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This handbook for the port of Villefranche, one in a series of severe weather guides for Mediterranean ports, provides decision-making guidance for ship captains whose vessels are threatened by actual or forecast strong winds, high seas, restricted visibility or thunderstorms in the port vicinity. Causes and effects of such hazardous conditions are discussed. Precautionary or evasive actions are suggested for various vessel situations. The handbook is organized in four sections for ready reference: general guidance on handbook content and use; a quick-look captain's summary; a more detailed review of general information on environmental conditions; and an appendix that provides oceanographic information.

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SEVERE WEATHER GUIDE MEDITERRANEAN PORTS

9. VILLEFRANCHE

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CONTENTS

Foreword iii
Preface v
Record of Changes vii

1. General Guidance 1-1
 1.1 Design 1-1
  1.1.1 Objectives 1-1
  1.1.2 Approach 1-1
  1.1.3 Organization 1-2
 1.2 Contents of Specific Harbor Studies 1-3

2. **Captain's Summary** **2-1**

3. General Information 3-1
 3.1 Geographic Location 3-1
 3.2 Qualitative Evaluation of Harbor as a Haven . . . 3-5
 3.3 Currents and Tides 3-6
 3.4 Visibility 3-6
 3.5 Hazardous Conditions 3-6
 3.6 Harbor Protection 3-10
  3.6.1 Winds and Weather 3-11
  3.6.2 Waves 3-11
  3.6.3 Wave Data Uses and Considerations 3-18
 3.7 Protective/Mitigating Measures 3-19
  3.7.1 Sortie/Move to a New Anchorage. 3-19
  3.7.2 Scheduling 3-19
 3.8 Local Indicators of Hazardous Weather Conditions 3-20
  3.8.1 Mistral 3-20
  3.8.2 Non - Mistral 3-22
 3.9 Significant Historical Environmental Events. . . 3-23
 3.10 Summary of Problems, Actions, and Indicators . . 3-23

References 3-30

Appendix A -- General Purpose Oceanographic Information . A-1

FOREWORD

This handbook on Mediterranean Ports was developed as part of an ongoing effort at the Naval Environmental Prediction Research Facility to create products for direct application to Fleet operations. The research was conducted in response to Commander Naval Oceanography Command (CNOC) requirements validated by the Chief of Naval Operations (CNO).

As mentioned in the preface, the Mediterranean region is unique in that several areas exist where local winds can cause dangerous operating conditions. This handbook will provide the ship's captain with assistance in making decisions regarding the disposition of his ship when heavy winds and seas are encountered or forecast at various port locations.

Readers are urged to submit comments, suggestions for changes, deletions and/or additions to NOCC, Rota with a copy to the oceanographer, COMSIXTHFLT. They will then be passed on to the Naval Environmental Prediction Research Facility for review and incorporation as appropriate. This document will be a dynamic one, changing and improving as more and better information is obtained.

M. G. SALINAS
Commander, U.S. Navy

PORT INDEX

The following is a tentative prioritized list of Mediterranean Ports to be evaluated during the five-year period 1988-92, with ports grouped by expected year of the port study's publication. This list is subject to change as dictated by circumstances and periodic review.

1988 NO.	PORT
1	GAETA, ITALY
2	NAPLES, ITALY
3	CATANIA, ITALY
4	AUGUSTA BAY, ITALY
5	CAGLIARI, ITALY
6	LA MADDALENA, ITALY
7	MARSEILLE, FRANCE
8	TOULON, FRANCE
9	VILLEFRANCHE, FRANCE
10	MALAGA, SPAIN
11	NICE, FRANCE
12	CANNES, FRANCE
13	MONACO
14	ASHDOD, ISRAEL
15	HAIFA, ISRAEL
	BARCELONA, SPAIN
	PALMA, SPAIN
	IBIZA, SPAIN
	POLLENSA BAY, SPAIN
	VALENCIA, SPAIN
	CARTAGENA, SPAIN
	GENOA, ITALY
	LIVORNO, ITALY
	SAN REMO, ITALY
	LA SPEZIA, ITALY
	VENICE, ITALY
	TRIESTE, ITALY

1989	PORT
	SPLIT, YUGOSLAVIA
	DUBROVNIK, YUGOSLAVIA
	TARANTO, ITALY
	PALERMO, ITALY
	MESSINA, ITALY
	TAORMINA, ITALY
	PORTO TORRES, ITALY

1990	PORT
	BENIDORM, SPAIN
	ROTA, SPAIN
	TANGIER, MOROCCO
	PORT SAID, EGYPT
	ALEXANDRIA, EGYPT
	ALGIERS, ALGERIA
	TUNIS, TUNISIA
	GULF HAMMAMET, TUNISIA
	GULF OF GABES, TUNISIA
	SOUDA BAY, CRETE

1991	PORT
	PIRAEUS, GREECE
	KALAMATA, GREECE
	THESSALONIKI, GREECE
	CORFU, GREECE
	KITHIRA, GREECE
	VALETTA, MALTA
	LARNACA, CYPRUS

1992	PORT
	ANTALYA, TURKEY
	ISKENDERUN, TURKEY
	IZMIR, TURKEY
	ISTANBUL, TURKEY
	GOLCUK, TURKEY
	GULF OF SOLLUM

PREFACE

Environmental phenomena such as strong winds, high waves, restrictions to visibility and thunderstorms can be hazardous to critical Fleet operations. The cause and effect of several of these phenomena are unique to the Mediterranean region and some prior knowledge of their characteristics would be helpful to ship's captains. The intent of this publication is to provide guidance to the captains for assistance in decision making.

The Mediterranean Sea region is an area where complicated topographical features influence weather patterns. Katabatic winds will flow through restricted mountain gaps or valleys and, as a result of the venturi effect, strengthen to storm intensity in a short period of time. As these winds exit and flow over port regions and coastal areas, anchored ships with large 'sail areas' may be blown aground. Also, hazardous sea state conditions are created, posing a danger for small boats ferrying personnel to and from port. At the same time, adjacent areas may be relatively calm. A glance at current weather charts may not always reveal the causes for these local effects which vary drastically from point to point.

Because of the irregular coast line and numerous islands in the Mediterranean, swell can be refracted around such barriers and come from directions which vary greatly with the wind. Anchored ships may experience winds and seas from one direction and swell from a different direction. These conditions can be extremely hazardous for tendered vessels. Moderate to heavy swell may also propagate outward in advance of a storm resulting in uncomfortable and sometimes dangerous conditions, especially during tending, refueling and boating operations.

This handbook addresses the various weather conditions, their local cause and effect and suggests some evasive action to be taken if necessary. Most of the major ports in the Mediterranean will be covered in the handbook. A priority list, established by the Sixth Fleet, exists for the port studies conducted and this list will be followed as closely as possible in terms of scheduling publications.

RECORD OF CHANGES

CHANGE NUMBER	DATE OF CHANGE	DATE ENTERED	PAGE NUMBER	ENTERED BY

1. GENERAL GUIDANCE

1.1 DESIGN

This handbook is designed to provide ship captains with a ready reference on hazardous weather and wave conditions in selected Mediterranean harbors. Section 2, the captain's summary, is an abbreviated version of section 3, the general information section intended for staff planners and meteorologists. Once section 3 has been read, it is not necessary to read section 2.

1.1.1 Objectives

The basic objective is to provide ship captains with a concise reference of hazards to ship activities that are caused by environmental conditions in various Mediterranean harbors, and to offer suggestions for precautionary and/or evasive actions. A secondary objective is to provide adequate background information on such hazards so that operational forecasters, or other interested parties, can quickly gain the local knowledge that is necessary to ensure high quality forecasts.

1.1.2 Approach

Information on harbor conditions and hazards was accumulated in the following manner:

A. A literature search for reference material was performed.

B. Cruise reports were reviewed.

C. Navy personnel with current or previous area experience were interviewed.

D. A preliminary report was developed which included questions on various local conditions in specific harbors.

E. Port/harbor visits were made by NEPRF personnel; considerable information was obtained through interviews with local pilots, tug masters, etc; and local reference material was obtained (See section 3 references).

F. The cumulative information was reviewed, combined, and condensed for harbor studies.

1.1.3 Organization

The Handbook contains two sections for each harbor. The first section summarizes harbor conditions and is intended for use as a quick reference by ship captains, navigators, inport/at sea OOD's, and other interested personnel. This section contains:

A. a brief narrative summary of environmental hazards,

B. a table display of vessel location/situation, potential environmental hazard, effect-precautionary/evasion actions, and advance indicators of potential environmental hazards,

C. local wind wave conditions, and

D. tables depicting the wave conditions resulting from propagation of deep water swell into the harbor.

The swell propagation information includes percent occurrence, average duration, and the period of maximum wave energy within height ranges of greater than 3.3 feet and greater than 6.6 feet. The details on the generation of sea and swell information are provided in Appendix A.

The second section contains additional details and background information on seasonal hazardous conditions. This section is directed to personnel who have a need for additional insights on environmental hazards and related weather events.

1.2. CONTENTS OF SPECIFIC HARBOR STUDIES

This handbook specifically addresses potential wind and wave related hazards to ships operating in various Mediterranean ports utilized by the U.S. Navy. It does not contain general purpose climatology and/or comprehensive forecast rules for weather conditions of a more benign nature.

The contents are intended for use in both pre-visit planning and in situ problem solving by either mariners or environmentalists. Potential hazards related to both weather and waves are addressed. The oceanographic information includes some rather unique information relating to deep water swell propagating into harbor shallow water areas.

Emphasis is placed on the hazards related to wind, wind waves, and the propagation of deep water swell into the harbor areas. Various vessel locations/situations are considered, including moored, nesting, anchored, arriving/departing, and small boat operations. The potential problems and suggested pre-cautionary/evasive actions for various combinations of environmental threats and vessel location/situation are provided. Local indicators of environmental hazards and possible evasion techniques are summarized for various scenarios.

CAUTIONARY NOTE: In September 1985 Hurricane Gloria raked the Norfolk, VA area while several US Navy ships were anchored on the muddy bottom of Chesapeake Bay. One important fact was revealed during this incident: Most all ships frigate size and larger dragged anchor, some more than others, in winds of over 50 knots. As winds and waves increased, ships 'fell into' the wave troughs, BROADSIDE TO THE WIND and become difficult or impossible to control.

This was a rare instance in which several ships of recent design were exposed to the same storm and much effort was put into the documentation of lessons learned. Chief among these was the suggestion to evade at sea rather than remain anchored at port whenever winds of such intensity were forecast.

2. CAPTAIN'S SUMMARY

The Port of Villefranche is located on the French Riviera at 43°42'N 07°19'E on the northwest shore of the Ligurian Sea (Figure 2-1).

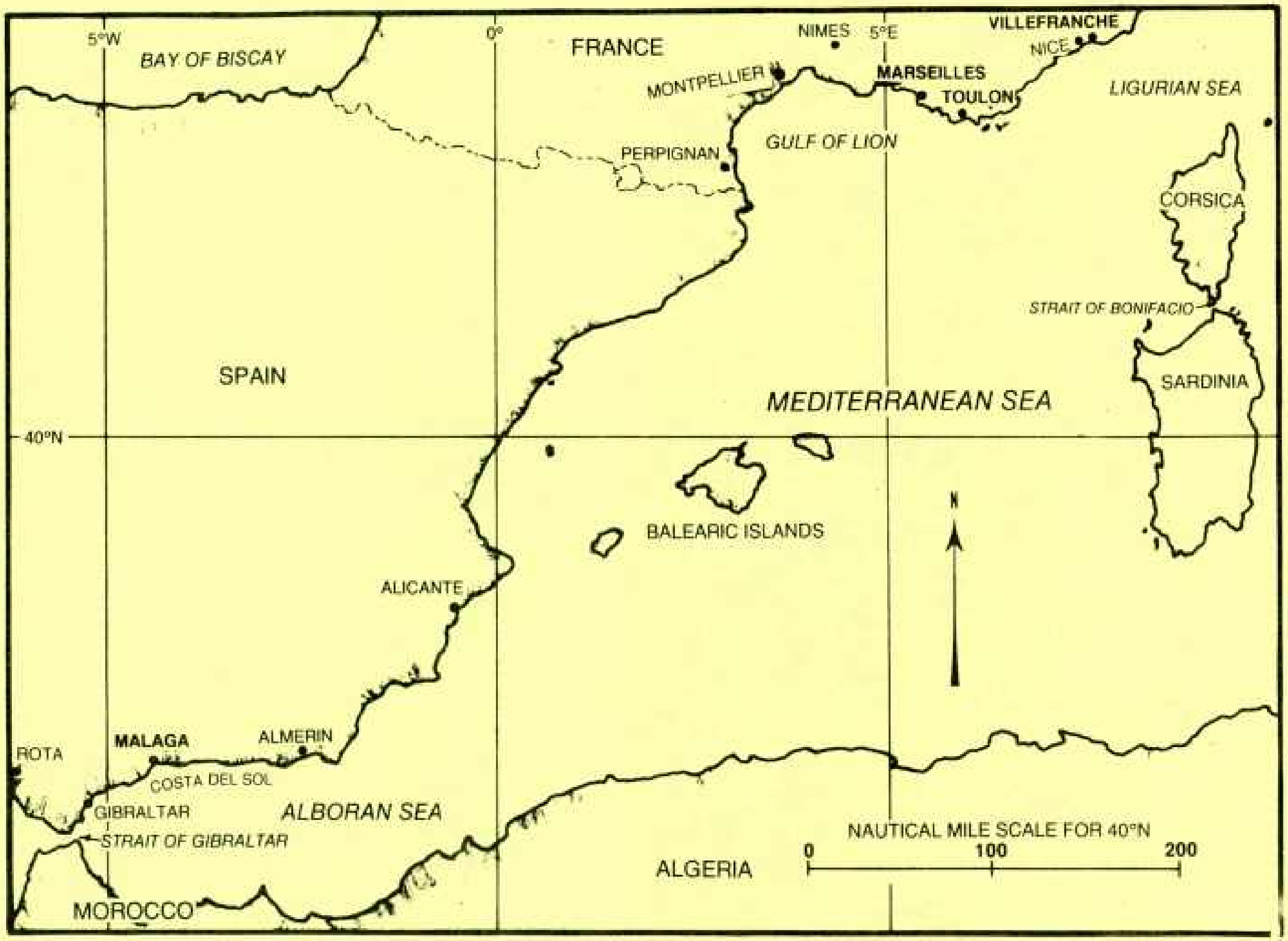

Figure 2-1. Western Mediterranean Sea.

