2

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AN OCEANOGRAPHIC AND CLIMATOLOGICAL ATLAS OF BRISTOL BAY

JAMES L. WISE
LYNN D. LESLIE
JOSEPH C. LABELLE

Arctic Environmental Information and Data Center
University of Alaska
707 A Street
Anchorage, AK 99501

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SAMUEL F. POWEL, III
Technical Director
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340-6096

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James L. Wise, Lynn D. Leslie, and Joseph C. LaBelle

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707 A Street
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16. Abstract

This is a reference document of oceanography, meteorology, sea ice, and climatology. It was prepared for use by the U.S. Coast Guard on-scene coordinator in the event of an oil spill in Bristol Bay at any time. The oceanography section contains information for bathymetry, circulation, water temperature and salinity, waves, tides, river discharge, and oil spill transport. The meteorology section includes seasonal weather and storm tracks, storm surges, superstructure icing, and wind chill. Climatology includes graphs and text on temperature, precipitation, wind, visibility, and cloudiness. Ice information includes seasonal formation and drift, concentration, thickness, nearshore ice, and freeze-up and breakup dates.

17. Key Words

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Bristol Bay	Ice
Oceanography	Climatology

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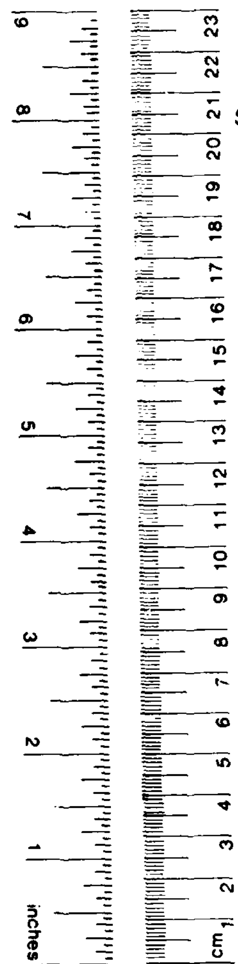
METRIC CONVERSION FACTORS

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

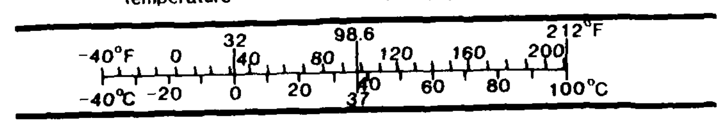


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

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INTRODUCTION

In the event of an oil spill in Bristol Bay or on its shoreline, the U.S. Coast Guard predesignated On-Scene Coordinator (OSC) is responsible for ensuring that timely and adequate containment and removal actions are taken. Responsible parties must take the appropriate clean-up action and the Coast Guard OSC's role will be to monitor these actions. If the spiller's response is inadequate, or when the responsible party is unknown, the OSC may initiate clean-up action using federal pollution funds. In either case, the OSC will be operating in a unique, remote, and hostile environment, where clean-up actions are expensive and environmental conditions are very sensitive.

In order to effectively respond to a spill in the Bristol Bay area, 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 this information for the Bristol Bay area. This atlas is designed so that the necessary 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 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 divided into four sections: Oceanography, Meteorology, Climatology, and Ice. It is designed to answer two questions an OSC responding to an oil spill might ask: (1) into what areas can the spill be expected to drift and how soon and (2) what environmental conditions will personnel be facing at the spill clean-up site? Current weather conditions and the specific geographical location of the spill source would be the atlas entry points for calculating estimated trajectories. This information is located in the oceanography section. Questions regarding expected environmental conditions can be answered from information available from the atlas meteorology, climatology, and ice sections. These sections contain comprehensive graphs, maps, and tables on means and extremes and frequency of occurrence of environmental conditions and, therefore, operational conditions that response personnel can expect to encounter. Maps and graphs are from the most up-to-date data compilations available at this time and should remain up to date for quite some time.

OCEANOGRAPHY

Many variables influence the oceanography of Bristol Bay and the adjacent Bering Sea. The physical characteristics of this region constitute one such variable. Shallow depths, broad reaches, and two peninsula-like capes have a profound effect on regional oceanographic phenomena. An equally important variable concerns the region's climate. Bristol Bay is characterized by seasonal climatic extremes. Air temperature, daylight, wind, and sea ice dynamics must be taken into account in the transport and cleanup of spilled oil.

Water density is another critical factor in that seasonal fluxes and advection influence circulation dynamics, particularly during low wind and ice-covered regimes. Salinities are slightly lower during the open-water season because of dilution by river runoff. Fresh water inflow into the bay is from several rivers, the largest of which are the Nushugak, Kuskokwim, and Kvichak. This runoff has a pronounced seasonal pattern with most of the annual inflow occurring between April and November.

Geostrophic circulation in the normal sense does not exist in Bristol Bay. While the possibility of such circulation is suggested by the size of the area, it is precluded by the shallow depth of the waters and particularly by the instability of local meteorologic conditions. Instead of geostrophic flow, estuarine mechanisms must be fitted to explain the system.

The fundamental circulation pattern in outer Bristol Bay during the ice-free months (April-November) appears to be a simple, counterclockwise gyre. The driving forces for this system are a combination of wind, tide, and estuarine thermohaline effects. Prevailing winds during the open water season blow from the southwest and west; so, in the region just north of the Alaska Peninsula, they tend to move the waters eastward and toward shore. This tends to force into the bay North Pacific water which has just entered the Bering Sea through Unimak Pass and the other eastern Aleutian passes. The incoming tide from the Pacific enters through the passes, is deflected toward the east by coriolis effect, and thus reinforces the eastward flow. The main stream of this part of the gyre follows the axis of a gentle trough which parallels the Alaska Peninsula, roughly 50 km offshore. Inshore of the current, during the runoff season, there is a region of brackish coastal waters dominated by very local influences, but with a similar eastward net flow.

At the boundary between the inner and outer bays, northeast of Port Heiden, the eastern segment of the gyre meets the brackish coastal waters of the inner bay. Considerable mixing occurs in this region, particularly in the area between Cape Constantine and Cape Newenham, after which the resulting waters move north and west. An uncertain but large percentage of the bay waters proceeds north in the Bering Sea at all seasons forming a significant part of the flow which is reinforced with the waters of the Kuskokwim and Yukon Rivers, and moves through Bering Strait into the Arctic Ocean Basin. The remainder moves westward toward the Pribilof Islands and ultimately mixes with the waters at the edge of the shelf. Thus the circulation "gyre" of Bristol Bay is really more of a U-shape than a complete circuit, although some indirect evidence from the trajectories of fish eggs and drift bottles suggests that a true gyre exists during some parts of the year.

THE PHYSICAL ENVIRONMENT

Bristol Bay waters are more estuarine than oceanic in their flow and water mass properties. The embayment, and its associated bays, estuaries, and tidelands, are among the most productive waters in the world. Tides in the shallow bay are influenced by the strong Bering Sea currents and a significant portion of the bay's water is exchanged daily (USDOI, no date). In addition, the many freshwater systems that discharge into the bay bring with them a rich nutrient load. The entire bay has been compared to an estuary in which North Pacific surface waters and local runoff mix. The large size, shallow depth, and high latitude subarctic climatic regime complicate the water mass picture. It is best characterized by its high variability, both seasonally and interannually, and even in the brief interval of a single storm event. See figure 1.

Bathymetry

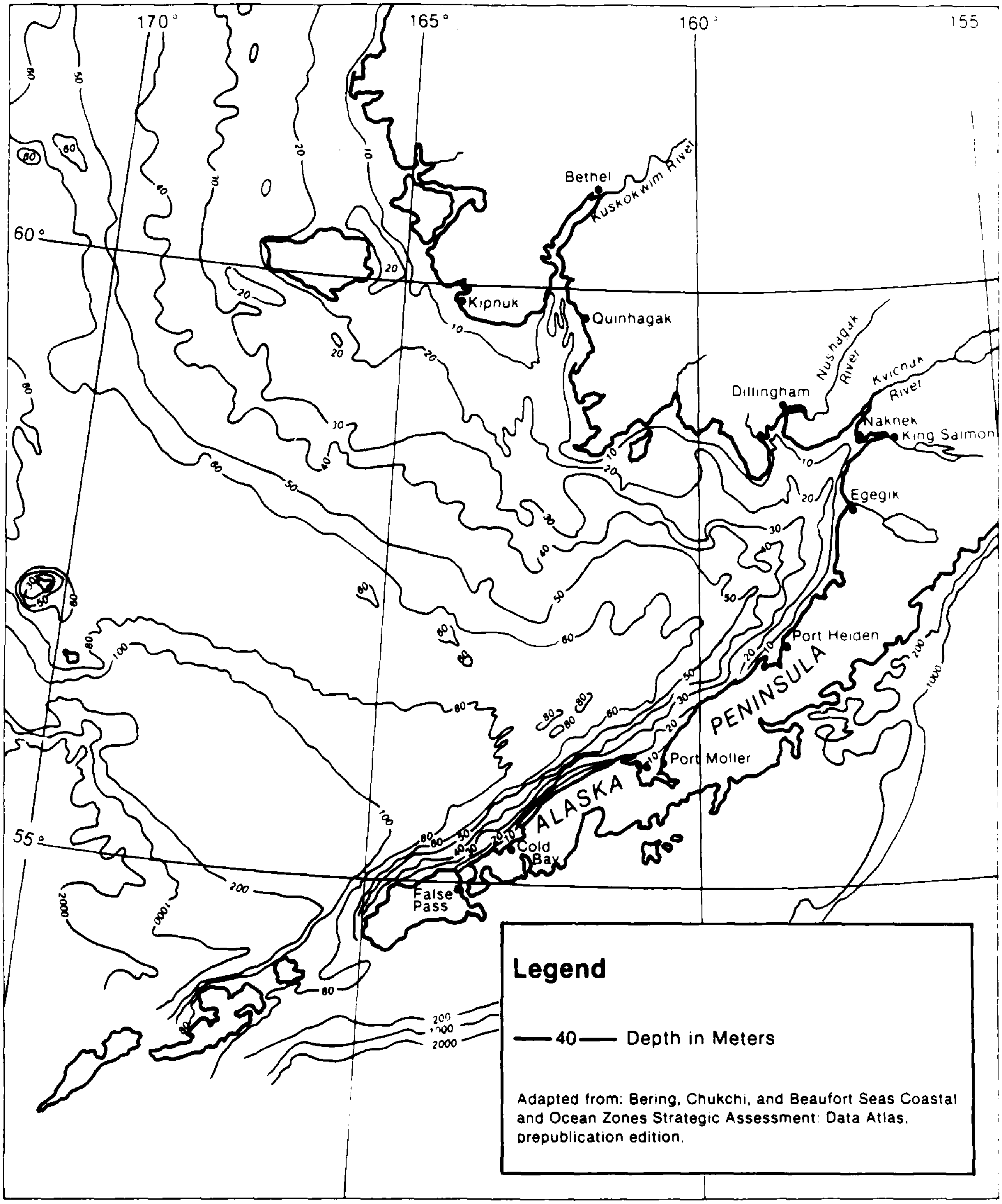


Figure 1

CIRCULATION

The primary flow of water into the Bering Sea originates at Unimak Pass. The source water of this flow is the Alaskan Coastal Current, from south of the Aleutians. Within the pass and north of Unimak Island, much of the coastal current is entrained into the wind-driven flow along the north Aleutian coast. Typically, this current flows to the northeast into Bristol Bay in the direction of the prevailing wind, following bathymetry contours along the coast. At times, the north Aleutian coastal current will undergo a reversal in direction due to changes in the large-scale and mesoscale wind direction. Atmospheric forcing produces a fluctuating influence on the net northeasterly flow within southern Bristol Bay. Because winds are highly variable, their contribution to net circulation is difficult to quantify, but the alongshore component of winds is highly correlated with both onshore and alongshore components of surface and subsurface currents.

Sea level changes on either side of Unimak Pass due to storm track and pressure cell movement are probably responsible for the fluctuation of magnitude and direction in the flow through the pass, which at times is southward. These reversals are more likely to occur when the flow from the seasonally variable Alaskan Coastal Current, from the Gulf of Alaska, is at its minimum. The shoaling bottom through Unimak Pass gives rise to vertical turbulence and mixes the water column.

On the north Aleutian shelf, the net northeasterly flow of 1-5 cm/s is present within the coastal zone (Baker 1983; Cline, et al. 1982; Thorsteinson 1984). This current is believed to be continuous with a weak current past Nunivak Island (Kinder and Schumacher 1981). Near Port Moller, currents have smaller magnitudes and do not intensify near the coast. Close inshore, within 50 km, currents ranges from 1 to 6 cm/s (Schumacher and Kinder 1982).

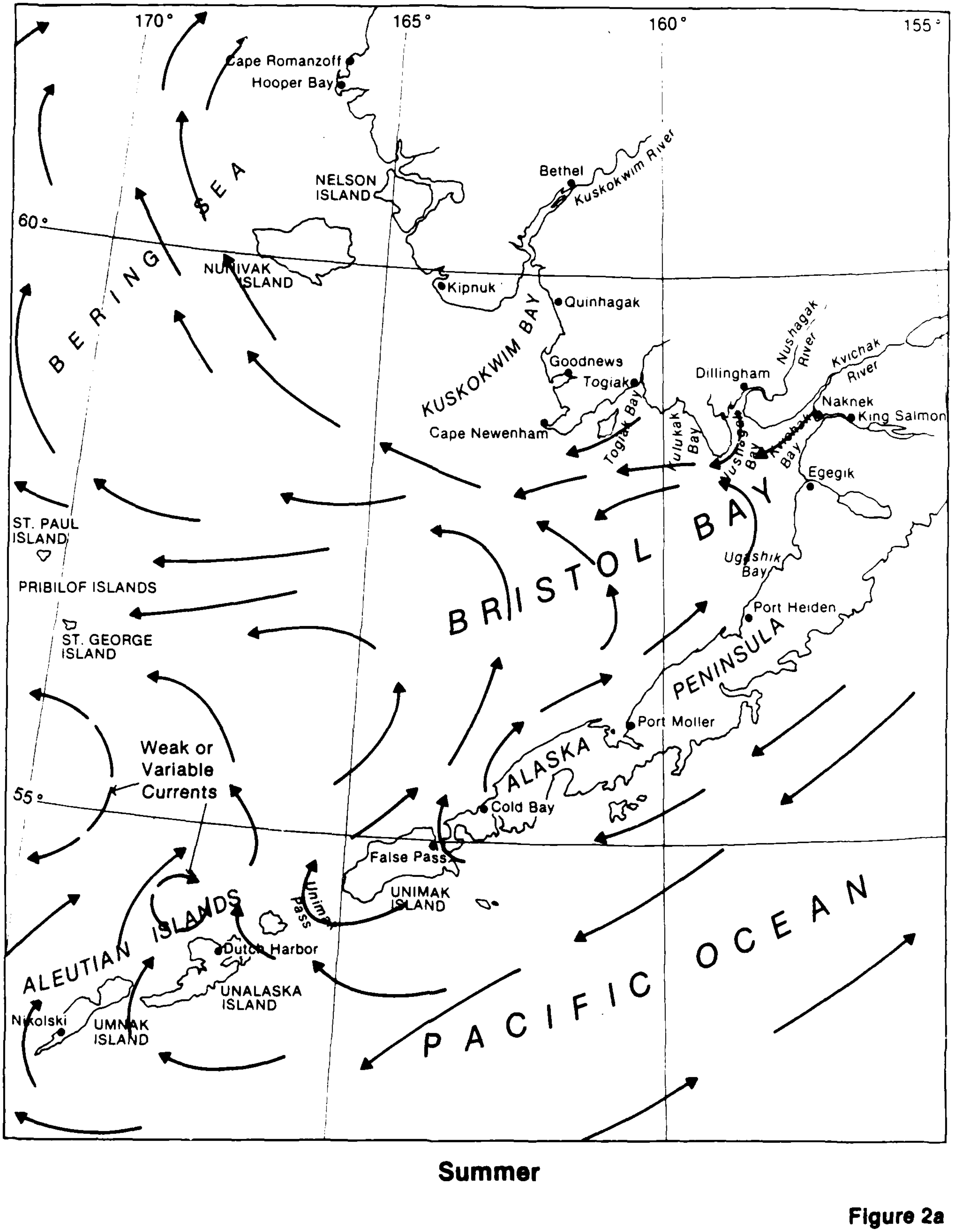
A weak mean flow shows a cyclonic tendency around the perimeter of Bristol Bay, with maximum speeds (roughly 3.5 cm/s) found near and inside the 50-m isobath and in the coastal domain. Mean speeds observed in the central shelf domain were less than 1.0 cm/s, with no sense of an organized circulation (Kinder and Schumacher 1981). There is apparently a net westward convection of water from the central basin of Bristol Bay into the Bering Sea which probably balances the mass of input via Unimak Pass. However, flow in this central region is highly variable, atmospherically forced, and difficult to quantify. Coastal waters along the northern boundary of Bristol Bay, also called the coastal current, continue to follow the bathymetry. The coastal current flows northwesterly into the Bering Sea and then northerly along the Yukon/Kuskokwim Delta. Thus, the fundamental circulation in outer Bristol Bay consists of a typically unclosed counterclockwise gyre open to the Bering Sea and driven by a combination of wind, tide, and estuarian thermohaline effects.

Ninety to ninety-five percent of the velocity variance within the bay is tidal, with tidal currents an order of magnitude larger than the mean flow. For example, on the north Aleutian shelf, where net currents are only 1-5 cm/s and the typical wind-driven currents are approximately 10 cm/s at 5 m, the tidal currents are 40-80 cm/s or more (Thorsteinson 1984). Turbulence resulting from tidal currents causes mixing of the water column from the bottom to about 50-m above the bottom.

Tidal currents in Bristol Bay are nearly reversing along the Alaska Peninsula and become more cyclonic and rotary offshore. National Ocean Survey current tables show a change in maximum ebb currents from 20-25 cm/s up to 30-40 cm/s in June near Amak Island. Near Port Moller, the tidal current speeds are as high as 100 cm/s (U.S. Department of Commerce 1980). At a depth of 2 m the calculated tidal residual current is approximately 3-4 cm/s, spatially highly variable, and directed to the northwest (Liu & Leendertse 1979). Figures 2a and 2b illustrate sea surface currents in Bristol Bay for the summer and winter regimes.

Kinder and Schumacher (1981) identified three separate hydrographic flow regimes in the southeastern Bering Sea. The **Coastal** regime is present inside the 50-m isobath in the vicinity of Nunivak Island. It is characterized by generally warm, low saline, vertically well-mixed water which has typical currents on the order of 2-5 cm/s toward the northwest. The **Middle** regime is present in the central Bristol Bay region, where water depths are on the order of 50 to 100 m. It is divided from the coastal regime by a front with an enhanced salinity gradient and is characterized by a strongly stratified, two-layered structure extending approximately to the 100-m isobath. Mean flow is generally less than 1 cm/s, with no characteristic vector-mean direction. The **Outer** hydrographic region is divided from the middle region by a front along the 100-m isobath and is present out to the shelf break in the open waters beyond Bristol Bay. A fine vertical structure separates surface layers from the deeper, more well-mixed layers. The vector-mean current in this regime is directed to the northwest, with magnitudes on the order of 1-10 cm/s and a statistically significant cross-shelf component of about 1-5 cm/s. See table 2.

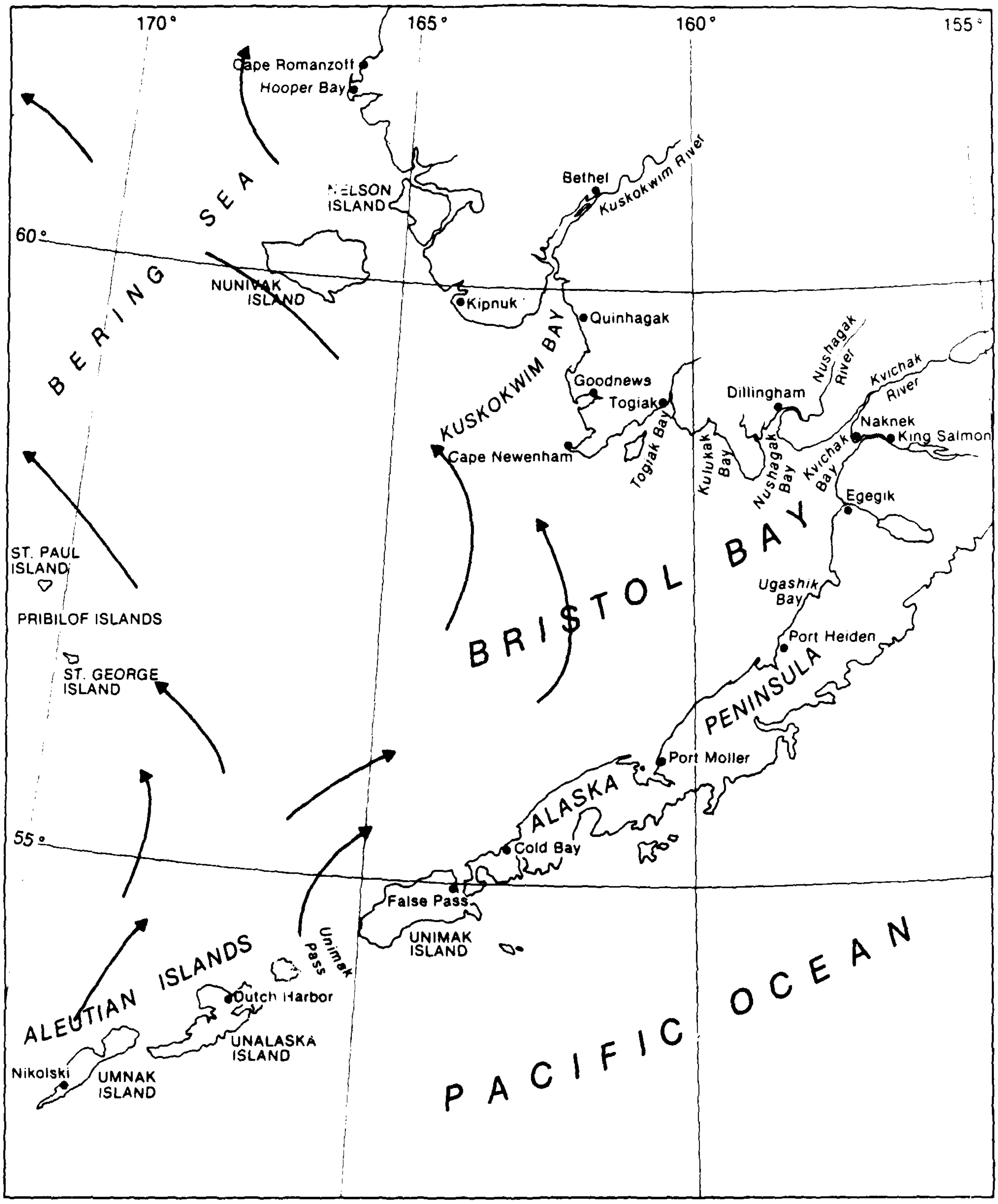
Sea Surface Currents



Summer

Figure 2a

Sea Surface Currents



Winter

Figure 2b

Table 2. Characteristics of southeastern Bering Sea flow regimes (adapted from Schumacher and Kinder 1983).

	Outer (100m-shelfbreak)	Middle (50-100m)	Coastal (Coast-50m)
1. Mean	1-10 cm/sec along isobaths, counterclockwise (due both to baroclinicity and tide-bathymetry interactions. 1-5 cm/sec across isobaths, shoreward (due primarily to oceanic forcing)	Not statistically significant except along middle and outer fronts	1-6cm/sec, counter-clockwise (due both to baroclinicity and tide-bathymetry interaction
2. Fluctuating horizontal kinetic energy	81% tidal-remainder equally due to meteorological and oceanic forcing	92% tidal-remainder primarily meteorological in form of rotating current	94% tidal-remainder primarily meteorological in form of Ekman divergence and associated longshore geostrophic current pulses*

*See Pearson, Baker, and Schumacher 1980.

WATER MASS PROPERTIES

Water density, a critical factor in the transport and cleanup of spilled oil, is a function of temperature, salinity, and pressure. It will impact the buoyancy, trajectory, and fate of spilled oil in Bristol Bay. At high latitudes (arctic and subarctic waters) salinity is the major component determining sea water density, which is represented by the function (sigma-t). At the sea surface, the average density is about 1.025 gm/cm^3. It is necessary to know the density to at least five decimal places, and all numerical values of seawater density (ρ) begin with 1.0. A custom of representing the density in an abbreviated form is given by

$$\text{sigma-t} = (\rho - 1) \times 10^3.$$

So a seawater density of 1.02478 has a sigma-t of 24.78. Seasonal vertical and horizontal fluxes and advection of water masses influence the circulation dynamics, particularly during times of low wind and ice cover.

If a single characteristic could typify the waters of Bristol Bay during the open water season it is erratic variability. The entire area has been regarded as an estuary system in which North Pacific surface waters and local runoff mix. The situation is complicated by the large size, shallow depths, and the high latitude subarctic climatic regime. Brief violent storms can alter density structures of the water, cause upwelling or downwelling, and lead to drastic changes in the characteristics of the surface water and entire water column. Furthermore, water properties from year to year are highly variable. All this variability in the system makes it difficult to characterize and define consistent long-term trends.

AEIDC (1974) divided the waters of Bristol Bay into four types identified by region, temperature, and salinity. These are not true oceanographic "water masses" but useful classifications for identifying the density distribution. The types are **North Pacific Water**, relatively normal sea water from the Pacific which occurs just north of Unimak Pass; **Bristol Bay Slope Water**, mixed water which lies along the continental slope between Unimak Pass and the Pribilof Islands; **Bristol Bay Central Water**, found in the gyre of the outer bay, and **Inner Bay and Coastal Water**, the water showing strong terrestrial influence that dominates the head of the Bay. The general characteristics of these water types are given in table 3.

Table 3 Typical Surface Water Characteristics in Bristol Bay, Summer (June-August). Data assembled from University of Alaska, Hokkaido University, U.S. National Marine Fisheries Service, and U.S. National Oceanographic Data Center

Water Type	Temperature (°C) Mean	Temperature (°C) Range	Salinity (ppt) Mean	Salinity (ppt) Range	No. of Obs.
North Pacific (North of Unimak Pass)	7.4	5.0-10.6	32.7	32.3-33.1	42
Bristol Bay Slope	8.6	5.4-10.6	32.0	31.4-32.8	58
Bristol Bay Central	7.9	1.8-12.3	31.4	30.0-32.6	68
Bristol Bay Inner and Coastal	11.4	1.3-18.2	28.9	12.4-31.2	44

Figures 3a-3c depict monthly sea surface temperature means.

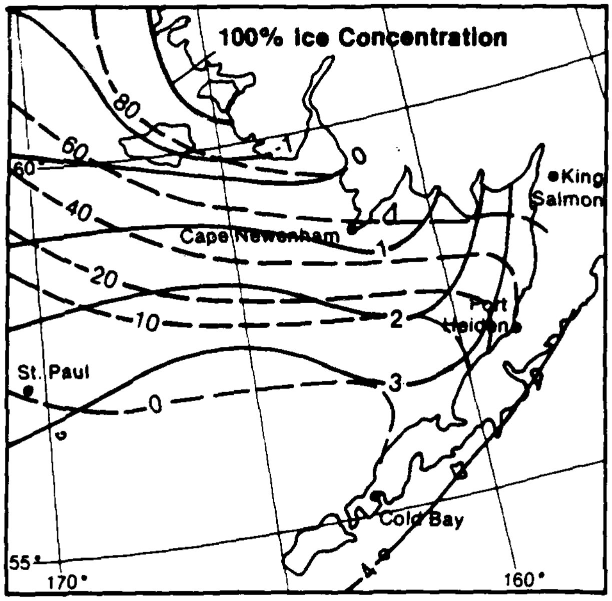
Figures 4a-4c depict monthly sea surface temperature extremes.

Figures 5a-5c depict monthly long-term mean near bottom temperatures.

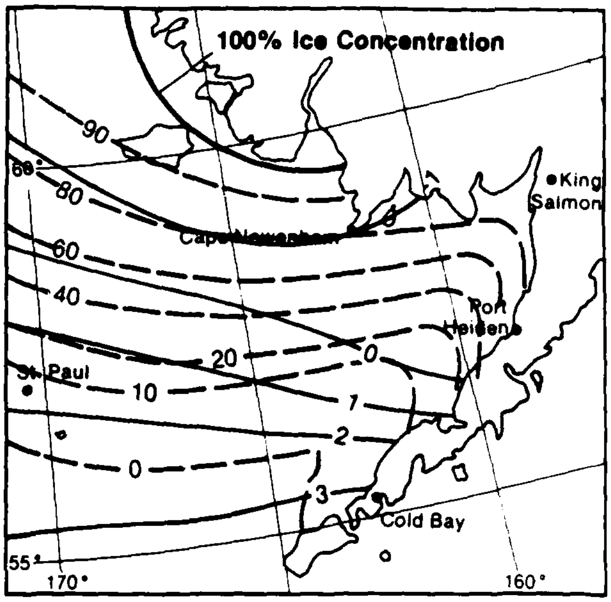
Figures 6a-6c depict monthly long-term mean sea surface salinities.

Figures 7a-7c depict monthly long-term near bottom salinities.

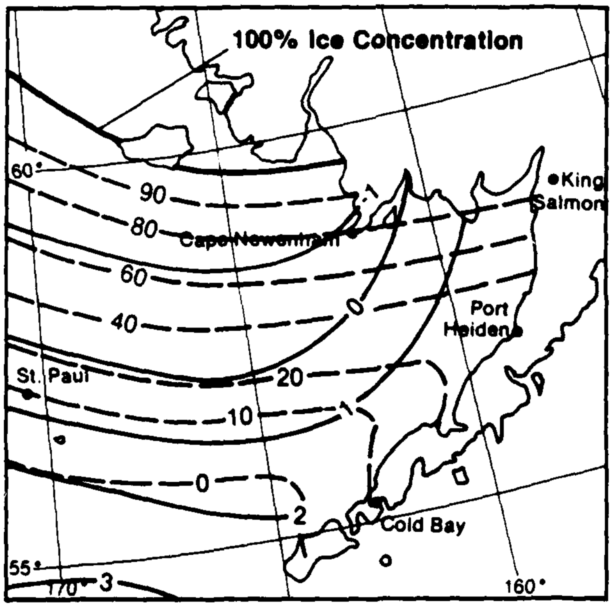
Sea Surface Temperature Means



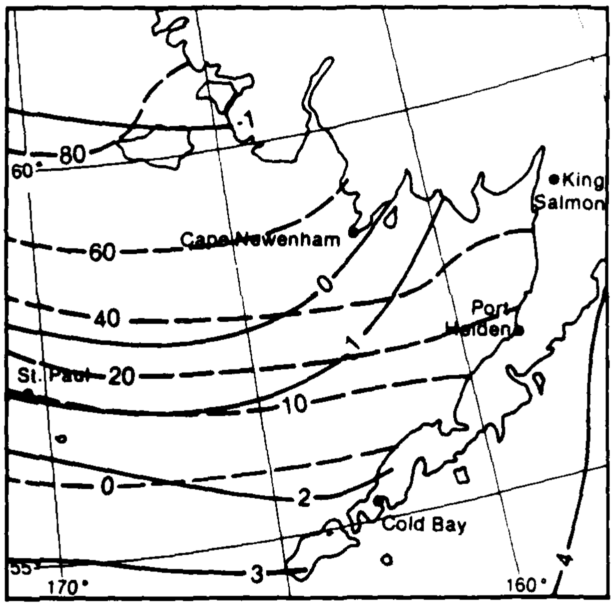
January



February



March



April

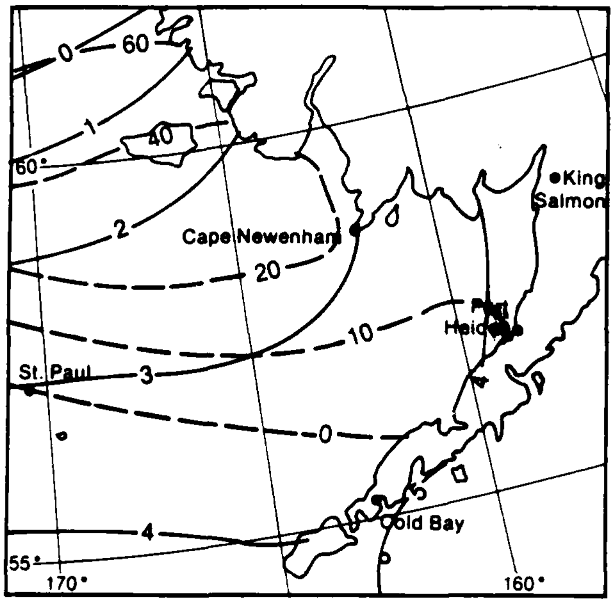
Legend

Sea Surface Temperature °C (solid line)

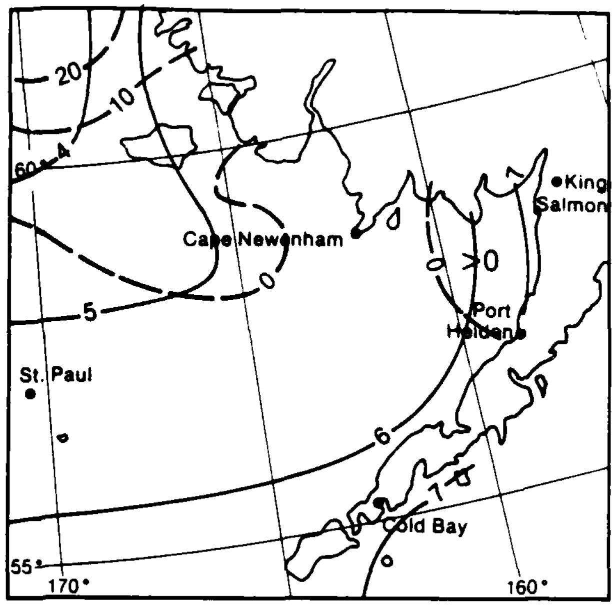
% Frequency of Ice of Any Kind (dashed line)

Figure 3a

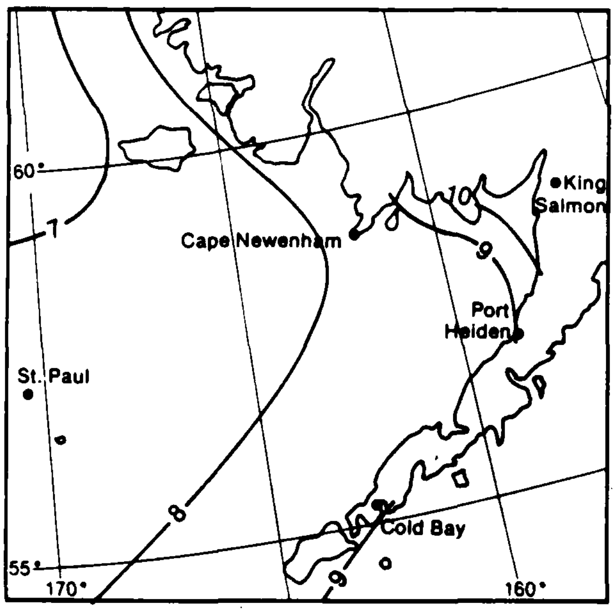
Sea Surface Temperature Means



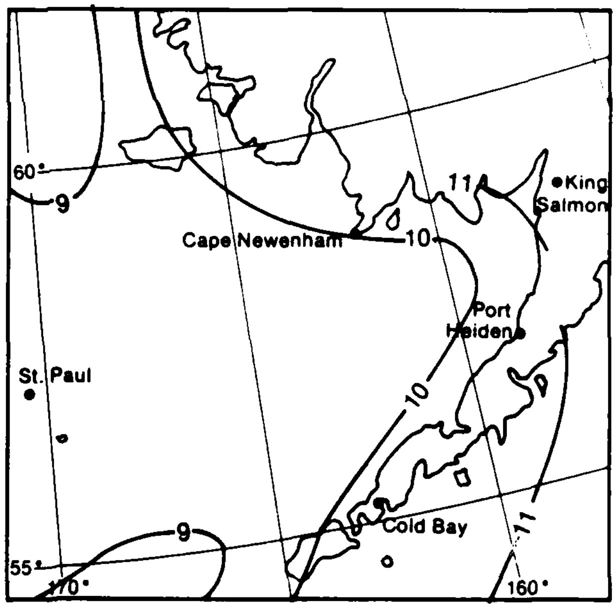
May



June



July



August

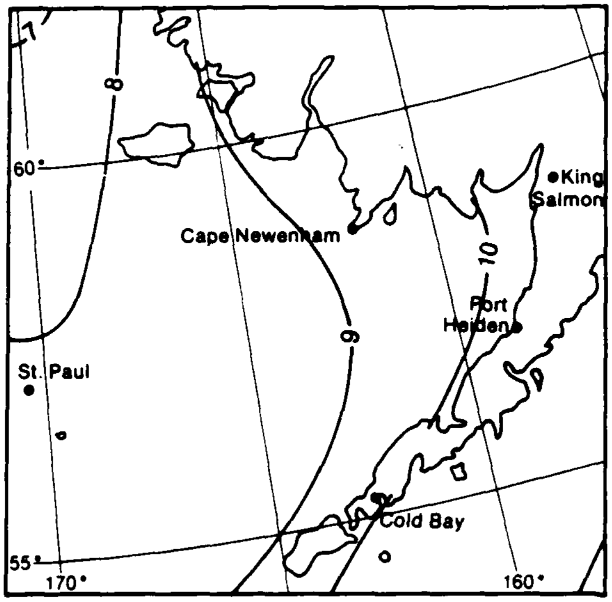
Legend

Sea Surface Temperature °C

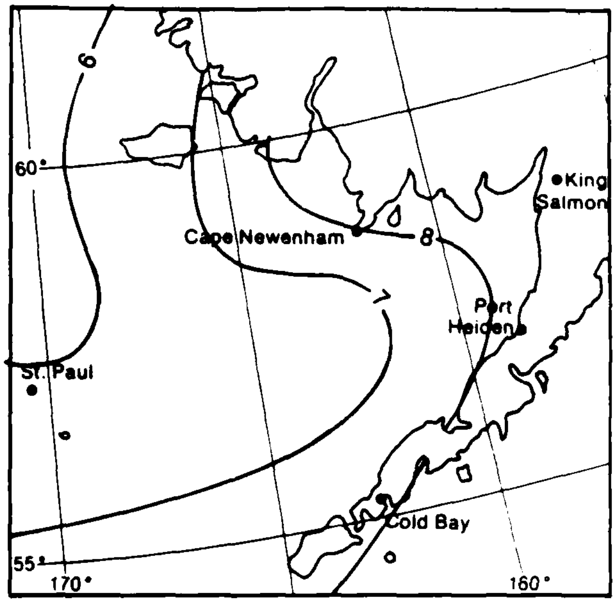
% Frequency of Ice of Any Kind

Figure 3b

Sea Surface Temperature Means



September



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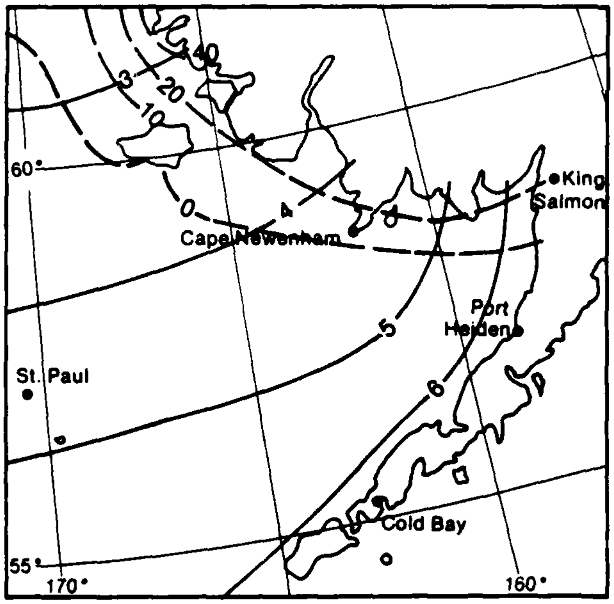

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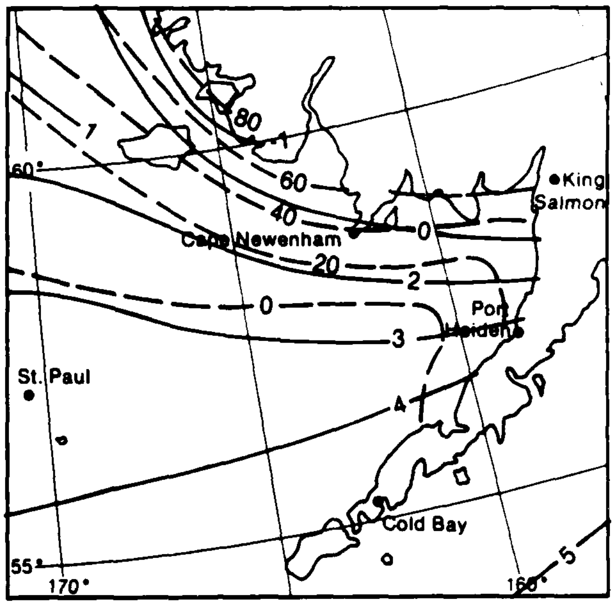
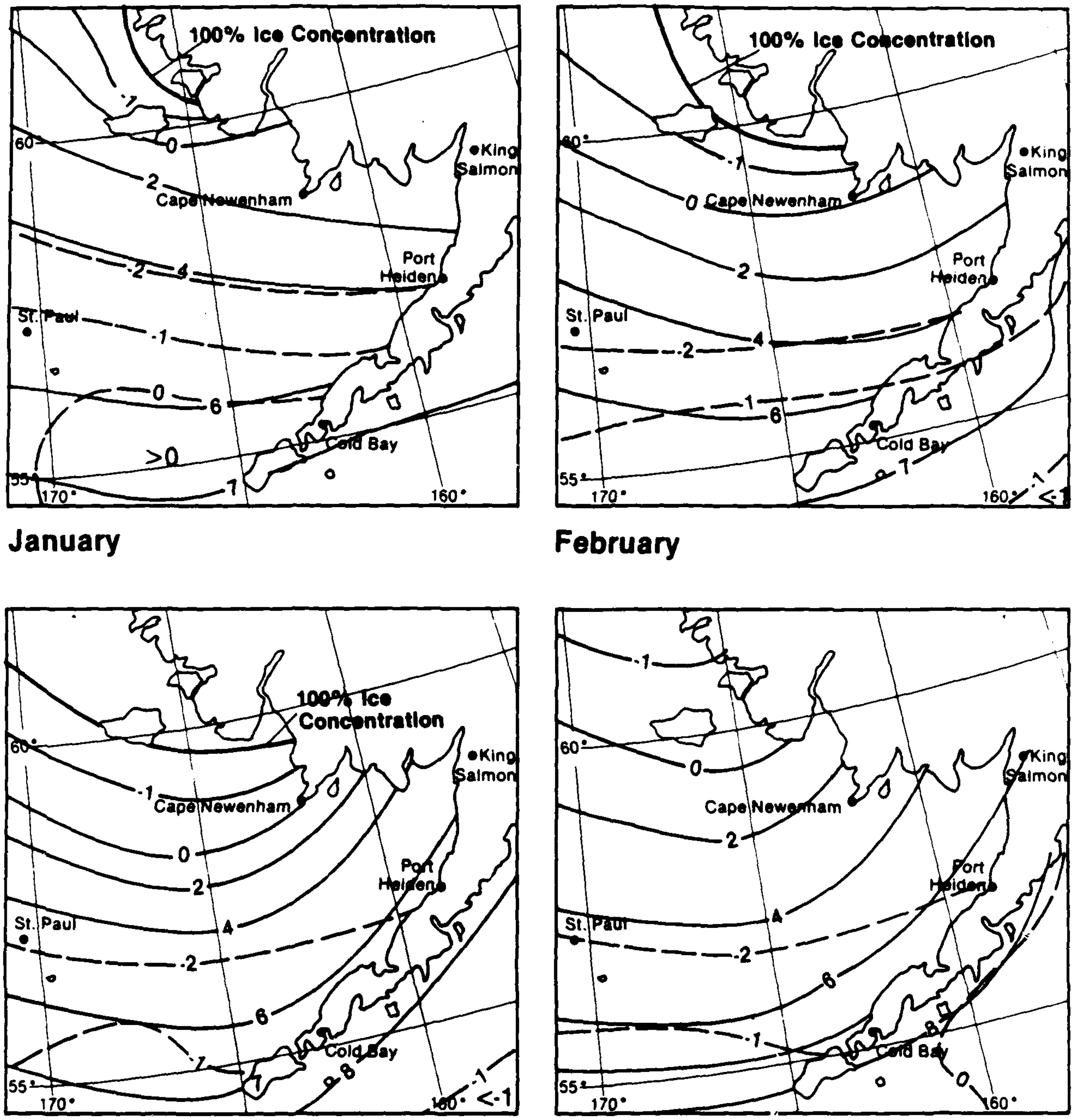


December

Figure 3c

Sea Surface Temperature Extremes °C



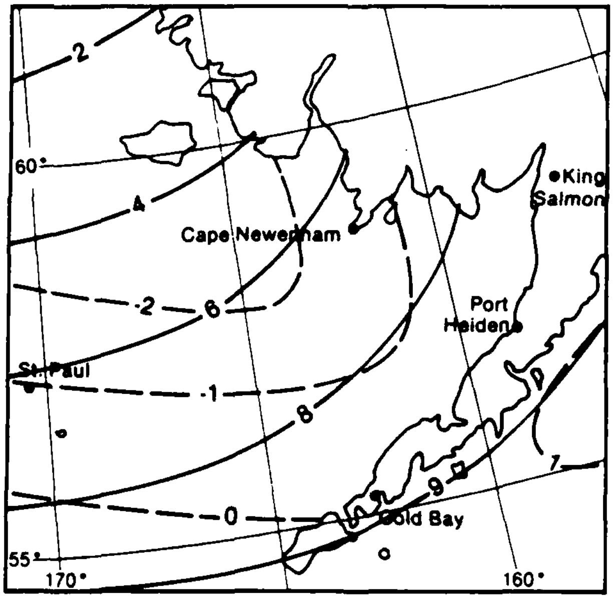
Legend

——————99% Sea Surface Temperature (Max.)

— — — —1% Sea Surface Temperature (Min.)

Figure 4a

Sea Surface Temperature Extremes °C



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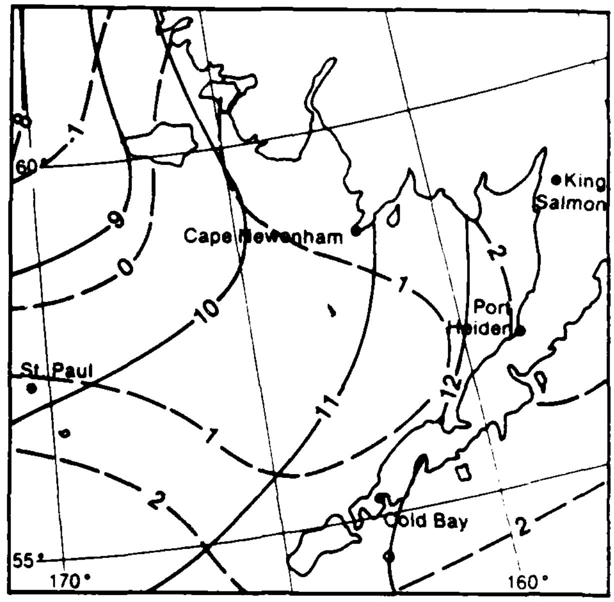

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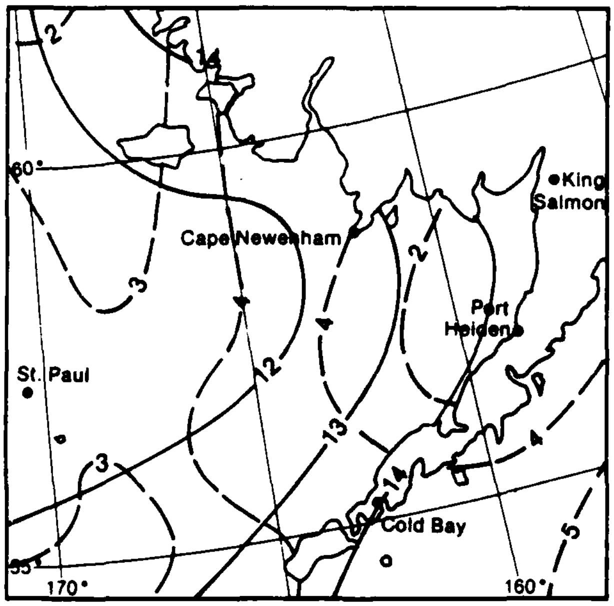

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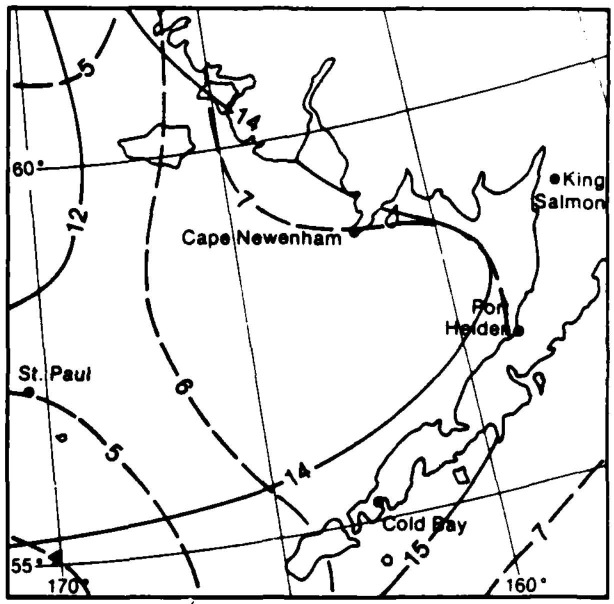
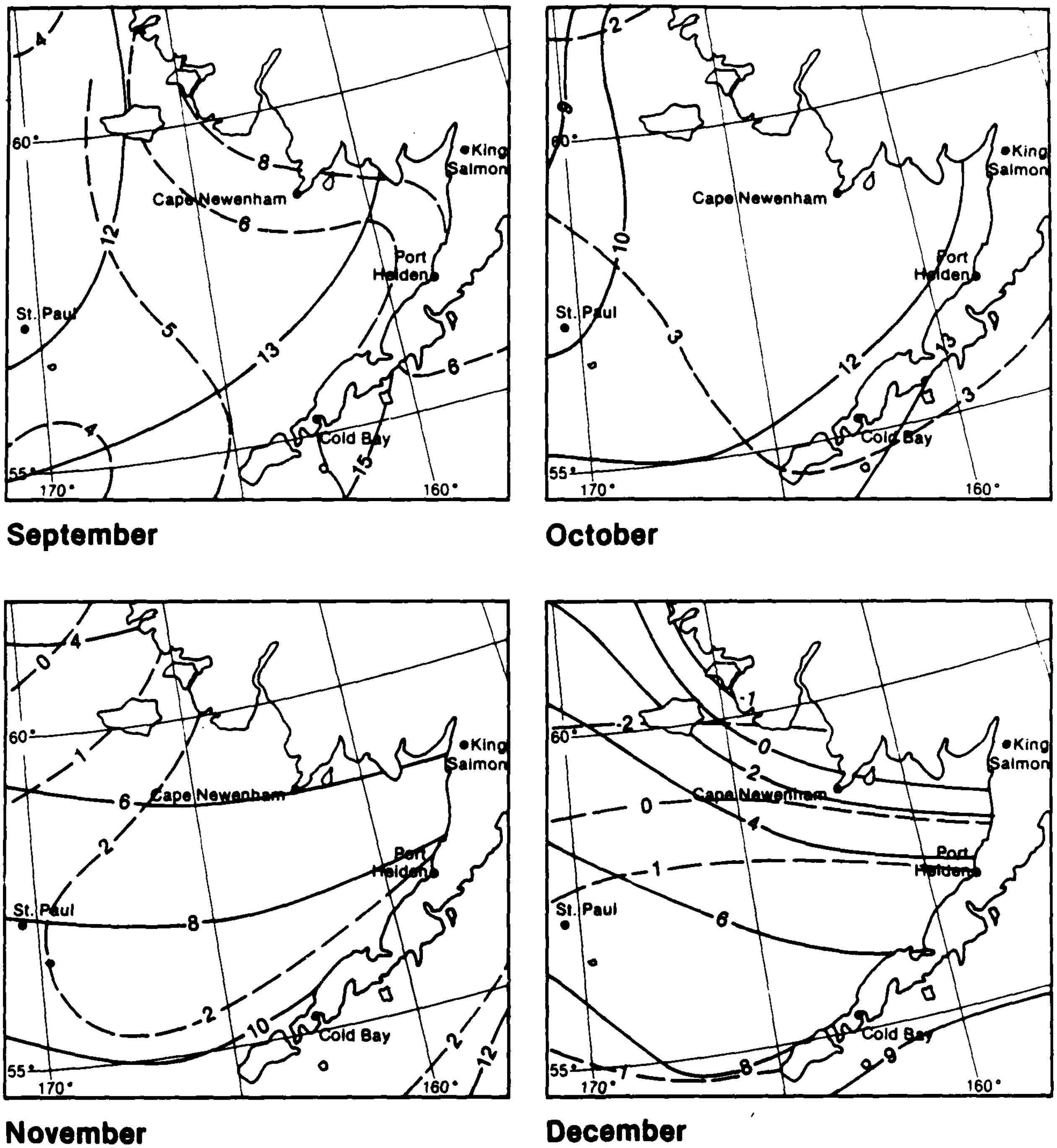


August

Figure 4b

Sea Surface Temperature Extremes °C



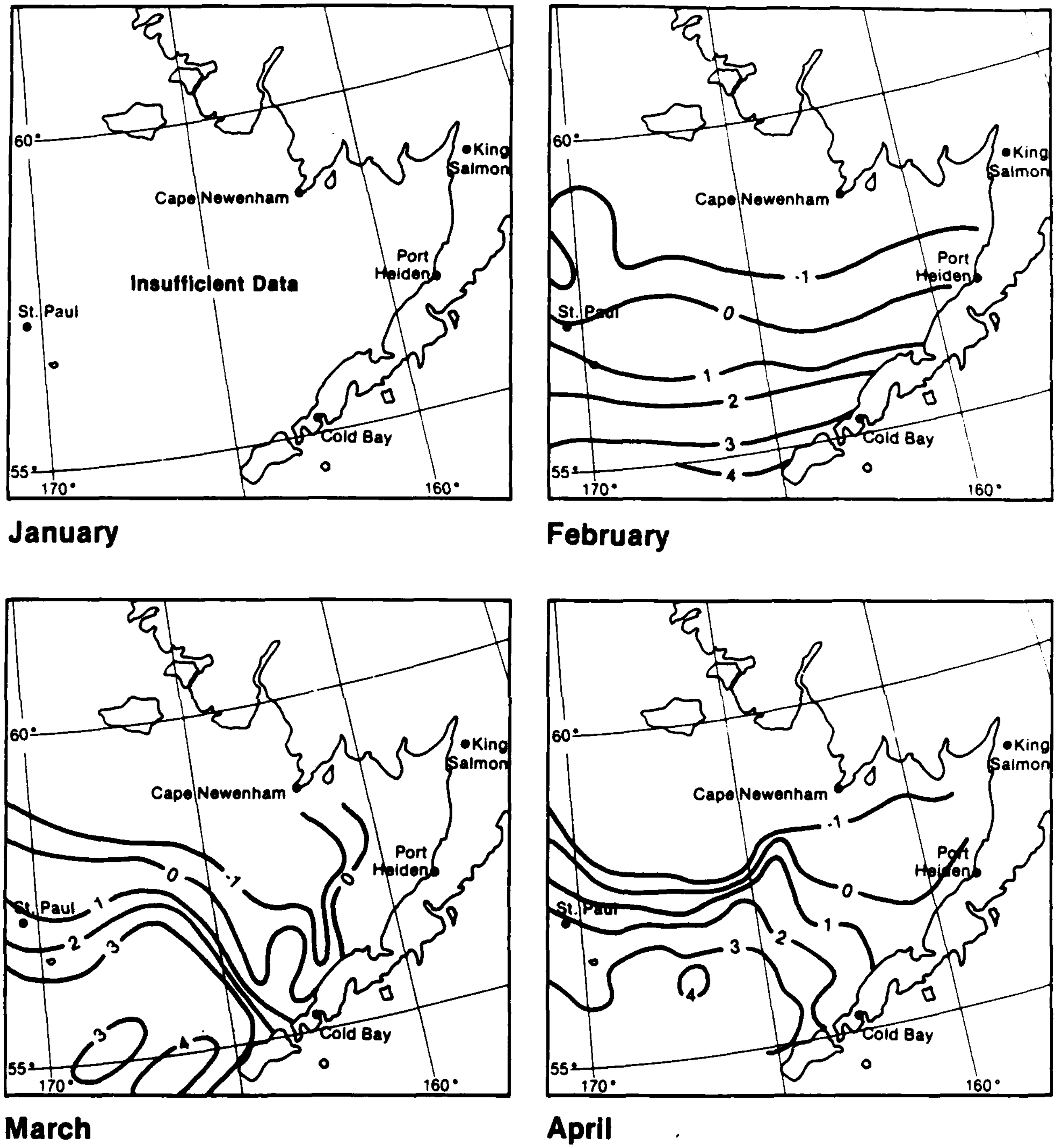
Legend

——— 99% Sea Surface Temperature (Max.)

— — — 1% Sea Surface Temperature (Min.)

Figure 4c

Long Term Mean Near Bottom Temperature (°C)



(Synthesized from Ingraham, 1981.)

Figure 5a

Long Term Mean Near Bottom Temperature (°C)

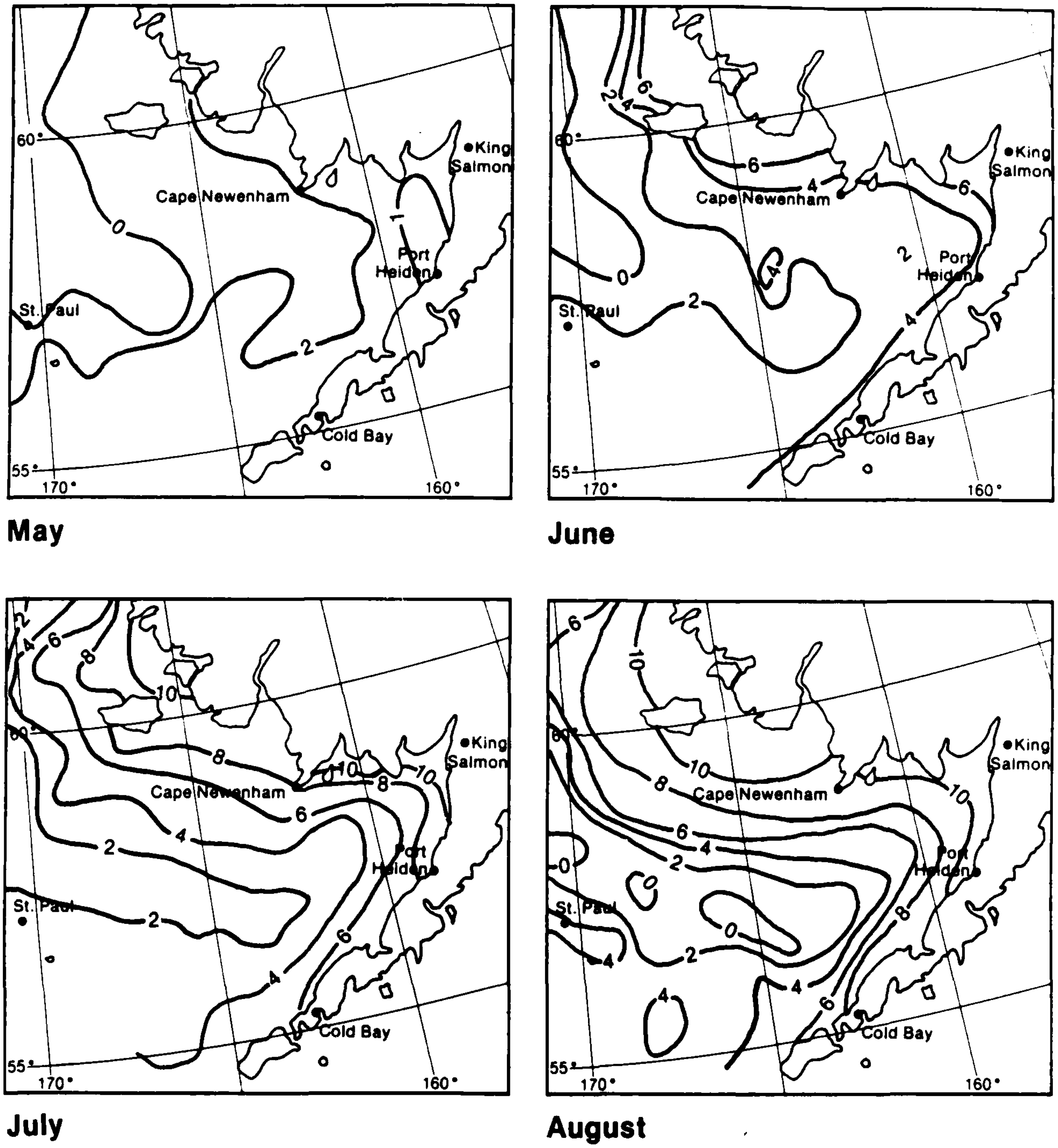
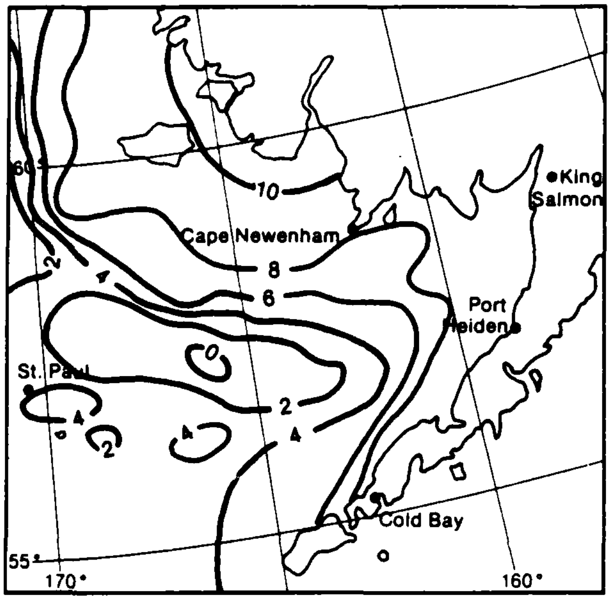
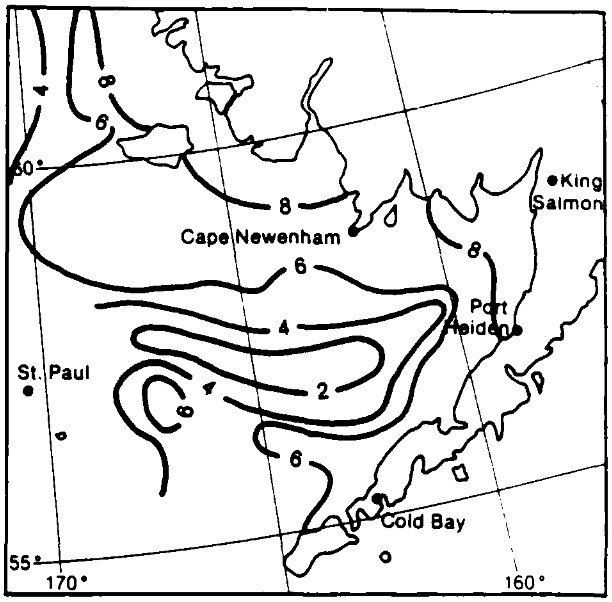


Figure 5b

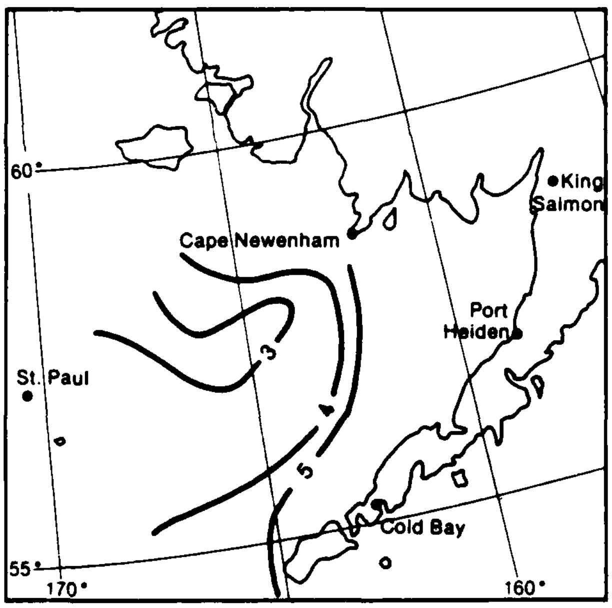
Long Term Mean Near Bottom Temperature (°C)



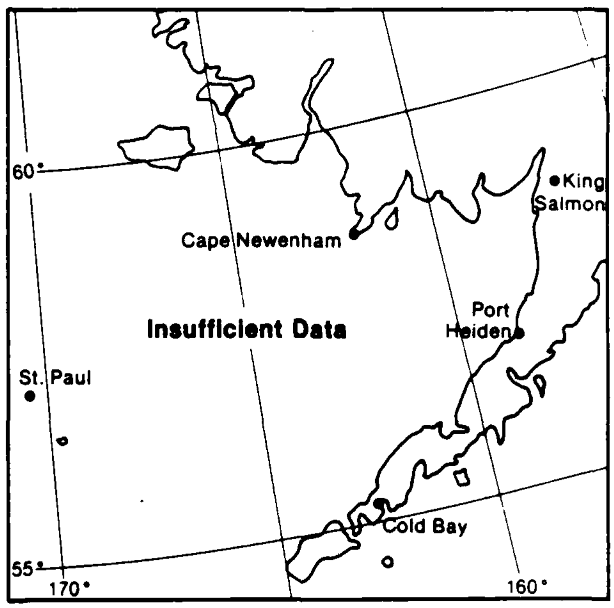
September



October



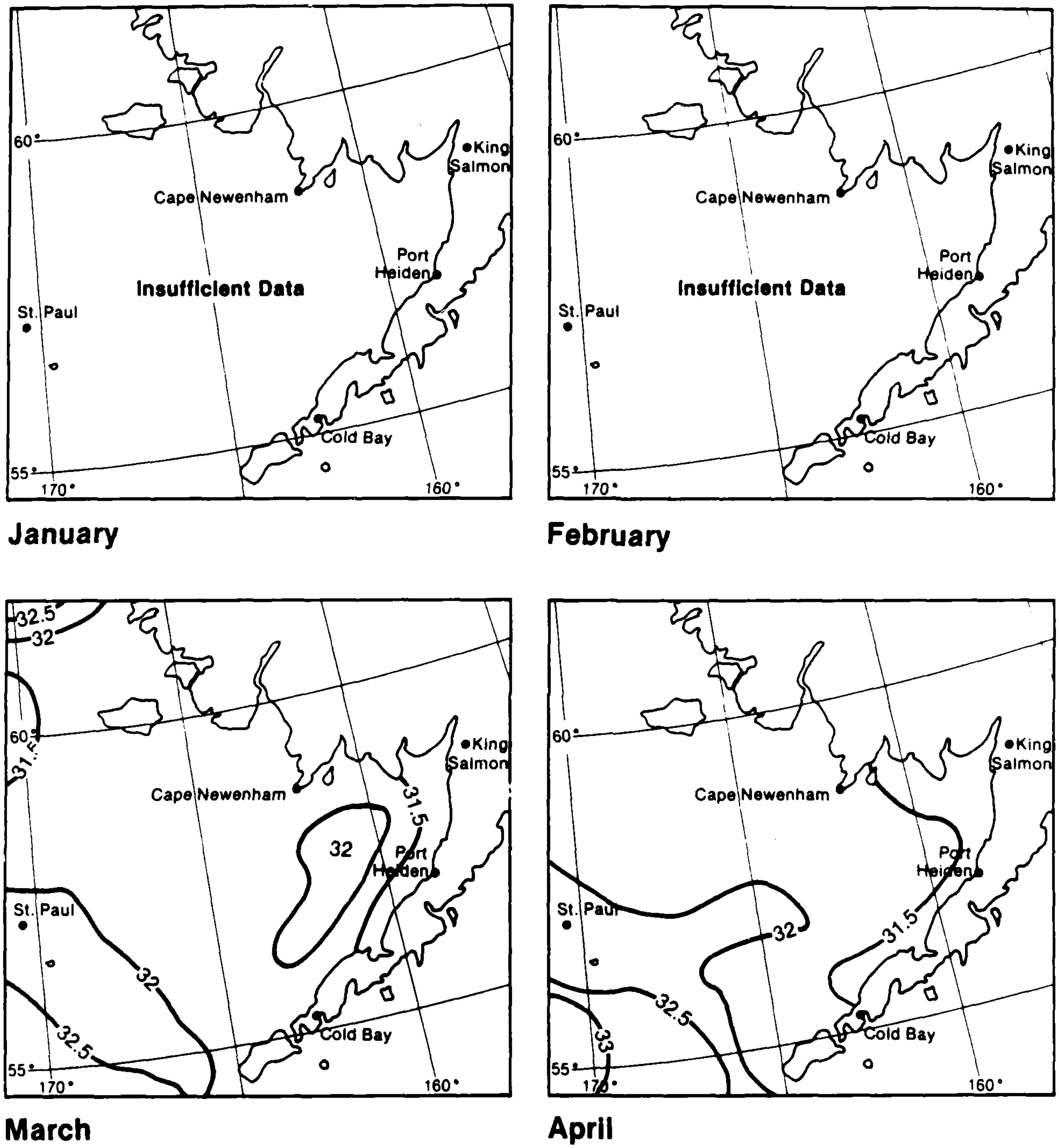
November



December

Figure 5c

Long Term Mean Sea Surface Salinity



Legend

—29— Parts Per Thousand

Figure 6a

Long Term Mean Sea Surface Salinity

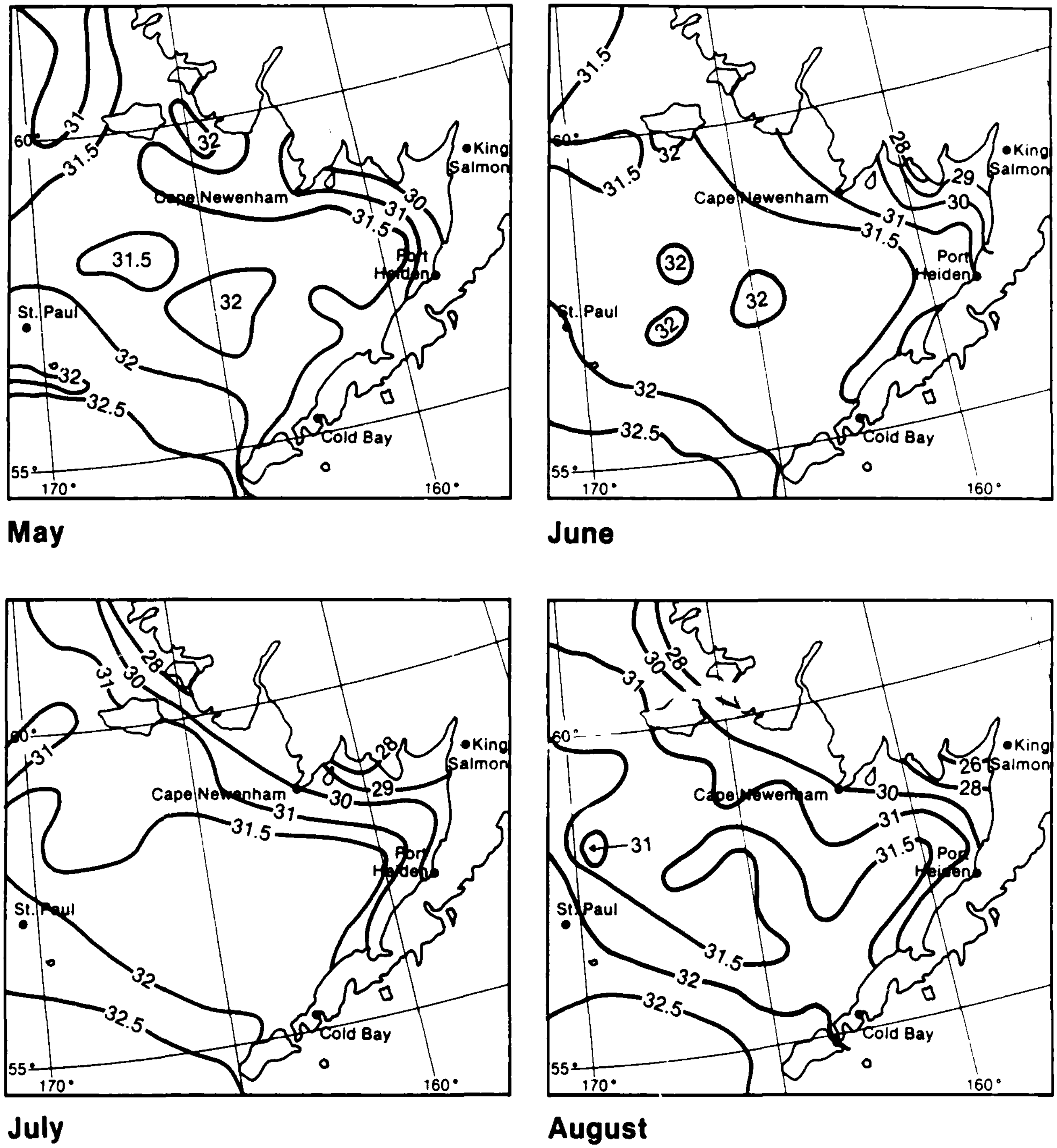
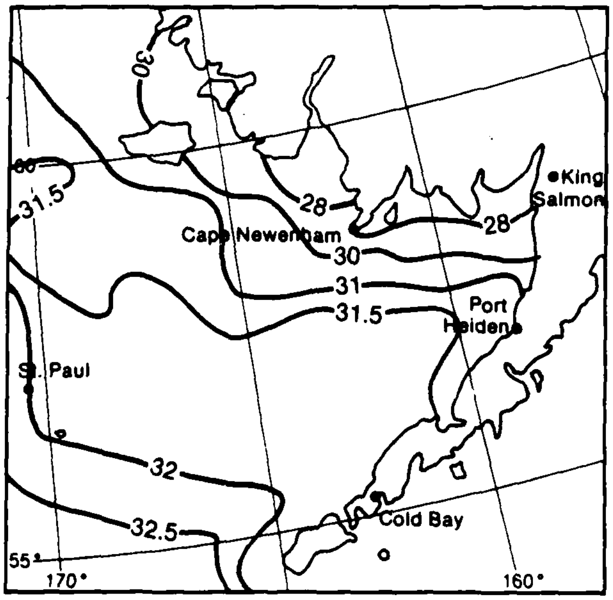
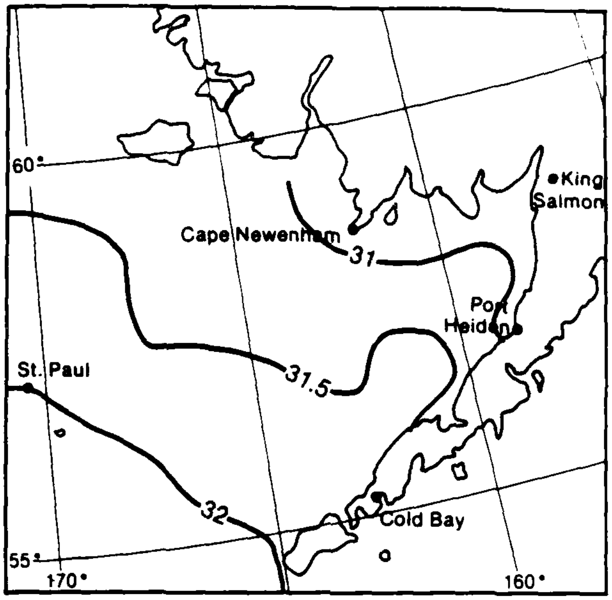


Figure 6b

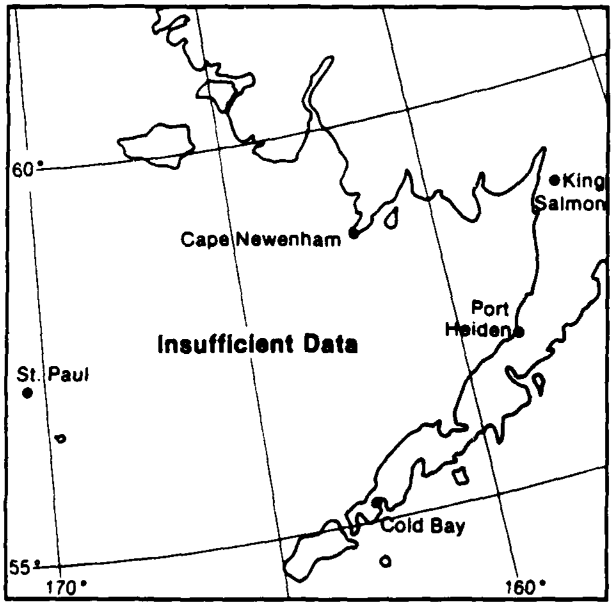
Long Term Mean Sea Surface Salinity



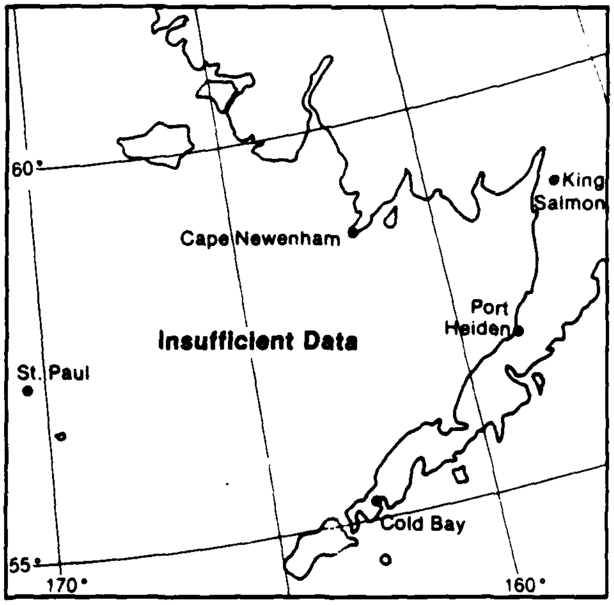
September



October



November



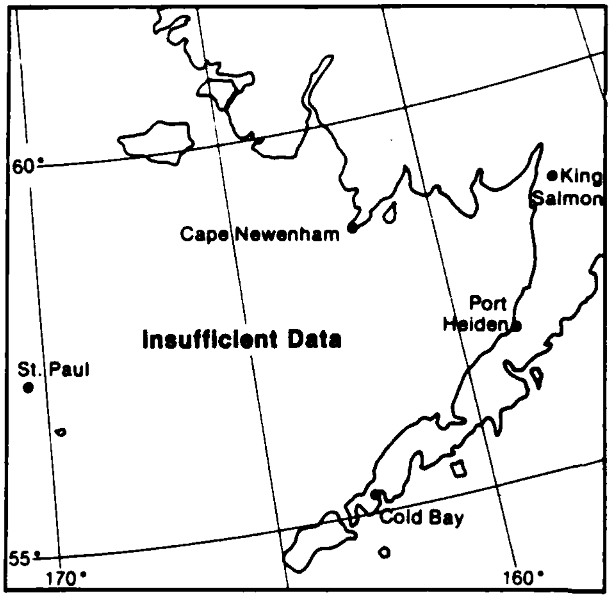
December

Legend

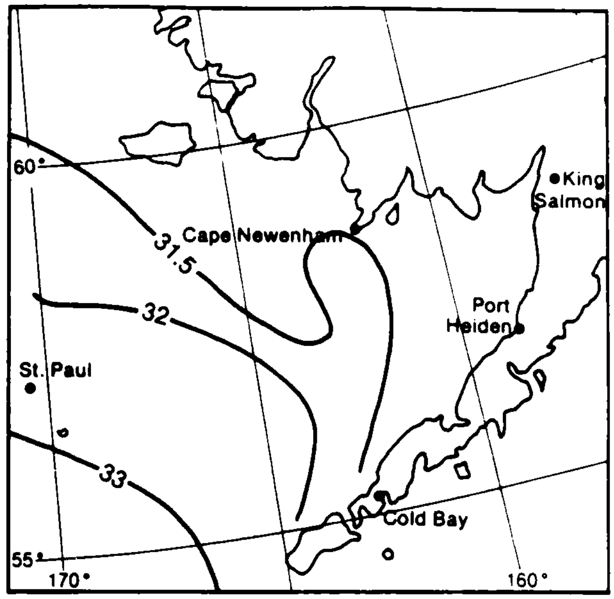
——29—— Parts Per Thousand

Figure 6c

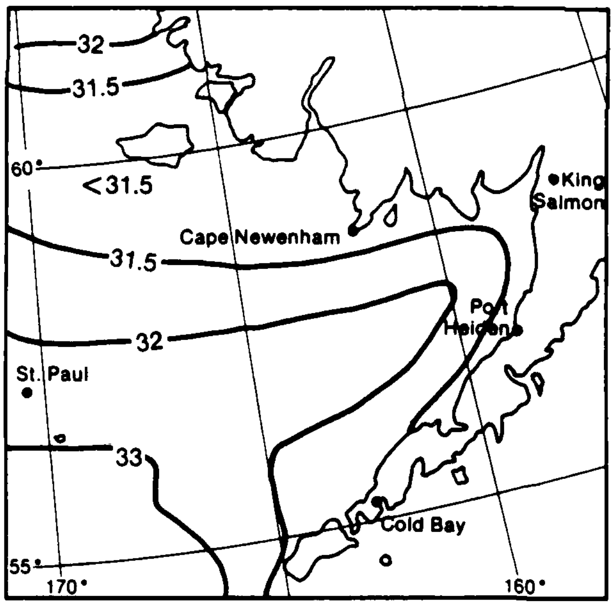
Long Term Mean Near Bottom Salinity



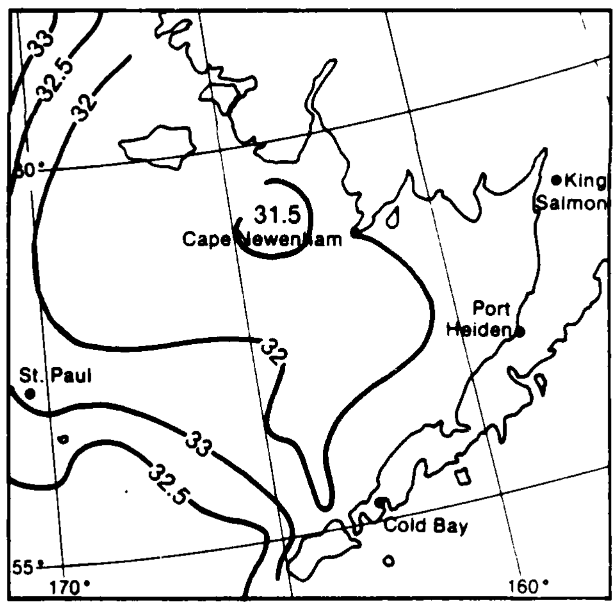
January



February



March



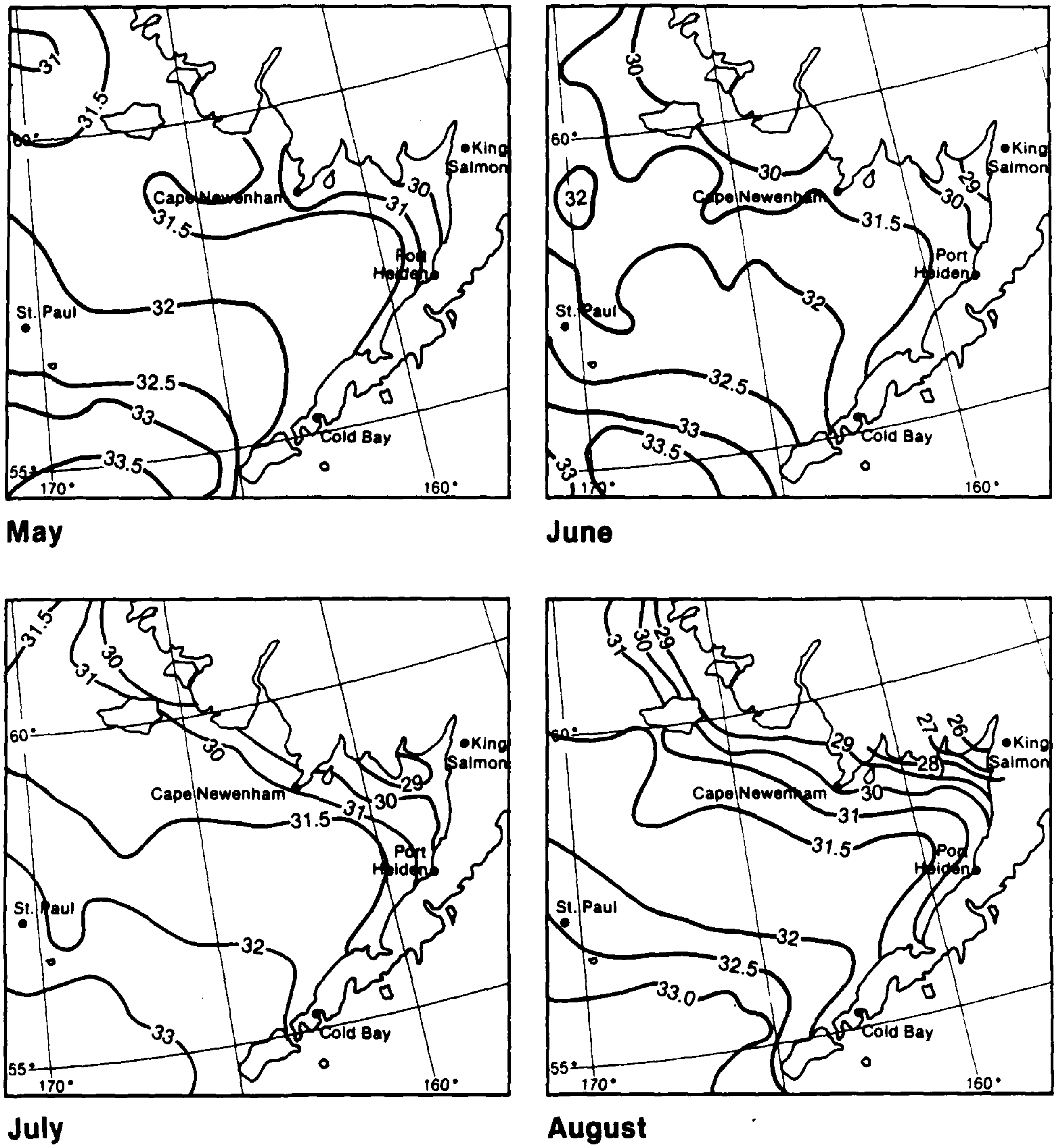
April

Legend

——29—— Parts Per Thousand

Figure 7a

Long Term Mean Near Bottom Salinity

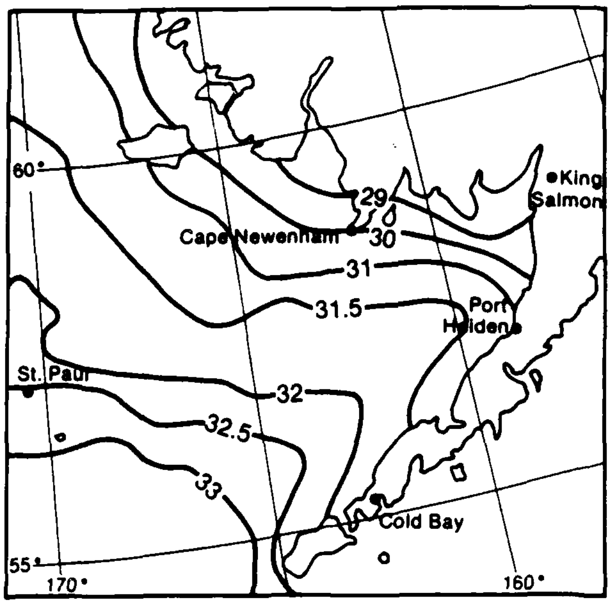


Legend

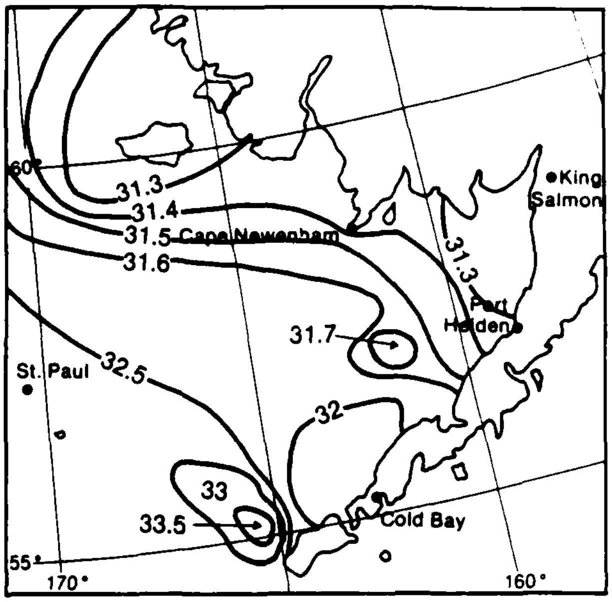
—29—— Parts Per Thousand

Figure 7b

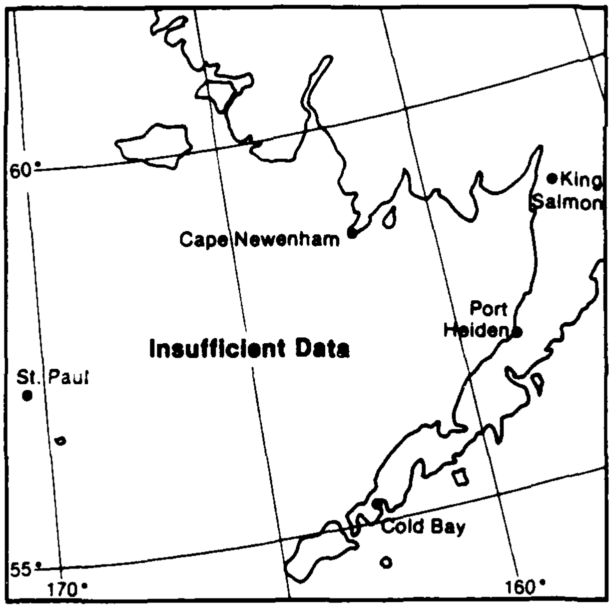
Long Term Mean Near Bottom Salinity



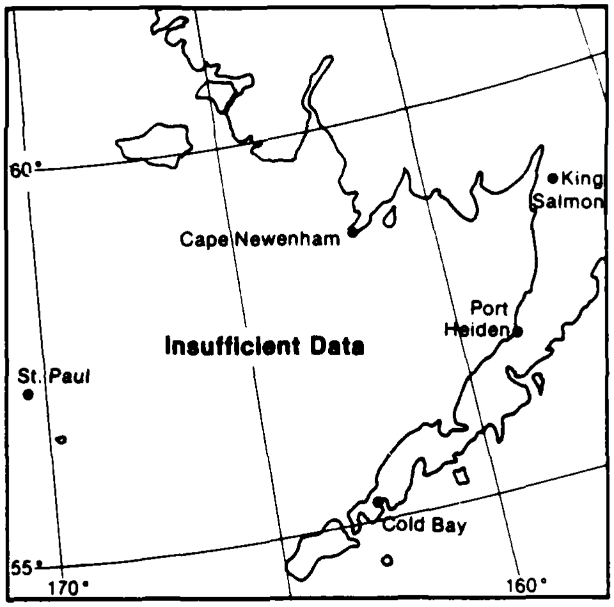
September



October



November



December

Figure 7c

WAVES

The north Aleutian shelf is characterized by severe waves generated by local storms. Long fetch, storm duration, and shallow depth contribute to high wave conditions. In summer, when winds are from the south the nearshore Bristol Bay area is in the lee of the Alaska Peninsula. Consequently locally generated waves are not too severe. In winter, winds are more northerly at about 10 to 15 m/s. This greater fetch and speed generates increased wave heights and periods. Maximum observed heights in June are about 5.5 m averaging about 1.5 m. Maximum observed heights in November are about 9.0 m with 60% exceeding 2.0 m (USDOI, no date). Maximum wave heights have been measured at 9.5 m in September and October (Brower, et al. 1977). Figure 8 shows monthly wave height thresholds for Bristol Bay. Marine area C on the accompanying graphs is that portion of the Bering Sea between 55° and 60°N latitude and east from 169°W longitude to the coast.

