storm track. Thus, most hurricanes have tended to move parallel to the coastline while remaining well offshore, or they have crossed over land and lost much of their energy before reaching Savannah.

Figures XVIII-4 through XVIII-8 depict statistical summaries of threat probability based on tropical cyclone tracks for the years 1871-1979. The data base is presented seasonally with light lines representing "percent threat" for the 180 n mi circle surrounding Savannah, and the heavy lines representing approximate approach times to Savannah based on climatology.

For example, in Figure XVIII-6 a tropical cyclone located near 22°N, 72°W in August has about a 40 percent chance of passing within 180 n mi of Savannah and if the speed remains close to the climatological normal for this month, it will reach Savannah in about 3-4 days.

The five figures depicting tropical cyclone threat probability reveal seasonal changes in the orientations of the threat axes and the speeds of advance of tropical cyclones toward Savannah.

For late and early season storms, those occurring from November through June, the primary threat axis runs from the Gulf of Mexico across northern Florida (Figure XVIII-4). As noted earlier, storms that approach Savannah with an overland track are much weaker. None of the late season storms have generated sustained gale force winds in Savannah.

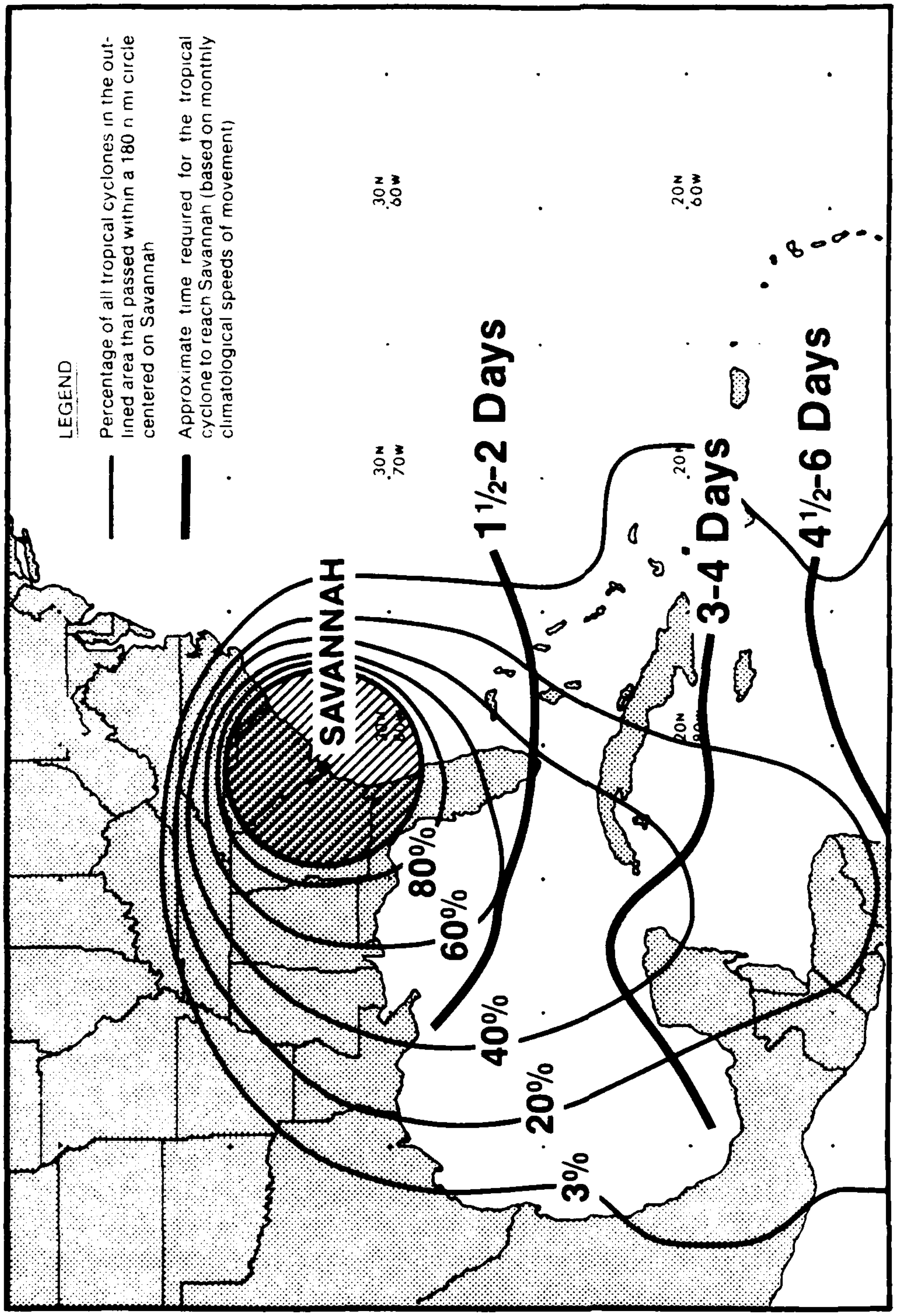

Figure XVIII-4. Probability that a tropical cyclone will pass within 180 n mi of Savannah for the months November through June. (Based on data from 1871 to 1979.)

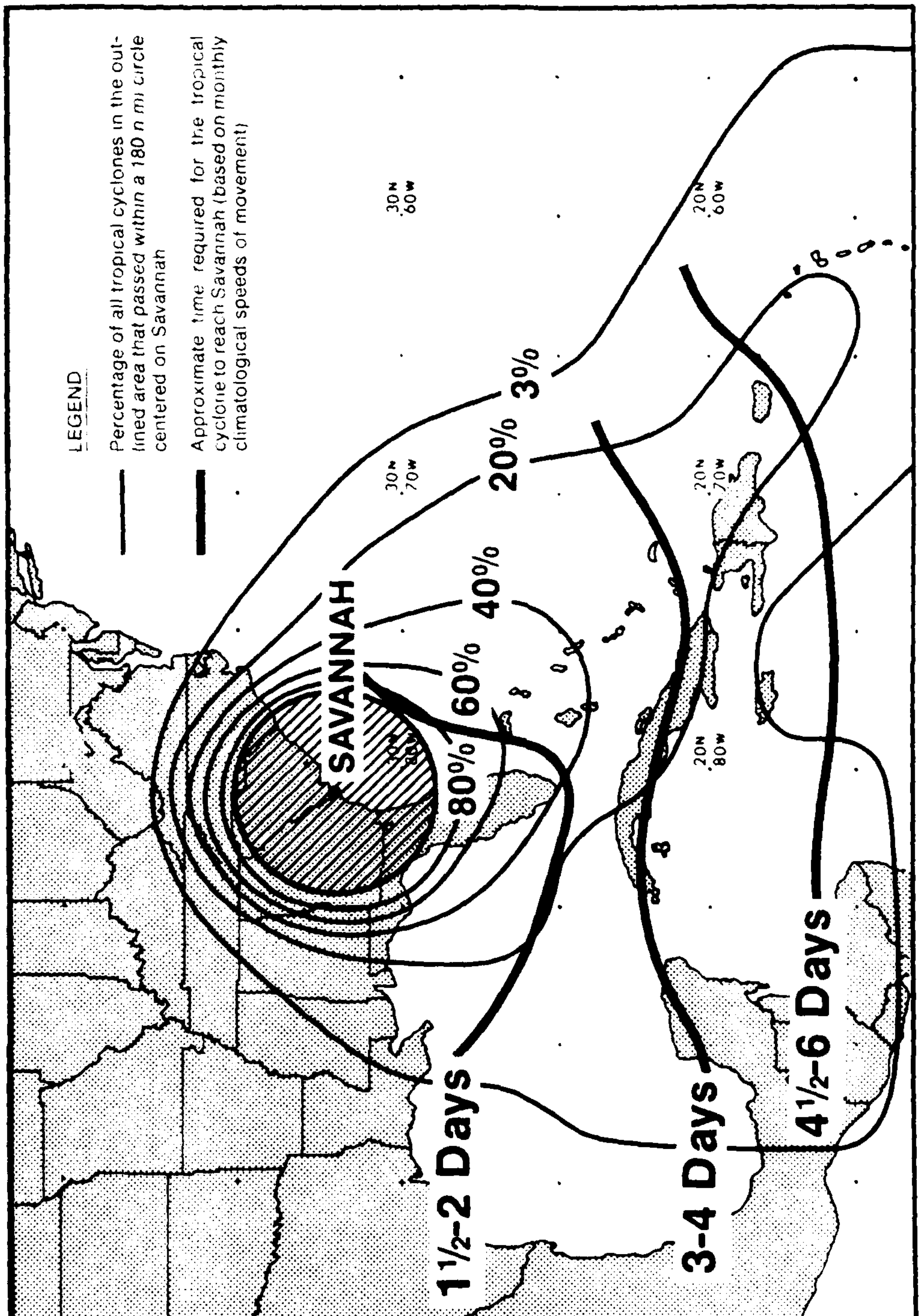

Figure XVIII-5. Probability that a tropical cyclone will pass within 180 n mi of Savannah for the month of July. (Based on data from 1871 to 1979.)

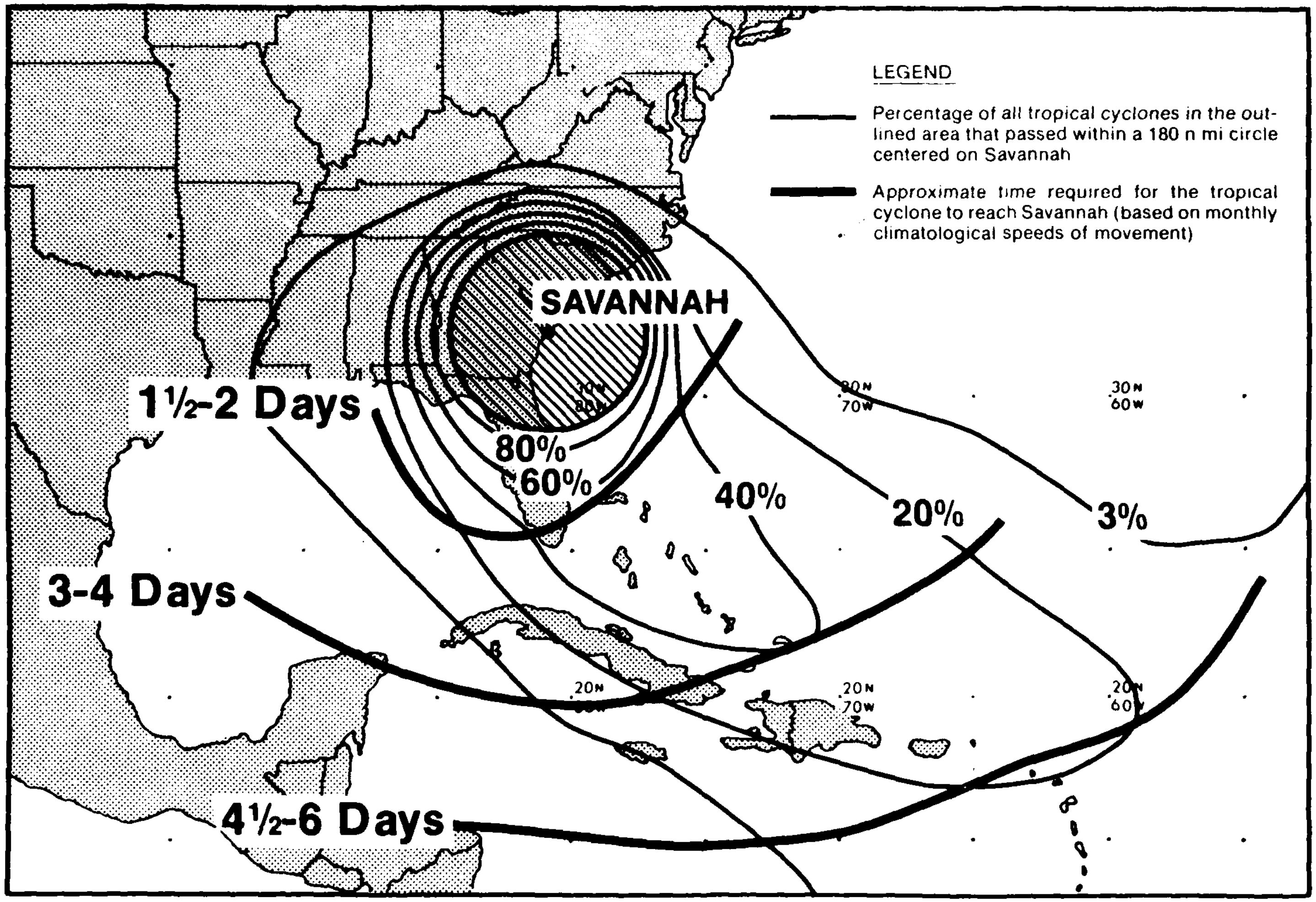

Figure XVIII-6. Probability that a tropical cyclone will pass within 180 n mi of Savannah for the month of August. (Based on data from 1871 to 1979.)

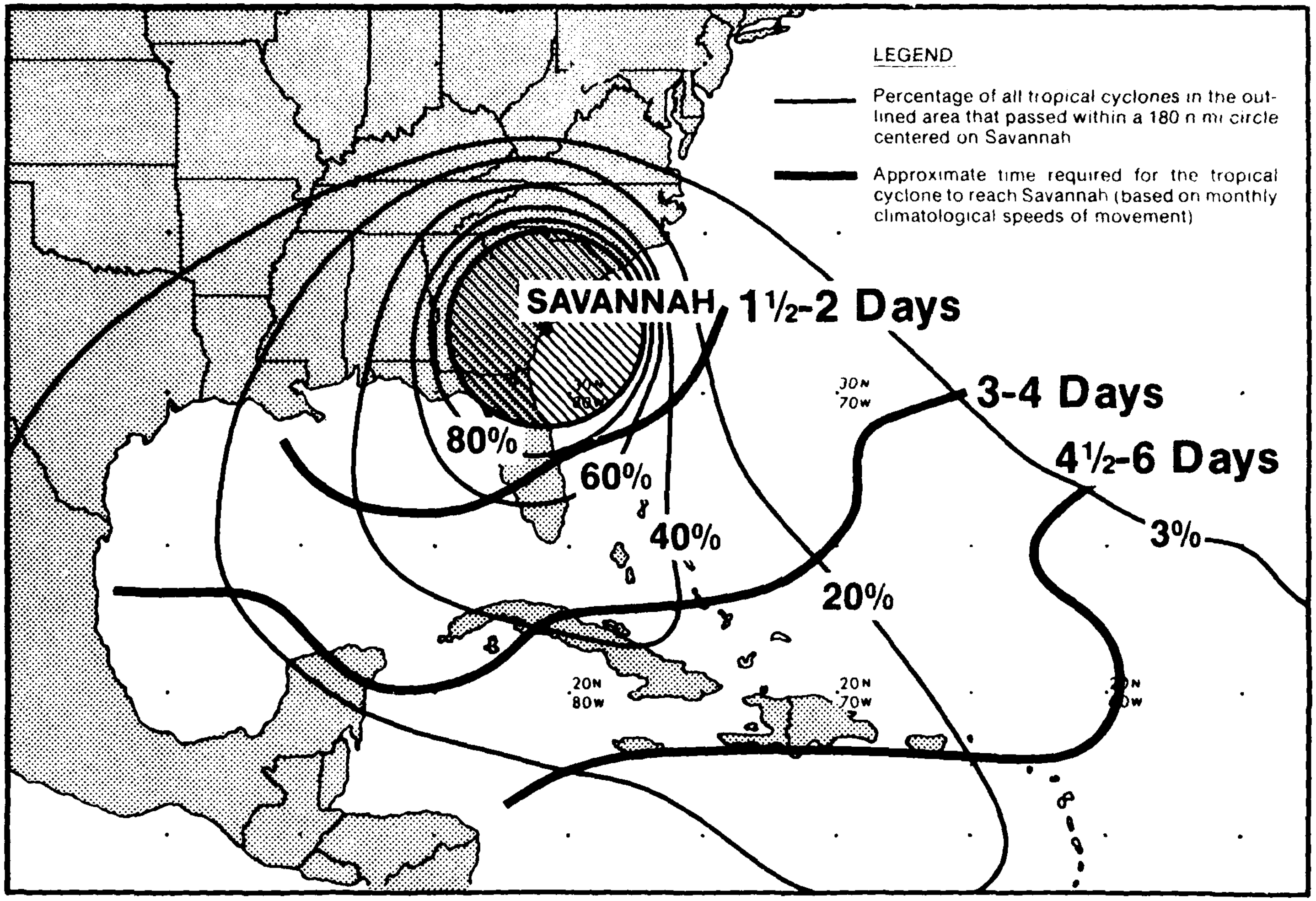

Figure XVIII-7. Probability that a tropical cyclone will pass within 180 n mi of Savannah for the month of September. (Based on data from 1871 to 1979.)

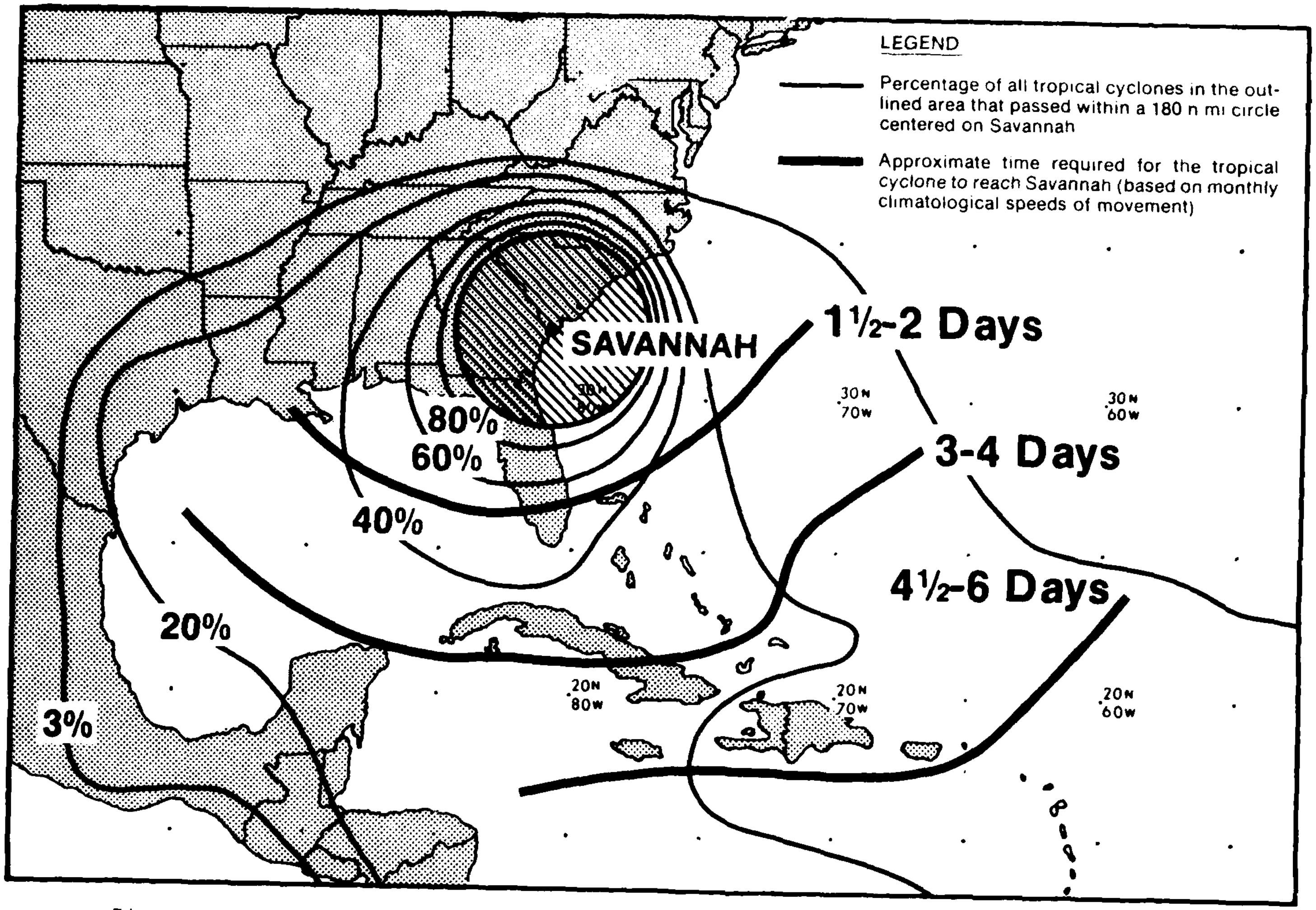

Figure XVIII-8. Probability that a tropical cyclone will pass within 180 n mi of Savannah for the month of October. (Based on data from 1871 to 1979.)

In July the threat axis of storm probability begins to shift in the direction of the West Indies (Figure XVIII-5). As North Atlantic sea surface temperatures increase in August, the axis extends even further eastward toward the Cape Verde Islands (Figure XVIII-6).

By September the axis begins to retrograde, again orienting toward the West Indies but also extending south over the Caribbean Sea (Figure XVIII-7). The seasonal shift of the threat axis continues westward in October (Figure XVIII-8).

4.2 HURRICANE PASSAGE RECORDS

4.2.1 Weather Station Locations

The National Weather Service is the primary source for weather data in Savannah. The first government weather office was established there in December 1870, and continuous records have been maintained ever since.

From 1870 to 1930 the weather office was housed in six different buildings adjacent to the harbor. The office then moved to Hunter Field (1930-50) and to Travis Field (1950 to present), although the wind instruments were kept downtown until May 1945.

Elevation of the wind instruments has varied considerably from an initial height of 67 ft above ground level (AGL) at the first site on Bay Street to a maximum elevation of 194 ft AGL atop the National Building on Bull Street (1909-1932).

In recent years elevations have ranged from 38 ft AGL at Hunter Field to the current 20 ft AGL at Travis Field. Records for the local wind data have not been adjusted to a standard reference height. Because of the difference in site and elevation of the instruments, observations prior to 1945 may be artificially high. With the inland location and lower anemometer height since May 1, 1945, it is likely that more recent observation do not adequately reflect conditions along Savannah Harbor. Winds in the harbor have probably been higher than those at the more sheltered inland site.

Tide gauges have been utilized along the Savannah River since the early 1900s. Currently, tide gauges are maintained and operated by both the U.S. Army Corps of Engineers and the National Ocean Service.

4.2.2 Weather Conditions During Hurricane Passage

During the 81-year period 1899-1979, 36 tropical cyclones of hurricane intensity passed within 180 n mi of Savannah. Most of these hurricanes tended to move parallel to the coastline while remaining well offshore, or they approached Savannah after landfall along the Gulf Coast, losing much of their energy before reaching Savannah.

Two notable exceptions occurred during modern times and both caused sustained hurricane force winds at Savannah. One occurred in October 1947, when the eighth storm of the season made a unique left turn near 32°N latitude and 74.5°W longitude approximately 350 n mi east of Savannah. The hurricane then traveled almost due west during the next 36 hours and, on the morning of the 15th, the core of the storm moved onshore eight miles southeast of Savannah. Maximum winds in Savannah were of hurricane force for two hours, with gusts to 74 kt. According to the report filed by the Savannah Weather Office there was "considerable commodity damage in warehouses (along the river) ... and high tides did the most of it." Barometric pressure reached an all-time low for Savannah at 974 mb during the passage of this hurricane. (A new pressure record of 970.3 mb was set during Hurricane David in September 1979, but maximum sustained surface winds were only 38 kt during this storm.)

The other major exception occurred in August 1911 when the hurricane, that approached Savannah from the southeast, slowed considerably in its forward motion before landfall. Winds increased to gale force on the evening of the 27th, then mounted to hurricane strength for nine consecutive hours during the morning of the 28th. The highest five-minute sustained wind speed was 77 kt. Even after the hurricane eye moved onshore, gale force winds continued until the early morning hours of the 29th. The account provided by the local weather office stated that "the greatest damage was sustained by the shipping interests."

In recent times only three tropical cyclones have generated sustained winds of gale force in Savannah: Flossy in 1956, Gracie in 1959, and David in 1979. Gale force conditions were of short duration and sustained winds did not exceed 50 kt in each storm. Table XVIII-2 and Figure XVIII-9 provide additional information on local conditions during these tropical cyclones and data on tropical cyclones that generated gale force conditions in Savannah during the period 1940-1979.

4.3 WAVE ACTION

The port facilities of Savannah Harbor are protected from extreme wave action because of their inland location. Water depths in the river channel are relatively shallow, being maintained at approximately 30 to 40 ft MLW by the dredging operations of the Corps of Engineers. In an extreme case, wave heights in the Savannah Harbor might reach three to four feet during a hurricane. Strongest wave action could be expected to occur whenever a hurricane approaches Savannah from the Atlantic and surface winds associated with the hurricane circulation are steady from the east to the northeast.

Table XVIII-2. Features of tropical cyclones, 1940-1979, which produced gale force conditions in Savannah. Tide heights were based upon data provided by the Corps of Engineers.

TROPICAL CYCLONE DATA					RELATED WEATHER IN SAVANNAH AREA			
Name	Date	SOA (kt)	DIR/CPA (n mi)	CNTR (kt)	Maximum Wind (kt)	Gusts (kt)	Precip (in) Total Storm Period/Max 6 Hours	Tides (Feet Above MSL
	8/11/40	9	SE 13	63	SSW 48	63	3.05/0.98	7.4
	10/19/44	13	SW 34	58	NE 37	-	7.87/6.77	5.2
	10/8/46	16	SW 126	58	S 37	42	4.25/2.94	5.1
	10/15/47	12	SE 8	83	NE 67	74	1.52/0.66	7.7
	8/28/49	13	S 90	56	SE 37	45	4.32/3.08	6.5
Flossy	9/24/56	14	SW 62	56	SW 34	43	3.76/2.11	5.2
Gracie	9/29/59	14	NE 45	86	WNW 45	51	3.94/2.45	6.1
David	9/4/79	11	N 24	65	W 38	50	7.39/3.03	6.5

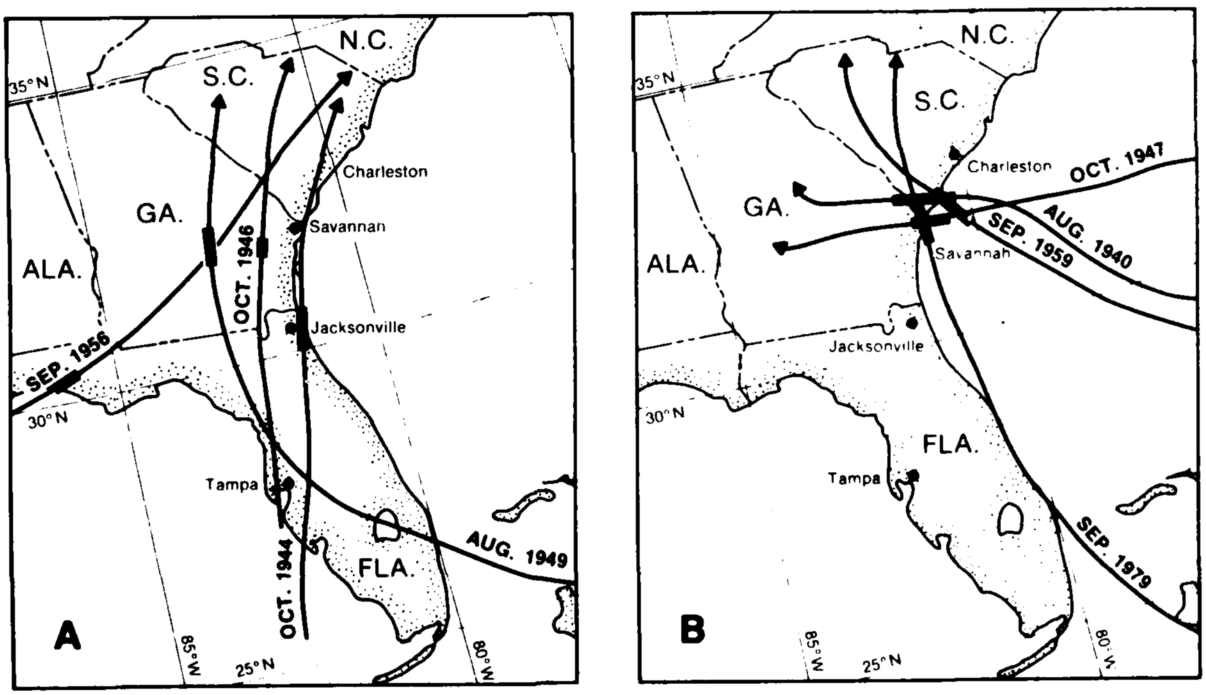

Figure XVIII-9. Eight tropical cyclones have produced sustained winds of gale force in Savannah since 1940. Four of these events have occurred with decaying storm systems which had tracked overland (A). The strongest winds and highest tides in Savannah have been associated with those tropical cyclones which have moved from the east or east-southeast, as the October 1947 hurricane (B). The heavy lines superimposed on the storm tracks represent the center position during the time period that wind conditions of gale force or higher were recorded in Savannah. At other times sustained wind speeds in Savannah were below 34 kt.

4.4 STORM SURGE AND TIDES

Historically, hurricane-induced storm surge has had a significant effect on the Savannah Harbor area. Water levels of one to two feet over the piers have been observed along the older sections of Savannah Harbor. The highest tides that have occurred since the establishment of tide records in 1912 were those generated by the October 1947 and August 1940 hurricanes. Tides produced within the harbor by these tropical cyclones were 4.1 and 3.6 ft, respectively, above mean high water. According to reports from the Weather Bureau and the Savannah News, ship berths and warehouses along the waterfront sustained considerable damage from the storm surge and wave action associated with the October 1947 hurricane. In contrast, available records for the August 1940 hurricane indicate only minimal damage in Savannah Harbor.

Perhaps as important as the height of the tide is the rate at which water levels can change whenever a storm surge does propagate up the Savannah River. During the hurricane of 1911, many vessels inadequately prepared for extreme and rapid changes in the tide, broke from their moorings and either sank or were carried into the marsh.

5. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for disaster preparedness by Navy ships and specific instructions to Navy vessels in Savannah are given in SOPA (ADMIN) CHASINST 5400.1. SOPA will direct action be taken by Navy ships present.

With the approach of a hurricane, the decision to evade or remain in port must be made. Evasion rationale should be based on consideration of four general factors:

(1) Vessel characteristics
(2) Harbor conditions and available berthing
(3) Most recent hurricane warning forecast
(4) Storm climatology/history.

Individual vessel factors are best determined by those responsible for each vessel. Besides vessel seaworthiness, considerations include such factors as anchorage or moored location, and tug and/or pilot needs. The interpretation of harbor and climatological factors are addressed in the following section.

5.1 EVASION RATIONALE

In response to the threat of an approaching hurricane, the general course of action for seaworthy Navy vessels in Savannah Harbor would be to evade at sea. Arguments for this course of action are: (1) there are no terrain features that could provide shelter from extreme winds; and (2) there are few berths and no anchorages in the harbor that are suitable for use during a hurricane.

As noted in Para. 1, the marsh system is extensive in sectors to the north through southeast of the harbor. Vessels remaining in port therefore could be openly exposed to damaging winds. There is also the chance that a storm surge could significantly increase water levels in the river, creating additional hazards for those vessels tied into a berth or moved in the river channel.

The recommended sortie action is to steam due east, clearing the shoals along the continental shelf, then to continue evasion as dictated by the storm.

Ships undergoing repairs may have to remain in port if the nature of the repair operations affects the ship's performance. If a hurricane should develop close to shore or accelerate in its forward motion and the vessel is in the harbor when Hurricane Condition Two is set (hurricane force winds within 24 hours), the captain should consider securing the ship in the harbor rather than risk being caught in strong winds and/or high seas.

A ship's captain must make a decision to evade or remain in Savannah Harbor at a time when the probability that the hurricane will actually strike the harbor is low, at least 36-48 hours before the onset of destructive force winds.

5.1.1. Evasion Timing

Timing of any evasion is always extremely critical. The decision for early sortie from Savannah, 36-48 hours before the onset of destructive force winds, is mandated by the combination of the coastline orientation, the normal track of tropical cyclones along the U.S. Atlantic coast, and characteristics of Savannah Harbor.

The orientation of the coastline limits evasion directions. Taking a southerly course could position the ship in an area with limited maneuvering space. Taking an easterly course from Savannah before an approaching hurricane results in crossing the track of storms that could potentially recurve. Once across the track, ships are in the hurricane's dangerous semicircle. Therefore, it is important to sortie early to steam far enough to the east to clear this dangerous semicircle before turning south.

Several berths in Savannah Harbor that are suitable for Navy use are located above the Eugene Talmadge Bridge. Because the clearance underneath this bridge is only 136 ft during mean high water, some vessels may need to schedule sortie for a time window around low tide. The major problem with timing, however, comes with avoiding ebb tide when the downstream current prohibits maintaining steerageway within reasonable speeds around the turns. From this consideration, flood tide is the optimal departure time.

Tropical cyclones that have affected Savannah have exhibited a speed of advance (SOA) which generally ranges from 8 to 16 kt. Figures XVIII-4 through XVIII-8 show that the climatological position for the average storm 48 hours from Savannah is an arc which crosses central southern Florida. The 72 hour position is represented, in general, by an arc from the Yucatan Peninsula across Cuba, thence northeast to the 65° west meridian.

5.1.2 Storms Approaching from Over Water

Storms approaching Savannah from the east to southeast constitute the prime threat, and mid-August to mid-October is the time this type of storm is most likely to occur. It is important to note that, while many intense tropical cyclones move from these compass directions, few adversely affect the Savannah area. As discussed earlier, the primary reason for this is that storms are often beginning to recurve as they approach the Georgia coast. Hence, ships must sortie at an early time to ensure clearance of the right front quadrant of an approaching tropical cyclone.

5.1.3 Storms Approaching from Over land

Storms approaching from over land (landfall on either the Florida Gulf or Atlantic coasts) can pose problems for Savannah. Several such storms have generated sustained winds exceeding gale force, with the tropical storm of October 1910 producing a one-minute maximum of 61 kt. Tropical cyclones with an overland track, however, rarely create abnormally high tides in Savannah Harbor.

5.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy vessels when winds of greater than 50 kt are expected. If sudden storm intensification makes a sortie dangerous, berthing at the Georgia Ports Authority terminals may be used. When evasion is contemplated, the importance of assessing the threat posed by the storm and acting quickly to retain flexibility is strongly emphasized.

Most berthing spaces used by Navy vessels in Savannah Harbor are above the Eugene Talmadge Bridge. Because the height of the bridge is only 136 ft above mean high water, ships may have to wait for low tide to leave the harbor. For ships below the bridge the major consideration is avoiding the strong outbound current associated with ebb tide. These factors and the nature of the coastline make an early departure imperative if a real threat is in the offing.

The decision to sail poses a new problem of the best course of action once at sea. The commanding officer, with his detailed knowledge of ship and crew, must judge each threat on its own merits, but the following subparagraphs describe the most likely threat situations and recommended courses of action.

5.3.1 North Atlantic Hurricanes Near the Bahamas

Tropical cyclones approaching from this sector pose the greatest threat for both wind intensity and probability of high storm surges. These storms are also the most difficult to evade since transiting east or northeastward can position the ship in the region into which the storm may move. The likely action of the storm is to recurve to a more northerly path, passing well offshore from Savannah. During August and September, storms near the Bahamas have a higher probability of passing within 180 n mi of Savannah.

If a storm is north of the 110° true radial of Savannah, then the recommended evasion direction is south. For storms south of this radial, the strike probability is higher and therefore the recommended evasion is east from Savannah. Early departure is imperative to either cross ahead of the storm and obtain sea room in which to maneuver toward the east or southeast, or to run to the south clear of any possible turn back to the west or southwest.

5.3.2 North Atlantic Hurricanes South of the Bahamas and East Caribbean Hurricanes

Tropical cyclones approaching from this region have a high probability of passing within 180 n mi of Savannah, particularly from July through September. During other months the climatological probability of tropical cyclone genesis and movement from this area to Savannah decreases considerably. The recommended evasion direction is east then southeast.

5.3.3 Gulf of Mexico and West Caribbean Hurricanes

Tropical cyclones approaching from this area have a moderatel_ high probability of passing within 180 n mi of Savannah, especially during May, June, October and November. Most of the tropical cyclones will pass overland as they approach Savannah and, therefore, few will be likely to generate destructive force winds or to create a storm surge hazard. It should be noted, however, that there have been cases in which tropical cyclones tracked from the Gulf of Mexico across Florida, then skirted the Georgia coast and generated wind gusts in the harbor of more than 50 kt. It is recommended that these storms be closely watched before sortie. If evasion is planned, a southeast departure is advisable. Because some of these storms have crossed over Florida to the Atlantic, caution may require an evasion course further east.

5.4 RETURNING TO HARBOR

After the passage and successful evasion of a tropical cyclone, the vessel returning to harbor may face hazards. There may be sunken wrecks in the channels and damage to the piers. Normal alongside services may be disrupted. There is also a high probability that channel markers and other navigation aids may have shifted position or become otherwise unreliable.

The Coast Guard broadcasts Notices to Mariners, which will contain navigation information for the Savannah River, and should be consulted. If a portion of the river is not navigable for any reason, the Coast Guard Captain of the Port of Savannah will issue closure orders for all vessel traffic. Naval vessels can contact the Coast Guard Captain of the Port directly for navigation information.

5.5 ADVICE FOR SMALL CRAFT

In the Savannah area, small craft should either be removed from the water to positions above projected flood levels, or be taken upstream past the industrial area and bottom moored in protected areas.

There are no recommended small craft hurricane facilities in the main harbor and the harbor area is subject to tidal increases caused by storm surge. The Savannah River is navigable as far inland as Augusta, and by moving a few miles upstream past Drakies Cut or into the Little Back River west of U.S.Highway 17, small craft can avoid extreme tidal changes.

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XIX. PORT EVERGLADES,FL

XIX: CONTENTS

XIX. PORT EVERGLADES, FLORIDA

SUMMARY

Port Everglades is a poor hurricane haven because it is vulnerable to storm surge and high winds, lacks sheltered facilities, and is geographically located within or close to the preferred tropical cyclone tracks for much of the hurricane season. Evasion at sea is recommended for all seaworthy deep-draft vessels when the port is threatened by an intense tropical storm or hurricane.

Located one-half mile inland on the southeast coast of Florida and surrounded by low, flat terrain, Port Everglades is the largest seaport in the area and the state's deepest harbor. It is the home port of the Naval Surface Weapons Center, Fort Lauderdale, and is a major consumer port and cruise ship facility.

The hurricane threat season for Port Everglades is June through November. Months of maximum storm occurrence are August, September, and October, which total 83% of threat activity.

Port Everglades has been threatened by an average of 1.4 *tropical cyclones* per year. About 1 out of 5 tropical cyclones (once every 3 1/2 years) causes sustained winds of gale force in the Port Everglades area and about 1 out of 16 (once every 11-12 years) causes sustained winds of hurricane force. Historically, the most likely direction of storm approach has been from the east.

1. LOCATION AND TOPOGRAPHY

Port Everglades on the southeast coast of Florida about 25 miles north of Miami, Florida, has a man-made harbor and is the largest seaport on Florida's lower east coast. As shown in Figure XIX-1, the harbor has a short entrance channel and is located on the Atlantic Intracoastal Waterway. The entrance channel serves as the main access route to the Atlantic Ocean for thousands of small yachts and other small craft located just north of the port in Fort Lauderdale. The port is two miles from major shipping lanes in the Atlantic.

The terrain surrounding the harbor is typical of the southeast Florida coastal area: low, flat, and seldom reaching over 10 ft elevation. Much of the nearby area is used for industrial purposes, mainly port facilities and petroleum storage, or as a residential area.

This hurricane haven evaluation was prepared by A.J. Compton of Science Applications, Inc. (SAI), Monterey, CA 93940.

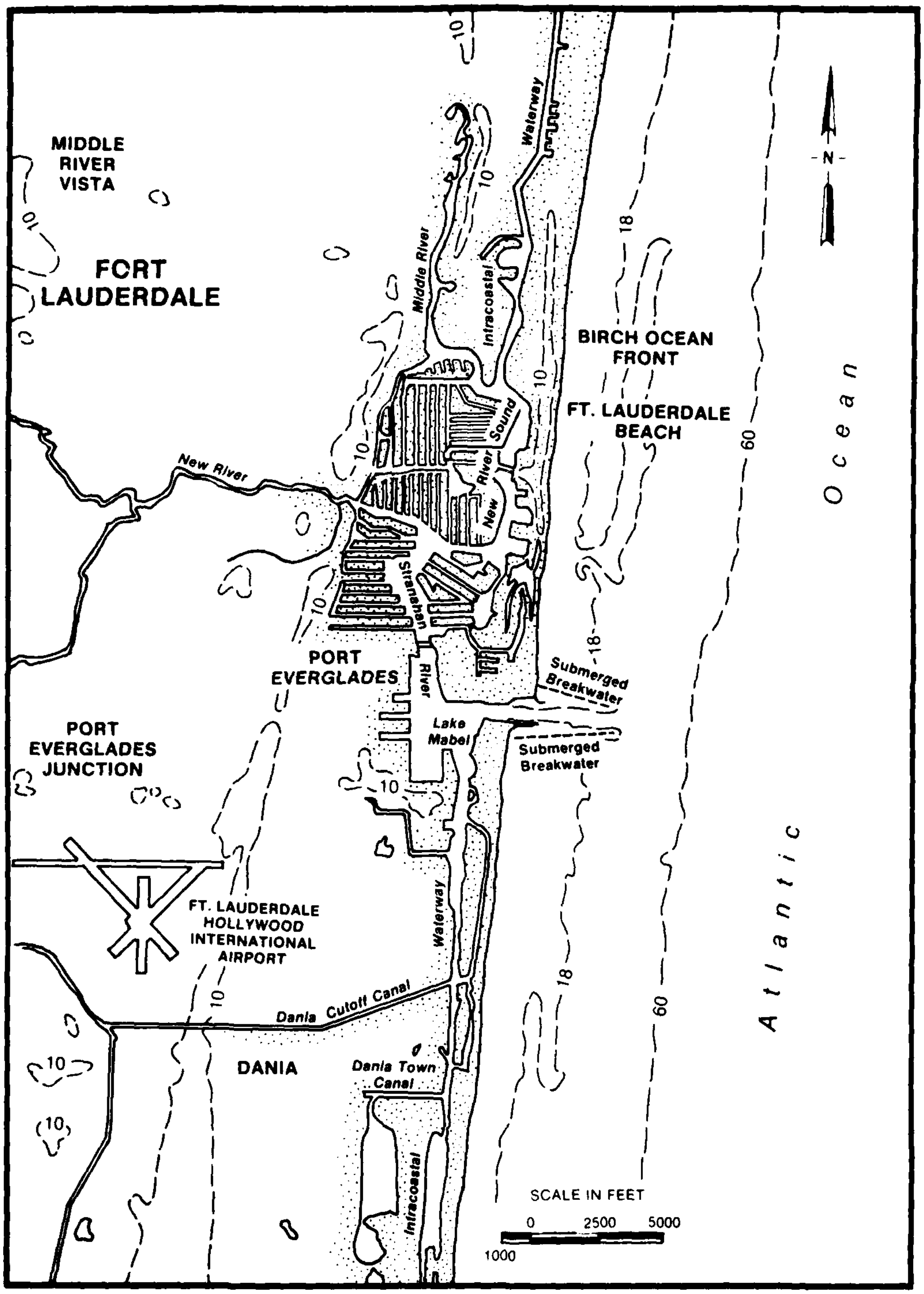

Figure XIX-1. Port Everglades and surrounding communities (heights in ft above mean high water and soundings in ft below mean low water).

The deep water entrance to the port is via a dredged east-west channel that extends from the ocean through a barrier beach into a large turning basin in Lake Mabel (Figure XIX-2). The channel entrance is protected by two rock jetty systems. Inner North and South Jetties are complemented by two outer, submerged, rock breakwaters with tops 10 to 15 ft below mean low water (MLW). The outer breakwaters are about 2,500 ft apart at their shoreward ends, converging to 1,200 ft apart at their seaward ends. These submerged jetties are about 100 ft wide across the top.