The Port of Villefranche is about 70 n mi northeast of Toulon and 11 n mi west of the border between France and Italy (Figure 2-2). The coastline in this area is oriented southwest-northeast, with the terrain providing a natural barrier to strong westerly winds.

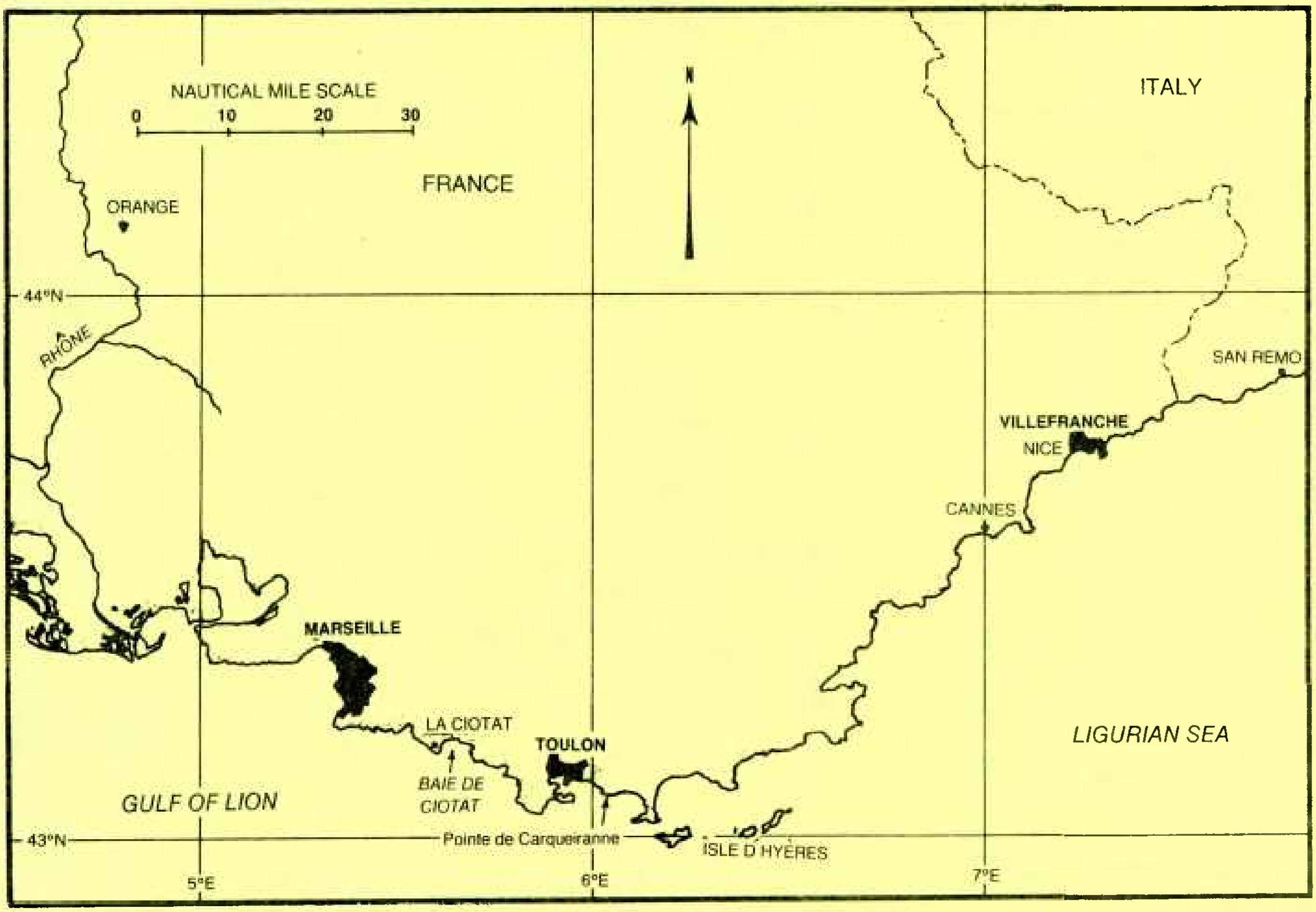

Figure 2-2. Ports of Marseille, Toulon, Villefranche.

The Port of Villefranche is comprised of two small harbors and a roadstead (Figure 2-3). The relatively small roadstead is well protected from winds and waves from most directions. Meteorologists with considerable experience in the Mediterranean consider the harbor at Villefranche to be one of the safest in the Mediterranean (Shaver, D.W., undated). According to local personnel, even with a strong Mistral (Marseille experiencing gale force or higher winds) it is tranquil in the protected area of Villefranche.

Except for a small gap in the hills east of the roadstead, the Port of Villefranche is bounded on three sides--west, north, and east--by steeply rising terrain. The roadstead is open to the south between Pointe des Sans-Culottes on the west and Pointe Malalongue on the tip of Cap Ferrat. That portion of the roadstead south of Pointe des Sans-Culottes is exposed and vulnerable to westerly winds and waves, usually of Mistral origin. The entire roadstead is exposed to southerly winds and waves, but such conditions are infrequent, and have minimal impact on vessels in the roadstead.

The gap in the hills on Cap Ferrat allows bothersome easterly winds to reach the roadstead. Moored/anchored vessels will swing into the wind, but are otherwise only minimally affected. The winds occasionally create a chop that may cause cancellation of boat runs to/from the Fleet Landing.

Except for the Fleet Landing established at Villefranche Port Nord, the protected inner harbors at the Port are not used by the U.S. Navy. Under good weather conditions, there is room in Rade de Villefranche to accommodate two medium sized combatants, with one normally moored to the seaward buoy and the other anchored. Small ships occasionally use the middle buoy, but because of shallow depths the northernmost buoy is not used by U.S. Navy ships. Due to the small size of the harbor and the close proximity to rocks (only 470 yd (430 m) away), the harbor is considered safe for only one vessel moored to the seaward buoy during strong and gusty wind conditions.

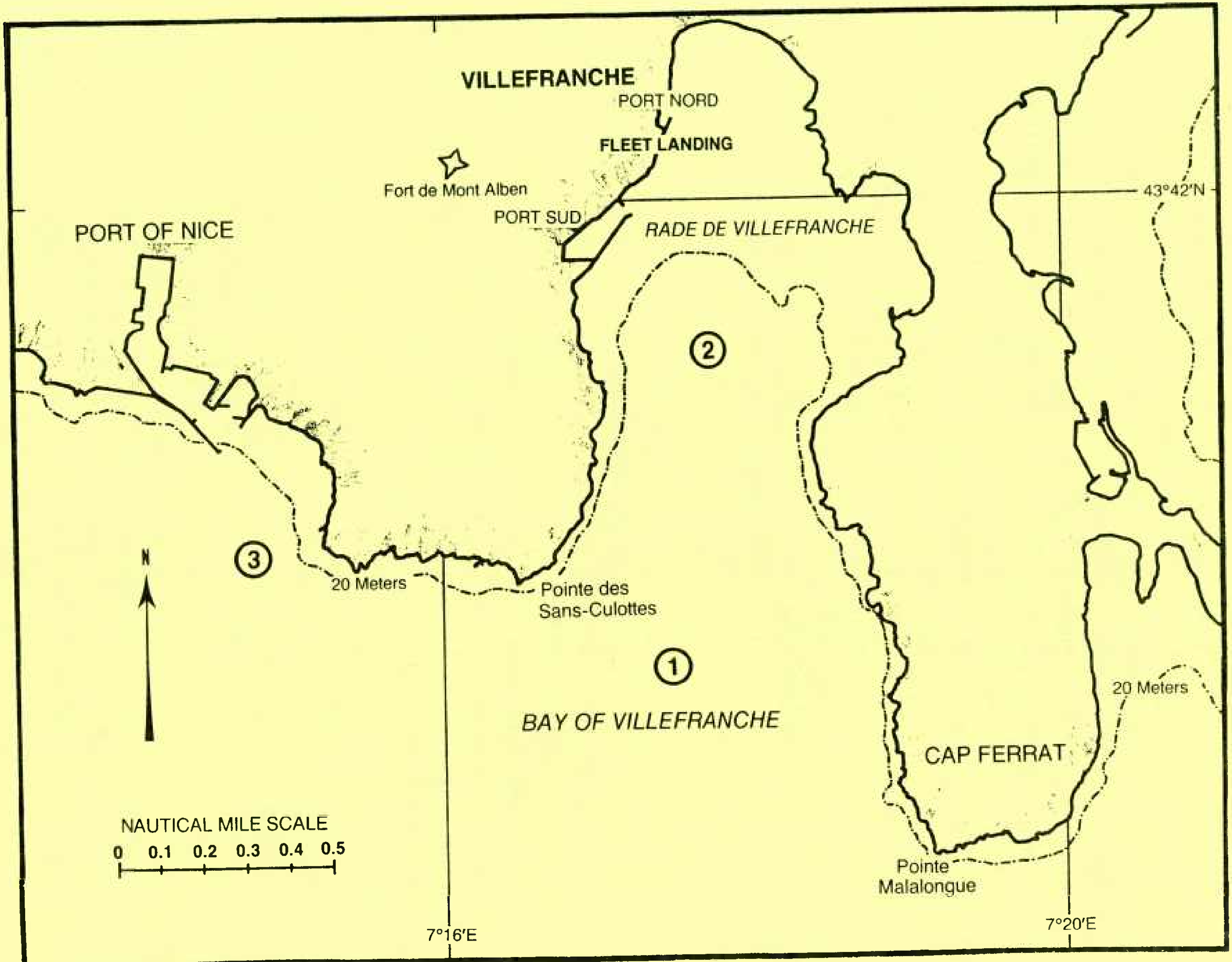

Figure 2-3. Port of Villefranche.

The harbors can only accommodate small craft, so U.S. Navy ships normally use the southernmost of three mooring buoys or anchor in the roadstead. The relatively small confines of the roadstead limits its use to two medium-sized combatants at any one time, with one usually on the mooring buoy and the other anchored. The middle buoy is sometimes used by smaller U.S. Navy ships. In the infrequent circumstance when Villefranche is subject to strong and gusty winds, lack of swinging room and close proximity to rocks precludes having more than one vessel in the roadstead. Due to their size and draft, aircraft carriers anchor farther south, about 1 n mi south of Villefranche Port Nord. The fleet anchorage is exposed to Mistral conditions and experiences winds to 280°/40 kt with 6-7 ft (2 m) swell. The bottom of the anchorage is soft mud covered with weed of unspecified holding quality.

Currents in the roadstead are negligible. Tides are insignificant, with a range of less than 4 inches (10 cm). In the neighboring Port of Nice, however, the water level may vary from 1 to 2 ft (0.3 to 0.6 m), with a rise of 3 ft (0.9 m) observed with strong easterly winds.

Specific hazardous conditions, vessel situations, and suggested precautionary/evasion action scenarios are summarized in Table 2-1.

Table 2-1. Summary of hazardous environmental conditions for the Port of Villefranche, France.

