Report No. CG-D-14-88

ATLAS OF OCEANOGRAPHIC INFORMATION FOR NORTON SOUND, ALASKA

Northern Technical Services, Inc.
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Anchorage, Alaska 99501

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16. Abstract

This is a reference document on oceanography, meteorology, climate and ice conditions for the Norton Sound. The Norton Sound area is defined as the area between 160 degrees 30'W to 170 degrees W, and 63 degrees 00N to 65 degrees 30'N. The oceanography section contains information for waves, circulation, tides, currents, bathymetry, ice conditions and storm surges in the Norton Sound. The meteorology section contains information on winds, climate, flying conditions, temperatures, and air mass stability. Included is a forecast procedure for estimating the height of a storm surge.

The ice section contains information on movement, character, growth and dissipation, and shearing and compressional forces.

The climatology section includes information on wind and wind driven currents, temperatures, visibility and superstructure icing.

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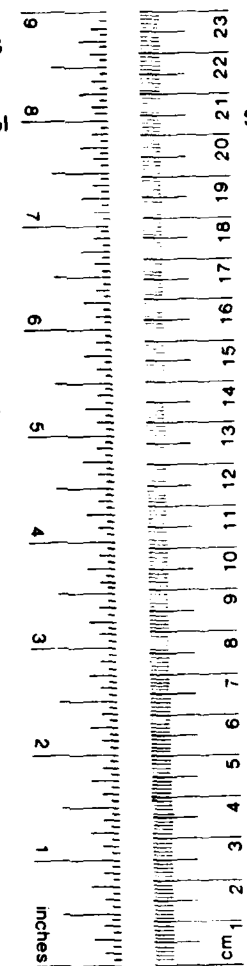
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

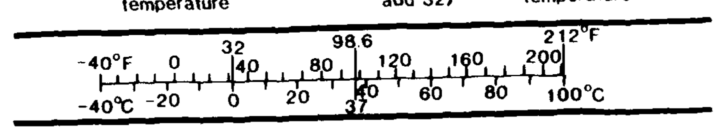


TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF FIGURES

LIST OF TABLES

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1.0 Introduction

The Norton Sound (Figures 1.0-1 and 1.0-2) in the northern Bering Sea, is an area in which industry has shown considerable interest in exploring for oil and gas. However, there are some potential hazards to the exploration and development of Norton Sound which include sea ice, winds, waves, icing of structures, storm surges, and weather. In the event of an accidental oil spill in the Norton Sound, the U.S. Coast Guard On-Scene Coordinator (OSC) would be responsible for ensuring that timely and adequate containment and clean-up activity is initiated by the responsible party. The responsible parties are required to take the appropriate cleanup action and the OSC's role will be to monitor these actions. If the responsible party is unknown, the OSC may initiate cleanup action. In any case, the OSC will be operating in a unique environment where an evaluation of the resources at risk and the protection of the resources is important.

In order to effectively respond to a spill on the Norton Sound, information on the conditions that could affect oil spill behavior and oil cleanup is essential. This Environmental Atlas has been compiled to provide the OSC with general and unique information for Norton Sound. This atlas is designed so that the information can be found quickly and is easily understood. It is important to emphasize that an atlas, no matter how complete, cannot replace actual field reconnaissance. It does, however, provide a means by which the user can become familiar with environmental conditions in the area. The atlas also provides reference material for decision making in response to needs. It can also help the OSC, who may not have special oceanographic training, obtain the necessary information in a straightforward manner.

The atlas is designed so that the subjects of interest are presented in more than one location and in varying detail. Sections 2 and 3 discuss all the factors affecting oil spill

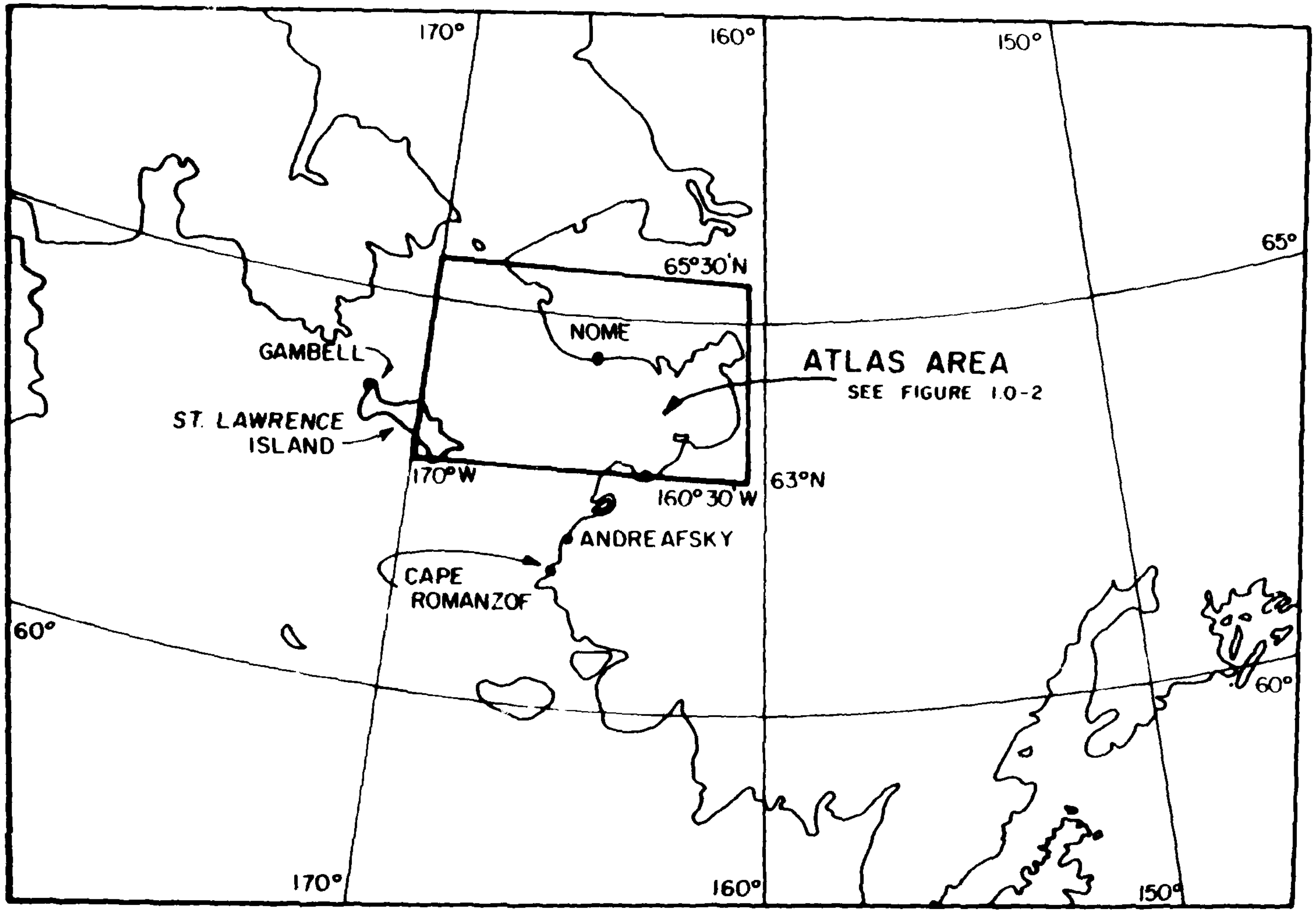


Figure 1.0-1. The Northern Bering Sea, western Alaska coastline, and the Norton Sound Atlas area.

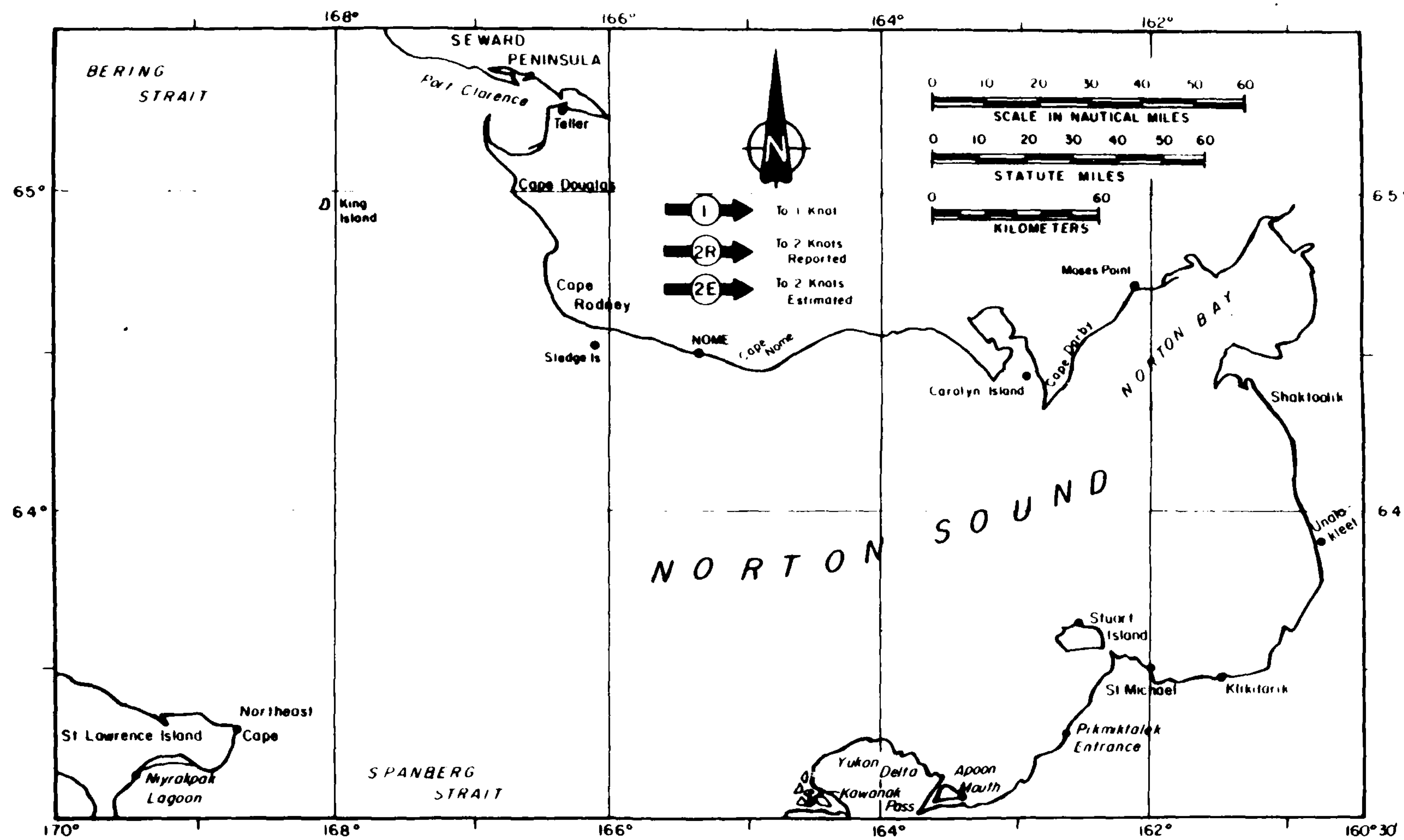


Figure 1.0-2. Norton Sound Atlas Area.

transport and oil spill containment, but each factor is discussed briefly unless it is not again discussed - such as ceiling and visibilities. Sections 4 through 7 discuss families of factors (oceanography, meteorology, etc.) that affect oil spills and these discussions are much more specific and detailed than previous discussions. For instance, the discussion of wind driven currents in 2.3 is much less specific and detailed than in 5.1. The reason for the above is to accomodate varying levels of reader interest or capability. The OSC may be interested only in the general current description (2.1) whereas the oil spill trajectory modelers may be interested primarily in 5.1.

The appendices contain information of a reference nature that may be useful to all persons involved in oil spill problems.

1.1 Physical Environment

The continental shelf is relatively shallow throughout the Norton Sound (Figure 1.1-1). A shallow (<10 m) deltaic fan platform created by sediment deposition from the Yukon River extends seaward in the southwest corner of Norton Sound for a few tens of kilometers. Norton Sound itself has an average depth of about 18 m (Cacchione and Drake, 1979).

Channels in an otherwise relatively flat bottom exist in Norton Sound just south of Nome, in the Bering Strait, and just east of St. Lawrence Island (Hanley et al. 1980; Starr et al. 1981).

The shoreline is generally smooth, interrupted intermittently by bays and isolated headlands. Throughout Norton Sound the coast consists mainly of narrow beaches with the terrain rising steeply behind them; wave-cut cliffs abutt the sound locally in the north and east. Extensive flat coastal lowlands are found along the entire east coast of Norton Bay and along the Yukon River delta. Sand and gravel spits are common along these mainland coasts, and frequently act as protective barriers for shallow lagoons (Sears and Zimmerman 1977; Starr et al., 1981).

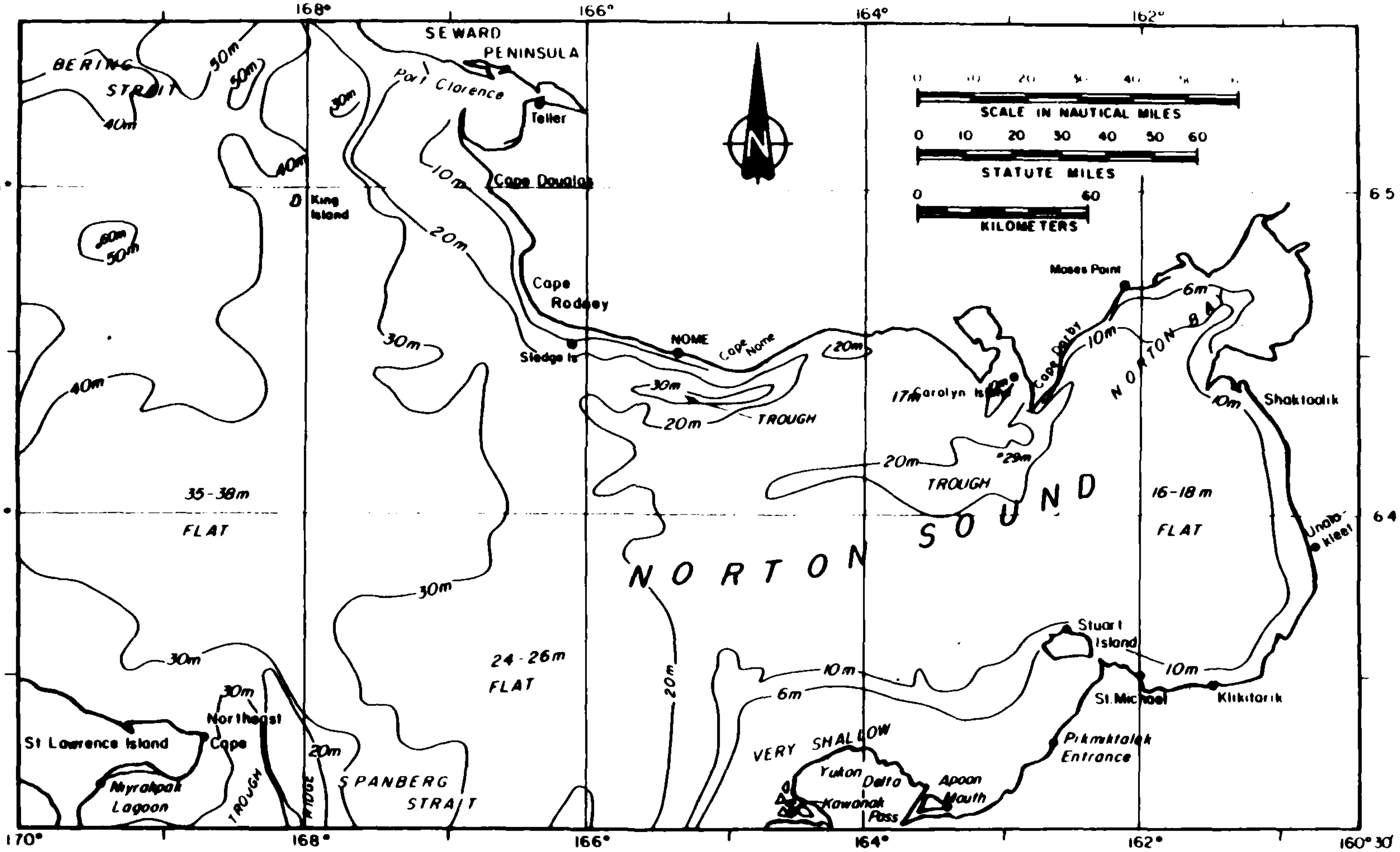


Figure 1.1-1. Bathymetry of Norton Sound. Contours are labeled in meters. See NOS Nautical Chart 16200 or 16006.

Depths in the Norton Sound vary from less than 10 meters in the southern portion to more than 30 meters in a trough-like feature which extends east-west in the nearshore region south of Nome. The bottom is relatively featureless and slopes gradually westward to depths of 50 meters or more in the Spanberg and Bering Straits. Figure 1.1-1 depicts the bathymetry of the Norton Sound area.

1.2 Climate and Meteorology

The Norton Sound area has two very different regimes of climate -- summer and winter. The summer season, June through October, coincides with the time that seas are essentially free of ice. During the winter season, November through May, sea-ice cover is complete or nearly so (McNutt 1981; Starr et al., 1981).

The seasonal presence or absence of the ice pack is extremely important for the climate. It introduces a continental-type influence in winter; this allows cold arctic and continental air to establish itself over the ice-covered sea with wind ranges in daily and seasonal temperature. In summer, the open seas cause a maritime climate to prevail, with a more uniform daily temperature regime and enhanced precipitation (Overland, 1981).

In winter, polar air masses usually predominate for extended periods. Temperatures average from -15° to -12° C. Winds prevail from the north and northeast, frequently reaching high speeds; velocities exceeding 70 knots (110 km/h) have been recorded during most months. Snowfall during this period may range from 130 to 180 cm (Overland 1981; Starr et al., 1981). Summer temperatures are maritime; they are frequently as much as 12° C, but drop below freezing late in the season. Winds are variable, but tend to be southwesterly; storms moving through from the northern Pacific can cause extended periods of cloudiness and rain. Precipitation in this period ranges from about 40 to 50 cm annually (Overland, 1981; Starr et al., 1981). Climate and meteorology is discussed more extensively in Section 5.

1.3 General Circulation

The regional circulation pattern appears to be generally the same in winter as it is in summer. Salo et al., (1983) found the vector-mean current in winter to be in general northward and parallel to the local trend in bathymetry. Current reversals to the south, promoted by strong northerly winds, appear to be common. Reversals generally occur 2-4 times per month and last less than 5 days (K. Aagaard, Univ. Washington, unpubl. data). The southward flow created by these reversals tends to extend to the south around the end of St. Lawrence Island, but do not enter very far into Norton Sound (Starr et al., 1981, quoting L. Coachman pers. comm.) The relationship of oil spill trajectories to general circulation in Norton Sound is nebulous at best; however, general circulation is discussed further in Section 2.1.

1.4 Tides

Tides in the Norton Sound atlas area are quite complicated. An amphidromic point (no tide area) exists in the northeastern portion of Norton Sound (Figure 1.4-1) (Pawlowski, 1986). The amphidromic point makes tidal predictions difficult in some areas and impossible in others if one does not know of its existence and if one is not close to a tidal reference point (from tide tables). In spite of the complicated cotidal, corange, and the changing diurnal and semi-diurnal tide occurrences, the tidal current on flood (Figure 1.4-2) and on ebb (Figure 1.4-3) is relatively simple. A more detailed discussion of the tidal situation is presented in Section 2.2.

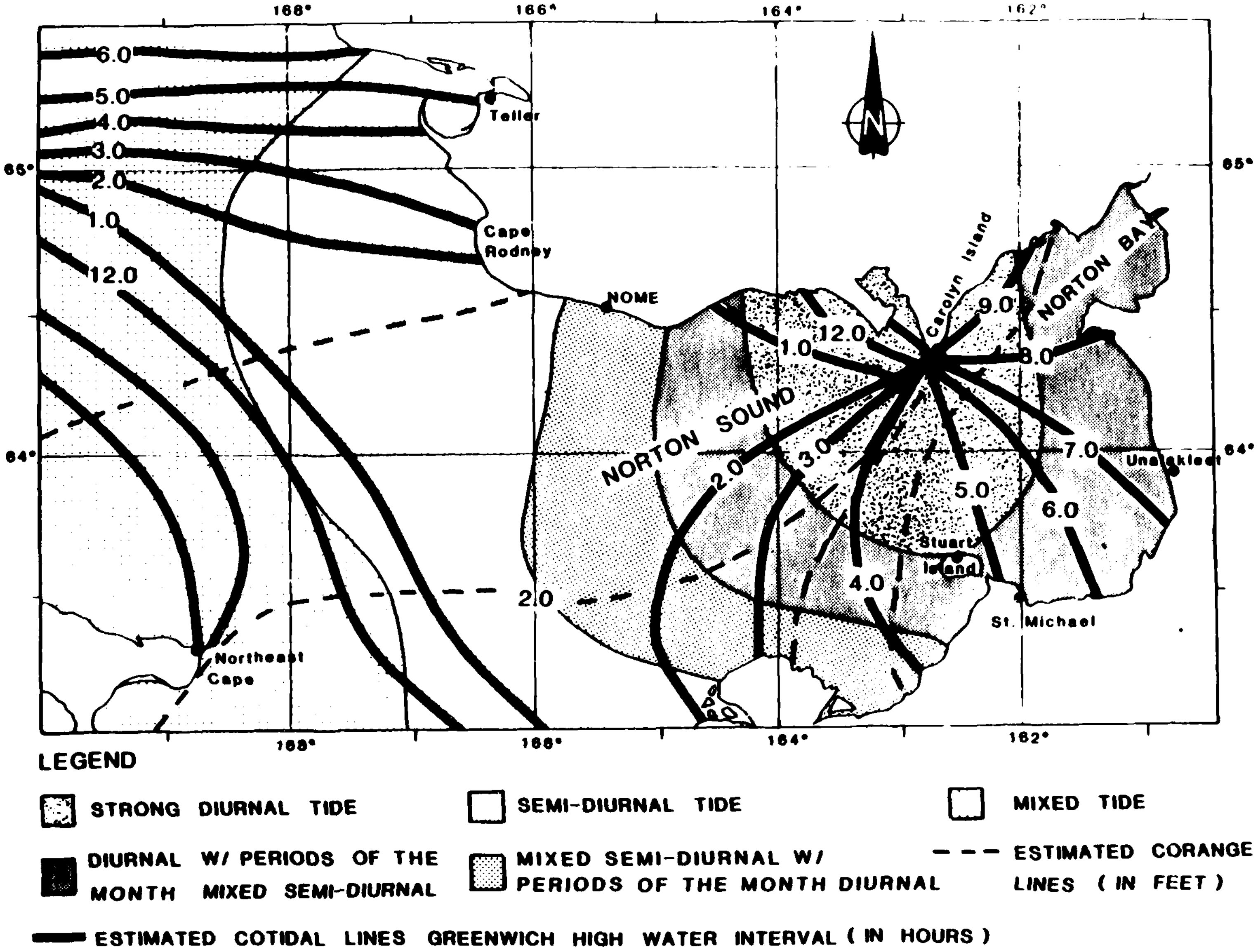


Figure 1.4-1. Norton Sound Cotidal, Corange and Diurnal-Semidiurnal Distributions.

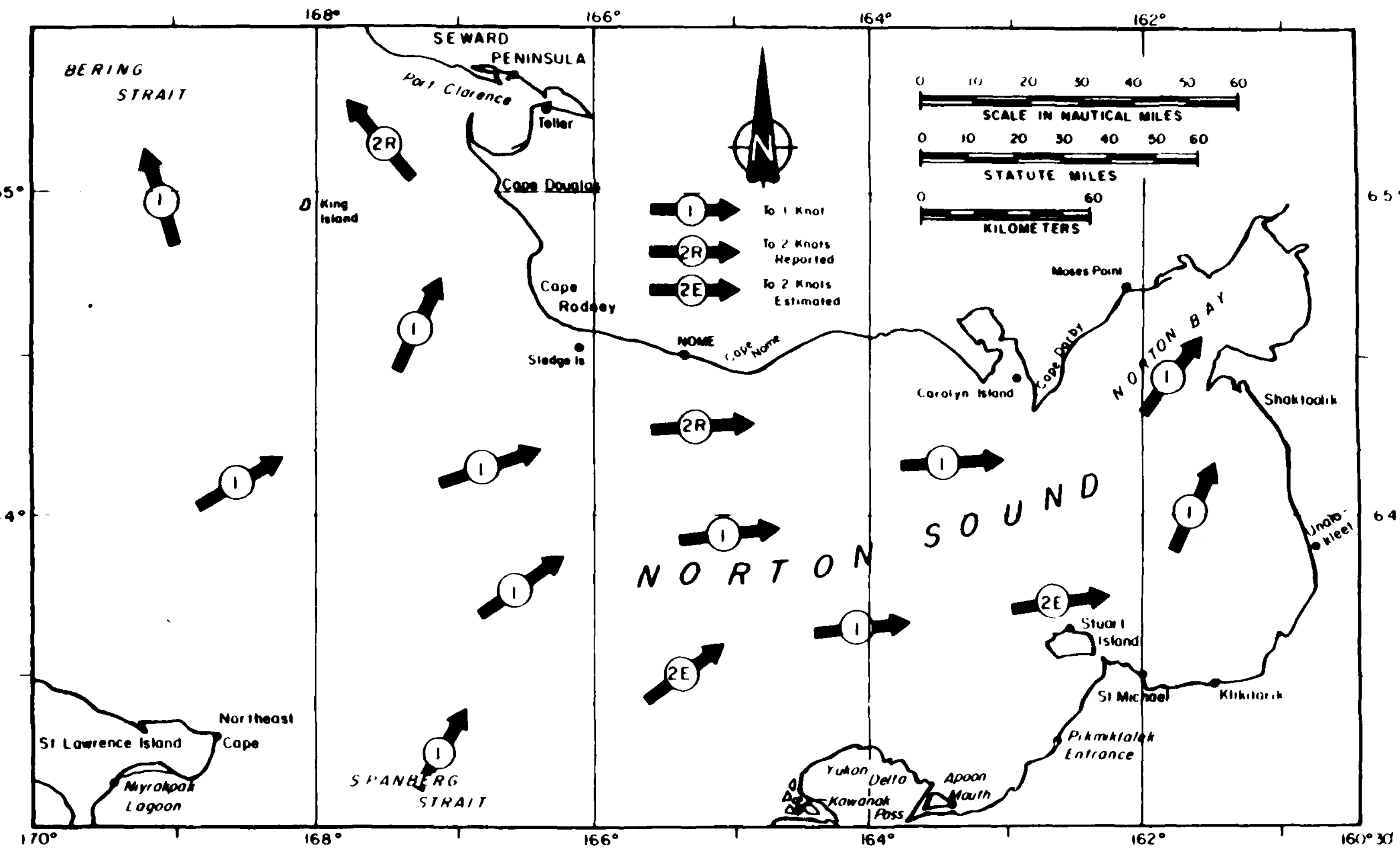


Figure 1.4-2. Arrows indicate direction and magnitude of flood tide currents.

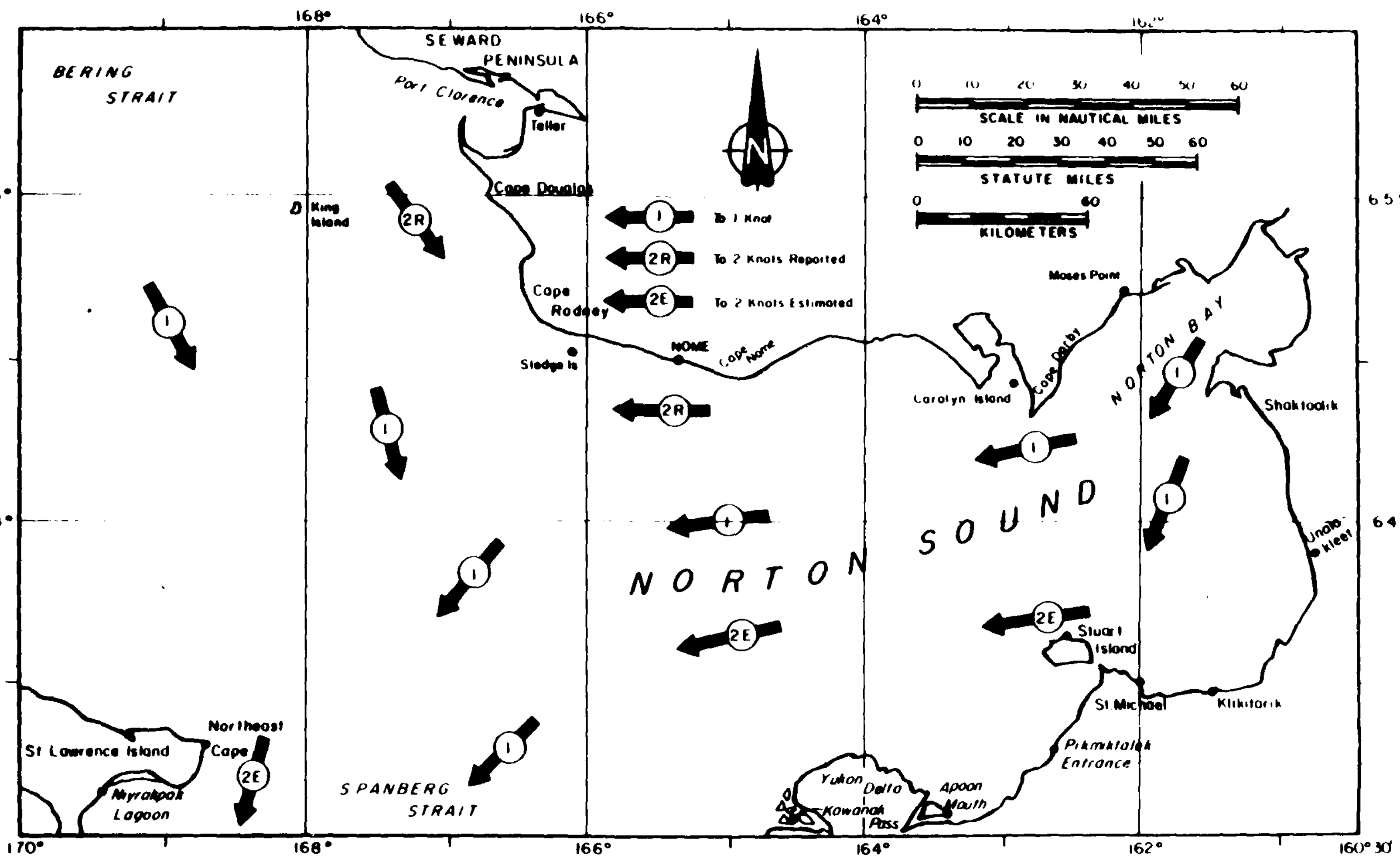


Figure 1.4-3. Arrows indicate direction and magnitude of ebb tide currents.

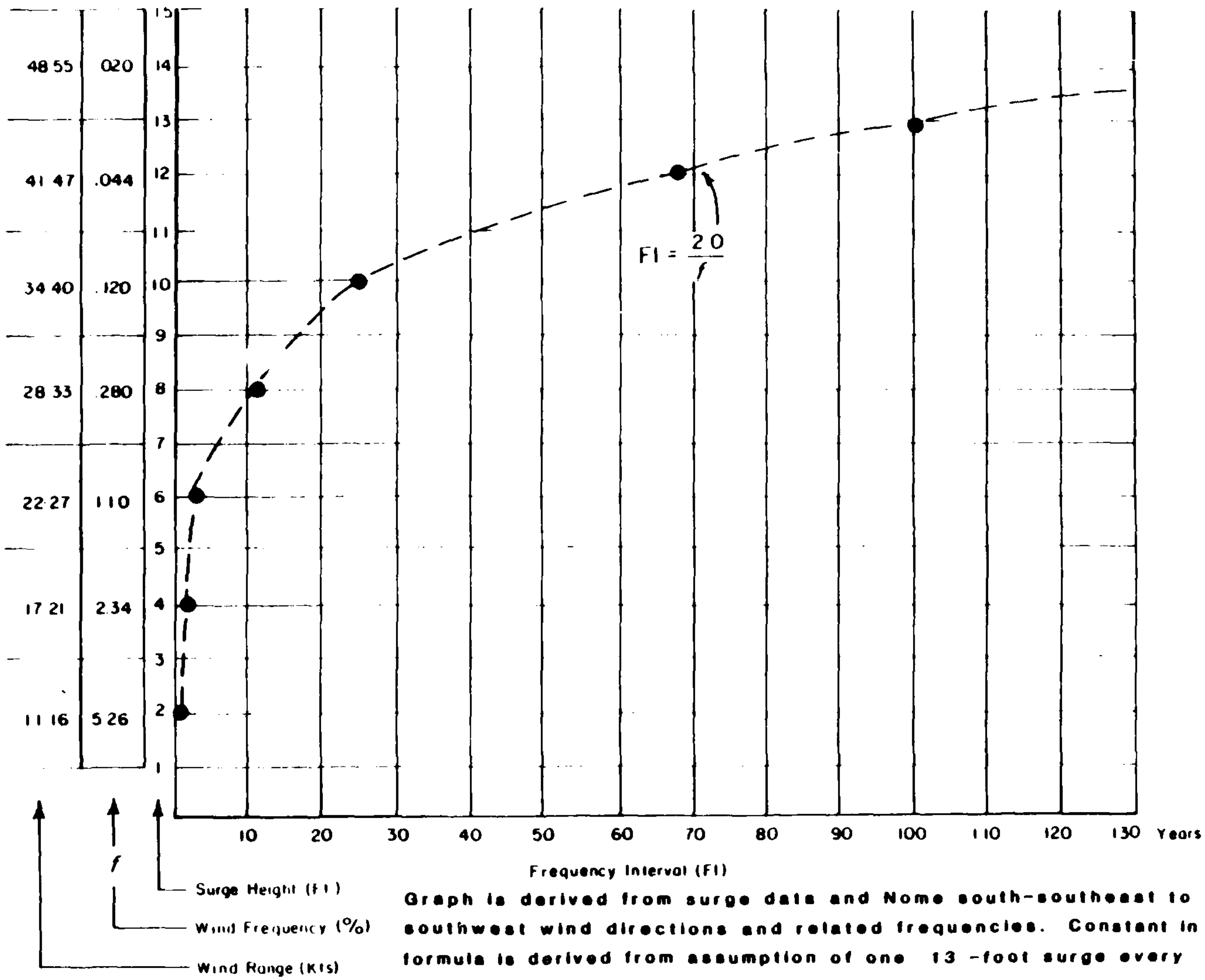
1.5 Storm Surges

Storm surges are not infrequent in the Norton Sound area. Figure 1.5-1 depicts the frequency of surges of varying heights (Wise and Comiskey, 1981) along one section of the Norton Sound Coast. Figure 1.5-1 relates wind speeds to the height of positive surges (heights above predicted water levels). Some wind directions can cause negative surges (heights below predicted water levels). Significant surges occur only during open water periods and are most commonly related to fall storms. Significant surges, in addition to causing wave and flood damage to the coastline area, can cause an extra-ordinary spread of oil over the beaches and low-lying coastal areas. Additional storm surge information can be found in Sections 2.8, 3.5, 4.6, and Appendix E.

