SUPERSTRUCTURE ICING AND WAVE HINDCAST STATISTICS IN THE NAVARIN AND ST. GEORGE BASIN AREAS

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TABLE OF CONTENTS

SUPERSTRUCTURE ICING

A. INTRODUCTION

Icing is mainly a function of the amount of water which remains liquid after striking a ship's or fixed platform's surface and the elapsed time before this water freezes. There are two types of ice accumulation, rime ice and glaze ice. Rime is rough, milky, opaque ice with minimal adhesion and is formed when small, super-cooled drops of water freeze on contact with a surface. It does not spread and can form at any temperature in the icing range. Glaze is formed on slow freezing of large super-cooled drops. It can spread over a larger surface and is harder to remove than rime icing (the preceding paragraph has been paraphrased from *Berry* et al., 1975).

Ice accretion depends on many factors. Meteorology and sea conditions are paramount (see below). However, vessel size, navigational peculiarities, structural design, kinematic and thermodynamic interaction at the surface of a design ❑ember and water droplets (stagnation zones on a surface, Ackley and Templeton, 1979) also become critical.

B. EFFECTS ON SHIPS

Ships such as fishing trawlers, smaller merchant ships, and Coast Guard Cutters are most vulnerable to icing due to less freeboard and the increased amount of travel time through an area experiencing icing conditions. It should be noted that the right combination of events can produce icing on large vessels also. Icing on a vessel increases its weight, changes its trim, elevates its center of gravity, decreases its metacentric height and increases its sail area and heeling moment leading to extreme handling difficulties (Berry et al. 1975).

C. ICING ON OFFSHORE STATIONARY PLATFORMS

As on ships, a coating of ice on external surfaces can elevate the platform's center of gravity. In addition, the ice will usually form in stagnation zones on the windward side (Ackley and Templeton, 1979) causing an imbalance weight distribution on a platform. Vertical and horizontal members of offshore structures are designed to meet oscillatory stresses due to wave action. The forces on the structure are made up of hydrodynamic drag and inertial (mass) components. Icing changes the physical characteristics of structure members, such as diameter, surface roughness, mass and flexural response (Ippen 1966). Therefore, a fixed structure's ability to withstand a design wave is questionable after and during an extreme ice accumulation.

Depending on freezing rates, the ice forming on structures due to sea spray will generally have a salt content much less than the sea salinity and may even approach 0 ‰ salinity. The maximum pressure produced by water freezing in a confined space is 30,000 lb in^{-2}. This stress on a structure or ship occurring during a freezing sea spray condition can drastically weaken support members.

D. METEOROLOGY AND SEA CONDITIONS (the following Parts 1-4 have been paraphrased from Berry et al. 1975).

1. Freezing Rain and Snow

Freezing rain itself seldom reaches large enough accumulations to be the sole source of danger to a ship. However, combined with freezing salt spray (see below) it becomes dangerous since, as freshwater, it freezes faster than salt water and can act as a nucleus for faster ice accumulation from salt spray. Snow is not considered a threat due to inherent lack of adhesion.

2. Arctic Sea-smoke

Arctic sea-smoke forms when extremely cold air flows over much warmer water. The water vapor that results from the ensuing evaporation condenses immediately in the cold air and super-cooled droplets become visible as rising columns of “steam”. Weight of ice deposited is only a problem if the condition exists for a long time since it is a low wind phenomenon.

3. “Sea Ice”

Water taken over the side of the ship will not freeze readily unless trapped by ice chocked rails and ports. This is considered a minimal hazard.

4. Freezing Spray

The Figs. 1-17 below have been developed mainly for freezing spray conditions. This is the most common and dangerous form of icing, resulting in glaze ice characterized by high density and great adhesion power. This type of icing is a function of several simultaneously occurring variables:

a. Air Temperature

The critical range for this study (Bering Sea Area) is from 0°F to 32°F (-18°C to 0°C). At temperatures below 0°F the water striking the structure will usually be in the form of non-adhering small dry ice crystals (Berry et al., 1975).

b. Wind

Sea spray generation depends on the wave height and period of waves. Waves in turn depend on the duration of the wind and fetch. Generally, the higher the wind speed for the above temperature range, the greater the ice accumulation. The range of wind speeds covered in this study are from 25 knots (12.5 ms^{-1}) to 60 knots (30 ms^{-1}). Data indicate that wind speeds below 25 knots do not produce icing, while wind speeds in excess of 60 knots are rare. Wu (1982) mentions that a wind speed of 12.5 ms^{-1} is considered the incipient velocity for entrainment of water particles in air (without need of waves).

c. Effect of the Ice Pack

When the ice pack concentration reaches 50% areal coverage, superstructure icing is thought to be minimal since wave formation is reduced and freezing spray is eliminated.

d. Sea Temperature

The criticial range of sea surface temperatures are 28° F (-2.2° C) to 48° F (8.9° C). Seawater of normal salinities is generally frozen below 28° F. The upper value of 48° F is not an impediment to freezing since sea spray can be cooled rapidly when air temperatures are below 28° F.

A dangerous layer of ice accumulation occurs at 3.9 in (10 cm, Berry et al., 1975). Of the five icing categories used in this study, extreme icing would produce this thickness in nine hours, heavy icing would produce this thickness in 16 hours, and light icing would produce this thickness in two days.

E. ICING MAPS

To construct the icing contours for Figs. 1-17, a combination of data sources were used. The 50% probability of 50% sea ice areal coverage position was taken from Webster (1981) for the middle of each month shown. The "positions of the 50% probability of 50% sea ice areal coverage and the 50% probability of any sea ice diverge only in the Spring (May on). The minimum and maximum positions of the 50% sea ice concentration edge which were used to construct the extreme icing condition maps (below) have also been taken from Webster (1981).

Average and extreme contours of sea surface and air temperatures for map construction came from Brewer et al. (1977).

The wind speed data for the Navarin Basin came from a combination of new data (Kozo, 1983) and Marine Areas A and B data (Brewer et al. 1977) on its eastern boundary. Wind speed data for St. George Basin came from Marine Areas B, C and nearby land stations (Brewer et al. 1977). There is no evidence of any area in the Bering having monthly mean winds of 25 knots (12.5 ms^{-1}). Therefore mean wind contours were not useful in constructing icing maps. However, David Liu of Rand Corporation has stated that the Bering Sea has an average of 3.5 cyclonic events per month (pers. comm. 1982). The World Meteorological

Organization (W.M.O.) "lists 28 knots (14 ins-l) as the onset of dangerous wind speeds (gale level winds) and 50 knots (25 ms^{-1}) as the onset of real storm level winds. Hence, these levels were used as the critical winds for mean and extreme icing. Table 1 (a. and b.) has been constructed to show the % time of occurrence of gale and storm level winds during possible icing months. Table la. is for the Navarin Basin (10 months of icing) and Table lb. is for St. George Basin (9 months of icing). In addition the % of air temperatures below 0° F (18° C), which generally preclude superstructure icing, are shown. It must be noted that while the percentages are low for the total time of occurrence of these wind speeds, the probability of -these speeds existing in each month is 100% and the duration of these speeds are sufficient to produce severe icing provided the other environmental conditions are met. Therefore, fixed structures which remain in place in one locaton over many months will be more susceptible to icing than vessels which may move in and out of a given area.

A new nomogram for superstructure icing has been used which replaces that of Brewer et al. (1977). The nomogram takes into account the lower wet and dry bulb temperatures, the lower relative humidity, and the higher freezing rates found in the Bering Sea and North Pacific (Wise and Comiskey, 1980).

Five rates of ice accumulation are used in icing maps (Figs. 1-17) constructed for this study.

1. Mean Maps

Mean monthly 50% ice coverage positions, sea surface temperatures and air temperatures were examined under 28 knot wind speed conditions. The Wise and Comiskey Nomogram (Eastern Bering Sea and Gulf of Alaska, 1980) was used to arrive at the icing rates.

a. Navarin Basin

Superstructure icing can be seen to exist at various levels for the months of October through April (Figs. 2, 4, 6, 8, 10, 12, and 14). Mean conditions and 28 knot winds did not produce icing in the Navarin for the months of May through September. From December through April (Figs. 6, 8, 10, 12, and 14), moderate icing conditions can exist for a long enough time period (see Table la) to easily reach the dangerous 10 cm accumulation mentioned above. Also a 10 knot increase in wind speed will normally change the icing category from moderate to heavy if the other parameters stay constant. By April under mean ice conditions (Fig. 14) over 50% of the Navarin Basin is covered with sea ice and therefore superstructure icing is eliminated north of the ice edge.

b. St. George Basin

Superstructure icing exists at certain levels from December through April (Figs. 6, 8, 10, 12 and 14). Mean conditions and 28 knot winds should not produce icing in St. George Basin from May through November. February (Fig. 10) is the only month capable of producing moderate icing conditions of sufficient duration (see Table lb) to reach the 10 cm dangerous accumulation stage. Sea ice covers a small percentage of St. George Basin under mean conditions; therefore, superstructure icing is a distinct possibility for most of the Basin from December through April.

2. Extreme Maps

a. Navarin Basin

Storm level winds (50 knots) and appropriate combinations of air temperatures, sea surface temperatures and sea ice edge conditions will produce icing in ten months from September through June (Figs. 1, 3, 5, 7, 9, 11, 13, 15, 16 and 17). It must be remembered that when ice edge positions are used (mean, minimum or maximum) the corresponding sea surface temperatures "adjust" to the edge position with the lowest sea temperatures adjacent to the ice. However, even on light sea ice years (minimal sea ice extent, higher than average sea surface temperature) a sudden cold front with high winds can move into the Bering Sea and produce severe icing. Atmospheric conditions will generally change on a shorter time scale than the oceanic conditions and appear to be the most important variable in superstructure icing. Figures 1, 3, 5, 7, 9, and 11 representing the months of September through February respectively show that the most extreme icing possible for 50 knot winds results under conditions of minimum air and ocean temperatures and maximum extent of 50%

of sea ice coverage. This occurs because the maximum 50% sea ice coverage is associated with low ocean temperatures over most of the Navarin Basin area, even though the sea ice edge position does not reach the basin as in September and October.

Figures 13, 15, and 16, representing the months of March, April, and May, depict conditions of 50 knot winds, minimum air temperatures, and minimum extent of 50% sea ice with ocean temperatures corresponding to the sea ice position. In these months the maximum 50% ice edge position covered too much of the Basin for extensive spray-induced icing to occur. Instead, the minimum ice edge position led to the necessary sea surface temperatures and wave action to produce the most severe conditions over most of the Navarin Basin.

In June, the maximum ice edge was too far south for minimum June air temperature to cause icing. The minimum ice edge for June was so far north that sea surface temperatures in the Navarin Basin precluded icing even under 50 knot winds . Hence, 50 knot winds at the mean 50% areal coverage ice edge position with corresponding water temperatures and minimum air temperatures produced June icing for the Navarin (Fig 17) .

b. St. George Basin

Extreme conditions (outlined above) will produce icing from October through June (Figs. 3, 5, 7, 9, 11, 13, 15, 16, 17). Figures 3, 5, 7, 9, and 11 representing the months of October through February respectively show that the most extreme icing possible for 50 knot winds results under conditions of minimum air and ocean temperatures and maximum extent of 50% sea ice coverage. Again, this occurs because the maximum of 50% sea ice coverage is associated with lower ocean temperatures over most of the St. George Basin area, even though the sea ice edge position does not reach the basin.

Figures 13, 15, and 16 represent the months of March, April, and May, respectively. They depict conditions of 50 knot winds, minimum air temperatures, and minimum extent of 50% sea ice with ocean temperature corresponding to the sea ice position. Again, the minimum ice edge position led to the necessary sea surface temperatures and wave action to produce the most severe conditions over the St. George Basin.

Fifty knot winds at the mean 50% areal coverage ice edge position with corresponding water temperatures and minimum air temperatures produced June icing for St. George Basin (Fig. 17).

Real icing conditions will fall somewhere between the conditions shown on the extreme and mean maps (Figs. 1-17). It should again be mentioned that the thermal inertia of the oceans makes atmospheric changes the most dangerous variables in the icing puzzle. Table 1 shows that 50 knot winds may exist for 1% of a month's time or approximately 7 hours. Seven consecutive hours of extreme icing will approach the critical accretion of 10 cm (3.9 in.) and be very dangerous.

F . FURTHER STUDY

A data gathering program should be initiated in the Navarin and St. George Basins, Among the parameters measured during **icing** events should be salinity of adhering ice, materials with or without coatings adhered to, percentage due to sea spray, ship size, **ship speed, types** of waves, directionality and thickness of ice.

WAVE HINDCAST STATISTICS

A. INTRODUCTION

The environmental conditions characterized by the wave field in the Navarin and St. George Basins (areas outlined by thin black lines east of 180° and northwest of the Aleutian Islands respectively, Fig. 1) were determined by a deep water wind wave hindcast scheme. The calculated deep water wave heights and periods were based on the assumption of uniform steady wind conditions along each wind direction. The fetch simulated for the establishement of wave statistics was chosen as the largest fetch across the basin along the direction of the wave hindcast. In months when the fetch was ice limited it corresponded to the 50% probability of the 50% ice edge position as shown in Figs. 4, 6, 8, 10, 12, 14, 18, and 19. In the Navarin Basin, the wind statistics derived by Kozo (1983) were adopted, adjusted for the desired directional distribution function, and used for the calculation of deep water wave statistics. Similarly, wind statistics from St. Paul (Pribilof Islands) Marine Area B, and Marine Area C (Brewer *et al.* 1977) were used for the derivation of St. George Basin deep water wave statistics.

B. DEEP WATER WAVE HINDCAST THEORY

Hasselmann's parametric wind-wave model (Hasselman, 1976) was adopted for the hindcast of the deep water wave. The fundamental concept of Hasselmann's one parameter model is based on the premise that the response of the wave field to the wind input can be described by two processes which occur at different rates: 1) the rapid adjustment of the spectrum to a universal shape and an energy level such that the input by the wind in the dominant region of the spectrum is balanced by the nonlinear transfer and possibly dissipation, and 2) the slower migration of the peak toward lower frequency due to the nonlinear energy transfer across the peak. This concept has been verified by JONSWAP'S field results (Hasselmann et al., 1973) and also by Wu's laboratory results (Wu et al., 1979). The one parameter model is limited to growing seas and cannot be extended into the swell range. The governing equation is:

$$\frac{1}{f_o}\frac{\partial f_o}{\partial \tau} + P_o \frac{\partial f_o}{\partial \eta} = -N_o f_o^{7/3} + \frac{1}{u}\left(\frac{\partial u}{\partial \tau} + \frac{\partial u}{\partial \eta}\right)$$

Where, $P_o = 0.95$

$N_o = 5.5 \times 10^{-4}$

$\frac{\partial}{\partial \tau} = \frac{u}{g}\frac{\partial}{\partial t}, \quad \frac{\partial}{\partial \eta} = \frac{u}{g}\vec{V}_m \cdot \vec{\nabla}, \quad |\vec{V}_m| = \frac{\alpha g}{4\pi f_m}$

$f_o = Uf_m/g$, $\alpha = 0.85$ for $\cos^2\theta$ spreading factor

U is wind speed, g is gravitional acceleration,

f_m is peak wave frequency.

For a uniform wind field, the governing equation for predicting a local peak frequency can be simplified as:

$$\frac{\partial f_m}{\partial t} = -5.5 \times 10^{-4} \cdot \left(\frac{g}{U}\right)^{-4/3} \cdot f_m^{10/3}$$

The analytical solution of the above equation in terms of the normalized peak wave period, T_p and normalized significant wave height, Hs can be expressed as follows:

For

$$X < 3.5 \times 10^3$$

$$H_s = 1.53 \times 10^{-3} X^{0.5}$$

$$T_p = 0.341\ X^{0.3}$$

otherwise

$$H_s = 0.283 \tanh (0.0125\ X^{0.42})$$

$$T_p = 7.54 \tanh (0.077\ X^{0.25})$$

Where $X = gX/U^2$, $H_s = g_s/U^2$, $T_p = gT_p/U$. The results calculated by the above equations compare quite well with experimental observations made in other parts of the world over many years.

