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A MARINE CLIMATOLOGY OF THE APPROACHES TO KITIMAT, BRITISH COLUMBIA

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PREFACE

In December 1976, a Committee was established by the Department of Transport to prepare a TERMPOL assessment of a proposed Marine Terminal System at Kitimat, B.C. Six working groups were established by the Committee with representatives from regional and headquarters offices of the Department of Fisheries and the Environment.

The Working Group on Navigation and Ship Safety considered a number of aspects regarding the safe approach and pilotage of the channels leading to the proposed site at Kitimat. Meteorological parameters useful for site planning, route selection, and assessment of potential environmental impacts were analyzed and incorporated into a preliminary report on the marine climatology. Portions of this report were submitted to the TERMPOL Committee. The complete report is published here as Project Report No. 34.

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1. Introduction

This report is a preliminary survey and interpretation of the climatological factors which are considered to be limiting in the operation of a supertanker marine facility at Kitimat, British Columbia. Weather phenomena to be considered are winds, surface waves, visibility, icing and precipitation.

The main factors that shape the climate of the coast of British Columbia include the presence of the Pacific Ocean; the complex topography of the Coast mountains with its rugged massif, innumerable islands, and fiords which cut nearly 100 miles inland; and the dominating influence of the prevailing westerlies, persistent large-scale pressure systems, and frequent smaller-scale travelling systems.

Several published studies of the climate of the northern coast of British Columbia, including the Queen Charlotte Islands, are available. Examples are: Kendrew and Kerr (1955), Walker (1961), and Williams (1968). These studies provide a general description of the regional climate of the coast. The object of this report is to provide a concise description of the weather elements which may be significant for year-round navigation through the several channels leading to Kitimat. Portions of the report may be useful for site planning, route selection, and assessment of potential environmental impacts.

2. Data Sources and Limitations

The primary source of data for this report was the hourly-data archives of the Atmospheric Environment Service. This material was further summarized and processed to prepare the subsequent analyses. Figure 1 is a map of weather observing sites which were used in the compilation of this report. Not all statistical tabulations were prepared for each site because of the varying program of meteorological observations in the area, inadequate lengths of record for statistical summarizing, and time-constraints in preparing the material which follows. The weather observing programs at Langara, McInnes Island, Bonilla Island and Ethelda Bay are not 24-hour operations. Consequently, occurrences of visibility, weather types and, in some instances, wind speed and direction, between observing hours were inferred. For these stations results are biased to daylight hours.

The complex interaction of atmosphere, ocean, and physiography is not easily understood in this part of Canada. It must be emphasized that, although they are representative of the sites at which they are taken, these observational data are influenced by peculiarities of local environments, and, hence, extrapolation to other coastal sites must be done with extreme caution. In fact, it soon will be evident to the reader that meaningful extrapolation in some instances is not possible and, if it is undertaken, will lead to erroneous projections of probable weather occurrences.

Another data file which was consulted was marine observations from ships in the vicinity of the Queen Charlotte Islands. Such ships tend to avoid both the coast and bad weather whenever possible, and, therefore, "seaward" and "good weather" biases are probably introduced. In addition, identifying the exact location of the ship is not possible, because of the procedures for reporting coordinates. This fact is especially critical among the numerous islands and inlets. It is often not possible to determine from the weather logs, for example, whether a ship is on the upwind or downwind side of an island. Nonetheless, it is felt that the available ship data give a helpful description of the type of weather to be expected in this area.

2.1 Description of Climatological Stations

Additional insight into the unique exposures of the climatological stations along the northern littoral of British Columbia is available from the inspection reports prepared by Atmospheric Environment Service personnel who visit these stations regularly. A general description of each site and its surroundings follows:

Bonilla Island 53°30'N 130°38'W 53' MSL

The instrument site is exposed on a landscaped area adjacent to the radio beacon/communications building and workshop. The site is on Bonilla Rocks which lay just off the northwest side of the Island. The anemometer is mounted on a ten-foot mast near the top of the light beacon, which is approximately 60 feet southeast of the instrument area on top of a knoll which is about 50 feet higher. Visibility is restricted from north through east to southeast by hills. Banks Island is 5 miles to the east with its northwest tip visible ten miles to the north-northeast. The Queen Charlotte Islands are 75 miles to the west across Hecate Strait.

Cape St. James 51°56'N 130°01'W 292' MSL

The observing site is located on a flat area on a summit of a 286-foot-high elongated hill at the southern end of the St. James Island. The shape of the island results in a certain amount of turbulence which effects precipitation catch and wind measurement during periods of strong winds. Visibility is restricted to 2½ miles to the northwest by the southern part of Kunghit Island, with nearby mountain peaks 800 to 1400 feet high. All other directions are open to the Pacific Ocean and Hecate Strait. Instruments are located in the best possible exposure on a limited area of flat open ground adjacent to the operations building.

During high winds, there is turbulence created by the winds hitting the island's steep cliffs and blowing up and over the station. Occasionally wind speeds are very localized. For example, a ship in Heater Harbour, 12 miles to the northeast, has reported winds of 20 miles per hour while the station is experiencing 40 miles per hour. A couple of hours later the situation had reversed.

Ethelda Bay 53°03'N 129°41'W 20' MSL

The instrument site is located in a shallow and narrow gully which runs northeast to the shoreline of Ethelda Bay, 100 feet away. The exposure is poor; however, it is the best available as there are no clear level areas nearby. The anemometer, located on a 50-foot mast on a 50-foot knoll, is 500 feet southwest of the instrument area, with the anemometer just above the tree-tops of the surrounding ridges. The island is thickly wooded, hilly, and extremely swampy in some areas. Visibility of more than 2 miles has to be estimated, due to nearby hills and islands.

Kitimat Townsite 54°03'N 128°38'W 420' MSL

The station is situated in a fair exposure on a grass boulevard in front of the firehall. The site is open but is surrounded on three sides by asphalt. The site is located at the end of Kitimat Arm. The surrounding country is mountainous and heavily wooded.

Langara 54°15'N 133°03'W 134' MSL

Langara has a well-exposed instrument site. Restrictions exist from the east through south quadrant by hills 100 to 200 feet above the station elevation. These hills begin to rise immediately behind the dwellings and rise at a moderate rate. The lighthouse beacon causes variable directions and speeds on wind sensors when the wind is blowing from the north quadrant. The exposure is unobstructed from southwest through northwest where the open Pacific Ocean lies.

McInnes Island 52°16'N 128°43'W 75' MSL

This island rises from the sea to 3 knolls with 80- to 100-foot elevations. The anemometer is 125 feet east of the helicopter pad and has fairly good exposure, except for slight sheltering by a few tall trees 100 feet to the north and 200 feet to the east-southeast with tops 10 to 20 feet higher than the anemometer.

3. Winds

The importance of winds in marine operations cannot be emphasized enough. Within a harbour, wind is an important factor in routing ship traffic, approaching berths, handling of cargo, and environmental clean-up. For design and planning purposes, including weather routing and offshore drilling, frequency statistics, especially the return periods of extreme events, are useful information. In addition, wind-generated waves may severely restrict marine transportation and cause damage to offshore installations that may result in serious environmental accidents. Freezing spray and heavy snow, which occur with strong winds, may also result in navigational problems through superstructure icing or radar interference.

3.1 Prevailing Wind

As a result of the strong topographic control in the region, surface winds over the water as measured aboard ship tend to be deflected near the British Columbia coast, resulting in a predominance of southeast winds year round (Table 1). At coastal stations, it is evident from the monthly wind roses in Figure 2 that there is a tendency for winds to come from the southeast in winter under the control of the Aleutian Low, while summer winds are directed more northwest around the persistent High area over the northern Pacific. Local topography of course imposes many modifications. This is well illustrated through comparison of the wind rose for Kitimat with those from stations along the outer coast.

The wind diagrams in Figure 2 also show the directions favoured by strong winds. Winds along the outer coast of British Columbia are perhaps the strongest in Canada. The average wind speed at Cape St. James is 23 mph. Gale force winds above 30 knots are encountered approximately ten percent of the time from October through February and less than 2 percent of the time from May through August.

3.2 Probability of Wind Speeds Above Specified Limits

Figure 3 shows, for three stations in or near Hecate Strait, the percentage of time when the wind is expected to exceed the indicated velocity for January, April, July, and October. Figure 4 shows these same statistics for all winds during the year. From these diagrams it is possible to obtain the expected length of time when various marine operations would not be desirable due to high winds. It is seen that McInnes Island and Langara are considerably windier than the more sheltered site at Ethelda Bay.

3.3 Wind Duration

Statistics on wind duration have practical application for many maritime groups to whom accurate scheduling is imperative. In this study, wind data were plotted in the form, - probability of occurrence of wind with durations greater than D (hours), for the various wind speed intervals (Figure 5). From this graph, the recurrence interval for various wind speeds and durations were then selected.

The following method was used to derive the statistics for Figure 5. Extreme wind data were ordered such that the largest duration of consecutive winds for speeds above various thresholds were chosen for each year of available records. Once the speed dropped below this limit for two consecutive hours the duration was terminated. The final analysis was based on approximately 20 years of record; extrapolating beyond this time frame: that is, to 50 and 100 years, is a rather questionable procedure. For Cape St. James, a wind speed in excess of 50 mph may occur for 20 consecutive hours once every two years, and for about 40 hours once in every 20 years.

3.4 Extreme Winds

An assessment of the occurrence of strong winds at a site is normally based on the statistical analysis of a relatively long and continuous time-series of wind observations. The choice of the best method of estimating extreme winds in a particular area is partially dependent on the nature of the available data. In the case of the northern littoral of British Columbia, the longest statistical time-series of wind observations taken at frequent intervals is from coastal stations.

A 10- to 20-year series of wind observations from stations in the vicinity of Douglas Channel was used. Wind speeds of one-minute average were obtained directly for Cape St. James and Prince Rupert A. For the other stations, the archived wind speed is a 60-minute average reported from recording anemometers. These latter winds were transformed into probable maximum speeds for one minute using an adjustment factor of 1.24 as suggested by Durst (1960).

In order to assess the frequency with which extreme events are expected to occur, statistical analysis is generally the vehicle used to describe probabilities or return periods. The Gumbel technique of extreme value theory has been widely accepted and has been used extensively in hydrologically- and meteorologically-related analyses. Shown in Figure 6 is an analysis of extreme wind speeds for six stations along the northern coast of British Columbia. From the fitted curve, return period statistics were obtained and are listed in Table 2.

Two things should be noted carefully: first, the reliability of the computed result falls off dramatically beyond twice the sample size: i.e., for a ten-year period of record, the value representing the twenty-year event is generally reliable. Extension beyond a fifty-year event for the sample size results in questionable projections. Although the calculations can be extended to 100-, 200-, 500-, and 1000-year events statistically, the computed values have little physical meaning. Secondly, the results are not applicable in areas where major topographical features may channel the wind. Locations near steep, high cliffs adjacent to the coast, and major valleys, are examples. Evaluation of wind regimes in areas such as these requires site-specific treatment.

3.5 Computed Gust Speed

Gust speed can be estimated from the mean hourly speeds by using an approximate "gust factor" (Durst 1960). For a five-second gust duration, a factor of 1.48 is widely used to convert hourly averaged wind speeds to a probable maximum gust. To the results shown in Figure 6, a factor of 1.19 may be applied to convert the one-minute winds to wind gusts of five second duration.

3.6 Winds in the Channels to Kitimat

Anyone familiar with the islands of Canada's Pacific coast is well aware of the strong katabatic or outflow winds that, on occasion, roar down the long, steep fiords to the sea. The right meteorological and topographical conditions for their occurrence include the presence of a high pressure system over the central and northern interior of British Columbia, and a strong pressure gradient to direct the Arctic air west and south along the narrow openings to the coast. These strong, often violent, winds are locally known as Squamishes.

Eastward from Ethelda Bay along the Douglas Channel to Kitimat, there are no climatological stations, only the occasional weather observation from commercial vessels, and these are of questionable quality. Ninety percent of the wind observations reported from ships in this region between 1970 and 1974 were observed with a hand-held anemometer aboard the M/V Queen of Prince Rupert. The scarcity of data at the seaward end of the Kitimat fiord makes difficult the detection of katabatic winds in this area. Nevertheless, there is a requirement to describe the wind regime along the numerous routes to Kitimat where supertankers may pass in the near future.

By comparing the few ship observations with those from land stations along the outer coast, it is barely possible to develop wind relationships between the channels and relatively open coastal areas. As a preliminary step, data from ships in the vicinity of Wright Sound and Principe Channel and five land stations: Kitimat, Bonilla Island, Cape St. James, McInnes Island, and Ethelda Bay, during the period 1970 to 1974, were used to calculate the ratio of wind observed aboard ship to that on land. The available data were stratified according to wind speed but without regard to the vessel, time of the year, wind direction, fetch, or air-water stability. Similar comparisons have been attempted for the Beaufort Sea by Berry (1975) et al and for the Great Lakes by Richards (1966) et al. Results from this study are shown in Table 3. Generally speaking, when light winds prevail in exposed locations such as Cape St. James, winds in sheltered inlets along the coast tend to blow stronger, perhaps in response to the funnelling which takes place and/or the presence of a brisk sea-breeze circulation. On the other hand, winds that are above 25 knots in the open sea reach only half that strength in sheltered bays and passages to Kitimat. Raynor (1968) concluded that winds offshore from Vancouver Island are frequently stronger than simultaneous winds recorded at exposed coastal stations on the Island. It is important, however, to note extreme variability in the sample. There were instances, for example, when ship winds were much stronger than those at Cape St. James. Moreover, there were occasions with a uniform synoptic situation over the entire region when no agreement between wind direction existed.

It is not only strong winds in the inlets which may cause navigational hazards. Ships travelling through the narrow channels may experience sudden changes in wind direction acting on the vessel. These changes, in conjunction with other constraints, such as tidal currents and other marine traffic, may become critical in accurately projecting the ship's route along the approaches. In outflow situations, north winds through Douglas Channel may become very strong. Under these same conditions, one would expect Granville Channel winds to be northwesterly and lighter. These northwesterlies would continue across Wright Sound to Black Fly Point, and there be deflected, resulting in a very complex pattern of head-, aft-, and cross-winds. A vessel running along the channel may suddenly encounter cross-winds as the ship reaches the area opposite passes or gaps in the surrounding mountains.