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
1. E'ly wind - Flows through small gap in hills east of the roadstead. * Most common in late autumn, winter, and early spring.	Advance warning. * Strong or strengthening high pressure cell over central Europe with low pressure S or SW of Villefranche.	(1) Moored to buoy/anchored in roadstead adjacent to mooring buoys.	(a) Moored/anchored vessels tend to wind cock. * Strong event may necessitate permitting only 1 vessel in the roadstead. Excess vessels should consider moving to Marseille, Toulon, or other more protected anchorage.
		(2) Arriving/departing.	(a) Inbound units should be aware of wind effect in roadstead. * If one vessel is already in roadstead, wind may preclude inbound vessel from mooring/anchoring nearby until conditions subside. (b) Outbound units will encounter heavier weather when out of the lee of Cap Ferrat. (c) Be aware of wind chill factor.
		(3) Small boats.	(a) Wind raises a chop in the roadstead. * Boating may be restricted/cancelled until conditions subside. (b) Be aware of wind chill factor.
2. W'ly wind - May precede Mistral onset farther west. * Most common in winter and early spring. * May bring winds of 35+ kt to Villefranche roadstead.	Advance warning. * A well developed low pressure center that moves SE into the Gulf of Genoa from central France is the primary cause of strong W to NW winds at Villefranche. * May occur coincident with Mistral onset farther west. Duration. * May last 1 to 6 hours but most commonly lasts 1 to 2 hours.	(1) Moored to buoy/anchored in roadstead adjacent to mooring buoys.	(a) Moored/anchored vessels tend to wind cock. * Strong event may necessitate permitting only 1 vessel in the roadstead. * Be aware of wind chill factor.
		(2) Anchored at fleet anchorage.	(a) Anchorage is exposed to westerly winds and waves. * Waves to 6 ft (2 m) may reach anchorage but cause no great problem to anchored vessels. * Be aware of wind chill factor.
		(3) Arriving/departing.	(a) Inbound units should be aware of wind effect in roadstead. * If one vessel is already in the roadstead adjacent to the mooring buoys, the wind may preclude inbound vessels from mooring/anchoring nearby until conditions subside. * Outbound units will encounter heavier weather when passing south of Pointe des Sans-Culottes. * Be aware of wind chill factor.
		(4) Small boats.	(a) Waters south of Pointe des Sans Culottes are exposed to westerly winds and waves. * Boat runs to/from the fleet anchorage can become hazardous and may be cancelled until conditions abate. * Be aware of wind chill factor.
3. S to SW'ly wind/swell - Infrequent event at Villefranche. * Swell to 10 ft (3 m) may cause anchored/moored vessels in the roadstead to roll, but does not cause great difficulty. * Wind alone is not a problem. * When occurring, most frequent in autumn, winter, and early spring.	Advance warning. * The early stages of cyclogenesis S of the Alps commonly result in SW'ly 30-40 kt winds in the region between the S French coast and Corsica * E'ly moving depression moving into Ligurian Sea or across Corsica into Italy. Duration. * Swell may persist for 2 to 3 days.	(1) Moored to buoy/anchored in roadstead adjacent to mooring buoys.	(a) Moored/anchored vessels tend to wind cock. * Strong wind (unusual) may necessitate permitting only 1 vessel in the roadstead. * Waves to 10 ft (3 m) may cause vessels in the roadstead to roll but pose no significant problems. * Protected anchorage can be found just north of Ile Ste. Marguerite near Cannes.
		(2) Anchored at fleet anchorage.	(a) Waves to 10 ft (3 m) may cause vessels to roll if wind is not from same direction. * Unless wind is unusually strong, no significant problems should result.
		(3) Arriving/departing.	(a) Inbound units should be aware of wind effect in the roadstead adjacent to mooring buoys. * An unusually strong event may necessitate permitting only 1 vessel in the roadstead.
		(4) Small boats.	(a) Waves to 6 ft (2 m) will impact boating to/from the roadstead, but are infrequent.
4. Mistral wind - Strong N to NW'ly wind. * Strongest and most common in late winter and early spring but may occur anytime. * Impact on surface normally limited to waters south of Pointe des Sans-Culottes. * May be accompanied by waves to 6 ft (2 m). * Wind shear may develop in lower levels of the atmosphere over Nice/Villefranche.	Advance warning. * Mistral will start west of Villefranche when the following pressure differences are achieved--highest pressure to west: * Perpignan - Marignane (Marseille), 3 mb. * Marignane (Marseille) - Nice, 3 mb. * Perpignan - Nice, 6 mb. * Conditions favorable for Genoa low formation are conducive for the start of a Mistral at Marseille. * For a Mistral to affect the Villefranche/Nice area, it will first be observed at Marseille/Toulon. * Mistral will spread east to Villefranche area if a 10 mb pressure difference exists between Toulon and Nice. With only 2 mb the Mistral will stop near Toulon.	(1) Anchored at fleet anchorage.	(a) Waters south of Pointe des Sans-Culottes are exposed to westerly winds and waves. * Waves to 6 ft (2 m) may reach anchorage but cause no significant problems. * Be aware of wind chill factor. * Protected anchorage can be found east of Pointe de la Croisette near Cannes.
		(2) Arriving/departing.	(a) Heavier weather will be encountered south of Pointe des Sans-Culottes. * Conditions in the roadstead adjacent to the mooring buoys may not reflect any evidence that Mistral conditions are occurring along the coast.
		(3) Small boats	(a) Small boat runs to the fleet anchorage can become hazardous and may be cancelled until conditions abate.
		(4) Flight operations.	(a) Strong winds in the lower levels of the atmosphere may create a wind shear that may make flying or landing conditions dangerous.

For estimating shallow water wave heights, three anchorage areas have been selected for Villefranche (Figure 2-3). Point 1 is the fleet anchorage area for vessels with drafts over 30 ft, Point 2 is for the seaward buoy, and Point 3 is along the route of the Nice liberty boat runs.

Table 2-2 provides the height ratio and direction of shallow water waves to expect at points 1, 2 and 3 when the deep water wave conditions are known.

The Villefranche Point 1 conditions are found by entering Table 2-2 with the forecast or known deep water wave direction and period. In the following example, the height is determined by multiplying the deep water height (8 ft) by the ratio of shallow to deep height (.9).

Example: Use of Table 2-2 for Villefranche Point 1 (Fleet Anchorage).
Deep water wave forecast as provided by a forecast center or a reported/observed deep water wave condition: 8 feet, 12 seconds, from 150°. The expected wave condition at Villefranche Point 1, as determined from Table 2-2: 7 feet, 12 seconds, from 150°.

NOTE: Wave periods are a conservative property and remain constant when waves move from deep to shallow water, but speed, height, and steepness change.

Table 2-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 2-3 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

VILLEFRANCHE POINT 1 (Fleet Anchorage) 504 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	125°	130°	130°	135°	140°	150°
	.3	.2	.2	.2	.2	.2
120°	125°	130°	135°	140°	155°	170°
	.5	.4	.2	.2	.3	.2
150°	150°	150°	150°	150°	155°	160°
	1.0	1.0	1.0	.9	.8	.7
180°	180°	180°	180°	180°	180°	180°
	1.0	1.0	1.0	1.0	1.0	.9
210°	210°	210°	210°	210°	210°	210°
	1.0	1.0	1.0	1.0	1.0	1.0
240°	240°	240°	240°	240°	240°	240°
	1.0	1.0	1.0	1.0	1.0	1.0

VILLEFRANCHE POINT 2 (Seaward Buoy) 150 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
150°	160°	160°	160°	170°	170°	170°
	.2	.2	.2	.2	.2	.2
180°	180°	180°	185°	200°	165°	175°
	.8	.6	.5	.4	.5	.4
210°	210°	205°	195°	170°	155°	175°
	.7	.4	.3	.2	.3	.4

Table 2-2 cont.

VILLEFRANCHE POINT 3 (Nice Liberty Boat Run)

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
120°	130° .7	145° .6	155° .4	125° .6	140° .3	155° .3
150°	150° 1.0	150° .9	150° .9	155° .8	155° .7	160° .7
180°	180° 1.0	180° .9	180° .9	180° .8	185° .8	185° .8
210°	210° 1.0	210° .9	210° .9	210° .9	210° .9	210° .9
240°	240° 1.0	240° .9	240° .9	240° .9	240° .9	240° .9
270°	270° .4	270° .4	270° .4	270° .4	260° .4	265° .4

The local wind generated wave conditions for the anchorage area identified as points 1 and 3 are given in Table 2-3. All heights refer to the significant wave height (average of the highest 1/3 waves). Enter the local wind speed and direction in this table to obtain the minimum duration in hours required to develop the indicated fetch limited sea height and period. The time to reach fetch limited height is based on an initial flat ocean. When starting from a pre-existing wave height, the time to fetch limited height will be shorter.

Table 2-3. Gulf of Villefranche. Local wind waves for fetch limited conditions at points 1 and 3 (based on JONSWAP model). Point 2 has negligible fetch.

Point 1.

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi)	Local Wind Speed (kt) 18	24	30	36	42
W 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
WSW 5 n mi	<2 ft	2/3-4 1	2-3/3-4 1	3/3-4 1	3-4/3-4 1

Point 3.

Direction and Fetch Length (n mi)	Local Wind Speed (kt) 18	24	30	36	42
WSW 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
W 2 n mi	<2 ft	<2 ft	<2 ft	<2 ft	2-3/2-3 1

Example:

To the west-southwest (240°) of Point 1 there is about a 5 n mi fetch (Figure 2-2). Given a west-southwest wind at 24 kt, the sea will have reached 2 feet with a period of 3-4 seconds after 1 hour. Wind waves will not grow beyond this condition unless the wind speed increases or the direction changes to one over a longer fetch length. If the wind waves are superimposed on deep water swell, the combined height may change in response to changing swell conditions. Wind wave directions are assumed to be the same as the wind direction.

Climatological factors of shallow water waves, as described by percent occurrence, average duration, and period of maximum energy (period at which the most energy is focused for a given height), are given in Table 2-4. See Appendix A for discussion of wave spectrum and energy distribution. These data are provided by season for two ranges of heights: greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m).

Table 2-4. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

VILLEFRANCHE POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	20	18	19	17
Average Duration (hr)	12	11	11	12
Period Max Energy (sec)	9	9	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	1	1	2
Average Duration (hr)	9	7	7	8
Period Max Energy (sec)	10	10	10	10
VILLEFRANCHE POINT 2:	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	0	<< 1	1
Average Duration (hr)	9	NA	6	8
Period Max Energy (sec)	9	NA	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	0	0	0	0
Average Duration (hr)	NA	NA	NA	NA
Period Max Energy (sec)	NA	NA	NA	NA
VILLEFRANCHE POINT 3:	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	21	17	19	17
Average Duration (hr)	12	10	10	12
Period Max Energy (sec)	9	9	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	1	1	2
Average Duration (hr)	9	8	7	7
Period Max Energy (sec)	10	10	10	10

SEASONAL SUMMARY OF HAZARDOUS WEATHER CONDITIONS

The hilly terrain around the Villefranche port protects it from most of the strong Mistral winds but it is exposed to easterly winds and to infrequent southerly winds.

WINTER (November thru February):

* Mistrals are most common in late winter and early spring but do not impact operations in port. On occasion, strong Mistral winds will occur aloft, creating hazardous shear for aircraft operations.
* A gap in the hills east of the port allows easterly winds to reach the roadstead and create a chop which under worst conditions can cause cancellation of boating operations.

SPRING (March thru May):

* Mistrals still affect the roadstead until late in the season but are less intense and less frequent.
* Easterly and southerly winds occur for short periods early in the season.

SUMMER (June thru September):

* Relatively uneventful.

AUTUMN (October):

* Short transition season as winter weather returns by month's end.

NOTE: For more detailed information on hazardous weather conditions see previous Summary Table in this section and Hazardous Weather Summary in Section 3.

REFERENCES

Shaver, D. W., Undated: Comments on Weather in the Mediterranean. Unpublished manuscript. Naval Environmental Prediction Research Facility, Monterey, CA 93941.

3. GENERAL INFORMATION

This section is intended for Fleet meteorologists/oceanographers and staff planners. Paragraph 3.5 provides a general discussion of hazards and Table 3-5 provides a summary of vessel locations/situations, potential hazards, effects-precautionary/evasive actions, and advance indicators and other information about the potential hazards by season.

3.1 Geographic Location

The Port of Villefranche is located on the French Riviera at 43°42'N 07°19'E on the northwest shore of the Ligurian Sea (Figure 3-1).

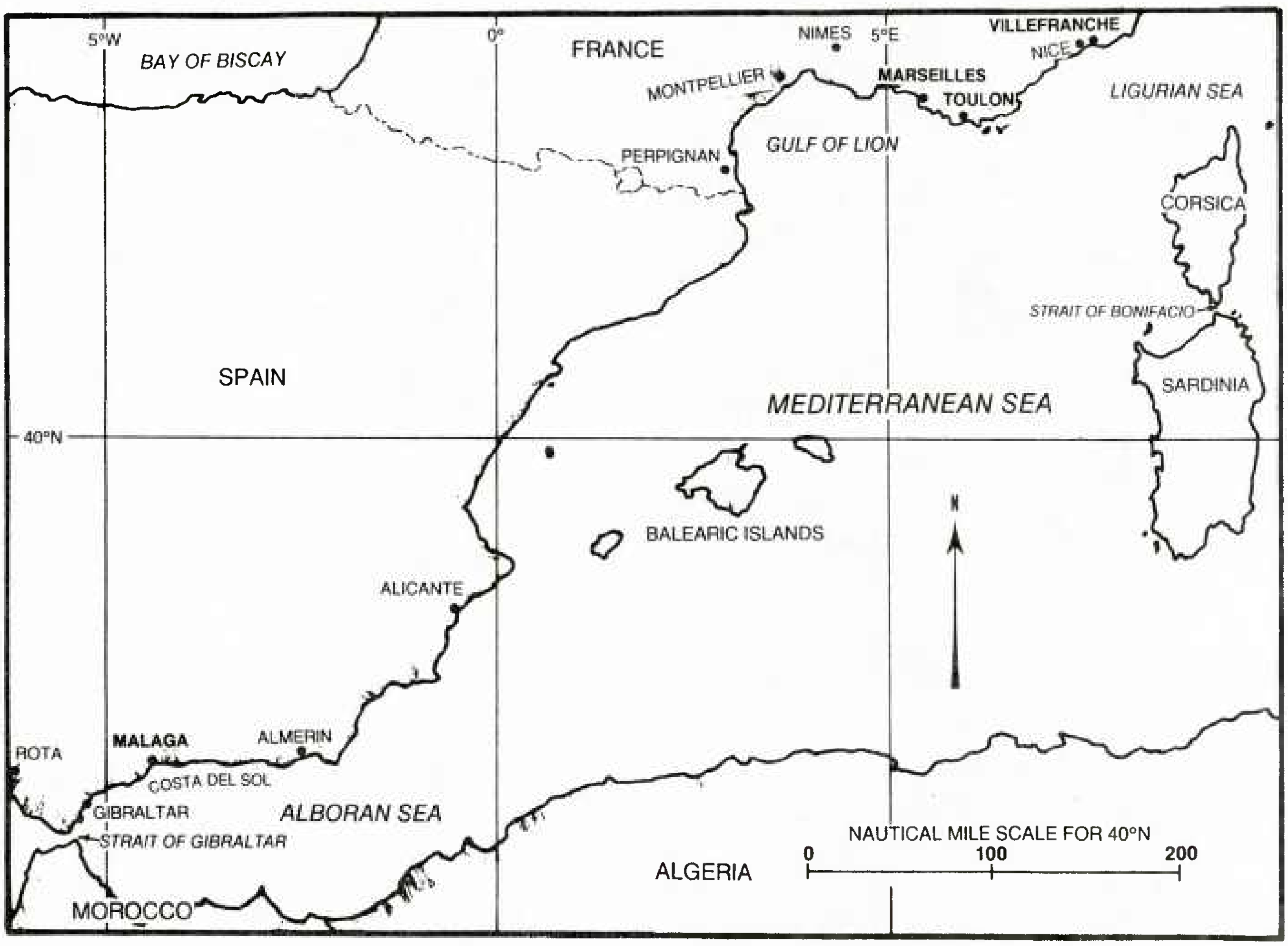

Figure 3-1. Western Mediterranean Sea.