A Federal project provides for a 500 ft wide entrance channel of 45 ft depth* that converges at the entrance jetties to 300 ft width and 40 ft depth (MLW). The channel leads into a turning basin with 42 ft depth at the main port facilities. The inner harbor depth is 38 ft (MLW), which makes it Florida's deepest harbor. Northern and southern extensions are of lesser depths at 31 and 37 ft respectively, as shown in Figure XIX-2.

The Intracoastal Waterway passes through the ports turning basin in a north-south direction. A bascule bridge with vertical clearance of 25 ft spans the waterway at the northern terminus of the port.

2. PORT AND HARBOR FACILITIES

2.1 BERTHS FOR DEEP DRAFT VESSELS

Waterfront facilities for deep-draft vessels are along the west side of the turning basin, along the sides of three slips on the west side of the turning basin, along the south and east sides of the south extension of the turning basin, and along the west side of the Atlantic Intracoastal Waterway, south of the turning basin (Figure XIX-2). There are 27 berths for ocean-going vessels at Port Everglades. U.S. Navy ships are assigned berths by the harbor master. Berths for the port are summarized in Table XIX-1.

A total of 22 piers, wharves and docks are located at the port of Port Everglades, and all but two are owned by the Port Everglades Authority. Seventeen of those owned by the Authority are operated by the Harbor of Port Everglades primarily for handling general cargo and petroleum products and as terminals for cruise vessels. Three others are used as marine repair facilities by Tracor Marine.

The two remaining facilities are not part of Port Everglades proper, but are located at Port Everglades. One is the U.S. Coast Guard Station; and the other, county owned, serves as a base for oceanographic research vessels operated by Nova University Oceanographic Laboratory. These two facilities are limited to small vessels by 8-9 ft (MLW) alongside depths.

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*See Notices to Mariners and latest editions of charts for controlling depths.

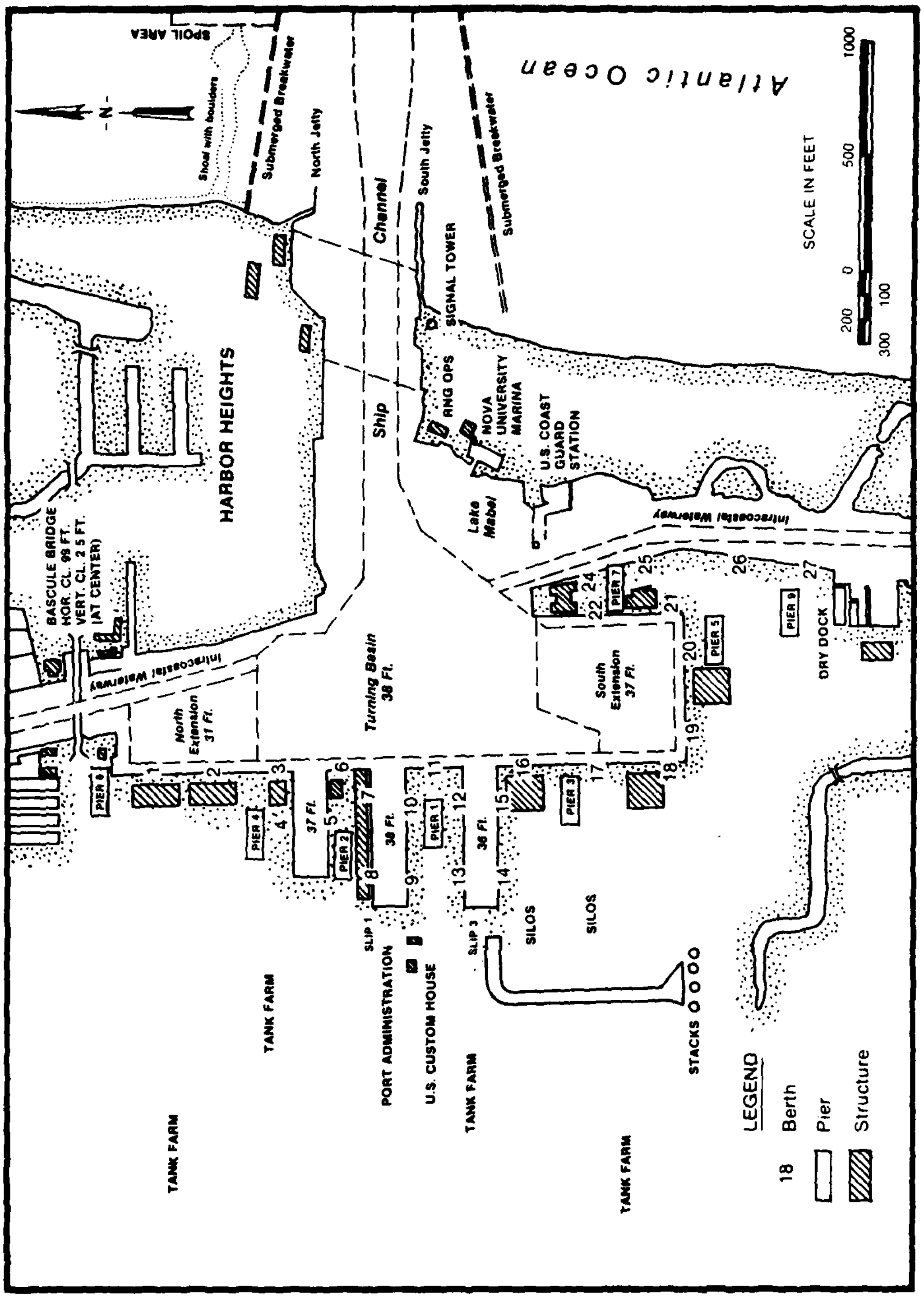

Figure XIX-2. The port of Port Everglades. Alongside depths may vary 1-2 ft from depths shown.

Table XIX-1. Summary of Port Everglades berthing facilities (refer to Figure XIX-2).

Berth Number	Length (Ft)	Depth Alongside at MLW (Ft)	Height of Dock Above MLW (Ft)
1,2,3	1,601	31*	8
4	900	42	8
4A	290	42	8
5	900	42	5
6	380	37	7
7,8	1,200	37	7
8A	300	37	7
9,10	1,200	37	7
11	500	37	7
12,13	1,226	37	7
14,15	1,226	37	8
16,17,18	1,648	37	8
19,20	1,300	34-37	8
21,22	1,325	34	8
23	240	38	8
24-25	1,369	38	8
26-27	1,337	38	8

*Depth for south 301 ft is 37 ft MLW.

Details of berthing facilities at Port Everglades can be found in Port Series No. 16, published in 1982 by the U.S. Army Corps of Engineers. The publication also provides detailed information on marine repair plants and dry-docking facilities. Tracor Marine operates water-front facilities at the port with a 3,200-ton capacity floating dry dock and a 4,270-ton capacity vertical boat lift.

Tugs and pilotage are arranged through the Chief Harbor Master. Pilot services are not mandatory for Navy ships. Two commercial tugs are available on one-hour notice 24 hours a day.

2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

Port Everglades offers little shelter from heavy weather. The low elevations of the surrounding terrain afford limited protection from strong winds. The port's proximity to the coast makes it vulnerable to effects of wind from any direction, but it is most vulnerable to those winds that come from over the open ocean (northeast through southeast) with strength not yet weakened by overland passage. The port is protected from sea and swell, in all directions except the east, by the jetty systems and the narrow, restrictive opening into the harbor.

The prescribed anchorage area at Port Everglades is outside the harbor and north of the channel (within an area designated by the harbor master) just northeast of Port Everglades Approach Lighted Buoy 2. Deep-draft vessels should await the pilot before anchoring off the entrance to avoid possible damage to underwater cables south of the channel and to prevent damage to reefs north of the channel. Much of the area south of the channel is a prohibited anchorage area; the current chart will provide information. Anchoring within the turning basin or channel is prohibited except in cases of emergency. Anchoring offshore to ride out a storm is not recommended.

Facilities are available for hull and machinery repair, but there are no major repair facilities for large vessels; the nearest of these is in Jacksonville, FL. Vessels up to 350 ft long and 80 ft wide can be handled by a syncrolift (4,200-ton capacity) or floating dry dock (1,000-ton capacity) at Tracor Marine shipyard. Two large diesel tugs are available for docking, undocking and towing. A third is available (4 hour call) in an emergency.

2.3 FACILITIES FOR COASTAL AND IN-SHORE VESSELS

Port Everglades is just south of Fort Lauderdale, a large city known as the "Venice of America" because of its many natural waterways and man-made canals that harbor thousands of small craft. The region is a major winter resort area as well as home to hundreds of fishing boats. The Atlantic Intracoastal Waterway serves as an inland water route in the area, with the Port Everglades entrance channel providing access to the Atlantic for small craft. Several thousand yachts are ported during the winter at Fort Lauderdale.

2.4 TIDES AND CURRENTS

The mean tide range at the entrance of Port Everglades is 2.5 ft above MLW. The average tidal current in the entrance is about one knot. In June 1975, it was reported that flood and ebb currents attained velocities of 3 kt and 4 kt respectively; these may have been associated with tropical depression Amy just off the Florida coast. Current swirls of varying characteristics often encountered in the turning basin can make ship handling difficult. Prevailing winds from the southeast and east coupled with a rising tide make the most hazardous conditions.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT PORT EVERGLADES

3.1 INTRODUCTION

A study of previous tropical cyclones' frequency of occurrence, direction of approach, speed of movement, and intensity at Port Everglades provides insight into storm behavior and potential annual threat to the harbor. It should be noted, however, that such a historical overview cannot be a totally reliable guide to predict behavior and impact of present-day storms.

3.2 CLIMATOLOGY

For this study, any tropical cyclone approaching within 180 n mi of Port Everglades is considered to represent a threat to the port.

Tropical cyclones that affect Port Everglades are spawned in several regions of origin, but primarily in the North Atlantic Ocean east of the Lesser Antilles and in the Caribbean Sea. This study will consider only those tropical cyclones that have affected Port Everglades and environs, passing within 180 n mi of the port.

Port Everglades' location on the southeast coast of Florida is significant since it is within or adjacent to preferred storm tracks for much of the hurricane season (Crutcher and Quayle, 1974). Port Everglades' latitude of 26.1N also places the port in the zone (approximately 25N to 35N) of tropical cyclone recurvature, an important factor because the character of a tropical cyclone may change during recurvature by slowing and intensifying.

The official hurricane season for the North Atlantic extends from 1 June to 30 November, but tropical cyclones occasionally occur outside that period; Port Everglades has recorded storms in February, May, and December. During the 109-year period from 1871-1979 there were 156 tropical cyclones that passed within the 180 n mi threat radius for Port Everglades, an average of 1.4 per year. Table XIX-2 shows the monthly totals and percentages. These data are presented graphically in Figure XIX-3.

Figure XIX-4 shows the directions of approach of the 156 storms as a function of compass octant. The numbers in parentheses represent the percentage of cyclones from the 109-year sample approaching from a particular octant. The figure shows that the major threat is from the eastern octant (28%), but also that a high threat exists for all southern approaches. Note that tropical cyclones have approached Port Everglades from all octants.

An evaluation of the frequency and motion of tropical cyclones in the Atlantic (Neumann and Pryslak, 1981) gives those tropical cyclones, that have winds of at least 34 kt and pass within a 2.5° latitude/longitude box containing Port Everglades, an average vector direction of 002° but a low degree of

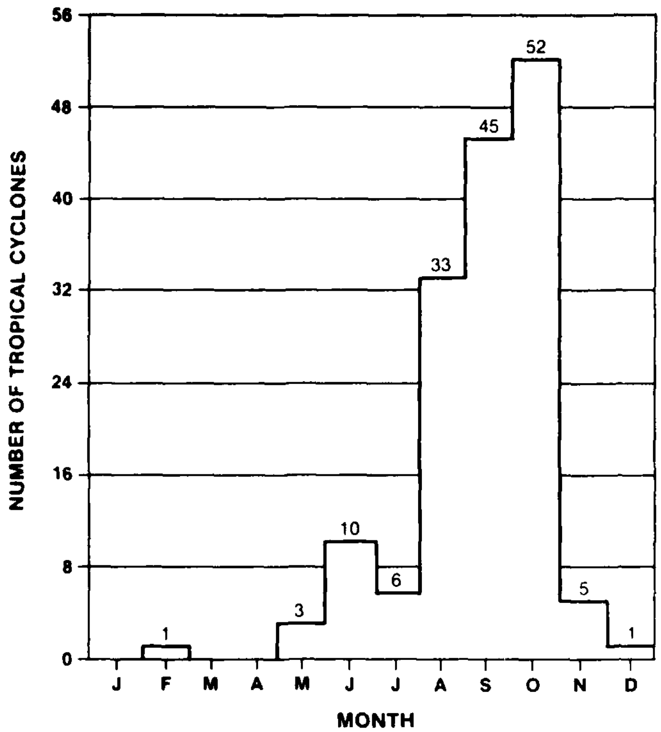

Figure XIX-3. Monthly totals of tropical cyclones that passed within 180 n mi of Port Everglades during the period 1871-1979.

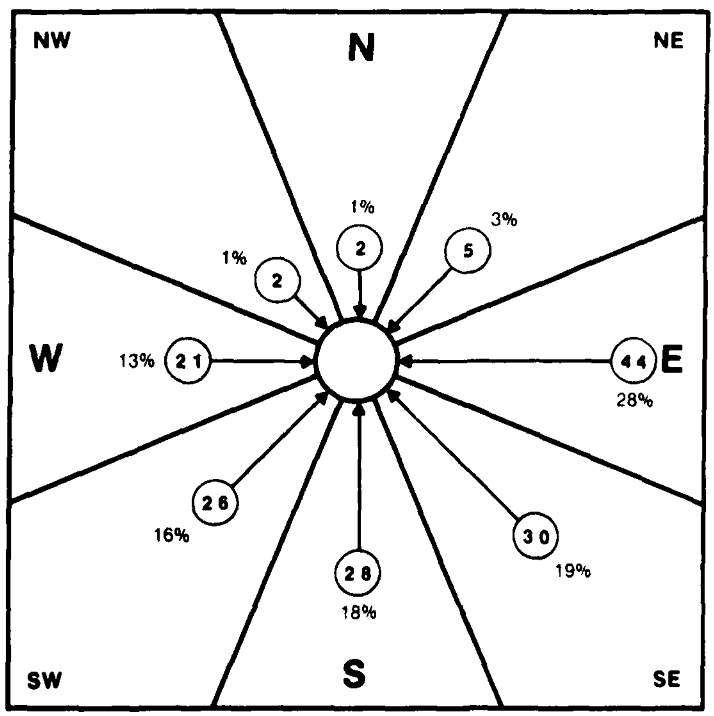

Figure XIX-4. Directions of approach of tropical cyclones that passed within 180 n mi of Port Everglades during the period 1871-1979. Circled numerals show number of storms approaching from each octant, and percentages are percent of total from each octant.

Table XIX-2. Monthly totals of tropical cyclones passing within 180 n mi of Port Everglades during the period 1871-1979.

Month	Number	% of Total
February	1	0.6
May	3	1.9
June	10	6.4
July	6	3.9
August	33	21.2
September	45	28.9
October	52	33.3
November	5	3.2
December	1	0.6

"steadiness." The steadiness is a measure of the probability that the storm will continue in the vector direction.

Tropical cyclones tend to be more intense in certain areas of the Atlantic Basin. A measure of tropical cyclone intensity can be obtained from the ratio of the number of hurricanes to the number of hurricanes and tropical storms combined. For the 2.5° box containing Port Everglades, this ratio is 31:51 -- about 61% of the tropical storms and hurricanes passing through this area have hurricane velocity winds. This compares, for example, to 48% (23:48) for Puerto Rico and 36% for both New Orleans, Louisiana (20:56) and New York, NY (7:19).

Records of the 103 tropical cyclones approaching within 180 n mi of Port Everglades during the 81-year period 1899-1979, for which tropical cyclone intensity data are available, are given in Table XIX-3 by intensity and month of occurrence. Of the 103, 52 (50%) had hurricane velocity winds, and of these 52, 40 (77%) occurred in September and October. Overall, 70 out of 103 (68%) tropical cyclones occurring during the 81 years were of the two strongest maximum intensity categories.

Table XIX-3. Classification of 103 tropical cyclones that passed within 180 n mi of Port Everglades during the period 1899-1979.

Maximum Intensity*	Nov-May	Jun Jul	Aug	Sep	Oct	Totals
Hurricane (≥64 kt)	2	4	6	19	21	52
Intense Tropical Storm (48-63 kt)	1	4	5	3	5	18
Weak Tropical Storm (34-47 kt)	1	2	5	5	5	18
Tropical Depression (<34 kt)	-	3	5	5	2	15
TOTALS	4	13	21	32	33	103

*Intensity values reflect the maximum intensity while in the 180 n mi critical radius of Port Everglades.

PORT EVERGLADES, FL

Figures XIX-5 through XIX-9 are statistical summaries of threat probability for the years 1871 through 1979. Representative summary periods of tropical cyclone frequency, track, and speed are the months of November through May, June and July, August and September, October, and all tropical cyclones of record during the 109-year period.

The thin lines in these figures are percent threat for any storm location. The thick lines are approximate approach times to Port Everglades based on the climatological approach speed for a particular location. For example, in Figure XIX-6, a tropical cyclone located at 22°N and 67°W has about a 40% probability of passing within 180 n mi of Port Everglades and would typically reach the harbor in three to four days.

Figure XIX-5 shows a multiple threat approach for tropical cyclones during the months November through May. It should be noted, however, that these threat axes were derived from only 10 tropical cyclones over the 109-year period. The northeast-southwest threat axis, in fact, represents only two tropical cyclones. The primary threat axis originates in the western Caribbean Sea east of Nicaragua, and extends northward across western Cuba to Port Everglades.

By June and July (Figure XIX-6), the main threat axis has shifted dramatically to the east to a position just north of the islands of Hispaniola and Puerto Rico. Originating east of the Lesser Antilles, the track passes north of the West Indies to strike the Port Everglades area. A secondary threat axis originates in the western Caribbean and passes over western Cuba as previously described.

In August and September (Figure XIX-7), conditions for tropical cyclone cyclogenesis have improved significantly as illustrated by the great increase in frequency of storms (Figure XIX-3) for these months. The main threat axis has shifted south with many of the tropical cyclones originating east of the Lesser Antilles and south of 17°N. The axis extends through the Lesser Antilles and West Indies to Port Everglades. A weak secondary axis originates in the central Caribbean and extends across Cuba to Port Everglades.

By October (Figure XIX-8), the main threat axis has shifted back to the western Caribbean south of Cuba. A secondary extension of this threat axis has its origins in the North Atlantic south of 15°N, east of the Lesser Antilles. This axis extends through the Lesser Antilles, south of the Greater Antilles and joins the main threat axis recurving to the north to Port Everglades.

Figure XIX-9 is a composite analysis of all tropical cyclones for the 109-year period 1871-1979 whose tracks passed within the 180 n mi threat radius of Port Everglades, showing threat probability and time to closest point of approach (CPA) curves for the entire period.

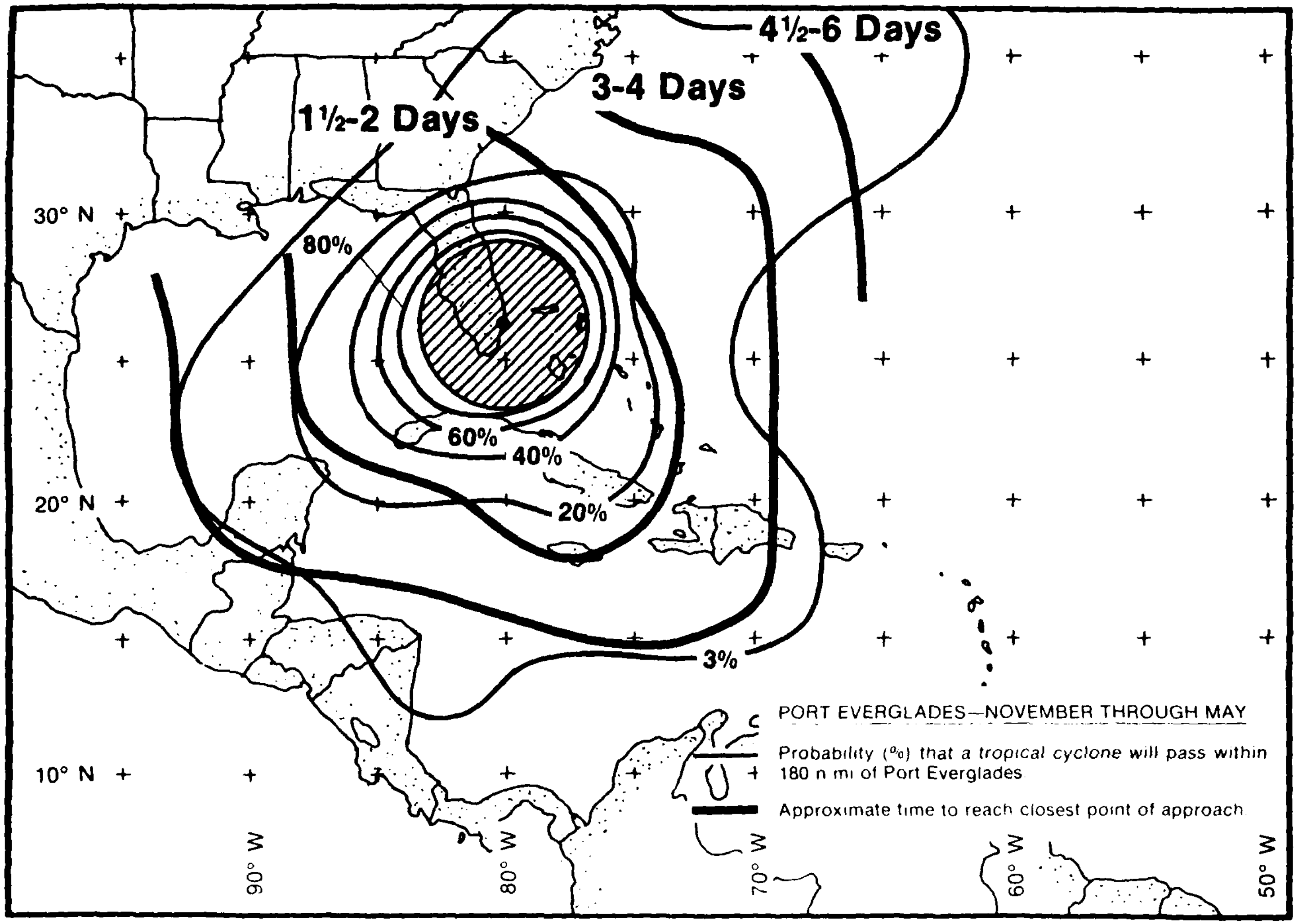

Figure XIX-5. Probability that a tropical cyclone will pass within 180 n mi of Port Everglades (shaded circle), and approximate time to reach closest point of approach during November through May (based on data from 1871-1979).

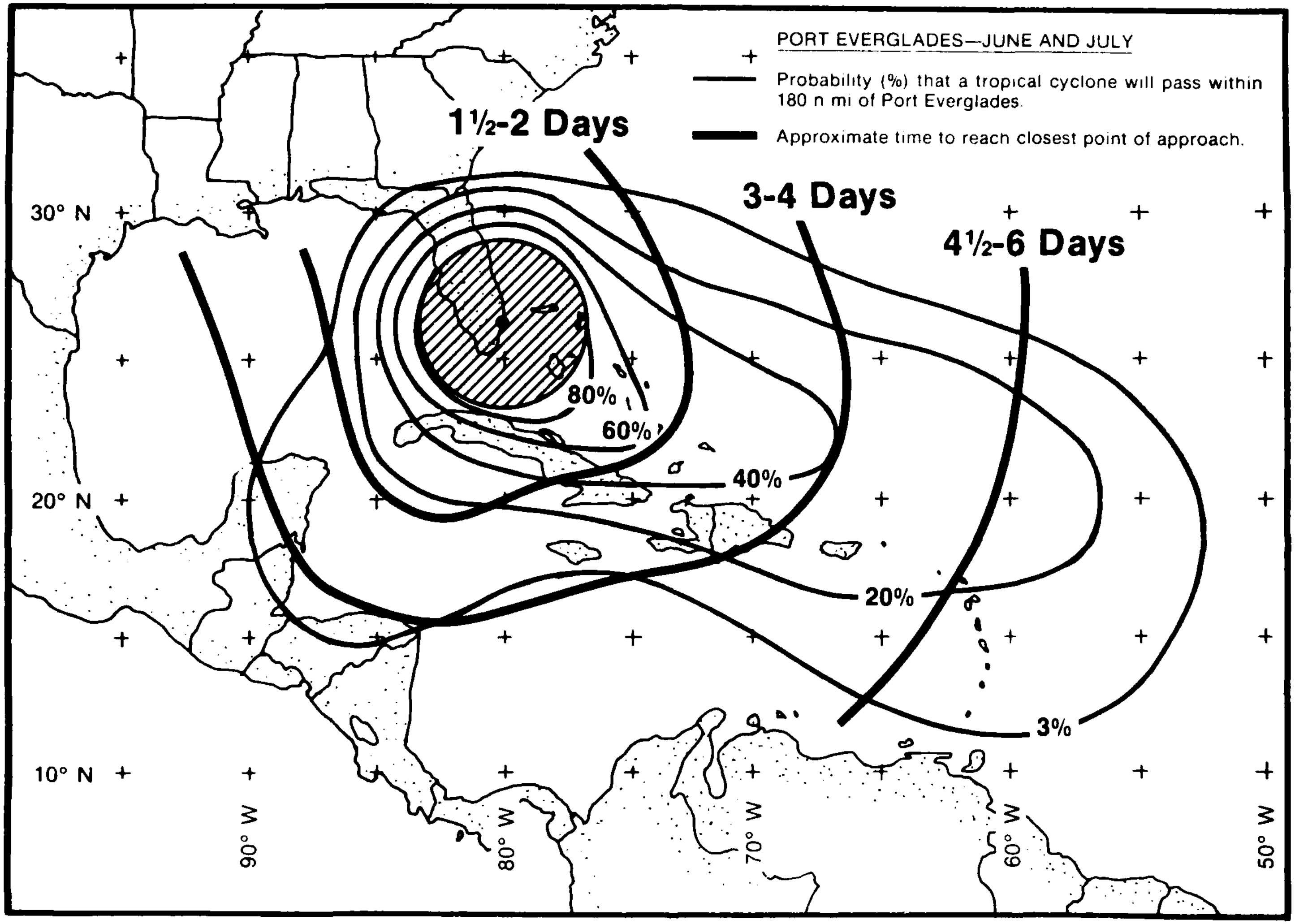

Figure XIX-6. Probability that a tropical cyclone will pass within 180 n mi of Port Everglades (shaded circle), and approximate time to reach closest point of approach during June and July (based on data from 1871-1979).

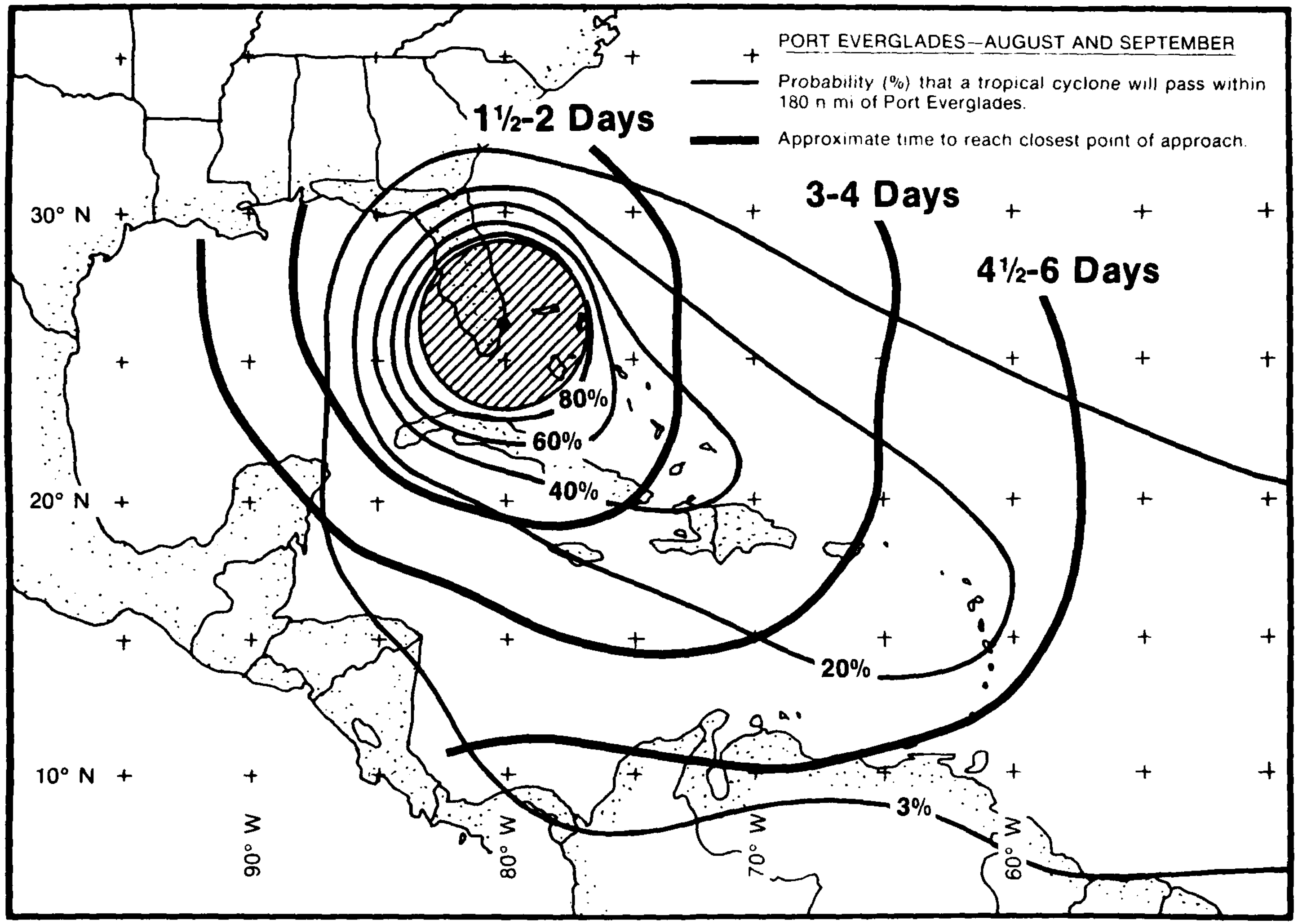

Figure XIX-7. Probability that a tropical cyclone will pass within 180 n mi of Port Everglades (shaded circle), and approximate time to reach closest point of approach during August and September (based on data from 1871-1979).

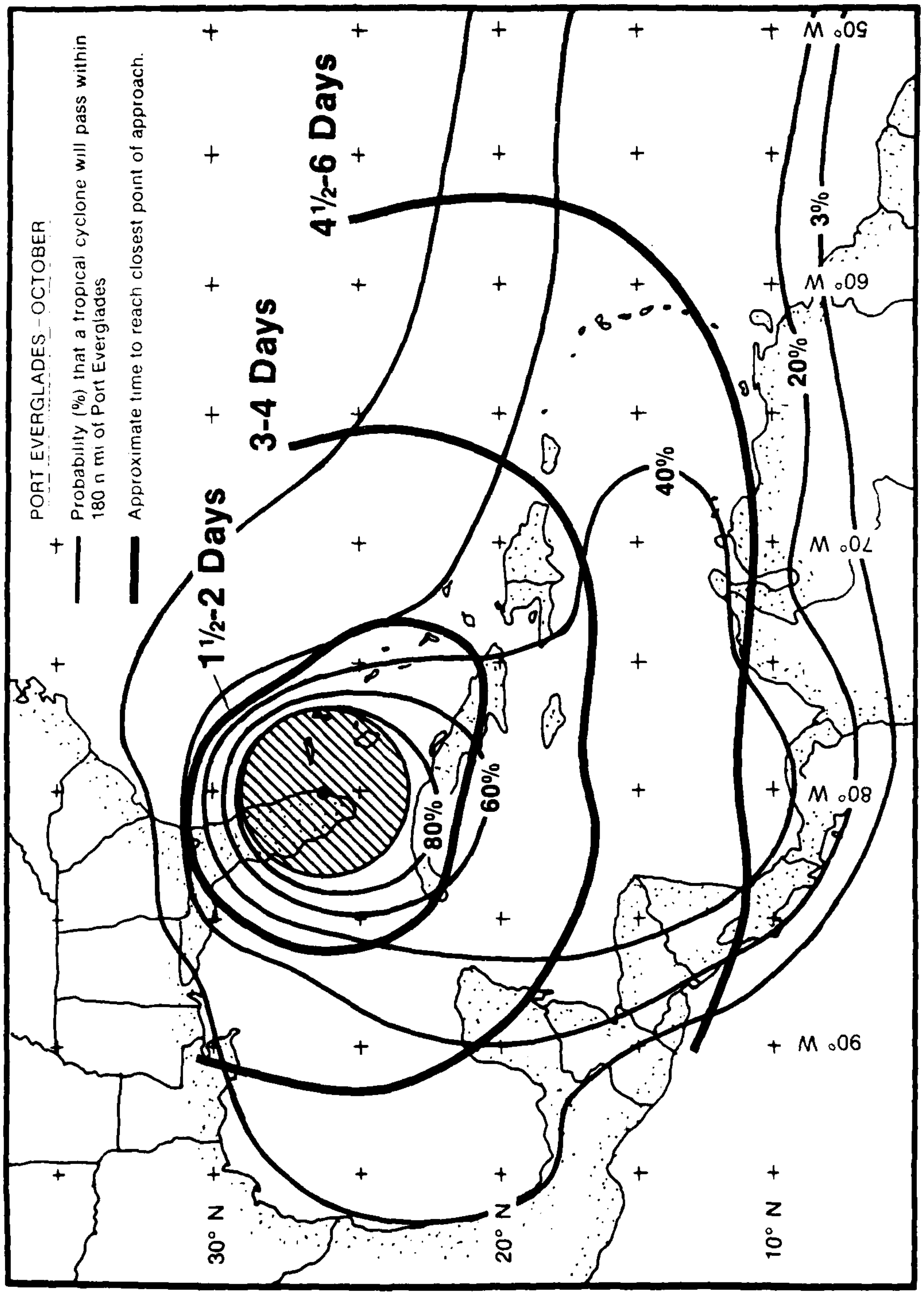

Figure XIX-8. Probability that a tropical cyclone will pass within 180 n mi of Port Everglades (shaded circle), and approximate time to reach closest point of approach during October (based on data from 1871-1979).

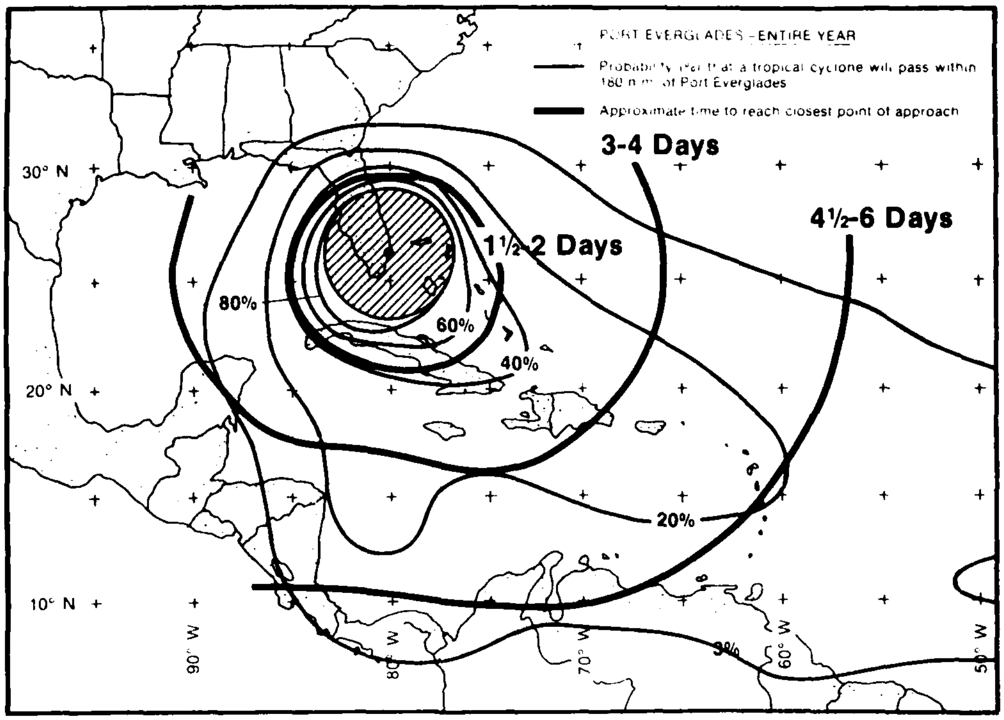

Figure XIX-9. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi of Port Everglades during the years 1871-1979.

3.3 WIND AND TOPOGRAPHICAL EFFECTS

Records of hourly wind data for Port Everglades are available only for the periods 1944-1946 and 1959-1979. These records are from the Fort Lauderdale-Hollywood International Airport (originally a naval air station) located about two miles southwest of the port. The hourly records used in this study were Fort Lauderdale NAS (October 1944-46) and Fort Lauderdale-Hollywood International Airport (October 1959-79).

During the 22-year period, for which wind data are available for Port Everglades, 33 tropical cyclones approached within 180 n mi of the port, an average of 1.5 per year. Of these, 12 were of hurricane intensity ($\geq$64 kt), 8 were tropical storms (34-63 kt), and 13 were tropical depressions (<34 kt). Of the 33 tropical cyclones, six caused sustained winds of 34 kt or greater in the Port Everglades area. Two of the six caused sustained winds of hurricane force and five caused gusts to hurricane force or greater. Based solely on the 1944-46 and 1959-79 wind data, gale force winds can be expected from 1 out of every 5.5 tropical cyclones passing within 180 n mi of Port Everglades, and hurricane force winds can be expected from 1 out of every 16.5 tropical cyclones.

Figure XIX-10 shows the tracks of 13 storms that caused winds of $\geq$23 kt in the Port Everglades area. The inset shows the locations of six storm centers when winds of 23 kt or greater and 34 kt or greater were recorded.

Port Everglades is most vulnerable to wind damage from the open ocean (northeast through southeast quadrant). Terrain around the port has a low elevation in all other directions; wind speed would be reduced only slightly from the greater frictional land roughness. Man-made structures at or near the port would provide some protection.

3.4 WAVE ACTION IN PORT EVERGLADES

Due to its narrow channel opening -- 300 ft wide with 40 ft depths -- and two jetty systems, Port Everglades is well protected from ocean wave activity except from a due-east approach. Large ocean waves from the east could move through the channel and into Port Everglades, but some energy would be lost when the deep water waves felt bottom at channel entry and the diffraction of wave energy occurred inside the harbor.

Maximum wind wave action in Port Everglades is severely restricted due to lack of fetch. Using a maximum of one mile north-south fetch and an average depth of 40 ft, it can be calculated that 35 kt winds would generate 1-2 ft wind waves, 50 kt winds would generate 2-3 ft wind waves, 75 kt winds would generate 4 ft wind waves, and 100 kt winds would generate 5 ft wind waves (U.S. Army Corps of Engineers, 1977). Adding a tidal surge height of 10 ft would increase the 100 kt wind waves to 5.5 ft. East-west fetch is limited to less than one-half mile except for those piers directly opposite the channel opening; these could be subjected to heavy wind/wave action due to the unrestricted over water ocean fetch.

3.4.1 Wave Effects at the Facilities in Port Everglades

Port Everglades is located on the west and south sides of Lake Mabel and the man-made turning basin (Figure XIX-2). Open to the east, the facilities on the west side (primarily Piers 1 and 2) are exposed directly to wind waves from the east with essentially unlimited ocean fetch of 150 miles. Winds waves are restricted to 13-14 ft heights from that direction, due to the reduced bottom depth in the channel and harbor. An average berthing deck height of 7-8 ft above MLW could cause a serious problem, especially if accompanied by an increased water height due to storm surge.

The facilities at the northern and southern extensions of the turning basin are better protected from both wind and waves. Some wind protection is offered by man-made structures located on the piers. Wave action in those areas is limited to much weaker, refracted ocean waves and wind waves with limited fetch generated within the port area.

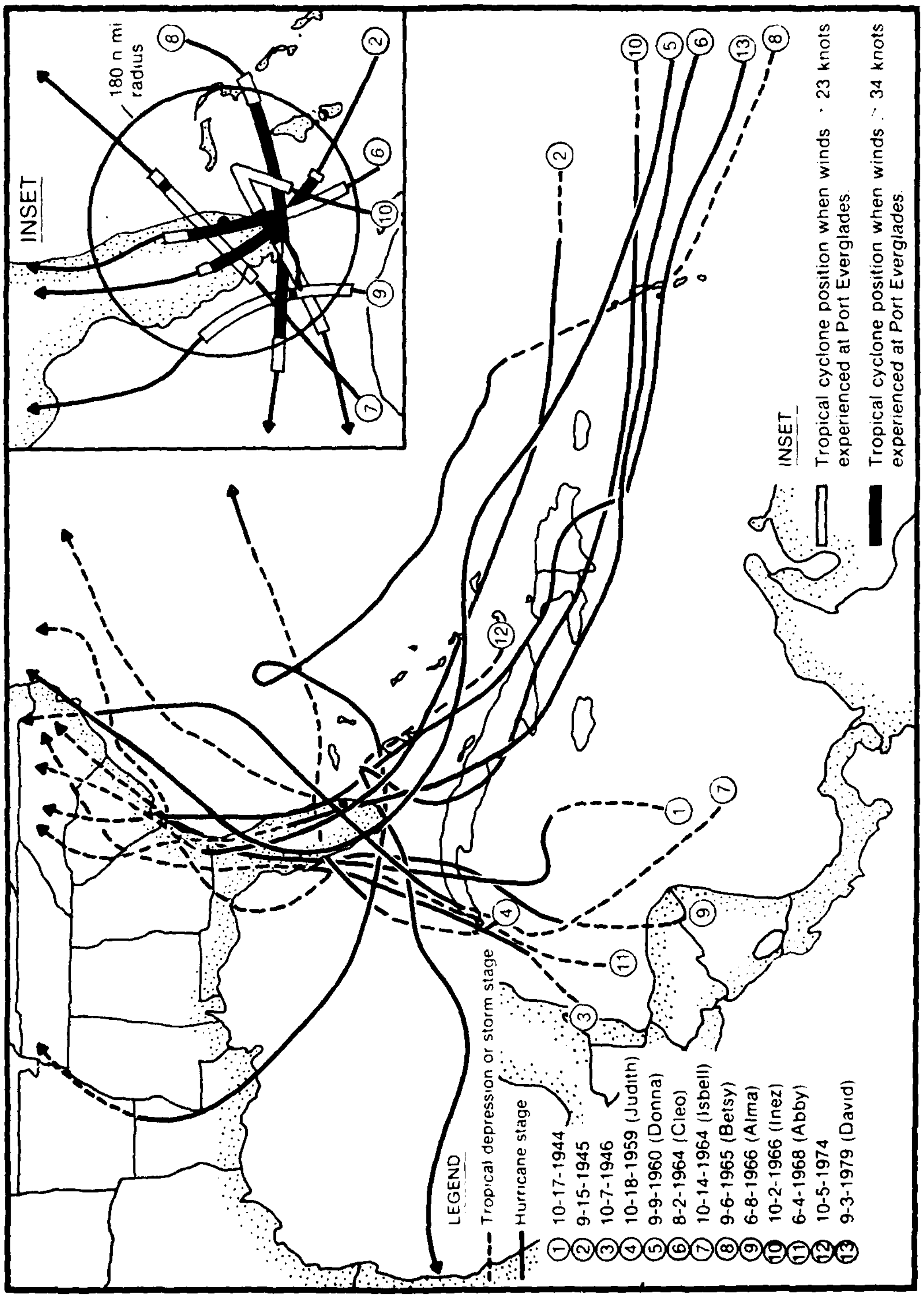

Figure XIX-10. Tracks of 13 tropical cyclones during the periods 1944-46 and 1959-79 that caused winds of 23 kt or greater at Port Everglades. Locations of storm centers when winds 23 kt and 34 kt or greater occurred at Port Everglades are shown in the inset.