C. Results and Conclusions

1. Navarin Basin

The calculated results of wave statistics are in Table 2 (a and b) through 13 (a and b) for the Navarin Basin. Both significant wave height (Hs) and peak wave period (Tp) are presented in frequency of occurrence and total percentage. The significant wave height is the average height of the 1/3 highest waves. The height of the 5% highest waves is 1.73 Hs. (Pierson et al., 1971). This value will be representative of individual wave height observations such as the 51 foot seas (15.5 m) reported (Petroleum Information, 1983) for the Navarin in October, 1983. For example, October in Table 10 shows a maximum Hs of 10 m. Therefore, 1.73 Hs yields 17.3 m, putting the 51 foot waves within the predicted envelope. The hindcasted maximum significant wave height and peak wave period are 13 m and 16 seconds for the Navarin Basin. These extreme events occurred in the months of February and November. During the months of ice coverage influence (November through June) most of the events occurred concurrently with the wind from the directions of north, northeast and east. The majority of wave heights ranged from 1 to 5 m and wave period ranged from 6 to 10 seconds. During the months from July to October (no ice coverage effect), both wind and waves had less directionality. The majority of significant wave heights ranged from 1 to 3 m and peak wave periods ranged from 4 t0 8 seconds.

2. St. George Basin

The calculated results of wave statistics are in Table 14 (a. and b.) through 25 (a. and b.) for the St. George Basin. Both significant wave height and peak wave period are presented in percentages. The hindcasted maximum significant wave height and peak wave period are 16 m and 18 seconds, respectively. These extreme events occurred in the months of February and November (also see Navarin Basin above). During the months of possible ice cover influence on fetch (November through May) most of the events occurred concurrently with wind directions from north, northeast and east. The majority of wave heights ranged from 1 to 5 m and wave periods ranged from 6 to 10 seconds. During the months from July to October (no ice coverage effect) both wind and waves had less directionality. The majority of significant wave heights ranged from 1 to 3 m and peak wave periods ranged from 4 to 8 seconds. The computed statistics for St. George Basin and the Navarin Basin were very similar. However, the position of the sea ice cover in the Bering Sea will always result in a greater fetch distance for St. George Basin simulations. Therefore, under conditions of similar duration the seas will be more fully developed in the southernmost basin. In addition, the tables will show that greater significant wave heights (from specified directions) do not always produce greater peak wave periods. Again, fetch is a controlling factor.

D. FURTHER STUDY

A more detailed raw data analysis is strongly recommended and required for the establishment of design wave criteria related to Artic region oil and gas development activity. In particular, wind time series records of at least five years duration in each month should be studied.

REFERENCES

Ackley, S. F. and M. K. Templeton, 1979: Computer modeling of atmospheric ice accretion, CRREL Rpt. #79-4. Hanover, New Hampshire, 36 pp.

Berry, M.O., P. M. Dutchak, M. E. Lalonde, J. A. W. McCulloch and I. Savdie, 1975: Weather, waves and icing in the Beaufort Sea, Technical Rpt. #21. Meteorological Applications Branch, Atmospheric Environment Service, Ottawa, Ontario. 57 pp.

Brewer, W. A., H. F. Diaz, A. S. Prechtel, H. W. Searby and J. L. Wise, 1977: Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska. Volume II Bering Sea, NOAA, NCC, EDS. Asheville, North Carolina. 409 pp.

Hasselmann, K., 1976: A parametric wave prediction model. J. Phys. Ocean. 6, 200-228.

Hasselman, K., T. P. Barnett, E. Bouws, and H. Carlson, 1973: Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project, Deutches Hydrographisches Institut, Hamburg, 20 pp.

Ippen, A. T., 1966: Estuary and Coastline Hydrodynamics. McGraw-Hill, New York, 744 pp.

Kozo, T. L., 1983: Navarin Basin Mesometeorology. Annual Rpt., MMS, NOS, NOAA, contract #03-5-022-6, R.U. 519, Juneau, Alaska, 43 pp.

Kozo, T. L., 1984: Alaskan Arctic Mesoscale Meteorology. Annual Rpt., MMS, NOS, contract #03-5-022-67, R.U. 519, Juneau Alaska, in press.

Petroleum Information, 1983: Alaska Rpt., vol. 29, #41. P.I. Corp., Anchorage, Alaska, Section 1, 2 pp.

Pierson, W. J., G. Neumann, and R. W. James, 1971: Observing and forecasting ocean waves, H.O. Pub. #603, U. S. Naval Oceanographic Office, Washington D. C, 284 pp.

Shore Protection Manual, 1977: Volume II. U. S. Army Coastal Engineering Research Center. Dept. of Army, Fort Belvoir, Virginia, 535 pp.

Webster, B. D., 1981: A climatology of the ice extent in the Bering Sea, NOAA Technical memo, NWS AR-33, -Anchorage, Alaska, 38 pp.

Wise, J. L. and A. L. Comiskey, 1980: Superstructure icing in Alaskan Waters, NOAA Special Rpt. Pacific Marine Environmental Laboratory, Seattle, Washington, 30 pp.

Wu, H. Y., E. Y. Hsu, and R. L. Street, 1979: Experimental study of non-linear wave-wave interaction and white cap dissipation of wind-generated waves, J. of Dynamics of Atmospheres and Oceans, 3, 55-78.

Wu, J., 1982: Sea Spray: A further look, J. Geoph. Res., 87, 8905-8912.

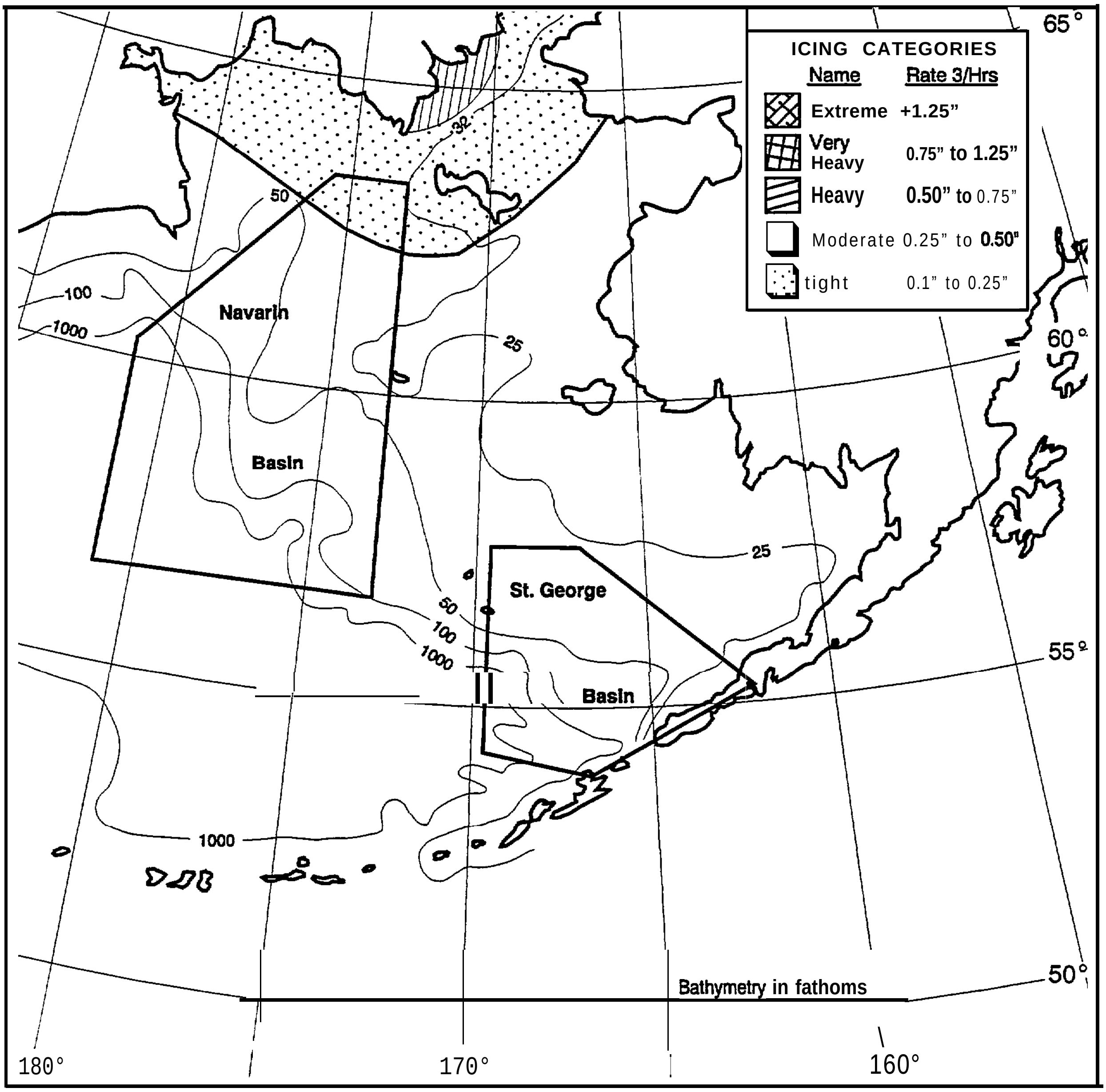

Figure 1. --September extreme conditions: produced by minimum recorded air and ocean temperatures (some ice in Bering Strait). A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, **Kozo,** 1984.)

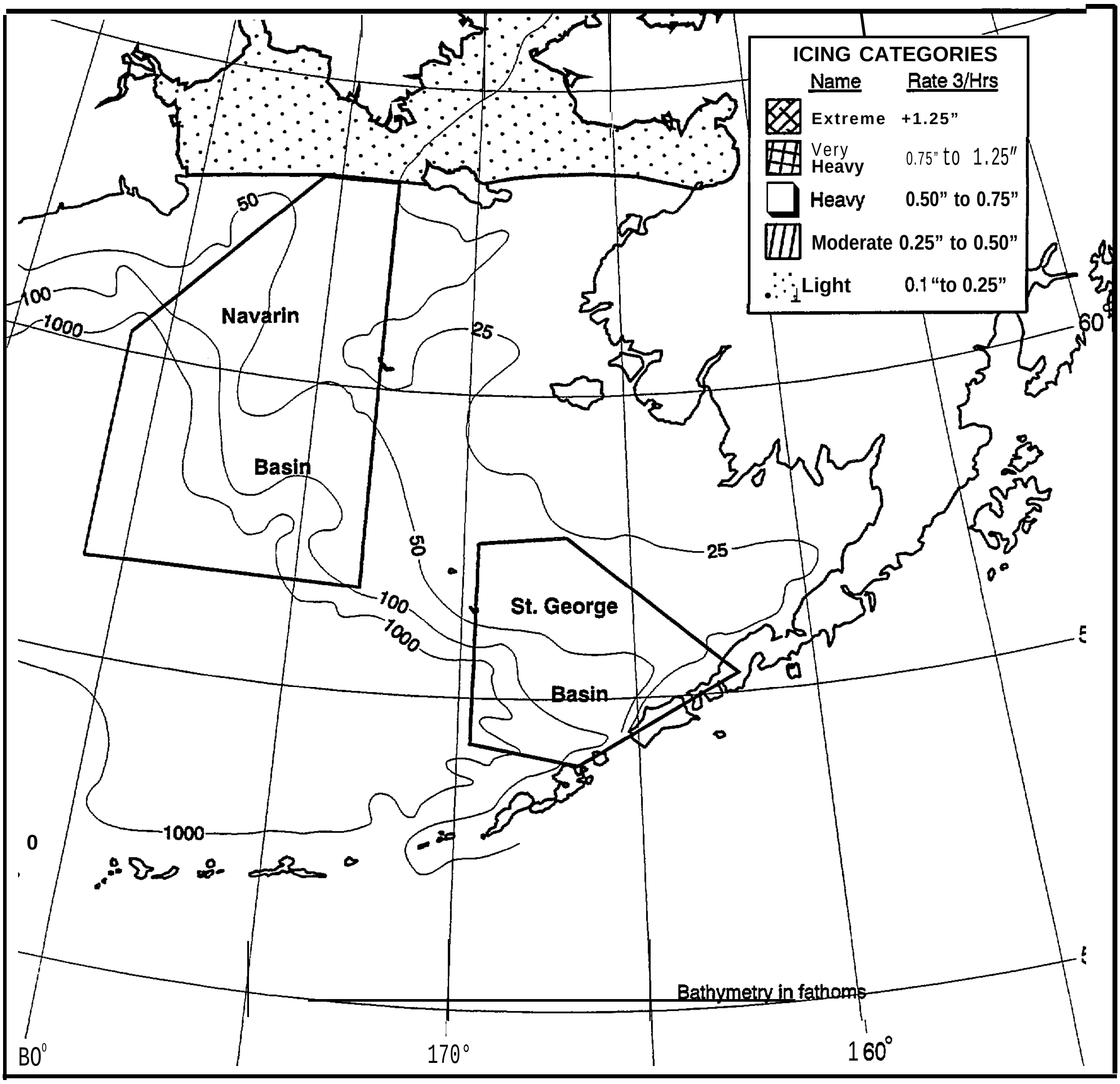

Figure 2.--October mean conditions: No ice in Bering Sea, mean air temperature, and mean ocean surface temperature. A 28 knot (14 m/s) wind speed (gale level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

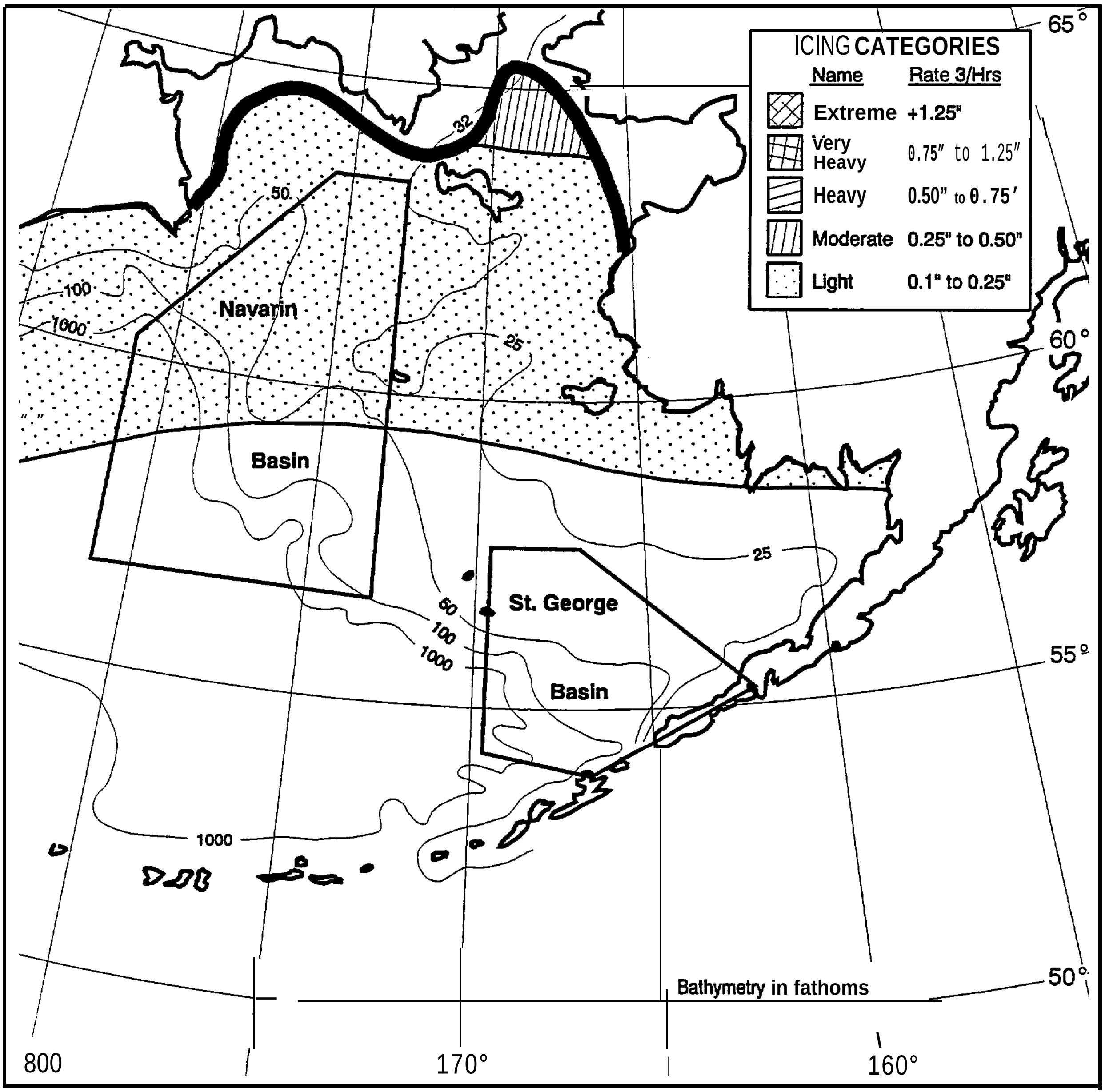

Figure 4. --November mean conditions: 50% probability of 50% ice coverage (heavy line), mean air temperature, and ocean surface temperature corresponding to ice coverage. A 28 knot (14 m/s) wind speed (gale level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