The port of Villefranche is about 70 n mi northeast of Toulon and 11 n mi west of the border between France and Italy (Figure 3-2). The coastline in this area is oriented southwest-northeast with the terrain providing a natural barrier to strong westerly winds.

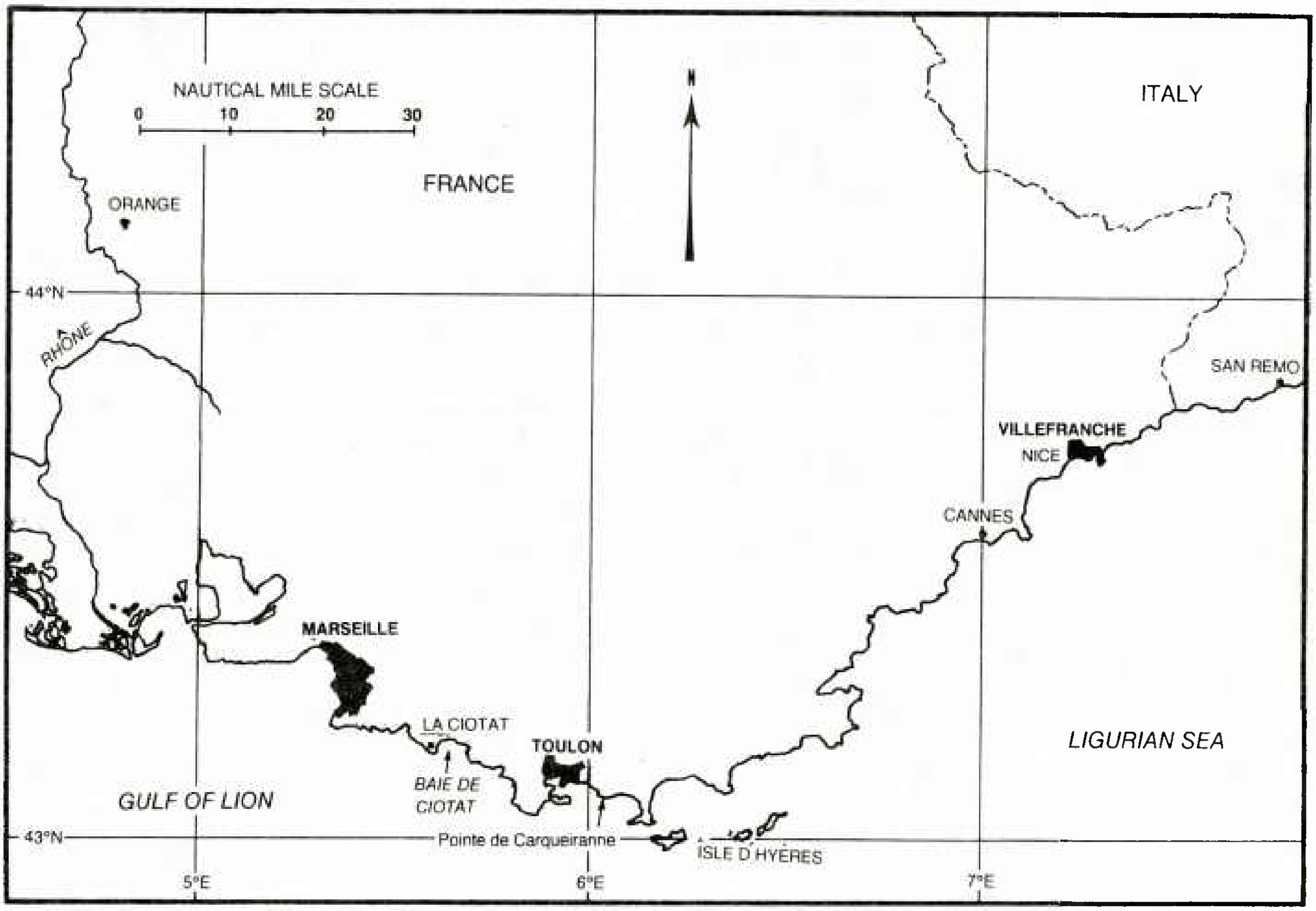

Figure 3-2. Ports of Marseille, Toulon, Villefranche.

Rade de Villefranche (the Roadstead of Villefranche) is situated at the head of the Bay of Villefranche, and extends about 1 1/2 n mi northward from its entrance between Pointe des Sans-Culottes on the west and Pointe Malalongue (Figure 3-3). Entering from the south, the Rade forms a natural amphitheater with high hills to the west, mountains to the north, and the hills of Cap Ferrat to the east. The neighboring port of Nice, France is situated less than 1 n mi west of Pointe des Sans-Culottes. The same Port Captain runs the Ports of Villefranche and Nice.

The Port is comprised of two small harbors, three mooring buoys located in the roadstead, and an anchorage. The southernmost of the harbors (Villefranche Port Sud) is located on the west side of Rade de Villefranche about 4/5 n mi north of Pointe des Sans-Culottes. It is suitable for small vessels with lengths of 197 ft (60 m) or less, and drawing no more than 13 ft (4 m). The second harbor (Villefranche Port Nord or Darse de la Santé) is situated about 500 yd (457 m) north of the first, and with depths of only 2.5 to 3.5 ft (0.9 to 1.1 m) is usable only by small boats (Hydrographer of the Navy, 1965). Because of the stringent limitations on vessel size, U.S. Navy ships do not use the inner harbors but use the two seaward mooring buoys or anchor farther south. A Fleet Landing is established at Villefranche Port Nord.

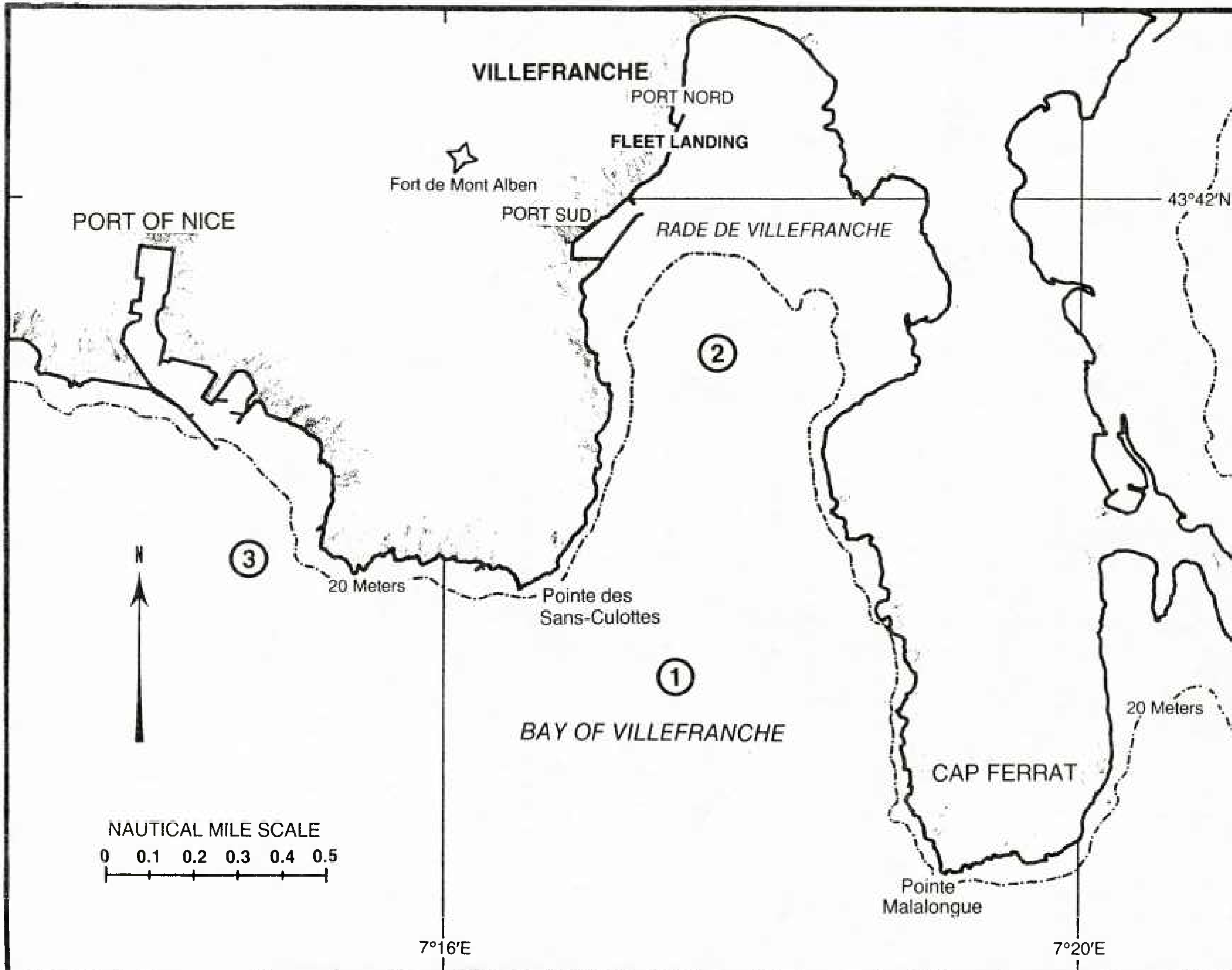

Figure 3-3. Port of Villefranche.

3.2 Qualitative Evaluation of Harbor as a Haven

Meteorologists with considerable experience in the Mediterranean consider the harbor at Villefranche to be one of the safest in the Mediterranean (Shaver, D.W., undated). According to local personnel, even with a strong Mistral (Marseille experiencing gale force or higher winds) it is tranquil in the protected area of Villefranche.

Except for the Fleet Landing established at Villefranche Port Nord, the protected inner harbors at the Port are not used by the U.S. Navy. Under good weather conditions, there is room in Rade de Villefranche to accommodate two medium sized combatants, with one normally moored to the seaward buoy and the other anchored. Small ships occasionally use the middle buoy, but because of shallow depths the northernmost buoy is not used by U.S. Navy ships. Due to the small size of the harbor and the close proximity to rocks (only 470 yd (430 m) away), the harbor is considered safe for only one vessel moored to the seaward buoy during strong and gusty wind conditions.

With two exceptions, the Port is sheltered from the effects of strong winds by the surrounding, steeply rising, hilly terrain. Rade de Villefranche is open to the south, with the result that infrequent southerly winds and waves can reach the Port area. Also, easterly winds can pass through a gap in the terrain east of the port and affect small boat operation to/from the moored/anchored vessels.

Large ships, such as aircraft carriers, must anchor farther south, about 1 n mi south-southeast of Villefranche Port Nord. Because of its more southerly location, the anchorage is more exposed and consequently more vulnerable to winds and waves with a westerly component than are the ships farther north in the roadstead. The bottom is soft mud covered with weed, of unspecified holding quality.

3.3 Currents and Tides

Currents at the Port of Villefranche are negligible. Tides are also insignificant, with a range of less than 4 inches (10 cm). In the neighboring harbor of Nice, the water level may vary from 1 to 2 ft (0.3 to 0.6 m). A rise of 3 ft (0.9 m) has been observed with strong easterly winds.

3.4 Visibility

Reduced visibility is not a significant problem at Villefranche. The poorest visibility tends to occur during spring and summer, but is seldom a problem due to the short distances involved in the Port area. A ship moored to one of the buoys is always visible from shore. Visibilities of less than 1/2 n mi are very infrequent, occurring about once each two years.