To illustrate the chaotic wind regime which may exist along the littoral, wind roses are presented in Figure 7. These diagrams are based on simultaneous wind observations reported aboard ships in the inlets and channels near Wright Sound, Grenville Channel, Whale Channel, and at Cape St. James. The period of record dates from 1902 to 1973. No adjustment factor for difference in anemometer height has been included and all winds have been grouped together regardless of the month. Winds as strong as 55 knots appear in the archives of ship observations for this part of the British Columbia coast. The average wind speed at Cape St. James for each of the wind roses is between 17 and 19 knots, which compares well with its average annual wind speed of 18.5 knots. Wind in the inlets average less than half of those at Cape St. James. This holds for each direction except northeast. These winds have speeds similar or stronger than those at Cape St. James. An exception to this is northeasterly winds at Wright Sound which are much lighter than northeasterlies blowing at the Cape. It is obvious from Figure 7 that calm conditions are absent at Cape St. James; however, in the sheltered passages leading to Kitimat, calms prevail for 12 to 25 percent of the time.

4. Significant Wave Height

It has been only in recent years that instrumental observations of waves have been attempted, and they have been too few to develop a wave climatology for the Kitimat area. However, visual wave observations from commercial vessels are included in the marine weather program on the oceans and have been summarized in SSMO Tables for the vicinity of the Queen Charlotte Islands (NOAA, 1970).

It must be remembered that the avoidance of certain types of weather situations by ships will introduce a fair-weather bias to the sample.

Although ship observations provide a useful source of information regarding wave conditions, their number, nature, and distribution both in space and time make any attempt to derive extreme values a risky venture.

Weather observers aboard ship are instructed to note the height and period of the significant wave. A significant wave is the highest one-third of all waves present. Higher waves may also exist. These are called extreme waves and their height may be estimated by multiplying the significant wave height by 1.8. Figure 8 shows the percentage frequency of occurrence of significant wave heights reported from ships in the vicinity of the Queen Charlotte Islands (53°N to 56°N and from the coast to approximately 135°W). The diagram is based on 2155 observations collected during the period 1960 to 1972. March and December are the months with the most frequent occurrence of waves above one foot, occurring in excess of 90 percent of the time. The greatest wave height reported was in excess of 20 feet in March and October.

From 1951 to 1970 Ocean Station "Papa" at 50.0°N, 145.0°W, three separate observations of significant wave heights between 41 feet and 48 feet were sighted each with a 13-second wave period. The total number of visual wave observations for that period was 36,401.

Oil drilling rigs, recently erected in the open sea, provide another source of wave sightings, albeit unofficial. One such rig, SEDCO 135F, anchored off the southern tip of the Queen Charlotte Islands, in mid-October 1968 was exposed to a prolonged period of high seas and hurricane-force winds. On October 22, sea and swell conditions combined with tidal currents to generate significant waves exceeding 65 feet in height, and at least one "monster" wave of close to 100 feet was observed. Within eight hours the waves grew from 10 feet to 60 feet in height and decreased even more abruptly shortly afterward.

An "extremes" climatology of waves is made possible by hindcasting. Wave hindcasting is a method of calculating heights and periods of significant deep-water waves from observed meteorological data (wind speed, direction, and duration) and oceanographic data (fetch and bathymetry). To hindcast a deep-water wave, it is necessary to select a fetch (generating distance), measure its length and estimate the wind speed and duration. The Sverdrup-Munk-Bretschneider (SMB) technique was selected for hindcasting deep-water wave parameters in this study.

Wind records for Cape St. James for 10 years, 1966 to 1975, were searched and classified for seven categories of wind speed with the longest duration for each year. From this selection, the annual storm with the greatest wave-raising potential was chosen. A Gumbel extreme value analysis was performed in order to obtain projections of probability and recurrence interval. The results are presented in Figure 9. While the information contained in Figure 9 should be helpful in quantifying an extremes climatology of wind-induced wave heights, there are certain limitations which must be recognized: the analysis was based on wind records rather than on wave data; it uses a statistical, theoretical and empirical approach; and it does not consider sea and swell effects which may combine to increase the height of the significant waves.

5. Visibility

Restricted visibility is a major hazard to ocean-going vessels, particularly near coasts and in areas of high traffic density. Although it is generally good along the northern coast, visibility in any month can be hampered by smoke, haze, fog, or precipitation. Smoke and haze from forest fires and industrial pollution can be transported hundreds of miles away by the wind and can persist for lengthy periods, causing poor visibility, usually during the summer when stagnant high pressure systems often occur.

Advection fog occurs frequently in late spring and summer, when the winds are from the south to southeast and the warm, humid air is cooled to its dew point by the cold ocean water. At all stations during summer there is an increase in the number of observations of restricted visibility. The greatest frequency of fog occurrence coincides with periods of lightest wind. Fog usually arrives with southerly winds (Figure 10). Occurrences of fog with gale-force winds are not uncommon; however, strong winds often have a tendency to lift fog and produce low stratus cloud, with resultant improvement in surface visibility.

Very shallow steam fog is sometimes experienced in the winter. This type of fog which occurs only in very cold weather when the air is much cooler than the water, is often reported as shallow fog below the ship's observational level. Another type of fog occurs when low clouds shroud coastal mountains. Peculiarities of fog reports in this area are indicated by comments from the Officer-in-Charge of Cape St. James, Kit Godin, who writes:

> "spring and summer fog forms over the sea and is quite often below station level, in spite of the fact, that the fog might be over 200 feet thick. Station level visibility in these cases is unrestricted. Fall and winter fog is mainly due to the fact that the station, because of its high elevation and surrounding sea, is obscured in the bottoms of low overcasts. Sea level visibility in these cases is often good, as it is only overcast at that level. Fog occurring during southwest to southeast winds is quite often denser on the northern leeward side of St. James Island than on the windward side. For example, visibility to the north may be zero but the visibility to the south may be two miles."

Because of the high elevation of Cape St. James and the sheltering effect at Ethelda Bay, the climatological stations at Langara and McInnes Island are probably most representative of visibility along the northern coast of British Columbia. Approximately six percent of all hourly observations report a visibility of less than two miles. There appears to be a definite maximum in summer (advection fog) and a secondary one in winter (steam fog). Tables 4, 5, and 6 display the percentage frequency of visibility for five stations in the vicinity of Kitimat. These tables cannot be compared readily because of the effect of local exposure. The longest duration of consecutive hours of visibility equal to or less than ½ mile for the period of record appears in Table 7 for McInnes Island, Langara, Cape St. James, and Ethelda Bay.

6. Precipitation

Information concerning precipitation, heavy snow, wet snow, and intense rain showers is useful for determining position-fixing and navigation siting by radar. Stations along the northern B.C. coast have a pronounced oceanic climate, with copious precipitation. Annual accumulations are among the highest in Canada. At Kitimat, yearly precipitation averages in excess of 110 inches, with snowfall exceeding 165 inches. Expected rainfall intensities for short durations are shown in Figure 11, based on 10 years of recording rain-gauge observations at Kitimat.

Restriction of visibility to less than 2 miles due to precipitation accounts for about 9 percent of all hourly observations, with less than 1 percent being due to frozen precipitation. Combination of freezing rain and/or heavy or blowing snow with wind speeds above 25 mph are extremely rare in the vicinity. Only 18 of 174,673 observations were reported at Cape St. James (Table 8).

7. Icing

The accumulation of ice on the superstructure of a vessel, even a large one, may seriously affect safety and operations on board. Such icing presents a greater hazard to smaller vessels.

All hourly cases of air temperature at or below 28°F and wind speeds at or exceeding 25 mph were abstracted from the climatological archives for Langara, Prince Rupert, and Cape St. James (Table 9). The total number of observations for Cape St. James (21 years of record) was 494 or 0.3 percent of the time.

8. Ideal Shipping Weather

Ideal weather conditions for most large-scale navigational operations would include ice-free waters, visibility greater than two miles, and wind speed less than 25 miles per hour (personal communication, Capt. D. Leitch, MOT Ship Safety). The joint probability of occurrence of these weather limits was calculated for representative locations near Kitimat and is plotted in Figure 12. It is quite obvious that McInnes Island more frequently has good shipping weather, 80 percent of the time for most months, than the other two stations. Strong winds and restricted visibility at Cape St. James and, to a lesser extent, at Langara, result in fewer occurrences of ideal shipping weather there. Duration of ideal weather and the average number of events expected per month are listed in Table 10 and 11, respectively.

9. Summary

From the climatological data presented, it is evident that the weather conditions deemed favourable for marine operations in the Kitimat region occur 75 to 85 percent of the time. On other occasions adverse weather may present difficulties and thereby increase the navigational risk. It is therefore essential to establish a data acquisition system to provide current information on weather conditions and to provide the basis for a satisfactory meteorological forecast service. It is also necessary to develop weather forecasting methods and services tailored for marine operations in this area.

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TABLE 1

Prevailing Wind Directions As Recorded From Ships
Near Queen Charlotte Islands (1960-1972)

J	F	M	A	M	J	J	A	S	O	N	D
SE	SE	SE	SE	NW	SW	W	SE	SE	SE	SE	SE

TABLE 2

WINDS (MPH) AND GUSTS (MPH) OCCURRING ONCE IN
ONE, TEN, AND FIFTY YEAR PERIODS

	One Hour Average			One Minute			5 Sec. Gust		
	1 yr	10 yr	50 yr*	1 yr	10 yr	50 yr*	1 yr	10 yr	50 yr*
Bonilla Is.	57	82	98	71	102	122	85	122	146
Cape St. James	52	89	106	65	110	132	78	132	158
Ethelda Bay	29	38	41	36	47	51	43	56	61
Kitimat 2	20	26	30	25	32	37	30	38	44
McInnes Is.	40	74	87	50	92	108	60	110	130
Prince Rupert	24	60	71	30	74	88	36	89	106
N.B.C. Coast	40	78	94	50	97	117	60	116	140

* extrapolated

TABLE 3

SHIP/LAND WIND SPEED RATIOS
VICINITY OF KITIMAT, B.C.

Wind Speed (KTS)	Cape St. James	Bonilla Is.	Ethelda Bay	McInnes Is.	Kitimat
0-9	1.40	0.71	1.72	1.23	1.47
10-25	0.56	0.64	1.37	0.95	1.41
> 25	0.40	0.58	1.52	0.94	2.24
All Observations	0.55	0.63	1.61	0.97	1.56

TABLE 4

PERCENTAGE FREQUENCY OF OBSERVATIONS WITH VISIBILITY
EQUAL TO OR LESS THAN 2 MILES

	J	F	M	A	M	J	J	A	S	O	N	D	YR	CASES/HOURS
Langara	5.3	4.0	3.3	2.2	4.0	5.7	11.6	10.1	7.8	2.5	2.5	4.5	5.3	2250/42476
Cape St. James	15.9	15.0	10.8	8.0	10.0	15.1	16.7	16.1	17.7	18.0	11.2	14.7	14.1	24673/174696
McInnes Island	8.1	5.1	3.3	2.4	3.7	4.8	7.0	10.1	10.1	6.6	4.4	5.7	6.0	2835/47643
Ethelda Bay*	11.4	8.3	6.5	4.0	5.1	6.4	7.3	9.1	11.3	9.9	6.0	9.9	7.9	2770/34844
Prince Rupert	8.7	5.2	4.6	1.8	2.1	5.8	9.1	9.8	8.6	4.0	3.6	6.5	5.9	7129/121788

* Observing Program Between 05-16 LST

TABLE 5

PERCENTAGE FREQUENCY OF OBSERVATIONS WITH VISIBILITY
EQUAL TO OR LESS THAN ½ MILE

	J	F	M	A	M	J	J	A	S	O	N	D	YR	CASES/HOURS
Langara	2.6	1.8	1.8	1.3	2.2	4.3	9.0	6.9	5.9	1.4	1.2	2.0	3.4	1432/42476
Cape St. James	7.3	6.9	5.0	3.9	6.2	10.7	12.9	12.4	13.1	11.3	5.2	6.1	8.4	14724/174696
McInnes Island	2.4	2.0	1.4	1.2	1.9	3.2	5.3	6.7	6.9	3.6	1.4	2.3	3.2	1526/47643
Ethelda Bay*	2.0	1.2	1.0	0.2	0.6	0.8	0.9	1.7	2.4	1.3	0.8	1.6	1.2	422/34844
Prince Rupert	1.7	1.2	1.2	0.5	0.5	2.5	4.7	5.4	5.2	1.2	0.8	1.6	2.2	2738/121788

* Observing Program Between 05-16 LST

TABLE 6

PERCENTAGE FREQUENCY OF OBSERVATIONS
WITH VISIBILITY ZERO

	J	F	M	A	M	J	J	A	S	O	N	D	YR	CASES/HOURS
Langara	0	0	0	0.4	0.3	0.3	1.1	1.9	1.1	0.1	0	0	0.4	184/42476
Cape St. James	1.7	1.4	0.5	0.6	1.2	3.2	4.0	3.6	4.5	3.8	0.9	1.1	2.2	3869/174672
McInnes Island	0.1	0.2	0.2	0.2	0.7	0.8	1.6	1.6	2.2	0.9	0.2	0.0	0.7	347/47643
Ethelda Bay*	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	8/34844
Prince Rupert	0.1	0	0.1	0	0.1	0.5	1.0	1.3	1.2	0.3	0.3	0	0.4	518/121788

* Observing Program Between 05-16 LST

TABLE 7

LONGEST DURATION (CONSECUTIVE HOURS) OF VISIBILITY EQUAL
TO OR LESS THAN ½ MILE FOR THE PERIOD OF RECORD

	J	F	M	A	M	J	J	A	S	O	N	D	Period Record
McInnes Island	15	24	21	15	24	42	33	57	57	36	30	18	1955-75
Langara	39	24	21	21	21	42	90	93	75	33	21	30	1954-75
Cape St. James	79	34	41	32	45	38	54	54	54	46	45	56	1953-75
Ethelda Bay	24	19	18	19	16	19	19	16	40	15	17	22	1957-75