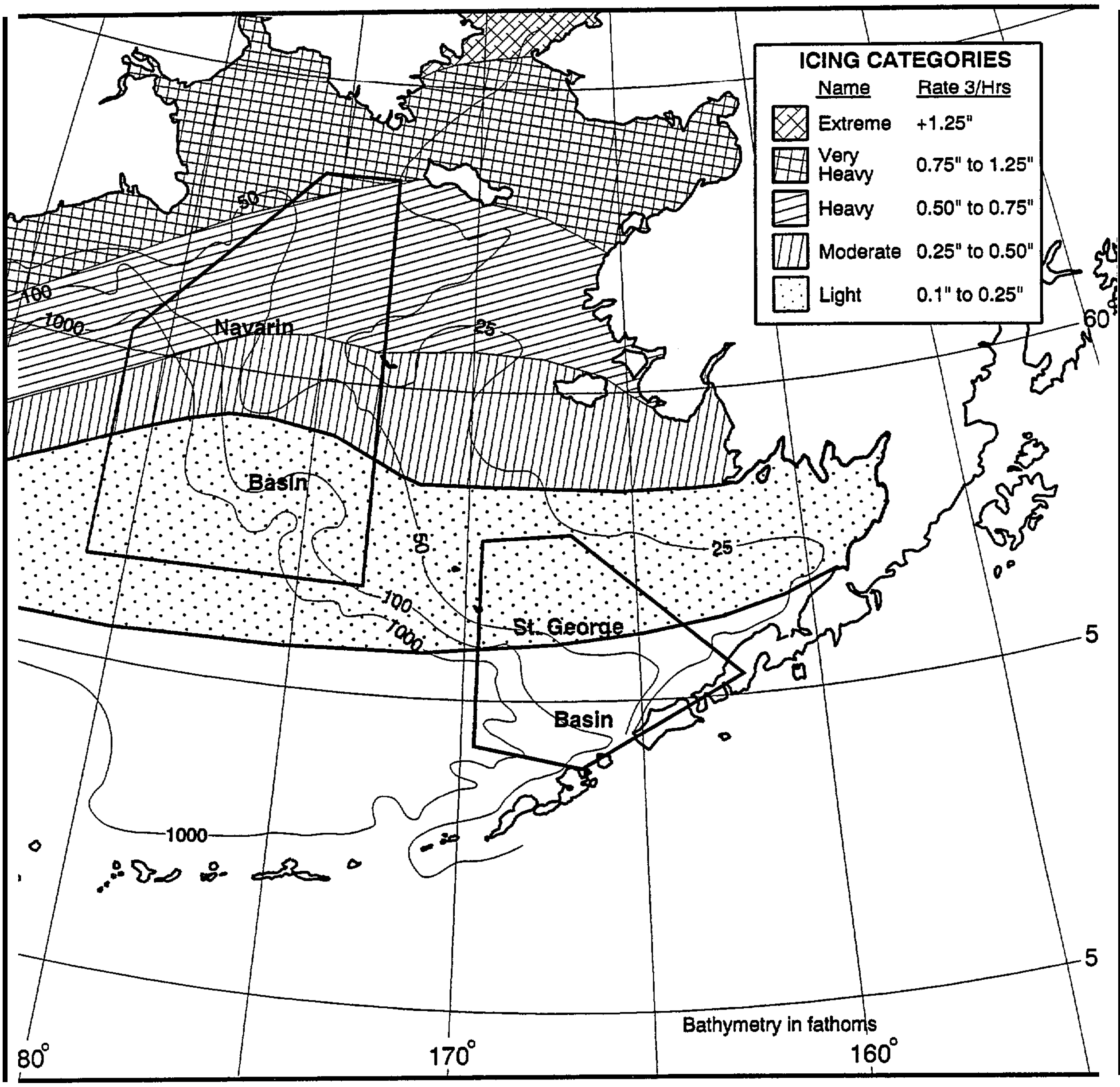

Figure 3. --October extreme conditions: produced by minimum recorded air and ocean surface temperatures. Maximum extent of 50% ice coverage does not reach the Navarin Basin area. It occurs in the Gulf of Anadyr and Norton Sound only. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

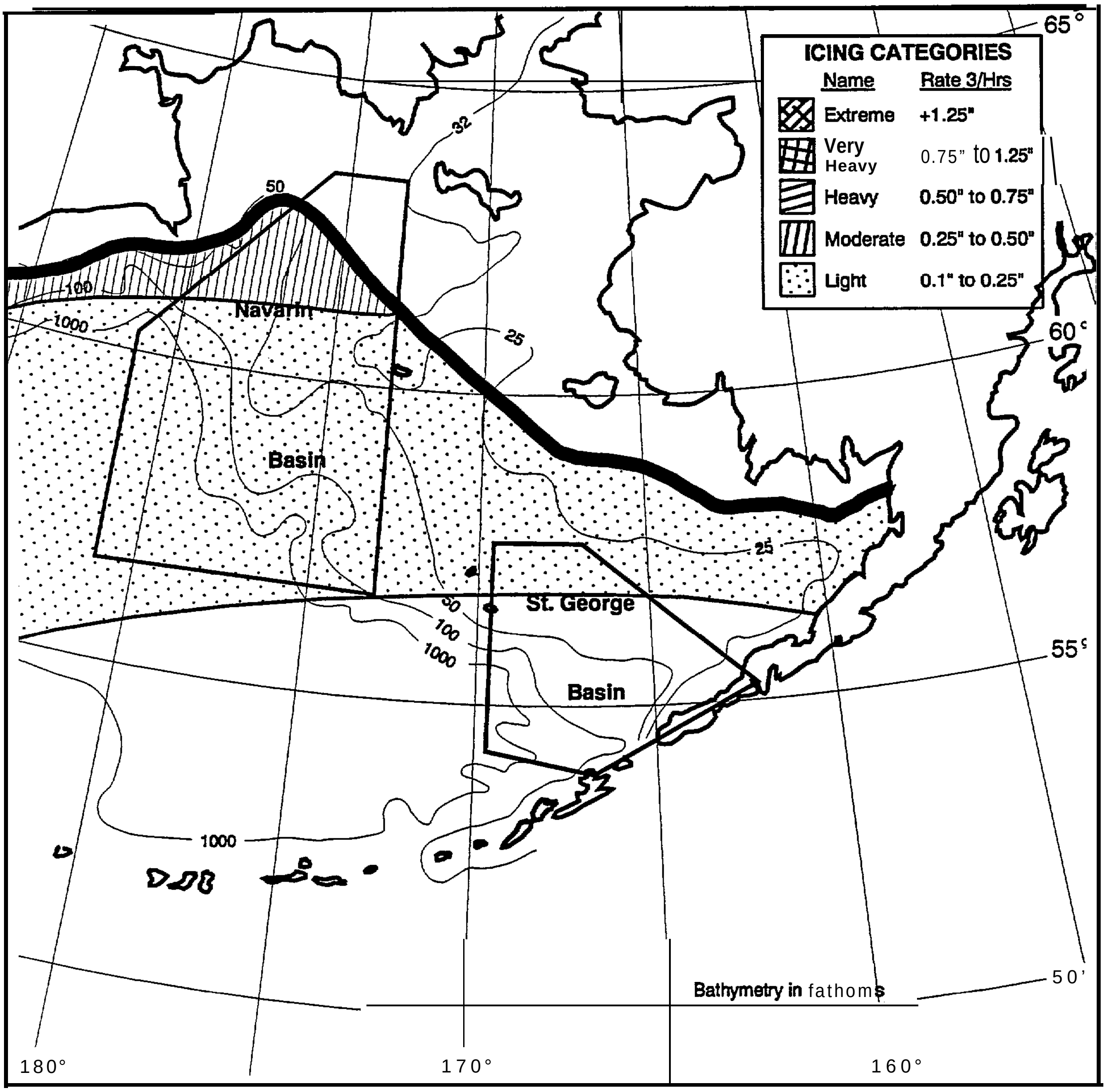

Figure 6.--December mean conditions: 50% probability of 50% ice coverage (heavy line), mean air temperature, and ocean surface temperature corresponding to ice coverage. A 28 knot (14 m/s) wind speed (gale level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

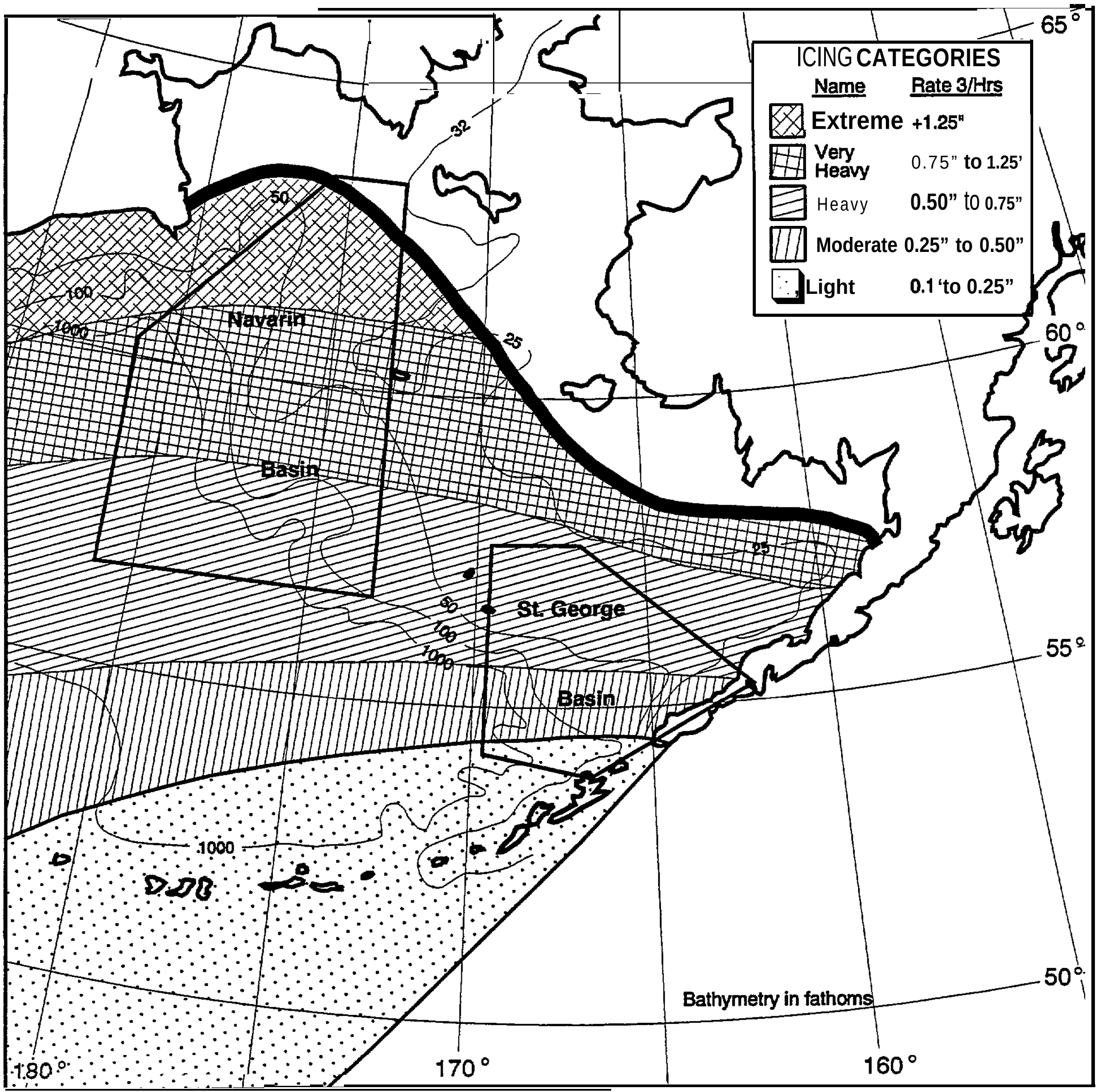

Figure 5. --November extreme conditions: produced by maximum extent of 50% ice coverage (heavy line) , minimum recorded air temperatures! and ocean surface temperatures corresponding to ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

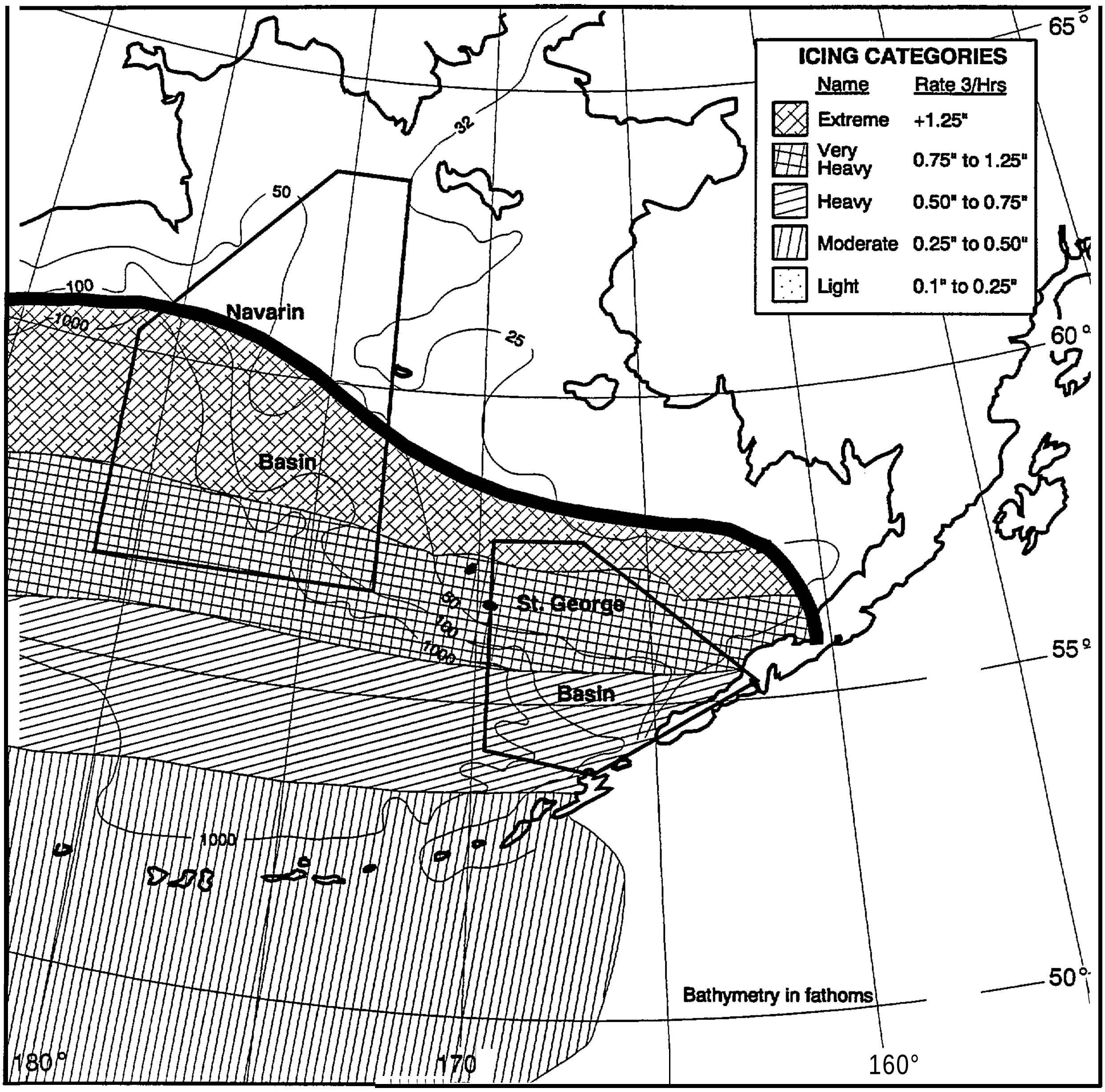

Figure 7.--December extreme conditions: produced by maximum extent of 50% ice coverage (heavy line), minimum recorded air temperatures, and ocean surface temperatures corresponding to ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