3.5 STORM SURGE AND TIDES

The term "storm surge" is used to indicate changes from normal water level due to the action of storms. Severe storms may produce surges in excess of 25 ft above normal on the open coast and even higher in bays and estuaries. The eventual height of the water level is determined mainly by the strength and characteristics of the storm and the hydrography of the coast or basin.

Table XIX-4 relates characteristics of Atlantic hurricanes to potential storm surge and subjective estimates of possible damage. The following combination of circumstances and features would generate a large storm surge at Port Everglades:

- An intense storm of Category 3 (Table XIX-4) or greater strength approaching perpendicular to the coast with landfall within 30-50 miles south of the port. This would place the harbor in the stronger, right semicircle of the hurricane and face the open mouth of the harbor directly into the winds and sea/swell.
- Broad, shallow, slowly shoaling bathymetry.
- Coincidence with high astronomical tide.

Table XIX-4. Saffir/Simpson damage-potential scale ranges.

Scale *Number* (Category)	Central Pressure (mb)	Winds (mph)	Winds (kt)	Surge (ft)	Damage
1	≥980	74-95	64-83	4-5	Minimal
2	965-979	96-110	84-96	6-8	Moderate
3	945-964	111-130	97-113	9-12	Extensive
4	920-944	131-155	114-135	13-18	Extreme
5	<920	>155	>135	>18	Catastrophic

The bathymetry along the east coast of Florida somewhat meets the shoaling criteria for potential storm surge. The lack of significant elevations (many areas below 5 ft) on barrier land strips subjects the entire Intracoastal Waterway area, including Port Everglades, to potential storm surge from significant hurricanes. Table XIX-5 lists recorded instances of significant storm surge at Fort Lauderdale for the period 1926-79. The levels were recorded at Bahia Mar Yacht Club, one mile north of Port Everglades.

The tracks for the seven tropical cyclones listed in Table XIX-5 are shown in Figure XIX-11. The September 1926 hurricane, which caused the highest recorded water level, was a Category 3-4 storm and hit perpendicular to the coast about 18 miles south of Port Everglades. The November 1935 storm, called the "Yankee Storm" due to its high latitude origin, also struck the coast almost perpendicular about 34 miles south of the port, but was only a Category 2 hurricane at landfall.

Table XIX-5. Hurricane water levels above National Geodetic Vertical Datum at Fort Lauderdale, 1926-79 (data from National Hurricane Center).

Hurricane Date/Name	Water Level at Fort Lauderdale (Ft)
September 18, 1926	12.6
November 4, 1936	8.8
September 17, 1947	6.5
October 18, 1950 (King)	6.0
September 9-10, 1960 (Donna)	3.1
August 27, 1964 (Cleo)	5.0
September 8, 1965 (Betsy)	7.0

4. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for hurricane preparedness at Port Everglades are contained in the Department of Transportation, U.S. Coast Guard Hurricane Contingency Plan. Hurricane advisories are issued by Naval Eastern Oceanography Center, Norfolk, VA. Conditions of readiness are set by Commanding Officer, Naval Air Station, Key West, FL. The prescribed condition is the minimum condition for all ships present. Unless directed to evacuate by higher authority or the harbor master, the decision whether to put to sea when a hurricane is approaching the Ft. Lauderdale-Miami area rests with the ship's captain.

4.1 THREAT ASSESSMENT

A review of the tropical cyclone threat analysis given in the previous section indicates that Port Everglades is at considerable risk to damage from both tropical cyclone storm surge and high wind. The nearness of the harbor to the open ocean suggests that the port is subject to the full force of a hurricane approaching from the east. The absence of sheltered berths or anchorages makes evasion at sea the safest course of action for all seaworthy deep-draft vessels when it can be established that a tropical cyclone poses a threat to Port Everglades.

Early assessment of each potential threat is essential, and should be related to the setting of hurricane conditions of readiness by military and civil authorities. Current advisories and forecasts by the National Weather Service and the Navy, as well as the climatology given in this port study, should be used in threat assessment.

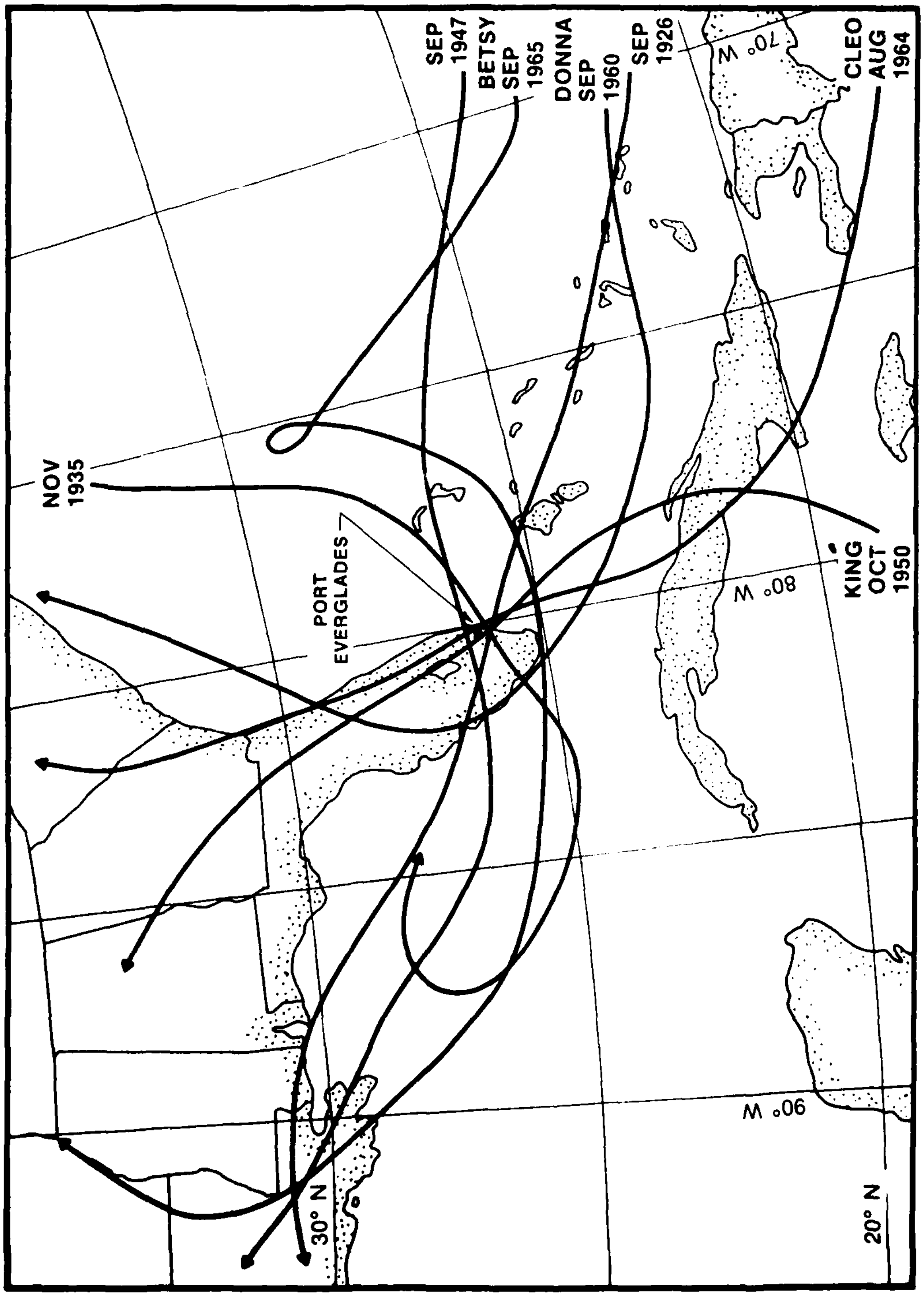

Figure XIX-11. Tracks of tropical cyclones that caused significant water level changes at Port Everglades during the years 1926-79.

The greatest threats to Port Everglades are tropical cyclones that move northward out of the central Caribbean Sea, or westward out of the Atlantic Ocean through the West Indies, and approach Port Everglades from the east-through-south-to-west octants (Figures XIX-4 through XIX-9). A greater threat of storm surge occurs when a tropical cyclone approaches Port Everglades from the east quadrant and makes landfall within 50 miles south of the port. The port is susceptible to high winds from all quadrants -- particularly from the eastward, open-ocean approach.

As a general rule, if an intense tropical storm or hurricane approaches from the Atlantic east of the port, the dangerous right front quadrant of the storm can cause severe wind and storm surge damage to Port Everglades. Overland approach from the west is less dangerous as there is some mitigation of wind intensity by the overland passage. An approach from the south should be less dangerous also, but Hurricane Cleo (August, 1964) made landfall south of Miami and tracked northward parallel to the coastline to cause considerable damage well up the Florida east coast.

The months of maximum frequency threat are August, September and October. Eighty-three percent of all tropical cyclones posing a threat to Port Everglades occurred in these three months. Five out of six of those storms causing sustained winds of 34 kt or greater in the port area occurred in the August through October period.

4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy deep-draft vessels when Port Everglades is threatened by an intense tropical storm ($\geq$48 kt) or hurricane ($\geq$64 kt).

The decision to evade at sea must be timed to allow safe passage to open waters. The timing is affected by:

(1) Preparation time necessary to get underway;

(2) forward speed of the tropical cyclone;

(3) forecast radius of high winds that would hamper/prevent a vessel's capability to maneuver to open water;

(4) direction of ship's track relative to storm, and

(5) number of hours of daylight/darkness.

Advice and consideration for leave/stay decisions are given in the General Guidance Section of this handbook (Section I). This guidance must be modified for Port Everglades by the harbor's location, the local topography and bathymetry (especially on how they affect the local wind and sea level), and the climatology of tropical cyclones approaching within 180 n mi of the harbor.

PORT EVERGLADES, FL

Port Everglades' harbor area is advantageously situated only two miles from normal deep-water shipping routes, which significantly reduces transit time to the open ocean. Once in deep water the vessels' tactics will depend on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement.

Hurricane Condition IV (equivalent to U.S. Navy Hurricane Condition III) is set by the U.S. Coast Guard when hurricane force winds are possible within 48 hr. The decision to prepare for sortie is apparent and should be made soon after setting of U.S. Navy Hurricane Condition III. Although the storm center may be more than 500 miles distant now, it should be remembered that the average tropical cyclone forecast error over a 48 hr period is 200 n mi for those tropical cyclones threatening Port Everglades. Departures coincident with the setting of U.S. Navy Hurricane Condition III are considered to be the wisest and safest course of action. Later departures wager the accuracy of information on the storm's behavior against mounting risks of heavy weather damage.

Once sea room is attained on departure from Port Everglades, it is essential that ship captains use up-to-date information to make sound decisions. Storm location and intensity information is accurate and timely with today's satellite technology. Forecasts and warnings are issued at 6 hr intervals and updated as necessary to reflect important changes in position, intensity, and movement. Ship captains with access to these advisories/warnings are in the best possible position to modify evasion routes and tactics to evade the storm. The cardinal rule of seamanship is to avoid the dangerous right-hand semicircle. The following guidelines are offered:

(1) Tropical Cyclones Approaching from the Northeast or East. After departure, steam south along the Florida coast and keep a close eye on the storm, whose normal tendency will be to move westerly or recurve to the north. If necessary, clear the storm to the southeast or southwest, north of Cuba. A tropical cyclone from the northeast is likely to be an early or late season (or off season) storm and may be more erratic in behavior due to unseasonal steering patterns.

(2) Tropical Cyclones Approaching from the Southeast or South. Steam to the northeast to clear Grand Bahama Island and then east to clear the tropical cyclone. The preferred storm track should be to the northwest or to the northeast on a recurvature path, either of which will be easy to clear.

(3) Tropical Cyclones Approaching from the Southwest or West. These storms will have crossed the Florida land mass, but should not be discounted as threats. Much of south Florida is composed of the Everglades which can still provide a source of heat energy and moisture to the storm. The flatness of the land mass also may not mitigate the wind intensity to any significant degree. For these tropical cyclones, proceed as in (2) above.

4.3 DELAYING DEPARTURE

A questionable threat (see Para. 4.5) may dictate "wait and see" as a reasonable course of action. A questionable threat situation here also would include those situations where an intense tropical storm or hurricane is a considerable distance away from Port Everglades (i.e., not likely to cause prohibitive departure sea conditions within 24 hr) and meandering with no established direction of movement. Because Port Everglades is only two miles from deep-water ocean shipping routes, quick escape either north or south is possible once the direction of storm movement is better established. The storm should be watched closely for any acceleration of movement toward Port Everglades.

4.4 RETURNING TO PORT

The damage and disarray at a port caused by a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Harbor facilities may be so damaged as to preclude offering even minimal services. Check with the Port Director before attempting to return.

4.5 REMAINING AT PORT EVERGLADES

Remaining in the harbor at Port Everglades is an option that should be seriously considered only in questionable threat situations or in those instances when a vessel is incapable of successful evasion at sea. Questionable threat situations include (1) a tropical cyclone developing within the 180 n mi radius critical area with forecast slow development, and (2) a weak tropical cyclone with maximum winds less than 48 kt approaching Port Everglades and forecast not to intensify.

If a decision is made to remain in port, the proper port authorities must be notified 36 hours before a forecasted storm arrival. For those vessels over 100 gross tons, a request must be made to the Captain of the Port in Miami. For those vessels remaining, close coordination with the Port Director is required to obtain the best berthing available. The northern and southern extensions of the turning basin may offer marginally better wind protection, but the entire port area is subject to high winds. Slips 1, 2 and 3, even though exposed to direct wave action through the ship channel, may afford the best protection due to superior mooring. (Wave action would be directly off the bow or stern.)

It is recommended that vessels be ballasted down as much as possible, and secured to the dock with sufficient lines to withstand predicted wind forces, yet allow for water height fluctuations of the predicted amounts.

Remaining in port exposes a vessel to hazards beyond those of wind and storm surge. Vessels may break loose from their moorings and become floating hazards, or a damaged or sunken vessel could effectively block the ship channel to the ocean.

5. ADVICE TO SHALLOW DRAFT VESSELS

Thousands of shallow draft boats are moored in the extensive canal system just north of Port Everglades. If feasible, they should be removed from the water and transported inland to higher elevations well before the threat. The low land elevations in the immediate area offer little protection if there is a significant rise in the water level due to storm surge. Because of the many boats in the area it might not be possible to go north or south on the Intracoastal Waterway to seek protection up a canal or river unless departure is quite early. Many bridges with low vertical clearances might further hinder such a plan.

Boat owners in this area should prepare an escape plan and implement it early to avoid the many people who may use the roads to leave the low lying coastal areas. If a boat must be moored in place, it should be ballasted to be low in the water to escape wind effects and be well secured with allowance for increased water heights.

XX. ROOSEVELT ROADS, PR

XX: CONTENTS

XX. ROOSEVELT ROADS, PUERTO RICO

SUMMARY

Roosevelt Roads is a poor hurricane haven because of its location in the tropical cyclone generation latitudes, lack of sheltered facilities, and vulnerability to storm surge. Evasion at sea is recommended for all seaworthy deep-draft vessels when the harbor is threatened by an intense tropical storm or hurricane. Small craft should be removed from the water and placed in a protected space or firmly secured above the predicted high water line.

Roosevelt Roads Naval Station is located on the southeast coast of Puerto Rico, which is the easternmost island of the Greater Antilles Islands of the West Indies. Situated between the Atlantic Ocean to the north and the Caribbean Sea to the south, Puerto Rico is located at the latitudes of easterlies wherein tropical cyclone generation occurs.

The hurricane threat season for Roosevelt Roads is June through November. The months of maximum storm occurrence are August and September, which total 80% of threat activity.

Roosevelt Roads has been threatened by an average of 1.2 tropical cyclones per year. However, examination of recorded wind data at the station revealed only one tropical cyclone that caused sustained winds of gale force and wind gusts of hurricane strength over a 24-year period (1948-50 and 1958-79).

The landmass of Puerto Rico and nearby islands offer limited protection from tropical cyclones to Roosevelt Roads. Low, rolling hills surrounding the harbor provide minimal wind protection, while the bathymetry and coastal configuration promote storm surge with a southeasterly wind component. Forty percent of all tropical cyclones approach the harbor from the southeast octant.

This hurricane haven evaluation was prepared by A.J. Compton of Science Applications, Inc. (SAI), Monterey, CA 93940.

1. LOCATION AND TOPOGRAPHY

Roosevelt Roads Naval Station is located on the extreme eastern portion of the island of Puerto Rico about 35 statute miles east-southeast of San Juan. Puerto Rico is the easternmost island of the Greater Antilles Group of the West Indies (Figure XX-1) and is located about 1000 miles southeast of Miami, Florida.

The Naval Station is constructed around the perimeter of Ensenada Honda (Bay of Honda). Ensenada Honda, approximately 1 to 1 1/2 miles wide and 2 miles long, and the surrounding area are used exclusively by the U.S. Navy with no civil facilities located within the harbor complex. Ofstie Field, a naval air station, is located about 1 mile north of the bay. (See Figure XX-2.)

The area surrounding Ensenada Honda consists of low, grass-covered hills typical of eastern Puerto Rico. The terrain ranges from low (40-50 ft) hills on either side of the harbor entrance to a low ridge in the northwest quadrant having a maximum elevation of about 300 ft. A 1060 ft peak is located 2.5 miles west of the air field. El Toro peak and El Yunque peak, with elevations of 3524 and 3496 ft respectively, lie about 10 miles to the west-northwest of Roosevelt Roads.

The ship channel into the harbor passes between Cabra de Tierra and Pta Cascajo (Figure XX-2). The channel is 1000 ft wide, and a controlling depth of 40 ft is available* in both the channel and the turning basin into which the channel leads. The channel is oriented southeast-northwest, and two mooring areas 31 ft deep are located at the northwest terminus of the channel. There is a third mooring area/turning basin just southeast of the pier area, and a fourth just inside the harbor south of Pier Three.

The harbor is somewhat protected from sea and swell (except from the southeast octant) by the partially encircling shore and reefs, which restrict the deep-water entrance to about 1/3 mile width. Water depths in the bay-proper decrease rapidly once outside the channel, pier areas, and other controlled depth areas.

Puerca Bay, a small open-mouth bay located one mile northeast of Ensenada Honda (Figure XX-2), has depths of 37 ft or more. Cabras Island separates the entrances to the two bays. Vieques Island, 17 miles long, lies five miles southeast of the harbor entrance (Figure XX-1).

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*See Notice to Mariners and latest editions of charts.

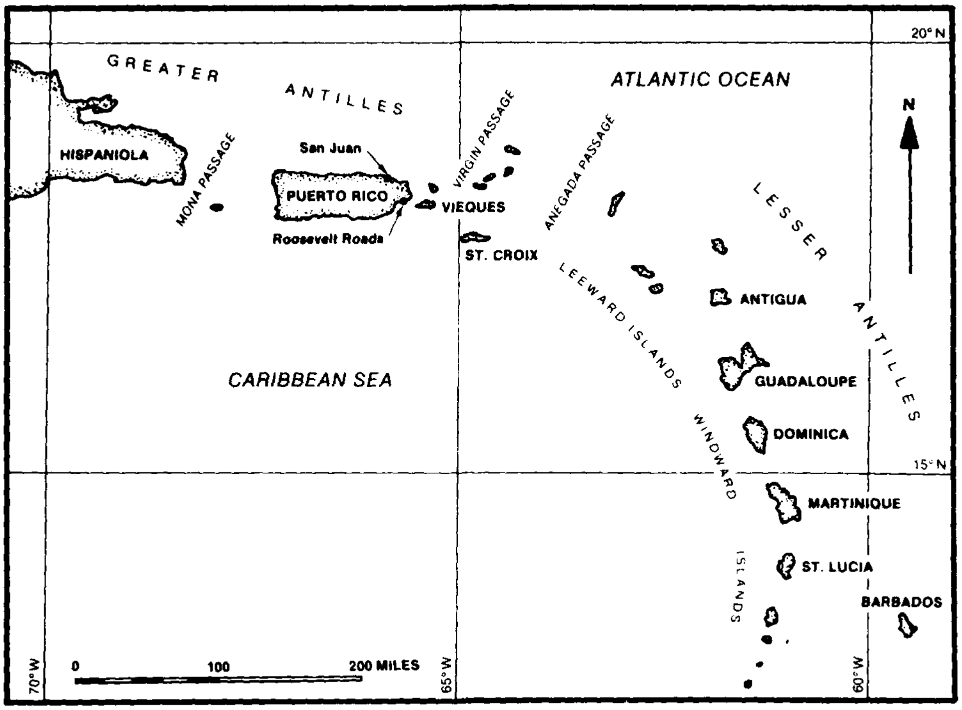

Figure XX-1. Geographical location of Roosevelt Roads, Puerto Rico.

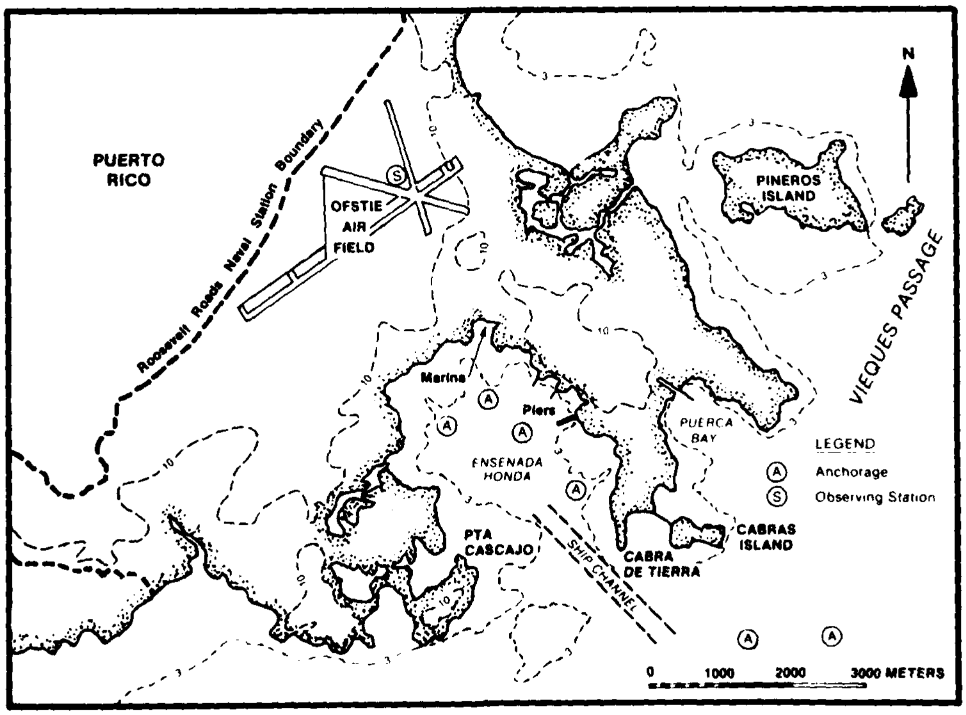

Figure XX-2. Ensenada Honda, Roosevelt Roads, with three fathom contour and 10 ft elevation contours shown.

AD-A144 437 HURRICANE HAVENS HANDBOOK FOR THE NORTH ATLANTIC OCEAN CHANGE 2(U) NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY MONTEREY CA R J TURPIN ET AL. 28 JUN 84 2/3

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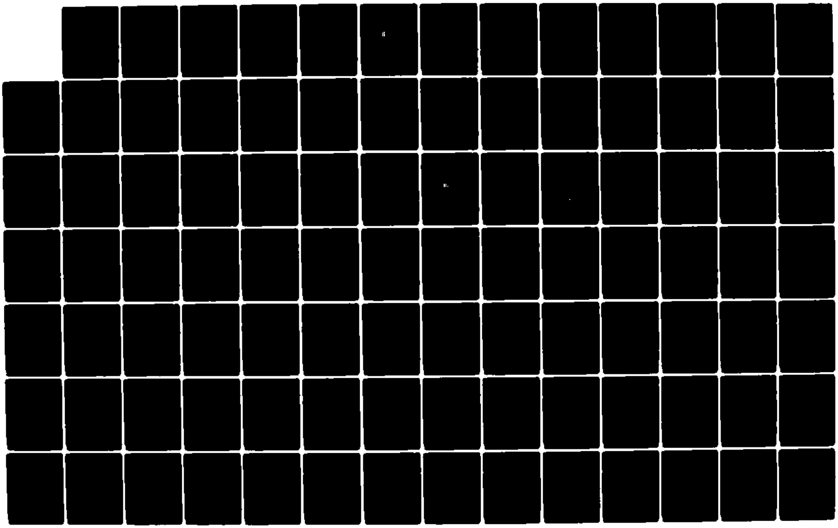

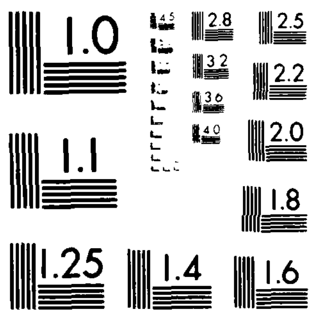

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

The approach to Ensenada Honda from the Atlantic Ocean is somewhat restricted by passage through shallow reef areas and narrow channels. Deep-draft ships (tankers) have made passage via Virgin Passage to Roosevelt Roads. The approach from the south or Caribbean Sea area is via Vieques Passage (between Puerto Rico and Vieques), which is less restricted but limited to drafts less than 34 ft.

2. PORT AND HARBOR FACILITIES

2.1 BERTHS FOR DEEP-DRAFT VESSELS

2.1.1 Ensenada Honda (Roosevelt Roads Harbor)

Ensenada Honda contains the harbor for the U.S. Naval Station Roosevelt Roads and a small craft marina used by the Navy for small boat mooring and recreational purposes. No facilities are available for repair of ships' hulls or machinery.

There are three Navy piers (Figure XX-3) located on the east side of the harbor with alongside depths 30-42 ft. The piers are constructed upon concrete pilings and have deck heights 8-10 ft above mean sea level. Bulkheads located between the piers provide additional mooring with depths to 15 ft.

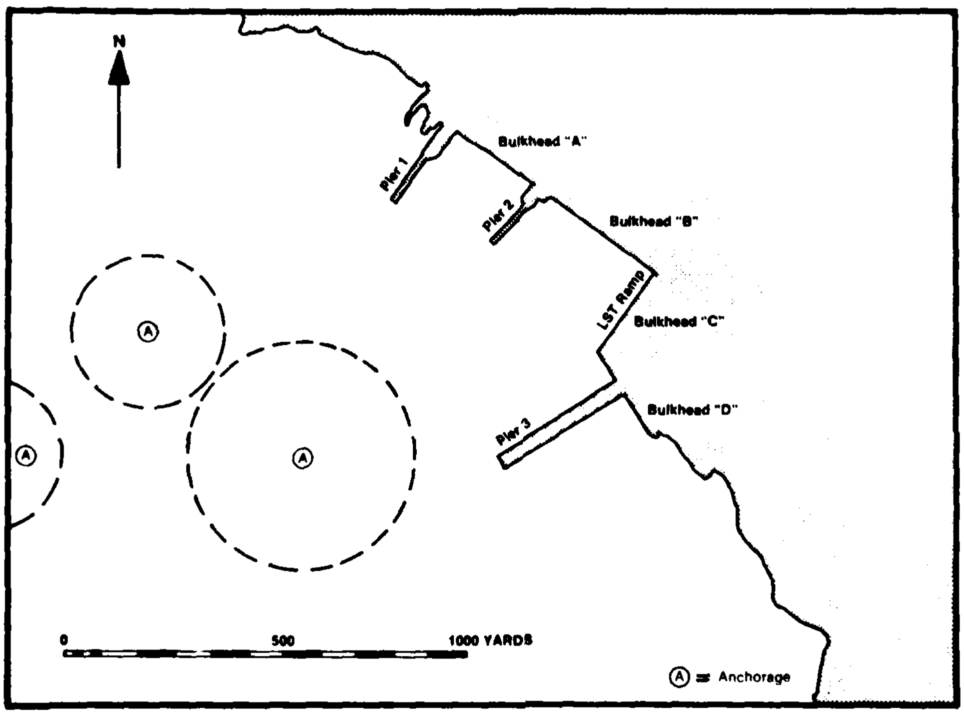

Figure XX-3. Roosevelt Roads pier area.

Pier 1, the U.S. Navy fuel pier, is the northernmost pier in the harbor. The pier is 450 ft long with depths alongside of 32-36 ft by the latest (1982) pilot soundings. Pier 2, a submarine pier, is located southeast of Pier 1 and is 400 ft long with alongside depths of 30-32 ft. An LST landing ramp is located about 300 yd southeast of the cargo pier. Pier 3, a 1,200 ft long U.S. Navy aircraft carrier pier, is about 400 yd south of Pier 2. Alongside depths are about 40 ft on the north side and 44 ft on the south side.

The U.S. Navy operates three tugboats in the harbor for docking and undocking vessels and towing as necessary. Pilots are required upon initial visits to the harbor, and available on request for subsequent visits. The three tugs meet all normal needs of the limited vessel traffic within the simple, compact harbor.

2.1.2 Bahia de Puerca

The Bay of Puerca lies about 1 mile northeast of Ensenada Honda. This bay, also a part of the U.S. Naval Station, is about 1/2 mile wide and 3/4 mile long with depths of 37 ft or more. A 1000 ft pier is located at the head of the bay. This pier has 37 ft depths alongside on either side, but it has a no facilities and is not currently maintained by the Navy. A large but inactive graving dock is inshore of the pier to the south side.

2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

Ensenada Honda and Bahia de Puerca offer little shelter from heavy weather of gale force (34 kt sustained) and above. The low hills surrounding the harbor area afford only limited protection from strong winds. The configuration of the bays, similar in aspect, make them most vulnerable to winds from the south or southeast, but the area overall is affected by winds from any direction.

Seven anchorage areas are available in or near Ensenada Honda. Limited wind protection restricts their safe use to winds of gale force or less. According to the U.S. Department of Commerce, 1980: "Vessels anchor inside the harbor according to draft; the holding ground is soft mud, which may cause some dragging during a hurricane." The designated anchorage areas outside the harbor have a hard bottom with unevaluated holding, and no wind protection available. The approximate locations of the anchorage areas are indicated by the letter "A" on Figure XX-2.

2.3 FACILITIES FOR SMALL VESSELS

Ensenada Honda is completely surrounded by U.S. Naval Station Roosevelt Roads, so the small vessels moored in or using the harbor are primarily recreational vessels belonging to the Navy and to individual service families. A small marina is located at the northern end of the harbor to accommodate small vessels. The approach to the marina is limited by depths of only 7-8 ft.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT ROOSEVELT ROADS

3.1 INTRODUCTION

A study of previous tropical cyclones' frequency of occurrence, direction of approach, speed of movement, and intensity at Roosevelt Roads provides insight into storm behavior and potential annual threat to the harbor. It should be noted, however, that such a historical overview cannot be a totally reliable guide to predict behavior and impact of present-day storms.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Roosevelt Roads is considered to represent a threat to the harbor.

Tropical cyclones that affect Roosevelt Roads are spawned in two main regions of origin in the North Atlantic Ocean: the Atlantic east of the Lesser Antilles, and the eastern Atlantic near Cape Verde. This study will consider only those tropical cyclones that have affected eastern Puerto Rico, passing within 180 n mi of Roosevelt Roads.

The location of Roosevelt Roads on the east coast of Puerto Rico has significant bearing on tropical cyclone threat to the harbor area. Puerto Rico lies at about 18°N, which places it in or near the preferred storm track for North Atlantic hurricanes for the months of July, August, and September (Crutcher and Quayle, 1974). However, at approximately 65°W, Puerto Rico is also located about mid-point along the tracks. Therefore many of the hurricanes that affect Roosevelt Roads may not be fully developed.

The official hurricane season for the North Atlantic extends from 1 June to 30 November, but occasionally a storm will occur outside of that period. There were 125 tropical cyclones that passed within the 180 n mi threat radius for Roosevelt Roads during the 109-year period 1871-1979, an average of nearly 1.2 per year. Table XX-1 shows the monthly totals and percentages. These data

Table XX-1. Monthly totals of tropical cyclones passing within 180 n mi of Roosevelt Roads during the period 1871-1979.

MONTH	NUMBER OF TROPICAL CYCLONES	PERCENT OF TOTAL
March	1	0.8
July	7	5.6
August	40	32.0
September	59	47.2
October	15	12.0
November	3	2.4

are presented graphically in Figure XX-4, which also shows the frequency of occurrence of hurricanes* over a shorter time period (1899-1979) for which wind data are available.

Figure XX-5 depicts 119** tropical cyclones as a function of compass direction, by octant, from which tropical cyclones have approached Roosevelt Roads during the 109 years 1871-1979. The numbers in each octant give the total number of tropical cyclones that have approached the harbor from that octant; numbers in parentheses give the percentage of the total sample.

The major threat sectors are the east and southeast octants, as 88% of the tropical cyclones approached from those two octants. Thus, although tropical cyclones have approached Roosevelt Roads from all but the northwest octant, the total number of these events in which approach direction is other than from the east or southeast octant is only 12% (about once every eight years).

This is primarily due to Puerto Rico's location at 18°N, placing it in the directional flow of the preferred storm tracks for August and September. These two months total 77% of all the tropical cyclones to affect Roosevelt Roads. An evaluation by Neumann and Pryslak (1981) of the frequency and motion of tropical cyclones in the Atlantic gives those tropical cyclones having winds of at least 34 kt and passing within a 2.5° latitude/longitude box containing Puerto Rico, an average vector direction of 196° with a high degree of "steadiness" in their motion.

Also significant is the fact that only one tropical cyclone (Donna, September 1960) caused sustained gale force winds (34 kt or greater) at Roosevelt Roads during 24 years (1948-49 and 1958-79) of available recorded data. Over a longer period of 66 years (1917-82), only 6 tropical cyclones caused winds of sustained hurricane intensity in the San Juan area. Most of these occurred in the period 1926-32.

The last hurricane that caused considerable loss of life and great property damage in San Juan occurred September 26, 1932. On August 12, 1956, however, Hurricane Betsy passed over Puerto Rico and hurricane force winds were felt in gusts in San Juan.

A measure of tropical cyclone intensity is also given by Neumann and Pryslak (1981), who note that tropical cyclones tend to be more intense in certain areas of the Atlantic Basin. The measure can be obtained from the ratio of the number of hurricanes, to the number of hurricanes and tropical storms

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*Tropical cyclones that were of hurricane intensity (≥64 kt) when passing within 180 n mi of Roosevelt Roads.

**Six tropical cyclones formed within the threat radius -- therefore were counted in total threat -- but did not approach the harbor, therefore were not counted in a threat octant.

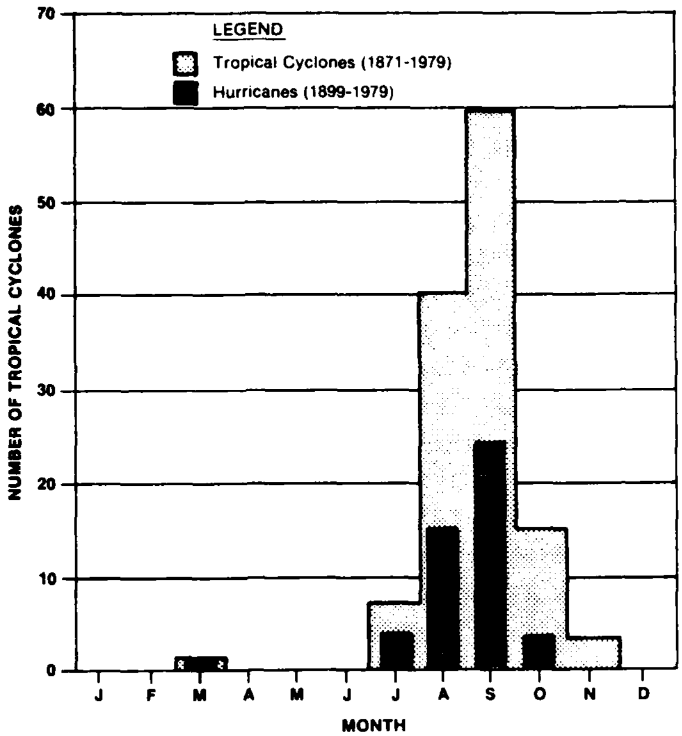

Figure XX-4. Frequency distribution of tropical cyclones and hurricanes that passed within 180 n mi of Roosevelt Roads during the periods 1871/99-1979.

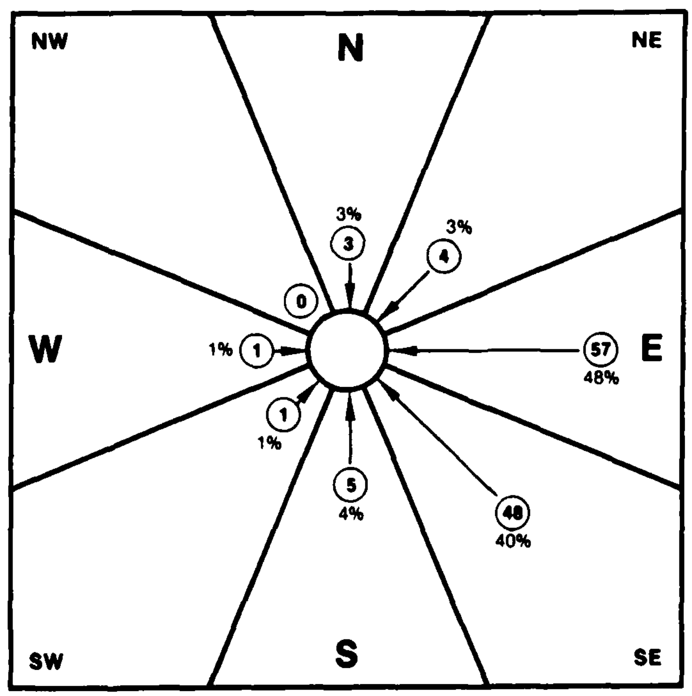

Figure XX-5. Direction of approach of tropical cyclones that passed within 180 n mi of Roosevelt Roads during the period 1871-1979. Circled numerals show number of storms approaching from each octant, and percentages are percent of total from each octant.

combined. For the 2 1/2° box containing Puerto Rico, this ratio is 23:48 -- about 48% of the tropical cyclones passing through this area have hurricane velocity winds. This compares, for example, to 61% (31:51) for Miami, and 36% (20:56) for both New Orleans and New York (7:19).

Mean tropical cyclone translation speeds are important because they can add to the total winds in the strong right quadrant (Northern Hemisphere) of the tropical cyclone, and can also give sustained winds associated with the storm more (or less) time to cause damage. The speed of advance is a planning factor for a ship's captain in hurricane evasion (note General Guidance section).

Puerto Rico's location places it in a more predictable situation due to generally small variations in tropical cyclone speed of advance. Mean tropical cyclone translation speeds near Puerto Rico and upstream in the tropical cyclone track vary only from 10 to 19 kt over the hurricane season (Neumann and Pryslak, 1981). Planners therefore do not usually face the possibility of rapid accelerations in the forward motion of the tropical cyclones as often happens after recurvature.

During the period 1899-1979, 22 tropical cyclones (23% of total within those years) formed within 300 n mi of Roosevelt Roads; of these, 8 developed rapidly to hurricane strength. Table XX-2 classifies tropical cyclones by initial position and shows that 22 of the 97 tropical cyclones had initial locations within 300 n mi or within 24 hours normal travel time of Roosevelt Roads. Thus, for approximately one quarter of the threats to the harbor, warning and preparation time was 24 hours or less.

Table XX-2. Classification of 97 tropical cyclones by initial position which passed within or formed within 300 n mi of Roosevelt Roads during the period 1899-1979.

INITIAL POSITION	NOV-JUN	JUL	AUG	SEP	OCT	TOTALS
Within 300 n mi*	1	1	6	11	3	22
Rapid development within 300 n mi	0	0	1	6	1	8
Greater than 300 n mi	3	6	28	33	5	75
Percentage less than 300 n mi	25%	14%	18%	25%	38%	23%

*300 n mi was selected because it is the distance a tropical cyclone will travel in 24 hours at a speed of 12.5 kt (average for tropical cyclones in the vicinity of Puerto Rico).

Table XX-3 shows the intensity of tropical cyclones by month for those tropical cyclones that passed through (or originated within) the 180 n mi threat radius. This table gives data for a reduced period of 81 years (1899-1979) for which intensity data were available. August and September -- with 39 (83%) of the 47 hurricanes and 77 (79%) of the 97 tropical cyclones -- are, by far, the months of greatest activity for the 81 years.

Table XX-3. Classification of 97 tropical cyclones by intensity which passed within 180 n mi of Roosevelt Roads during the period 1899-1979.

INTENSITY*	NOV-JUN	JUL	AUG	SEP	OCT	TOTALS	% OF TOTAL TC's
Hurricane (≥64 kt)	1	3	15	24	3	46	48%
Strong Tropical Storm (48-63 kt)	1	1	8	9	-	19	20%
Weak Tropical Storm (34-47 kt)	-	3	8	8	4	23	24%
Tropical Depression (<34 kt)	1	-	2	3	1	7	7%
TOTAL	3	7	33	44	8	97	

*Intensity values reflect the maximum intensity while within the 180 n mi critical radius of Roosevelt Roads.

Figures XX-6 through XX-10 are statistical summaries of threat probability for the years 1871 through 1979. Representative summary periods of tropical cyclone frequency, track, and speed are the months of November through June, July and August, September, October, and all tropical cyclones of record during the 109-year period.

The solid lines are percent threat for any storm location. The dashed lines are approximate approach times to Roosevelt Roads based on the climatological approach speed for a particular location. For example, in Figure XX-8, a tropical cyclone located at 10°N and 50°W has a 40% probability of passing within 180 n mi of Roosevelt Roads and typically would reach the harbor in three to four days (72 to 96 hours).

A comparison of Figures XX-6 through XX-10 shows that early season or late season tropical cyclones tend to be more variable in location of origin, track, and speed than those that occur July through September.