TABLE 8

PERCENTAGE FREQUENCY OF OBSERVATIONS WITH WIND SPEED EQUAL TO OR ABOVE 25 MPH AND FREEZING RAIN OR BLOWING SNOW

	J	F	M	A	M	J	J	A	S	O	N	D	YR	CASES/HOURS
Langara	0.3	0.0	0.1									0.1	0.0	17/42476
Cape St. James	0.1	0.0	0.0									0.0	0.0	18/174673

TABLE 9

PERCENTAGE FREQUENCY OF OBSERVATIONS WITH WIND SPEED EQUAL TO OR ABOVE 25 MPH AND TEMPERATURE EQUAL TO OR BELOW 28°F

	J	F	M	A	M	J	J	A	S	O	N	D	YR	CASES/HOURS
Langara	4.2	0.7	0.1								0.1	1.6	0.6	239/42476
Cape St. James	2.1	0.3	0.0								0.0	0.8	0.3	494/174908
Prince Rupert	0.0												0.0	3/121789

TABLE 10

LONGEST DURATION (CONSECUTIVE HOURS) OF VISIBILITY GREATER THAN 2 MILES AND WIND SPEED LESS THAN 25 MPH

	J	F	M	A	M	J	J	A	S	O	N	D	Period Record
McInnes Island	345	585	363	792	576	870	552	300	357	282	441	270	1955-75
Langara	261	336	573	360	453	645	441	264	336	219	189	174	1954-75
Cape St. James	191	108	195	234	210	153	187	195	240	159	137	123	1953-75
Ethelda Bay	504	837	999*	999*	999*	999*	672	999*	585	921	794	454	1957-75

* in excess of 999 hours (indeterminate)

TABLE 11

AVERAGE NUMBER OF EPISODES PER MONTH WITH VISIBILITY GREATER THAN 2 MILES AND WIND SPEED LESS THAN 25 MPH (IDEAL SHIPPING WEATHER) OCCURRING FOR AT LEAST 12 CONSECUTIVE HOURS

	J	F	M	A	M	J	J	A	S	O	N	D	Period Record
McInnes Island	10	9	8	7	6	6	7	9	8	10	9	9	1955-75
Langara	9	10	11	10	8	9	8	10	10	11	10	11	1954-75
Cape St. James	9	8	9	10	10	10	10	11	10	9	9	8	1953-75

FIGURES

FIGURE 1 AES STATIONS ALONG THE NORTHERN BRITISH COLUMBIA COAST

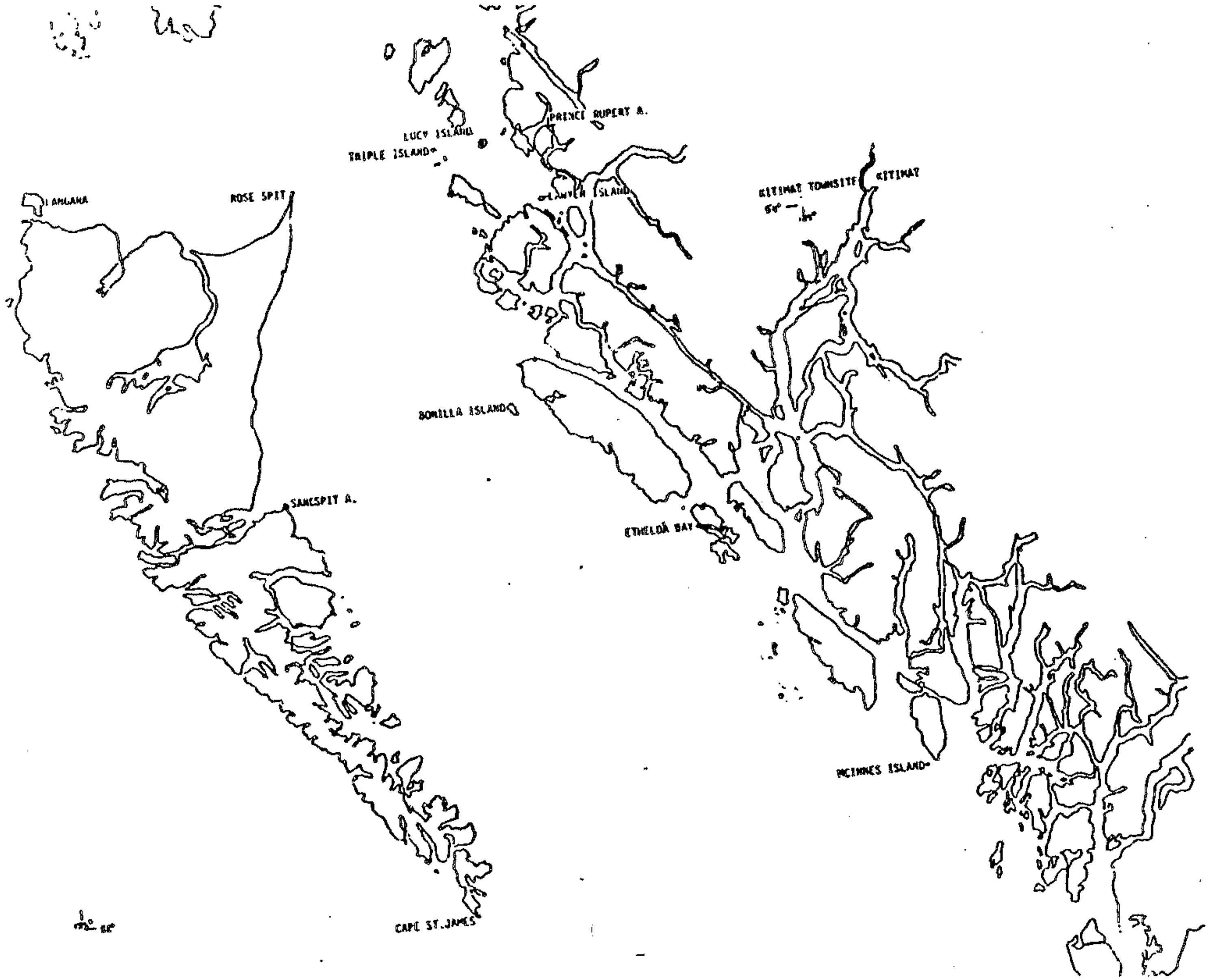


FIGURE 2a MONTHLY WIND ROSE FOR KITIMAT 2, B.C.

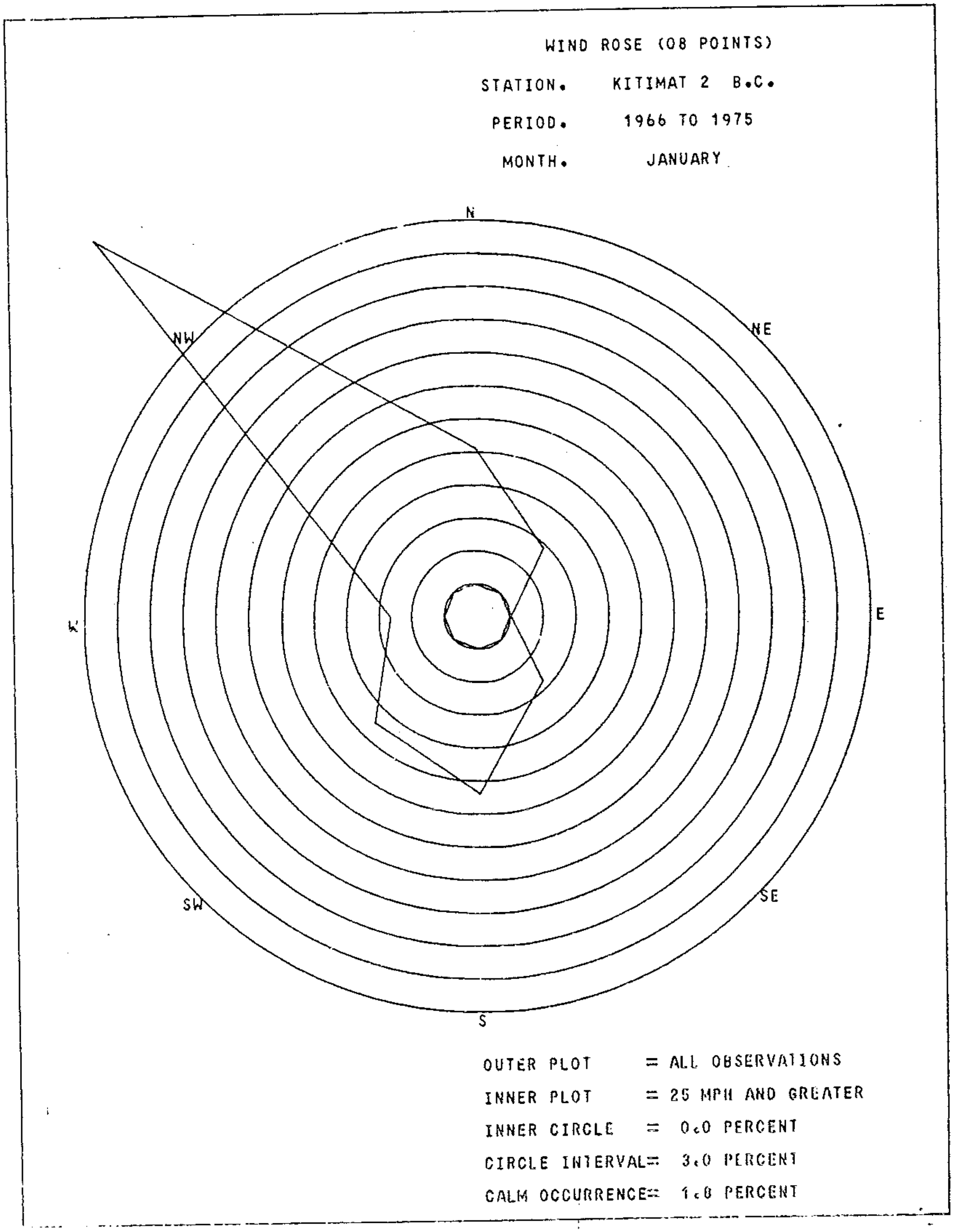


FIGURE 2a MONTHLY WIND ROSE FOR KITIMAT 2, B.C.

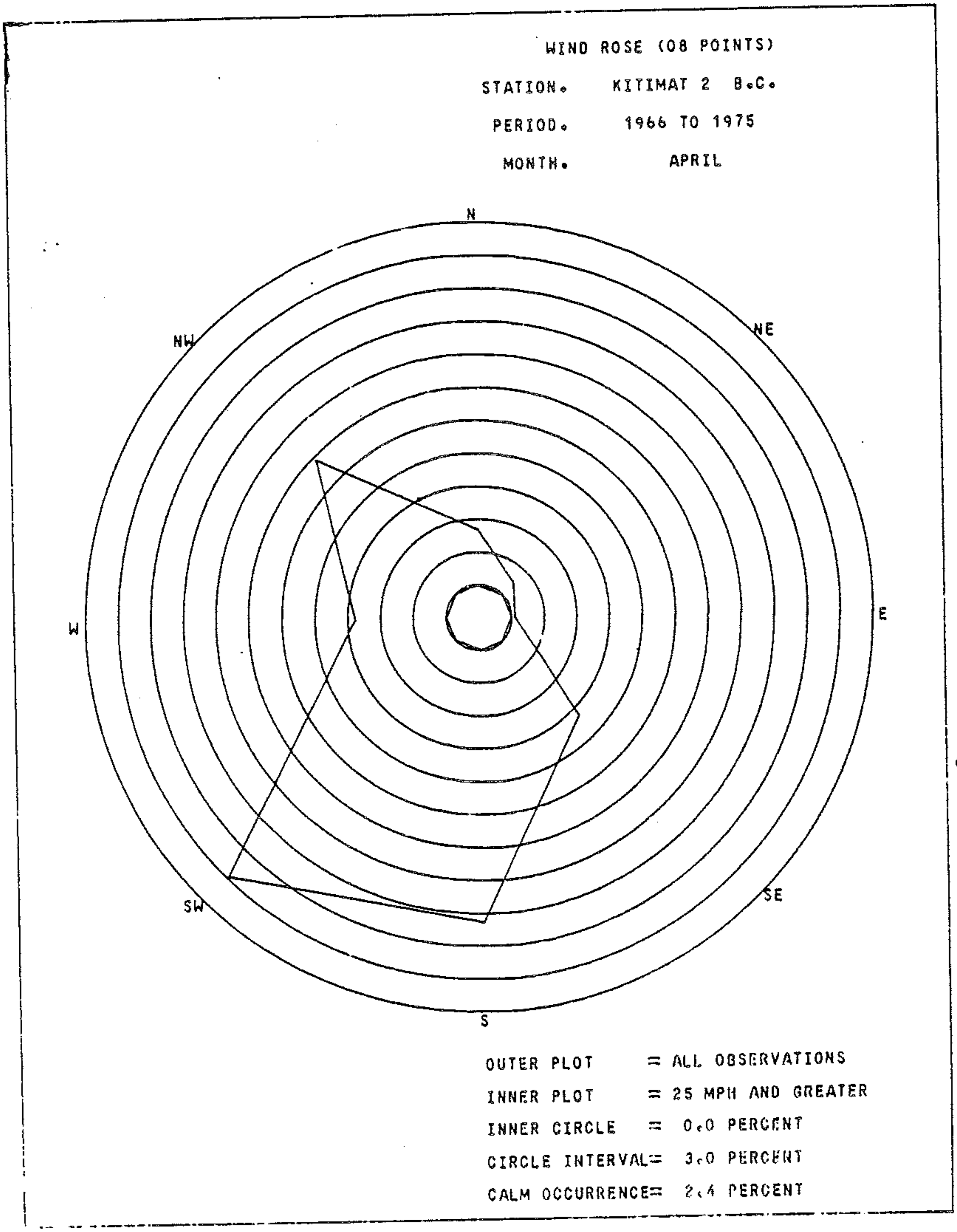


FIGURE 2a MONTHLY WIND ROSE FOR KITIMAT 2, B.C.