1.6 Sea Ice

Sea Ice may affect the rate of spread of oil, its concentration (both horizontal and vertical), and is most likely to impede clean-up efforts.

Ice begins to form in the northeastern portion of Norton Sound in October. The eastern half is essentially ice covered by mid November. Except during occasional strong east to northeast wind episodes, the area is almost 100 percent ice covered until late April. Coverage is less than 50 percent by mid May and the area is ice free by the end of May (LaBelle, 1983). The shorefast ice acquires a thickness of 1.5 to 1.8 m due to freezing degree days and additional thicknesses because of shearing and compression forces. The pack ice probably averages less than 1 m in the thickest portion of the pack during the winter cycle. Although the pack ice forms in eastern Norton Sound, the maximum thickness occurs farther to the west as the ice migrates from east to west and continues to thicken. A more detailed description of the ice situation is contained in Section 6.0. Figure 2.4-1 depicts average ice cover in Norton Sound.



Graph is derived from surge data and Nome south-southeast to southwest wind directions and related frequencies. Constant in FI formula is derived from assumption of one 13-foot surge every 100 years.

Figure 1.5-1. Surge Height - Frequency Curve for Northern Coast of Norton Sound.

2.0 Factors Affecting Oil Spill Transport

2.1 General Circulation

Norton Sound can be characterized as a shallow subarctic embayment within which the water properties and general circulation are driven, at least in part, by the Alaska Coastal current which flows north parallel to the Alaska coast toward the Chukchi Sea. A portion of this flow enters the southern area of the Norton Sound and induces a counterclockwise flow within the sound. The strength of this general flow is dependent upon conditions in the Pacific Ocean and Bering Sea. Speeds have been reported (Drake et al., 1980 and Moser, 1984) as pulses of 50 to 100 centimeters per second offshore. Most of the river discharge from the Yukon River is entrained in this coastal flow and enters the Norton Sound counterclockwise circulation. (See Figure 2.1-1).

Water enters the southern part of the Sound and flows out along the northern part. The westward flow of water along the south coast of the Seward Peninsula is a common feature, but it may vary in intensity and extent.

The circulation pattern also extends, with varying intensity, into the eastern part of Norton Sound. Here the upper layer is more intense while circulation in the lower layer appears to be sluggish for the most part. A strong pycnocline separates the two lower layers and very little of the horizontal motion in the upper layer is transmitted to the lower layer. During the summer, waters in the eastern part of the Sound show a tendancy to become more strongly stratified than the western waters. If vertical mixing or horizontal replacement does not occur, the water in the lower layer becomes stagnant. However, severe summer and fall storms are capable of breaking down this stratification and replacing the lower layer in a period of a few days (Muench et al, 1981).

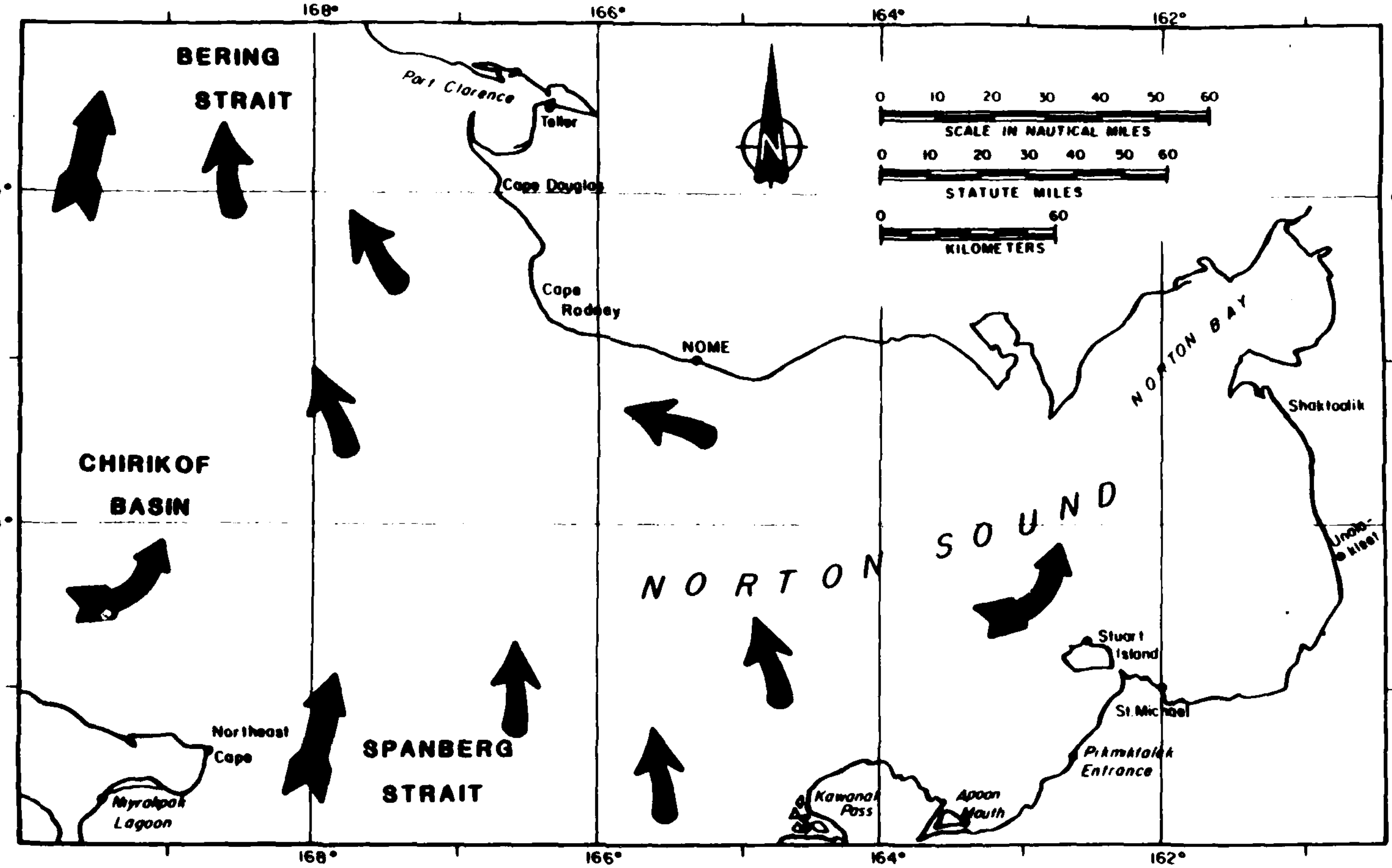


Figure 2.1-1. General circulation of current in Norton Sound, directions are depicted by arrows. Current speeds may reach up to 180 cm/sec in the Bering Strait and up to 100 cm/sec elsewhere but only in pulses which may be tidally induced. The net northward flow is 15 to 25 cm/sec with the strongest flows in the Bering Strait, Spanberg Strait, and Anadyr Strait (west of Chirikof Basin).

The mean speed of surface currents in the western part of Norton Sound ranges from about 5 to 20 centimeters per second; the maximum velocity was about 50 centimeters per second (Muench et al, 1981). (These currents were measured in the fall of 1976 and are not representative of the very near surface currents, i.e., within 5 cm of the sea surface). Bottom current speeds are about 10 to 20 centimeters per second in the western part of the Sound and less than 10 centimeters per second in the eastern part (Drake et al., 1980).

2.2 Tidal Currents

Astronomical tides within Norton Sound are predominantly diurnal (one high and one low each day) except near the entrance where semi-diurnal components are also important. The height of these tides range from negligible to approximately 6.8 feet. The high and low tides occur at different times at different locations as the water level changes within the sound. Because of the phase difference a tidal current is produced. In Norton Sound, the embayment is oriented east-west and tidal currents varying from 0.7 to 1.1 km/hr are oriented east to west.

Near shore where channels or restrictions exist, current will align with the configuration of the shore line or bathymetry and increase in speed. These conditions occur just south of Nome where a deep channel is located which runs east west, near Golovin Bay where the currents run north and south, between Sledge Island and the mainland, and in the Yukon Delta where deep channels control the tidal current speed and direction.

Tidal currents for flood and ebb are essentially as depicted on Figures 1.4-2 and 1.4-3. The tidal current speed values are estimated to be the maximum that may occur during the flood or ebb cycle (Starr et al., 1981; Muench, 1980; NOS, 1979). It is recommended that the OSC refer to the United States Coast Pilot 9 (USCP 9) when in the Norton Sound area or to this atlas; however, the problem of the prediction of tidal current speeds is relatively minor when compared to the prediction of times of flood or ebb, which drastically affect the direction of flow.

As mentioned in Section 1.4, a amphidromic point exists in the northeastern portion of Norton Sound near Carolyn Island. A amphidromic point is generally defined as an area of no tide; however, the tide level at the Norton Sound amphidromic point actually rises and falls about 2 ft (.61 m) as shown by the co-tidal lines on Figure 2.1-2. This situation might best be explained by visualizing a rapid rise in water level shortly after slack tide (0-3 hours) at the amphidromic point.

At the amphidromic point, the tide level remains high while the tidal crest to the southwest rotates counterclockwise. This takes about 12 hours and the tide is relatively high at the amphidromic point much of this time. The tide then falls at the amphidromic point and remains low for an equal period of time while the tidal trough rotates around the amphidromic point.

This brief explanation of Norton Sound tidal anomalies, or aberrations, is included because an oil spill may not occur near a tidal reference station. If it does not, calculation of periods of flood or ebb can be seriously in error if not impossible using coastal reference stations. The spilled oil will have a short term (approximately 12 hours) tidal direction component which when considered along with wind induced components, will make short term trajectory forecasting more accurate. Long term (more than 24 hours) tidal effects on oil spill trajectories are negligible.

2.3 Wind Driven Currents

Wind driven currents are most important when considering oil spill transport. The wind and coriolis force determine both the speed and direction of oil spill trajectories. In brief, the speed of movement is 2 to 5 percent of the wind speed. A single

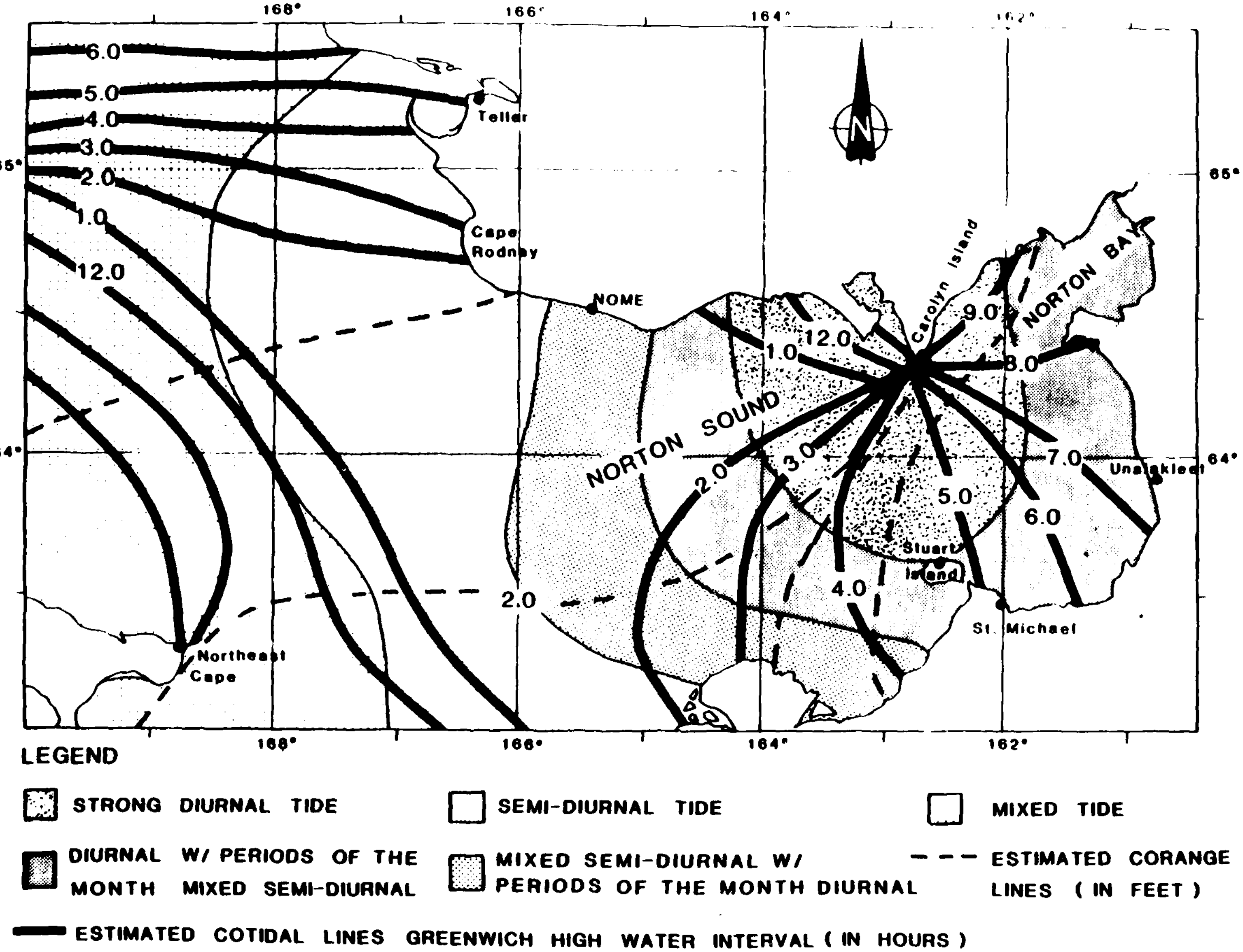


Figure 2.1-2. Norton Sound Anomalies

value of 3 percent may be used, but it is easily possible to subjectively derive a more accurate estimate by injecting known relationships between wind speed, sea roughness, and boundary layer stability.

In summary, the direction of oil movement will be in the same direction as the gradient wind (Hughes, 1956), or 25 to 30 degrees to the right of the actual wind when measured at an elevation of 10 to 20 m (Overland and Pease, pers. comm.). Tidal effects will modify the rate of oil movement for relatively short periods of time but the net affect is near zero. With an onshore wind, the oil will approach the coast at varying speeds determined by the tide. However, with offshore winds, the oil is not likely to move onshore even with an adverse tide because the net water transport <u>on the surface</u> of the ocean will be offshore. It is possible for locally strong and persistent indigenous currents (not caused by winds or tides) to significantly affect oil movement, but no such currents are known at this time. An example of this type of current is described in the United States Coast Pilot 9 (USCP 9)just offshore Barrow, Ak. (NOS, 1979).

2.4 Ice Coverage

Ice begins to form in the northeastern portion of Norton Sound in October. The eastern half is essentially ice covered by mid November. Except during occasional strong east to northeast wind episodes, the area is almost 100 percent ice covered until late April. Coverage is less than 50 percent by mid May and the area is ice free by the end of May (LaBelle, 1983). (See Figure 2.4-1). The shorefast ice acquires a thickness of 1.5 to 1.8 m due to freezing degree days and additional thicknesses, because of shearing and compressional forces. The pack ice probably averages less than 1 m in the thickest portion of the pack during the winter cycle. Although the pack ice begins in eastern Norton Sound, the maximum thickness occurs farther to the west as the

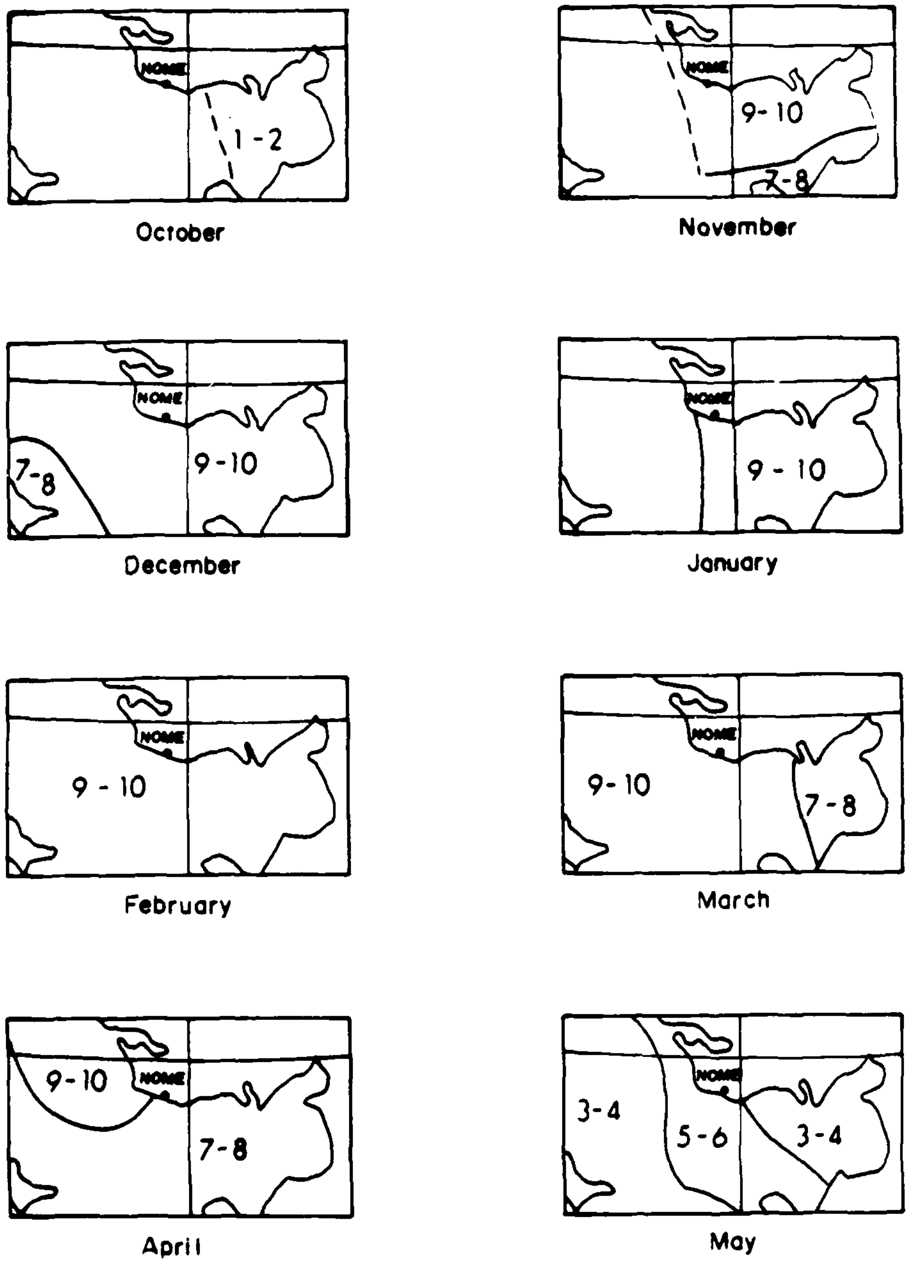


Figure 2.4-1 Average ice cover in tenths in Norton Sound. Dashed lines indicate most probably ice edge. Note lesser concentrations of ice in eastern Norton Sound in March, April, and May. (LaBelle and Wise, 1983).

ice migrates from east to west and continues to thicken. A more detailed description of the ice situation is contained in Section 6.0.

2.5 River Discharge

Most of the Yukon River is discharged directly into the Bering Sea from the west side of the delta (Muench et al., 1981). The discharge mixes with the water flowing northwesterly past the entrance to Norton Sound, and some of this water may enter the southern part of the sound as part of the general circulation pattern (Cacchione and Drake, 1979). However, part or all of the Yukon River discharge may flow south of St. Lawrence Island when the winds are from the north, when the tide is ebbing, or when both phenomenon occur simultaneously (Ingraham, 1981). A minor amount of river water is discharged directly into the southern part of the sound.

The discharge of Yukon River water varies seasonally. The lowest discharge rates occur from December through March. In April, the discharge rate begins to increase rapidly. This rate reaches a maximum in June; but, at peak discharge, the Yukon River contributes only about 2 percent of the water flowing through the Bering Strait (Kinder, 1981). From July through November, the discharge rate decreases rapidly.

The waters discharged from the Yukon River are quite turbid. Satellite photographs show bands of turbid water extending along the western and northern sides of the Delta and across the entrance to Norton Sound (Feely et al., 1981). The concentration of suspended material in the surface water is greatest near the river mouths and decreases seaward. The suspended matter from the Yukon River enters Norton Sound principally from the southwest and is transported through the sound in a counterclockwise manner.

Analyses of satellite imagery also indicate the presence of two areas of relatively clear water lying offshore between the mouths of the tributaries along the northern and western sides of the Yukon Delta (Zimmerman, 1982). The appearance of these clear areas in the turbid waters along the delta is a phenomena that is poorly understood.

The extent to which a saltwater wedge reaches upstream beneath the surface outflow in the major distributaries is not known in detail, but during periods of low discharge, brackish water is found near the surface at St. Mary's, approximately 160 kilometers from the sea (Zimmerman, 1982).

During the open water season, the freshening of the water near shore by runoff and high insolation rates overall cause a high degree of water-column stratification. This stratification is a significant feature which dictates the circulation in Norton Sound. As a result, the upper-layer circulation is largely uncoupled from that of the lower layer.

2.6 Temperatures - Oceanographic and Atmospheric

Atmospheric temperatures along the coast of Norton Sound average from -24°C to -7°C in winter and from 10°C to 13°C in summer with extremes from -48°C to 30°C (Selkregg, 1976).

Water temperatures in Norton Sound range from 10°C in the central part to 16°C in the eastern part during the summer and -1.85°C in winter (essentially the freezing point). The mean temperature of the bottom water increases from 2°C or 3°C in the western part of the sound to about 8°C in the eastern part.

2.7 Bathymetry

The Ocean Bottom is relatively featureless, or flat, with the following exceptions. A relatively deep area to 29 m is located south of Golovin Bay. An east to west trench to 33 m is located offshore Nome. Depths to 50 m or more can be found in Spanberg Strait (between St. Lawrence Island and the Yukon Delta), and again in the northwest corner of the atlas area (Figure 1.1-1).

2.8 Storm Surges

Storm surges are a factor affecting oil spill transport because of the related flooding of low lying land. During a storm surge, surface-borne pollutants can be transported well beyond the normal shoreline. Past storm surge heights have been poorly documented because of superimposed wind waves, absence of tide gauges, and lack of detailed topographic maps along the coast. One of the best documented surges was a surge of 4 m at Nome during a severe storm November 12, 1984. A 4 m surge probably occurs on an average of once every 100 years. A surge of 3 m about once every 25 years and a surge of 2 m about once every 5 years (Wise and Comiskey, 1981). Within the atlas area, the highest surges (to 4 m) occur along the northern shores of Norton Sound; the eastern shore to 3.4 m; and the southern shore (Klikitarik to the Yukon Delta) 2.5 to 3.0 m. No specific heights have been reported from southern Norton Sound, but storm surge flooding has been reported as far as 7.8 nm inland on the lower Yukon Delta. Surges along St. Lawrence Island are probably less than 2 m because of relatively good return flow conditions created by bathymetry and topography. Surges to 2 m are most likely only along the southern coast and then only in the area of Maknik Lagoon, and the shallow bight between Siknik Cape and Southwest Cape (just out of atlas area).

In summary, if a storm occurs during an oil spill episode, the oil will move rapidly with the wind driven currents. If the oil reaches the coast, it will penetrate inland over low lying areas. Its extent of penetration is dependent on the storm surge height and height of the land. For a more detailed discussion of storm surges, see Section 4.6.

3.0 Factors Affecting Oil Spill Containment or Mitigation

3.1 Net Surface Currents

The current observed near the surface of the sea can be divided into its component parts based upon the driving mechanisms. In general, this current is the vectorial summation of wind driven current, tidal current, wave induced drift, and general oceanic induced circulation. The last component, oceanic induced circulation, is the current which would exist in Norton Sound in the absence of any local wind field or tidal effects. If a wind of 15 to 20 knots is blowing during clean up operation, the oceanic induced circulation is of little or no significance.

Net surface currents are the resultant currents derived by combining general circulation currents (see Section 2), tides (Section 2.2), and wind driven currents (Section 2.3). General circulation is weak - usually less than .25 m/s (DOI MMS, 1985). In addition, general circulation includes movement within the entire water column. The surface component of general circulation is almost always overcome, obscured, or masked by the much stronger tidal and wind-driven currents. General circulation currents have little significance when computing oil spill trajectories, or when deploying equipment.

Tidal currents are significant reaching speeds of 05 m/s to 1.0 m/s during maximum flood and ebb with maximum speed estimated to be within 2 hours of change of tide. Keep in mind that in much of Norton Sound, the tide changes diurnally (about every 12 hours). The average tidal current during flood or ebb may be less than 50 percent of maximum flow in northern Norton Sound and less than 75% of maximum flow in southern Norton Sound. For short term calculations of net currents, the tidal component of current speed would be used to derive the net current. For long term calculations, the tidal current can be ignored because of its oscillatory nature.

Thus, the net current is the combined components of the tidal current and the wind-driven current (short term), or, for long term, only the wind driven currents. See Section 2.3.

3.2 Sea Conditions

The wave character of the sea surface including height, period and direction is critical to the ability of ships, crew, and equipment to successfully operate containment and cleanup operations. Therefore, knowledge of the range of wave conditions expected during the open water season is essential.

Wind wave generation occurs when wind blowing over open water transfers energy to the sea surface through surface stress. During the period May through October or occasionally November, open water exists in Norton Sound and wave conditions control activity at the air sea interface. During the period, prevailing winds are from the east to north quadrant. Therefore, along the north and east shores sea conditions are quite mild. However, as you move farther offshore, wave heights increase and longer waves occur along the southern shoreline. The longest waves come from winds blowing from the south and southwest. Such conditions usually occur in the late fall or early winter.

A description of the wave statistics for the Norton Sound area is discussed in Section 4.2.

3.3 Ice Coverage

Ice begins to form in the northeastern portion of Norton Sound in October. The eastern half is essentially ice covered by mid November. Except during occasional strong east to northeast wind episodes, the area is almost 100 percent ice covered until late

April. Coverage is less than 50 percent by mid May and the area is ice free by the end of May (LaBelle, 1983). See Figure 2.4-1. The shorefast ice acquires a thickness of 1.5 to 1.8 m due to freezing degree days and additional thicknesses because of shearing and compressional forces. The pack ice probably averages less than 1 m in the thickest portion of the pack during the winter cycle. Although the pack ice begins in eastern Norton Sound, the maximum thickness occurs farther to the west as the ice migrates from east to west and continues to thicken. A more detailed description of the ice situation is contained in Section 6.0

3.4 Ice Character

Ice character refers to the type of ice occurring in the ice pack. Of most importance, is the undisturbed floes. These types of floes are characterized by large areas of new ice forming under low wind conditions and not subjected to compressional or shearing forces so as to deform, or crush the floe except at its edges. As the floe thickens, its resistance to deformation increases, but it frequently migrates along with other thickening ice forms so that the potential for deformation also increases. The ice is subjected to external (wind and tidal) forces and these forces frequently overcome the structural strength of the ice floes. When this happens, large floes are broken into smaller floes. If the forces are strong and persistent, the disintegration of the flow continues until only "rubble" remains. If, because of cold temperatures, the rubble is frozen together, the result is a "rubble floe".

While all these forces are acting, other processes are taking place wherein new ice is forming in various shapes ranging from pancake ice to large ice floes but of different thickness than the older ice. The end result is a semi-organized spectra of floes, rubble and different thicknesses. In general, there will be more undisturbed floes in northern Norton Sound and more rubble in southern Norton Sound. The ice is thickest in eastern

Norton Sound in early winter but the thickness crest migrates westward and southward with the ice pack during middle and late winter as the ice continues to be subjected to freezing temperatures as it moves from eastern Norton Sound. Eastern Norton Sound is a polynyna area with new ice being formed there. Occasional warm easterly winds will move the ice pack westward leaving nothing but open water in eastern Norton.

Shore ice is the exception. It will occasionally break away from the shore, but for the most part, remains shorefast. Shorefast ice is most likely to resemble undisturbed floe ice, except where it has been deformed by interaction with the pack ice. The shorefast ice is also about twice as thick as the thickest pack ice and about three times as thick as average pack ice. A less generalized discussion of ice character is contained in Section 6.2.

3.5 Storm Surges

See Section 2.8 for a brief discussion of storm surges. For oil spill containment or mitigation relating to storm surges, it is sufficient to say that an oil spill may be driven past traditional shorelines. But it may not be possible to take mitigating action, such as booms, etc. because of the related storm conditions of wind, waves, and weather. Storm surges can occur along coasts with offshore winds, put present no oil spill pollution hazard, because the oil is being transported away from the coast. For a more detailed discussion of storm surges, see Section 4.6.

3.6 Superstructure Icing

Superstructure icing is the freezing of liquid water on structures. The structures can be on land, or on or near water. Those structures on or near water are herein defined as marine structures. This discussion is restricted to superstructure icing on marine structures.

Icing can occur from spray caused by waves hitting the marine structure (freezing spray), spray being blown off the crest of waves (spindrift), freezing rain or drizzle, snow mixed with any of the above, and supercooled water droplets (fog). Numerous observations confirmed by various studies indicate that the major cause of superstructure icing is freezing spray. This is particularly true in Alaska and in Norton Sound.

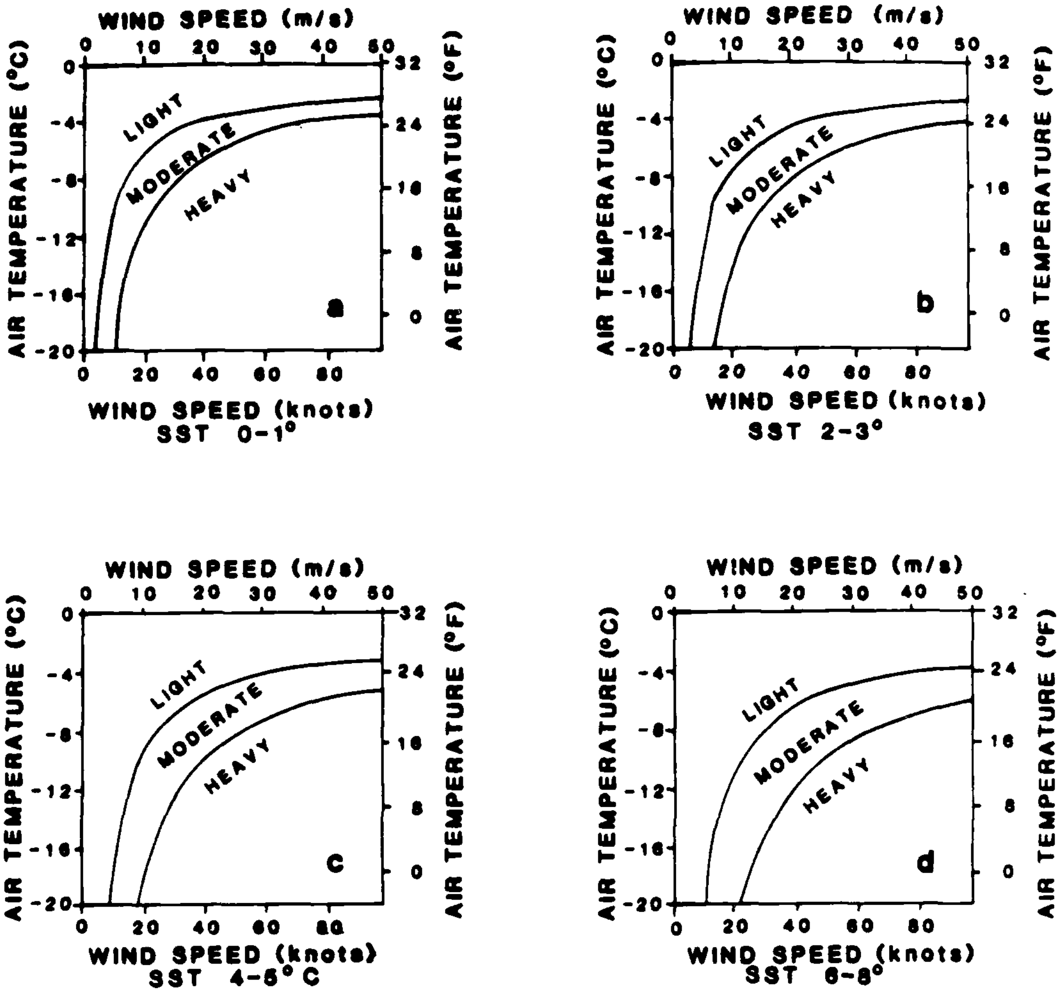
The file on superstructure icing research in North American is quite small. Canadian researchers (Stallabrass, 1980; Lozowski and Gates, 1984; and others) spent considerable time and resources investing and developing mathematical and physical superstructure icing models. Their major stumbling blocks were the lack of data and the lack of quality data from which they could verify, or tune, the mathematical models. Consequently, models were derived, but nobody knew how well they worked.

On the other hand, U.S. Investigations (Wise and Comiskey, 1980) made a brief attempt to compile a data base and concluded that resources were not available at that time for an adequate effort. Subsequently, they adapted, for use in Alaska, nomograms derived by a German meteorologist (Mertins, 1968), based on Atlantic trawler data. A few years later, Comiskey et al., 1984, compiled a set of data from ships and boats operating in Alaska waters. New superstructure icing rates were suggested that more than doubled the past forecast rate of ice accumulation. Overland (1985) developed, from the data, an algorithm for the prediction of superstructure icing. The algorithm predicted "potential" superstructure ice which is defined as the maximum icing rate likely to be encountered by a ship or boat which is moving into the wind. That is, not running before the wind or taking other evasive action. Overland's algorithm forecast three times the amount of icing indicated on the Wise, Comiskey, Mertin's nomograms. The difference is explainable in that the Mertin's data must have included a large number of downwind cases. That is, many of the trawlers were running downwind during icing episodes, which one might expect.

At any rate, Pease and Comiskey (1985), using the Overland algorithmn, developed nomograms for the prediction of potential superstructure icing. The data set was also published in the same paper. The nomograms developed are shown in Figure 3.6-1. These nomograms are recommended for forecasting superstructure icing rates.

The interpretation of the forecast rates requires some thought by the user. For instance, a forecast of heavy icing with low wave heights means little to a large ship because the freezing spray may be well below the main deck line, and the center of gravity of the ship is not significantly affected. However, with heavy seas, spray may come over most of the ship and freeze on the superstructure.