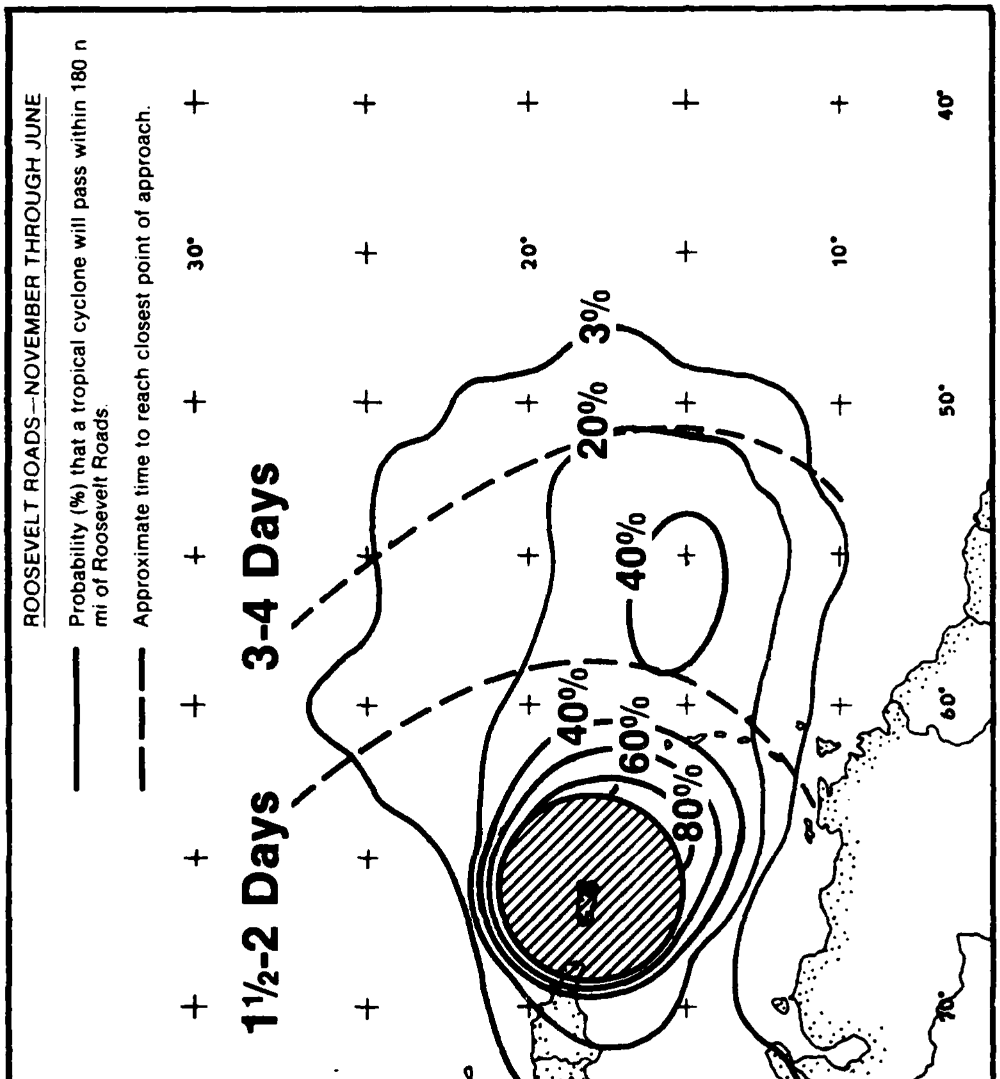

Figure XX-6. Probability that a tropical cyclone will pass within 180 n mi of Roosevelt Roads (shaded circle), and approximate time to reach closest point of approach, during November through June (based on data for 1871-1979).

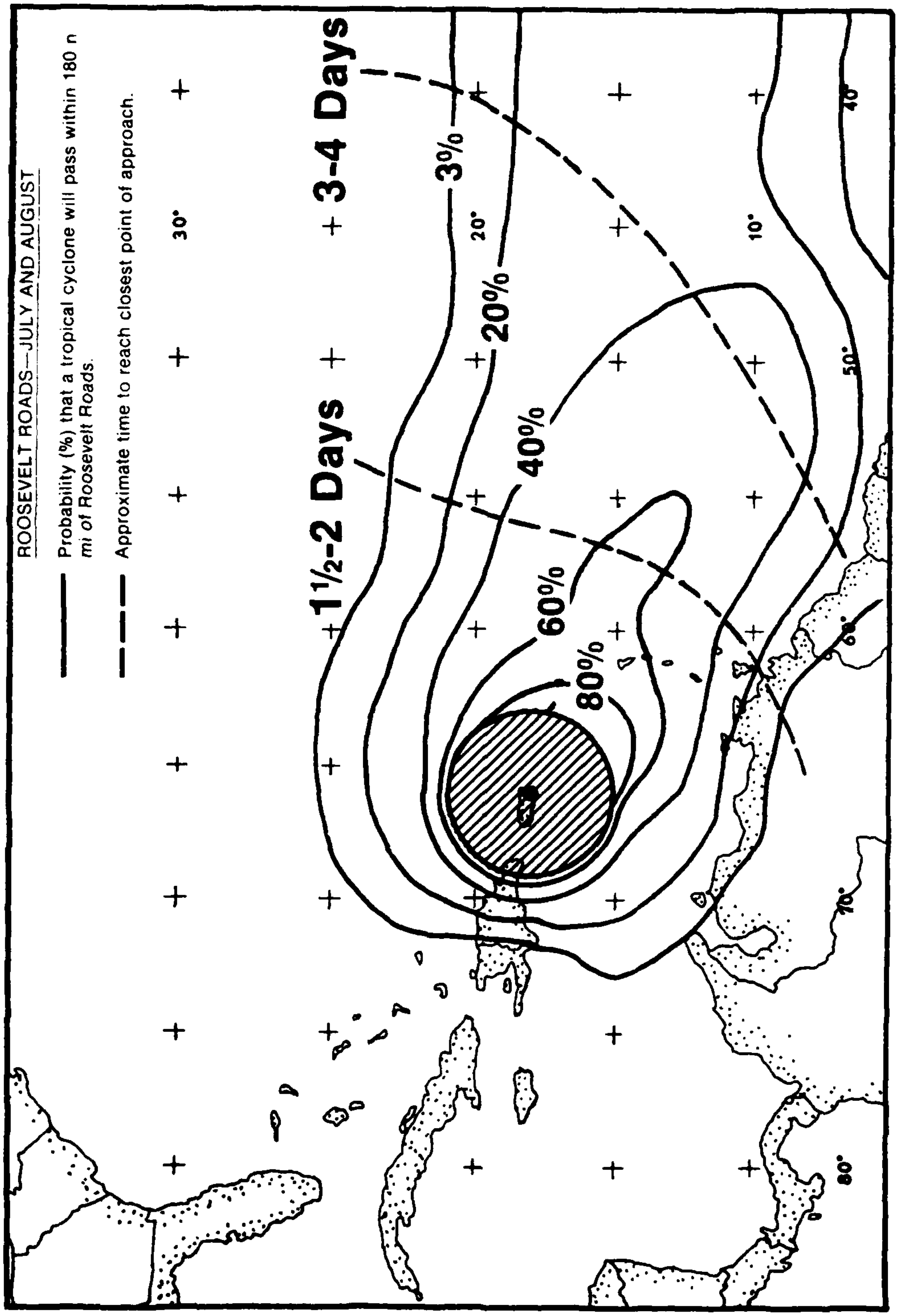

Figure XX-7. Probability that a tropical cyclone will pass within 180 n mi of Roosevelt Roads (shaded circle), and approximate time to reach closest point of approach, during July and August (based on data for 1871-1979).

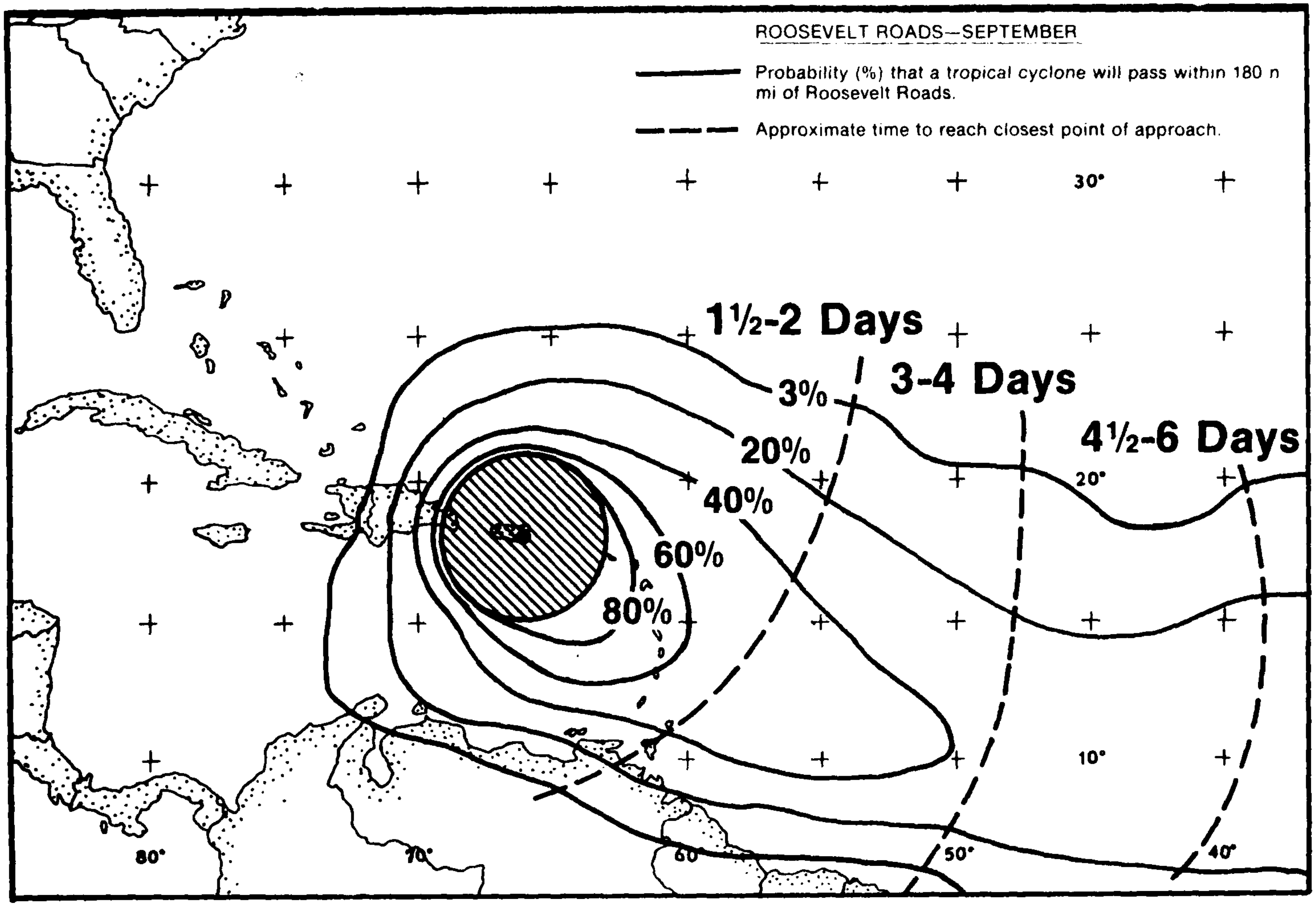

Figure XX-8. Probability that a tropical cyclone will pass within 180 n mi of Roosevelt Roads (shaded circle), and approximate time to reach closest point of approach, during September (based on data for 1871-1979).

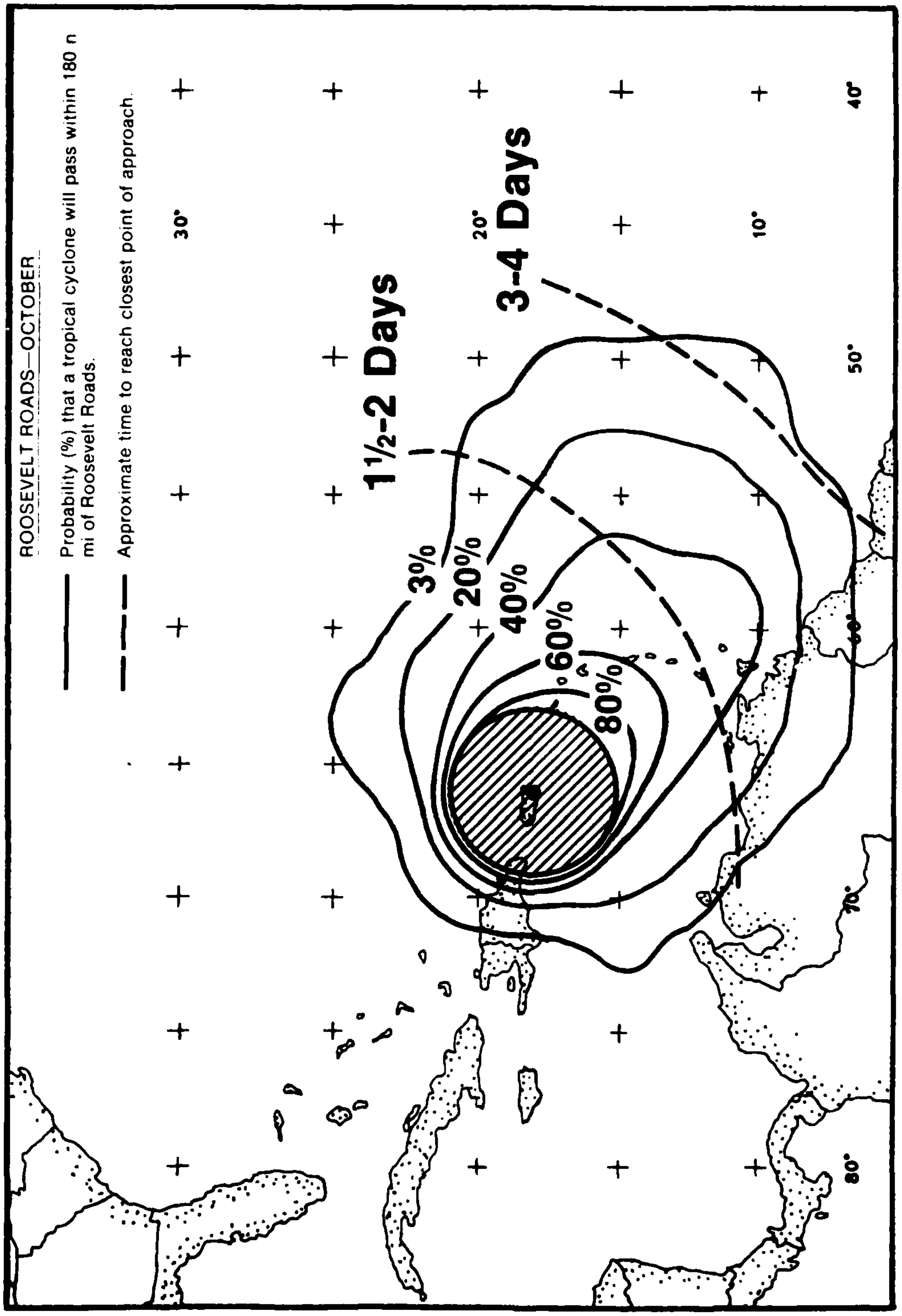

Figure XX-9. Probability that a tropical cyclone will pass within 180 n mi of Roosevelt Roads (shaded circle), and approximate time to reach closest point of approach, during October (based on data for 1871-1979).

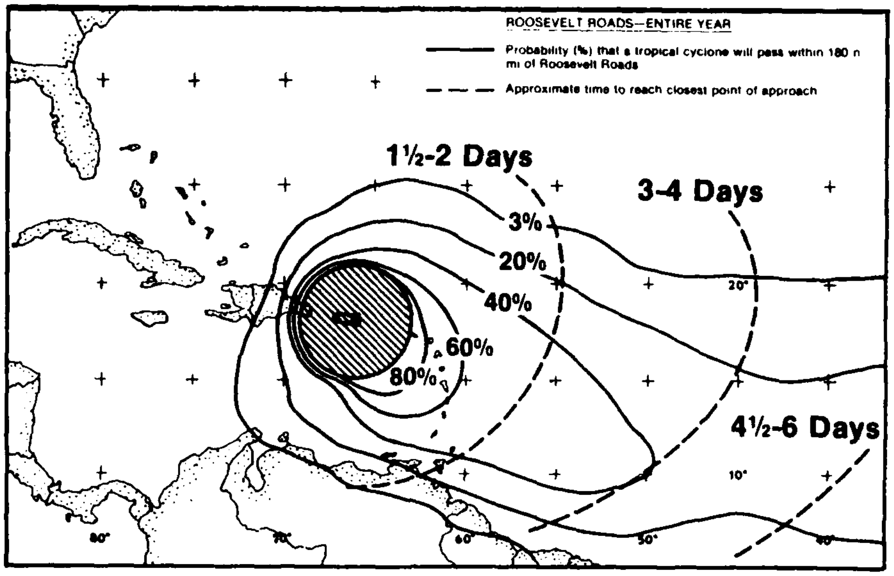

Figure XX-10. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi of Roosevelt Roads during the years 1871-1979.

Figure XX-6 shows a multiple threat approach for tropical cyclones during the months November through June. It should be noted, however, that these threat axes were derived from only five tropical cyclones over the 109-year period 1871-1979. The western threat axis, in fact, depicts one tropical cyclone which originated near Panama, tracked east-northeast, and passed north of Puerto Rico. The eastern threat axis shows a general threat to Roosevelt Roads from the east-southeast from an area along 15°N through the Windward and Leeward Islands to Puerto Rico.

In July and August, Figure XX-7, the frequency of tropical cyclones increases and the threat axis drops farther south from a point of about 10°N, 50°W through the Leeward Islands to Puerto Rico. The point of origin for these threats may be anywhere along the threat axis (note Table XX-2) from the Cape Verde Islands off the coast of Africa to within the threat radius. For these two months the tropical cyclone threat axis and direction of approach are fairly predictable.

September, Figure XX-8, is the month with the highest frequency of tropical cyclones. The main threat axis for September closely resembles that of July and August, with the exception of a small increase in speed west of 50°W. Originating near the Cape Verde Islands the track passes almost due west before swinging slightly west-northwest to pass over the northern end of the Windward Islands and threaten Roosevelt Roads from the southeast. Again, as in July and August, the threat axis and direction of approach for tropical cyclones in September are fairly predictable.

The threat analysis for October, Figure XX-9, is more unpredictable because it is spread throughout a wider sector. October had the highest percentage (38%) of tropical cyclones originating within 300 n mi of Roosevelt Roads (see Table XX-2).

Figure XX-10 is a composite analysis of all tropical cyclones for the 109-year period 1871-1979 whose tracks passed within the 180 n mi threat radius of Roosevelt Roads, showing threat probability and time to closest point of approach (CPA) curves for the entire period.

3.3 WIND AND TOPOGRAPHICAL EFFECTS

Records of hourly wind data for Roosevelt Roads* are available only for the period mid-1948 through 1949 and 1953 through 1979, a total of 24 years. Records are available for San Juan, Puerto Rico, located about 35 miles west-northwest of Roosevelt Roads, for the period 1940 through 1979 (40 years). The hourly records used in this study were:

Roosevelt Roads, Puerto Rico	July 1948 through February 1950 February 1958 through December 1979
San Juan, Puerto Rico	August 1940 through September 1979

During the 24-year period for which wind data are available for Roosevelt Roads, 24 tropical cyclones approached within 180 n mi, an average of one per year. A breakdown of these tropical cyclones based on intensity while within the 180 n mi threat radius is given in Table XX-4. Similar data are given for the 40-year period for which wind data are available for San Juan.

Table XX-4. Classification by intensity of the tropical cyclones that that passed within 180 n mi of Roosevelt Roads and San Juan.

	Roosevelt Roads (1948-49 and 1959-79)	San Juan (1940-79)
Hurricane (≥64 kt)	9*	21
Tropical Storm (34-63 kt)	12	17
Tropical Depression (<34 kt)	3	6
TOTAL	24	44

*Note: The average CPA to Roosevelt Roads was 93 n mi for the 9 hurricanes.

*The location of the observing station for Roosevelt Roads is indicated by an "S" on Figure XX-2.

Although there was a total of 21 tropical storms and hurricanes within the 180 n mi threat radius at Roosevelt Roads, only one caused sustained winds of 34 kt or greater based on hourly wind observations at that site. That hurricane (Donna, September 1960) also caused the only hurricane strength wind gust at Roosevelt Roads. No sustained winds of $\geq$64 kt were recorded during the period examined.

A similar analysis of 40 years of wind records at San Juan revealed two tropical cyclones that caused sustained winds of 34 kt or greater and only one tropical cyclone during which wind gusts greater than 63 kt were recorded. Based on the short period of record at Roosevelt Roads (24 years), gale force winds can be expected in only one out of every 21 tropical storms/hurricanes passing within 180 n mi of Roosevelt Roads.

This assumption must be tempered by two facts, however: (1) a time of greater hurricane activity in the 1926-1932 period produced hurricane strength winds upon several occasions at San Juan (NOAA, 1975); and (2) the average CPA to Roosevelt Roads for the 9 tropical cyclones of hurricane strength was 93 n mi.

Figure XX-11 depicts the tracks of the 9 tropical cyclones that had winds of 64 kt or greater while within the 180 n mi threat radius.

The harbor and facilities at Roosevelt Roads are most vulnerable to strong winds and wind-generated waves from the south-southeast through south-southwest quadrant (storm passage to the south). The harbor opens to the southeast and all piers, wharves and harbor facilities are located on the east side of the bay. The harbor area is surrounded by low, rolling hills that offer limited protection from high winds. Vieques Island, with heights to 988 ft and located 8-12 miles southeast of the harbor, offers little wind protection but some protection from sea swell/wind waves from that direction.

3.4 WAVE ACTION IN VIEQUES PASSAGE (PASAJE DE VIEQUES) AND ON ENSENADA HONDA

Ensenada Honda opens directly into Vieques Passage and, with a harbor opening of approximately one mile in width, is subject to wind waves and swell generated outside the harbor area. Depths in Vieques Passage range roughly 10-30 fathoms, therefore sea and swell wave heights will be affected by "bottoming" and lose some wave height as they approach the harbor area. (Deep-water waves generated by a hurricane can reach 25-30 ft in height with only 64 kt winds and 100 n mi fetch.)

Sea and swell may be further reduced by a large shoaling area located on the western side of the harbor entrance that covers about two-thirds of the bay entrance (note 3 fathom contour on Figure XX-2).

Maximum wind wave action with the greatest potential for damage to harbor piers would result from strong southern or southwesterly winds, which would bring large waves from the Caribbean Sea into Ensenada Honda. Adding a storm

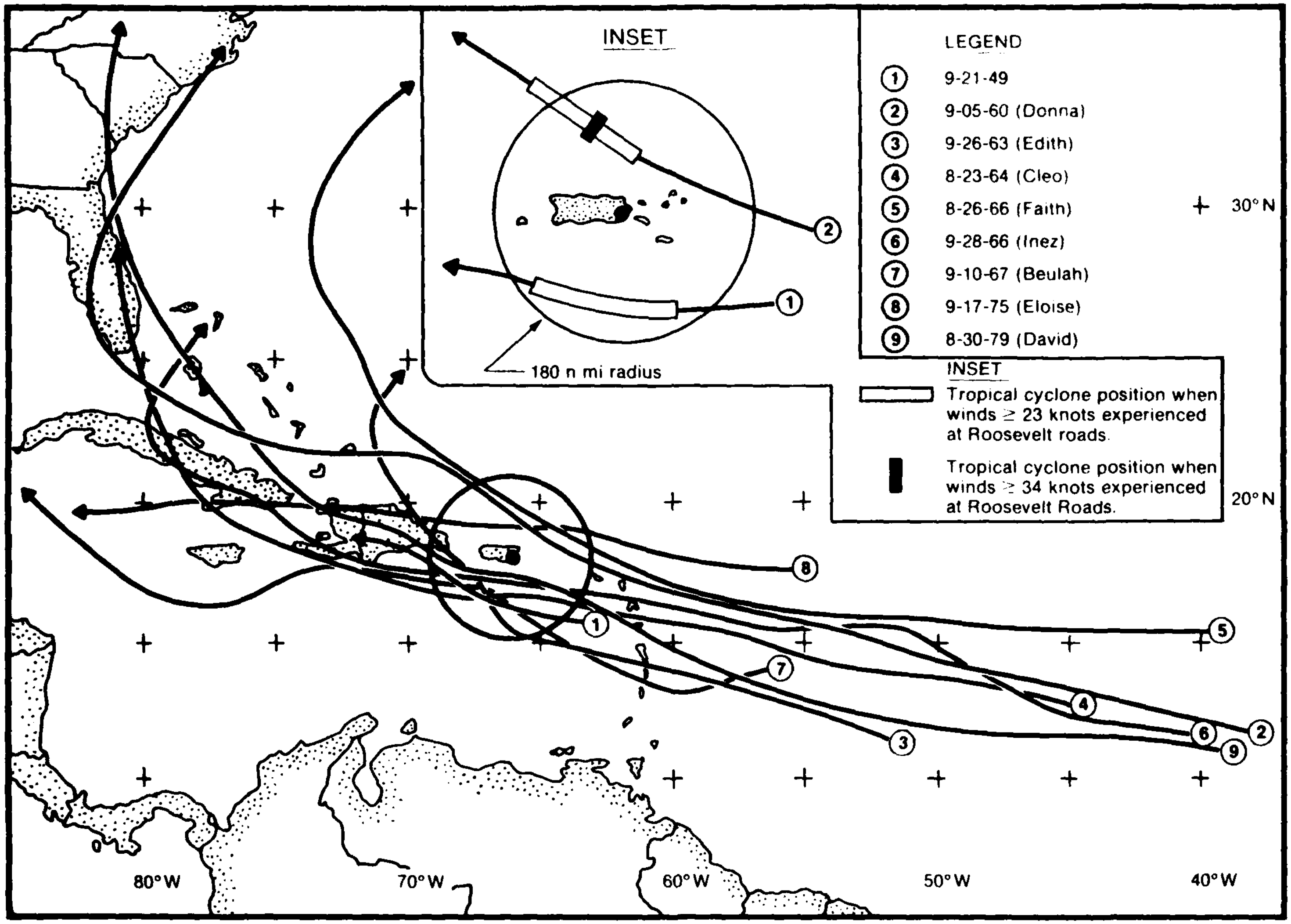

Figure XX-11. Tracks of nine tropical cyclones during the periods 1948-49 and 1959-79 that had hurricane force winds while within the 180 n mi threat radius of Roosevelt Roads.

surge height of 9-12 ft -- associated with a hurricane with maximum winds of 97-113 kt -- would raise the base height of the waves, thus inundating a significant portion of Roosevelt Roads and exposing a greater area to water and wave damage.

Wind wave action from other than south to southwesterly directions would be limited to the harbor and therefore very limited in fetch. Using an average water depth of 40 ft and a fetch length of one mile, it can be calculated that 35 kt winds would generate 2 ft wind waves, 65 kt winds would generate 4 ft wind waves, and 100 kt winds would generate 5.5 ft wind waves (U.S. Army Corps of Engineers, 1977).

3.4.1 Facilities on Ensenada Honda

Roosevelt Roads piers, wharves, and facilities are located on the east side of Ensenada Honda (refer to Figure XX-2). Being open to the south-southeast, the harbor is susceptible to sea swell and wind waves that can directly threaten the pier and wharf area. With unlimited fetch, only shoaling upon 3 fathom depths at the harbor entrance and the blocking presented by Vieques Island offer some protection to the harbor.

Winds from any other direction present a high wind threat but only a limited wave threat (as the limiting fetch of one mile restricts wave generation). However, a Category 3 hurricane (97-113 kt maximum wind) or greater storm making landfall on the southeastern tip of Puerto Rico has the potential to create a 9-12 ft storm surge that would put all of the piers underwater.

3.5 STORM SURGE AND TIDES

The term 'storm surge' is used to indicate changes from normal water level due to the action of storms. Severe storms may produce surges in excess of 25 ft above normal on the open coast and even higher in bays and estuaries. The eventual height of the water level is determined mainly by the strength and characteristics of the storm and the hydrography of the coast or basin. Table XX-5 relates characteristics of Atlantic hurricanes to potential storm surge and subjective estimates of possible damage.

Table XX-5. Saffir/Simpson damage-potential scale ranges.

Scale Number (Category)	Central Pressure Millibars	Winds (mph)	Winds (kt)	Surge (ft)	Damage
1	>980	74-95	64-83	4-5	Minimal
2	965-979	96-110	84-96	6-8	Moderate
3	945-964	111-130	97-113	9-12	Extensive
4	920-944	131-155	114-135	13-18	Extreme
5	<920	>155	>135	>18	Catastrophic

The following combination of circumstances and features would help generate a large storm surge at Roosevelt Roads:

(1) An intense storm of Category 3 (97-113 kt) or greater strength passing over, or within 50-60 n mi of, the harbor.

(2) A storm track from the south or southeast with landfall 20 to 50 n mi west of the harbor. This would place the harbor in the stronger, right semicircle of the hurricane and face the open mouth of the harbor directly into the winds and sea/swell.

(3) A large, strong hurricane passing north or south of the island with slow movement that could cause surge in the harbor.*

(4) Bottom bathymetry that shoals up to the harbor entrance. (Shoaling tends to help pile the water up and increases surge heights.)

(5) An open, non-constrictive harbor mouth and closed basin configuration.

Tidal changes in Ensenada Honda are less than one foot and would not be a major factor in any storm surge.

Due to the lack of hurricane strikes and few close approaches to Roosevelt Roads during the last 30 years by a hurricane of major intensity, few opportunities for severe surge occurred during this period. Betsy (August 1956) and Donna (September 1960) were the only two hurricanes to approach within 90 n mi of Roosevelt Roads during this period with hurricane strength winds, 30 n mi with 83 kt winds and 66 n mi with 134 kt winds, respectively. No storm surge/water-level observations (observed or mechanical) were available for either storm; Ensenada Honda does not have a tidal gauge in the bay. The lack of severe surge in recent recorded history does not preclude the event in the future, however, and Ensenada Honda certainly has the potential for storm surge from a major hurricane as indicated earlier.

Currents are not a problem within the harbor. A southwesterly set is present in the entrance channel with a 1.0 kt maximum flow. Due to the closed configuration of the harbor, currents are not expected to be a major consideration within the harbor during tropical cyclone approach. However, the normal set at the harbor entrance may be influenced by an approaching storm and should be watched.

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*Note that unusual circumstances can cause large surge and wave action. Hurricane Greta (October, 1956) moved from west to east passing 275 miles north of Puerto Rico, and caused high tides and high swells (16-20 ft) on the southern coast of Puerto Rico due to the long southwesterly fetch.

4. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for hurricane preparedness at the Naval Station, Roosevelt Roads are addressed in COMNAVFORCARIB DISASTER PREPAREDNESS PLAN 2103 and NAVSTA ROOSEVELT ROADS INST. 3140.2 series.

4.1 THREAT ASSESSMENT

Ensenada Honda and the harbor facilities at Roosevelt Roads potentially face considerable risk of damage in case of close landfall or passage by a hurricane. Damage to the harbor and facilities can result from high winds and/or associated storm surge depending on storm track and landfall.

The absence of sheltered berths or anchorages makes evasion at sea the safest course of action for all seaworthy deep-draft vessels. Early assessment of a potential threat is recommended, based on current advisories and forecasts issued by the Navy and the National Weather Service through the San Juan office. This information should be related to the climatology of past hurricanes as presented in this study and the recommendations of this section.

As can be seen in Figure XX-4 and Figures XX-6 through XX-11, the greatest threat to Roosevelt Roads occurs during the months of August and September from tropical cyclones that form to the east-southeast of Puerto Rico and move west-northwest across the Lesser Antilles and Windward Islands. Storms approaching from the south or southeast octant (approximately 44% of total) would pose the greatest storm surge threat, especially with landfall within 60 n mi to the west of the harbor. Storms approaching Roosevelt Roads from other octants would pose less surge threat, but the harbor is susceptible to high winds from all quadrants.

As a general rule, any intense tropical storm or hurricane with a close CPA has great potential to cause significant damage in the harbor. If the storm track places Roosevelt Roads in the right semicircle of the approaching tropical cyclone, the potential threat is increased. The lack of sufficient recorded data at Roosevelt Roads to verify significant damage in past hurricanes should not encourage complacency. A hurricane strike by David (August 1979) on Dominica (340 miles southeast of Puerto Rico) left 56 persons dead and 60,000 homeless.

4.2 EVASION AT SEA

When Roosevelt Roads is threatened by a tropical storm or hurricane producing gale force (34 kt) or higher winds, evasion at sea is the recommended course of action for all seaworthy deep-draft vessels.

The decision to evade at sea must be timed to allow safe passage to open waters. The timing is affected by:

(1) Preparation time necessary to get underway.

(2) Forward speed of the tropical cyclone.

(3) Forecast radius of high winds that would hamper/prevent a vessel's capability to maneuver to open water.

(4) Direction of ship's track (relative to storm) and elapsed time to reach open water.

(5) Number of hours of daylight/darkness and preference by vessel's captain to evade storm in Atlantic or Caribbean.

Advice and considerations for leave/stay decisions are given in the General Guidance section of this Handbook (Section I). This guidance must be modified for Roosevelt Roads by the harbor's location, the local geography, the local wind and wave effects, and the climatology of the tropical cyclones approaching within 180 n mi of the harbor. The location of Roosevelt Roads on the southeast coast of Puerto Rico presents some navigation problems when evasion is to be considered.

Puerto Rico is bounded on the north by the Atlantic Ocean and on the south by the Caribbean Sea. Immediately to the east of Puerto Rico are the islands of Vieques and Calebra, the Virgin Islands, and the Lesser Antilles Islands extending eastward and then southward towards the South American coast. Evasion northward to the Atlantic is complicated by numerous reefs, shoals and narrow passages.

Hurricane Condition III is set when hurricane force winds are possible within 48 hours. A decision to prepare for a sortie should be made soon after the setting of Hurricane Condition III to allow adequate storm clearance prior to high winds and seas, even though the storm may be 500-600 n mi distant. The average tropical cyclone forecast error for a 48-hour forecast is around 200 n mi for those tropical cyclones threatening Roosevelt Roads, and this error should be considered in any sortie planning. The following evasion guidelines are offered:

(1) <u>Tropical Cyclones Approaching from the East or Southeast (88% of Total Threats)</u>. Evasion north to the Atlantic would require steaming east-northeast through an area of many scattered, shallow reefs and shoals toward the approaching storm initially, or steaming first south and then west through Mona Passage west of Puerto Rico. The first choice may be risky. Going east toward the storm would further reduce evasion lead time and might place the ship in dangerous waters in high seas. Steaming west and then north would delay clearing the storm track and would require close monitoring of the storm's progress prior to turning north to evade.

Evasion south to the Caribbean Sea incurs less risk, because the most probable threat path is westward with recurvature to the north-northeast. This also allows more flexibility in departure because passage to open water to maneuver is achieved much quicker. Departure from Ensenada Honda is simple, and once a vessel is in Vieques Passage it is only 15 n mi to clear Puerto Rico and Vieques Island into the Caribbean.

(2) Tropical Cyclones Approaching from Other than East or Southeast (12% of Total Threat). A tropical cyclone approaching from other than the east and southeast octants may predetermine which of the three routes discussed above is most appropriate to use to evade the storm. A storm approaching from the north or northeast octants (6%) or west (1%) would dictate a route south into the Caribbean and then probably east (monitoring warnings) to escape storm effects.

Approach from the south or southwest octant (5%) would preclude the southern routes and force a passage through the Leeward Islands to the east-northeast into the Atlantic Ocean. Early departure should be made to ensure good passage conditions.

4.3 RETURNING TO PORT

Damage to a port due to a tropical cyclone strike may be severe. Returning vessels should check with surface Operations Office for navigation hazards such as blocked channels and displaced or missing channel markers, and for pier conditions and services.

4.4 REMAINING AT ROOSEVELT ROADS

Remaining at Roosevelt Roads is an option that should be seriously considered when a vessel is unable to evade the storm at sea, or when the threat is questionable. The latter might be:

(1) A weak tropical cyclone (maximum winds less than 50 kt) is approaching Roosevelt Roads, but is forecast not to intensify. (A close watch must be kept, because these tropical cyclones may intensity rapidly; see Para. 3.2.)

(2) A weak tropical cyclone with slow forecast development is within the 180 n mi threat radius, but is well north or south of the harbor and moving to the west.

If a decision is made to remain at Roosevelt Roads, the following recommendations are offered.

(1) Ensenada Bay topography, bathymetry and orientation with respect to port facilities suggest that Wharf (Bulkhead) Charlie would offer greatest protection from wind and wave action. Past local experience bears this out.

(Note: Alongside depths are limited to 12-14 ft for about 200 ft near the southwest end of the 750 ft wharf. Depths to 20 ft are available for the remaining length of the wharf.)

(2) The poor holding for anchorage within the harbor and the limited maneuvering room (less than one mile across in any direction) suggests that steaming at anchor may be necessary.

(3) Ensenada Honda is a small harbor and does not offer much protection. If a vessel chooses to remain for a forecast weak tropical cyclone, sufficient dock lines to withstand predicted wind forces and yet allow for possible water height fluctuation, should be carefully calculated and used.

5. ADVICE TO SHALLOW DRAFT VESSELS

Shallow draft vessels should be removed from the water and placed under shelter in an aircraft hangar or garage if possible. If shelter is not available, vessels should be firmly secured ashore at an elevation 20-30 ft above water level to prevent increased water levels and large waves from reaching them. Particular attention should be given to probable wind forces and areas of potential flooding from heavy rains and run-off.

An alternative for shallow draft boats is a small enclosed cove with depths to 18 ft located near the southwest entrance to Ensenada Honda. The entrance is 4 ft deep and must be carefully navigated. Once inside, boats should moor to the mangrove trees and also put out an anchor. The bottom is mud and holds well, and the water is 5-6 ft deep adjacent to the mangroves. Allowance for increased water levels should be made. This cove is protected by a two-foot shoal at its entrance.

Ensenada Honda, the main harbor of the Island of Culebra (22 miles northeast) is used by boaters from Puerto Rico and Saint Thomas as a refuge during tropical cyclones. With a small deep-water harbor, it offers good protection but may be crowded with many small craft seeking shelter.

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XXI. GUANTANAMO BAY, CUBA

XXI: CONTENTS

XXI. GUANTANAMO BAY, CUBA

SUMMARY

Guantanamo Bay is a poor hurricane haven because of its lack of sheltered facilities and the poor holding within the harbor. Evasion at sea is recommended for all seaworthy deep-draft vessels when Guantanamo Bay is threatened by an intense tropical storm or hurricane. Small craft should be removed from the water and firmly secured above the predicted high water line.

The geographic location of the Guantanamo Bay area (i.e., downstream from the island of Hispaniola, whose high mountains weaken tropical cyclones in passage) and the surrounding terrain give the area some protection from both high winds and stormy seas, but this protection is limited. Records show that Guantanamo Bay is vulnerable to tropical cyclones approaching from all directions.

Guantanamo Bay has been threatened by an average of 0.9 tropical cyclones per year, of which one out of seven caused sustained gale force wind in the harbor area. While there was no recorded instance of sustained hurricane force wind, two tropical cyclones caused hurricane force gusts during the years 1945-1979.

The hurricane season for the North Atlantic is from June through November, but Guantanamo Bay has been threatened on rare occasions by off-season tropical cyclones. The month of maximum occurrence for tropical cyclones is September, but August and September had an equal number of occurrences of threat tropical cyclones of hurricane strength.

This hurricane haven evaluation was prepared by A.J. Compton and J.D. Jarrell of Science Applications, Inc. (SAI), Monterey, CA 93940.

GUANTANAMO BAY, CUBA

1. LOCATION AND TOPOGRAPHY

Guantanamo Bay, located on the southeast coast of the island of Cuba about 500 statute miles southeast of Miami, Florida, is approached via the Windward Passage from the north or the Caribbean Sea from the south (Figure XXI-1). Guantanamo Bay is the largest bay on the extreme south coast of Cuba, and affords anchorage for deep-draft ships.

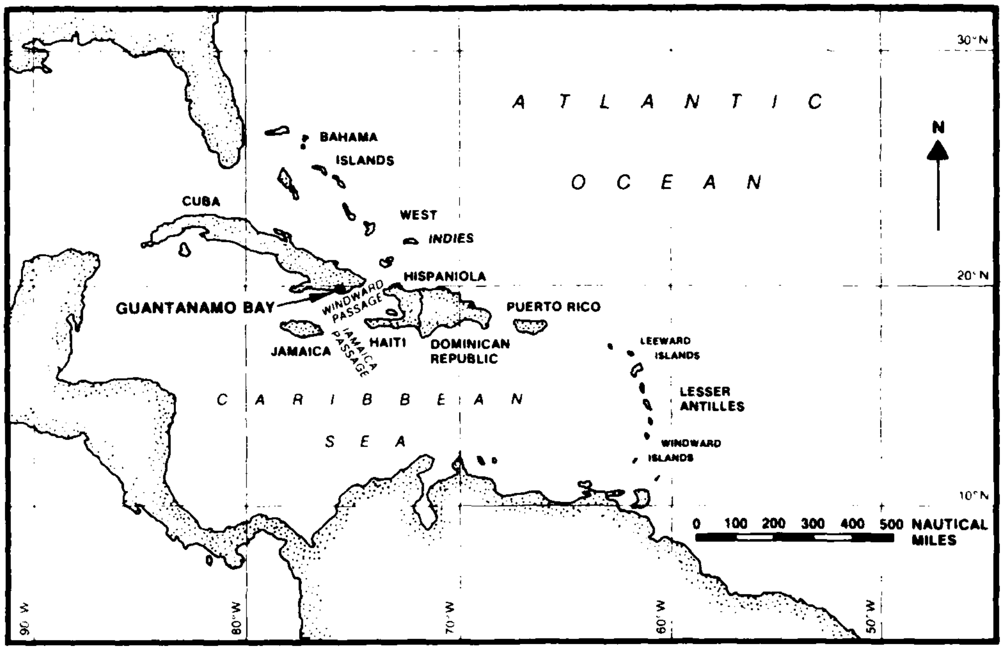

Figure XXI-1. Location of Guantanamo Bay, Cuba.

The bay is a pouch-shaped indentation about 12 miles long in a northeast-southwest direction and about 6 miles across at its greatest width. Guantanamo Valley, a low, hilly district, extends westward from the bay along the Sierra Maestra. The deep bay is sheltered by the nearby Cuzco Hills (elevations to 495 ft) to the south and east and by mountains to the north.

Entrance into the bay, between Leeward Point and Windward Point, is made through a 1 1/4 mile-wide channel with 42 ft least dredged depth up to a point westward of Fisherman Point (Figure XXI-2). From there to a point southwestward of Caravela Point, the least dredged depth is 32 ft.

The bay complex is divided into an Outer Harbor and an Inner Harbor. The Outer Harbor stretches from the entrance to the Naval Reservation Boundary about 5 miles northeastward. The channel narrows to 250 yards here, at Palma Point, then widens into two separate bays whose total width is about 5 miles; the upper

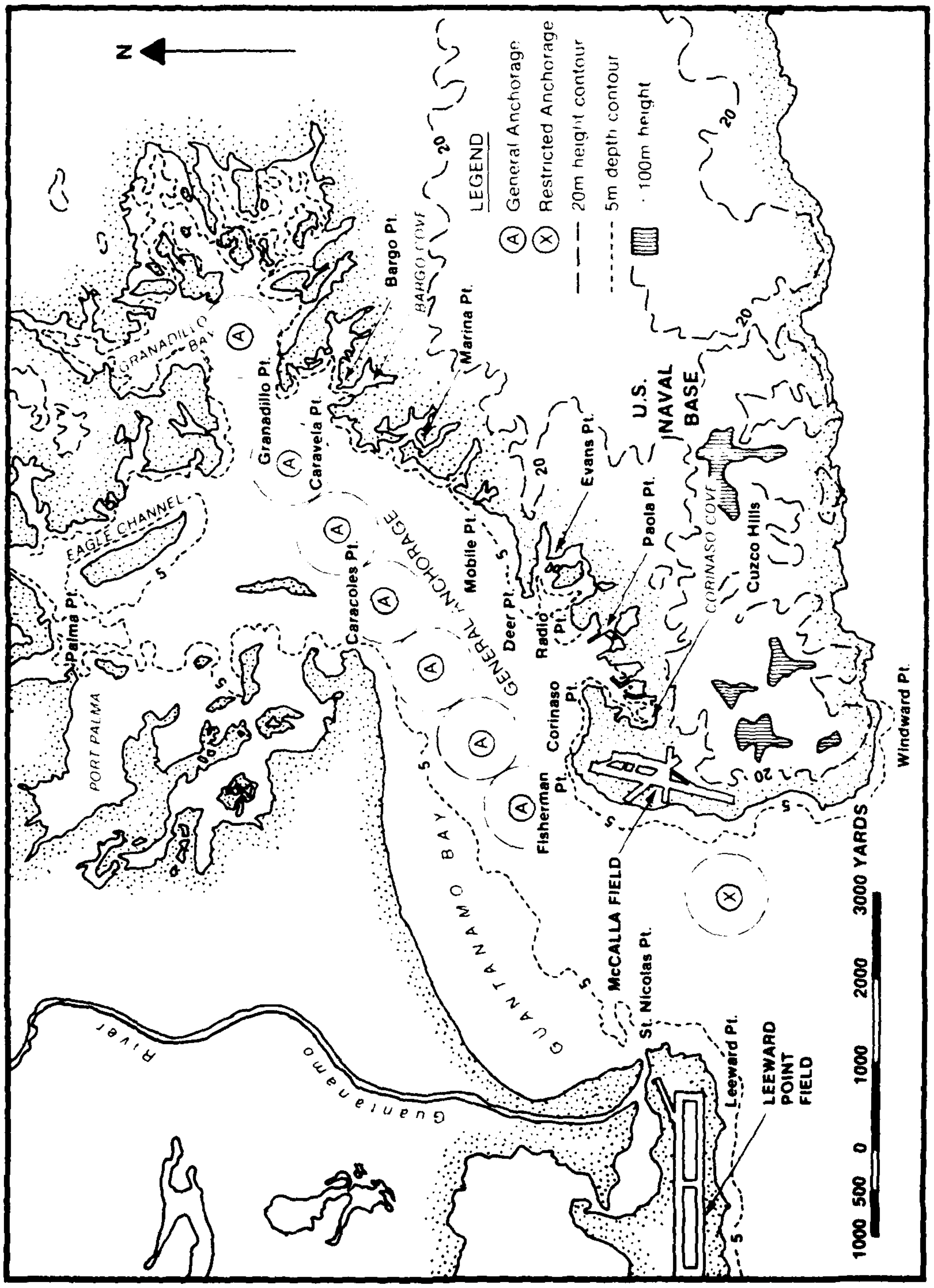

Figure XXI-2. Guantanamo Bay, Cuba.

half, known as Ensenada de Joa, forms the Inner Harbor in which commercial ports are located. The naval base and the main anchorage area are contained within the Outer Harbor area.