Graphs: Wave height thresholds

Wave height frequencies.

WAVE HEIGHT (M)	%
0–0.5	10.0
1–1.5	20.0
2–2.5	30.0
3–3.5	20.0
4–5.5	10.0
≥6.0	10.0
N=	1363

Percent frequency of various ranges within the area.

(30.0% of all observed wave heights were in the range 2 to 2.5 meters.)

N = Observation count.

Wave data for these tables were selected from the higher of sea or swell when both were reported.

Figure 8-legend

Wave Height Thresholds

January

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	11.8
1–1.5	33.1
2–2.5	28.2
3–3.5	14.9
4–5.5	9.6
≥6.0	2.4
N=	3378

February

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	14.9
1–1.5	28.4
2–2.5	28.9
3–3.5	17.2
4–5.5	9.3
≥6.0	1.3
N=	3324

March

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	20.7
1–1.5	35.9
2–2.5	26.7
3–3.5	10.7
4–5.5	4.7
≥6.0	1.3
N=	3720

April

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	19.8
1–1.5	39.2
2–2.5	25.5
3–3.5	8.5
4–5.5	5.6
≥6.0	1.4
N=	4070

May

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	30.1
1–1.5	42.7
2–2.5	19.3
3–3.5	5.1
4–5.5	2.4
≥6.0	0.4
N=	5197

June

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	33.8
1–1.5	46.3
2–2.5	15.9
3–3.5	2.6
4–5.5	1.3
≥6.0	0.0
N=	5175

July

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	30.6
1–1.5	48.6
2–2.5	15.7
3–3.5	4.3
4–5.5	0.7
≥6.0	0.1
N=	5657

August

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	20.5
1–1.5	50.9
2–2.5	21.9
3–3.5	4.9
4–5.5	1.4
≥6.0	0.3
N=	5072

September

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	16.4
1–1.5	43.5
2–2.5	26.3
3–3.5	8.7
4–5.5	4.2
≥6.0	0.9
N=	5573

October

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	8.8
1–1.5	35.8
2–2.5	29.9
3–3.5	14.8
4–5.5	8.6
≥6.0	2.2
N=	3593

November

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	7.3
1–1.5	29.3
2–2.5	29.3
3–3.5	17.9
4–5.5	12.7
≥6.0	3.5
N=	2793

December

Marine Area C

WAVE HEIGHT (M)	%
0–0.5	13.2
1–1.5	29.9
2–2.5	26.8
3–3.5	18.7
4–5.5	9.4
≥6.0	2.1
N=	3161

Figure 8a

TIDES

Tides are dominated by a tidal bulge which enters the Bering Sea through central and western Aleutian Strait, principally Unimak Pass, and progresses as a free wave onto the Bering Sea shelf. The tide is predominantly a mixed semidiurnal tide over the southeast portion of the shelf. Both diurnal and semidiurnal components are present. A portion of the the area from Cape Newenham northward is primarily of the semi-diurnal type which means there is little difference in tide levels between the two high waters and two low waters that occur daily.

Tide ranges in the area vary from over 5 m (16 ft) in Kvichak and Nushagak Bays, 3 m (10 ft) in the north end of Kuskokwim Bay down to slightly less than 2 m (6 ft) west of Port Moller and Cape Newenham area. Tide ranges decrease to the west throughout the area. Toward the head of Bristol Bay the largest amplitudes exceed 6 m. Tidal ranges at Port Moller average 3.3 m compared to a range of 6.9 m at Naknek River entrance (Brower, et al. 1977). Tidal ranges, types, and corange lines for Bristol Bay can be seen on Figure 9.

RIVER DISCHARGE

The major point sources of freshwater discharge into Bristol Bay are the Kuskokwim River which drains into Kuskokwim Bay, the Nushagak River in the northeastern corner of Bristol Bay near Dillingham, and the Kvichak River at the eastern junction of the Alaska Peninsula and southwest Alaska.

Figure 10 depicts hundreds of small streams, creeks, and various sized rivers along the North Aleutian Shelf and Alaska Peninsula. These cumulatively discharge a line source of freshwater to the surface waters of Bristol Bay. The volumetric flow rates for only five streams and rivers have been measured by the U.S. Geological Survey Water Data Report. Multiyear averaged monthly and annual discharge rates for these rivers, as well as total runoff volume, are shown on tables 4 through 8.

Overall, the total freshwater input into Bristol Bay is estimated to be the sum of the three major rivers plus the cumulative drainage of the smaller streams. The line source of freshwater from these streams is probably two orders of magnitude greater than that produced by a single stream. Hence, if discharge from Russell Creek and Eskimo Creek range from 1×10^7 to 2×10^8, total small stream drainage into Bristol Bay is approximately 1×10^9-10^{10} m^3 per year, in addition to the discharge from the Kuskokwim, Nushagak, and Kivchak rivers. The entire annual volume of freshwater discharge is estimated to be on the order of 1×10^{11} m^3/year or 8×10^7 acre-feet/year.

Types and Tide Range

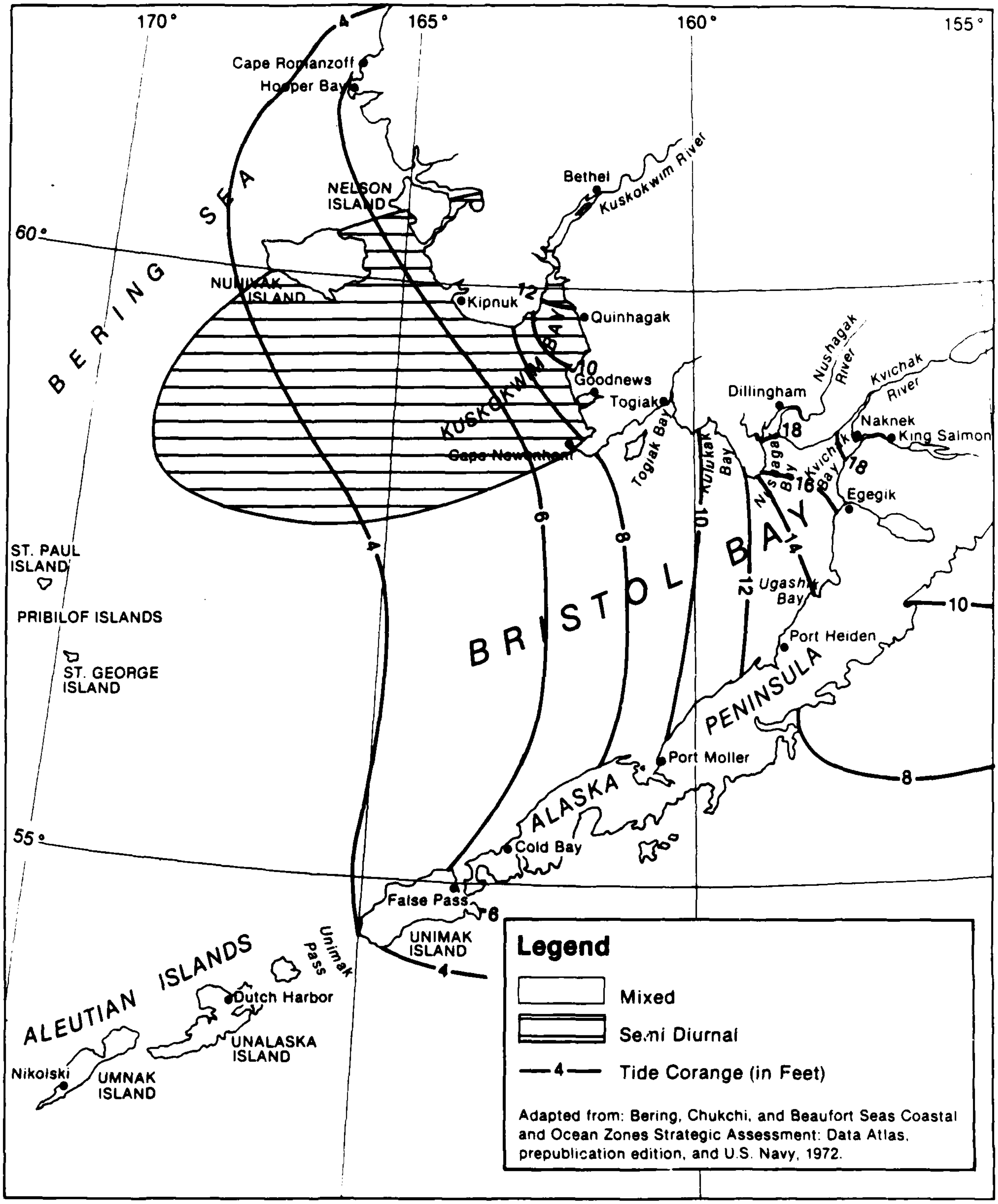


Figure 9

River Drainage Pattern in Bristol Bay

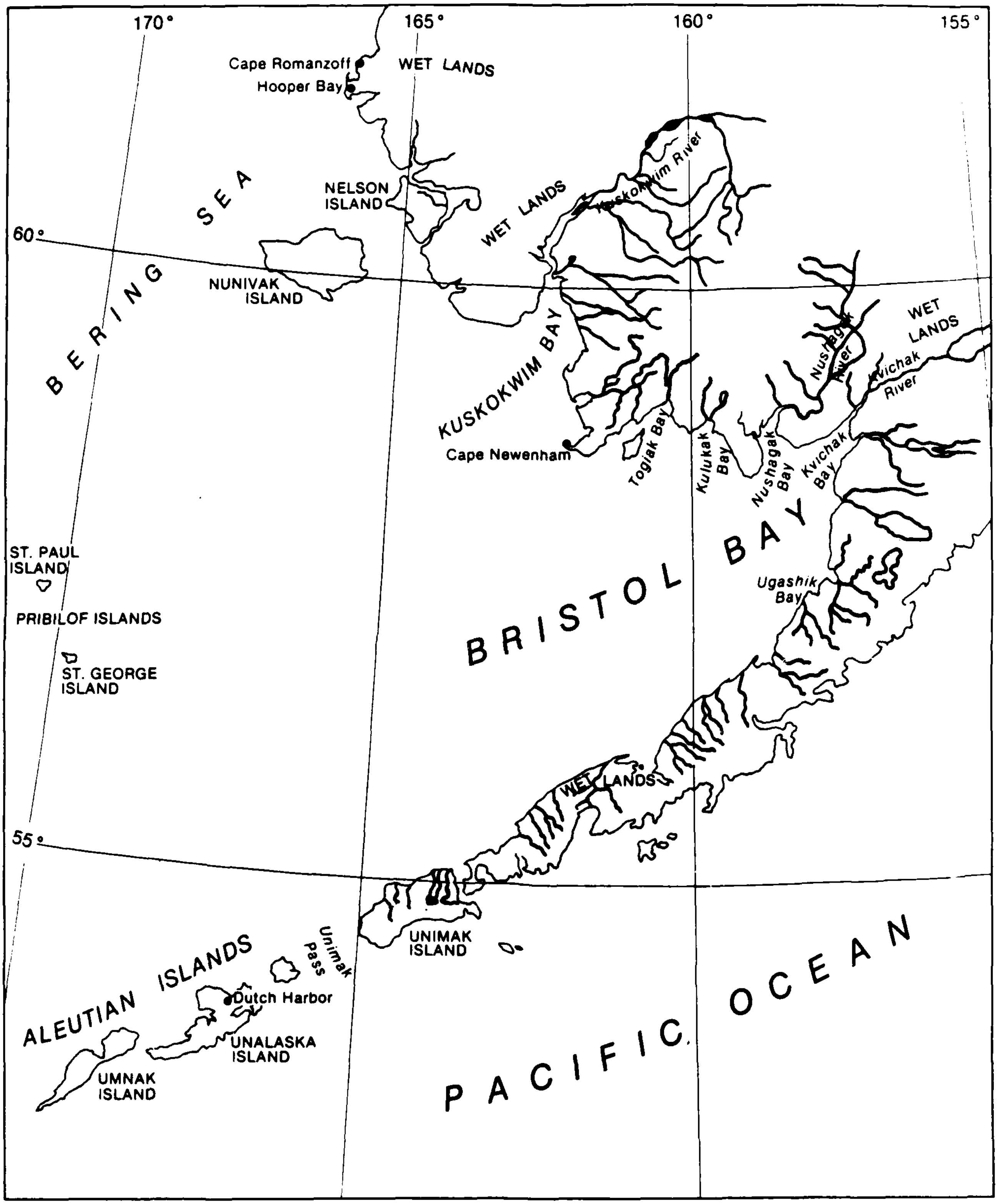


Figure 10

Table 4. Russell Creek drainage (near Cold Bay). Hydrologic Unit 19040003.

Gage Location: 55°10'55"N; 162°41'08"W.

Drainage Area: Approximately 25 mi^2.

Flow Rates: Presented for water years 1983-1985.

	Cubic feet per second (ft^3/s)			Volume	
Month	Mean	Maximum	Minimum	Acre-feet	$Meters^3$
Jan	190	365	133	11,677	1.4×10^7
Feb	121	193	84	6,817	8.4×10^6
Mar	132	316	74	8,137	1.0×10^7
Apr	134	265	81	7,953	9.8×10^6
May	188	392	117	11,577	1.4×10^7
Jun	244	395	181	14,540	1.8×10^7
Jul	285	521	199	17,563	2.2×10^7
Aug	313	750	186	19,207	2.4×10^7
Sep	350	1,117	181	14,761	1.8×10^7
Oct	262	991	151	16,090	2.0×10^7
Nov	311	675	175	18,497	2.3×10^7
Dec	345	947	191	21,210	2.6×10^7
Annual Average	343	577	146	Total 168,024 acre-feet/year	Total 2.1×10^8 m^3/year
Record Extremes		6,000 10/22/81	49 03/13-14/83		

Table 5. Eskimo Creek drainage (at King Salmon). Hydrologic Unit 19040002.

Gage Location: 58°41'08"N; 156°40'08"W.

Drainage Area: Approximately 16.1 mi^2.

Flow Rates: Presented for water years 1978-1985.

	Cubic feet per second (ft^3/s)			Volume	
Month	Mean	Maximum	Minimum	Acre-feet	$Meters^3$
Jan	7.9	11.2	5.7	482.0	5.9×10^5
Feb	6.1	22.6	3.9	353.6	4.3×10^5
Mar	15.1	27.4	6.6	927.8	1.1×10^6
Apr	15.4	28.8	9.0	915.0	1.1×10^6
May	11.3	21.2	7.6	696.6	8.5×10^5
Jun	13.7	29.2	7.0	815.8	1.0×10^6
Jul	10.8	16.3	7.1	661.8	8.2×10^5
Aug	15.9	23.4	8.7	975.6	1.2×10^6
Sep	13.7	20.0	9.2	817.2	1.0×10^6
Oct	21.7	44.0	12.0	1,330	1.6×10^6
Nov	17.3	29.6	10.6	1,029	1.3×10^6
Dec	10.8	28.8	6.5	662.0	8.1×10^5
Annual Average	12.8-13.3	74.5	16.2	Total 9,668 acre-feet/year	Total 1.19×10^7 m^3/year
Record Extremes		227 June 1967	1.5 January 1980		

Table 6. Kvichak River drainage (at Igiugig). Hydrologic Unit 19040002.

Gage Location: 59°19'44"N; 155°33'57"W.

Drainage Area: Approximately 6,500 mi².

Flow Rates: Presented for water years 1980-1985.

	Cubic feet per second (ft^3/s)			Volume	
Month	Mean	Maximum	Minimum	Acre-feet	Meters^3
Jan	16,366	17,500	15,620	1,006,420	1.24×10^9
Feb	14,792	15,760	13,960	833,580	1.02×10^9
Mar	14,386	15,200	13,240	884,640	1.09×10^9
Apr	13,234	13,900	12,532	787,500	9.71×10^8
May	12,588	14,050	11,686	834,100	1.03×10^9
Jun	15,352	17,700	13,354	913,460	1.13×10^9
Jul	20,956	23,680	17,800	1,288,680	1.59×10^9
Aug	26,888	29,560	23,880	1,653,200	2.04×10^9
Sep	28,222	30,240	23,360	1,678,800	2.07×10^9
Oct	25,396	27,700	22,500	1,561,600	1.93×10^9
Nov	22,560	25,140	19,840	1,342,600	1.66×10^9
Dec	19,322	21,620	17,280	1,188,080	1.47×10^9
Annual Average (for 31 yrs)	6,137	21,004	17,504	Total 13,972,660 acre-feet/year	Total 1.72×10^{10} m^3/year
(for '80-'85)	19,171				
Record Extremes		32,200 07/02/77	770 04/16-30/60		

Table 7. Nushagak River drainage (at Ekwok). Hydrologic Unit 19040002.

Gage Location: 59°20'57"N; 157°28'23"W.

Drainage Area: Approximately 9,850 mi².

Flow Rates: Presented for water years 1980-1985.

	Cubic feet per second (ft^3/s)			Volume	
Month	Mean	Maximum	Minimum	Acre-feet	Meters^3
Jan	9,249	9,720	8,920	568,640	7.01×10^8
Feb	9,090	9,440	8,760	514,220	6.34×10^8
Mar	9,303	10,000	8,880	572,060	7.06×10^8
Apr	14,421	24,680	9,440	858,120	1.06×10^9
May	36,514	52,660	23,620	2,245,200	2.77×10^9
Jun	43,038	57,140	34,380	2,661,000	3.28×10^9
Jul	33,520	44,380	26,700	2,061,200	2.54×10^9
Aug	28,340	36,640	22,020	1,742,600	2.15×10^9
Sep	22,362	30,700	18,200	1,330,520	1.64×10^9
Oct	26,538	42,300	17,660	1,631,800	2.01×10^9
Nov	18,632	29,440	12,600	1,103,600	1.37×10^9
Dec	11,226	11,960	9,840	690,320	8.51×10^8
Annual Average (for 7 yrs of record)	21,853 to 22,990	29,922	16,751	Total 15,539,980 to 16,660,000 acre-feet/year	Total 1.92×10^{10} to 2.21×10^{10} m^3/year
Record Extremes		89,200 06/08/82	6,000 03/01-12/79		

Table 8. Kuskokwim River drainage (at Crooked Creek). Hydrologic Unit 19040001.

Gage Location: 61°52'16"N; 158°06'03"W.

Drainage Area: Approximately 31,000 mi^2.

Flow Rates: Presented for water years 1980-1985.

	Cubic feet per second (ft^3/s)			Volume	
Month	Mean	Maximum	Minimum	Acre-feet	Meters^3
Jan	12,940	13,800	12,600	780,120	9.62×10^8
Feb	12,090	12,400	11,500	690,860	8.52×10^8
Mar	11,206	12,100	11,000	681,620	8.41×10^8
Apr	16,370	22,900	4,200	974,020	1.20×10^9
May	82,460	131,200	43,600	5,070,400	6.25×10^9
Jun	76,102	109,760	56,620	4,527,600	5.58×10^9
Jul	72,424	96,020	55,300	4,453,400	5.49×10^9
Aug	78,052	107,280	55,520	4,799,400	5.92×10^9
Sep	53,624	73,660	40,860	3,190,800	3.94×10^9
Oct	33,978	52,920	21,400	2,088,800	2.58×10^9
Nov	17,545	21,600	15,800	1,047,940	1.29×10^9
Dec	14,462	15,200	13,800	889,180	1.10×10^9
Annual Average (for 34 yrs) of record	41,070			Total 29,194 to 29,760,000 acre-feet/year	Total 3.6×10^{10} m^3/year
Record Extremes		392,000 06/05/64	6,100 03/01-31/66		

OIL SPILL TRANSPORT

Possible Fate of Oil Spilled in Bristol Bay

The fate of spilled oil depends upon a complex interaction of four principal processes: currents and all circulation components; Stokes drift (surface wind wave drift), ice, and weather patterns. These four processes in Bristol Bay were included in an oil spill trajectory model developed by Liu and Leendertse (1979) and presented in Thorsteinson (1984). Probable movements of oil slicks and risk analysis to coastal regions were computed.

The shallow depths of Bristol Bay and Kuskokwim Bay, variety and plentitude of suspended particulate matter from river drainage, and resuspension by coastal circulation argue for a rapid sorption and sinking of oil (Sharma 1974, Burrell, et al. 1981). Some oil will be sedimented through incorporation into zooplankton fecal pellets.

In the event of an oil spill reaching the coast along Bristol Bay its persistence there would be highly variable. Coastal currents are slow compared with tidal currents and will be less effective in circulating the oil around the outer gyre out of the bay than the pulsing tidal flow which will mix and remove oil from the central basin. The intertidal zone is the most vulnerable region should oil make contact. High wave energy and ice abrasion in winter should mitigate the impact somewhat by facilitating removal.

In summer when winds are predominantly from the southwest, oil will move generally to the east into Bristol Bay from lease areas along the north Aleutian shelf. In summer or fall, oil may reach the Alaska Peninsula within 30 days under certain scenarios.

Fate of Spilled Oil in Presence of Sea Ice

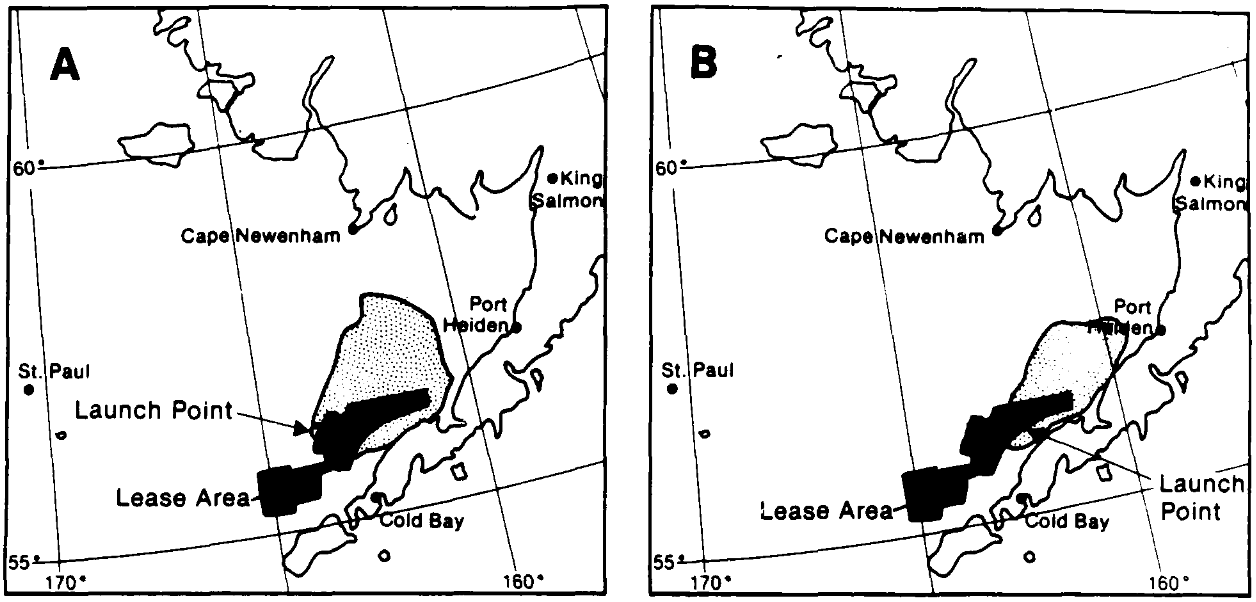
Inferences about the possible fate of oil spilled in Bristol Bay during the presence of sea ice are tenuous due to the near absence of documentation of oil spills in ice-infested waters and the relative immaturity of the experimental state of the art concerning oil-ice interactions. Obviously, the oil-ice spill situation presents a more complex picture than an open-water situation. The spectrum of potential scenarios is large, varying according to the particular circumstances of spill location, ice coverage, morphology and structure, prevailing weather conditions, time of year, and myriad other factors.

Martin (1981) has categorized oil-ice interaction processes in the Bering Sea as those that capture oil and those that transport it. Processes that capture oil include the interaction of oil with smooth, unbroken, first-year ice and by grease and pancake ice, as well as the interaction of ocean swell, oil and the ice floes at the ice edge. Processes that transport oil include the interaction in lee-shore polynyas where grease ice is found, the general advection of oil by large-scale ice movement, and specific advection of oil by the bands of ice found at the ice edge during periods of off-ice winds. Oil trapped in sea ice may be carried distances on the order of hundreds of kilometers before being released when the ice melts (Martin 1981). In Bristol Bay depths are shallow and ice generally hugs the shoreline. Strong tidal currents tend to break up the pack ice in the central bay most years. Oil released into Bristol Bay would probably encounter the fast ice and nearshore polynyas.

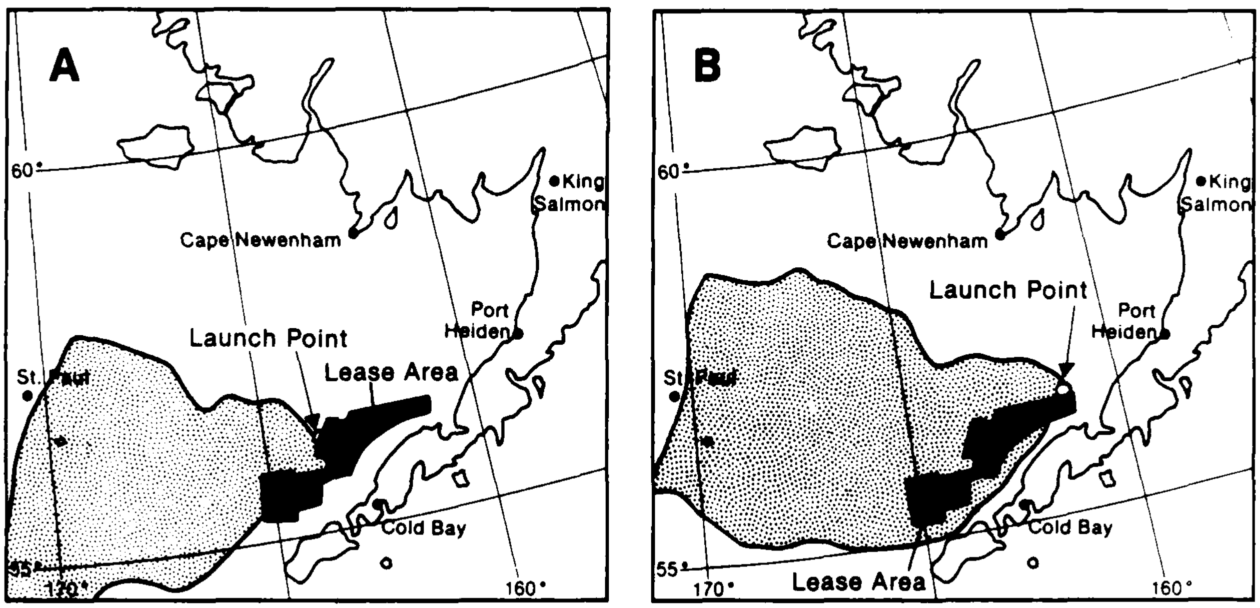
In winter, during the predominantly northeasterly winds, spilled oil should generally move westward into the Bering Sea at a mean speed two to three times greater than during summer conditions and may do so without reaching land (Thorsteinson 1984).

An oil spill event in the vicinity of Bristol Bay could result in the intertidal zones being contaminated by unweathered oil. An oil spill during the ice-covered season in Bristol Bay could have a variety of outcomes, depending upon the time of year, location, and prevailing weather, among other factors. (See figure 11.) If the spill occurred in the open water outside the pack ice, the fate of oil probably would be comparable to that during the ice-free period. A spill occurring in close pack ice would likely persist for an extended period due to the lower ambient water and wind energy levels acting to disperse and evaporate the petroleum, and the physical containment of the oil by ice. Oil released under the ice could remain there or move, depending upon the speed of the ice relative to the underlying water. The time of occurrence of an oil spill in sea ice would be influential in its fate. A spill during early winter could result in significant incorporation of oil in ice, extended oil persistence, and concomitant long transport before release. Figure 11 shows the envelope of areal spreading likely to be impacted by oil spilled in the Bristol Bay lease sale area. Envelopes enclose possible trajectory and dispersal regions during various seasonal and regional source scenarios.

Oil Spill Transport



Calculated 30-day areal spreading for spilled oil under stochastic summer weather conditions. *A* and *B* differ only in the selection of launch points. The weather patterns used in the development of the trajectories were the same in both cases (Liu and Leendertse 1982).



Calculated 30-day areal spreading for oil under stochastic winter weather conditions. *A* and *B* differ only in the selection of launch points. The weather patterns used in the development of the trajectories were the same in both cases (Liu and Leendertse 1982).

Figure 11

METEOROLOGY

SEASONAL WEATHER

Surface terrain features in the vicinity greatly influence weather patterns. The Aleutian Range to the south along the Alaska Peninsula tends to prevent storms moving south to north from crossing the peninsula into Bristol Bay. Those that do cross the Aleutian Range lose most of their precipitation on the south side of the peninsula resulting in small precipitation amounts on the south shore of Bristol Bay. The Kuskokwim Mountains and their extension into the Ahklun Mountains tend to enhance precipitation on the north side of Bristol Bay.

Seasonal atmospheric pressure patterns also have a large effect on the weather of Bristol Bay. In winter the mainland of Alaska is often occupied by a strong high pressure area which can persist for weeks at a time. This high pressure area effectively prevents storms from penetrating the mainland from the west or south. Storms that approach from west or south tend to develop a strong pressure gradient between the cold high pressure of the interior and the approaching low pressure area. The result is strong southerly and easterly winds in the Bristol Bay area in winter. In spring the mainland high pressure area breaks down with surface heating of the land area into weak low pressure in summer. This allows the storms from the southwest to penetrate the interior.

Storms are most frequent in late summer and fall with a secondary maximum in spring. Storms are the least frequent in early summer and winter. The seasonal storm tracks show a primary track south of the Alaska Peninsula throughout the year. In summer this track is farther south in the North Pacific and is not on the maps in figure 12. Each season has either primary or secondary storm tracks from south to north in the eastern Bering Sea. These are generally well off shore in the cold part of the year and often come over land in summer and fall. The most intense and frequent storms are in the fall with higher frequencies of storm surge flooding and rough seas.

Nearly every winter there is a warming period where the high pressure area over the mainland breaks down and a storm from the south or southwest brings a warming trend throughout the area. This warming trend can persist for a few days to several weeks. During this warming trend the ice edge retreats northward and above freezing temperatures occur throughout the area. Timing of the warm trend is usually late December or early January. Cold temperatures with advancing sea ice cover occurs again in late January and February. Often the month of January is warmer than either December or February because of this mid-winter warming. The seasonal weather patterns cause the east end of Bristol Bay to be much warmer in summer and colder in winter than the western portions of the area more subject to strictly maritime influences.

Seasonal Storm Tracks

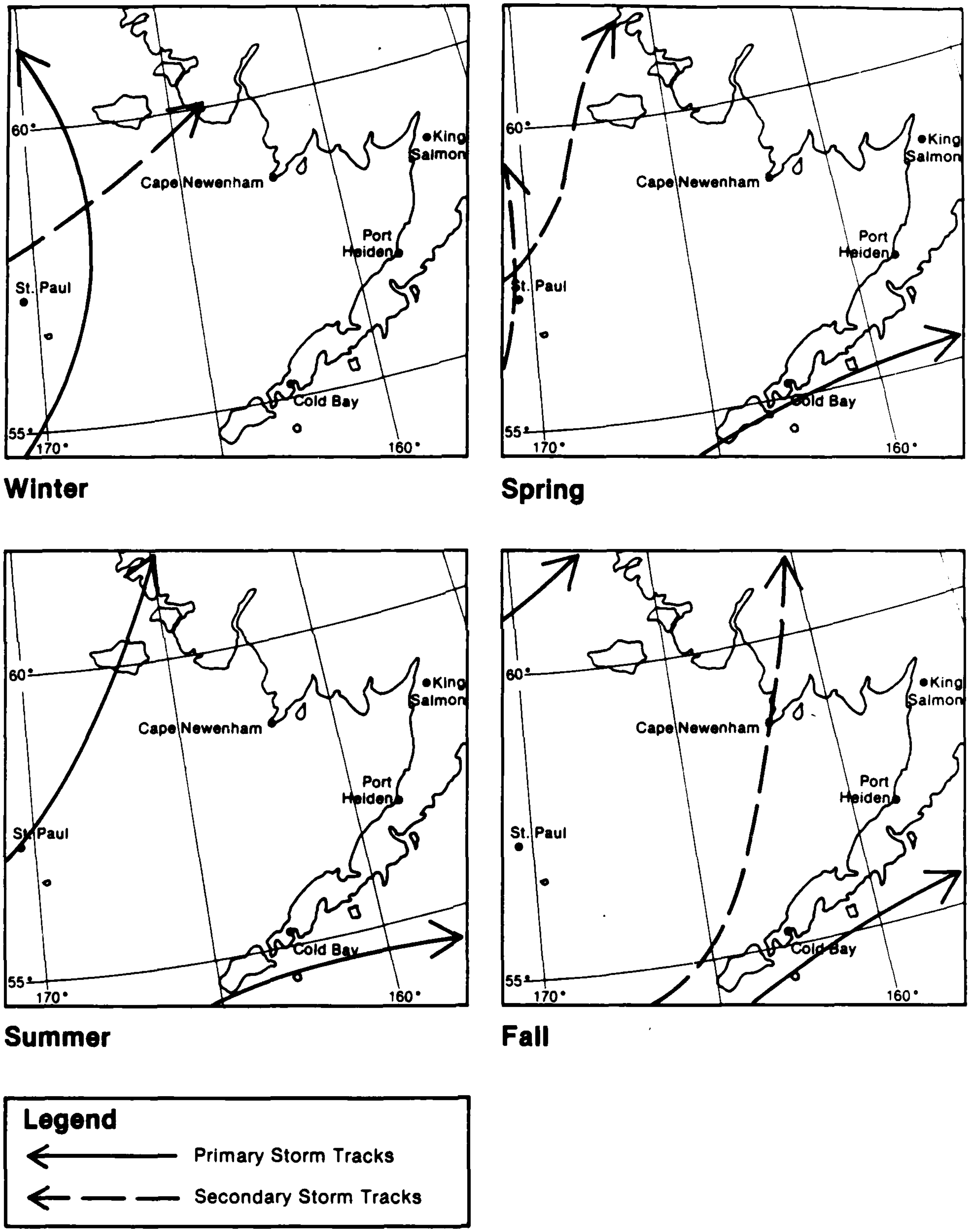


Figure 12

STORM SURGES

Storm surges are waves oscillating in the period range of a few minutes to a few days, in a coastal or inland water body, resulting from forcing from atmospheric weather systems (Murty 1984). By this definition, wind-generated waves (often referred to as wind waves) and swell, which have periods of several seconds, are excluded. The spectrum of storm surge waves is centered around 10^{-4} cycles per second (CPS), which gives a period of about three hours. However, depending mainly on the topography of the water body and secondarily on other parameters such as the direction of movement of the storm, strength of the storm, stratification of the water body, presence or absence of ice cover, and nature of tidal motion in the water body, the periods of the water level oscillations may vary considerably. Even in the same water body, storm surge records at different locations can exhibit different periods. The range or height of a storm surge depends not only on characteristics of the storm but also on the topography onshore and bathymetry offshore. Shallow water bodies generally experience surges with greater ranges. Also, the height of a storm surge is less if the sea floor is steep than if there is a shallow slope to the sea floor (Murty 1984). Storm characteristics that effect the height of a surge include atmospheric pressure; wind speed, direction, and length of fetch; the latitude; and the direction and speed of storm movement. Air and water temperature differences also affect the height of surges.

Following is a discussion of the storm surge potentials in the Bristol Bay area from a study done in 1981 (Wise, Comisky, and Becker, 1981), supplemented by storm statistics since then (NOAA Storm Data, 1981-1986).

The coastal area is generally of low relief from the Kuskokwim Delta to Goodnews Bay, with numerous lakes, sloughs, and marshes. From Goodnews Bay to the Nushagak Peninsula the coastline is more rugged due to the proximity of the Ahklun Mountains. The remainder of the north and east coastline is similar to the stretch from the Kuskokwim River to Goodnews Bay. Offshore the shape of the sea floor is conducive to the formation and enhancement of storm surges. Most of the north shore of the Alaska Peninsula east of Cold Bay is favorable for the occurrence of storm surge flooding, with low, marshy terrain onshore and a moderately sloping sea floor offshore. West of Cold Bay the Aleutian Islands and the south shore of the Alaska Peninsula conditions are not favorable due to rugged terrain onshore and steep ocean floor offshore.

The accompanying map (figure 13) shows the tracks of storms that may cause storm surge flooding. Because of the high tide range at the east end of Bristol Bay and Kuskokwim Bay, the timing of a storm surge is very important in determining the amount of flooding with a storm surge.

From Goodnews Bay northward an adequate fetch can be generated with storm winds from south through west to northwest. East of Goodnews Bay, west-southwest to west are the only directions from which an adequate fetch can develop. Northerly to westerly winds are favorable for storm surges along the Alaska Peninsula west of Ugashik.

Autumn and late summer are the seasons for destructive storm surge flooding in this area. There are ten known cases of storm surge flooding of populated areas; seven were in autumn and three were in August. Two storms, in November 1979 and in August 1980, account for most of the factual reports of storm surge flooding. The November 1979 storm caused storm surge flooding from Cape Newenham to Scammon Bay. Surges were estimated at 8 ft in exposed locations in the Kuskokwim Delta. The storm was on a track from west-southwest to east-northeast, and a long fetch of more than 400 mi developed with the storm. The August 1980 storm, one of the few summer flooding events, caused flooding on the shore of Bristol Bay. The storm was on a track from south-southwest toward north-northeast from near Atka Island, in the Aleutians, to Kuskokwim Bay. Exposed locations showed surge flooding up to 12 ft.

The coastal area from Hooper Bay to Kinak Bay is a favored nesting area of migratory birds in the spring and summer. Minor storm surges that cover nests in this area at the wrong time can be detrimental to the annual production of several species of birds. Five cases of minor summer flooding of the salt flats were documented in an annual report for the Clarence Rhode National Wildlife Refuge (USFWS 1964). One event (June 22, 1963) caused a loss of black brant offspring estimated at 80% to 90% of the year's production.

The following manual surge height forecast procedure is adopted from Appendix III of *Storm Surge Climatology and Forecasting in Alaska* (Wise, Comisky, and Becker 1981). One of the inputs into the procedure is the surge height vs. wind speed curve for sections 11 to 15 shown in figure 14. This curve is adapted from the above reference.

Storm Tracks for Storm Surges

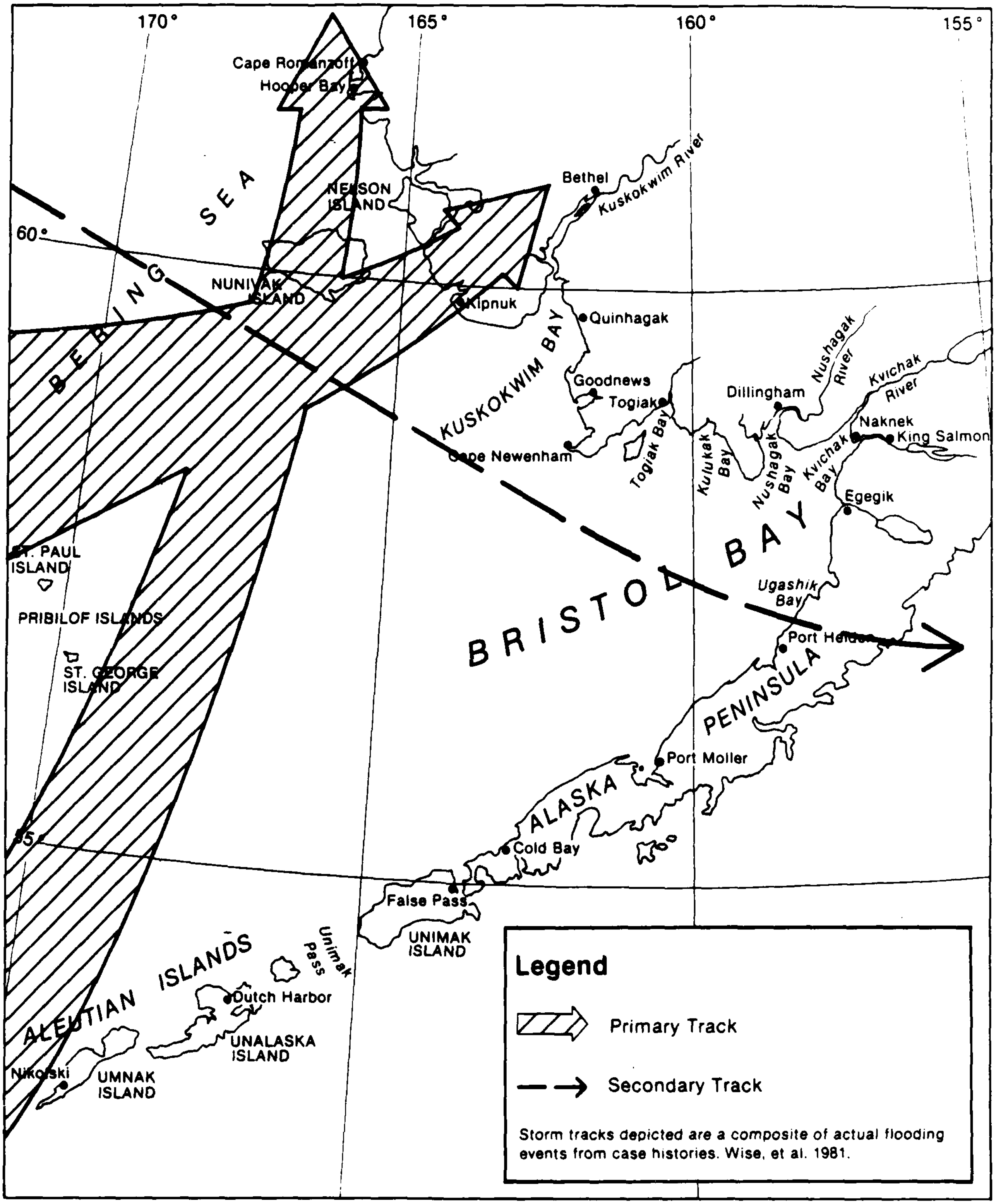


Figure 13

Manual Forecast Procedures

I. Definitions

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

B. FAVORABLE RELATIVE FETCH WIND DIRECTION - Assume the coastal configuration to be straight line segments as shown on figure 15, Coastal Sectors for Storm Surge Forecasting. When facing seaward the **relative** wind direction is measured **clockwise** from the coast. Thus the coast to the left is 0°; seaward +090°; to the right 180°. If offshore, values are from 0°-180° measured counterclockwise from left coast. Favorable relative wind directions are:

SECTOR	FAVORABLE DIRECTION
11	-020 to 120
12	050 to 150
13	-020 to 090
14	070 to 120
15	010 to 090

In an idealized model the most favorable directions are from -020 to 090 but topography working in conjunction with gravity acting on anomalous sea surface slopes creates surges (generally of lesser magnitude) in areas wherein the *wind is not blowing* from an idealized "favorable" direction. The favorable directions shown above are those relative directions where the wind creates an anomalous sea height somewhere nearby that, in turn, affects the sector of interest.

C. FETCH - An area in which wind direction and speed are reasonably constant and do not vary past the following limits:
   1) The wind direction or orientation of the isobars does 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% from the average wind speed. Example: average wind is 40, acceptable range is 32 to 48.

D. FETCH DURATION - the number of hours a coastal area is subjected to fetch winds.

E. LOWEST PRESSURE - The lowest pressure coincident with fetch induced surge.

F. SEA ICE COVERAGE (minimum expected during storm) - Percent of sea ice coverage in tenths.

G. SEA ICE CHARACTER - Primary concern is thinness and weakness. Thin or unconsolidated ice can be destroyed by storm action.

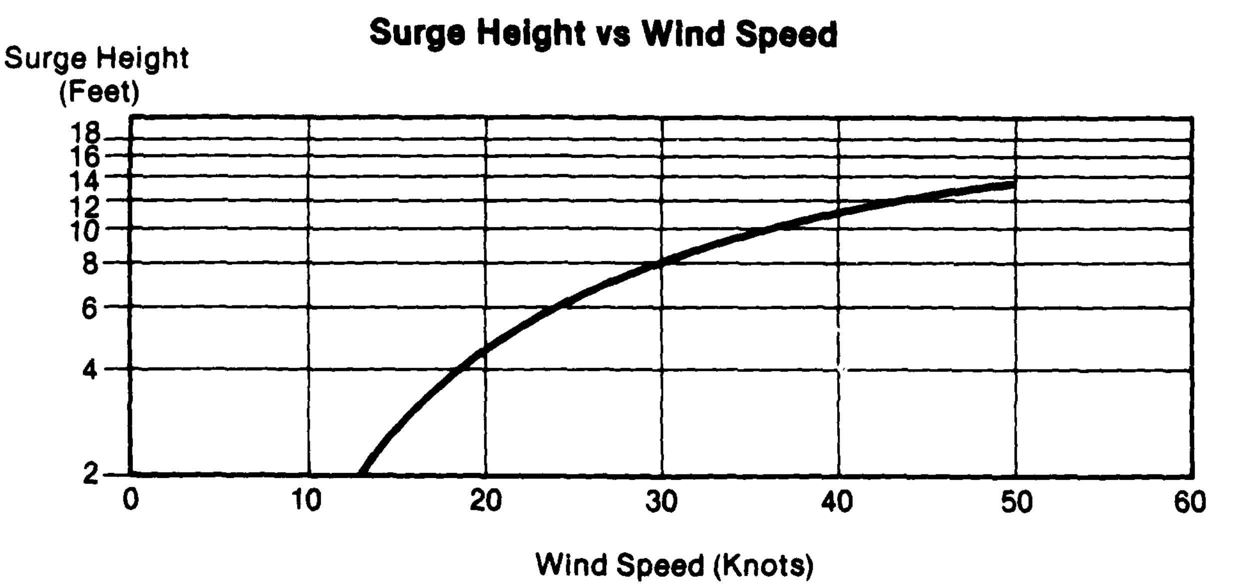


Figure 14

H. BOUNDARY LAYER STABILITY - The difference between the sea and air temperatures. The boundary layer temperature difference should be used when estimating the fetch wind speed. The following guidelines are suggested:

Correction to Geostrophic Wind for the Sea-Air Temperature Difference

$T^s - T^a$ °C	Percent of geostrophic winds used
0 or negative	50
0 to 10	55
10 to 20	60
20 or above	65

II. Procedure

A. Determine:

1) Fetch wind (speed and direction) from a surface map analysis of pressure gradient and reported wind. Consider boundary layer conditions. If direction is favorable continue with determination of:
   - a) fetch duration
   - b) ice cover
   - c) lowest pressure
   - d) tidal variation if over 1 ft

B. Preliminary Surge Height - Using wind speed, read correlated surge height from appropriate coordinate labels in figure 14, surge height vs. wind speed.

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

1) 3 hours reduce surge by 60%
2) 6 hours reduce surge by 40%
3) 9 hours reduce surge by 20%
4) 12 hours reduce surge by 10%
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% (cumulative to above)
3) 5.0 tenths reduce surge by 50% (cumulative)
4) 10.0 tenths reduce surge by 75% (cumulative)
5) Surges to 3 ft with 10 tenths ice cover have been reported with ice to 3 feet thick between October and January. Also, consider sea ice character. Thin ice, weak ice, or unconsolidated ice can be effectively destroyed during storm conditions—particularly in the northern Bering Sea, with subsequent surges to 9 ft.

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

F. Tidal Adjusted Surge Height - Check tide tables or other sources. Forecast time of highest range based on loss of favorable wind direction, speed, or fetch. If peak of surge time is reasonably coincident with normal high water, make no correction. If surge misses normal high water, subtract as appropriate from surge height.

III. Example

A possible surge condition is developing in sector 15. Fetch wind is southwest 35 kts. Relative wind direction is 35, a favorable direction for Sector 15. Preliminary surge height is 10 ft (figure 14). Duration is 10 hours. Reduce surge 10% (10-1 = 9). Ice cover is 2 tenths. Reduce surge 20% (9.0-1.8 = 7.2). Lowest pressure coincident with surge is 964 mb. Raise surge height 1.3 ft (7.2 + 1.3 = 8.5). Time of high water is coincident with time of surge, no correction. Final surge height forecast is 8.5 ft.

The above surge reductions were subjectively derived and may be adjusted with time and experience.

Coastal Sectors for Storm Surge Forecasting

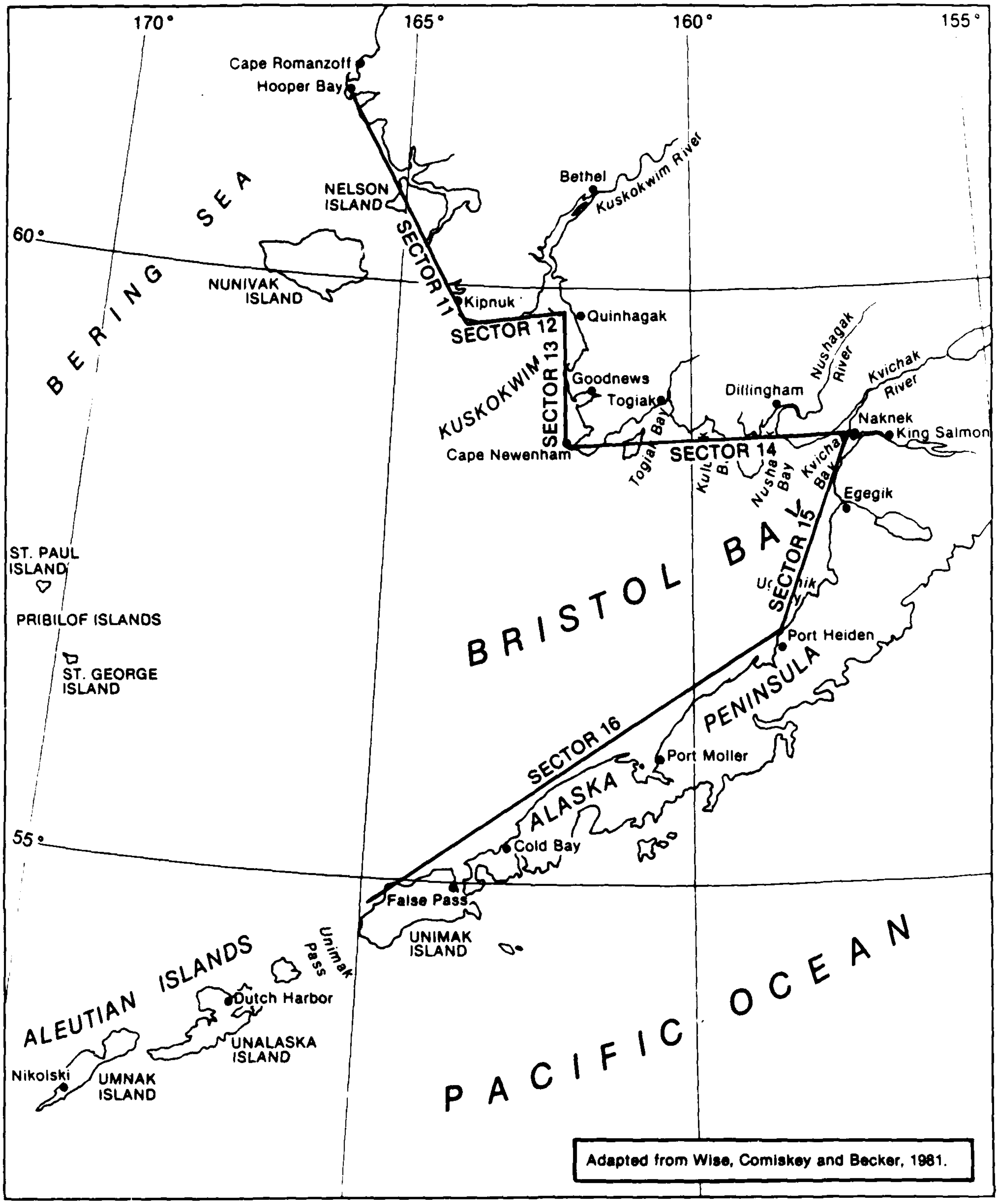


Figure 15

SUPERSTRUCTURE ICING

Structural icing on ships, offshore structures, and port facilities is a winter hazard in open waters and coastal sections of Alaska. The icing causes slippery decks, renders moving parts inoperable, and, in extreme cases, causes uneven loading and raises the center of gravity on small ships. Accumulation of ice on rigging and on deck equipment such as crab pots also increases wind effects because a larger surface area is presented to the wind. Ice forming on structural surfaces above or close to a body of water arises principally from sea spray (Nauman and Tyagi 1985; Liljestrom 1985), with lesser amounts from atmospheric precipitation (freezing rain and wet snow) and fog (arctic sea smoke, white frost, black frost). Sea spray, the most dangerous source of icing, is produced by the breaking of waves either by themselves or by splashing against obstacles such as ships' hulls, other floating objects, shore structures, and possibly other sources (Minsk 1977).

Statistical analysis (Borisenkov and Panov 1972) of more than 3,000 cases of ship icing indicates that in 86% of the cases icing was caused by ocean spray alone. Spray combined with fog, rain, or drizzle (liquid sources) accounted for only 6.4% of the cases, and spray combined with (solid source) snow only 1.1%. The cases of icing attributable only to fog, rain, or drizzle account for 2.7% (Minsk 1977). In the remainder of icing cases data were not sufficient to determine the cause. Figure 16 identifies locations of reported superstructure icing incidents in the study region.

Since the overwhelming majority of superstructure icing on ships and offshore structures is from sea spray, the remainder of this section will concentrate on this type of icing. Since a ship can present different aspects to the wind and spray, it is to be expected that the amount of spray reaching the ship will vary: Observations have shown that the greatest frequency of spray and, therefore, icing occurs when a ship is heading into the wind at an angle between 15° and 45°. Asymmetrical icing occurs under this condition, with the greater accumulation on the windward side. Less icing occurs with the ship headed directly into the wind, and then accumulation tends to be uniform. With ships heading downwind, spray icing is generally much less than at other angles. In developing the nomogram for forecasting spray icing potential, downwind cases (those for which the ship's heading was 120° or greater off the wind) were not used.

Meteorological/oceanographic conditions necessary for significant spray icing are water temperatures less than 8°C, winds of 25 knots (13 meters per second) or more, and air temperatures less than -2°C (28°F, the freezing temperature of seawater of average salinity). Generally, the stronger the wind, and the colder the air and water, the higher the rate of icing on comparable vessels or structures. In some cases, however, where the wind fetch is not sufficient to fully develop waves, icing rates are lower.

The accompanying potential superstructure icing rate nomogram (figure 17) is a modification of that shown in Wise and Comisky (1980), using the open ocean cases appearing in Pease and Comisky (1985), developed from icing case histories in the Gulf of Alaska and southern Bering Sea. Icing intensities in inches per hour are also from Pease and Comisky (1985). This nomogram was developed for use in the *Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska* (in press). If a vessel experiencing icing takes evasive action (i.e., changes heading, reduces speed, seeks shelter, etc.), icing rates experienced would probably be less.

To use the superstructure icing nomogram, enter the upper left portion with the air temperature and wind speed, at the intersection of these proceed diagonally to the right to the intersection with the sea surface temperature and read the icing rate classification.

Reported cases of ship icing in the northern Gulf of Alaska and the Bering Sea are shown from two sources; Borisenkov and Panov (1972) and WBH29 (Dyson 1974-86). The lack of reported icing in Bristol Bay and Kuskokwim Bay may be a result of reduced ship traffic more so than conditions not favorable for icing.

The potential for superstructure icing in the area exists from November to April in the northern part of the area and only December to March in the south. Highest potential is January when up to 6% of the time superstructure icing can occur near the ice edge. Landfast and pack ice will limit ship traffic in much of the area from December to March, thereby decreasing the potential for superstructure icing as well.

Superstructure Icing Reports, 1976-1983

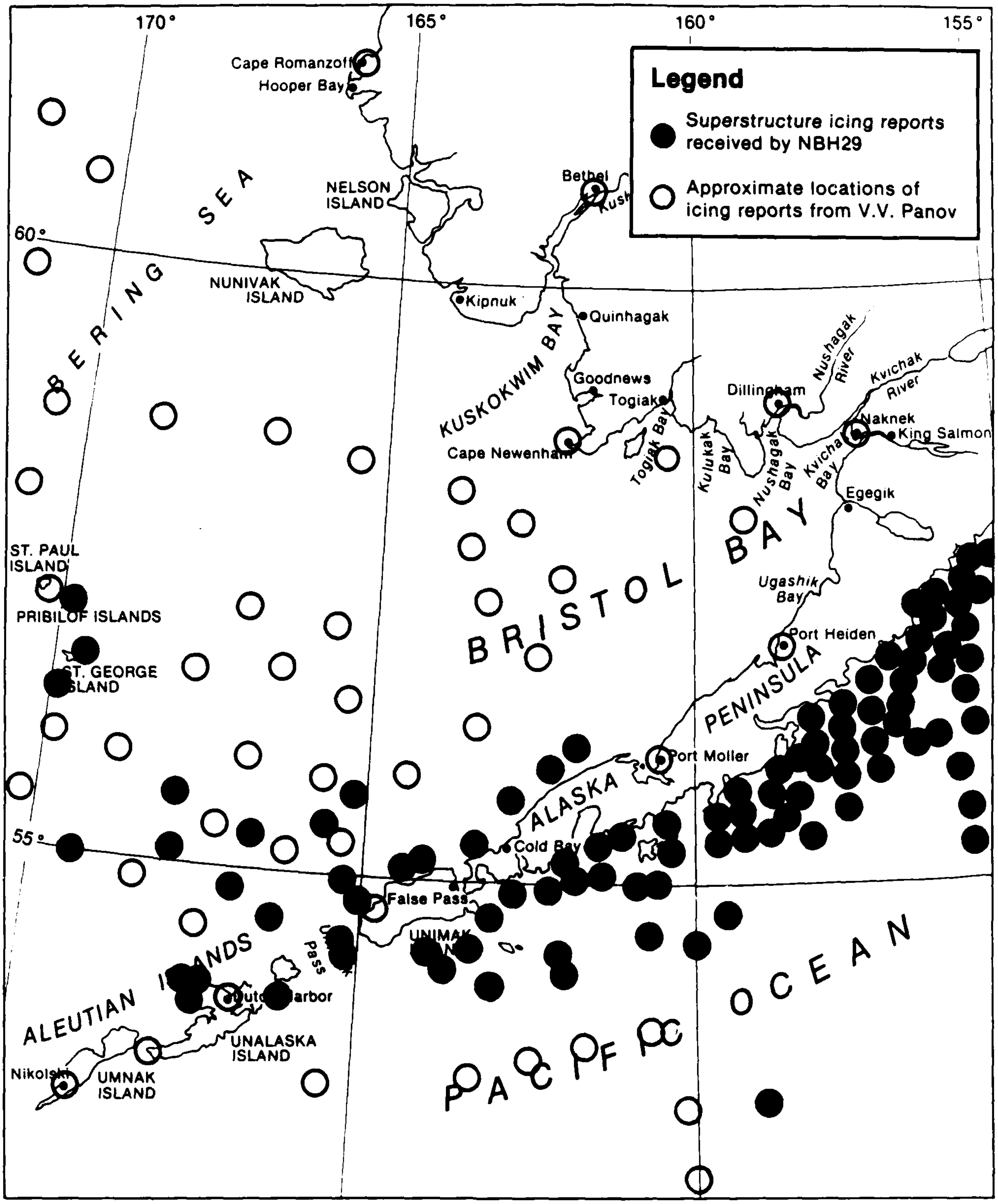
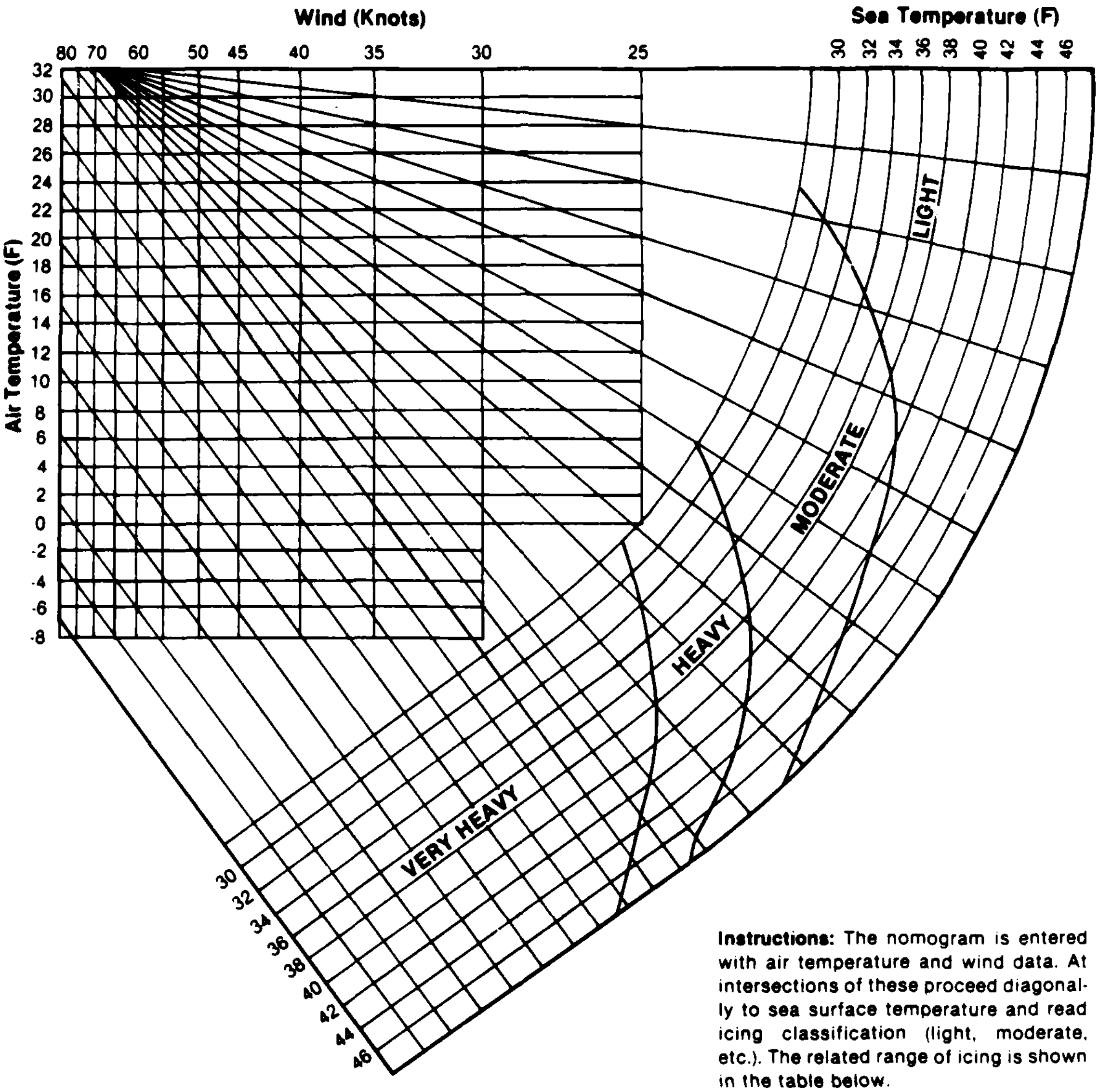


Figure 16

Superstructure Icing Nomogram



Instructions: The nomogram is entered with air temperature and wind data. At intersections of these proceed diagonally to sea surface temperature and read icing classification (light, moderate, etc.). The related range of icing is shown in the table below.

Icing Classification	Rate per Hour
Light	0 to .3 inches
Moderate	.3 to .8 inches
Heavy	.8 to 2 inches
Very Heavy	2 inches

Adapted from Wise and Comiskey, 1980, using data from Pease and Comiskey, 1985.

Figure 17

WIND CHILL
(Equivalent Temperatures)

The temperature of the air is not always a reliable indicator of how cold a person will feel outdoors. Other weather elements, such as wind speed, relative humidity, and sunshine (solar radiation), also exert an influence. In addition, the type of clothing worn, together with the state of health and the metabolism of an individual, influence how cold a person will feel. Cooling may be described as loss of heat from exposed flesh. Freezing occurs when there is such total heat loss that ice forms in the exposed tissues. The cooling power of the atmosphere (by wind) is primarily heat transfer by advection—in human cases, by exposure of uncovered flesh to the environment. Even small amounts of air movement have considerable chilling effect because this movement disrupts or removes the thin layer of warmed air that builds up near and about the body. This air movement leads to loss of total heat, since heat is transferred from the core of the body to rewarm the new colder air, replacing that blown away. Therefore, wind chill not only leads to frostbite locally, but may contribute to general hypothermia.

During the antarctic winter of 1941 a formula was developed to determine wind chill from experiments made at Little America (Antarctica). The formula relates heat loss (H) from an object or person to wind speed and to the difference in temperature between the air and the object or person (ΔT). The skin temperature of most people is approximately 33°C (91.4°F). H is measured in heat units (calories) per unit area over time. Heat losses for the human body can then be computed for any combination of wind and temperature. Equivalent temperature is based on calm conditions and a person walking vigorously at 3 knots (4 mph). Each combination of wind and air temperature produces a heat loss (H). The equivalent temperature is that temperature that would compute the same heat loss at a wind of 3 knots. The accompanying chart (figure 18) shows equivalent wind chill temperatures in °C for various combinations of winds in knots or km/hr and temperatures.

Concepts in the following discussion of wind chill are from an appendix to an article by William J. Mills, Jr., M.D., as published in *Alaska Medicine* (1973). Dr. Mills is still active in the treatment of cold injuries in Alaska.

Almost everyone knows that the increased speed of wind may cause increased danger of skin freezing. Many assume that the increase in wind speed causes the ambient air temperature to fall lower. This is not so. What does occur is air movement, so that warmed air is moved away from the individual exposed to the wind, causing first local, then general body cooling. Any resultant decrease of skin temperature is due to heat loss, insidious or sudden. Local vasoconstriction, vascular shunting, and cellular changes take place; eventually ice forms in the tissues, with true tissue freezing or frostbite.

Wind chill may occur not only from natural wind, but also with air movement generated by a moving vehicle such as boats, aircraft, or helicopter rotoblades. These vehicles may predispose passengers to frostbite or general hypothermia. Equivalent temperatures of -30°C (-22°F) or colder are considered to severely limit outdoor activity. The maps which follow (figure 20) in the section on temperature show the percent of time that wind chill of -30°C (-22°F) occurs in the Bristol Bay area (Brower, et al. in preparation).

Equivalent Wind Chill Temperature

Wind Speed knots	Wind Speed km/hr	Cooling Power Of Wind Expressed As "Equivalent Chill Temperature" — Temperature (°C)																		
Calm		12	8	4	0	- 4	- 8	- 12	- 16	- 20	- 24	- 28	- 32	- 36	- 40	44	- 48	- 52	- 56	- 60
		Equivalent Chill Temperature																		
3	6	12	8	4	0	- 4	- 8	- 12	- 16	- 20	- 24	- 28	- 32	- 36	- 40	- 44	- 48	- 52	- 56	- 60
5	10	9	5	0	- 4	- 8	- 13	- 17	- 22	- 26	- 31	- 35	- 40	- 44	- 49	- 53	- 58	- 62	- 67	- 71
11	20	5	0	- 5	- 10	- 15	- 21	- 26	- 31	- 36	- 42	- 47	- 52	- 57	- 63	- 68	- 73	- 78	- 84	- 89
16	30	3	- 3	- 8	- 14	- 20	- 25	- 31	- 37	- 43	- 48	- 54	- 60	- 65	- 71	- 77	- 82	- 88	- 94	- 99
22	40	1	- 5	- 11	- 17	- 23	- 29	- 35	- 41	- 47	- 53	- 59	- 65	- 71	- 77	- 83	- 89	- 95	- 101	- 107
27	50	0	- 6	- 12	- 18	- 25	- 31	- 37	- 43	- 49	- 56	- 62	- 68	- 74	- 80	- 87	- 93	- 99	- 105	- 112
32	60	0	- 7	- 13	- 19	- 26	- 32	- 39	- 45	- 51	- 58	- 64	- 70	- 77	- 83	- 89	- 96	- 102	- 109	- 115
38	70	- 1	- 7	- 14	- 20	- 27	- 33	- 40	- 46	- 52	- 59	- 65	- 72	- 78	- 85	- 91	- 98	- 104	- 111	- 117
43	80	- 1	- 8	- 14	- 21	- 27	- 34	- 40	- 47	- 53	- 60	- 66	- 73	- 79	- 86	- 92	- 99	- 105	- 112	- 118
49	90	- 1	- 8	- 14	- 21	- 27	- 34	- 40	- 47	- 53	- 60	- 66	- 73	- 79	- 86	- 92	- 99	- 105	- 112	- 118
54	100	- 1	- 8	- 14	- 21	- 27	- 34	- 40	- 47	- 53	- 60	- 66	- 73	- 79	- 86	- 92	- 99	- 105	- 112	- 118

Little Danger

Increasing Danger

(Flesh May Freeze Within 1 Minute)

Great Danger

(Flesh May Freeze Within 30 Seconds)

Danger of Freezing Exposed Flesh For Properly Clothed Individuals

Adapted from NWS/NOAA Technical Procedures Bulletin No 165
Effective Temperature (Wind Chill Index) 1976

Figure 18

CLIMATOLOGY

Data in this section is depicted in the form of isopleth maps and graphs. Graphed data are for land stations (Cape Newenham, King Salmon, Port Heiden, Cold Bay, and St. Paul) and for marine area C between 55-60°N and east of 169°W, which includes the entire area of interest plus some additional area to the west. Note also that the vertical scale on the graphs varies considerably from one location to another and by time of year. There is considerably more data for the land stations than the marine areas because land stations have more observations per day than ships. Also ship traffic, historically has decreased considerably during the winter months when water transportation and fishing are at a minimum and sea ice is present during late winter. Figure 19 is a graph of the duration-of-daylight for the northern hemisphere and defines daylight as the period from sunrise to sunset. Additional light (during twilight) may be usable for many purposes. Duration of daylight in high latitudes (poleward of about 60°) becomes increasingly dependent upon atmospheric conditions and refraction which may cause some departure from the values depicted on the chart.

TEMPERATURE

The air temperature in Bristol Bay shows a wide variability in both the warmest and coldest months due to whether wind is offshore or onshore. The east end of the Bristol Bay and the north end of Kuskokwim Bay are coldest in winter and warmest in summer because of offshore winds. In the coldest months of January and February mean air temperatures in the area vary from -8°C to -10°C in the north and east up to 0-2°C in the southwest part of the area. In the warmer months of July and August, mean temperatures are 9-12°C throughout the area. Graphed data for marine area C show monthly mean temperatures varying from -1.8°C in February up to 9.8°C in August.

Marine area C on the accompanying graphs is that portion of the Bering Sea between 55° and 60°N latitude and east from 169°W longitude to the coast.

Minimum temperature extremes in the east end of Bristol Bay are down to -32°C in the coldest months of January and February. During the warmest months of June, July, and August, maximum temperatures of over 20°C occur in the east end of Bristol Bay and are down to 15°C at the west end of the area.

Temperature variations with wind direction in marine area C show a difference of up to 10°C between northerly and southerly wind directions during the coldest months and very little difference with wind direction from May through October. Adjacent land stations show more temperature variation with wind direction than marine area C.

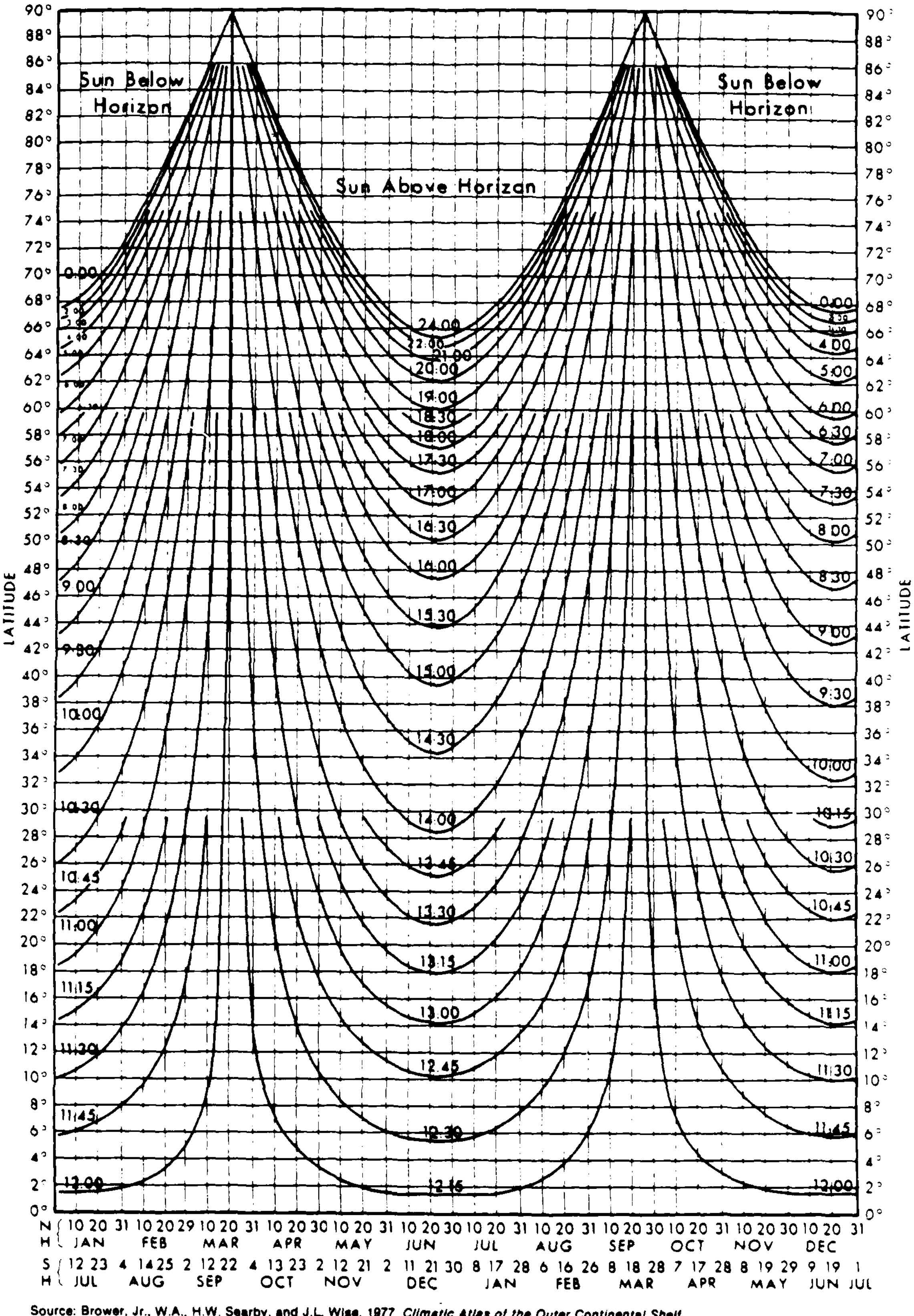
Figures 20a-20c indicate mean air temperature and frequency of wind chill factor below -30°C.

Figures 21a-21c depict air temperature extremes.

Figures 22a-22f, the air temperature/wind speed charts, indicate the percent frequency that a given air temperature occurs coincidentally with a given wind speed.

Figures 23a-23f, the air temperature/wind direction charts, indicate the percent frequency that a given air temperature occurs coincidentally with a given wind direction.

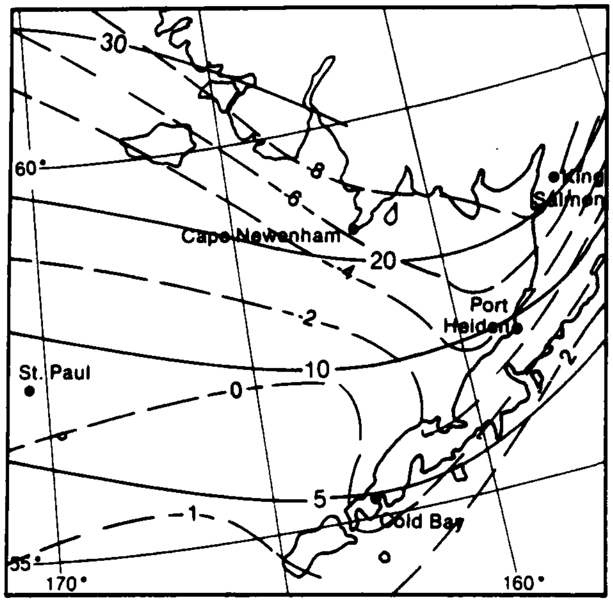
Duration of Daylight (Hours)



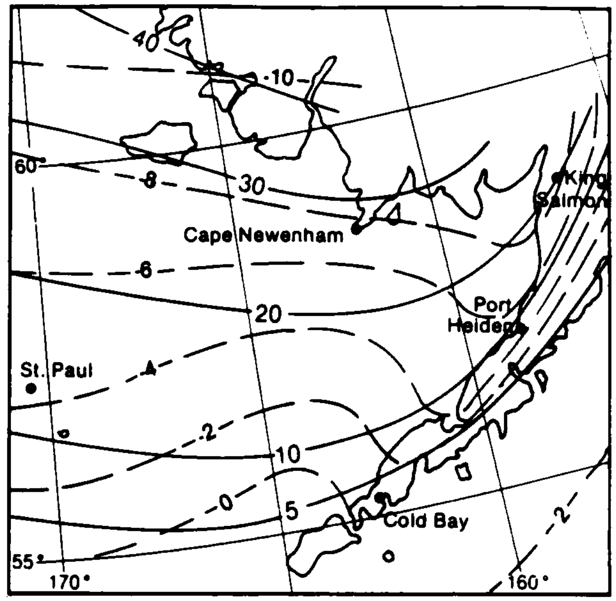
Source: Brower, Jr., W.A., H.W. Searby, and J.L. Wise. 1977. *Climatic Atlas of the Outer Continental Shelf and Coastal Regions of Alaska*. Vol. I, p.25. Arctic Environmental Information and Data Center, University of Alaska, Anchorage and U.S. National Climatic Center, Asheville, NC. 3 vols.

Figure 19

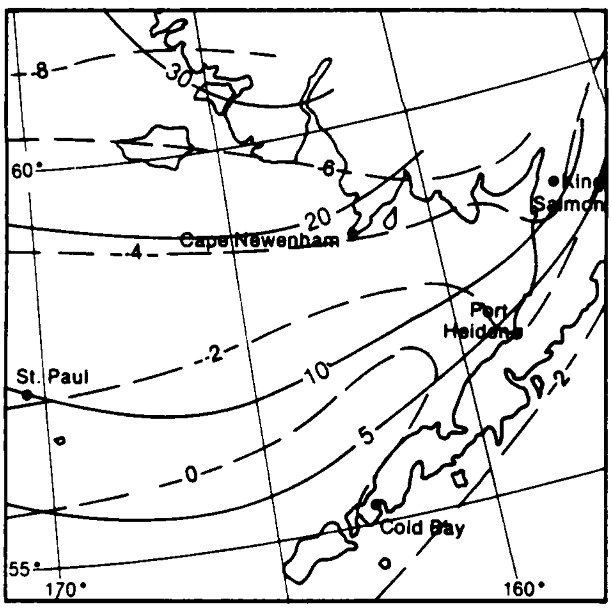
Mean Air Temperature and Wind Chill ≤-30°C



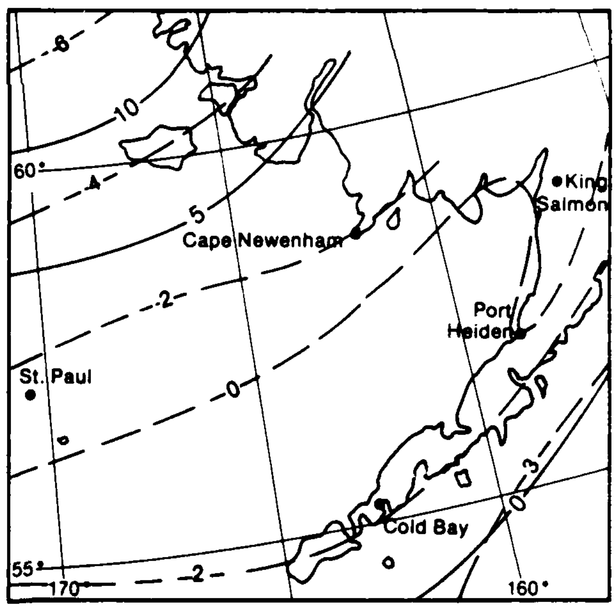
January



February



March



April

Legend

———	%Frequency of Wind Chill ≤-30°C
– – – –	Mean Air Temperature °C

Figure 20a

Mean Air Temperature and Wind Chill ≤-30°C

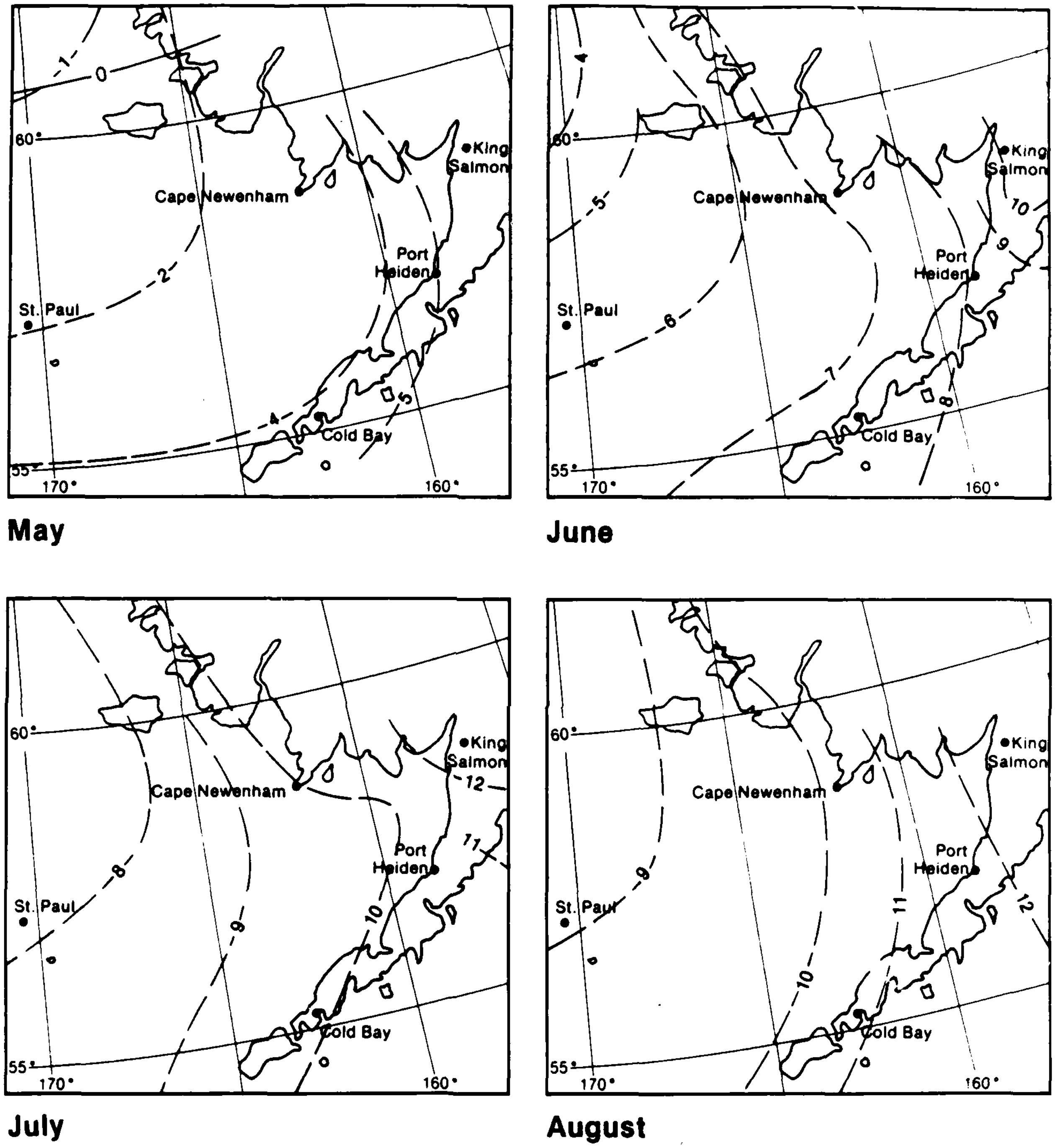
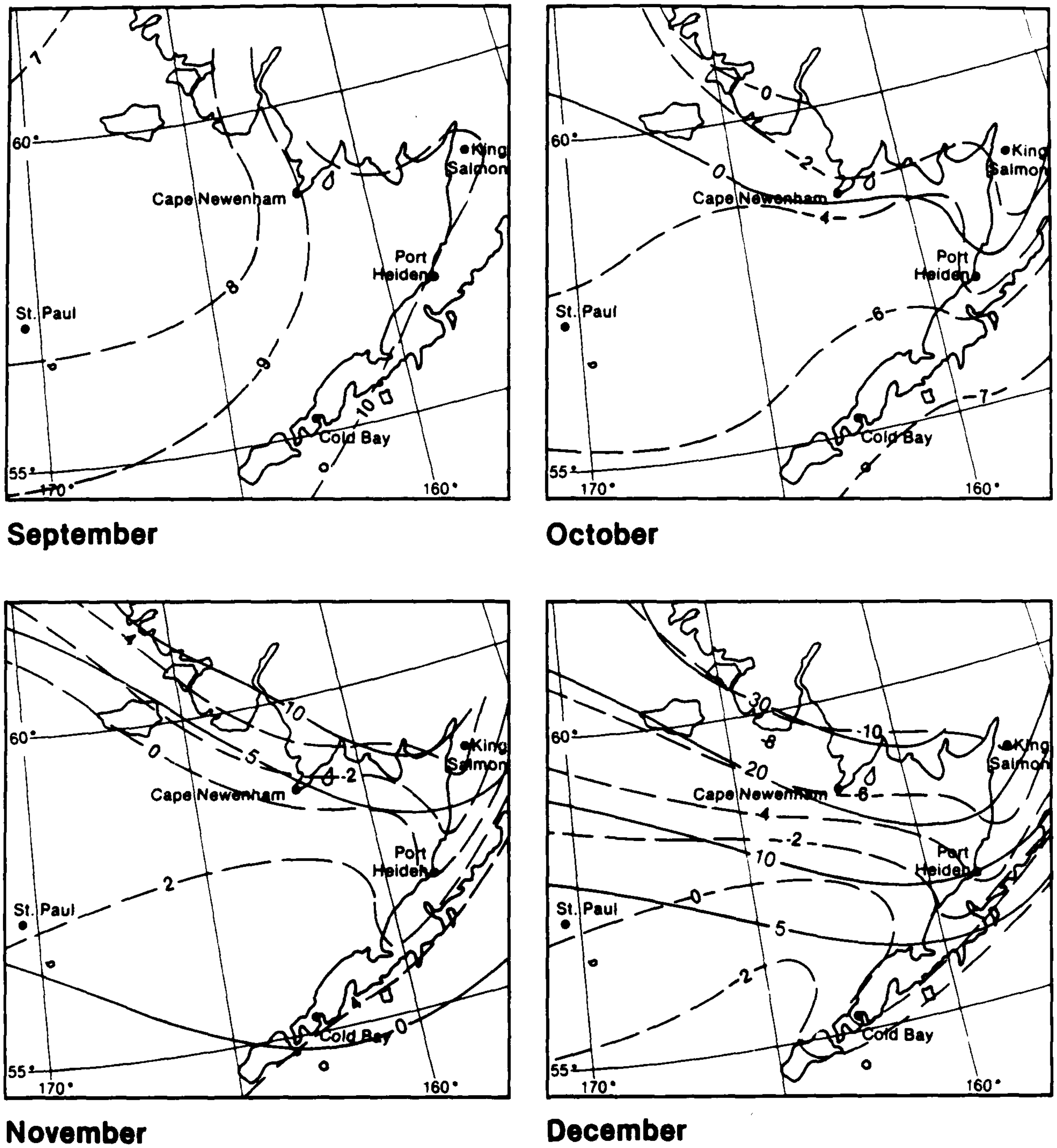


Figure 20b

Mean Air Temperature and Wind Chill ≤-30°C



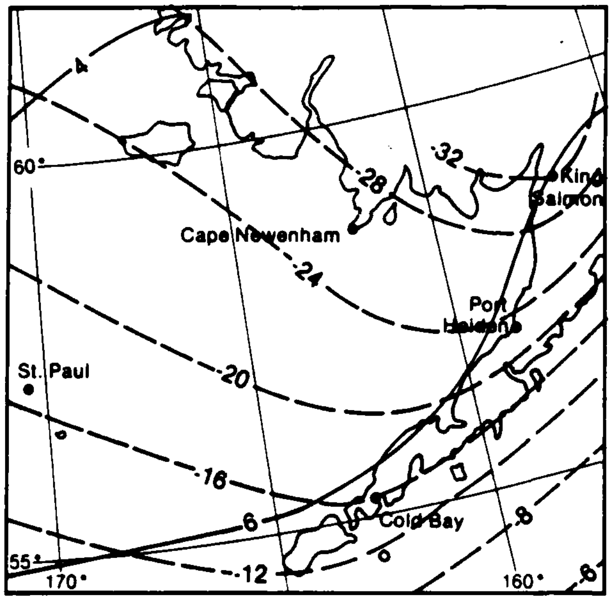
Legend

——— %Frequency of Wind Chill ≤-30°C

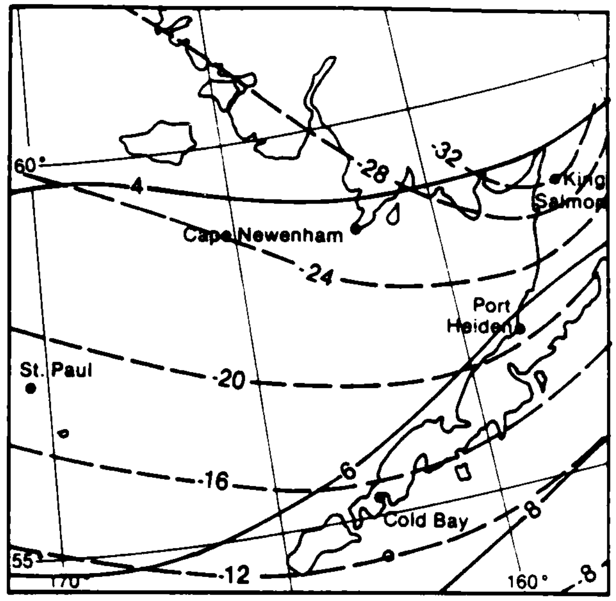
– – – Mean Air Temperature °C

Figure 20c

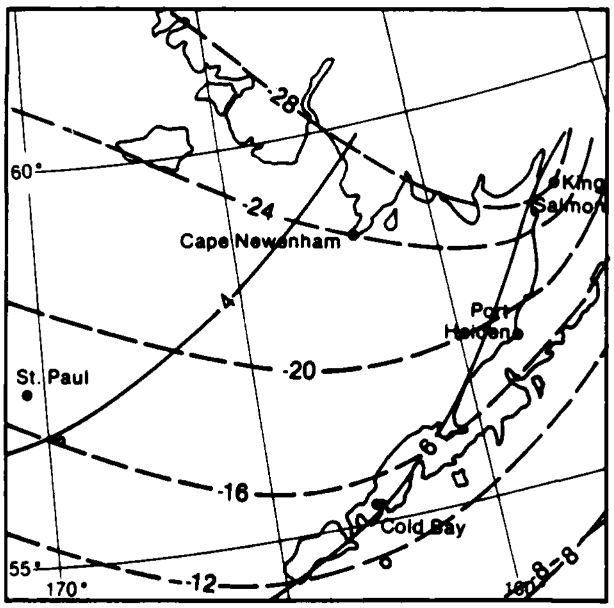
Air Temperature Extremes



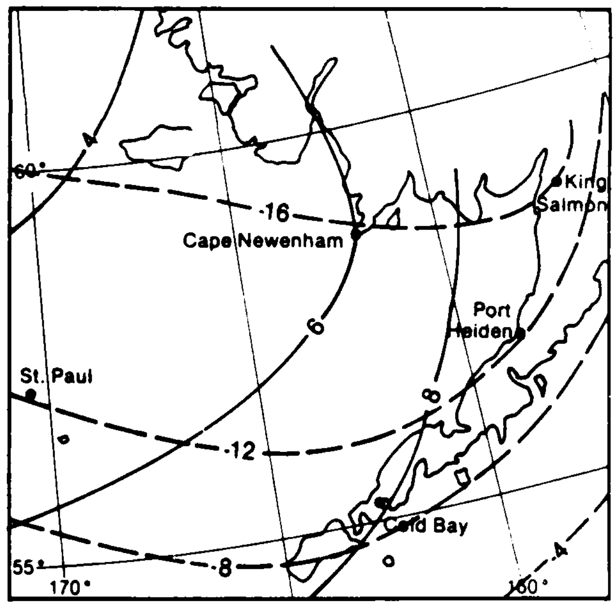
January



February



March



April

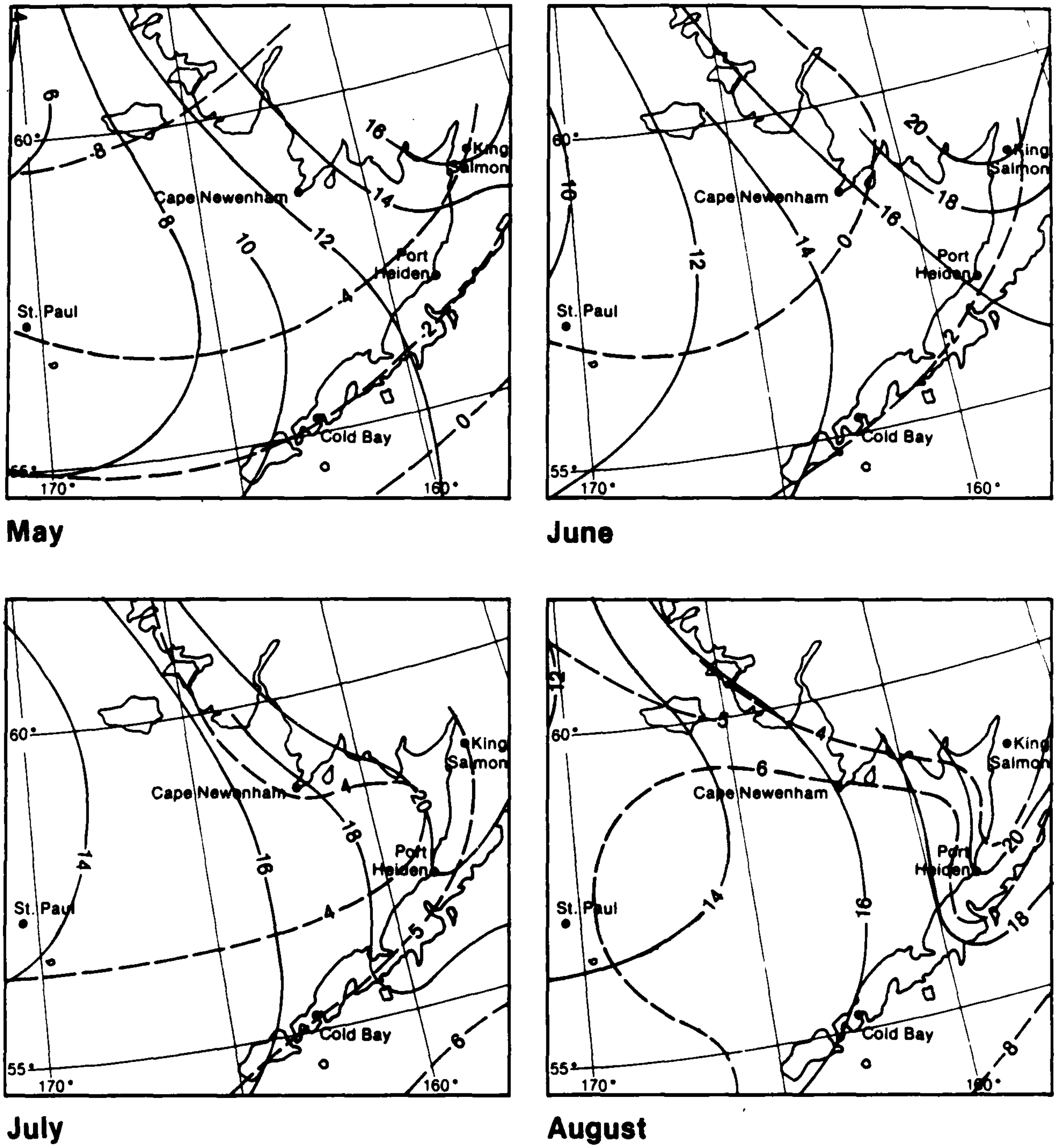
Legend

—————— 99% Air Temperature °C (Max.)