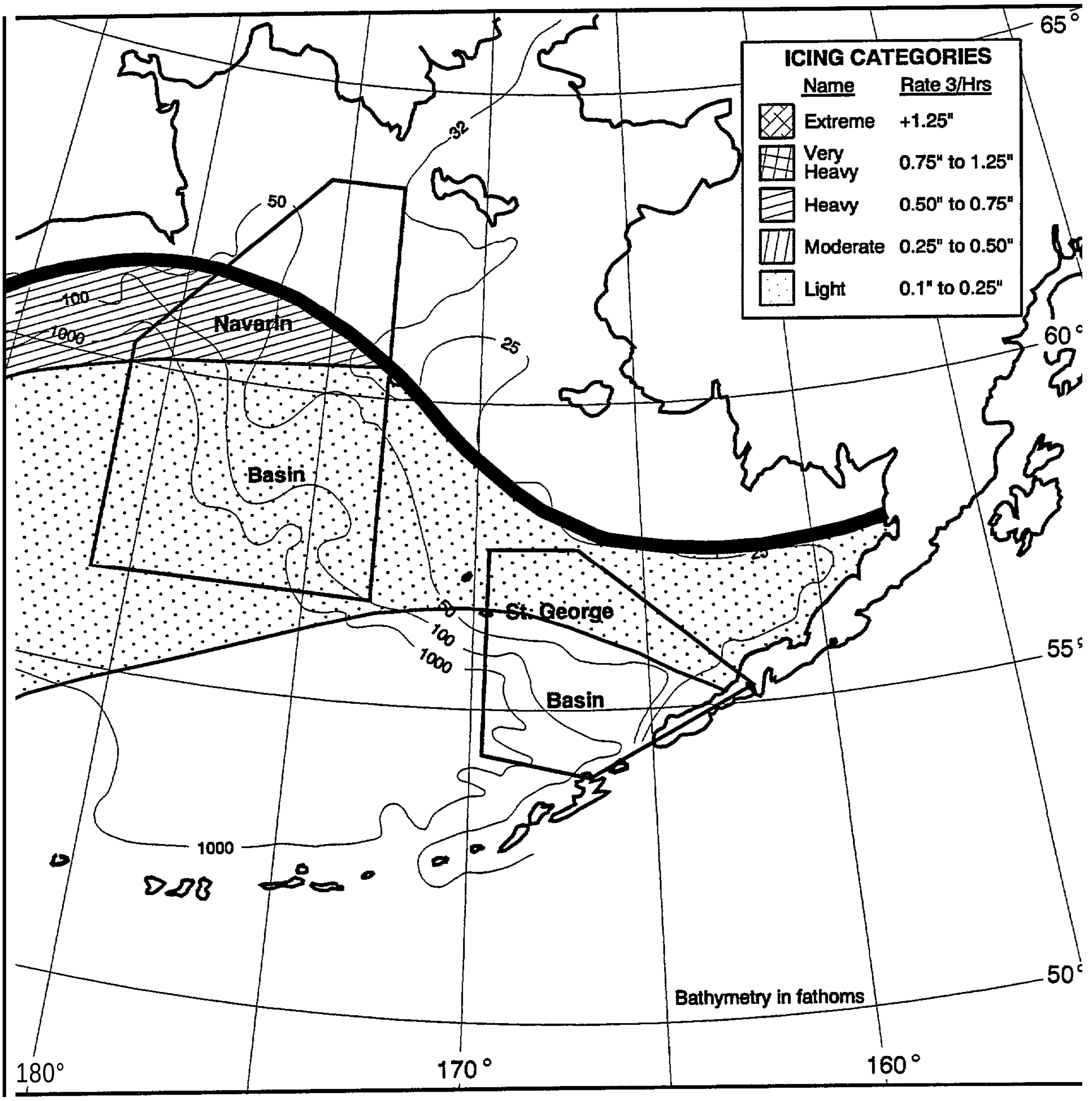

Figure 8. --January mean conditions: 50% probability of 50% ice coverage (heavy line), mean air temperature, and ocean surface temperature corresponding to ice coverage. A 28 knot (14 m/s) wind speed (gale level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

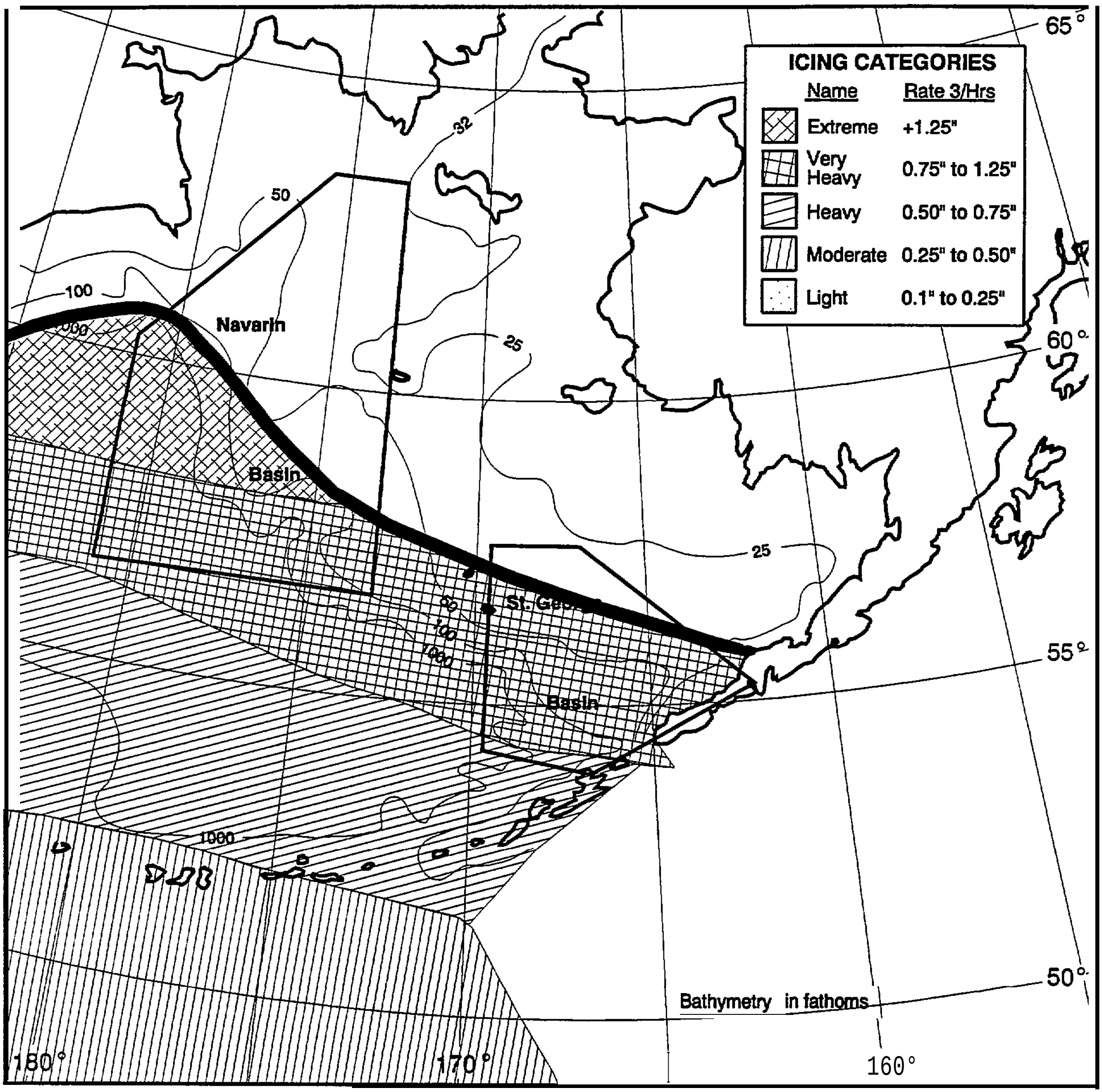

Figure 9.--January extreme conditions: produced by maximum extent of 50% ice coverage (heavy line), minimum recorded air temperatures, and ocean surface temperatures corresponding to ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

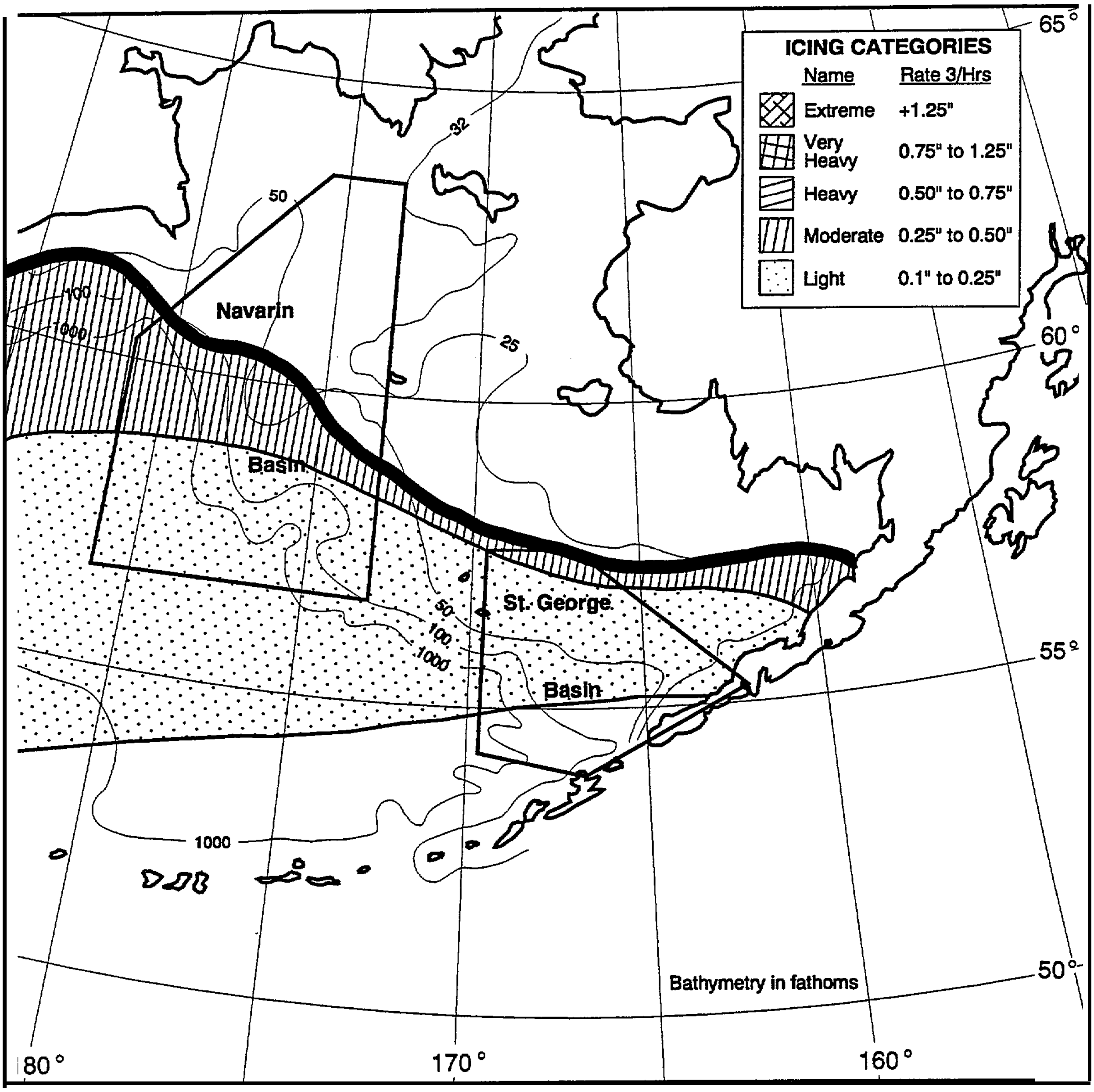

Figure 10.--February mean conditions: 50% probability of 50% ice coverage (heavy line), mean air temperature, and ocean surface temperature corresponding to ice coverage. A 28 knot (14 m/s) wind speed (gale level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

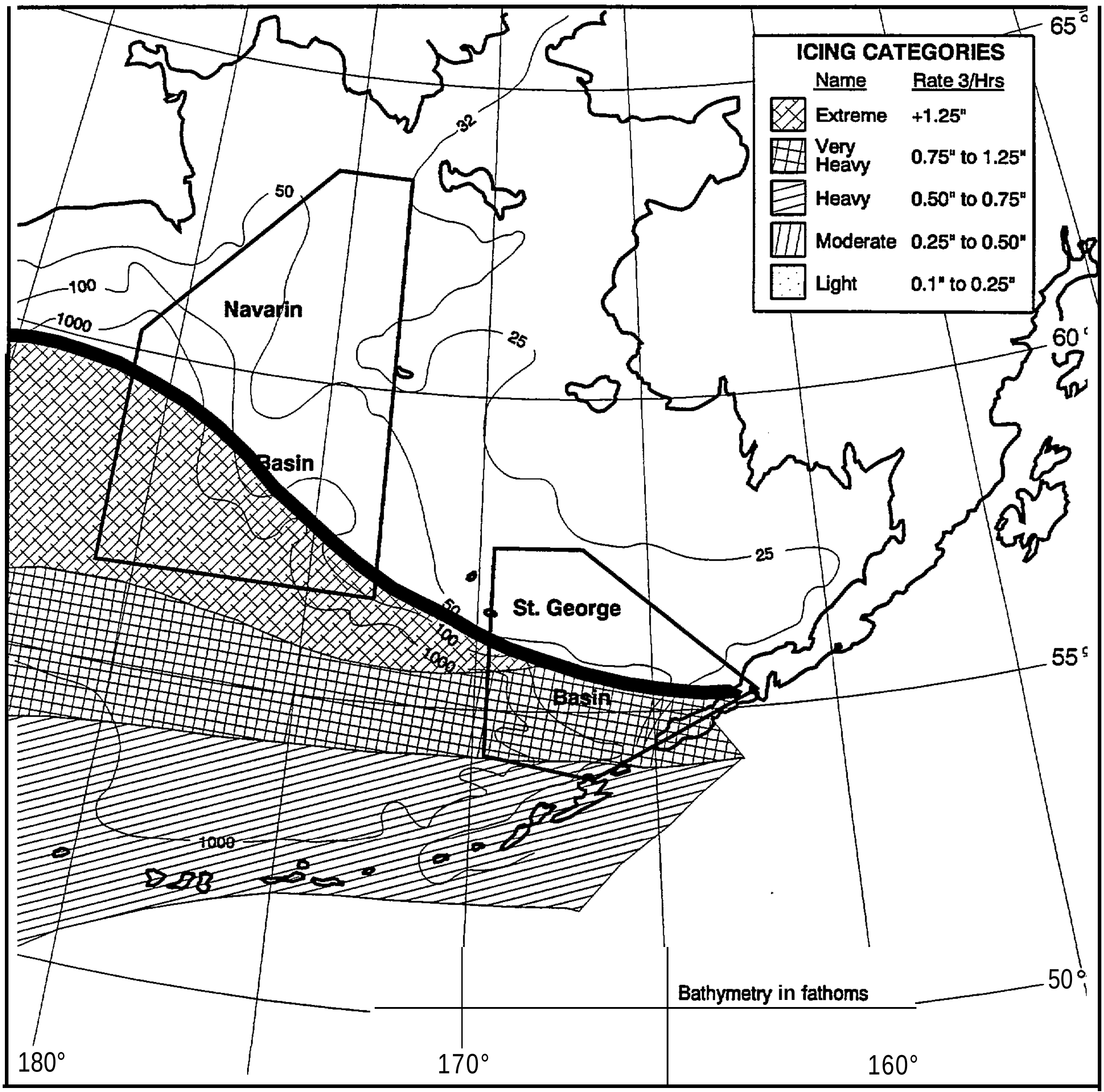

Figure 11.--February extreme conditions: produced by maximum extent of 50% ice coverage (heavy line), minimum recorded air temperatures, and ocean surface temperatures corresponding to ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