3.5 Hazardous Conditions

When compared to other ports along the north coast of the western Mediterranean Sea, the Port of Villefranche has limited exposure to hazardous wind and wave conditions. It is positioned near the eastern limit of the area affected by Mistral winds, and the surrounding hilly terrain protects the Port from most strong winds. The roadstead is exposed to infrequent southerly winds and waves, and experiences some difficulty from easterly winds which funnel through a gap in the hills east of the Port.

Although rare, storms having tropical cyclone characteristics with fully developed eyes have been observed on at least three occasions in the Mediterranean Basin: 23-26 September 1969, 22-28 January 1982, and 26-30 September 1983. On the latter occasion the storm moved northwest from the Gulf of Gabes (on the southeast coast of Tunisia), through the Straits of Sicily, along the east coast of Sardinia, and into the Gulf of Genoa. Winds of 100 kt were observed near the eye while Cagliari, Sardinia reported winds of 60 kt. While the probability of such a storm striking Villefranche is very slight, the meteorologist must be aware of the possibility.

A seasonal summary of various known environmental hazards that may be encountered in the Port of Villefranche follows.

A. Winter (November through February)

The winter season is a time of cool temperatures, frequent precipitation, and generally unsettled weather at Villefranche. The proximity of Villefranche to the Gulf of Genoa, one of the most active regions of cyclogenesis in the world, is a major factor in the winter weather regime of the Port.

Villefranche lies near the eastern limit of the area normally affected by Mistral winds. The southern portion of the Roadstead is exposed and vulnerable however, and occasionally experiences westerly (280°) Mistral winds to 40 kt accompanied by waves of about 6 ft (2 m). Maximum occurrence is in late winter/early spring. In those instances when Mistral winds reach as far eastward as the Nice/Villefranche area, they seldom are felt at the surface in the protected Port areas. But because the Mistral is blowing over the area above the surface friction level, a strong wind shear develops in the lower levels of the atmosphere and creates hazardous landing conditions at the Nice airport. In the rare circumstance when strong winds from the land are felt at the Port, they occur as west to northwesterly 35 gusting to 45 kt that can last up to 6 hours (most likely 1 to 2 hours) as low pressure centers from central France move southeastward into the Gulf of Genoa. This sequence of events normally results in the onset of a Mistral over the Gulf of Lion.

A gap in the hills east of the Port allows easterly winds to reach the central roadstead. The winds are usually not strong enough to create problems for the moored/anchored vessels other than causing them to wind cock, but can create a chop that may cause cancellation of boating. Easterly winds are caused by high pressure over central Europe and/or low pressure south or southwest of Villefranche.

Southerly winds and waves are rare. Usually caused by depressions moving into the Ligurian Sea or across Corsica into Italy, the swell is more of a problem than the wind. With directions varying from 160° clockwise to 220° depending on the particular situation, the swell arrives after the wind changes direction. This frequently results in a swell direction 45° to 90° perpendicular to the moored/anchored ships longitudinal axis, causing the vessels to roll (Shaver, undated). Swell wave height seldom exceeds 6 ft (2 m) but may be as high as 10 ft (3 m) and persist for 2 or 3 days. Boat runs to/from the anchorage and Fleet Landing experience little difficulty. It is more of a problem for boats anchored near the north shore of Rade de Villefranche, where the waves crest and break in the shallows.

Precipitation is common, with about 4.2 inches (107 mm) being the average accumulation during November, the wettest winter month. Amounts decrease to about 2.2 inches (57 mm) in January.

Temperatures are moderate during winter. January, the coldest month, has mean maximum and minimum temperatures of 55°F (13°C) and 39°F (4°C) respectively, based on 17 years of records for the adjacent airport at Nice. While the lowest recorded temperature for the same period is only 25°F (-4°C), wind chill (temperature combined with wind) can be very cold. Table 3-1 can be used to determine wind chill for various temperature and wind combinations.

Table 3-1. Wind Chill. The cooling power of the wind expressed as "Equivalent Chill Temperature" (adapted from Kotsch, 1983).

Wind Speed		Cooling Power of Wind expressed as "Equivalent Chill Temperature"								
Knots	MPH	Temperature (°F)								
Calm	Calm	40	35	30	25	20	15	10	5	0
		Equivalent Chill Temperature								
3-6	5	35	30	25	20	15	10	5	0	-5
7-10	10	30	20	15	10	5	0	-10	-15	-20
11-15	15	25	15	10	0	-5	-10	-20	-25	-30
16-19	20	20	10	5	0	-10	-15	-25	-30	-35
20-23	25	15	10	0	-5	-15	-20	-30	-35	-45
24-28	30	10	5	0	-10	-20	-25	-30	-40	-50
29-32	35	10	5	-5	-10	-20	-30	-35	-40	-50
33-36	40	10	0	-5	-15	-20	-30	-35	-45	-55

B. Spring (March through May)

Springtime weather at Villefranche is characterized by periods of stormy winter-type weather that alternates with false starts of more settled summer-type weather (Brody and Nestor, 1980). Mistral events still affect the roadstead until late in the season, but become less strong and more infrequent after March and are rare by the end of May.

Easterly winds and southerly winds/swell occur for short periods early in the season as extratropical storm systems transit the area, but occur with decreasing frequency after March. March is a wet month at Villefranche, with an average accumulation of 3.5 inches (90 mm). Precipitation amounts decrease through the remainder of the season. Thunderstorms occur occasionally during periods of rainy weather but are usually not severe.

Temperatures show considerable warming during the season. By May, the mean daily maximum temperature has increased to 70°F (21°C), with a corresponding minimum of 55°F (13°C). Wind chill is not normally a problem after March.

C. Summer (June through September)

The summer season is marked by warm temperatures and settled weather conditions at Villefranche. The extratropical storm track has moved north of the Mediterranean Basin, so extratropical cyclones and associated wind and weather are not common. Precipitation is at its yearly minimum, with an average of only 3/4 inch (19 mm) recorded during July. Prevailing wind directions are southeast shifting clockwise through southwest during early afternoon. Calm winds are common during early morning hours. Mean daily maximum temperatures are about 81°F (27°C) in July and August, with minimum temperatures averaging about 66°F (19°C) for the same months.

D. Autumn (October)

Autumn is a short, transitional season at Villefranche that usually lasts only for the month of October. It is characterized by an abrupt change to winter-type weather (Brody and Nestor, 1980).

October is the wettest month of the year at Villefranche (over 5.1 inches (130 mm) average amount) as the extratropical storm track returns to the northern Mediterranean Basin. Eastward-moving extratropical storms transiting the waters south of Villefranche once again bring strong, gusty winds, rain, and occasional thunderstorms to the area. Temperatures decrease from the warm readings of summer but wind chill is not usually a problem until winter.

3.6 Harbor Protection

The Port of Villefranche is generally well protected, but as detailed below, portions of the roadstead are exposed and vulnerable to some conditions.

3.6.1 Wind and Weather

The Port area north of Pointe des Sans-Culottes is bordered on three sides by steeply rising, hilly or mountainous terrain. The elevations of the surrounding countryside are sufficient to mitigate or block the effects of most winds, but a gap in the hills on the peninsula east of the mooring buoys allows easterly winds to reach the Port. The effect of the wind is usually limited to "wind-cocking" the ships moored to buoys or anchored.

Rade de Villefranche is open to the south, so southerly winds can readily reach the Port area. Fortunately, such conditions are not common and cause only minimal problems.

Due to the small size of the harbor and the close proximity (470 yd (430 m)) to rocks, the Port is considered safe for only one vessel moored to a buoy during the infrequent periods of strong and gusty wind conditions. Such situations are rare but have posed problems in the past.

That portion of Rade de Villefranche south of Pointe des Sans-Culottes, where aircraft carriers occasionally anchor, is exposed and vulnerable to westerly Mistral winds to 40 kt.

3.6.2 Waves

The Port is well protected from most open-ocean waves. Because Rade de Villefranche is open to the south, southerly swell as high as 10 ft (3 m) occasionally reaches the Port area, but is mainly a problem for small boats anchored near the north shore, where the water shallows and breakers form. According to Hydrographer of the Navy (1965), the southerly swell may cause anchored vessels to roll, but "it does not strain the cable." Small boat runs to/from the moored/anchored vessels and the Fleet Landing at Villefranche Port Nord experience little difficulty.

Swell waves to about 6 ft (2 m) may accompany Mistral winds at the fleet anchorage. These conditions coupled with winds to 40 kt are likely to cause boating to be cancelled.

Easterly winds flowing through the gap in the hills east of the Port can raise a chop sufficient to cause concern for boating to/from the buoy moored vessels.

Table 3-2 provides the shallow water wave conditions at the three designated points when deep water swell enters the harbor.

Example: Use of Table 3-2.

For a deep water wave condition of:

8 feet, 12 seconds, from 150°

The approximate shallow water wave conditions are:

Point 1:	7 feet, 12 seconds, from 150°
Point 2:	2 feet, 12 seconds, from 170°
Point 3:	6 feet, 12 seconds, from 155°

Table 3-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 3-3 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

VILLEFRANCHE POINT 1 (Fleet Anchorage) 504 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	125° .3	130° .2	130° .2	135° .2	140° .2	150° .2
120°	125° .5	130° .4	135° .2	140° .2	155° .3	170° .2
150°	150° 1.0	150° 1.0	150° 1.0	150° .9	155° .8	160° .7
180°	180° 1.0	180° 1.0	180° 1.0	180° 1.0	180° 1.0	180° .9
210°	210° 1.0	210° 1.0	210° 1.0	210° 1.0	210° 1.0	210° 1.0
240°	240° 1.0	240° 1.0	240° 1.0	240° 1.0	240° 1.0	240° .9

VILLEFRANCHE POINT 2 (Seaward Buoy) 150 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
150°	160° .2	160° .2	160° .2	170° .2	170° .2	170° .2
180°	180° .8	180° .6	185° .5	200° .4	165° .5	175° .4
210°	210° .7	205° .4	195° .3	170° .2	155° .3	175° .4

Table 3-2 cont.

VILLEFRANCHE POINT 3 (Nice Liberty Boat Run)

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
120°	130° .7	145° .6	155° .4	125° .6	140° .3	155° .3
150°	150° 1.0	150° .9	150° .9	155° .8	155° .7	160° .7
180°	180° 1.0	180° .9	180° .9	180° .8	185° .8	185° .8
210°	210° 1.0	210° .9	210° .9	210° .9	210° .9	210° .9
240°	240° 1.0	240° .9	240° .9	240° .9	240° .9	240° .9
270°	270° .4	270° .4	270° .4	270° .4	260° .4	265° .4

Situation specific shallow water wave conditions resulting from deep water wave propagation are given in Table 3-2 while the seasonal climatology of wave conditions in the harbor resulting from the propagation of deep water waves into the harbor are given in Table 3-3. If the actual or forecast deep water wave conditions are known, the expected conditions at the three specified harbor areas can be determined from Table 3-2. The mean duration of the condition, based on the shallow water wave heights, can be obtained from Table 3-3.

Example: Use of Tables 3-2 and 3-3.

The forecast for wave conditions tomorrow (winter case) outside the harbor are:

8 feet, 10 seconds, from 180°

Expected shallow water conditions and duration:

	Point 1	Point 2	Point 3
height	8 feet	4 feet	7 feet
period	10 seconds	10 seconds	10 seconds
direction	from 180°	from 185°	from 180°
duration	9 hours	9 hours	9 hours

Interpretation of the information from Tables 3-2 and 3-3 provide guidance on the local wave conditions expected tomorrow at the various harbor points. The duration values are mean values for the specified height range and season. Knowledge of the current synoptic pattern and forecast/expected duration should be used when available.

Possible applications to small boat operations are selection of the mother ships anchorage point and/or areas of small boat work. The condition duration information provides insight as to how long before a change can be expected. The local wave direction information can be of use in selecting anchorage configuration and related small boat operations, including tending activities.

Table 3-3. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

VILLEFRANCHE POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	20	18	19	17
Average Duration (hr)	12	11	11	12
Period Max Energy (sec)	9	9	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	1	1	2
Average Duration (hr)	9	7	7	8
Period Max Energy (sec)	10	10	10	10
VILLEFRANCHE POINT 2:	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	0	<< 1	1
Average Duration (hr)	9	NA	6	8
Period Max Energy (sec)	9	NA	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	0	0	0	0
Average Duration (hr)	NA	NA	NA	NA
Period Max Energy (sec)	NA	NA	NA	NA
VILLEFRANCHE POINT 3:	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	21	17	19	17
Average Duration (hr)	12	10	10	12
Period Max Energy (sec)	9	9	9	9
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	1	1	2
Average Duration (hr)	9	8	7	7
Period Max Energy (sec)	10	10	10	10

Local wind wave conditions are provided in Table 3-4 for Villefranche points 1 and 3. The fetch lengths are specifically for points 1 and 3. The time to reach the fetch limited height assumes an initial flat ocean. With a pre-existing wave height, the times are shorter.

Table 3-4. Gulf of Villefranche. Local wind waves for fetch limited conditions at points 1 and 3 (based on JONSWAP model). Point 2 has negligible fetch.

Point 1

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
W 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
WSW 5 n mi	<2 ft	2/3-4 1	2-3/3-4 1	3/3-4 1-2	3-4/3-4 1

Point 3.

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
WSW 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
W 2 n mi	<2 ft	<2 ft	<2 ft	<2 ft	2-3/2-3 1

Example: Small boat wave forecasts for Point 1 (based on the assumption that swell is not a limiting condition).