— — — — 1% Air Temperature °C (Min.)

Figure 21a

Air Temperature Extremes



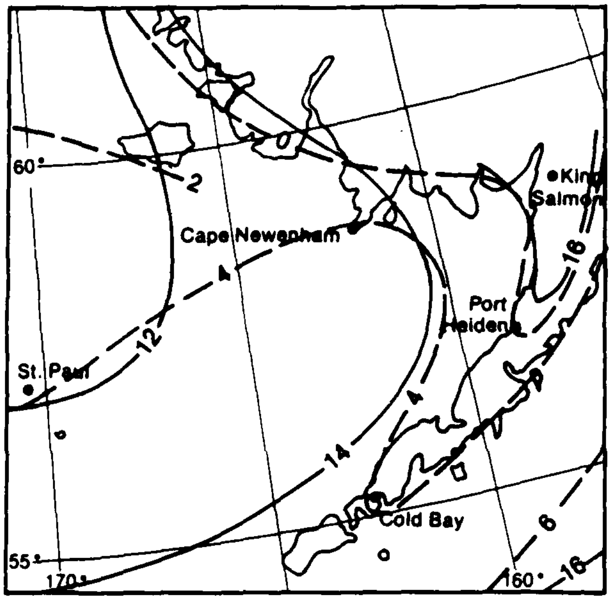
Legend

——— 99% Air Temperature °C (Max.)

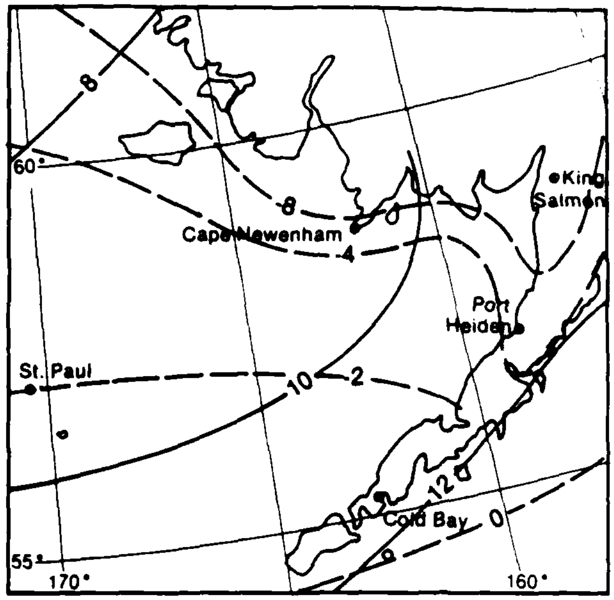
– – – 1% Air Temperature °C (Min.)

Figure 21b

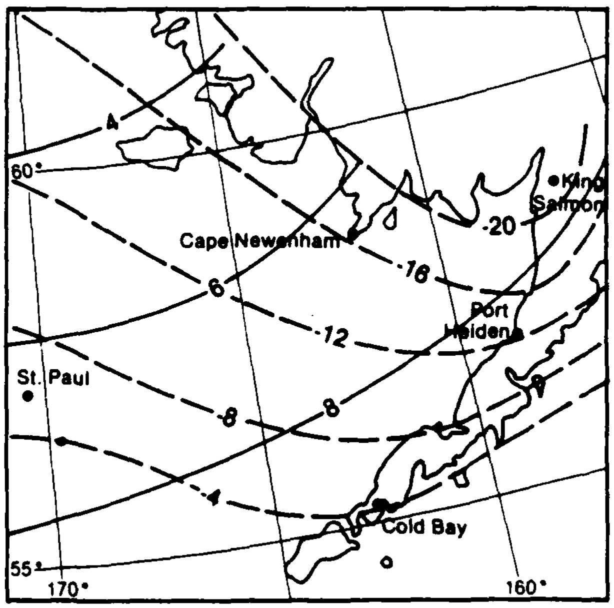
Air Temperature Extremes



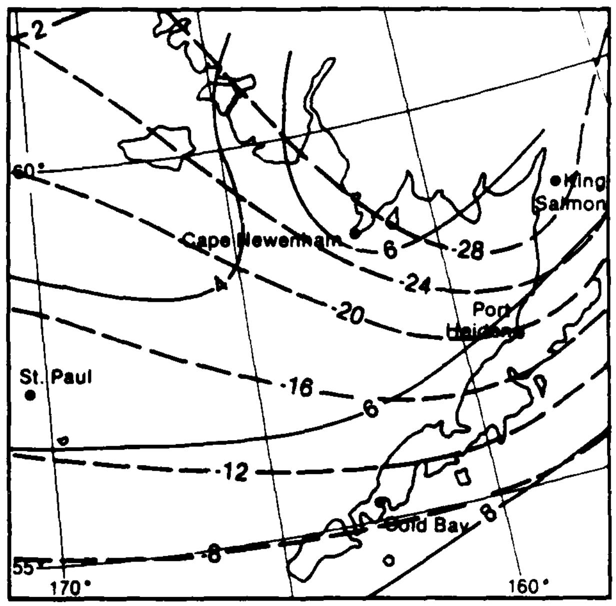
September



October



November



December

Figure 21c

Graphs: Air temperature/wind speed

1694 — Number of observations.

Wind Speed (knots) — Percent frequency of simultaneous occurrence of specified temperature (°C) and wind speed (knots).

TEMP (°C)	0–3	4–10	11–21	22–33	≥34
8,9	+	+	+	+	+
6,7	+	1	2	2	1
4,5	1	7	13	9	1
2,3	2	5	11	6	1
0,1	1	3	5	4	+
-2,-1	1	2	4	3	1
-4,-3	+	1	4	3	+
-6,-5	+	1	1	1	1
-8,-7	0	+	+	+	+
-10,-9	0	+	+	+	+
-12,-11	0	0	0	0	0

(2% of all observations reported temperature 6-7°C simultaneously with wind speed of 22-33 knots.)

+ Indicates <.5% but >0.

Figure 22 - legend

Air Temperature/Wind Speed

Marine Area C

3884 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	0	+	0	0	0
8,9	0	+	+	+	0
6,7	+	+	+	+	+
4,5	+	2	6	3	1
2,3	1	5	4	7	2
0,1	1	5	10	5	1
-2,-1	1	2	4	2	+
-4,-3	1	1	2	2	1
-6,-5	+	1	2	2	+
-8,-7	+	1	2	2	1
≤-9	+	+	2	2	1

Cape Newenham

18410 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥2	+	1	6	4	+
0,1	1	4	9	3	+
-2,-1	2	3	5	2	+
-4,-3	3	3	4	1	+
-6,-5	2	1	1	1	+
-8,-7	3	2	1	1	+
-10,-9	3	2	1	+	+
-12,-11	2	1	1	1	+
-14,-13	2	1	1	+	+
-16,-15	2	1	1	+	+
≤-17	6	5	6	1	0

King Salmon

19078 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥0	1	9	11	5	+
-2,-1	1	4	2	+	+
-4,-3	1	4	2	+	+
-6,-5	1	3	1	+	0
-8,-7	2	3	1	+	0
-10,-9	2	3	1	+	0
-12,-11	1	2	1	+	0
-14,-13	2	2	1	+	0
-16,-15	1	2	1	+	+
-18,-17	1	2	1	+	0
≤-19	6	11	7	1	+

Port Heiden

6361 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥6	+	+	1	+	+
4,5	+	1	2	1	+
2,3	1	4	9	4	1
0,1	2	8	9	2	+
-2,-1	2	8	3	+	0
-4,-3	2	5	2	+	0
-6,-5	1	3	2	+	+
-8,-7	1	2	1	+	0
-10,-9	1	2	1	+	0
-12,-11	+	2	1	0	0
≤-13	1	5	7	1	0

Cold Bay

13894 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	0	+	+	+	0
6,7	+	+	+	1	+
4,5	+	+	3	3	1
2,3	+	2	10	6	1
0,1	1	8	11	4	1
-2,-1	1	4	4	1	+
-4,-3	1	4	4	1	+
-6,-5	1	3	2	1	+
-8,-7	+	3	3	2	+
-10,-9	+	2	3	1	+
≤-11	+	2	3	1	+

St. Paul

11604 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥6	0	0	+	+	+
4,5	0	+	+	1	+
2,3	+	2	8	5	+
0,1	1	6	15	6	1
-2,-1	1	3	6	2	+
-4,-3	1	2	5	2	+
-6,-5	1	2	3	3	+
-8,-7	+	2	3	3	+
-10,-9	+	1	3	2	+
-12,-11	+	1	2	1	+
≤-13	+	1	2	2	+

January

Marine Area C

4298 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	0	+	+	+	+
6,7	+	+	+	+	+
4,5	+	1	2	1	+
2,3	+	4	11	6	1
0,1	1	5	12	6	1
-2,-1	+	2	5	3	1
-4,-3	+	1	3	2	1
-6,-5	+	2	3	3	1
-8,-7	+	1	3	2	1
-10,-9	+	1	1	1	1
≤-11	+	1	3	4	1

Cape Newenham

17474 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥2	+	1	4	2	+
0,1	1	3	9	2	+
-2,-1	2	3	5	1	+
-4,-3	2	3	3	1	+
-6,-5	1	2	2	1	+
-8,-7	2	1	1	+	+
-10,-9	2	2	1	+	+
-12,-11	2	2	1	+	+
-14,-13	2	2	2	+	+
-16,-15	1	2	1	+	0
≤-17	6	8	9	2	+

King Salmon

17369 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥-2	2	11	13	3	+
-4,-3	1	4	2	+	0
-6,-5	1	2	1	+	0
-8,-7	1	3	2	+	0
-10,-9	1	3	1	+	0
-12,-11	1	2	1	+	0
-14,-13	1	3	2	+	0
-16,-15	1	2	1	+	0
-18,-17	1	2	2	+	0
-20,-19	1	3	2	+	0
≤-21	4	10	6	+	+

Port Heiden

5709 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥4	+	1	3	2	+
2,3	1	2	6	3	+
0,1	1	6	6	1	+
-2,-1	1	5	3	+	0
-4,-3	1	4	2	+	0
-6,-5	1	3	2	+	0
-8,-7	1	2	2	+	0
-10,-9	1	3	2	+	0
-12,-11	1	2	2	+	0
-14,-13	1	2	3	+	0
≤-15	1	9	10	2	0

Cold Bay

12682 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥6	+	+	+	+	+
4,5	+	+	1	1	+
2,3	+	3	8	5	1
0,1	1	7	11	4	1
-2,-1	1	4	5	1	+
-4,-3	1	5	5	1	+
-6,-5	+	2	4	1	+
-8,-7	1	2	5	2	+
-10,-9	+	2	3	2	+
-12,-11	+	1	1	1	+
≤-13	+	1	2	1	+

St. Paul

10600 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥4	0	+	+	+	+
2,3	+	1	3	2	+
0,1	+	4	14	4	1
-2,-1	+	3	6	3	+
-4,-3	1	2	5	2	+
-6,-5	+	1	3	3	+
-8,-7	+	2	3	3	1
-10,-9	+	1	4	3	1
-12,-11	+	1	2	2	+
-14,-13	+	1	2	2	+
≤-15	+	2	6	3	+

February

Figure 22a

Air Temperature/Wind Speed

Marine Area C

5089 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	+	+	+	0	+
6,7	+	+	+	+	0
4,5	+	1	2	1	+
2,3	1	6	12	6	1
0,1	1	6	12	5	1
-2,-1	1	5	5	3	1
-4,-3	1	3	4	2	+
-6,-5	+	1	3	2	+
-8,-7	+	1	2	1	+
-10,-9	+	1	2	1	+
≤-11	+	1	2	1	+

Cape Newenham

19576 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥4	+	+	+	+	+
2,3	1	1	3	1	+
0,1	3	6	10	2	+
-2,-1	3	5	6	2	+
-4,-3	3	4	4	1	+
-6,-5	2	2	2	1	+
-8,-7	2	3	2	+	+
-10,-9	2	3	2	+	+
-12,-11	1	2	1	+	+
-14,-13	2	2	2	+	+
≤-15	3	4	5	1	+

King Salmon

19064 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥4	+	2	3	1	+
2,3	1	4	5	2	+
0,1	1	7	6	1	+
-2,-1	1	5	3	+	+
-4,-3	2	5	3	+	+
-6,-5	1	3	1	+	0
-8,-7	1	4	2	+	0
-10,-9	1	3	2	+	+
-12,-11	1	2	1	+	+
-14,-13	1	3	2	+	0
≤-15	4	9	5	+	0

Port Heiden

6377 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	+	+	+	+	0
6,7	+	1	1	+	0
4,5	+	2	3	1	+
2,3	1	5	8	2	1
0,1	2	9	9	2	+
-2,-1	2	7	5	1	+
-4,-3	1	5	4	+	+
-6,-5	1	3	2	+	0
-8,-7	+	2	3	+	0
-10,-9	+	2	2	+	0
≤-11	1	5	4	1	0

Cold Bay

13876 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	0	+	+	+	+
6,7	+	+	+	+	+
4,5	+	1	2	2	+
2,3	+	4	9	5	1
0,1	1	8	12	6	1
-2,-1	1	4	5	2	+
-4,-3	1	4	5	2	+
-6,-5	+	2	4	1	+
-8,-7	+	2	3	1	+
-10,-9	+	1	2	1	+
≤-11	+	2	3	1	+

St Paul

11595 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥4	0	+	+	+	0
2,3	+	1	2	1	+
0,1	+	5	14	6	+
-2,-1	+	4	7	3	+
-4,-3	1	3	6	3	+
-6,-5	+	2	4	2	+
-8,-7	+	2	5	2	+
-10,-9	+	1	3	2	+
-12,-11	+	1	2	1	+
-14,-13	+	1	2	2	+
≤-15	+	2	3	2	+

March

Marine Area C

6548 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	0	+	+	+	0
8,9	+	+	+	+	0
6,7	+	1	1	+	+
4,5	1	3	4	2	+
2,3	1	8	14	6	1
0,1	1	6	12	5	1
-2,-1	1	3	7	4	1
-4,-3	1	2	4	2	1
-6,-5	+	1	2	1	+
-8,-7	+	+	1	1	+
≤-9	+	+	+	+	+

Cape Newenham

19052 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥6	+	+	+	+	0
4,5	1	1	1	+	+
2,3	2	3	5	2	+
0,1	5	9	9	2	+
-2,-1	4	6	5	1	+
-4,-3	3	5	4	1	+
-6,-5	1	3	3	+	+
-8,-7	1	3	3	+	+
-10,-9	1	2	3	+	0
-12,-11	1	1	2	+	0
≤-13	1	2	2	+	0

King Salmon

18473 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	+	2	2	+	+
6,7	+	3	3	1	+
4,5	1	4	3	1	+
2,3	1	7	6	1	+
0,1	3	11	6	+	0
-2,-1	2	7	3	+	0
-4,-3	2	6	3	+	0
-6,-5	1	3	2	+	0
-8,-7	1	4	2	+	0
-10,-9	1	2	1	+	0
≤-11	1	4	2	+	0

Port Heiden

6547 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	+	1	1	1	0
6,7	+	2	3	1	+
4,5	1	3	4	1	+
2,3	1	7	6	1	0
0,1	3	11	6	1	+
-2,-1	2	7	3	+	0
-4,-3	2	7	4	+	+
-6,-5	1	3	4	+	0
-8,-7	+	1	2	+	0
-10,-9	+	1	1	+	0
≤-11	+	2	2	+	0

Cold Bay

13437 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	+	+	+	+	0
8,9	0	+	+	+	0
6,7	+	1	1	1	+
4,5	+	2	4	3	+
2,3	+	5	11	6	1
0,1	1	7	13	4	+
-2,-1	+	4	6	2	+
-4,-3	+	3	8	2	+
-6,-5	+	2	3	1	+
-8,-7	+	1	2	1	+
≤-9	+	1	1	+	0

St. Paul

11095 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	0	0	0	0	0
6,7	0	+	+	+	0
4,5	+	+	1	+	+
2,3	+	2	6	2	+
0,1	1	7	19	5	+
-2,-1	1	5	8	3	+
-4,-3	+	3	6	3	+
-6,-5	+	2	3	2	+
-8,-7	+	2	4	2	+
-10,-9	+	1	3	1	+
≤-11	+	1	2	1	+

April

Figure 22b

Air Temperature/Wind Speed

Marine Area C

9790 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥12	+	+	+	0	0
10,11	+	1	+	+	0
8,9	1	2	1	+	+
6,7	2	5	3	1	+
4,5	2	9	11	3	1
2,3	2	10	14	4	1
0,1	1	6	9	3	+
-2,-1	+	2	2	1	+
-4,-3	+	+	1	+	+
-6,-5	+	+	+	+	0
≤-7	0	0	+	+	0

Cape Newenham

19580 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥12	+	1	+	0	0
10,11	1	1	+	0	0
8,9	2	2	1	+	0
6,7	4	5	3	+	+
4,5	5	7	5	1	+
2,3	7	9	7	1	+
0,1	6	9	7	1	+
-2,-1	2	4	3	+	0
-4,-3	1	2	2	+	0
-6,-5	+	+	1	+	0
≤-7	+	+	1	+	0

King Salmon

18357 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥14	+	2	1	+	0
12,13	+	3	2	+	0
10,11	1	4	4	1	+
8,9	1	5	4	1	+
6,7	2	9	7	1	+
4,5	2	8	5	1	+
2,3	3	10	4	+	+
0,1	2	8	3	+	0
-2,-1	1	3	1	+	0
-4,-3	1	1	+	+	0
≤-5	+	1	+	0	0

Port Heiden

6326 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥14	+	+	+	+	0
12,13	+	1	1	+	0
10,11	+	2	3	1	0
8,9	+	3	4	1	+
6,7	1	7	8	2	+
4,5	2	8	7	1	0
2,3	3	11	6	1	0
0,1	3	9	4	+	+
-2,-1	1	3	3	+	0
-4,-3	1	1	1	0	0
≤-5	+	1	+	0	0

Cold Bay

13153 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥14	0	+	+	0	0
12,13	+	+	+	+	0
10,11	+	1	1	+	0
8,9	+	2	2	+	+
6,7	+	5	9	4	+
4,5	1	7	12	5	+
2,3	1	9	14	4	+
0,1	1	6	8	2	+
-2,-1	+	2	1	+	0
-4,-3	+	1	1	+	0
≤-5	+	+	+	0	0

St. Paul

10507 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	0	+	+	+	0
8,9	0	+	+	+	0
6,7	+	1	2	+	0
4,5	+	3	5	1	0
2,3	1	10	19	3	+
0,1	1	12	18	3	+
-2,-1	1	5	6	2	+
-4,-3	+	2	2	1	+
-6,-5	+	+	+	+	+
-8,-7	+	+	+	+	0
≤-9	+	+	+	+	0

May

Marine Area C

10565 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥16	+	+	+	0	0
14,15	+	+	+	+	0
12,13	1	1	+	+	+
10,11	2	4	2	+	+
8,9	3	8	6	1	+
6,7	3	12	11	2	+
4,5	2	10	11	2	1
2,3	1	4	6	1	+
0,1	+	1	2	1	+
-2,-1	+	+	+	+	+
≤-3	0	0	0	+	+

Cape Newenham

18313 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥16	+	+	+	0	0
14,15	+	1	+	+	0
12,13	2	2	1	+	0
10,11	4	6	2	+	0
8,9	5	8	4	+	0
6,7	9	14	7	1	+
4,5	6	8	5	+	+
2,3	3	5	3	+	+
0,1	1	1	1	+	+
-2,-1	+	+	+	0	0
≤-3	0	0	0	0	0

King Salmon

17756 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥20	+	2	1	+	0
18,19	+	1	1	+	0
16,17	+	3	2	+	0
14,15	+	4	3	+	+
12,13	1	7	4	1	+
10,11	2	10	6	1	+
8,9	2	10	4	+	+
6,7	3	12	5	+	+
4,5	1	6	2	+	+
2,3	1	3	1	+	0
≤1	+	1	+	0	0

Port Heiden

6135 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	+	+	+	0	0
16,17	0	+	1	+	0
14,15	+	1	1	+	+
12,13	+	3	4	1	0
10,11	1	8	7	1	+
8,9	2	9	6	1	+
6,7	5	14	8	1	+
4,5	3	7	3	+	0
2,3	2	5	2	+	0
0,1	1	1	1	0	0
≤-1	+	+	0	0	0

Cold Bay

12720 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥16	0	+	+	0	0
14,15	0	+	+	+	0
12,13	+	1	2	+	0
10,11	+	5	7	2	+
8,9	1	6	10	3	+
6,7	1	11	18	6	1
4,5	1	6	9	2	+
2,3	+	2	4	1	+
0,1	+	+	1	+	0
-2,-1	+	0	0	0	0
≤-3	0	0	0	0	0

St. Paul

10026 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥14	0	+	0	0	0
12,13	0	+	+	+	0
10,11	0	1	1	+	0
8,9	+	2	3	+	0
6,7	+	10	14	1	+
4,5	1	13	16	1	0
2,3	1	10	14	1	+
0,1	+	4	3	1	0
-2,-1	+	+	+	+	0
-4,-3	+	+	+	0	0
≤-5	0	+	0	0	0

June

Figure 22c

Air Temperature/Wind Speed

July

Marine Area C

10077 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	+	+	+	0	0
16,17	+	+	+	+	0
14,15	1	1	+	+	0
12,13	2	3	1	+	0
10,11	3	9	8	1	+
8,9	3	13	14	3	+
6,7	2	11	12	2	1
4,5	1	2	3	1	+
2,3	+	+	+	0	0
0,1	+	+	+	0	0
≤-1	+	+	0	0	0

Cape Newenham

19391 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	+	+	+	+	0
16,17	1	1	+	+	0
14,15	2	2	1	+	0
12,13	4	5	3	+	0
10,11	7	12	6	+	0
8,9	7	13	8	+	+
6,7	6	10	7	+	0
4,5	1	2	1	+	0
2,3	+	+	+	0	0
0,1	0	0	+	0	0
≤-1	0	0	0	0	0

King Salmon

18345 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥22	+	2	1	+	0
20,21	+	2	1	+	0
18,19	+	3	1	+	0
16,17	1	5	3	+	0
14,15	1	6	3	+	0
12,13	2	11	5	+	0
10,11	4	16	6	+	+
8,9	3	10	3	+	+
6,7	2	5	2	+	0
4,5	+	1	+	0	0
≤3	+	+	+	0	0

Port Heiden

5917 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥20	+	+	1	+	0
18,19	+	1	1	+	+
16,17	+	2	2	+	+
14,15	+	3	2	1	+
12,13	2	7	5	1	+
10,11	3	14	7	1	+
8,9	3	11	8	1	+
6,7	3	9	6	+	0
4,5	2	2	+	0	0
2,3	+	+	+	0	0
≤1	+	+	0	0	0

Cold Bay

13871 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	0	+	+	+	0
16,17	+	+	1	+	0
14,15	+	1	1	+	0
12,13	+	3	6	1	+
10,11	1	10	16	5	+
8,9	1	9	15	4	+
6,7	1	7	11	2	+
4,5	+	1	1	+	0
2,3	+	+	+	0	0
0,1	0	+	0	0	0
≤-1	0	0	0	0	0

St. Paul

10306 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥16	+	+	+	0	0
14,15	0	+	+	0	0
12,13	+	1	+	+	0
10,11	+	3	4	+	0
8,9	1	10	13	1	0
6,7	2	24	24	1	0
4,5	1	7	5	+	0
2,3	+	2	1	+	0
0,1	+	+	+	0	0
-2,-1	+	+	0	0	0
≤-3	0	0	0	0	0

July

August

Marine Area C

8537 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥20	+	+	+	0	+
18,19	+	+	+	0	0
16,17	+	+	+	+	0
14,15	+	1	1	+	+
12,13	1	4	3	1	+
10,11	2	12	17	5	+
8,9	2	14	22	6	+
6,7	+	2	4	1	+
4,5	+	+	+	+	0
2,3	0	+	+	0	0
≤1	0	0	0	0	0

Cape Newenham

20043 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥20	0	+	+	0	0
18,19	+	+	+	+	0
16,17	+	+	+	+	0
14,15	1	1	1	+	0
12,13	3	6	5	1	0
10,11	8	17	11	1	+
8,9	6	16	10	1	+
6,7	3	5	4	+	0
4,5	+	+	+	+	0
2,3	0	+	+	0	0
≤1	0	0	0	0	0

King Salmon

18824 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥22	+	1	+	+	0
20,21	+	1	1	+	0
18,19	+	2	1	+	0
16,17	+	4	3	+	+
14,15	1	6	4	1	+
12,13	2	13	7	1	+
10,11	4	16	7	+	+
8,9	2	8	3	+	0
6,7	2	4	1	+	0
4,5	1	1	+	0	+
≤3	1	1	+	0	0

Port Heiden

5631 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥20	+	+	+	+	0
18,19	+	1	1	+	0
16,17	+	2	2	1	0
14,15	1	3	3	1	0
12,13	2	9	8	1	+
10,11	4	16	12	1	+
8,9	4	10	8	1	+
6,7	2	3	1	+	0
4,5	1	1	+	0	0
2,3	+	+	0	0	0
≤1	+	+	0	0	0

Cold Bay

14377 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥20	0	+	+	+	0
18,19	+	+	+	+	0
16,17	+	+	1	+	0
14,15	+	1	2	1	+
12,13	+	4	8	4	+
10,11	1	12	22	7	+
8,9	1	8	14	2	+
6,7	1	4	4	+	0
4,5	+	+	+	0	0
2,3	+	+	0	0	0
≤1	0	0	0	0	0

St. Paul

11089 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	0	0	0	0	0
16,17	0	+	+	0	0
14,15	+	+	+	+	0
12,13	0	+	1	+	0
10,11	+	5	10	1	+
8,9	1	17	16	3	+
6,7	1	14	14	2	+
4,5	+	1	1	+	0
2,3	+	+	+	0	0
0,1	+	+	0	0	0
≤-1	+	+	0	0	0

August

Figure 22d

Air Temperature/Wind Speed

September

Marine Area C

9055 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	0	+	+	0	0
16,17	+	+	+	0	0
14,15	+	+	+	+	+
12,13	+	1	1	+	+
10,11	1	6	8	3	+
8,9	1	11	23	10	1
6,7	1	6	13	6	1
4,5	+	+	2	1	+
2,3	+	+	+	+	+
0,1	0	+	+	+	0
≤-1	0	0	0	0	0

Cape Newenham

20493 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥12	0	+	+	+	0
10,11	+	+	+	+	0
8,9	1	1	2	+	+
6,7	1	5	5	+	+
4,5	2	7	6	1	+
2,3	3	9	9	1	+
0,1	3	8	7	1	+
-2,-1	1	4	4	1	+
-4,-3	1	3	4	1	+
-6,-5	1	1	2	+	+
≤-7	+	1	1	+	+

King Salmon

8846 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	+	1	2	+	+
8,9	+	2	2	1	+
6,7	1	5	5	1	+
4,5	1	6	4	1	+
2,3	2	8	4	+	+
0,1	2	10	4	+	0
-2,-1	2	5	2	+	0
-4,-3	2	5	2	+	0
-6,-5	1	3	1	+	+
-8,-7	1	3	1	+	0
≤-9	2	4	1	+	0

Port Heiden

6048 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥12	+	+	+	+	0
10,11	+	1	2	+	0
8,9	+	2	4	1	+
6,7	1	6	8	2	+
4,5	1	7	9	1	+
2,3	1	7	8	1	0
0,1	1	8	6	+	+
-2,-1	1	5	2	+	0
-4,-3	1	3	2	+	0
-6,-5	+	2	1	+	0
≤-7	+	2	1	+	0

Cold Bay

14379 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥14	0	0	+	+	+
12,13	+	+	+	+	+
10,11	+	1	1	1	+
8,9	+	1	4	2	+
6,7	+	5	12	5	+
4,5	1	5	10	3	+
2,3	1	8	12	4	+
0,1	1	7	7	2	+
-2,-1	+	2	1	1	+
-4,-3	+	1	+	+	+
≤-5	+	+	+	+	0

St. Paul

11311 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥12	0	0	0	0	0
10,11	0	+	+	0	0
8,9	+	+	1	+	+
6,7	+	3	11	4	+
4,5	+	4	12	5	+
2,3	1	6	13	5	1
0,1	1	7	10	4	1
-2,-1	+	2	2	1	+
-4,-3	+	1	1	+	0
-6,-5	+	+	+	0	0
≤-7	+	+	0	0	0

October

Marine Area C

5124 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥14	+	+	+	0	+
12,13	+	+	+	+	+
10,11	+	+	1	+	+
8,9	+	2	5	3	1
6,7	+	5	13	8	2
4,5	1	6	15	9	2
2,3	+	3	9	5	1
0,1	+	1	3	2	+
-2,-1	+	+	+	+	+
-4,-3	+	+	+	+	+
≤-5	0	0	0	0	0

Cape Newenham

19728 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	0	0	+	0	0
16,17	+	+	+	0	0
14,15	+	+	+	0	0
12,13	1	1	1	+	0
10,11	4	9	6	1	+
8,9	5	15	10	1	+
6,7	4	13	11	1	+
4,5	1	4	3	+	0
2,3	1	2	2	+	0
0,1	+	1	+	+	0
≤-1	+	+	+	0	0

King Salmon

18211 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	+	+	+	+	0
16,17	+	1	1	+	0
14,15	+	2	2	+	+
12,13	1	6	5	1	+
10,11	2	11	8	1	+
8,9	2	10	5	+	+
6,7	3	12	4	+	+
4,5	2	5	1	+	0
2,3	1	4	1	+	0
0,1	1	3	1	+	0
≤-1	1	2	+	+	0

Port Heiden

6205 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	0	0	+	+	0
16,17	+	+	+	+	+
14,15	+	1	1	+	+
12,13	1	4	4	1	+
10,11	2	8	10	2	0
8,9	2	12	12	2	+
6,7	2	10	8	1	0
4,5	1	5	2	+	0
2,3	1	3	1	+	0
0,1	+	2	+	0	0
≤-1	+	+	+	0	0

Cold Bay

13918 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥18	0	+	+	+	0
16,17	0	0	+	+	0
14,15	+	+	+	+	0
12,13	+	2	3	1	+
10,11	1	7	14	4	+
8,9	1	8	15	4	+
6,7	1	9	14	3	+
4,5	1	3	3	+	+
2,3	+	2	1	+	0
0,1	+	+	+	0	0
≤-1	+	+	0	0	0

St. Paul

10316 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥16	0	0	0	0	0
14,15	0	+	+	0	0
12,13	0	+	+	+	0
10,11	+	1	3	1	0
8,9	+	8	18	3	+
6,7	1	14	22	5	+
4,5	1	5	5	2	+
2,3	+	3	2	1	+
0,1	+	2	+	+	0
-2,-1	+	+	+	0	0
≤-3	+	+	0	0	0

Figure 22e

Air Temperature/Wind Speed

November

Marine Area C

4139 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥12	0	+	0	+	0
10,11	0	+	0	0	0
8,9	+	+	+	+	0
6,7	+	1	2	3	1
4,5	1	6	14	9	3
2,3	1	7	13	7	2
0,1	+	4	7	5	1
-2,-1	+	1	3	2	1
-4,-3	+	+	1	1	+
-6,-5	0	+	1	+	+
≤-7	0	+	+	+	+

Cape Newenham

19267 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	0	+	+	0	0
6,7	+	+	1	1	+
4,5	+	1	3	1	+
2,3	1	5	8	1	+
0,1	4	9	8	1	+
-2,-1	3	4	4	1	+
-4,-3	3	4	5	1	+
-6,-5	2	3	3	1	+
-8,-7	2	2	2	1	+
-10,-9	1	2	2	1	+
≤-11	2	3	3	1	+

King Salmon

18239 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥4	+	2	6	2	+
2,3	1	4	6	1	+
0,1	2	9	4	+	+
-2,-1	1	5	2	+	0
-4,-3	2	5	2	+	0
-6,-5	1	3	1	+	0
-8,-7	2	5	2	+	0
-10,-9	2	4	1	+	0
-12,-11	1	2	1	+	0
-14,-13	1	3	2	+	+
≤-15	3	7	3	+	0

Port Heiden

5524 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	+	+	+	1	+
6,7	+	+	1	1	+
4,5	+	1	3	1	+
2,3	1	6	8	3	1
0,1	2	9	6	1	+
-2,-1	2	9	5	1	+
-4,-3	2	6	4	+	0
-6,-5	1	5	2	+	0
-8,-7	+	3	2	+	0
-10,-9	+	2	1	+	0
≤-11	+	3	2	+	0

Cold Bay

13919 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	+	+	+	+	+
8,9	0	+	+	+	+
6,7	+	1	3	2	1
4,5	+	3	6	3	1
2,3	1	8	13	5	1
0,1	1	10	11	3	+
-2,-1	1	4	4	2	+
-4,-3	1	3	4	2	+
-6,-5	+	1	1	+	+
-8,-7	+	1	+	+	+
≤-9	+	+	+	+	0

St. Paul

11380 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	0	0	0	0	0
8,9	0	+	+	+	0
6,7	0	+	1	1	+
4,5	+	1	6	4	+
2,3	+	4	15	7	1
0,1	1	8	14	7	1
-2,-1	1	4	6	2	+
-4,-3	1	3	4	2	+
-6,-5	+	1	1	1	+
-8,-7	+	1	1	1	+
≤-9	+	+	+	+	0

November

December

Marine Area C

4161 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥10	0	0	+	+	0
8,9	+	+	+	+	0
6,7	+	+	1	1	+
4,5	1	4	8	7	1
2,3	1	6	11	7	2
0,1	+	4	8	6	1
-2,-1	+	3	5	3	1
-4,-3	+	2	4	3	1
-6,-5	+	1	2	1	+
-8,-7	0	+	1	1	+
≤-9	+	+	+	1	+

Cape Newenham

19087 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥2	+	2	5	3	+
0,1	1	4	7	2	+
-2,-1	2	3	4	1	+
-4,-3	3	4	3	1	+
-6,-5	2	2	2	1	+
-8,-7	3	2	2	1	+
-10,-9	3	2	2	1	+
-12,-11	2	1	1	+	+
-14,-13	2	2	2	+	+
-16,-15	2	2	1	+	+
≤-17	5	4	6	1	0

King Salmon

18840 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥-2	2	13	13	3	+
-4,-3	1	4	2	+	0
-6,-5	1	3	1	+	0
-8,-7	1	4	1	+	+
-10,-9	1	3	1	+	0
-12,-11	1	2	1	+	0
-14,-13	1	3	1	+	0
-16,-15	1	2	1	+	0
-18,-17	1	2	1	+	0
-20,-19	2	3	2	+	0
≤-21	7	9	5	+	+

Port Heiden

5839 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥4	+	1	3	2	+
2,3	+	3	8	3	+
0,1	1	7	8	2	+
-2,-1	1	6	5	1	+
-4,-3	1	5	4	1	+
-6,-5	1	3	2	+	+
-8,-7	+	2	1	+	0
-10,-9	1	2	1	+	0
-12,-11	+	2	2	+	0
-14,-13	+	3	3	+	0
≤-15	+	4	8	1	0

Cold Bay

14359 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	0	0	+	+	+
6,7	+	+	1	1	+
4,5	+	1	2	3	+
2,3	+	4	9	5	1
0,1	1	10	12	4	+
-2,-1	1	5	6	1	+
-4,-3	1	5	6	2	0
-6,-5	+	3	3	1	+
-8,-7	1	2	3	1	+
-10,-9	+	1	1	1	+
≤-11	+	1	+	1	+

St. Paul

11798 Wind Speed (knots)

TEMP (°C)	0-3	4-10	11-21	22-33	≥34
≥8	0	0	0	0	0
6,7	0	0	+	+	0
4,5	0	+	1	1	+
2,3	+	2	10	5	1
0,1	1	6	13	6	1
-2,-1	+	2	6	3	1
-4,-3	1	4	7	4	1
-6,-5	1	2	5	2	1
-8,-7	1	2	4	2	+
-10,-9	+	1	1	1	+
≤-11	+	+	1	2	+

December

Figure 22f

Graphs: Air temperature/wind direction

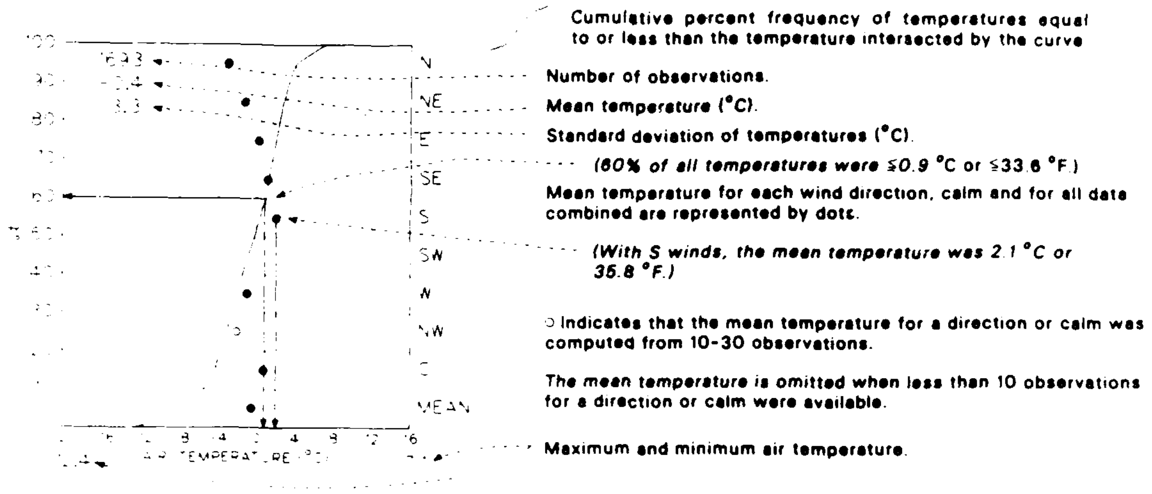
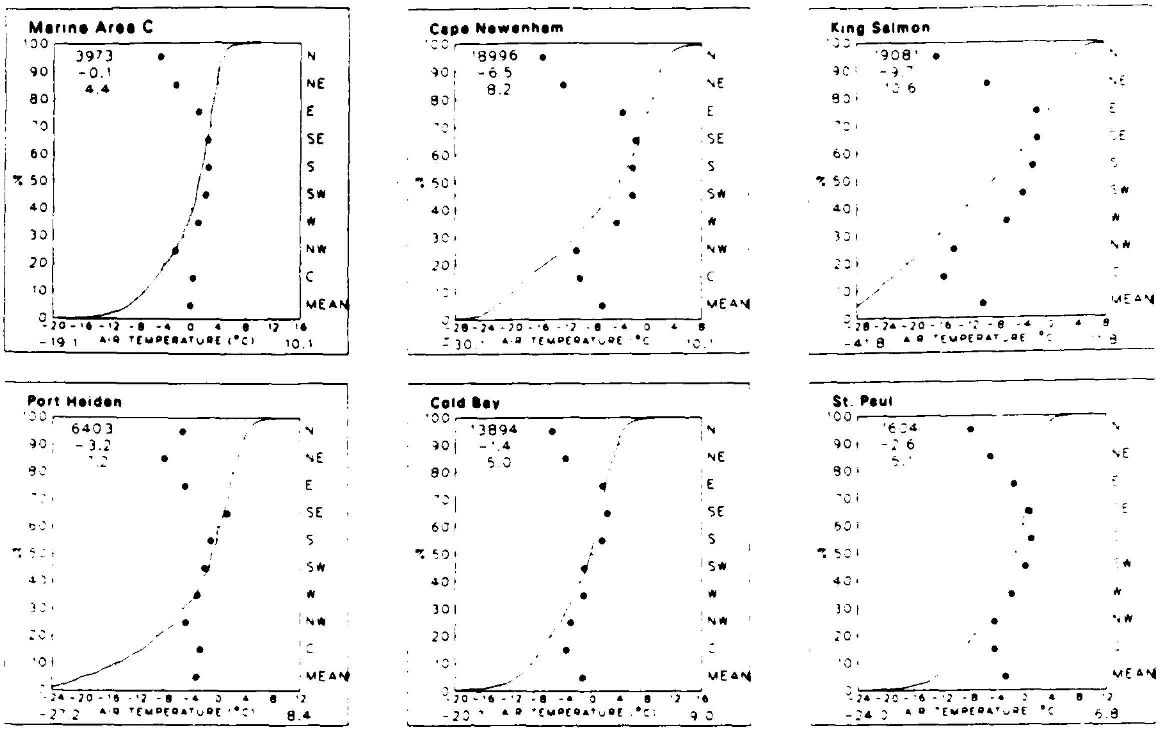
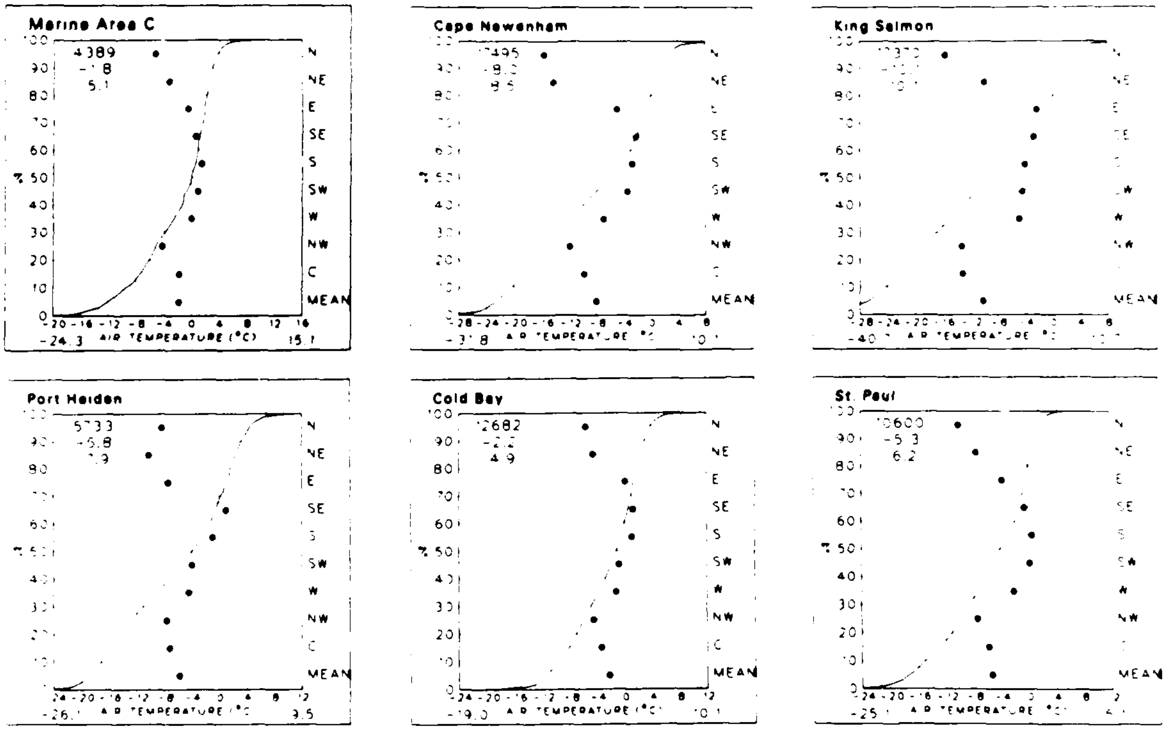


Figure 23 - legend

Air Temperature/Wind Direction



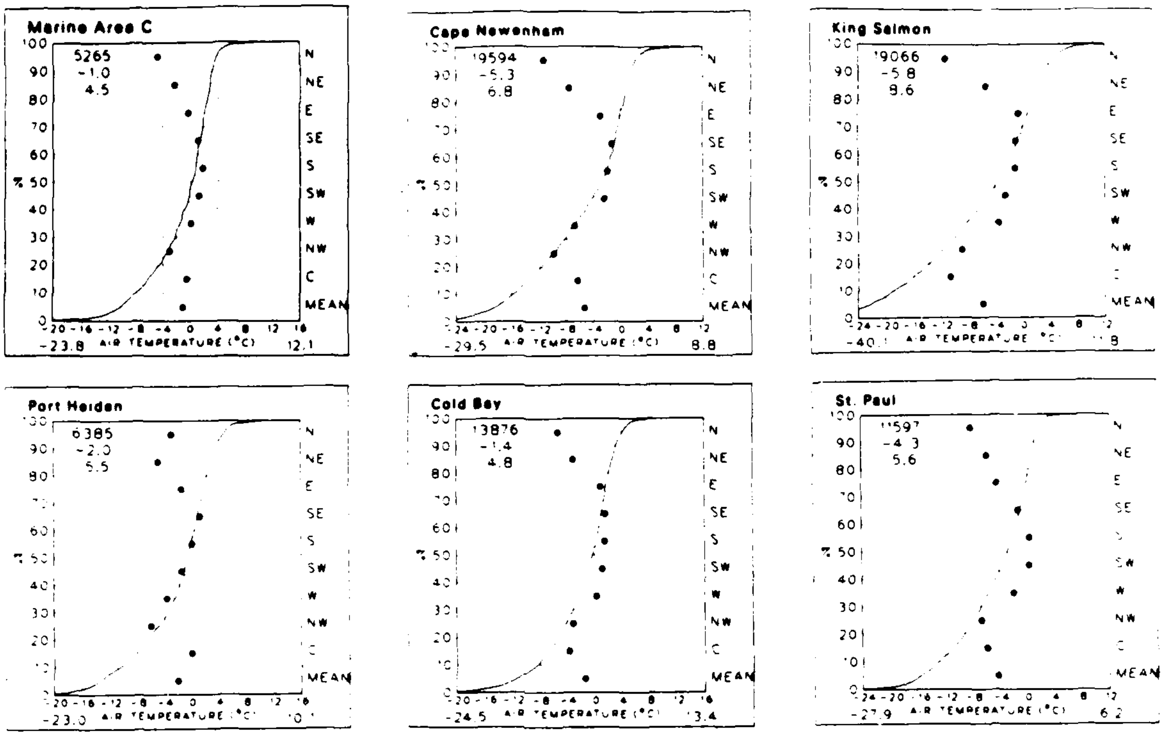
January



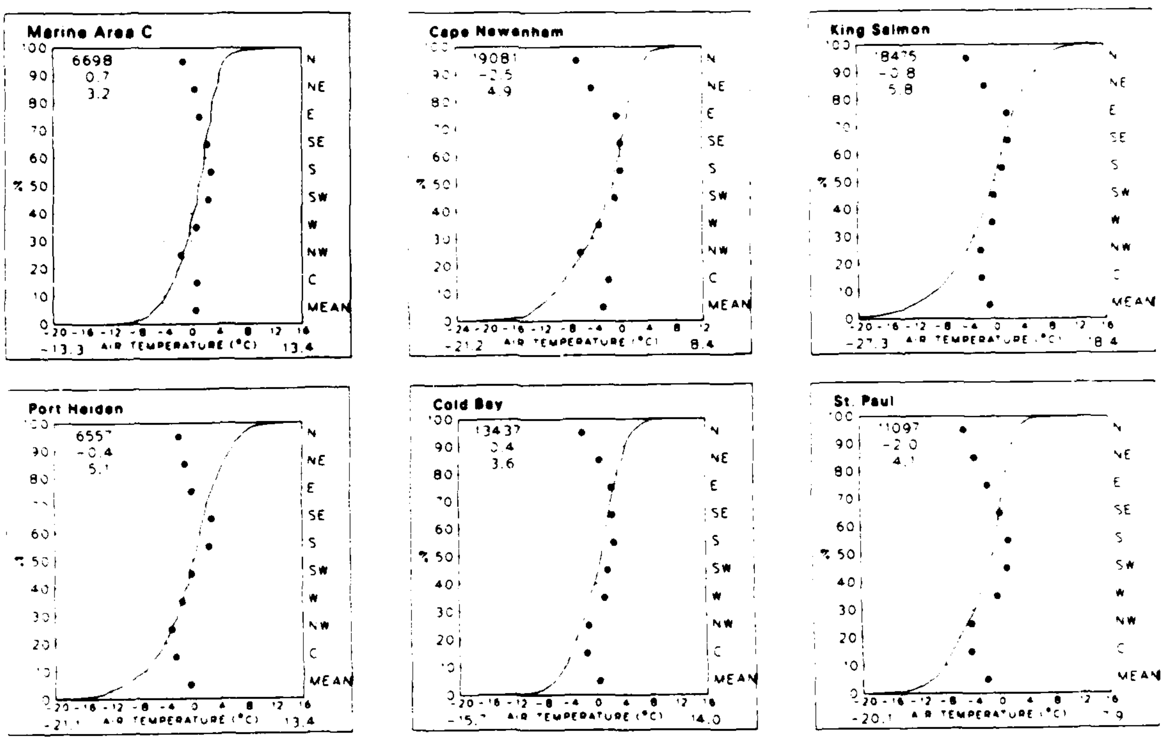
February

Figure 23a

Air Temperature/Wind Direction



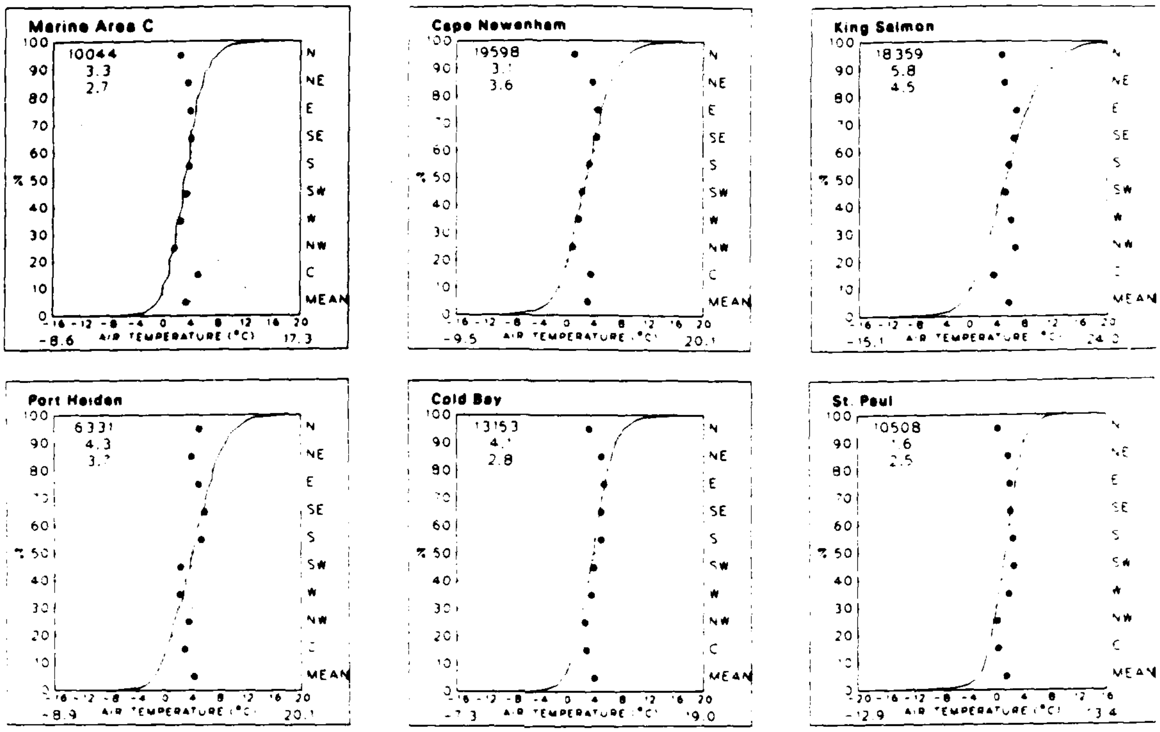
March



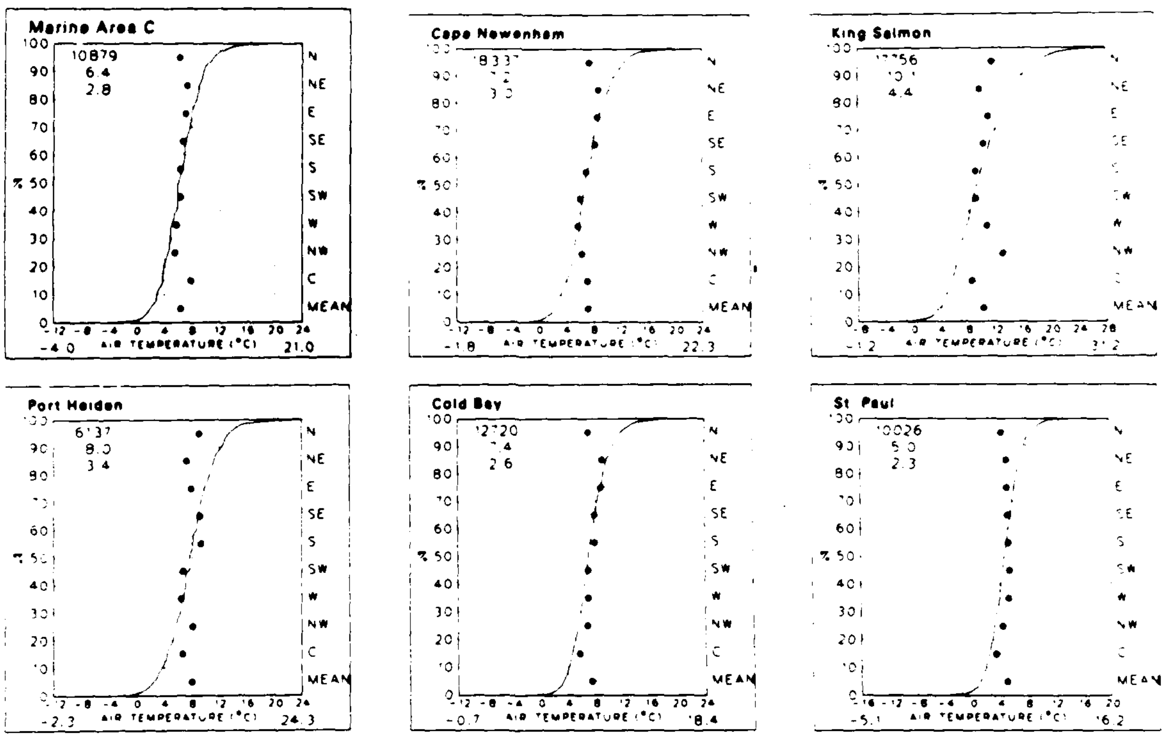
April

Figure 23b

Air Temperature/Wind Direction



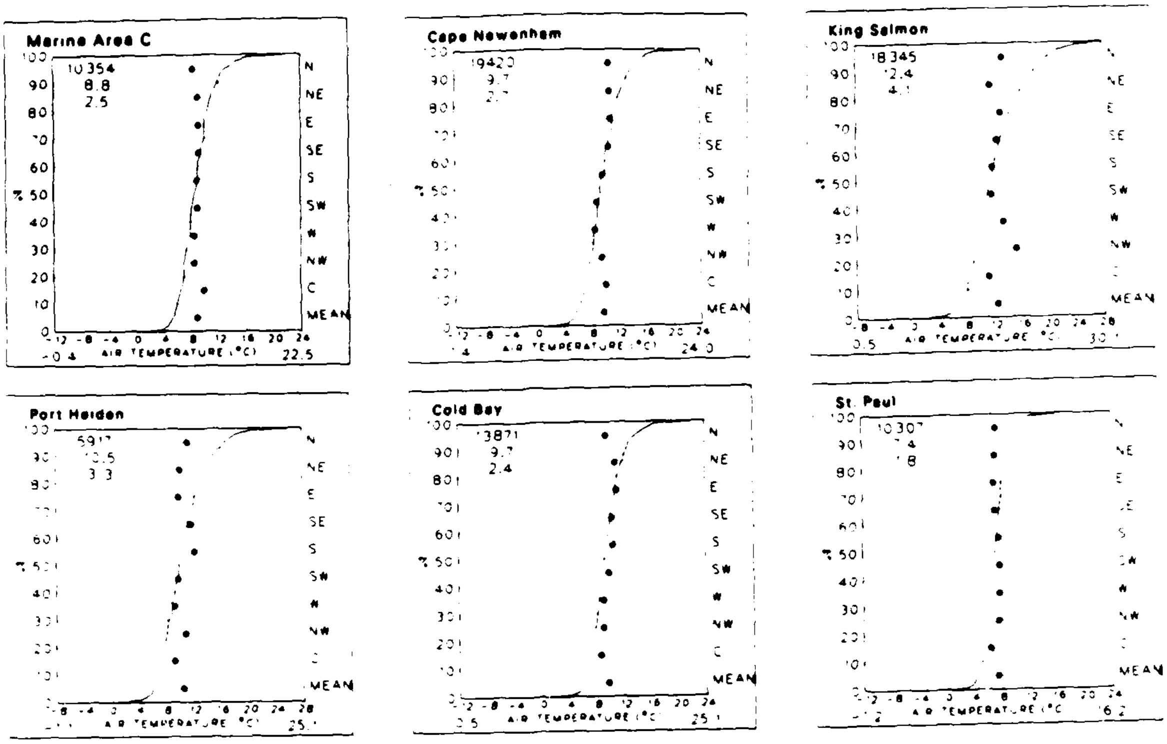
May



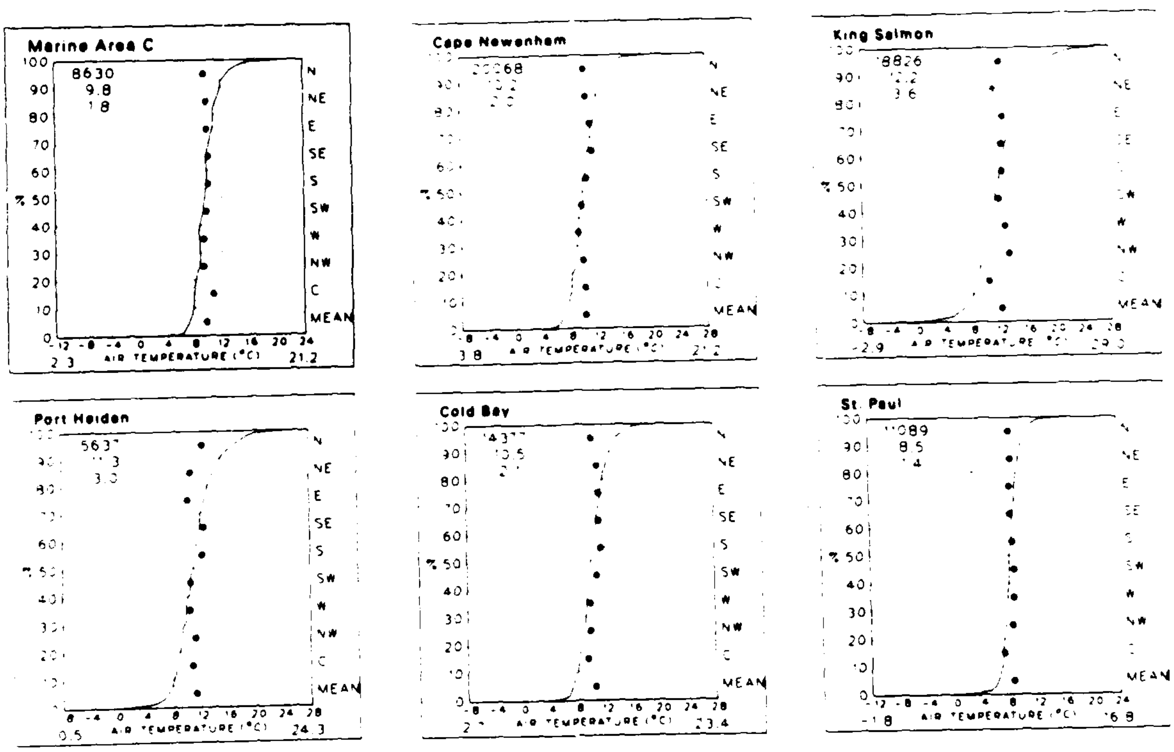
June

Figure 23c

Air Temperature/Wind Direction



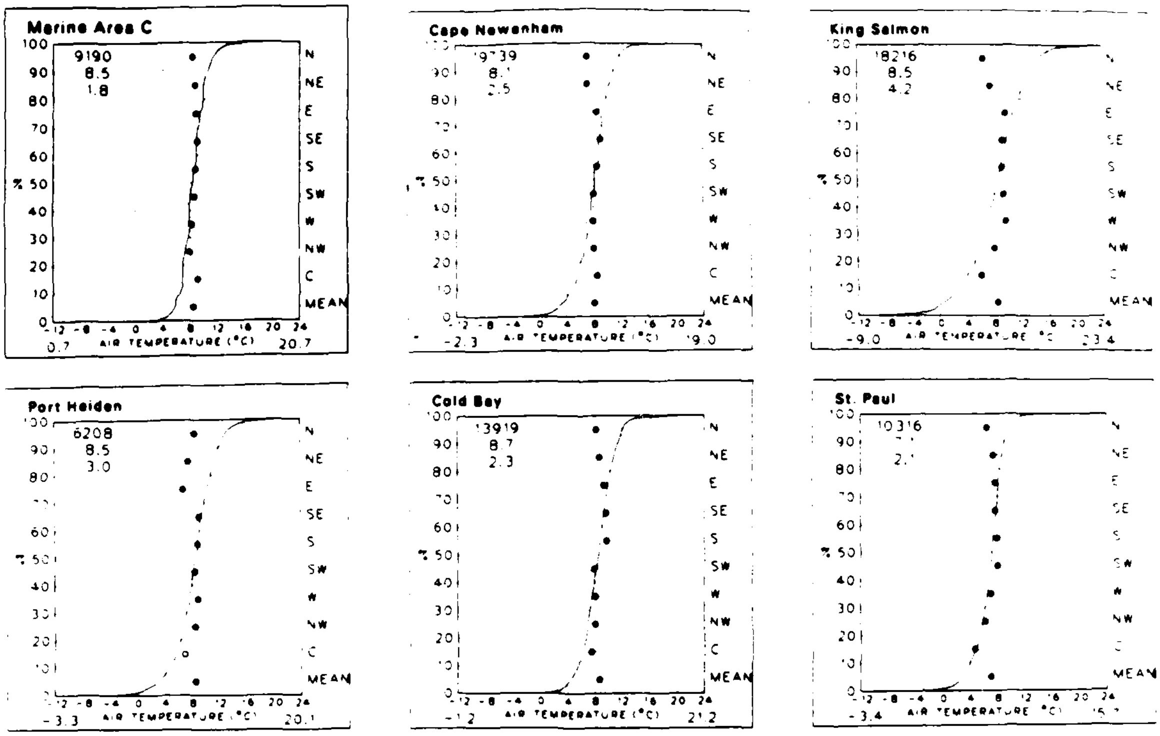
July



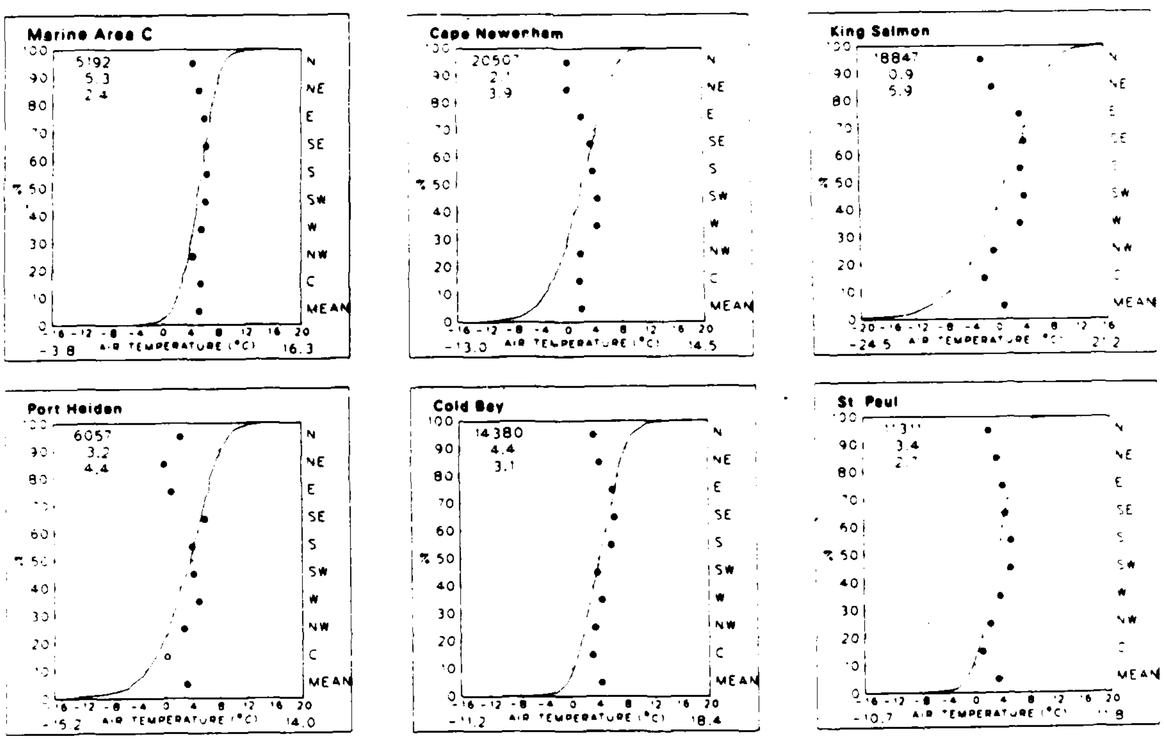
August

Figure 23d

Air Temperature/Wind Direction



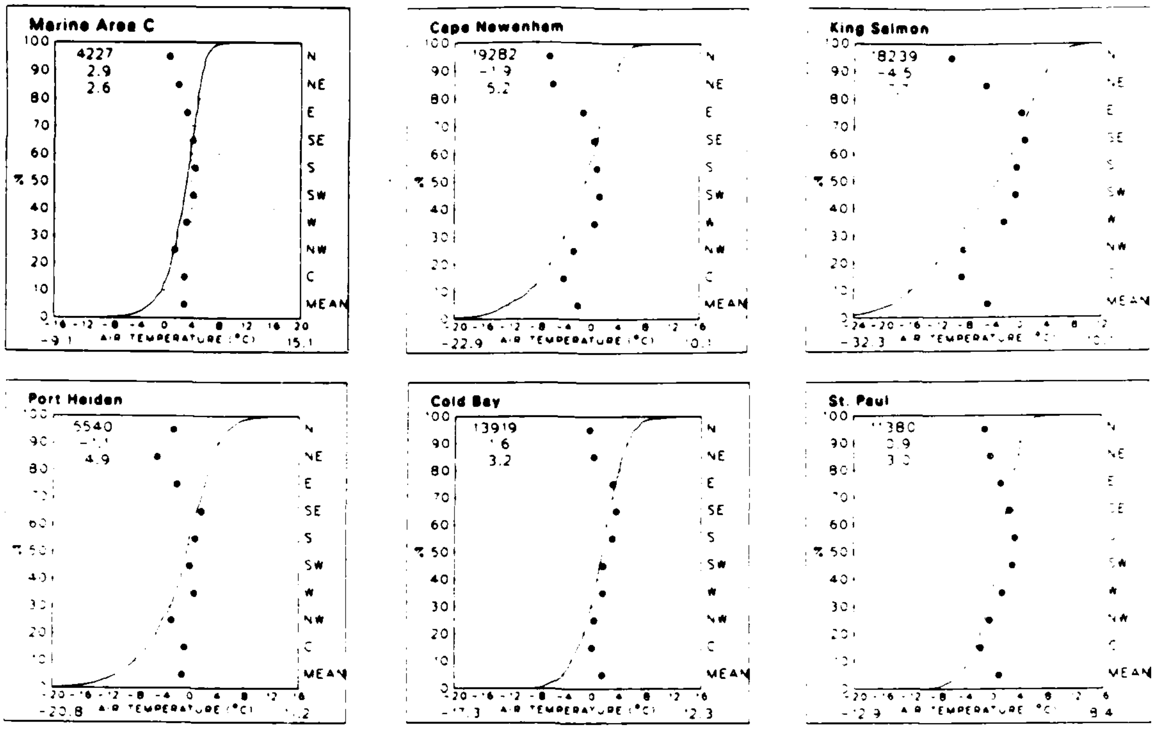
September



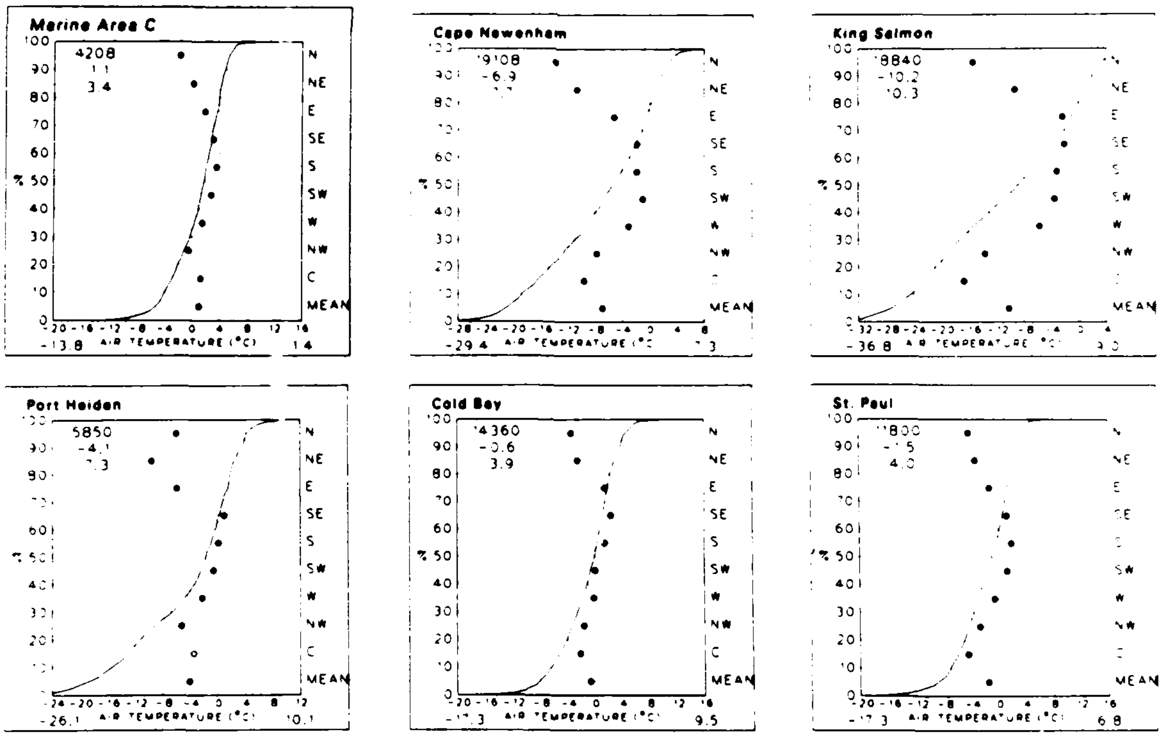
October

Figure 23e

Air Temperature/Wind Direction



November



December

Figure 23f

PRECIPITATION

In the open waters of marine area C on the accompanying graphs (that portion of the Bering Sea between 55° and 60°N latitude and east from 169°W longitude to the coast), we note that frequency of precipitation averages 19% of the time annually with individual months varying from 11% in June to 28% in December. The cold months from November to April show the highest frequency of precipitation, most of which is snow, while from May to October the most frequent precipitation is rain. Snow has occurred in all months except July and August while rain and drizzle occur in all months of the year. A similar pattern prevails at land stations. Heaviest precipitation occurs in late summer and fall with the wettest months either August, September, or October.

Figures 24a-24f indicate the percent frequency of various types of precipitation in Bristol Bay.