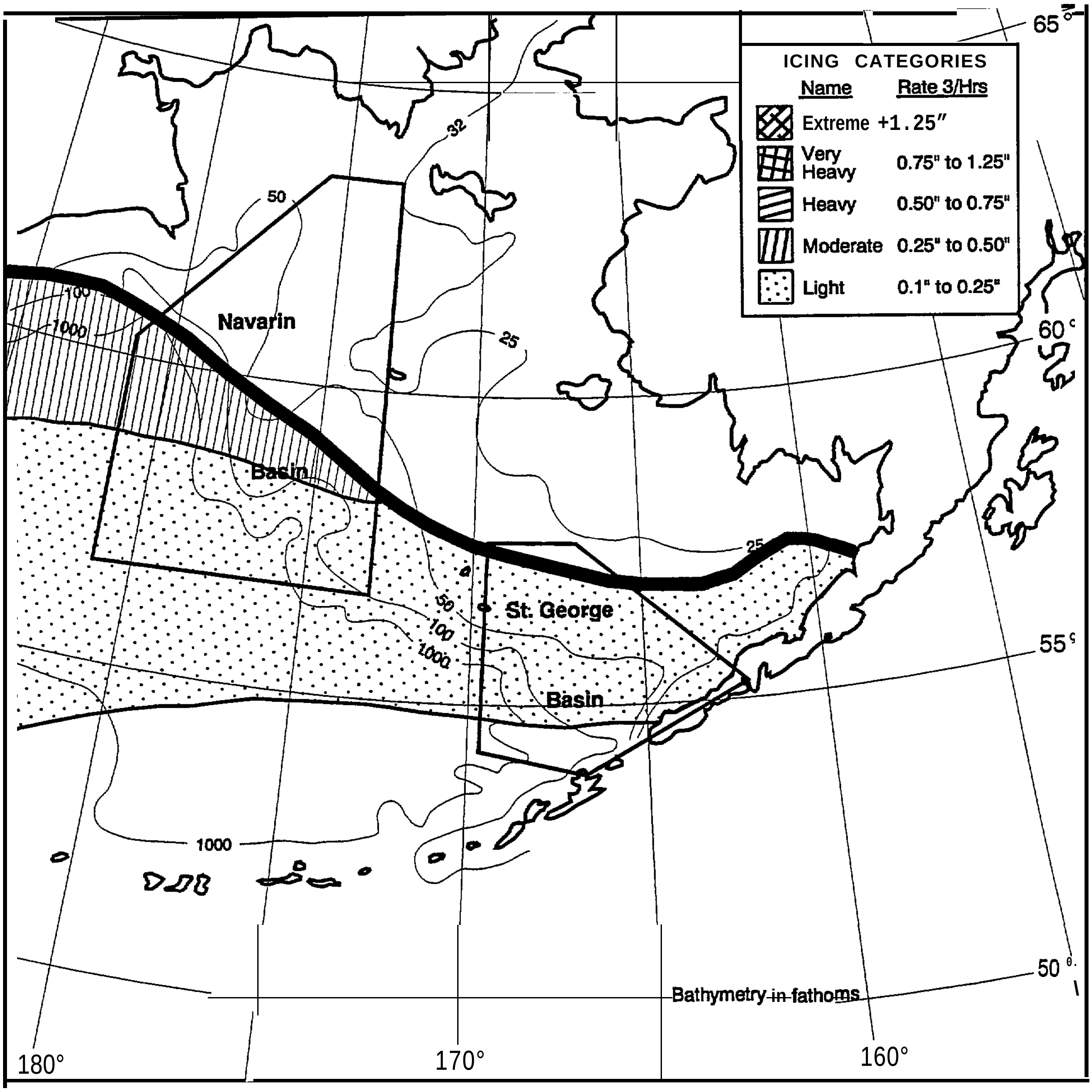

Figure 12.--March mean conditions: 50% probability of 50% ice coverage (heavy line), mean air temperature, and ocean surface temperature corresponding to ice coverage. A 28 knot (14 m/s) wind speed (gale level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

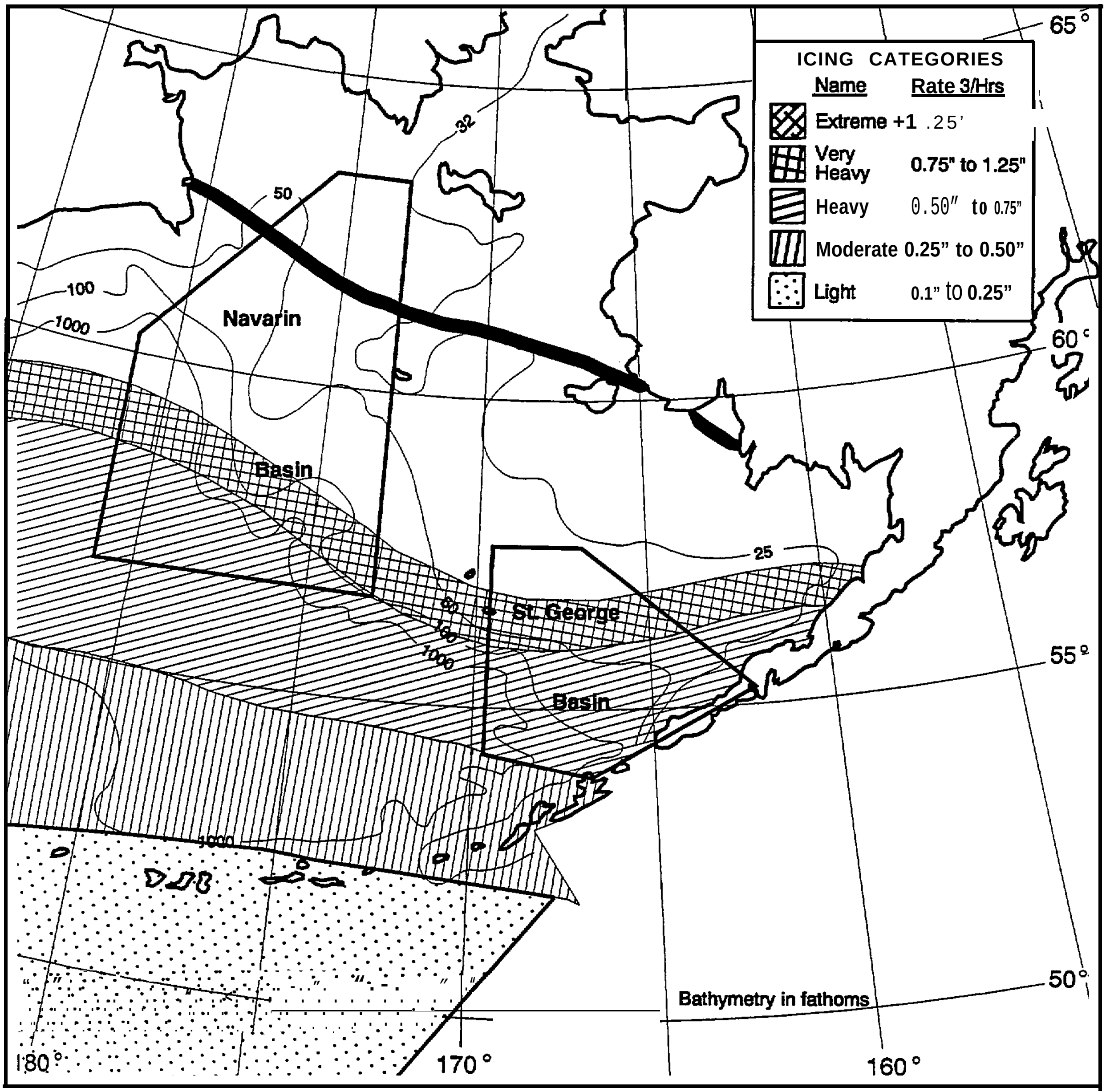

Figure 13. --March extreme conditions: produced by minimum extent of 50% ice coverage (heavy line), minimum recorded air temperatures, and ocean surface temperatures corresponding to ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

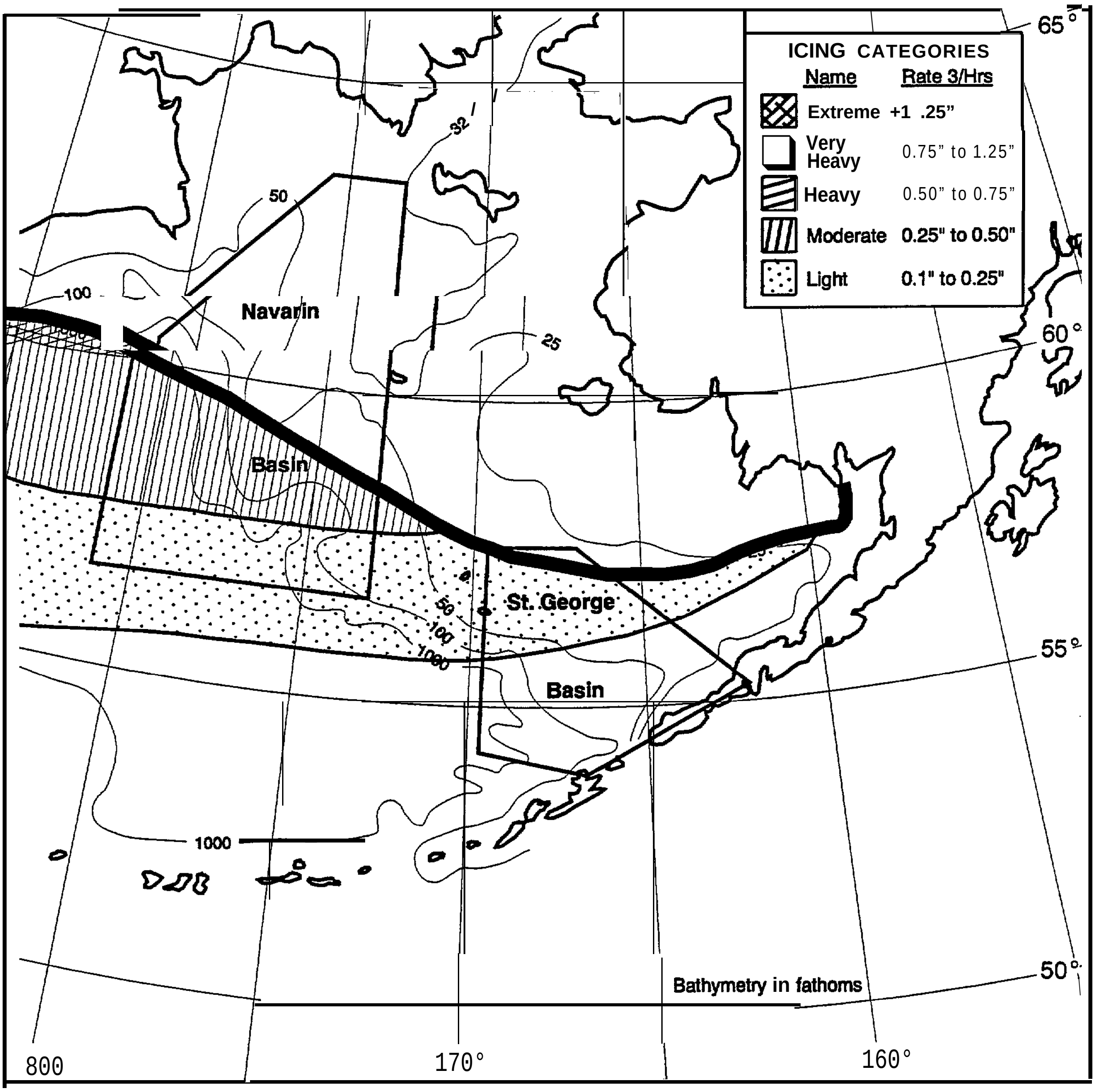

Figure 14. --April mean conditions: 50% probability of 50% ice coverage (heavy line), mean air temperature, and ocean surface temperature corresponding to ice coverage. A 28 knot (14 m/s) wind speed (gale level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

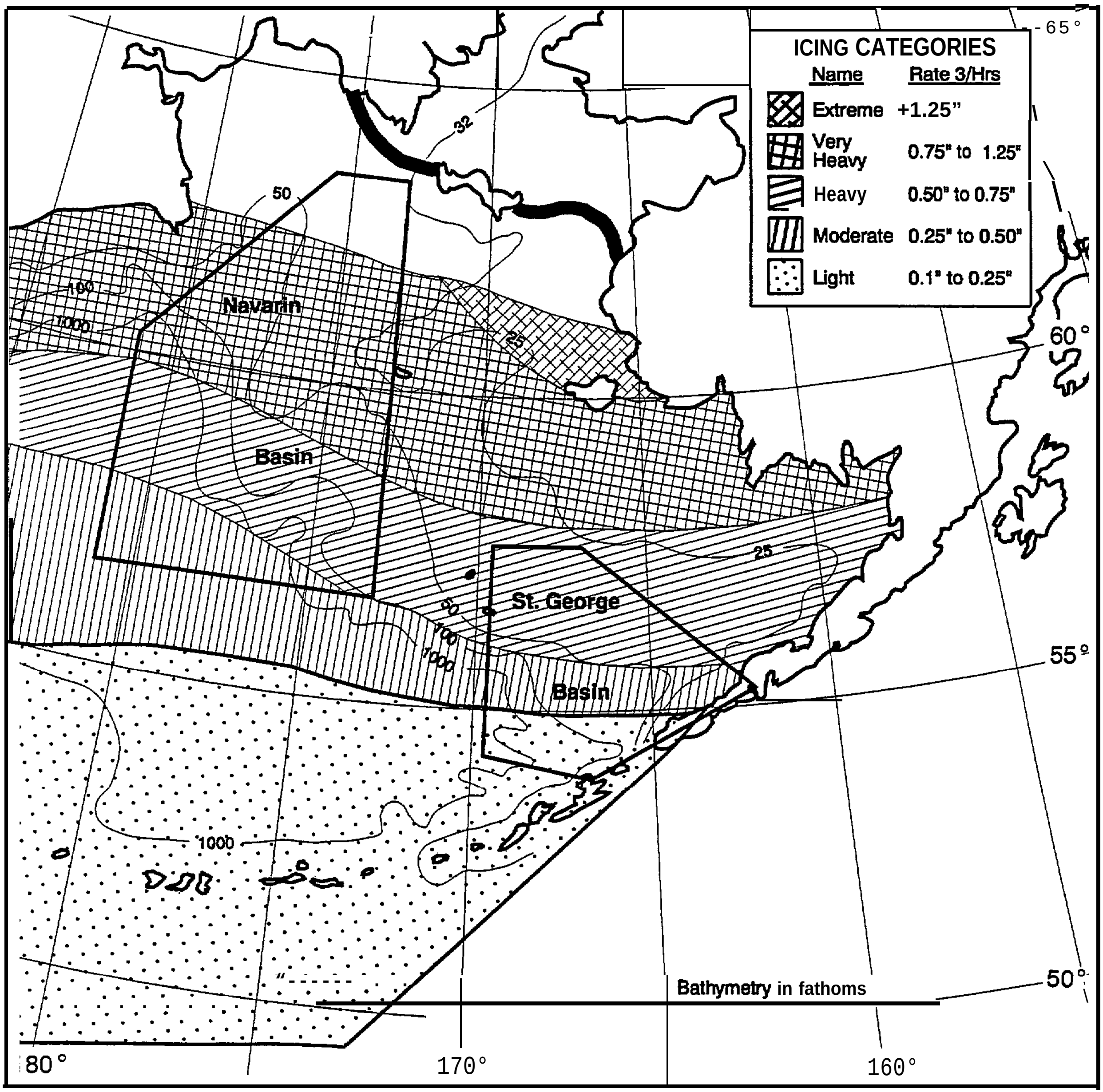

Figure 15.--April extreme conditions: produced by minimum extent of 50% ice coverage (heavy line), minimum recorded air temperatures, and ocean surface temperatures corresponding to ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, Kozo, 1984.)