The naval complex is located on the east side of the harbor between Fisherman Point (1 3/4 miles north of Windward Point) and Granadillo Point, abut 2 3/4 miles northeastward (Figure XXI-2). The area contains many coves and peninsulas and a few islands. Much of the land here is elevated well above water level. The western side of Guantanamo Bay, generally low and mangrove-covered, contains many mud flats.

The more important coves, located between Corinaso Point and Deer Point, contain the pier and wharf facilities of the naval base. The land is lower and flatter here for a few hundred yards inland. Two airfields are located within the naval complex: McCalla Airfield, on the east side of the harbor entrance, is inactive; Leeward Point Field on the west side is an active naval air station.

Water depths vary from about 60 ft just inside the harbor entrance to approximately 30 ft in Granadillo Bay (on the east side of the Outer Harbor) and at the entrance to Eagle Channel. Many of the coves are only 25 ft deep.

The mean tide range is 1.0 ft and the spring tide range is 1.3 ft. Periodic tidal variations as great as 4-5 ft have been observed, but these probably were meteorological* versus astronomical phenomena. Harbor tidal currents in Guantanamo Bay are estimated to be about .25 kt on the flood to .50 kt on the ebb. Locally at the river mouth, stronger currents are observed periodically. Swells ranging 3-5 ft are common during the afternoons and nights, extending upbay from the harbor entrance to Fisherman Point. During an extended period of fresh southerly winds from a recent winter storm on the Gulf of Mexico (Apr 83), waves up to 10-12 ft were observed in the outer harbor; these disrupted the lifeline ferry service from Leeward Point for two days.

2. PORT AND HARBOR FACILITIES

2.1 BERTHS FOR DEEP DRAFT VESSELS

At Guantanamo Bay, the Outer Harbor is used by the U.S. Navy and the Inner Harbor serves as a commercial (Cuban) port. This evaluation deals with the facilities of the Outer Harbor only, although the climatology section is appropriate for both harbors.

The Outer Harbor includes that portion of Guantanamo Bay from the entrance north to Palma Point (approximately 19° 58' 24"N). The major naval facilities are contained within Corinaso Cove from Corinaso Point to Radio Point. There are five piers available, varying in length from 180-900 ft with depths

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*These observations are probably due to weather disturbances in the Caribbean Sea or Atlantic, but those reporting the variations were unable to verify this.

alongside from 20 to 35 ft*. Three wharves provide accommodations up to 1065 ft with depths to 38 ft. Piers and wharves range from 6 to 10 ft in height above MSL. Table XXI-1 lists dimensions of pier, wharves, and berths in Guantanamo Bay. (It should be noted that dredge depths decrease along some piers (see Pier B) and also that dredge width may be minimal and maneuvering is consequently difficult.) Figure XXI-3 depicts Corinaso Cove and the naval piers and wharves. Berths and anchorages in Guantanamo Bay are assigned by the Port Services Officer.

The naval anchorage areas for deep-draft vessels are in the Outer Harbor. The area designated "X" on Figure XXI-2 is a restricted anchorage due to interference with the landing and takeoff patterns of Leeward Point Naval Air Station.

Pilots are available and required for ships engaged in commercial trade, but are not compulsory for ships of the U.S. Navy. Tugs (normally two available) and other harbor services may be arranged through Port Control. Emergency harbor services are available 24 hours a day.

2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

Due to its configuration and location, Guantanamo Bay offers limited protection against hurricanes. Wind protection is provided from the south and southeast by the Cuzco Hills. Tropical cyclones historically have approached eastern Cuba across the island of Hispaniola, which, with its mountainous terrain, tends to mitigate the strength of the storm in passage and thus protect eastern Cuba. The "S" shaped configuration of the Outer Harbor helps to protect the pier and wharf area from ocean swell and wind waves.

Several anchorages are available in the Outer Harbor. They offer limited protection from storms (i.e., the Cuzco Hills south and east), but are not considered to be safe hurricane anchorages. Holding in the harbor is only fair in soft mud bottom, and anchor dragging may occur in winds over 30 kt.

Facilities for ship repairs are available, normally at Pier A. This pier, however, is limited by size and line configuration to DD and smaller ships; Pier L is normally used for cold steel ships. It should be noted that Pier BB1 (fuel pier) is inappropriate for use during a threatening situation because of the potential fire hazard. A floating drydock (LOA 200 ft) is also available with a lifting capacity of 1,000 tons.

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*All depths should be checked against latest charts, Notice to Mariners, and local information. Depth and height are feet above mean sea level. Note that although pier B is 1065 ft in length, there is only 800 ft with dredged depth in excess of 30 ft.

Table XXI-1. Major piers, wharves, and berths in Guantanamo Bay. Note Figure XXI-3 to key this table to pier, wharf and berth location.

Pier/ Wharf	Length (feet)	Width (feet)	Depth[1] (feet at MLW)
A West[2]	300	56	30
A East	405	56	32
B (North End)	1065(750)	32	26(38)
BB1[2]	305	50	36
C	350	34	35
D	180	30	20
L West	820	60	30
L East	525	60	35
T[2]	410	25	29
U[2]	140	18	26
V West	700	60	35
V East	900	60	30

[1]Depths should be checked against latest charts, Notice to Mariners, and local information.

[2]Not used for transients.

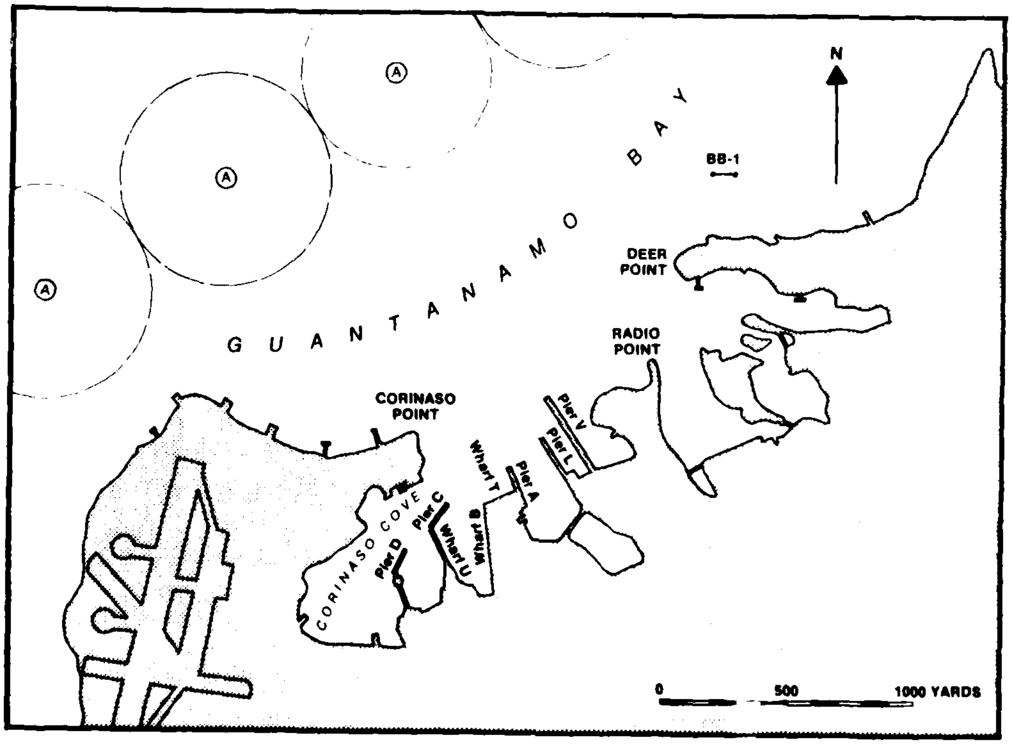

Figure XXI-3. Guantanamo Bay pier area.

2.3 FACILITIES FOR COMMERCIAL AND IN-SHORE VESSELS

Bay rules require all ships to be identified upon approaching the pier areas, and unidentified ships are immediately reported to the harbor police for investigation. United States commercial vessels moving to or from the facilities require both tug and pilot services for Outer Harbor transit.

There are numerous small boat landings located on the east side of the Outer Harbor. Wharf R in Corinaso Cove is a designated small craft wharf; privately owned boats can be pulled out of the water at the seaplane ramp near this wharf. There is a designated hurricane slip for tugs and ferries between Radio Point and Deer Point. Station gigs normally would be taken into the mangroves of the back bay, and the floating dry dock would be flooded in place for an approaching hurricane.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT GUANTANAMO BAY

3.1 INTRODUCTION

A study of previous tropical cyclones' frequency of occurrence, direction of approach, speed of movement, and intensity at Guantanamo Bay provides some insight into storm behavior and potential annual threat to the harbor. It should be noted, however, that such a historical overview cannot be a totally reliable guide to predict behavior and impact of present-day storms. This threat analysis focuses on the Outer Harbor (naval facilities), but also has application to the Inner Harbor.

3.2 CLIMATOLOGY

For the purposes of this study, any tropical cyclone approaching within 180 n mi of Guantanamo Bay is considered to represent a threat to the harbor.

Guantanamo Bay's location on the southeast coast of Cuba is significant, since the normal tropical cyclone path east-to-west is interrupted by the island of Hispaniola just east of Cuba. The preferred tracks thus tend to be just north or just south of eastern Cuba (Crutcher and Quayle, 1974). Tropical cyclones proceeding directly across Hispaniola and eventually striking Guantanamo Bay would be seriously weakened by Hispaniola's mountainous terrain (up to 10,775 ft). The area's location at latitude 20°N also puts it in a region where tropical cyclones behave more predictably than at more northern latitudes (25°-35°N) where recurvatures occur to complicate track/speed forecasting.

The official hurricane season for the North Atlantic is from 1 June through 30 November, but tropical cyclones have occurred outside of that period. Guantanamo Bay has recorded only two non-season storms -- May 1948 and May 1981 -- since 1871. During the 109-year period 1871-1979 there were 98 tropical cyclones that met the 180 n mi threat criteria for Guantanamo Bay, an average of less than one (0.9) per year. Table XXI-2 gives monthly totals and percentages, which are shown graphically in Figure XXI-4.

Table XXI-2. Monthly totals of tropical cyclones passing within 180 n mi of Guantanamo Bay during the period 1871-1979.

Month	No. of Tropical Cyclones	Percent of Total
May	1	1.0
June	2	2.0
July	3	3.0
August	23	23.0
September	41	42.0
October	20	20.0
November	8	8.0

Figure XXI-5 depicts threat occurrences as functions of the compass octants from which tropical cyclones have approached Guantanamo Bay during 1871-1979. The numbers in parentheses represent the percentage of the total approaching from that octant. The figure shows that the major threat sector is from the east through the southeast -- 65% of the cyclones approached from that quadrant -- and that cyclones have approached Guantanamo from all octants except the north.

An evaluation by Neumann and Pryslak (1981) of the frequency and motion of tropical cyclones in the Atlantic gives an average vector heading of 335° with an unreliable degree of "steadiness" in their motion for those cyclones within a 2 1/2° latitude/longitude box northeast of Guantanamo Bay. For the 1 1/2° latitude/longitude box just southeast of Guantanamo the average vector direction of the cyclones was 294° with an average degree of "steadiness" in their vector motion. Thus those cyclones passing just northeast of the harbor would tend to head more northeast, but would behave more unpredictably. Those from just southeast would tend to head toward the harbor (at 294°) and be more predictable.

A measure of tropical cyclone intensity is also given by Neumann and Pryslak (1981). Due to their characteristic development, tropical cyclones tend to be more intense in certain areas of the Atlantic basin. A measure of tropical cyclone intensity can be obtained from the ratio of the number of hurricanes to the number of hurricanes and tropical cyclones combined. For the 2 1/2° box containing Guantanamo Bay, this ratio is 14:32, i.e., 43% of

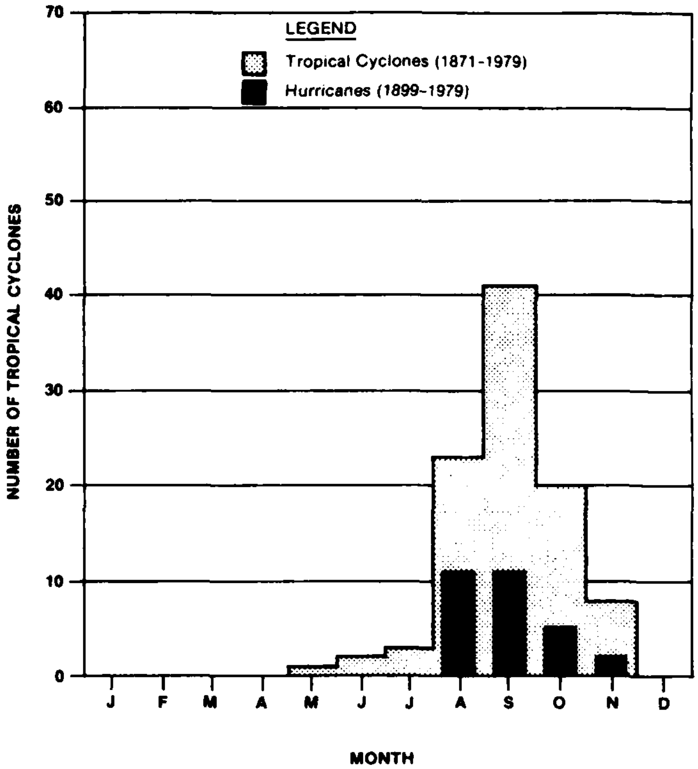

Figure XXI-4. Monthly totals of tropical cyclones passing within 180 n mi of Guantanamo Bay during the period 1871-1979. Totals for hurricanes (heavy shading) is the number of tropical cyclones passing within 180 n mi and being of hurricane intensity while within 180 n mi.

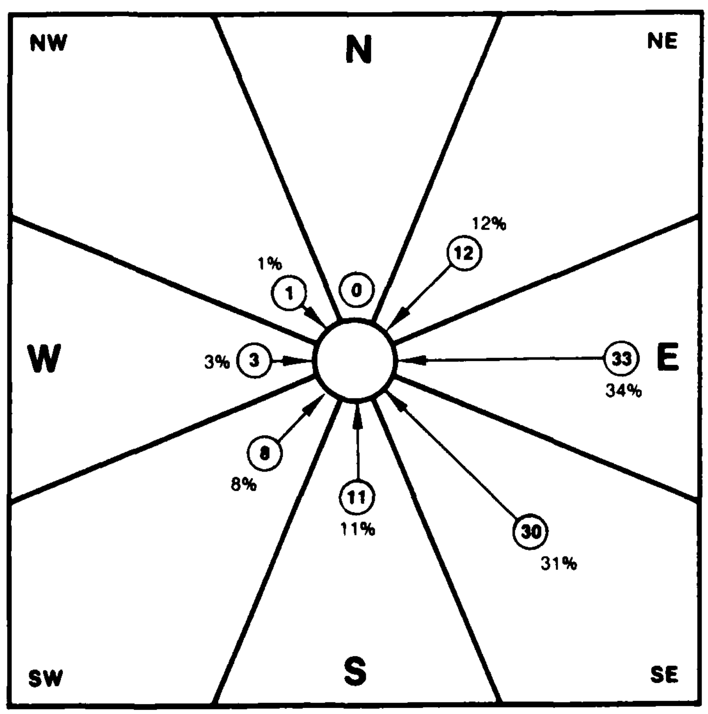

Figure XXI-5. Direction of approach of tropical cyclones that passed within 180 n mi of Guantanamo Bay during the period 1871-1979. Example: 33 tropical cyclones approached from the east; 34% of the total sample approached from the east.

the tropical cyclones passing through the area have hurricane velocity winds. This compares, for example, to 61% (31:51) for Miami, Florida and 36% for both New Orleans, Louisiana (20:56) and New York (7:19). Note, however, the relative frequency of occurrence.

Records of tropical cyclones that approached within 180 n mi of Guantanamo Bay during the 81-year period for which intensity data are available are tabulated in Table XXI-3 by intensity and month of occurrence. Table XXI-2 showed that September is the month for greatest tropical cyclone activity (42%) for the period 1871-1979. For the period 1899-1979, however, August and September had an equal number of tropical cyclones of hurricane strength: 11 each out of a total of 30.

Table XXI-3. Classification by intensity of 74 tropical cyclones that passed within 180 n mi of Guantanamo Bay during the period 1899-1979.

Intensity*	Nov-Jun	Jul-Aug	Sep	Oct	Totals	Percent of Total
Hurricane (>63 kt)	2	12**	11	5	30	41%
Strong Tropical Storm (48-63 kt)	3	3	9	1	16	22%
Weak Tropical Storm (34-47 kt)	5	2	5	6	18	24%
Tropical Depression (<34 kt)	-	3	3	4	10	14%
Total	10	20	28	16	74	

*Intensity values reflect the maximum intensity while within 180 n mi of Guantanamo Bay.

**Eleven occurred in August.

Figures XXI-6 through XXI-10 are statistical summaries of threat probability for the years 1871 through 1979. Summary data are shown for five periods: November through June, July and August, September, October, and all tropical cyclones of record 1871-1979.

The solid lines are percent threat for any tropical cyclone location. The dashed lines are approximate approach times to Guantanamo Bay based on the average climatological approach speed for a particular location. For example, in Figure XXI-7, a tropical cyclone at 15°N and 68°W has about a 50% probability of passing within 180 n mi of Guantanamo Bay and typically would reach the harbor in 1 1/2-2 days.

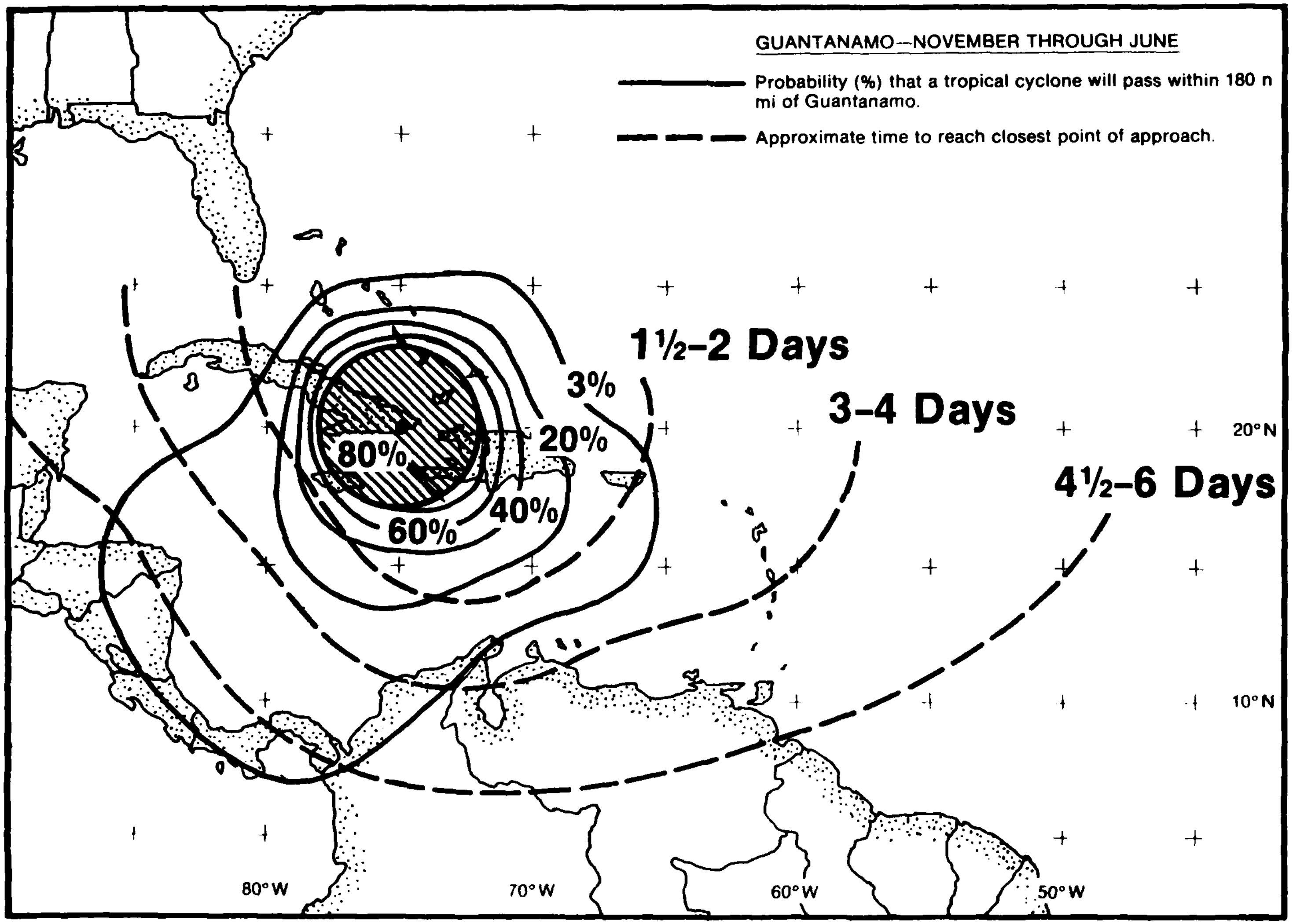

Figure XXI-6. Probability that a tropical cyclone will pass within 180 n mi of Guantanamo Bay (shaded circle), and approximate time to reach closest point of approach, during November through June (based on data for 1871-1979).

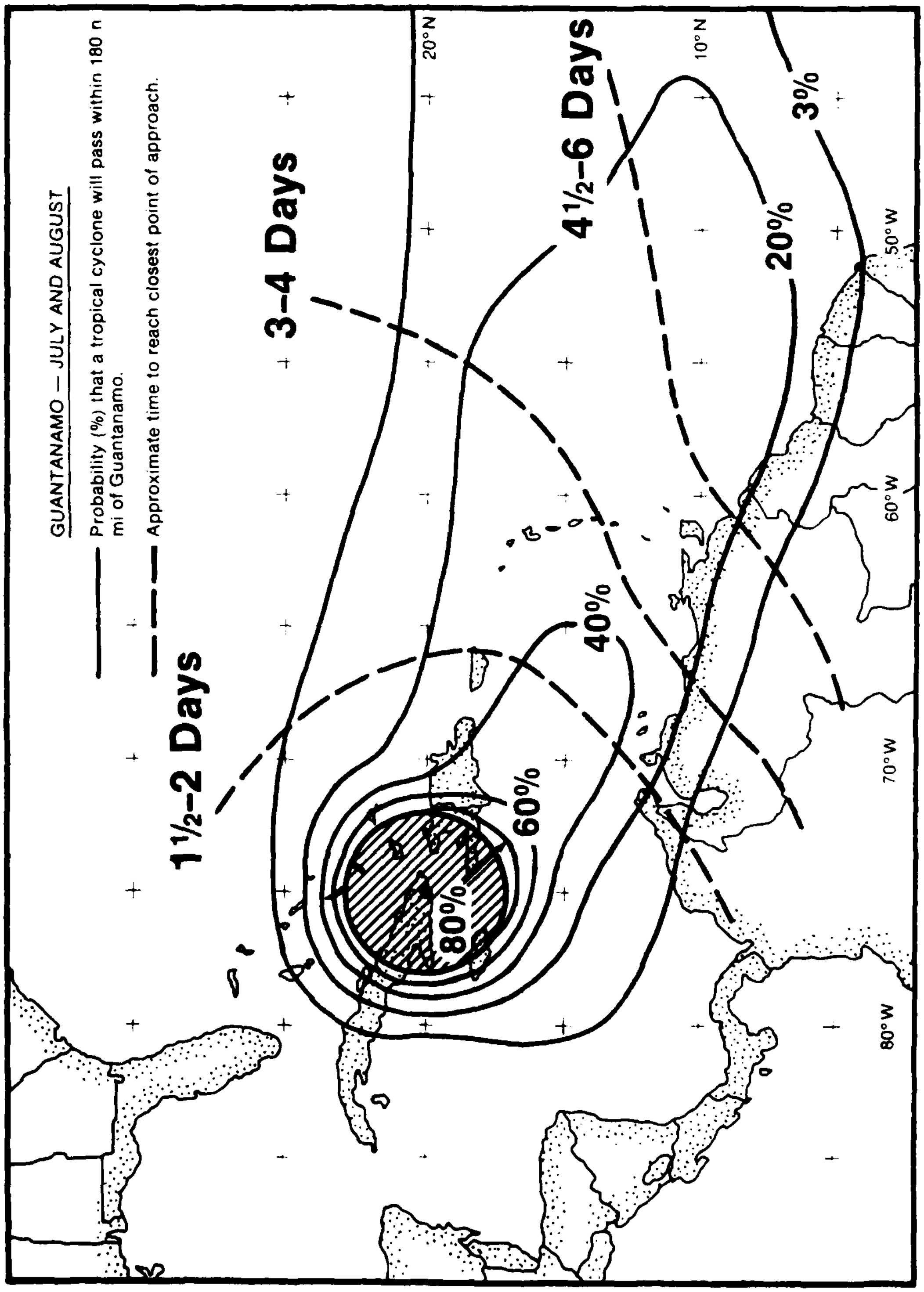

Figure XXI-7. Probability that a tropical cyclone will pass within 180 n mi of Guantanamo Bay (shaded circle), and approximate time to reach closest point of approach, during July and August (based on data for 1871-1979).

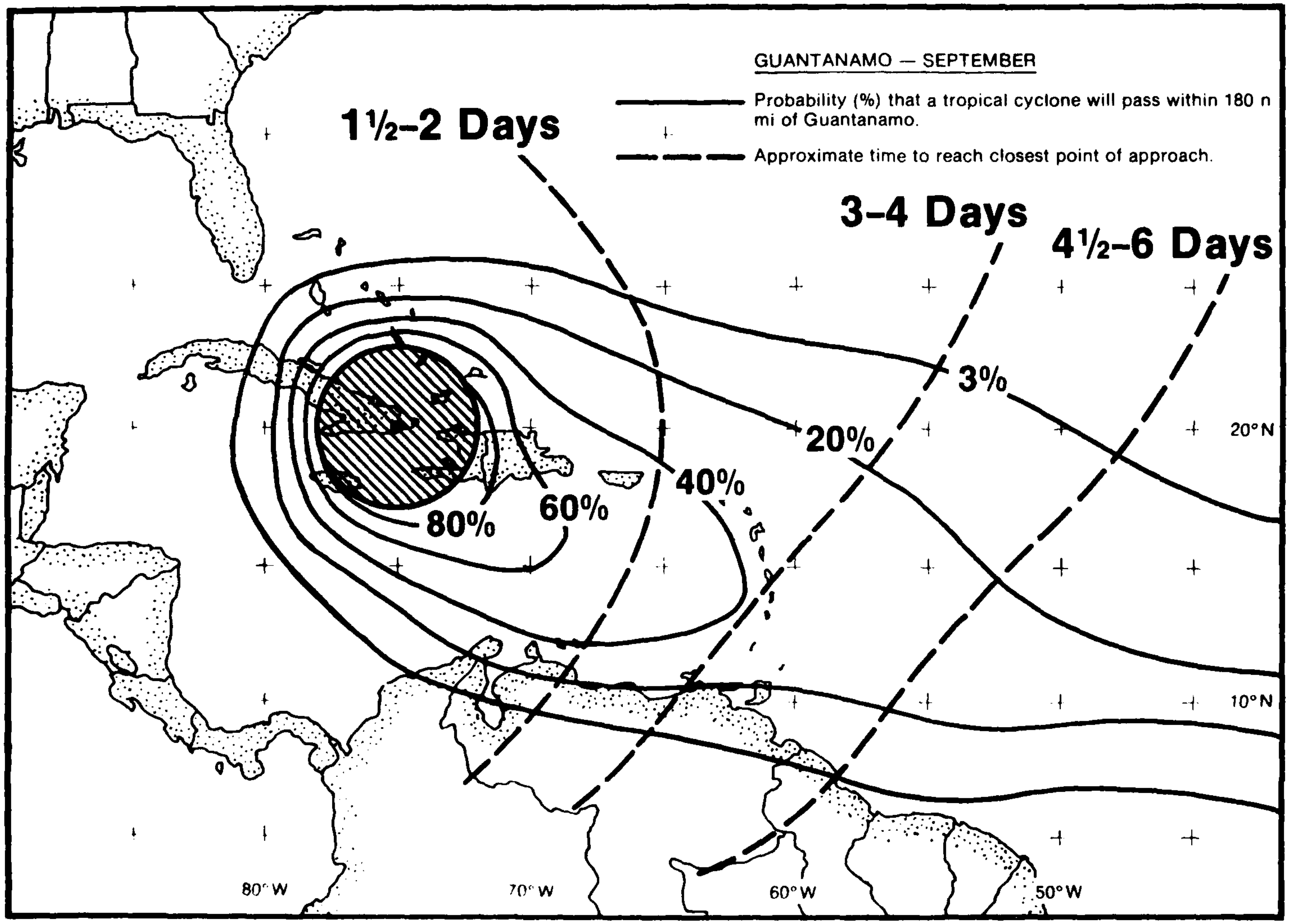

Figure XXI-6. Probability that a tropical cyclone will pass within 180 n mi of Guantanamo Bay (shaded circle), and approximate time to reach closest point of approach, during September (based on data for 1871-1979).

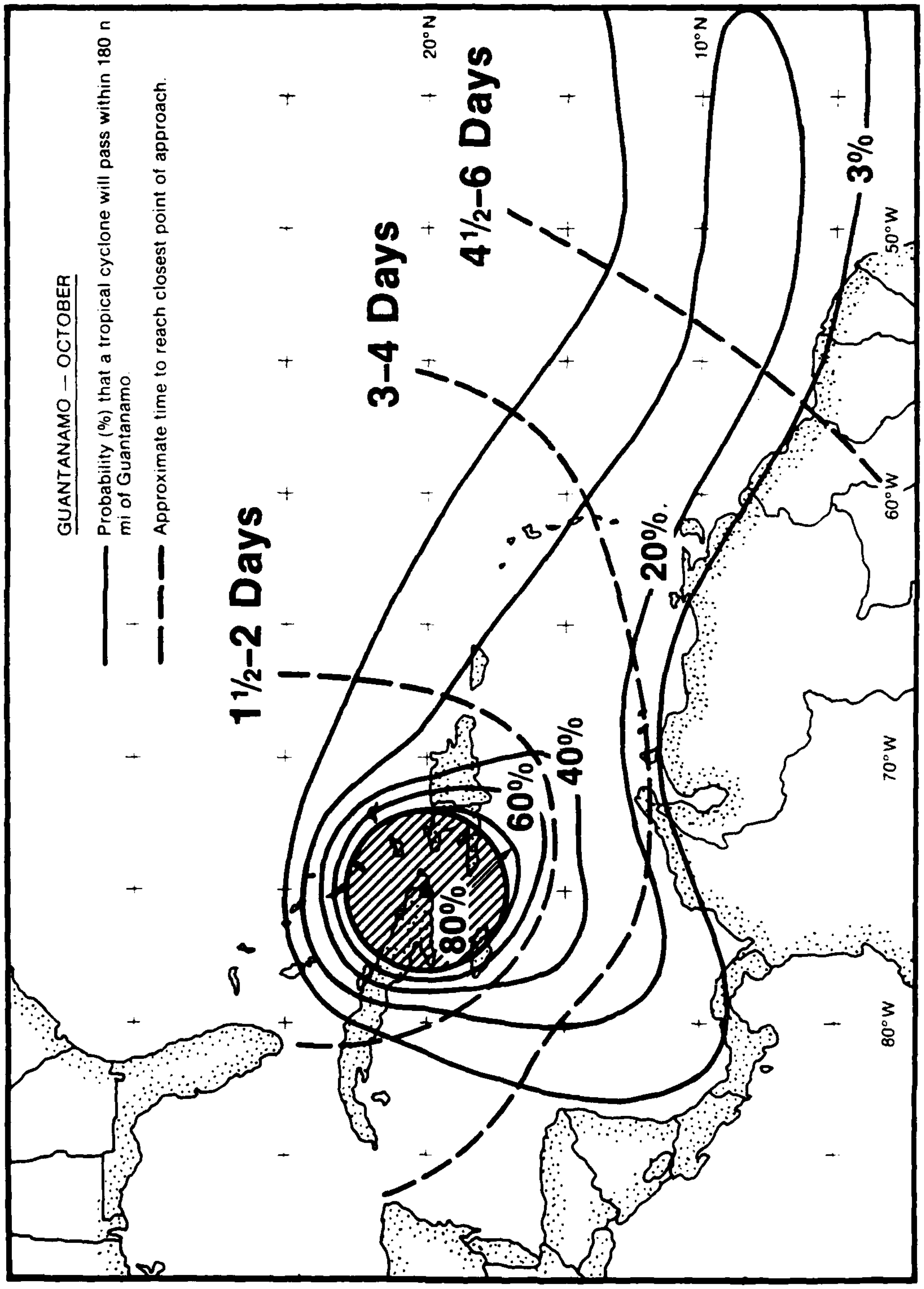

Figure XXI-9. Probability that a tropical cyclone will pass within 180 n mi of Guantanamo Bay (shaded circle), and approximate time to reach closest point of approach, during October (based on data for 1871-1979).

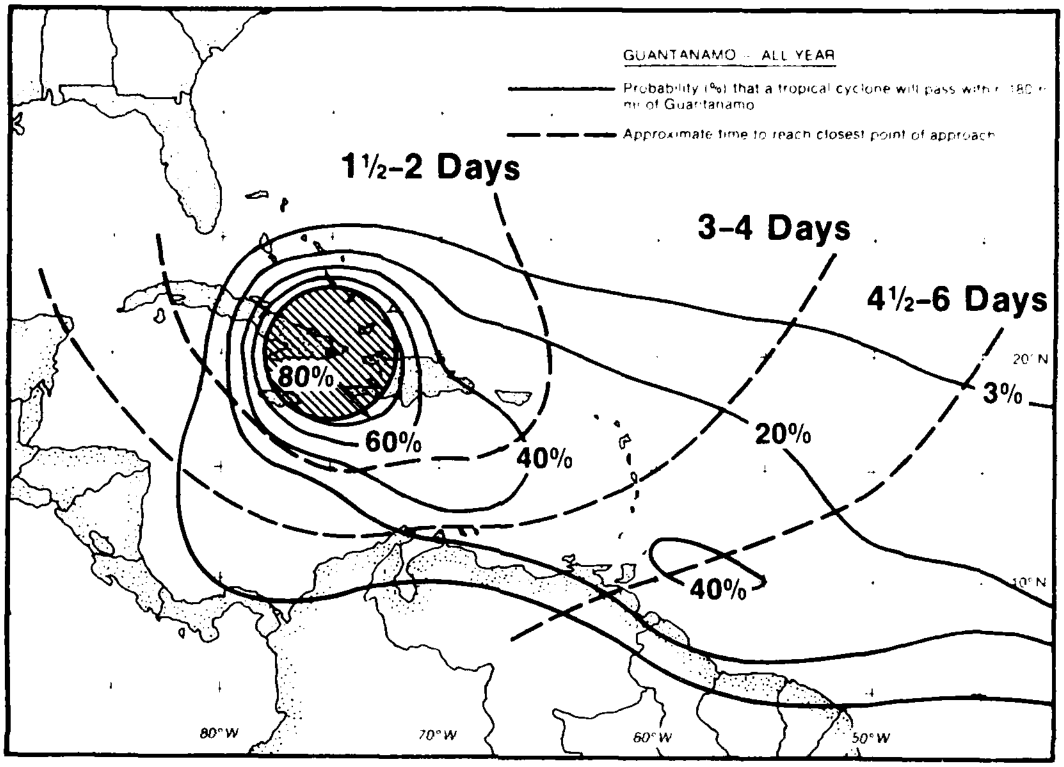

Figure XXI-10. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi of Guantanamo Bay during the years 1871-1979.

The average speed of advance of all tropical cyclones that have threatened Guantanamo Bay is about 10 kt. Early season (May to mid-July) storms were rare over eastern Cuba during the 109-year period. Mid-season (mid-July to mid-September) speeds averaged 12 kt, and late season (mid-September to end of November) speeds averaged about 8 kt (Neumann and Pryslak, 1981).

A comparison of Figures XXI-6 through XXI-10 shows some distinct changes in threat axis according to seasonal changes during the year. During off season and early/late season (Figure XXI-6), the primary threat axis originates in the western Caribbean Sea east of Nicaragua and extends northeastward across Jamaica to Guantanamo Bay.* A secondary axis originates southeast of Hispaniola and extends west-northwestward across Hispaniola to Guantanamo.

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*Due to their point of origin and direction of travel, these hurricanes, which move north or northeast toward Guantanamo Bay, represent an anomaly compared to those moving with the easterlies. They usually drift slowly at an average speed of only 4-5 kt until they are picked up by either the easterlies or mid-latitude westerlies.

By July and August (Figure XXI-7), the two axes have become one and this has shifted to the southeast to a position off the northern coast of South America. Originating in and east of the Lesser Antilles, this threat axis progresses through the Windward Islands across southern Hispaniola to Guantanamo Bay.

The threat axis for September (Figure XXI-8) is similar to that of July and August. Originating east of the Lesser Antilles, primarily along 10°N latitude, it proceeds just north of the coast of South America through the Windward Islands and across Hispaniola to Guantanamo.

In October a more complex pattern evolves again as shown in Figure XXI-9. The primary threat axis has moved farther south to below 10°N and a secondary threat again develops in the western Caribbean. Passage of tropical cyclones over coastal South America is suggested, but is in fact a rare event (Neumann et al., 1978). The major threat axis is again from east of the Lesser Antilles and through the Windward Islands, to approach Guantanamo across southern Hispaniola. The secondary threat axis is similar to the one in Figure XXI-6; from the western Caribbean, it proceeds just east of Jamaica to Guantanamo Bay.

Figure XXI-10 is a composite analysis of tracks that passed within 180 n mi of Guantanamo Bay during the period 1871-1979, showing threat probability and time to closest point of approach (CPA) curves for the entire year.

3.3 WIND AND TOPOGRAPHICAL EFFECTS

Records of hourly wind data for the Guantanamo Bay area are available only for the 35 years September 1945 through September 1979, from the naval air station. Supporting wind data from nearby Cuban cities are not available. The NAS anemometer was located at McCalla Field (now inactive) until 1976 when it was relocated to Leeward Point Field (shown in Figure XXI-2).

During the 35 years 1945-79, 27 tropical cyclones approached within 180 n mi of Guantanamo Bay, an average of 0.8 per year or four cyclones every five years. Of these 27 occurrences, 11 were hurricanes (>63 kt), seven were tropical storms (34-63 kt) and nine were tropical depressions (<34 kt) when within 180 n mi.

Of the 18 occurrences classified as tropical storms or hurricanes, only two caused sustained winds of 34 kt or greater at Guantanamo Bay. There were seven storms in which wind gusts of 34 kt were recorded and two in which hurricane force or greater gusts were recorded. The average CPA to Guantanamo Bay for these 18 cyclones was 95 miles. Figure XXI-11 shows the tracks of the 11 storms that had hurricane force winds while within the 180 n mi threat radius.

Two recent storms had very close CPA's to Guantanamo Bay. Both were Category 4 (extreme damage potential) hurricanes, yet local winds and damages were relatively light at Guantanamo for storms of such intensity. Ships in the

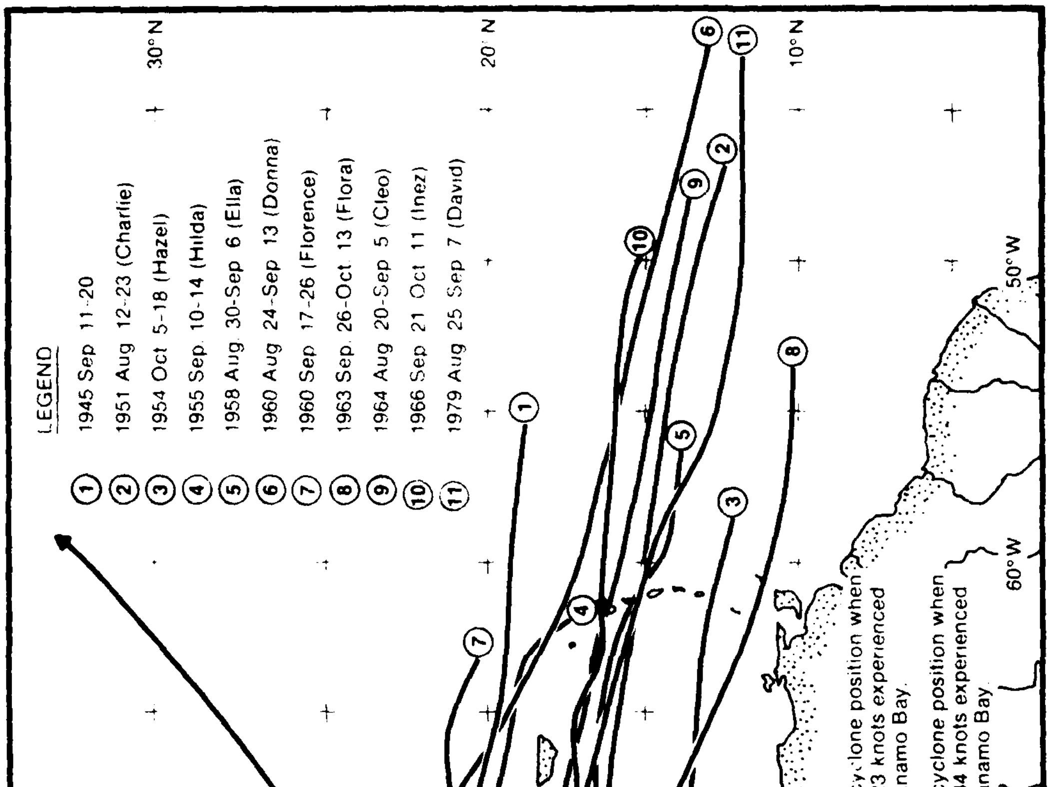

Figure XXI-11. Tracks of eleven tropical cyclones during the period 1945-79 that had hurricane force winds while within 180 n mi threat radius of Guantanamo Bay.

harbor were sortied for both storms. Hurricane Flora (4 Oct 63) had winds of 124 kt when it made landfall 29 miles east of Guantanamo Bay. Highest sustained winds at Guantanamo were recorded at 38 kt from the northwest with gusts to 50 kt. Hurricane Inez (30 Dec 66) passed only 13 miles southwest of the harbor with winds of 126 kt, while Guantanamo recorded maximum sustained winds of 48 kt from the northeast with gusts to 78 kt. The mitigation of winds by the mountains (elevations to 3750 ft) 30 miles to the north and Cuzco Hills south and east of the bay, suggests that Guantanamo Bay offers some protection when the winds are from those quadrants.*

3.4 WAVE ACTION IN GUANTANAMO BAY

Guantanamo Bay, with almost a full 90° turn only one mile from its entrance, is well protected from ocean wave activity. The bay entrance between Leeward Point and Windward Point is about 1 1/4 miles wide with water depths of 45-60 ft. Large ocean waves moving in an approximate 045° direction could be diffracted around Fisherman Point (Figure XXI-2) into the naval port area, but most of the wave energy would be lost. Anchorage areas located within three miles of the bay entrance, however, would be directly exposed to the deep ocean waves approaching from that direction.