Forecast for Tomorrow:

Time	Wind (Forecast)	Waves (Table 3-4)
prior to 0700 LST	light and variable	< 1 ft
0700 to 1200	WSW 22-26 kt	building to 2 ft at 3-4 sec by 0800
1200 to 1800	WSW 34-38 kt	becoming 3 ft at 3-4 sec by 1300-1400

Interpretation: Assuming that the limiting factor is waves greater than 3 feet, small boat operations will become marginal between 1300 and 1400.

Combined wave heights are computed by finding the square root of the sum of the squares of the wind wave and swell heights. For example, if the wind waves were 3 ft and the swell 8 ft the combined height would be about 8.5 ft.

$$\sqrt{3^2 + 8^2} = \sqrt{9 + 64} = \sqrt{73} \approx 8.5$$

Note that the increased height is relatively small. Even if the two wave types were of equal height the combined heights are only 1.4 times the equal height. In cases where one or the other heights are twice that of the other, the combined height will only increase over the larger of the two by 1.12 times (10 ft swell and 5 ft wind wave combined results in 11.2 ft height).

3.6.3 Wave Data Uses and Considerations

Local wind waves build up quite rapidly and also decrease rapidly when winds subside. The period and therefore length of wind waves is generally short relative to the period and length of waves propagated into the harbor (see Appendix A). The shorter period and length result in wind waves being characterized by choppy conditions. When wind waves are superimposed on deep water swell propagated into shallow water, the seas can become quite complex and confused. Under such conditions, when more than one source of waves is influencing a location, tending or joint operations can be hazardous even if the individual wave train heights are not significantly high. Vessels of various lengths may respond with different motions to the diverse wave lengths present. The information on wave periods, provided in previous tables, should be considered when forecasts are made for joint operations of various length vessels.

3.7 Protective/Mitigating Measures

3.7.1 Sortie/Move to a New Anchorage

A vessel moored to the seaward (southernmost) buoy, which is designed for vessels to 35,000 tons (Hydrographer of the Navy, 1965), should experience no major problems if remaining at the buoy during strong, gusty winds. But, as discussed above in section 3.6.1, the small size of the roadstead and nearness of rocks makes the harbor safe for only one vessel moored to a buoy during such conditions. Vessels in excess of one should sortie, to either a larger or better protected anchorage, or remain at sea until conditions abate. Depending on wind direction, the Ports of Marseille, Toulon, or Cannes should be considered as alternates.

3.7.2 Scheduling

Except for a sea breeze effect during the period April through October, a review of wind statistics (based on Nice airport) reveals little diurnal variation in wind intensity. During the stated period mean wind velocities are 3 to 6 kt higher in the early afternoon than they are during early morning hours. Calm winds are observed during early morning over 50 percent of the time in June and July. Consequently, if calm or near calm conditions are required for an evolution during late spring, summer, or autumn, it should be scheduled for early morning. But since mean afternoon wind velocities do not exceed 9 kt during any month, the conduct of normal operations should not be a problem on most days.

3.8 Local Indicators of Hazardous Weather Conditions

The Port of Villefranche is well sheltered from the effects of most severe weather conditions which may be adversely affecting other area ports and harbors. It is located near the eastern limit of the area experiencing the Mistral, so when Mistral winds do reach the Port, they are less strong than those experienced farther west along the coast.

The following guidelines have been extracted from various sources and are intended to provide the insight necessary to enable the meteorologist to better understand the various phenomena that affect the Port of Villefranche. Because Villefranche is not in an area normally subjected to wind during an initial Mistral onset, most of the more technical guidelines for Mistrals have been omitted from this listing. If a more comprehensive list is desired, the reader is referred to section 3.8 of the port studies of either Marseille or Toulon, France or to Regional Forecasting Aids for the Mediterranean Basin, Brody & Nestor, 1980.

3.8.1 Mistral

1. Conditions which favor the formation of a Genoa low are conducive to the start of a Mistral at Marseille. A strong Mistral at Marseille may spread eastward to the coastal waters near Villefranche.

2. The Mistral will start at Marseille when one (or more) of three pressure differences is achieved:

Perpignan-Marignane (Marseille), 3 mb; Marignane-Nice, 3 mb; or Perpignan-Nice, 6 mb. A difference usually occurs from 0 to 24 hr after a closed Genoa low appears, but it occasionally occurs earlier (Brody and Nestor, 1980).

3. Eastward from Iles d'Hyères (Figure 3-2) there is a rapid decrease in the frequency and in the average force of the Mistral. It blows at times all along this coast but because of its reduced frequency and intensity it is not the same strength as around the Rhône delta. The general climate of the French Riviera benefits from being sheltered from the most intense form of Mistral which is experienced farther west. On many occasions light easterlies are reported from Nice when strong northwesterlies are reported at Marseille (Hydrographer of the Navy, 1965).

4. For Mistral winds to affect the Villefranche-Nice area, they will first be observed at Marseille and Toulon. Alongshore pressure gradient is important in predicting Mistral extent. When a 10 mb difference exists between Toulon and Nice, the Mistral will spread eastward. With only a 2 mb difference between Marseille and Toulon, the Mistral will cease near Toulon. If surface pressure in Toulon is 1 mb or more greater than that of La Ciotat (a coastal station between Toulon and Marseille), the Mistral will stop.

5. The eastern boundary of the Mistral extends downwind from the western edge of the Alps through San Remo, Italy (Brody and Nestor, 1980).

6. Farther west, in the vicinity of Marseille and the Gulf of Lion, the Mistral commonly lasts from 3 to 6 days. A period of strong Mistral may last for only a few hours, but on occasions for as many as 12 days without any important lulls. The most frequent length of a Mistral event is about 3 1/2 days (Meteorological Office, 1962).

7. Skies along the coast are usually clear. Precipitation is uncommon, except when the Mistral is shallow with a southerly flow at mid-levels that causes middle cloudiness and rain. Other exceptions are at the

cold front associated with the onset of the Mistral and at secondary cold fronts associated with reintensification of Mistral conditions. However, as the cold air moves out over the warmer water, convective cloudiness increases.

8. If a Mistral is occurring at Marseille while light winds are observed at Villefranche/Nice, wind shear in the lower levels of the atmosphere may create hazardous landing conditions at the Nice airport.

3.8.2 Non - Mistral

1. A well defined low pressure center that moves southeastward into the Gulf of Genoa from central France is the primary cause of west to northwest winds greater than 35 kt at Villefranche. Such an event may initiate Mistral onset farther west. See guideline 3.8.1.1 above.

2. The early stages of lee cyclogenesis south of the Alps commonly result in southwesterly 30-40 kt winds in the region between the southern French Coast and Corsica (Brody and Nestor, 1980). But swell waves from open ocean are not generally a problem at the anchorage as they seldom exceed 6 ft (2 m). Boating to/from the fleet anchorage may be hazardous however.

3. Poorest visibility tends to occur during spring and summer but visibility restriction is seldom a problem; visibility decreases to less than 1/2 n mi only about once every two years.

4. Ceiling and visibility combinations for aircraft operations rarely fall below 1,000 ft and 3 mi at Villefranche.

5. Easterly winds which tend to funnel through a gap in the hills of Cap Ferrat result when there is high pressure north of Villefranche and lower pressure south or southwest of the Port.

3.9 Significant Historical Environmental Events

The following cited examples of substantiated events are presented to provide insight into how certain environmental conditions can impact fleet operations.

USS Puget Sound (AD-38) tended two ships (alongside) on two occasions at Villefranche during the winters of 1984 and 1985; it was moored at position 2 (Fig 3-3). During both occasions, moderate to strong southwesterly winds of 20-30 kt with gusts to 40 kt, or south-southwesterly swell 2-3 ft, 6-7 second periods (indicating not a local wind wave), either delayed mooring to the buoy, caused problems getting underway, or created hazardous excessive movement of the tended vessels.

During the onset of the northwesterly Mistral over south-central France when strong high pressure builds into the Alps, the wind flow along the southeastern coast of France is forced by the topography of the Alps to produce a southwesterly flow along the coast near Villefranche. On occasion this flow extends into the Gulf of Genoa as witnessed by the USS Richmond K. Turner not being able to anchor at Monaco during the same storm during the winter of 1985. Wind speeds are approximately 60-70% of those over the Gulf of Lion. Seas 6-8 ft or higher occur at mooring position 1 at Villefranche, 2-3 ft at position 2 with lower seas in the inner harbor and at the Fleet Landing. Tending at position 2 becomes difficult and small boating from position 1 is usually secured. Conditions persist until the low in the Gulf of Genoa ceases to intensify (usually 1 day after onset).

An additional incident occurred during the winter of 1984. A very cold dome of high pressure built over the Alps. The intensity of this dome was reflected by very tight packing of the isobars on the north side of the mountains. About 2200L, the winds picked up from the light and variable to northerly 45-65 kt. This condition lasted less than one hour and winds diminished to northerly less than 10 kt for the remainder of the evening. This event resulted from the breakout of the cold air directly over the Alps, possibly as a katabatic wind. Due to the orientation of the harbor, only choppy seas resulted and small boating was not affected.

3.10 Summary of Problems, Actions, and Indicators

Table 3-5 is intended to provide easy to use seasonal references for meteorologists on ships using the Port of Villefranche. Table 2-1 (section 2) summarizes Table 3-5 and is intended primarily for use by ship Captains.

Table 3-5. Potential problem situations at Port of Villefranche - ALL SEASONS

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
1. Moored to buoy/Anchored in roadstead adjacent to mooring buoys. Strongest in Winter & early Spring Uncommon in Summer Late Autumn	a. E'ly wind - A gap in the hills east of the Port allows E'ly flow to reach the mooring buoy/anchorage area. Most common in late autumn, winter, and early spring.	a. Moored/anchored vessels tend to wind cock but most adverse impact is limited to small boats as discussed in section 4.a below. Ensure that vessels have adequate swinging room. If strong winds are forecast, only 1 vessel may be allowed in the anchorage. Vessels in excess of 1 may have to depart and seek a more protected anchorage in Marseille, Toulon, or other port. Be aware of wind chill factor during cold weather.	a. A strong or strengthening high pressure cell over central Europe with a low pressure center S or SW of the French Riviera can create strong E'ly flow over Villefranche.
Most likely in Winter & early Spring Autumn	b. W'ly wind - Infrequent event at Villefranche. Can produce winds of 35+ kt lasting 1 to 6 hours. May be associated with events preceding Mistral onset farther west.	b. Can cause moored/anchored vessels to wind cock. Ensure that vessels have adequate swinging room. If strong winds are forecast, only 1 vessel may be allowed in the anchorage. Vessels in excess of 1 may have to depart and seek a more protected anchorage in Marseille, Toulon, Cannes or other port. Be aware of wind chill factor during cold weather.	b. A well defined low pressure center that moves SE into the Gulf of Genoa from central France is the primary cause of W to NW winds greater than 35 kt at Villefranche. This sequence may be a precursor to Mistral onset W of the French Riviera.
Winter Spring Uncommon in Summer Autumn	c. S to SW'ly swell - Rare at Villefranche, and when occurring, cause little difficulty. Waves to 10 ft (3m) may cause anchored/moored vessels to roll.	c. Vessels in the roadstead may roll but the conditions do not pose much of a hazard. The most significant problem is posed to civilian small craft anchored near the north shore, where the water shallows and waves break.	c. The early stages of cyclogenesis S of the Alps commonly result in SW'ly 30-40 kt winds in the region between the S French coast and Corsica. Southerly (160° to 220°) winds and swell can be caused by depressions moving into the Ligurian Sea or across Corsica into Italy. Swell waves seldom exceed 10 ft (3 m).
2. Anchored at fleet anchorage. Strongest in late Winter & early Spring Uncommon in Summer Common in Autumn	a. Mistral wind - N to NW'ly wind common in Marseille/Toulon and over Gulf of Lion. Occasionally spreads eastward to Villefranche area. Most common in late winter/early spring. May bring winds to 40 kt and waves to 6 ft (2 m) to fleet anchorage.	a. No significant problem for the anchored vessels but small craft making runs to/from the Fleet Landing may have interrupted service due to wave conditions near the anchorage. Protected anchorage can be found east of Pointe de la Croisette near Cannes.	a. Although the Mistral seldom affects the more protected areas of the roadstead, it can create problems at the fleet anchorage for small boat operations. It is, therefore, prudent to be aware of forthcoming Mistral events. (1) Conditions which favor the formation of a Genoa Low are conducive to the start of a Mistral at Marseille. A strong Mistral may spread eastward to the coastal waters near Villefranche. (2) The Mistral will start at Marseille when one of three pressure differences is achieved: Perpignan - Marignane (Marseille), 3 mb; Marignane - Nice, 3 mb; or Perpignan - Nice, 6 mb. A difference usually occurs from 0 to 24 hr after a closed Genoa low appears, but it occasionally occurs earlier. (3) There is a rapid decrease in the frequency and average force of the Mistral E of Iles d'Hyères. On many occasions light E'lys are reported from Nice when strong NW'lys are blowing at Marseille (Hydrographer of the Navy, 1965). (4) For Mistral winds to affect Nice/Villefranche, they must first be observed at Marseille/Toulon. Alongshore pressure gradient is important in predicting Mistral extent. When a 10 mb difference exists between Toulon and Nice, the Mistral will spread eastward. With only a 2 mb difference the Mistral will stop near Toulon. (5) The eastern boundary of the Mistral extends downwind from the western edge of the Alps through San Remo, Italy. (6) When fully established the Mistral is usually accompanied by clear skies. However, rain (or in winter, rain and/or snow) and violent squalls commonly accompany the cold front which introduces the Mistral.
Most likely in Winter & early Spring Autumn	b. W'ly wind - Infrequent event at Villefranche. May produce winds of 35+ kt lasting 1 to 6 hours. May be associated with events preceding Mistral onset farther west.	b. Wind may cause anchored vessels to wind cock.	b. A well defined low pressure center that moves SE into the Gulf of Genoa from central France is the primary cause of W to NW winds greater than 35 kt at Villefranche. This sequence may be a precursor to Mistral onset W of the French Riviera.
Winter Spring Uncommon in Summer Autumn	c. S to SW'ly swell - Rare occurrence at Villefranche. Waves to 10 ft (3 m) may move into the roadstead.	c. No problem for the anchored vessels but small craft making runs to/from the Fleet Landing may have interrupted service due to wave conditions near the anchorage. Protected anchorage can be found just north of the Ile Ste. Marguerite near Cannes.	c. The early stages of cyclogenesis S of the Alps commonly result in SW'ly 30-40 kt winds in the region between the S French coast and Corsica. Southerly (160° to 220°) winds and swell can be caused by depressions moving into the Ligurian Sea or across Corsica into Italy. Swell waves seldom exceed 10 ft (3 m).