Icing events in Norton Sound are not expected to be numerous, because of the unique set of circumstances required. The essential requirements are cold winds over ice free, or mostly ice free waters. Cold winds over open water are most likely to occur in early winter before the sound freezes. The cold wind direction is most likely to come from the east through north, or at least with a northerly component. In these cases, the nomograms may predict heavy icing, but few boats or ships would be significantly affected because of the limited wind fetch and low wave heights. However, with surface borne equipment of small size or low freeboard, icing can be heavy if spray is generated. For instance, a small aluminum whaling boat of 5 - 6 m could experience heavy icing in seas over 0.3 - 0.4 m if running into the wind. Booms and skimming equipment could experience the same problem although to a much lesser extent on the booms because of their relatively stationary position. However, the booms could



Icing conditions for vessels heading into or abeam of the wind for water temperatures of +5°C (41°F)

Light icing -Less than 0.7 cm/hr (0.3 in/hr)

Moderate icing - 0.7cm/hr (0.3in/hr) to 2.0cm/hr (0.8in/hr)

Heavy icing - Greater than 2.0 cm/hr (0.8 in/hr)

SST - Sea Surface Temperature

Figure 3.6-1. Nomograms for prediction of potential superstructure icing rates. Potential is defined as the maximum icing rate likely to be encountered by a ship or boat which is moving into the wind. That is, not running before the wind or taking other evasive action.

lose some of their buoyancy with ice loading, or they may roll if top heavy with ice. These factors might be considered in boom design.

In conclusion, superstructure icing is a function of the generating phenomena (wind, temperatures and seas) as well as the characteristics of the receivers of icing. The characteristics of receivers are ships size, configuration, heading, percent of heated surfaces, sensitivity to wave action, etc. Some of the above can be collectively defined as the spray characteristics of the vessel. Each vessel, or class of vessels, has its own signature spray characteristics and these spray characteristics should be considered when operating in areas of possible superstructure icing.

3.7 Bathymetry

The ocean bottom is relatively featureless, or flat, with the following exceptions. A relatively deep area to 29 m is located south of Golovin Bay. An east to west trench to 33 m is located offshore Nome. Depths to 50 m or more can be found in Spanberg Strait (between St. Lawrence Island and the Yukon Delta), and again in the northwest corner of the atlas area, Figure 3.7-1 (same as Figure 1.1-1).

3.8 Ceilings and Visibilities

3.8.1 Background Information

Very little ceiling and visibility data exists for Norton Sound. Marine traffic consists primarily of itinerant bulk cargo ships scheduled once or twice a year, a few tugs and barges, an occasional geophysical survey ship, and random visits by U.S. Coast Guard and NOAA ships. During the last several summers, exploratory drill rigs have taken observations in the sound but the data has not been processed. Therefore, aircraft operators, dispatchers, and government and private meteorologists rely on

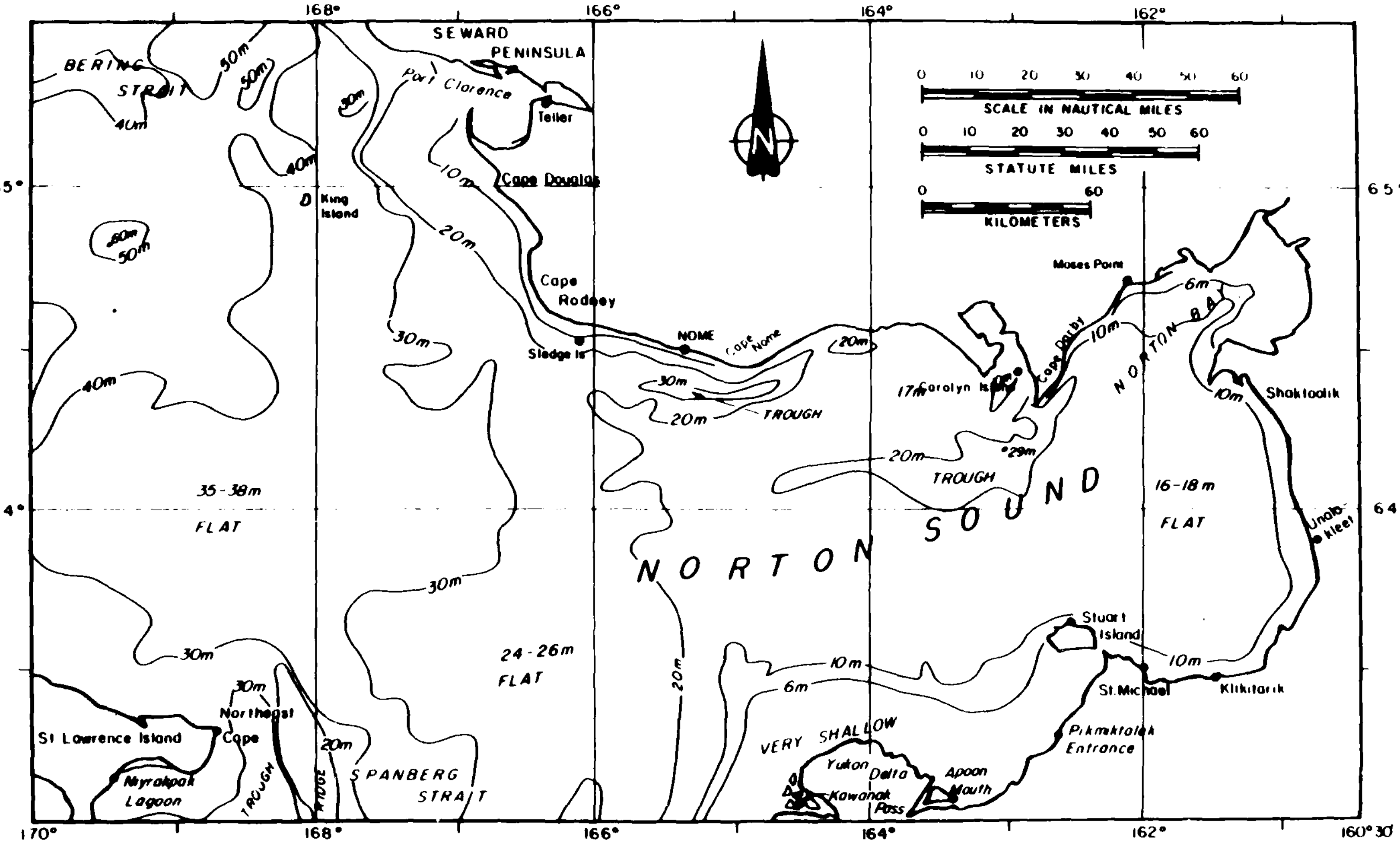


Figure 3.7-1. Bathymetry of Norton Sound. Contours are labeled in meters. See NOS Nautical Chart 16200 or 16006.

observations from shorebased stations and from drilling rigs, if available. Two persistent deficiencies in providing forecast services have been identified. The shorebased observations are not always representative of weather conditions over the water and there is a general deficiency of overwater forecaster expertise. This lack stems from little experience (most forecasters spend their careers forecasting overland conditions), lack of data, intermittent requirement of services, priorities, and personnel management.

3.8.2 User and Forecaster Guidelines

The present service deficiencies can be improved somewhat by carefully considering the height of reporting stations, the conditions being reported, and the air-sea temperature difference. Consideration of these factors may indicate only one or two hundred feet difference in ceilings which may be significant to aircraft operations. Sometimes a difference of 500 feet may be significant to fixed wing operations.

Persistent low ceilings and visibilities are usually related to stable atmospheric conditions. If the low conditions are caused by clouds or fog, they tend to be uniform, except when differences of elevation are involved and when the air moves from over water to over land or visa versa. Because all present shorebased observations are at an elevation of less than 50 feet, the elevation correction for ceilings is not significant. The observations from ships is generally less than 65 feet. Observations from drill ships are usually near 100 feet and from other drilling rigs 100 to 200 feet (except the wind which could be measured as high as 300 feet). If the observer made an error of reporting the ceiling from his reference level rather than sea level, that observation should be corrected for sea level. When operation ceilings are marginal, efforts should be made to ascertain the exact ceiling level. Sea surface temperature (SST) is also a factor relating to consistency or reliability of ceiling height observations. Before discussion that, the combination of ceiling and visibility values should be considered.

The nature of extensive sea fog is that it tends to be uniform. Theoretically, when fog is uniform, the vertical and horizontal visibilities should be identical. In practice, this does not appear to be the case, possibly because the fog (suspended water droplets) are more dense at 400 to 500 feet above the ground than at the surface. This may or may not be true but a reported ceiling of 200 feet obscured and a visibility of 1/16 of a mile is reasonably consistent even though the visibility (in the horizontal) of 300 feet is 1.65 times the vertical visibility. Even when a visibility of 1/8 mile is reported with a ceiling of 200 feet obscured, the observation might withstand scrutiny, but the horizontal visibility is now 3.3 times the vertical visibility. Because the visibility is normally the more accurate of the two measurements or estimates, it becomes likely that the ceiling is estimated or "measured" too low. Users should be aware that measured ceilings can be varied simply by tuning the ceiling measuring equipment. Thus, whenever visibility to obscured ceiling ratio exceeds 3.0, the ceiling should be suspected of being too low. The same rule does not necessarily apply to low cloud ceilings (as opposed to obscured ceilings); even so, ratios of over 3.0 are unlikely when the visibility is below 1 mile.

The most neglected tool is the difference between the air temperature and sea surface temperature. When the SST is higher than the air temperature, the ceiling will accurately reflect the difference. This relationship has been observed and is substantiated by the laws of atmospheric physics. If the SST is higher than the air temperature, the layer of air near the surface of the sea is unstable so that moisture emanating from the sea is rapidly mixed throughout the unstable layer with a ceiling developing near the top of the unstable layer. The depth of the unstable layer is partially determined by the air-sea temperature difference. The greater the difference (SST higher), the higher the ceiling. The actual height of the ceiling at any given time depends on the vertical temperature profile of the air as well as SST. A profile that already tends toward instability will indicate a higher ceiling than one that tends towards stability. Further discussion exceeds the scope of this atlas, but the fact that high SST "holds up the ceiling" should be useful to any aviator operating in marginal conditions over water.

When the SST is lower than air temperature, the lowest layer of air becomes very stable. Moisture from the sea is trapped near the surface and low ceilings and visibilities are common. As the difference increases, the probability of lower ceilings, lower visibilities, and persistence increases. The ceilings will be obscured by fog as opposed to low clouds created by high SST. The extensive fog created over the entire Bering Sea and Norton Sound during the summer is typical of the type of low ceilings and visibilities generated by low SSTs.

3.8.3 Recommendations for maximizing aircraft support services

The simple aspect of whether or not observational elevations need adjusting can usually be determined by the user. It would be beneficial to question or observe closely, the observers ceiling biases from drill platforms.

It is also simple to check the visibility -- ceiling ratio for surface-based obscurities (fog, drizzle). If not satisfied, query the observer; if still not satisfied, ask for a balloon measurement. The last recourse is measurement with any suitable aircraft, usually a helicopter. Observer awareness that his observations are closely scrutinized will usually equate to higher quality observations.

The matter of SST versus air temperature is not so simple. It is helpful if the user remembers that warm SSTs will hold up the ceiling. THe SST changes little from day to day; however, the air mass temperature may change. If the air mass warms, the ceilings will drop; if the air mass cools, the ceilings will rise. Of course, there are exceptions generated by atmospheric dynamics, but for long-term ceiling and visibility forecasts, the above generalities are useful.

In spite of the useful generalities, it is strongly recommended that the regional response team (RRT) make provisions to have one or more meteorologists specifically delegated to support RRT activities. The meteorological support can come from either federal or private resources, but with the assurance that their energies are devoted primarily to RRT activities and not as an add-on to present meteorological services being provided by them.

If an atmospheric sounding is not available nearby, consideration should be made to request on-site or near-site soundings. These near-site soundings improve the quality of all meteorological forecasts as well as oceanic-atmospheric interface forecasts (currents, ice movement, spill movement, and superstructure icing).

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4.0 Ocean Waves

4.1 Fundamental Concepts

Waves formed in a generation area are called sea. Three factors influence generation of sea waves: wind velocity, time (or duration) over which the wind blows, and fetch distance across which the wind blows. Waves become higher and steeper until a limiting point is reached after which individual waves break forming white caps. Waves travel across the ocean at speeds which are proportional to their wave lengths. Longer waves may leave the generation area as fast moving low frequency swell. Figure 4.1-1 illustrates wave growth to full development, propagation as swell, and dissipation on distant beaches as surf.

Sea waves have shorter periods and are generated locally while swell waves are generated over large areas of open water and have longer periods. The coastal configuration of the sound and the presence of sea ice restrict swell propagation to directions from the southwest during the open water season.

Wave heights discussed in this section are significant wave heights (H_s). The significant wave height is defined as the average value of the heights of the one-third highest waves in a given observation. The following table presents the relationship between H_s and other reported heights.

$$H_{1/20} = 1.22\ H_s$$

$$H_{1/100} = 1.52\ H_s$$

$$H_{1/500} = 1.76\ H_s$$

$$H_{1/1000} = 1.86\ H_s$$

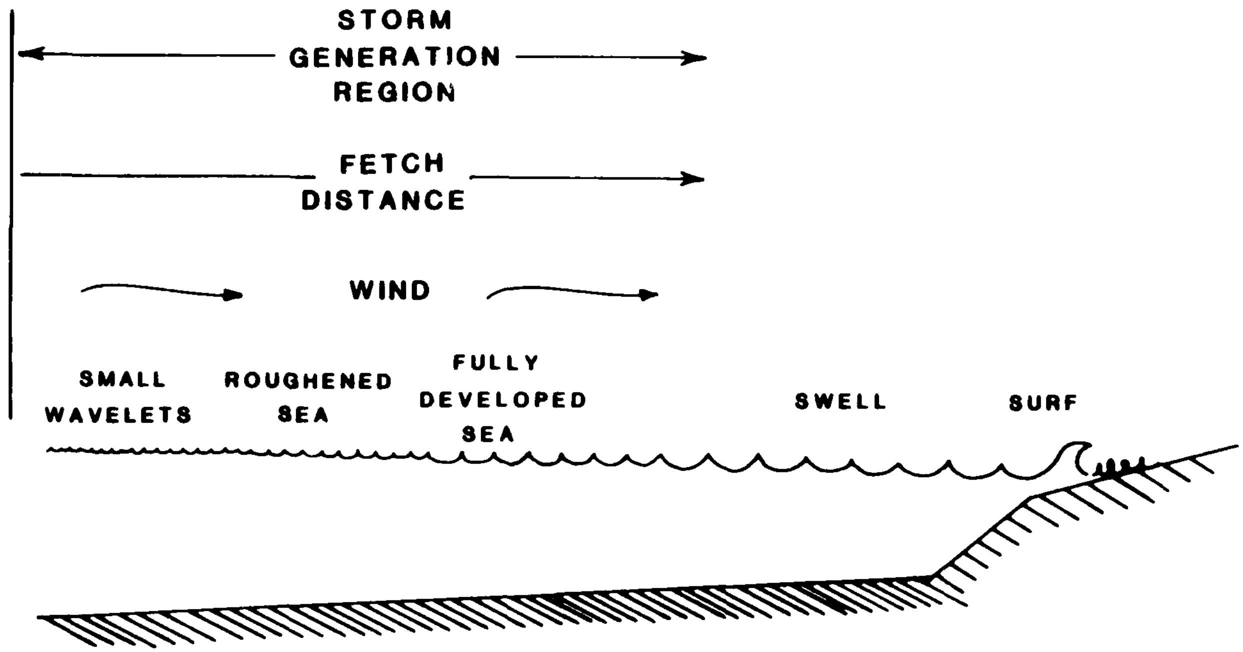

Figure 4.1-1 Wind wave growth with fetch to full-development showing sea, swell, and surf.

where $H_{1/20}$ is the highest wave in 20 waves observed in a single continuous observation.

4.2 Waves in Norton Sound

In general open water conditions allow wave generation and propagation during the period May through September. In some years broken ice conditions in the Norton Sound during October and November allow wave generation to take place resulting in sea heights reaching 3 to 4 feet, although severe storms can result in much longer waves. During the open water season prevailing winds (normal conditions) are from the east and north. Therefore along the north and east shores seas are quite mild since fetch lengths are short. During these wind conditions, wave heights increase offshore and naturally are longer along the southern shore of the sound. Winds from the southwest can bring large sea and swell conditions into the sound. During these conditions the southern and southeastern shores are protected but the northern shore is open to winds from the southwest.

Table 4.2-1, Summary of Synoptic Meteorological Observations, gives the percent frequency of occurrence of wave heights versus period.

Extreme wave conditions result from sustained winds in excess of 30 knots, durations in excess of 6 hours and fetch lengths of several hundred miles. Such storms produce large waves when winds are from the southwest. One of the more severe storms to effect the Nome area occurred on November 11 and 12, 1974. Winds reached sustained speeds of over 70 knots with gusts to 100 knots. This storm produced waves offshore Nome in excess of 18 feet significant height and is believed to have a 50 to 100 year return period.

Table 4.2-1. Percent Frequency of Wave Height (ft) vs Wave Period (Seconds)

Period (seconds)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	Total	Mean Height
<6	11.4	27.1	17.5	5.6	1.5	1.2	.2	.3	.0	.0	.0	.0	732	2
6-7	.0	2.7	3.8	4.3	1.9	1.8	.6	.4	.1	.1	.0	.0	177	5
8-9	.0	1.5	1.2	.9	1.4	1.2	.7	.5	.9	.1	.0	.0	96	6
10-11	.0	.4	.3	.2	.2	.4	.1	.1	.1	.0	.0	.0	19	6
12-13	.0	.0	.0	.1	.1	.4	.2	.1	.1	.0	.0	.0	10	8
>13	.0	.0	.0	.0	.2	.1	.2	.0	.2	.0	.0	.0	7	9
Indet	7.2	.1	.4	.0	.0	.0	.1	.0	.0	.0	.0	.0	88	0
Total	210	358	263	125	60	58	23	15	15	2	0	0	1129	3
Percent	18.6	31.7	23.3	11.1	5.3	5.1	2.0	1.3	1.3	.2	.0	.0	100.0	

4.3 Currents (General Circulation and Tidal)

The circulation in Norton Sound has at least two seasons. During summer, open water allows local wind to stress the sea surface and wind generated current are often an important component of net circulation. During winter, sea ice covers the sea and currents are controlled by oceanic and tidal effects. These transitional periods occur in November through December and May through early June. As would be expected, the transitional periods are characterized by highly variable current in both speed and direction.

In summer, the circulation is dominated by the presence of the strength and position of the Alaska coastal current, tidal effects, and local wind-driven currents. The general direction of flow is northward. Within the sound a counterclockwise flow is induced. Water enters the southern portion of the sound and flows along the southern coastline. Most of the water discharged from the Yukon River is entrained in this flow and moves east into Norton Sound.

The circulation pattern also extends, with varying intensity, into the eastern part of Norton Sound. Here the upper layer is more affected while circulation in the lower layer appears to be sluggish for the most part. A strong pycnocline separates the two lower layers and very little of the horizontal motion in the upper layer is transmitted to the lower layer. During the summer, waters in the eastern part of the sound show a tendency to become more strongly stratified than the western waters. If vertical mixing or horizontal replacement does not occur, the water in the lower layer becomes stagnant. However, severe summer and fall storms are capable of breaking down this stratification and replacing the lower layer in a period of a few days (Muench et al., 1981).

The mean speed of surface currents in the western part of Norton Sound ranges from about 5 to 20 centimeters per second; the maximum velocity was about 50 centimeters per second (Muench et al., 1981). (These currents were measured in the fall of 1976 and are not representative of the very near surface currents, i.e., within 5 cm of the sea surface). Bottom current speeds are about 10 to 20 centimeters per second in the western part of the sound and less than 10 centimeters per second in the eastern part (Drake et al., 1980).

Superimposed upon this mean circulation are tidal and locally generated wind-driven currents. The tidal currents generally tend east and west following the east-west orientation of the embayment and speeds generally range from 0.7 to 1.1 km/hr. However, both speeds and directions change nearshore where channels or restrictions exist. These conditions occur just south of Nome where a deep channel is located which runs east west, near Golovnin Bay where the currents run north and south, between Sledge Island and the mainland, and in the Yukon Delta where deep channels control the tidal current speed and direction.

Locally generated wind driven currents are significant to surface currents. A 20 kts wind sustained for several hours will result in over 0.5 knot of current near the sea surface. Therefore, as discussed in Section 2.3, wind driven currents are most important when considering oil spill transport. Because of the shallowness of the embayment and the local nature of the wind stress the wind generated current directions for all practical purposes align with the wind direction at the surface. The speeds are generally 3 percent of the wind speed.

4.4 Sea Temperature, Salinity and Suspended Sediments

Water column characteristics including salinity, temperature and suspended sediments are strongly affected by the Yukon River plume and effects of tides winds and offshore northerly currents during summer. During winter sea ice covers the sound and currents are controlled by the mean circulation of the Bering Sea.

During summer salinities within the sound decrease to less than 19 parts per thousand (ppt). Near the Yukon River delta salinities are reduced to less than 3 ppt. Mean sea water temperatures increase due to river discharge and solar heating. During July water temperatures at 10 m within the sound have reached 12°C. Suspended sediment concentrations increase to 50 mg/l or higher due to river discharge and wave and current generated turbulence.

During winter salinities increase to oceanic condition (34 to 35 ppt). During this period, the sea ice canopy prevents wave induced particle motions reducing suspended sediment concentration to a range of 1 to 5 mg/l. Additionally during winter, river water and sediment discharges are significantly reduced from the summer months.Sea water temperatures range from -1.86 to 2°C beneath this ice canopy.

4.5 Sedimentary Processes

Shoreward of the 30 m depth contour, wind generated waves and currents strongly control erosional and depositional processes during summer. During winter sea ice gouges the shallower areas of the seafloor and sediments are held within the sea ice structure.

Sources of sediments include coastal erosion and river discharge. Nelson et al., 1974, estimate that 90 percent of all sediments entering the Bering Sea are contributed by the Yukon River. Discharge rates and suspended sediment concentration data collected over the past 20 years suggests an annual Yukon River suspended sediment discharge of close to 50 million tons. Most of this material is carried into Norton Sound.

During storms, currents scour bottom sediments resulting in substantial transport of bed material (Carlson, et al., 1981) and flushing of the sound. During calm periods the inner portions of the sound retain cold, nearly stagnant, saline waters formed during the previous winter. However, even during such quiescent periods much of the fine grained material is resuspended during spring tides and transported northward with the mean current. During storms larger grained sediments are resuspended and transported.

Entrainment of suspended sediments within the sea ice during freeze-up is an important process in transporting sediment. Storm induced mixing of the water column in Norton Sound during freeze-up results in resuspension of bottom sediment which when combined with rapid accretion of sea ice entrains sediment in the ice. Sediment transport via this mechanism is an important process in Norton Sound.

4.6 Storm Surges

This discussion is based primarily upon the data and concepts developed in Storm Surge Climatology and Forecasting in Alaska (Wise and Comiskey, 1981). Little new data has been collected since 1981; however, the concept of secondary surges has been developed. Secondary surges are surges which occur with winds not normally related to surges.

Storm surges are caused by strong winds associated with strong to intense storms. Surge heights are with respect to predicted water level (tidal height). A storm surge prediction of 2m would therefore be 2m above the predicted tide height. Storm surges that are coincident with high tide have the greatest impact along the coast. In addition to potential flooding, there is increased wave activity because of the deeper water along the coast.

The types of coasts most susceptible to surges are those with shallow water offshore and low lying land along the coast. Norton Sound has these characteristics and has experienced the largest recorded surge in Alaska, slightly over 4m at Nome. The 4m surge at Nome was accurately measured by the U.S. Geological Survey shortly after occurrence.

The most favorable wind directions in the Norton Sound area are from south-southeast to west-southwest. The wind causes a net transport of water in the upper boundary layer of water affected by the wind (the boundary layer) almost 90 degrees to the right of the wind direction. The surge increases until the return flow, along the ocean's bottom, reaches equilibrium with the wind induced flow. It is possible to get a negative surge (below predicted tide levels) with strong winds from the east through north but these negative surges are probably less than 1m and none have been reported from Norton Sound.

Of greater interest is the subject of secondary, or gravity, surges. For instance, when the north coast of Norton Sound is being subjected to strong southerly storm surge winds, the south coast is being subjected to strong offshore, or negative surge, winds. However, the south coast will not have a negative surge. It will have a positive surge. As the water heights increase along the north coast, and the southern Yukon Delta as well, an anomalous slope to the ocean's surface is created. The force of gravity trying to return the ocean's surface to equilibrium causes a flow below the wind induced boundary layer toward the area of lower sea surface heights. When the sea surface slope exceeds a given value, the gravity induced flow exceeds the wind drag flow, and a positive surge begins in the "negative surge" area. This type of surge is called a secondary surge.

It is likely that the secondary surge along the south coast of Norton Sound is about 65 percent of the surge along the north coast (for south winds). As the winds become more westerly, the surge will become higher on the south coast with a secondary surge along the north coast. The secondary surge will be higher in the northeastern portion of the sound and lower as one moves westward along the north coast with the secondary surge probably being negligible near Cape Nome. No specific height values relating secondary surges to primary surges have been derived, however, it is suggested that an ocean slope of .09U meters per 100NM be used. U is the wind speed in meters per second. Example: A sustained southerly wind of 20 mps (45 mph) may create a surge of 3.65 M (12 ft) along the coast between Nome and Cape Darby (Appendix E). The wind induced north-south slope of the ocean is -1.8 M (.09 x 20) per 100 NM. The distance to the south shore is approximately 70 NM. Thus, the water height along the south shore is 1.26 M lower than the water height along the north slope, or, put another way, the south shore may experience a surge of 2.39 M (3.65 - 1.26) while the north shore is surging to 3.65 M.

The forecasts of storm surges involves factors other than wind speed and direction. A suggested procedure is shown in Appendix E. The National Weather Service (NWS) Forecast Office in Fairbanks monitors the Norton Sound area rather closely because of surge history in that area. The NWS can be contacted directly during an oil spill episode, but it may be more effective to hire a private meteorologist to interface between the NWS and the OSC and to do specialized forecasts as required.

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5.0 Climatology and General Meteorology

5.1 Wind and Wind Driven Currents

The wind driven currents are most important when considering oil spill transport. Thus, it is important to work closely with the relationship of winds to wind driven currents. The winds can be classified into two general groups: (1) climatological, and (2) real time (episode) winds.

5.1.1 Climatological Wind Data

The primary use of climatological wind data is for the purpose of identifying the areas and resources at greatest risk based on climatological wind probabilities. Because of the extreme paucity of wind data from Norton Sound, it is necessary to use coastal wind data. However, local knowledge precludes the use of coastal winds without considerable qualifications. Monthly wind summaries from the climatic atlas (Brower, et al., 1977) are reproduced in Appendix B. The wind summaries are grouped by month and by reporting station. Station 'ocations are shown in Figure 1.0-1 and 1.0-2. The monthly summaries of the coastal stations reveals that during the "winter months", September through May, the prevailing winds are northeasterly. In July and August the prevailing winds are southwesterly. June and September are transition months. In addition, topography has a significant affect on several of the coastal stations. Unalakleet's wind direction is primarily easterly (from the east) during the winter months and westerly during the "summer months" because of the Unalakleet river valley. Moses Point during the winter months is primarily northerly and during the summer months is primarily southwesterly. In short, easterly winds at Unalakleet equate to northerly winds at Moses Point. Westerly winds at Unalakleet equates to southwesterly at Moses Point. Nome is in a somewhat protected location tending to easterly winds during the winter months similar to Unalakleet but of considerably lesser speed. Nome during the summer months closely approximates the southwesterly winds at Moses Point. Cape Romanzoff, actually outside of the Norton Sound boundary tends to be northeasterly (winter) and southwesterly (summer), but is located on a promontory 130 m (430 ft) above water and is not representative of the standard 20 m wind over water. The same is true of Northeast Cape. Gambell, also outside of the atlas boundary, tends to be northerly in the winter and southwesterly in the summer. Gambell was included because local knowledge considers it to be quite representative of the western quarter of the atlas area.

When the air moves offshore, it can be said with reasonable certainty that the direction and speed anomalies of the land stations disappear and that the air flow correlates better with the pressure gradient. Studies by Pease et al., 1982 verify the winter pressure gradient directions which agree with climatological directions but not the speeds. Brower et al, 1977 indicates a very weak summer pressure gradient with no definable direction; however, it is rather apparent that the semi-permanent weak high pressure area over the Bering Sea, coupled with summertime low pressure over interior Alaska accounts for the predominantly southwesterly winds in summer. Keep in mind that summer wind regime refers mostly to July and August.

In addition to the qualifications described above, we must also remember that 1) wind measurements over land are taken at 10 M, on most ships at 19 - 20 M, and on drill rigs at 30 - 90 M; 2) the frictional affects over water are usually less than over land; 3) the stability of air over water varies considerably (the affects of stability are discussed extensively in Section 5.4). Because of the above, we can say with reasonable certainty that the wintertime east to north winds over Norton Sound are most accurately represented by Unalakleet, Moses

Point, and Gambell on the premise that topographically accelerated winds at Unalakleet and Moses Point compensate for the increased speed to be expected over water because of less friction, instability, and correction for elevation over water. The Gambell wind is measured as it comes off the water where the accelerating affects of less friction, and more instability have already increased the speed. The difference in wind speed between 10 and 20 m is relatively insignificant.

During the summer months the south to southwest winds at all locations are representative of winds over Norton Sound except that they should be increased about 2 kts to approximate the 20 m level over water. See Table 5.1-1.

Further evidence of the long-term prevalence of the seasonal wind is shown in Appendix A. (U.S. Naval Weather Service Command, 1970).

5.1.2 Real Time Winds

The real time or actual winds during an oil spill episode may differ significantly from the climatological winds, and because the oil spill trajectory models are driven by, or sensitive to, the real-time winds, it is important that the real time wind data input be as accurate as possible.

Most models will perform reasonably well when using accurate wind input; however, there are at this time two significant weaknesses in the wind reporting system. Those weaknesses are: 1) the wind speed is not always reduced to the wind elevation (reference level) to which the model was designed, and 2) either the reduction procedure or the model does not provide for the effects of atmospheric stability on the wind itself. For instance, if the wind speed is measured at 60 m, it may not be representative of the wind at 20 m or any other reference level wind required by the model. In addition, unstable air will exert a greater shearing force on the water surface, and consequently, a greater wind-driven current than stable air. Drill ships tend to measure and report winds at the 30 m level. Drill platforms tend to measure and report winds at the 60 to 100 m level. To further complicate matters, the wind forecasts provided routinely to the drill rigs are anemometer level (30 to 100 m) winds. Thus, if the wind forecasts are correct for the anemometer level, they are not correct for the model.

In addition, when one realizes that wave, ice movement, and superstructure icing models as well as oil spill trajectory models are primarily wind driven, it becomes quite important that winds be reduced to a correct reference level, particularly when strong winds during stable conditions are occurring. Strong winds and stable conditions have the greatest vertical winds shears (change of wind speed with height). Interestingly, when an observer estimates the wind speed from the sea state, the estimated wind closely approximates the measured wind at 20 m (Quale, 1980).

There are several formulae for reducing a measured or forecast wind to a desired level. The vertical wind speed profile tends to approximate a natural logarithmic curve. The general form of the equation is:

$$\frac{U_K}{U_R} = k \ln \frac{H}{R} \qquad (1)$$

Where U_H = measured wind at H

U_R = reference level wind (usually 10 or 20 m)

H = height of measured wind

R = height of reference level

k = a constant that may vary according to application or area

Algebraically, this reduces to:

$$\frac{U_H}{U_R} = \frac{H}{R}^k$$

One suggested value of k is 0.143 (Elliot, 1979b). The equation does not provide for changes in air mass stability but the reference level wind can now be estimated by:

$$U_R = \frac{U_H}{\left(\frac{H}{R}\right)^{.143}} \qquad (2)$$

The exponent of 0.143 most likely represents the vertical wind profile over land.

A more refined estimate of the reference level wind (U_R) which takes into consideration air mass stability as indexed by the air-sea temperature difference to the wind values derived by Smith (1981) can be derived from the following equation developed by Northern Technical Services for this publication

$$U_R = \frac{U_H - .0028\ (T_a - T_s)\ (H_M - H_R)}{\left(\frac{H_M}{H_R}\right)^{0.11}} \qquad (3)$$

U_R = wind at reference level in m/s
U_H = measured wind at height H in m/s
T_a = air temperature in degrees Celsius
T_s = sea temperature in degrees Celsius
H_m = height of measured wind in meters
H_R = height of reference wind in meters

Equation (3) yields approximately the wind values given in Table 5.1-1. If we reverse the procedure and assign a wind of 20 m/s at 90 m and then reduce the wind to 10 m, still using equation (3), we find that for $T_a - T_s = -10$ (unstable) the computed wind for 10 m is 17.5 m/s, a reduction of only 2.5 m/s. For $T_a - T_s = 10$ (stable) the computed wind is 14.0 m/s, a reduction of 6 m/s. A reduction of 6 m/s equates to a reduction of 11.65 kts (from 39 kts to 27.5 kts). When one considers that a five knot change in wind speed can equate to a 1.5 m (5 ft) change in sea height as well as changes in oil spill transport speeds, it is apparent that the wind speeds used for oil spill containment planning must be used with care.

In general, the speed of the wind driven current is 2 to 5 percent of the 10m wind speed (Wiegel, 1964). Measurements of surface wind driven currents are not easily accomplished. Factors affecting variability of wind-driven currents are the coriolis force, tides, general circulation, surface roughness, air mass stability and even the design of measuring equipment (Wiegel, 1964). However, from the collective measurements and theoretical derivations described by Wiegel, when considered in concert with wind induced ice movements (Overland, 1985; Pease et al. 1983; Macklin 1983), it is reasonable to assume that the speed of wind-driven currents are largely a function of wind speed, ocean roughness and stability of the atmosphere. In general terms then, light winds, smooth water surfaces and stable air (air warmer than water) equate to a wind-driven current of 2 percent of the wind speed. Conversely, at the

	STABILITY (T_a-T_s)				
Elevation	Very Unstable $T_a-T_s=-10$	Stable $T_a-T_s=-5$	Neutral $T_a-T_s=0$	Stable $T_a-T_s=+5$	Stable $T_a-T_s=+10$
10m	20 m/s	20 m/s	20 m/s	20 m/s	20 m/s
20m	21.3	21.5	21.6	21.8	21.9
30m	22.0	22.3	22.6	22.9	23.1
40m	22.5	22.9	23.3	23.7	24.1
50m	22.8	23.4	23.9	24.0	25.0
60m	23.0	23.7	24.4	25.1	25.8
70m	23.1	23.9	24.8	25.7	26.5
80m	23.2	24.3	25.1	26.1	27.1
90m	23.2	24.5	25.5	26.6	27.7

Table 5.1.1 The wind values derived from equation (3) are given for a wind speed of 20 m/s at a reference 10 m level over a set of constant air-sea temperature differences.

other extreme, high winds, a very rough surface and very unstable air (air colder than water) equate to a wind-driven current of 5 percent. We recognize that high winds, roughness, and stability are inter-related but not necessarily so. For instance, it is possible to have high winds with relative water smoothness when the fetch is short. It is also possible to have roughness without instability, etc. Keep in mind that wind measurements should be reduced to the desired reference level, usually 10 or 20 m and that stability should also be considered.