Graphs: Precipitation types

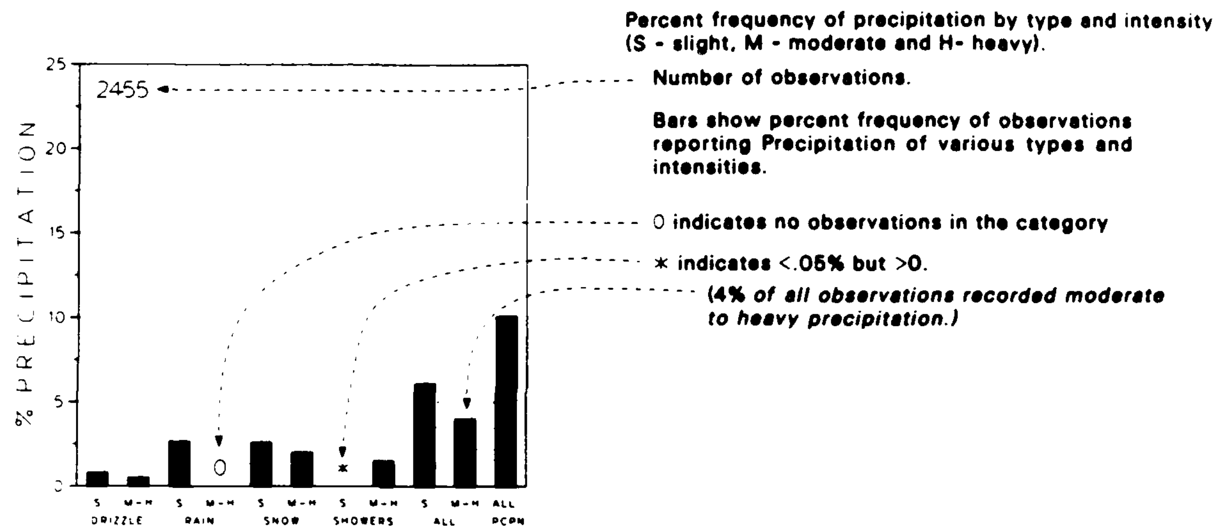
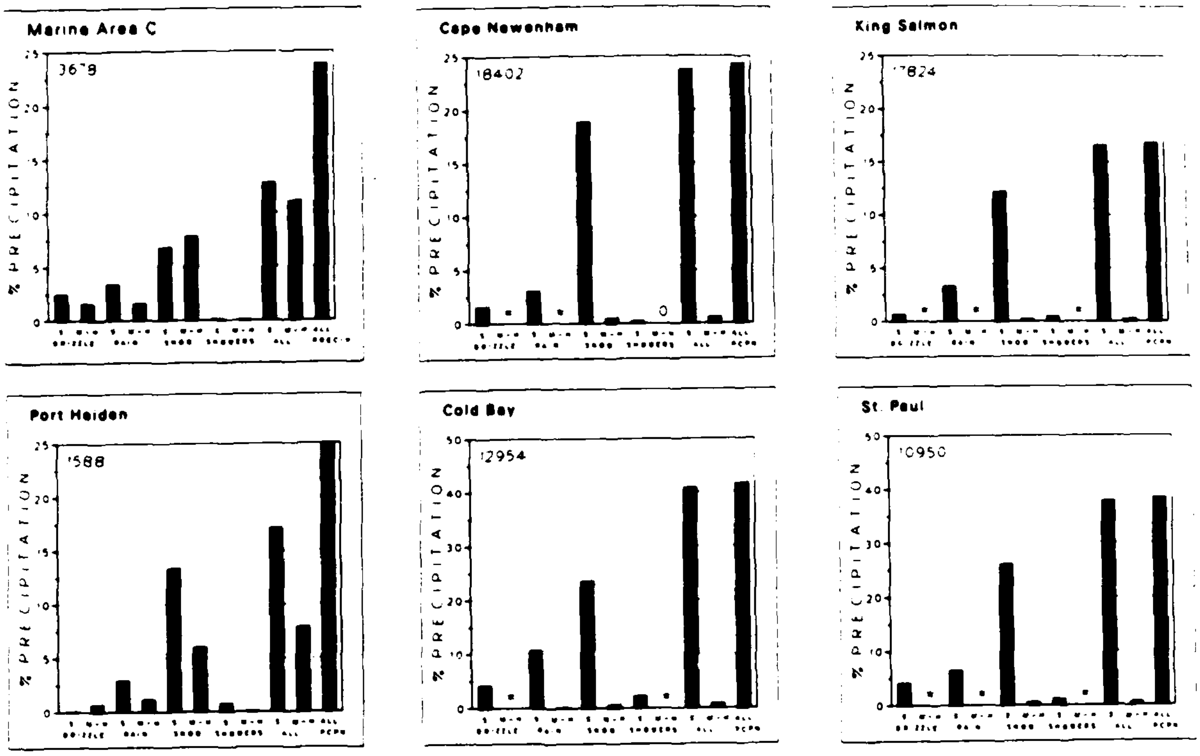
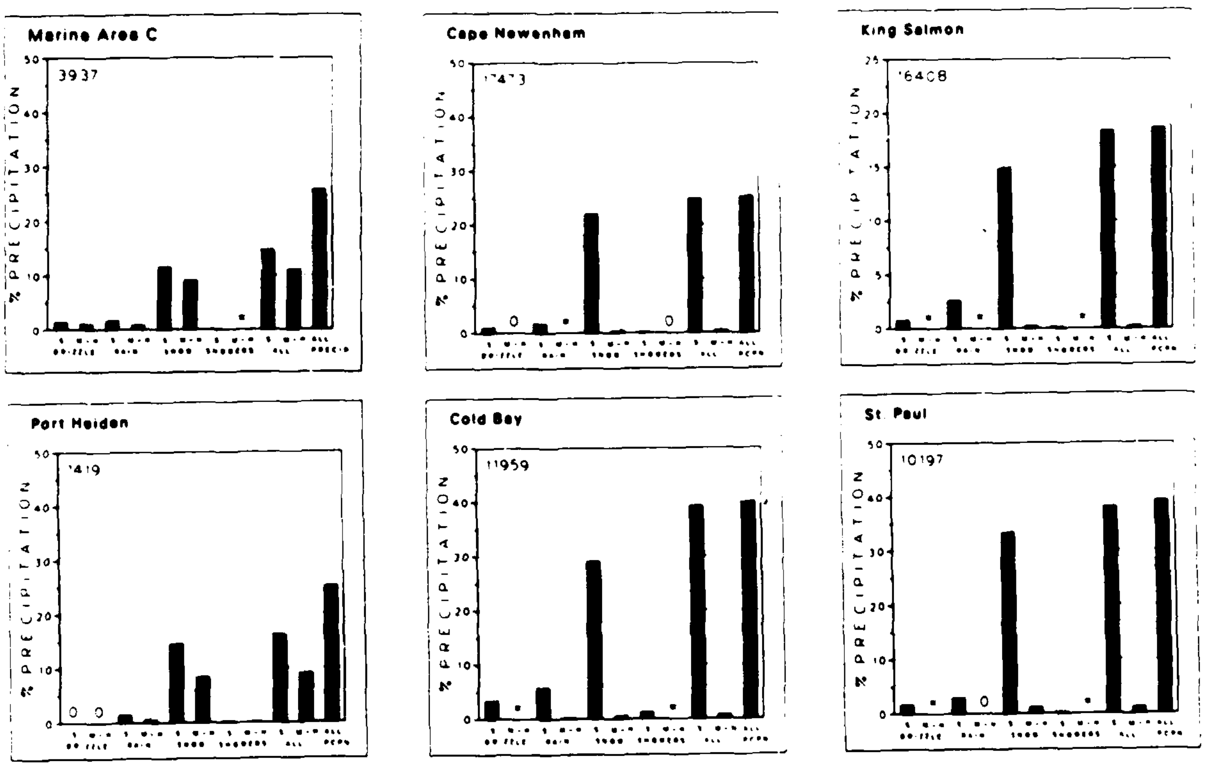


Figure 24 - legend

Precipitation Types



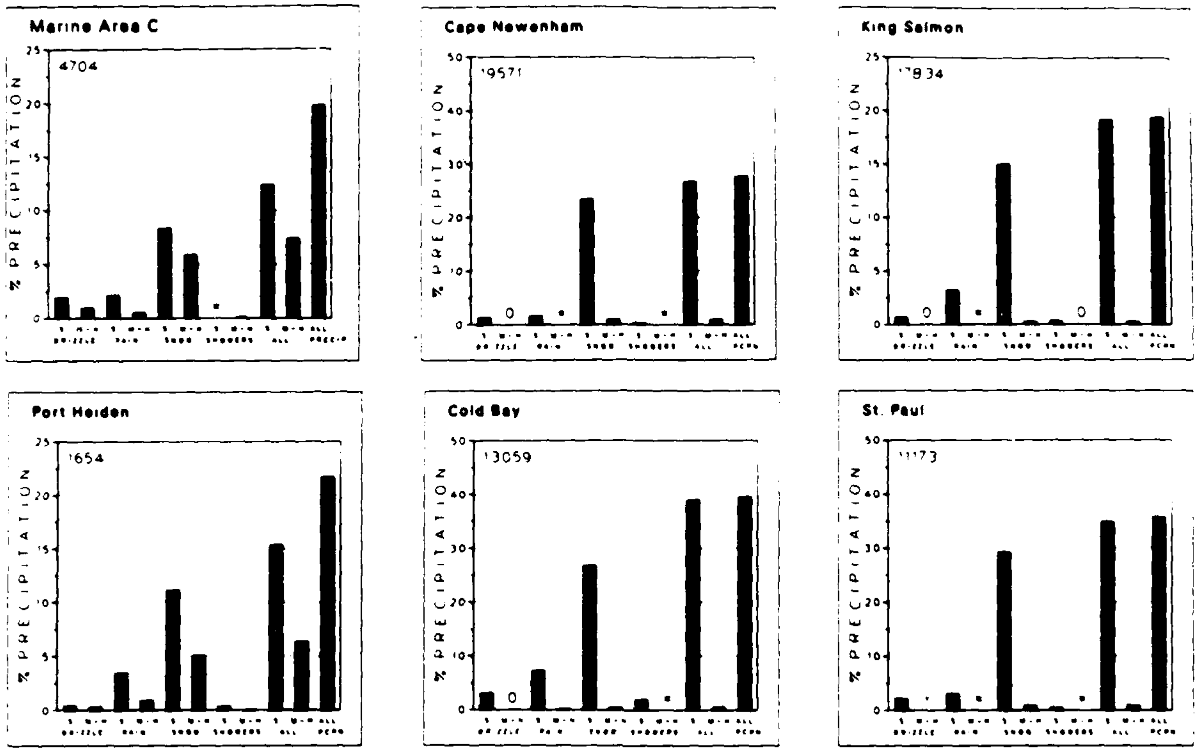
January



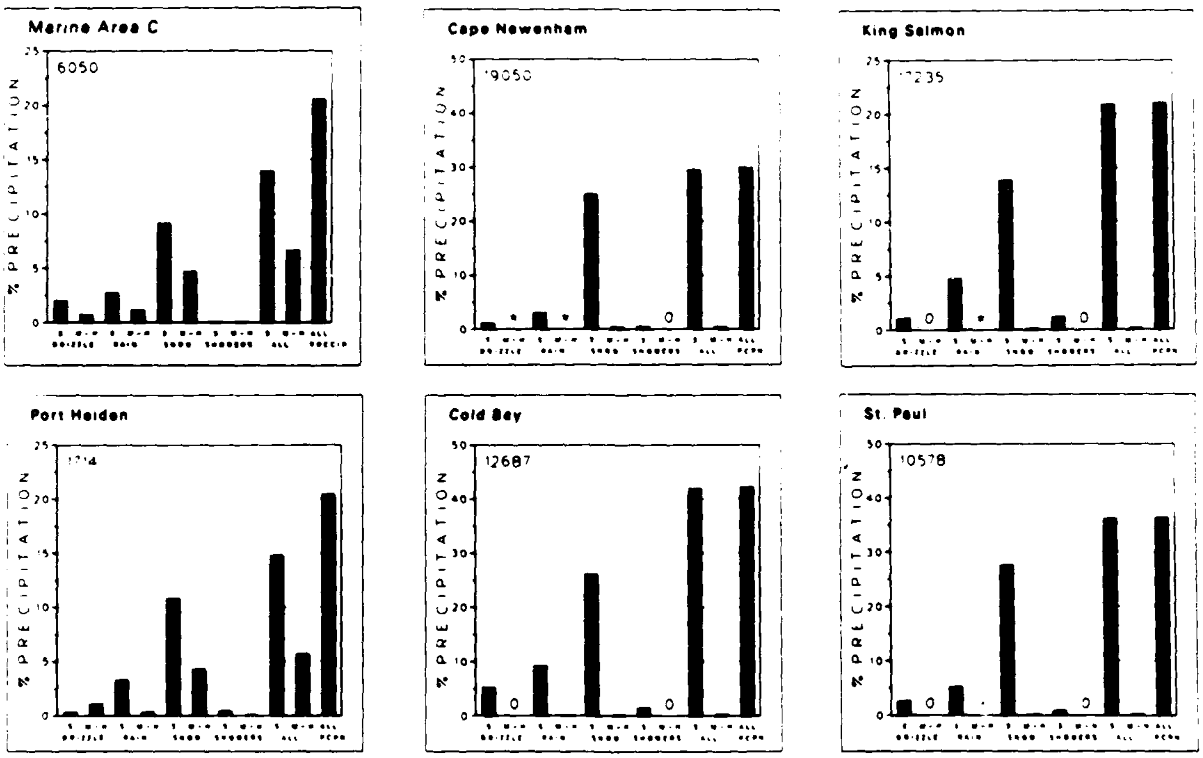
February

Figure 24a

Precipitation Types



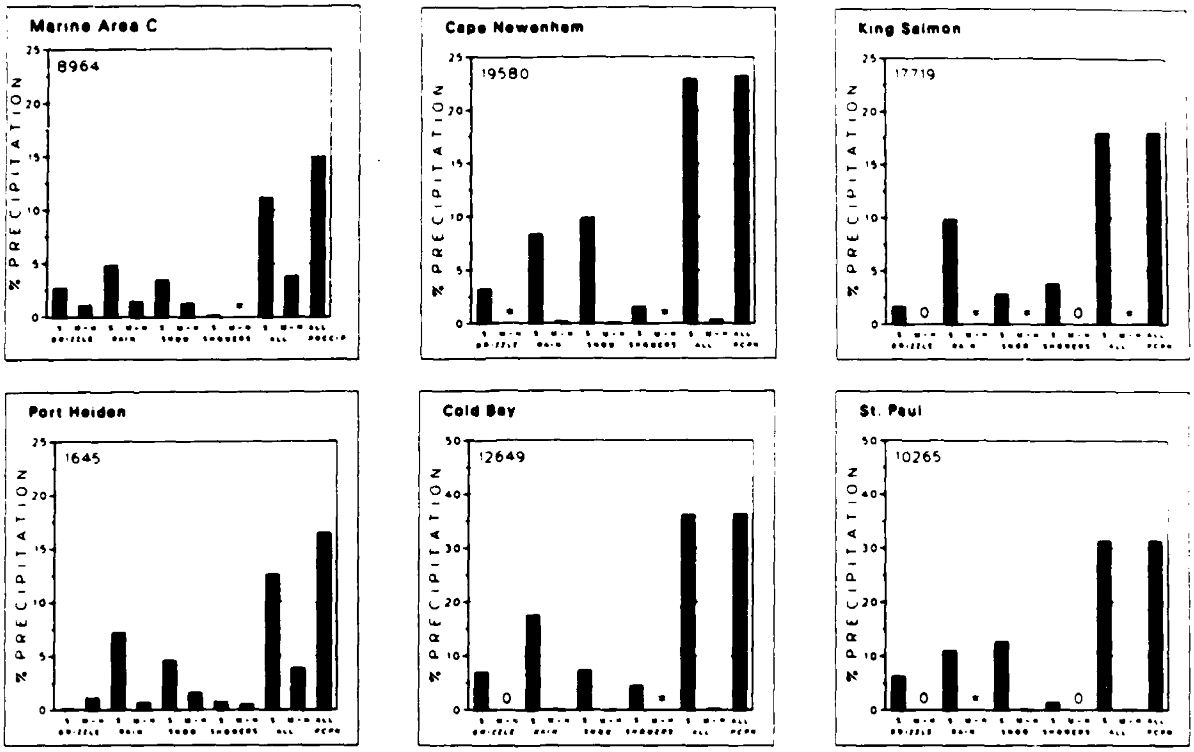
March



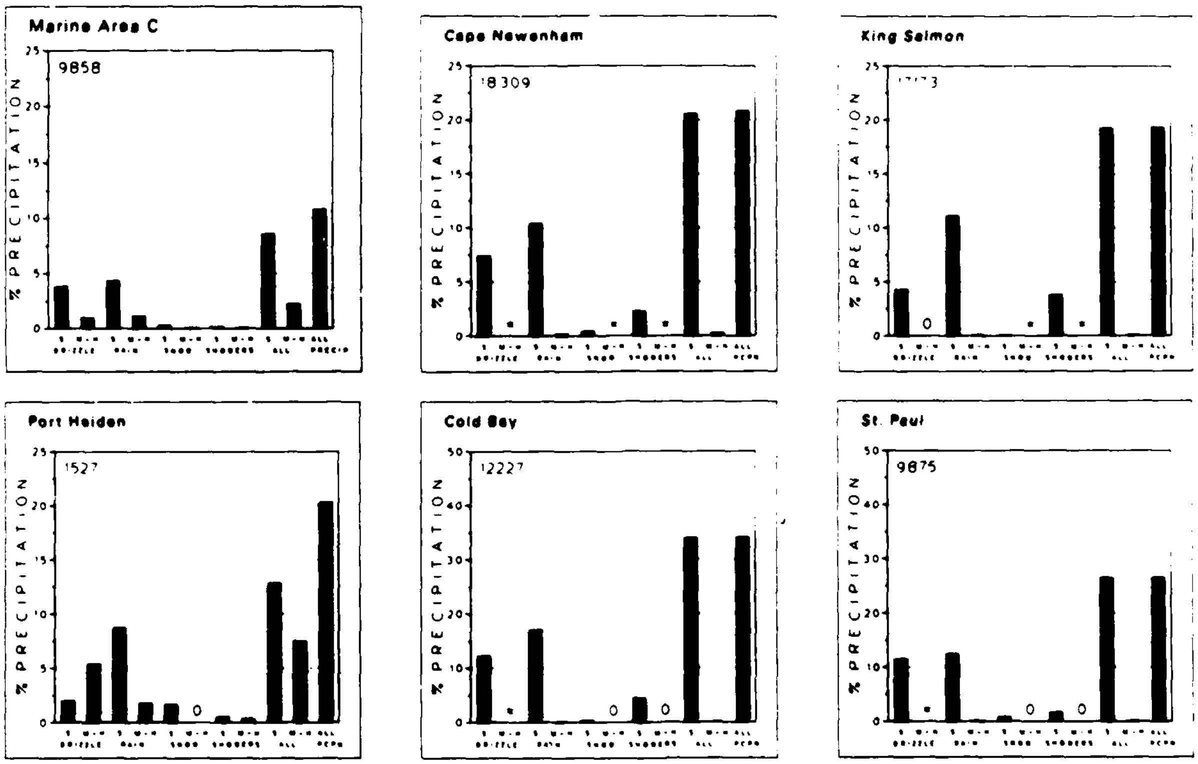
April

Figure 24b

Precipitation Types



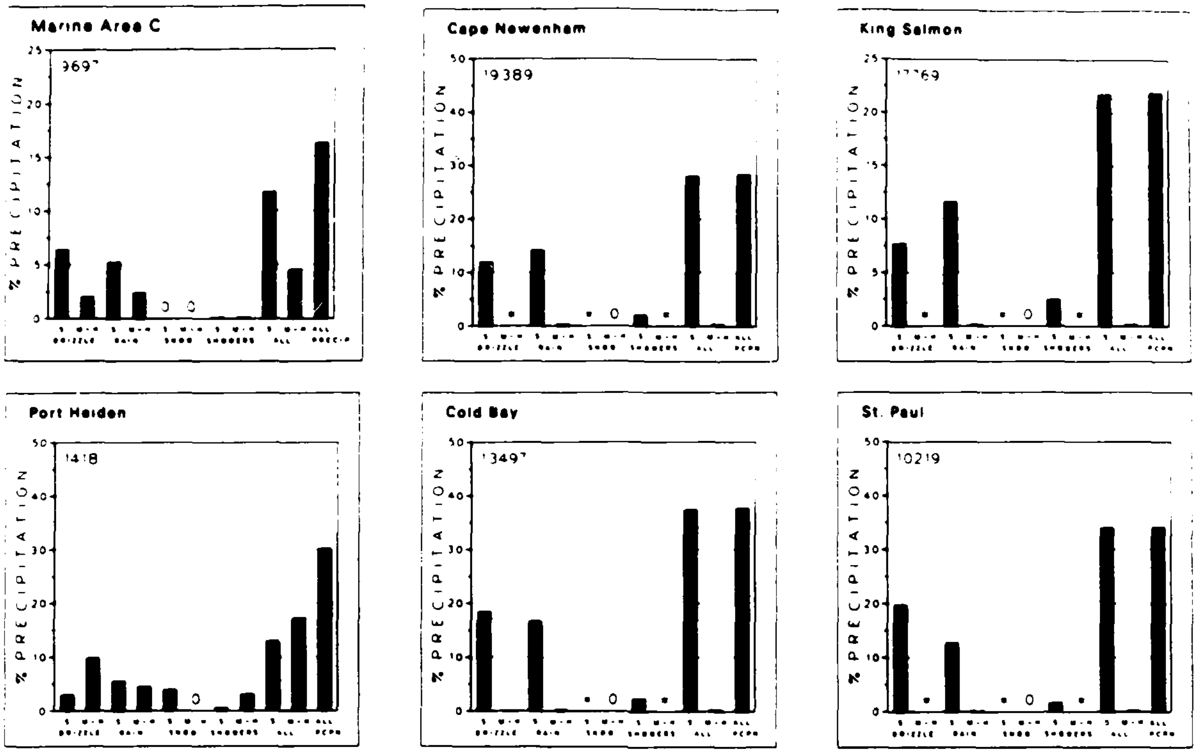
May



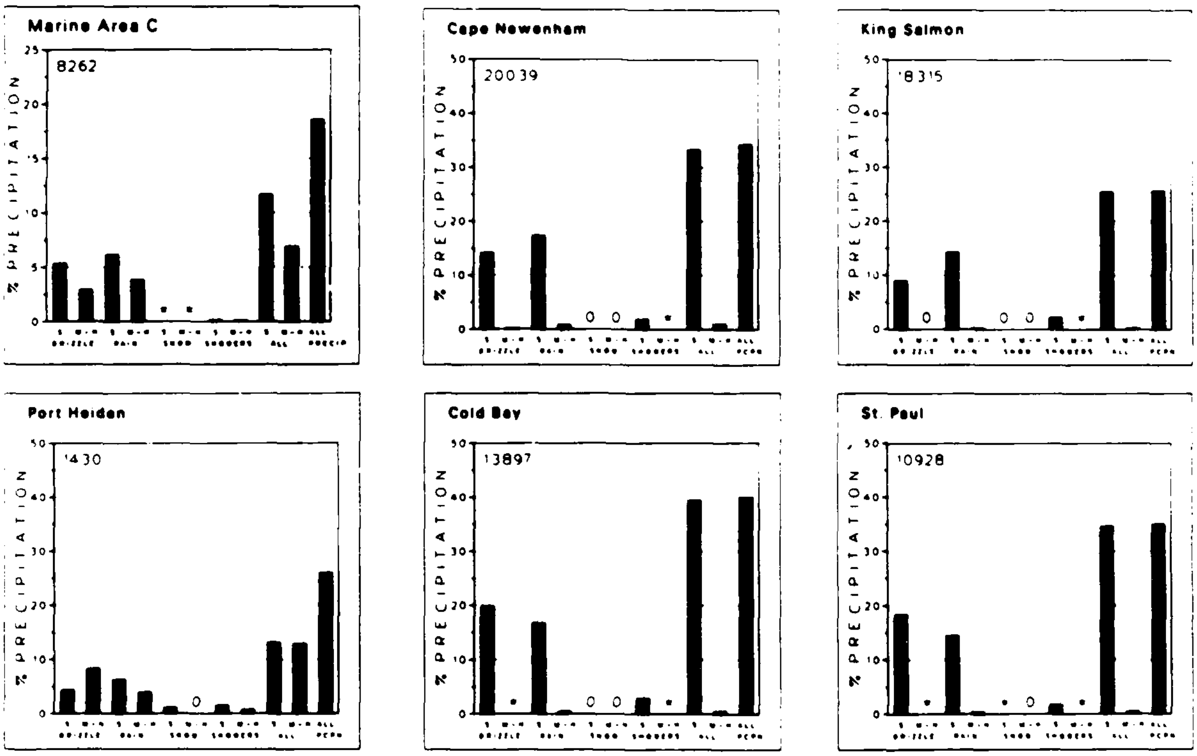
June

Figure 24c

Precipitation Types



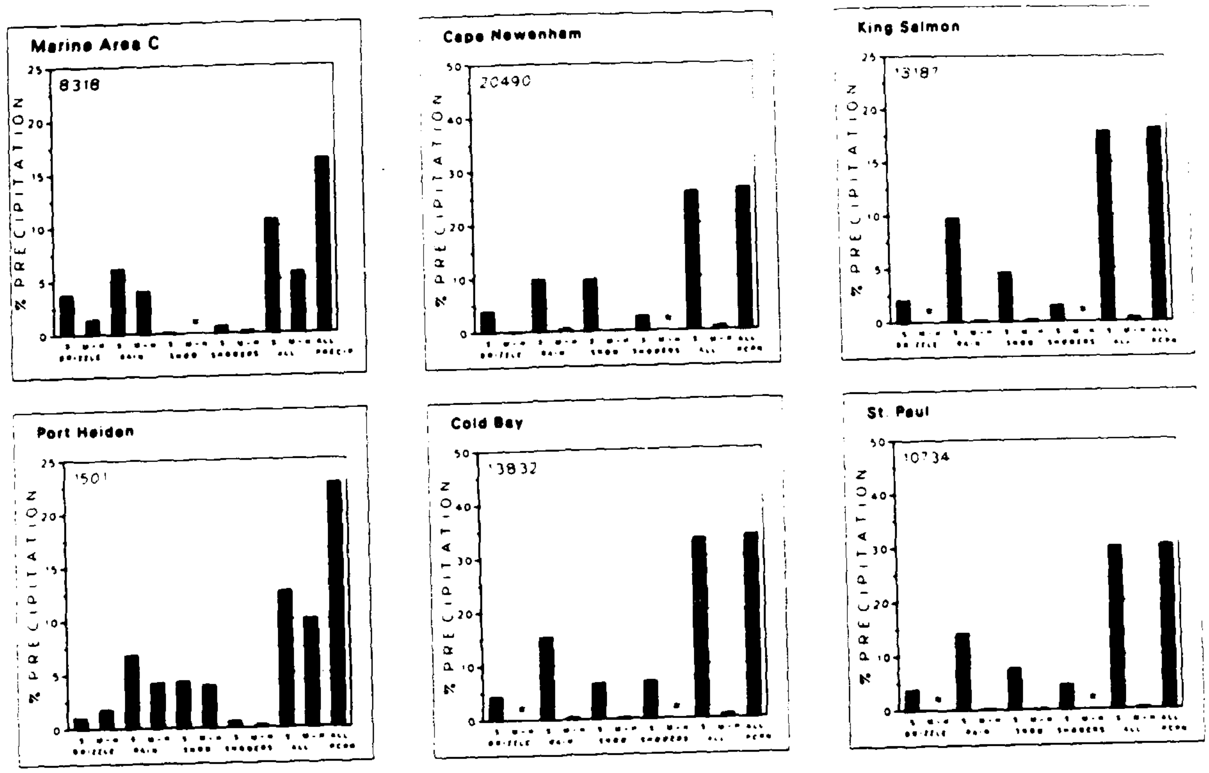
July



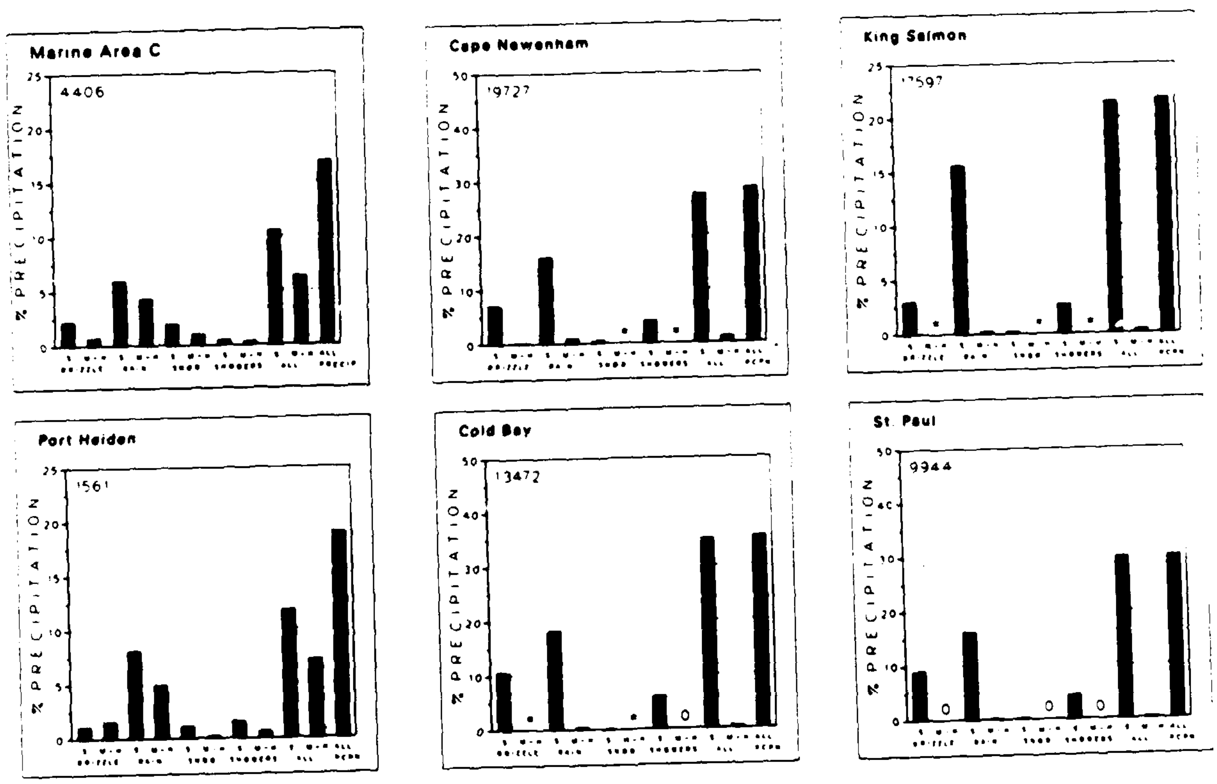
August

Figure 24d

Precipitation Types



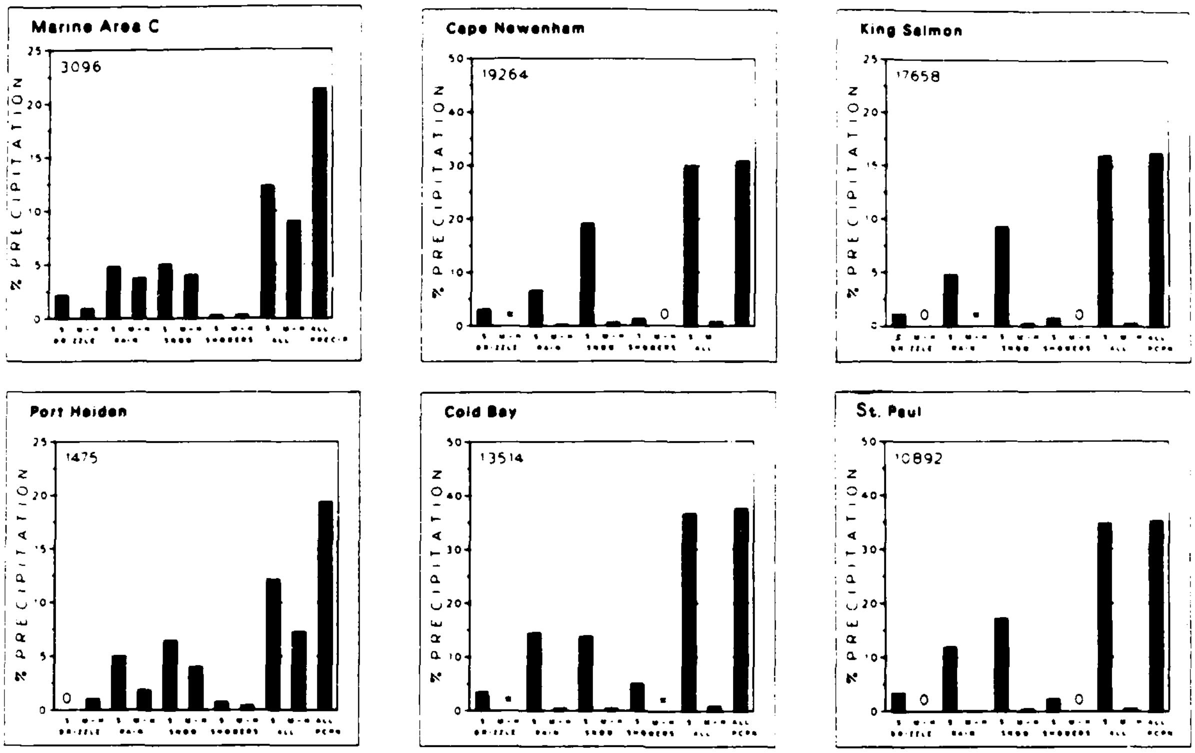
September



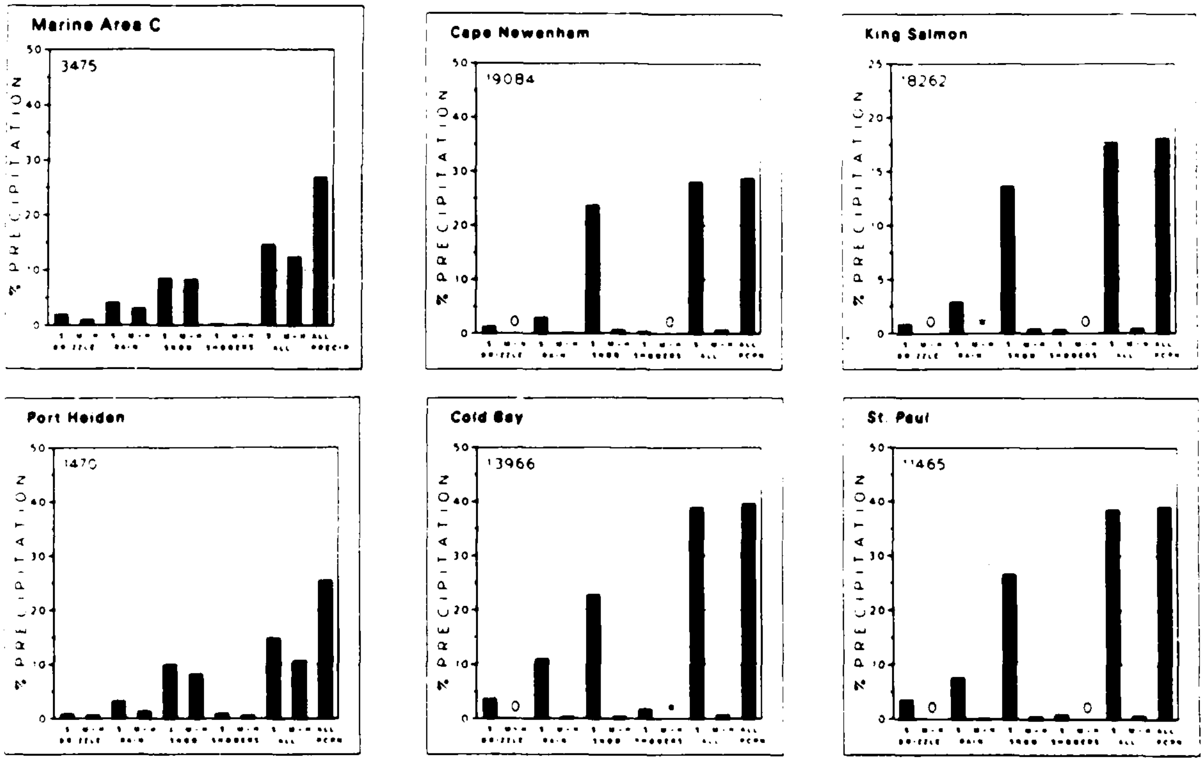
October

Figure 24e

Precipitation Types



November



December

Figure 24f

Wind Equivalent-Beaufort Scale

Table A10-5. Wind Equivalent--Beaufort Scale

Beaufort Number	MPH	Knots	International Description	Specifications
0	Less than 1	Less than 1	Calm	Calm; smoke rises vertically
1	1- 3	1- 3	Light air	Direction of wind shown by smoke drift but not by wind vanes.
2	4- 7	4- 6	Light Breeze	Wind felt on face; leaves rustle; vanes moved by wind
3	8-12	7-10	Gentle Breeze	Leaves and small twigs in constant motion; wind extends light flag
4	13-18	11-16	Moderate	Raises dust, loose paper; small branches moved
5	19-24	17-21	Fresh	Small trees in leaf begin to sway; crested wavelets form on inland waters
6	25-31	22-27	Strong	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty
7	32-38	28-33	Near gale	Whole trees in motion; inconvenience felt walking against wind
8	39-46	34-40	Gale	Breaks twigs off trees; impedes progress
9	47-54	41-47	Strong gale	Slight structural damage occurs
10	55-63	48-55	Storm	Trees uprooted; considerable damage occurs
11	64-72	56-63	Violent storm	Widespread damage
12	73-82	64-71	Hurricane	

Federal Meteorological Handbook No.1, Surface Observations, CH10 Wind, Page A10-11.

Figure 25

WIND

Wind data from marine area C (that portion of the Bering Sea between 55° and 60°N latitude and east from 169°W longitude to the coast) shown on the following wind speed/direction graphs do not show a strong preference for any direction at any time during the year. However, there is a preference for winds northwest to north to northeast in the cool part of the year from September through June with west and southwest directions prevailing in July and August. Over the open water wind speeds average 16.1 knots annually varying from 19.1 knots in November down to 13.8 knots in August.

At coastal and island stations in the Bristol Bay area, wind speeds are somewhat less varying from an annual speed of 9.2 knots at King Salmon to 15.0 knots at St. Paul. Prevailing winds show a pattern of northerly in winter and southerly to westerly in summer except where local terrain channels wind, like Cold Bay. As over the open water winds tend to be strongest in winter and least in summer. Note that in the following map set, winds greater than 34 knots occur up to 5% of the time in the west portion of the area from October through February, with no occurrences from March to September. Moderate winds 22-33 knots occur over 20% of the time October to April in the west end of the area dropping off to less than 10% at the east end of the bay. Winds less than 11 knots occur up to 20% of the time in July and August in eastern portions of Bristol Bay and down to 20% at the west end of the area in November.

Figure 25 presents the Beaufort Scale, a visual wind equivalent scale.

Figures 26a-26f show the wind speed and wind direction.

Figures 27a-27c show the occurrence of winds exceeding 35 kts and those less than 10 kts.

Figures 28a-28c show the occurrence of winds in the ranges of 11-21 kts and 22-23 kts.

Graphs: Wind speed/direction

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

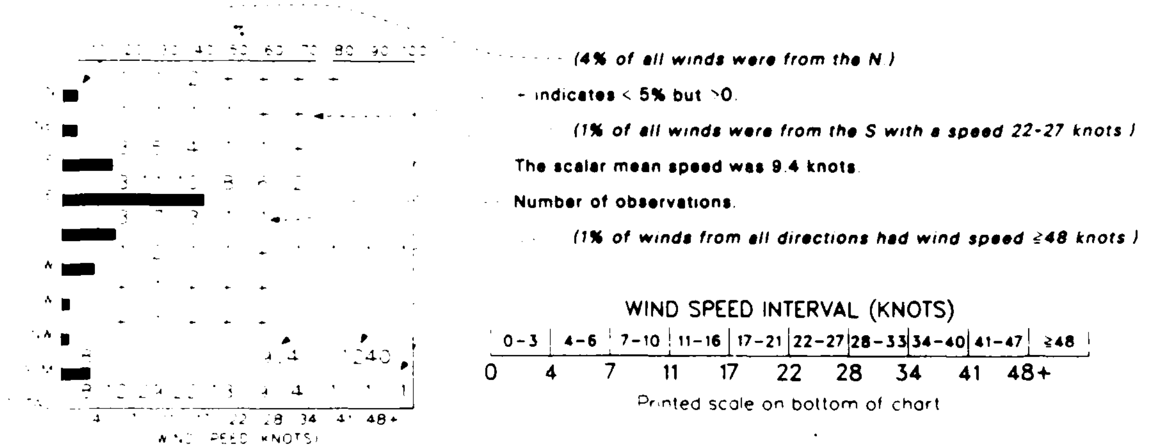
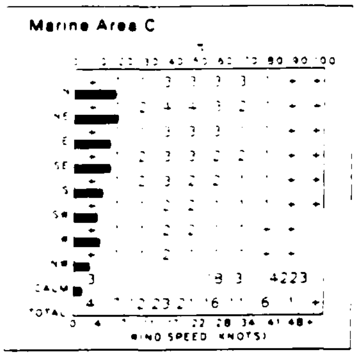
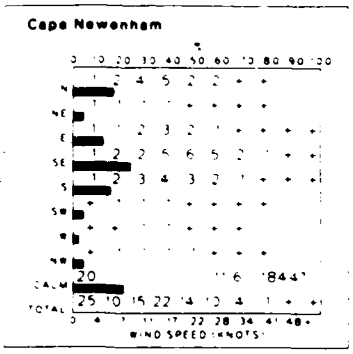
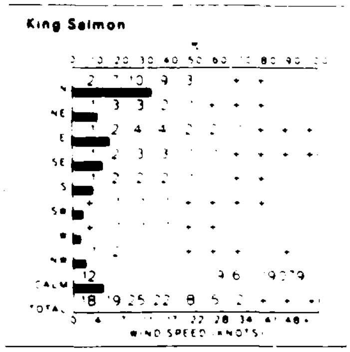


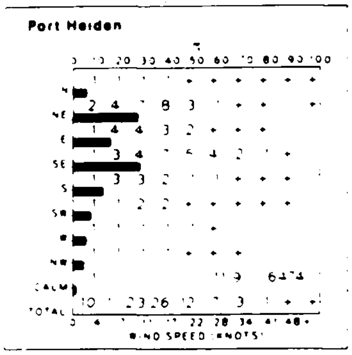
Figure 26 - legend

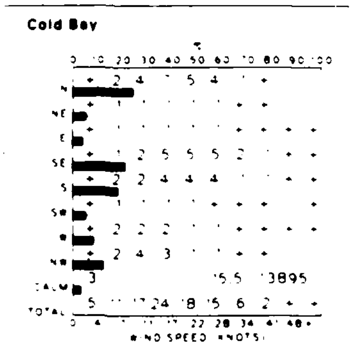
Wind Speed/Direction

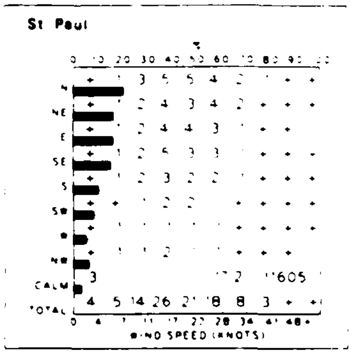




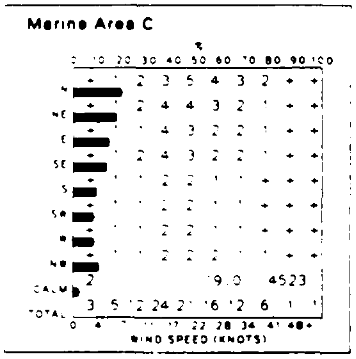


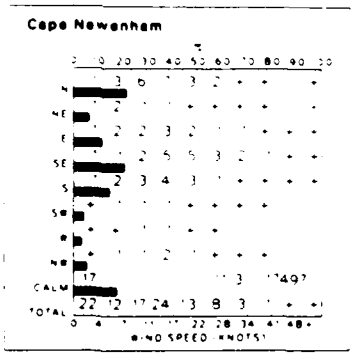


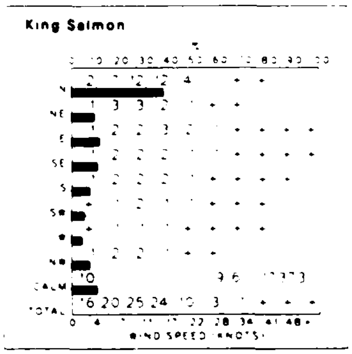


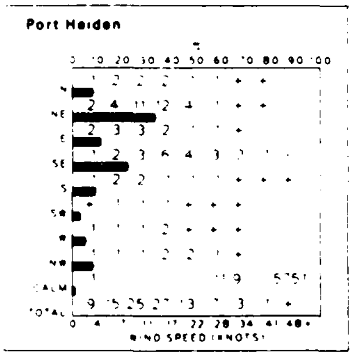


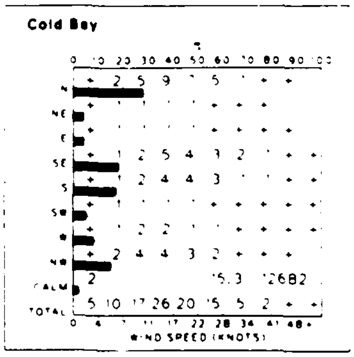
January

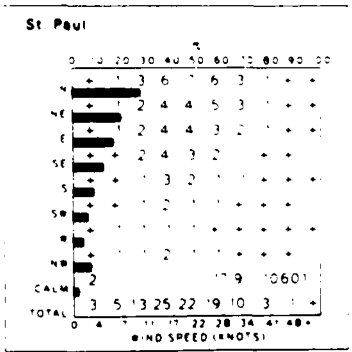








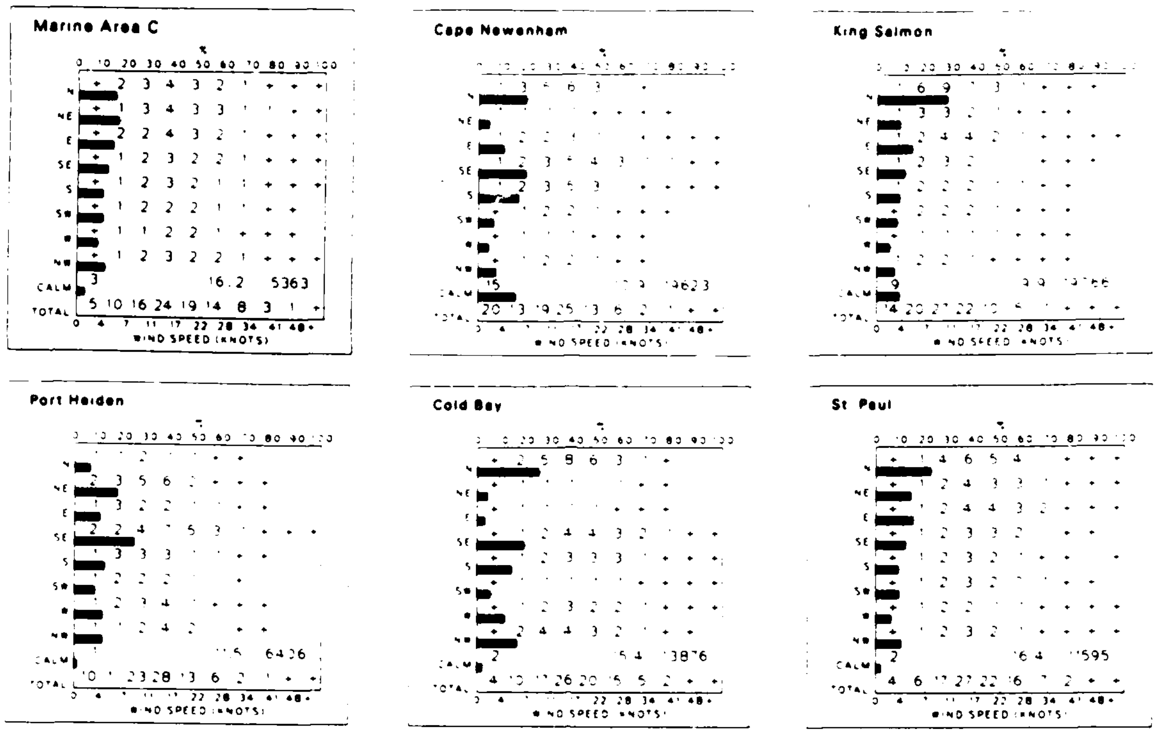




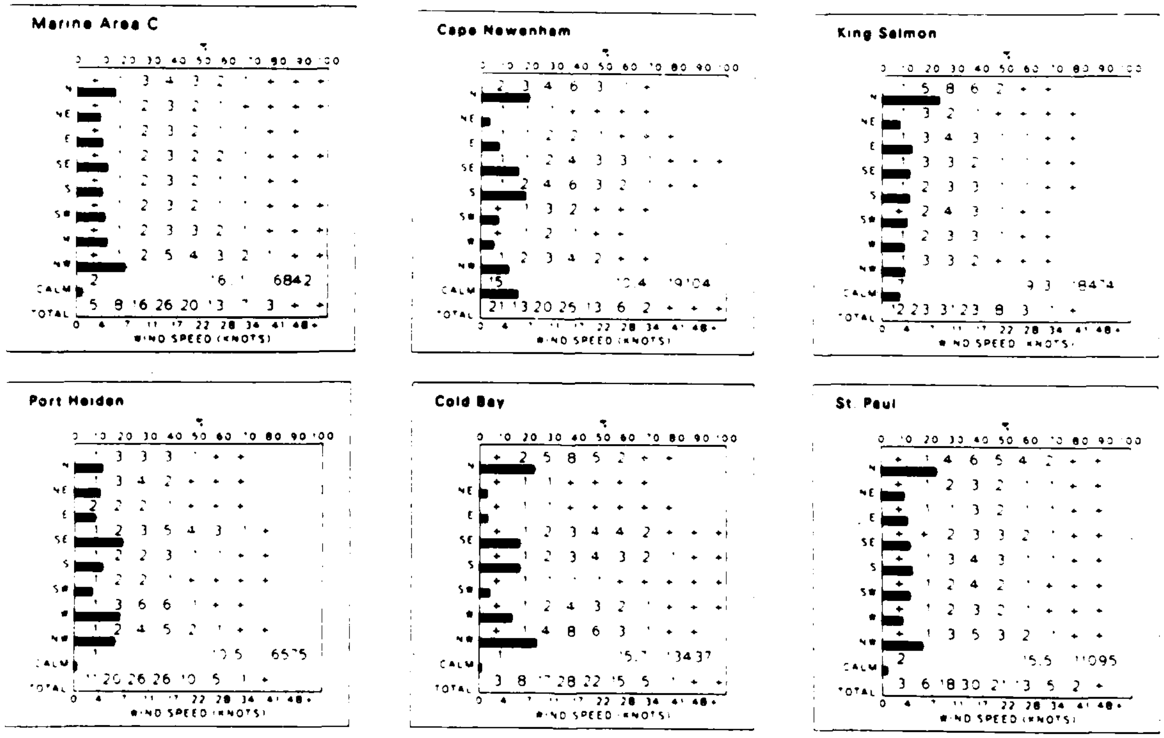
February

Figure 26a

Wind Speed/Direction



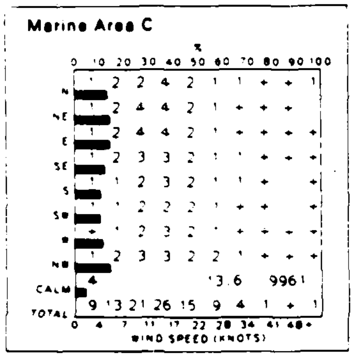
March

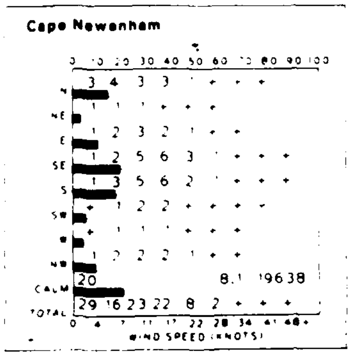


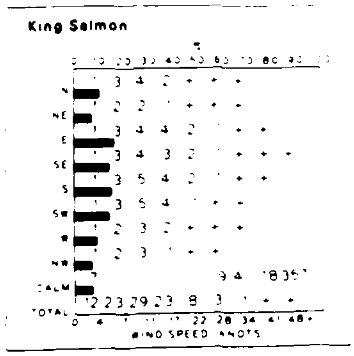
April

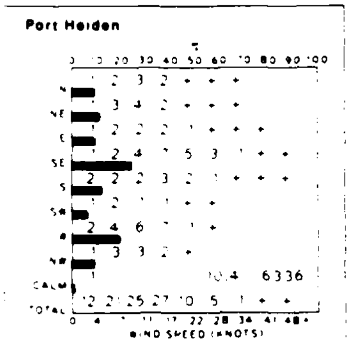
Figure 26b

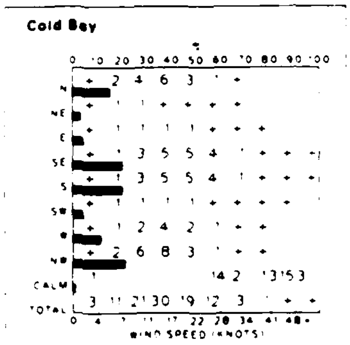
Wind Speed/Direction

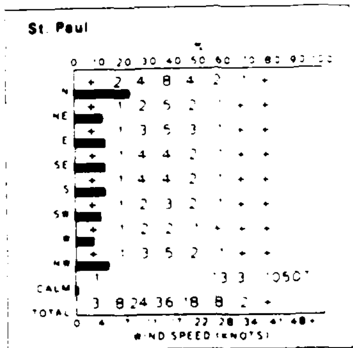




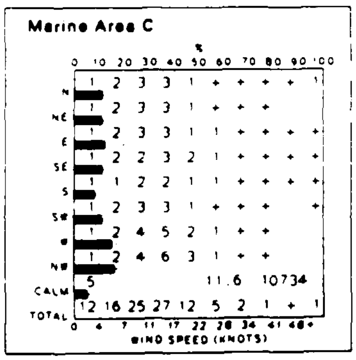


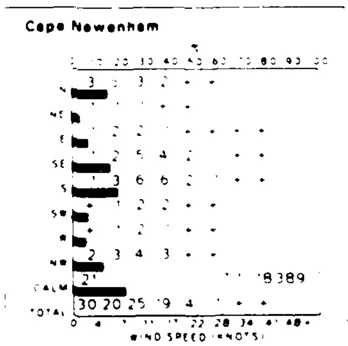


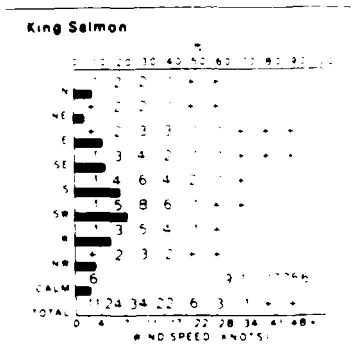


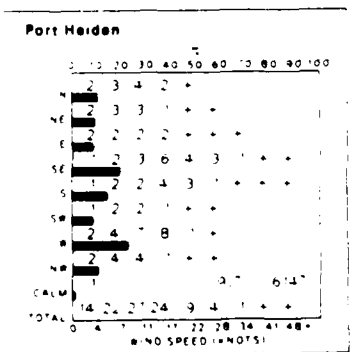


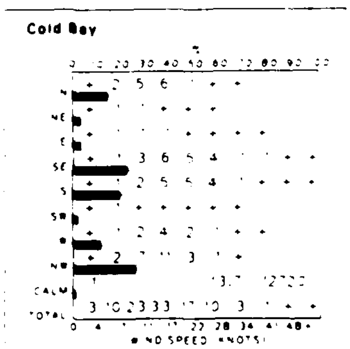
May

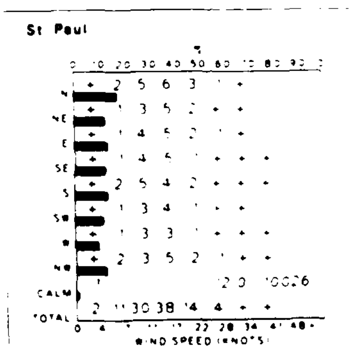








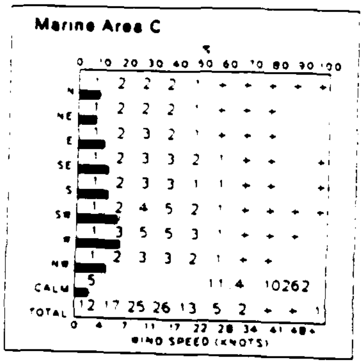


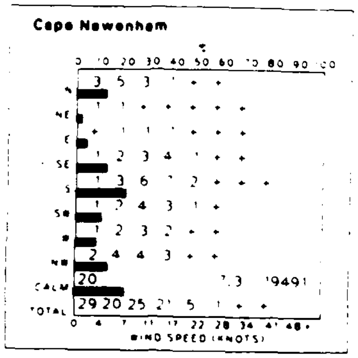


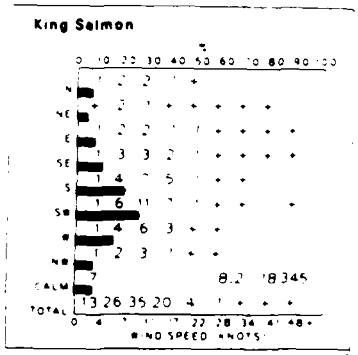
June

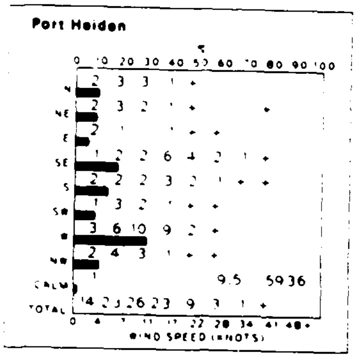
Figure 26c

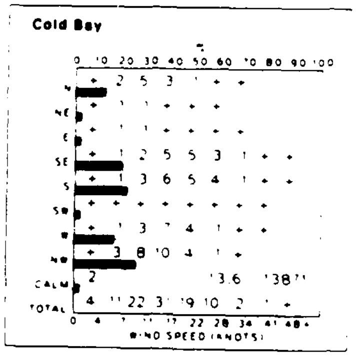
Wind Speed/Direction

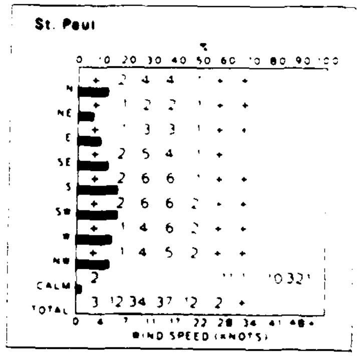




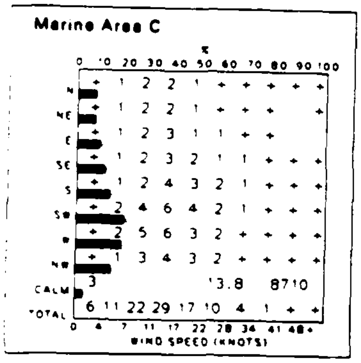


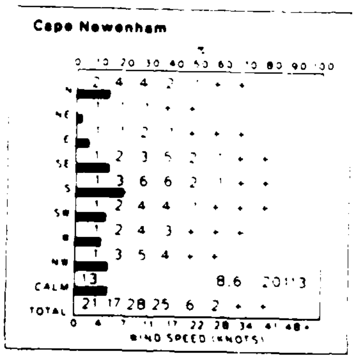


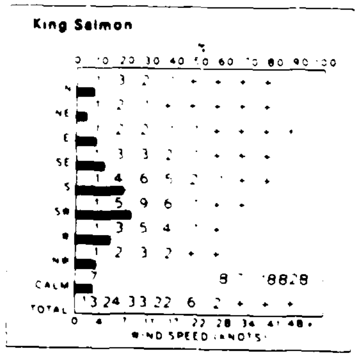


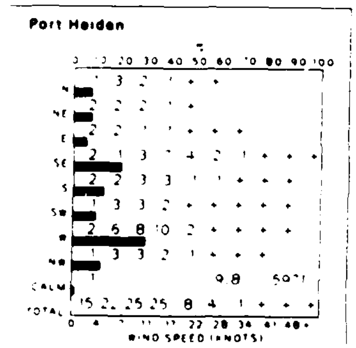


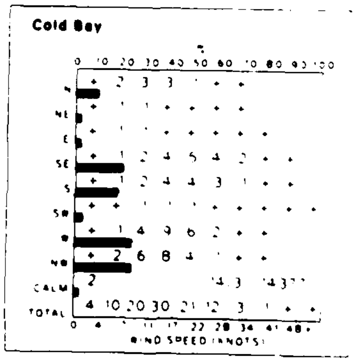
July

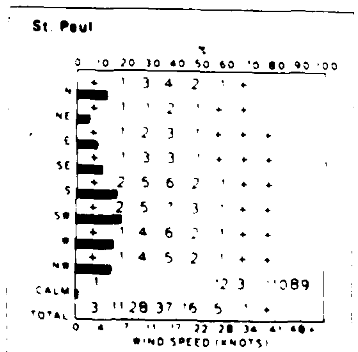








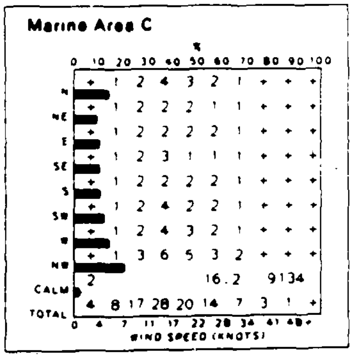


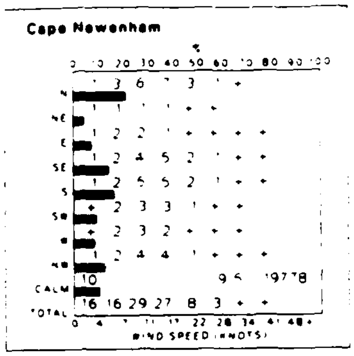


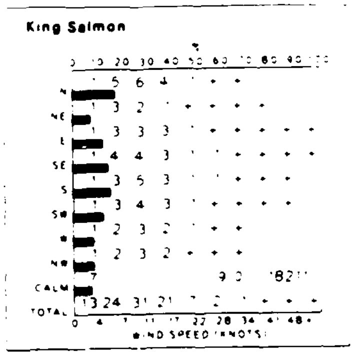
August

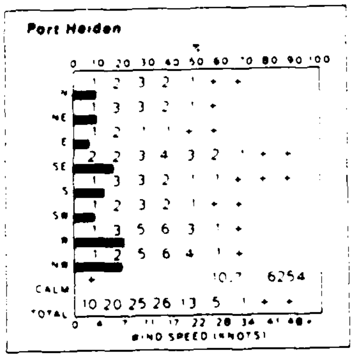
Figure 26d

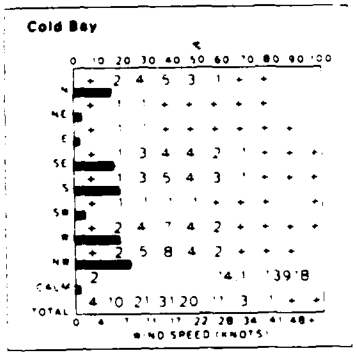
Wind Speed/Direction

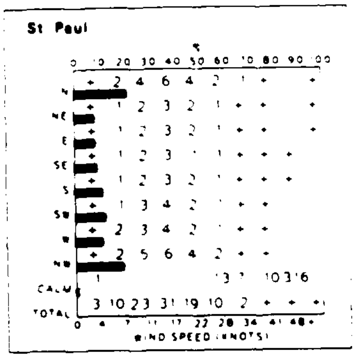




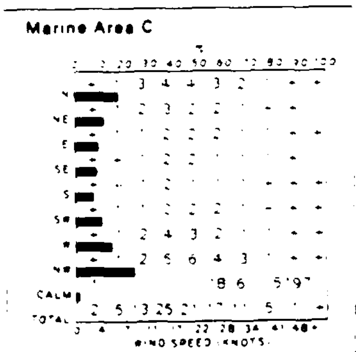


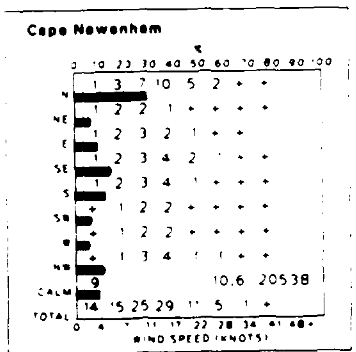


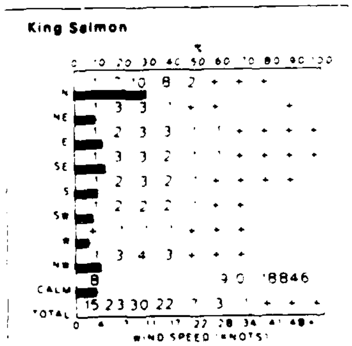


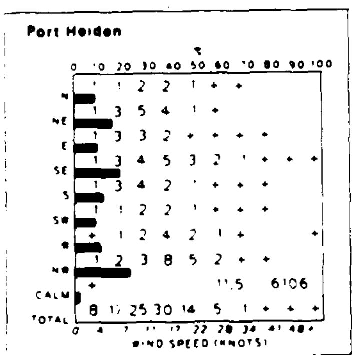


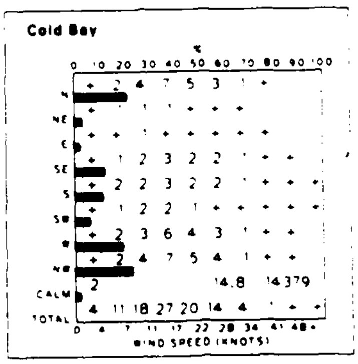
September

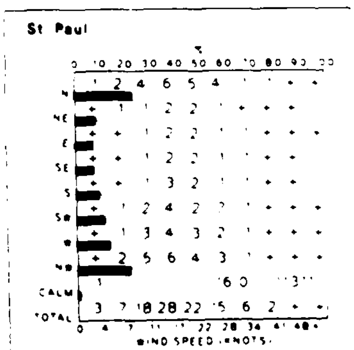








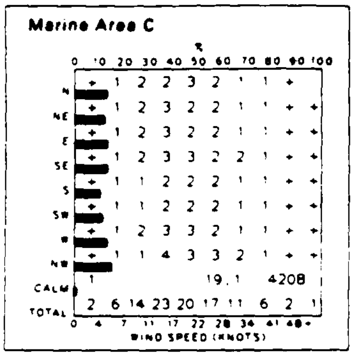


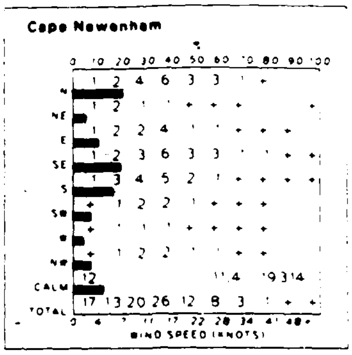


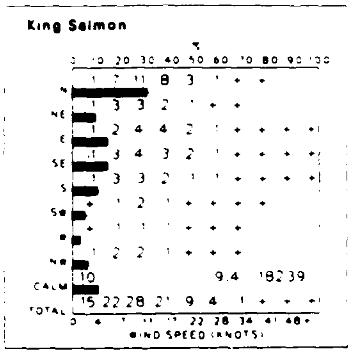
October

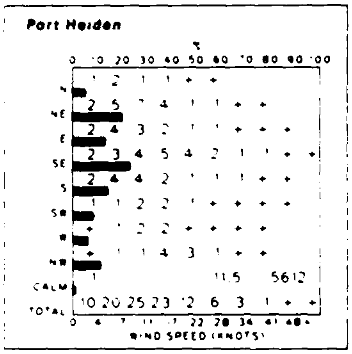
Figure 26e

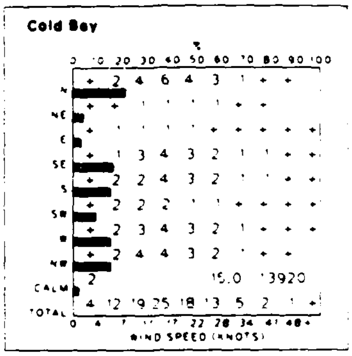
Wind Speed/Direction

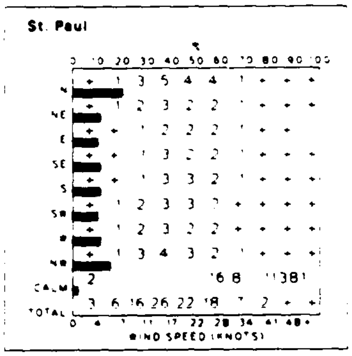




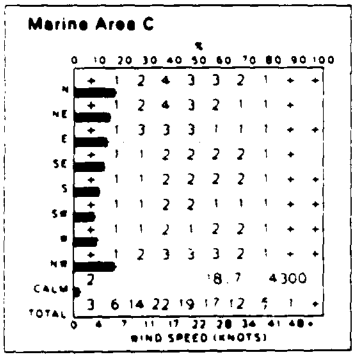


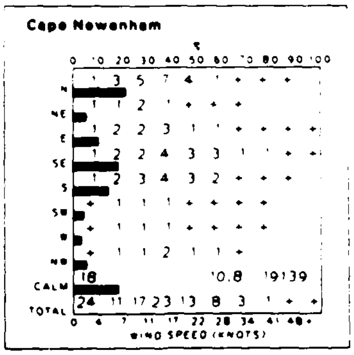


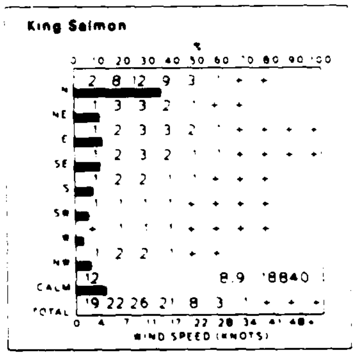


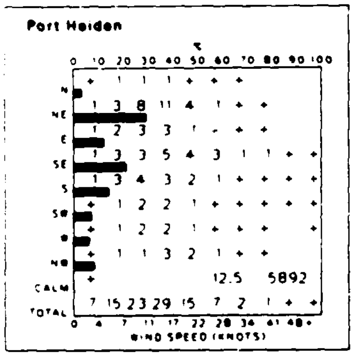


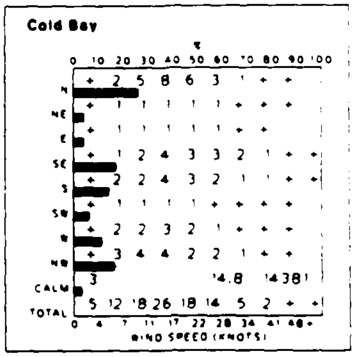
November

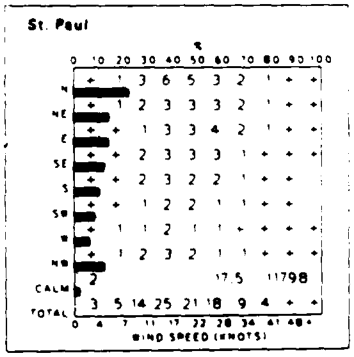








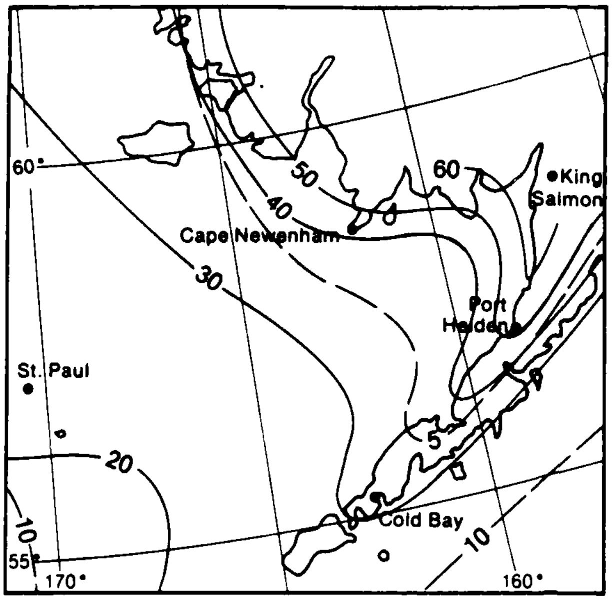




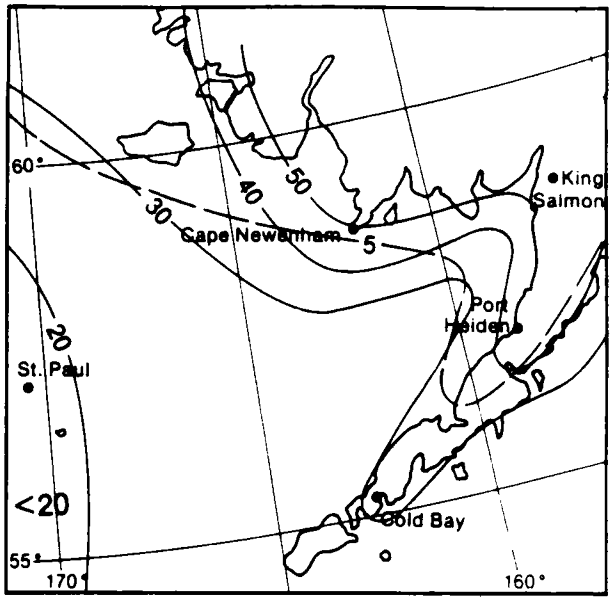
December

Figure 26f

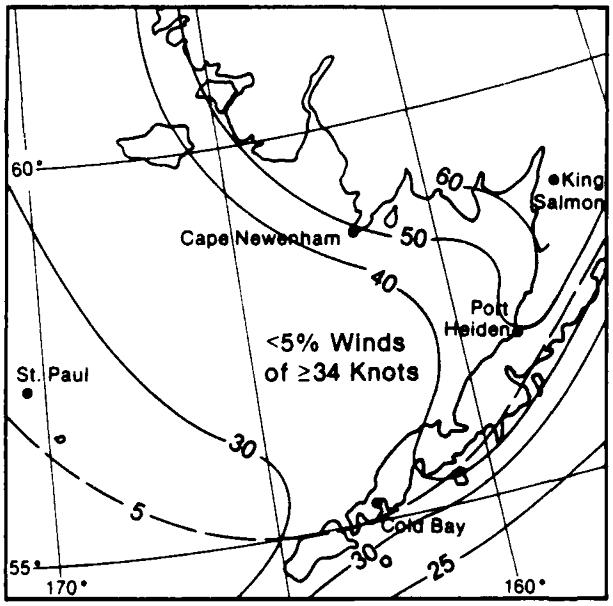
Wind Speed ≤10 Knots and ≥34 Knots



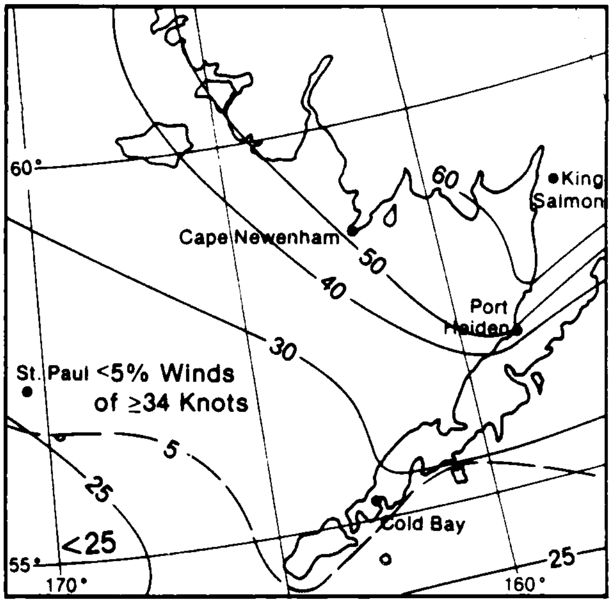
January



February



March



April

Legend

——————— % of Wind ≤10 Knots

— — — — % of Wind ≥34 Knots

Figure 27a

Wind Speed ≤10 Knots and ≥34 Knots

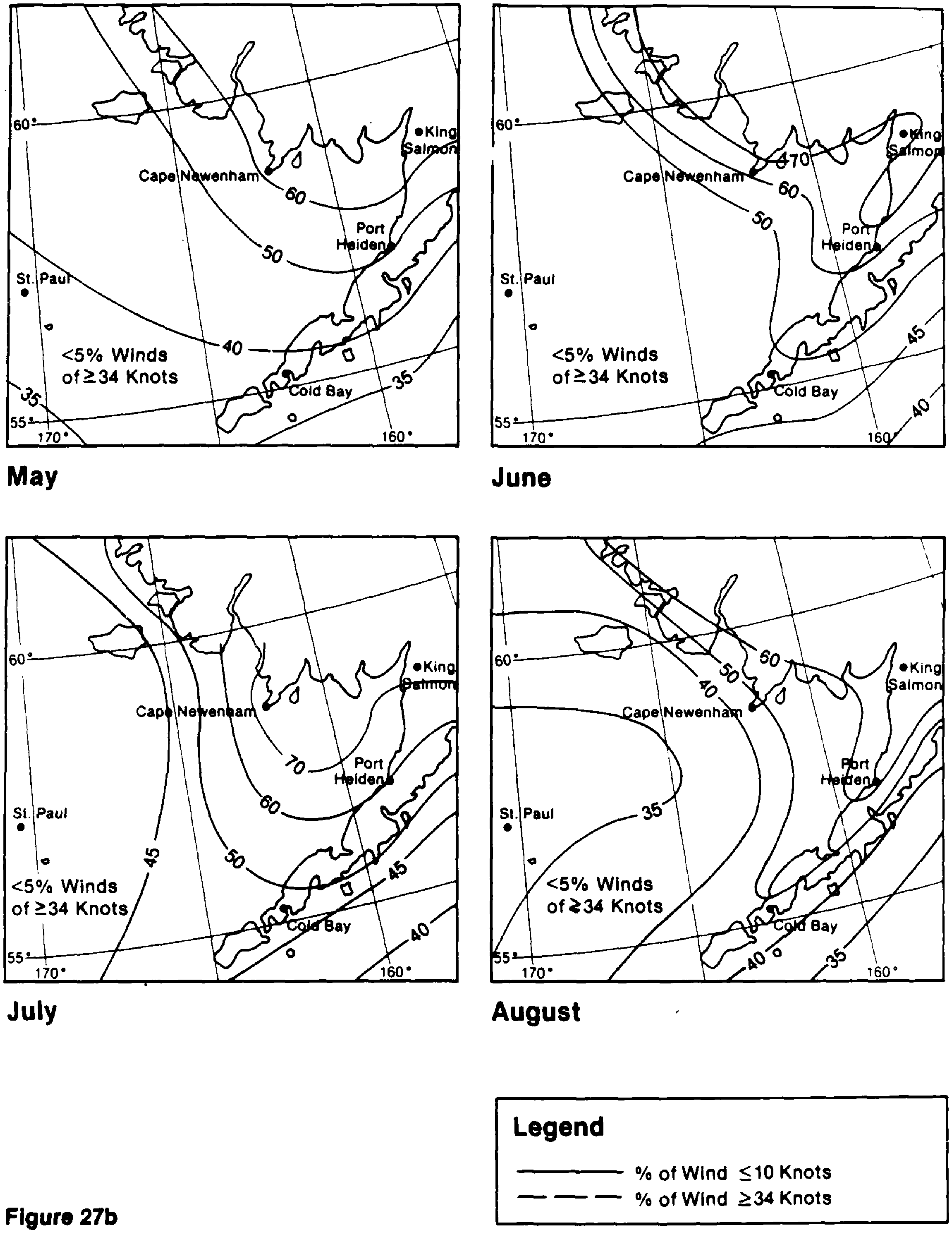
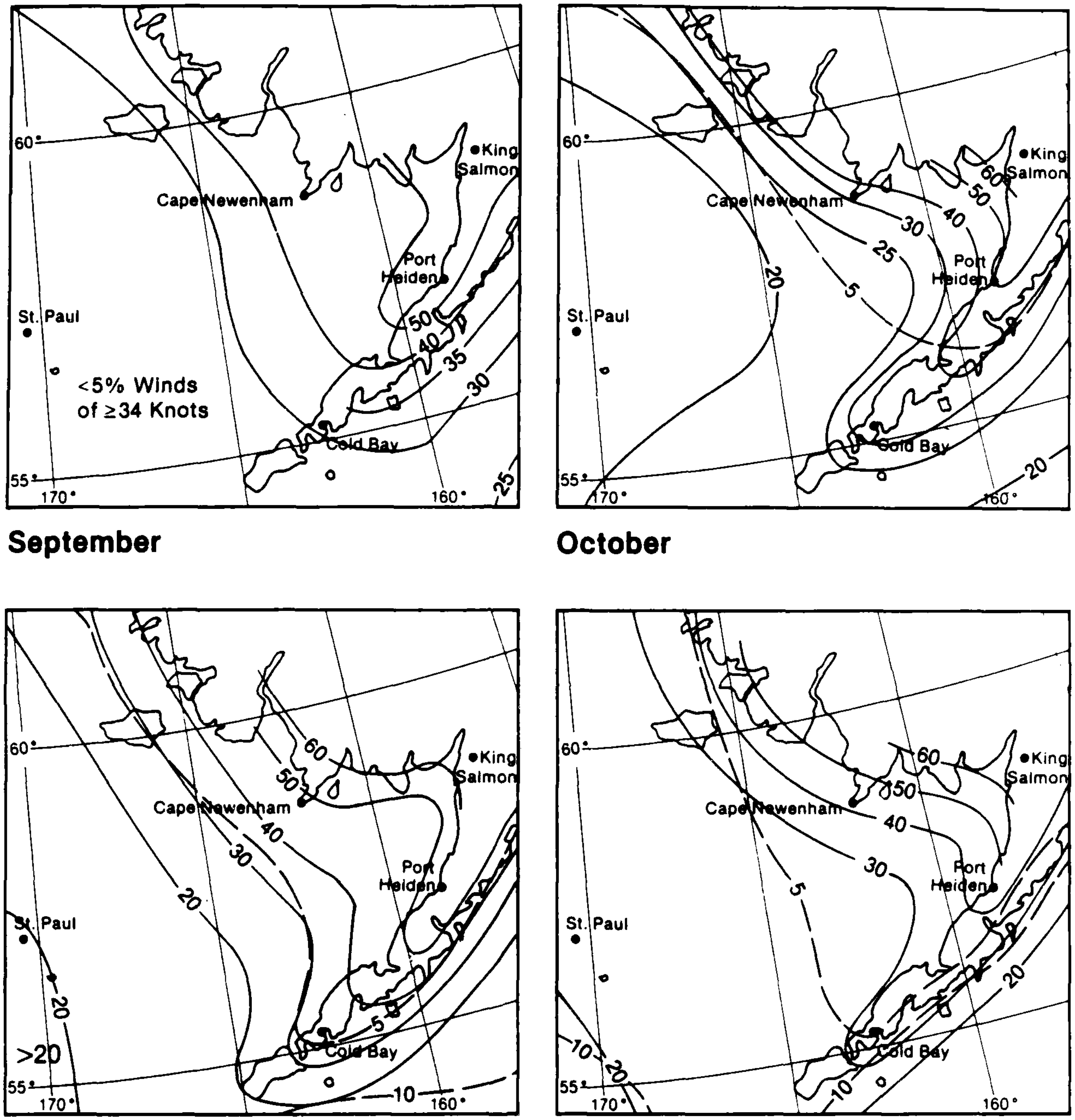


Figure 27b

Wind Speed ≤10 Knots and ≥34 Knots



September

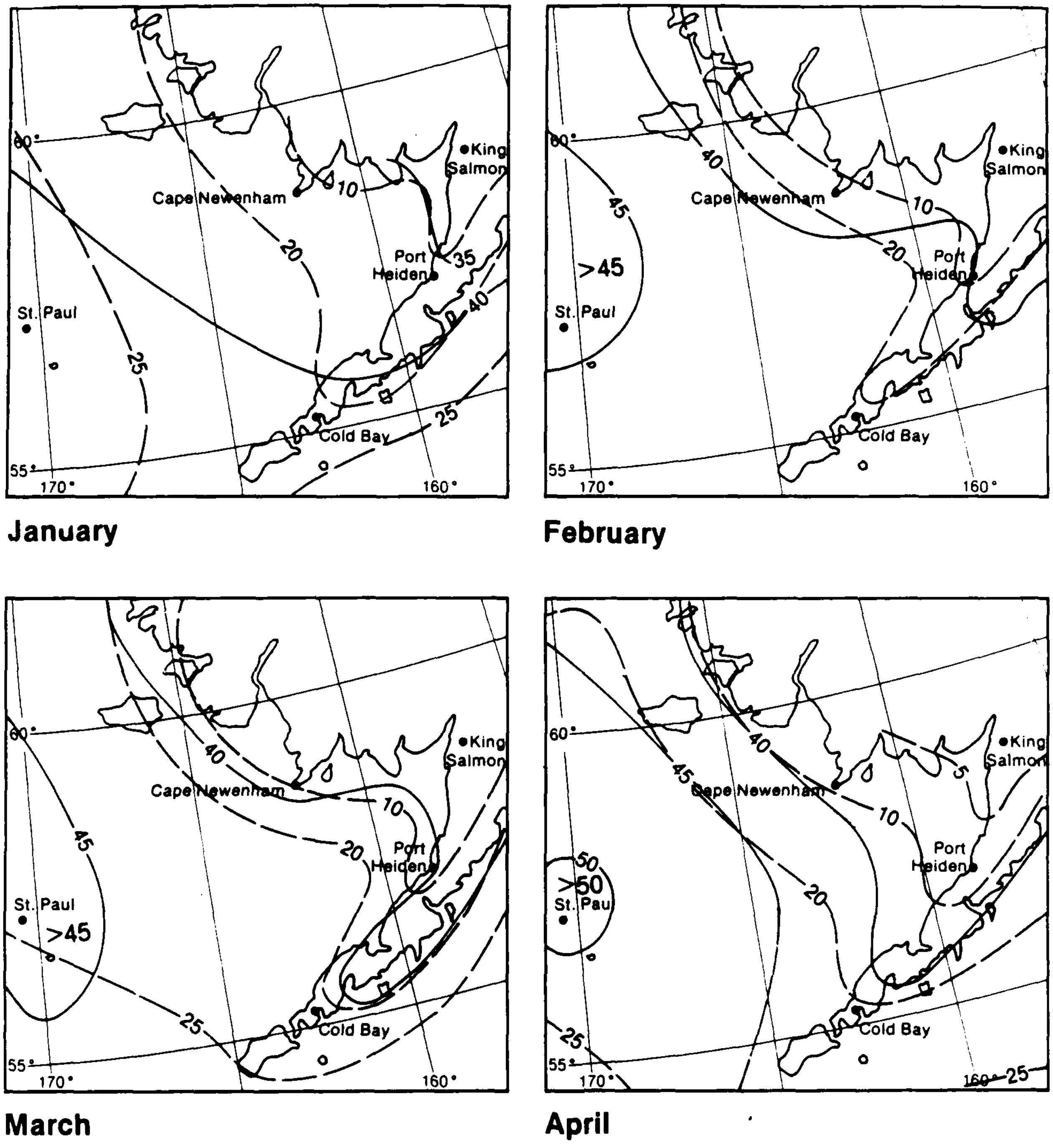
October

November

December

Figure 27c

Wind Speed 11-21 Knots and 22-33 Knots

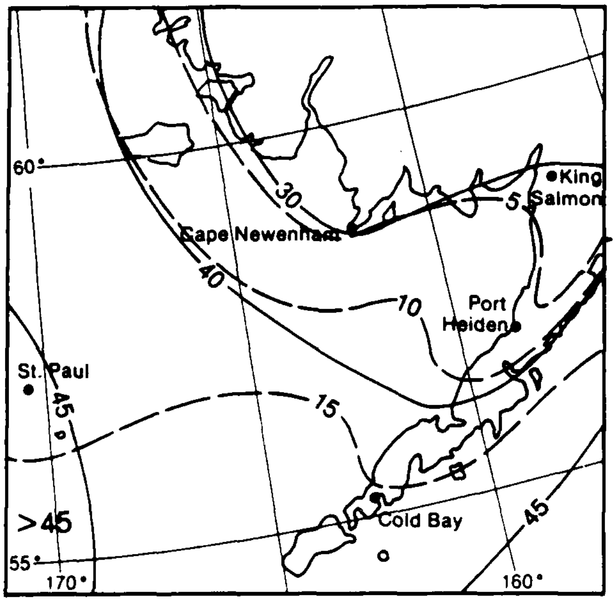


Legend

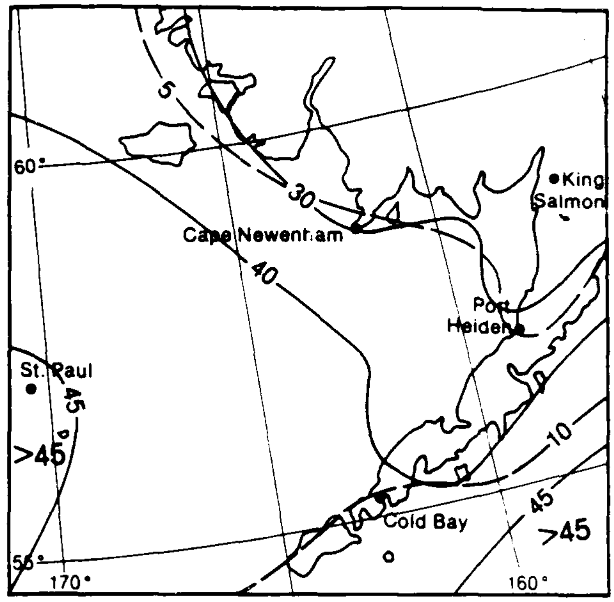
——— % of Wind 11-21 Knots
— — — % of Wind 22-33 Knots

Figure 28a

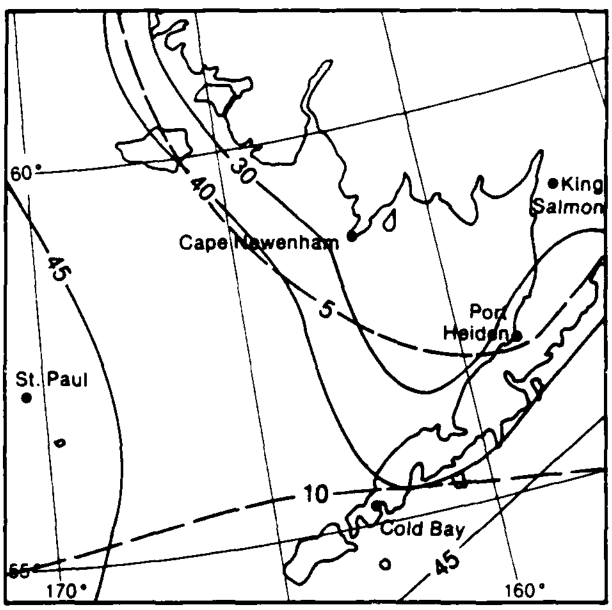
Wind Speed 11-21 Knots and 22-33 Knots



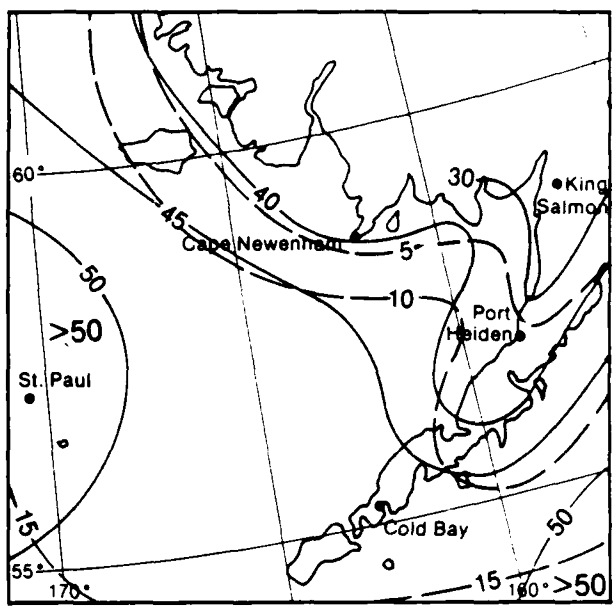
May



June



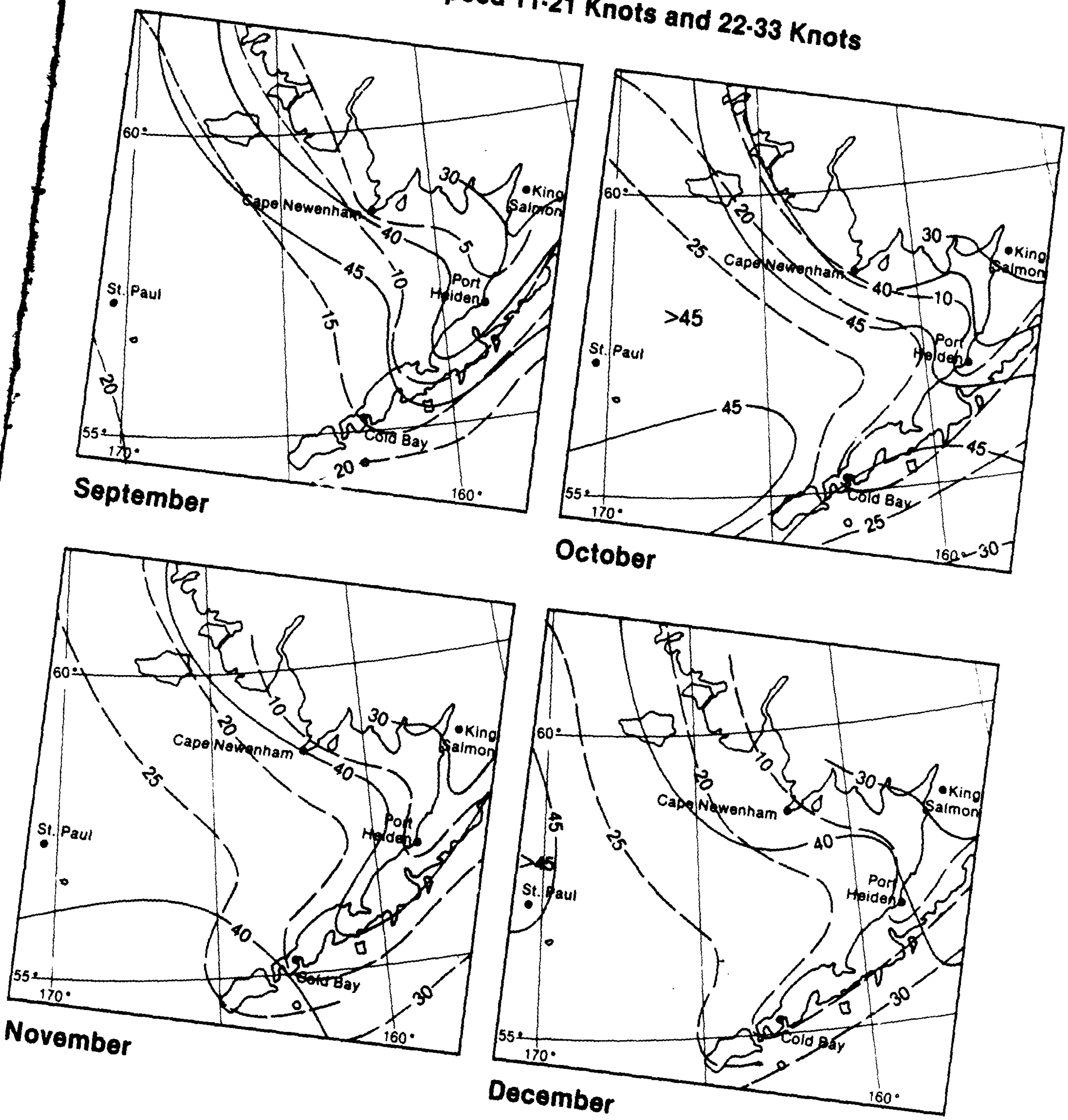
July



August

Figure 28b

Wind Speed 11-21 Knots and 22-33 Knots



Legend

——— % of Wind 11-21 Knots

— — — % of Wind 22-33 Knots

Figure 28c

VISIBILITY

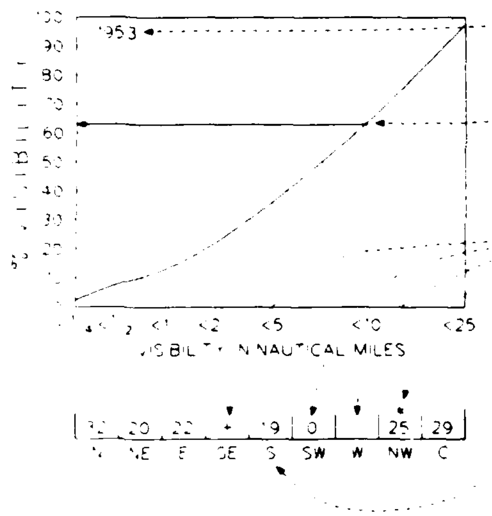
Visibility is quite variable during the year in the area. Heavy fog, visibility less than one-quarter mile, with or without precipitation, averages 4% of the time in marine area C (that portion of the Bering Sea between 55° and 60°N latitude and east from 169°W longitude to the coast). The summer months of June and July have the most frequent extremely low visibility at 10% while the months of September through February show only 0-2% of the time with visibility less than one-quarter mile. Less than one mile visibility in marine area C averages 11% of the time annually varying from 3% in October to 20% in July. St. Paul Island, west of the area of interest shows even poorer visibility with 5% annually less than one-quarter mile and 14% less than one mile. Other land stations on the mainland of Alaska and the Alaska Peninsula show considerably better conditions with visibility less than one mile 4-8% of the time and less than one-quarter 1-2%. The primary cause of low summer visibility is fog caused by lighter winds and air warmer than the water. Air tends to be warmer than the water from May to September and colder from October to April.

Figures 29a-29f depict the visibility coincidental with various wind directions.

Figures 30a-30f depict the occurrence of fog versus various wind directions and time of day.

Figure 31 charts the incidence of fog at various air-sea temperature differences.

Graphs: Visibility/wind direction



Number of observations.

Curve is the cumulative percent frequency of visibilities less than the visibility intersected by the curve.

(63% of all visibilities reported were <10 nautical miles.)

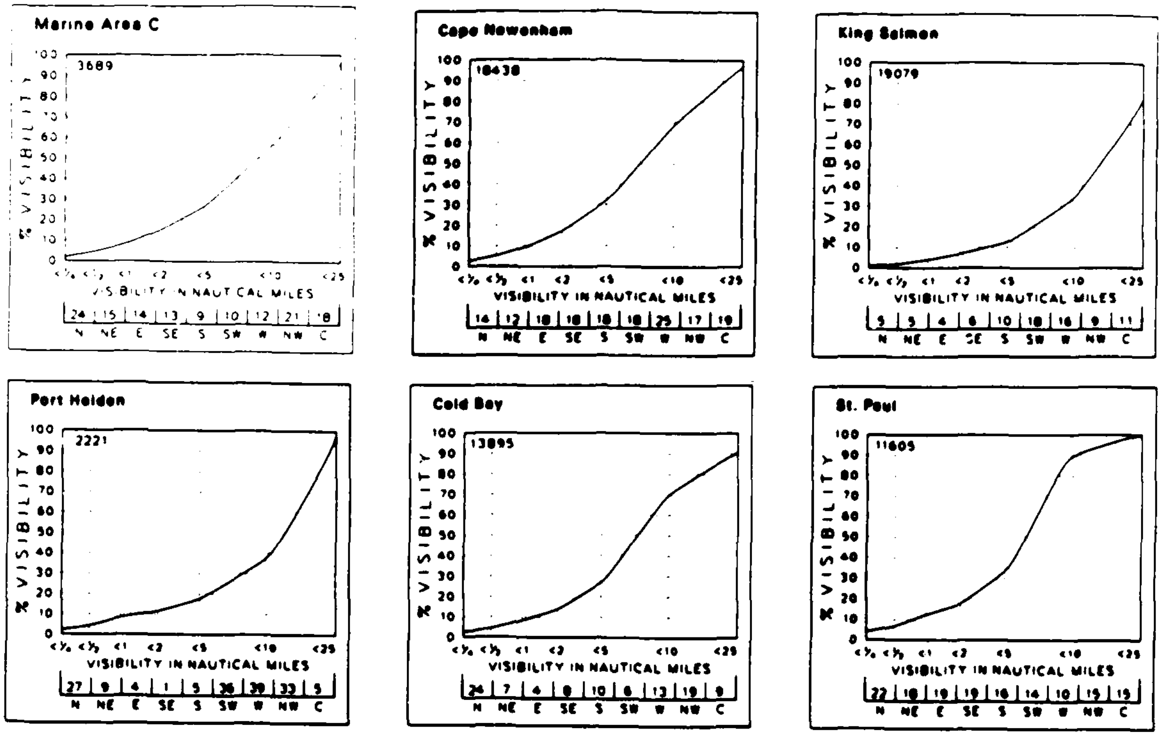
The table below the graph indicates percent frequency of occurrence of visibility <2 nautical miles versus wind direction.

+ indicates <.5% but >0. 0 indicates that no visibilities <2 nautical miles were observed with winds from a direction or calm. No percentage is given if less than 10 observations were available for visibility and wind direction. An asterisk indicates that the percentage was based on 10-30 observations of visibility and wind direction.