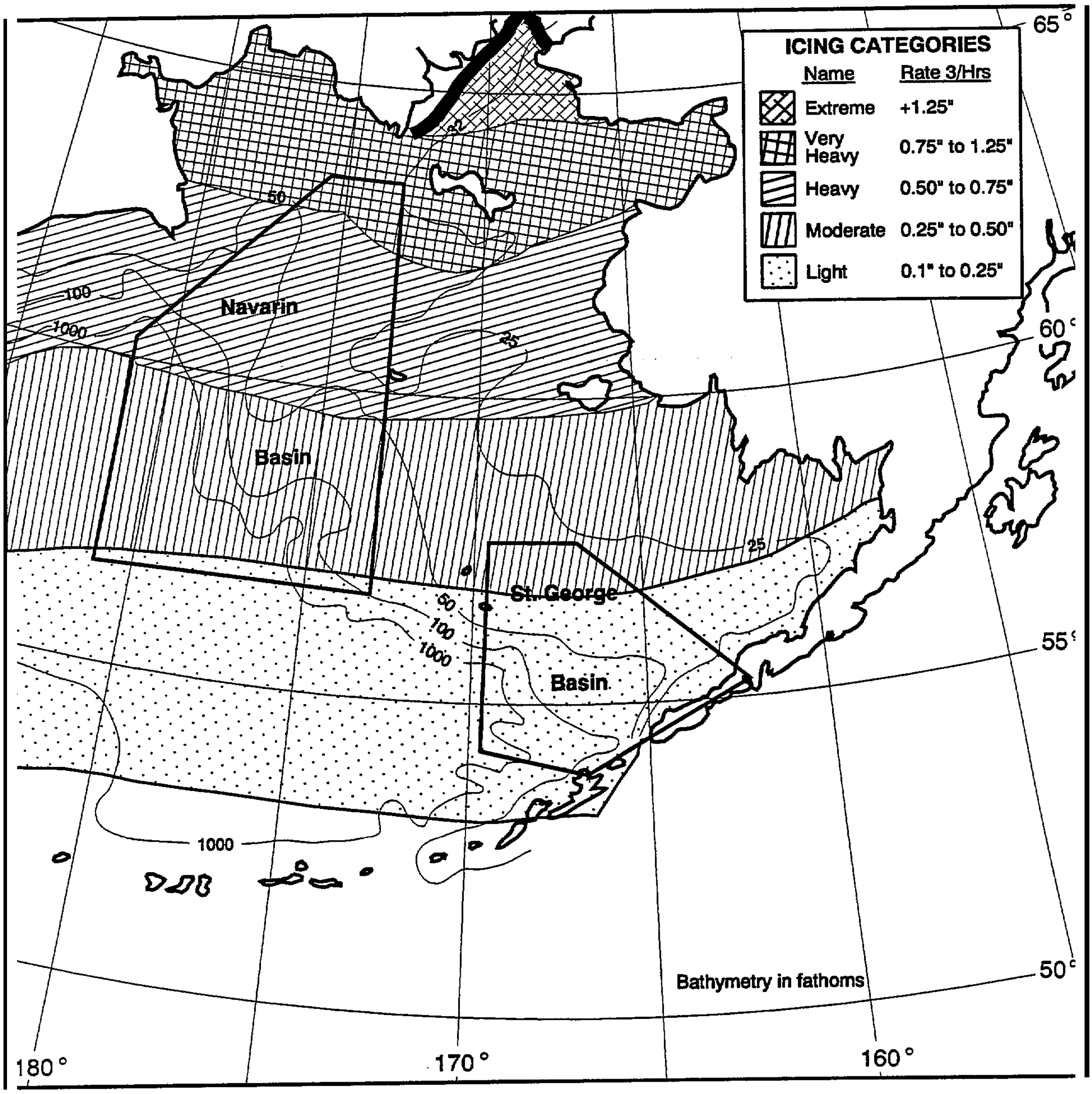

Figure 16. --May extreme conditions: produced by minimum extent of 50% ice coverage (heavy **line),** minimum recorded air temperatures, and ocean surface temperatures corresponding **to** ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, **Kozo, 1984.)**

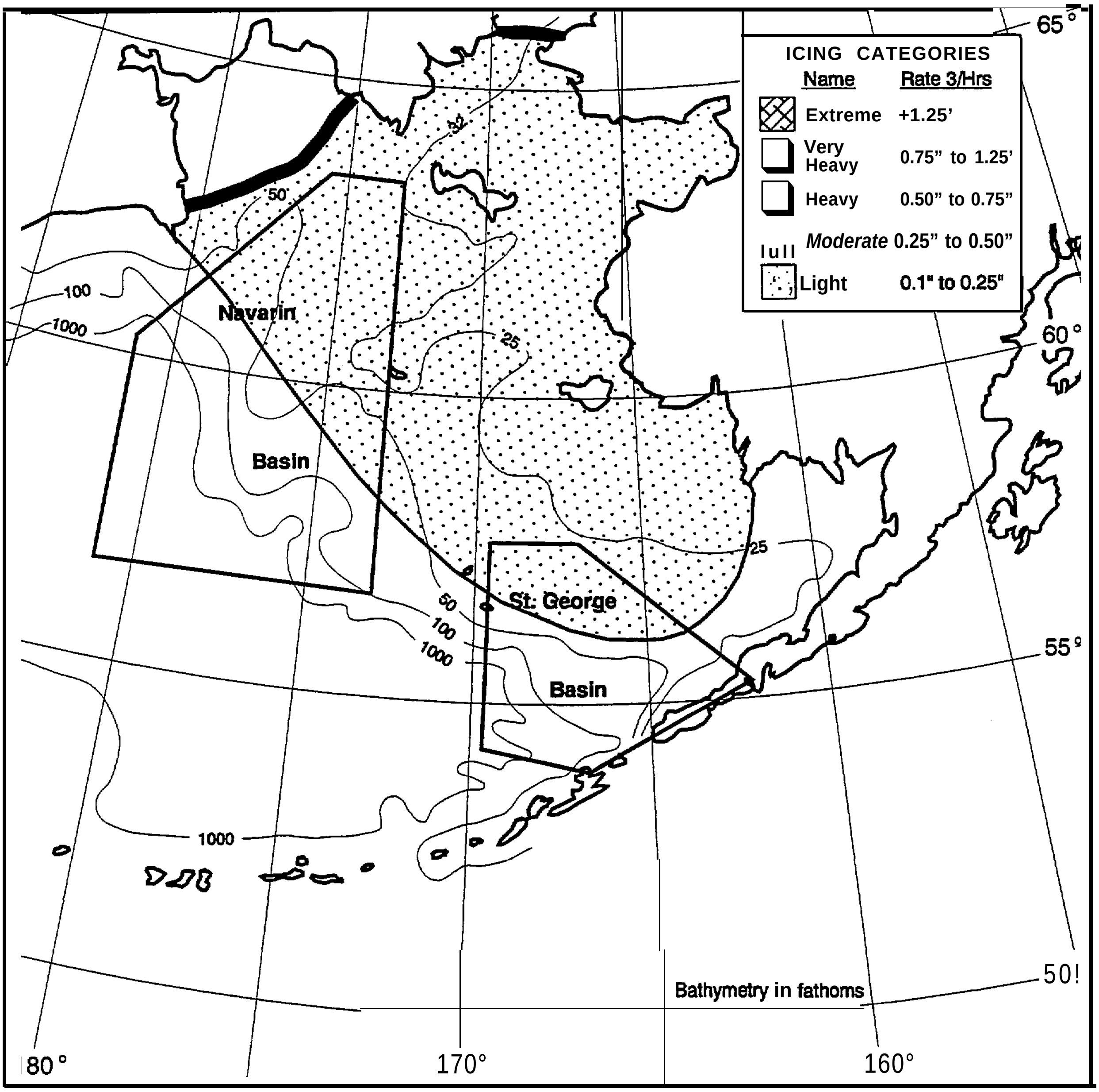

Figure 17.--June extreme conditions: produced by mean **extent** of 50% ice coverage (heavy line), minimum recorded air temperatures, and ocean surface temperatures corresponding to ice coverage. A 50 knot (25 m/s) wind speed (storm level) is imposed. (Adapted from VANTUNA Research Group, **Kozo,** 1984.)

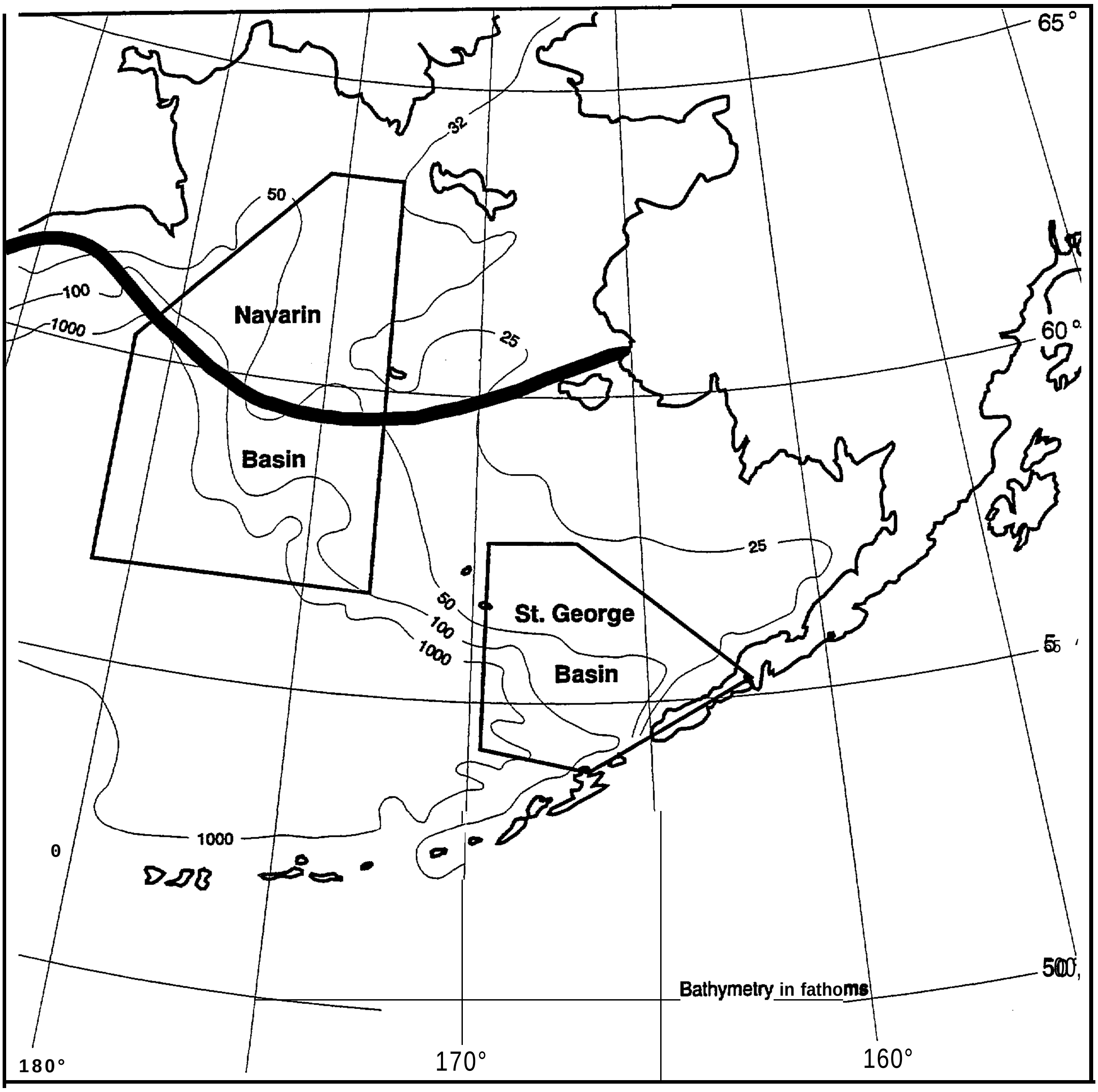

Figure 18. --50% probability of 50% ice coverage (heavy line) for May.

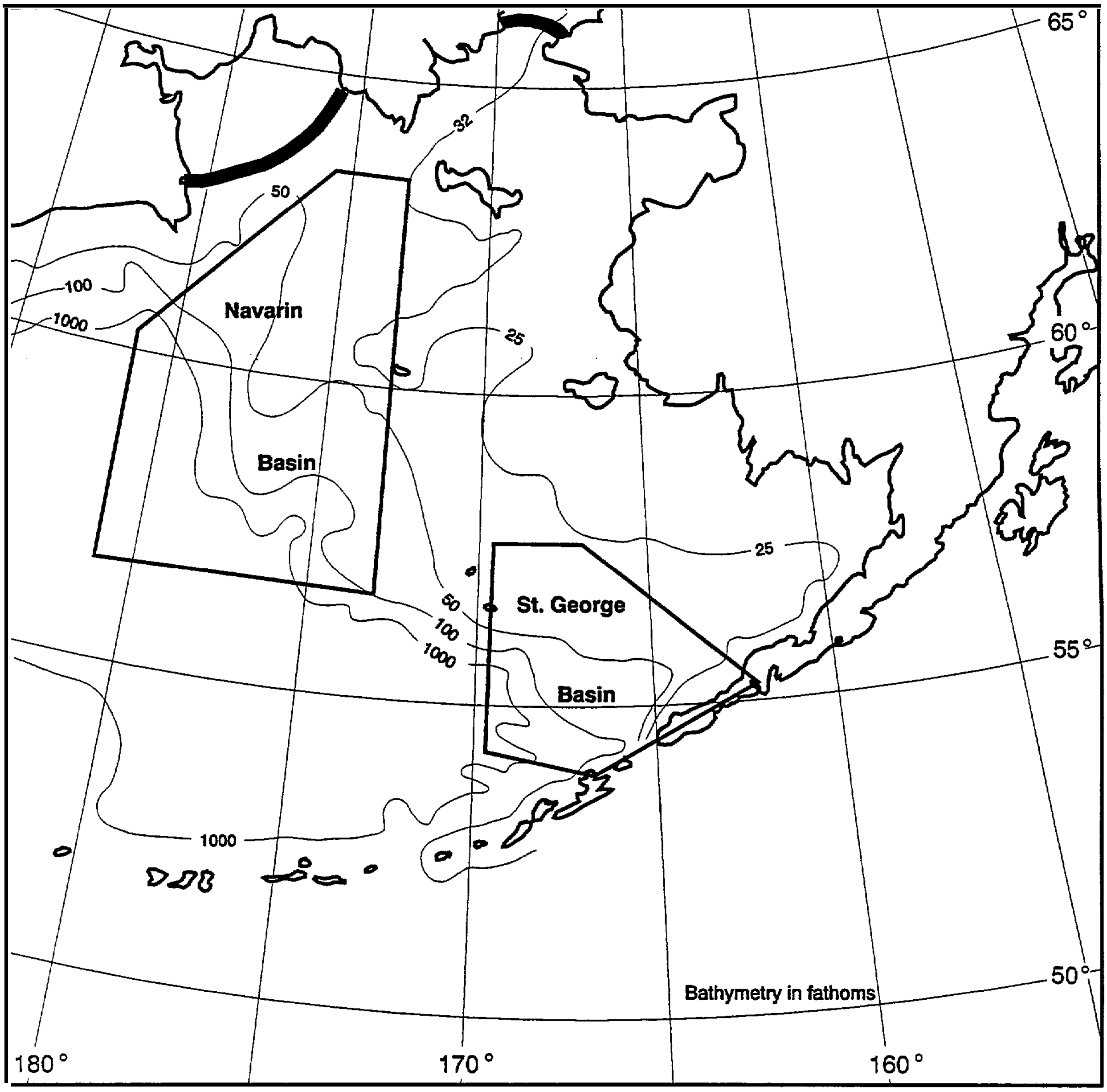

Figure 19.--50% probability of 50% ice coverage (heavy line) for June.