In addition to the speed of the wind driven surface currents, it is also necessary to consider the direction of water movement. To do this, we must differentiate between currents at the very top of the ocean (wind drift) and the currents at lower levels. Wind drift is defined here as the direction of movement of the top 5 cm or less of the waters' surface and is used to clarify the general term "surface current direction". Surface current directions as used by oceanographers can mean the net transport direction in a boundary layer (such as the column of water affected by the wind), or relatively shallow layers, or levels, of interest such as 5 m or 15 m. It is generally agreed amongst oceanographers that the wind drift is in the same direction as the gradient wind (Krummel, 1911; Bowden, 1953; Hughes, 1956). The gradient wind is defined as a wind which blows along a constant pressure surface as depicted by the pressure contour lines (isobars) on a weather map. Meteorologists universally agree that the real or actual winds at the surface blow at an angle of 15 to 30 degrees to the left of the isobars. Put another way, the wind drift is 15 to 30 degrees to the right of the measured wind when facing downward. The deviation of wind drift to wind direction is a function of surface roughness. An average deviation of 30 degrees is recommended for the Norton Sound area (Pease, C.H., 1987 pers. comm.) keep in mind that historically, the average height of measured and estimated winds from ships is 19.5 m. If input winds from other elevations are used, an adjustment should be considered along the lines suggested in equation 3.

Finally, if for some reason it becomes necessary to look at current directions below the wind drift level, theoretical calculations of surface currents by Rossby and Montgomery (1935) indicate a deflection to the right of the wind direction of 41.5 to 53.5 degrees for the latitudes of Norton Sound. The lower degree value (41.5) relates to a wind of 5 m/s and the upper value to a wind of 20 m/s. The measurement of direction of wind-driven currents is somewhat more complicated than wind-driven speeds because of the time required for the direction to become in dynamic equilibrium with the wind speed. Initially, the wind current direction is the same as the wind direction, but continues to rotate to the right, assuming a steady state of wind. Actual wind direction measurements indicated angles varying from 0 to 100 degrees for a large number of observations. (All from Wiegel, 1964). At any rate, the angles derived by Rossby and Montgomery appear reasonable. If ice is present, the angle of direction should be reduced to that suggested by Wilson and Zubov in subsection 6.3.

5.2 Air Temperature

Temperatures within the Norton Sound area vary between a January mean of -15° to -17°C (5° to -1.4°F), and a July mean of 10° to 13°C (50° to 55°F). Table 5.2-1 gives the normal daily mean air temperatures for Nome and Unalakleet in degrees Fahrenheit for the period of record, 30 years, 1941 to 1970. Table 5.2-2 gives the normal daily maximum and minimum air temperatures in degrees Fahrenheit for Nome and Unalakleet for the period of record, 30 years, 1941 to 1970. Table 5.2-3 gives highest and lowest temperature of record in degrees Fahrenheit for Nome and Unalakleet covering 36 and 28 years, respectively.

Table 5.2-1 Normal Daily Mean Temperature, Degrees Fahrenheit

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nome	6.0	5.2	7.4	18.9	34.8	45.5	50.1	49.2	42.1	28.5	15.6	4.4
Unalakleet	3.4	4.6	9.4	22.1	37.8	48.5	54.0	51.9	43.5	27.3	13.3	1.6

Table 5.2-2 Normal Daily Maximum/Minimum Temperatures, Degrees Fahrenheit

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nome:												
Maximum	13.5	13.7	16.6	27.0	41.4	52.2	55.8	54.6	48.2	34.4	22.1	11.7
Minimum	-1.6	-3.3	-1.9	10.8	28.1	38.8	44.4	43.7	35.9	22.6	9.1	-3.0
Unalakleet:												
Maximum	10.3	12.0	18.0	30.1	45.5	55.3	60.5	58.3	50.5	33.3	19.3	8.2
Minimum	-3.5	-2.9	0.7	14.1	30.1	41.6	47.4	45.5	36.4	21.2	7.3	-5.1

Table 5.2-3 Highest and Lowest Temperature of Record, Degrees Fahrenheit

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nome:												
High	43	47	42	51	78	81	86	81	71	59	44	43
Low	-40	-42	-46	-30	-11	23	31	27	15	-10	-39	-41
Unalakleet:												
High	47	40	47	62	78	86	87	85	70	57	44	41
Low	-48	-50	-50	-30	-6	25	32	28	6	-20	-47	-50

5.3 Air Mass Stability

Air mass stability is specifically mentioned here, as well as in other portions of the text, because its consideration is so frequently neglected as an operational tool. Stability is the tendency, on non-tendency of an atmospheric layer to overturn or mix. Little mixing of the layers takes place when the atmosphere is stable, particularly over water. If unstable, the lowest layer (for marine purposes), or boundary layer, is more buoyant than the next higher layer. This buoyancy causes the two layers to mix. This condition occurs when cold air is heated by relatively warm water or warm ice especially during the winter months.

The height of mixing is determined by the degree of warming (air-sea temperature difference) and the vertical distribution of temperature in the air mass (vertical temperature profile -VTP). The operator in the field usually has no knowledge of the VTP, but he can easily obtain the air-sea temperature difference which is a good index of low-level stability. A competent meteorologist can acquire both VTP and air-sea temperature differences to provide maximum service to the forecast user.

The stability affects the vertical wind shear which is important for reducing wind speeds to desired reference levels. Because the wind is the main driving force in many predictive models (trajectories, waves, ice movement, etc.) it is important to input correct wind data - both current and forecast winds. Stability also affects ceilings and visibilities as described in section 3.8.

5.4 Flying Conditions

The various climatic regions of Alaska experience different types of cloudiness, and differing frequencies of poor visibility, icing, and turbulence. Extensive icing conditions can occur in advance of frontal systems, in areas of extensive upward vertical motion over mountainous areas, in turbulent buildups caused by strong onshore flows of moist air, and in freezing rain or drizzle at lower levels. During summer the freezing level is high enough so that aircraft can fly below it and icing becomes less of a hazard. From October to May, surface temperatures drop to freezing or lower and aircraft icing can then occur at low levels. During the winter, serious icing can also be encountered from supercooled low clouds with tops as low, or even lower than, 3,500 ft. This icing condition occurs when the low level atmospheric winds are very light.

On the south side of the Seward Peninsula are a series of foothills with heights of 500 to 1,200 feet extending from northwest through north to east of Nome at distances of 4 to 8 miles. The terrain increases in ruggedness and height farther north of Nome with the Kigluaik Mountains reaching a height of 5,000 feet at a distance of 30 miles. From June to mid-October, Norton Sound is ice free and the open water creates a very different weather regime from that of the ice covered Sound (Oct - June). Storms moving through this area during June to mid-October cause extended periods of cloudiness and rain. In addition, vast areas of low cloudiness (stratus) form over the Bering Sea during the summer and the low clouds frequently move into the Norton Sound area causing persistent low ceilings and visibilities.The nearly continuous cloud cover during July and August results in an average of 45 cloudy, 12 partly cloudy, and only 5 clear days for the 2-month period. During the summer months the daily temperature range is very slight. The freezing of Norton Sound in November causes a rather abrupt change from a maritime to a continental climate. The majority of low pressure systems during this period take a path south of Nome, resulting in strong easterly winds accompanied by frequent blizzards.

In winter, clear skies offer frequent opportunities for high-level visual flying. They occur on an average of 10 to 15 days per month, more often north of the Seward Peninsula than to the south. In summer, such conditions occur only 2 to 3 days per month. Broken conditions occur for relatively short periods of time as skies are predominantly either clear or completely overcast. Broken conditions are most frequent in spring. Through most of this region, low-level operations could be conducted in spite of low ceilings. Much of the terrain is relatively flat and may be approached by flying over water. The interior of the Seward Peninsula requires higher ceilings for safe flying. The primary advantage of winter flying is the clear days when missions from all levels are possible. When cloudiness is present in winter, it is frequently at levels which would restrict operations. In summer, cloud bases are at somewhat higher levels than over water, but fog and low clouds frequently cause extended periods of non-operational weather at coastal localities. When occasional storms move into the Bering Sea in winter, cloudiness can build up to great heights.

Table 5.4-1 provides the percent frequency of flying weather for Nome with varying ceilings and visibilities for each month.

Table 5.4-1. Percent Frequency of Flying Weather for Nome

Flying Weather (% Freq)	Hours (LST)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	00-02	33	30	29	32	34	32	47	49	36	30	37	29	35
Ceilings	03-05	34	29	29	34	36	33	49	53	37	30	37	30	36
less than	06-08	33	28	27	33	38	36	50	54	38	33	39	30	37
3000 feet	09-11	31	27	24	31	37	35	47	56	39	31	37	27	35
and/or	12-14	31	26	24	32	33	32	44	54	38	31	36	26	34
Visibility	15-17	33	27	26	32	30	29	43	50	38	33	38	29	34
less than	18-20	35	30	30	34	31	30	42	49	36	33	38	28	35
3 miles	21-23	33	29	29	33	32	31	43	48	34	30	35	28	34
	All Hours	33	28	27	33	34	32	46	52	37	31	37	29	35
	00-02	24	21	22	22	23	24	38	36	20	15	20	17	24
Ceiling	03-05	24	20	21	22	25	25	39	38	20	14	22	19	24
less than	06-08	24	19	19	23	26	28	39	40	21	16	22	19	25
1500 feet	09-11	24	20	18	21	25	27	36	40	20	16	22	20	24
and/or	12-14	24	19	18	22	22	25	33	38	19	16	22	19	23
Visibility	15-17	26	19	20	23	20	22	32	36	20	16	23	18	23
less than	18-20	24	21	21	24	19	22	33	36	19	15	22	17	23
3 miles	21-23	25	21	21	24	21	23	36	37	19	14	21	17	23
	All Hours	24	20	20	23	23	24	36	37	20	15	22	18	24
	00-02	17	14	15	16	17	19	29	25	11	7	13	12	16
Ceiling	03-05	17	13	15	16	19	20	30	26	11	7	13	14	17
less than	06-08	16	13	14	17	19	21	29	27	11	8	13	13	17
1000 feet	09-11	19	14	14	14	17	19	26	25	11	9	15	13	16
and/or	12-14	19	14	13	14	14	19	23	24	10	9	15	13	16
Visibility	15-17	20	14	15	16	13	17	22	24	10	9	15	13	16
less than	18-20	19	15	16	16	13	17	24	25	11	7	15	12	16
2 miles	21-23	19	14	16	17	16	19	28	25	10	7	15	12	17
	All Hours	18	14	15	16	16	19	27	25	11	8	14	13	16
	00-02	3	2	2	2	2	4	3	1	*	*	1	2	2
Ceiling	03-05	3	2	2	1	2	3	3	2	1	*	1	2	2
less than	06-08	3	2	2	1	2	2	1	1	*	*	1	1	1
200 feet	09-11	4	3	2	1	1	1	*	*	*	*	2	2	1
and/or	12-14	4	3	2	1	*	1	*	*	*	*	1	3	1
Visibility	15-17	4	3	3	1	1	1	*	*	*	1	2	2	2
less than	18-20	3	2	4	1	1	2	1	*	1	*	2	2	2
1/2 mile	21-23	3	2	3	2	2	4	2	1	*	*	2	2	2
	All Hours	3	2	3	1	1	2	1	1	*	*	1	2	2

6.0 Sea Ice

6.1 General

Sea ice coverage (average), is illustrated on Figure 6.1-1. The ice edge (dashed lines) and the ice coverage boundaries (solid lines) represent the 50 percent probability lines. You should expect the ice edge or designated concentration to be on one side of the line 50 percent of the time and on the other side 50 percent of the time. Anomalous weather conditions can cause very anomalous ice coverage conditions. Figure 6.1-2 shows the eastern half of Norton Sound almost ice free. The surface weather map, Figure 6.1-3 shows the weather pattern of strong easterly winds, and high temperatures that created the huge polynya area in eastern Norton Sound. Polynyas also occur with strong easterly winds and very low temperatures but in that type of situation new ice forms rapidly in the polynya area. Note that the ice north of the Bering Strait is relatively unaffected. After March 18 the winds continued easterly and by March 23 much of Norton Sound was free of ice (Figure 6.1-4) and remained so until the following winter. Strong northeasterly or northerly winds cause large leads and polyna areas along the north and northwest coasts of Norton Sound but these wind directions rarely occur with above freezing temperatures as shown in Figure 6.1-3 (Brower et al, 1977).

6.2 Ice Character

Ice can occur in wide variety of forms (pans, flows, etc.), internal conditions (temperature, entrapped air or water, and salinity), and thickness. Flows range from several km in diameter to less than 1m (pancake ice). The edges of the flows will be crushed to varying degrees depending upon their history. Because of compressional or shearing forces within

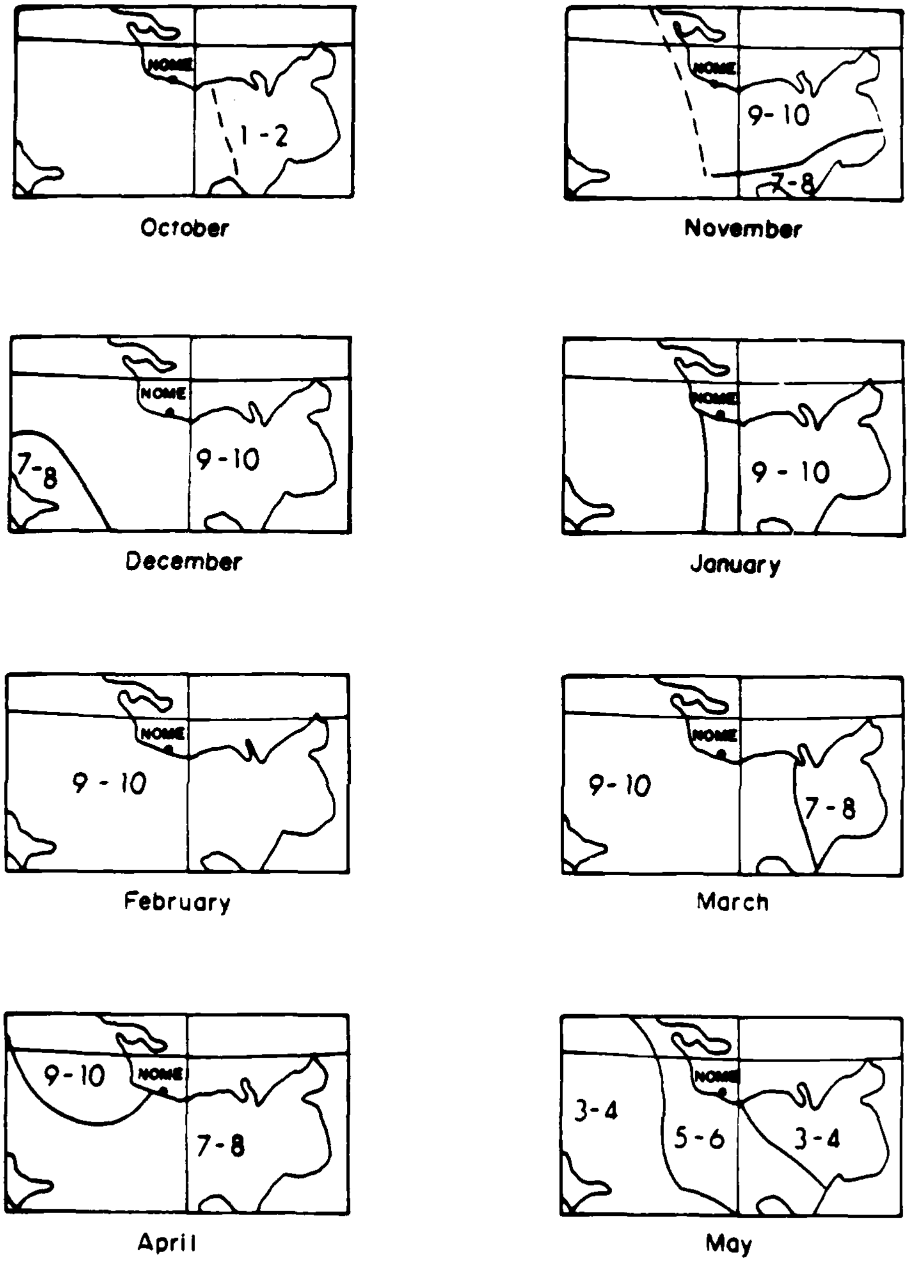

Figure 6.1-1. Average ice cover in tenths in Norton Sound. Dashed lines indicate most probable ice edge. Note lesser concentrations of ice in eastern Norton Sound in March, April, and May. (LaBelle and Wise, 1983).

Figure 6.1-2. Note polyna covering eastern half of Norton Sound. This huge anomalous polyna occurs with the weather pattern shown in Figure 6.1-3. Photo by NOAA orbiting satellite, from NORTEC files.

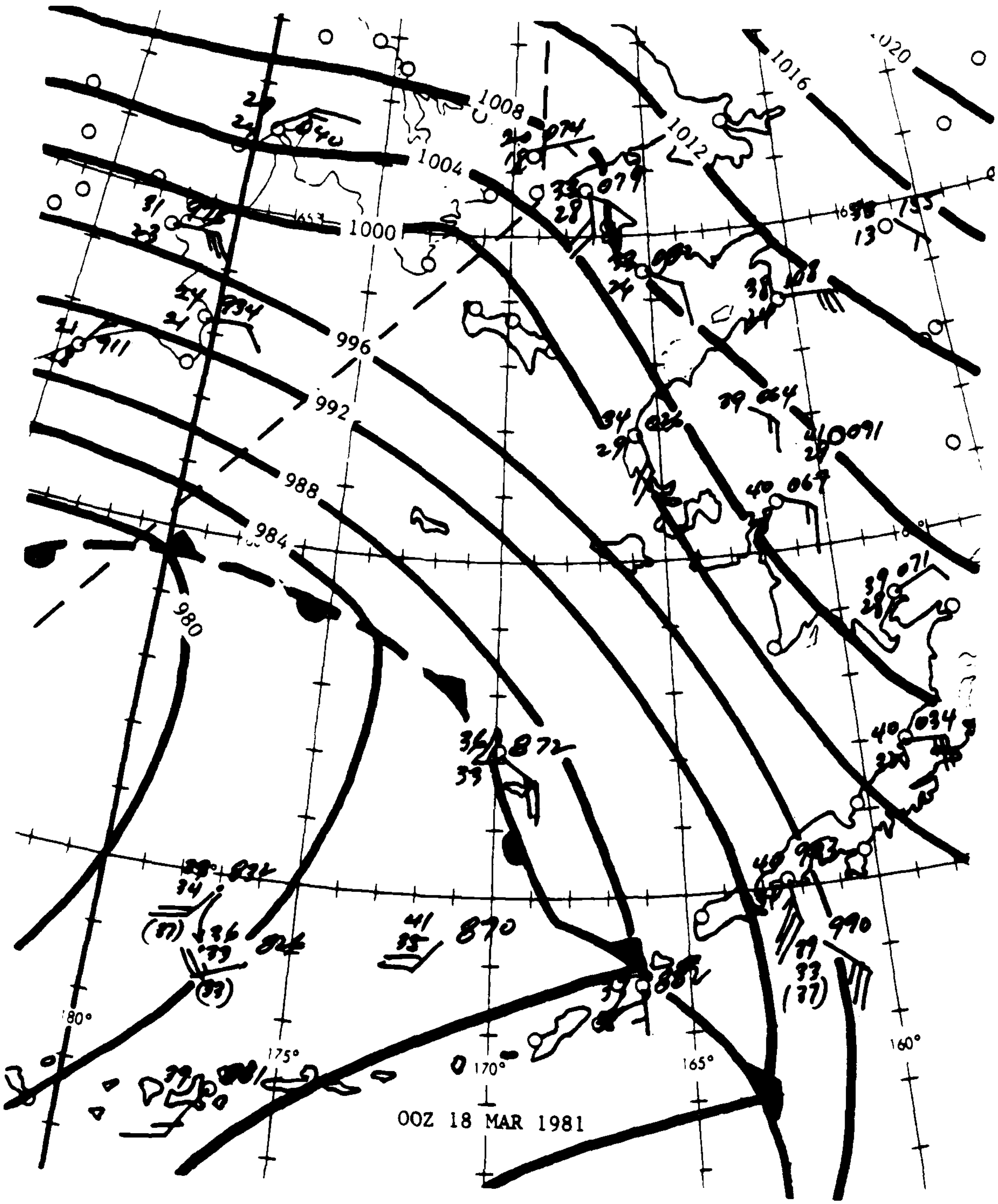

Figure 6.1-3. One of several surface weather patterns that cause anomalous ice conditions in Norton Sound (Lindsay and Comiskey, 1982).

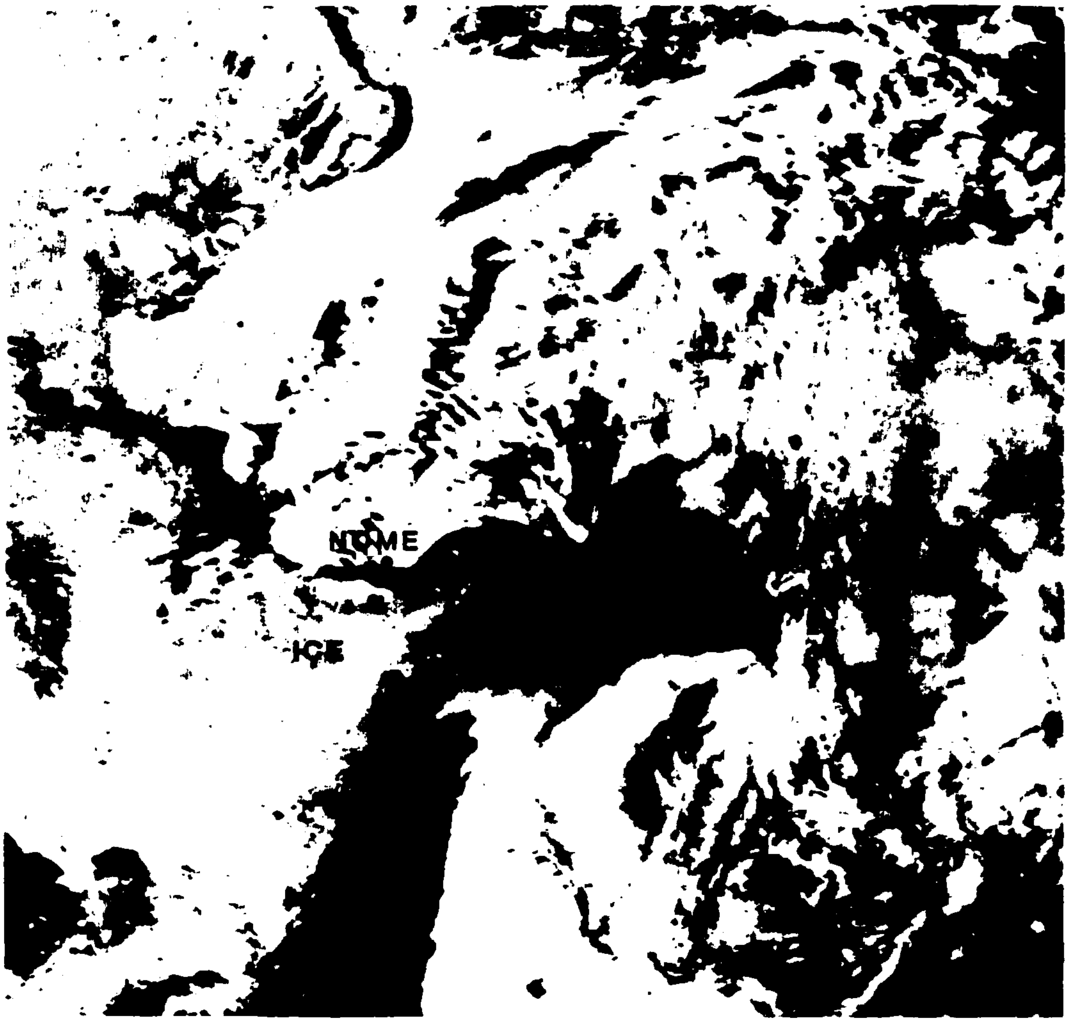

Figure 6.1-4. Note Norton Sound almost free of ice as general weather pattern depicted in Figure 6.1-3 continues. Photo by NOAA orbiting satellite, from NORTEC files.

the ice pack many of the ice flows are crushed, or reduced to rubble. When the rubble predominates, the area of rubble is called a rubble field. A rubble field wherein the rubble has frozen together is called a consolidated rubble field and becomes an entity similar to an ice flow but with different internal characteristics. A further discussion of ice character as it relates to shearing and compressional forces is contained in subsection 6.6. The entire spectra of ice characteristics is described in the U.S. Navy-NOAA Joint Ice Center Ice Observers Handbook, 1981 (Langemo, 1981).

The objective of this narrative is simply to discuss ice to enhance the feasibility of ship operations in ice (other than specifically designed icebreakers) and to enhance the decision making process with respect to oil spill containment equipment. Briefly a ship will operate with less difficulty when:

1. Operating in a rubble field as opposed to large ice flows even though the rubble field may be thicker.

2. Operating in an unconsolidated rubble field as opposed to a consolidated rubble field.

3. Operating during divergent ice conditions as opposed to convergent ice conditions. Convergence and divergence is discussed at length in subsection 6.4.

4. Operating in "warm" (-1 to -7°C) ice as opposed to "cold" (<-7°C) ice.

In addition, ice thickness is critical at certain values depending on variables 1 through 4 and individual ship capability. See Figures 7.2-1 through 7.2-10 in subsection 7.2 which show the near maximum ice that can be navigated by a seagoing tug, of 3000 HP, pulling a 100m by 15m loaded barge with draft of 4.2m.

6.3 Ice movement

Net ice movement is determined by the summation of forces and factors affecting the ice or surrounding water. There are three types of currents (excluding river induced currents) to be considered. The general circulation current is weak and includes water speeds and directions in the entire water column. The upper boundary of the water column (sea surface) has current velocities determined mostly by the wind and to a lesser degree by the tide. Tidal currents can be significant but because of their oscillatory nature, can be ignored except in the very short term (less than 24 hours). Thus, the primary driving force for ice movement in Norton Sound is wind. One other factor not frequently thought of as an ice movement factor is air and water temperature. Temperature is a factor when considering the ice edge. If the air is very cold blowing off the ice edge and the water is near or at freezing, new ice will form ahead of the wind-driven ice pack so that the leading edge of the ice pack both moves and grows, giving a relatively rapid "movement" to the edge of the pack. Conversely, if the wind is blowing the ice into water well above freezing, the ice pack edge will melt thereby retarding the "movement" of the edge.

In addition to the above, the internal drag (ice to ice) of the ice pack is a factor which can range from zero (open pack) to 1.0 (ice movement totally stopped by very close compaction created by contact with shorefast ice, land, or ocean bottom). Various measured wind-ice drag coefficients do not significantly reflect internal drag values; however, for ice that is "allowed" to move with the wind, its movement is quite predictable.

Fortunately, there have been several recent, sophisticated, and definitive studies made of air-ice drag coefficients over the northeastern Bering Sea (Overland, 1985; Pease et al., 1983; Macklin, 1983). All of the referenced studies were based on gust probe data collected by NOAA P-3 aircraft in February 1983. In addition, the paper by Overland demonstrates consistency with drag coefficient measurements from other sources, and that drag coefficiency values are a function of ice roughness, heat flux, and atmospheric conditions. Drag coefficient-wind correlations indicate that ice will move at a speed of 2 to 4 percent of the wind speed. A single value rule of thumb of 3 percent is reasonable. Tuning of the 3 percent value can be done as follows:

If the ice is smooth and the air temperature is -5°C or warmer, use 2 percent movement. If there is internal stress, use zero to 2 percent.

If the ice is rough and the air temperature is colder than -5°C, use 3.5 percent. If there is no significant internal stress as characterized by visible water surrounding the flows, along with continued roughness and cold air, use 4.5 percent. The most rapid movement usually occurs along the edge of the ice pack, also called the marginal ice zone (MIZ).

The reference level wind is 10m. Winds at different elevations, usually higher, must be reduced to the reference level. See subsection 5.1.2 Real Time Winds.

Finally, the sea ice, because of the coriolis force generated by the earth's rotation, moves to the right of the wind direction approximately 25 degrees (Wilson, et al. 1984; Zubov 1945). Thin ice tends to move at an angle less than 25 degrees but not less than 20 degrees. Thick ice (more than 2m) tends to move at an angle between 25 and 28 degrees (Pease and Overland, 1984).

6.4 Ice Convergence and Divergence

The state of convergence or divergence of the ice pack is very critical to ships, boats, or other equipment operating within the ice pack -- particularly non-ice designed equipment. Convergence and divergence (C and D) also determine, to a considerable degree, the character of the ice pack (roughness, size of floes, etc.). Before discussing the effects of C and D, in non-mathematical terms, convergence is simply defined as "the coming together" of ice within the ice pack. Divergence is defined as "the going apart" of ice within the ice pack. No significant literature has been found to exist on the subject of C and D although the effects of C and D, (ice roughness, leads, etc.) are sometimes documented but usually without reference to ship operations, especially ship operations in first year ice by non-icebreaking type ships or equipment. This is because non-icebreaking ships do not routinely penetrate the ice, even first year ice, and when they do, the operators or personnel have been notably non-productive in generating and documenting observations or data on this subject. It is believed that both Swedish and Finnish navigators have operated routinely for decades in the first year ice of the Bay of Finland and the Gulf of Bothnia but the Swedish and Finnish operations hinge more on brute force (powerful ice breakers) than on finesse (the exploitation of C and D conditions).

The following information, concepts, and opinions documented for this atlas were derived from Albert L. Comiskey, a member of the NORTEC staff. Mr. Comiskey has directly observed the dynamics of first year ice in Cook Inlet and both directly and indirectly observed both first year and multiyear ice throughout the state of Alaska continuously since 1956. Mr. Comiskey also developed a procedure for vectoring sea going tugs and barges through Cook Inlet ice utilizing the concepts of convergence and divergence. Mr. Comiskey accompanied the tugs and barges during their passage through the ice thereby bridging the gap between concepts, theory, and operations.

The factors affecting C and D are primarily winds and tides. Secondary factors are topography, bathymetry, and general macroscale circulation.

In Cook Inlet the primary, most frequent, and most predictable indicator of C or D are the extreme tides (>10m). In Norton Sound tides undoubtedly contribute to the C and D patterns but the contribution is subtle because of the relatively low tidal ranges, generally less than 2m, and the relatively weak tidal currents, generally less than 0.5 m/s. If we neglect for the moment the drag effect of the wind or assume a no wind condition, the ice will move at the speed and direction of the tidal current. If we further assume there is uniform ice coverage, then during flood tide, the ice will move from west to east in Norton Sound with general convergence most likely in the southern portion of Norton Sound with strong convergence along the edge of the shore fast ice and any place where topography or bathymetry impedes the flow of ice. Such areas are Stuart Island and the shoal waters off the Yukon Delta. Also during flood tide, the waters along the northern coast of Norton Sound tend to be divergent. Consequently, if a ship were to transit Norton Sound, from tidal considerations, it is best to transit the sound in the northern portion during flood and in the southern portion during ebb. Because the tide only changes once a day in many parts of Norton Sound, considerable distance can be accomplished during one flood or one ebb tide. In general, do not become preoccupied with trying to follow leads particularly if those leads take you to a convergent area or an area that will soon become convergent. Concentrate on staying in divergent areas and follow small leads or paths of opportunity. Figure 6.4-1 shows an aerial photo of Cook Inlet ice in an apparent innocuous condition. At the time of the photo, any tug of 500 HP or more could have easily transited the entire area. Sixteen hours later a 3500 HP tug with barge was completely stopped for almost five hours (Figure 6.4-2) because of a combination of tide, topography, and bathymetry that created an extremely convergent condition. The ice relaxed 1.5 hours after the tide changed (in the divergence process) and the tug proceeded into Anchorage.

In Norton Sound it is frequently the case that the greatest ice resistance will be found in the area from Nome to the Yukon Delta and westward because of the climatological wind induced polynyna in eastern Norton Sound and thicker ice in western Norton Sound. Consequently, once a ship gets into eastern Norton Sound, it can frequently operate with relative ease.

The "tend to be divergent" condition predicted along the northern coast of Norton Sound during flood tide is further qualified. If heavier concentrations of ice are moving from west to east, the effect of tidal divergence could be completely overcome by internal ice pack forces. At any rate transit offshore the north coast is still the best bet during flood tide. Finally, consider that the wind has a considerable affect on the tide as now described.

Section 6.3 described the movement of ice as a function of wind speed and direction. In summation, the ice will move at 3 percent of the wind speed and at a direction 25 degrees to the right of the wind direction (if wind is northeasterly, ice movement is to the west-southwest). Simple arithmatic shows that a wind of about 30 kts will balance a tidal current of 1 knot with respect to ice movement when the two are directly opposed. However, the wind tends to be persistent while the tides are oscillatory. Thus any persistent wind of more than 5-10 kt will soon create divergent areas along lee coasts and convergent areas along windward coasts. If one were to

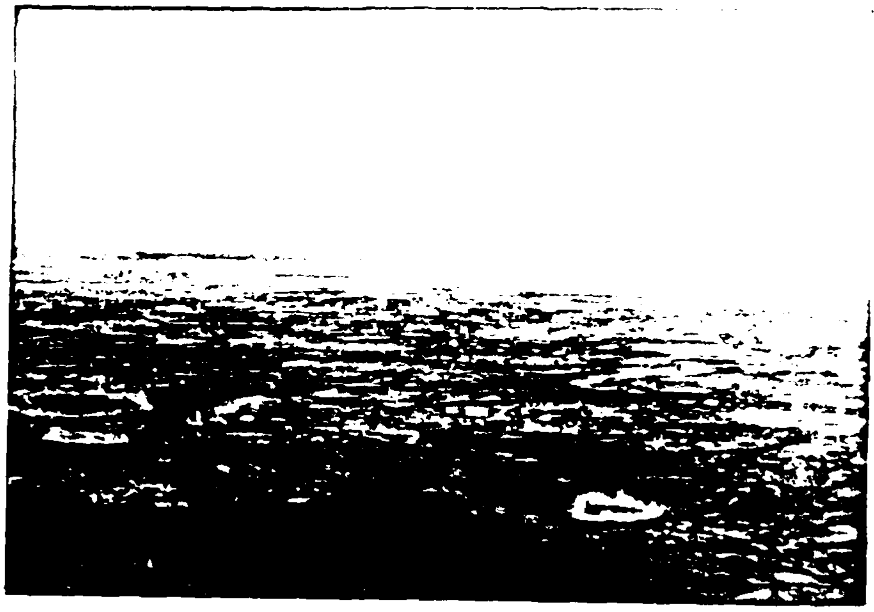

Figure 6.4-1. Apparent innocuous ice pack. See Figure 6.4-2.