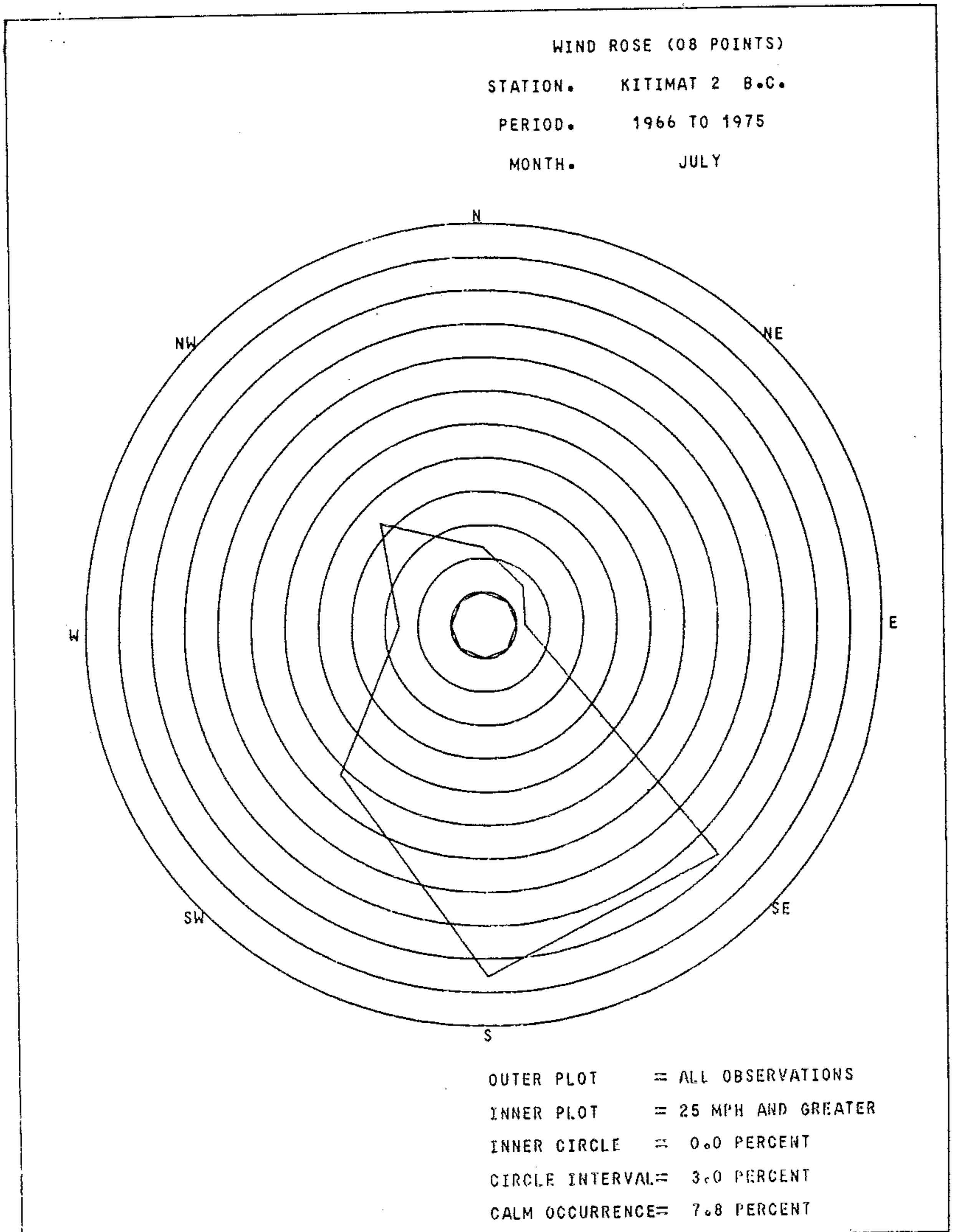


FIGURE 2a MONTHLY WIND ROSE FOR KITIMAT 2, B.C.

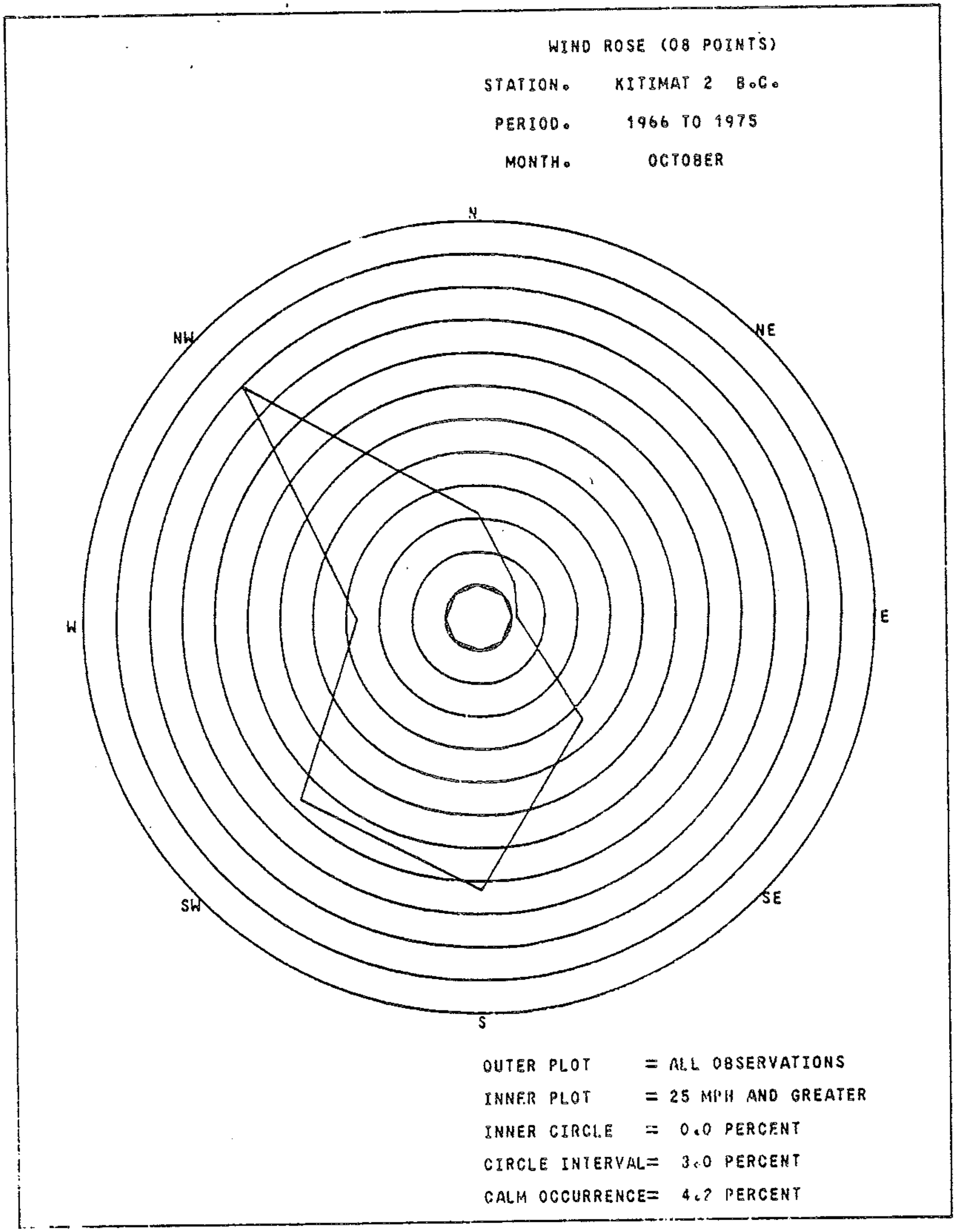


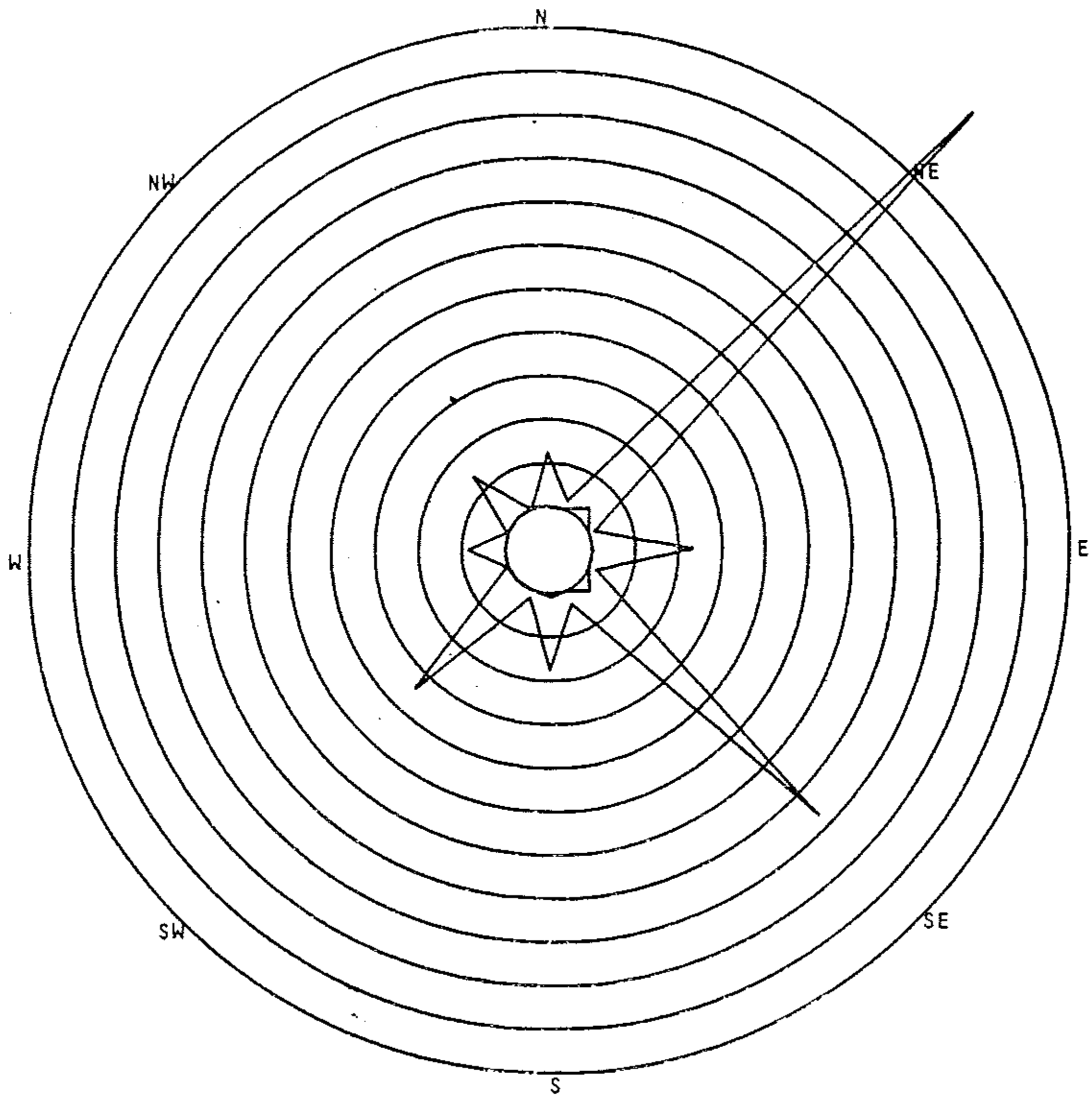
FIGURE 2b MONTHLY WIND ROSE FOR ETHELDA BAY, B.C.

WIND ROSE (16 POINTS)

STATION. ETHELDA BAY B.C.

PERIOD. 1957 TO 1975

MONTH. JANUARY



OUTER PLOT = ALL OBSERVATIONS

INNER PLOT = 25 MPH AND GREATER

INNER CIRCLE = 0.0 PERCENT

CIRCLE INTERVAL= 3.0 PERCENT

CALM OCCURRENCE= 1.6 PERCENT

FIGURE 2b MONTHLY WIND ROSE FOR ETHELDA BAY, B.C.

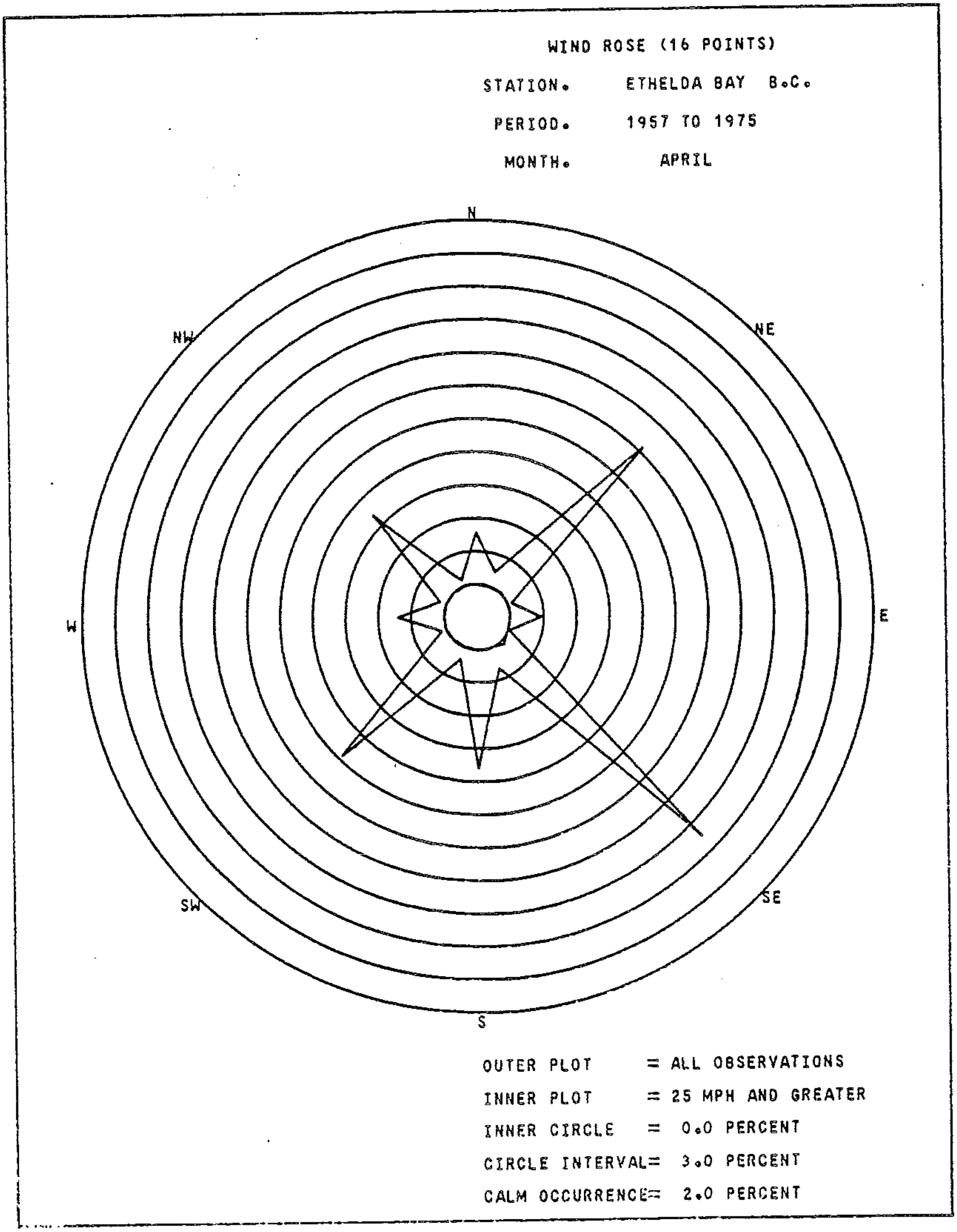


FIGURE 2b MONTHLY WIND ROSE FOR ETHELDA BAY, B.C.