During a gale in 1983, 10-12 ft seas reached north to Fisherman Point and forced a shutdown of ferry service for two days. Due to its irregular shape and narrow width, wind wave action (from other than a south to southwesterly direction) within Guantanamo Bay's Outer Harbor is not considered a serious threat. Using an average water depth of 30 ft and a fetch length of two miles, a northeasterly or southwesterly wind would generate the following calculated waves from the indicated wind intensity: 35 kt winds, 2 ft wind waves; 50 kt winds, 3 ft wind waves; and 65 kt winds, 4 ft wind waves (U.S. Army Corps of Engineers, 1977).

3.4.1 Naval Facilities

The Corinaso Cove area, which contains most of the naval piers, wharves and facilities, is well protected from ocean swell and waves by its location behind Windward Point. Northerly winds, direct into the piers, would generate waves similar to those described in the previous paragraph. The northerly wind necessary to create wind waves for the port area, however, would also mean the absence of a storm surge that would require a southerly wind. Piers are 6-10 ft above MSL.

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*Note that the wind anemometer was located at McCalla Field for these two tropical cyclones. The location of the Cuzco Hills just southeast of the field provides a barrier to the wind, so maximum winds over the bay probably were higher.

Naval facilities in the Outer Harbor that are not located within Corinaso Cove could be subject to some ocean swell or seas with southwesterly winds, but these would be greatly weakened by wave diffraction. Facilities north of Deer Point could be subject to wind waves with westerly or northwesterly winds. (These waves would be of the magnitudes calculated previously in Para. 3.4.) Some important facilities are located well within the possible range of wave action or elevated water levels.

3.5 STORM SURGE AND TIDES

Storm surge can be visualized as a raised dome of water generated by the low pressure and wind field of the tropical cyclone. The dome moves with the storm, having its greatest height to the right of storm center relative to direction of travel. Surge height also can be influenced by such other factors as bottom topography, storm speed, and local tides and currents.

Storm surge is not a major problem in Guantanamo Bay, for several reasons. There is no broad, shallow, slowly shoaling bathymetry to enhance potential storm surge. The size of the bay entrance and the configuration of the bay itself would tend to slow the filling process necessary to raise the water level in the bay (i.e., small mouth, large and irregular bay). Local tides are small and would not contribute much to elevated water levels. Local pilots have reported abnormal tides of 3-5 ft with no obvious explanation, and there is a possibility that these were seiches from earlier storms; locally available information could not explain the phenomenon further.

One naval facility, the base desalinization plant and water and power sources, could be vulnerable to damage from storm surge. Close passages by two major hurricanes, Flora (1963) and Inez (1966), did not generate serious storm surges in Guantanamo Bay, but the direction of approach (southeast) was not optimum for storm surge (i.e., due south or southwest). Strongest winds for both storms also were from the north, which tended to negate storm surge that would have required a southerly wind. (Figure XXI-11 shows the tracks of these two storms.)

4. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for hurricane preparedness at Guantanamo Bay are contained in COMNAVBASE GTMO Disaster Preparedness Plan 2103. During hurricane conditions, the SOPA (normally COMNAVBASE or COMFLETRAGRU) is responsible for the safety of all ships in the Guantanamo Bay area. COMFLETRAGRU GTMO will take appropriate measures to ensure safety of ships present in the area, including the issuance of Sortie Plans when considered necessary.

GUANTANAMO BAY, CUBA

4.1 THREAT ASSESSMENT

Guantanamo Bay is not a protected harbor for most hurricane threats. The natural configuration of the harbor and the elevated surrounding terrain does offer some protection from direct wind and wave effects, but the absence of sheltered berths or sheltered anchorages with good holding diminishes the safety of this port. Close CPA's by two recent hurricanes (see Para. 3.3) caused considerable damage to the harbor facilities, and losses could have been greater if ships had remained in port.

The greatest threats to Guantanamo Bay (see Figures XXI-6 through XXI-11) are posed by tropical cyclones moving northwestward out of the western Caribbean. Most storms that threaten the harbor approach from the east or southeast. The intensity of the storm and its direction and speed of movement will largely determine how much damage can be expected.

The months of most frequent storm occurrence are August, September and October (refer to Table XX1-2 in Section 3). Of these, statistically, September is the month of maximum threat.

The greatest storm surge threat to Guantanamo Bay would be posed by a storm approaching from the south or southwest, driving a sea ahead of it and landing just west of the harbor, but such storms are rare. With the Cuzco Hills south and east of the harbor and the Sierra del Cristal Mountains 30-40 miles to the north with elevations to 3750 ft, the harbor seems most vulnerable to winds from the west. A storm passing slowly on the north side of Cuba therefore could bring high winds from the west, as could the unusual case of west to east passage north of the harbor. (Both of these movements, however, are subject to mitigation by Cuba's mountainous terrain.)

If evasion at sea is the SOPA's choice, the potential threat must be assessed early. This assessment should be related to the setting of hurricane conditions of readiness by the naval base and the use of current Navy and National Weather Service advisories and forecasts, as well as to the climatology given in this study.

4.2 EVASION AT SEA

Evasion at sea is the generally recommended action in the face of a storm threat. The decision to evade must be timed to allow passage to open waters, and several factors can affect this timing:

(1) Preparation time necessary to get underway

(2) Forward speed of the tropical cyclone

(3) Forecast radius of high winds that would hamper a vessel's capability to maneuver to open water

(4) Direction of ship's proposed track relative to the storm, and elapsed time to reach open water.

Advice and considerations for leave/stay decisions are given in Section 1, General Guidance, of this Handbook. These must be considered because of the location of the tropical cyclone, the local geography, and the climatology of the storm threatening the harbor.

Hurricane Condition III is set when hurricane force winds are possible within 48 hours. The decision to sortie should be made near or soon after the setting of Hurricane Condition III. For a "most-likely" storm of mid-season, an upstream average approach speed of 12 kt should be expected. This would place the threat near Puerto Rico at 48 hours.

Evasion from Guantanamo Bay can be to the north into the Atlantic via the Windward Passage between Cuba and Hispaniola, or to the south steaming either east or west of Jamaica to the Caribbean Sea. Evasion to the Atlantic to escape an approaching tropical cyclone requires careful route selection and navigation through the West Indies. For planning purposes, it should be understood that the average 48 hr forecast error for those tropical cyclones threatening Guantanamo Bay is 180-200 n mi.

Once sea room is gained, the tactics employed will depend on the forecast location for the tropical cyclone, its speed of advance, and its forecast direction of movement. Up-to-date information is essential if tactically sound evasion decisions are to be made. Forecasts and warnings are issued at 6 hr intervals and updated as necessary to reflect important changes in storm position, intensity, and movement.

The following guidelines are provided with the stipulation that the dangerous right-hand semicircle of the storm should be avoided:

(1) Tropical Cyclones Approaching from the East or Southeast. Two routes are recommended, depending on forecast movement of the storm:

(a) If the storm is forecast to pass south of Cuba, then evasion north is recommended around the east side of Cuba and through the Windward Passage, thence northwest through Crooked Island Passage* to the Atlantic. Departure time and tropical cyclone characteristics must be closely watched here, because initial heading is toward a possible collision course with the tropical cyclone if it turns north of Hispaniola. Darkness and sea conditions may be a consideration depending on the navigation route chosen through the West Indies. Once in the Atlantic, steaming to the northeast is recommended until storm clearance is guaranteed.

(b) If the storm is forecast to pass north of Cuba, then evasion south to the Caribbean may be made through the Jamaica Passage between Jamaica and Haiti. Steaming due south is recommended, because normal tropical cyclone movement is westward or northwestward. This places the ship in the left-hand,

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*Caicos Passage or Turks Island Passage may be used in daylight in good weather conditions.

weaker semicircle of the storm. This route should also be used for tropical cyclones forecast to pass directly over Guantanamo Bay because this route is quicker, less hazardous to navigate, and less likely to encounter storm effects.

(2) Tropical Cyclones Approaching from the Northeast Through Northwest

Evasion south through Jamaica Passage to the Caribbean Sea is recommended. Close watch must be maintained on tropical cyclones moving from these directions because they are not "normal" storms and therefore their paths may be less predictable.

(3) Tropical Cyclones Approaching from the South Through West

Steaming north into the Atlantic via the Windward Passage is recommended, as in Para. (1)(a) above. The storm should be watched closely because it may be more likely to move northeasterly earlier than a tropical cyclone approaching from the east or southeast.

4.3 RETURNING TO PORT

Passage of a tropical cyclone through a port may result in damage and disarray to channel markers, navigation aids, and port facilities. Vessels returning to port should check with the Port Services Officer to determine the extent of damage before attempting to return.

4.4 REMAINING AT GUANTANAMO BAY

Remaining at Guantanamo Bay is an option that should receive serious consideration only in cases of questionable vessel condition or questionable threat situation. Guantanamo Bay can offer some protection for ships correctly secured at berths. Questionable threat situations include:

(1) A weak tropical cyclone (maximum winds less than 48 kt)approaching Guantanamo, but forecast not to intensify.

(2) A tropical cyclone developing within the 180 n mi threat radius.

(3) A tropical cyclone forecast to pass several hundred miles from Guantanamo Bay at less than hurricane strength.

If a decision is made to remain at Guantanamo Bay, two factors should be considered:

(1) The configuration and geography of Guantanamo Bay suggest that all of the piers and wharves within Corinaso Bay offer some protection from wind and wave action. Wharf T, however, is open to the bay and, facing north, could set up a dangerous wave reflection with a northerly wind. Wharf B, which is within Corinaso Cove, offers the best protection.

(2) Anchorage areas within the harbor should be evaluated carefully for exposure to wind and wave action. Those near the bay entrance, especially, could be subject to wind/wave action directly off the Caribbean with a southerly wind. Anchorage in Granadillo Bay, draft permitting in 30 ft depths, would offer the best protection from wind and wave action, but maneuvering room is limited if steaming at anchor is planned. Bottom holding is also known to be poor for sustained winds above 30 kt.

5. ADVICE TO SHALLOW DRAFT VESSELS

Shallow draft vessels should be removed from the water and placed under shelter if possible. If shelter is not available the vessel should be firmly secured ashore at an elevation above potential elevated water level or wave action. Guantanamo Bay has several natural coves that offer good protection, and local authorities should be asked to identify them. Particular attention should be given to probable wind forces as well as to areas of potential flooding and runoff from heavy rains.

Using open anchorages in Guantanamo Bay or piers exposed directly to the bay could be hazardous. Wind/wave activity can be quite destructive to small craft, and floating debris could pose an additional threat.

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XXII. BERMUDA

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XXII. BERMUDA

SUMMARY

Bermuda is not a hurricane haven. Its small islands and low terrain elevations provide little protection from storm forces; there are no harbor anchorages, berths or moorings suitable for deep-draft vessels during hurricane conditions. Shoals and coral heads in the inner harbor restrict ship movement to narrow, dredged channels.

Once beyond a 10 n mi radius from Bermuda, there is open sea for several hundred miles in all directions and no restrictions on maneuvering to evade a storm. If a deep-draft vessel is unable to go to sea when threatened in harbor by winds 50 kt or greater, the best moorings or anchorages are in Port Royal Bay and the southwest sector of the Great Sound; best berthing is in the Dockyard.

The harbor is entered or departed only in daylight hours, so deep-draft vessels customarily put to sea well before arrival of forecast hurricane force winds. Departure planning must allow enough time for channel transit in daylight and for completing harbor, channel and reef transit before sustained winds exceed 25 kt.

Small craft should be removed from the water when a hurricane threatens, or else moored to the branches of trees in the upper reaches of the most protected bays.

Bermuda's tropical cyclone season is May through November, with one or more storms passing within 180 n mi each year. During the years of record 1871-1979, 75% of the passages occurred during September and October. The U.S. Navy at Bermuda routinely sets Hurricane Condition IV throughout the June-November period.

Bermuda is located near the northern limit of the Atlantic recurvature band where it is difficult to forecast tropical cyclone movement during (erratic track) and after (rapid acceleration) recurvature. Almost 90% of all tropical cyclones that have passed within 180 n mi of Bermuda either have been recurving or have recently completed recurvature.

This hurricane haven evaluation was prepared by R.E. Englebretson and J.D. Jarrell of Science Applications, Inc. (SAI), Monterey, CA 93940.

BERMUDA

1. LOCATION AND TOPOGRAPHY

The islands of Bermuda -- located in the western Atlantic near 32.4°N, 64.7°W about 575 n mi east-southeast of Cape Hatteras (Figure XXII-1) -- comprise a small, crescent-shaped archipelago extending about 15 n mi in a northeast-southwest orientation. The main islands NE to SW are Saint Georges, Saint Davis, Bermuda, Somerset, and Ireland (Figure XXII-2). The total land area is about 21 square miles, of which Bermuda Island comprises about 90%.

Extensive reef formations encircle the islands. They extend 5-10 n mi to the west and north and historically have been known as a "graveyard of ships." Access to all the harbors inside the reef area is limited to passage via dredged channels. An extensive area of shallows and flats curve clockwise from the southwestern tip of the crescent-shaped archipelago around to the northeastern portion. The channels and anchorage areas lie between this area of flats and the western coast of the islands. Reefs are close to shore along the southeastern coast, which is exposed to swells and waves from the open sea and has no suitable harbor locations.

The larger islands are somewhat wooded and have low, rolling hills seldom more than 200 ft in height; the highest point is Town Hill at 250 ft in the north part of Bermuda Island (Figure XXII-3). The islands rise from the Great Bermuda Reef, which is a coral cap about 328 ft thick deposited on a volcanic pedestal.

2. THE HARBOR, APPROACH, AND HEAVY WEATHER FACILITIES

2.1 BERMUDA HARBOR AND APPROACH

The Bermuda harbors include the deep-draft vessel ports at the U.S. Navy Annex, Hamilton, St. George, and the Ireland Island Dockyard. The approach point to Bermuda lies on the 100 fathom curve at 32°23'03"N, 64°34'44"W, bearing 084° at 3.6 n mi from the pilot station at Five Fathom Hole. The pilot station is at the entrance to the Narrows off the east coast of Saint Georges Island at the northeast end of the Bermuda Archipelago.

Prominent landmarks (Figure XXII-3) distinguishable from a distance seaward include: Saint Georges Harbor, reported (1970) radar conspicuous at a distance of about 15 miles; Folly Towers, very conspicuous on Town Hill north slope; Gibbs Hill, near the southernmost part of Bermuda Island, 72.8 m (239 ft) high and reported radar conspicuous at a distance of 14 miles; and Wreck Hill, near Bermuda Island western extremity, a small but very conspicuous conical hill particularly useful as a landmark when approaching from north or south (Defense Mapping Agency, 1983).

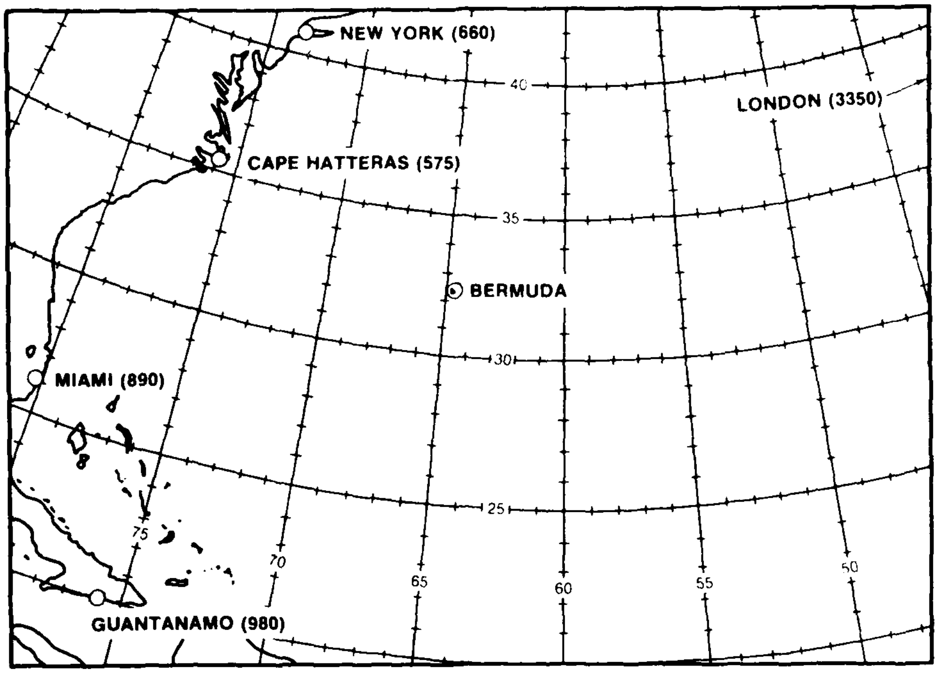

Figure XXII-1. Location of Bermuda in the western Atlantic. Numbers in parentheses are distances (n mi) to Bermuda from these locations.

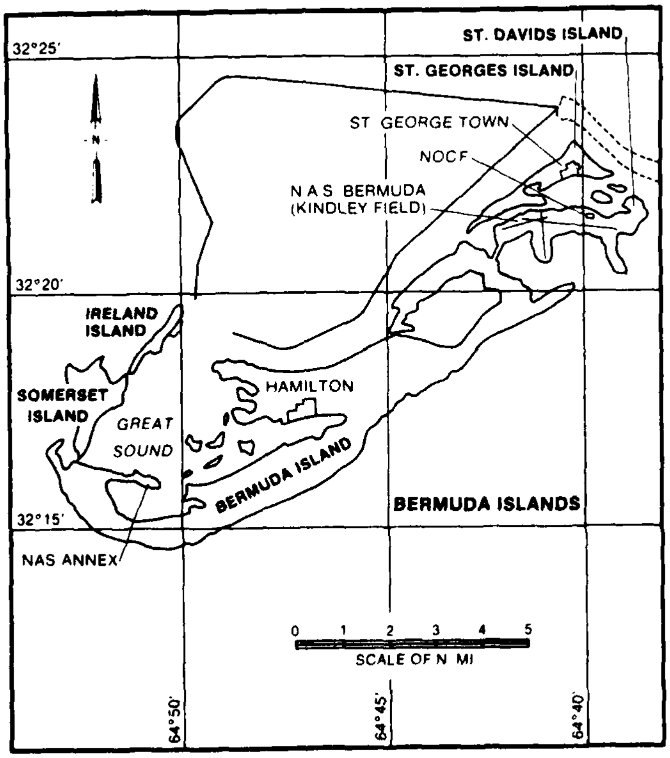

Figure XXII-2. The Bermuda archipelago.

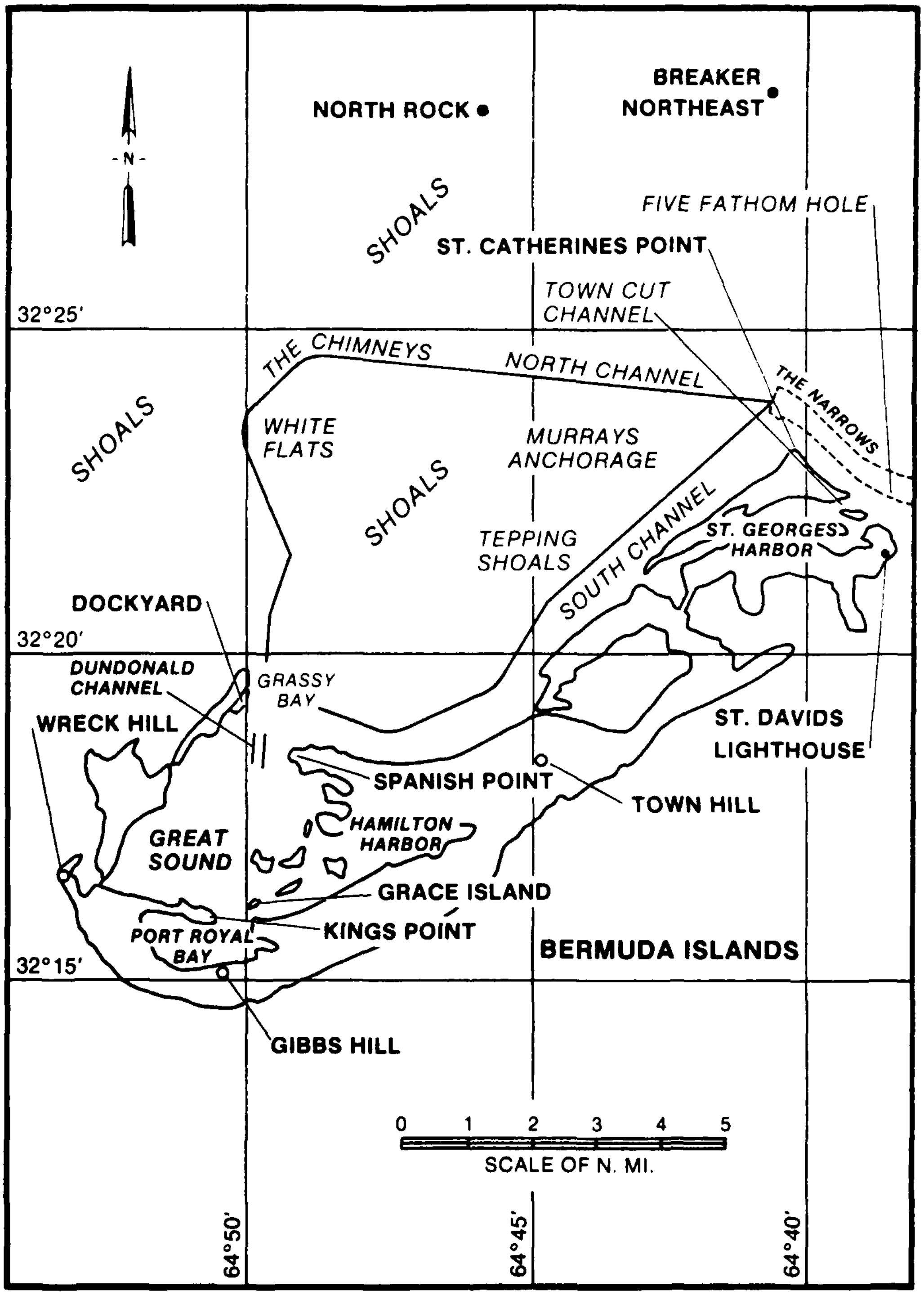

Figure XXII-3. The greater Bermuda area.

Table XXII-1 provides information on approach lights and radio navigation aids for the Bermuda area. The Fleet Guide cautions all craft including shallow draft,regarding approach to the shoreline other than by the ship channel, to beware of underwater coral heads (see DMA charts 26340-26345).

Table XXII-1. Bermuda's approach lights distinguishable from seaward and radio navigation aids, with latitude and longitude from British Admiralty charts (Department of Marine and Port Services, 1983). Difference in position between British Admiralty charts and NAVOCEANO chart 26342 of 1977 is 0° 0'±6".

APPROACH LIGHT TO BERMUDA

Name and Position	Character	Remarks
North Rock Beacon 32° 28.5'N 64°46.0'W	Group flash white (4) every 20 sec.	60 ft steel structure. Radar reflector. Visible 12 miles.
North East Breaker Beacon 32°28.7'N 64°40.9'W	Flash white every 2 1/2 secs.	Tower height 45 ft. "NORTH EAST" in red letters on a white background. Radar reflector. Visible 12 miles.
Kitchen Shoal Beacon 32°26.0'N 64°37.6'W	Group flash white (3) every 15 secs.	Tower height 45 ft "KITCHEN" in red letters on a on a white background. Radar reflector. Visible 12 miles.
St. David's Island Lighthouse 32°21.8'N 64°39.0'W	Fixed red and green sectored light below a group flashing white (2) every 20 secs. Red Sector: 135°T-221°T 276°T-044°T 044°T-135°T Green Sector: 221°T-276°T (Bearings from seaward)	Height 212 ft. Range - red and green sectors 20 miles. White flashing light 15 miles between 044°T-135°T, both lights partially obscured by land.
Kindley Field Aero Beacon 32°21.95'N 64°40.55'W	Alternating group flash (3) every 10 secs. 2 white 1 green (Rotating Aero Beacon).	Height 140 ft (light/loom) visible 15 miles.
Gibbs Hill Lighthouse 32°15.1'N 64°50.0'W	Revolving white flash every 10 secs.	Height 354 ft. Visible 26 miles.

RADIO AIDS TO NAVIGATION

Gibb's Hill Beacon

Call Sign . . . . . BDA
Frequency . . . . . 295 kHz
Position . . . . . . 32°15.1'N 64°50.0'W
Range . . . . 100 miles
Operation . . . . . Continuous

St. David's Radio Beacon

Call Sign . . . . . BSD
Frequency . . . . . 323 kHz
Position . . . . . . 32°22.0'N 64°38.9'W
Range . . . . 150 miles
Operation . . . . . Continuous

U.S. Navy ships on official visits are berthed at the U.S. Navy Annex facilities located on the inner side of the extreme southwestern portion of Bermuda Island (see Figure XXII-2). The Hamilton facilities, the primary cruise ship and yacht club port, are located on the inner coast of the west central portion of Bermuda Island just across the Great Sound from the U.S. Navy Annex. There is a small Patrol Dock for small boats in Hamilton Harbor.

The Ireland Island Dockyard is located on the northwesternmost island of the Bermuda chain about 3 n mi north of the Navy Annex. It consists of two basins sheltered by breakwaters, the South Basin which includes the British Royal Navy (RN) facilities and the North Basin which is the Bermuda free port. The RN facilities are the primary submarine berthing space and can be used, if available, by U.S. vessels. Saint Georges Harbor, located between Saint Georges and Saint Davids Islands at the northeastern extension of the islands, is used by cruise ships and U.S. ships making port liberty calls and by various pleasure craft.

2.2 ENTRANCE TO BERMUDA HARBOR

All ships including U.S. Navy ships must obtain clearance (from the Fort George Signal Station 2182 kHz, voice call BERMUDA HARBOR RADIO, visual signal ZULU) for entry or departure so traffic can be controlled through the Narrows (*Figure* XXII-3). Because of the various narrow dredged passages and unlighted ranges, entry and departure are limited to daylight hours for other than emergency movements. Pilots will not be provided for routine night passages. Communication frequencies of interest are listed in Table XXII-2.

Entry to the U.S. Navy Annex, Ireland Island Dockyard, and Hamilton harbors is via the Narrows, Murrays Anchorage, North or South Channel, Grassy Bay, Dundonald Channel, and the Great Sound (Figure XXII-3), then southward via a channel between Kings Point and Grace Island to Port Royal Bay and the Annex, or east-southeast to the entrance of Hamilton Harbor (see DMA charts 26340-26344).

The entrance to the Ireland Island Dockyard is located in the southwestern reaches of Grassy Bay. Dundonald Channel is a dredged passage through a sunken ridge that extends from Ireland Island to Spanish Point. The Channel extends south-southwestward from Grassy Bay well into the bight of the Great Sound and east-southeast to the entrance of Hamilton Harbor. It has a least depth of 37 ft (1966) through the sunken ridge and 27 ft (1966) to the entrance of Hamilton Harbor (Two Rock Passage).

The South Channel paralleling the western coastline has a reported least depth of 29 ft (1960). The North Channel, which extends first westward about 6.5 n mi from Murrays Anchorage and then southward to near Ireland Point (the extreme northwest tip of the island chain), has a reported least depth of 38 ft (1943). Both channels pass through areas of flats and shallows with numerous underwater hazards. No bridges cross any of the harbor entrances or channels.

Table XXII-2. Communication frequencies for Bermuda.

Fort George Signal Station

Voice call BERMUDA HARBOR RADIO

Visual call sign ZULU

Entrance and Departure Clearance

Guards (V) 2182 kHz - Channel 16 VHF

Control VHF Channels 10, 12, 27

Listens on Distress Frequencies
Channel 16 VHF - 500 and 2182 kHz

North Atlantic Weather

Broadcasts (High Seas) at 1235 and 2035 GMT on 2582 kHz and UHF Channel 27

Local Weather at 0900 Local Time on VHF Channel 7

U.S. Navy - Channel 10, 16 VHF

Voice Call NAVY BERMUDA CONTROL

Ship-to-Shore Harbor Common (NWU)

Arrivals and Departures from Navy Harbor Control Area (Navy Annex)

Commercial TUGS - Monitor Channel 10, F3

Entry to Saint Georges Harbor is from the east via the Town Cut Channel, for which DMA chart 26343 shows a least depth of 28 ft (1978). From about a mile outside the Town Cut channel, a dredged channel (38 ft least depth, 1979) known as the Narrows extends northwestward around St. Catherines Point to Murrays Anchorage. Depths in this anchorage area are more than 50 ft.

Bermuda pilotage is a governmental service under control of the Department of Marine and Port Services. Pilotage is not compulsory for U.S. Navy ships, but is highly recommended (Defense Mapping Agency, 1981). Pilots board incoming ships at Five Fathom Hole in the entrance to the Narrows. Outbound ships are boarded at their berthing or mooring area before sailing.

Inbound U.S. Navy ships may request pilots by naval message, action NAS BERMUDA; outbound ships may arrange for pilots through the Port Services Office.

There are four tugs available in Bermuda, one U.S. Navy YTM and three commercial tugs operated by the Bermuda Government Department of Marine and Ports. The commercial tugs normally berth at the Ireland Island Dockyard; two have 1200 HP with single screw and the third has 1800 HP with twin screw.

2.3 BERTHS AND ANCHORAGES

2.3.1 Navy Annex

The U.S. Navy Port Services Office will instruct U.S. Navy ships to moor pierside (Annex Tender Pier), moor to a buoy in Port Royal Bay (Little Sound), or anchor near the Navy Annex (Figure XXII-4). Additional berths for U.S. Navy vessels on a space-available basis are located in the Dockyard, and Hamilton and Saint Georges Harbor.

Pier 12 (Tender Pier) is 450 ft long. As of January 1984, the condition of this pier was poor and use was limited to mooring on the east side using the existing contiguous fueling dolphins.

The small boat fuel pier is 115 and 150 ft long on the east and west sides, respectively, and 8 ft wide. Depth alongside is less than 10 ft at MLW. Fuel is available only for small boats and consists of DFM and motor gasoline. The Boat Basin Pier is 100 ft long and 20 ft wide; alongside depth at MLW is less than 10 ft.

The mooring buoys in Port Royal Bay were originally rated as ECHO class moorings and considered safe for ships of cruiser size or smaller in winds to 60 kt. These buoys were not maintained for many years and their conditions as of January 1984 was unknown. As of that date, however, a project was planned to restore five buoys at the Annex and three buoys off the marginal pier at the Naval Air Station (Saint Georges Harbor) to their original classification.

2.3.2 Ireland Island Dockyard

Dockyard berths, with a total length of 1000 ft and dredged to 34 ft, are the Knuckles, Flagship and Commercial berths (Figure XXII-5). The Knuckles are cleared for nuclear submarines. The Flagship berth, located in the center of the quaywall, is suitable for berthing starboard side to. At the Commercial berth ships normally berth port side to. The normal limiting length of vessels allowed is 600 ft with draft of 32 ft.

2.3.3 Hamilton Harbor

Hamilton Harbor has four berths that allow vessels with a maximum draft of 26 ft (locations 1, 2, 5 and 6 in Figure XXII-6). Cruise ships generally berth at Hamilton during the summer. The largest vessel to enter Hamilton as of 1983 was 704 ft long with a draft of 26 ft. U.S. Navy ships may be permitted to

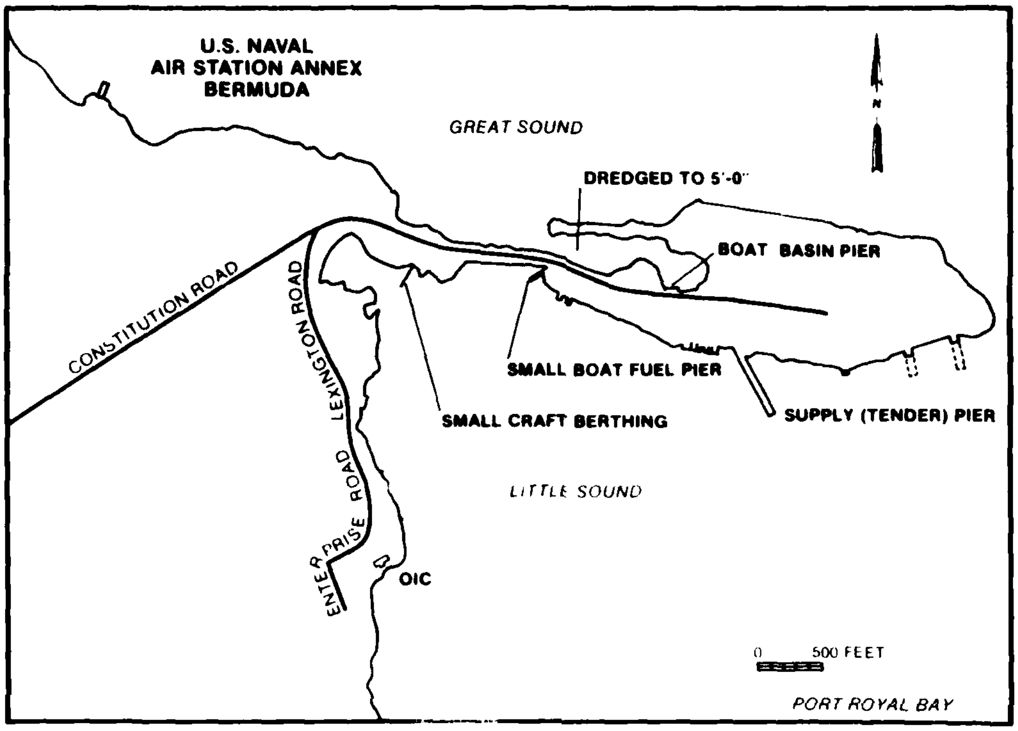

Figure XXII-4. U.S. Naval Air Station Annex.

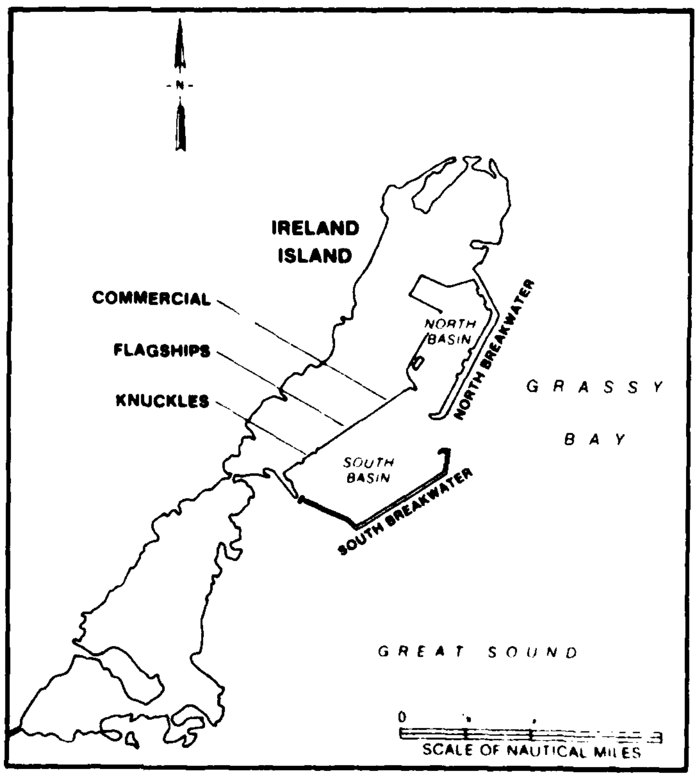

Figure XXII-5. The Ireland Island Dockyard.

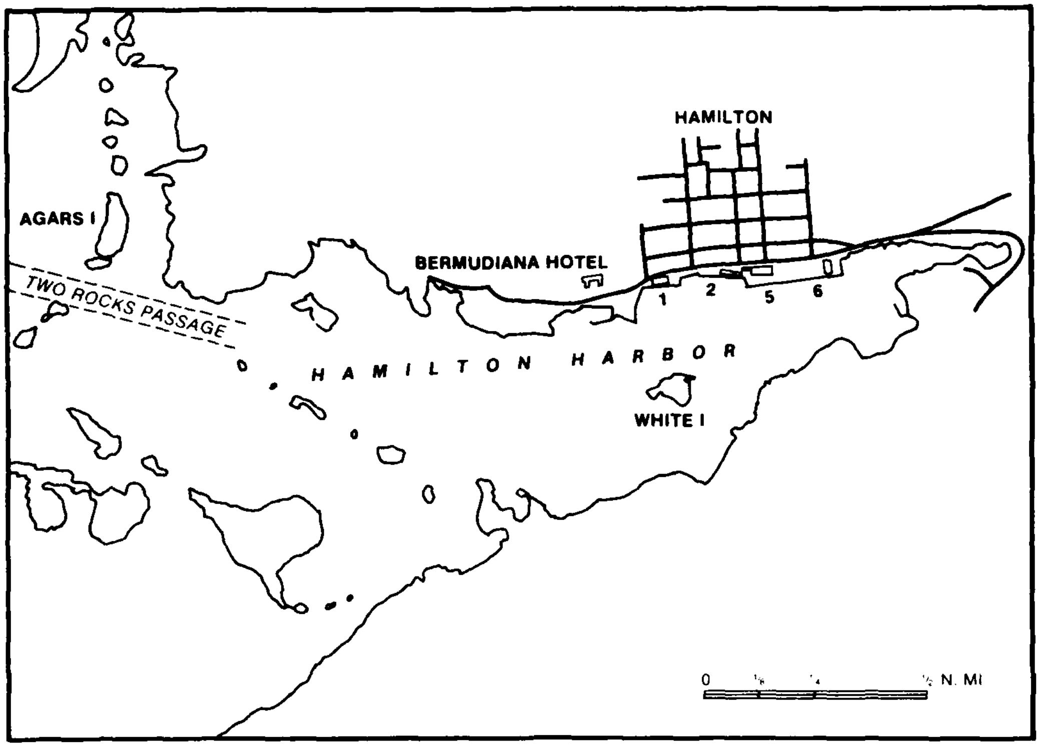

Figure XXII-6. Hamilton Harbor.

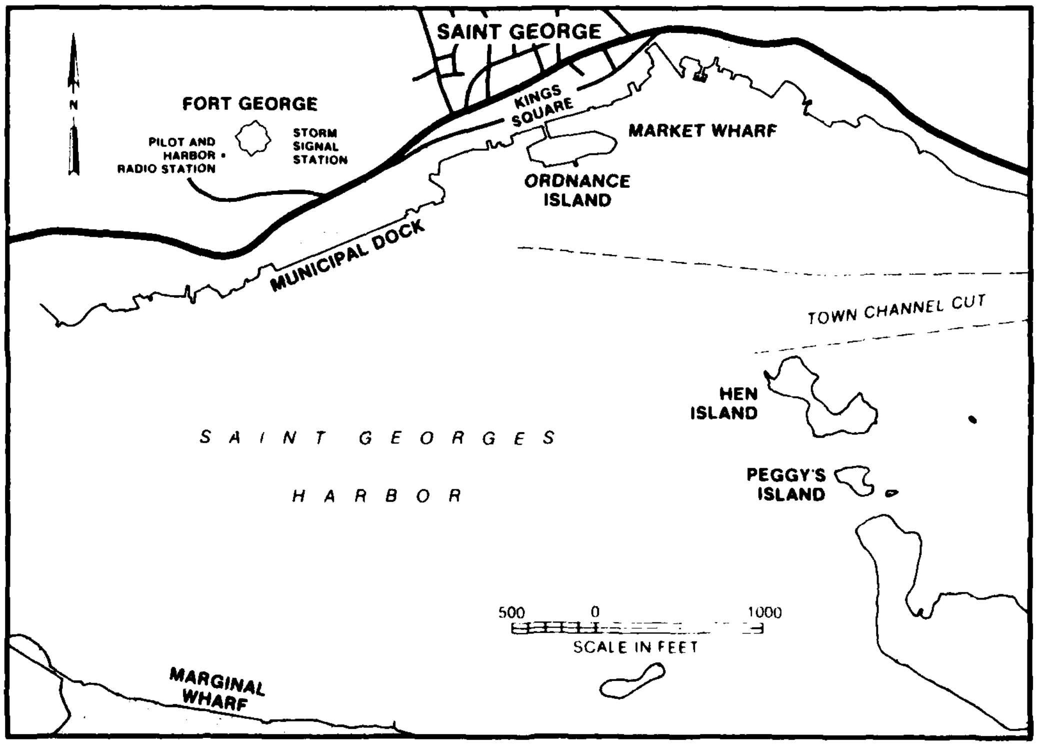

Figure XXII-7. Saint Georges Harbor.

berth in Hamilton subject to current policy on pollution -- ships should be able to connect existing sewers or have sewage holding tanks. Cruise ships and merchant ships have first priority at berths in Hamilton Harbor, and requests for berthing by U.S. Navy ships are handled case by case.

2.3.4 Saint Georges Harbor

Market Wharf at King Square, Saint Georges Harbor (Figure XXII-7), is in the center of the shoreline of Saint Georges Town directly opposite Ordnance Island with alongside depth of less than 10 ft. It is approached around the eastern end of Ordnance Island via the channel between the island and Saint George Town.

Municipal Dock with alongside depths of 29 ft is about 300 yards westward of Ordnance Island. This dock is normally used for shipping. Boats using this landing should stand off except when embarking or disembarking passengers and stores.

Marginal Wharf is on the southwestern shore of Saint Georges Harbor with alongside depth of 17 ft (1966). The boat landing is at the western end of Marginal Wharf. There are many mooring buoys in the harbor that vessels should avoid.

Saint Georges Harbor has anchorages for large vessels in 29-47 ft of water, but holding is considered poor in stiff mud and tidal action will cause vessels to swing. On a rising tide the tidal current sets directly into the harbor; on a falling tide the current sets directly out of the harbor. Berths available for U.S. Navy ships in Saint Georges include Penno's Wharf at the Municipal Dock and Ordnance Island. Cruise ships and merchant ships have first priority at berths in Saint Georges Harbor, and requests for berthing of U.S. Navy ships are handled case by case. The normal draft limit for entry into Saint Georges Harbor is 28 ft with a maximum vessel length of 600 ft (limitations are based on turning problems within harbor).

2.4 HEAVY WEATHER CONDITIONS, ANCHORAGES, BERTHS AND MOORINGS

2.4.1 Hurricane Conditions of Readiness

The Commanding Officer, Naval Air Station, Bermuda performs SOPA functions (Commander Disaster Preparedness Unit, 1984).

SOPA will direct action to be taken by U.S. Navy ships present during heavy weather preparations. Local severe weather warnings are issued by the Naval Oceanography Command Facility (NOCF), and conditions of readiness are set by the Coordinating Authority Bermuda (C.O. NAS, Bermuda).

The Hurricane Alert Committee at Police Headquarters, Prospect, provides information on hurricane threats to local residents through local disaster control agencies.