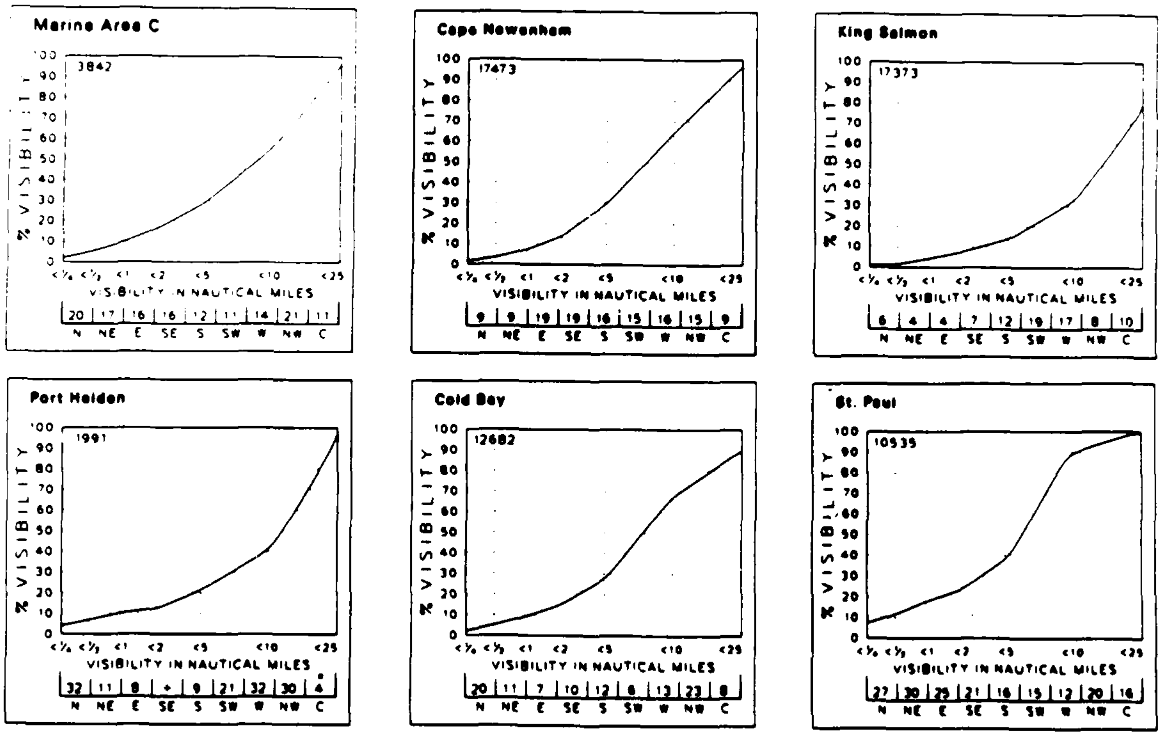
(19% of all S winds were accompanied by visibilities <2 nautical miles.)

Figure 29 · legend

Visibility/Wind Direction



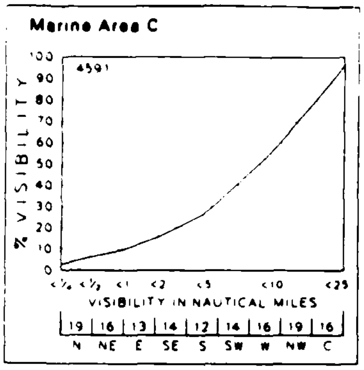
January

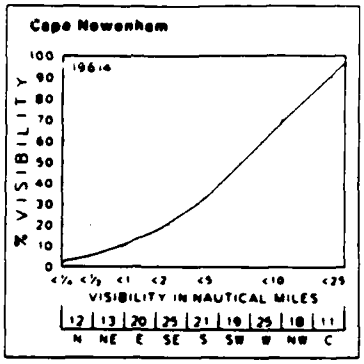


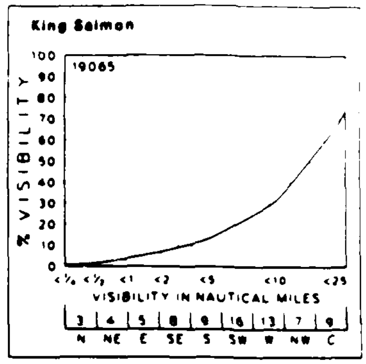
February

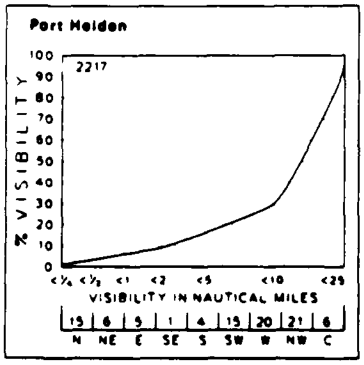
Figure 29a

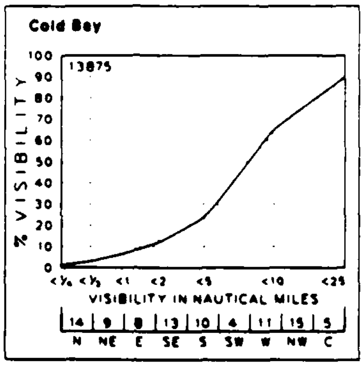
Visibility/Wind Direction

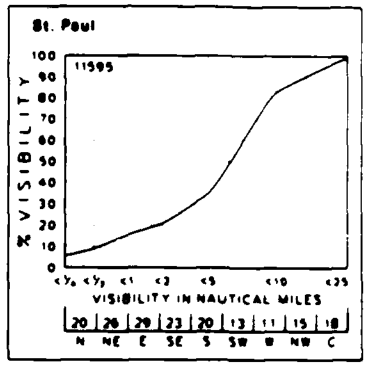




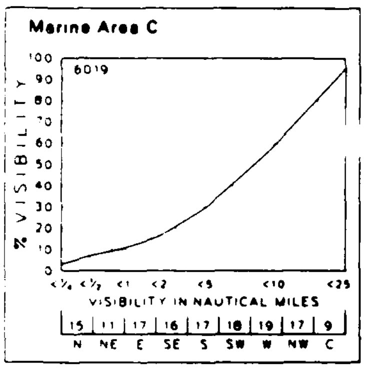


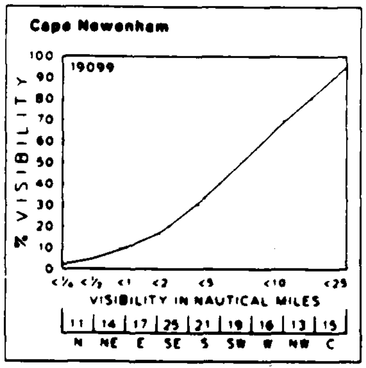


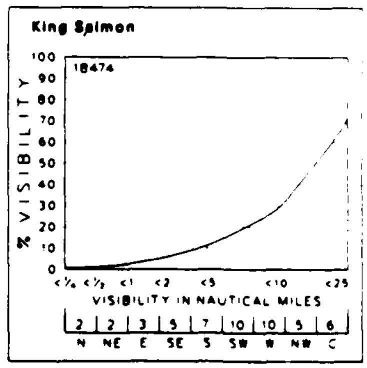


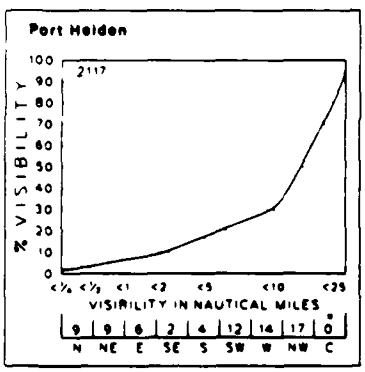


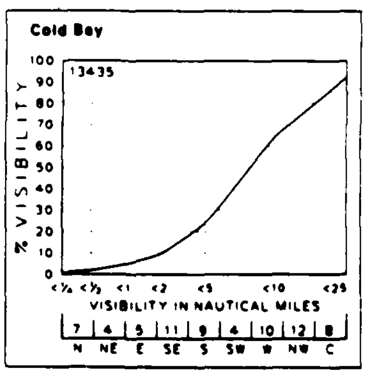
March

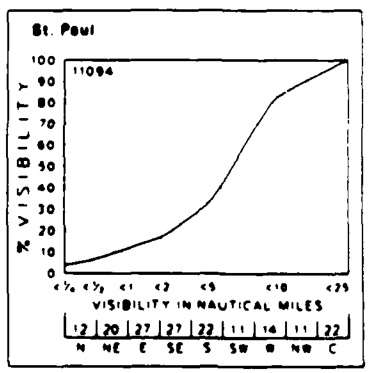








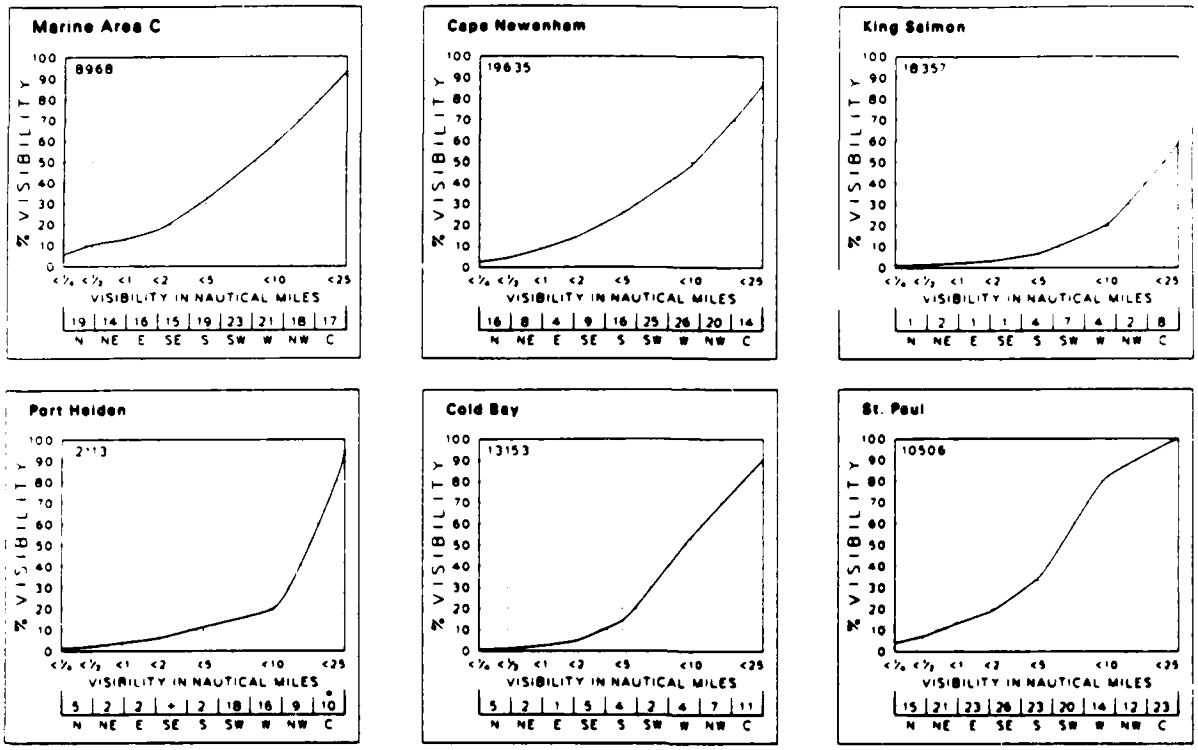




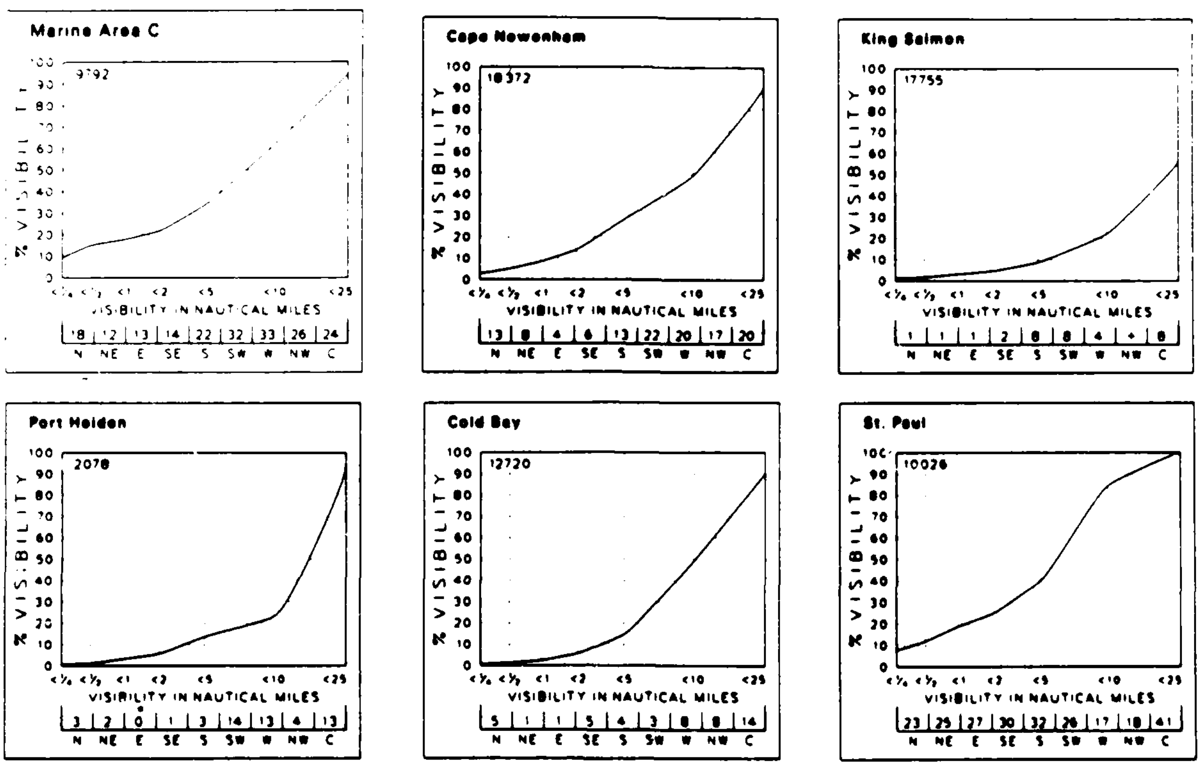
April

Figure 29b

Visibility/Wind Direction



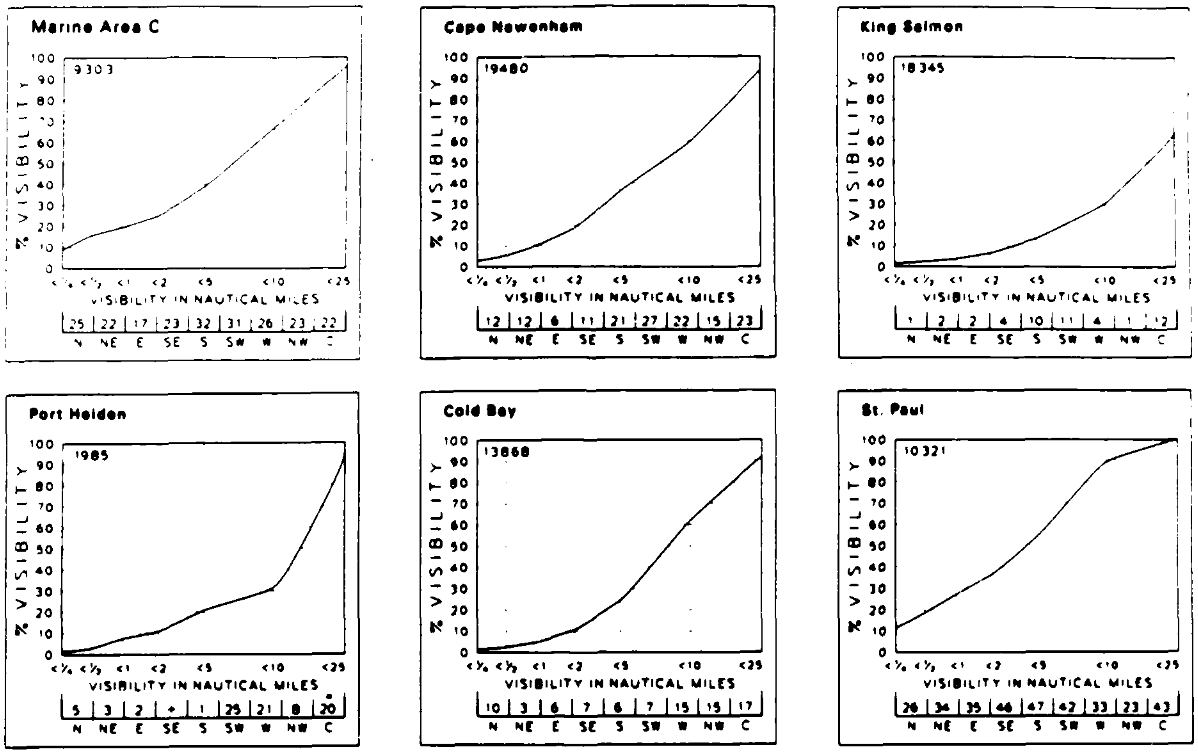
May



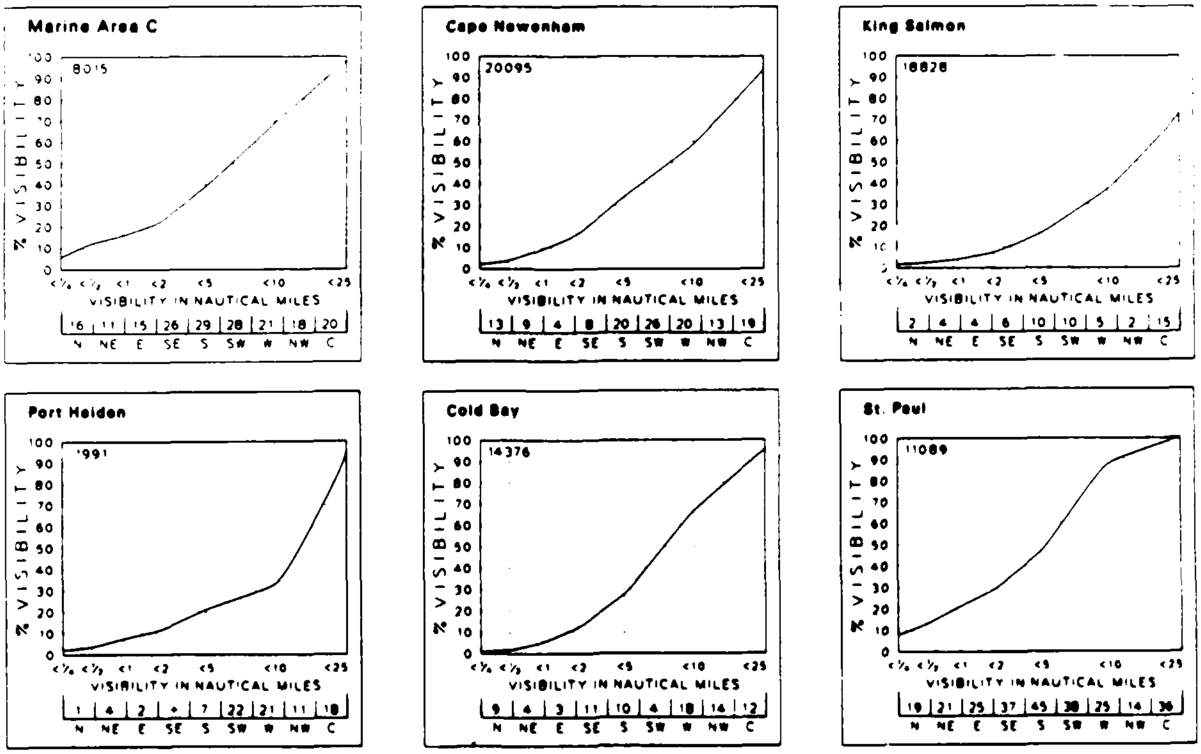
June

Figure 29c

Visibility/Wind Direction



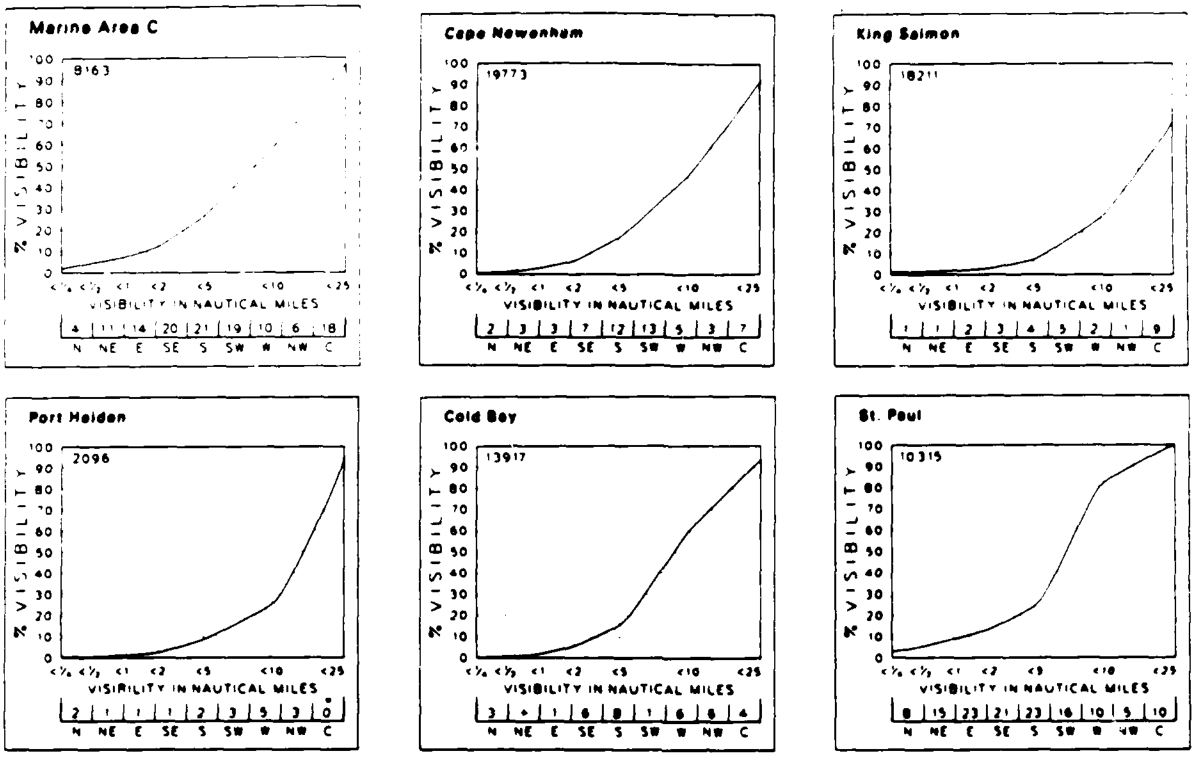
July



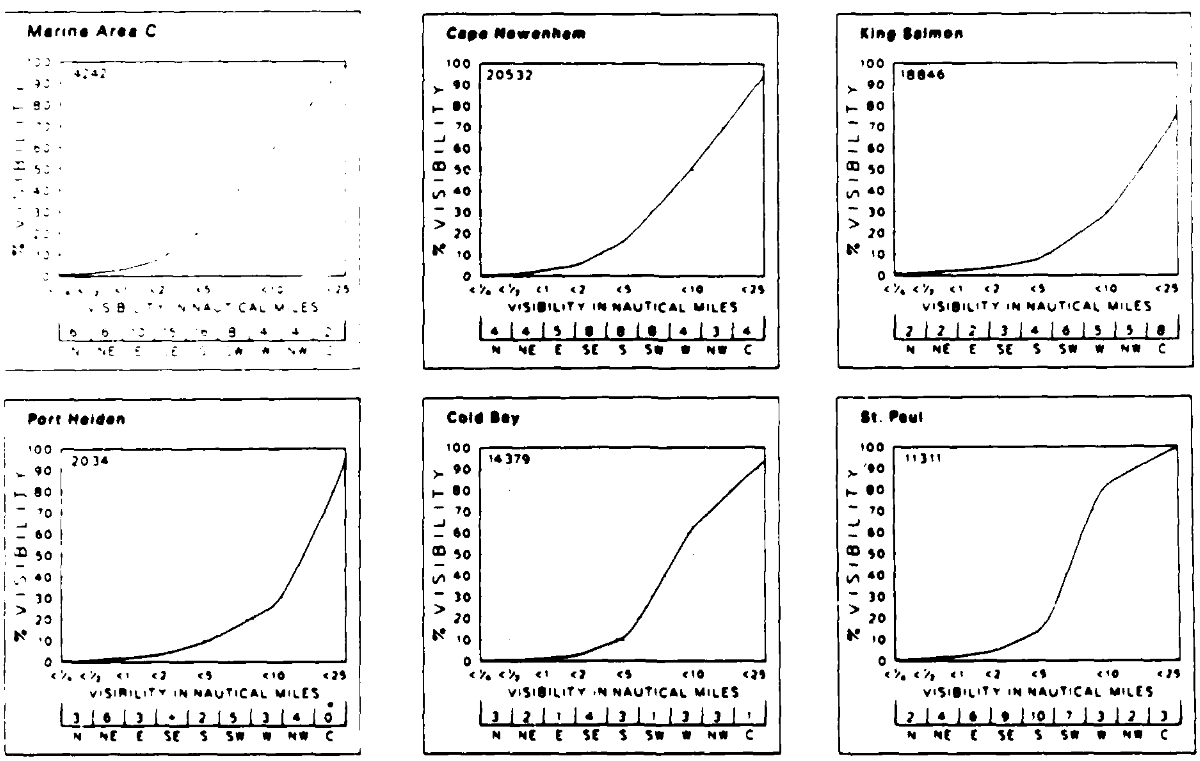
August

Figure 29d

Visibility/Wind Direction



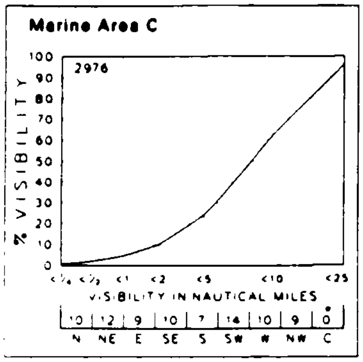
September

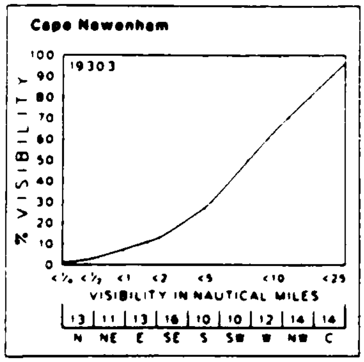


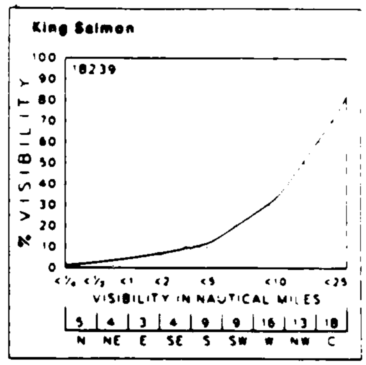
October

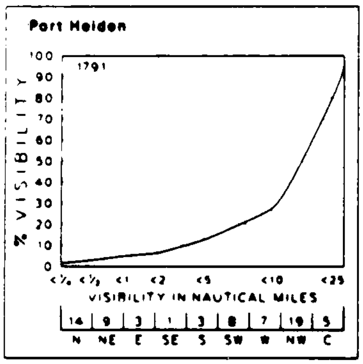
Figure 29e

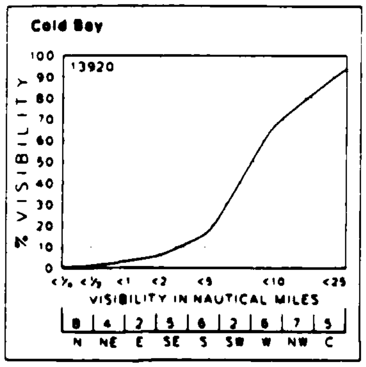
Visibility/Wind Direction

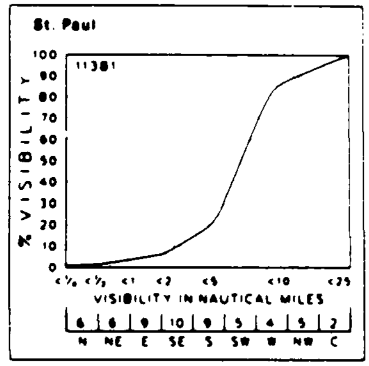




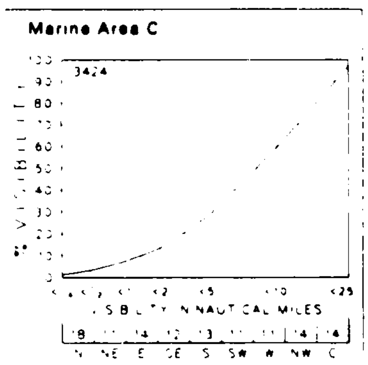


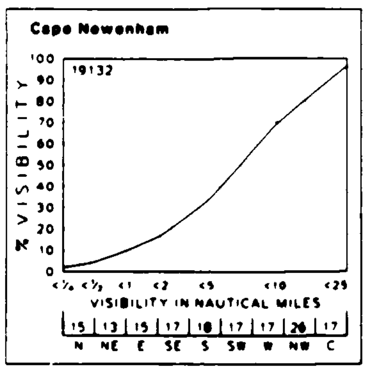


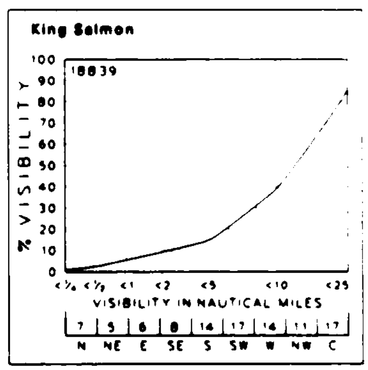


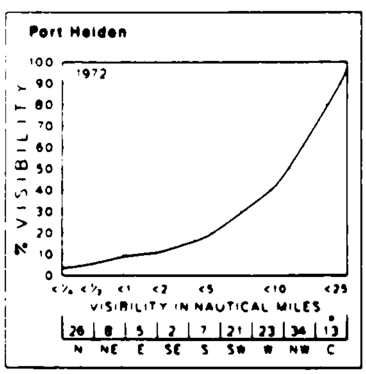


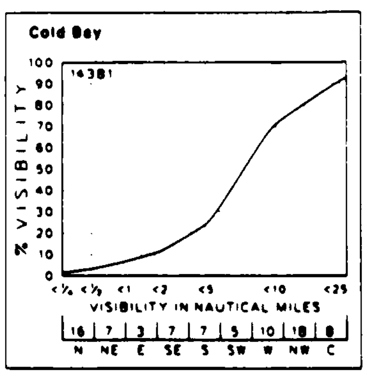
November

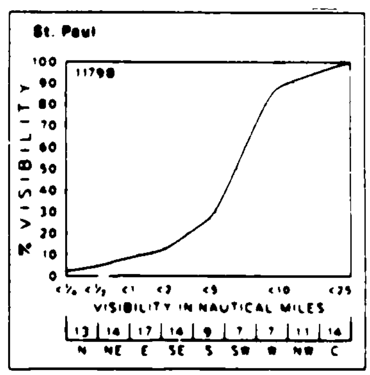








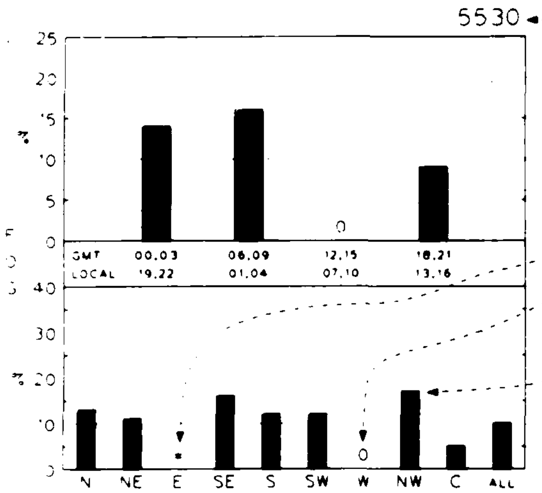




December

Figure 29f

Graphs: Fog/time and fog/wind direction



Number of observations.

Bar graphs represent percent frequency of fog (without precipitation) for various hour groupings and wind directions. Data are based on 100% for each hour-group and direction category.

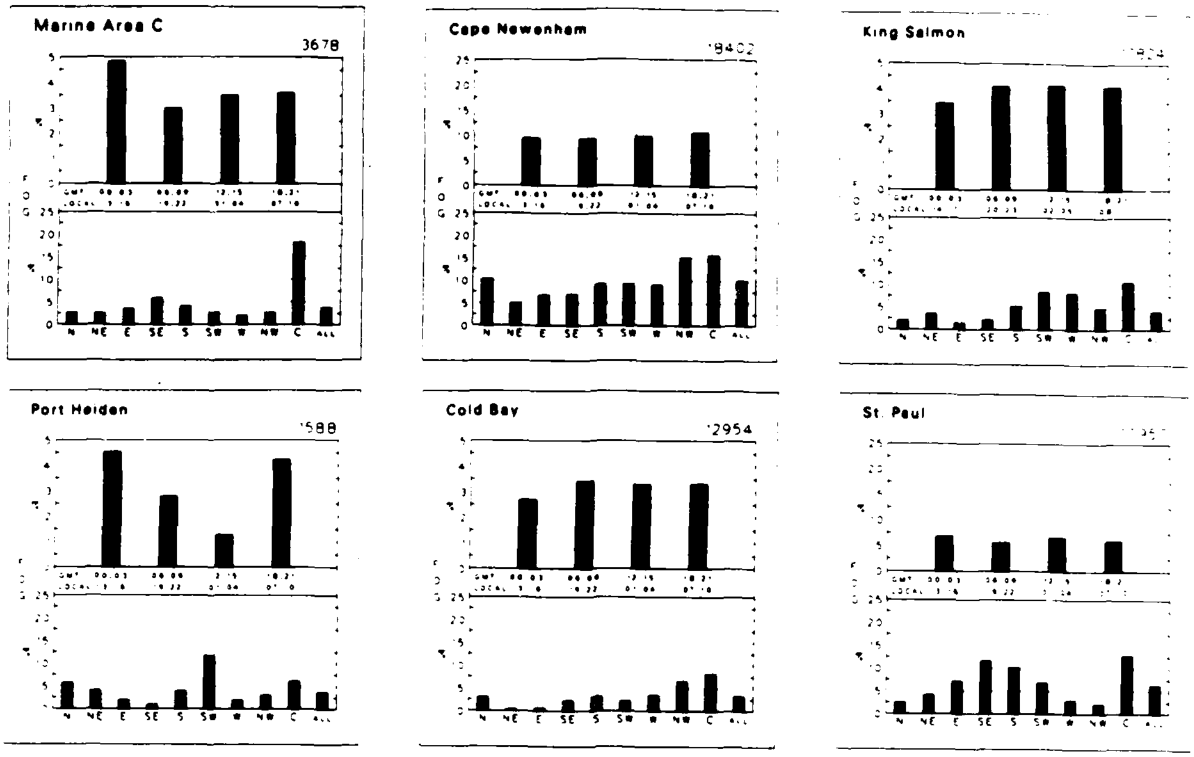
* indicates <.05% but >0.

0 indicates no fog occurred with the wind direction.

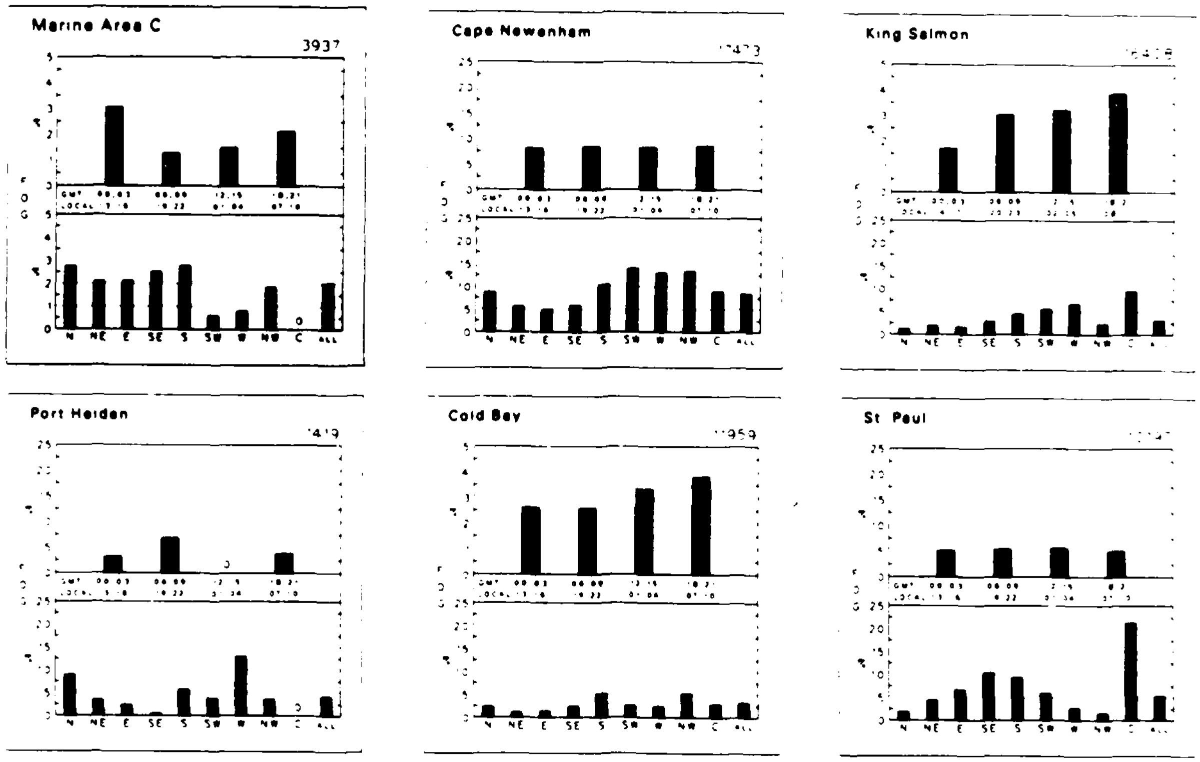
(Data show that 17% of all NW winds were accompanied by Fog (without precipitation).)

Figure 30 - legend

Fog/Time and Fog/Wind Direction



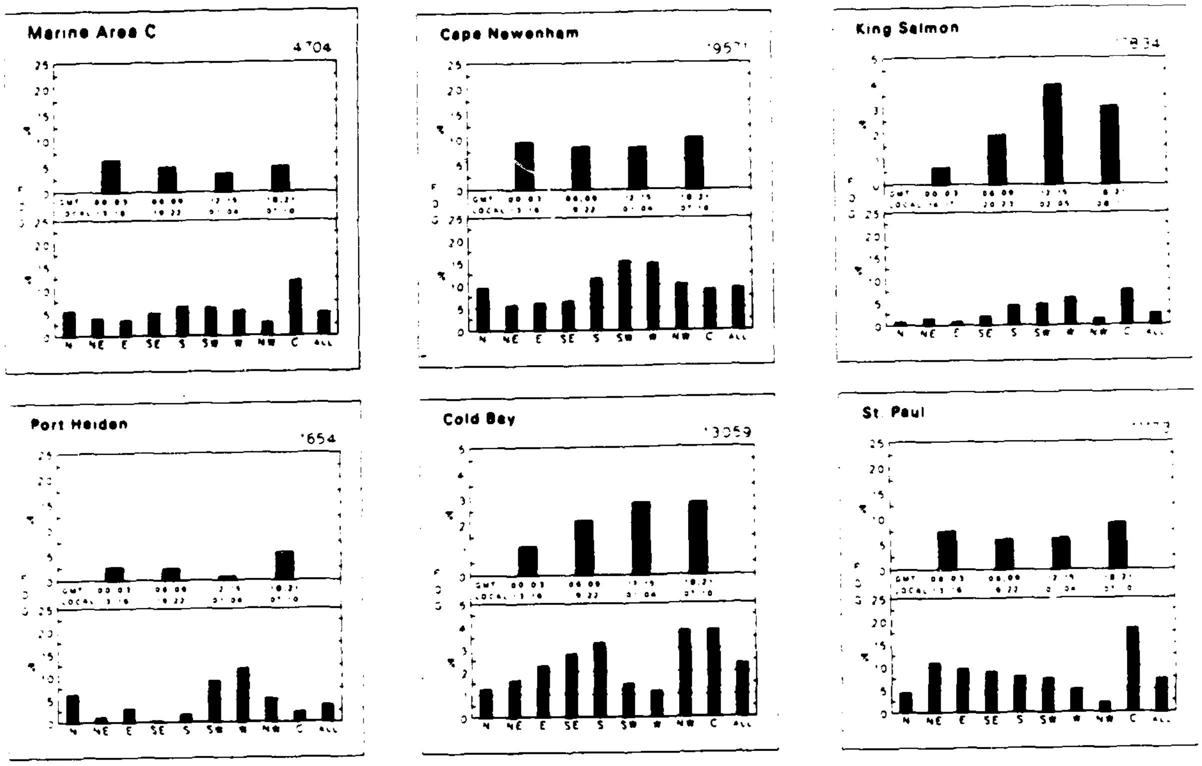
January



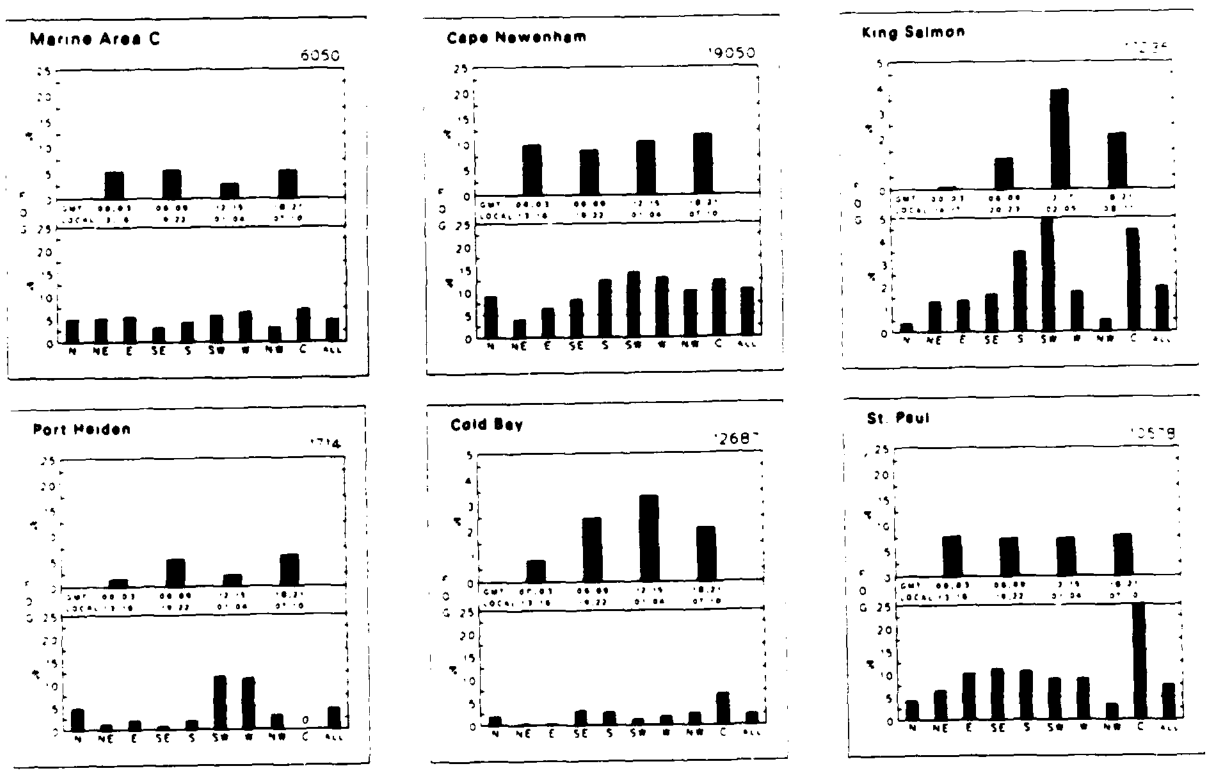
February

Figure 30a

Fog/Time and Fog/Wind Direction



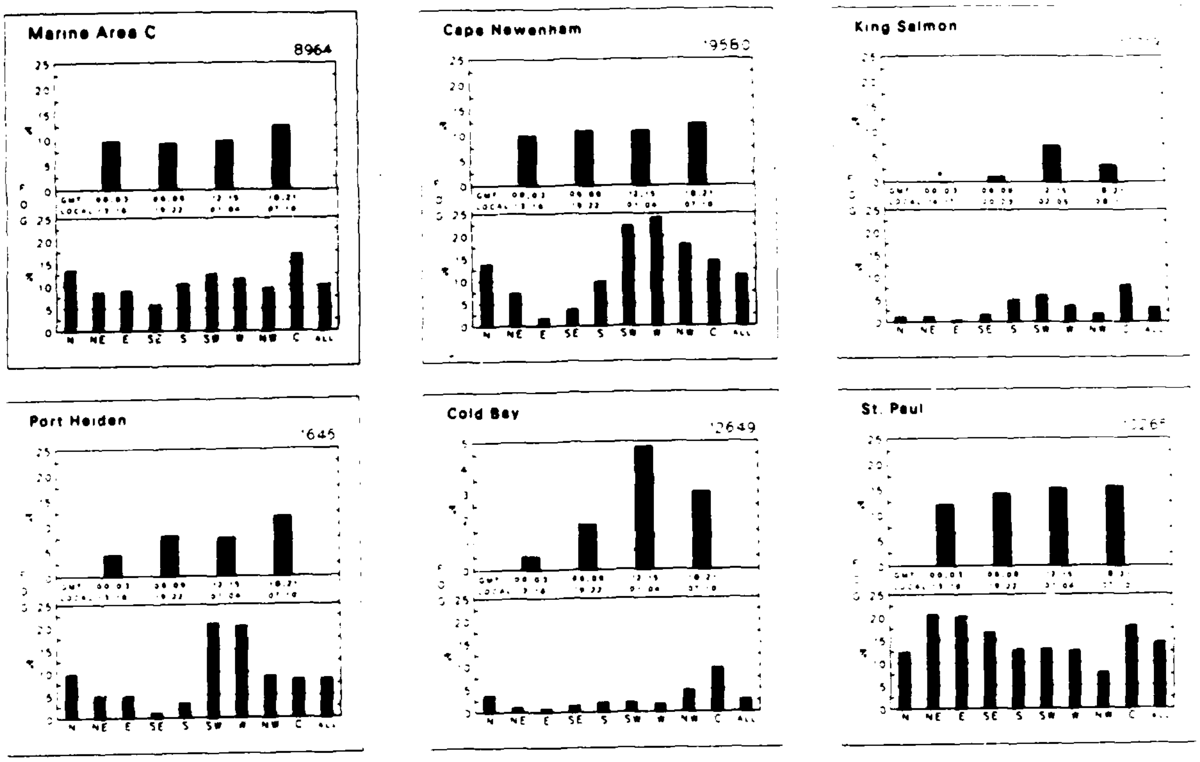
March



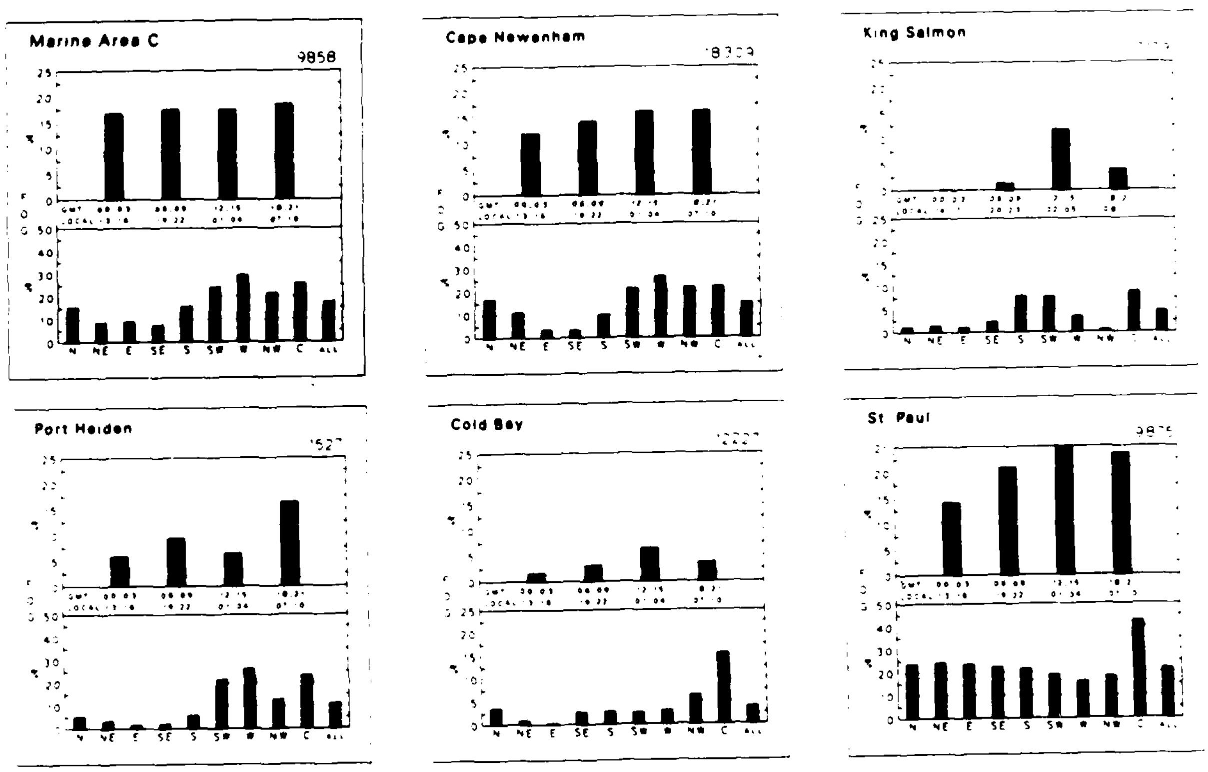
April

Figure 30b

Fog/Time and Fog/Wind Direction



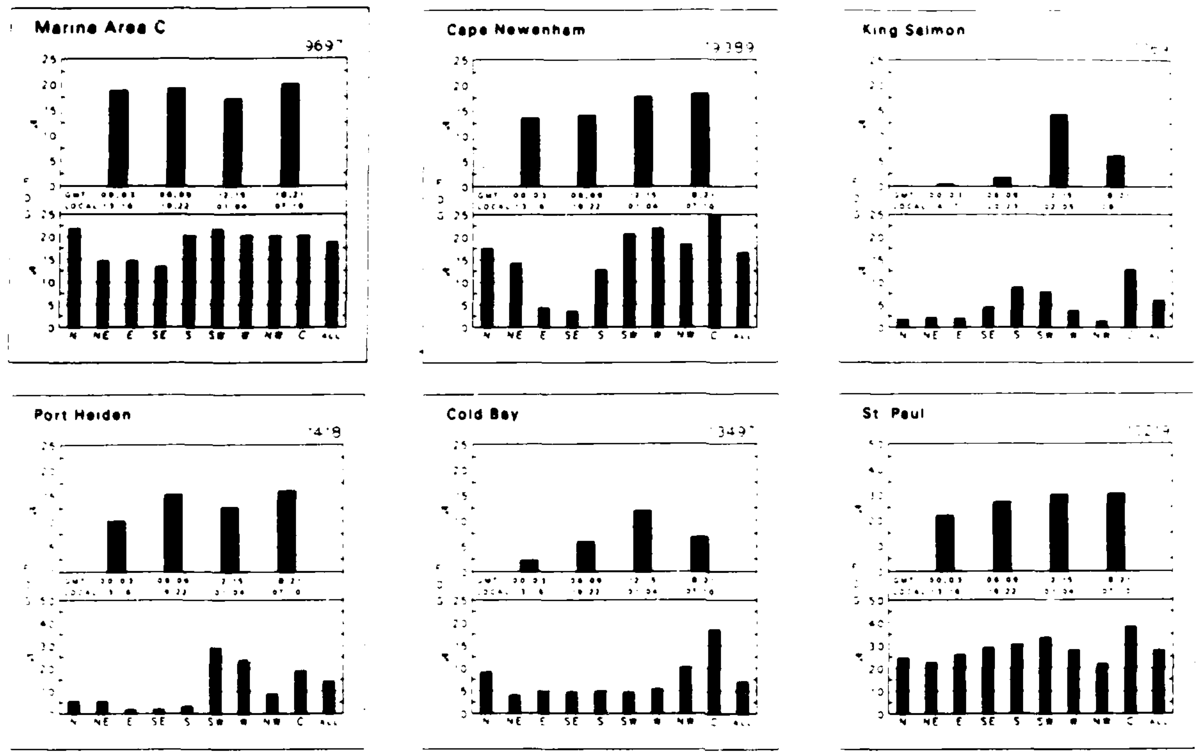
May



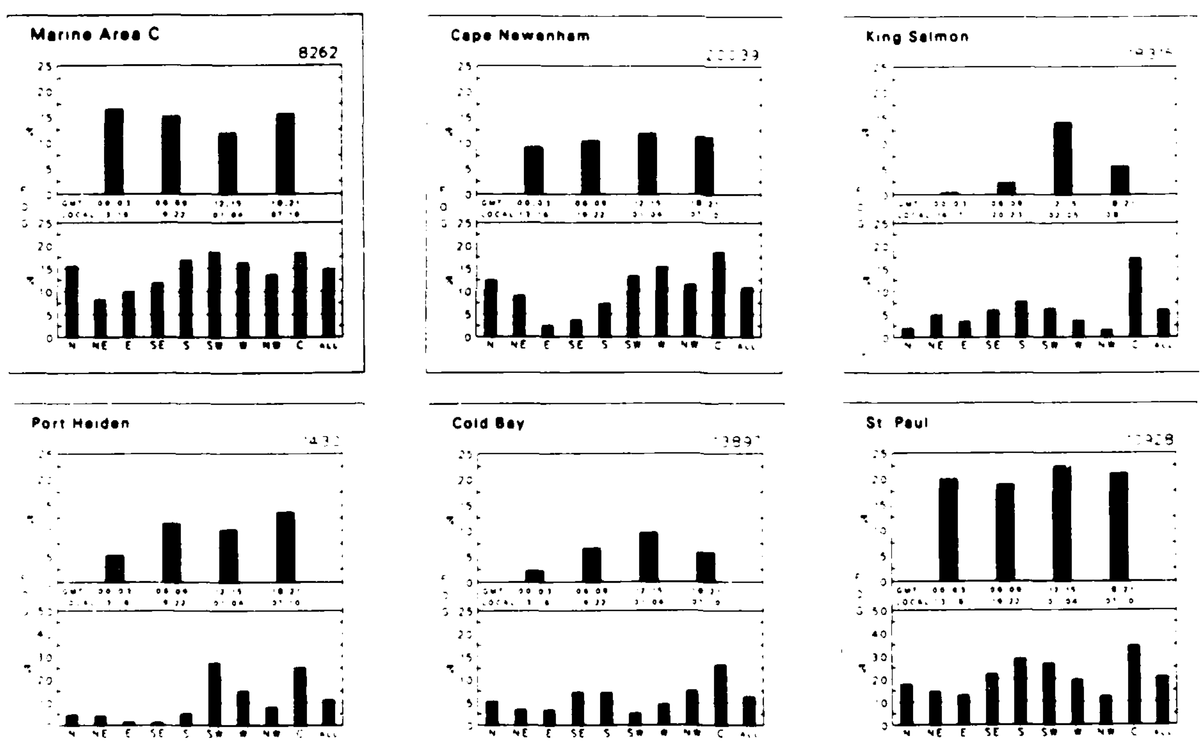
June

Figure 30c

Fog/Time and Fog/Wind Direction



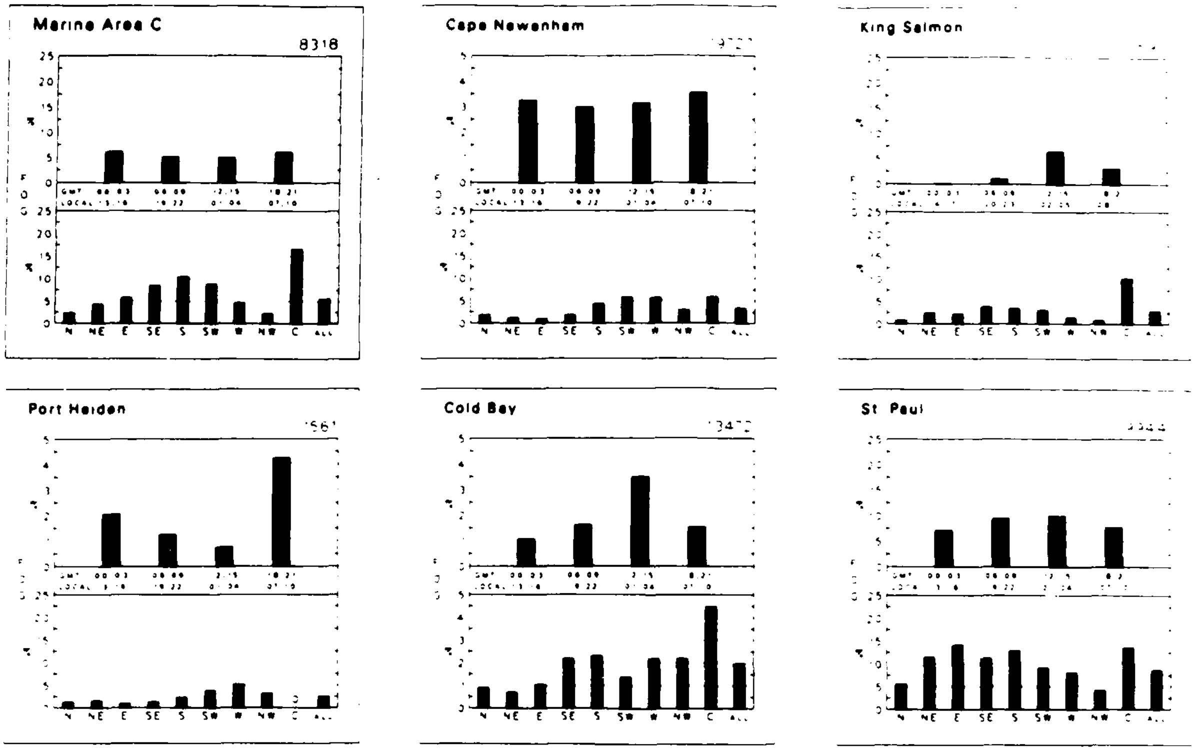
July



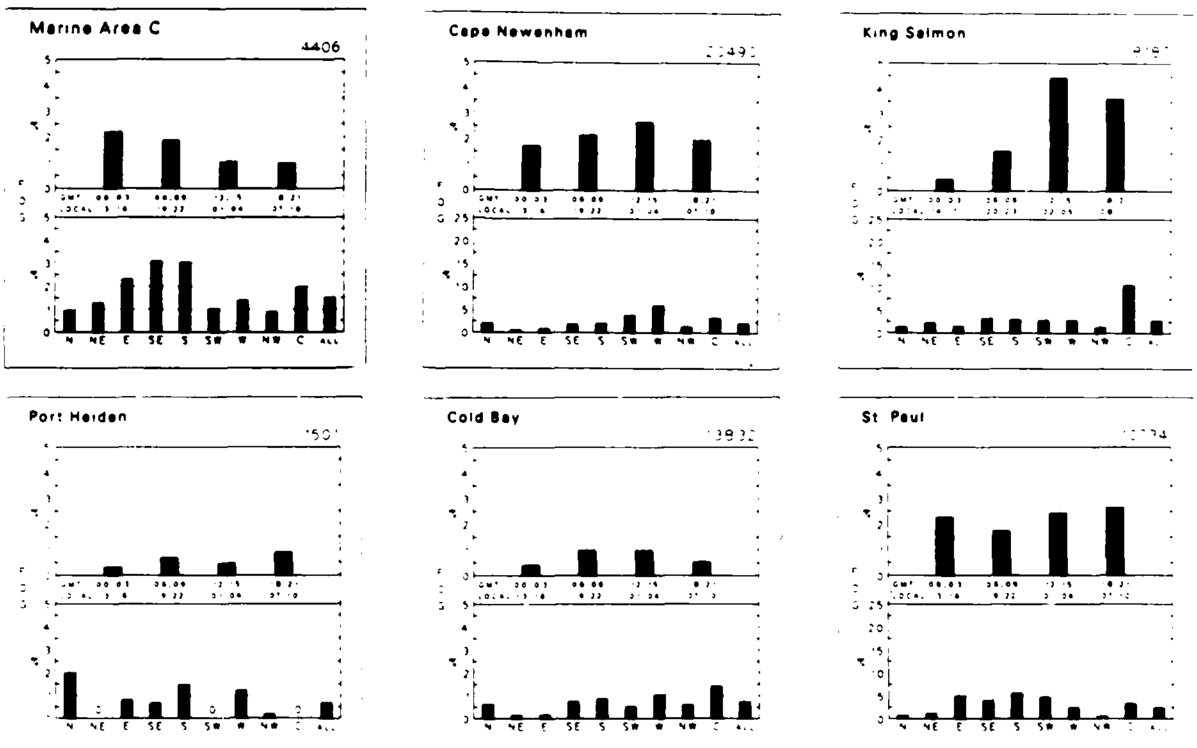
August

Figure 30d

Fog/Time and Fog/Wind Direction



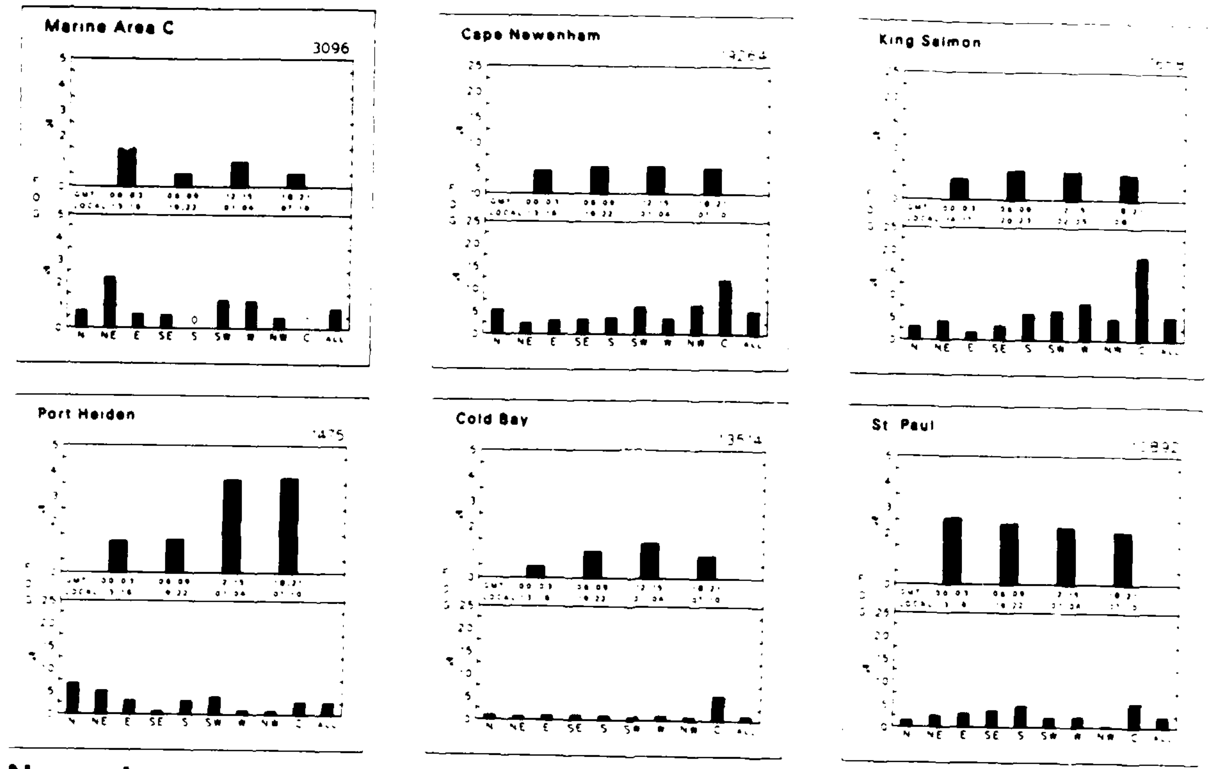
September



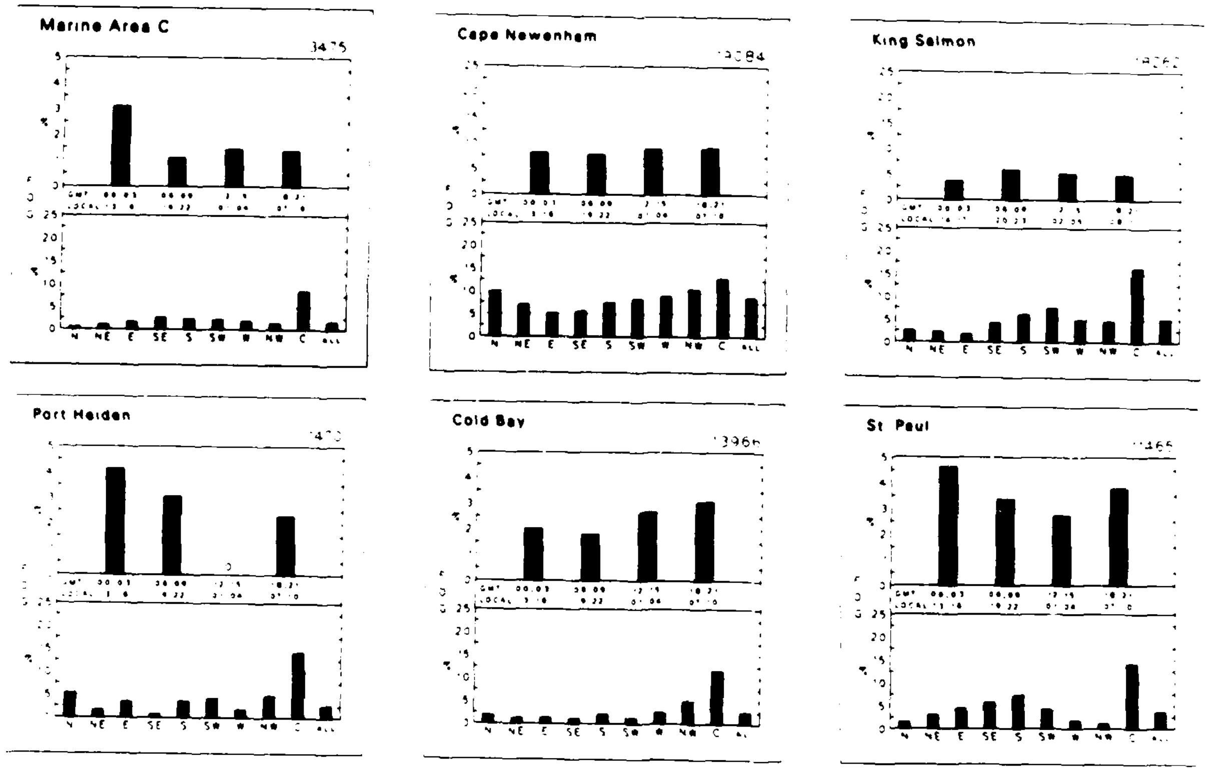
October

Figure 30e

Fog/Time and Fog/Wind Direction



November



December

Figure 30f

Graphs: Fog/air-sea temperature difference

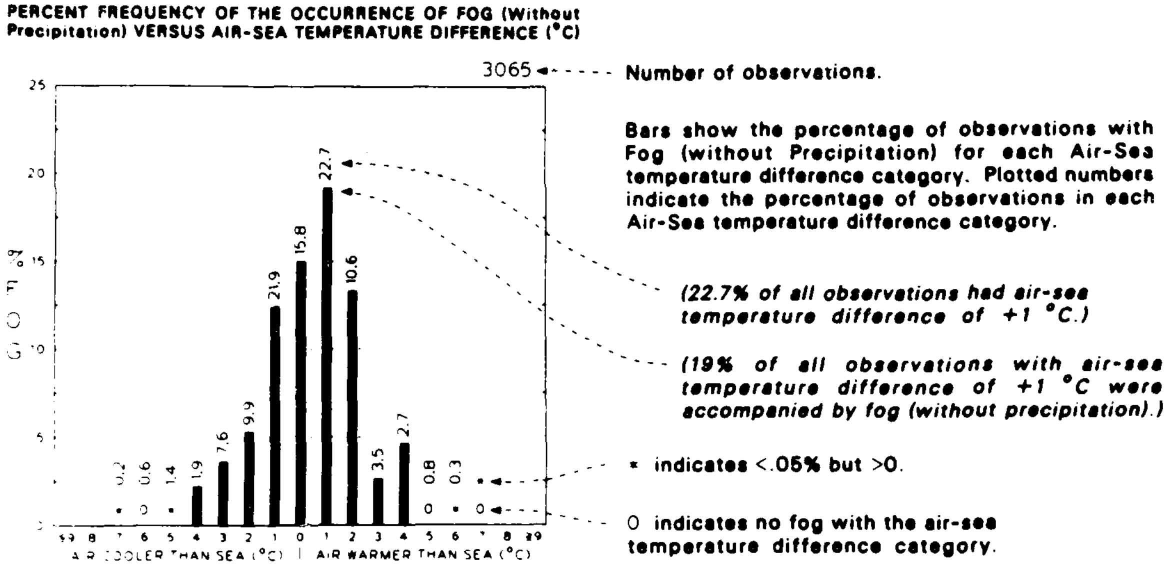


Figure 31

Fog/Air-Sea Temperature Difference

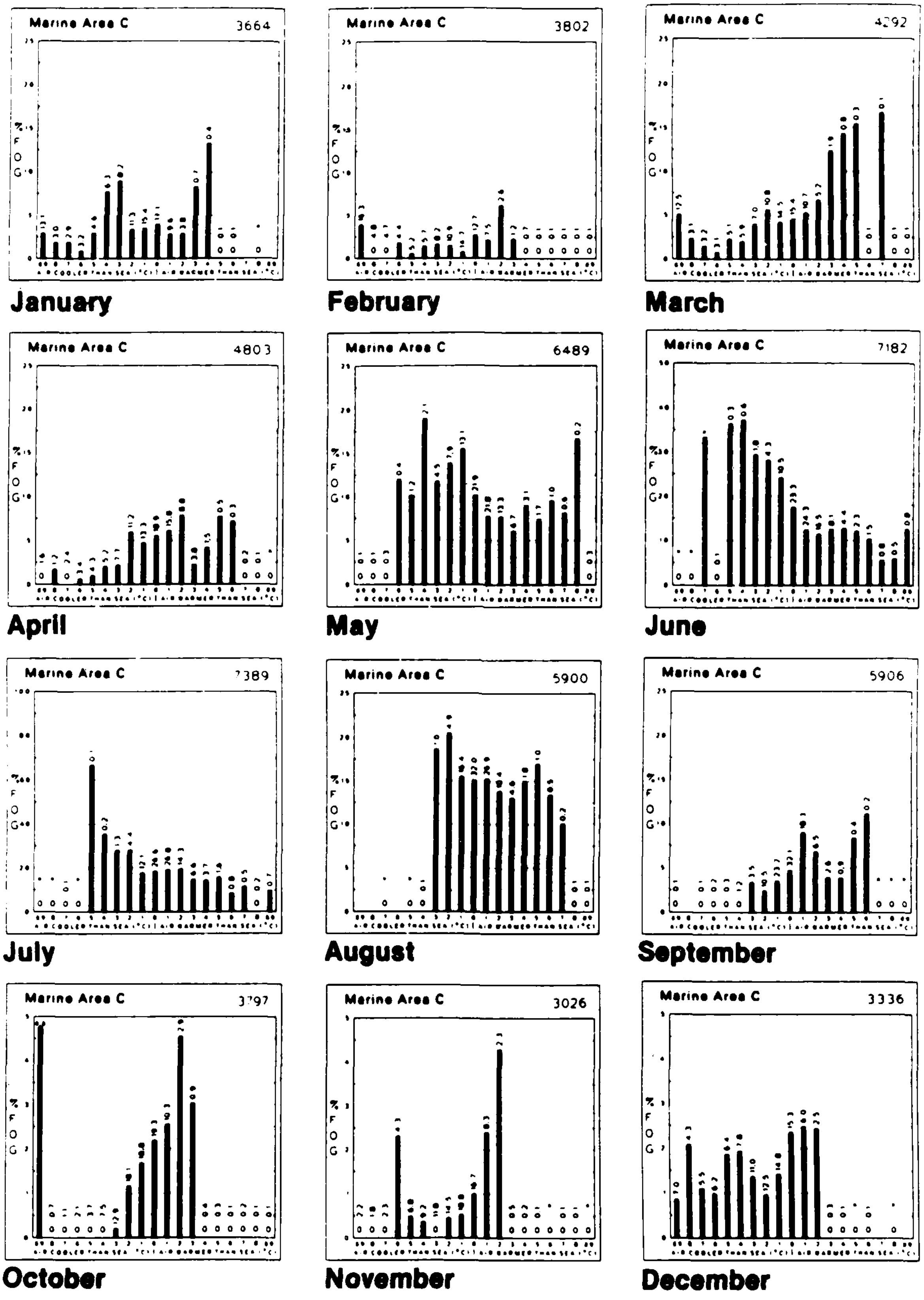


Figure 31a

CLOUDINESS

Generally there are more low clouds (i.e., below 5,000 ft) in the western portion of the area than eastern, often more than twice as much. Most low cloudiness is in summer (June, July, and August) and the least is in October and November. In marine area C (that portion of the Bering Sea between 55° and 60°N latitude and east from 169°W longitude to the coast), scattered low clouds or clear skies occur 23-27% of the time in all months except July and August when frequencies are near 15%. Ceiling and visibility frequency maps from Brower, et al. 1987 (in preparation) show that ceilings less than 600 ft, visibility less than two miles occur around 10% of the time in October to over 30% of the time in June and July in the northern portion of the area. The eastern end of Bristol Bay shows less than 15% of the time with ceilings less than 600 ft and visibility less than two miles for June and July. There is more variability in cloudiness from southeast to northwest in summer than in winter.

Figures 32a-32f show the amount of cloud cover coincidental with various wind directions.

Graphs: Cloud cover/wind direction

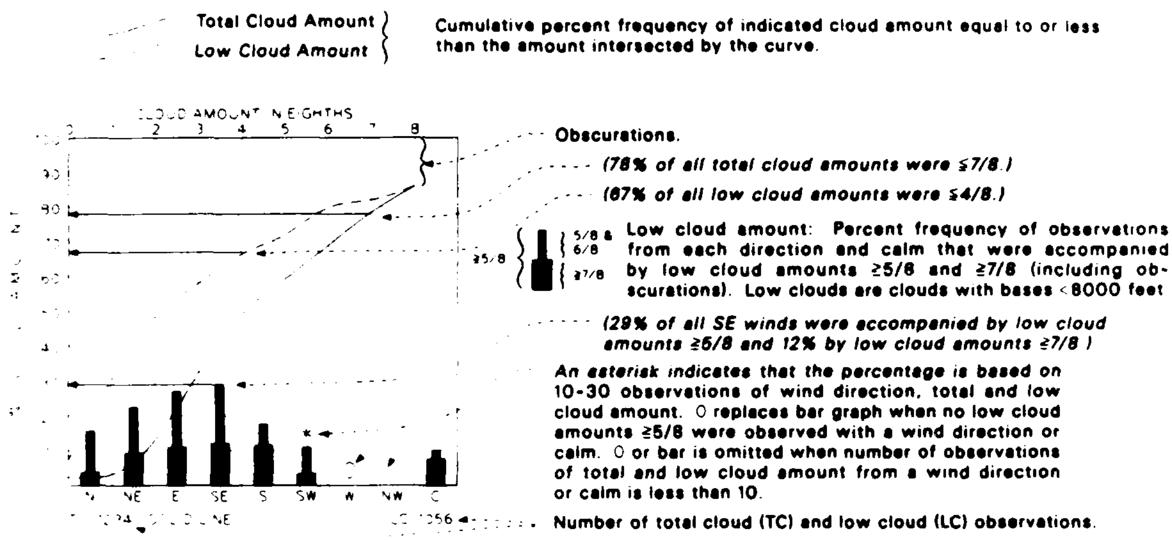
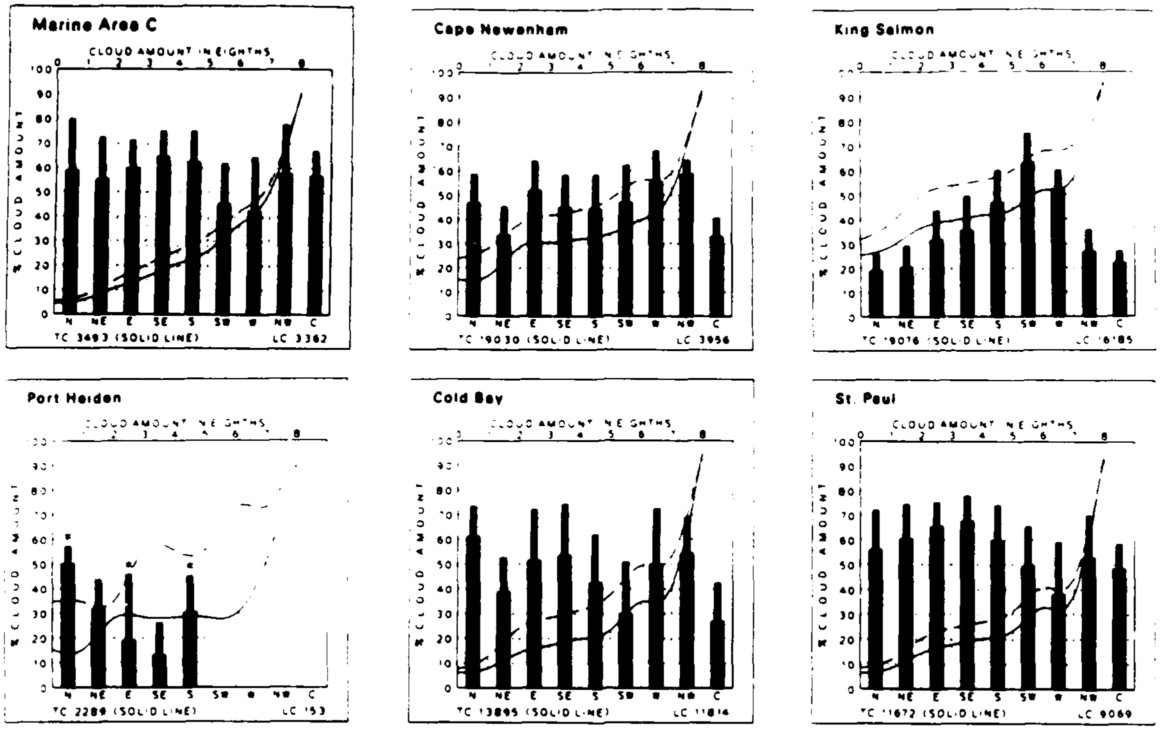
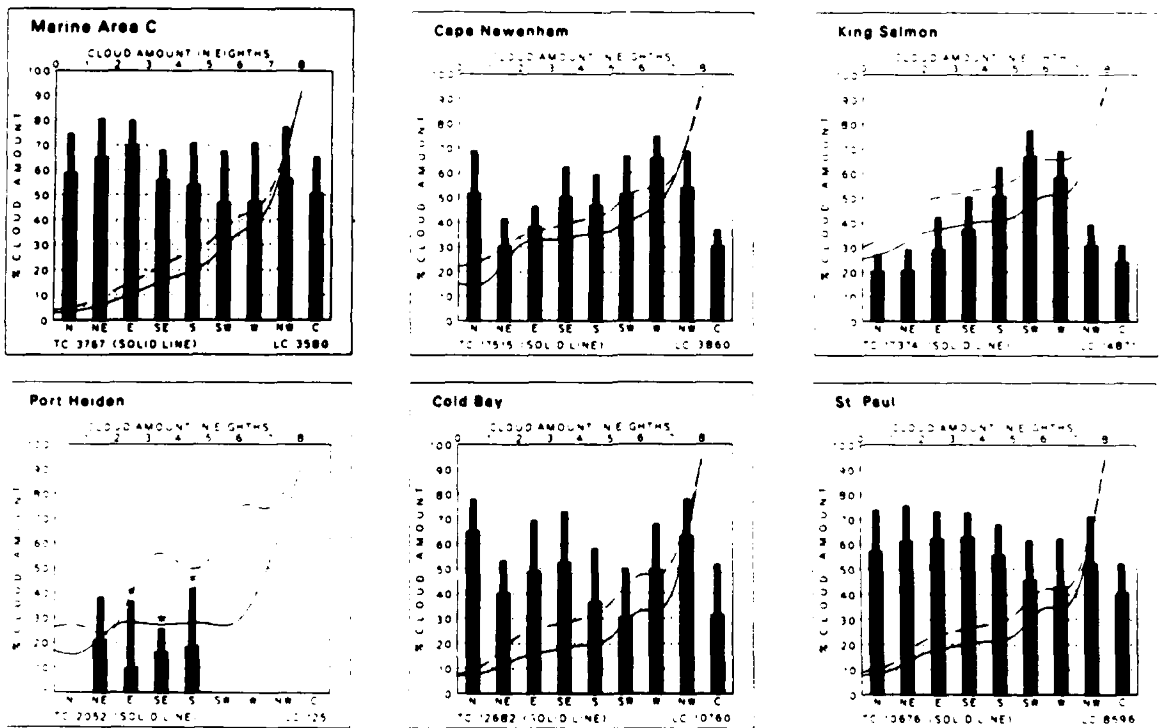