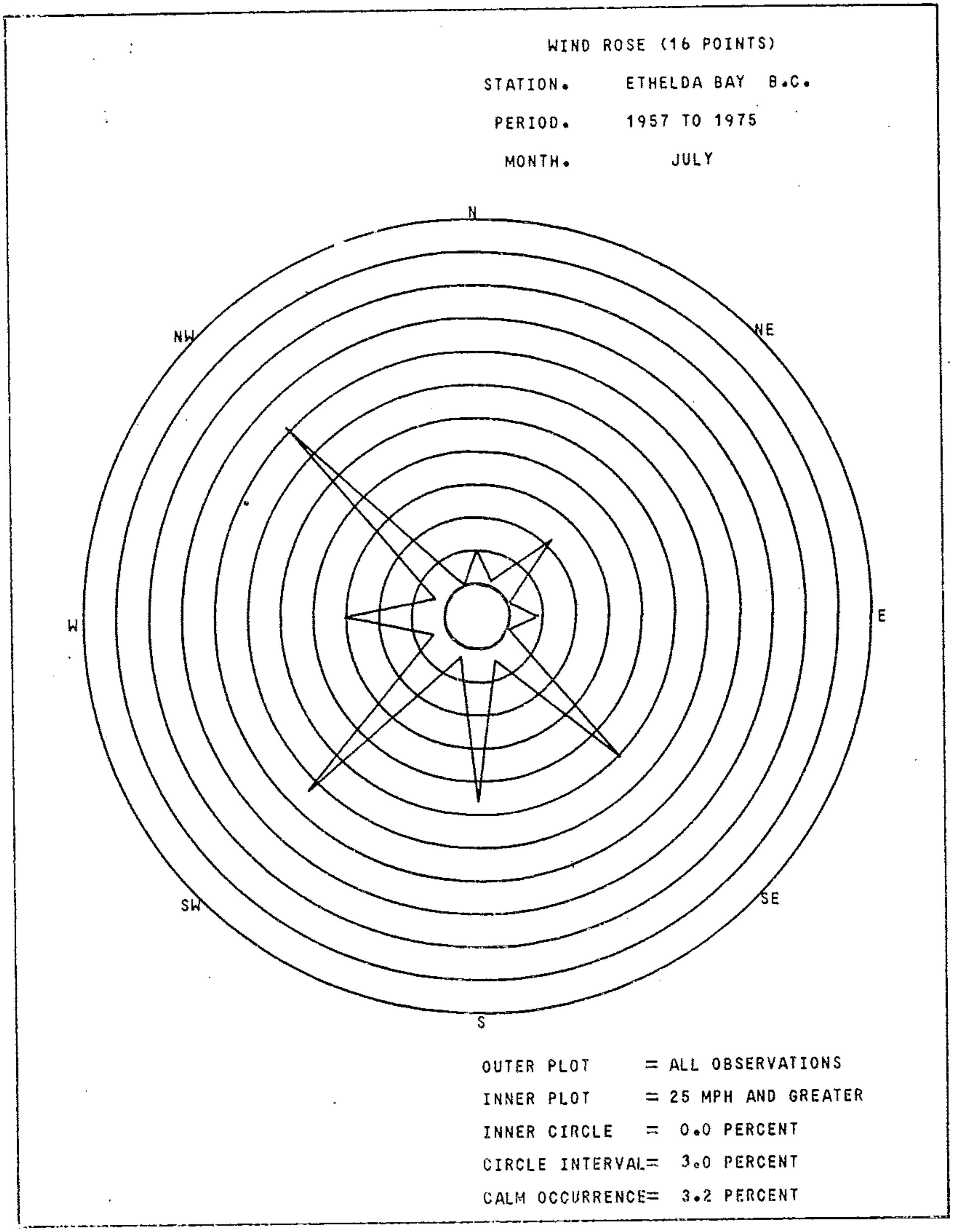


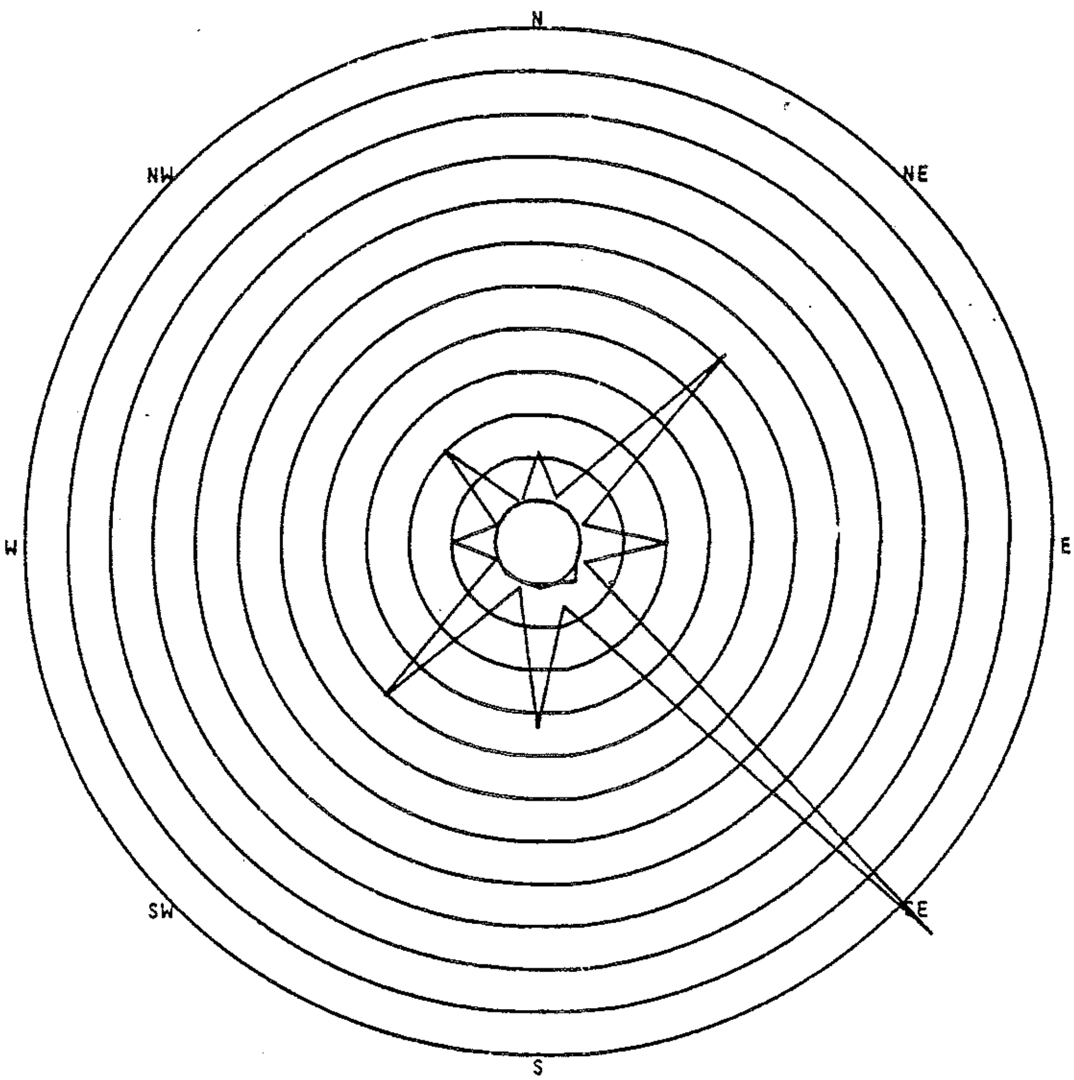
FIGURE 2b MONTHLY WIND ROSE FOR ETHELDA BAY, B.C.

WIND ROSE (16 POINTS)

STATION. ETHELDA BAY B.C.

PERIOD. 1957 TO 1975

MONTH. OCTOBER



OUTER PLOT = ALL OBSERVATIONS

INNER PLOT = 25 MPH AND GREATER

INNER CIRCLE = 0.0 PERCENT

CIRCLE INTERVAL= 3.0 PERCENT

CALM OCCURRENCE= 4.4 PERCENT

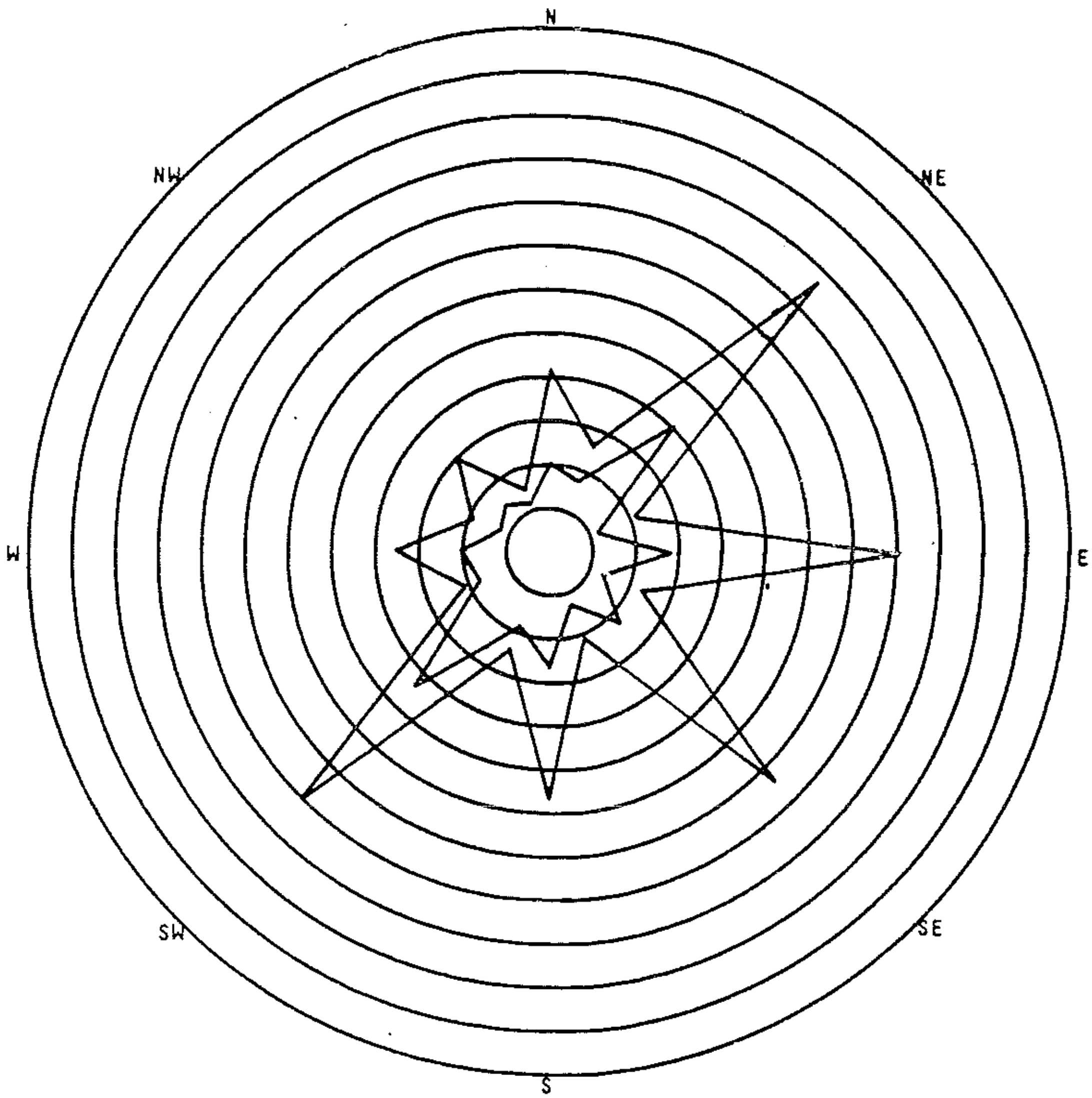
FIGURE 2c MONTHLY WIND ROSE FOR LANGARA, B.C.

WIND ROSE (16 POINTS)

STATION. LANGARA B.C.

PERIOD. 1954 TO 1975

MONTH. JANUARY



OUTER PLOT = ALL OBSERVATIONS

INNER PLOT = 25 MPH AND GREATER

INNER CIRCLE = 0.0 PERCENT

CIRCLE INTERVAL= 2.0 PERCENT

CALM OCCURRENCE= 0.7 PERCENT

FIGURE 2c MONTHLY WIND ROSE FOR LANGARA, B.C.