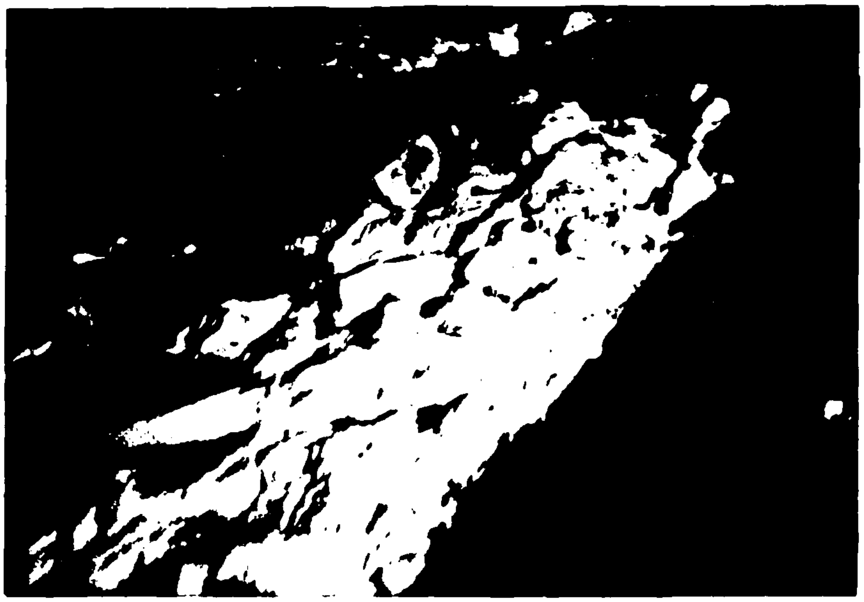

Figure 6.4-2. Same ice pack as in Figure 6.4-1 only 16 hours later. Tug and barge totally stopped by extreme convergent conditions.

quantify the convergent condition of ice at any point in time, the lowest limit would be zero with zero ice (open water). The upper limit would be a combined function of wind affects, tide affects, topography, bathymetry, and ice pack characteristics. Unfortunately, no attempt has been made to quantify convergence either as a function of one variable or several. However, it is obvious that the upper limit of convergence can be very high and variable. It could be high enough to threaten the structural integrity of ships or equipment, and operators of surface borne equipment should be particularly aware of actual or potentially high convergence areas.

6.5 Ice Growth and Dissipation

Ice growth can be measured directly in some cases but the normal procedure is to equate ice growth to freezing degree days (FDD). FDD is defined as the difference between a representative air temperature and another temperature that represents the freezing temperature of water (0°C for fresh water and near -1.8°C for salt water). The air temperature is normally the mean air temperature as measured at a selected coastal site. Various empirical relationships between air temperature and freezing points have been derived.

One of the oldest and most frequently quoted relationships was developed by Zubov (1945).

$$I^2 = \frac{FDD - 28.61}{1.43} \qquad 6.1$$

The equation has been modified to yield ice thickness in inches.

I = ice thickness (in)

FDD = cumulative sum of frost degree days in Fahrenheit based on water freezing temperature of 0°C.

Why Zubov chose 0°C for arctic ice is not known, but if we rectify the freezing temperature to -1.8°C, more representative of Norton Sound, the equation takes the following form:

$$I^2 = \frac{FDD - 28.6}{1.26} \qquad 6.2$$

Equation 6-2 is now more comparable to Bilello's equation for ice melt (Bilello and Bates, 1960).

$$I_M = -.12\ WDD \qquad 6.3$$

I_M = Ice melt

WDD = Sum of warming degree days in degrees Fahrenheit using a melting point of 28.8°F (-1.8°C)

There are very significant differences in the two equations. The equation for freezing is non-linear with a logarithmic profile. Simply this means that the thicker the ice the slower it grows for each increase in FDD. However, Bilello's equation is linear which says that the ice melts at the same rate no matter the thickness. In short, the ice melts more rapidly than it freezes for equal absolute values of FDD and WDD. How much more rapidly? A few calculations yield the following: To freeze and then melt 12 inches of ice would require a factor of 2.43 times more FDD than WDD; 24 inches would require 3.09 more FDD than WDD; and for 36 inches the ratio is 3.46.

However, to increase the ice thickness from 36 inches to 48 inches requires 1270 FDD. To decrease ice thickness from 48 inches to 36 inches requires only 100 WDD. In other words, ice melts almost 13 times faster than it freezes in the 36-48 inch range.

Both Zubov's and Bilello's equations are simplistic relationships on which considerable improvement could be made. It has been noted that ice in Cook Inlet which we view almost daily has been seen to disappear with amazing rapidity with only moderate warming degree days but with strong winds. Transits of the inlet by boat or plane do not find large pile-ups of ice on the windward shores. The ice just seems to vanish. Conversely, the ice build-up seems to follow more predictable rates. Rather than a simple relationship between FDD, WDD, and ice thickness, we feel there is a complex physical relationship involving turbulent heat fluxes both above and below the water's surface, varying vapor pressures, frictional affects, etc. that could more accurately describe ice thickness changes.

The term "ice thickness" requires definition. Ice thickness is described as the thickness an undisturbed flow of ice would have at some point distance from its edge where no deformation has taken place because of compressional forces, or no distorting drag or shear forces have occurred. Thus, in eastern Norton Sound, it would be very unusual to witness or measure ice thicknesses representative of the sum of the FDD. The two main reasons are: 1) the ice is constantly being subjected to deformation forces; and 2) those floes that develop with no deformation (except along the edge) normally drift westward or southwestward because of the prevailing northeasterly winds during the winter. New ice forms as the old ice moves out with the new ice developing its own thickness regime. Now comes the part that many people do not realize. During mid-winter when cold east to northeast winds prevail, the ice floes become steadily thicker as they move toward the central Bering Sea. This is because the air over the ice is still much colder than the freezing temperature of the water and the ice continues to accumulate FDD and thicken. This movement toward the central Bering Sea is called, by several authors, the conveyor belt system. To complete the simile, the conveyor belt continues to acquire a heavier load until the FDD changes to WDD and/or certain other factors contributing to melt, such as warmer water, begin to predominate.

6.6 Shearing and Compressional Forces

Shearing and compressional forces of the ice pack (also defined as internal stress) are anything that causes movement within the ice pack wherein two or more components (floes, cakes, etc.) come in contact creates internal stress. When the ice is divergent, internal stress is minimum and ice deformation is a minimum. When the ice is convergent, internal stress and deformation is maximum. Within the ice pack, wind and current stress equate to internal stress and when accompanied by convergence cause crushing of the edges of flows, thereby causing the ice to move vertically either downward or upward. The vertically displaced ice frequently become consolidated to the ice floe so thus a characteristic of ice floes, particularly older floes, is that they are much thicker along the edge than away from the edge.

If two floes come together and become consolidated through freezing, a ridge is formed away from the edge of the consolidated floes. The ridge and keels of first year ice are not as spectacular as in multi-year ice (the Arctic) because of the relative thinness, softness, and lesser areal extent of first year ice in addition to the general lack of macroscale wind and current forces acting on the ice pack. Broad fields of moderate or strong winds over any portion of the Arctic can cause internal ice stress in other portions of the Arctic. The ridges and keels of first year ice can be thought of as occurring in an array of different forms. For instance, if two relatively thin flows come together, one may be forced under the other (rafting) with no significant "ridging". This merely causes a thickening where the two floes come together. During the winter the maximum average thickness of Arctic ice is 3m. In Norton Sound the average thickness of the ice pack in mid-winter is considerably less than 1 meter because of the conveyor belt effect. The thinner ice deforms at much lower external force levels with subsequently less spectacular resultant ice shapes.

Also within the ice pack, floes of no great internal strength which are repeatedly subjected to alternating convergent and divergent forces tend to break up into small pieces. These small pieces when close together form a rubble field. If for some reason, such as a change in air temperature, the rubble field freezes together, it is called a consolidated rubble field or a consolidated rubble floe which may acquire a floe-like identity, but with quite different internal and external differences in both appearance and strength. It is suspected that rubble and rubble fields are more prevalent in southern Norton Sound and that relatively undisturbed floes are more prevalent in northern Norton Sound.

Major shearing and compressional forces occur along the edge of the shorefast ice. During the winter the shorefast ice remains attached to the shore. If, for some reason, it separates from the shore, it merely joins the moving ice pack. The significance of continuity of shorefast ice is that it is not part of the conveyor belt system. Its thickness is determined by frost degree days (FDD, see Section 6.5) and continues to thicken as long as FDD continue to accumulate. The end result is that shorefast ice becomes thicker and stronger than the moving pack ice. Thus when the pack ice moves into the shorefast ice, the shorefast ice normally holds firm thereby creating considerable stress along its edge. If the shorefast ice is thin, rafting or other forms resulting from convergence, may occur. In either case, the shorefast ice may continue to build seaward with evidences of ridging and rafting now internal to the shorefast ice. In short, shorefast ice does not have a uniform thickness. Its maximum thickness from accumulated frost degrees is estimated to be between 1.5 and 1.8 m. However, it is thicker in places because of past shear and compressional forces. Shorefast ice can extend up to 60 NM from shore, at pastol bay, but is more likely to extend 2.6 NM from shore along most of the eastern, northern, and western shores of Norton Sound.

In summary, internal stress occurs within the ice pack and determines much of the character of the ice pack. The greatest stress occurs along the shorefast ice edge but the character of the shorefast ice is more dependent on FDD and ice-edge forces than on internal stress.

7.0 Ship and Equipment Operations in First Year Ice

7.1 Background Information

In the past, mariners did not find it necessary to operate in first year ice and it was generally considered that effective operations in multi-year ice were impossible. However, during the last decade the more adventuresome mariners have successfully experimented with operations in first year ice. Now with the advent of fossil fuel exploration and development, and supportive activities, the subject of operations in first year ice is getting more and more attention.

What about present first year ice operations? We know that a German trawler processor, the Friedrich Busse, has trawled within the Bering Sea ice pack at least five winters and has been trawling in ice since construction in 1969 (Pennington, 1986. Pers. Comm.). We know that both the Japanese and Russian processor-trawlers and cooperative work boats, including other trawlers, routinely penetrate the Bering Sea ice pack. Both NOAA ships and Coast Guard ships operate in the ice pack. The Finnish and Swedish icebreakers and other ships have operated for decades in the Bay of Finland and Gulf of Bothnia. Bulk cargo carriers have transited Cook Inlet every week each year since the early 1960s. Rig tenders operate in Cook Inlet year round. Finally, boats of less than 3500 HP operated successfully in Cook Inlet the entire 1984-1985 winter when ice to .75m (undisturbed flows) was encountered.

All of these except the 1984-1985 tugboat (Pacific Western Lines) operations, were conducted without benefit of concepts of convergence or divergence, drag coefficients, etc. The primary modus operandi is to overcome the ice with horsepower and if that fails, wait until the ice condition changes enough

Figure 7.2-1 Aerial view of pack ice showing affects of convergence. Light to moderate.

Figure 7.2-2 Aerial view of pack ice about 2 hours after tidally induced divergence has occurred. Note sun glint from open water.

Figure 7.2-3 Aerial view of pack ice about 4 hours after tidally induced divergence has occurred. Note large open area along coast (upper portion dark area) and large mostly open area in lower portion of photo. Heaviest ice is concentrated over deep channel where convergence is expected during ebb tide.

Figure 7.2-4 Tugboat is entering known convergent area, but ice is thin and relatively soft. Thickness of undisturbed flow (smooth flow) is 25-30 cm.

Figure 7.2-5 Tugboat is entering thicker ice (0.3 to 0.6m), but it is only moderately consolidated. Note small area of open water, upper left, indicating the first signs of divergence.

Figure 7.2-6 Tugboat is entering thicker portion of ice pack, but the pack is mostly consolidated rubble. That, along with divergence, allows the tug to continue. Thickness of consolidated rubble is about 1m.

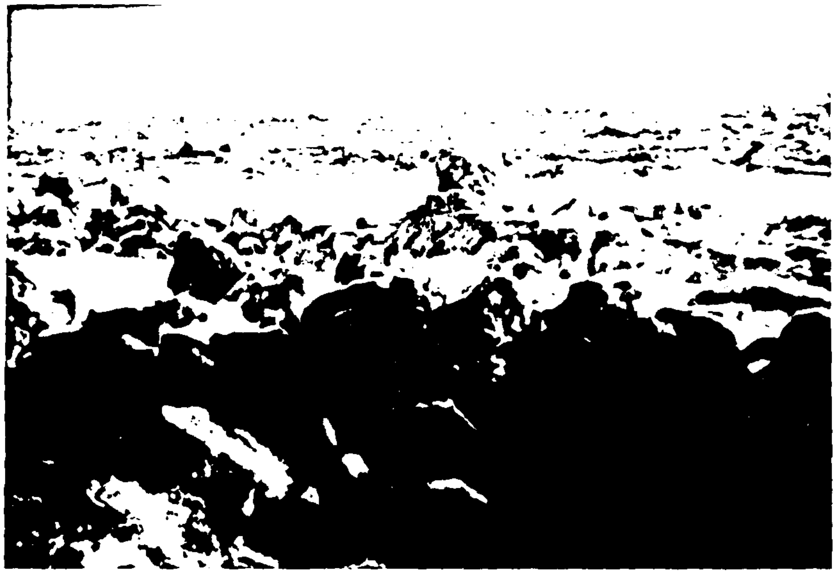

Figure 7.2-7 Pack is now at its thickest. Tug must actively avoid consolidated flows. The tug is now headed from a convergent area to a known divergent area. In this figure, divergence has been occurring about 2 hours. Undisturbed flow thickness is .75m. Rubble varies from 1m to 3m.

Figure 7.2-8 Tug has passed through heaviest ice and has reached an area that has been undergoing divergence about 3 to 3.5 hours. Tug is now able to move in open water most of the time. Thickness of consolidated rubble flow in foreground is 1.5 - 1.7m.

Figure 7.2-9 Tug breaks out into large lake-like polynyna area with only 3 - 5 cm of new ice and a few stamuki. There is little doubt that the eastern portion of Norton Sound would at times resemble this photo during mid winter.

Figure 7.2-10 Tug has left polynyna area and entered new light flow ice again. Note how ice is moving away from ship's track indicating divergence.

to allow movement and/or continued operations. Little has been learned about improving ice operations through experience because the ship operator experiences only a tiny portion of the entire ice pack and is generally unaware of the dynamic mesoscale and macroscale forces at work. In short, the present approach is limited to horsepower and patience with little or no scientific finesse. Hull strength has been given little attention and at this time does not appear to be a problem.

7.2 Operating Recommendations

First and foremost, stay out of convergent areas (see subsection 6.4). First year ice with undeformed thickness of 1m or less and deformed thicknesses of 2m or less can be navigated in non-convergent areas. See Figures 7.2-1 through 7.2-10 for examples of a tugboat navigating ice thickness of 1 to 2m. Keep in mind that thicknesses refer to the thickest flows. In non-convergent conditions, ships can usually avoid the thickest flows and penetrate and split the thinner flows. Figures 7.2-1 through 7.2-10 depict almost maximum thickness and congestion that a sea-going tug is capable of handling. Most first year ice is much less imposing.

Be careful following leads. Under convergent conditions, they can close rapidly. It is sometimes necessary to leave a lead that appears good to navigate toward a known or suspected divergent area.

Avoid headlands on the flood tide when the tide tends to push the ice up against the shore and particularly on one side of the headland or another depending on the direction of the tidal current.

Avoid windward coasts if the wind is over 4-5 knots.

Do not be discouraged by thick ice enroute to your destination. The ice could range from light to non-existent at the destination.

Prior to and during transit of the ice, assemble and integrate all available weather information in order to determine probable convergent and divergent area (including polynyas).

Compute the tides in advance for any place along the projected route of the ship. A change from convergence to divergence, or visa versa, frequently takes place at tidal change time even though the visual effects of condition change may not be obvious for 1-2 hours.

The ship is in a convergent area if the ice closes in rapidly astern after forward passage through the ice. If the open water created by the screw(s) widens behind the ship, it is in a divergent area. If the open water behind the ship closes very slowly, the ship is in a neutral area. The change from convergence to divergence, and visa versa, can be detected by observing the character of the trail of the ship.

Rubble flows are less resistant to ship movement than undisturbed flows of equal thickness.

7.3 Recommendations for Improving First Year Ice Operation Concept

Most ships that have penetrated first year ice have done little to enhance our understanding. Icebreakers are designed to cope with multi-year ice and tend to neglect data relating to first year ice. When in the ice pack, fishing vessels tend to stay near its edge where heavy convergence is unlikely. Rig tender and tugboat operators give little thought to the overall forces at work. In addition, no one has laid any comprehensive or systemized requirements on any operators to submit ice information. It is our view that one or two simple studies in a discrete area, such as Norton Sound could greatly accelerate the knowledge and understanding of first year ice pack characteristics and dynamics. Sophisticated studies have already been made that support the purely physical and mathematical approaches to the subject. Shipboard experience data is now needed to effectively join the presently fragmented knowledge to produce effective operational procedures.

When one considers that the discovery of oil in Norton Sound is likely, that there may be a strong desire to produce throughout the winter months, and that a major marine terminal is about to begin construction, the increased knowledge of first year ice will be particularly useful to all persons affected by the activities. Those persons include oil spill contingency planners, environmentalists, search and rescue personnel, and a variety of scientists.

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APPENDIX A

Percent Frequency of Wind Direction by Speed - St. Matthew Area
January through September
Period: 1953-1970 (Primary)
1879-1970 (Overall)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.1	1.5	3.1	1.6	.7	.1	138	7.0	19.1
NNE	.2	1.0	2.8	1.9	.2	.0	120	6.1	18.2
NE	.1	2.4	6.0	3.5	.6	.0	249	12.6	18.2
ENE	.1	2.2	3.9	1.5	.9	.1	170	8.6	17.6
E	.0	2.9	3.7	2.2	.6	.1	186	9.4	17.5
ESE	.0	1.4	1.8	.7	.1	.0	78	4.0	15.2
SE	.4	2.0	3.2	1.3	.5	.2	149	7.6	16.8
SSE	.1	1.5	1.7	1.1	.2	.1	92	4.7	16.5
S	.1	2.0	3.2	1.1	.2	.0	128	6.5	15.7
SSW	.2	1.7	3.2	1.1	.2	.0	126	6.4	15.5
SW	.1	2.0	2.5	.8	.2	.0	110	5.6	14.7
WSW	.1	1.1	1.8	1.2	.1	.0	82	4.2	16.7
W	.3	1.6	2.7	.9	.1	.0	109	5.5	14.8
WNW	.0	.9	1.7	.6	.1	.0	65	3.3	16.1
NW	.1	1.2	2.4	.8	.0	.0	88	4.5	14.7
NNW	.1	1.1	1.3	.4	.2	.0	60	3.0	14.6
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	1.1						22	1.1	.0
TOT OBS	57	524	888	409	87	7	1972		16.5
TOT PCT	2.9	26.6	45.0	20.7	4.4	.4		100.0	

January through February

APPENDIX A

Percent Frequency of Wind Direction (16 pts)
by Speed - Norton Sound Area,
February through September 1955 to 1970

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	1.1	2.3	10.7	8.7	.2	.0	224	23.0	18.5
NNE	.3	1.9	9.7	7.8	.6	.0	197	20.3	20.1
NE	.5	5.2	10.6	5.3	1.1	.0	222	22.8	17.4
ENE	.4	.9	4.5	2.6	.2	.0	84	8.6	17.8
E	.4	.6	2.6	2.0	.1	.0	55	5.7	18.5
ESE	.1	.3	1.3	1.0	.0	.0	27	2.8	17.1
SE	.0	.1	1.5	.0	.0	.0	16	1.6	17.3
SSE	.0	.0	.2	.1	.0	.0	3	.3	19.3
S	.0	.1	.5	.0	.0	.0	6	.6	12.2
SSW	.2	.1	.2	.0	.0	.0	5	.5	7.4
SW	.0	.0	.1	.0	.0	.0	1	.1	16.0
WSW	.3	.0	.0	.0	.0	.0	3	.3	2.7
W	.3	.2	.0	.0	.0	.0	5	.5	3.8
WNW	.4	.3	.0	.0	.0	.0	7	.7	3.1
NW	.5	.6	.1	.2	.0	.0	14	1.4	7.9
NNW	1.9	1.4	2.5	1.5	.0	.0	71	7.3	13.4
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	3.3						32	3.3	.0
TOT OBS	95	137	433	285	22	0	972		17.0
TOT PCT	9.8	14.1	44.5	29.3	2.3	.0		100.0	

February

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	.2	5.9	.3	.0	.0	.0	39	6.4	7.9
NNE	.2	1.6	.0	.0	.0	.0	11	1.8	6.5
NE	.7	4.1	.8	.3	.0	.0	36	1.8	8.0
ENE	.0	1.5	2.0	.0	.0	.0	21	3.5	11.2
E	.3	5.1	3.3	.8	.0	.0	58	9.5	11.3
ESE	.3	3.6	4.4	.5	.8	.0	59	9.7	14.3
SE	.0	2.5	2.0	.7	.3	.0	33	5.4	15.0
SSE	.2	.2	.7	.5	.0	.0	9	1.5	15.9
S	.2	1.2	1.2	.3	.0	.0	17	2.8	13.8
SSW	.0	1.3	1.2	.8	.0	.0	20	3.3	15.4
SW	.5	1.8	2.0	.7	.3	.0	32	5.3	14.6
WSW	.0	1.5	1.2	.0	.0	.0	16	2.6	11.2
W	.0	2.3	.3	.0	.0	.0	16	2.6	7.4
WNW	.5	2.3	1.5	.2	.0	.0	27	4.4	9.4
NW	1.0	4.4	3.0	.2	.0	.0	52	8.6	8.8
NNW	.0	2.8	6.3	.7	.0	.0	59	9.7	13.1
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	16.9						103	16.9	.0
TOT OBS	127	256	182	34	9	0	608		9.6
TOT PCT	20.9	42.1	44.5	29.3	2.3	.0		100.0	

March

APPENDIX A (cont'd.)

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	3.1	19.1	9.9	1.1	.0	.0	87	33.2	9.9
NNE	1.1	5.0	.8	.0	.0	.0	18	6.9	7.0
NE	.0	.8	.8	.0	.0	.0	4	1.5	9.3
ENE	.0	3.4	.4	.0	.0	.0	10	3.8	8.1
E	.0	.8	.0	.0	.0	.0	2	.8	10.0
ESE	.0	.0	.0	.0	.0	.0	0	.0	.0
SE	.0	.0	.0	.0	.0	.0	0	.0	.0
SSE	.0	.0	.0	.0	.0	.0	0	.0	.0
S	.0	.0	.0	.0	.0	.0	0	.0	.0
SSW	.0	.0	.0	.0	.0	.0	0	.0	.0
SW	.0	.0	.0	.0	.0	.0	0	.0	.0
WSW	.0	.4	.0	.0	.0	.0	1	.4	7.0
W	.0	.4	.0	.0	.0	.0	1	.4	5.0
WNW	.8	4.2	.0	.0	.0	.0	13	5.0	6.3
NW	1.1	11.1	1.9	.0	.0	.0	37	14.1	8.2
NNW	.4	13.0	8.4	1.5	.0	.0	61	23.3	10.9
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	10.7						28	10.7	.0
TOT OBS	45	152	58	7	0	0	262		8.3
TOT PCT	17.2	58.0	22.1	2.7	.0	.0		100.0	

April

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	.7	3.0	5.6	2.7	.0	.0	97	12.1	14.4
NNE	.7	3.1	3.1	1.0	.0	.0	64	8.0	11.6
NE	.7	4.4	4.1	.0	.0	.0	74	9.2	10.1
ENE	.9	4.0	3.9	.0	.0	.0	70	8.7	9.9
E	1.9	5.4	5.4	.7	.0	.0	107	13.4	10.9
ESE	.2	2.0	1.4	1.0	.0	.0	37	4.6	13.8
SE	.2	1.0	1.7	.4	.0	.0	27	3.4	12.5
SSE	.4	.4	.0	.1	.0	.0	7	.9	6.4
S	.1	.1	.0	.0	.0	.0	2	.2	5.5
SSW	.9	.1	.5	.0	.0	.0	12	1.5	5.8
SW	.4	.2	.2	.0	.0	.0	7	.9	6.6
WSW	.4	.7	.0	.0	.0	.0	9	1.1	3.9
W	2.5	3.9	3.5	.0	.0	.0	79	9.9	7.6
WNW	1.0	5.9	1.0	.1	.0	.0	64	8.0	6.5
NW	1.2	3.1	2.6	.2	.0	.0	58	7.2	9.6
NNW	.4	3.4	3.9	1.1	.1	.0	71	8.9	13.7
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	2.0						16	2.0	.0
TOT OBS	118	326	296	60	1	0	801		10.4
TOT PCT	14.7	40.7	37.0	7.5	.1	.0		100.0	

May

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	.0	2.0	2.6	2.6	.0	.0	11	7.2	17.7
NNE	.0	2.6	5.3	2.0	.7	.0	16	10.5	16.7
NE	.7	1.3	2.6	.0	.0	.0	7	4.6	12.1
ENE	.0	.7	2.0	.0	.0	.0	4	2.6	13.0
E	2.0	2.6	2.6	.0	.0	.0	11	7.2	8.4
ESE	.0	1.3	3.3	2.0	.0	.0	10	6.6	19.3
SE	.0	3.3	2.6	.0	.0	.0	9	5.9	11.8
SSE	.7	2.6	.7	.7	.0	.0	7	4.6	9.4
S	.0	10.5	3.9	.0	.0	.0	22	14.5	9.8
SSW	.0	3.3	2.0	.0	.0	.0	8	5.3	9.6
SW	.0	3.3	.7	.0	.0	.0	6	3.9	7.3
WSW	.0	2.0	.0	.0	.0	.0	3	2.0	6.7
W	.0	3.9	2.0	.0	.0	.0	9	5.9	8.9
WNW	.0	.7	1.3	.0	.0	.0	3	2.0	11.3
NW	.7	2.6	2.0	.7	.0	.0	9	5.9	12.4
NNW	.0	1.3	2.0	.0	.0	.0	5	3.3	12.0
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	7.9						12	7.9	.0
TOT OBS	18	67	54	12	1	0	152		11.2
TOT PCT	11.8	44.1	35.5	7.9	.7	.0		100.0	

June

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	.7	3.0	3.8	1.0	.1	.0	131	8.4	13.4
NNE	.2	1.0	1.8	.4	.0	.0	54	3.5	13.4
NE	.6	1.8	.8	.2	.0	.0	53	3.4	9.0
ENE	.1	1.1	1.0	.0	.0	.0	34	2.2	10.7
E	.1	2.5	1.3	.4	.1	.0	70	4.5	11.7
ESE	.5	1.3	.9	.5	.0	.0	51	3.3	11.5
SE	.5	1.7	1.7	.3	.0	.0	65	4.2	11.0
SSE	.3	1.9	4.0	1.1	.3	.0	119	7.6	16.0
S	.6	4.8	8.4	1.3	.0	.0	236	15.1	13.5
SSW	.1	2.8	4.3	.5	.1	.0	120	7.7	13.4
SW	.7	4.0	4.7	.6	.0	.0	157	10.0	11.5
WSW	.2	3.6	2.8	.4	.0	.0	109	7.0	11.5
W	.4	3.3	2.4	.5	.0	.0	104	6.7	10.9
WNW	.6	1.3	1.5	.1	.0	.0	55	3.5	10.2
NW	.4	2.1	.9	.3	.0	.0	57	3.6	9.1
NNW	.2	2.2	1.9	.4	.0	.0	75	4.8	12.1
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	4.7						73	4.7	.0
TOT OBS	166	601	661	125	10	0	1563		11.7
TOT PCT	10.6	38.5	42.3.	8.0	.6	.0		100.0	

July

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	.8	3.8	5.7	3.1	.3	.0	217	13.6	15.6
NNE	.3	1.5	2.4	.7	.0	.0	77	4.8	14.0
NE	.3	2.1	2.8	.4	.0	.0	91	5.7	12.6
ENE	.3	1.8	.9	.3	.1	.0	52	3.3	11.5
E	.5	2.2	2.8	.4	.1	.0	95	6.0	12.3
ESE	.2	1.4	2.1	.6	.0	.0	69	4.3	13.7
SE	.9	1.8	2.0	1.2	.0	.0	94	5.9	13.4
SSE	.3	1.6	2.3	.7	.0	.0	78	4.9	14.5
S	.4	2.4	4.0	1.0	.0	.0	124	7.8	13.8
SSW	.3	1.9	2.9	1.1	.0	.0	100	6.3	14.1
SW	.5	2.5	3.9	.7	.0	.0	121	7.6	12.9
WSW	.2	2.2	2.5	.9	.0	.0	91	5.7	13.2
W	.6	2.6	1.9	.6	.0	.0	90	5.7	11.5
WNW	.3	1.2	.9	.3	.0	.0	44	2.8	11.6
NW	.6	2.3	1.8	.6	.0	.0	83	5.2	11.9
NNW	.4	1.9	2.6	1.7	.1	.0	107	6.7	15.5
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	3.6						58	3.6	.0
TOT OBS	166	530	657	231	7	0	1591		13.0
TOT PCT	10.4	33.3	41.3	14.5	.4	.0		100.0	

August

Wind Direction	Wind Speed (knots) 0-3	4-10	11-21	22-33	34-47	48+	Total OBS	Percent Frequency	Mean SPD
N	.5	2.9	8.4	4.7	.4	.0	163	16.9	17.7
NNE	.4	2.2	5.5	1.4	.0	.0	91	9.5	15.1
NE	.2	2.3	2.0	.3	.0	.0	46	4.8	11.1
ENE	.0	2.1	1.6	.5	.0	.0	40	4.2	12.4
E	.7	2.4	3.1	.3	.1	.0	64	6.7	11.9
ESE	.2	1.0	2.3	.8	.0	.0	42	4.4	13.7
SE	.2	1.5	3.3	.6	.0	.0	54	5.6	14.2
SSE	.3	1.8	2.8	.5	.0	.0	52	5.4	13.4
S	.5	4.7	3.6	1.7	.4	.0	105	10.9	13.8
SSW	.2	1.4	2.3	1.5	.1	.0	52	5.4	16.5
SW	.0	2.1	1.5	.5	.1	.0	40	4.2	13.7
WSW	.4	.8	.8	.4	.0	.0	24	2.5	11.8
W	.3	1.6	1.4	.4	.0	.0	35	3.6	12.5
WNW	.6	2.0	.3	.1	.0	.0	29	3.0	7.3
NW	.4	1.9	1.8	.7	.3	.0	49	5.1	13.9
NNW	.4	1.2	1.9	.6	.0	.0	40	4.2	13.5
VAR	.0	.0	.0	.0	.0	.0	0	.0	.0
CALM	3.7						36	3.7	.0
TOT OBS	89	305	409	145	14	0	962		13.6
TOT PCT	9.3	31.7	42.5	15.1	1.5	.0		100.0	

September

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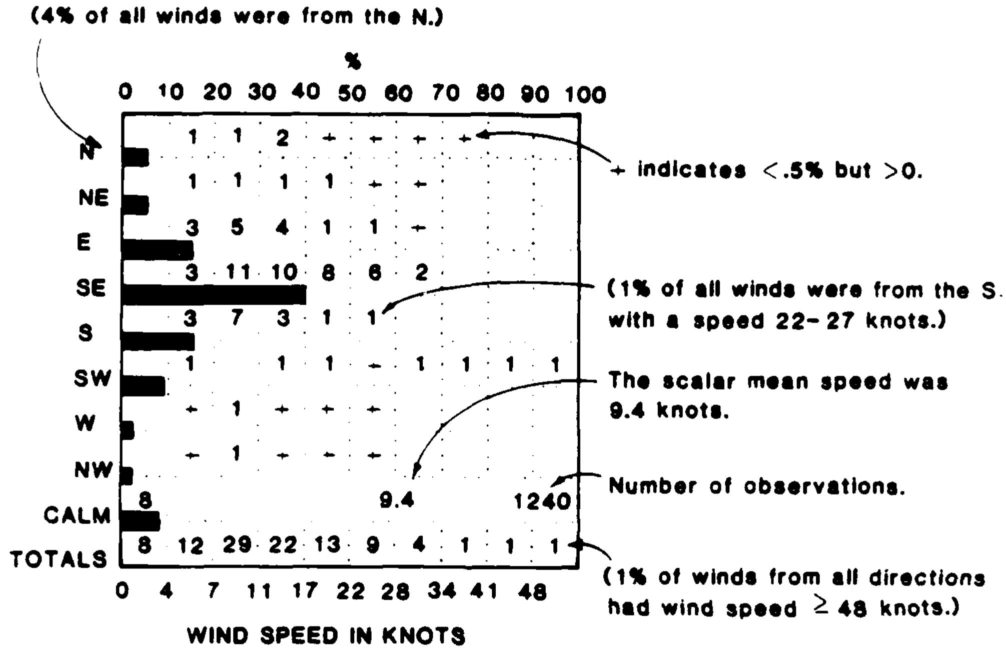
LEGEND

Direction frequency (top scale) : Bars represent per cent frequency of winds observed from each direction.
Speed frequency (bottom scale) : Printed figures represent per cent frequency of wind speeds observed from each direction.