There are noteworthy differences between U.S. Navy Hurricane Conditions of Readiness and the Conditions of Alert used by the Bermuda government. Hurricane Condition IV is the normal Navy condition from 1 June to 30 November; Condition III implies hurricane force (HF) winds expected within 48 hr, Condition II HF winds within 24 hr, and Condition I HF winds within 12 hr. The Bermuda Conditions of Alert are "Condition Alpha" for hurricane force winds within 24 hr and "Condition Bravo" for HF winds within 12 hr; "Condition Zulu" means the hurricane is no longer a threat (Commissioner of Police, 1983).

2.4.2 Hurricane Anchorages, Berths and Moorings

There are no designated hurricane anchorages, berths, or moorings for deep-draft vessels in Bermuda's harbors. The best moorings and anchorage areas for deep-draft vessels during high wind conditions are in Port Royal Bay and are under the control of the U.S. Navy Port Services Office. The most suitable berthing spaces during high wind conditions are in the Dockyard. With strong northeasterly through southerly winds, heavy chop can be expected in the Dockyard.

2.4.3 Heavy Weather Anchorages

Five Fathom Hole (Figure XXII-3) has a bottom of coral and rock and offers poor holding. It is recommended not to veer too much chain, because it may become fouled on coral and rock outcropping. Some protection is offered for winds from the south-southwest through west-northwest. Vessels should get underway if the wind shifts to north.

Saint Georges Harbor has anchorage for large vessels in 29-47 ft of water, but has poor holding ground in stiff mud. Entry through Town Cut Channel is restricted. Deep-draft vessels should transit at high tide and proceed at minimum speed to maintain steerage. Large vessels should not transit when cross winds exceed about 15 kt.

Murrays Anchorage is a large and unencumbered deep-water basin with good holding ground. Sea conditions frequently prevent small boat operations in this area during heavy weather.

Grassy Bay is a small, deep (36-48 ft), unencumbered basin with good holding ground of marl. Vessels should veer a goodly scope of chain during storm force winds from the north.

The Great Sound is a spacious, mostly landlocked bight inside the southern arc of the Bermuda islands. The southwest part of the bight is the preferred heavy weather anchorage, and better than the Hamilton Harbor anchorage.

Hamilton Harbor has an anchorage with a depth of 40 ft in the outer (west of White Island) part with good holding ground of mud and shells. This harbor, however, is a poor choice for deep-draft vessels anchored during high winds;

because of small craft congestion, deep-draft vessels are limited to transit through Two Rock Passage (which is only 450 ft wide) where backwash from the south shore may induce a sheer.

Port Royal Bay, located south of the U.S. Navy Annex, has an anchorage for U.S. Navy use that is considered the best available in the Bermuda area during high winds.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT BERMUDA

3.1 INTRODUCTION

A review of historical records of tropical cyclones affecting the Bermuda islands -- one such account dates back to the initial colonizing of Bermuda by survivors from a ship driven aground in 1609 -- gives insight into such storm traits as season of occurrence, source regions, movement, intensity, and frequency.

Local records for the years 1609-1871 show 39 occurrences of damage caused by tropical cyclones (Tucker, 1966), indicating a frequency of damaging winds about once every 6-7 years during this period. An updated version of the U.S. Navy records used in this hurricane haven study* shows 127 passages of tropical cyclones within 180 n mi of Bermuda during the 109 years 1871-1979, an average of more than one storm per year for this later period.

During the 34 years 1949-83, on the other hand, only two occurrences of minimal hurricane force winds (64 kt) were recorded: in 1953 and 1963. This rarity of occurrence is in direct contrast to the 33 years before 1949, when eight such events occurred. (Of these eight, six had maximum sustained winds greater than 87 kt. In 1948, hurricane force winds occurred in both September and October.)

3.2 CLIMATOLOGY

For this study, any tropical cyclone approaching within 180 n mi of Bermuda is considered a threat to the port.

Bermuda's hurricane season is May-November, as indicated by Table XXII-3; these data are shown graphically in Figure XXII-8. Primary hurricane activity is in September and October. During the 109 years 1871-1979, 75% of all tropical cyclone passages within 180 n mi occurred during September and October (95 out of 127).

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*Track information from Neumann et al., 1978.

Table XXII-3. Monthly totals of tropical cyclones passing within 180 n mi of Bermuda during the period of 1871-1979.

Month	Number	% of Total
May	2	1.5
June	3	2.4
July	1	0.8
August	19	15.0
September	48	37.8
October	47	37.0
November	7	5.5

Bermuda (32.4°N) is located near the northern limit of the normal Atlantic tropical cyclone recurvature band of 25°-35° north latitude. This location relative to the classic tropical cyclone track adds inherent forecast problems.

The movement of tropical cyclones tends to vary in speed, be erratic in direction during recurvature, and be followed by rapid east-northeastward acceleration after recurvature. Figure XXII-9 shows that the most frequent direction of approach to Bermuda has been from the southwest (29%), and 89% of all approaches have been from southeast through west. This indicates that most tropical cyclones that have had a closest-point-of-approach (CPA) within 180 n mi of Bermuda were either undergoing or had recently completed recurvature.

Nine tropical storms developed within 180 n mi of Bermuda during the years 1942-79. Four of the nine caused sustained winds greater than 22 kt at the official Bermuda observation site, but none of the nine storms caused sustained winds over 33 kt. Five of the nine eventually reached hurricane force, but none were within 180 n mi of Bermuda at the time.

Intensity and months of occurrence data are tabulated in Table XXII-4 for 90 tropical cyclones that passed within 180 n mi of Bermuda during 1899-1979.

Table XXII-4. Classification of 90 tropical cyclones which passed within 180 n mi of Bermuda during the 1899-1979 period.

Maximum Intensity*	May-July	Aug	Sept	Oct-Nov	Totals
Hurricane (≥64 kt)	2	7	26	14	49
Intense Tropical Storm (48-63 kt)	0	1	5	8	14
Weak Tropical Storm (34-47 kt)	1	1	6	8	16
Tropical Depression (<34 kt)	2	1	2	6	11
TOTALS	5	10	39	36	90

*Intensity values are the maximum sustained center winds at the time of closest point of approach to Bermuda.

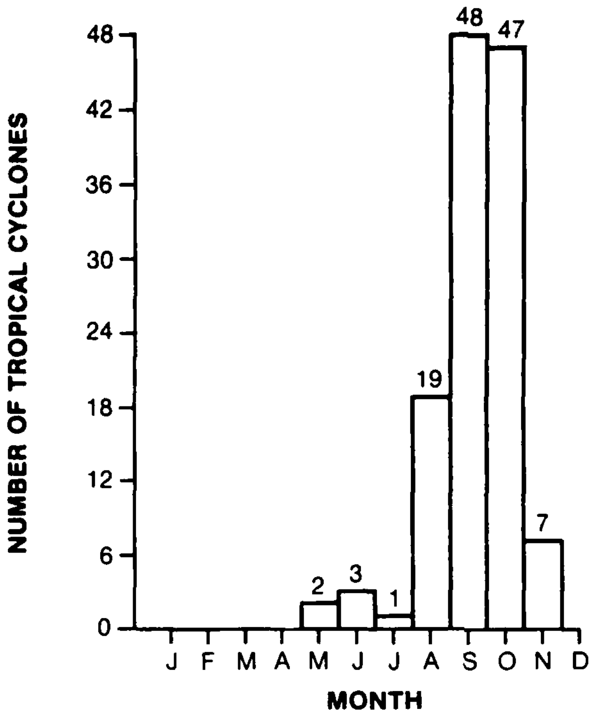

Figure XXII-8. Seasonal distribution of tropical cyclones that passed within 180 n mi of Bermuda (based on data from 1871-1979).

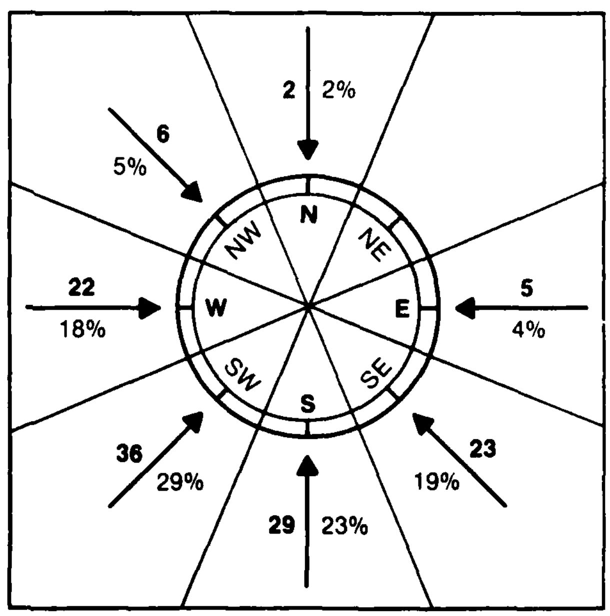

Figure XXII-9. Directions of approach of tropical cyclones that passed within 180 n mi of Bermuda during the period 1871-1979. Numbers of storms approaching from each octant are shown in bold type; percentages are of the total approaching from that octant.

September clearly is the major threat month in regard to both frequency (43% of all threats) and intensity (over 50% of all hurricane force threats). Tropical cyclones tend to be most intense during August-September, with 67% of all passages (33 of 49) having hurricane force winds at the time of CPA. The overall frequency of hurricane force center passages within 180 n mi was slightly over one every two years (49 hurricanes in 90 years).

Figures XXII-10 through XXII-14 are statistical summaries of threat probability for the years 1871-1979. Representative summary periods of tropical cyclone frequency, track, and speed are the months of May through July, August, September, October and November, and all tropical cyclones of record during the 109-year period.

The thin lines are percent threat for any storm location. The heavy lines show approximate times to CPA to Bermuda based on historical tropical cyclone tracks. For example, in Figure XXII-10, a tropical cyclone located over southern Florida has a 20% probability of passing within 180 n mi of Bermuda, and would make its CPA to Bermuda in 72-96 hr (3-4 days).

A comparison of major threat axes for May through July (Figure XXII-10) and August (Figure XXII-11) shows a distinct shift from the southwest in the early season to the southeast in August. The September (Figure XXII-12) and October-November (Figure XXII-13) major threat axes reflect a slow clockwise rotation to a southerly position. This late season pattern reflects development of a secondary threat axis from the southwest.

Figure XXII-14 is a composite analysis of threat probability and time to CPA curves for the entire year; it is derived from all tropical cyclone tracks that passed within 180 n mi of Bermuda during 1871-1979.

The threat axes and frequencies of tropical cyclones affecting Bermuda closely resemble those of Atlantic tropical cyclones in general in terms of seasonal changes. The following description of Atlantic activity -- taken from this Handbook's first section, General Guidance, Para. 3 -- may also be applied locally to Bermuda patterns:

> "Early Season Storms mostly originate in the west Caribbean Sea and Gulf of Mexico while Mid-Season Storms mostly originate in the main basin of the tropical Atlantic Ocean and show a much stronger westerly component in their movement. The Late Season witnesses a more gradual change in which tropical cyclone activity in the main basin of the tropical Atlantic Ocean declines but is accompanied by a revival in such activity in the Caribbean Sea and Gulf of Mexico. Although the movement of Caribbean and Gulf storms in Late Season resembles Early Season activity in this area, there is a larger proportion of tropical cyclones of full hurricane intensity later in the year because of the larger reservoir of heat available in the ocean towards the end of the season. Tropical cyclone activity is rare in the Atlantic Ocean and its adjacent seas outside the period 1 May to 30 November."

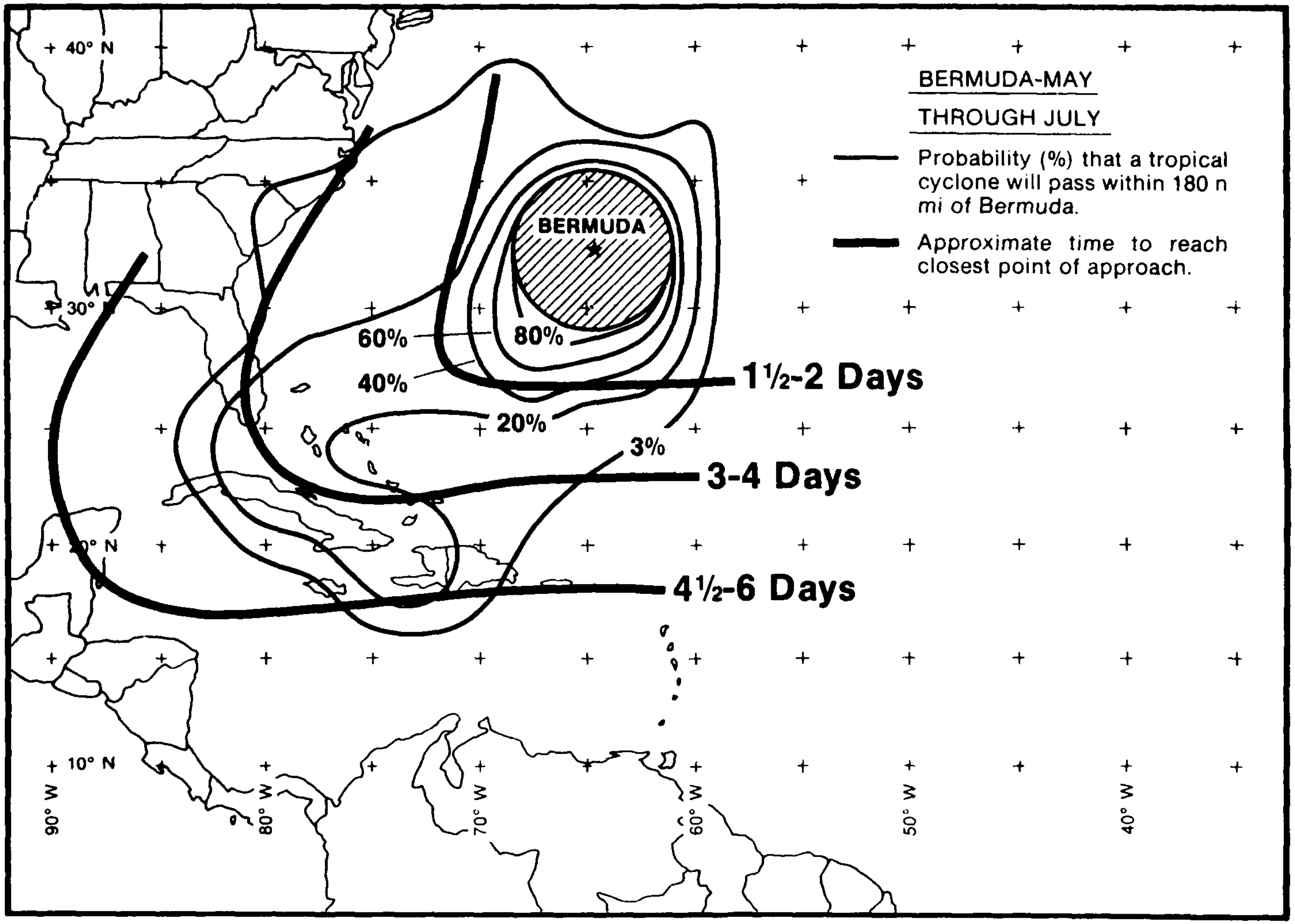

Figure XXII-10. Probability that a tropical cyclone will pass within 180 n mi of Bermuda (shaded circle), and approximate time to reach closest point of approach during May through July (based on data from 1871-1979).

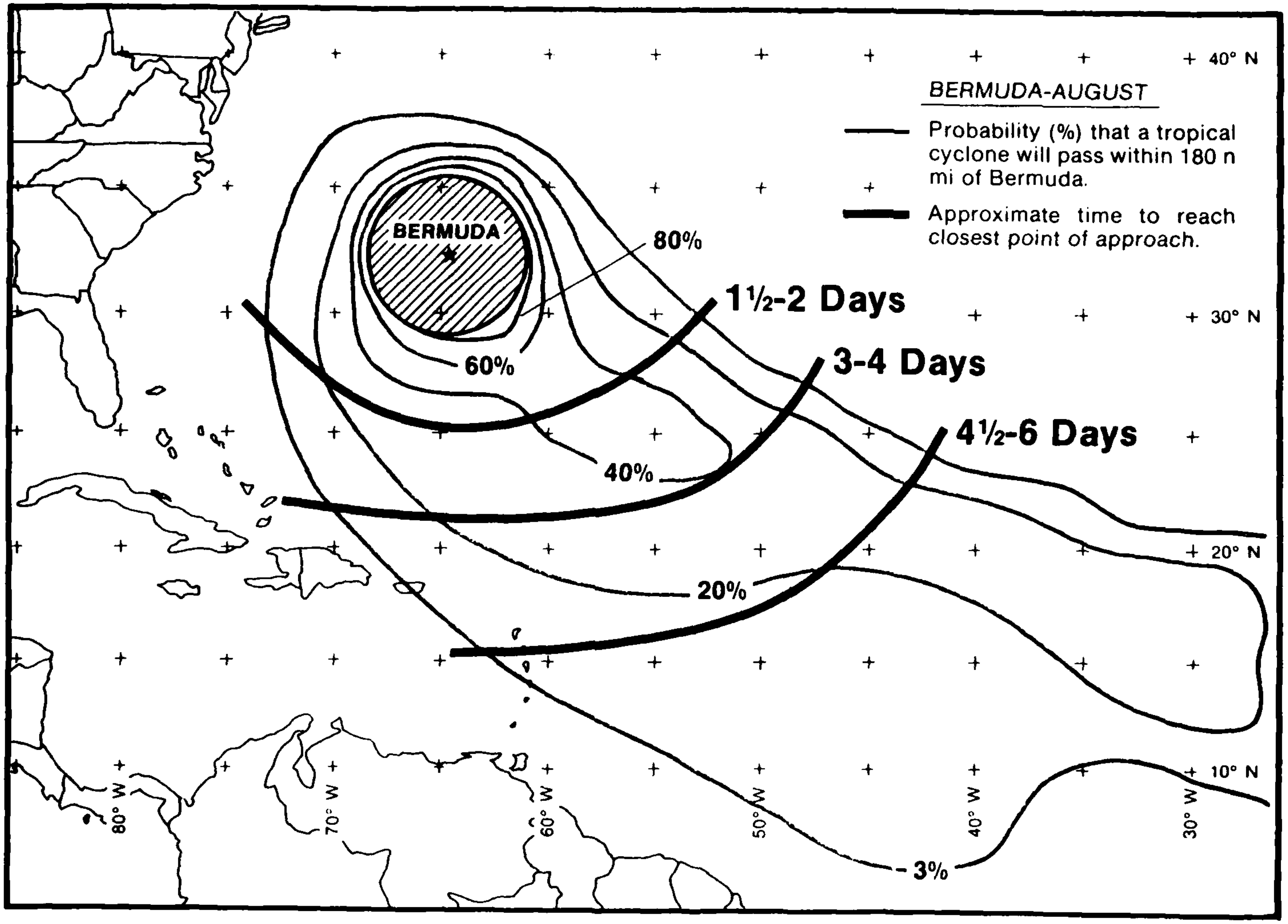

Figure XXII-11. Probability that a tropical cyclone will pass within 180 n mi of Bermuda (shaded circle), and approximate time to reach closest point of approach during August (based on data from 1871-1979).

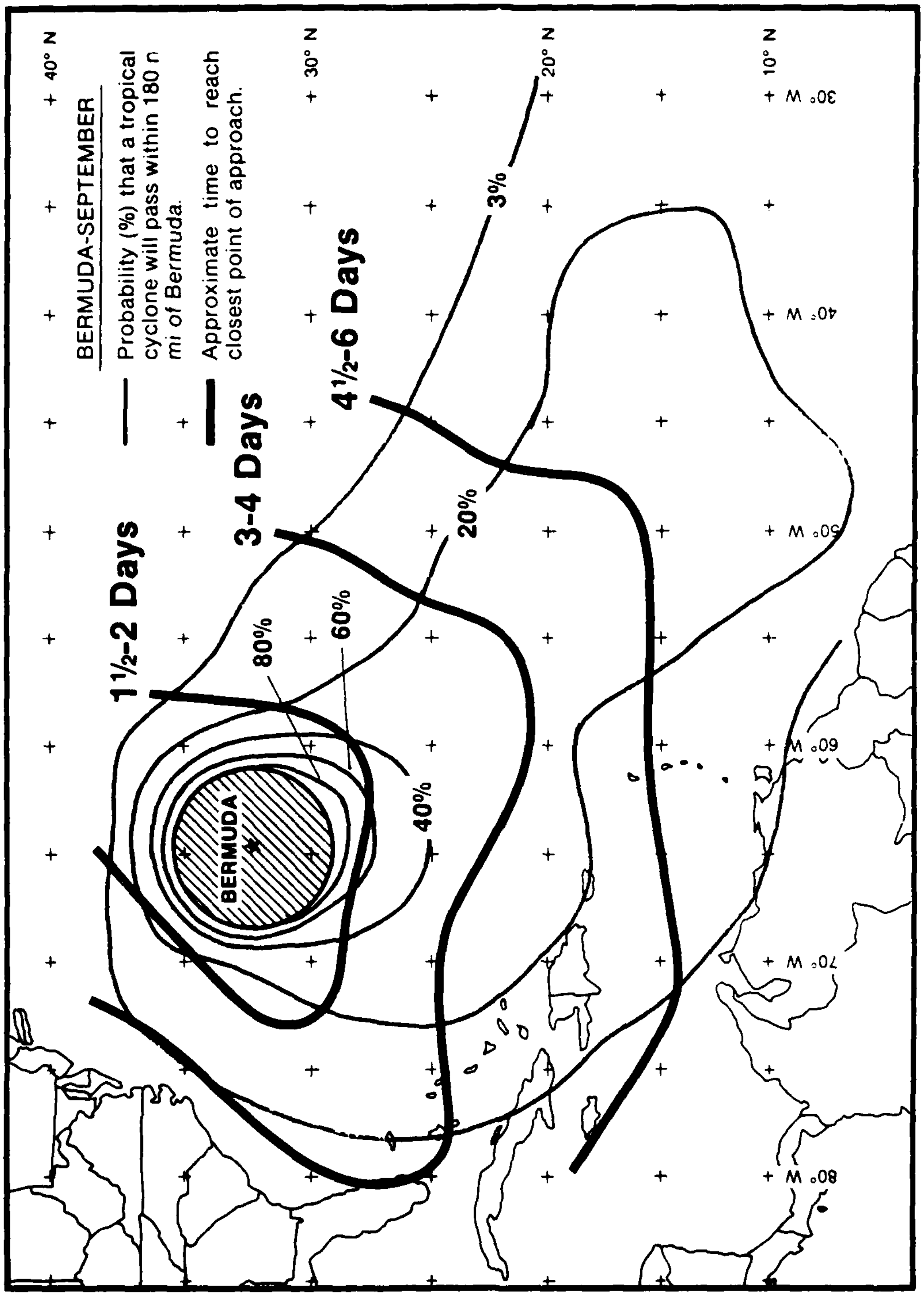

Figure XXII-12. Probability that a tropical cyclone will pass within 180 n mi of Bermuda (shaded circle), and approximate time to reach closest point of approach during September (based on data from 1871-1979).

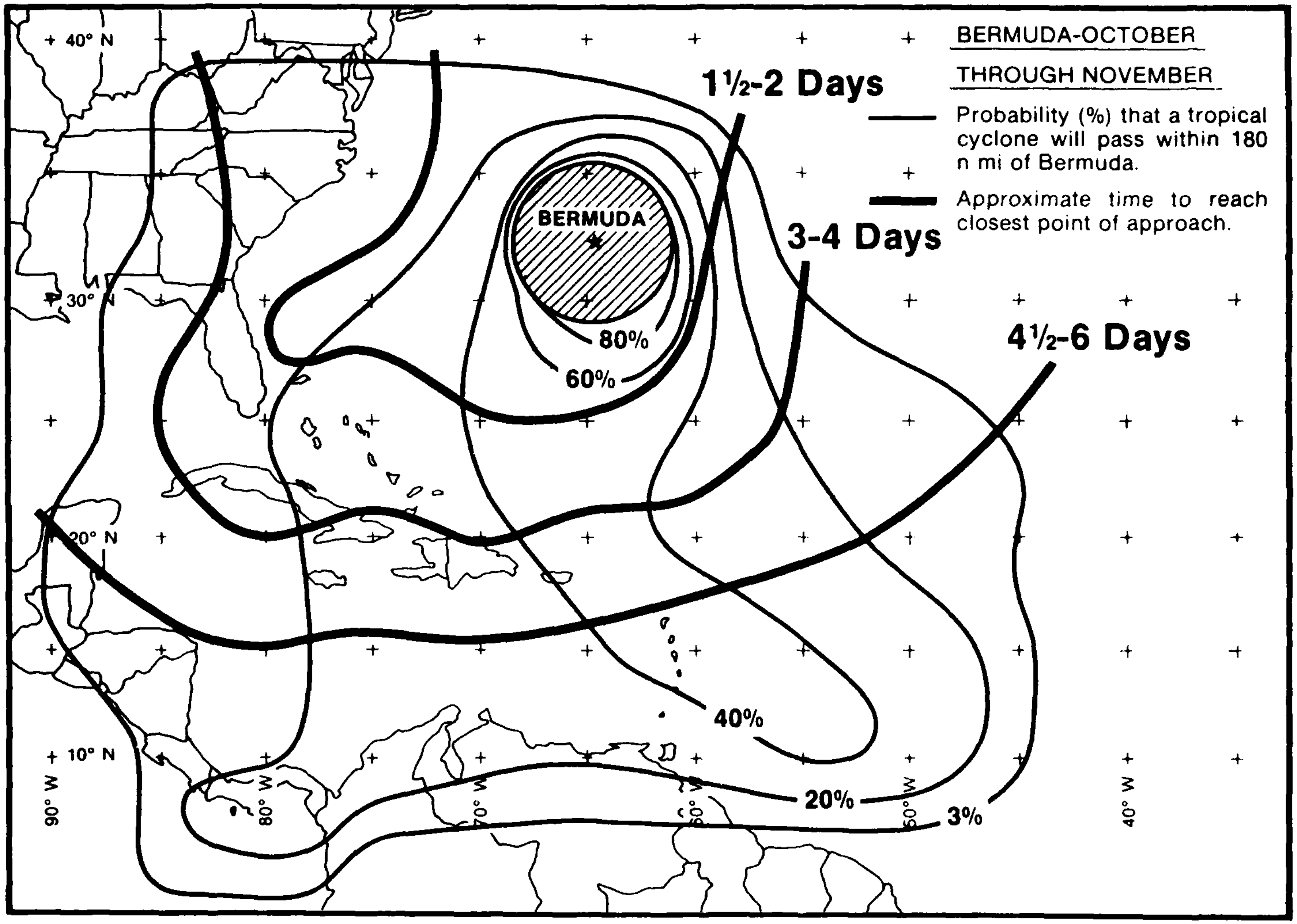

Figure XXII-13. Probability that a tropical cyclone will pass within 180 n mi of Bermuda (shaded circle), and approximate time to reach closest point of approach during October (based on data from 1871-1979).

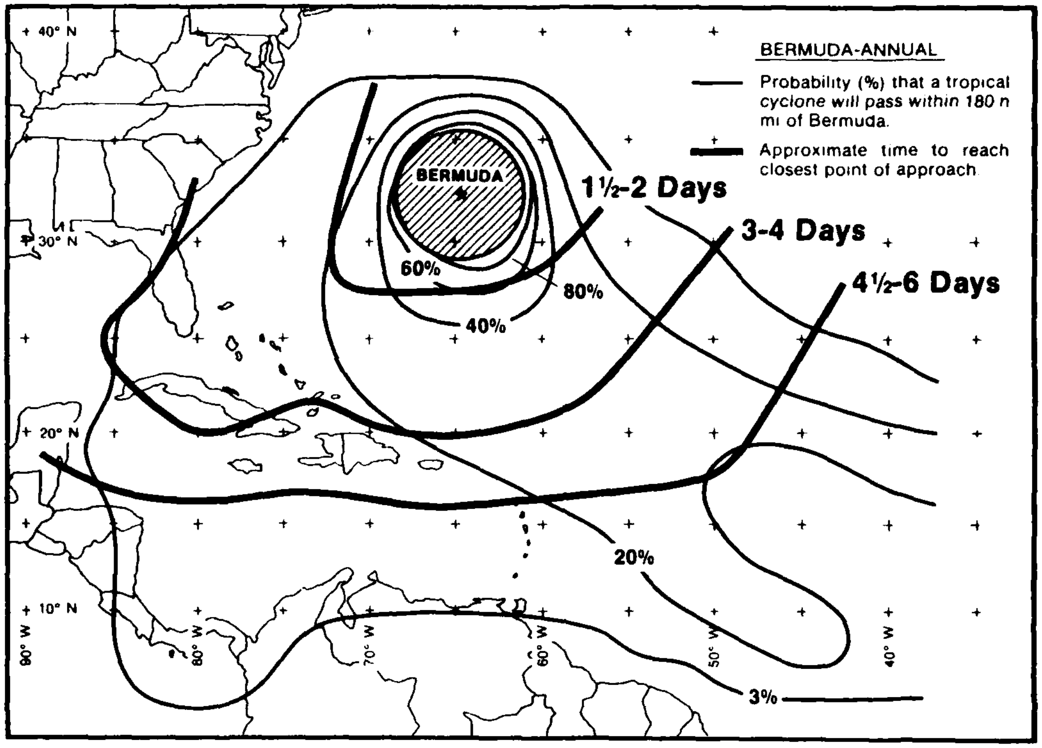

Figure XXII-14. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi of Bermuda during the years 1871-1979.

3.3 LOCAL WEATHER CONDITIONS DURING TROPICAL CYCLONE PASSAGE

Data on weather conditions during tropical cyclone passages at Bermuda are drawn mainly from the hourly observations taken at the U.S. Naval Air Station. During 1942-69 the observing station was staffed by the U.S. Air Force; since 1970 it has been operated by the U.S. Naval Oceanography Command Facility, Bermuda.

During the 38 years 1942-79, 28 hurricane-force tropical cyclones passed within 180 n mi of Bermuda. Only 14 of these caused winds of 34 kt or more, and only three caused (officially recorded) sustained hurricane force winds. The last time sustained hurricane force winds were officially recorded at Bermuda, as of January 1984, was in October 1948. Hurricane Arlene in 1963 had recorded sustained winds of 60 kt and gusts to 88 kt, with unofficial reports of winds over 100 kt. Table XXII-5 provides information on these 14 tropical cyclones' characteristics and resulting station conditions.

Table XXII-5. Tropical cyclone data and related weather conditions associated with hurricane passages within 180 n mi that contributed to official observed sustained winds of 34 kt or greater at Bermuda.

HURRICANE DATA				RELATED LOCAL WEATHER		
Date MMDDYR	Movement DIR/SOA	DIR/CPA FM STAT	Center Wind (kt)	Maximum Wind (kt) Sustained	Gusts	Comments
8/24/43	N/17	SW140	113	51	65	
10/20/47	NE/16	NW53	91	78	104	All instruments lost. Vsby 1/8 ocean spray. 3rd major storm in 22 yrs, others in Oct '26 and Oct '39.
9/13/48	N/14	NW64	111	87	117	
10/07/48	ENE/26	S76	85	70	105	20 min of hurricane force winds. 2nd hurricane of year over islands.
9/08/49	NNE/11	SE66	100	55	65	
9/08/50	W/03	SW171	134	39		
10/02/50	WNW/06	SSW114	76	40	50	
9/27/52	ENE/26	NNW177	81	36		
9/18/53	NE/21	NW77	65	55	89	3rd hurricane of '53 to affect islands. Wind gear damaged, unofficial reports of 100 kt winds. Heavy boat damage Hamilton Harbor.
10/06/62	NNE/19	W172	83	40	59	
8/09/63	ENE/26	Eye	67	60	88	Station in eye for 30 min. Hurricane Arlene.
9/13/64	NNE/11	NW83	91	46	63	Shark-oil changed to consistency of candle wax.
10/16/70	NE/18	NW23	73	42	53	
7/04/73	N/09	W27	73	43	57	

Table XXII-5 also indicates a significant decrease in strong tropical cyclone activity over Bermuda in the last 40 years. Since there has not been a similar decrease in Atlantic tropical cyclone activity, it must be expected that hurricanes will return to Bermuda at some indeterminate future time.

Figure XXII-15 shows tracks of the 14 tropical cyclones that had hurricane strength during passage within 180 n mi and caused gale force (>33 kt) winds in the Bermuda area.* Nine of the 14 tropical cyclones causing gale force winds at Bermuda passed to the west through north while moving north to northeast. Two centers passed to the east through south while moving northeast, and two others passed to the south while moving west. In at least one case (Arlene, September 1963) the eye of the hurricane passed directly over the islands.

Figure XXII-16 shows the tracks of tropical cyclones, regardless of center intensity or distance from Bermuda, when winds of 23 kt and 34 kt or greater were being recorded at NAS Bermuda. The strongest winds were generally recorded when the centers were approaching and located in the southwest semicircle relative to Bermuda, which placed Bermuda in the dangerous right semicircles of the tropical cyclones. It should be noted that the winds in areas exposed to the open sea will be stronger than those at the airfield. It also is likely that due to the exposure to the north, the western side of the islands would have stronger winds for a longer time following center passage.

3.4 WAVE ACTION

The Bermuda islands are exposed to wind wave and swell action from all directions. Wave and swell action induced by storms is the most severe along the southeastern coastline because of the abrupt rise of the ocean floor and near-shore shallow reef. Because tropical cyclones typically approach from the south and southwest, the southeastern coastline is also the most exposed to the long period swell that moves out ahead of the center. Wave trains approaching from the western direction break over the outer reefs several miles offshore. Wind-enhanced tides of 5-7 ft, however, have occurred and could cause a significant increase in the wave energy and heights crossing the shallows and affecting the western shores.

3.5 STORM SURGE AND TIDES

Storm surge during tropical cyclone passage has not been a major problem for the Bermuda harbors. The highest surge height of recent record is about 7 ft, occurring with Arlene in August of 1963. Unofficial records report earlier cases of significant storm surge damage: in 1917 "unprecedentedly high tides were reported; in 1899 the causeway was demolished; and in 1878 the sea made a clean breach of the dockyard breakwater.

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*Track information from Neumann et al., 1978.

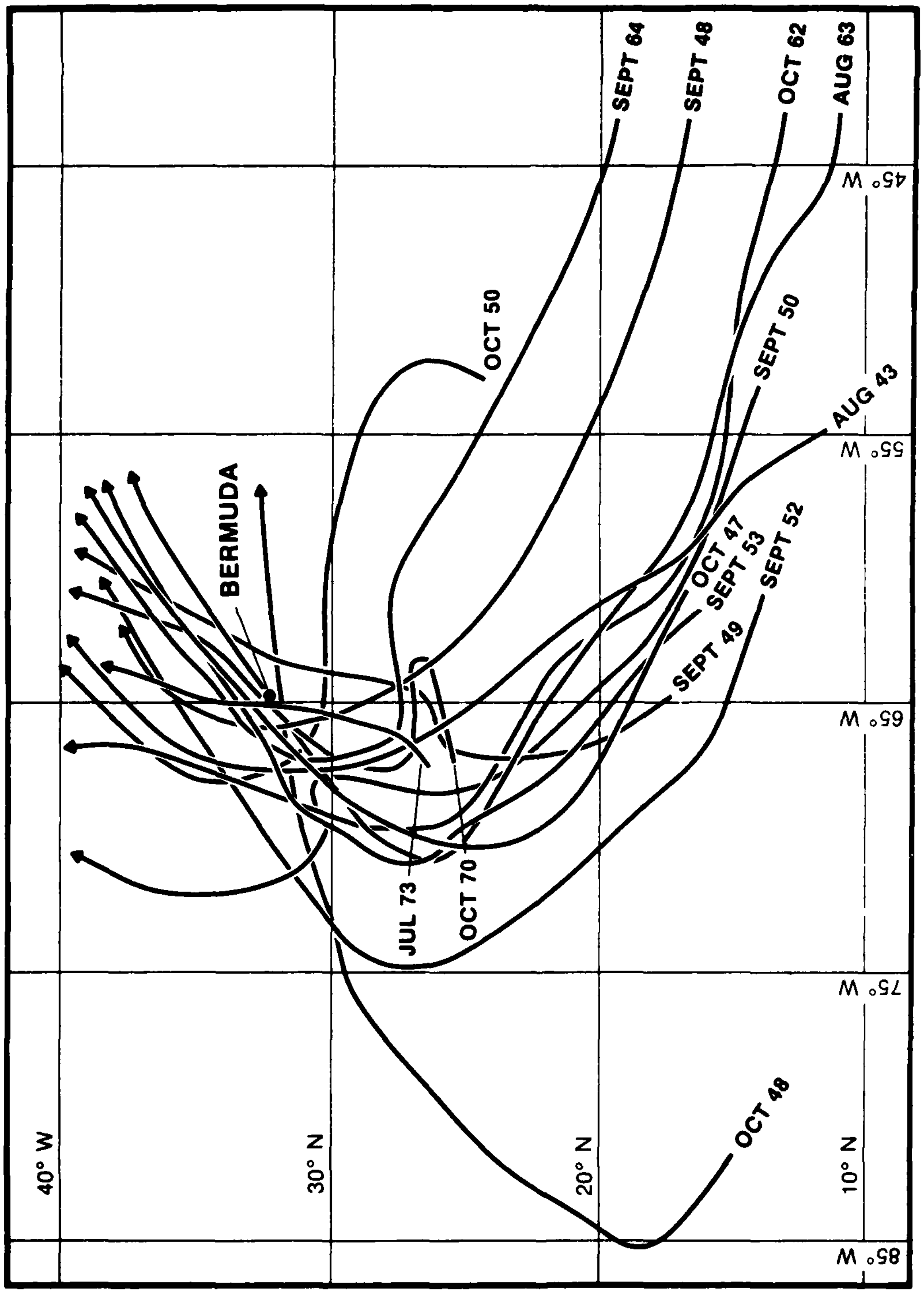

Figure XXII-15. Tracks of the 14 hurricanes that passed within 180 n mi and caused sustained winds of 34 kt or greater at Bermuda during the years 1942-79.

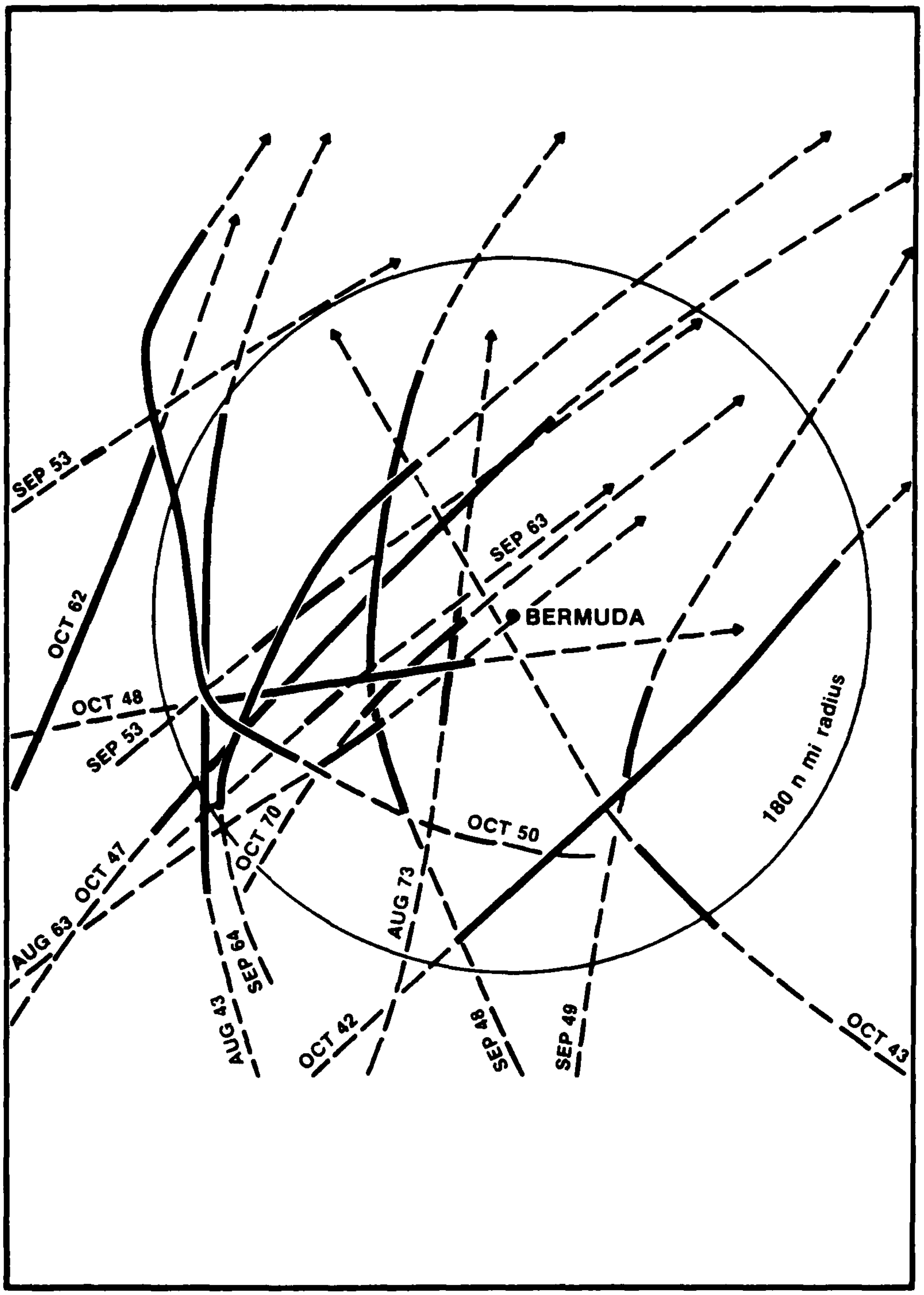

Figure XXII-16. Track segments of the tropical cyclones during 1942-79 that produced winds of 34 kt or greater (heavy lines) at Bermuda, and track segments with winds 23 kt or greater (dashed lines) at Bermuda.

The Bermuda area has a small tidal range of about 3 ft, and harbor facilities built in regions of small tidal ranges generally have little freeboard clearance. Therefore, wind-enhanced tides of even 4-5 ft typically cause considerable problems. Areas under U.S. Navy control that appear most threatened by storm surge are the lower portion of the Navy Annex, the marginal wharf area of NAS, and the airport runway. A storm surge of 8-10 ft could inundate large portions of these areas.

4. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for hurricane preparedness by the U.S. Navy in Bermuda are addressed in the Disaster Preparedness Plan, NAS BERMUDA, DPP 1-74. The Commander Disaster Preparedness Unit (C.O. NAS Bermuda) issues the plan, which defines the Destructive Weather Bill, Organizational Action, Dissemination Procedures, and the Evacuation Plan. The Coordinating Authority Bermuda passes the condition of readiness by message to all military commands and activities in Bermuda and by Navy broadcast to military ships in the area.

4.1 THREAT ASSESSMENT

Bermuda's harbors and surrounding inner waters do not provide safe havens during hurricane conditions. Passage through narrow, dredged channels is hazardous or restricted in some cases in less than gale force winds (Town Cut Channel). Underwater coral heads and shoal areas greatly restrict ship movements. The small land area and low terrain of the islands provide little shelter from the full force of the wind. There are no designated hurricane anchorages, moorings, or berths.

4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy deep-draft vessels when Bermuda is threatened by winds 50 kt or greater from a tropical cyclone. Factors to consider in timing the evasion action include:

(1) Forward speed of the tropical cyclone. The speed of advance generally increases as the tropical cyclone approaches and passes Bermuda.

(2) Elapsed time to make preparations for getting underway and time to reach open water. Tropical cyclones have been known to form within 180 n mi of Bermuda, so extra precautions should be taken during hurricane season.

(3) Local restriction of departure during daylight hours. Only imposed because of the unlighted ranges and navigational hazards of passage through narrows such as Two Rock Passage (Hamilton), Town Cut Channel (Saint Georges), The Chimmeys and White Flats (North Channel), and the much encumbered South Channel between Tipping Shoals and Grassy Bay.