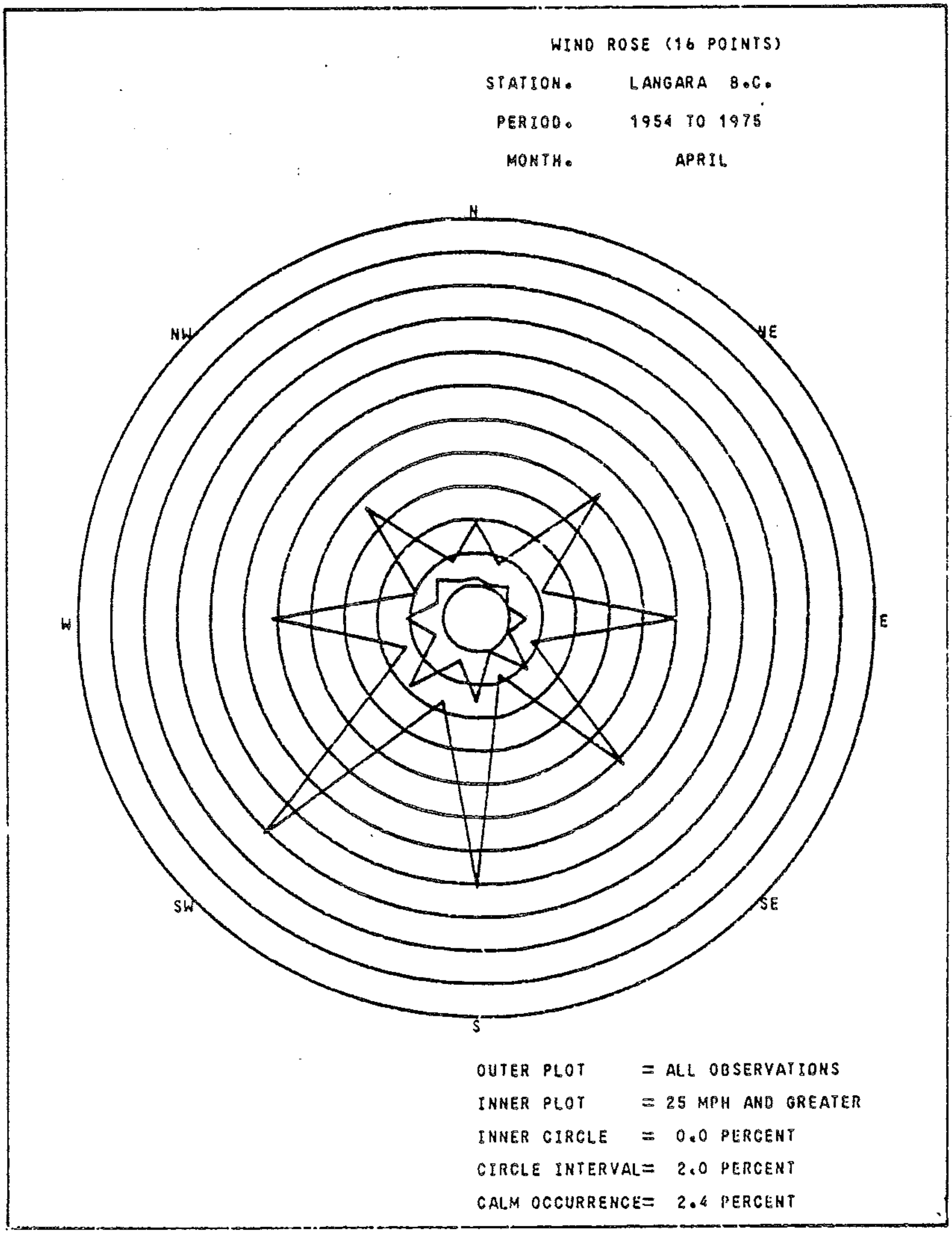


FIGURE 2c MONTHLY WIND ROSE FOR LANGARA, B.C.

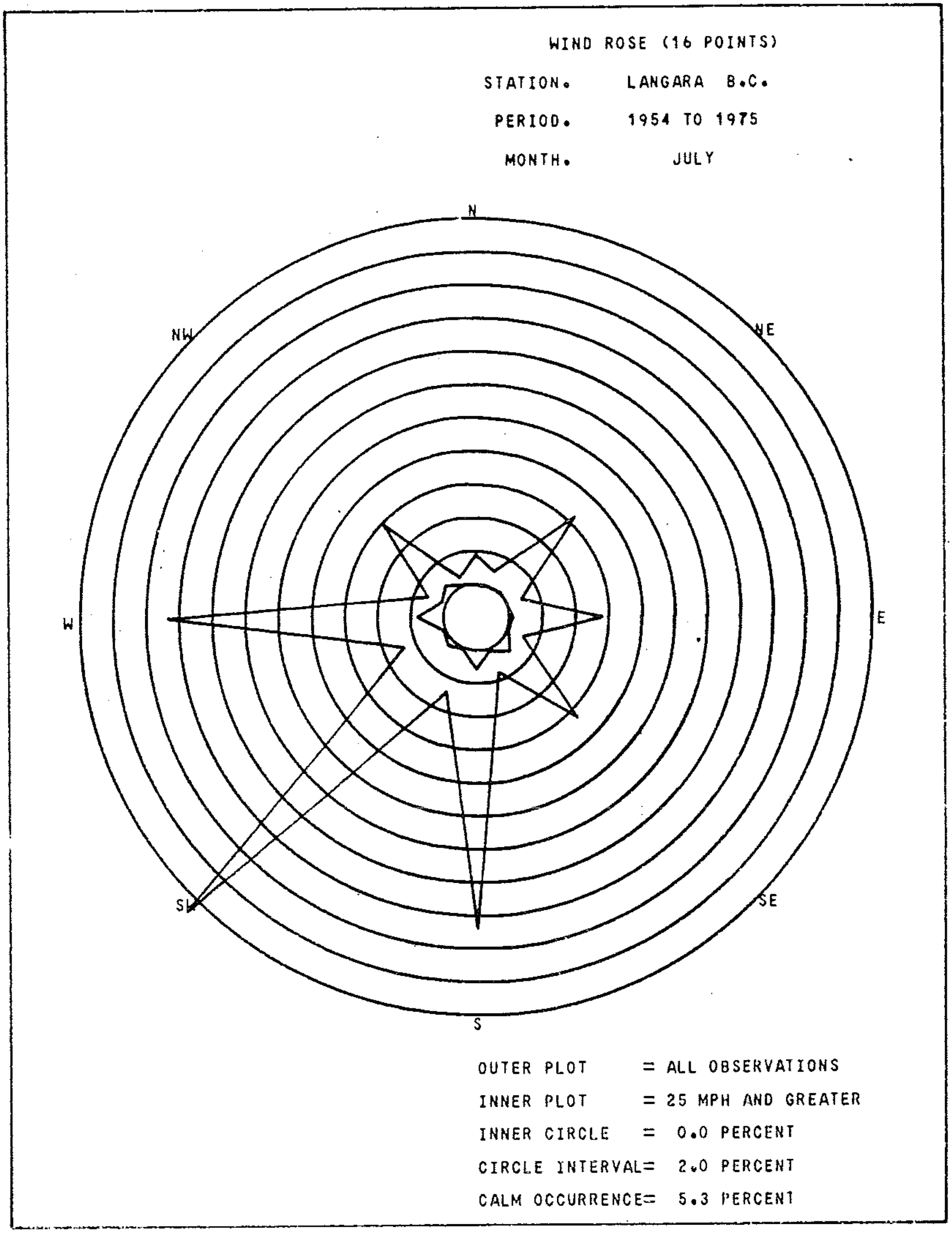


FIGURE 2c MONTHLY WIND ROSE FOR LANGARA, B.C.

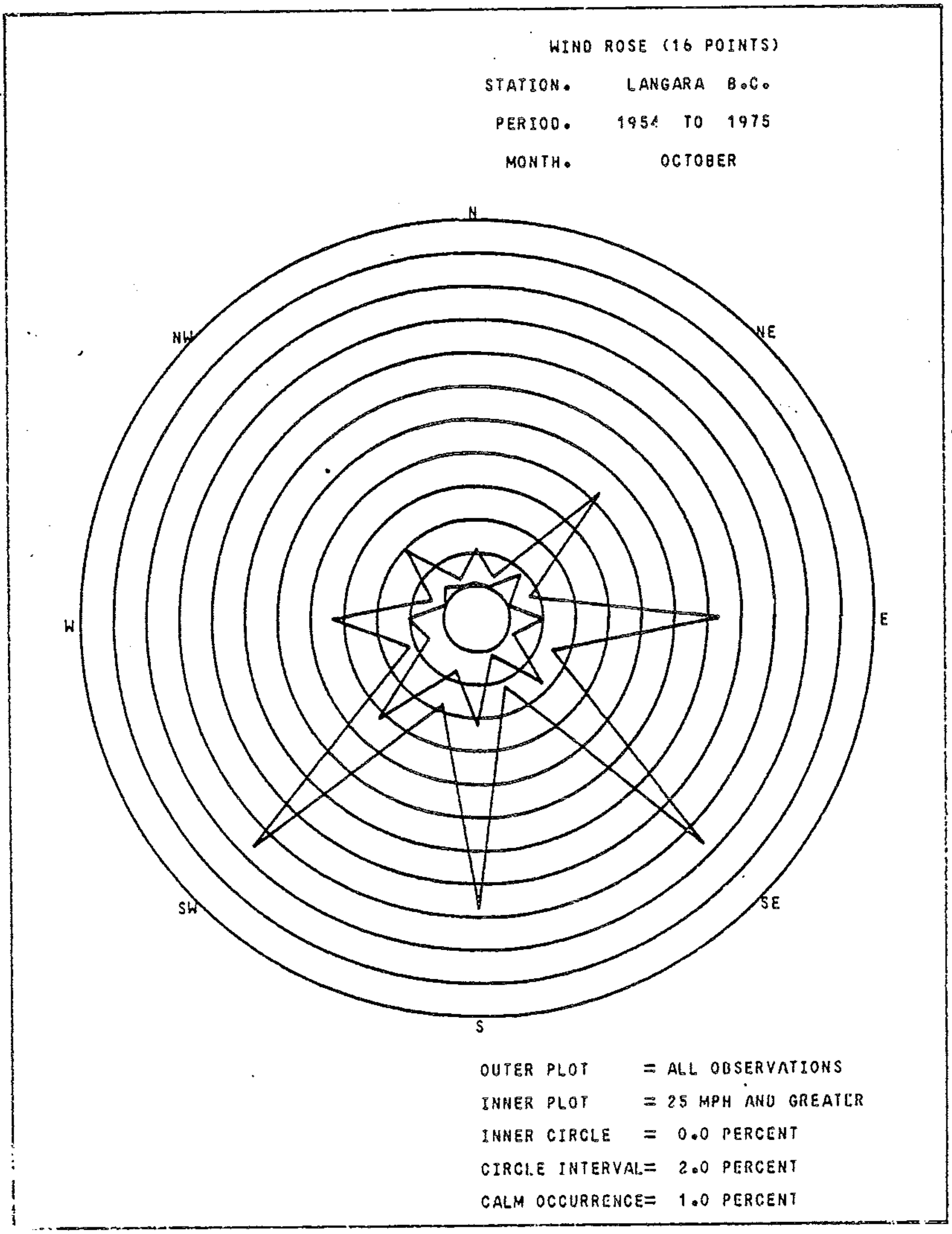


FIGURE 2d MONTHLY WIND ROSE FOR MCINNES ISLAND, B.C.

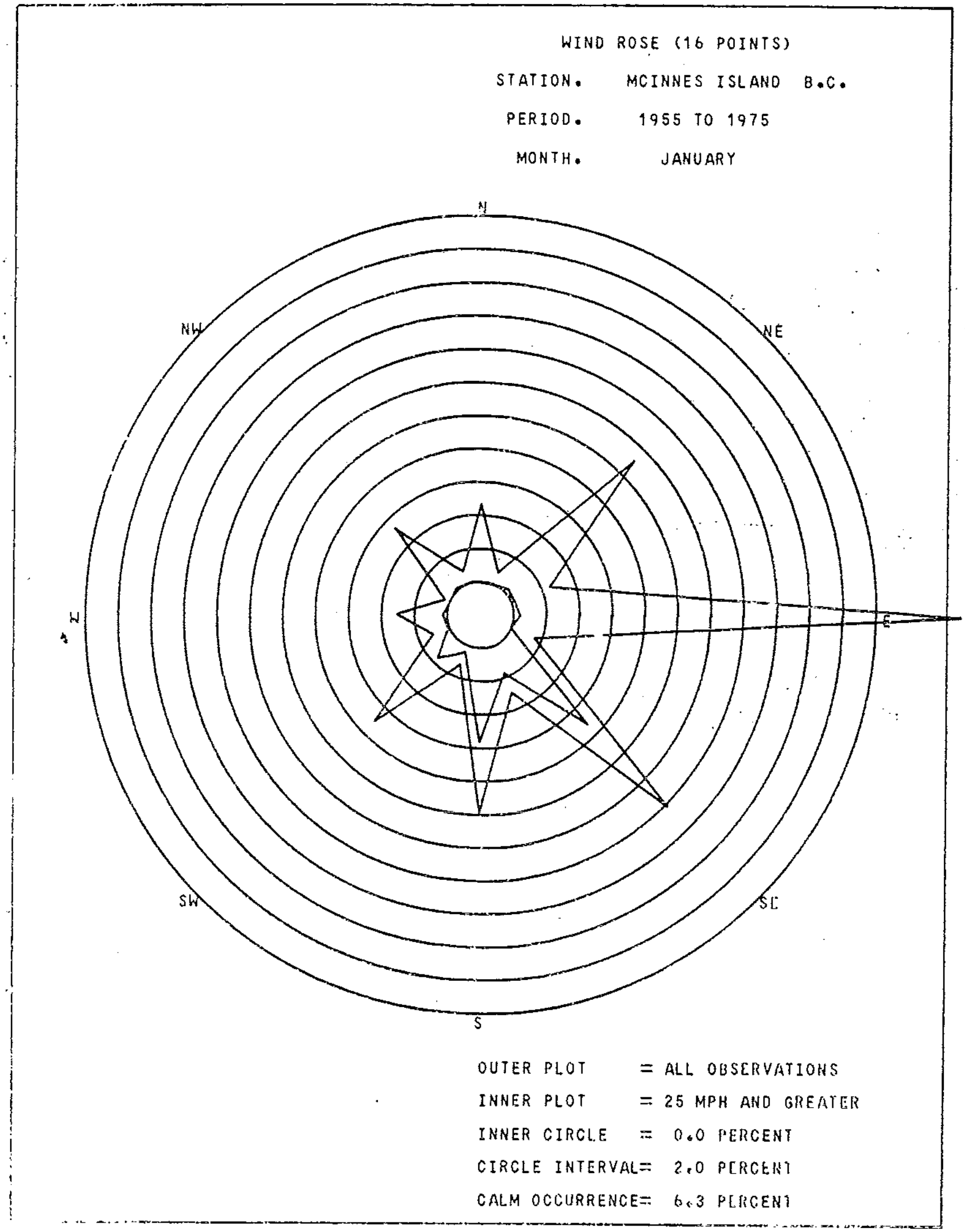


FIGURE 2d MONTHLY WIND ROSE FOR MCINNES ISLAND, B.C.