Figure 32-legend

Cloud Cover/Wind Direction



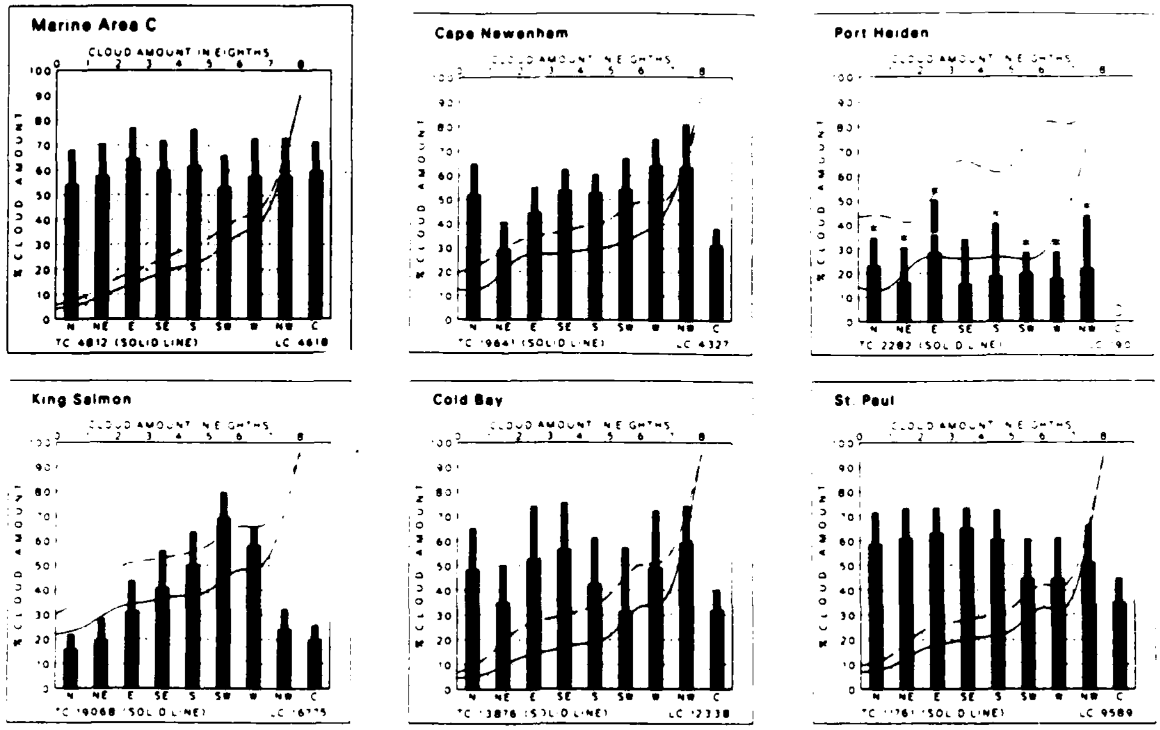
January



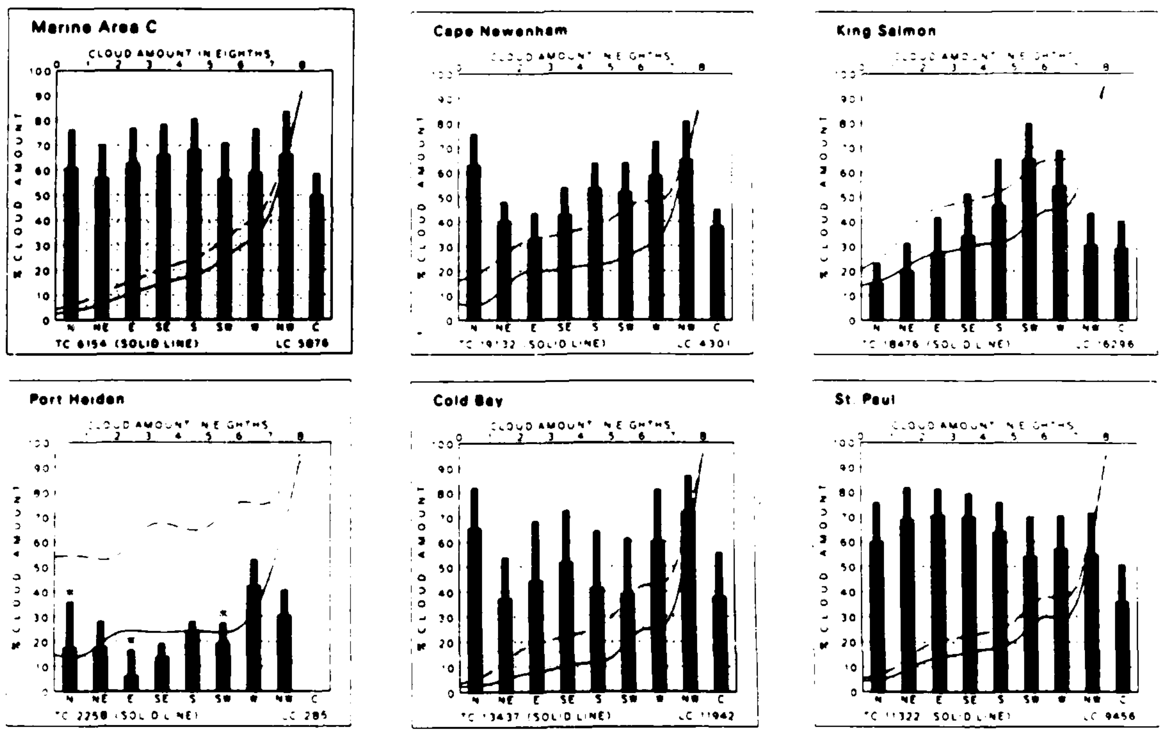
February

Figure 32a

Cloud Cover/Wind Direction



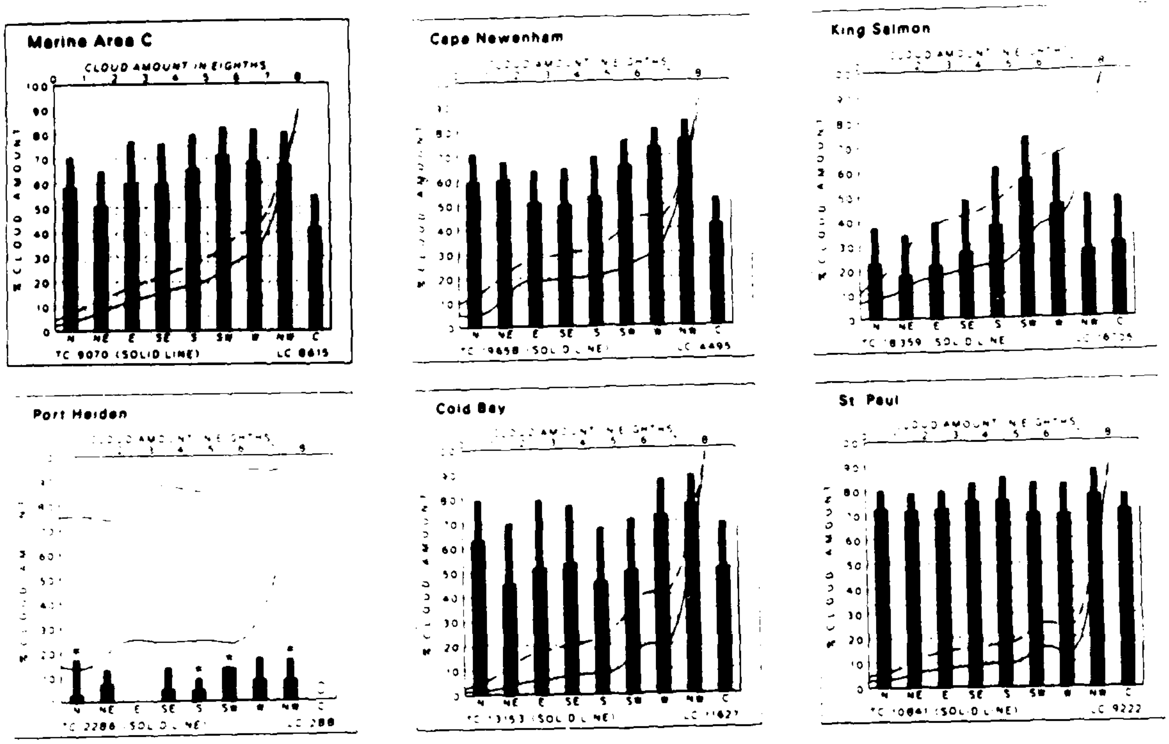
March



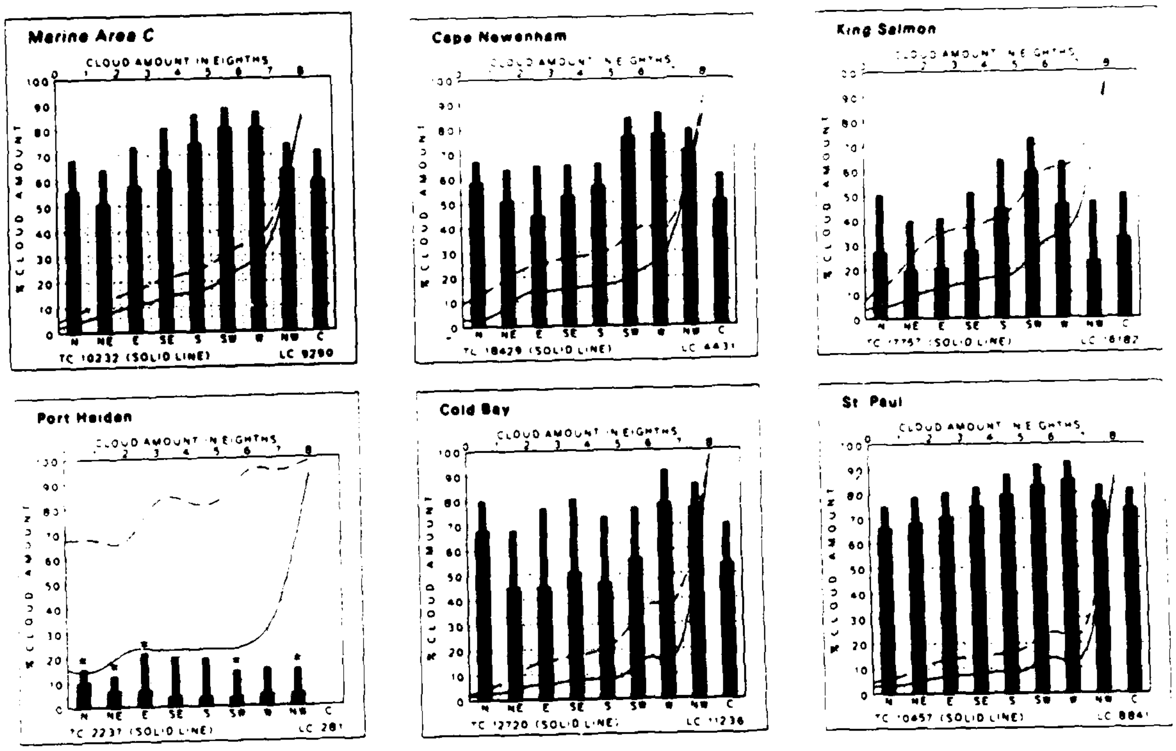
April

Figure 32b

Cloud Cover/Wind Direction



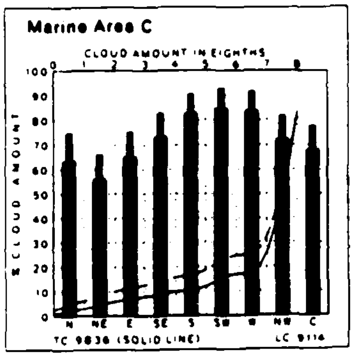
May

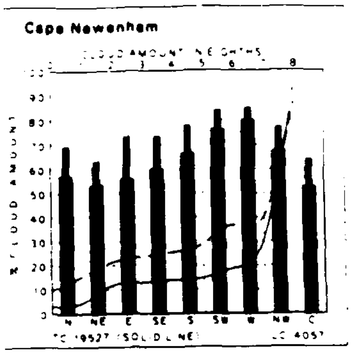


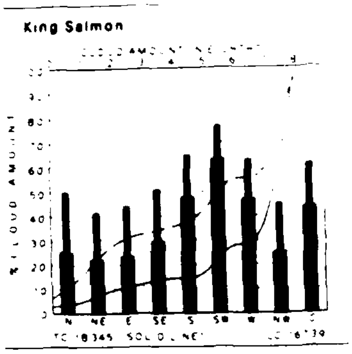
June

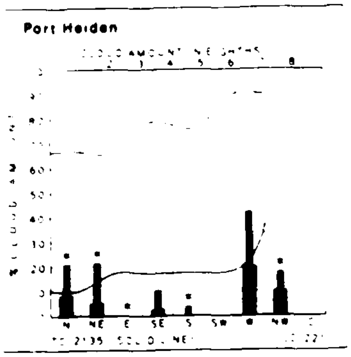
Figure 32c

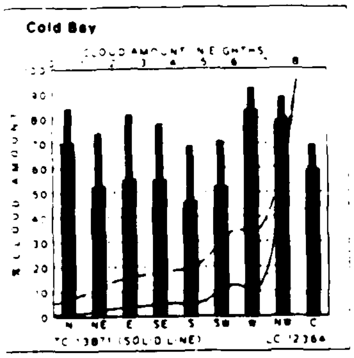
Cloud Cover/Wind Direction

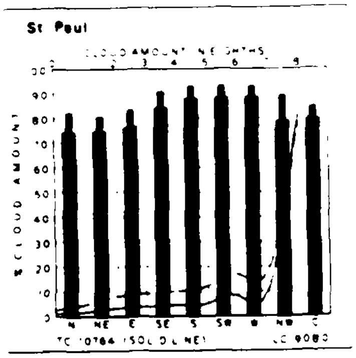




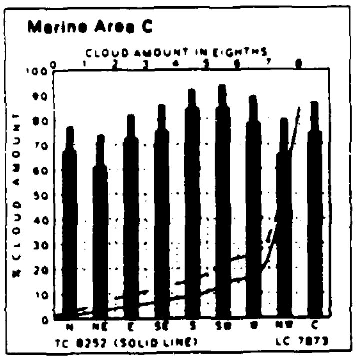


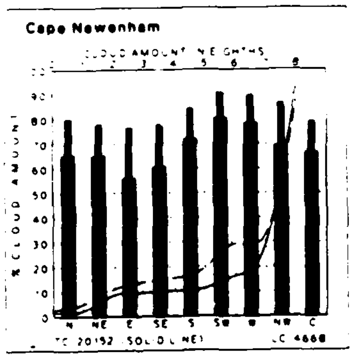


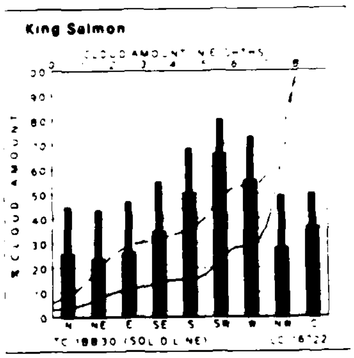


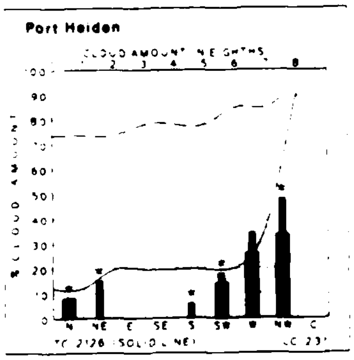


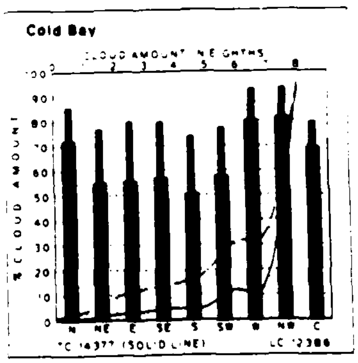
July

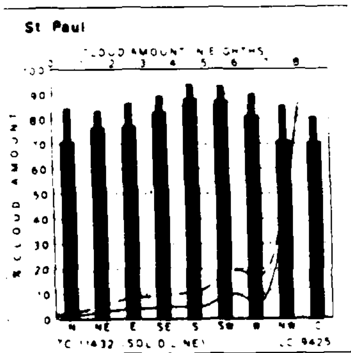








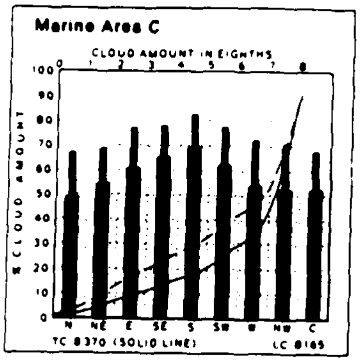


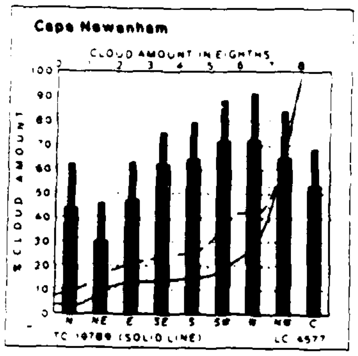


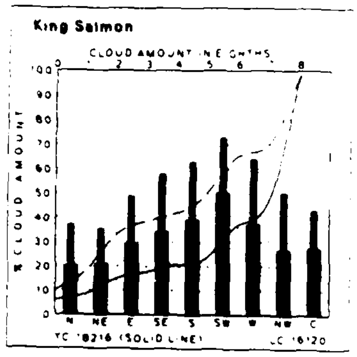
August

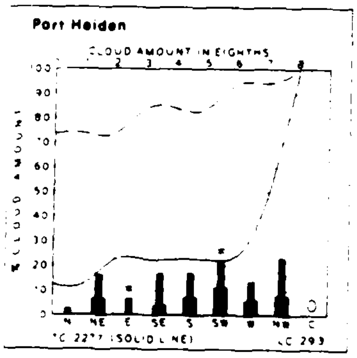
Figure 32d

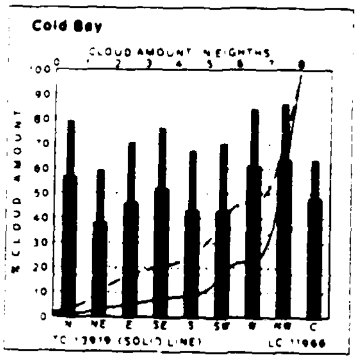
Cloud Cover/Wind Direction

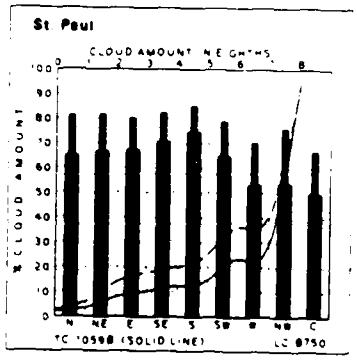




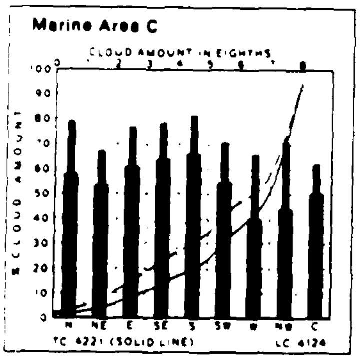


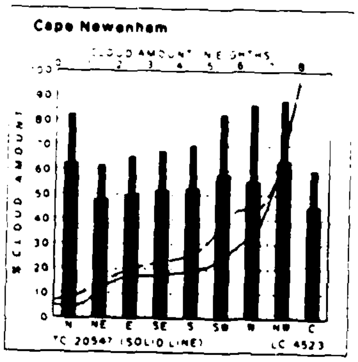


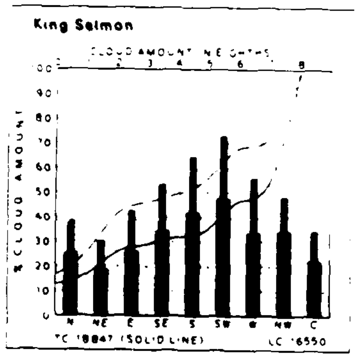


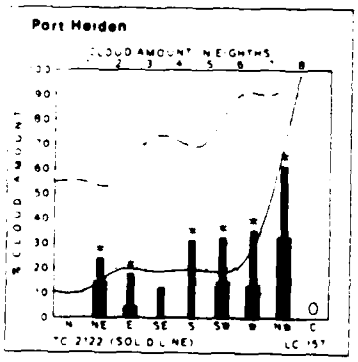


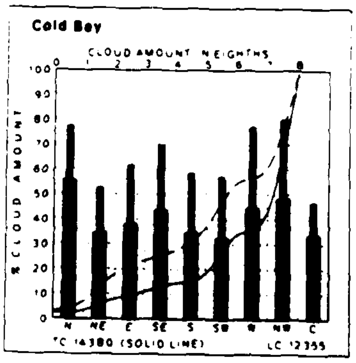
September

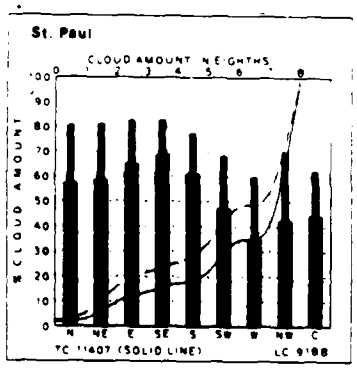








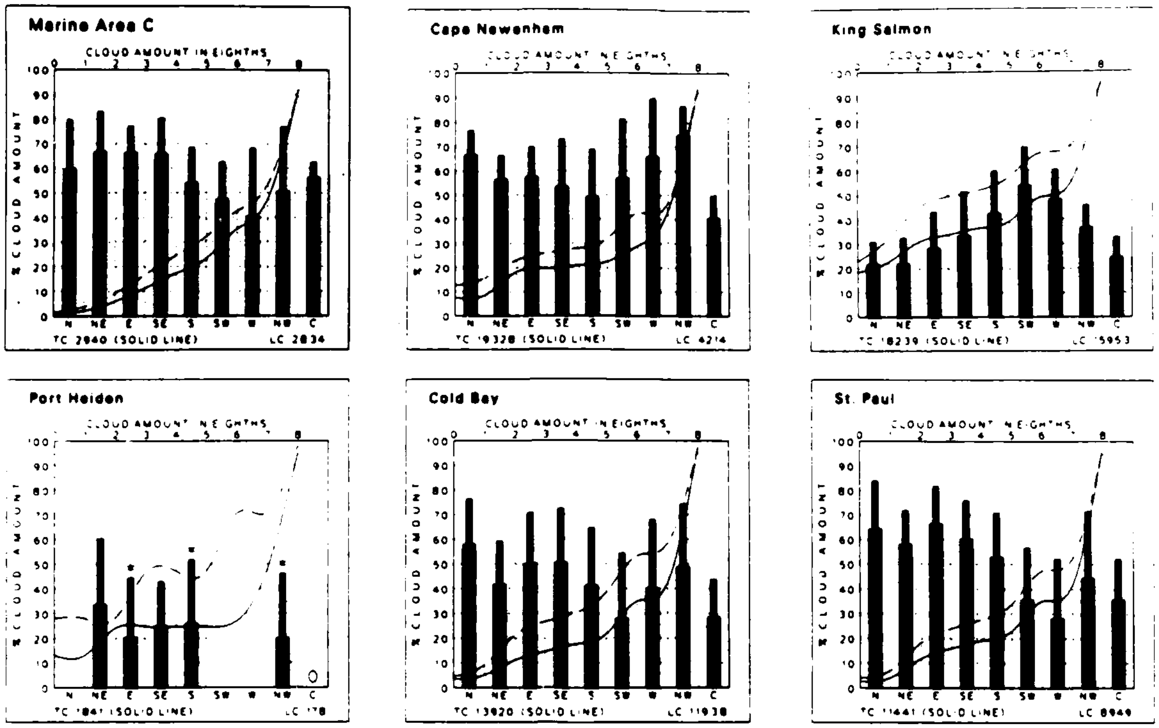




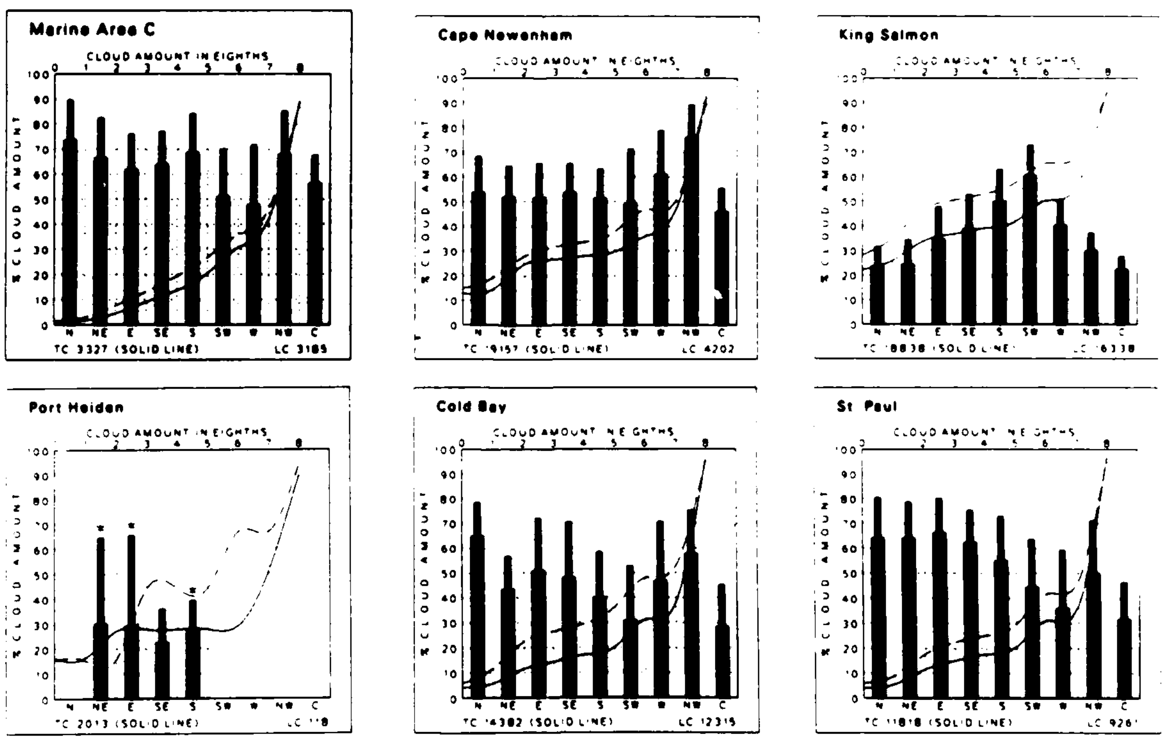
October

Figure 32e

Cloud Cover/Wind Direction



November



December

Figure 32f

BRISTOL BAY SEA ICE FORMATION AND DRIFT

Bristol Bay lies at the southern limit of true seasonal ice. In an average year, the ice in the Bering Sea begins to form and move southward during late October, reaching its southern limit during February.

By mid-October, sheltered lagoons of the inner bay, whose waters are significantly diluted with fresh water and less affected by winds, start to form ice covers. Considerable amounts of freshwater ice formed in the larger tributary rivers may enter the bay at this season. By December, low air temperatures cause widespread local freezing. Persistent northerly winds move pack ice from farther north in the Bering Sea into the bay producing conditions in which more than 50% of the inner bay has greater than 10% ice cover. Scattered ice floes are found south and east as far as a line between Port Moller and the Pribilof Islands.

The most severe sea ice conditions occur in February and March, when coverage varying from 10% to 70% may persist over the bay. Ice coverage varies according to the height of the tide, with maximum coverage occurring at low tide.

Due to highly variable temperatures, tides, and winds, pack ice in Bristol Bay consists of a continually changing mass of irregular, detached floes and cakes which are always in motion. The ice field constantly breaks up, piles, and telescopes through ever-changing pressures and is never really a continuous ice cover. Voids between pans freeze, then this new sheet breaks up followed by freezing of ever newer leads and voids. This process usually continues through many cycles. The ice edge is generally ragged and scattered during fall and winter when ice is forming.

Long, linear pressure ridges in the pack ice—common features in polar ice—seldom occur in Bristol Bay. Instead, low circumferential ridges form on the peripheries of the interacting floes and cakes.

When persistent northeasterly winter winds cause movement of sea ice southwestward into the less confined area of the mouth of the bay and beyond, it breaks up into large pans about 10-20 km (6-12 mi) in diameter.

Pack ice is occasionally blown southward across Bristol Bay by strong northerly winds and piles up quickly into massive grounded ridges along the Alaska Peninsula shores in waters less than 20 m (66 ft) deep. These ridges then become the root of a fast ice zone along the Alaska Peninsula for that season. In the inner bay there are many scattered areas of fast ice in small bays and inlets, and the mouths of small streams feeding them may be frozen.

In the spring, generally beginning in April, sea ice begins to move northward out of Bristol Bay. At this time the ice edge is usually more compact. Fast ice breaks up as coastal streams break out, flooding the ice and accelerating its decay. Serious ice conditions may persist in the outer bay well into the spring. Large masses of scattered ice have interfered with shipping well into May and June of some years (AEIDC and ISEGR 1974; Stringer 1980; U.S. National Ocean Survey 1985).

ICE EDGE LOCATION AND FIVE-TENTHS ICE CONCENTRATION BOUNDARY

Semimonthly information on the probabilities of the locations of the ice edge and the five-tenths ice concentration boundary are presented in figures 33a through 33p and figures 34a through 34p, respectively, from source information covering a 29-year period from 1953 to 1981 (Webster 1981, 1982), as displayed in LaBelle, et al. (1983). The ice edge is the southernmost extent of sea ice coverage of any concentration at any given time. The five-tenths ice concentration boundary is the ice concentration above which icebreaking vessels are needed for navigation. Ice concentration, however, implies nothing about ice thickness or strength.

The separation between the ice edge and the five-tenths ice concentration boundary is greatest during the period that the ice edge is retreating northward, during the late spring and summer months. During periods when the ice edge is either stationary or advancing southward during then fall, winter, and early spring, the two boundaries are coincident.