Table 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
3. Arriving/departing. Strongest in Winter & early Spring Uncommon in Summer Late Autumn	a. E'ly wind - A gap in the hills east of the Port allows E'ly flow to reach the mooring buoy/anchorage area. Most common in late autumn, winter, and early spring.	a. Inbound vessels should experience no problems while in the lee of Cap Ferrat until the mooring buoy area is reached. Winds funnelled to the buoy area may pose problems during mooring maneuvers due to limited maneuvering room and close proximity of rocks. Outbound vessels should experience minimal problems once clear of buoy area and in the lee of Cap Ferrat. Wind and wave conditions will worsen when seaward of the lee of Cap Ferrat. Be aware of wind chill factor.	a. A strong or strengthening high pressure cell over central Europe with a low pressure center S or SW of the French Riviera can create strong E'ly flow over Villefranche.
Most likely in Winter & early Spring Autumn	b. W'ly wind - Infrequent event at Villefranche. May produce winds of 35+ kt lasting 1 to 6 hours. May be associated with events preceding Mistral onset farther west.	b. Worst conditions will be experienced seaward of Pointe des Sans-Culottes. Winds in the roadstead may dictate limiting moored/anchored vessels to 1 due to restricted swinging room and close proximity of rocks.	b. A well defined low pressure center that moves SE into the Gulf of Genoa from central France is the primary cause of W to NW winds greater than 35 kt at Villefranche. This sequence may be a precursor to Mistral onset W of the French Riviera.
Winter Spring Uncommon in Summer Autumn	c. S to SW'ly swell - Rare at Villefranche, and when occurring, cause little difficulty. Waves to 10 ft (3m) may cause anchored/moored vessels to roll.	c. Vessels should experience only minimal problems in the roadstead. Moored/anchored units may roll when their longitudinal axis is perpendicular to the swell direction. Protected anchorage can be found just north of Ile Ste. Marguerite near Cannes.	c. The early stages of cyclogenesis S of the Alps commonly result in SW'ly 30-40 kt winds in the region between the S French coast and Corsica. Southerly (160x to 220x) winds and swell can be caused by depressions moving into the Ligurian Sea or across Corsica into Italy. Swell waves seldom exceed 10 ft (3 m).
Strongest in late Winter & early Spring Uncommon in Summer Common in Autumn	d. Mistral wind - W to NW'ly wind common in Marseille/Toulon and over Gulf of Lion. Occasionally spreads eastward to Villefranche area. Most common in late winter/early spring. May bring winds to 40 kt and waves to 6 ft (2 m) to fleet anchorage.	d. Worst conditions will be experienced seaward of Pointe des Sans-Culottes. The roadstead at Villefranche is generally tranquil when Mistral conditions are observed at Marseille/ Toulon and other locations west of the French Riviera. Protected anchorage can be found east of Pointe de la Croisette near Cannes.	d. Although the Mistral seldom affects the roadstead north of Pointe des Sans Culottes, it can create problems at the fleet anchorage and cause hazardous flying conditions over Nice/Villefranche. It is, therefore, prudent to be aware of forthcoming Mistral events. (1) Conditions which favor the formation of a Genoa Low are conducive to the start of a Mistral at Marseille. A strong Mistral may spread eastward to the coastal waters near Villefranche. (2) The Mistral will start at Marseille when one (or more) of three pressure differences is achieved: Perpignan - Marignane (Marseille), 3 mb; Marignane - Nice, 3 mb; or Perpignan - Nice, 6 mb. A difference usually occurs from 0 to 24 hr after a closed Genoa low appears, but it occasionally occurs earlier. (3) There is a rapid decrease in the frequency and average force of the Mistral E of Iles d'Hy#res. On many occasions light E'lys are reported from Nice when strong NW'lys are blowing at Marseille. (4) For Mistral winds to affect Nice/Villefranche, they must first be observed at Marseille/Toulon. Alongshore pressure gradient is important in predicting Mistral extent. When a 10 mb difference exists between Toulon and Nice, the Mistral will spread eastward. With only a 2 mb difference the Mistral will stop near Toulon. (5) The eastern boundary of the Mistral extends downwind from the western edge of the Alps through San Remo, Italy. (6) When fully established the Mistral is usually accompanied by clear skies. However, rain (or in winter, rain and/or snow) and violent squalls commonly accompany the cold front which introduces the Mistral.

Table 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
4. Small boats. Strongest in Winter & early Spring Uncommon in Summer Late Autumn	a. E'ly wind - A gap in the hills east of the Port allows E'ly flow to reach the mooring buoy/anchorage area. Most common in late autumn, winter, early spring.	a. Wind may raise a chop sufficient to cause cancellation of boating to/from Fleet Landing and moored/anchored vessels in the roadstead.	a. A strong or strengthening high pressure cell over central Europe with a low pressure center S or SW of the French Riviera can create strong E'ly flow over Villefranche.
Strongest in late Winter & early Spring Uncommon in Summer Common in Autumn	b. Mistral wind - W to NW'ly wind common in Marseille/Toulon and over Gulf of Lion. Occasionally spreads eastward to Villefranche area. Most common in late winter/early spring. May bring winds to 40 kt and waves to 6 ft (2 m) to fleet anchorage.	b. No problem in the northern part of the roadstead, but boating may be interrupted to/from vessels in the fleet anchorage and the Fleet Landing due to winds and waves in the anchorage.	b. Although the Mistral seldom affects the more protected waters of the roadstead, it can create problems at the fleet anchorage. It is, therefore, prudent to be aware of forthcoming Mistral events. (1) Conditions which favor the formation of a Genoa Low are conducive to the start of a Mistral at Marseille. A strong Mistral may spread eastward to the coastal waters near Villefranche. (2) The Mistral will start at Marseille when one (or more) of three pressure differences is achieved: Perpignan - Marignane (Marseille), 3 mb; Marignane - Nice, 3 mb; or Perpignan - Nice, 6 mb. A difference usually occurs from 0 to 24 hr after a closed Genoa low appears, but it occasionally occurs earlier. (3) There is a rapid decrease in the frequency and average force of the Mistral E of Iles d'Hyères. On many occasions light E'lys are reported from Nice when strong NW'lys are blowing at Marseille. (4) For Mistral winds to affect Nice/Villefranche, they must first be observed at Marseille/Toulon. Alongshore pressure gradient is important in predicting Mistral extent. When a 10 mb difference exists between Toulon and Nice, the Mistral will spread eastward. With only a 2 mb difference the Mistral will stop near Toulon. (5) The eastern boundary of the Mistral extends downwind from the western edge of the Alps through San Remo, Italy. (6) When fully established the Mistral is usually accompanied by clear skies. However, rain (or in winter, rain and/or snow) and violent squalls commonly accompany the cold front which introduces the Mistral.
Winter Spring Uncommon in Summer Autumn	c. S to SW'ly swell - Rare at Villefranche, but when occurring may cause interruption of boat runs between the fleet anchorage and the Fleet Landing. Minimal impact is felt near mooring buoys farther north in the roadstead.	c. May cause difficulties and possible interruption of boating between the fleet anchorage and the Fleet Landing. No appreciable impact on boating in the northern part of the roadstead.	c. The early stages of cyclogenesis S of the Alps commonly result in SW'ly 30-40 kt winds in the region between the S French coast and Corsica. Southerly (160° to 220°) winds and swell can be caused by depressions moving into the Ligurian Sea or across Corsica into Italy. But swell waves seldom exceed 10 ft (3 m).
5. Flight operations. Strongest in late Winter & early Spring Uncommon in Summer Common in Autumn	a. Mistral wind - W to NW'ly wind common in Marseille/Toulon and over Gulf of Lion. Occasionally spreads eastward to Villefranche but is seldom felt at the surface. When a strong Mistral is occurring at Marseille, a wind shear may develop over the Nice/Villefranche area. Most common in late winter and early spring.	a. The wind shear in the lower levels of the atmosphere creates turbulent flying conditions and a dangerous landing environment in the Nice/Villefranche area.	a. Although the Mistral seldom affects the Port of Villefranche, it can create problems at the fleet anchorage and cause hazardous flying conditions over Nice/Villefranche. It is, therefore, prudent to be aware of forthcoming Mistral events. (1) Conditions which favor the formation of a Genoa Low are conducive to the start of a Mistral at Marseille. A strong Mistral may spread eastward to the coastal waters near Villefranche. (2) The Mistral will start at Marseille when one (or more) of three pressure differences is achieved: Perpignan - Marignane (Marseille), 3 mb; Marignane - Nice, 3 mb; or Perpignan - Nice, 6 mb. A difference usually occurs from 0 to 24 hr after a closed Genoa low appears, but it occasionally occurs earlier. (3) There is a rapid decrease in the frequency and average force of the Mistral E of Iles d'Hyères. On many occasions light E'lys are reported from Nice when strong NW'lys are blowing at Marseille. (4) For Mistral winds to affect Nice/Villefranche, they must first be observed at Marseille/Toulon. Alongshore pressure gradient is important in predicting Mistral extent. When a 10 mb difference exists between Toulon and Nice, the Mistral will spread eastward. With only a 2 mb difference the Mistral will stop near Toulon. (5) The eastern boundary of the Mistral extends downwind from the western edge of the Alps through San Remo, Italy. (6) When fully established the Mistral is usually accompanied by clear skies. However, rain (or in winter, rain and/or snow) and violent squalls commonly accompany the cold front which introduces the Mistral.

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PORT VISIT INFORMATION

JUNE 1986. NEPRF meteorologists R. Fett and R. Picard met with the Acting Port Captain and Chief Forecaster to obtain much of the information included in this port evaluation.

APPENDIX A

General Purpose Oceanographic Information

This section provides general information on wave forecasting and wave climatology as used in this study. The forecasting material is not harbor specific. The material in paragraphs A.1 and A.2 was extracted from H.O. Pub. No. 603, Practical Methods for Observing and Forecasting Ocean Waves (Pierson, Neumann, and James, 1955). The information on fully arisen wave conditions (A.3) and wave conditions within the fetch region (A.4) is based on the JONSWAP model. This model was developed from measurements of wind wave growth over the North Sea in 1973. The JONSWAP model is considered more appropriate for an enclosed sea where residual wave activity is minimal and the onset and end of locally forced wind events occur rapidly (Thornton, 1986), and where waves are fetch limited and growing (Hasselmann, et al., 1976). Enclosed sea, rapid onset/subsiding local winds, and fetch limited waves are more representative of the Mediterranean waves and winds than the conditions of the North Atlantic from which data was used for the Pierson and Moskowitz (P-M) Spectra (Neumann and Pierson 1966). The P-M model refined the original spectra of H.O. 603, which over developed wave heights.

The primary difference in the results of the JONSWAP and P-M models is that it takes the JONSWAP model longer to reach a given height or fully developed seas. In part this reflects the different starting wave conditions. Because the propagation of waves from surrounding areas into semi-enclosed seas, bays, harbors, etc. is limited, there is little residual wave action following periods of locally light/calm winds and the sea surface is nearly flat. A local wind developed wave growth is therefore slower than wave growth in the open ocean where some residual wave action is generally always present. This slower wave development is a built in bias in the formulation of the JONSWAP model which is based on data collected in an enclosed sea.

A.1 Definitions

Waves that are being generated by local winds are called "SEA". Waves that have traveled out of the generating area are known as "SWELL". Seas are chaotic in period, height and direction while swell approaches a simple sine wave pattern as its distance from the generating area increases. An in-between state exists for a few hundred miles outside the generating area and is a condition that reflects parts of both of the above definitions. In the Mediterranean area, because its fetches and open sea expanses are limited, SEA or IN- BETWEEN conditions will prevail. The "SIGNIFICANT WAVE HEIGHT" is defined as the average value of the heights of the one-third highest waves. PERIOD and WAVE LENGTH refer to the time between passage of, and distances between, two successive crests on the sea surface. The FREQUENCY is the reciprocal of the period (f = 1/T) therefore as the period increases the frequency decreases. Waves result from the transfer of energy from the wind to the sea surface. The area over which the wind blows is known as the FETCH, and the length of time that the wind has blown is the DURATION. The characteristics of waves (height, length, and period) depend on the duration, fetch, and velocity of the wind. There is a continuous generation of small short waves from the time the wind starts until it stops. With continual transfer of energy from the wind to the sea surface the waves grow with the older waves leading the growth and spreading the energy over a greater range of frequencies. Throughout the growth cycle a SPECTRUM of ocean waves is being developed.