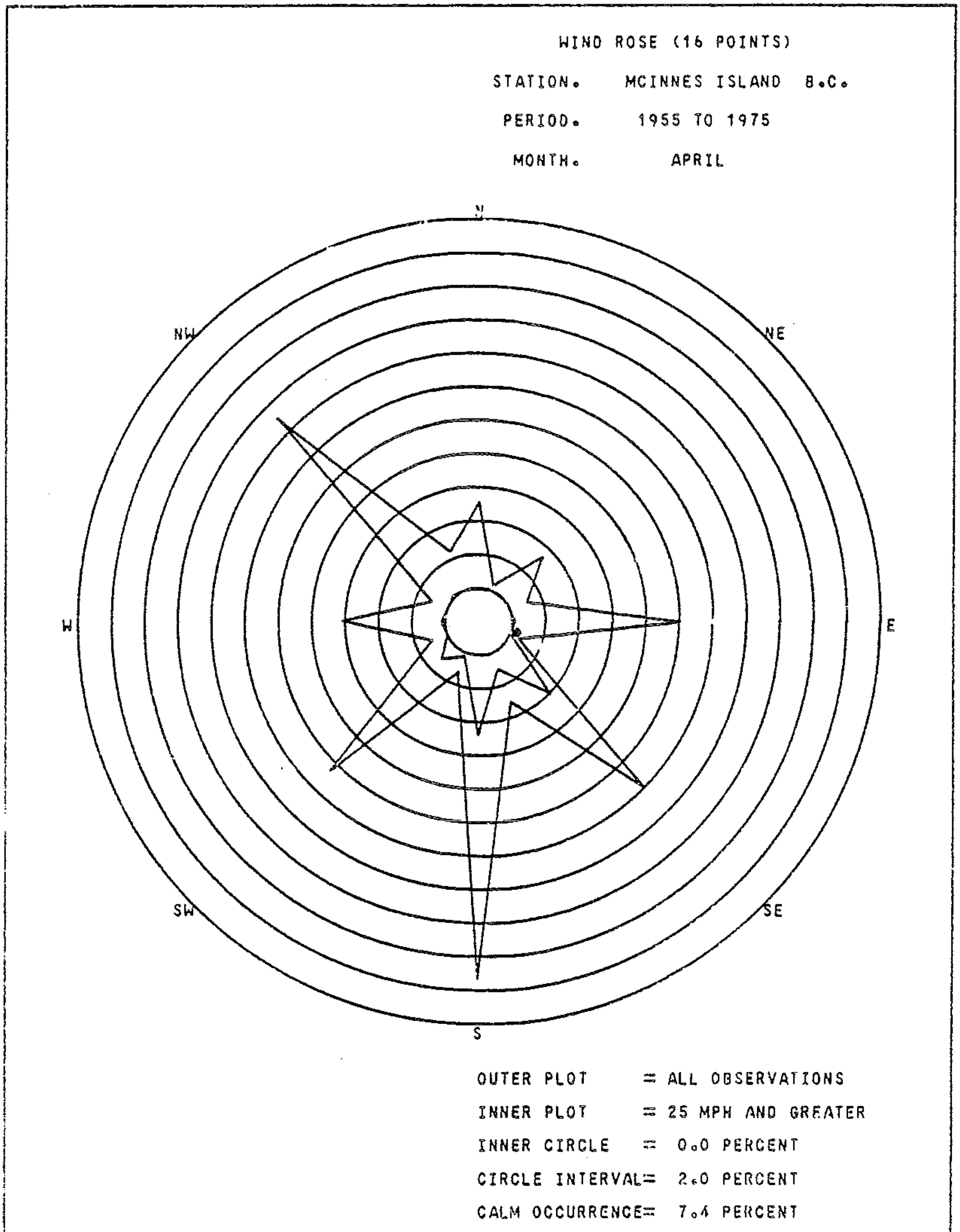


FIGURE 2d MONTHLY WIND ROSE FOR MCINNES ISLAND, B.C.

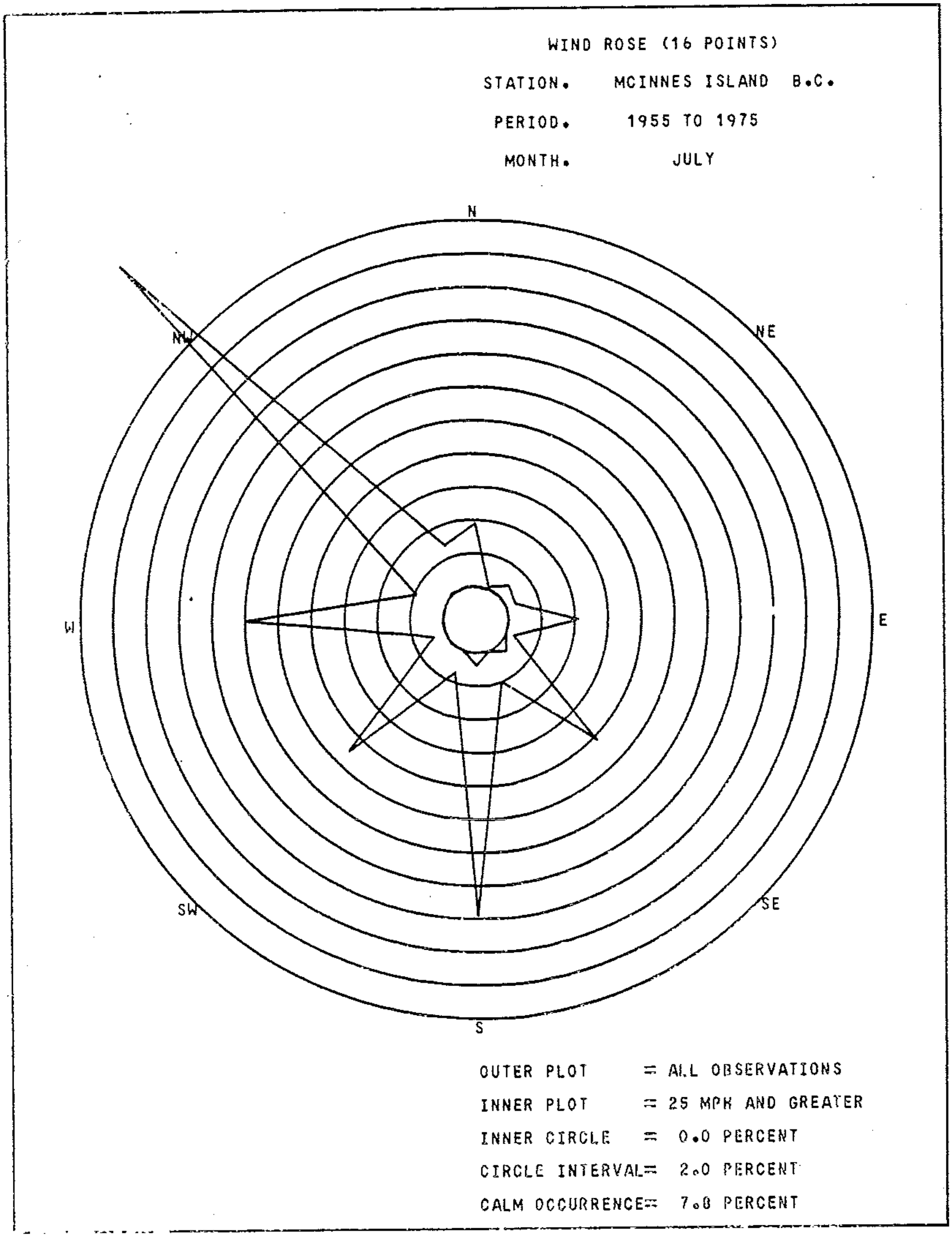


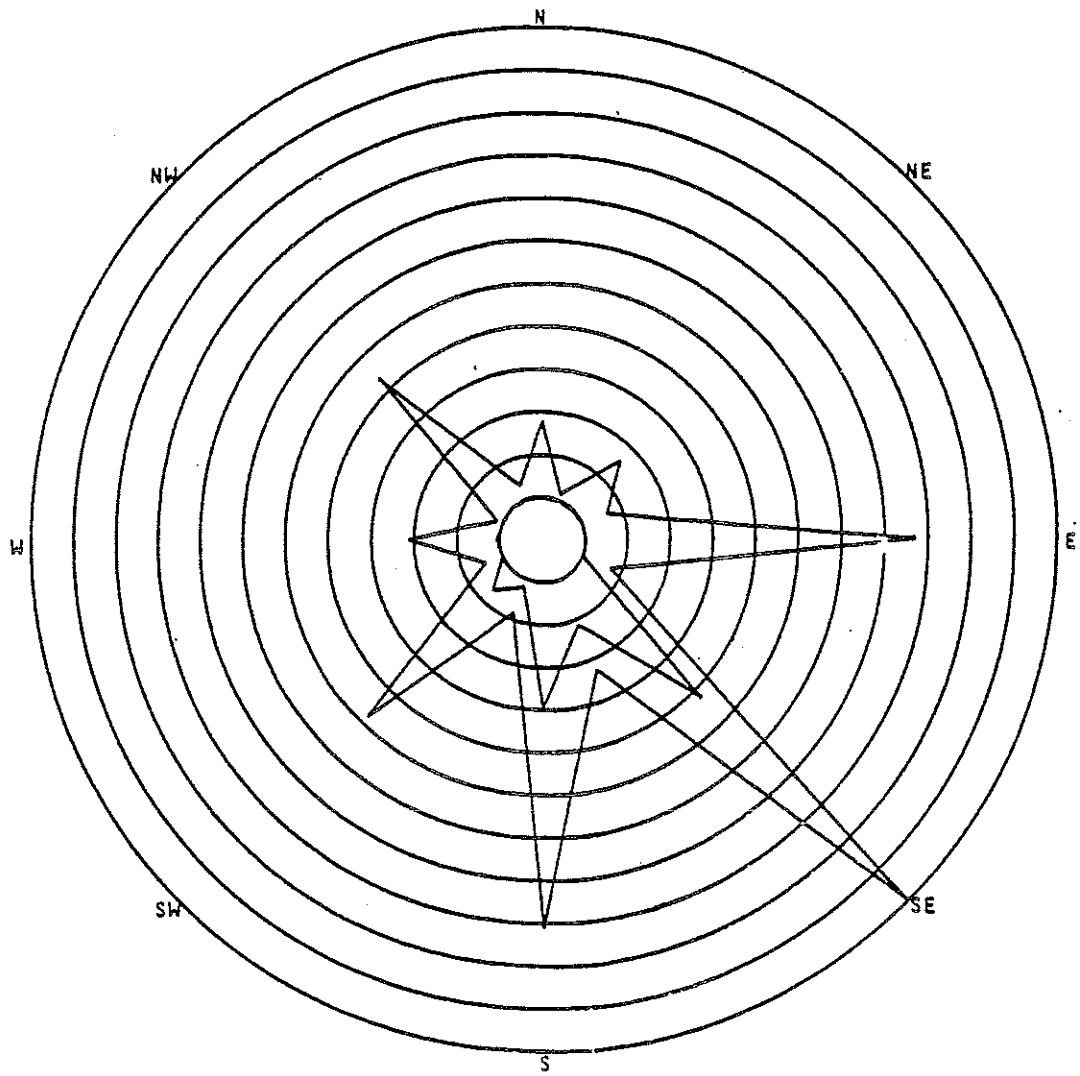
FIGURE 2d MONTHLY WIND ROSE FOR MCINNES ISLAND, B.C.

WIND ROSE (16 POINTS)

STATION. MCINNES ISLAND B.C.

PERIOD. 1955 TO 1975

MONTH. OCTOBER



OUTER PLOT = ALL OBSERVATIONS

INNER PLOT = 25 MPH AND GREATER

INNER CIRCLE = 0.0 PERCENT

CIRCLE INTERVAL= 2.0 PERCENT

CALM OCCURRENCE= 5.9 PERCENT

FIGURE 2e MONTHLY WIND ROSE FOR BONILLA ISLAND, B.C.