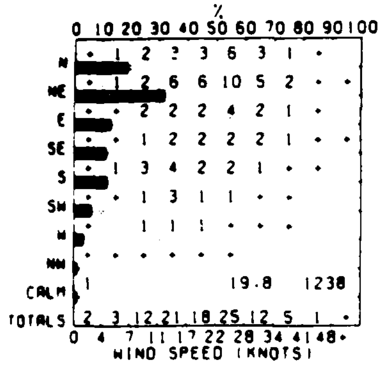
WIND SPEED INTERVAL (KNOTS)

0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	≥ 48

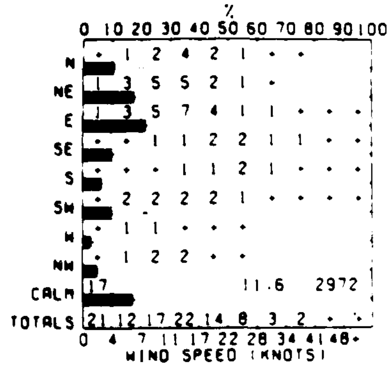
0 4 11 17 22 28 34 41 48

Printed scale on bottom of chart

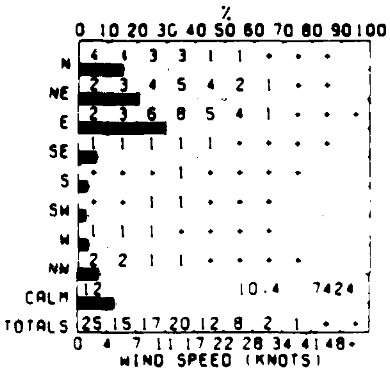
JANUARY WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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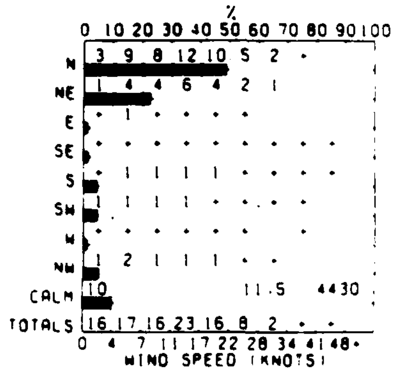
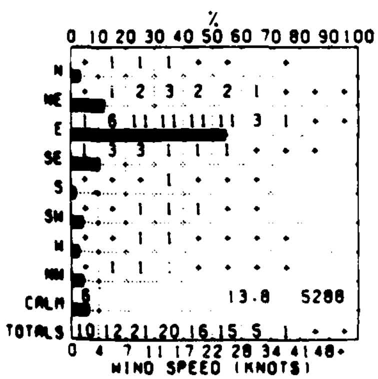
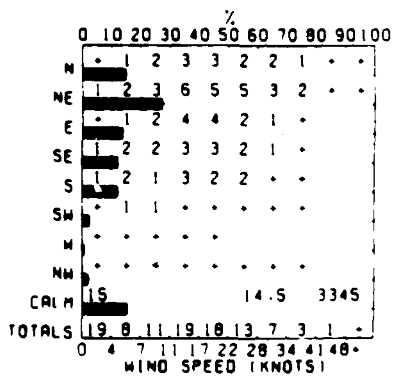


MOSES POINT

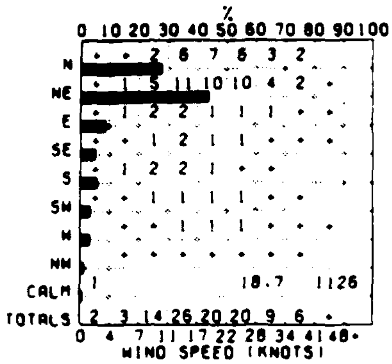


UNALAKLEET

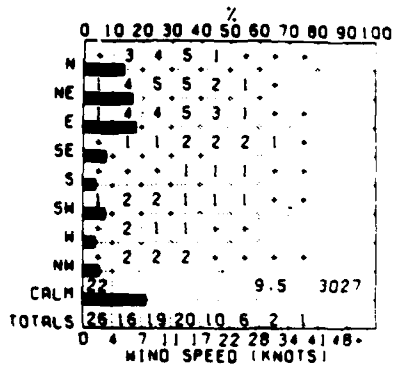


CAPE ROMANZOF

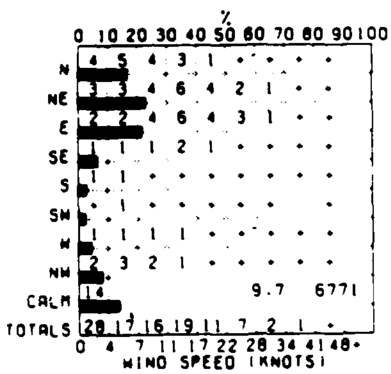
FEBRUARY WIND SUMMARIES



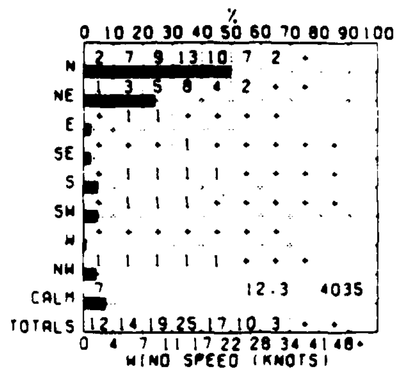
GAMBELL



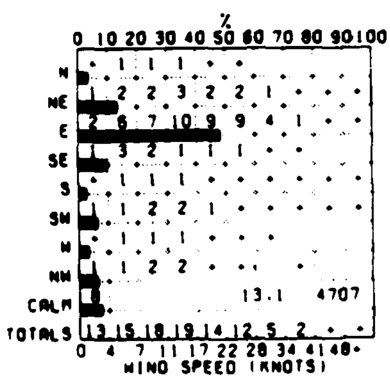
NORTHEAST CAPE



NOME



MOSES POINT



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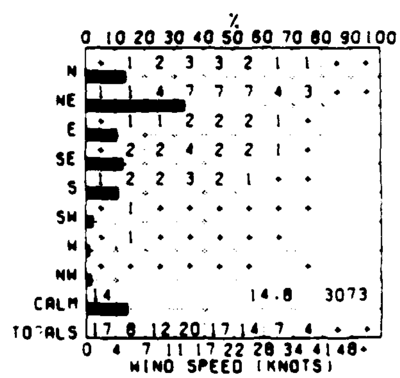
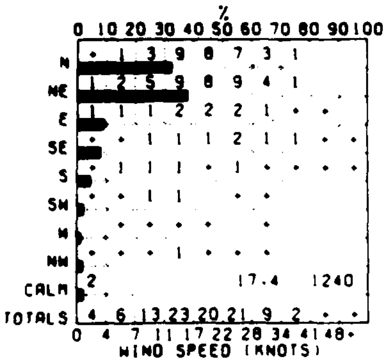


CAPE ROMANZOF

MARCH WIND SUMMARIES



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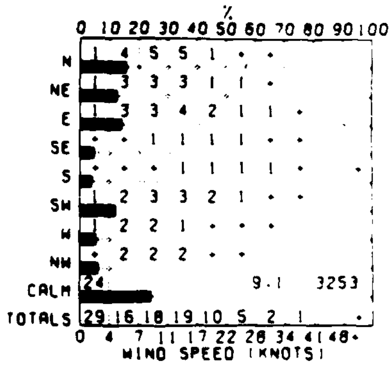

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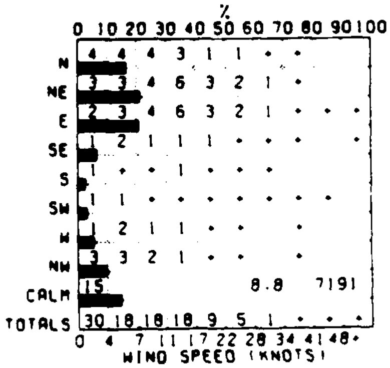

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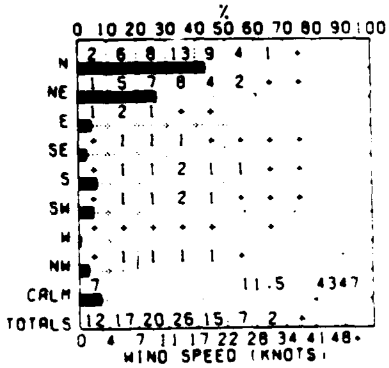

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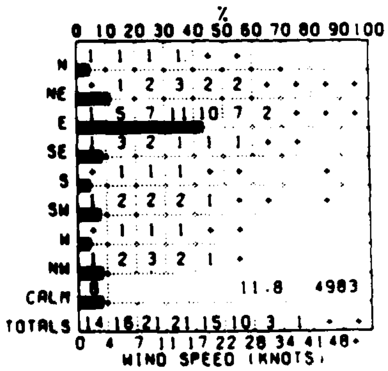

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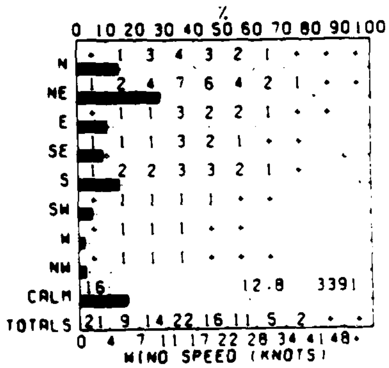
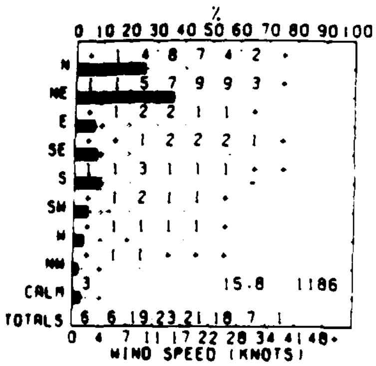
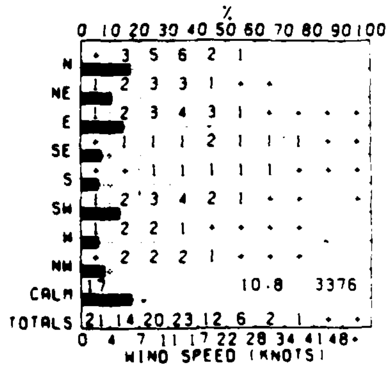


CAPE ROMANZOF

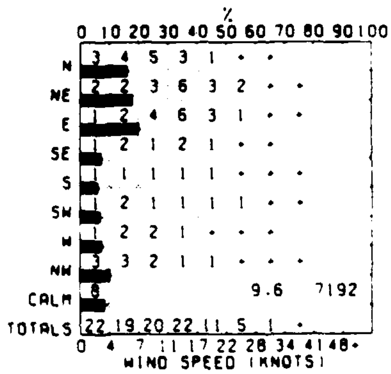
APRIL WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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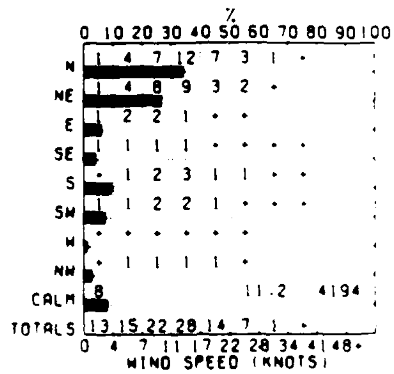

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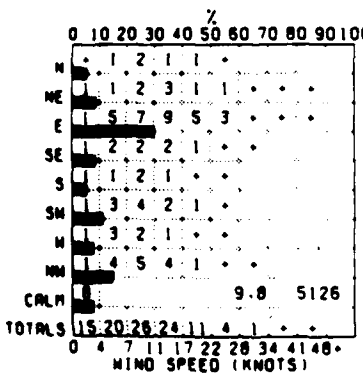

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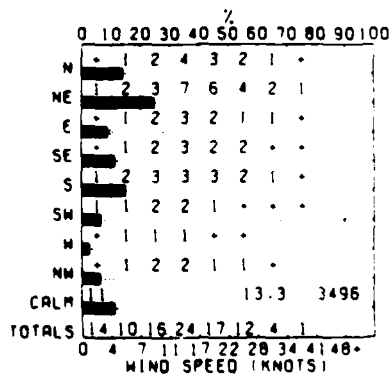
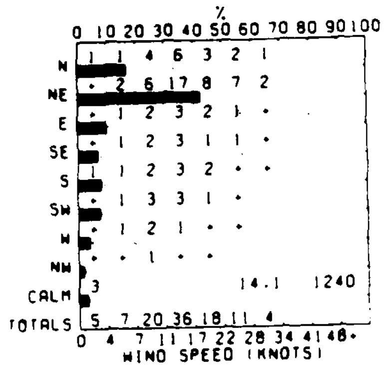
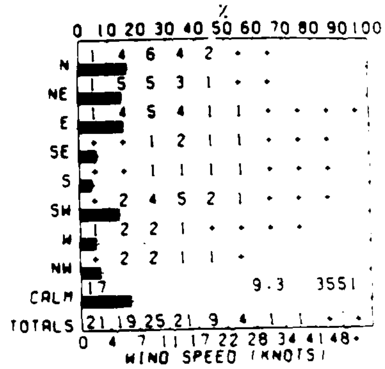


CAPE ROMANZOF

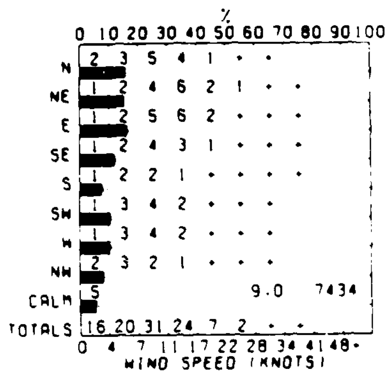
MAY WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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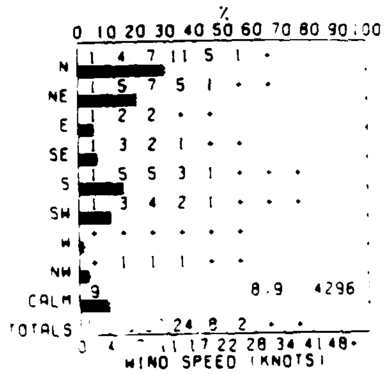

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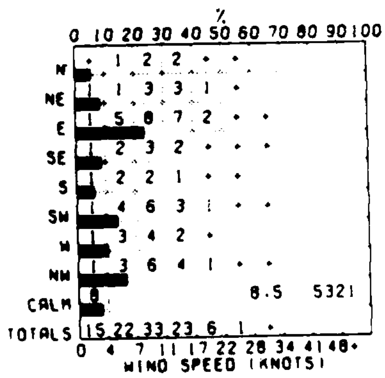

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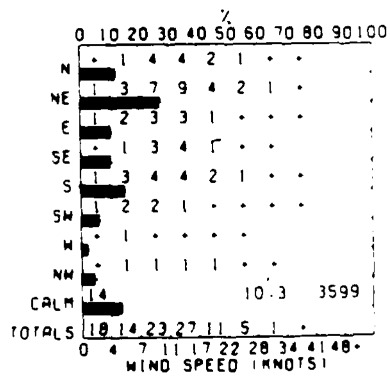
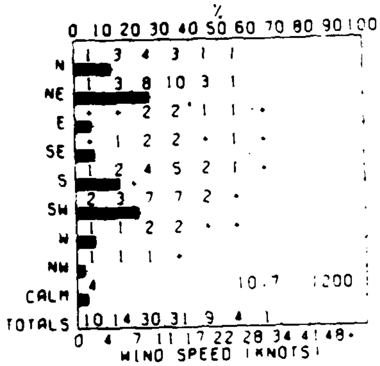
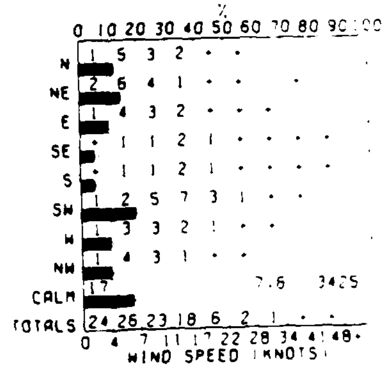


CAPE ROMANZOF

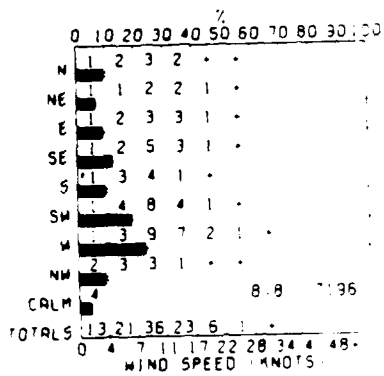
JUNE WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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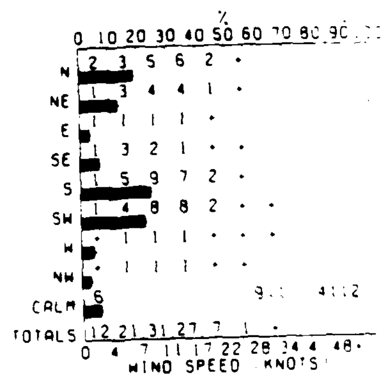

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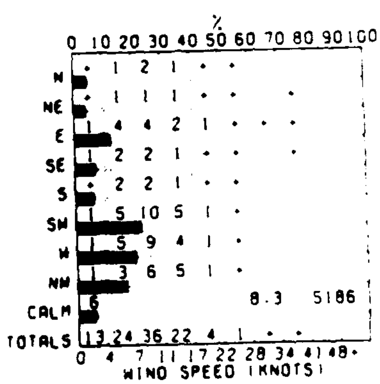

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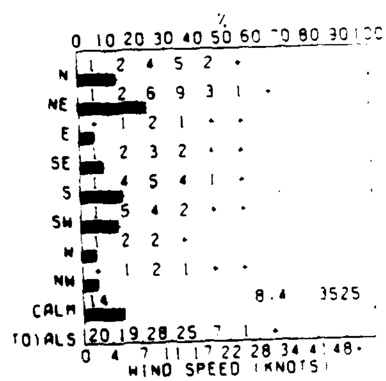
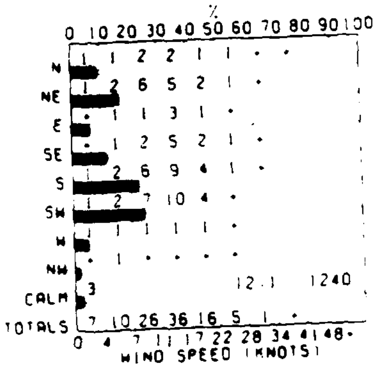
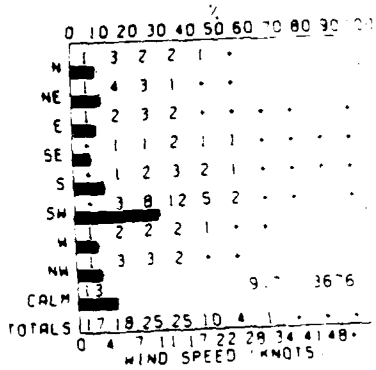


CAPE ROMANZOF

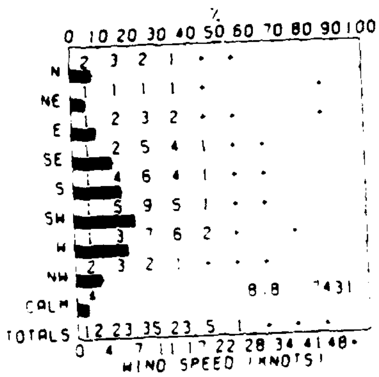
JULY WIND SUMMARY



GAMBELL



NORTHEAST CAPE



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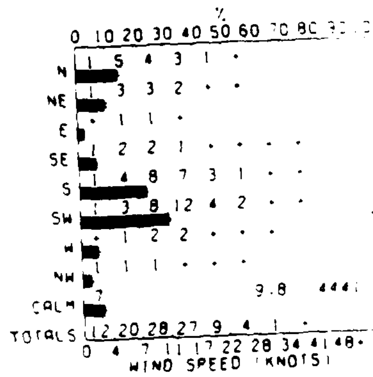

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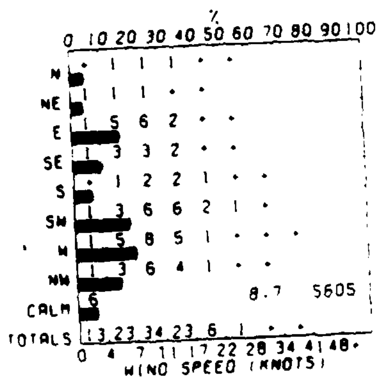

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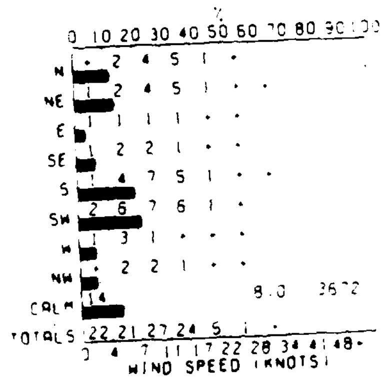
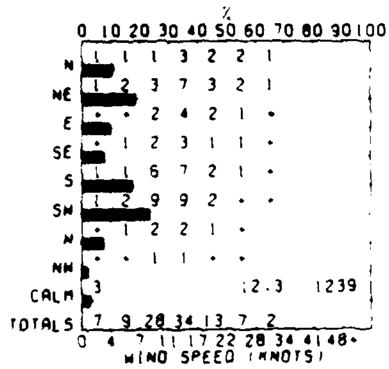
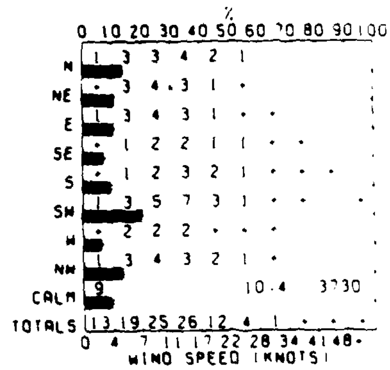


CAPE ROMANZOF

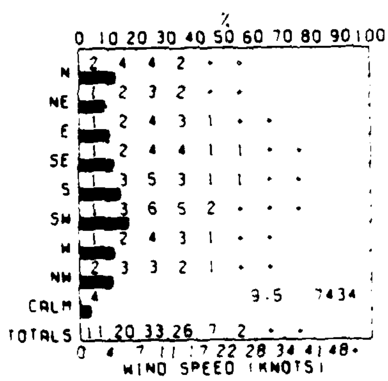
AUGUST WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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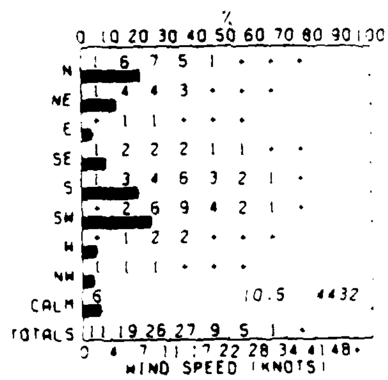
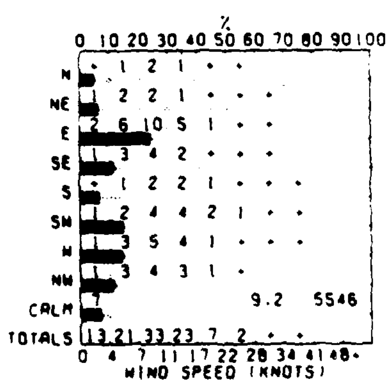


MOSES POINT



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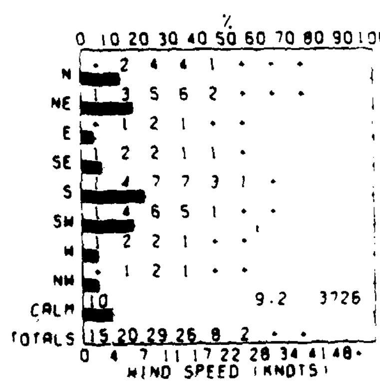
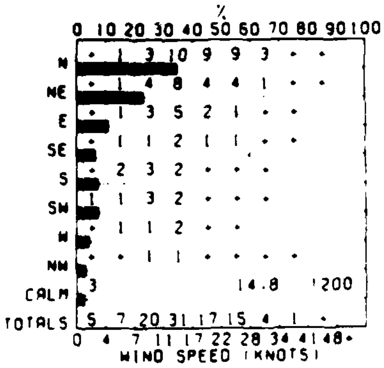
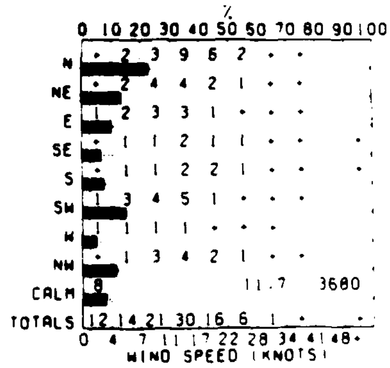


CAPE ROMANZOF

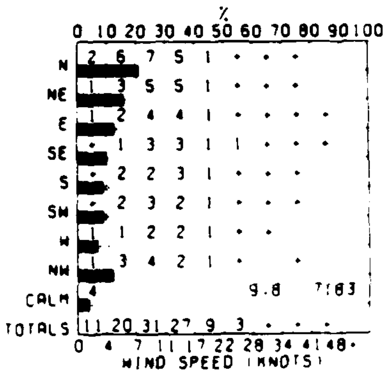
SEPTEMBER WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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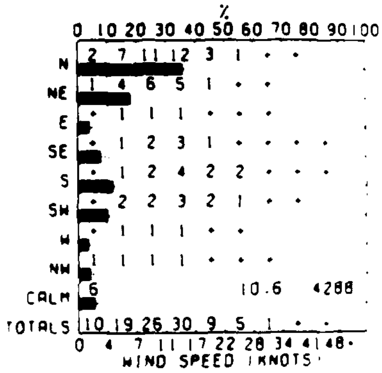
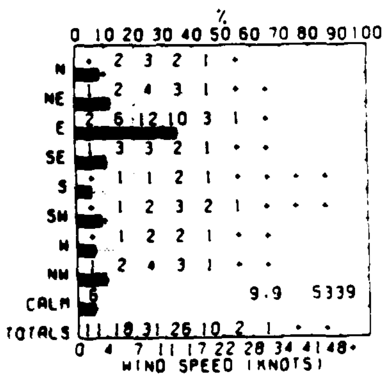


MOSES POINT



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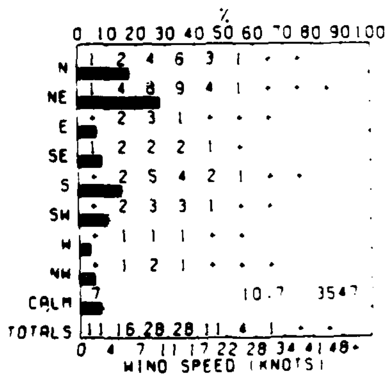
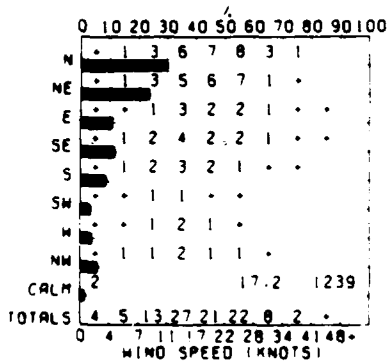
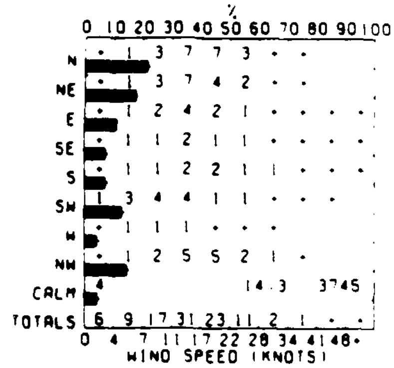


CAPE ROMANZOF

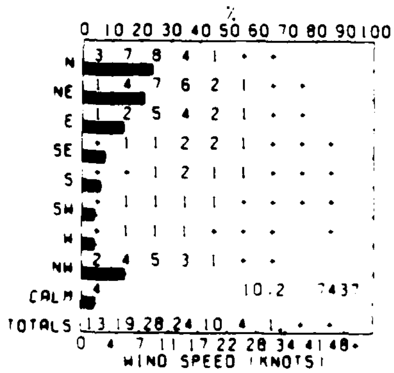
OCTOBER WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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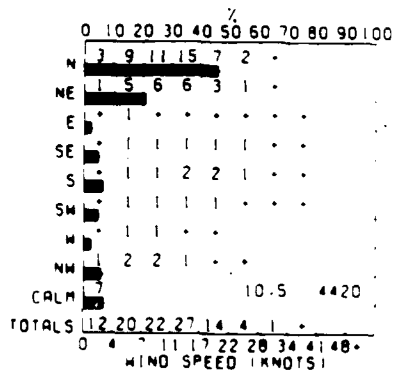
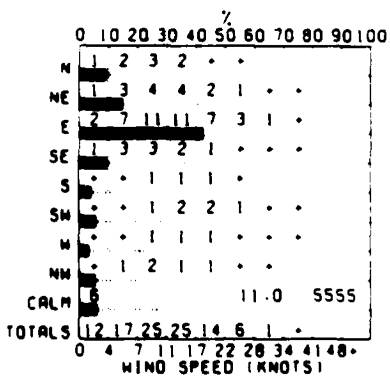


MOSES POINT



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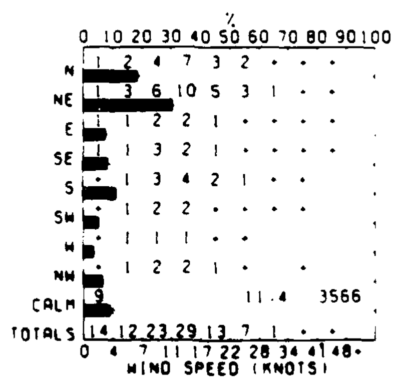
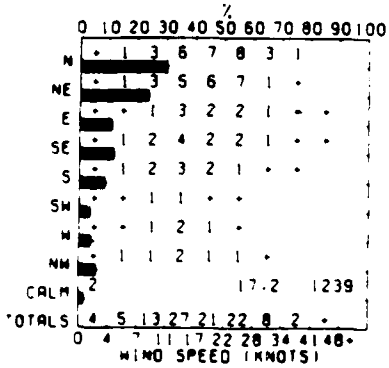
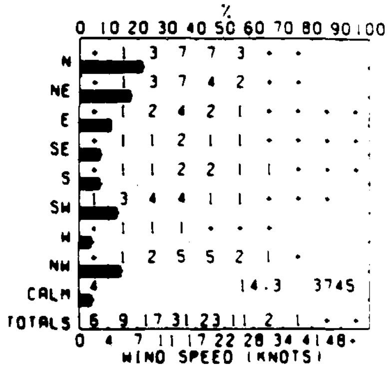


CAPE ROMANZOF

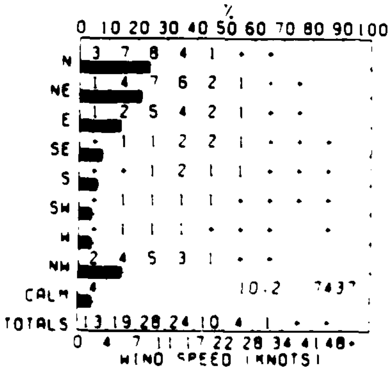
NOVEMBER WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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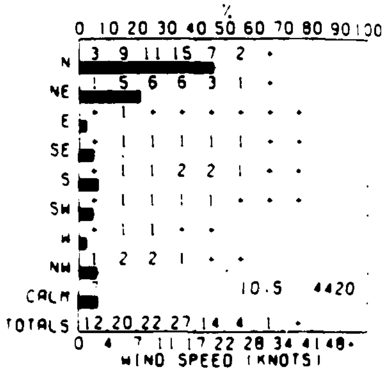
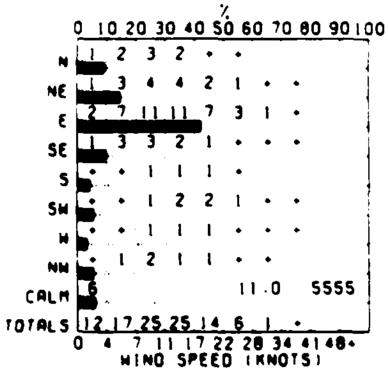


MOSES POINT



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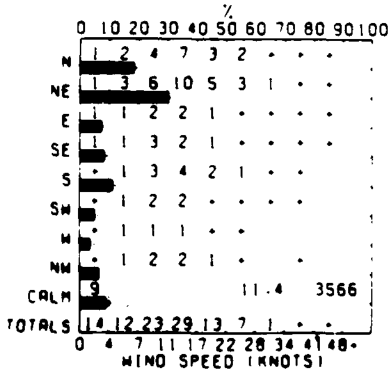
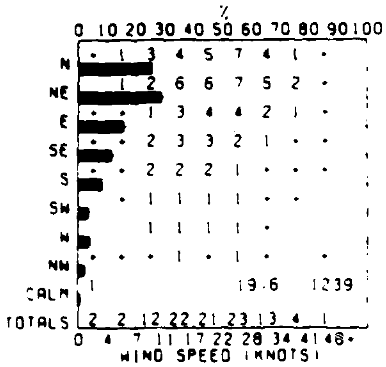
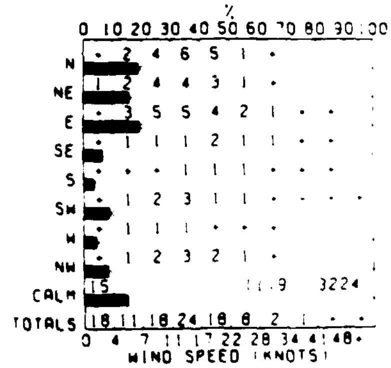


CAPE ROMANZOF

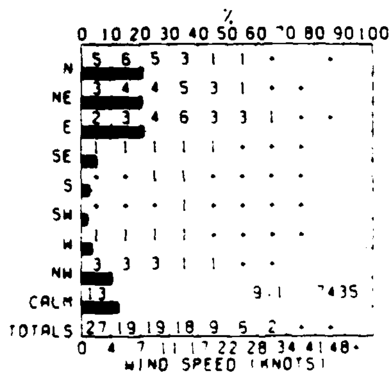
DECEMBER WIND SUMMARIES



GAMBELL



NORTHEAST CAPE



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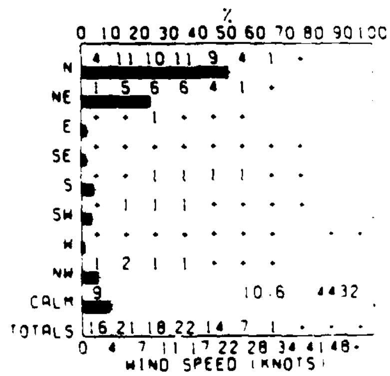
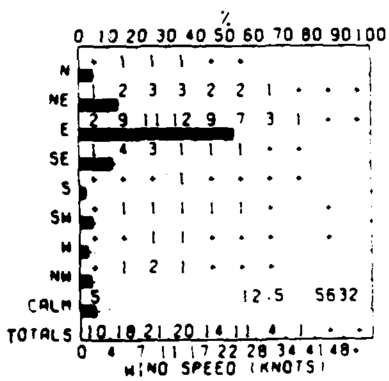


MOSES POINT



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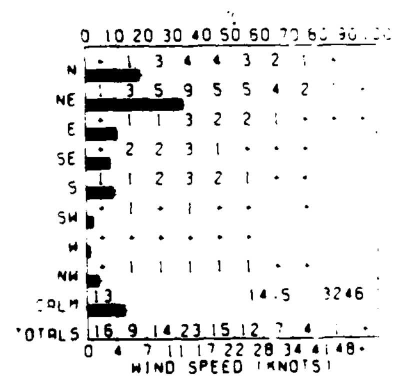
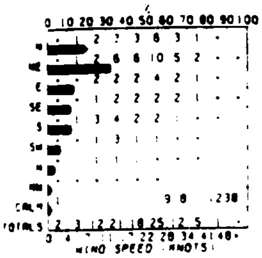
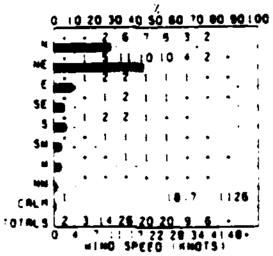