(4) Wind restrictions for using the various channels. Departure should be made before the wind builds past 25 kt (15 kt crosswind for Town Cut Channel).

Ships at sea should stand well clear of the extensive reefs and shoals that encircle Bermuda from the northeast sector counterclockwise through the southwest. The Sailing Directions (1983) state that the only safe approach to the Bermuda islands in times of poor visibility is from the southeast. This advice applies equally to departures under hazardous weather conditions until a vessel is well clear of Bermuda.

Once a vessel has gained sea room beyond Bermuda, evasion tactics will depend on the location, speed of advance and direction of movement of the threatening tropical cyclone. Today's satellite technology provides the accurate and timely information on tropical cyclone location and intensity that is essential for sound decisions. This information is used in the production of forecasts and warnings issued at 6 hr intervals and updated as necessary to reflect important changes.

The cardinal rule of seamanship is to avoid the dangerous righthand semicircle of the storm. The following evasion guidelines should be executed at least 36 hours before the storm center's CPA to Bermuda.

(1) Tropical cyclone approaching from the west or southwest and forecast to pass south or within 60 n mi north of Bermuda: Evasion should be northwest to reach or remain in the safe semicircle.

(2) Tropical cyclone approaching from the west or southwest and forecast to pass more than 60 n mi north of Bermuda: Evasion should be southeast.

(3) Tropical cyclone approaching from the south or southwest and forecast to pass east or within 60 ni mi west of Bermuda: Evasion should be west or southwest to reach or remain in the safe semicircle.

(4) Tropical cyclone approaching from the south or southeast and forecast to pass more than 60 n mi west of Bermuda: Evasion should be to the east and then southeast.

Decision makers should be aware of three general considerations: Crossing the track of an approaching hurricane, as recommended in (1) and (3) above, can be hazardous and should be accomplished 36 hr or more ahead of the storm; after recurvature tropical cyclones generally track north of east and accelerate northeastward; and the mean 24 hr position error for tropical cyclones approaching Bermuda is about 120 n mi and the mean 48 hr position error is about 280 n mi.

4.3 RETURNING TO PORT

Port damage and disarray after a hurricane strike at Bermuda may include such navigation hazards as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Harbor facilities may be so damaged that they cannot provide even minimal services. The Sailing

Directions (1983) warn that buoys marking the dredged channel through the Narrows can be displaced from their intended positions by heavy weather. Vessels should check with the Bermuda Harbor Radio before attempting to return.

4.4 REMAINING AT OR ENTERING BERMUDA HARBORS DURING TROPICAL CYCLONES THREATS

U. S. Navy ships at sea that are considering seeking shelter at Bermuda should be aware of several constraints. The harbors are not considered havens from hurricane force winds. The surrounding waters are extremely hazardous due to reefs and shoals. Movements in the inner waters are restricted to the channels. Large areas of shoals less than a fathom deep surround the islands and extend several miles to the southwest through west to northeast. Only limited tug resources are available. Entrance and departure clearance must be obtained from the Fort George Signal Station, a measure necessary to control traffic in the Narrows and channels. There are no designated hurricane mooring buoys, anchorages, or berths in the harbor. There are no pier or wharf berthing facilities suitable for use during hurricane force winds. The Navy mooring buoys in Port Royal Bay and Saint Georges Harbor have not been maintained and their structural integrity is uncertain as of January 1984.

For all other vessels, several additional constraints apply. The area of general anchorage is Murrays Anchorage, which extends beyond the western end (inner water area) of the Narrows. Entrance to Saint Georges Harbor requires passage through the narrow Town Cut Channel. There are no hurricane anchorages in either Saint George or Hamilton Harbors, and there are no piers or wharves suitable for hurricane berthing.

If a vessel is unable to go to sea during a tropical cyclone passage, the most suitable mooring and/or anchorages are in Port Royal Bay and the southwest sector of the Great Sound. The most substantial berths are in the Dockyard.

4.5 ADVICE FOR SMALL CRAFT

The normal advice to small craft owners is to remove their boats from the water and firmly secure them ashore at an elevation of at least 20 feet. This may be difficult in Bermuda because of restrictions on private ownership of trailers, the shortage of available landings, and the low terrain elevations. If removal is not feasible, small craft should seek shelter in the numerous small bays and harbors that would provide some protection for small craft during hurricane conditions. The Yachtsman's Guide to the Bermuda Islands by Michael Voegeli (1983) is suggested as an excellent reference for small craft operators in Bermuda waters.

Factors to be remembered in hurricane mooring of small craft are: the likelihood of water levels increasing by several feet and the need for increased scope of lines; the need for protection from open fetches where wind waves can develop; the hazards of derelicts, debris and falling trees and structures; and, most of all, a need for advanced planning and early action.

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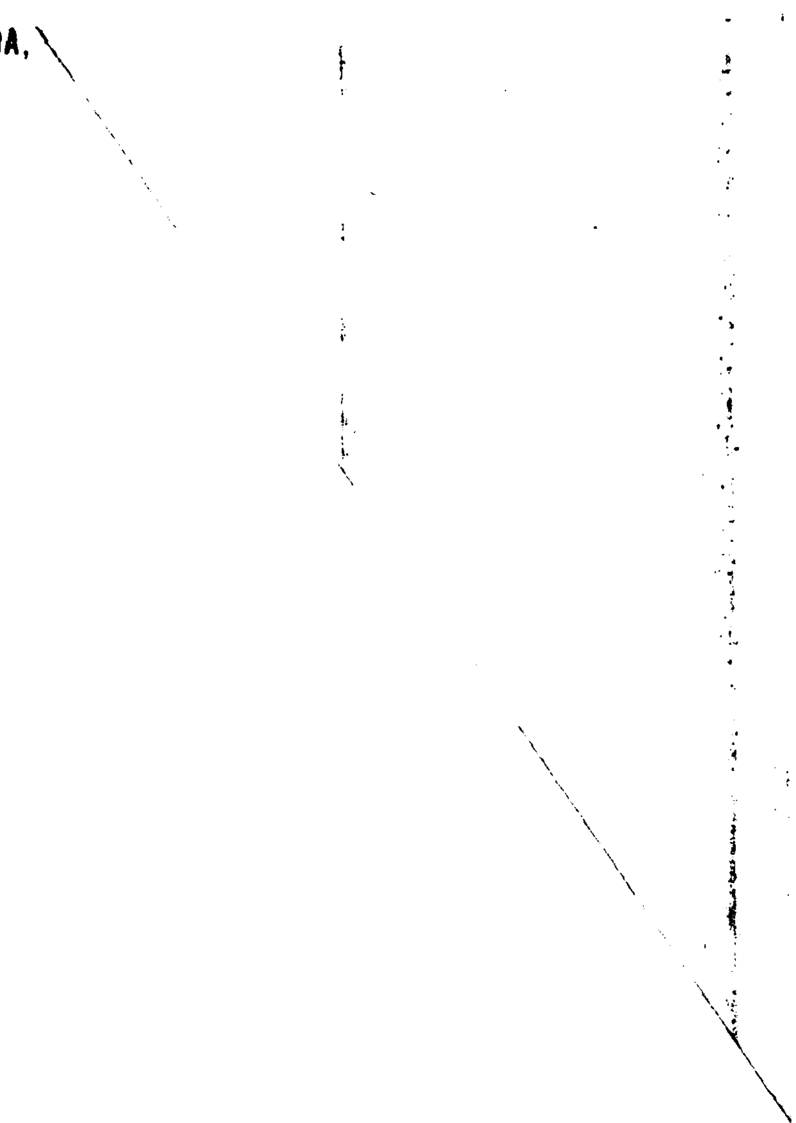
XXIII. PONTA DELGADA,
AZORES



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XXIII. PONTA DELGADA, AZORES

SUMMARY

Ponta Delgada is a hurricane haven from most threats of tropical cyclones. It is not a haven under two combinations of storm conditions:

(1) Approach from the southwest -- 24 hr forecast indicates hurricane strength of storm during passage within 180 n mi south or 60 n mi north.

(2) Approach from the south -- 24 hr forecast indicates hurricane strength of storm during passage within 180 n mi west or 60 n mi east.

Several factors favor Ponta Delgada as a hurricane haven.

Tropical cyclones of hurricane force are rare in the area. Only seven such passages have occurred in the 113 years 1871-1983.

The approach sector southwest to west has been well defined, and the season of occurrence has been limited to the narrow six-week period 28 August through 7 October.

The port at Ponta Delgada is well protected from all but southeasterly winds.

With unencumbered open seas in all directions from Ponta Delgada, decisions to evade at sea can be delayed until the threat is clearly defined. After that, there is running room to sortie to all sectors. The lee side of the island also provides some protection.

1. LOCATION AND TOPOGRAPHY

The port of Ponta Delgada is in the eastern North Atlantic near 37.7°N, 25.7°W on Sao Miguel, the largest of the nine islands that form the Azores archipelago (Figure XXIII-1). The islands lie between longitudes 25° and 31°W, and latitudes 37° and 40°N. The archipelago consists of three groups of islands:

(1) Western -- Flores and Corvo

(2) Central -- Terceira, Fayal, Pico, Sao Jorge, and Graciosa

(3) Eastern -- Sao Miguel and Santa Maria

This hurricane haven evaluation was prepared by R.E. Englebretson and J.D. Jarrell of Science Applications, Inc. (SAI), Monterey, CA 93940.

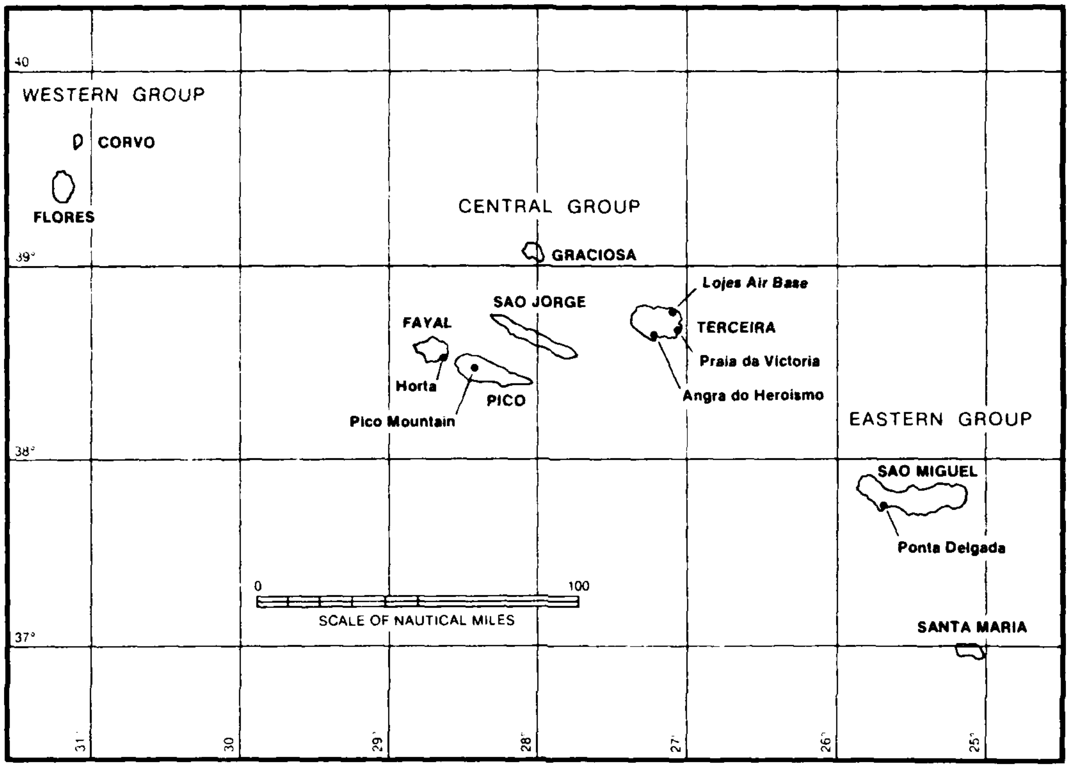

Figure XXIII-1. The Azores.

The eastern group is 760 n mi west of Portugal, and the western group is abut 1070 n mi east-southeast of Cape Race, Newfoundland, the nearest point of the North American continent. The archipelago is oriented west-northwest to east-southeast and is about 330 n mi in extent.

The island chain is of nearly pure volcanic origin. Landscape features are characteristic of volcanic formation: sharp peaks and ridges, craters, ravines, and lava fields. Each island consists of a mountainous interior bounded by high basaltic cliffs with few inlets. The highest mountain in the Azores, Pico at 7,613 ft, is frequently snow-capped in winter with the snow level occasionally extending down to 4000 ft.

There are no natural harbors in the Azores. The best anchorages are in the open bays of Horta, Ponta Delgada, Praia da Victoria and Angra do Heroismo (Figure XXIII-1). They are all located on the south or southwest side of islands. Therefore, while they are protected from the wind and waves generated by extratropical storms, they may have maximum exposure to the wind and waves generated by tropical cyclones typically approaching from the south or southwest.

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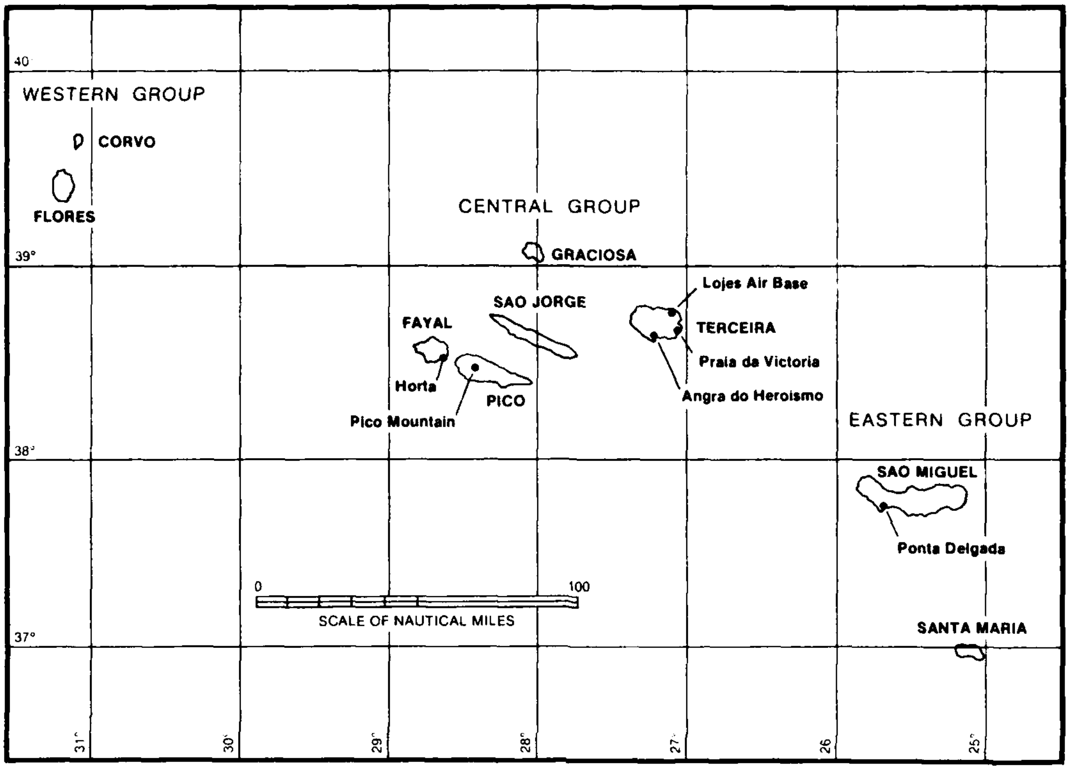

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The islands are quite small. The largest, Sao Miguel, is about 35 n mi E-W and 8.7 n mi N-S; the smallest, Corvo, is about 2.2 n mi E-W and 4.4 n mi N-S. The islands are covered by heavy vegetation with cultivated crops up to the 1000 ft level, cattle grazing above that to about 2000 ft, and woodland and scrub brush at the higher elevations.

Ponta Delgada on the island of Sao Miguel is the largest town in the Azores and is located in a region of fairly flat terrain (Figure XXIII-2). The mountains of Sao Miguel are in three separate groups, Site Cidades (2,867 ft) in the west, Planalta Graminhaes (3,625 ft) in the east, and the Serra de Agua de Pau (3,114 ft) in the center. There is a gap about 5 n mi wide between the western and central massifs, and this gap and the air flow through it strongly influence wind and cloud conditions at Ponta Delgada.

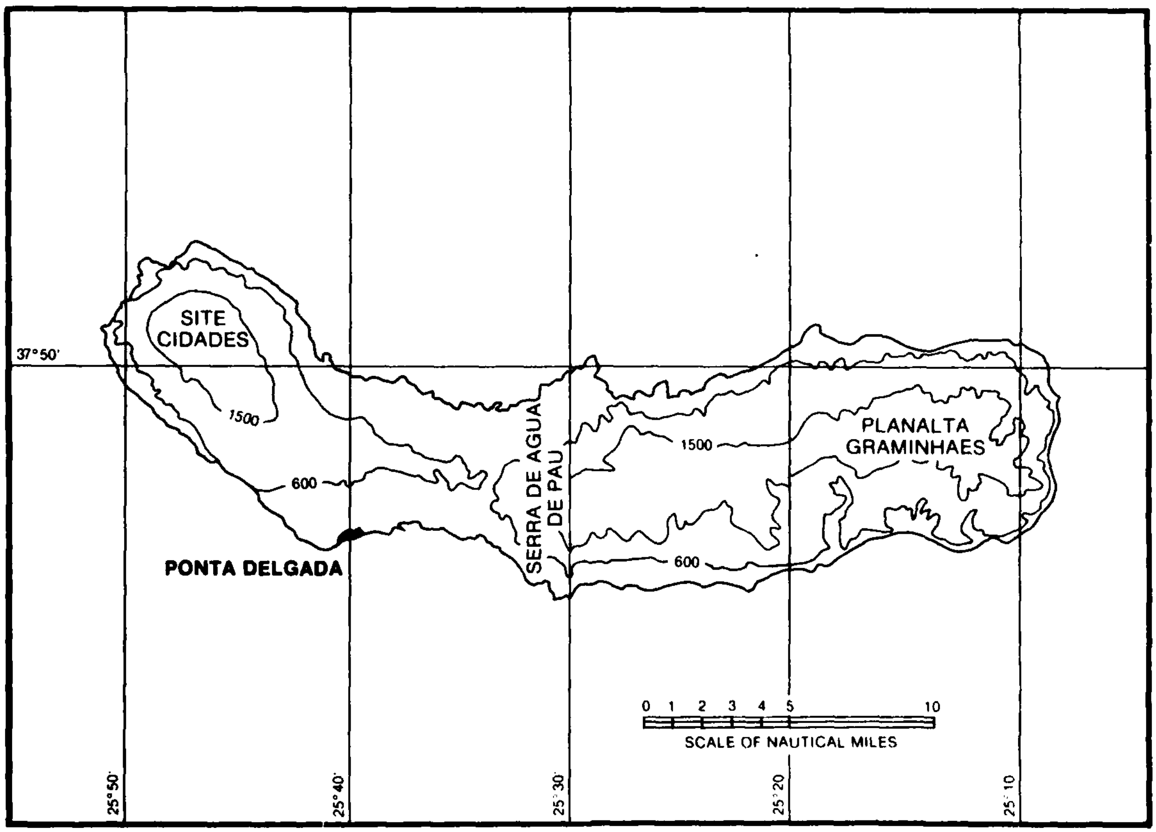

Figure XXIII-2. Sao Miguel Island and the Port of Ponta Delgada. Elevations are given in feet.

2. THE HARBOR, APPROACH AND HEAVY WEATHER FACILITIES

2.1 PONTA DELGADA HARBOR AND APPROACH

Ponta Delgada Harbor (Figure XXIII-3) is formed by a breakwater, the Molhe Salazar, which extends easterly and parallel to the shoreline for abut 4000 ft (Fleet Intelligence Center Europe and Atlantic, 1979). The seaward approach to Ponta Delgada is unencumbered and the largest ships can approach the port without difficulty. The approach is made on a heading of 321°T, keeping the fixed green range lights in line. The inner harbor, about 55 acres in size, permits entry and mooring of ships with a displacement of up to 25,000 tons and a mean draft of 35 ft. The harbor is well sheltered except from east-southeasterly winds.

There is an abnormal magnetic variation in the vicinity; it can run up to 25°.

Pilotage is compulsory for harbor entry, but the requirement usually is waived for departure after the Port Captain is notified of the intended sailing. Pilots are readily available from a black and white craft with "Piloto" painted on the side. The usual boarding point is about 1000 yards south of the breakwater tip, near the harbor entrance.

2.2 ENTRANCE TO PONTA DELGADA HARBOR

The overall width of the harbor entrance at Ponta Delgada is about 1500 ft; depths are 30-37 ft over a width of 1000 ft between the 5 fathom curve and the breakwater tip. There is no channel as such. The harbor is entered from the east between the head of Molhe Salazar (the breakwater) and the shoal water near the northern shore. Entrance to the harbor is generally easy, except on the rare occasions when winds blow from the east-southeast or when heavy swells are running. There are no bridges, overhead cables or other elevated obstructions to hamper navigation.

2.3 BERTHS AND ANCHORAGES

All berthing spaces for deep-draft vessels at Ponta Delgada are along the north face of the Mohle Salazar (breakwater); the NATO berth is near its eastern end. The Mohle provides over 4000 ft of protected quayage. The west quay has space for four coastal vessels with up to 12 ft draft. The middle quay will take one vessel with up to 25 ft draft. The east quay has space for two vessels with alongside depth of 40 ft. The dock apron runs the length of the Mohle and is about 100 ft wide. There is one 1100 HP tug available to assist ships in making their berths.

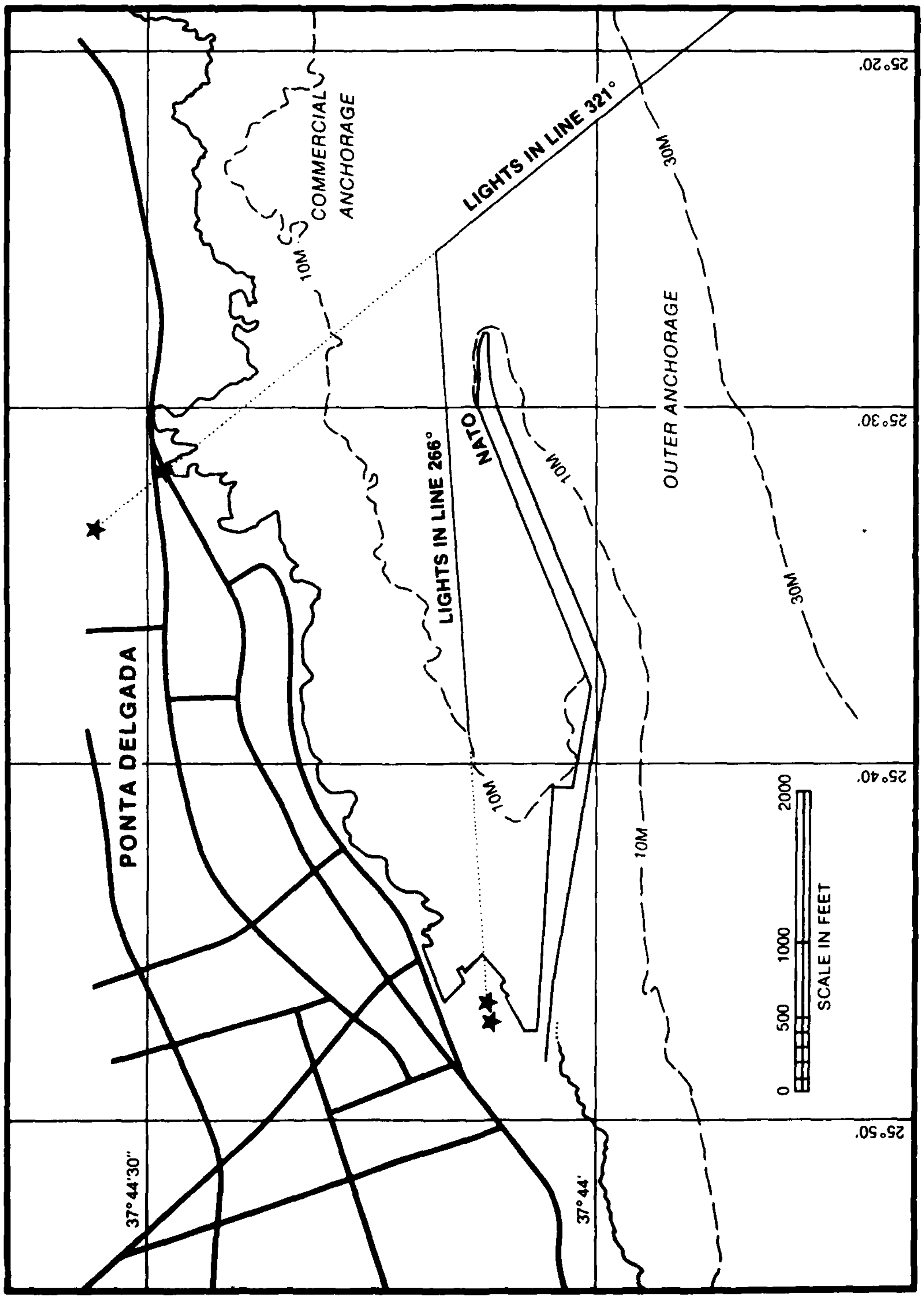

Figure XXIII-3. Ponta Delgada Harbor.

There is good holding ground for anchorage to the south and southeast of the breakwater for a distance of about 1 n mi. There are five can riser-type buoys and two sphere-type buoys for mooring in this area. This anchorage is fully exposed to southerly winds. There are also mooring chains in the harbor, but these are not recommended during southerly or easterly winds due to the restricted maneuvering area.

The tide rises about 5.5 ft above mean sea level for mean high water springs and 1.0 ft for mean low water springs. Ships will surge at pierside when there is a moderate sea running. Considerable spray occasionally will come over the breakwater.

2.4 HEAVY WEATHER CONDITIONS, ANCHORAGES, BERTHS AND MOORINGS

There are no designated hurricane anchorages, berths, or moorings for deep-draft vessels in Ponta Delgada harbor. The harbor location on a southern coast, and configuration opening to the east, provide maximum protection from wind and waves from the west clockwise through northeast. Thus excellent protection is provided from the winter extratropical storms that generally approach from the west through north.

Tropical cyclones, on the other hand, generally approach from the southwest and at least one approached from the south. The extensive breakwater provides protection from wave action in southerly winds, but the harbor itself is exposed to these winds. The harbor provides little or no protection from easterly winds and seas.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT PONTA DELGADA

3.1 INTRODUCTION

Tropical cyclones pass only infrequently within 180 n mi of Ponta Delgada. The U.S. Navy records (Neumann et al., 1978) used in this study record such passages by only 16 tropical cyclones during the years 1871 through 1976. Updated Atlantic tropical cyclone data indicate an additional close passage in 1980, for a total of 17 approaches within 180 n mi during the 11^-year period 1871-1983. This is an average of only one passage every 6-7 years.

Seven of the 17 storms were classified as hurricanes at CPA to Ponta Delgada. A 1926 hurricane was the most intense, with center winds of 100 kt. Four of the ten non-hurricane storms had weakened to tropical storm intensity (34-63 kt) and the remaining six had became extratropical at CPA. Three of these extratropical cyclones, however, still had hurricane force winds at CPA with maximums of 65-81 kt.

Winter extratropical cyclones occur more frequently in the Azores area than do tropical cyclones. According to port authorities (C.M.J. Rieff and Sons), the most severe winds on record in the last 50 years (120 mph/104 kt) occurred during a 1981 winter storm. Several container vessels were lost in the open seas of the Azores area, but six vessels of similar size rode out the storm in Ponta Delgada harbor without experiencing significant damage.

It must be stressed, however, that extratropical storm winds and seas tend to have a more westerly component than tropical cyclones. Wind and seas with a southweasterly component could create a dangerous situation in Ponta Delgada harbor.

3.2 CLIMATOLOGY

For this study, any tropical cyclone approaching within 180 n mi of Ponta Delgada is considered to represent a threat to the port.

The location of the Azores, under the east-northeastern portion of the Bermuda anticyclone (known locally as the Azores anticyclone), positions the islands out of the typical path of Atlantic tropical cyclones. This explains the low overall frequency of tropical cyclone threats of about one every 6-7 years. In their formative stages, Atlantic tropical cyclones generally are steered westward along the southern boundary of the Bermuda high. Recurvature typically occurs in the western Atlantic and is followed by a general northeasterly movement and weakening of the cyclone as it takes on extratropical characteristics or dissipates. Thus few of the tropical cyclones, if any, that threaten the eastern seaboard of the U.S. and then recurve, ever threaten the Azores. Data indicate that only one of the 17 tropical cyclones threatening the Azores ever was located west of 70°W (Neumann et al., 1978). The major threat historically has been from systems that recurved relatively early, between 40° and 70°W.

The hurricane season for the Azores is August through November. Primary activity has been in September with seven near passages of tropical cyclones, and in August and October with four each (Figure XXIII-4).

Five of the 17 tropical cyclones that approached within 180 n mi of Ponta Delgada showed looping or bent-back tracks near the Azores. This kind of movement probably is related to the weak steering currents near the axis of the upper level subtropical ridge. It is difficult to forecast a "looping" movement; therefore, it is important to watch for such an occurrence even though a storm has passed beyond the area.

Although only 17 tropical cyclones have approached within 180 n mi of Ponta Delgada (1871-1983) as specified in Figure XXIII-4, in fact there have been 20 "approaches" within this radius. Of the five storms that followed looping tracks as noted in the preceding paragraph, three reapproached within 180 n mi. This phenomenon is reflected in Figure XXIII-5, which shows numbers of tropical cyclone approaches from each octant and these numbers as percentages of total

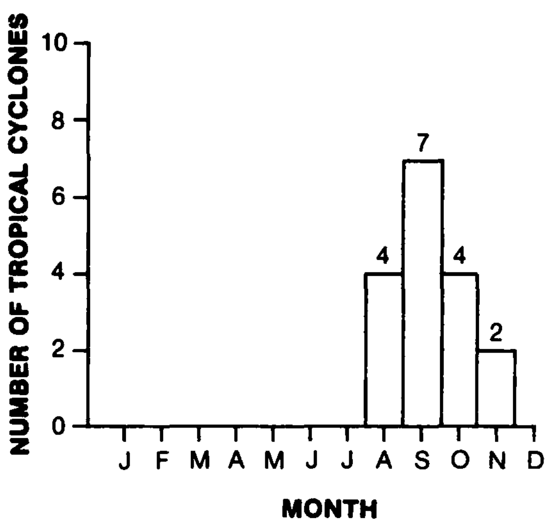

Figure XXIII-4. Seasonal distribution of tropical cyclones that passed within 180 n mi of Ponta Delgada (based on data from 1871-1983).

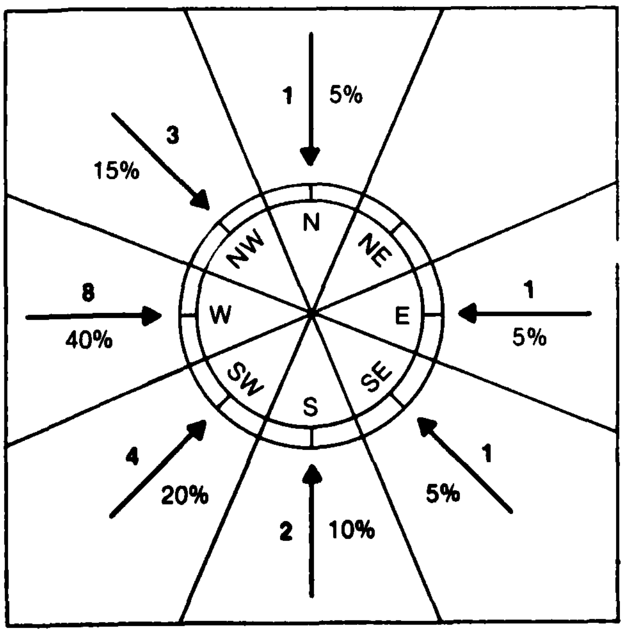

Figure XXIII-5. Directions of approach of tropical cyclones that approached within 180 n mi of Ponta Delgada during 1871-1983. Numbers of storms approaching from each octant shown in bold type; percentages are percent of total approaching from that octant. (For explanation of 20 "approaches" vs. only 17 "occurrences," see text.)

occurrences. There indeed have been 17 tropical cyclones, but three of them approached twice. The major threat sector, 15 out of 20 approaches, extends from the southwest through northwest.

Figure XXIII-6 is an annual summary of tropical cyclone threat probability to Ponta Delgada based on data for the years 1871-1983. (There have been so few close approaches in all these years that it is not feasible to develop seasonal/monthly breakdowns of probabilities.) The thin lines are percent threat for any storm location and the heavy lines are the approximate climatological average times to CPA.

Figure XXIII-7 shows the major portions of the tracks of the seven tropical cyclones that were classified as hurricanes at the time of CPA to Ponta Delgada, with the primary threat axis well defined as the sector from southwest to west. Note that the dates of CPA were within the six-week period 28 August through 7 October, which roughly corresponds with the season of most intense Atlantic tropical cyclones as discussed in the General Guidance section of this handbook.

3.3 LOCAL WEATHER CONDITIONS DURING TROPICAL CYCLONE PASSAGE

No weather records for Ponta Delgada itself were available for this study, but records were available for Lajes Airfield on the northeast side of Terceira Island some 85 n mi to the northwest of Ponta Delgada.

The generally weak nature of tropical cyclones in this part of the Atlantic is shown by the Lajes observations. In the 29 years 1950-78, only nine tropical cyclones passed within 180 n mi of the airfield. The maximum sustained (1 min avg) wind recorded was 45 kt and the maximum peak gust was 68 kt, both occurring in September 1957 when the eye of Hurricane Carrie passed directly over the base. At least one other eye passage was recorded during this 29-year period, this one with even lighter winds and a peak gust of only 52 kt. Both of these tropical cyclones were officially designated hurricanes at the time of passage over Lajes, so hurricane force wind conditions would have been expected over the open seas.

A historical record of wind conditions for Angra do Heroismo harbor on southern Terceira was also available,* but the latest date recorded was in 1944. Nineteen storms were listed with occurrences in all months except May, June, and July. Only four of the 19 occurrences corresponded with the tropical cyclone dates in the Neumann data, so most of the 19 probably were extratropical cyclones. The wind speed values given in the Terceira record were means for at least a 10 minute period, which differs from the current standard for aviation hourlies where the sustained winds are the mean value for a one minute period.

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*Air Ministry, 1949. Data accredited to Director, Azores Meteorological Service titled, "Principal Tropical Cyclones Reaching Terceira from 1893 Onward."

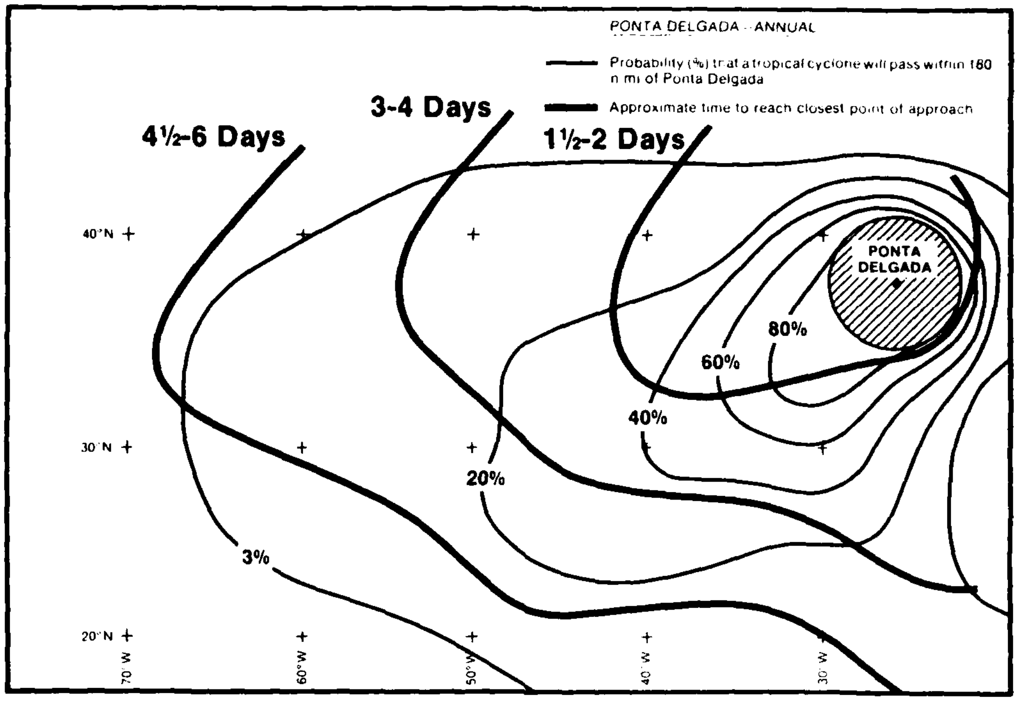

Figure XXIII-6. Probability that a tropical cyclone will pass within 180 n mi of Ponta Delgada (shaded circle), and approximate time to reach closest point of approach for all months (based on data from 1871-1979).

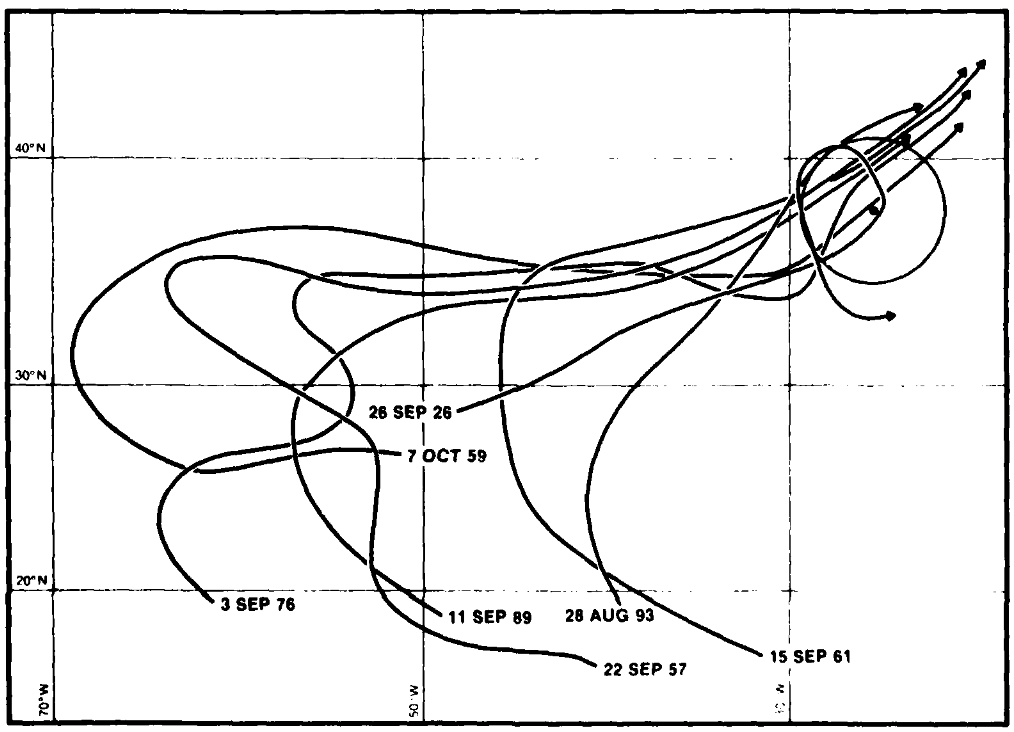

Figure XXIII-7. The tracks of tropical cyclones of hurricane intensity at closest point of approach to Ponta Delgada. Period of record 1871-1983 (dates are those of CPA).

Evaluation of Terceira data for the four tropical cyclones that correspond with Neumann data shows that the most intense tropical cyclone passage occurred on 28 August 1893. The Neumann data indicates this tropical cyclone was of hurricane intensity at the time of its passage about 90 n mi west of Angra do Heroismo. The maximum 10 min mean wind recorded at the harbor was 60 kt.

Available data indicate that the occasional tropical cyclone reaching the Azores area poses a threat similar to the one posed by the more frequent winter extratropical storms. Because of their direction of approach, however, tropical cyclones pose a special threat to Ponta Delgada harbor and to other area harbors exposed to the south and southeast.

3.4 WAVE ACTION IN PONTA DELGADA HARBOR

Ponta Delgada harbor is well protected from all but east or southeast ocean waves. Entrance to the harbor is easy except on the rare occasions when winds blow from the east-southeast. While the harbor provides protection from the primary wind and wave forces, there are some wave and current influences. Ships will surge at pierside with a moderate sea running. During high wind conditions and/or heavy swell, spray will come over the breakwater. The maximum range of tidal changes is 5-6 ft.

3.5 STORM SURGE

No storm surge data were available, but storm surge generally is not a problem for volcanic islands that rise rapidly from the ocean depths and provide little or no shoal area where surge can pile up.

4. THE DECISION TO EVADE OR REMAIN IN PORT

Because berths are protected and there is ready access to the open sea, captains of deep-draft vessels in Ponta Delgada harbor have a high degree of freedom in assessing tropical cyclone threats. The relative location of Ponta Delgada in the weakened late stages of tropical cyclones also makes the threat less serious than in areas where the threat is from mature, intense hurricanes. These factors, combined with the infrequent passage of tropical cyclones of hurricane force, produce a low climatological threat probability for Ponta Delgada harbor.

There are two tropical cyclone approaches that constitute primary threats to this harbor. One is the approach from the southwest sector with passage over the island of Sao Miguel or within 120 n mi to the south. This is the normal approach sector, but passage is typically to the north of the island. The other is the approach from the south, resulting from an early recurvature, with passage nearly over or within 120 n mi to the west. This is a rare event, but it has happened in the past.

In both approaches, hurricane force winds from the east through south with accompanying seas would pose a serious threat to the harbor of Ponta Delgada. In the approach from the south, there is also a threat from easterly winds with passage within 60 ni mi to the east. The threat would be reduced as the center approached the latitude of the harbor because the island would provide protection from winds coming from north of east.

4.1 EVASION AT SEA

If the 24 hr forecast for a tropical cyclone approaching from the southwest sector is for hurricane strength at passage within 60 n mi to the north or 180 n mi to the south, sortie and evasion at sea are recommended. The timing of the final decision to sortie can be delayed to a minimum, 24-36 hr, because of the unencumbered open sea surrounding the islands. If the forecast track is to the north of Ponta Delgada, the suggested evasion route is to the southeast; for forecast passage over or to the south of the island, evasion to the northwest is suggested.

For similar forecast *intensity, but approach from the south*, evasion should be to the east if passage is forecast to be 60-180 n mi to the west. Suggested evasion is to the west if passage is forecast to be within 60 n mi (east or west) of Ponta Delgada.

The tendency for tropical cyclones to loop or bend back in the Azores area warrants special consideration. Regardless of the evasion action, the movements of storm centers should be closely monitored until they are well clear of the area.

4.2 REMAINING IN PONTA DELGADA

Remaining in the Ponta Delgada harbor is a reasonable option for all situations except those previously addressed in Para. 4.1. If the decision is to remain, the vessel should be moved to the innermost available part of the harbor. Appropriate ballasting and additional lines and wires should be used in mooring.

5. ADVICE TO SMALL CRAFT

No streams or protected small bays are available, so the only safe option is to remove small craft from the water.

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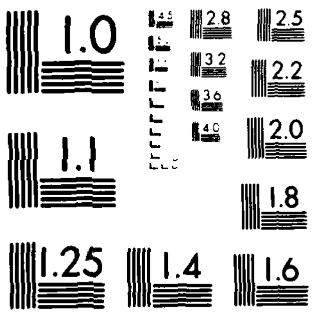

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