Table la. Navarin Basin Area.

Months	% Winds >28 kn (14 ms^{-1}) *W.M.O. Gale	% Winds >50 kn (25 in^{s-}l) *W.M.O. Storm	% air temperature <0° F (18° C)
September	7.0	<1	0.0
October	15.0	1	0.0
November	18.0	1	0.0
December	13.0	<1	0.0
January	17.0	1	0.0
February	20.0	1	2.5
March	7.3	<1	4.0
April	5.3	<1	0.0
May	3.5	<<1	0.0
June	2.0	0.0	0.0

Table lb. St. George Basin Area.

Months	% Winds >28 kn (14 in^{s-}l) *W.M.O. Gale	% Winds >50 kn (25 in^{s-}l) *W.M.O. Storm	% air temperature <0° F (18° C)
October	20.0	<1	0.0
November	23.5	1	0.0
December	16.5	<1	0.0
January	16.5	<1	1.0
February	18.5	1	1.5
March	12.0	<1	1.0
April	11.5	<<1	0.0
May	5.0	<<1	0.0
June	2.5	0.0	0.0

*W.M.O. ≡ World Meteorological Organization.

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	43	18	25	17	33	9	7	5	3	1	1			162	22..4
NE	51	34	45	35	38	23	17	10	7	2				262	36.3
E	29	23	24	15	15	0	7	5	3	0	1			122	16.9
SE	34	11	13	7	2	0	4	0	2					73	10.1
S	27	5	8	2	2	2	0	2	1					49	6.8
SW	9	2	2	-0	1									14	1.9
W	7	2	2	2	0	5								18.	2.5
NW	19	1	2											22	3.1
TOTAL	219	96	121	78	91	39	35	22	16	3	2			722	
'/0	30.3	13.3	16.8	10. B	12.6	5.4	4.9	3.1	2.2	.4	.3				

Table 2a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in January. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
N	13	13	35	42	42	15	2		162	22.4
NE	4	15	66	80	61	36			262	36.3
E	6	9	37	24	30	12	4		122	16.9
SE	11	13	21	20	2	6			73	10.1
S					8 10 14 10 4 3				49	6.8
SW	3	6	0	4	1				14	1.9
W	2	3	4	2	7				18	2.5
NW	2	11	7	2					22	3.1
TOTAL	49	80	184	184	147	72	6		722	
%	6.8	11.1	25.5	25.5	20.4	10.0	.8			

Table 2b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in January. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	38	19	20	69	19	19	8	6	5	1				204	35.7
NE	23	6	18	25	37	19	7	5	0	1				141	24.7
E	34	9	5	2	1	0	0	1	2	2	0	0	2	58	10.2
SE	22	12	6	4	3	0	5	5						57	10.0
S	15	7	4	4	1									31	5.4
SW	15	1	3											19	[illegible]
W	17	4	2											23	4.0
NW	23	7	4	3	1									38	6.7
TOTAL	187	65	62	107	62	38	20	17	7	4	0	0	2	571	
%	32.8	11.4	10.9	18.7	10.9	6.7	3.5	3.9	.4	.4	.4	0	.4		

Table 3a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in February. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
N	6	16	35	89	38	19	1		206	35.7
NE	4	9	16	43	56	12	1		144	24.7
E	5	16	22	5	3	1	4	2	58	10.2
SE	6	8	20	10	3	10			57	10.0
S	3	4	15	8	1				31	5.4
SW	5	4	6	4					19	3.3
W	5	4	12	2					23	4.0
NW	6	8	16	7	1				38	6.7
TOTAL	40	69	142	168	102	42	6	2	571	
%	7.0	12.1	24,9	29.4	17.9	7.4	1.1	.4		

Table 3b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in February. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	72	35	36	50	8	5	2	2	1					211	33.0
NE	30	14	19	35	8	4	1	2						113	17.7
E	25	7	6	4	6	0	1	1	2					52	8.1
SE	16	9	5	5	4	0	3							42	6.6
S	21	5	7	5	3	2	1							44	6.9
SW	28	11	9	0	2	1	0	0	0	1				52	8.1
W	22	9	3	1	0	2	1	0	1					39	6.1
NW	34	21	14	9	8	1								87	13.6
TOTAL	248	111	99	109	39	15	9	5	4	1				640	
%	38.8	17.3	15.5	17.	6.1	2.3	1.4	.8	.6	.2					

Table 4a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in March. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
R	11	19	77	86	13	5			211	33.0
NE	3	10	31	54	12	3			113	17.7
E	4	7	21	6	10	2	2		32	8.1
SE	3	,	18	10	4	3			42	6.6
S	6	3	17	12	5	1			44	6.9
SW	6	15 7	20	2	1		1		52	8.1
W	3	8	20	3	3	2			39	6.1
NW	4	12	39	23		9			87	13.6
TOTAL	40	78	230	214	58	17	3		640	
%	6.3	12.2	35.9	33.4	9.1	2.7	1.3			

Table 4b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in March. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1.	2.	3.	4.	5.	6.	7.	8.	9,	10.	II.	12.	13	T	0
N	3 7 ″	2 0	3 3 ″	5	2									97	20.9
NE	37	22	40	8	3	3	1							114	24.5
E	10	7	12	9	4									42	9.0
SE	32	10	3	2	3									50	10.8
S	27	3	2	1										33	7.1
SW	21	3	0	0	1									25	5.4
W	48	8	2											58	12.5
NW	35	4	6	1										46	9.9
TOTAL	247	77	98	26	13	3	1							465	
°/o	53.1	16.7	21.1	5.6	2.8	.7	.2								

Table 5a. The predicted frequency of significant wave heights (Hs) 'n meters for waves coming from 8 specified directions in April. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4.	6.	8.	10.	12.	14.	16	TOTAL	%
N	9	13	35	38	2				97	20.9
NE	3	11	45	48	7				114	24.5
E	0	6	11	12	13				42	9.0
SE	5	11	26	5	3				50	10.8
S	6	10	14	3					33	7.1
SW	3	7	11	3	1				25	5.4
W	5	22	29	2					58	12.5
NW	5	17	17	7					46	9.9
TOTAL	36	97	188	118	26				465	
%	7.7	20.9	40.4	25.4	5.6					

Table 5b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in April. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	61	18	14	16	1	1								111	22.8
NE	60	17	21	12	8	3								121	24.9
E	22	15	6	3	3	0	2							51	10.5
SE	27	4	0	1										32	6.6
S	36	6	7	1										50	10.3
SW	43	6	1	0	“	1								51	10.5
U	22	5												27	5.6
NW	35	7	1											43	8.9
TOTAL	306	78	50	33	12	5	2							486	
%	63.0	16.1	10.3	6.6	2.5	1.0	.4							I	

Table 6a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in Hay. These data were derived from 3 hourly wind velocity ❑easurements (Kozo, 1983).

Tp (S)	2	4	6	8	10	12	14	16	TOTAL	%
N	6	23	50	30	2				111	22.8
NE	4	19	54	33	11				121	24.9
E	6	6	25	6	6	2			51	10.5
SE	10	9	12	1					32	6.6
S	14	13	15	8					50	10.3
SW	8	21	14	7	0	1			51	10.5
W	3	10	14						27	5.6
NW	6	16	20	1					43	8.9
TOTAL	57	117	204	86	19	3			486	
%	11.7	24.1	42.	17.7	3.9	.6				

Table 6b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in May. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	45	16	13	5	1	1								81	18.2
NE	28	13	14	10	1									66	14.8
E	10													10	2.3
SE	34													34	7.6
S	36	1	1											38	8.5
SW	67	2												69	15.5
W	56	22	3	2	0	1	1							85	19.1
NW	42	12	5	2	1									62	13.9
TOTAL	318	66	36	19	3	2	1							445	
%	71.5	14.8	8.1	4.3	.7	.5	.2								

Table 7a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in June. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4	6	8	10	12	PI	16	TOTAL	%
N	12	18	31	18	2				81	18.2
NE	7	9	25	14	11				66	14.8
E	3	5	2						10	2.3
SE	13	17	4						34	7.6
S	9	20	8	1					38	8.5
SW	17	33	17	2					69	15.5
W	14	13	51	3	3	1			85	19.1
NW	13	17	24	7	1				62	13.9
TOTAL	88	132	162	45	17	1			445	
%	19.8	29.7	36.4	10.1	3.8	.2				

Table 7b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in June. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	34	12	10	4	8	2								70	9.6
NE	32	13	10	2	6	0	2							65	9.1
E	42	5	2											49	6.9
SE	83	5	2	4										94	13.2
S	112	5	1											118	16.6
SW	118	5	2											125	17.5
W	104	11	5	1	0	1								122	17.1
NW	52	10	7	1										70	9.8
TOTAL	577	66	39	12	14	3	2							713	
%	80.9	9.3	5.5	1.7	2.0	.4	.3								

Table 8a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in July. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
N	7	12	27	14	10				70	9.8
NE	8	10	27	10	8	2			65	9.1
E	4	14	29	2					49	6.9
SE	27	41	20	6					94	13.2
S	42	58	17	1					118	16.6
SW	41	56	21	7					125	17.5
W	14	49	52	5					122	17.1
NW	7	24	31	8	2				70	9.8
TOTAL	150	264	224	53	20	2			713	
%	21.0	37.	31.4	7.4	2.8	.3				

Table 8b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in July. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	121″	44″	1917″		5″	1								207	17.1
NE	109	28	25	10	4	0	1							177	14.6
E	72	27	24	12	1	0	2							138	11.4
SE	107	17	18	10	3	0	1							156	12.9
S	106	18	6	4	4									138	11.4
SW	104	18	13	0	2	1								138	11.4
W	100	26	20	1	0	1								148	12.2
NW	85	17	5	1	1									109	9.0
TOTAL	804	195	130	55	20	3	4							1211	
%	66.4	16.1	10.7	4.5	1.7	.3	.3								

Table 9a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in August. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
N	12	46	107	36	6				207	17.1
NE	12	57	68	25	14	1			177	14.6
E	10	25	64	24	13	2			138	11.4
SE	30	48	46	28	3	1			156	12.9
S	29	49	46	10	4				138	11.4
SW	22	44	38	31	2	1			138	11.4
W	18	38	70	20	2				148	12.2
NW	14	39	49	6	1				109	9.0
TOTAL	147	346	688	180	65	5			1211	
%	12.1	28.6	40.3	14.9	3.7	.4				

Table 9b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in August. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5.	6.	7.	8.	9.	10.	11.	12.	13	TOTAL	%
N	102	46	40'	11-	6"	2								207	21.8
NE	63	7-0	15	4	1	0	3							106	11.2
E	57	8	5	2	4	0	3	2						81	6.5
SE	47	10	5	3										65	6.8
S	51	15	9	3	2									80	8.4
SW	79	23	14	"	3	1								120	12.6
W	100	25	11	2	0	2								140	14.7
NW	98	31	16	7										152	16.0
TOTAL	597	178	115	32	16	5	6	2						951	
%	62.8	18.7	12.1	3.4	1.7	.5	.6	.2							

Table 10a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in September. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983),

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
N	12	40	96	51	8				207	21.8
NE	7	21	55	15	5	3			106	11.2
E	7	23	35	5	6	5			81	8.5
SE	12	19	26	8					65	6.8
S	12	21	33	12	2				80	8.4
SW	19	31	29	37	3	1			120	12.6
W	19	40	66	11	4				140	14.7
NW	13	48	68	23					152	16.0
TOTAL	101	243	408	162	28	9			951	
%	10.6	25.6	42.9	17.0	2.9	1.0				

Table 10b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in September. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	58	28	23	11	8	8	3	0	7					146	31.4
NE	34	14	10	4	3									65	14.0
E	26	7	10	8	3	0	0	4	3					61	13.1
SE	18	6	6	4	2	0								36	7.7
S	7	2	3	3	1	0	2							18	3.9
SW	8	6	8	(0	4	1	0	1						28	6.0
W	12	11	9	0	2	2	0	2	0	1				39	8.4
NW	37	20		8	2	1	2	1						72	15.5
TOTA.	200	94	77	32	24	13	6	8	10	1				465	
%	43.	20.2	16.6	6.9	5.2	2.8	1.3	1.7	2.2	.2					

Table ha. The predicted frequency of significant wave heights (Hs) in meters **for** waves coming from 8 specified directions in **October**. These data were derived from 3 hourly wind velocity measurements (**Kozo**, 1983).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
N	8	26	52	34	16	10			146	31.6
NE	6	13	29	10	7				65	14. 0
E	7	7	19	10	11	4	3		61	13.1
SE	4	4	16	10	2				36	7.7
S	2	3	4	6	1	2			18	3.9
SW	1	5	2	14	4	2			28	6.11
W	3	4	5	11	11	4	1		39	8.4
NW	3	14	40	10	3	2			72	15.5
TOTAL	34	76	167	105	55	24	4		465	
%	7.3	16.3	35.9	22.6	11. S	5.2	.9			

Table **11b**. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in October. These data were derived from 3 hourly wind velocity measurements (**Kozo**, 1983).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	%
N	83	41	59	33	10	4	1							231	32.4
NE	29	25	28	16	15	25	0	14	7	3	1			163	22.9
E	16	9	21	17	16	0	14	8	4	0	2	1	1	109	15.3
SE	9	7	9	6	4	0	3	1						39	5.5
S	17	9	9	2	1									38	5.3
SW	10	4	1											15	2.1
W	23	6	2											31	4.4
NW	69	8	8	1										86	12.1
TOTAL	256	109	137	75	46	29	18	23	11	3	3	1	1	712	
0/0	36.	15.3	19.2	10.5	6.5	4.1	2.5	3.2	1.5	.4	.4	.1	.1		

Table 12a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in November. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL	%
N	15	18	91	92	14	1			231	32.4
NE	1	6	47	44	40	21	4		163	22.9
E	1	4	20	21	33	22	7	1	109	15.3
SE	1	2	13	15	4	4			39	5.5
S	0	6	20	11	1				38	5.3
SW	1	7	2	5					15	2.1
W	1	9	19	2					31	4.4
NW	22	29	26	9	0				86	12.1
TOTAL	42	81	238	199	92	48	11	1	712	
%	5.9	11.4	33.4	28.	12.9	6.7	1.5	.1		

Table 12b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in November. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Hs (m)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	Il.	12.	13	TOTAL	%
N	64	44	23	23	4	6	2	1	0	1				168	23.1
NE	71	39	34	26	13	12	14	1	2					212	29.2
E	37	11	9	7	11	010	12	7	0	5	3			112	15.4
SE	9	9	3	8	0	4	5	2						50	6.9
S	14	11	7	11	11	u	3	0	1					58	8.0
SW	17	5	6	0	7	5	0	2						42	5.8
W	2	0	9	8	5	0	6	2						50	6.9
NW	29	4	1 .:	1										35	4.8
TOTAL	261	132	98	76	54	29	35	21	12	1	5	3		727	—
%	35.9	18.2	13.5	10.5	7.4	4.0	4.8	2.9	1.7	.1	.7	.4			

Table 13a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in December. These data were derived from 3 hourly wind velocity measurements (Kozo, 1983).