CAPE ROMANZOF

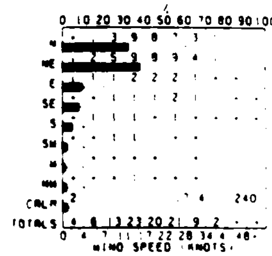
WIND SUMMARIES FOR GAMBELL



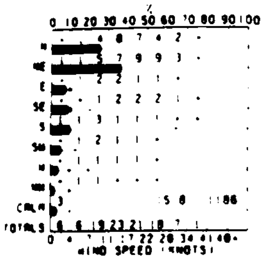
JANUARY



FEBRUARY



MARCH



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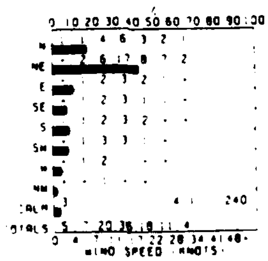

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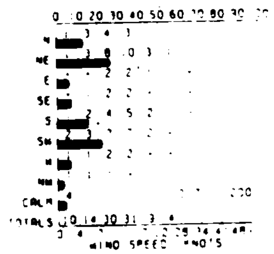

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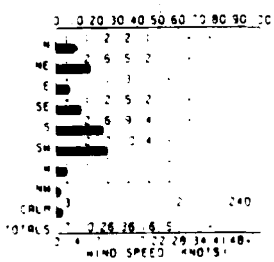

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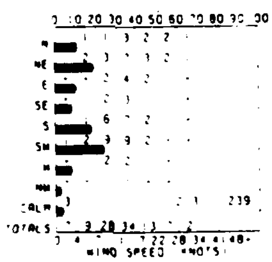

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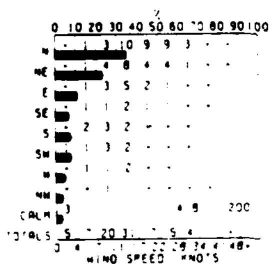

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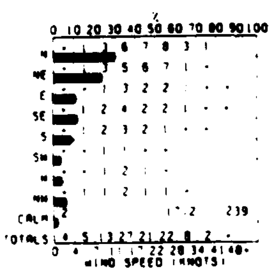

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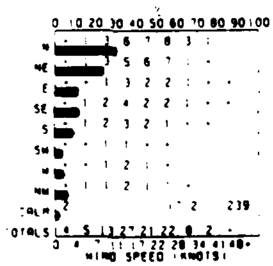

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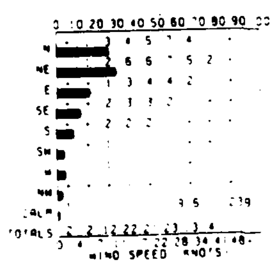

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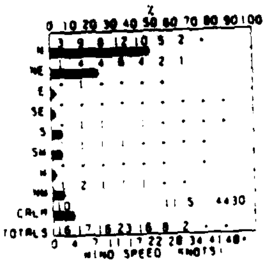

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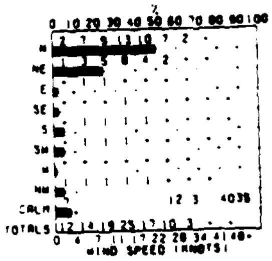

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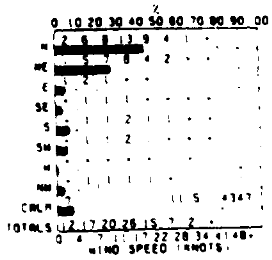

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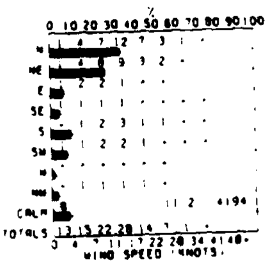

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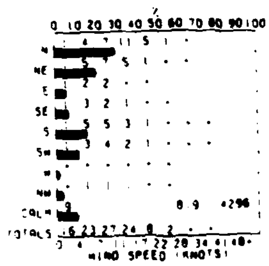

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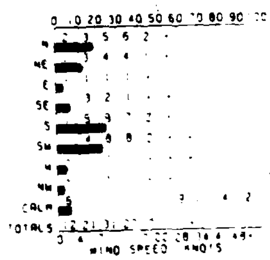

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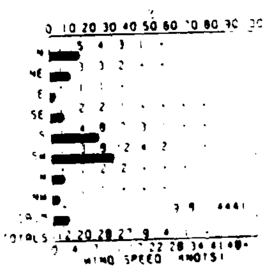

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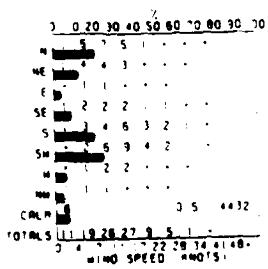

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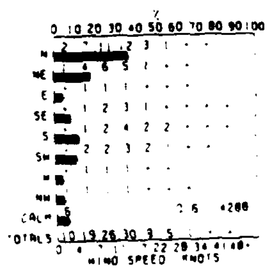

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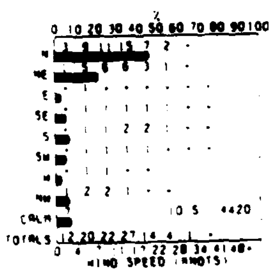

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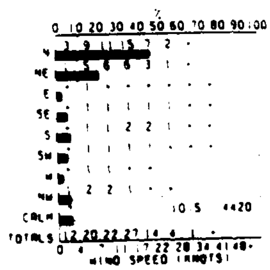

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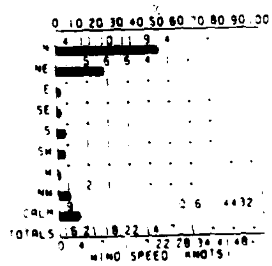

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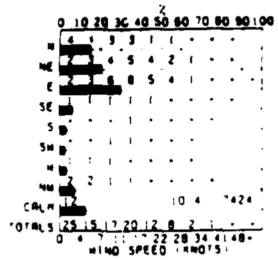

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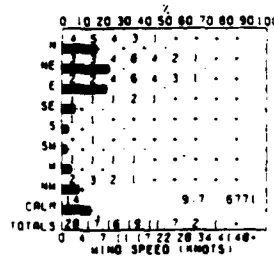

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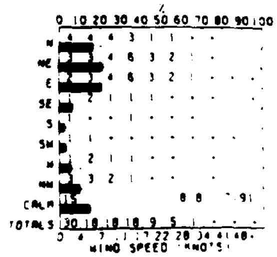

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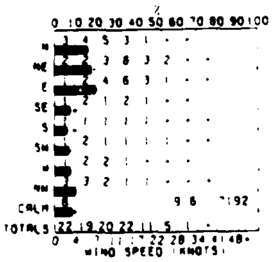

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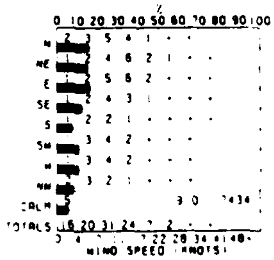

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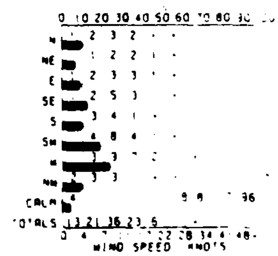

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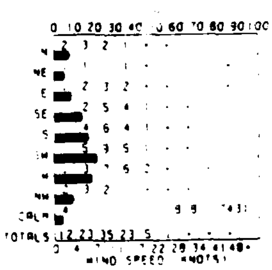

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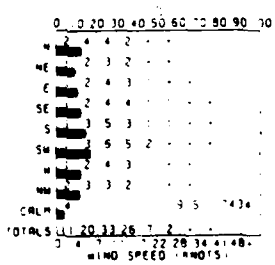

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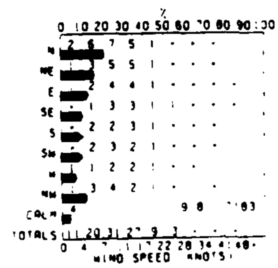

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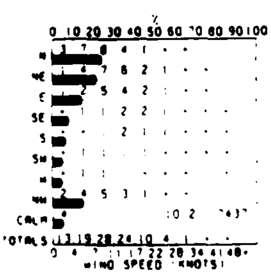

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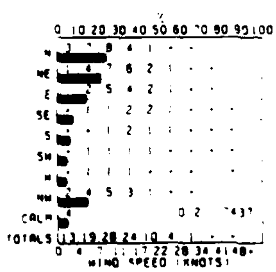

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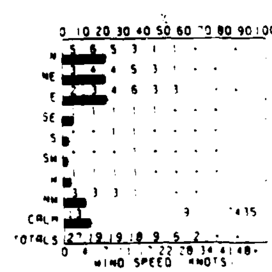

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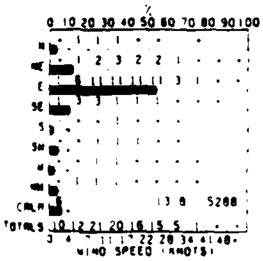

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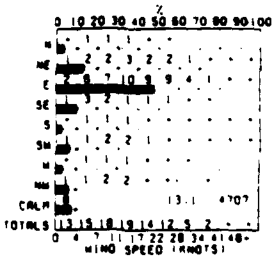

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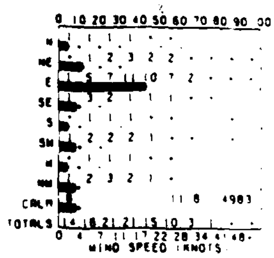

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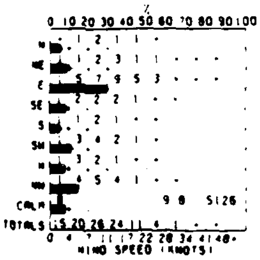

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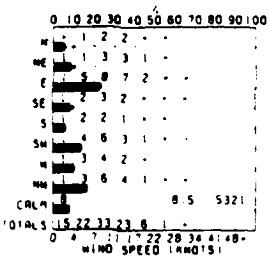

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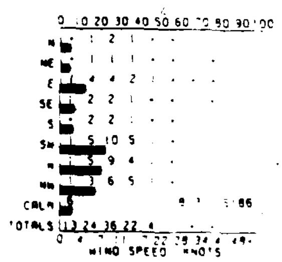

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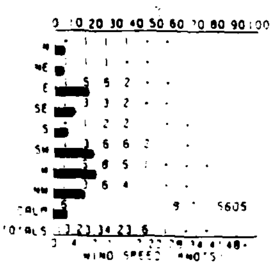

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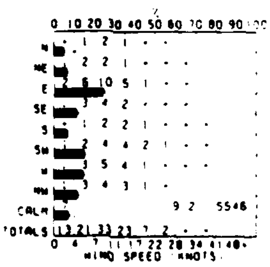

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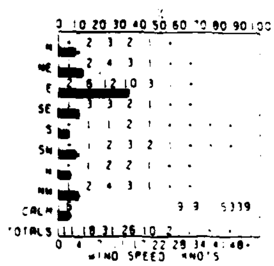

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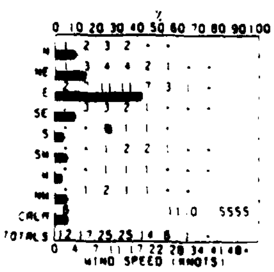

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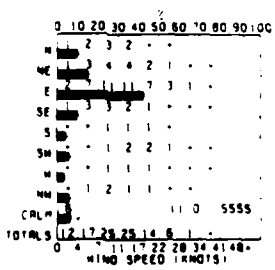

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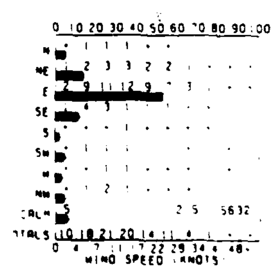

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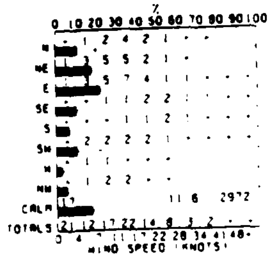

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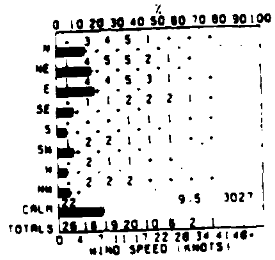

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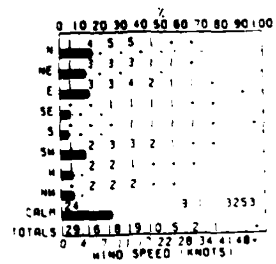

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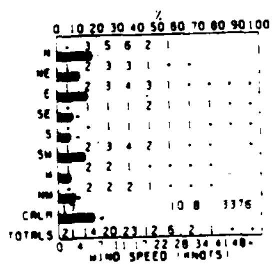

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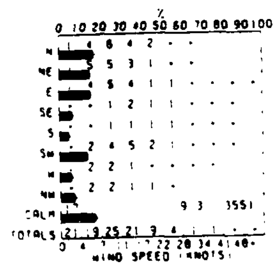

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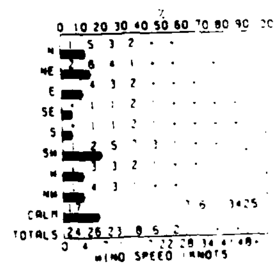

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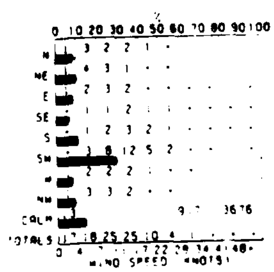

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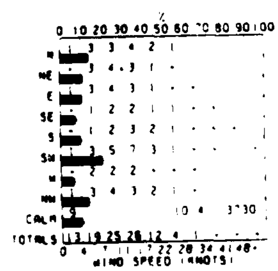

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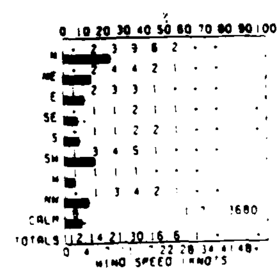

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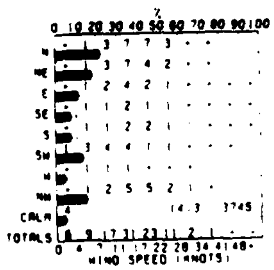

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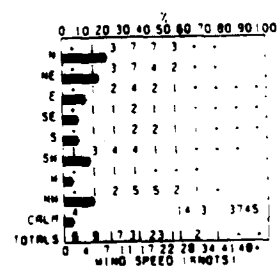

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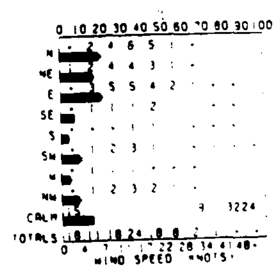

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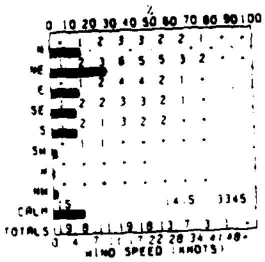
WIND SUMMARIES FOR CAPE ROMANZOF



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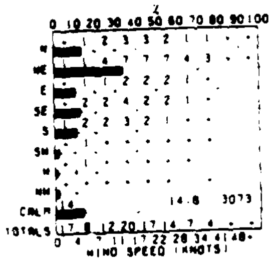

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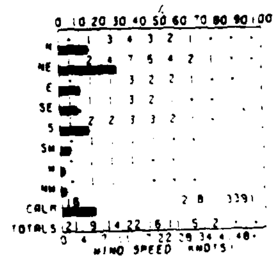

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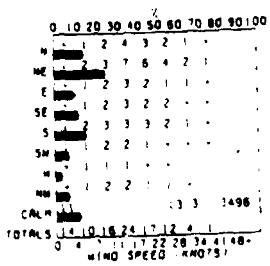

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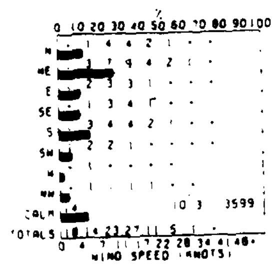

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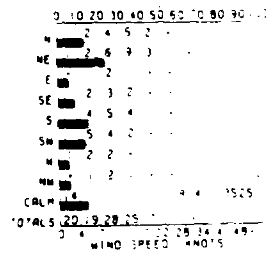

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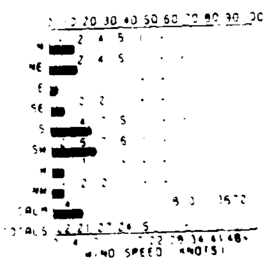

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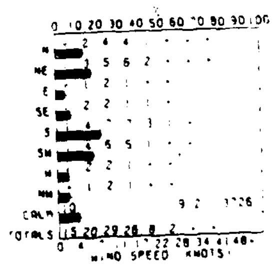

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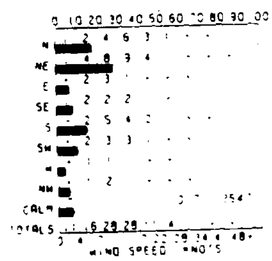

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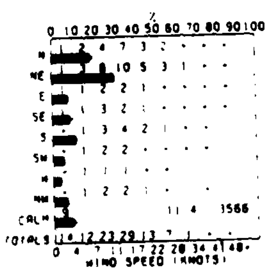

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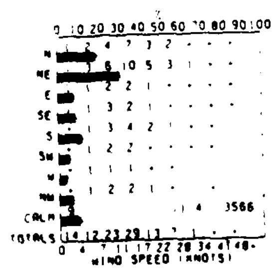

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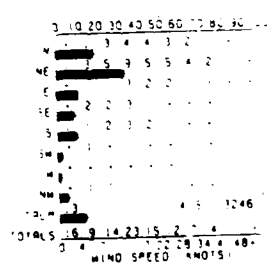

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APPENDIX C

Glossary of Ice Terms

This glossary is compiled from the "WMO Sea-Ice Nomenclature Handbook" distributed by the Naval Polar Oceanography Center, Suitland, Maryland. Ice terms are arranged in alphabetical order and are limited to those terms most likely to be encountered in the Cook Inlet sea ice literature.

Bergy bit: A large piece of floating glacier ice, generally showing less than 5 m above sea-level but more than 1 m and normally about 100-300 sq. m in area.

Big floe: (See Floe).

Brash ice: Accumulations of floating ice made up of fragments not more than 2 m across, the wreckage of other forms of ice.

Calving: The breaking away of a mass of ice from an ice wall, ice front, or iceberg.

Close pack ice: Pack ice in which the concentration is 7/10 to 8/10, composed of floes mostly in contact.

Compacted ice edge: Close, clear-cut edge compacted by wind or current; usually on the windward side of an area of pack ice.

Compacting: Pieces of floating ice are said to be compacting when they are subject to a converging motion which increases ice concentration and/or produces stresses which may result in ice deformation.

Compact pack ice: Pack ice in which the concentration is 10/10 and no water is visible.

Concentration: The ratio in tenths of the sea surface actually covered by ice to the total area of sea surface, both ice-covered and ice-free, at a specific location or over a defined area.

Concentration boundary: A line approximating the transition between two areas of pack ice with distinctly different concentrations.

Consolidated pack ice: Pack ice in which the concentration is 10/10 and the floes are frozen together.

Consolidated ridge: A ridge in which the base has frozen together.

Crack: Any fracture which has not parted.

Dark nilas: Nilas which is under 5 cm in thickness and is very dark in color.

Deformed ice: A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are rafted ice, ridged ice, and hummocked ice.

Diffuse ice edge: Poorly defined ice edge limiting an area of dispersed ice; usually on the leeward side of an area of pack ice.

Diverging: Ice fields or floes in an area are subjected to diverging or dispersive motion, thus reducing ice concentration and/or relieving stresses in the ice.

Dried ice: Sea ice from the surface of which melt-water has disappeared after the formation of cracks and thaw holes. During the period of drying, the surface whitens.

Fast ice: Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea level. Fast ice may be formed in situ from sea water or by freezing of pack ice of any age to the shore, and it may extend a few meters or several hundred kilometers from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category (old, second-year, or multi-year). If it is thicker than about 2 m above sea-level, it is called an ice shelf.

Fast-ice boundary: The ice boundary at any given time between fast ice and pack ice.

Fast-ice edge: The demarcation at any given time between fast ice and open water.

Finger rafting: Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternately over and under the other. Common in nilas and gray ice.

First-year ice: Sea ice of not more than one winter's growth, developing from young ice; thickness 30 cm-2 m. May be subdivided into thin first-year ice/white ice, medium first-year ice, and thick first-year ice.

Flaw lead: A passage-way between pack-ice and fast ice which is navigable by surface vessels.

Floating ice: Any form of ice found floating in water. The principal kinds of floating ice are lake ice, river ice, and sea ice which form by the freezing of water at the surface, and glacier ice (ice of land origin) formed on land or in an ice shelf. The concept includes ice that is stranded or grounded.

Floe: Any relatively flat piece of sea ice 20 m or more across. Floes are subdivided according to horizontal extent as follows:

GIANT:	Over 10 km across
VAST:	2-10 km across
BIG:	500-2000 m across
MEDIUM:	100-500 m across
SMALL	20-100 m across

Flooded ice: Sea ice which has been flooded by melt-water or river water and is heavily loaded by water and wet snow.

Fracture: Any break or rupture through very close pack ice, compact pack ice, consolidated pack-ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with nilas and/or young ice. Length may vary from a few meters to many kilometers.

Fracture zone: An area which has a great number of fractures.

Fracturing: Pressure process whereby ice is permanently deformed and rupture occurs. Most commonly used to describe breaking across very close pack ice, compact pack ice, and consolidated pack ice.

Frazil ice: Fine spicules or plates of ice, suspended in water.

Giant floe: (see Floe).

Glacier ice: Ice in, or originating from a glacier, whether on land or floating on the sea as icebergs, bergy bits, or growlers.

Grease ice: A later stage of freezing than frazil ice when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light giving the sea a matte appearance.

Gray ice: Young ice 10-15 cm thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.

Gray-white ice: Young ice 15-30 cm thick. Under pressure more likely to ridge than to raft.

Grounded ice: Floating ice which is aground in shoal water.

Growler: Smaller piece of ice than a bergy bit, often transparent but appearing green or almost black in color, extending less than 1 m above the sea surface and normally occupying an area of about 20 sq m.

Hummock: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a bummock.

Hummocked ice: Sea ice piled haphazardly one piece over another to form an uneven surface. When weathered it has the appearance of smooth hillocks.

Hummocking: The pressure process by which sea ice is forced into hummocks. When the floes rotate in the process it is termed screwing.

Ice boundary: The demarcation at any given time between fast ice and pack ice or between areas of pack ice of different concentrations.

Ice cake: Any relatively flat piece of sea ice less than 20 m across.

Ice cover: The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic locale.

Ice edge: The demarcation at any given time between the open sea and sea ice of any kind whether fast or drifting. It may be termed compacted or diffuse.

Ice field: Area of pack ice consisting of any size of floes which is greater than 10 km across.

Ice-free: No sea ice present. There may be some ice of land origin.

Ice jam: An accumulation of broken river ice or sea ice caught in a narrow channel.

Ice limit: Climatological term referring to the extreme minimum or extreme maximum extent of the ice edge in any given month or period based on observation over a number of years. Term should be preceded by minimum or maximum.

Ice of land origin: Ice formed on land or in an ice shelf, found floating in water. The concept includes ice that is stranded or grounded.

Lead: Any fracture or passage-way through sea ice which is navigable by surface vessels.

Light nilas: Nilas which is more than 5 cm in thickness and rather lighter in color than dark nilas.

Mean ice edge: Average position of the ice edge in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge and mean minimum ice edge.

Medium ice field: An ice field 15-20 km across.

New Ice: A general term for recently formed ice which includes frazil ice, grease ice, and slush. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

Nilas: A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlock "fingers" (finger rafting). Has a matte surface and is up to 10 cm in thickness. May be subdivided into dark nilas and light nilas.

Open pack ice: Pack ice in which the ice concentration is 4/10 to 6/10, with many leads and polynyas, and the floes are generally not in contact with one another.

Open water: A large area of freely navigable water in which sea ice is present in concentrations less than 1/10. When there is no sea ice present, the area should be termed ice-free even though icebergs are present.

Pack ice: Term used in a wide sense to include any area of sea ice, or other than fast ice, no matter what form it takes or how it is disposed.

Pancake ice: Predominantly circular pieces of ice from 30 cm to 3 m in diameter, and up to about 10 cm in thickness with raised rims due to the pieces striking against one another. It may be formed on a slight swell from grease ice or slush, or as a result of the breaking of ice rind, nilas, or gray ice under severe conditions of swell or waves. It may also form at some depth from where it floats to the surface, possibly at an interface between water bodies of different physical characteristics.

Polynya: Any non-linear shaped opening enclosed in ice. Polynyas may contain brash ice and/or be covered with new ice, nilas, or young ice. Sometimes the polynya is limited on one side by the coast and is called a shore polynya or by fast ice and is called a flaw polynya. If it recurs in the same position every year it is called recurring polynya.

Puddle: An accumulation on ice of melt-water mainly due to melting snow, or also to melting ice in the more advanced stages.

Rafting: Pressure processes whereby one piece of ice overridges another. Most common in new and young ice.

Ridge: A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an ice keel.

Ridged ice: Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice.

Ridging: The pressure process by which sea ice is forced into ridges.

River ice: Ice formed on a river, regardless of observed location.

Rotten ice: Sea ice which has become honeycombed and which is in an advanced state of disintegration.

Sea ice: Any form of ice found at sea which has originated from the freezing of sea water.

Shore lead: A lead between pack ice and the shore or between pack ice and an ice front.

Slush: Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

Small floe: (see Floe).

Small fracture: 50 to 200 m wide.

Small ice cake: An ice cake less than 2 m across.

Snow-covered ice: Ice covered with snow.

Snowdrift: An accumulation of wind-blown snow deposited in the lee of obstructions or heaped by wind eddies.

Stamukhas: Ice cakes which have been created by beach ice that has broken free, been deposited higher on the mud flats, and frozen to the underlying mud. Ice floes floating toward the beach are caught on top of the higher piece of ice and, as the tide recedes, the overhanging pieces break off leaving a stack of layered ice.

Stranded ice: Ice which has been floating and has been deposited on the shore by retreating high water.

Strip: Long narrow area of pack ice, about 1 km or less in width, usually composed of small fragments detached from the main mass of ice and run together under the influence of wind, swell, or current.

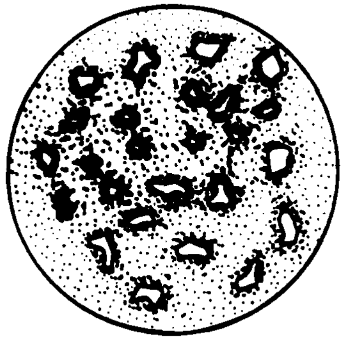
Thaw holes: Vertical holes in sea ice formed when surface puddles melt through to the underlying water.

Very close pack ice: Pack ice in which the concentration is 9/10 to less than 10/10.

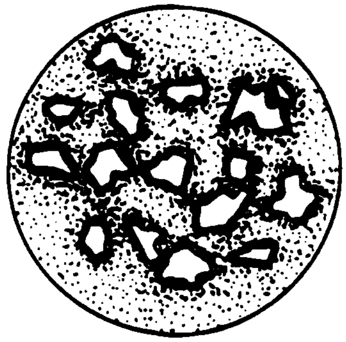
Very open pack ice: Pack ice in which the concentration is 1/10 to 3/10 and water preponderates over ice.

Young coastal ice: The initial stage of fast ice formation consisting of nilas or young ice, its coverage varying from a few meters up to 100-200 m from the shoreline.

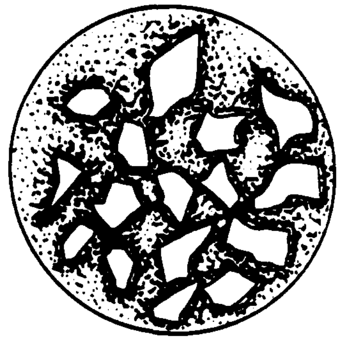
Young ice: Ice in the transition stage between nilas and first-year ice, 10-30 cm in thickness. May be subdivided into gray ice and gray-white ice.



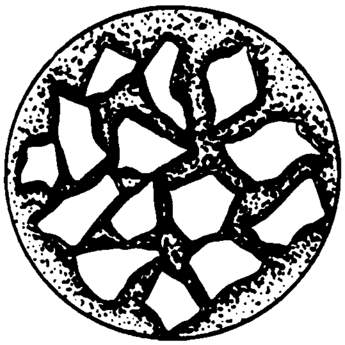
OPEN WATER
LESS THAN 1 OKTA OR
LESS THAN 1/10 COVERAGE



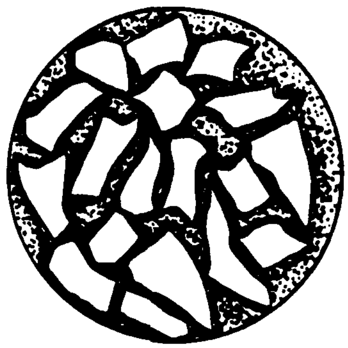
VERY OPEN PACK
1 OKTA OR
2/10 COVERAGE



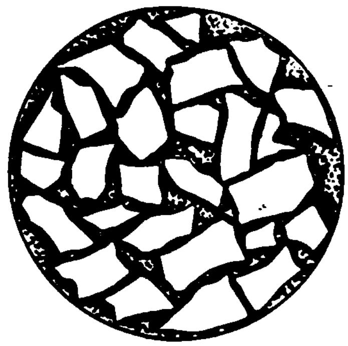
VERY OPEN PACK
2 OKTAS OR
3/10 COVERAGE



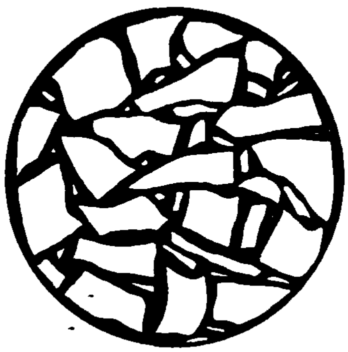
OPEN PACK
3 OKTAS OR
4/10 COVERAGE



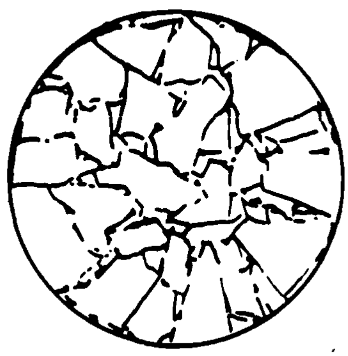
OPEN PACK
4 OKTAS OR
5/10 COVERAGE



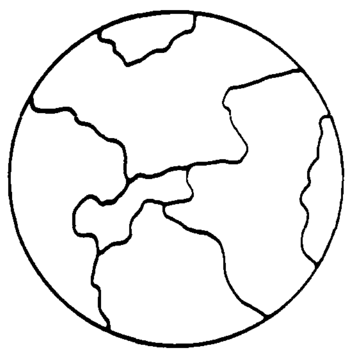
OPEN PACK
5 OKTAS OR
6/10 COVERAGE



CLOSE PACK
6 OKTAS OR
7/10 COVERAGE

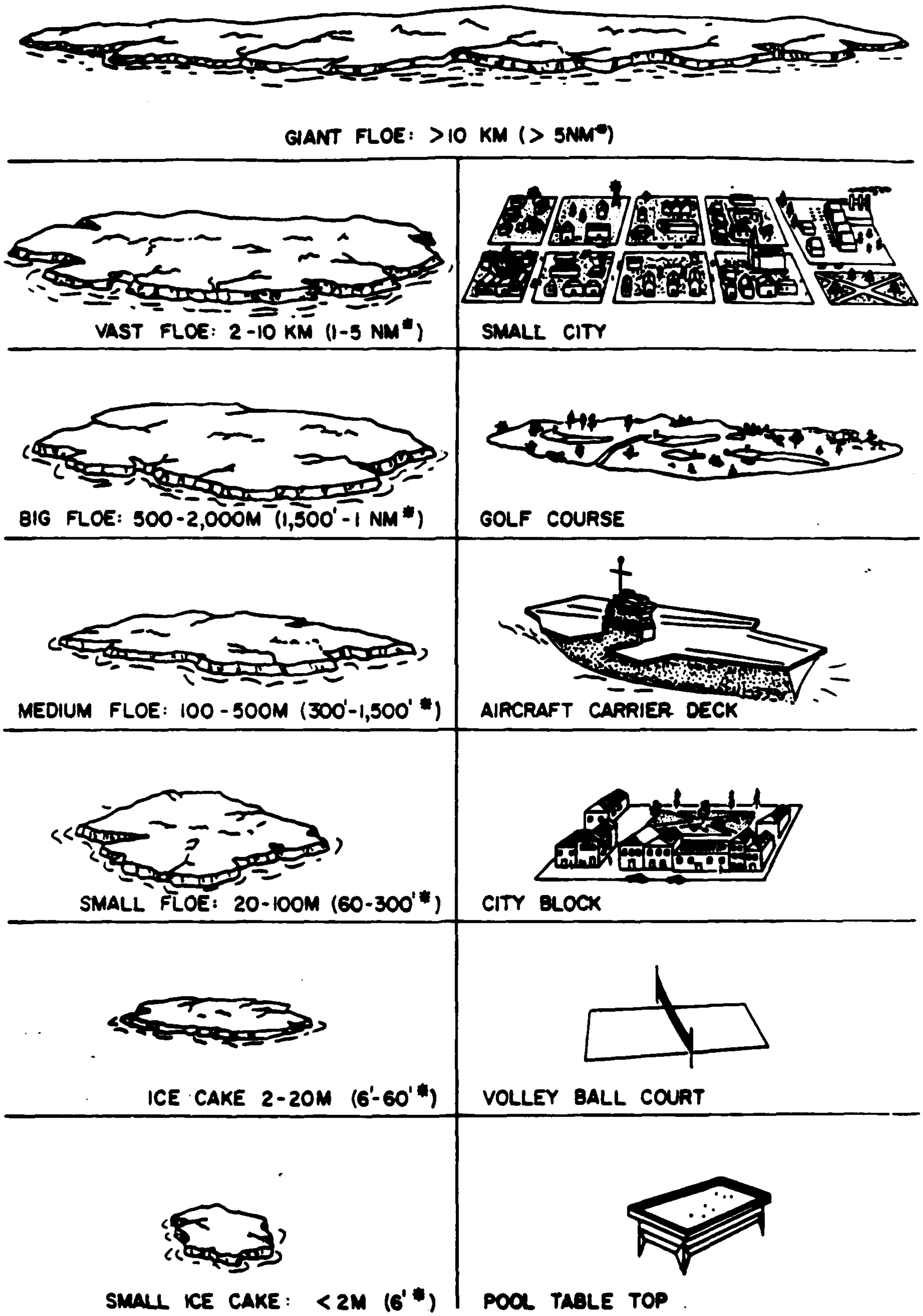


VERY CLOSE PACK
7 OKTAS OR
8/10 - 9/10 COVERAGE



COMPACT PACK
8 OKTAS OR
9/10 - 10/10 COVERAGE

REPRESENTATIVE ICE DISTRIBUTIONS



(* APPROXIMATELY)

RELATIVE ICE SIZE

APPENDIX D

Sunrise, Sunset, Civil and Nautical
Twilight Table for Nome, Alaska

Tables D-1, D-2, and D-3 provide the standard time for sunrise and sunset, Civil twilight times, and Nautical twilight times for Nome. These times are valid for any year in the 20th Century with errors not exceeding two minutes. Times are given in standard time of the 150th meridian west. Preparation of these tables was by the U.S. Naval Observatory, Washington, D.C.