Probability in Percent of the Ice Edge Location

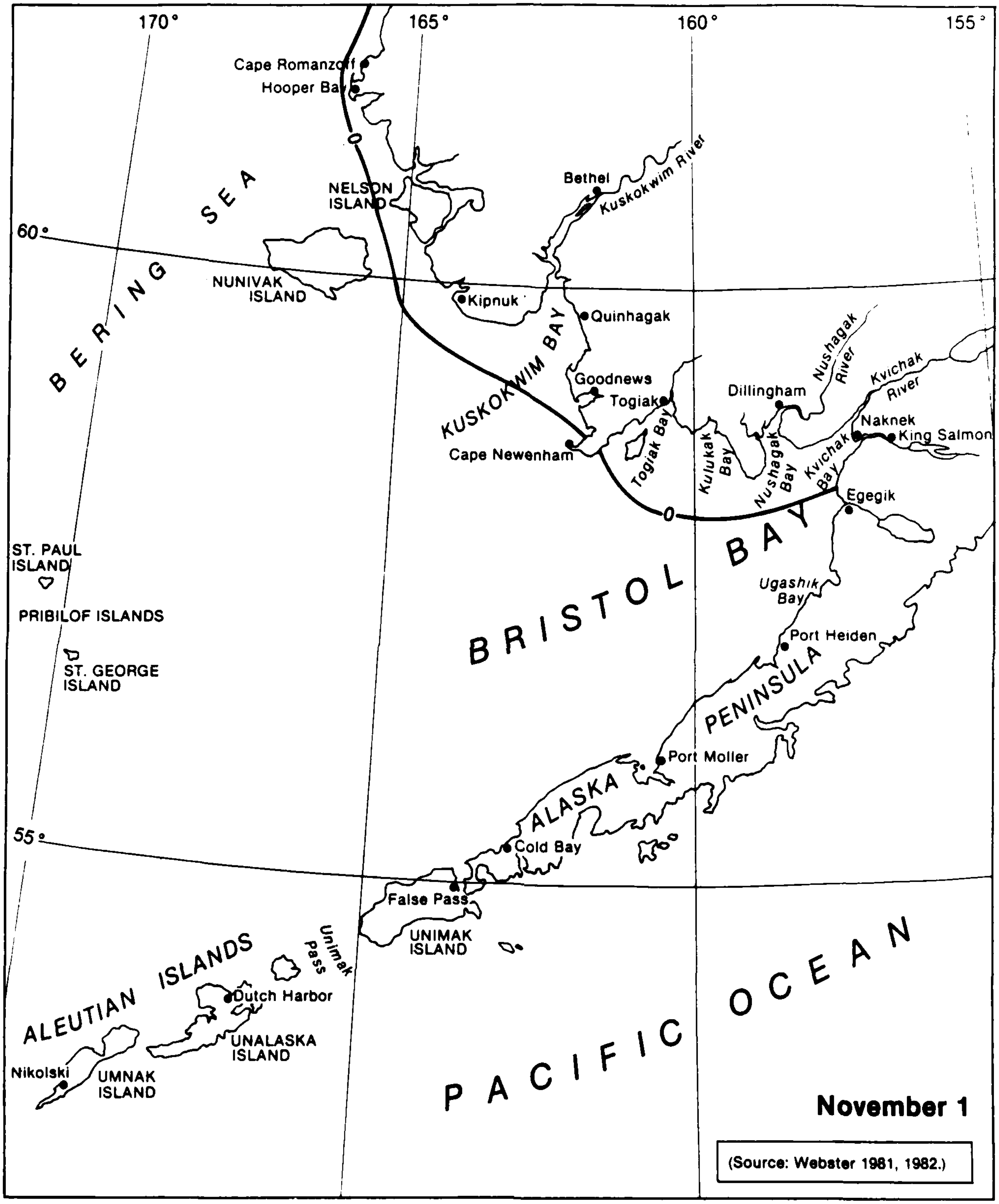


Figure 33a

Probability in Percent of the Ice Edge Location

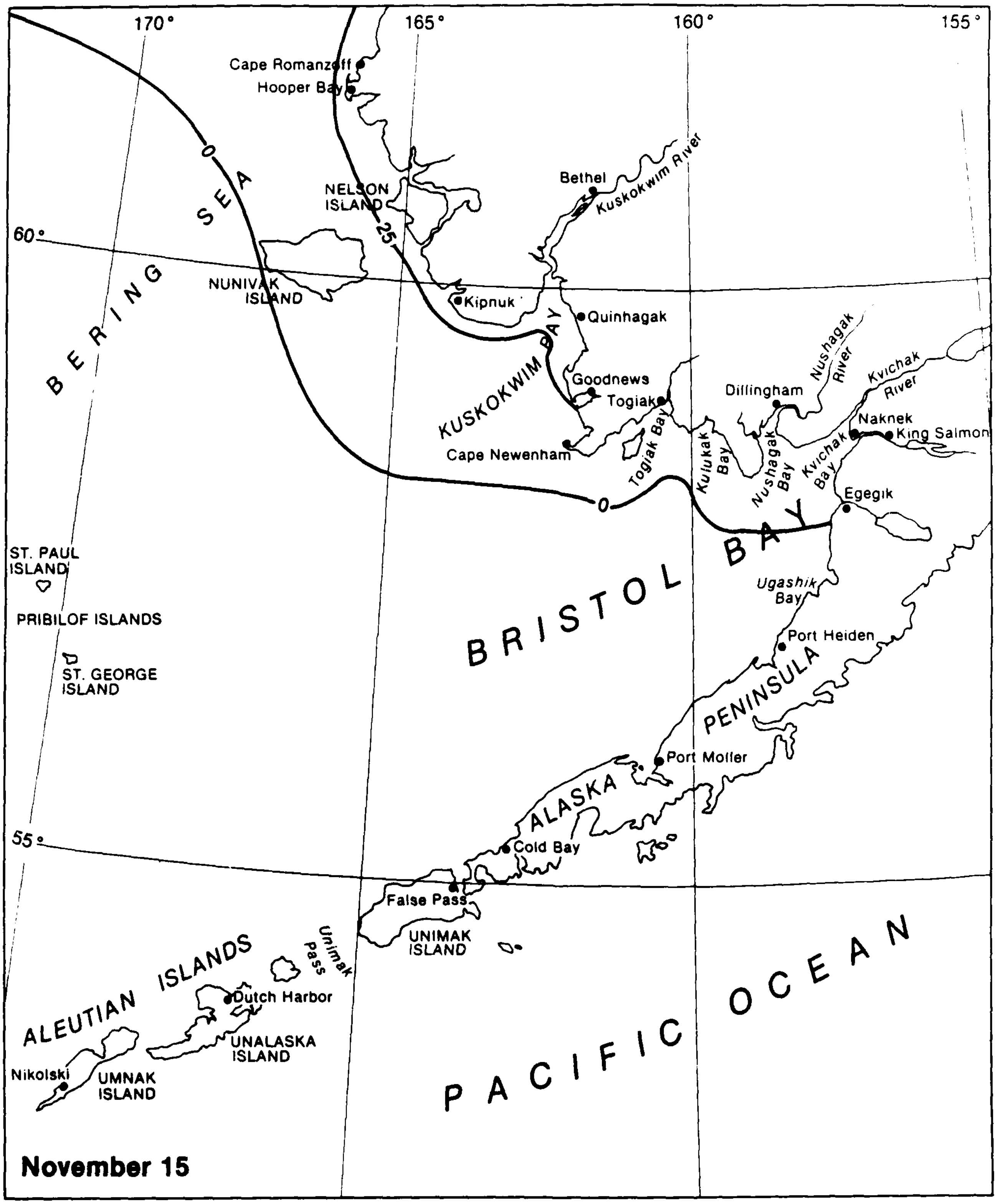


Figure 33b

Probability in Percent of the Ice Edge Location

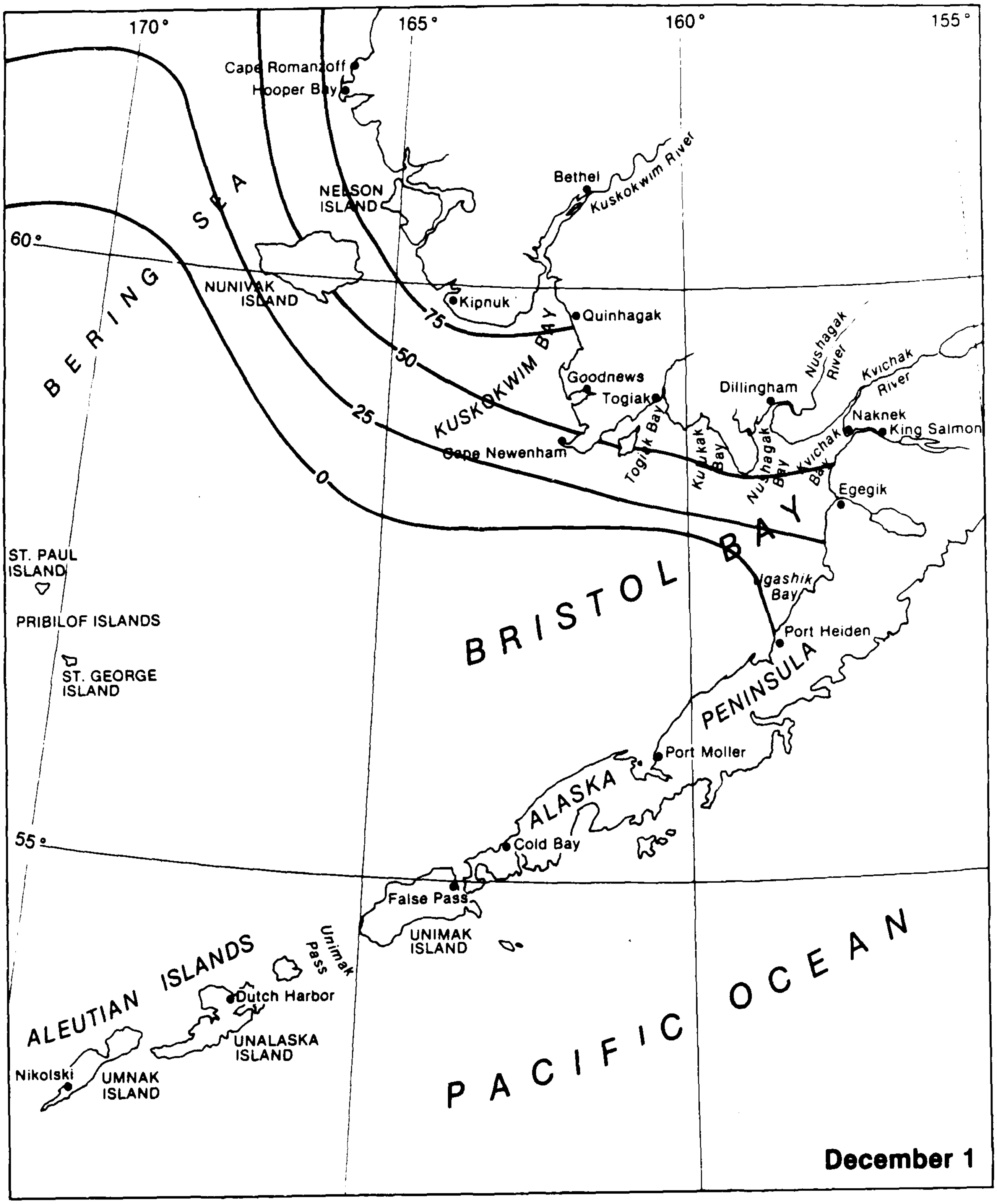


Figure 33c

Probability in Percent of the Ice Edge Location

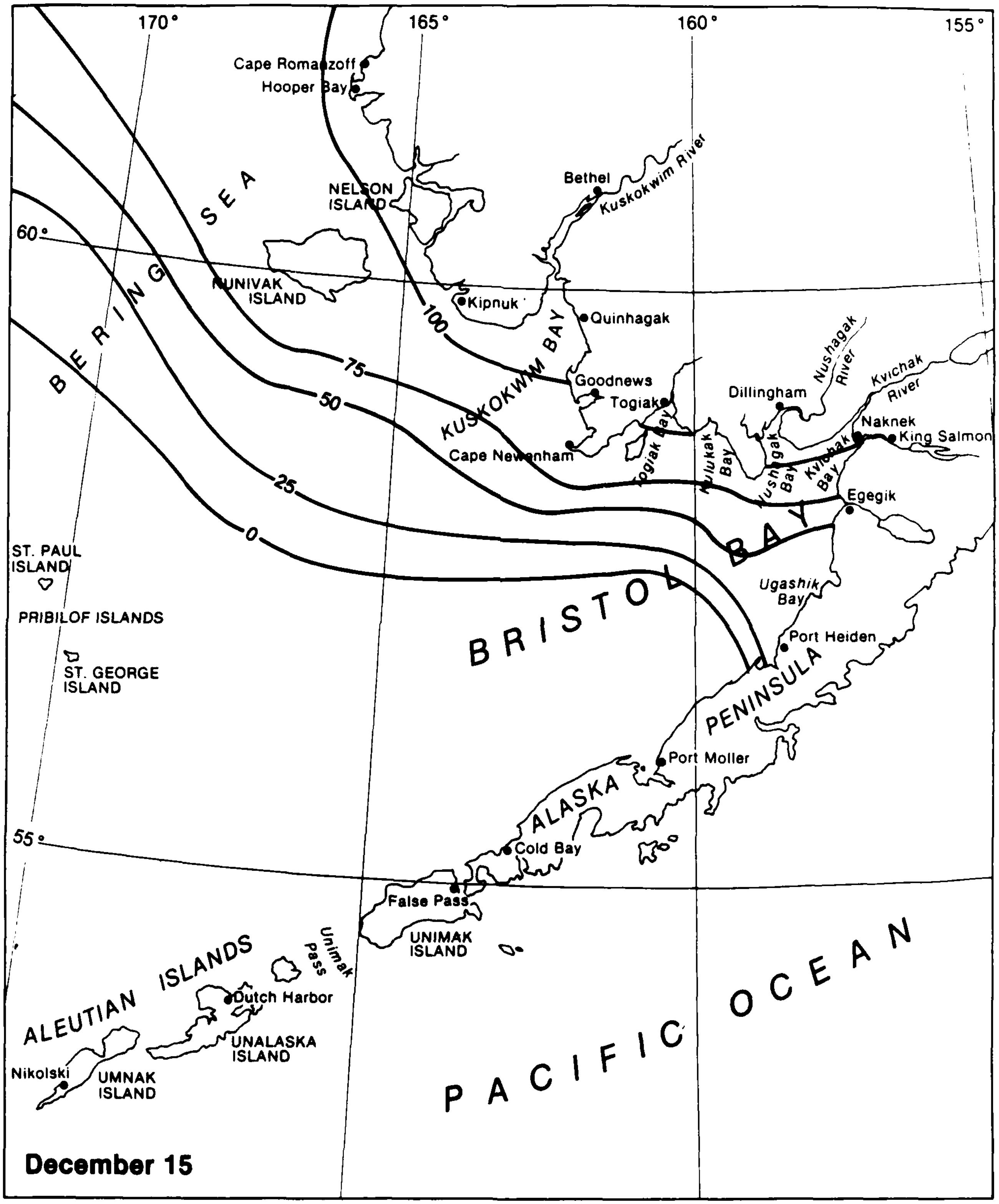


Figure 33d

Probability in Percent of the Ice Edge Location

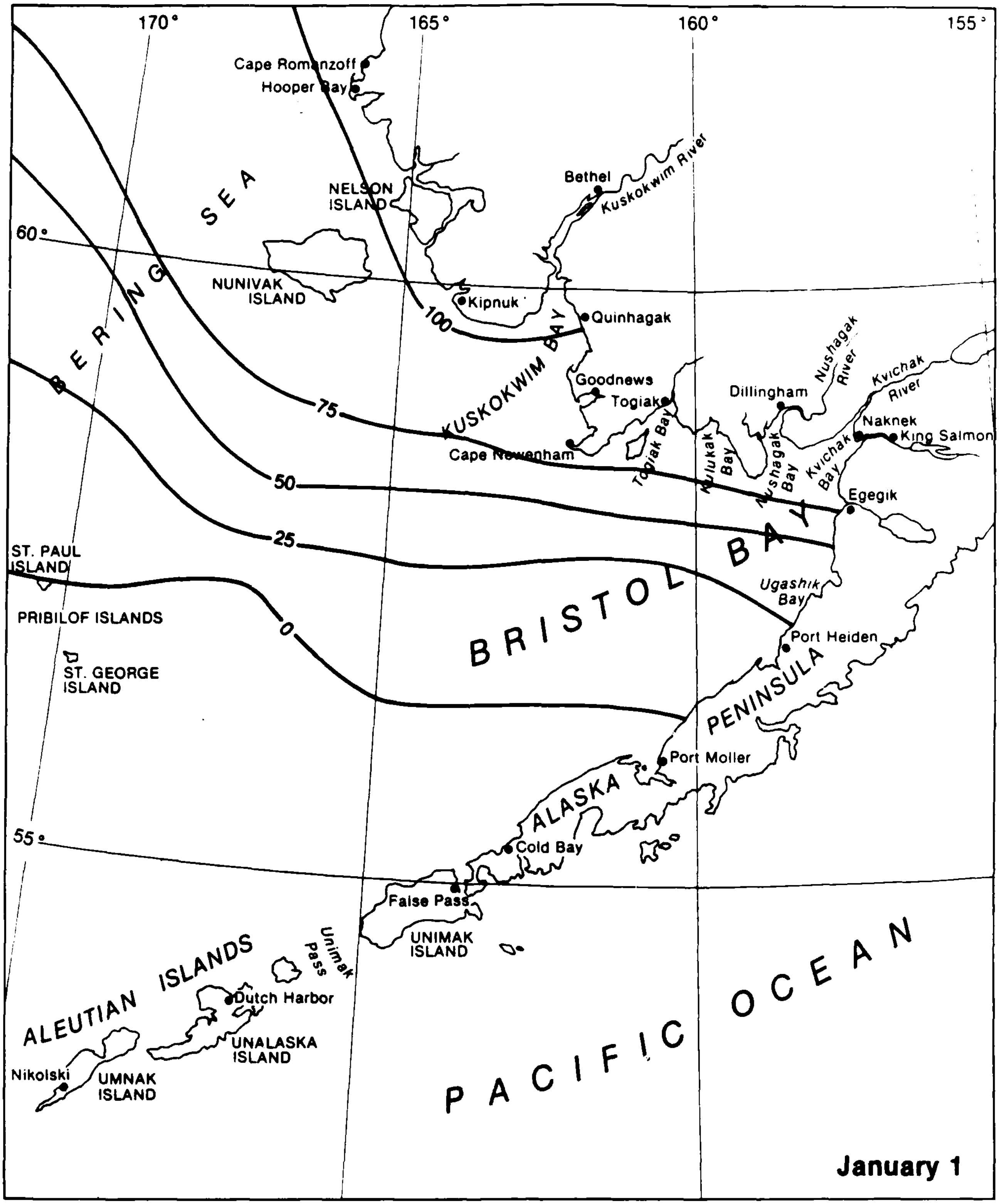


Figure 33e

Probability in Percent of the Ice Edge Location

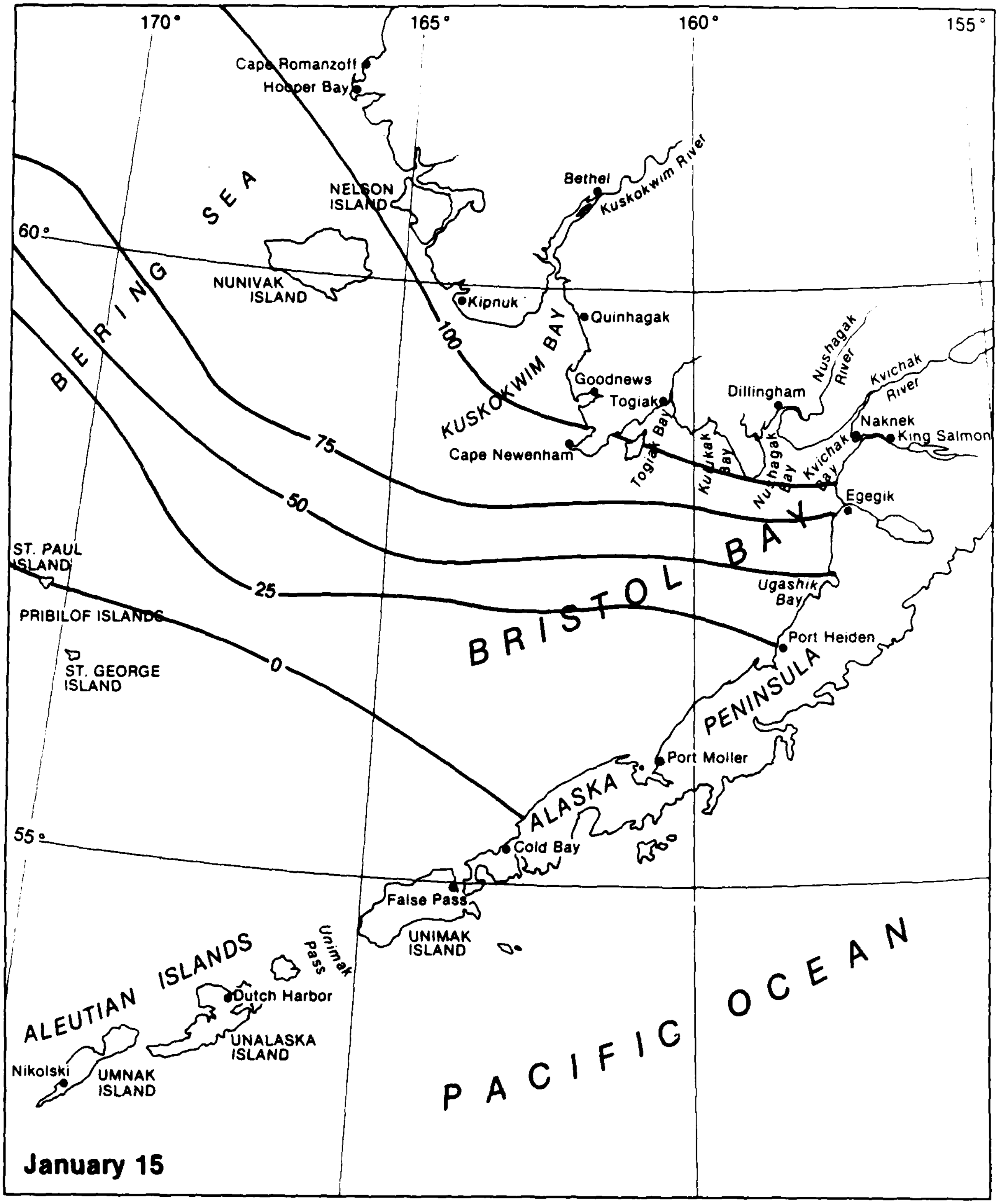


Figure 33f

Probability in Percent of the Ice Edge Location

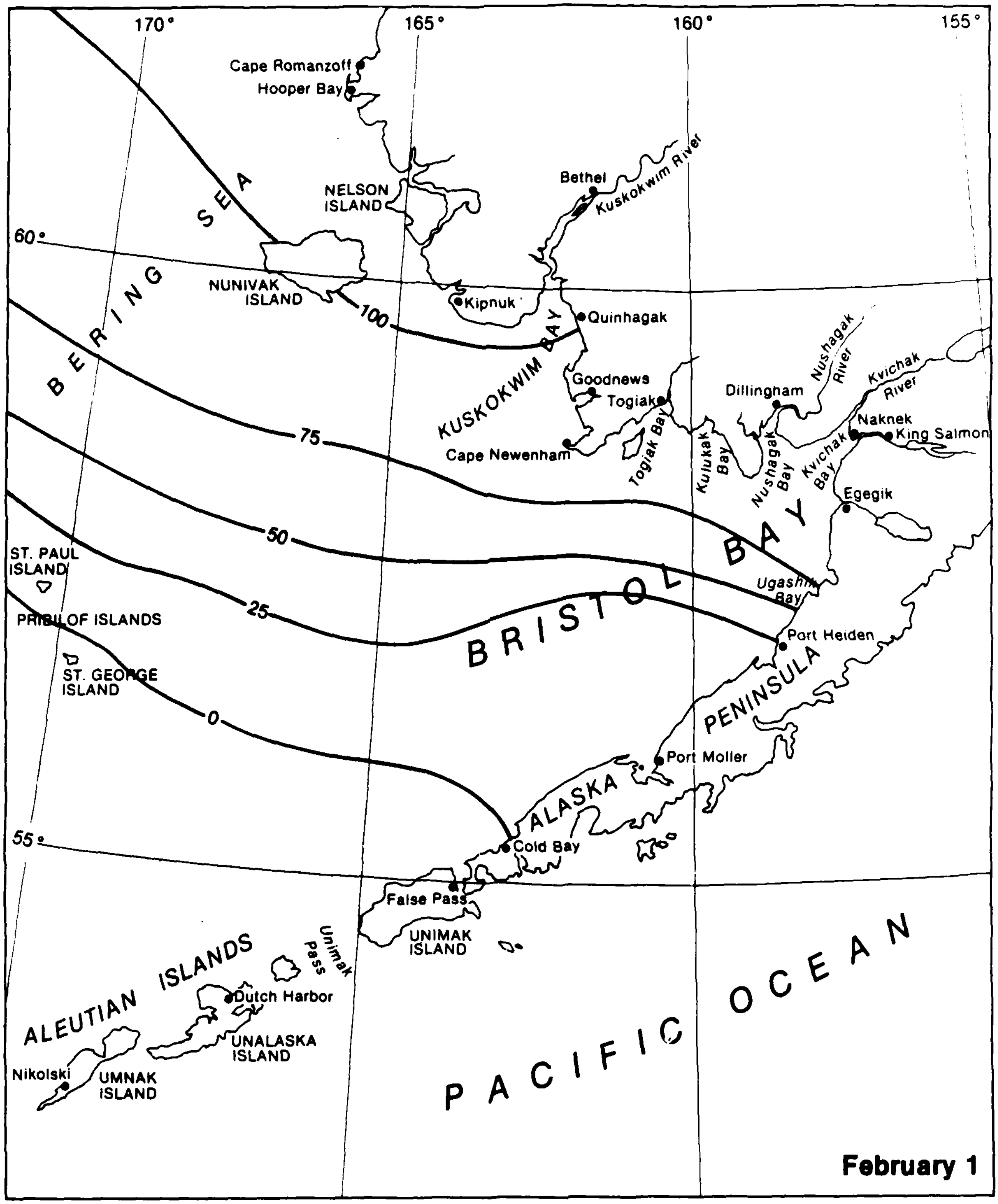


Figure 33g

Probability in Percent of the Ice Edge Location

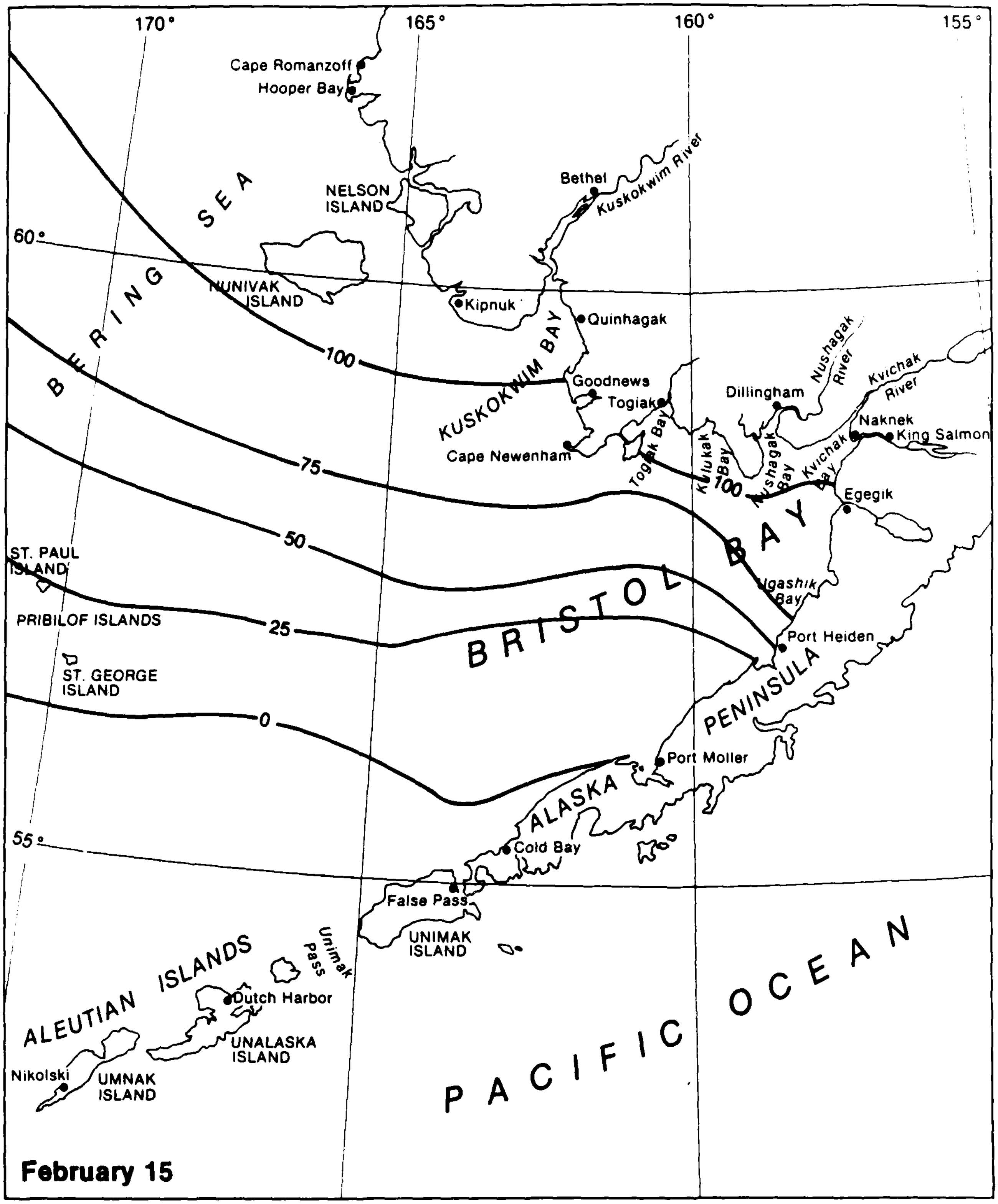


Figure 33h

Probability in Percent of the Ice Edge Location

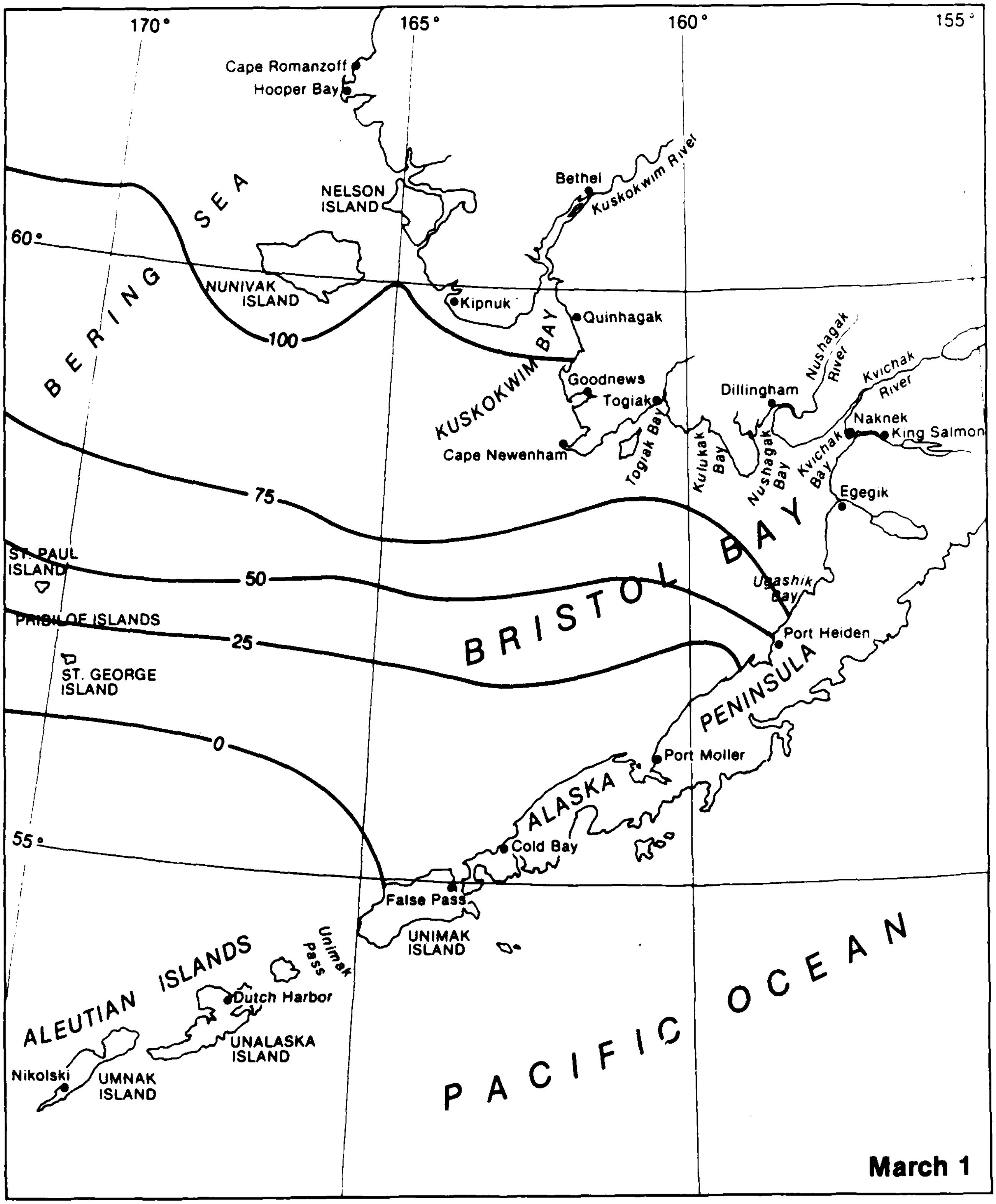


Figure 33i

Probability in Percent of the Ice Edge Location

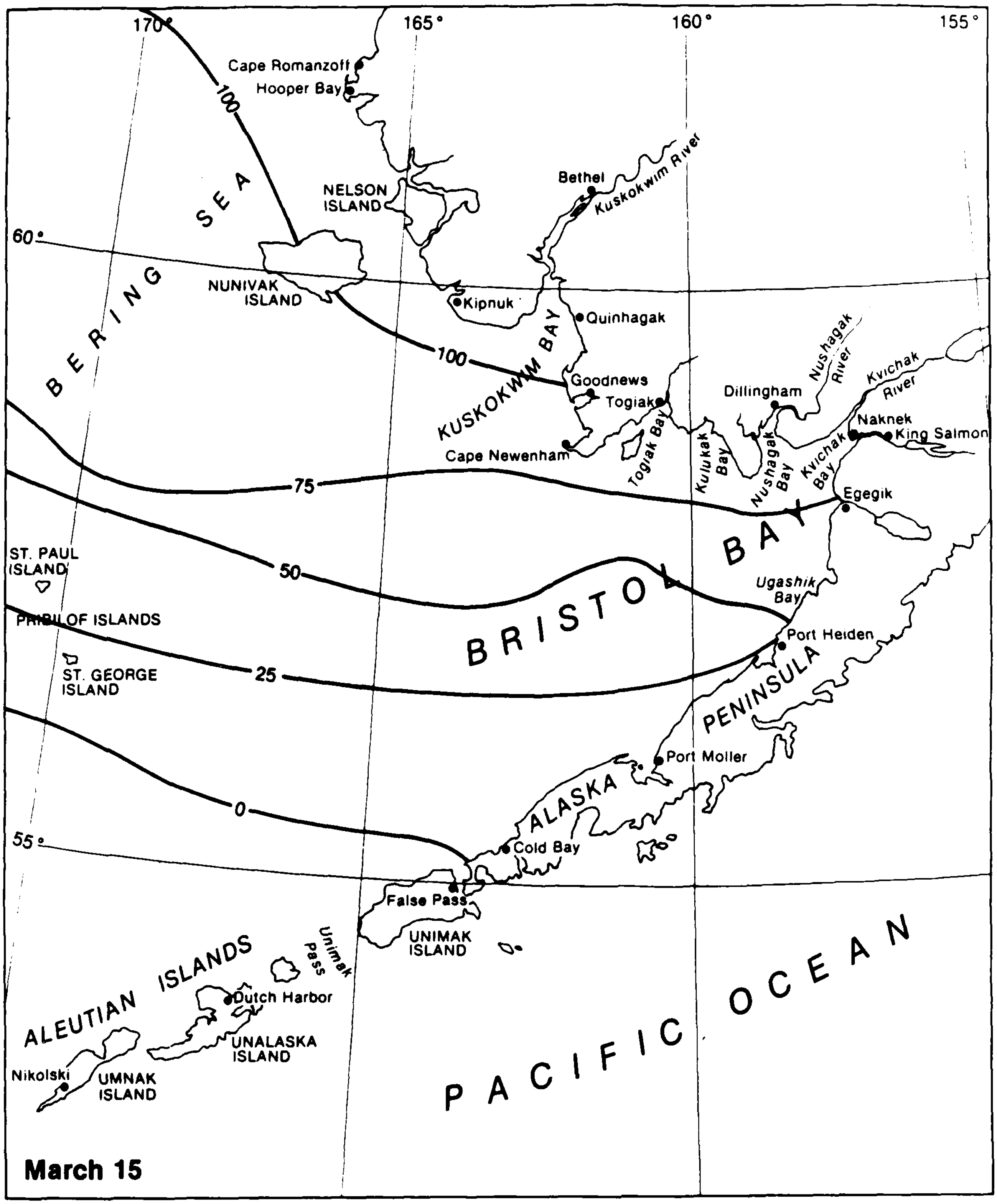


Figure 33j

Probability in Percent of the Ice Edge Location

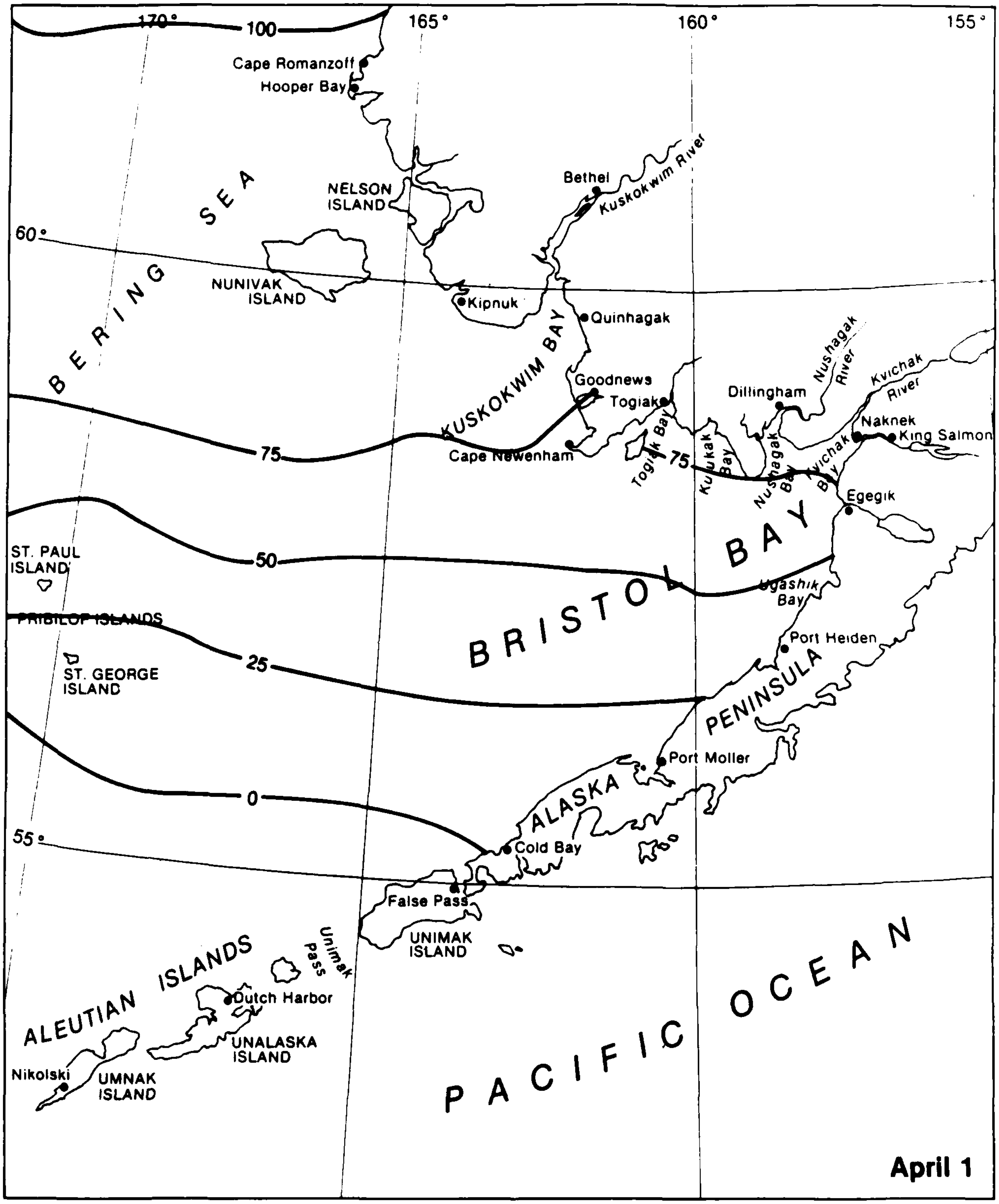


Figure 33k

Probability in Percent of the Ice Edge Location

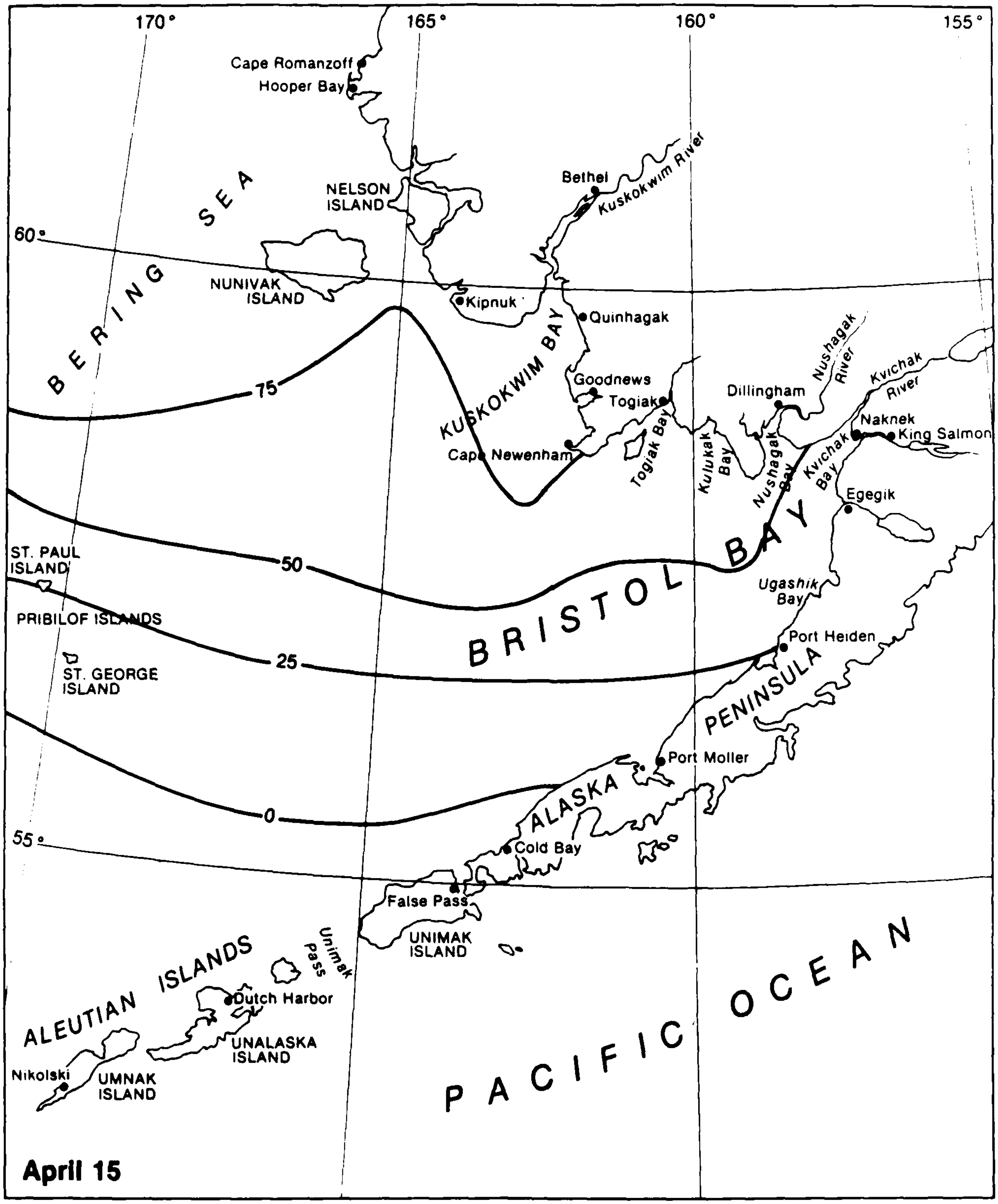


Figure 33I

Probability in Percent of the Ice Edge Location

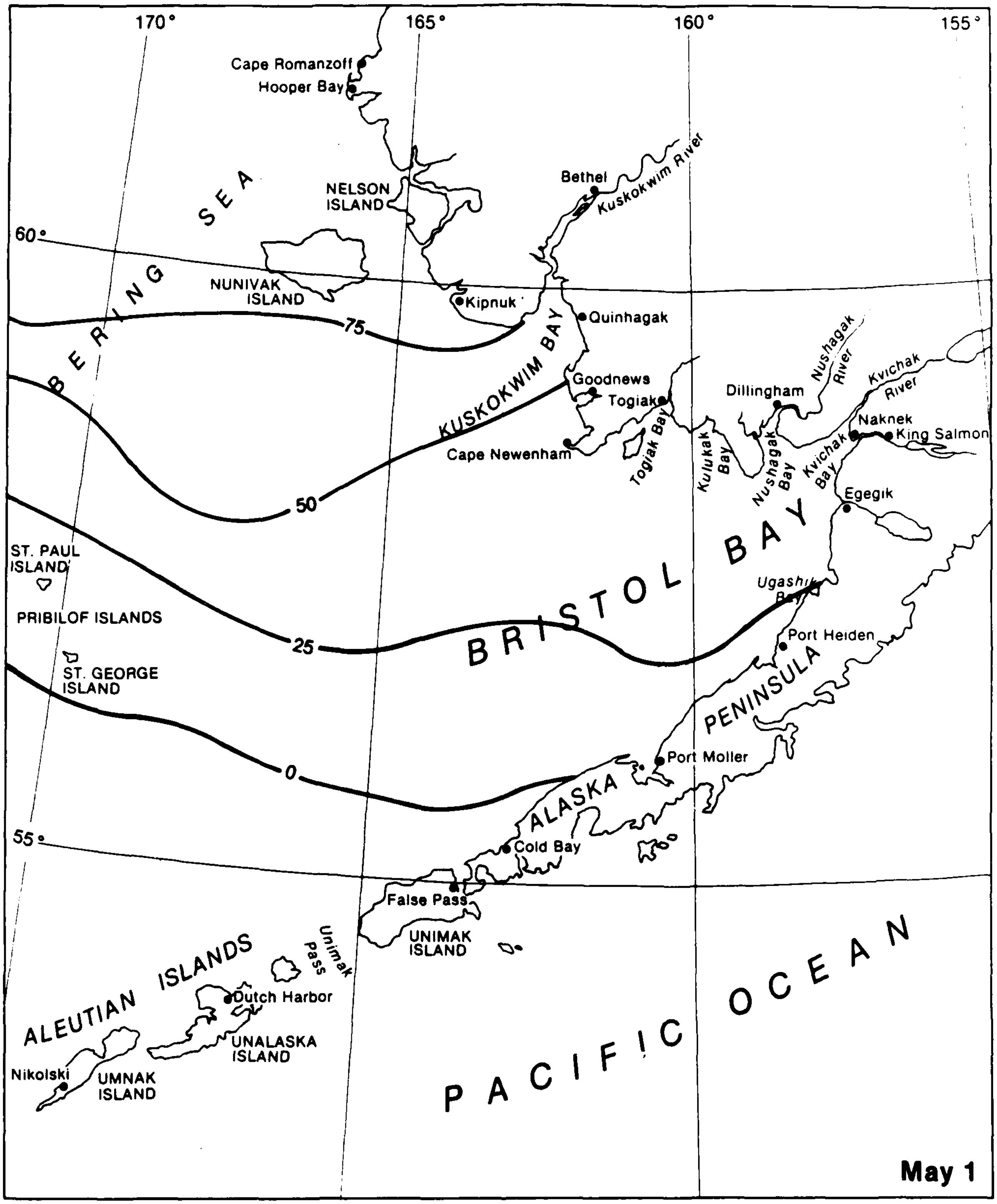


Figure 33m

Probability in Percent of the Ice Edge Location

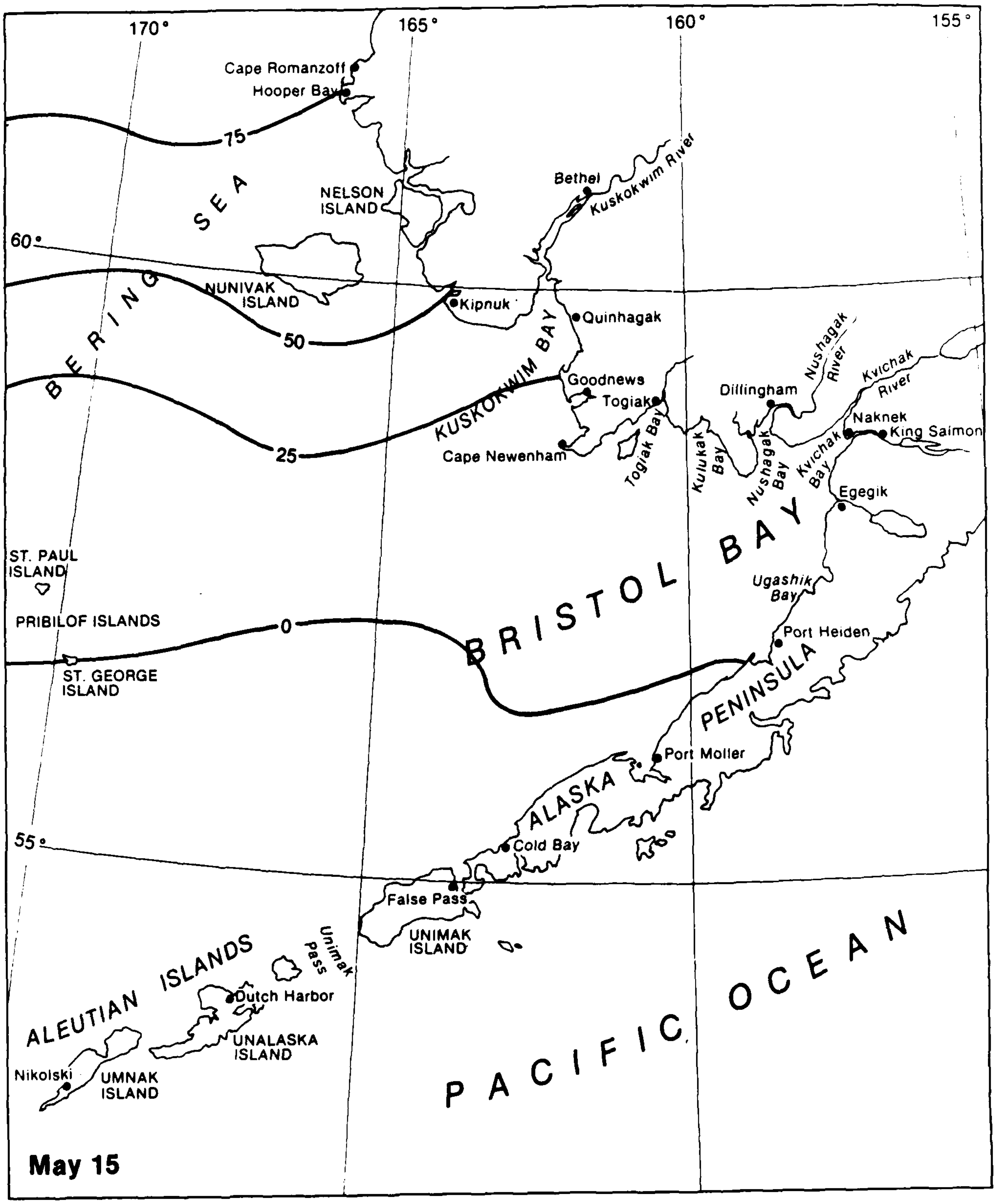


Figure 33n

Probability in Percent of the Ice Edge Location

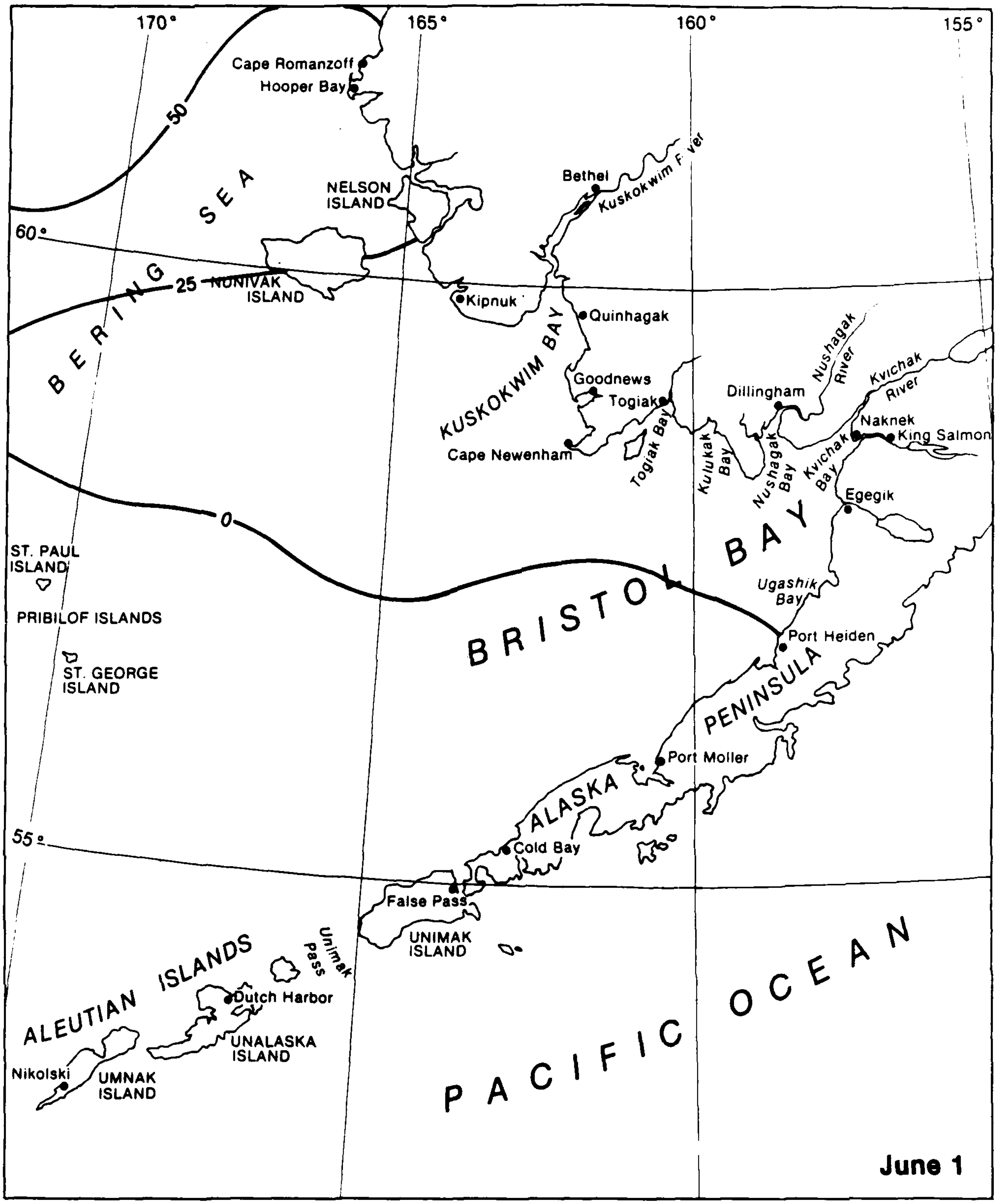


Figure 33o

Probability in Percent of the Ice Edge Location

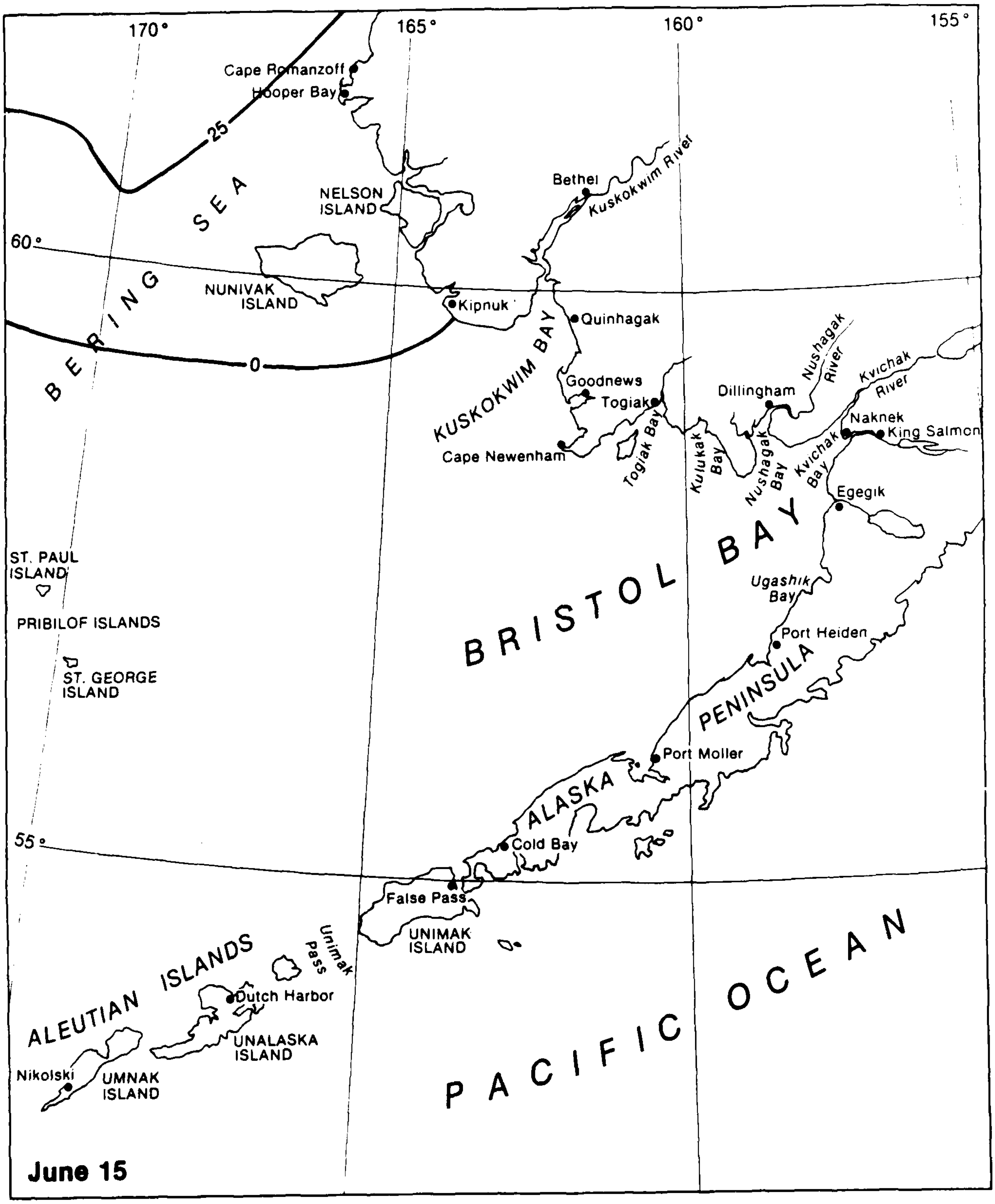


Figure 33p

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

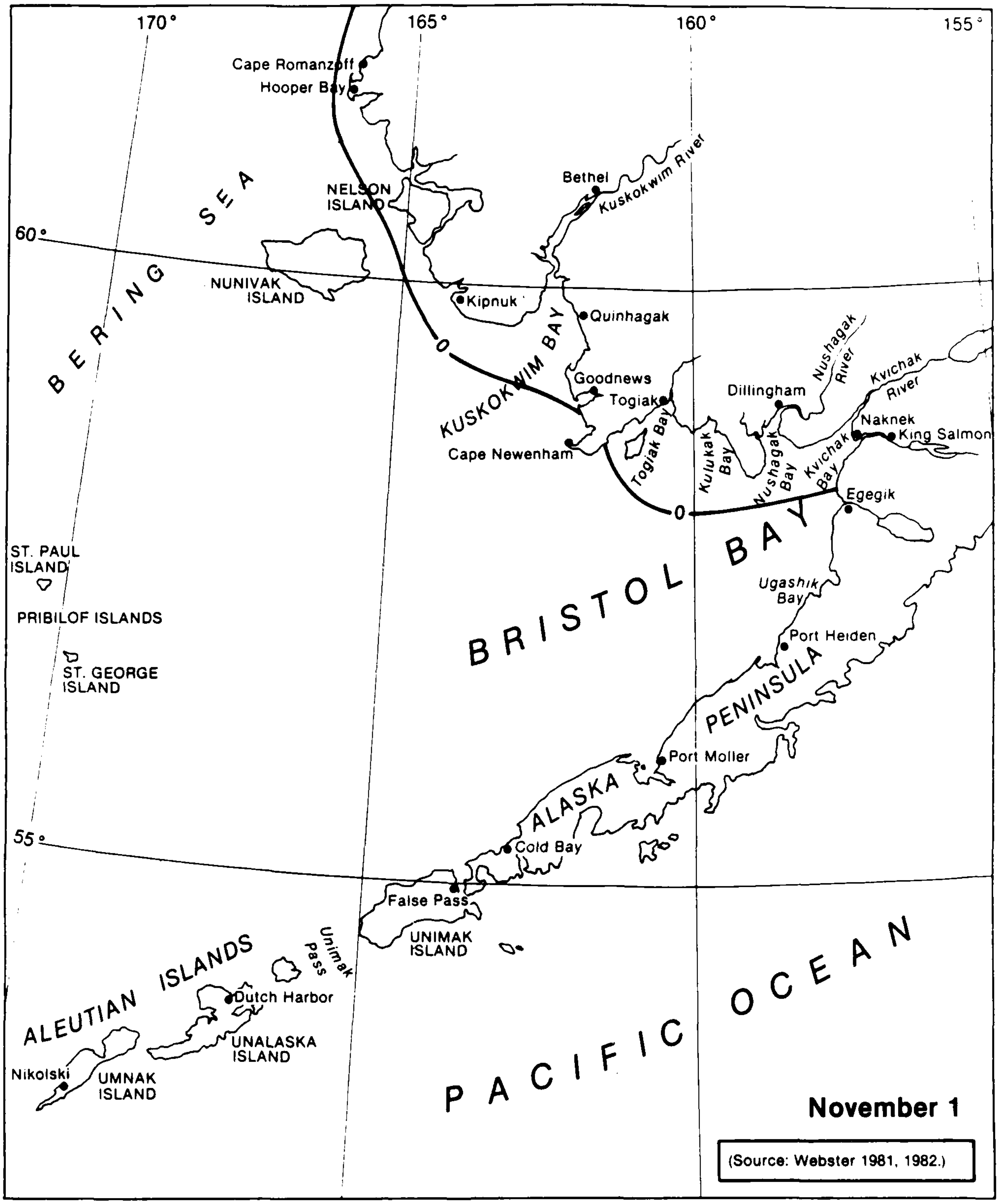


Figure 34a

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

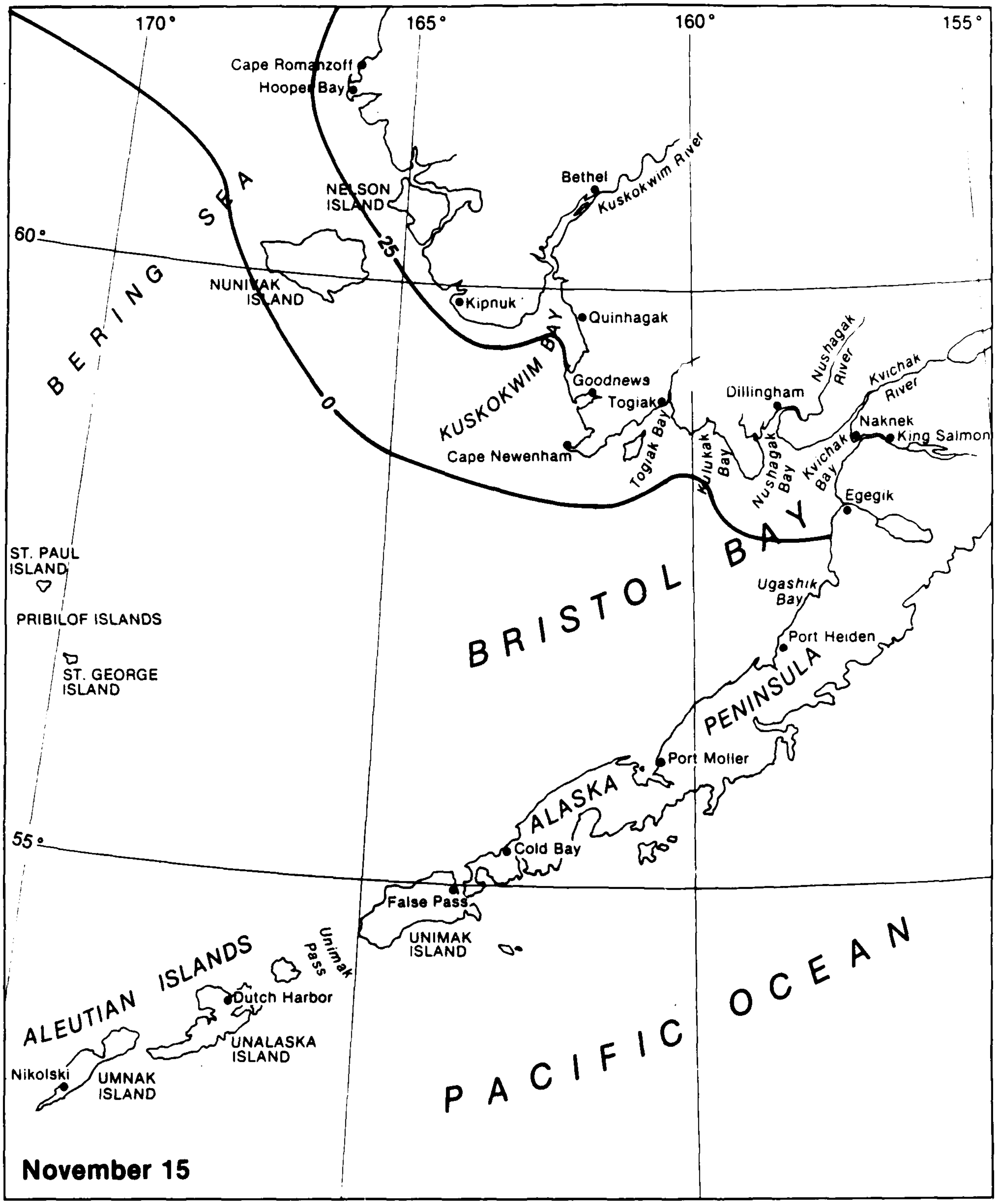


Figure 34b

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

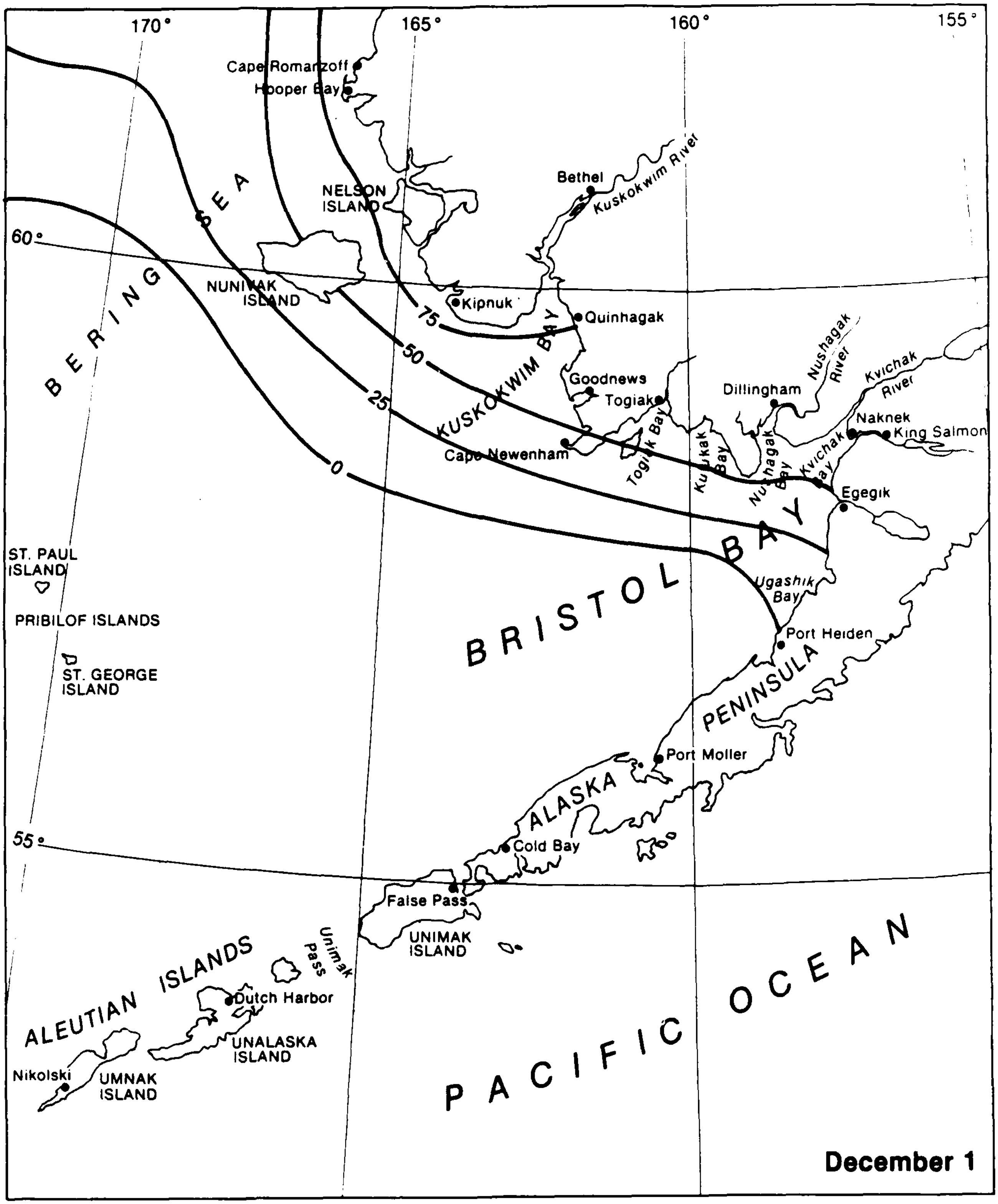


Figure 34c

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

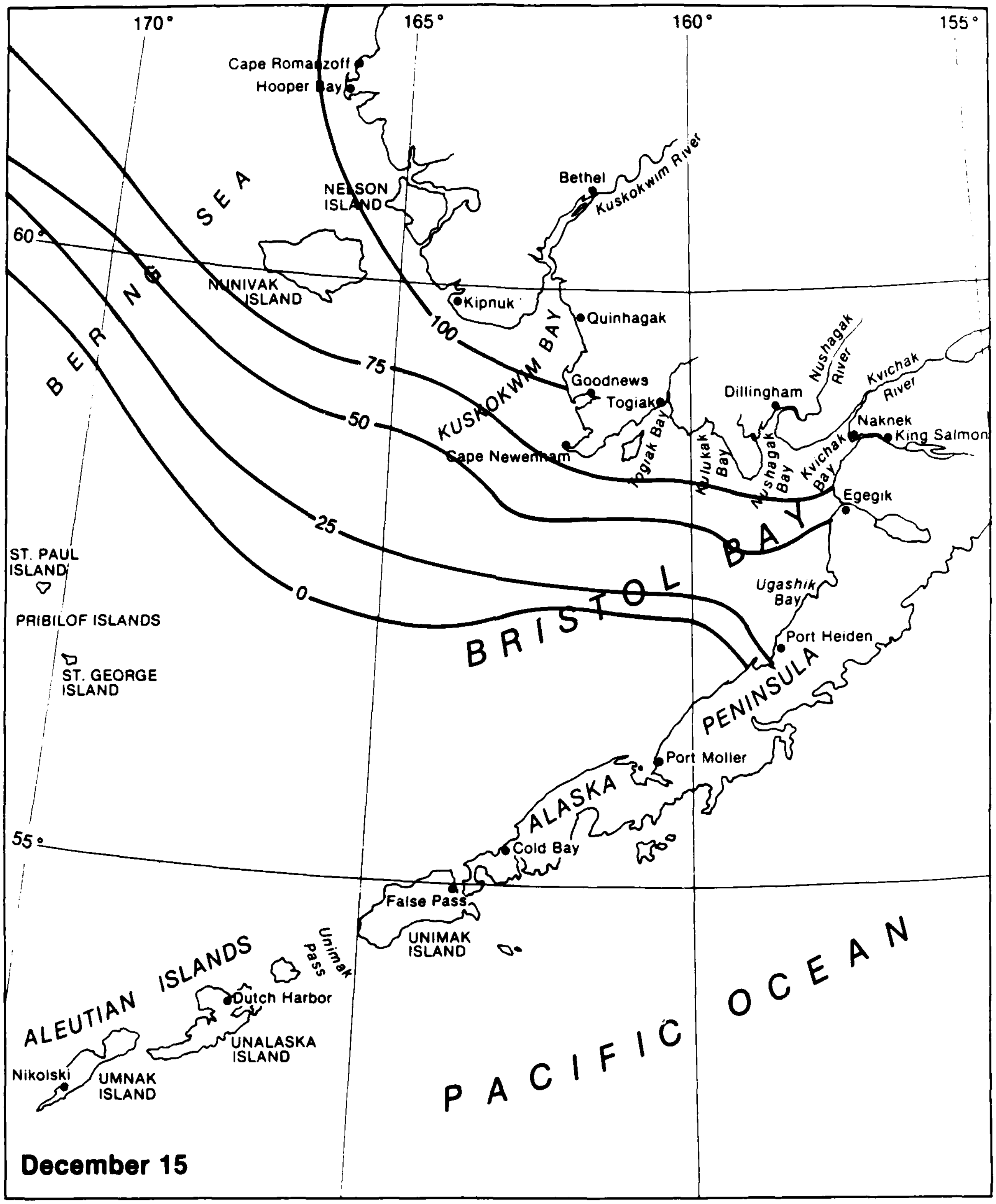


Figure 34d

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

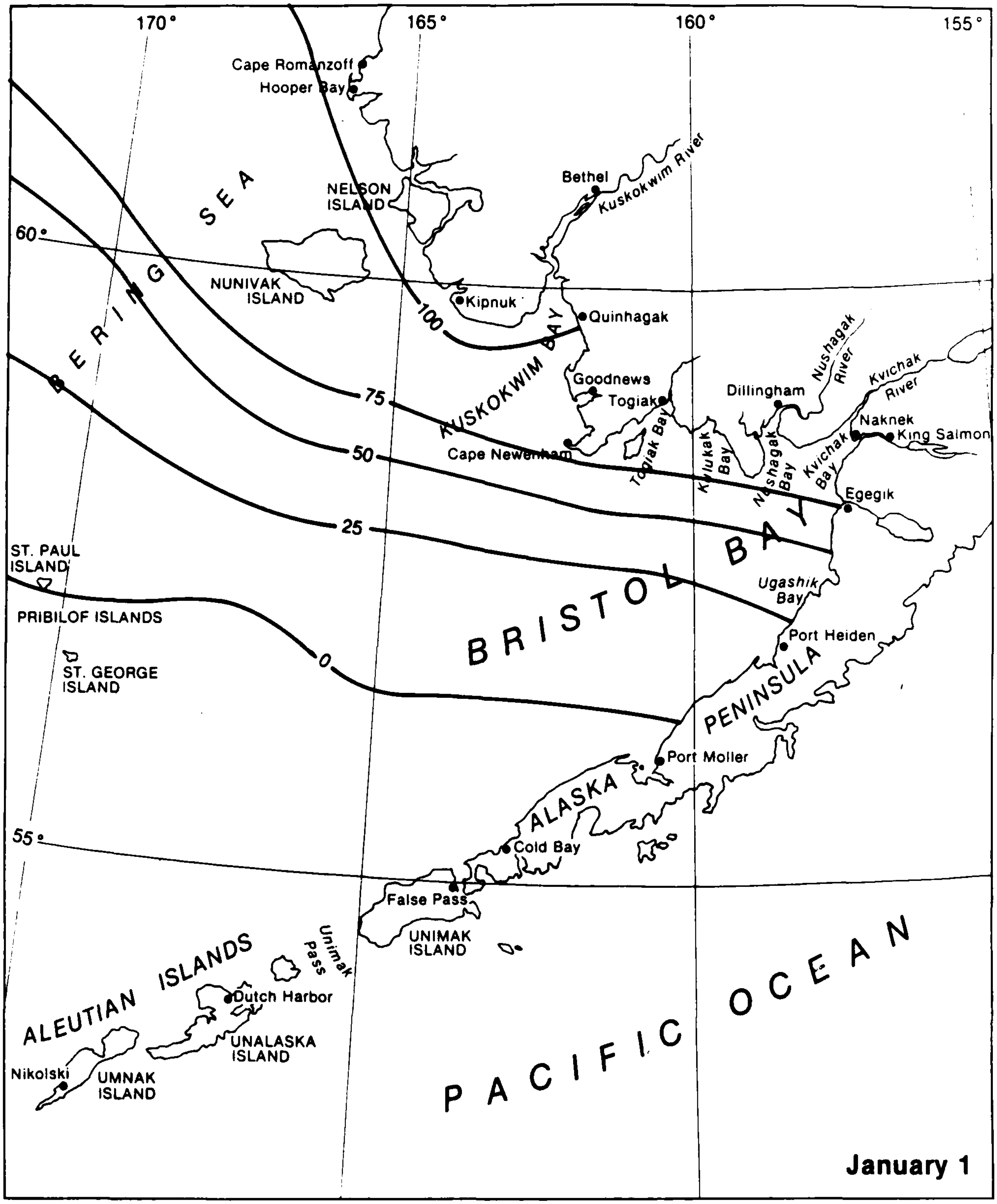


Figure 34e

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

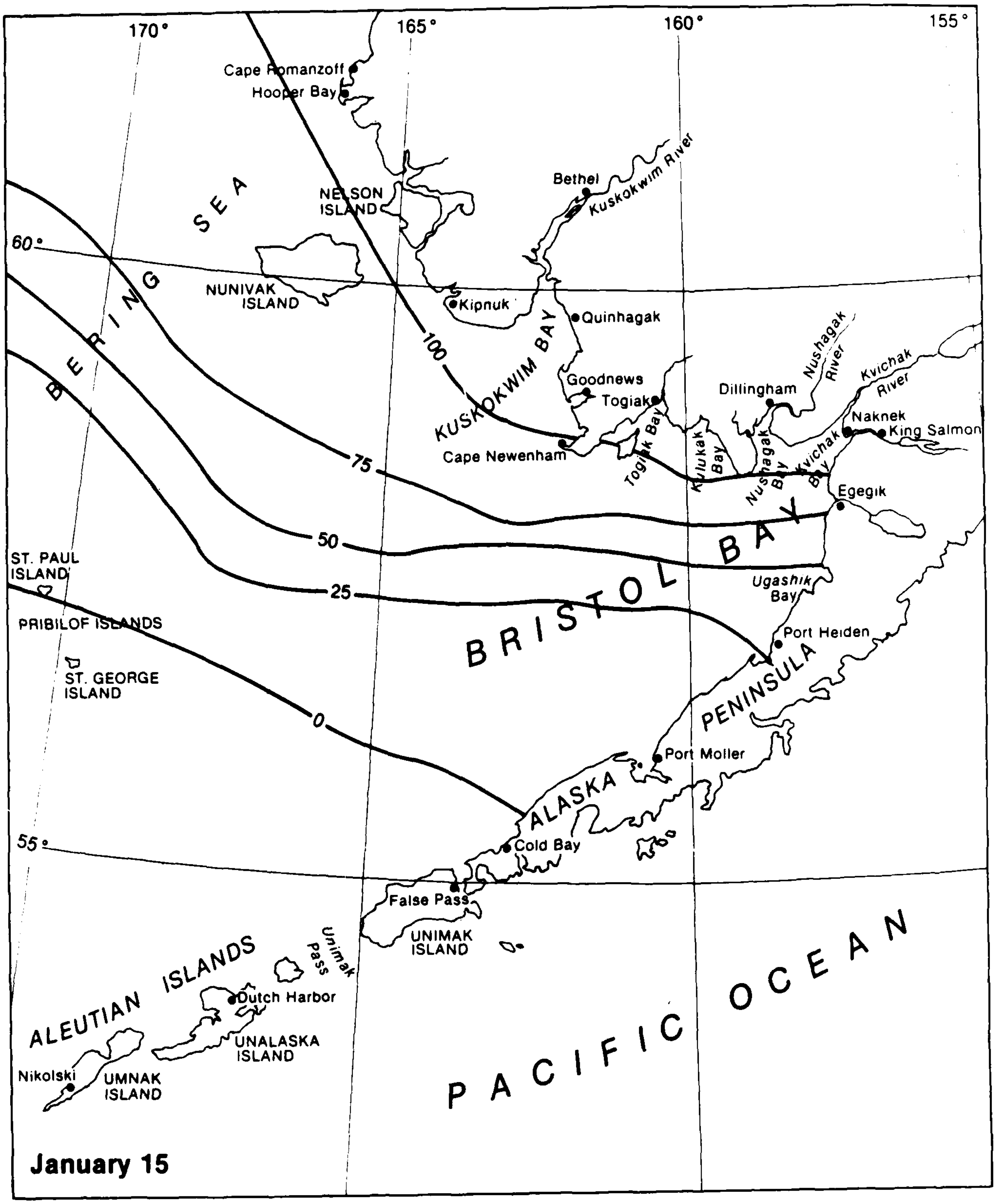


Figure 34f

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

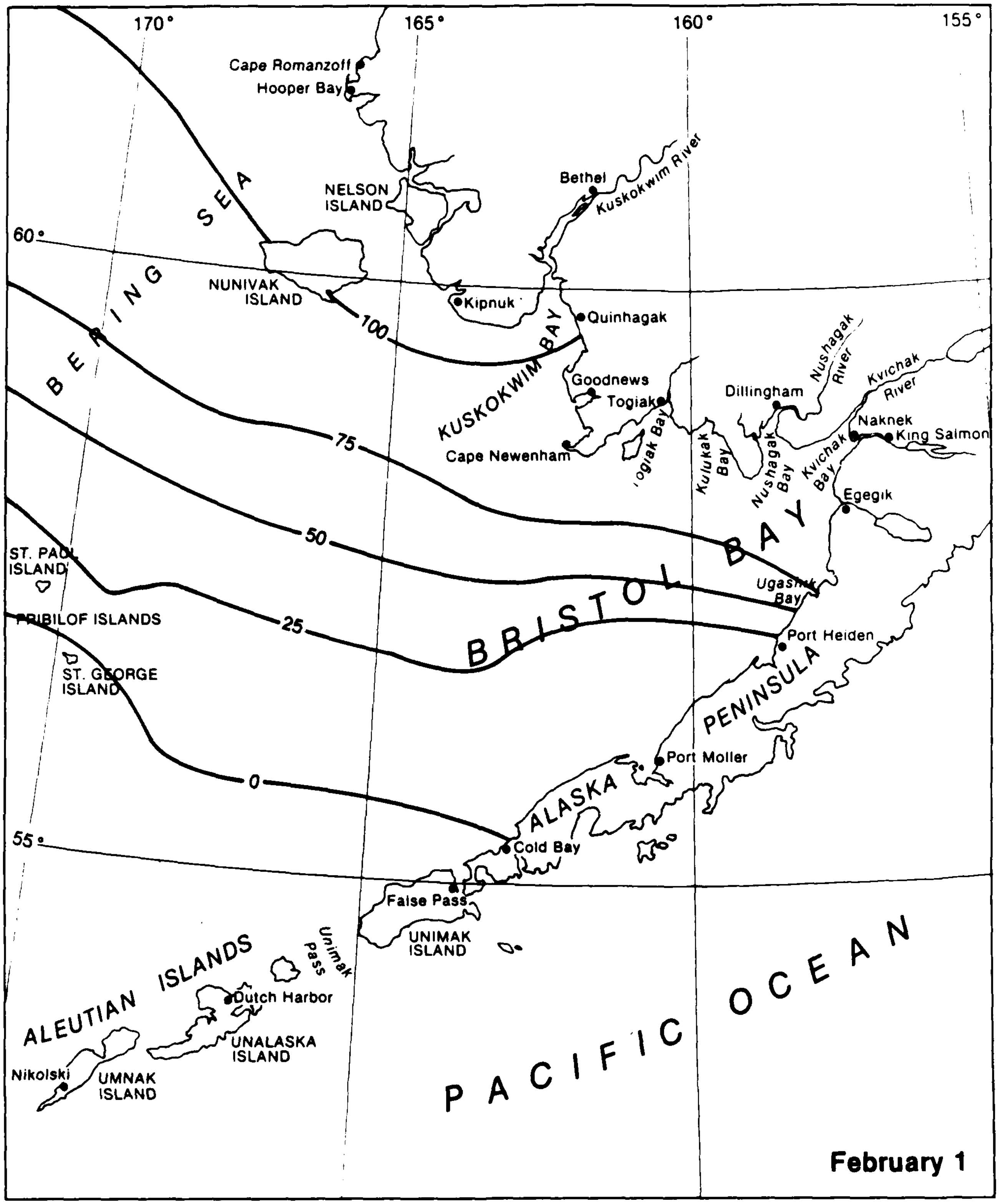


Figure 34g

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

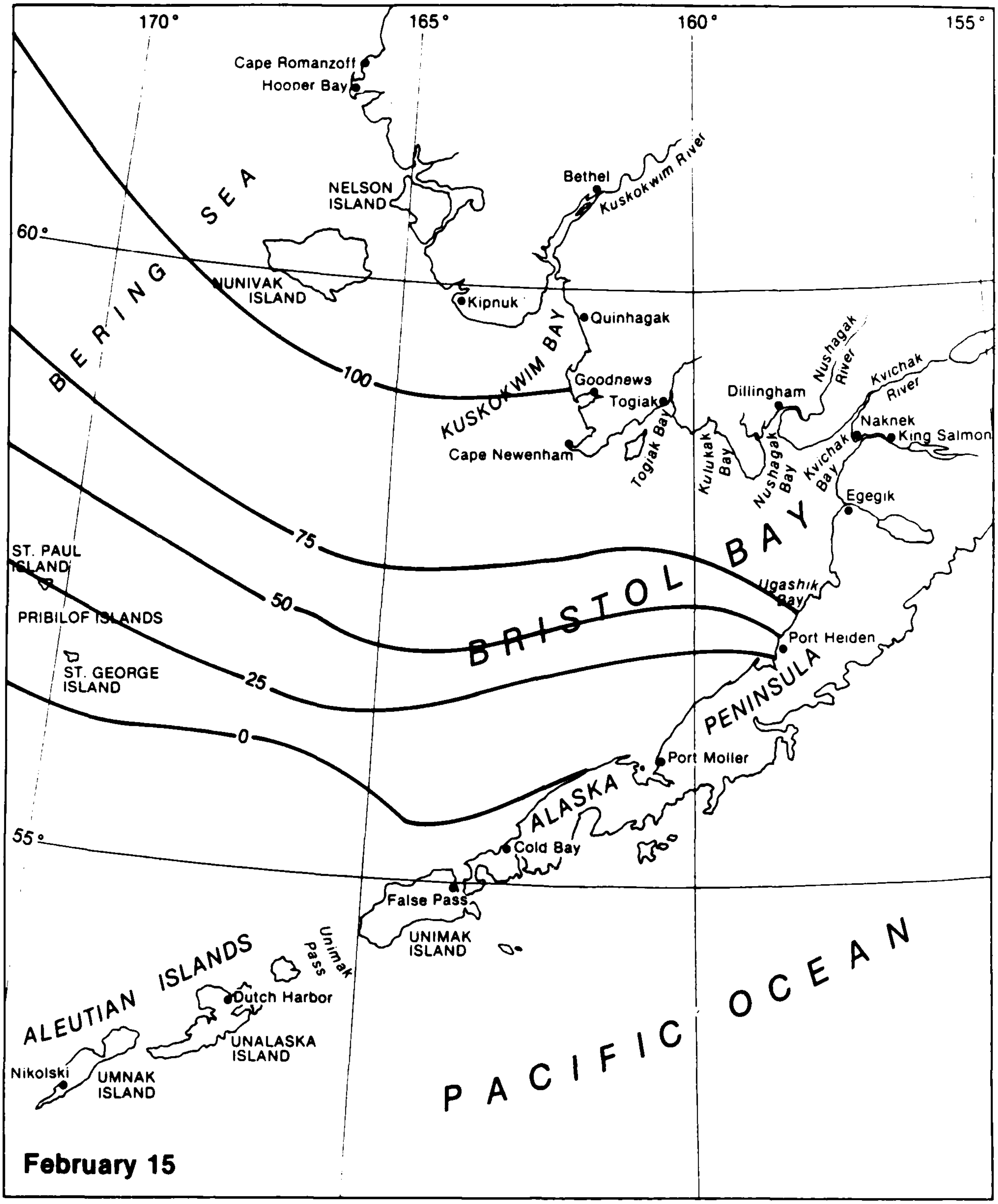


Figure 34h

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

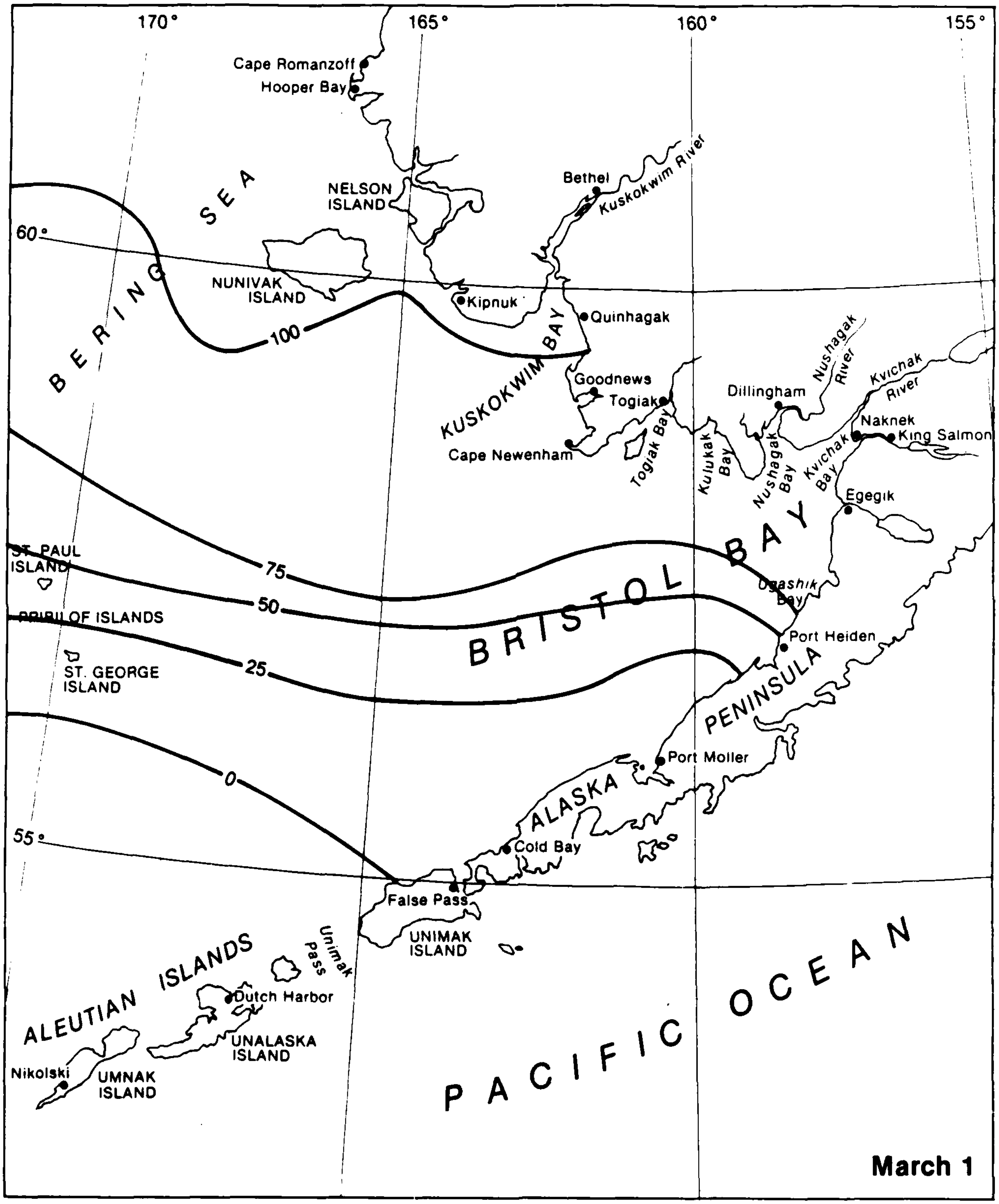


Figure 34l

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

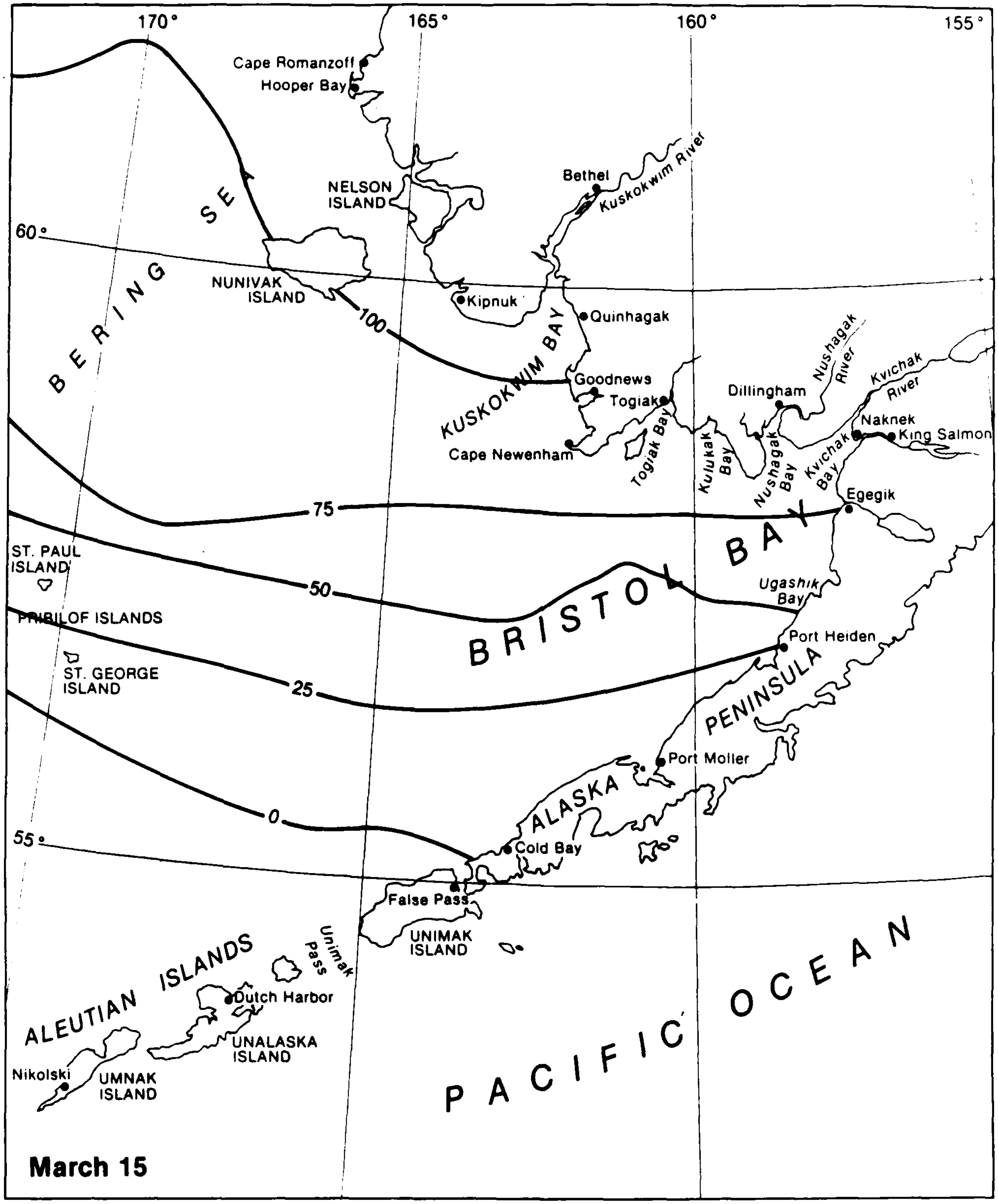


Figure 34j

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

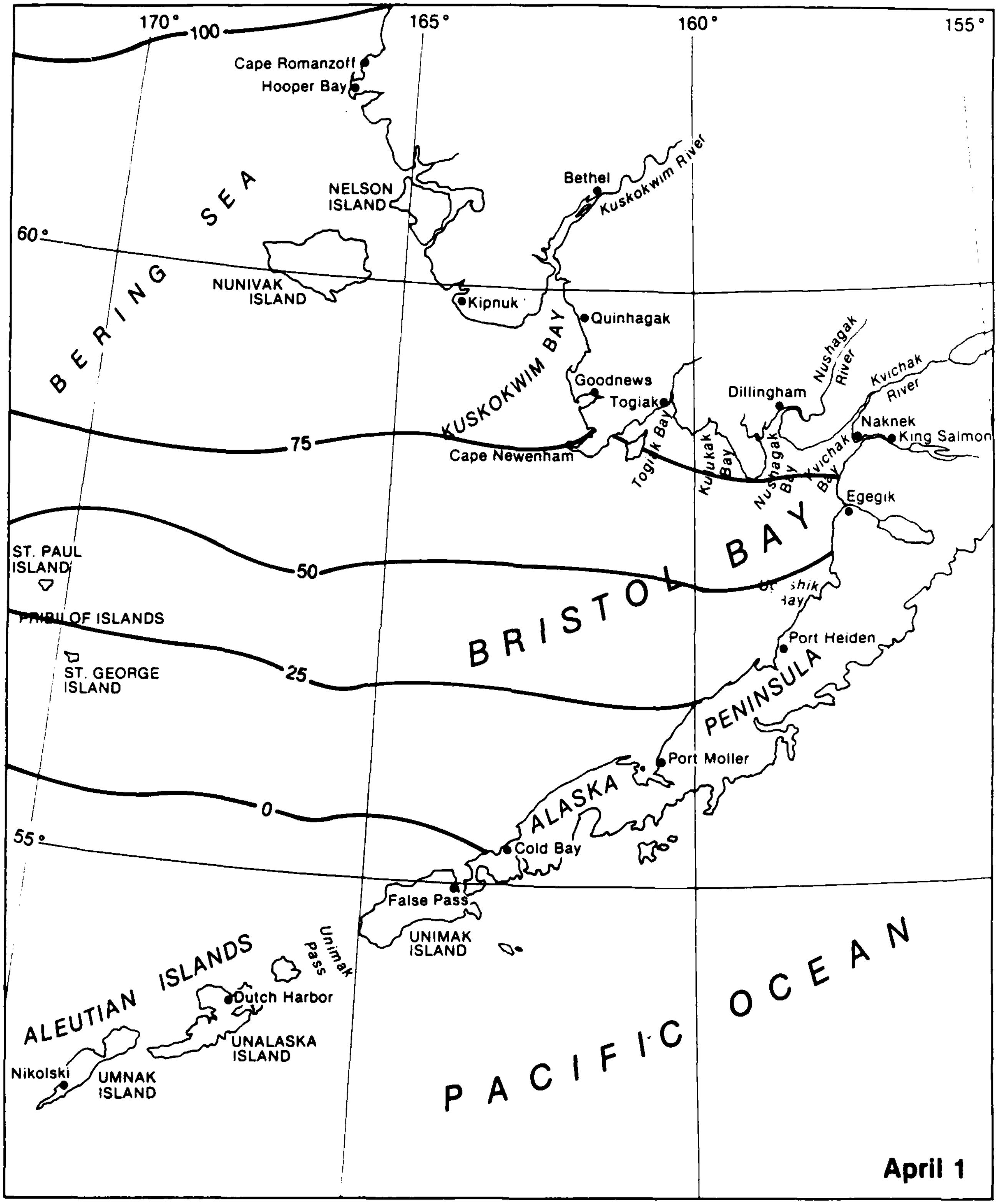


Figure 34k

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

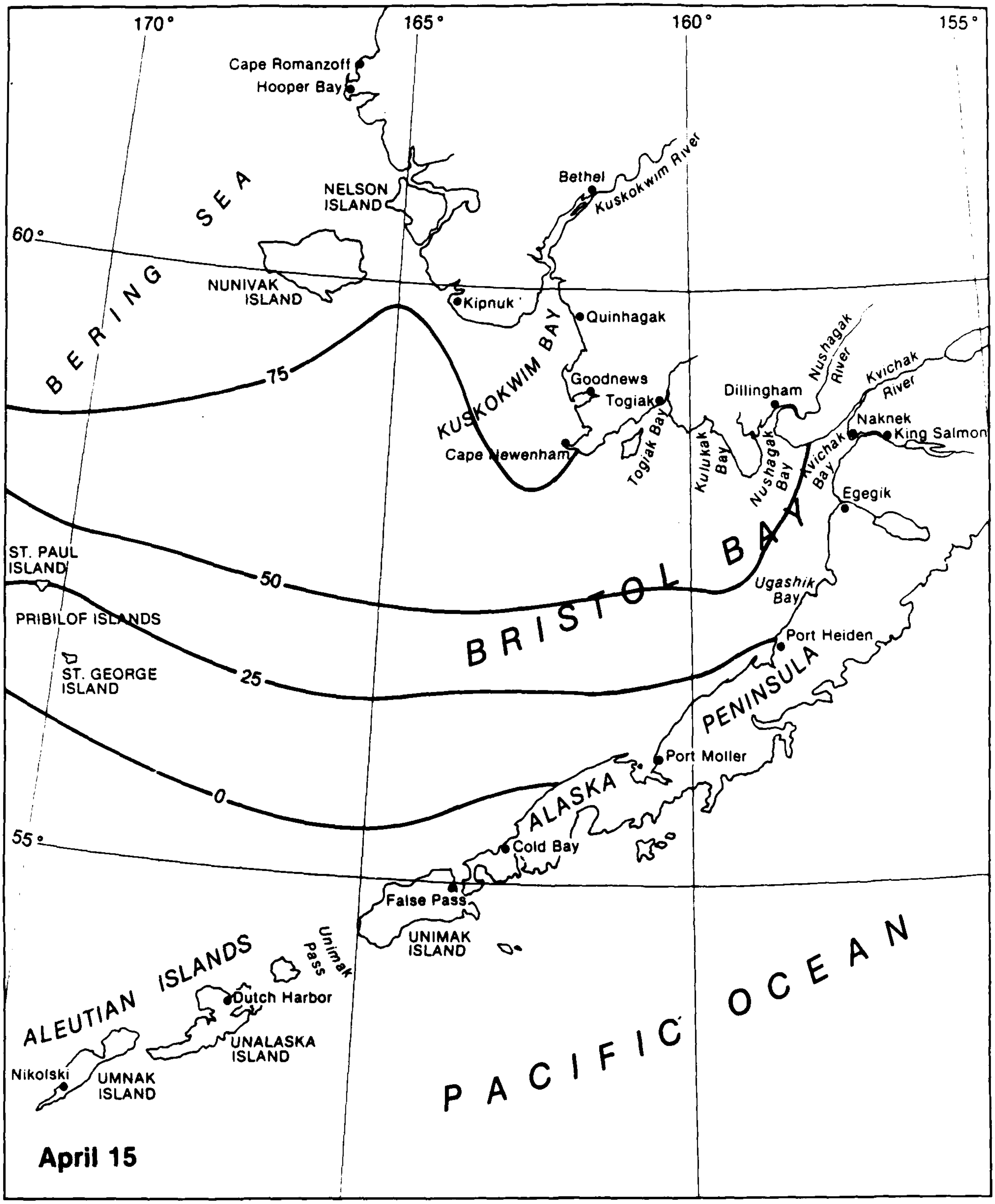


Figure 34l

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

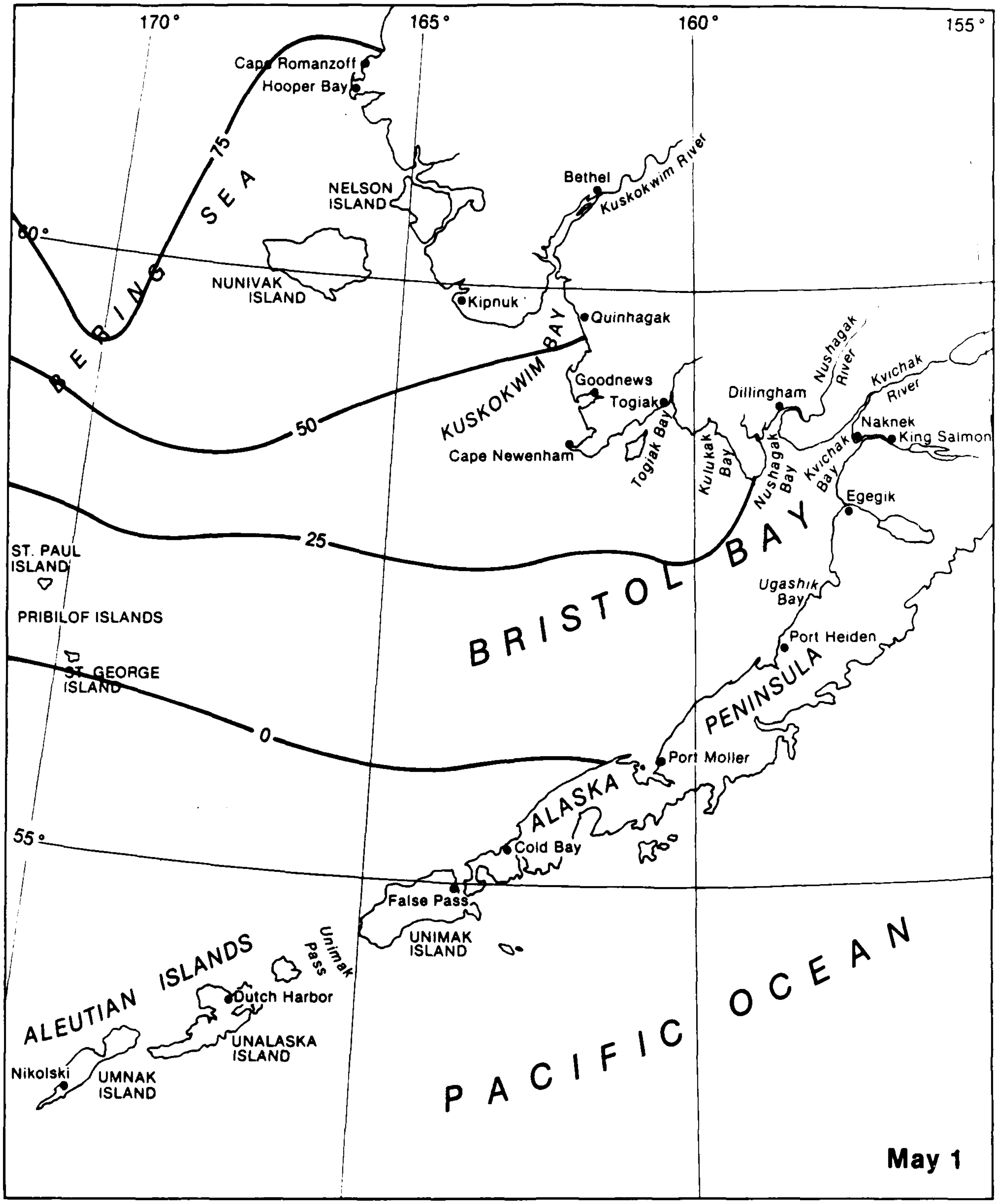


Figure 34m

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

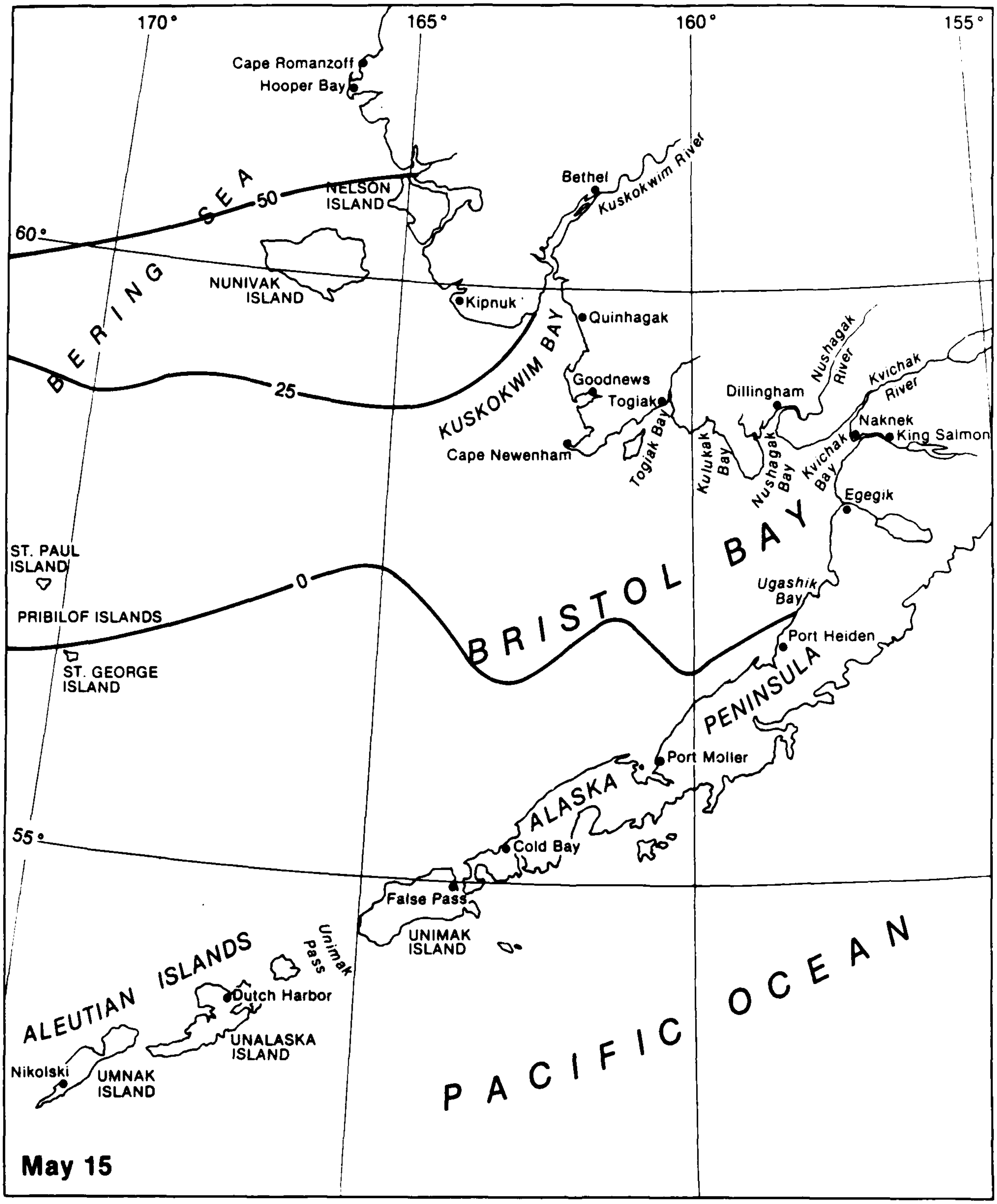


Figure 34n

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

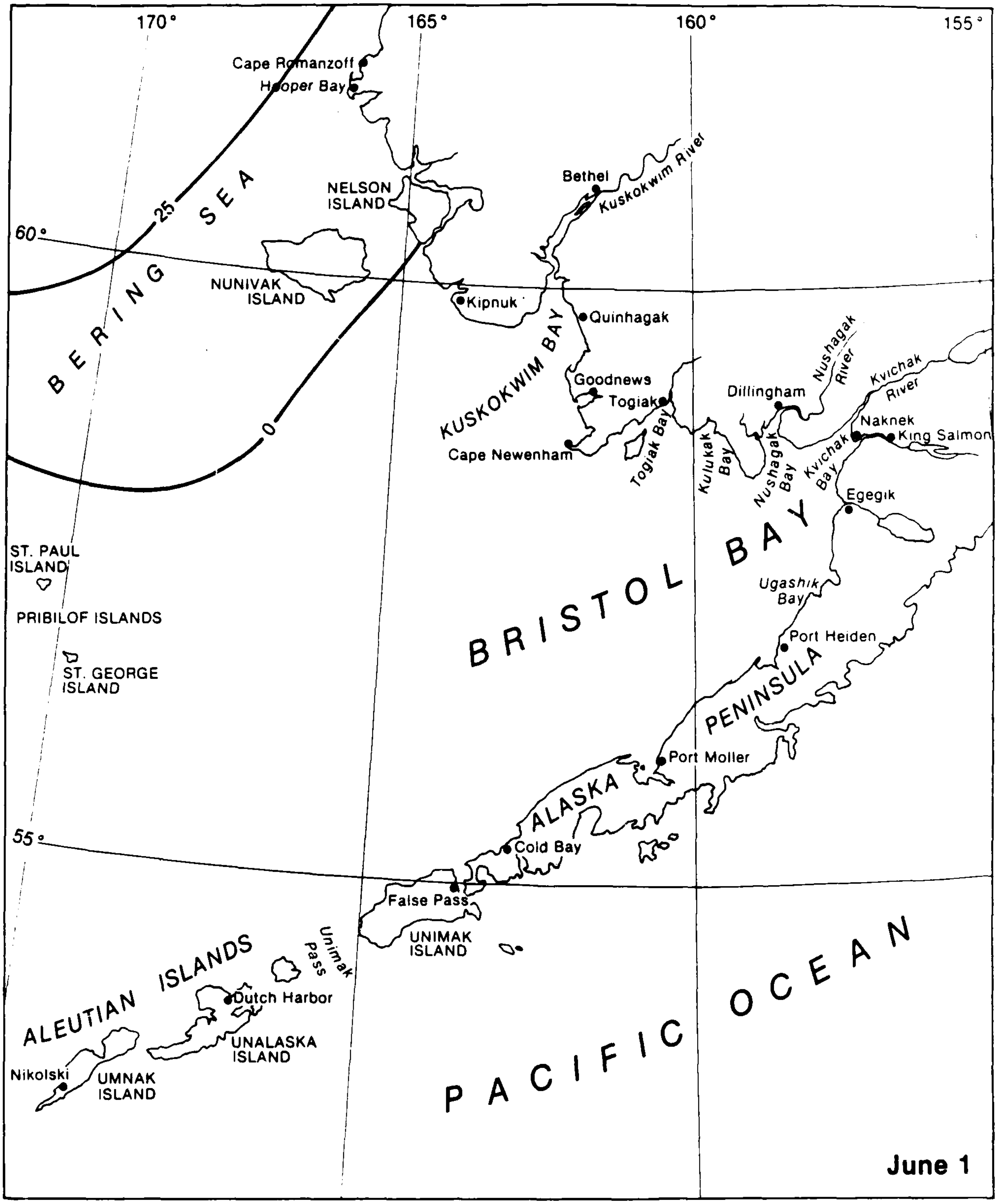


Figure 34o

Probabilities in Percent of the Five-Tenths Ice Concentration Boundary

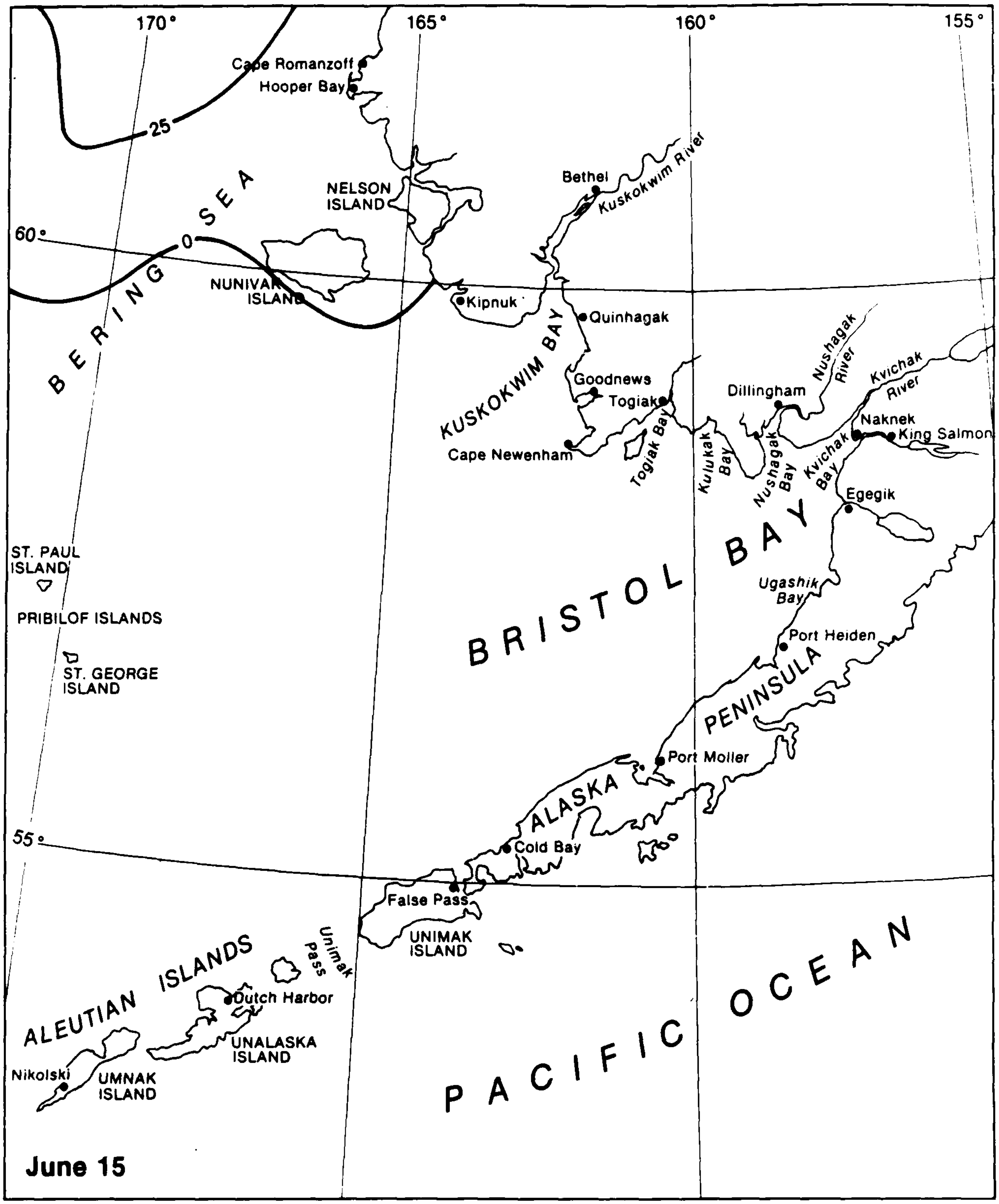


Figure 34p

ICE CONCENTRATION

Monthly ice concentrations from data for the years 1954 to 1977, adapted from Potocsky (1975) and Walsh (1978, 1979), as displayed in LaBelle, et al. (1983), are presented in figures 35a through 35g. The estimated ice edge shown in the maps is the mean location of the ice edge over the period of time covered. This means that you could expect the ice edge to be north of the line 50% of the time, and south of the line 50% of the time.

Ice concentrations are plotted in categories (in tenths of ice coverage) of 1-2, 3-4, 5-6, 7-8, and 9-10.

ICE FLOE DISTRIBUTION

Figures 36a through 36n show semimonthly profiles of floes that are from 500 m (1640 ft) to greater than 10 km (16 mi) in diameter (i.e., big, vast, and giant floes), as displayed in LaBelle, et al. (1983). This information was derived from Potocsky (1975), using data from 1954 to 1970. These data do not imply anything about ice thickness.

CALCULATED ICE THICKNESS

Ice thicknesses, as calculated from normal freezing degree day accumulations, are presented in figures 37a through 37g. Data from 1922 to 1984 were used. Ice thickness data shown apply to level first-year ice formed in situ with no snow cover. Actual ice thicknesses for any given season will vary depending on actual air temperatures, the amount of snow cover, and underlying sea surface currents. Generally, as snow cover increases, forming an insulating cover over the ice, ice growth decreases.

In order to provide as great an area coverage as possible, ice thicknesses were calculated for the nearest reporting weather stations. In some cases, these stations were not located on the coast (i.e., Bethel is located about 50 mi up the Kuskokwim River from Kuskokwim Bay). In these cases, accumulated freezing degree days may be slightly higher than those that would be recorded at the coast, leading to slightly higher ice thickness calculations.