A.2 Wave Spectrum

Wave characteristics are best described by means of their range of frequencies and directions or their spectrum and the shape of the spectrum. If the spectrum of the waves covers a wide range of frequencies and directions (known as short-crested conditions), SEA conditions prevail. If the spectrum covers a narrow range of frequencies and directions (long crested conditions), SWELL conditions prevail. The wave spectrum depends on the duration of the wind, length of the fetch, and on the wind velocity. At a given wind speed and a given state of wave development, each spectrum has a band of frequencies where most of the total energy is concentrated. As the wind speed increases the range of significant frequencies extends more and more toward lower frequencies (longer periods). The frequency of maximum energy is given in equation 1.1 where v is the wind speed in knots.

$$f_{max} = \frac{2.476}{v} \qquad (1.1)$$

The wave energy, being a function of height squared, increases rapidly as the wind speed increases and the maximum energy band shifts to lower frequencies. This results in the new developing smaller waves (higher frequencies) becoming less significant in the energy spectrum as well as to the observer. As larger waves develop an observer will pay less and less attention to the small waves. At the low frequency (high period) end the energy drops off rapidly, the longest waves are relatively low and extremely flat, and therefore also masked by the high energy frequencies. The result is that 5% of the upper frequencies and 3% of the lower frequencies can be cut-off and only the remaining frequencies are considered as the "significant part of the wave spectrum". The resulting range of significant frequencies or periods are used in defining a fully arisen sea. For a fully arisen sea the approximate average period for a given wind speed can be determined from equation (1.2).

$$\bar{T} = 0.285v \qquad (1.2)$$

Where v is wind speed in knots and T is period in seconds. The approximate average wave length in a fully arisen sea is given by equation (1.3).

$$\bar{L} = 3.41\ \bar{T}^2 \qquad (1.3)$$

Where $\bar{L}$ is average wave length in feet and $\bar{T}$ is average period in seconds.

The approximate average wave length of a fully arisen sea can also be expressed as:

$$\bar{L} = .67\text{"L"} \qquad (1.4)$$

where "L" = $5.12T^2$, the wave length for the classic sine wave.

A.3 Fully Arisen Sea Conditions

For each wind speed there are minimum fetch (n mi) and duration (hr) values required for a fully arisen sea to exist. Table A-1 lists minimum fetch and duration values for selected wind speeds, values of significant wave (average of the highest 1/3 waves) period and height, and wave length of the average wave during developing and fully arisen seas. The minimum duration time assumes a start from a flat sea. When pre-existing lower waves exist the time to fetch limited height will be shorter. Therefore the table duration time represents the maximum duration required.

Table A-1. Fully Arisen Deep Water Sea Conditions Based on the JONSWAP Model.

Wind Speed (kt)	Minimum Fetch/Duration (n mi) / (hrs)	Sig Wave (H1/3) Period/Height (sec) / (ft)	Wave Length (ft)[1,2] Developing/Fully /Arisen L X (.5) /L X (.67)
10	28 / 4	4 / 2	41 / 55
15	55 / 6	6 / 4	92 / 123
20	110 / 8	8 / 8	164 / 220
25	160 / 11	9 / 12	208 / 278
30	210 / 13	11 / 16	310 / 415
35	310 / 15	13 / 22	433 / 580
40	410 / 17	15 / 30	576 / 772

NOTES:

[1] Depths throughout fetch and travel zone must be greater than 1/2 the wave length, otherwise shoaling and refraction take place and the deep water characteristics of waves are modified.

[2] For the classic sine wave the wave length (L) equals 5.12 times the period (T) squared ($L = 5.12T^2$). As waves develop and mature to fully developed waves and then propagate out of the fetch area as swell their wave lengths approach the classic sine wave length. Therefore the wave lengths of developing waves are less than those of fully developed waves which in turn are less than the length of the resulting swell. The factor of .5 (developing) and .67 (fully developed) reflect this relationship.

A.4 Wave Conditions Within The Fetch Region

Waves produced by local winds are referred to as SEA. In harbors the local sea or wind waves may create hazardous conditions for certain operations. Generally within harbors the fetch lengths will be short and therefore the growth of local wind waves will be fetch limited. This implies that there are locally determined upper limits of wave height and period for each wind velocity. Significant changes in speed or direction will result in generation of a new wave group with a new set of height and period limits. Once a fetch limited sea reaches its upper limits no further growth will occur unless the wind speed increases.

Table A-2 provides upper limits of period and height for given wind speeds over some selected fetch lengths. The duration in hours required to reach these upper limits (assuming a start from calm and flat sea conditions) is also provided for each combination of fetch length and wind speed. Some possible uses of Table A-2 information are:

1) If the only waves in the area are locally generated wind waves, the Table can be used to forecast the upper limit of sea conditions for combinations of given wind speeds and fetch length.

2) If deep water swell is influencing the local area in addition to locally generated wind waves, then the Table can be used to determine the wind waves that will combine with the swell. Shallow water swell conditions are influenced by local bathymetry (refraction and shoaling) and will be addressed in each specific harbor study.

3) Given a wind speed over a known fetch length the maximum significant wave conditions and time needed to reach this condition can be determined.

Table A-2. Fetch Limited Wind Wave Conditions and Time Required to Reach These Limits (Based on JONSWAP Model). Enter the table with wind speed and fetch length to determine the significant wave height and period, and time duration needed for wind waves to reach these limiting factors. All of the fetch/speed combinations are fetch limited except the 100 n mi fetch and 18 kt speed.

Format: height (feet)/period (seconds)
duration required (hours)

Fetch Length (n mi) \ Wind Speed (kt)	18	24	30	36	42
10	2/3-4 1-2	3/3-4 2	3-4/4 2	4/4-5 1-2	5/5 1-2
20	3/4-5 2-3	4/4-5 3	5/5 3	6/5-6 3-4	7/5-6 3
30	3-4/5 3	5/5-6 4	6/6 3-4	7/6 3-4	8/6-7 3
40	4-5/5-6 4-5	5/6 4	6-7/6-7 4	8/7 4	9-10/7-8 3-4
100	5/6-7[1] 5-6	9/8 8	11/9 7	13/9 7	15-16/9-10 7

[1] 18 kt winds are not fetch limited over a 100 n mi fetch.

An example of expected wave conditions based on Table A-2 follows:

WIND FORECAST OR CONDITION

An offshore wind of about 24 kt with a fetch limit of 20 n mi (ship is 20 n mi from the coast) is forecast or has been occurring.

SEA FORECAST OR CONDITION

From Table A-2: If the wind condition is forecast to last, or has been occurring, for at least 3 hours:

Expect sea conditions of 4 feet at 4-5 second period to develop or exist. If the condition lasts less than 3 hours the seas will be lower. If the condition lasts beyond 3 hours the sea will not grow beyond that developed at the end of about 3 hours unless there is an increase in wind speed or a change in the direction that results in a longer fetch.

A.5 Wave Climatology

The wave climatology used in these harbor studies is based on 11 years of Mediterranean SOWM output. The MED-SOWM is discussed in Volume II of the U.S. Naval Oceanography Command Numerical Environmental Products Manual (1986). A deep water MED-SOWM grid point was selected as representative of the deep water wave conditions outside each harbor. The deep water waves were then propagated into the shallow water areas. Using linear wave theory and wave refraction computations the shallow water climatology was derived from the modified deep water wave conditions. This climatology does not include the local wind generated seas. This omission, by design, is accounted for by removing all wave data for periods less than 6 seconds in the climatology. These shorter period waves are typically dominated by locally generated wind waves.

A.6 Propagation of Deep Water Swell Into Shallow Water Areas

When deep water swell moves into shallow water the wave patterns are modified, i.e., the wave heights and directions typically change, but the wave period remains constant. Several changes may take place including shoaling as the wave feels the ocean bottom, refraction as the wave crest adjusts to the bathymetry pattern, changing so that the crest becomes more parallel to the bathymetry contours, friction with the bottom sediments, interaction with currents, and adjustments caused by water temperature gradients. In this work, only shoaling and refraction effects are considered. Consideration of the other factors are beyond the resources available for this study and, furthermore, they are considered less significant in the harbors of this study than the refraction and shoaling factors.

To determine the conditions of the deep water waves in the shallow water areas the deep water conditions were first obtained from the Navy's operational MED-SOWM wave model. The bathymetry for the harbor/area of interest was extracted from available charts and digitized for computer use. Figure A-1 is a sample plot of bathymetry as used in this project. A ray path refraction/shoaling program was run 'for selected combinations of deep water wave direction and period. The selection was based on the near deep water wave climatology and harbor exposure. Each study area requires a number of ray path computations. Typically there are 3 or 4 directions (at 30° increments) and 5 or 6 periods (at 2 second intervals) of concern for each area of study. This results in 15 to 24 plots per area/harbor. To reduce this to a manageable format for quick reference, specific locations within each study area were selected and the information was summarized and is presented in the specific harbor studies in tabular form.

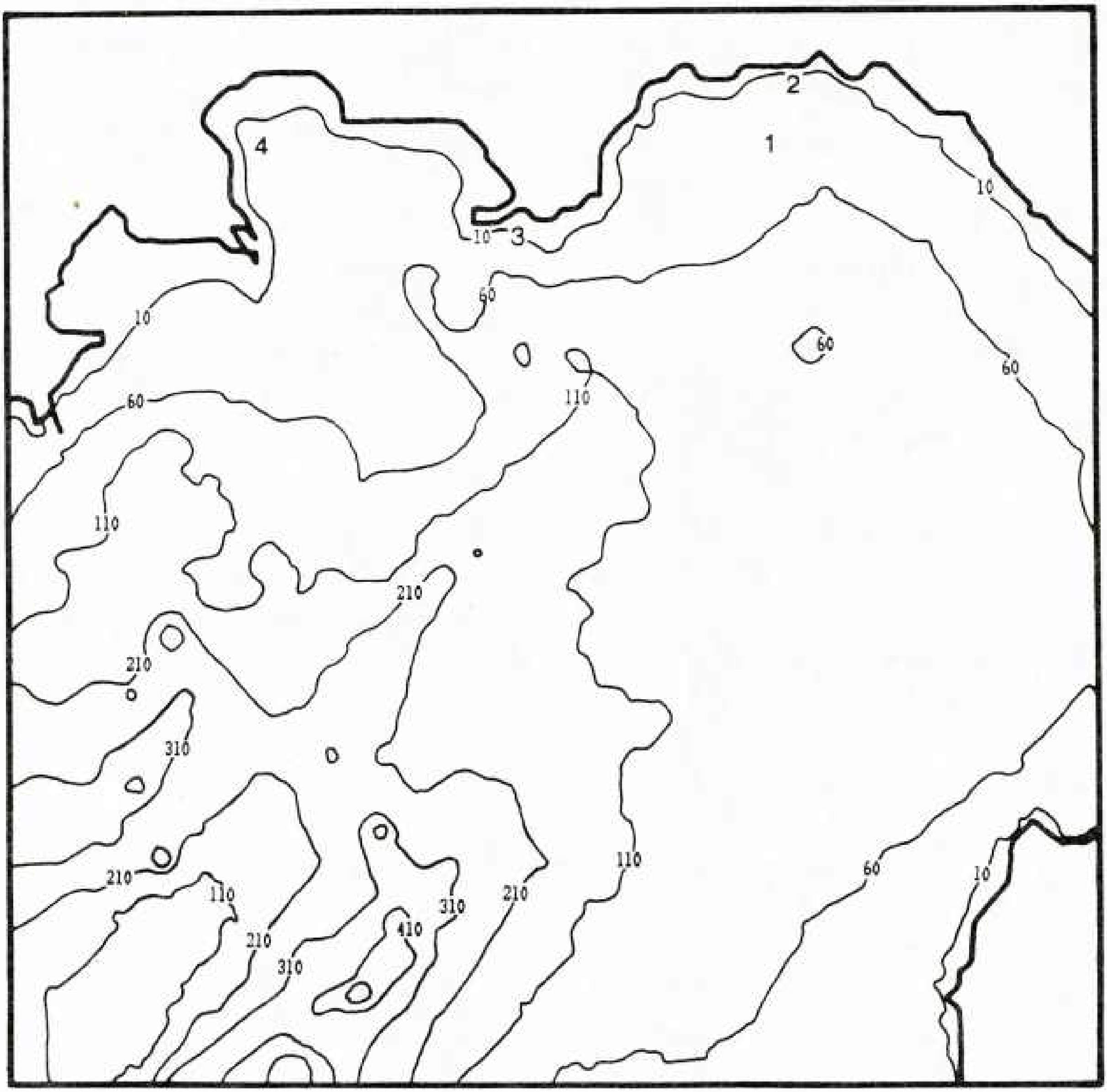

Figure A-1. Example plot of bathymetry (Naples harbor) as used in this project. For plotting purposes only, contours are at 50 fathom intervals from an initial 10 fathoms to 110 fathoms, and at 100 fathom intervals thereafter. The larger size numbers identify specific anchorage areas addressed in the harbor study.

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