Tp(S)	2.	4.	6.	8.	10.	12.	14.	16.	TOTAL	0/0
N	14	14	80	46	10	3	1		168	23.1
NE	7	22	81	60	25	17			212	29.2
E	5	6	37	9	18	22	15		112	15.4
SE	1	3	14	13	8	11			50	6.9
S	2	4	19	18	11	4			58	8.0
SW	2	9	6	1	1	7	7		42	5.8
W	5	6	18	8	11	2			50	6.9
NW	9	10	14	2					35	6.8
TOTAL	45	74	269	167	90	66	16		727	
%	6.2	10.2	37.	23.	12.4	9.1	2.2			

Table 13b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in December. These data were derived from 3 hourly wind velocity measurements (Kozo,1983).

Hs (m)	1	2	3,	4,	5.	6,	7,	8.	9.	10,	Il.	12,13	TOTAL %
N	3	4	4	0	4	1	0	1	0	+	+		17
NE	3	5	0	3	4	0	2	0	1	0	+	+	18
E	2	4	0	4	4	2	0	1	0	+			17
SE	3	4	3	0	3	2	0	+	+	+			15
S	2	3	2	0	2	1	0	+	0	+	+		10
SW	1	0	2	2	2	0	1	0	+	0	0	+	8
W	2	0	1	1	0	1	0	0	1	0	0	+	6
NW	3	0	2	2	0	1	+	0	0	+	0	+	8
CALM	2												2
TOTAL %	20	20	14	12	19	8	3	2	2	+	+	+	

Table 14a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in January. These data **were** derived from wind velocity measurements (Brewer et *al.*, 1977).

Tp (S)	2.	4.	6.	8.	10.	12.	14.	16.	TOTAL %
N	+	3	4	4	5	1	+	+	17
NE	+	1	7	3	4	3	+	+	18
E	+	+	6	4	6	1	+		17
SE	+	3	4	3	5	+	+		15
S	+	2	3	2	3	+	+	+	10
SW	+	+	1	4	2	1	+		8
W	+	1	1	1	1	2	+		6
NW	+	1	2	4	1	+	+		8
CALM	2								2
TOTAL %	2	11	28	25	27	8	+	+	

Table 14b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in January. These data were derived from wind velocity measurements (Brewer *et* al., 1977).

ST. GEORGE BASIN

Hs (m)	1	2	3	4	5	6	7	8	9	10		12	13	14	15	16	TOTAL %
N	4	5	5	0	5	3	0	1	+	+							23
NE	3	5	0	5	5	0	3	0	1	0	+	+					22
E	3	3	0	3	2	2	0	1	0	+	+						14
SE	1	4	2	0	2	1	0	+	+								10
S	1	3	2	0	2	1	0	+	0	+	+						9
SW	1	0	2	2	1	0	1	0	+	0	0	+					7
W	2	0	1	1	0	1	0	0	1	0	0	+	0	0	+	+	6
NW	2	0	2	1	1	0	1	0	0	+	0	+					8
CALM																	
TOTAL%																	

Table 15a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in February. These data were derived from wind velocity measurements (Brower *et al.*, 1977).

Tp(S)	2	4	6	8	10	12	14	16	18	TOTAL%
N	+	4	5	5	8	1	+			23
NE	+	1	7	5	5	4	+	+		22
E	+	1	5	3	4	1	+	+		14
SE	+	1	4	2	3	+				10
S	+	1	3	2	3	+	+	+		9
SW	+	+	1	4	1	1	+			7
W	+	1	1	1	1	2	+	+	+	6
NW	+	1	2	3	1	1	+			8
CALM	1									1
TOTAL%	1	10	28	25	26	10	+	+	+	

Table 15b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in February. These data were derived from wind velocity measurements (Brower *et al.*, 1977).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL%
N	4	5	4	0	3	2	1	0	+	+							19
NE	3	5	0	3	3	0	2	0	1	0	+	+					17
E	3	4	0	4	3	2	0	1	0	+							17
SE	4	3	2	0	1	1	0	+	+	+							11
S	3	3	2	0	2	1	0	+	0	0	+						11
SW	2	0	2	2	1	0	+	0	+	0	0	+					7
W	2	0	2	1	0	1	0	0	+	0	0	+	0	0	+	+	6
NW	4	0	3	3	2	0	1	0	0	+							13
CALM	2																2
TOTAL%	28	20	15	13	15	7	4	1	1	+	+	+	0	0	+	+	

Table 16a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in March. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Tp(S)	2	4	6	8	10	12	14	16	18	TOTAL%
N	+	4	5	4	5	1	+			19
NE	+	1	7	3	3	3	+	+		17
E	+	1	6	4	5	1	+			17
SE,	+	4	3	2	2	+	+			11
	+	3	3	2	3	+	0	+		11
S:.	+	1	1	4	1	+	+			7
W	+	1	1	2	1	1	+	+	+	6
NW	+	1	3	6	2	1	+			13
CALM	2									2
TOTAL%	2 16	29		27	22		7			

Table 16b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in March. These data were derived from wind velocity measurements (Brewer et *al.*, 1977).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL%
N	4	6	4	0	3	2	0	1									20
NE	2	3	0	3	1	0	1	0	+	O	+						10
E	3	3	2	0	2	1	0	+	0	+							11
SE	3	3	2	0	1	1	0	+	0	+							10
S	3	3	3	0	2	1	0	+	0	+	+						12
SW	3	0	3	2	1	0	+	0	+								9
W	3	0	3	2	0	1	0	0	+	0	0	+	0	0	+		9
NW	4	0	5	4	3	0	1	0	0	+							17
CALM	2																2
TOTAL%	27	18	22	11	13	6	2	1	+			/ +	+	0	0	+	

Table 17a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in April. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Tp(S)	2	4	6	8	10	12	14	16	TOTAL %
N	+	4	6	4	5	1			20
NE	+	+	5	3	1	1	+		10
E	+	3	3	2	3	+	+		11
SE	+	3	3	2	2	+	+		10
S	+	3	3	3	3		+ +	+	12
SW	+	1	2	5	1	+			9
W	+	1	2	3	2	1	+	+	9
NW	+	1	3	9	3	1	+		17
CALM	2								2
TOTAL%	2 16	27	31		20	4	[illegible]		

Table 17b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in April. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Hs (m)	,	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL “/o
N	4	7	0	4	3	0	1	0	+					19
NE	2	0	4	3	2	0	+							11
E	4	5	0	2	1	+	0	+						12
SE	4	4	2	0	1	+	0	+						11
S	5	5	2	0	1	+	0	+						13
SW	3	0	3	2	1	0	+	0	+					9
W	3	0	3	1	0	+	0	0	+	0	0	+		7
NW	4	0	5	3	0	2	0	+	0	+				14
CALFI	1													1
TOTAL%	30	21	19	15	9	2	1	+	+	+	0	+		

Table 18a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in Hay. These data were derived from wind velocity measurements (Brewer *et al.*, **1977).**

Tp(S)	2	4	6	8	10	12	14	16	TOTAL 0/0
N	+	1	10	4	3	1			19
NE	+	+	6	3	2	+			11
E	+	1	8	2	1	+			12
SE	+	4	4	2	1	+			11
S	+	5	5	2	1	+			13
SW	+	1	2	5	1	+			9
W	+	1	2	3	1	+	+		7
NW	+	1	3	8	2	+	+		14
CALM	1								1
TOTAL%	1	14	40	29	12	1	+		

Table 18b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in May. These data were derived from wind velocity measurements (Brewer *et* al., 1977).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL %
N	6	0	6	3	0	1	0	+						16
NE	4	0	5	2	1	0	+							12
E	4	4	6	2	1	+								11
SE	5	4	1	0	+	+	0	+						10
S	7	5	1	0	+	+								13
SW	4	0	4	1	+									9
W	4	0	3	1	0	+	0	0	+	0	0	+		8
NW	6	0	3	1	0	+	0	+						10
CALM	1													1
TOTAL %	41	13	23	10	2	1	+	+	+	0	0	+		

Table 19a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in June. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Tp (S)	2	4	6	8	10	12	14	16	TOTAL %
N	+	2	4	9	1	+			16
NE	+	1	8	2	1	+			12
E	+	1	7	2	1				11
SE	+	5	4	1	+	+			10
S	+	7	5	1	+				13
SW	+	1	3	5	+				9
W	+	1	3	3	+	+	+		8
NW	+	2	4	3	1	+	+		10
CALM	1								1
TOTAL %	1	20	38	26	5	+	+		

Table 19b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in June. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL %
N	4	0	3	1	0	+								8
NE	4	0	3	1	+									8
E	5	4	0	1	+									10
SE	7	5	1	o	+									13
S	10	6	1	0	1	+								16
SW	7	0	6	2	+	o	+							15
W	5	0	5	2	0	+	0	0	+					12
NW	5	0	5	2	0	+								12
CALM	2													2
TOTAL%	51	15	24	9	1	+	+	o	+					

Table 20a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in July. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Tp (S)	2	4	6	8	10	12	14	16	TOTAL %
N	+	1	3	4	+				8
NE	+	1	6	1	+				8
E	+	1	8	1	+				10
SE	+	7	5	1	+				13
S	+	10	6	1	1				18
SW	+	2	5	8	+	+			15
W	+	1	4	5	2	+			12
NW	+	1	4	7	+				12
CALM	2								2
TOTAL%	2	24	41	28	3	+			

Table 20b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in July. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL %
N	4	0	4	2	0	1	0	+						11
NE	1	0	2	1	+	0	+							4
E	2	2	0	1	+	+	0	+						5
SE	4	4	1	0	1	+	0	+						10
S	8	7	2	0	1	+	0	+						18
SW	7	0	7	3	1	0	+	0	+					18
W	6	0	5	2	0	1	0	0	+					14
NW	6	0	6	2	0	1	0	+						15
CALM	1													1
TOTAL%	41	13	27	11	3	3	+	+	+					

Table 21a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in August. These data were derived from wind velocity measurements (Brewer *et al.*, **1977)**.

Tp(S)	2	4	6	8	10	12	14	16	TOTAL %
N	+	1	3	6	1	+			11
NE	+	+	3	1	+	+			4
E	●	+	4	1	+	+			5
SE	+	4	4	1	1	+			10
S	+	8	7	2	1	+			18
SW	+	2	5	10	1	+			18
W	+	2	4	5	2	1			14
NW	+	1	5	8	1	+			15
CALM	1								1
TOTAL%	1	18	35	34	7	1			

Table 21b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in **August.** These data were derived from wind velocity measurements (Brewer *et* al., 1977).

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL %
N	4	0	6	4	0	2	0	1	+	o	+			17
NE	3	0	4	2	1	0	+	+	0	+				10
E	3	3	0	2	1	+	0	+						9
SE	3	3	2	0	1	+	0	+	+					9
S	4	4	2	0	1	+	0	+	+					11
SW	3	0	3	2	1	0	+	0	+					9
W	5	0	3	2	0	1	0	0	+					11
NW	8	0	7	4	0	2	0	+	0	+				21
CALM	1													1
TOTAL%	35	10	27	16	5	5	+	1	+	+	+			

Table 22a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in September. These data were derived from wind velocity measurements (Brewer *et al.*, **1977).**

Tp(S)	2	4	6	8	10	12	14	16	18	TOTAL%
N	+	1	3	10	2	1	+	0	+	17
NE	+	1	6	2	1	+	+	+		10
E	+	1	5	2	1	+				9
SE	+	3	3	2	1	+				9
		4	4	2	1	+	+			11
S;.	:	1	2	5	1	+	+			9
W	+	2	3	3	2	1				11
NW	+	2	6	11	2	+	+			21
CALM	1									1
TOTAL%	1	15	32	37	11	2	+	+	+	

Table 22b. The predicted frequency of peak wave periods (Tp) in **seconds for waves coming from 8 specified directions in September.** These data were derived from wind velocity measurements (Brewer *et al.*, 1977) .

Hs (m)	1	2	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13	TOTAL '/0
N	4	0	5	4	0	4	0	1	+	+				18
NE	2	0	2	2	2	0	1	+	0	+	+			9
E	1	1	0	1	1	1	0	+	0	+				5
SE	1	1	2	0	1	1	0	+	+					6
S	2	3	3	0	2	1	0	+	+					11
SW	3	0	4	3	2	0	1	0	+	+	+			13
W	4	0	4	3	0	2	0	0	1̄	0	0	+	+	14
NW	7	0	7	5	0	3	0	1	0	+	+	+		23
CALM	2													2
TOTAL%	25	5	27	18	8	12	2	2	1	+	+	+	+	

Table 23a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in October. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Tp(S)	2.	4.	6.	8.	10.	12.	14.	16	18	TOTAL%
N	+	1	3	9	4	1	+	+		18
NE	+	1	3	2	2	1	+	+		9
E	0	+	2	1	2	+	0	+		5
SE	+	1	1	2	2	+				6
	+	2	3	3	3	‡	‡			11
s ; .	+	1	2	7	2	1	+	+		13
W	+	1	3		3	4	+	+		14
NW		+		2	5	12	3 1	+ ,	+	23
CALM	2									2
TOTAL%	2	9	22	40	21	7	+	+	+	

Table 23b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in October. These data were derived from wind velocity measurements (Brewer *et al.*, 1977) .

Hs (m)	1	2	3	4	5.	6.	7.	8.	9,	10,	11,	12,	13	14	15	. 16	TOTAL%
N	3	0	3	3	0	3	0	2	0	+	0	+	+				14
NE	2	0	3	2	2	0	1	+	0	+	+						10
E	1	3	0	3	2	1	0	+	0	+							10
SE	1	2	2	0	2	1	0	1	+	+							9
S	1	3	3	0	3	1	0	+	+	+							11
SW	2	0	3	4	3	0	1	0	+	+	+						13
W	3	0	3	2	0	1	0	0	+	0	0	+	+	+			9
NW	4	0	4	4	0	3	0	1	0	+	+	+					16
M																	1
TOTAL%	21	8	21	18	12	10	2	4	+	+	+	+	+	+			

Table 24a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in November. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Tp(S)	2.	4,	6.	8.	10.	12,	14.	16,	18	TOTAL%
N	+	1	2	6	3	2	+	+		14
NE	+	1	4	2	2	1	+	+		10
E	+	+	4	3	3	+	+			10
SE	+	1	2	2	3	1	+			9
S	+	1	3	3	4	+	+	+		11
SW	+	+	2	7	3	1	+	+		13
W	+	1	2	3	2	1	+	+	+	9
NW	+	1	3	8	3	1	+	+	+	16
CALM	1									1
TOTAL%	1	6	22	34	23	7	+	+	+	

Table 24b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in November. These data were derived from wind velocity measurements (Brewer *et* al., **1977).**

Hs (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL %
N	4	5	0	4	3	0	2	1	0	+				19
NE	3	4	0	4	4	0	2	0	1	0	+	+	+	18
E	1	3	0	2	3	2	0	1	0	+	+			12
SE	2	3	2	0	2	1	0	+	+	+				10
S	1	2	3	0	Z	1	0	+	+					9
SW	1	0	2	2	1	0	1	0	+	+				7
W	2	0	1	1	0	1	0	0	1	0	0	+	+	6
NW	4	0	4	2	0	2	0	1	0	+	0	+		13
CALPI	1													1
TOTAL %	23	17	12	15	15	7	5	3	2	+	+	+	+	

Table 25a. The predicted frequency of significant wave heights (Hs) in meters for waves coming from 8 specified directions in December. These data were derived from wind velocity measurements (Brewer *et al.*, 1977).

Tp(S)	2	4	6	8	10	12	14	16	18	TOTAL%
H	+	1	8	4	5	1	+			19
NE	+	1	6	4	4	3	+	+		18
E	+	+	4	2	5	1	+	+		12
SE	+	2	3	2	3	+	+			10
S	+	1	2	3	3	+	+			9
SW	+	+	1	4	1	1	+			7
W	+	1	1	1	1	2	+	+		6
NW	+	1	3	6	2	1	+			13
CALM	1									1
TOTAL%	1	7	28	26	24	9	+	+		

Table 25b. The predicted frequency of peak wave periods (Tp) in seconds for waves coming from 8 specified directions in December. These data were derived from wind velocity measurements (Brewer *et* al., 1977).