Ice Concentration

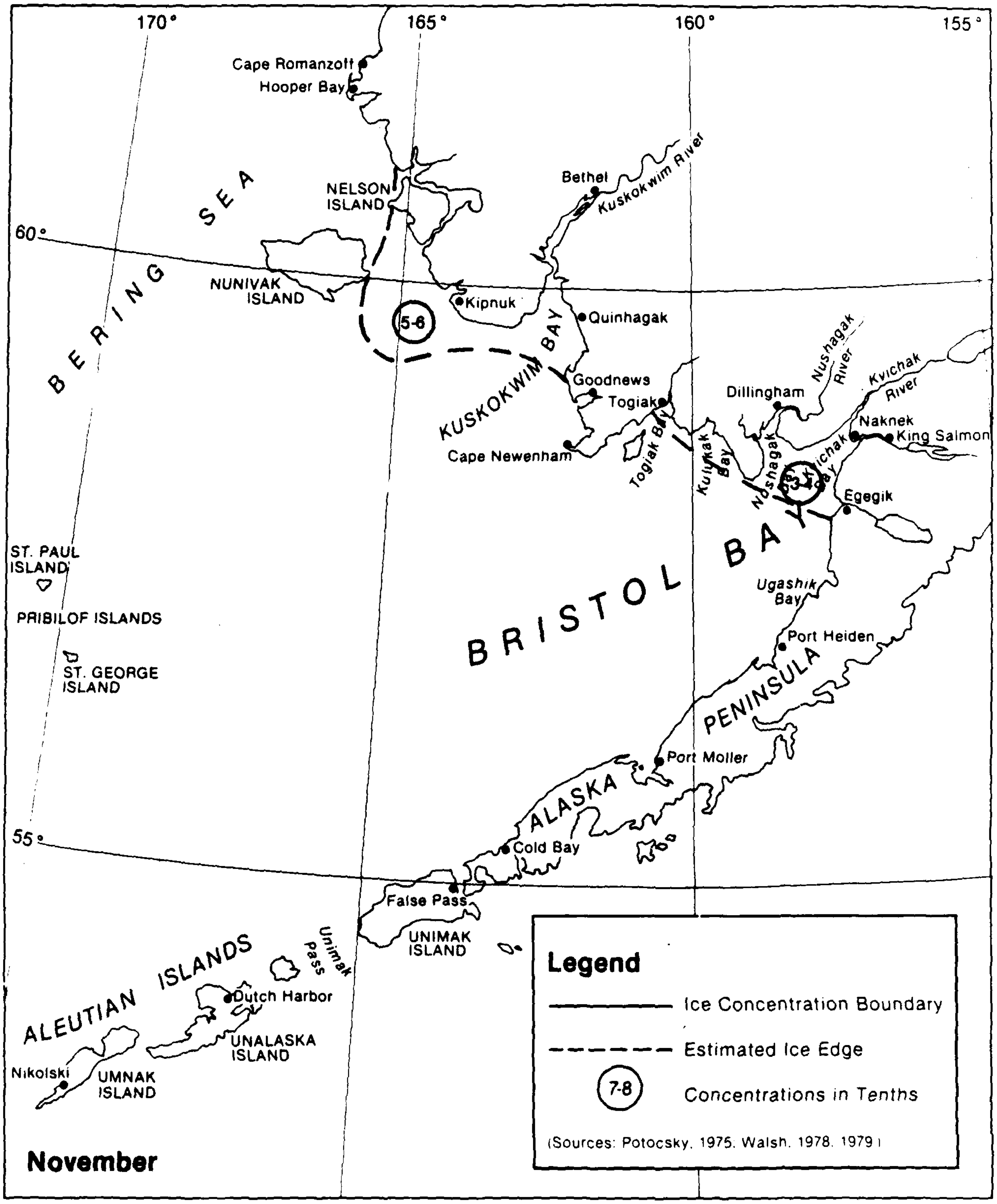


Figure 35a

Ice Concentration

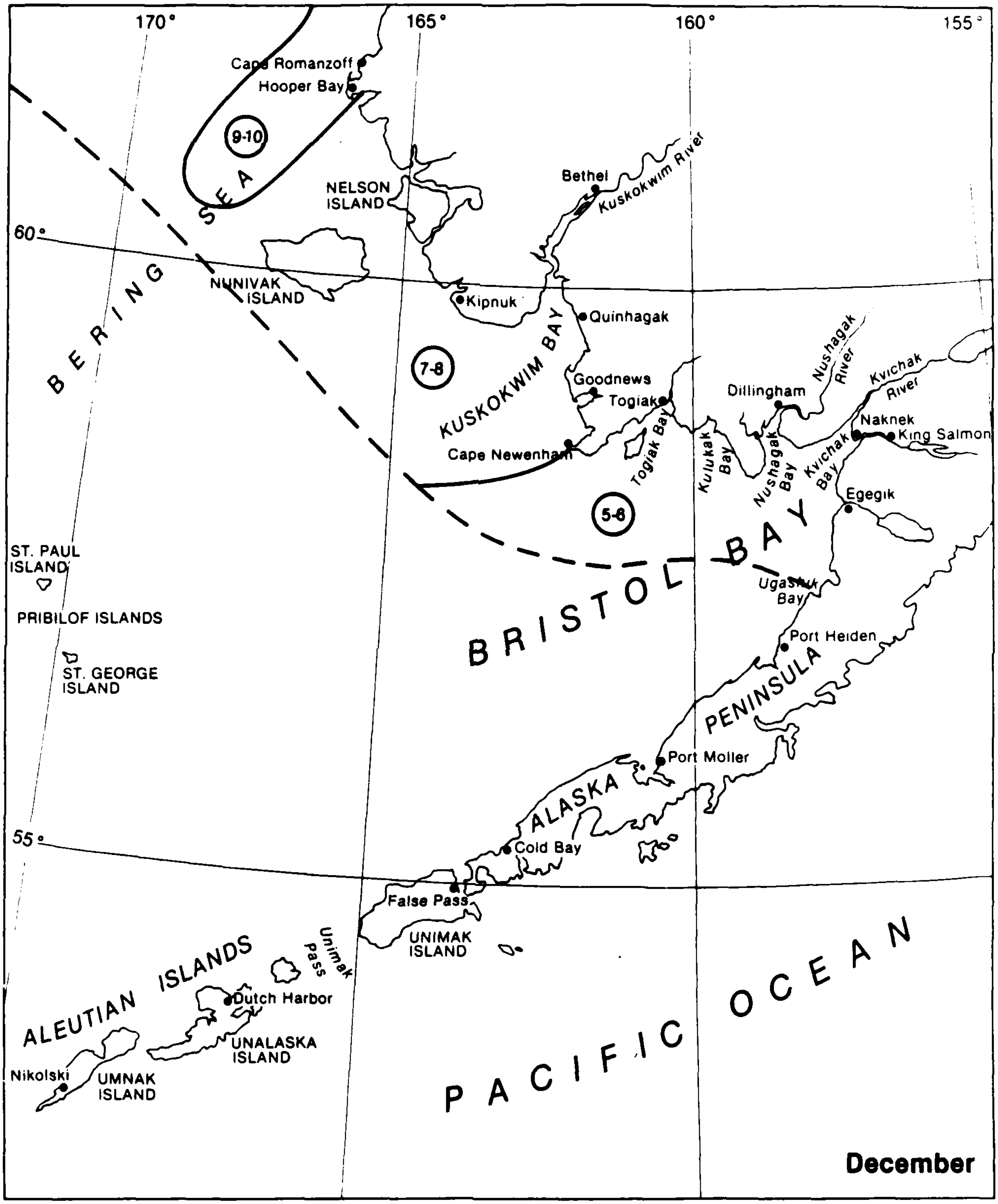


Figure 35b

Ice Concentration

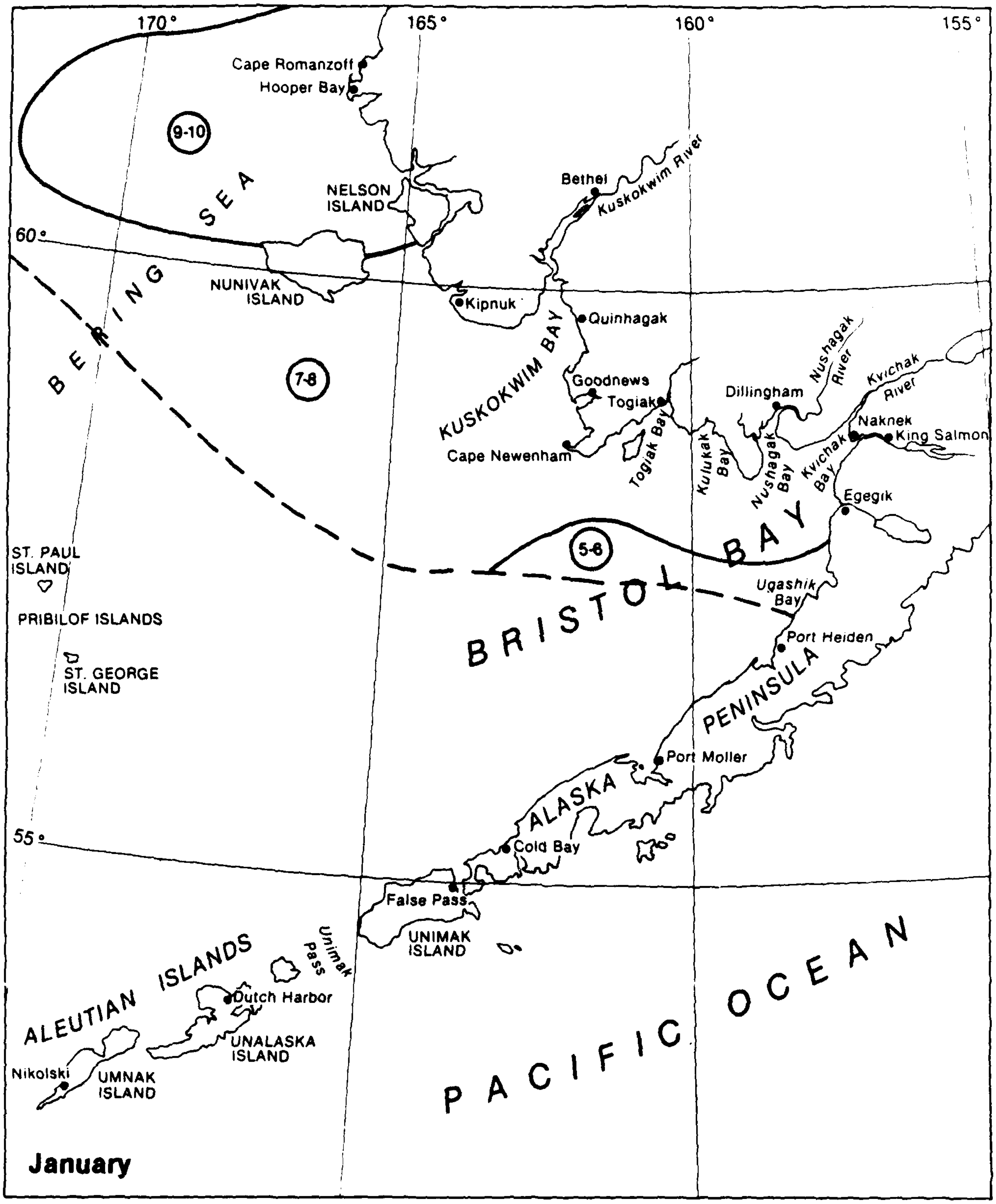


Figure 35c

Ice Concentration

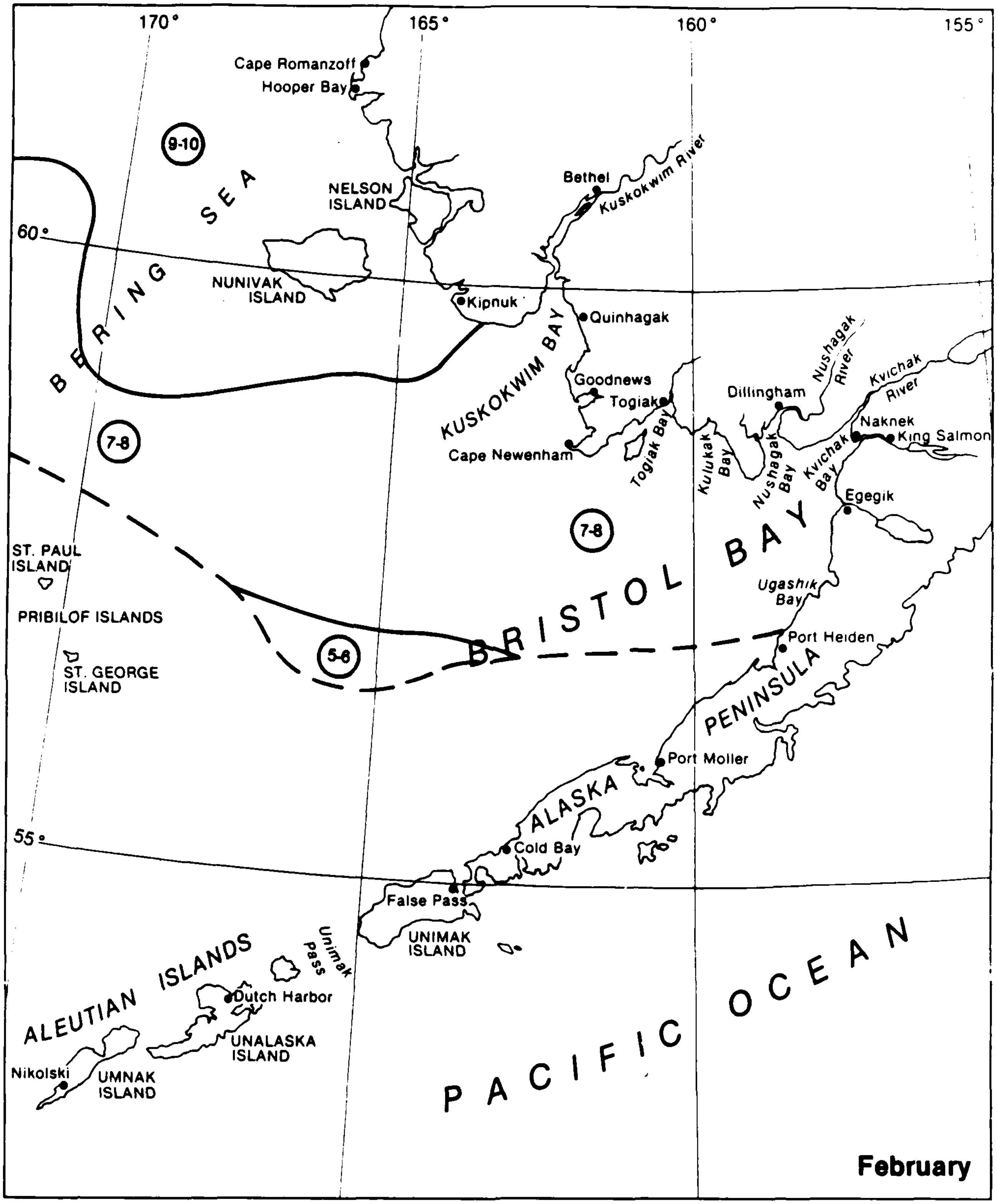


Figure 35d

Ice Concentration

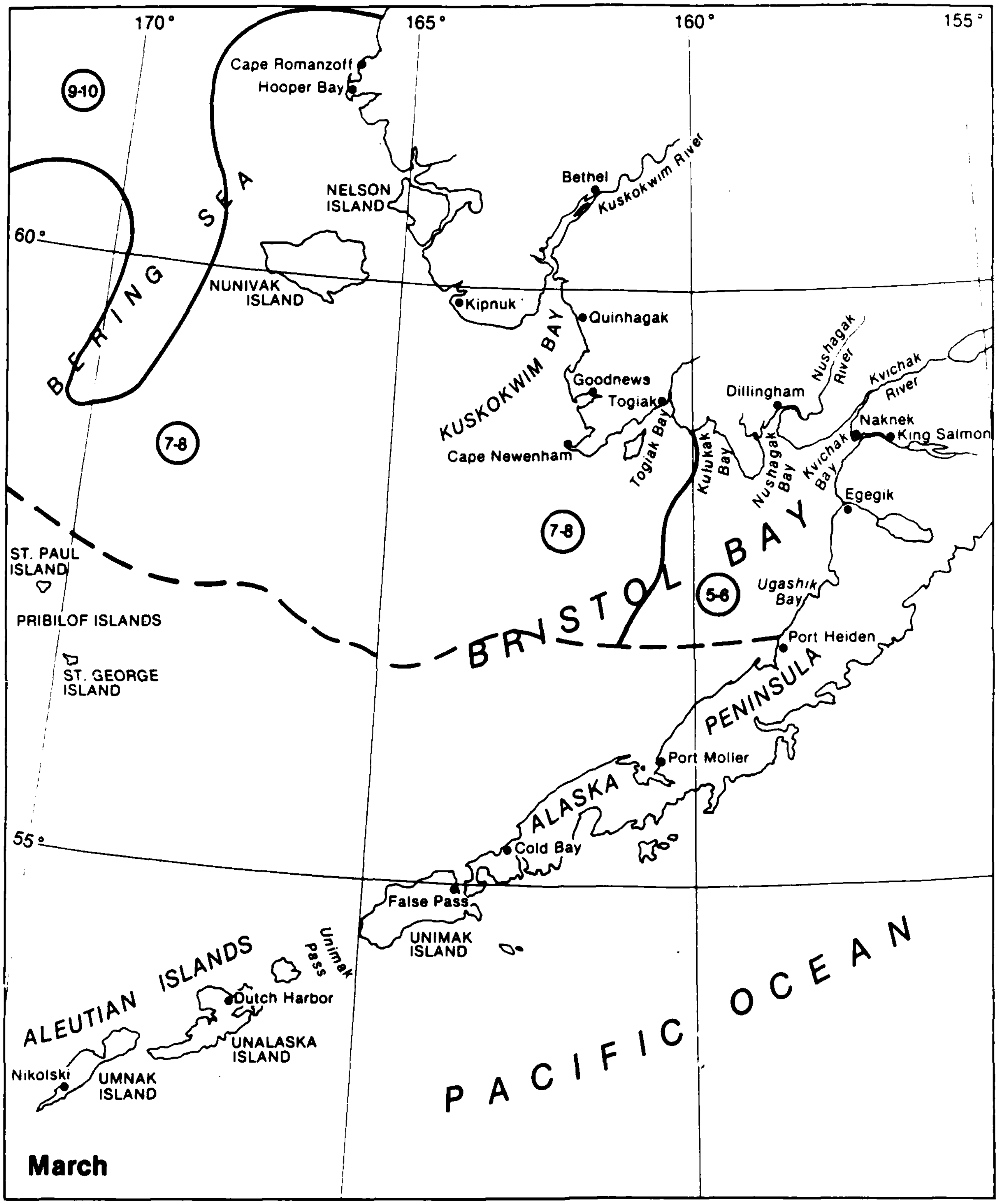


Figure 35e

Ice Concentration

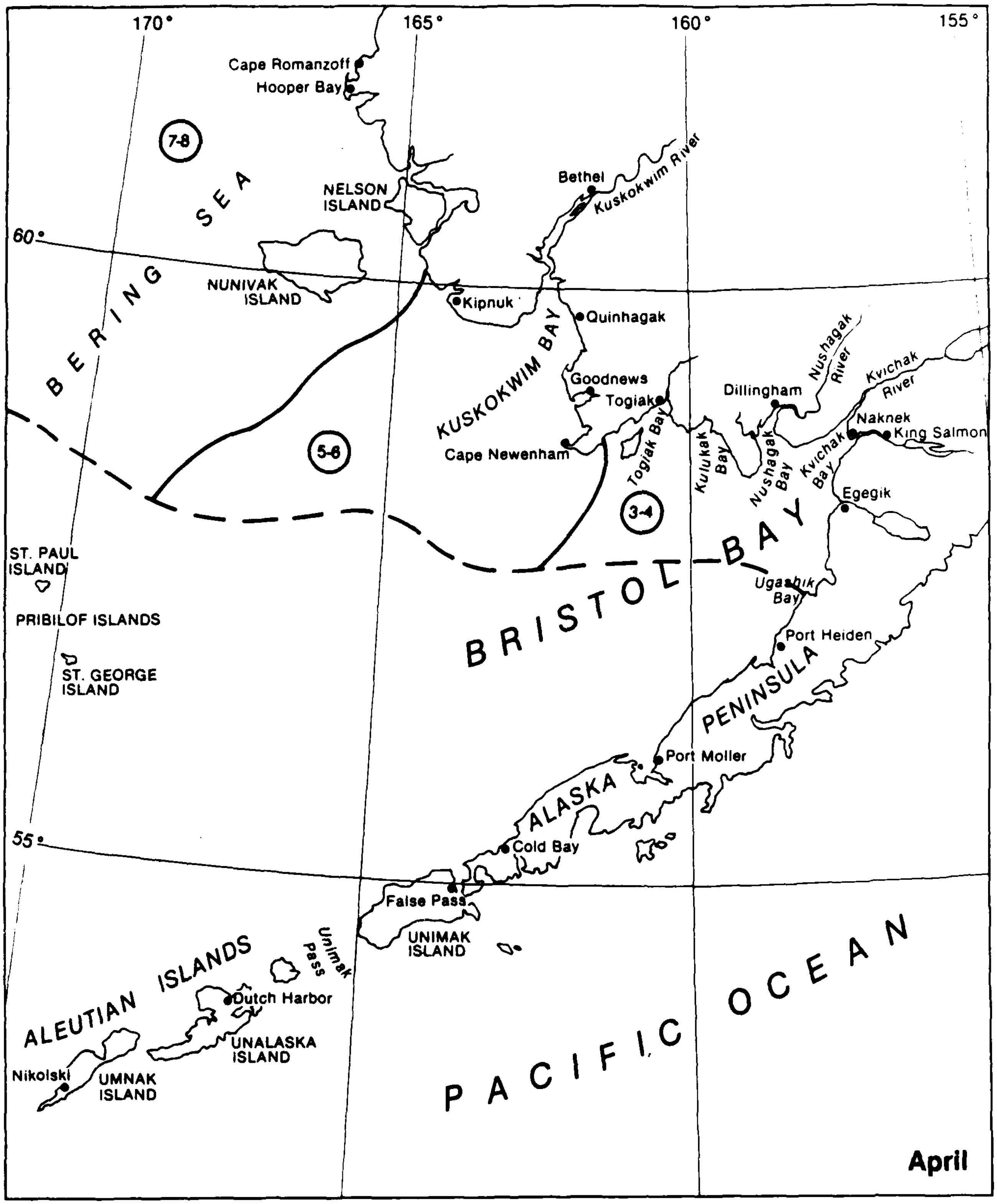


Figure 35f

Ice Concentration

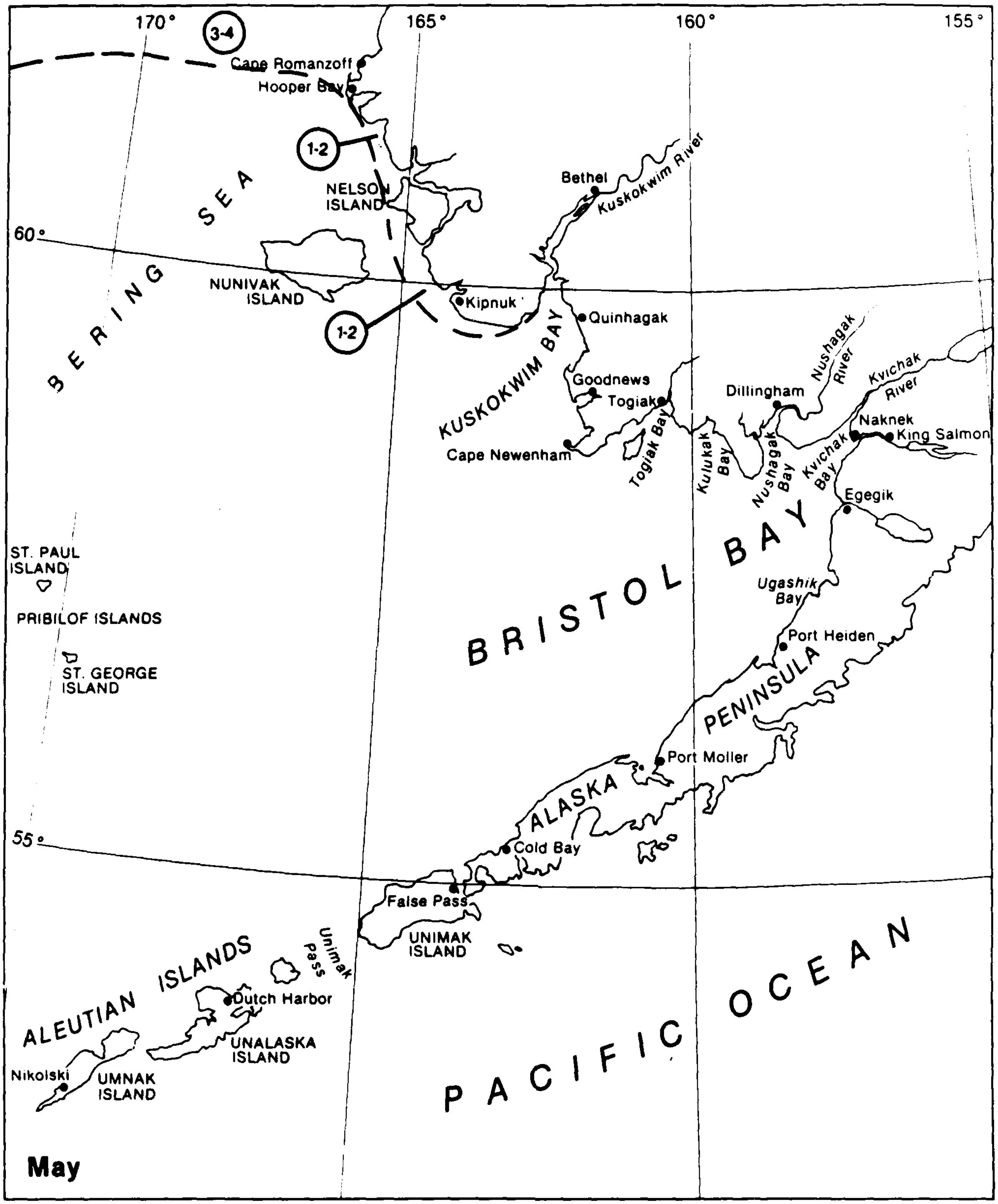


Figure 35g

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

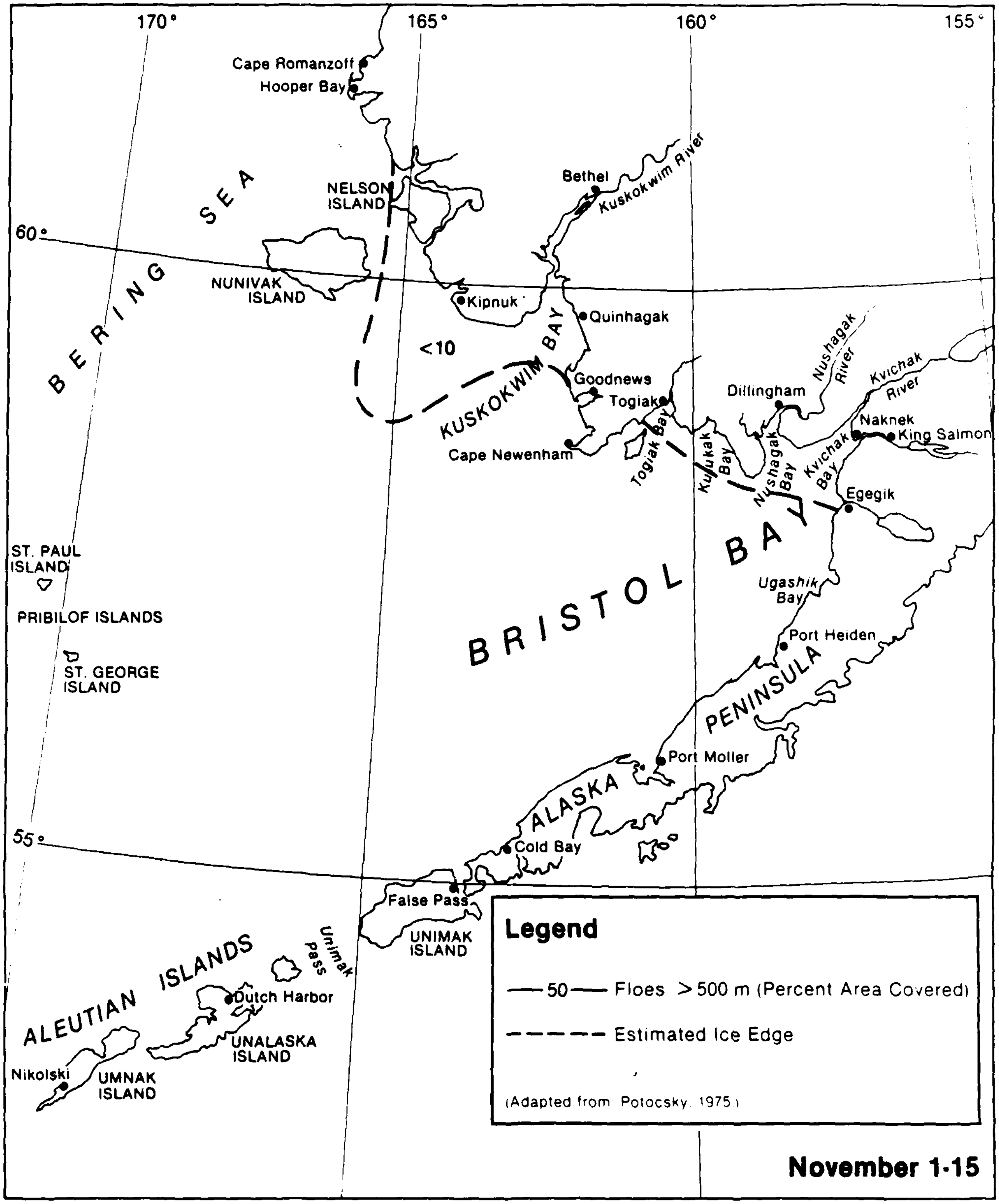


Figure 36a

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

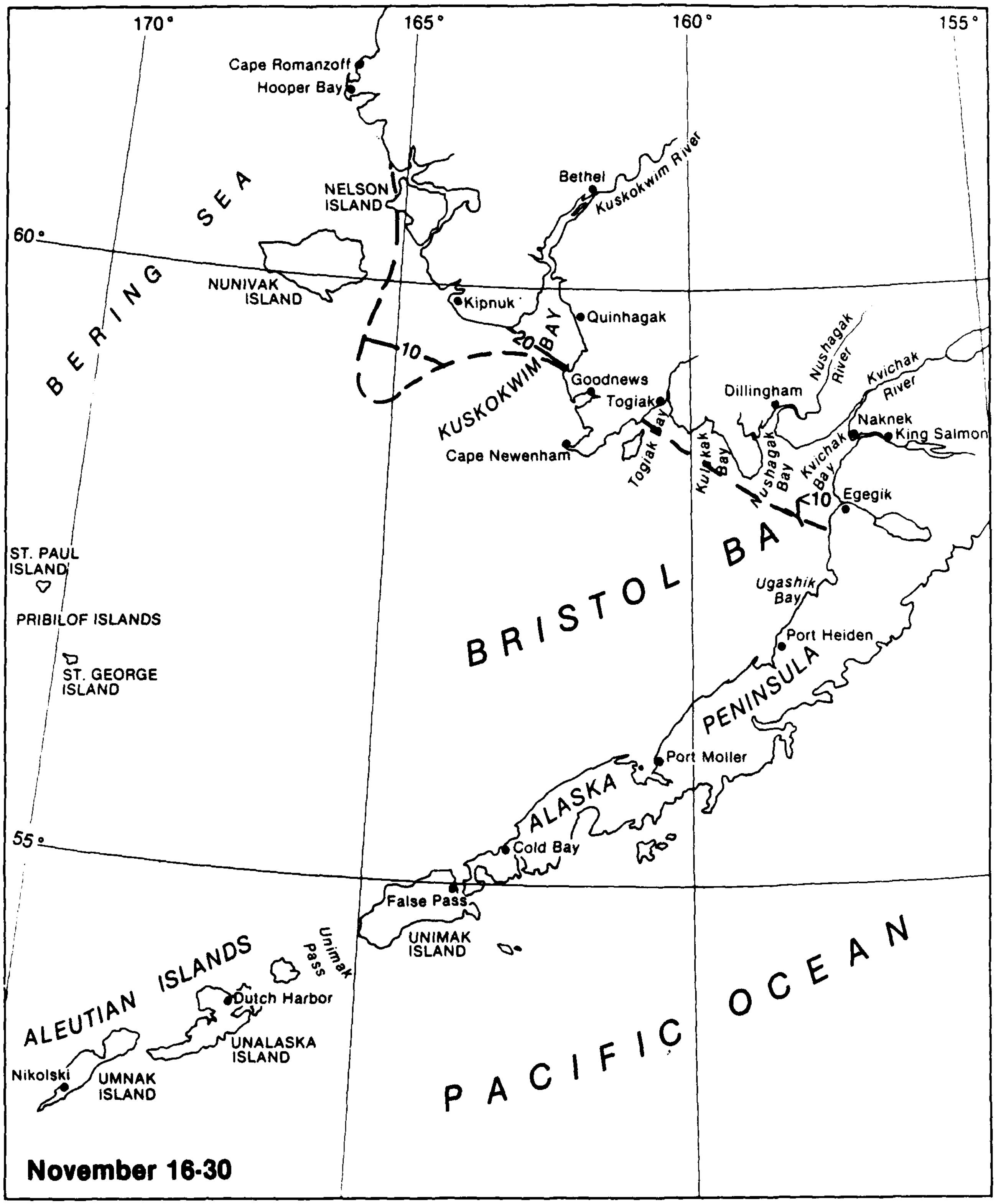


Figure 36b

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

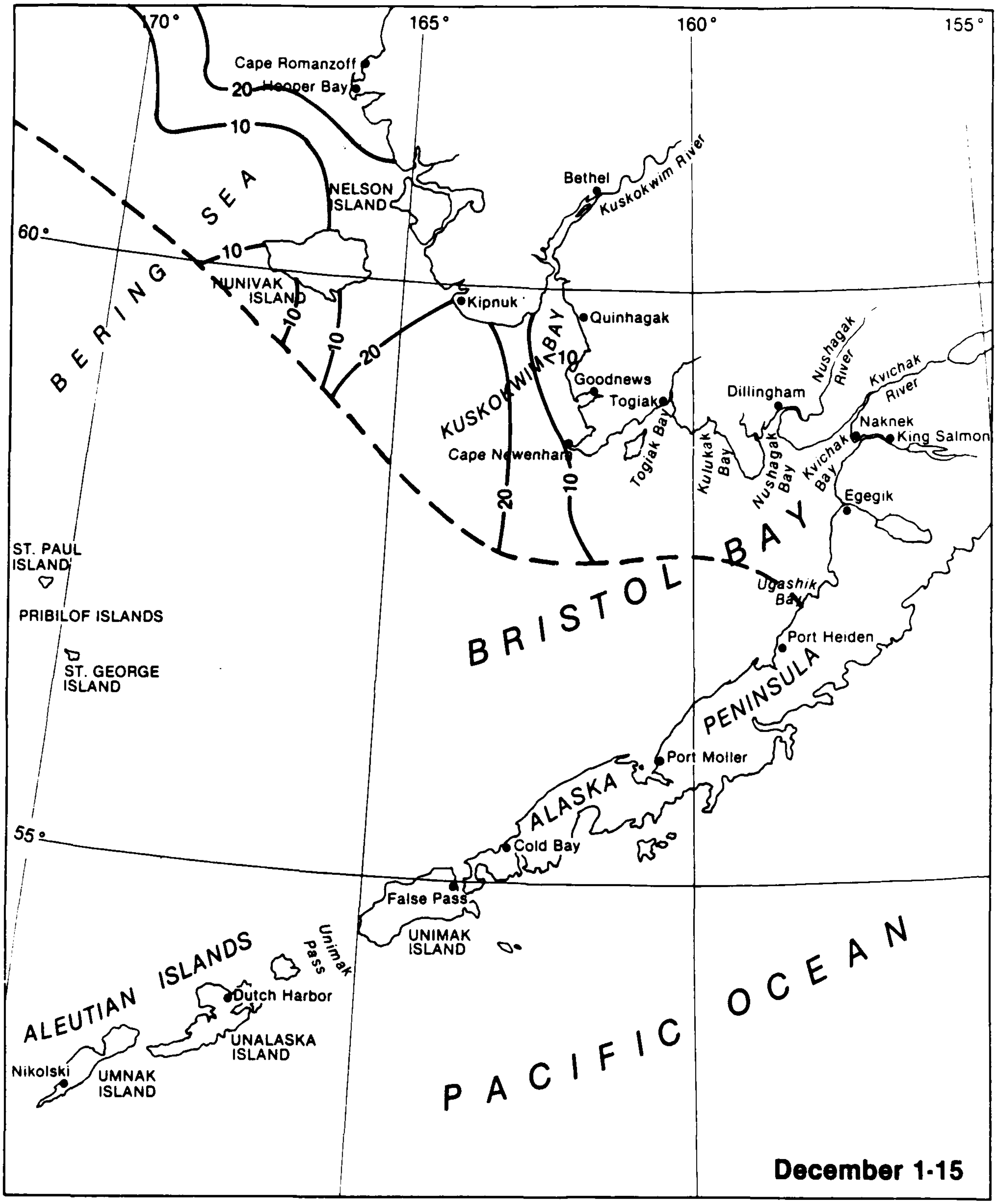


Figure 36c

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

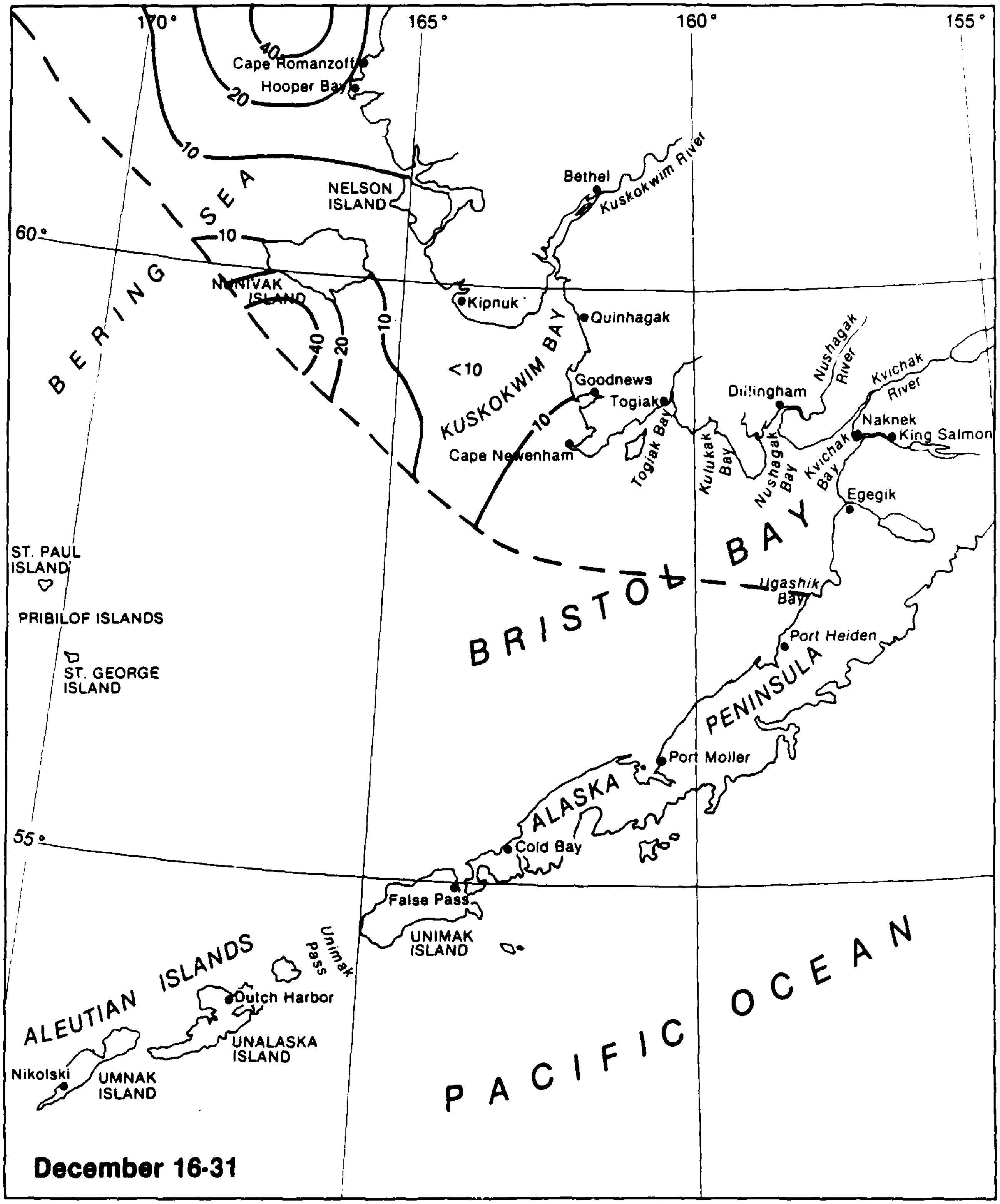


Figure 36d

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

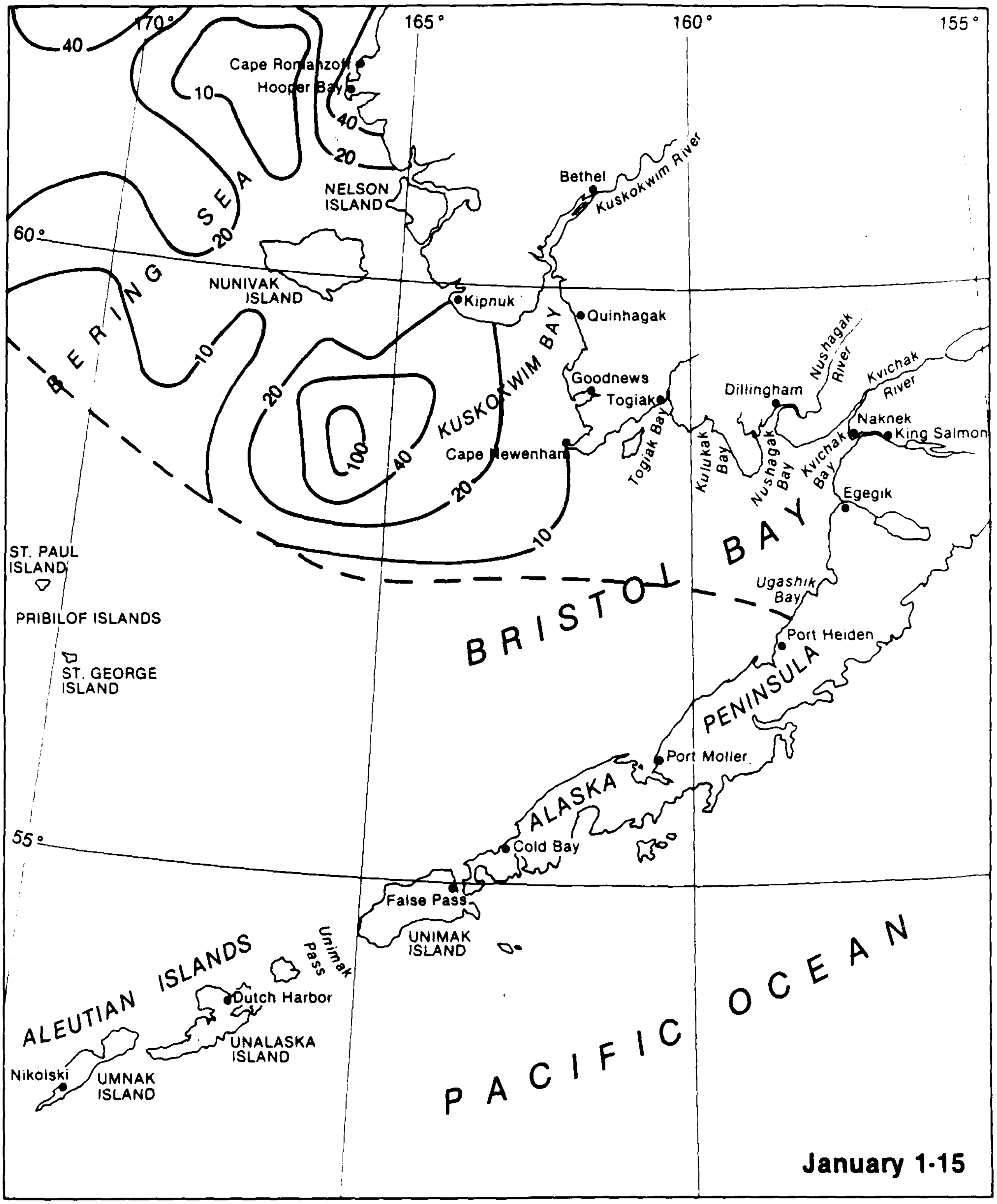


Figure 36e

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

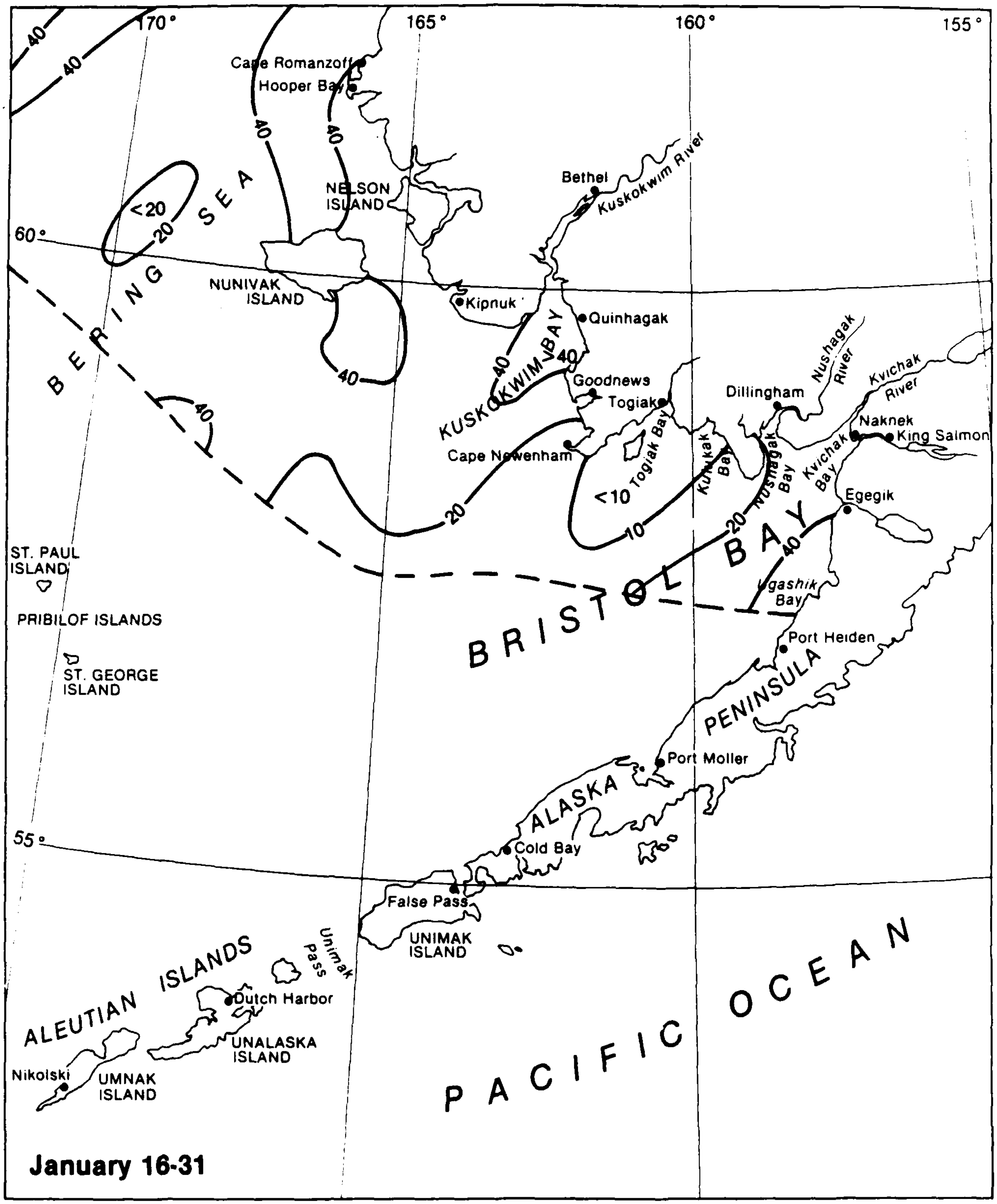


Figure 36f

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

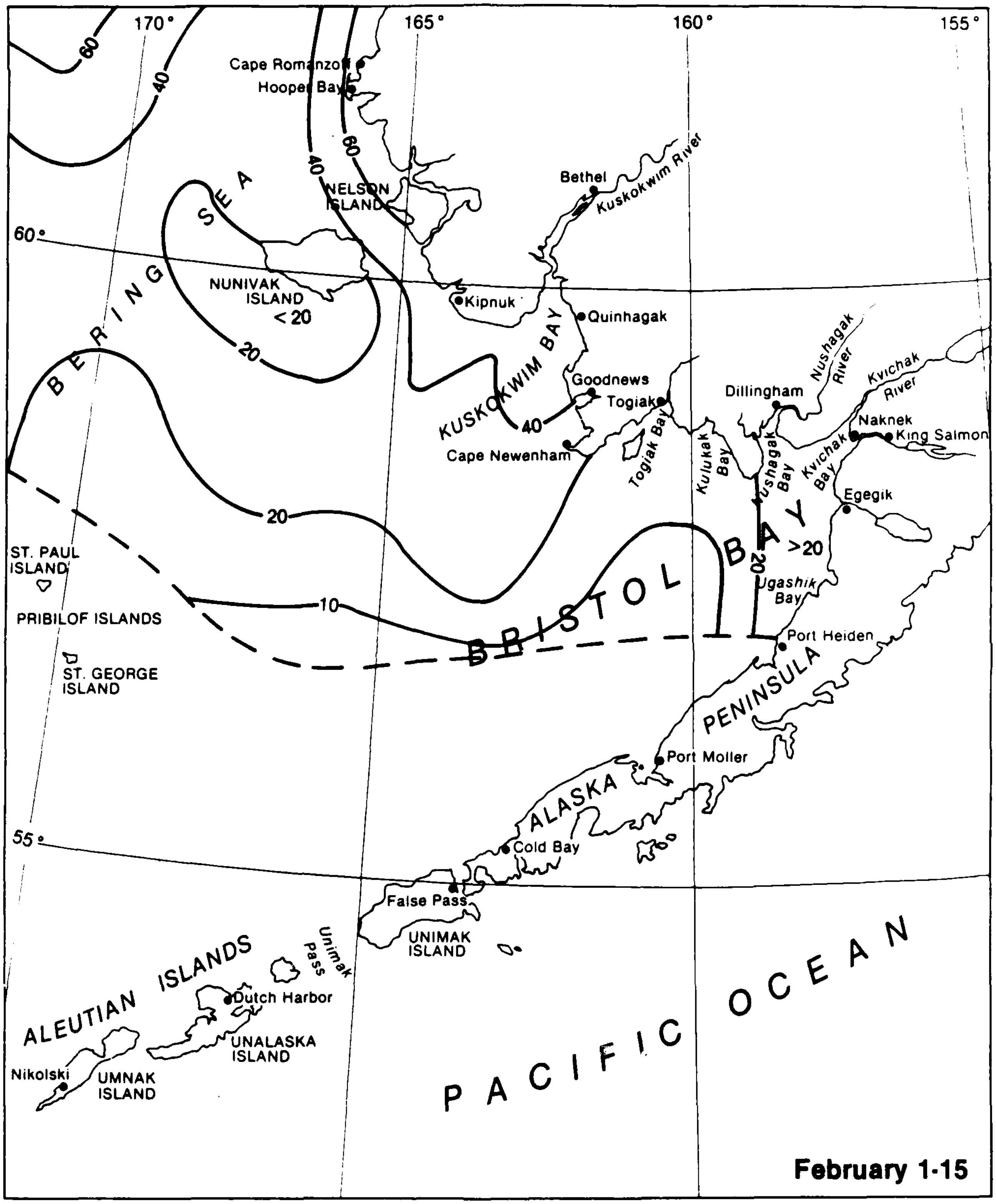


Figure 36g

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

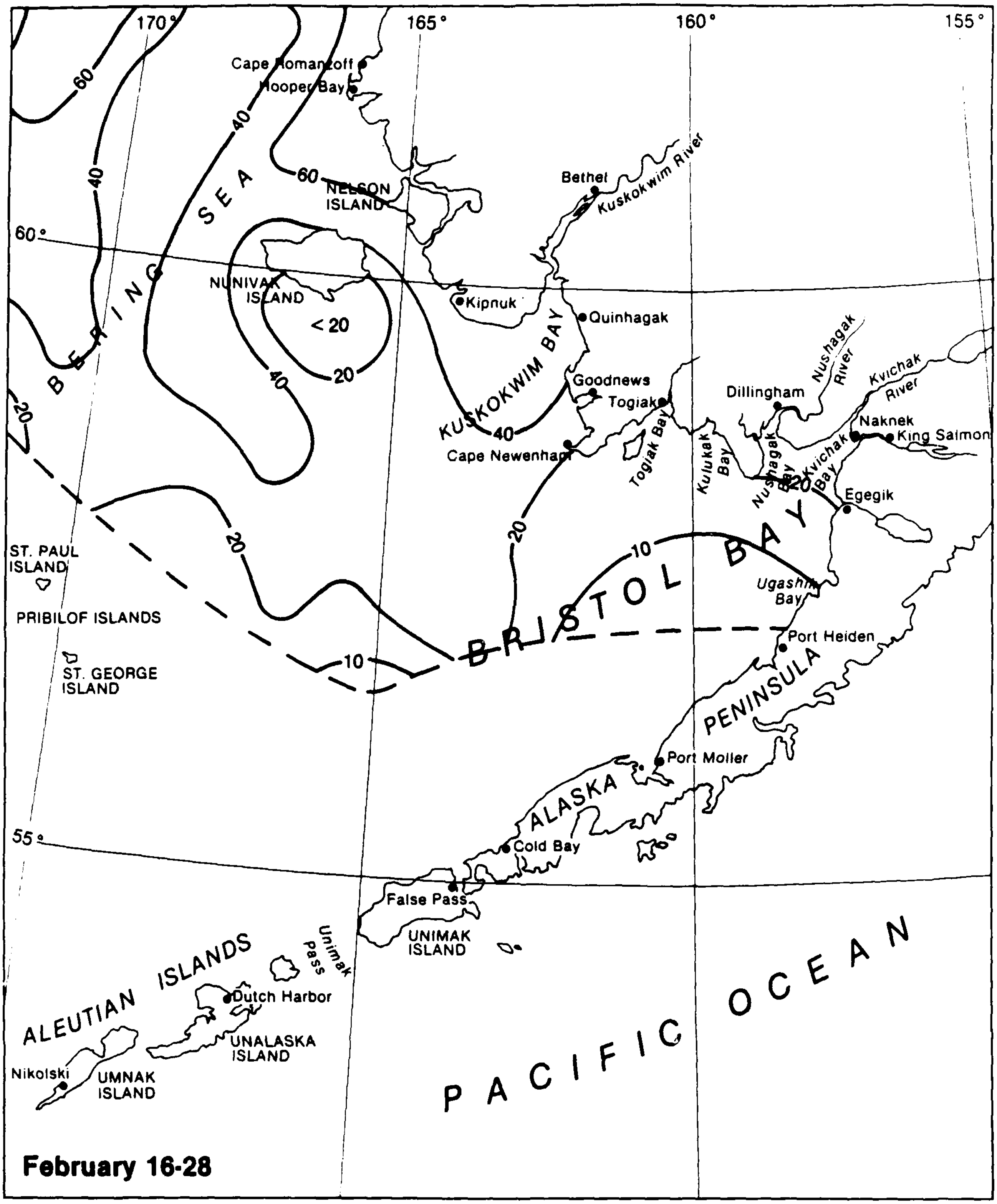


Figure 36h

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

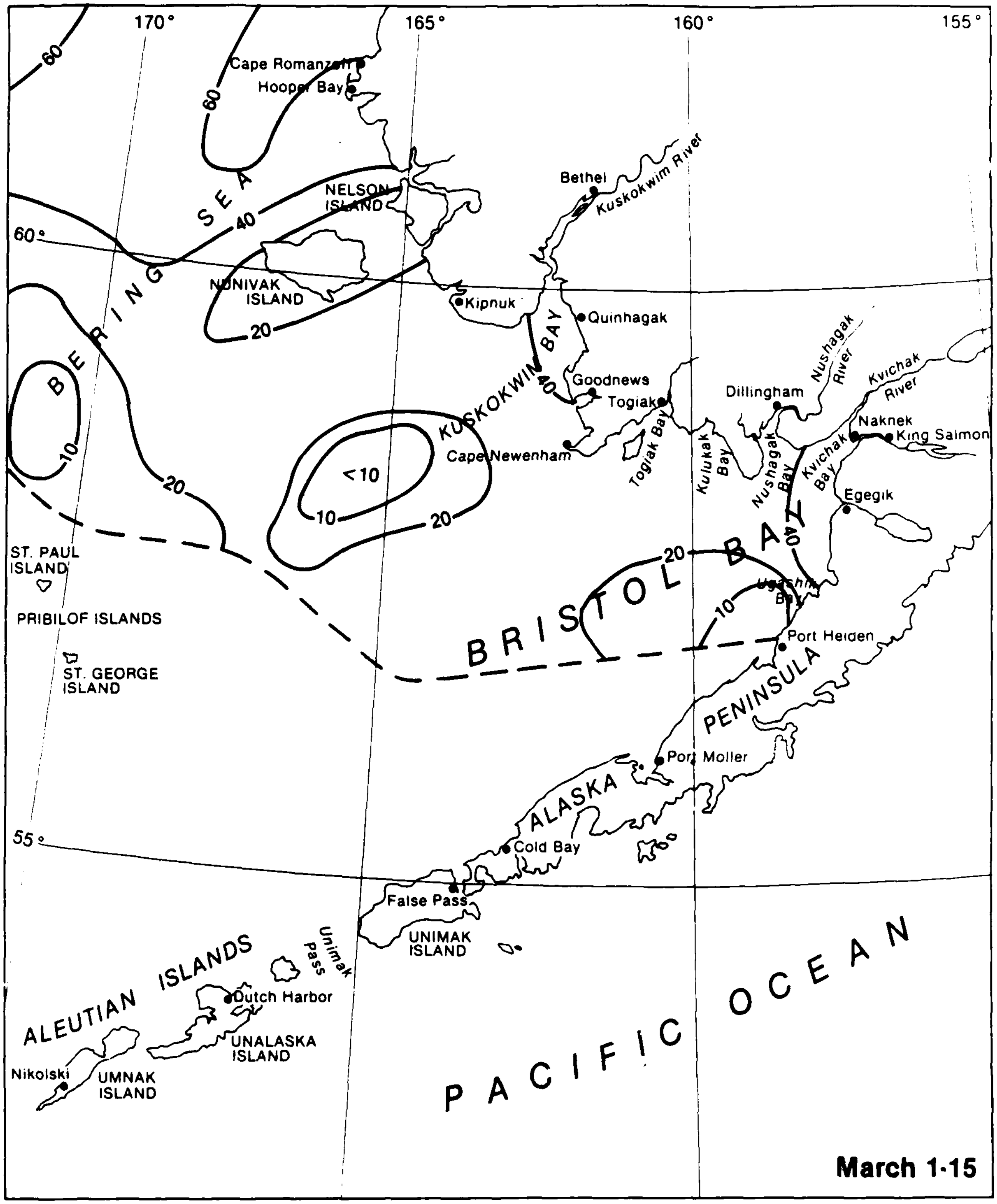


Figure 36I

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

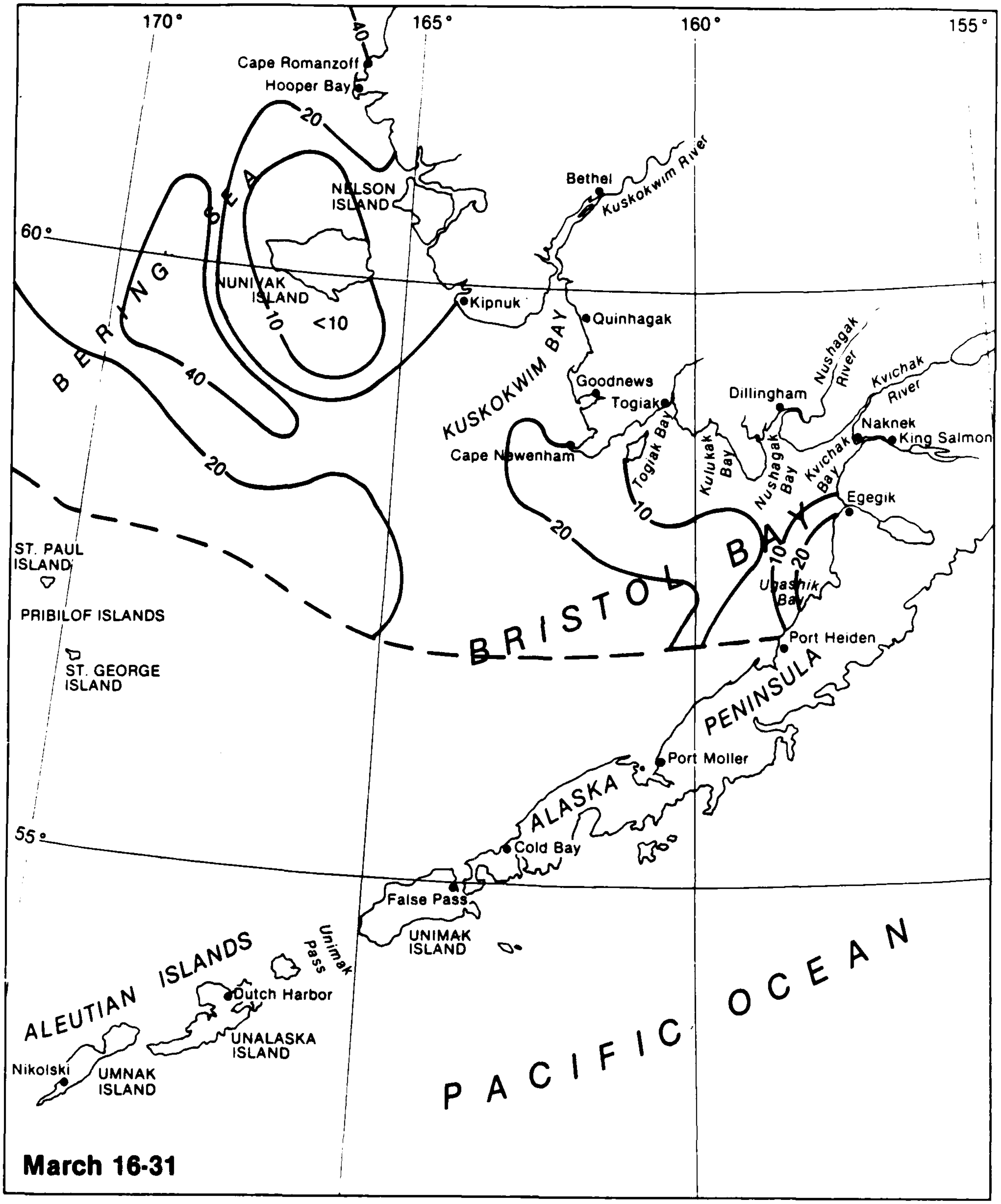


Figure 36j

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

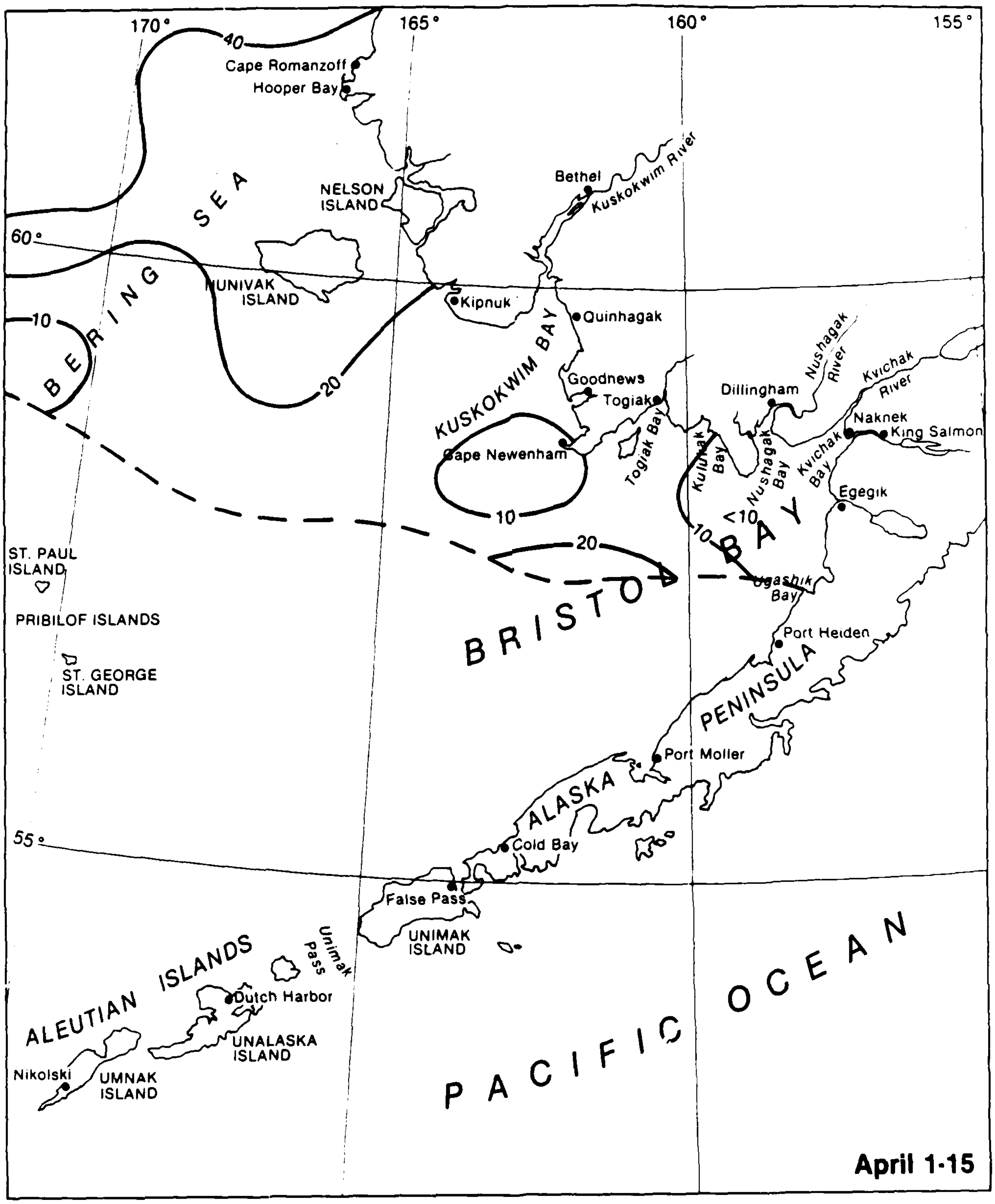


Figure 36k

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

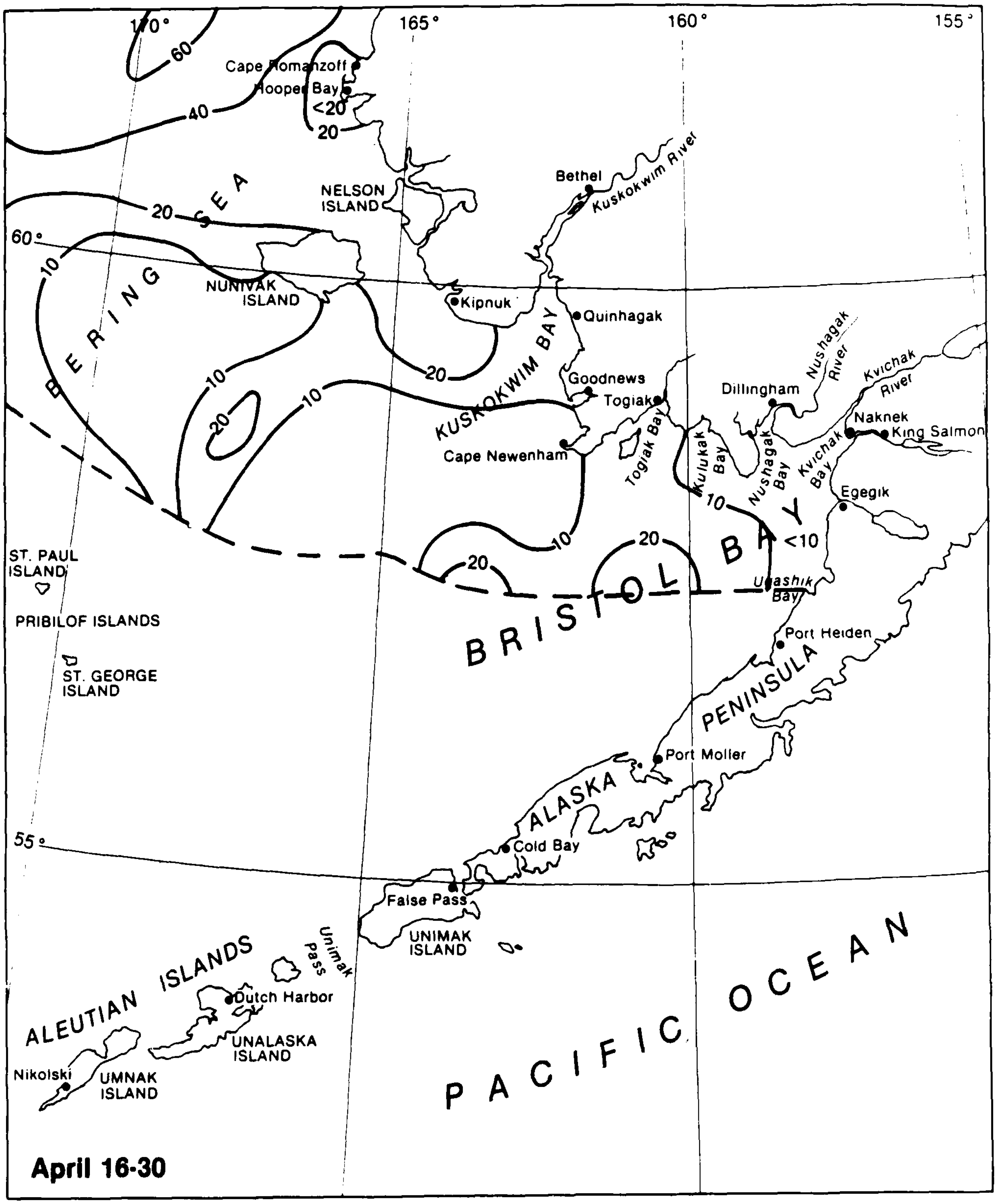


Figure 36I

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

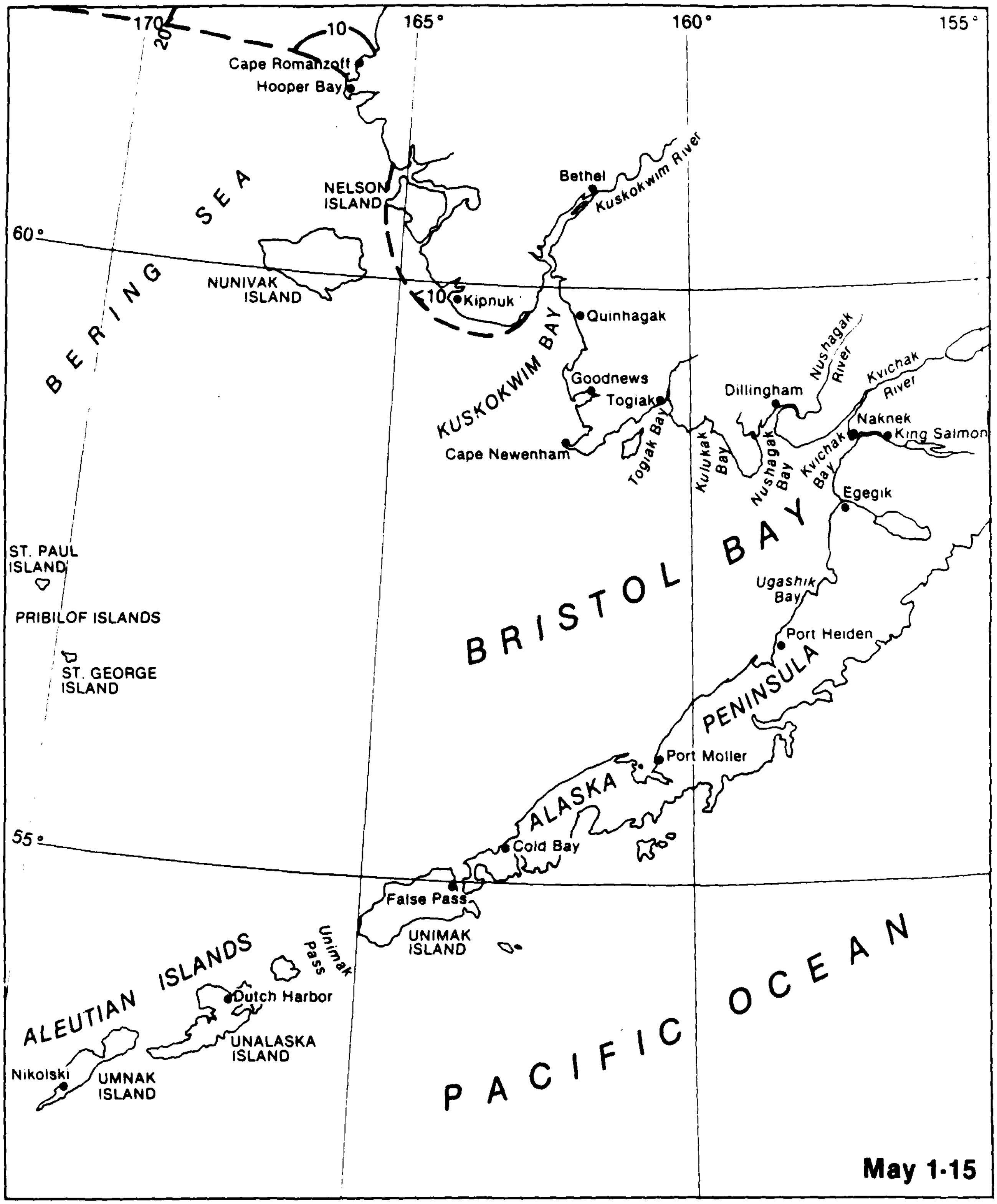


Figure 36m

Ice Floes Larger than 500 m (1640 ft), in Percent Coverage

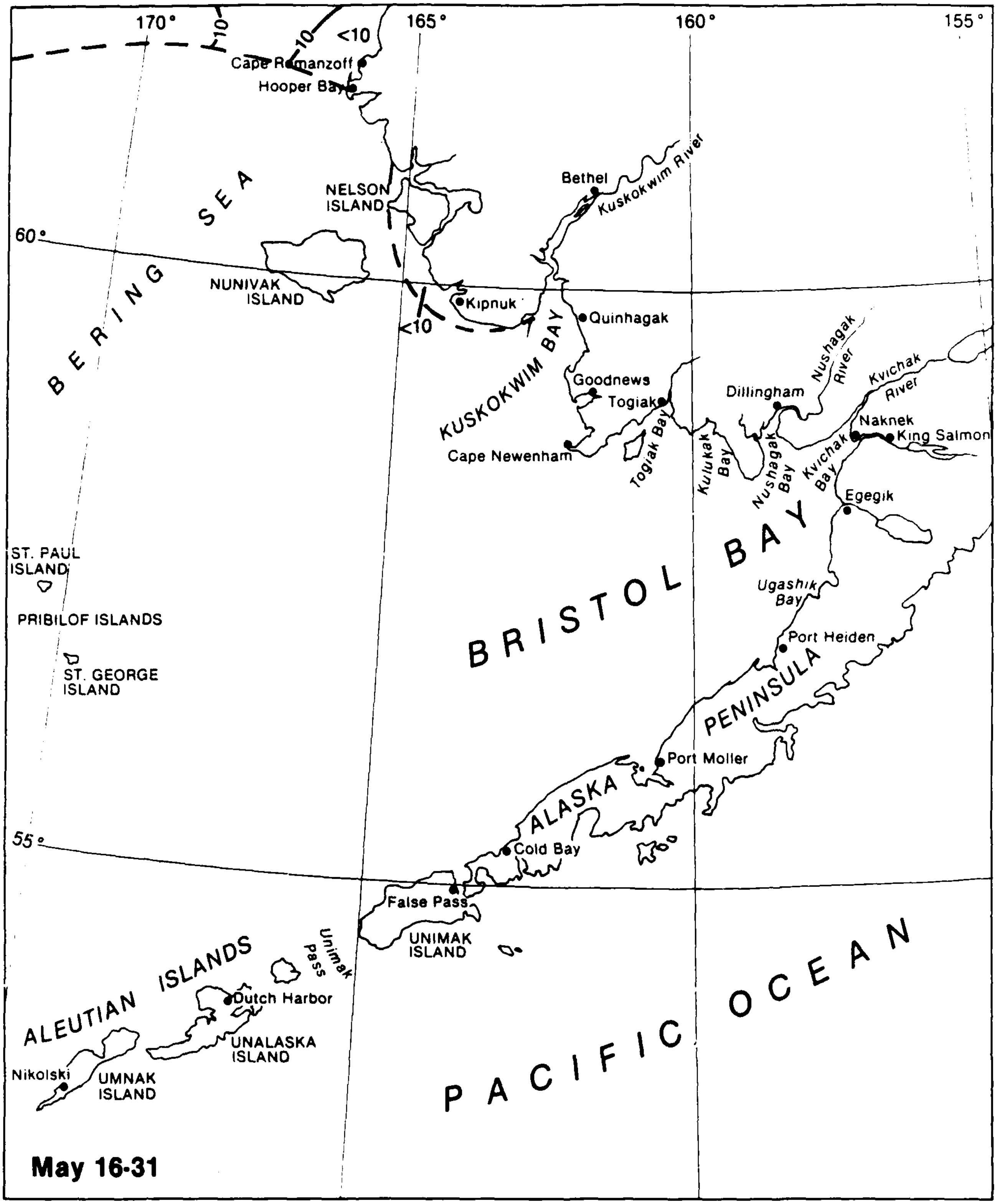


Figure 36n

Calculated Ice Thickness (Inches)

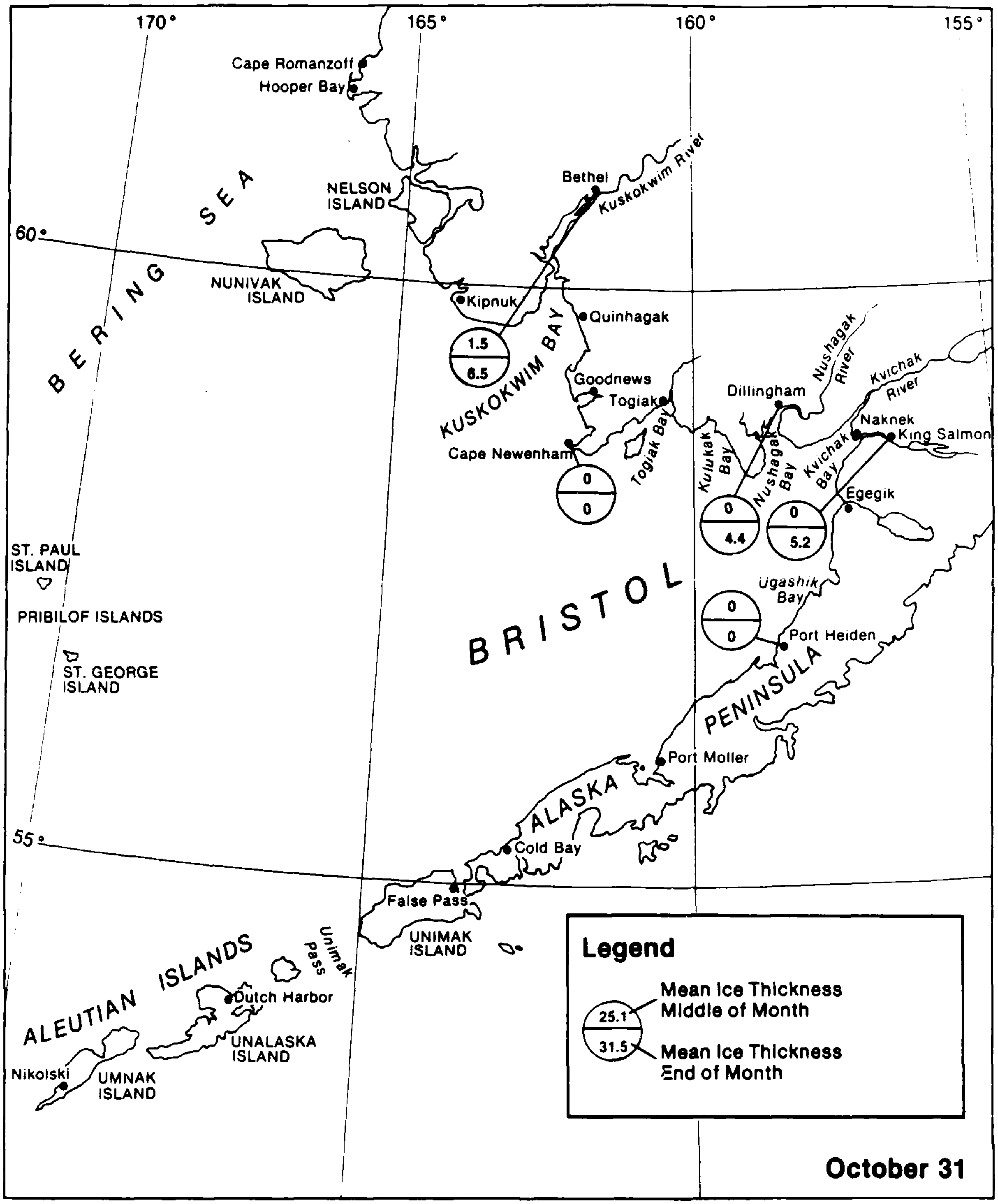


Figure 37a

Calculated Ice Thickness (Inches)

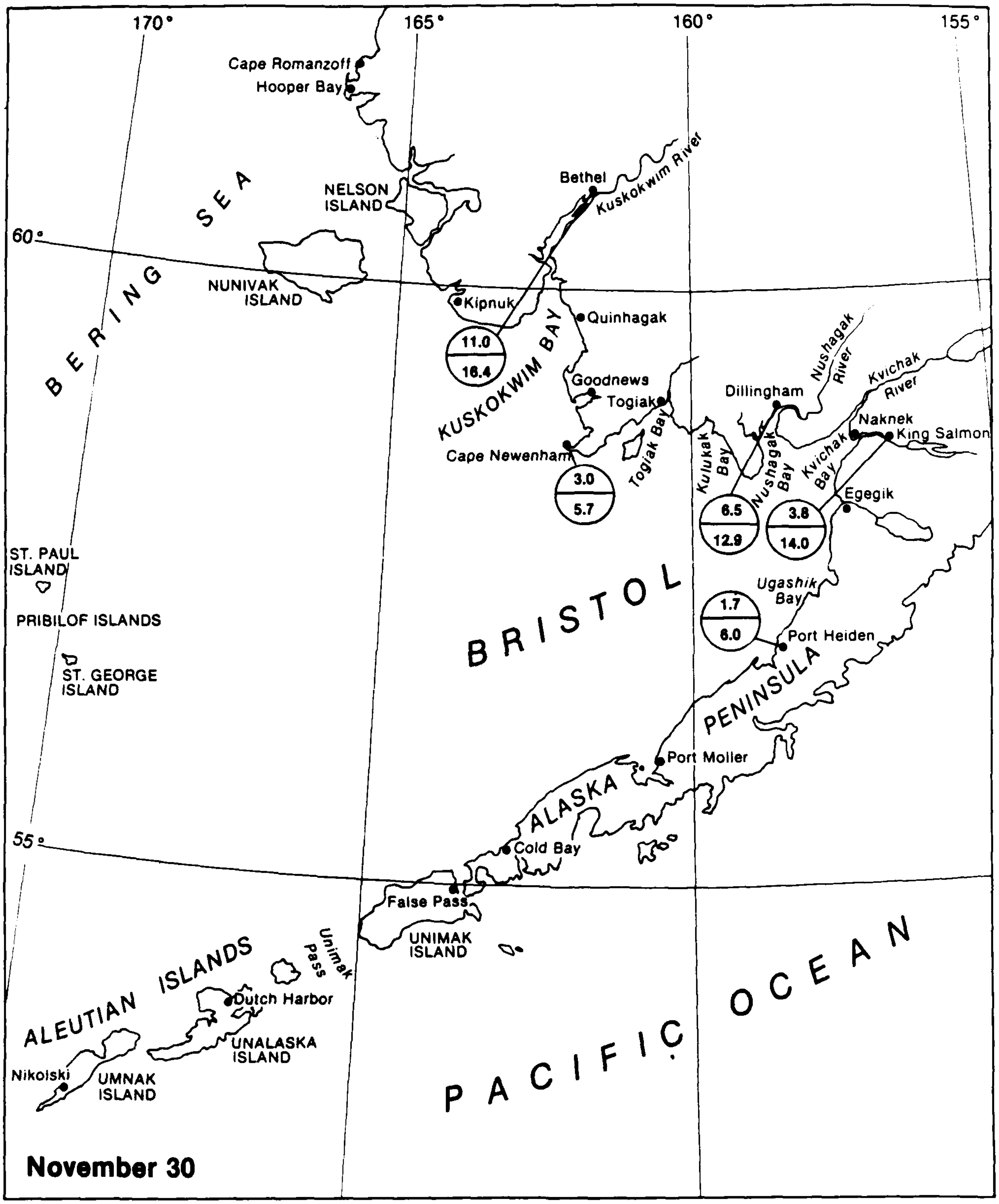


Figure 37b

Calculated Ice Thickness (Inches)

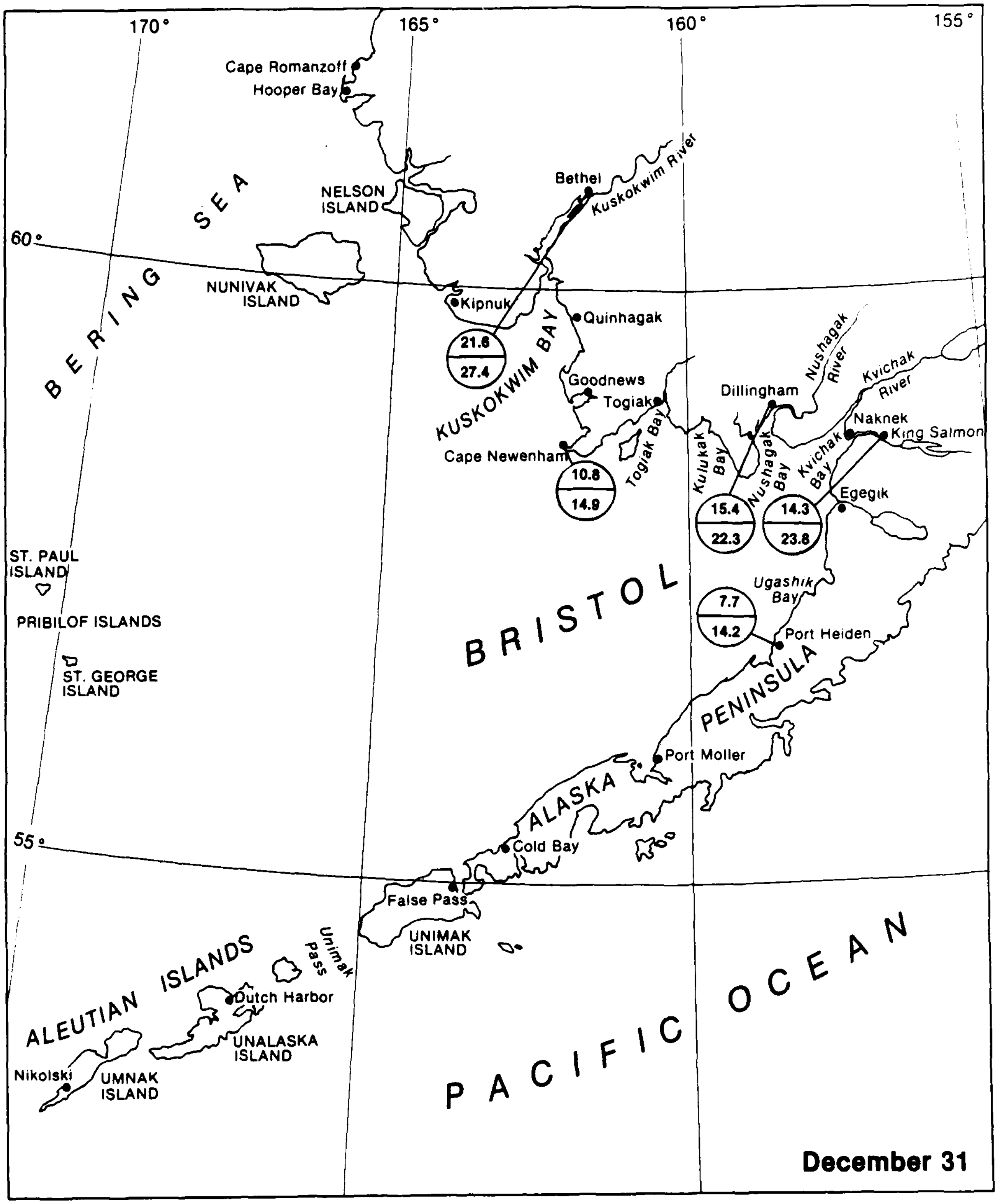


Figure 37c

Calculated Ice Thickness (Inches)

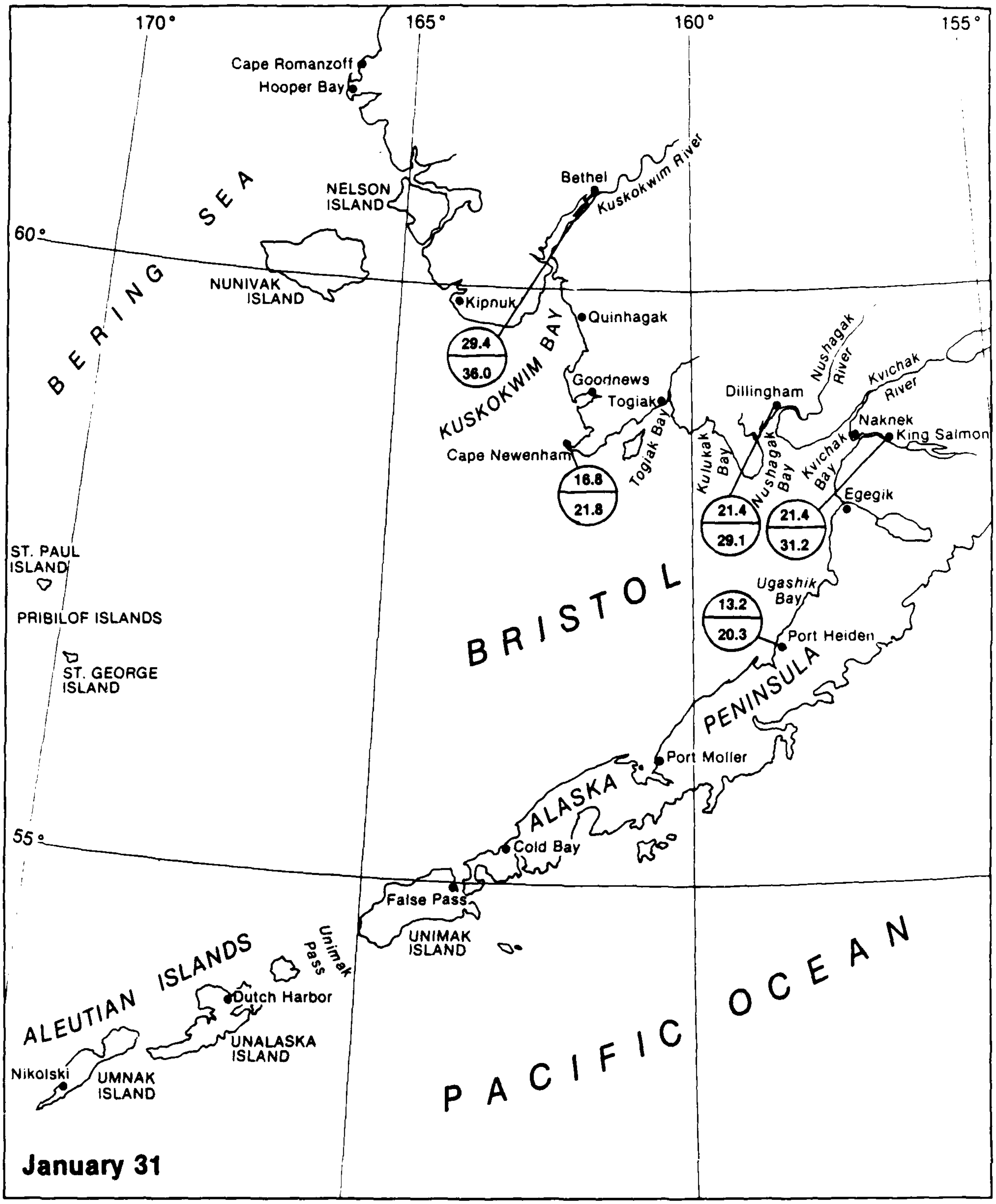


Figure 37d

Calculated Ice Thickness (Inches)

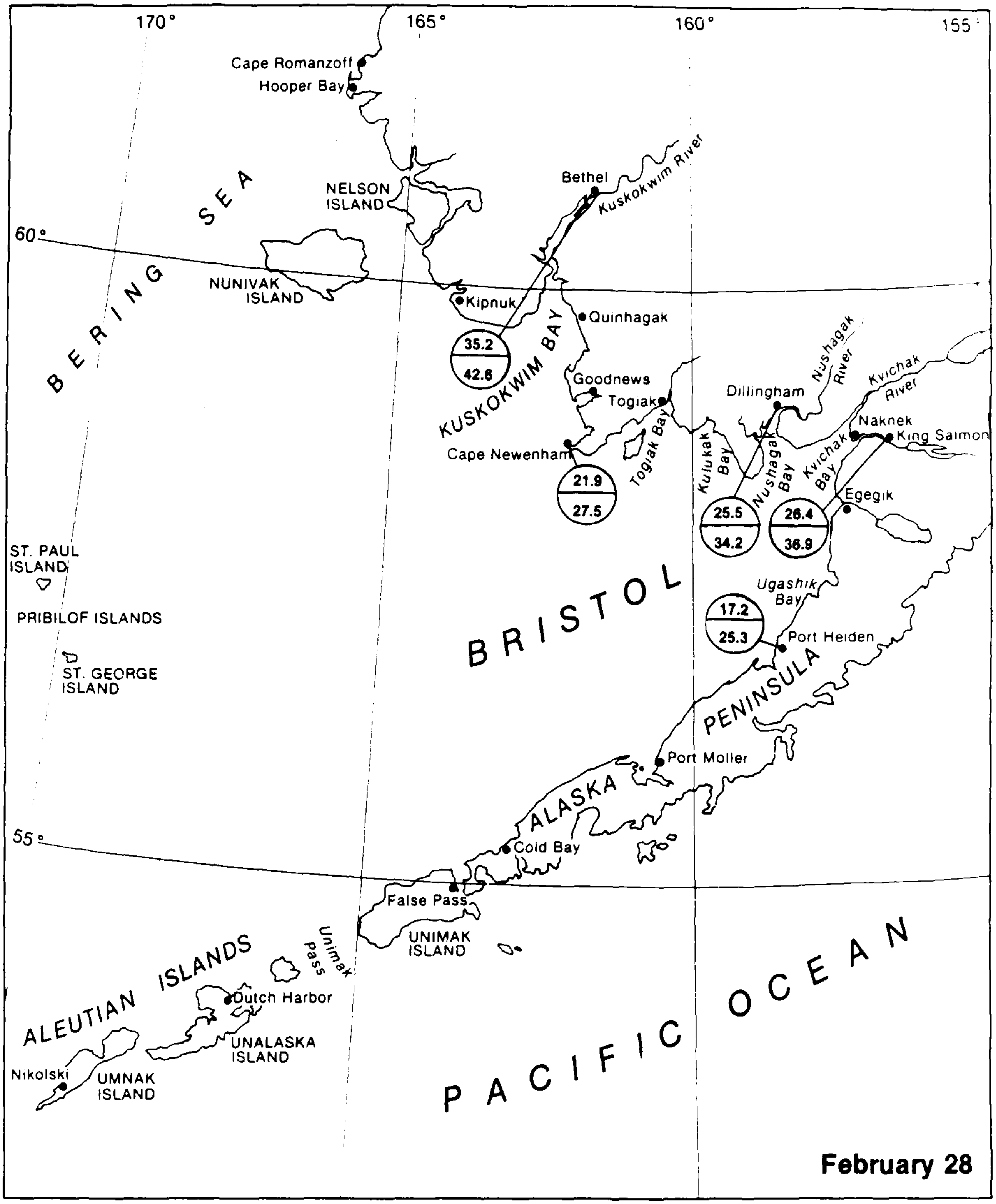


Figure 37e

Calculated Ice Thickness (Inches)

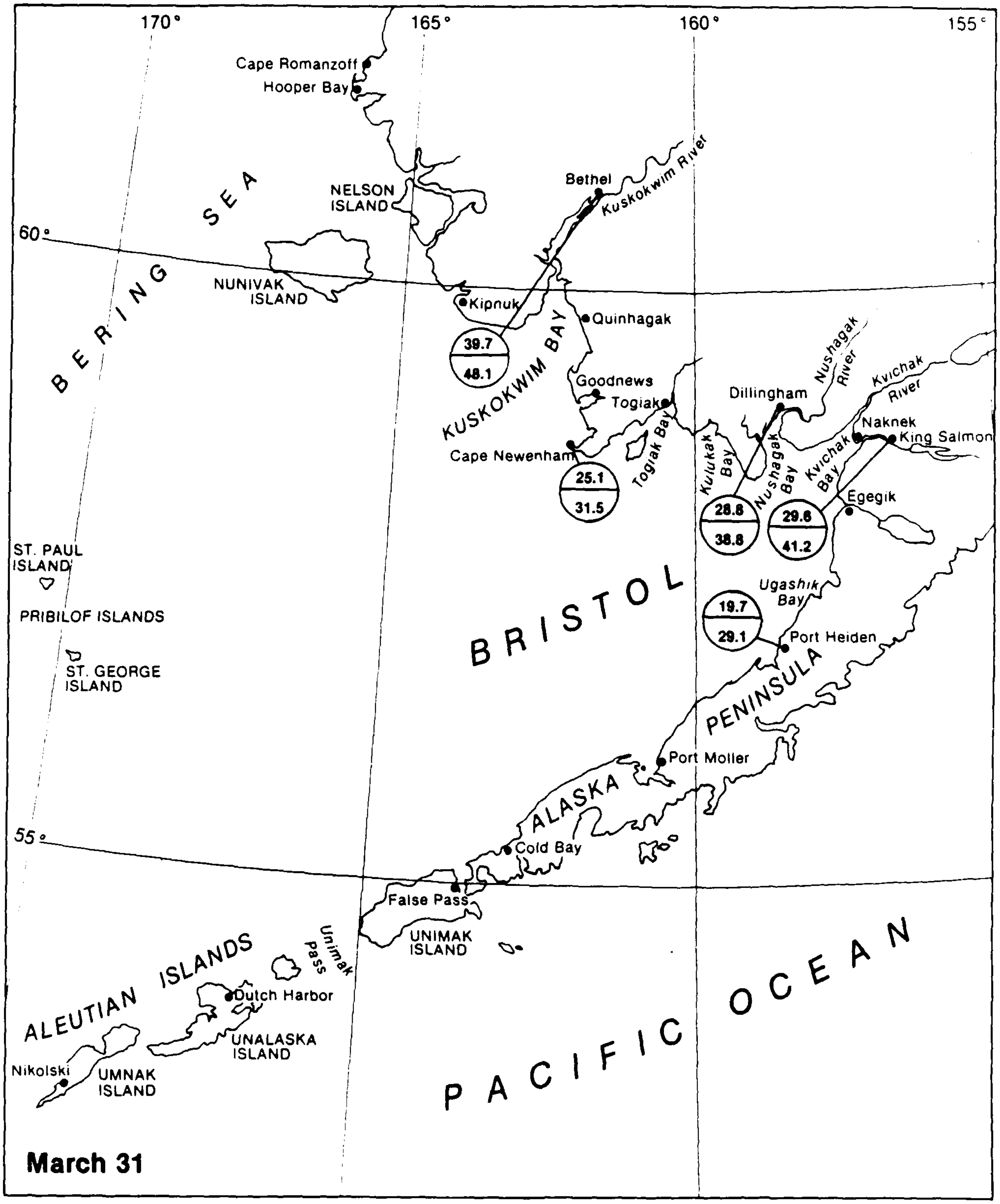


Figure 37f

Calculated Ice Thickness (Inches)

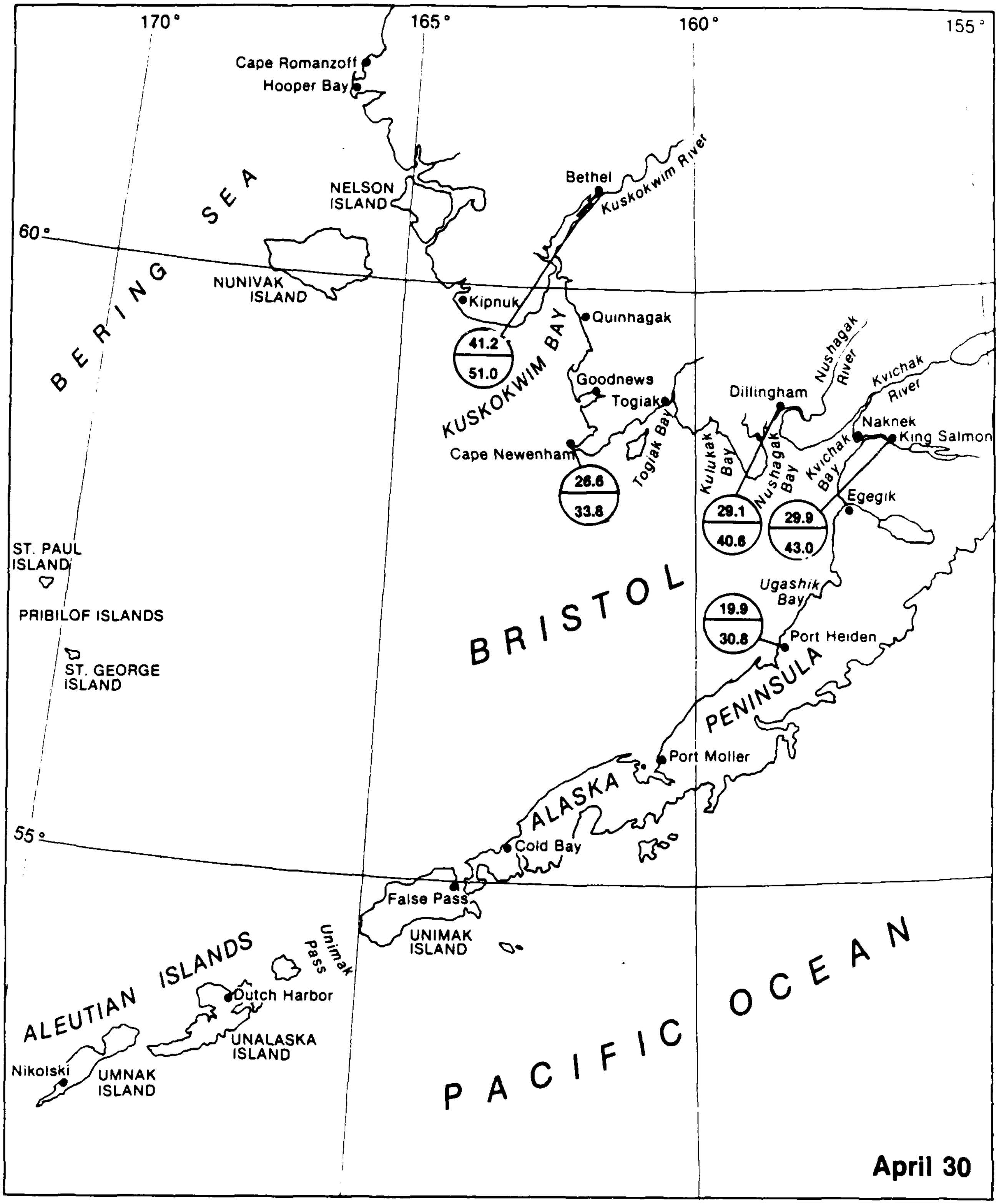


Figure 37g

RECURRING POLYNYAS

Strong northeasterly offshore winds around the perimeter of Bristol Bay, combined with a lack of a barrier to pack ice movement in the southwest, frequently cause a southwestward movement of pack ice out of the bay. This causes the formation of open water polynyas south of much of the bay's northern shores and islands in which new ice is constantly forming (Stringer 1980).

These wind-induced polynyas are frequent but undependable features. The features are temporal and close when the wind shifts to southerly flow (usually accompanying cloudy weather). Figure 38 presents the recurring wind-induced polynyas in the Bristol Bay area (LaBelle, et al. 1983).

NEARSHORE ICE

Fast ice is defined as any ice that is attached to the shore. Most fast ice forms in place, but pack ice that drifts into the area and freezes into place may be included. Figures 39a through 39c present the seasonal fast ice boundaries for the Bristol Bay area. These are derived from LANDSAT data analysis from 1973 to 1977 (Stringer, Barrett, and Shreurs 1980), as displayed in LaBelle, et al. (1983). Figure 40 presents a generalized summary of nearshore ice characteristics (Stringer 1980).

In some locations in Bristol Bay fast ice forms in place, growing thicker over time. Frequently, however, formation of fast ice is dependent on ice dynamics during a particular season. For example, the fast ice may begin to form in place, but a storm may blow in that withdraws the ice from shore and breaks much of it into small cakes. Following this the storm may drive the ice back to shore again. The small ice cakes would then freeze together in an extensive rubble field and become the fast ice for that year.

Fast ice is sometimes formed along the northern shores of the Alaska Peninsula in heavy ice years when persistent northerly winds drive Bristol Bay pack ice southward into shallow waters. The ice quickly piles up into grounded ridges which then form the core of a fast ice zone. When ice drives ashore, it may overtop the shore and bulldoze part of the beach surface ahead of it, forming low ice-push ridges of gravel and sand (up to about 2 ft high).

Fast ice is grounded in the shallow water nearshore. Beyond its seaward extent, which is dependent upon ice thickness, the fast ice is afloat. At the boundary between grounded and floating fast ice, a series of tide cracks forms which act as a hinge allowing the floating ice to move upward and downward as the tide cycles. As the ice thickens during the winter and the grounded ice boundary moves seaward, active tide cracks form anew leaving behind a series of older, inactive tide cracks. These are often covered with snow. With the high tidal range in Bristol Bay, a zone of active tide cracks often forms, with the currently active tide cracks determined by the current tide state and ice thickness.

Grounded pressure ridges occur at the fast ice edge, resulting from the impingement of the moving pack ice against the stationary fast ice. The grounded keels of these ridges often gouge the sea floor to depths of about 0.5-1 m (1.6-3.3 ft). Forces due to large tidal variations commonly cause breaks and other disruptions in these ridges. Also, there are many areas in Bristol Bay, especially along its northern shores, where ice motion has a significant seaward component due to prevailing northerly winds. In these areas, interaction between pack ice and fast ice is minimal and grounded ridges seldom occur (Stringer 1980; LaBelle, et al. 1983).

Recurring Polynyas with Prevailing ENE Winds Over Many Days

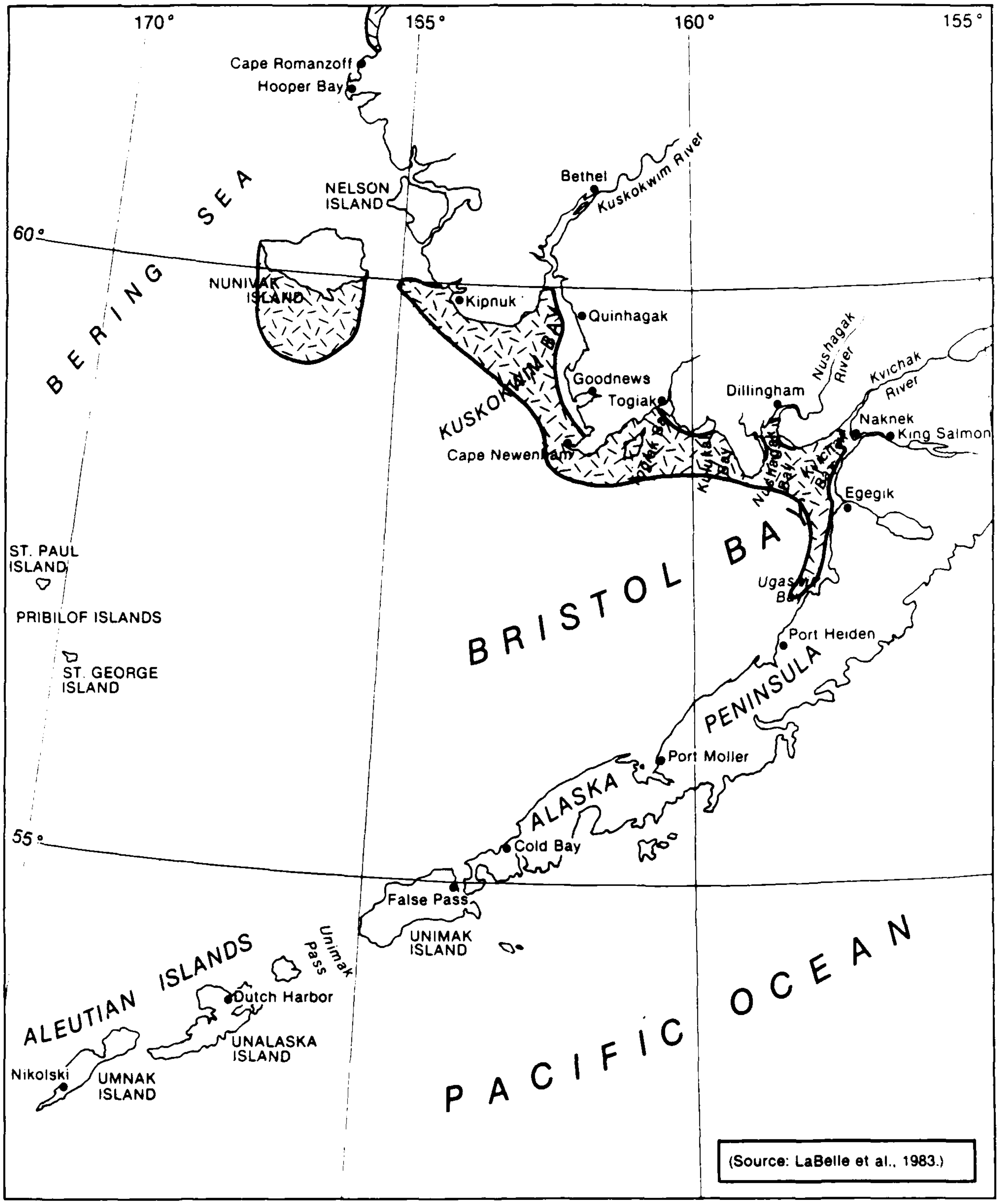


Figure 38

Seasonal Fast Ice Boundary

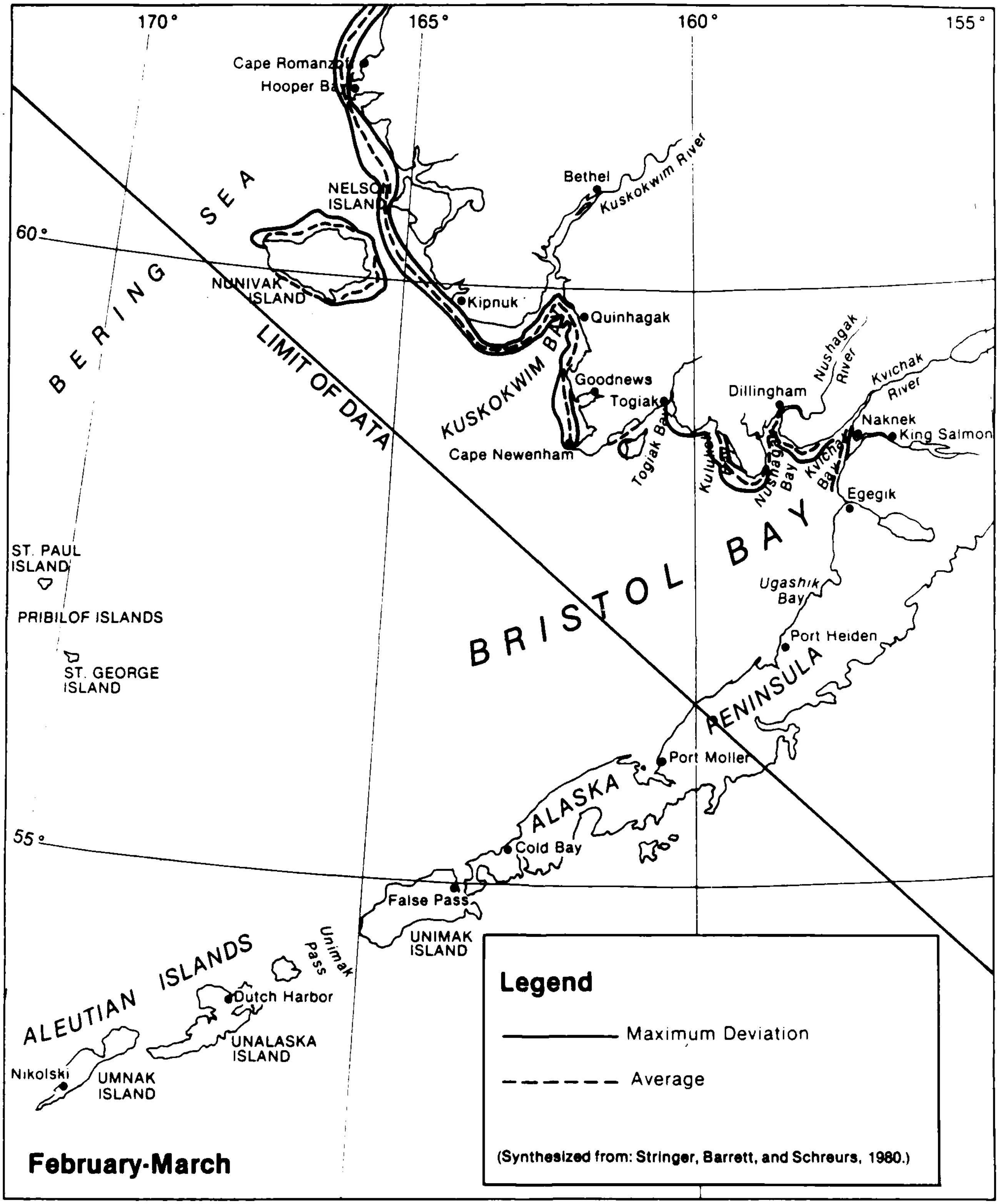


Figure 39a

Seasonal Fast Ice Boundary

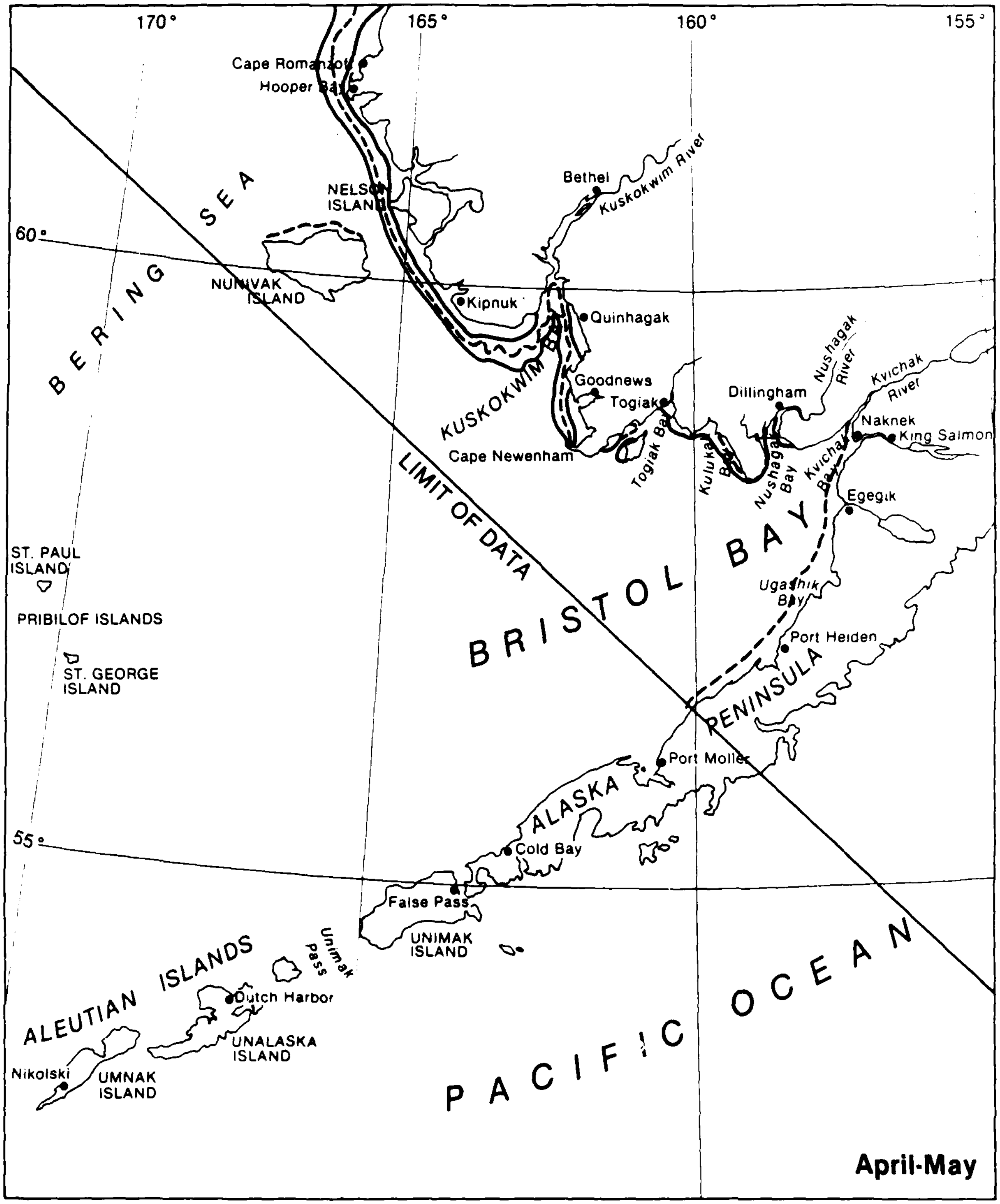


Figure 39b

Seasonal Fast Ice Boundary

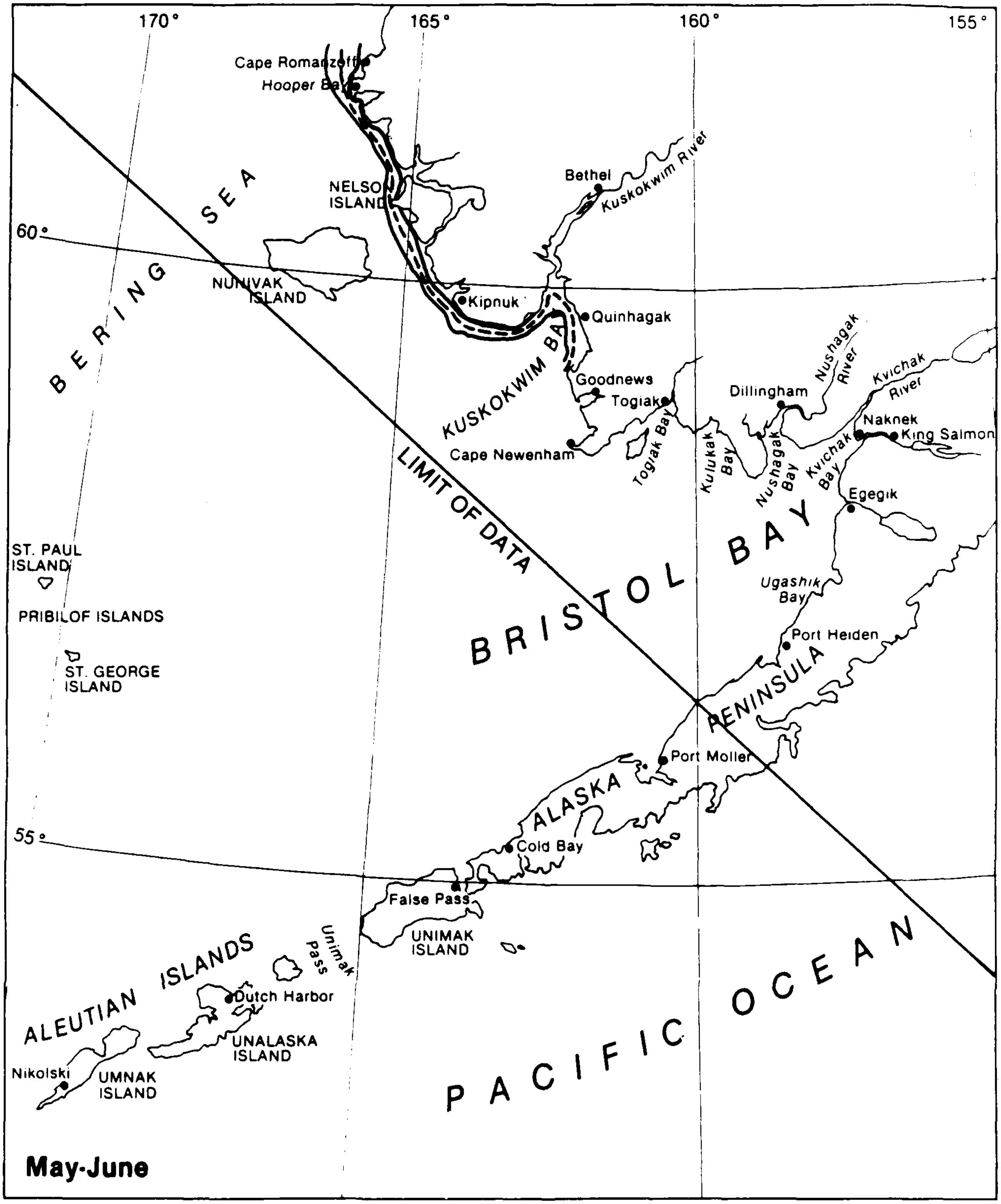


Figure 39c

Generalized Summary of Nearshore Ice Characteristics

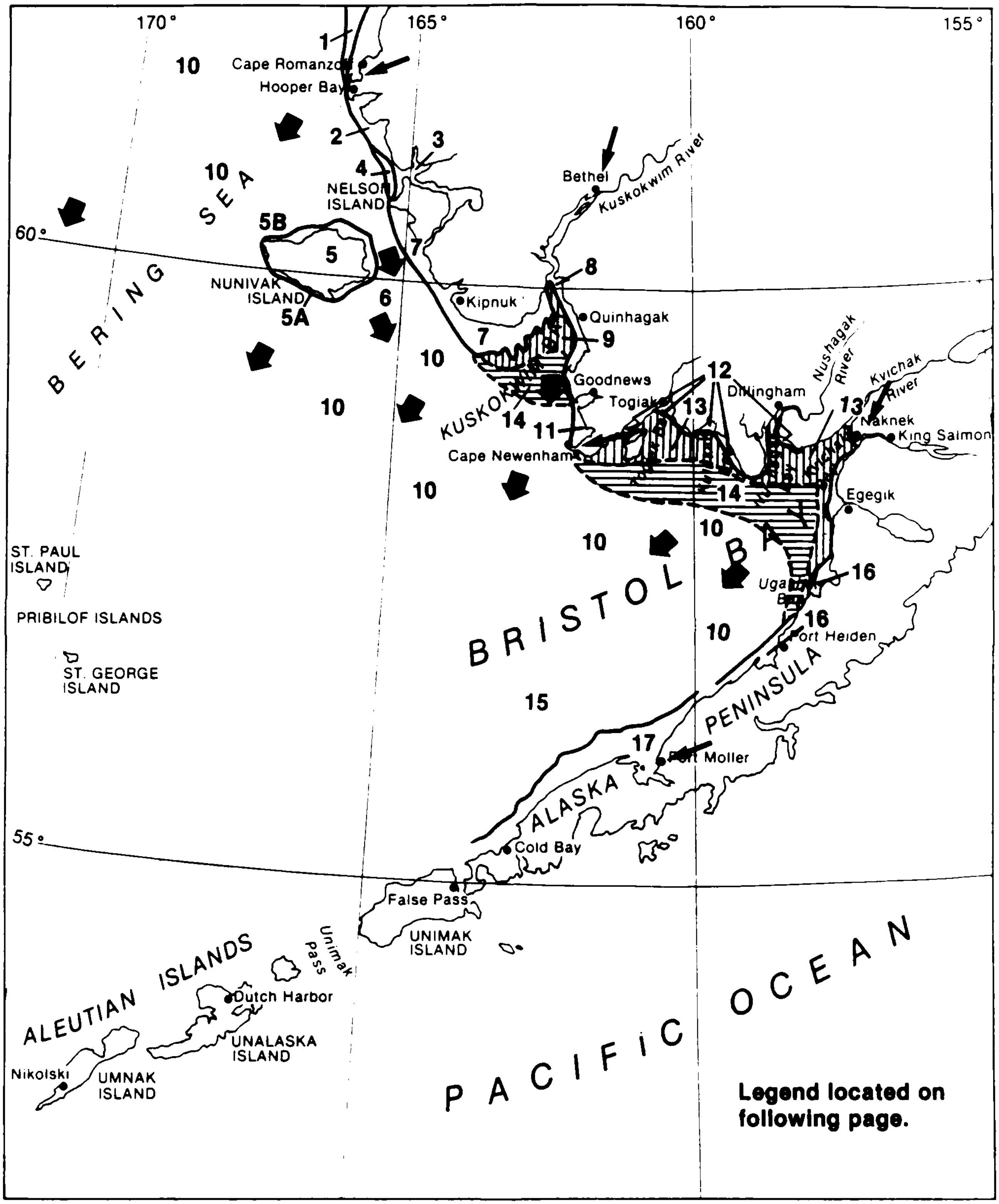


Figure 40

LEGEND TO GENERALIZED SUMMARY OF NEARSHORE ICE CHARACTERISTICS

Most frequently observed ice motion.

Prevailing wind direction, November to April.

Generalized edge of fast ice.

1. Area of great variability of fast ice edge. Ice grounds on extensive shoals during winter months, extending fast ice. These features tend to erode back as spring approaches.

2. Fast ice usually is located in waters less than 6 m (20 ft) deep at top of bench, dropping off abruptly to 14 m (46 ft). Tidal activity and absence of ridging are responsible for lack of fast ice past these depths, making fast ice edge stable.

3. Fast ice in Hazen Bay correlates with mud flats.

4. Area of great variability of fast ice edge. The seaward limit of the average edge of fast ice coincides with the 6 m (20 ft) isobath, while the shoreward limit is in waters about 3 m (10 ft) deep. Flushing action by tides may be responsible.

5. Fast ice around Nunivak Island is confined to waters inshore of the 20 m (66 ft) isobath with the exception of two locations:

   A. In this portion of the southern coast the 20 m (66 ft) isobath is very close to shore, yet because of protection offered in this area, fast ice extends far seaward.
   B. It appears that southward moving ice piles up in this area.

6. Pack ice generally in motion southward through Etolin Straits can pile up on shoals.

7. Fast ice is located over mud flats in waters no deeper than a few meters.

8. Tidal action is responsible for removing ice from Kuskokwim River channel.

9. This area often contains open water and broken ice, with ice rubble piles found on shoals.

10. Pack ice often shows signs of repeated breakage and formation of newer ice.

11. Fast ice shows some variation in extent due to occasional grounding on shoals, and is generally found in waters less than 6 m (20 ft) deep.

12. Fast ice on the northern side of Bristol Bay is confined to highly protected areas with water depths less than 4 m (13 ft).

13. This area often contains open water or newly formed ice.

14. Ice in this area is often compacting or growing in thickness as it moves southward.

15. Ice within Bristol Bay is often composed of several ages, formed as older ice breaks into pans and the voids freeze with new ice.

16. Fast ice along the eastern end of Bristol Bay is limited to an area close to shore by offshore winds and currents.

17. During years with extensive Bering Sea ice, fast ice can be found along this coast. Winds tend to drive ice onto shore. In some of these years an extensive shear ridge forms along the seaward fast ice boundary.

FREEZEUP AND BREAKUP DATES

Table 9 presents ice freezeup and breakup dates for several coastal locations in the Bristol Bay area (LaBelle, et al. 1983; Potocsky 1975; U.S. National Ocean Survey 1985). The earliest, average, and latest dates of freezeup and breakup are shown.

Table 9. Freezeup and breakup dates.

	FREEZEUP			BREAKUP			
Location	Earliest	Average	Latest	Earliest	Average	Latest	
Naknek	Oct 28	Nov 15	Nov 28	Mar 30	Apr 21	May 10	(1954-71)
Egegik	Nov 12	Dec 12	Jan 11	Mar 16	Apr 14	May 1	(1937-52)
Koggiung	Nov 23	Dec 22	Jan 30	Apr 26	May 4	May 13	(1937-40)
Dillingham	Oct 16	Nov 7	Dec 22	Apr 25	May 9	May 27	(1919-52)
Kanakanak	Oct 14	Nov 20	Dec 21	Apr 17	May 2	May 22	(1937-43)
Cape Newenham	Nov 29	Dec 10	Dec 25	Mar 17	Apr 13	May 17	(1954-71)
Platinum	Oct 23	Nov 19	Dec 12	Apr 8	May 1	May 25	(1928-52)
Quinhagak	Oct 20	Nov 15	Dec 30	Apr 10	May 1	May 17	(1929-52)

(Sources: LaBelle, et al. 1983; Potocsky 1975; U.S. National Ocean Survey 1985)

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