Twilight is the period of incomplete darkness observed following sunset and before sunrise. Morning Civil and Nautical twilights begin when the sun is 6° and 12° below the horizon, respectively. Evening Civil and Nautical twilights end when the sun is 6° and 12° below the horizon, respectively.

Table D-1 Sunrise and Sunset at Nome, Alaska
(Standard Time)

DAY	JAN. RISE AM	JAN. SET PM	FEB. RISE AM	FEB. SET PM	MAR. RISE AM	MAR. SET PM	APR. RISE AM	APR. SET PM	MAY RISE AM	MAY SET PM	JUNE RISE AM	JUNE SET PM	JULY RISE AM	JULY SET PM	AUG. RISE AM	AUG. SET PM	SEPT. RISE AM	SEPT. SET PM	OCT. RISE AM	OCT. SET PM	NOV. RISE AM	NOV. SET PM	DEC. RISE AM	DEC. SET PM
1	1059	312	945	447	811	619	619	754	432	928	250	1111	230	1139	404	1009	542	819	711	631	847	443	1025	316
2	1058	314	942	450	807	622	616	757	428	932	248	1114	233	1137	408	1006	545	815	714	627	850	439	1028	314
3	1057	316	939	454	804	625	612	800	425	935	245	1117	235	1135	411	1002	548	812	717	623	854	436	1030	312
4	1056	318	936	457	800	628	609	803	421	938	242	1120	237	1133	414	959	551	808	719	620	857	433	1033	311
5	1054	321	932	500	756	632	605	806	418	942	240	1122	240	1131	417	955	554	804	722	616	900	430	1036	309
6	1052	323	929	504	753	635	601	809	414	945	238	1125	242	1129	421	952	557	801	725	613	904	426	1038	307
7	1051	326	926	507	749	638	558	812	411	948	235	1128	245	1126	424	948	600	757	728	609	907	423	1041	305
8	1049	329	923	511	746	641	554	815	407	952	233	1130	247	1124	427	945	603	754	731	606	910	420	1043	304
9	1047	332	919	514	742	644	550	818	404	955	231	1132	250	1121	431	941	606	750	734	602	914	417	1045	303
10	1045	335	916	517	739	647	547	821	400	958	229	1135	253	1118	434	938	609	746	738	559	917	414	1048	301
11	1043	337	913	521	735	650	543	824	357	1002	227	1137	256	1116	437	934	612	743	741	555	920	410	1050	300
12	1040	340	909	524	731	653	540	827	353	1005	226	1139	259	1113	440	931	615	739	744	551	924	407	1052	259
13	1038	343	906	527	728	656	536	831	350	1009	224	1140	302	1110	443	927	618	736	747	548	927	404	1053	258
14	1036	347	903	531	724	659	532	834	347	1012	223	1142	305	1107	447	924	621	732	750	544	930	401	1055	258
15	1033	350	859	534	721	702	529	837	343	1015	222	1143	308	1104	450	920	624	728	753	541	934	358	1057	257
16	1031	353	856	537	717	705	525	840	340	1019	221	1145	312	1101	453	917	627	725	756	537	937	355	1058	257
17	1028	356	852	541	714	708	522	843	337	1022	220	1146	315	1058	456	913	630	721	759	534	940	352	1059	257
18	1026	359	849	544	710	711	518	846	333	1026	220	1147	318	1055	459	909	632	717	802	530	944	349	1100	256
19	1023	403	845	547	706	714	514	849	330	1029	219	1147	321	1052	502	906	635	714	805	527	947	347	1101	256
20	1021	406	842	550	703	717	511	853	327	1032	219	1148	324	1049	506	902	638	710	808	523	950	344	1102	257
21	1018	409	839	554	659	720	507	856	323	1036	219	1148	328	1046	509	859	641	707	812	520	954	341	1103	257
22	1015	413	835	557	656	723	504	859	320	1039	219	1148	331	1043	512	855	644	703	815	517	957	338	1103	258
23	1012	416	832	600	652	726	500	902	317	1042	220	1148	334	1039	515	851	647	659	818	513	1000	336	1104	258
24	1009	419	828	603	648	729	456	905	314	1046	220	1147	338	1036	518	848	650	656	821	510	1003	333	1104	259
25	1006	423	825	606	645	732	453	909	311	1049	221	1147	341	1033	521	844	653	652	824	506	1006	330	1104	300
26	1003	426	821	610	641	736	449	912	308	1052	222	1146	344	1029	524	841	656	649	827	503	1010	328	1104	301
27	1000	430	818	613	637	739	446	915	305	1055	224	1145	348	1026	527	837	659	645	831	459	1013	326	1103	303
28	957	433	814	616	634	742	442	918	302	1059	225	1143	351	1023	530	833	702	641	834	456	1016	323	1103	304
29	954	436	813	618	630	745	439	922	259	1102	227	1142	354	1019	533	830	705	638	837	453	1019	321	1102	306
30	951	440			627	748	435	925	256	1105	228	1141	358	1016	536	826	708	634	840	449	1022	319	1102	307
31	948	443			623	751			253	1108			401	1013	539	823			844	446			1101	309

THIS TABLE MAY BE USED IN ANY YEAR OF THE TWENTIETH CENTURY AND WITHIN THE GEOGRAPHICAL BOUNDARY OF THE STATED PLACE WITH AN ERROR NOT EXCEEDING TWO MINUTES AND GENERALLY LESS THAN ONE MINUTE. ADD ONE HOUR FOR DAYLIGHT SAVING TIME IF AND WHEN IN USE.

Table D-2 Civil Twilight at Nome, Alaska
(Standard Time)

DAY	JAN. BEG. AM	JAN. END PM	FEB. BEG. AM	FEB. END PM	MAR. BEG. AM	MAR. END PM	APR. BEG. AM	APR. END PM	MAY BEG. AM	MAY END PM	JUNE BEG. AM	JUNE END PM	JULY BEG. AM	JULY END PM	AUG. BEG. AM	AUG. END PM	SEPT. BEG. AM	SEPT. END PM	OCT. BEG. AM	OCT. END PM	NOV. BEG. AM	NOV. END PM	DEC. BEG. AM	DEC. END PM
1	940	431	847	545	722	708	529	845	321	1041	////	////	////	////	228	1142	448	913	622	719	753	537	912	429
2	940	432	844	548	718	711	525	848	316	1046	////	////	////	////	235	1135	451	909	625	715	756	534	914	428
3	939	434	842	551	715	714	521	851	310	1051	////	////	////	////	242	1129	455	905	628	711	758	531	916	427
4	938	436	839	553	712	717	517	855	305	1056	////	////	////	////	248	1123	458	901	631	708	801	528	918	425
5	937	438	836	556	708	720	513	858	300	1101	////	////	////	////	253	1117	502	857	634	704	804	525	920	424
6	936	439	834	559	705	723	509	901	255	1107	////	////	////	////	259	1111	505	853	637	701	807	523	922	423
7	935	441	831	602	701	726	505	905	249	1112	////	////	////	////	304	1106	508	849	640	657	810	520	924	422
8	934	443	828	605	658	729	501	908	243	1118	////	////	////	////	310	1101	512	845	643	654	813	517	926	422
9	933	445	825	608	654	732	457	912	237	1124	////	////	////	////	315	1056	515	841	646	650	816	515	927	421
10	932	447	822	611	651	735	453	916	231	1131	////	////	////	////	320	1050	518	837	649	647	818	512	929	420
11	931	450	819	614	647	738	449	919	224	1138	////	////	////	////	324	1045	521	833	652	644	821	509	930	420
12	929	452	816	617	644	741	445	923	217	1145	////	////	////	////	329	1041	524	829	655	640	824	507	932	419
13	928	454	813	620	640	744	441	926	210	1153	////	////	////	////	334	1036	528	825	658	637	827	504	933	419
14	926	457	810	623	636	747	437	930	202	////	////	////	////	////	338	1031	531	822	700	633	830	502	934	419
15	924	459	807	626	633	750	433	934	////	////	////	////	////	////	342	1026	534	818	703	630	832	500	935	418
16	923	501	804	629	629	754	428	938	////	////	////	////	////	////	347	1022	537	814	706	627	835	457	936	418
17	921	504	801	632	625	757	424	941	////	////	////	////	////	////	351	1017	540	810	709	624	838	455	937	418
18	919	506	758	635	622	800	420	945	////	////	////	////	////	////	355	1013	543	806	712	620	840	453	938	418
19	917	509	755	638	618	803	416	949	////	////	////	////	////	////	359	1008	546	803	715	617	843	451	939	419
20	915	511	751	641	614	806	411	953	////	////	////	////	////	////	403	1004	549	759	718	614	846	448	940	419
21	913	514	748	644	611	809	407	957	////	////	////	////	////	////	407	959	552	755	721	611	848	446	940	419
22	911	517	745	647	607	812	402	1001	////	////	////	////	////	////	411	955	556	751	724	607	851	444	941	420
23	909	519	742	650	603	815	358	1005	////	////	////	////	////	////	415	951	559	748	727	604	853	442	941	421
24	907	522	738	653	600	819	353	1009	////	////	////	////	////	////	419	946	602	744	730	601	856	440	942	421
25	904	525	735	656	556	822	349	1014	////	////	////	////	////	////	423	942	605	740	732	558	858	439	942	422
26	902	528	732	659	552	825	344	1018	////	////	////	////	////	////	426	938	608	737	735	555	901	437	942	423
27	900	531	729	702	548	828	340	1022	////	////	////	////	////	////	430	933	611	733	738	552	903	435	942	424
28	857	533	725	705	544	831	335	1027	////	////	////	////	////	////	434	929	614	729	741	549	905	434	942	425
29	855	536	724	707	541	835	330	1032	////	////	////	////	////	////	437	925	616	726	744	546	908	432	942	426
30	852	539			537	838	325	1036	////	////	////	////	////	1156	441	921	619	722	747	543	910	430	941	428
31	850	542			533	841			////	////			221	1148	444	917			750	540			941	429

THIS TABLE MAY BE USED IN ANY YEAR OF THE TWENTIETH CENTURY AND WITHIN THE GEOGRAPHICAL BOUNDARY OF THE STATED PLACE WITH AN ERROR NOT EXCEEDING TWO MINUTES AND GENERALLY LESS THAN ONE MINUTE. ADD ONE HOUR FOR DAYLIGHT SAVING TIME IF AND WHEN IN USE.

//// INDICATES TWILIGHT LASTS ALL NIGHT.

NEAR THE DATES WHEN TWILIGHT LASTS ALL NIGHT A PHYSICAL INDETERMINACY EXISTS AND NO ABSOLUTE LIMIT ON THE ACCURACY CAN BE ASSIGNED.

Table D-3 Nautical Twilight at Nome, Alaska
(Standard Time)

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM	BEG. AM	END PM
1	831	540	747	645	626	804	424	951	////	////	////	////	////	////	////	////	331	1028	525	615	655	635	805	536
2	831	542	745	647	623	807	419	955	////	////	////	////	////	////	////	////	336	1023	528	612	657	632	807	535
3	830	543	743	650	619	810	414	959	////	////	////	////	////	////	////	////	341	1017	531	608	700	629	809	534
4	830	544	740	653	616	813	409	1004	////	////	////	////	////	////	////	////	346	1012	535	604	703	627	810	533
5	829	546	738	655	612	816	404	1008	////	////	////	////	////	////	////	////	350	1007	538	601	705	624	812	532
6	828	548	735	658	609	819	359	1013	////	////	////	////	////	////	////	////	355	1002	541	757	708	622	814	532
7	828	549	733	701	605	823	354	1017	////	////	////	////	////	////	////	////	359	957	544	753	711	619	815	531
8	827	551	730	703	601	826	349	1022	////	////	////	////	////	////	////	////	403	952	547	750	713	617	817	530
9	826	553	727	706	558	829	344	1027	////	////	////	////	////	////	////	////	407	947	550	746	716	614	818	530
10	825	554	725	709	554	832	338	1032	////	////	////	////	////	////	////	////	411	943	553	743	718	612	820	529
11	824	556	722	712	550	835	333	1037	////	////	////	////	////	////	////	////	415	938	556	739	721	610	821	529
12	823	558	719	714	547	839	327	1042	////	////	////	////	////	////	////	////	419	934	559	736	723	607	822	529
13	822	600	716	717	543	842	322	1048	////	////	////	////	////	////	////	////	423	929	602	733	726	605	823	529
14	820	602	713	720	539	845	316	1053	////	////	////	////	////	////	////	////	427	925	605	729	728	603	824	529
15	819	604	710	723	535	848	309	1059	////	////	////	////	////	////	////	////	431	920	607	726	731	601	825	529
16	818	606	707	726	531	852	303	1105	////	////	////	////	////	////	////	////	435	916	610	723	733	559	826	529
17	816	608	704	729	527	855	256	1112	////	////	////	////	////	////	////	////	439	911	613	719	735	557	827	529
18	815	611	701	731	523	859	249	1119	////	////	////	////	////	////	////	////	442	907	616	716	738	555	828	529
19	813	613	658	734	519	902	242	1126	////	////	////	////	////	////	////	////	445	903	619	713	740	553	829	529
20	811	615	655	737	515	905	234	1134	////	////	////	////	////	////	////	1150	449	859	622	710	742	552	829	530
21	810	617	652	740	511	909	226	1143	////	////	////	////	////	////	220	1141	452	855	625	707	745	550	830	530
22	808	620	649	743	507	913	217	1153	////	////	////	////	////	////	229	1133	456	851	627	704	747	548	830	531
23	806	622	646	746	503	916	206	////	////	////	////	////	////	////	237	1125	459	847	630	700	749	546	831	531
24	804	625	643	749	459	920	////	////	////	////	////	////	////	////	244	1117	503	842	633	657	751	545	831	532
25	802	627	639	752	455	924	////	////	////	////	////	////	////	////	251	1110	506	839	636	654	753	543	831	533
26	800	629	636	755	450	927	////	////	////	////	////	////	////	////	258	1104	509	835	638	652	755	542	832	533
27	758	632	633	758	446	931	////	////	////	////	////	////	////	////	304	1057	512	831	641	649	758	541	832	534
28	756	634	629	801	442	935	////	////	////	////	////	////	////	////	310	1051	516	827	644	646	800	539	832	535
29	754	637	626	803	437	939	////	////	////	////	////	////	////	////	315	1045	519	823	647	643	801	538	832	536
30	752	639			433	943	////	////	////	////	////	////	////	////	321	1039	522	819	649	640	803	537	832	537
31	750	642			428	947			////	////			////	////	326	1034			652	637			831	539

THIS TABLE MAY BE USED IN ANY YEAR OF THE TWENTIETH CENTURY AND WITHIN THE GEOGRAPHICAL BOUNDARY OF THE STATED PLACE WITH AN ERROR NOT EXCEEDING TWO MINUTES AND GENERALLY LESS THAN ONE MINUTE. ADD ONE HOUR FOR DAYLIGHT SAVING TIME IF AND WHEN IN USE.

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APPENDIX E
Storm Surge Forecast Procedures

I. DEFINITIONS

A. Surge - The height of the ocean's surface above forecast (tidal levels).

B. Primary Surge - The surge that directly results from favorable relative winds.

C. Secondary Surge - The surge that is caused from anamolous sea heights generated by favorable relative winds. See discussion in subsection 4.6 of text.

D. Favorable Relative Wind Direction for Primary Surges Calculation - Assume the coastal configuration to be straight line segments as shown on Figure 1. When facing seaward the relative wind direction is measured clockwise from the coast. Thus the coast to the left is 0°; seaward + 90°; to the right 180°. If to the left and offshore, it has negative values. Favorable relative wind directions are:

Sector	Favorable Direction
1	020 to 060
2	070 to 130
3	030 to 070
4	-020 to 070

E. Fetch An area in which wind direction and speed are reasonably constant and do not vary past the following limits:

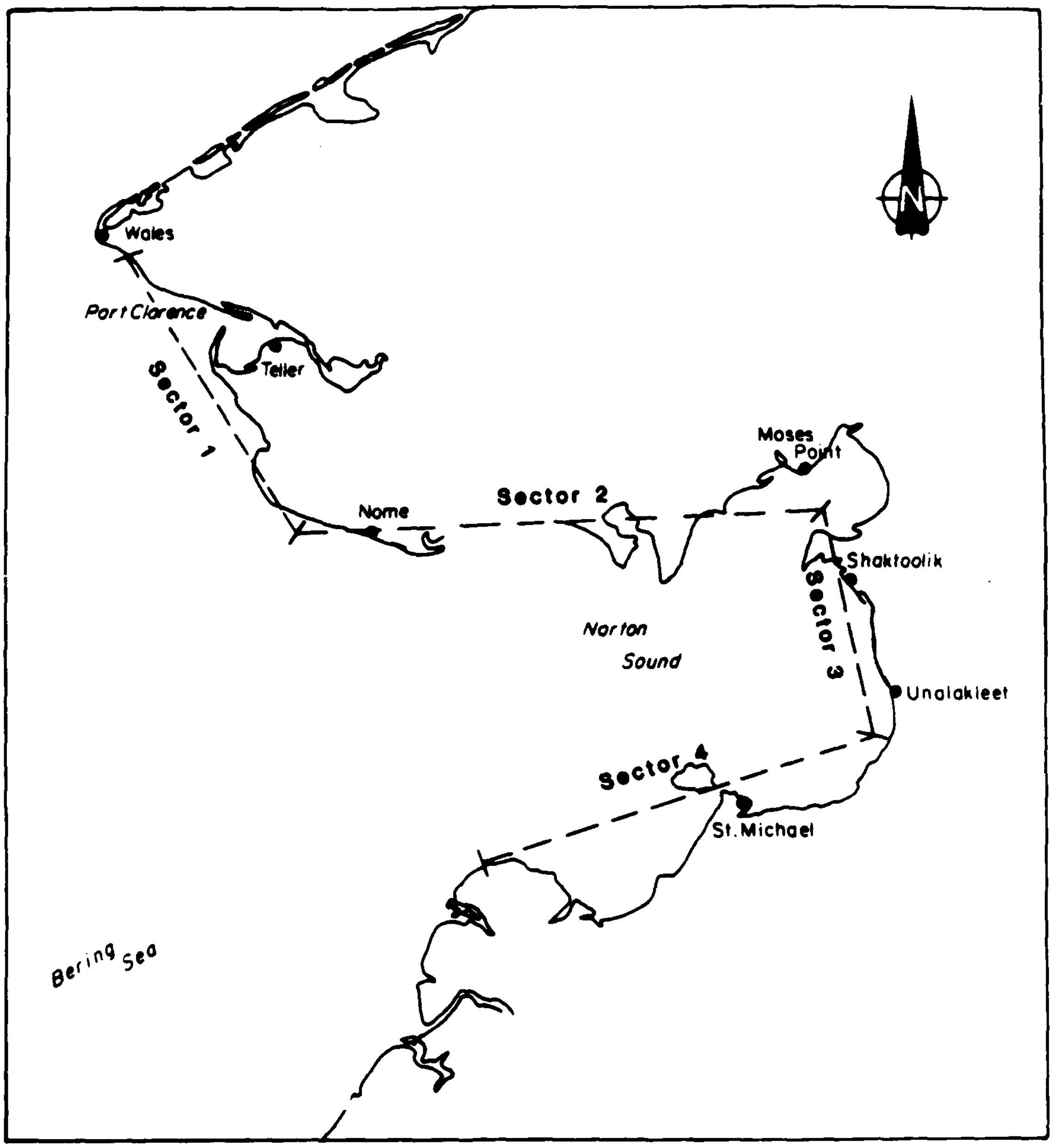


Figure 1. Map of Storm Surge Sectors.

(1) The wind direction or orientation of the isobars do not change direction at a rate greater than 15° per 180 nmi and the total changes do not exceed 30°.

(2) The wind speed does not vary more than 20 percent from the average wind speed in the area of the direction fetch being considered. Example: average wind is 40; acceptable range is 32 to 48.

F. Fetch Duration - The number of hours a coastal area is subjected to fetch winds.

G. Lowest Pressure - The lowest pressure coincident with fetch induced surge.

H. Sea Ice Coverage (minimum expected during storm) -Percent of sea ice coverage in tenths.

I. Sea Ice Character - Primary concern is thinness and weakness. Thin or unconsolidated ice can be destroyed by storm action.

J. Boundary Layer Stability - The difference between the sea and air temperatures. The boundary layer temperature difference should be used when estimated the fetch wind speed. The following guidelines are suggested:

Correction to Geostrophic Wind for the Sea-Air Temperature Difference

$T_s - T_a$	Percent of Geostrophic Winds Used
0 or negative	60
0 to 10	65
10 to 20	75
20 or above	90

II. PROCEDURES

A. Determine:

(1) Fetch wind (speed and direction). Consider boundary layer conditions. If direction is favorable continue with determination of:

(a) fetch duration
(b) ice cover and character
(c) lowest pressure
(d) tidal variation if over 1 foot

B. Preliminary Surge Height - Using wind speed, read correlated surge height from Figures 2 or 3.

C. Duration Adjusted Surge Height - If fetch duration is less than:

(1) 3 hours reduce surge by 60 percent
(2) 6 hours reduce surge by 40 percent
(3) 9 hours reduce surge by 20 percent
(4) 12 hours reduce surge by 10 percent
(5) 12+ hours no reduction

D. Ice Cover Adjusted Surge Height - If ice cover is less than:

(1) 1.5 tenths no reduction
(2) 3.0 tenths reduce surge by 20 percent (cumulative to above)
(3) 5.0 tenths reduce surge by 50 percent (cumulative)
(4) 10.0 tenths reduce surge by 75 percent (cumulative)

E. Pressure Adjusted Surge Height - Raise the surge height one foot for every 30 mb pressure increment below 1004 mb.

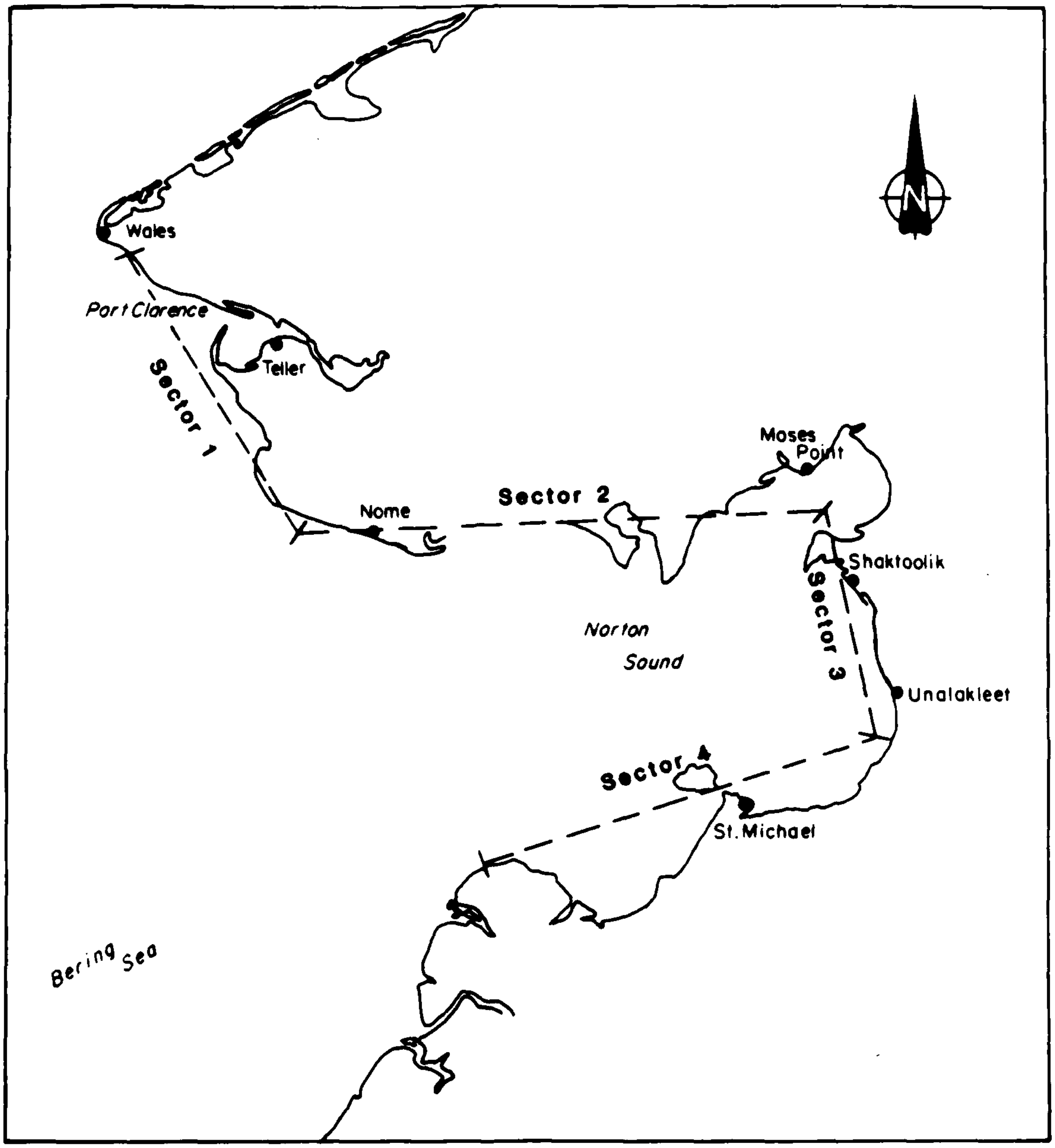
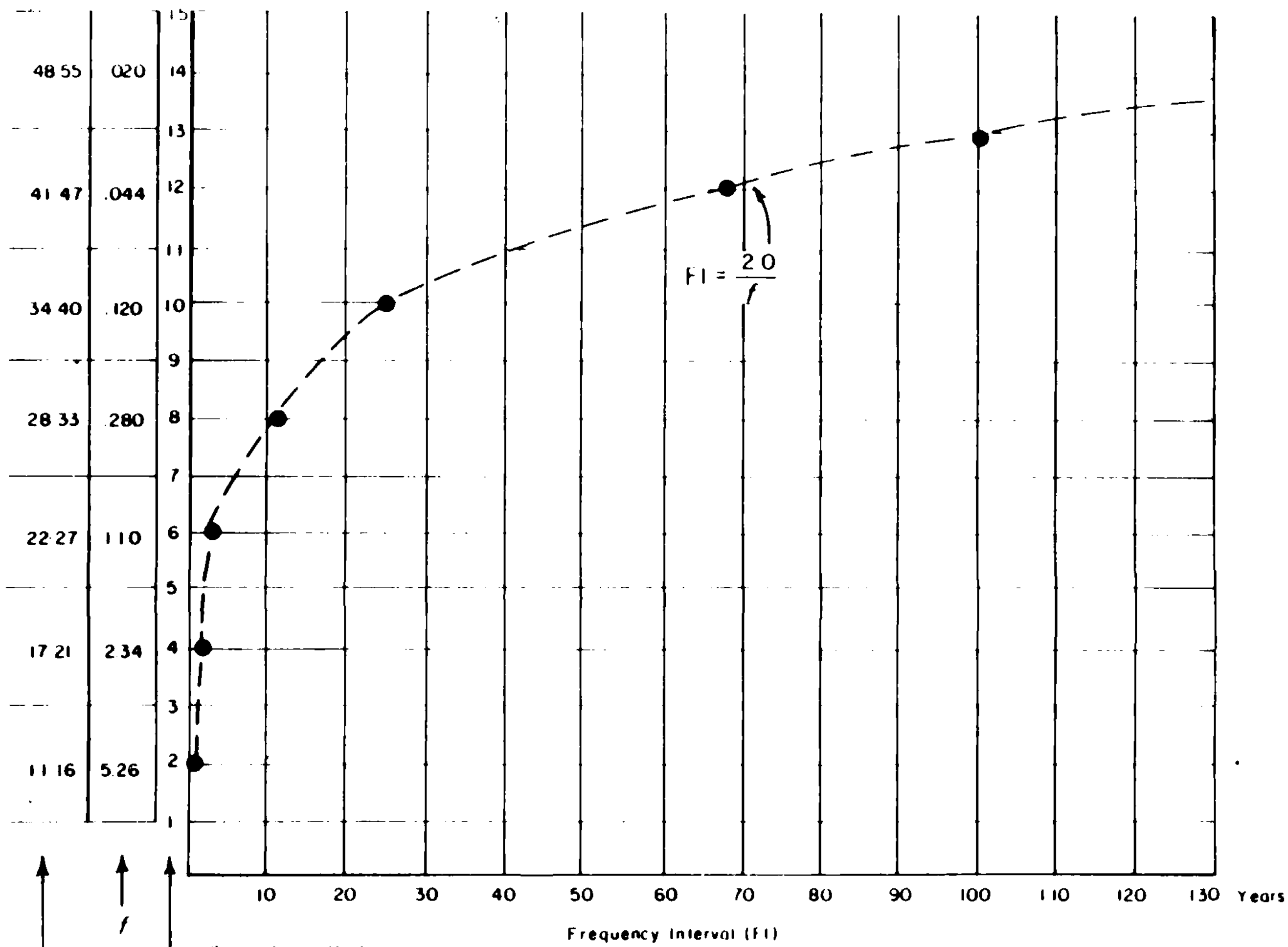


Figure 1. Map of Storm Surge Sectors.



Graph is derived from surge data and Nome south-southeast to southwest wind directions and related frequencies. Constant in FI formula is derived from assumption of one 13-foot surge every 100 years.

Figure 2. Surge Height - Frequency Interval Curve, Sector 2.

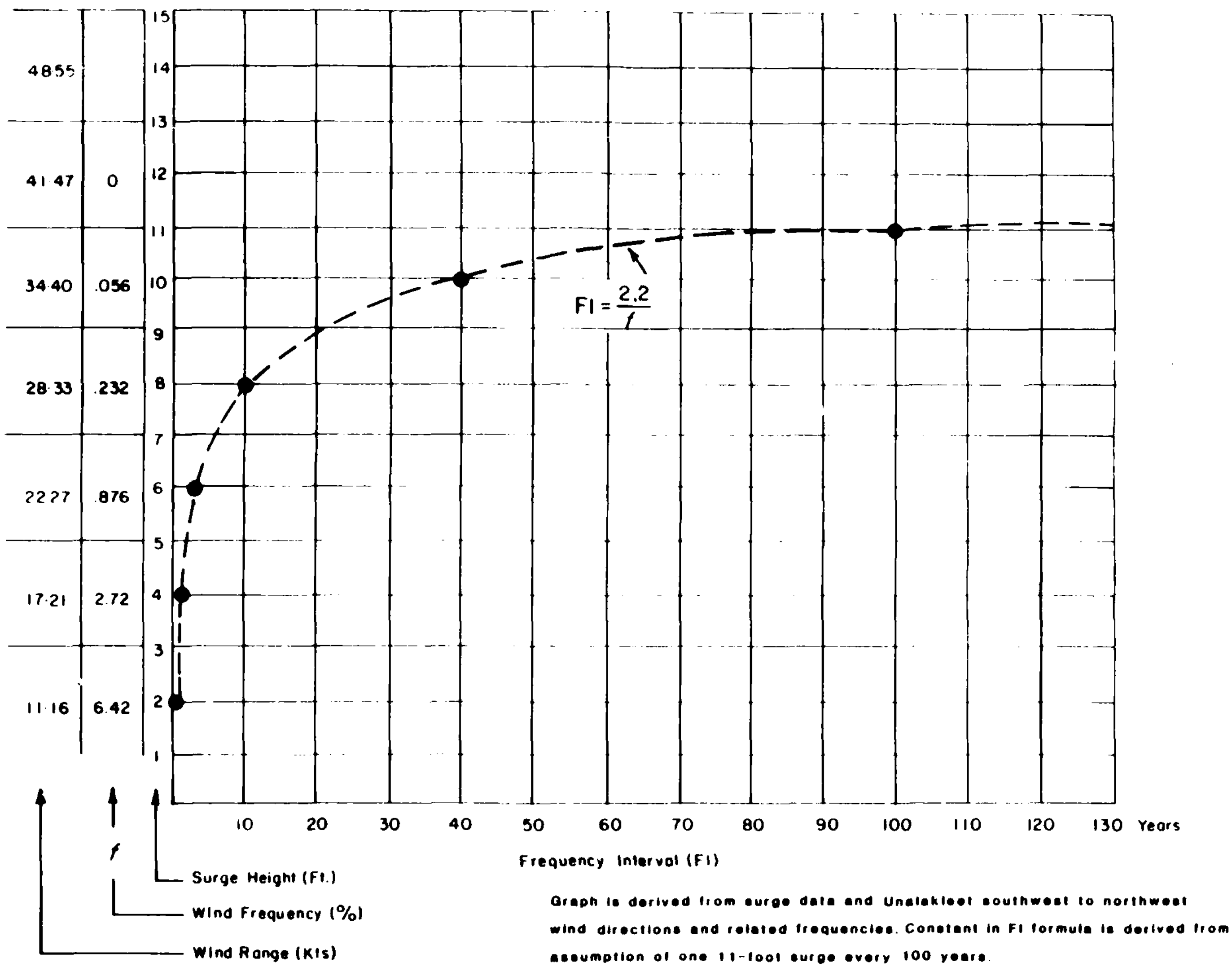


Figure 3. Surge Height – Frequency Interval Curve, Sectors 1, 3, and 4

F. Tidal Adjusted Surge Height - Check tide tables or other sources. If peak of surge is reasonably concident with normal high water, make no correction. If surge misses normal high water, subtract as appropriate from surge height.