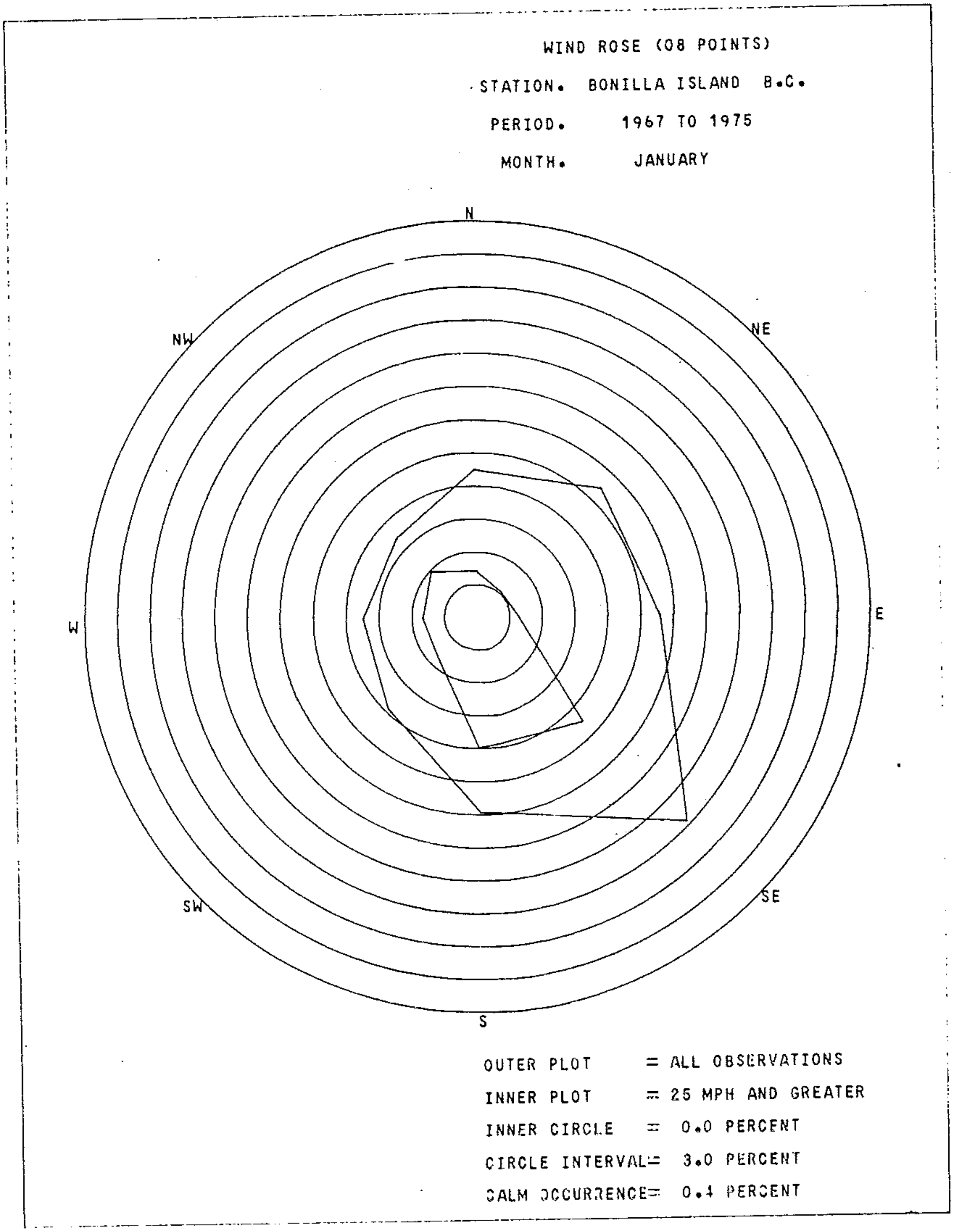


FIGURE 2e MONTHLY WIND ROSE FOR BONILLA ISLAND, B.C.

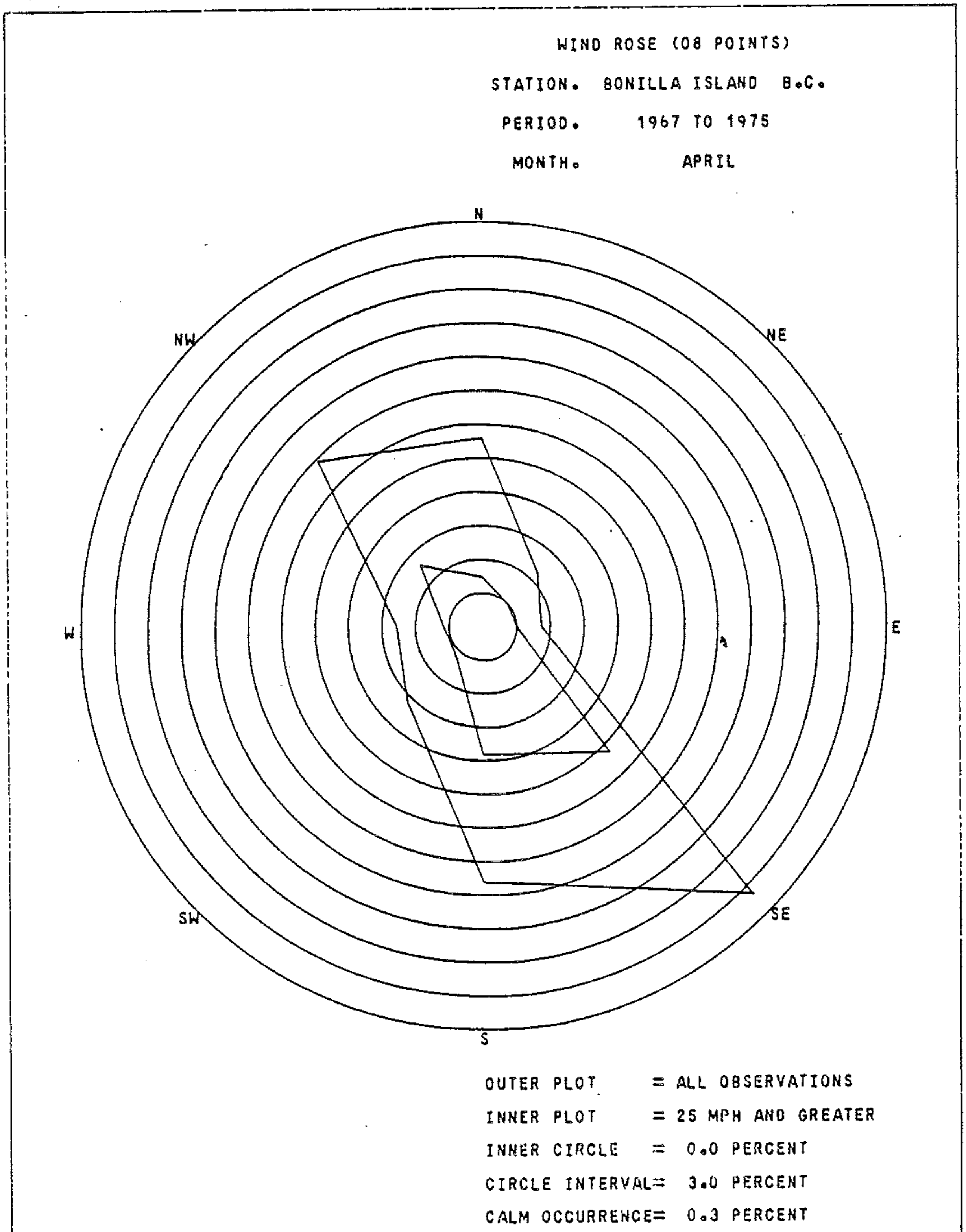


FIGURE 2e MONTHLY WIND ROSE FOR BONILLA ISLAND, B.C.

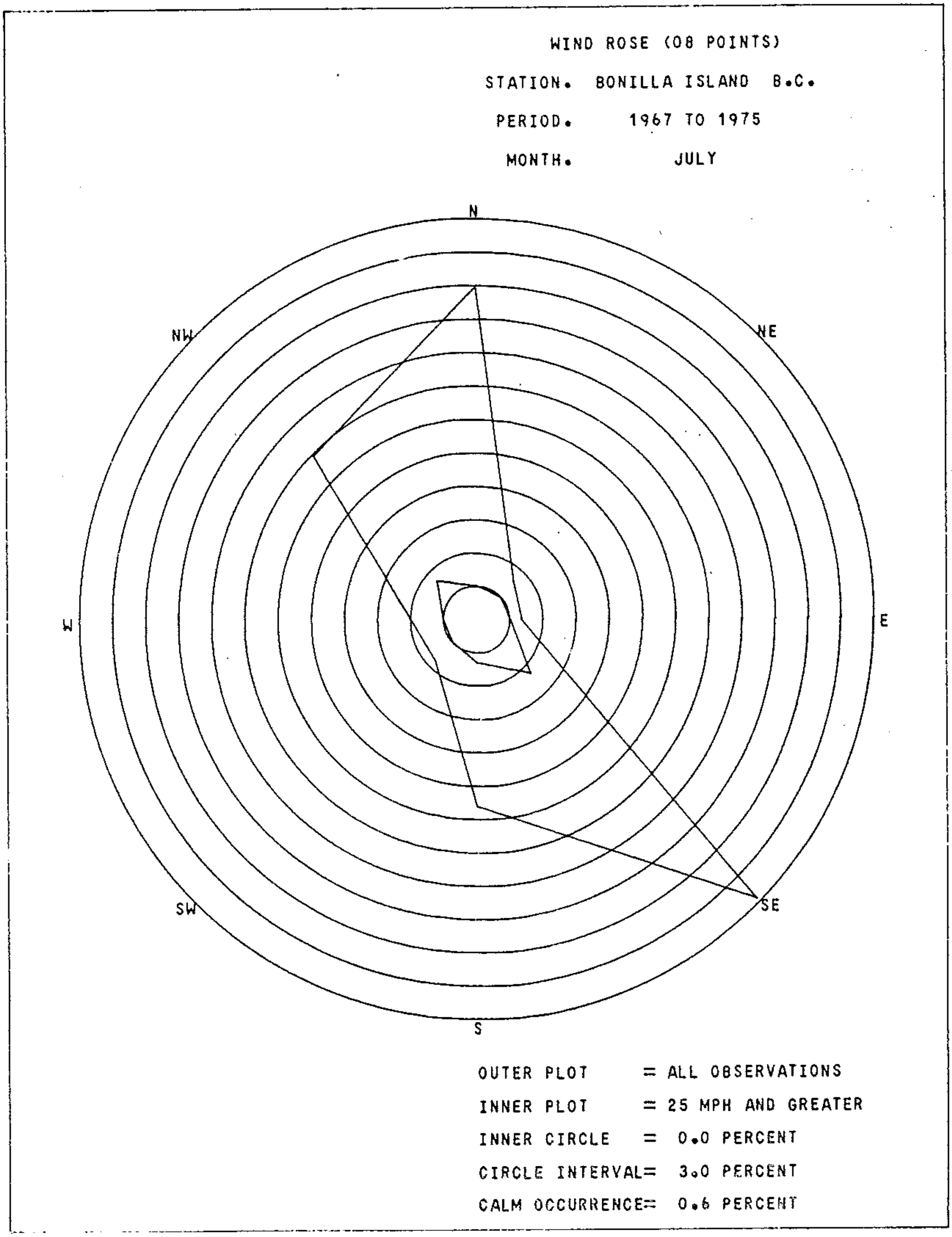


FIGURE 2e MONTHLY WIND ROSE FOR BONILLA ISLAND, B.C.

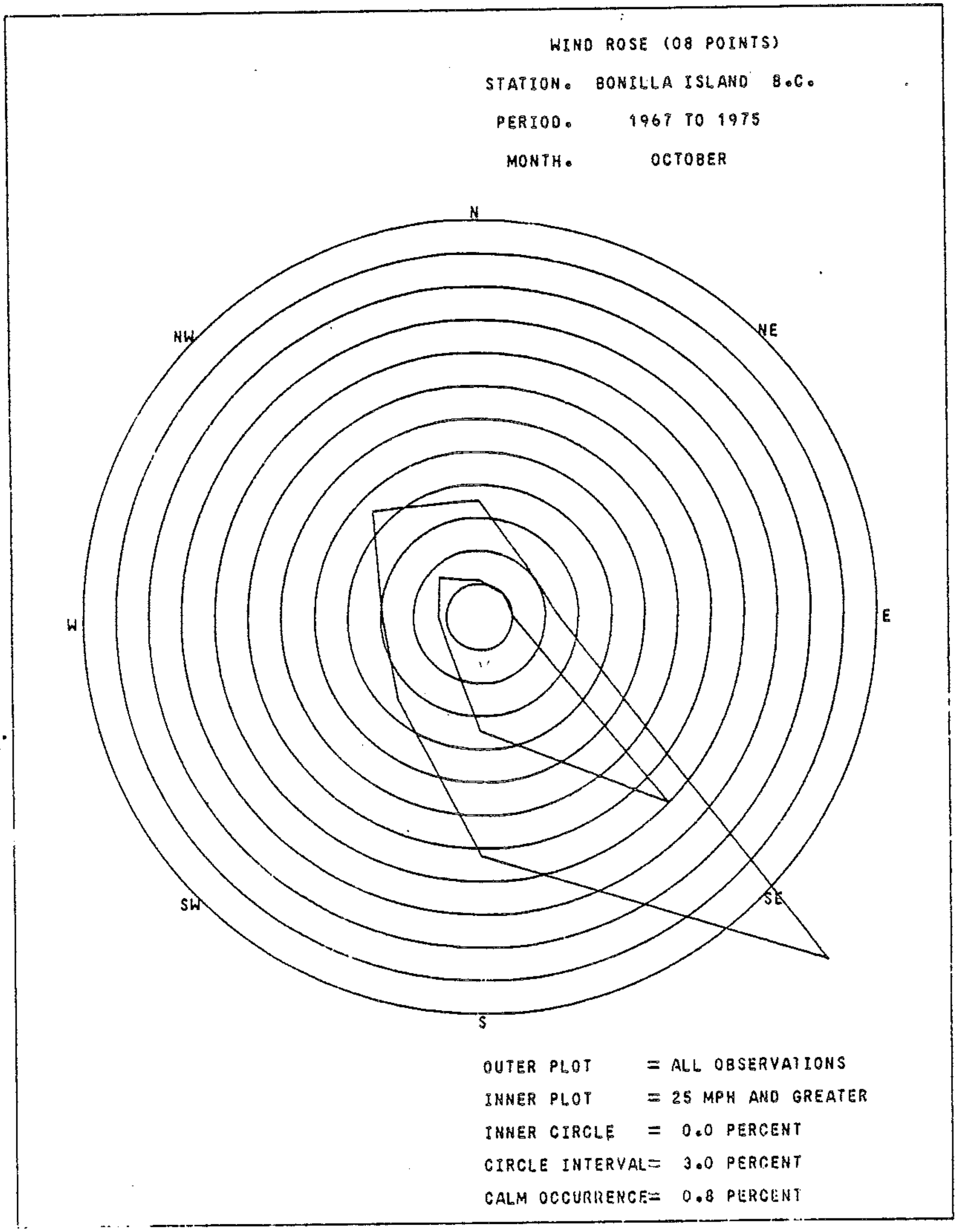


FIGURE 3a PERCENTAGE OF TIME AND HOURS PER MONTH WHEN WIND SPEED EQUALS OR EXCEEDS "V" AT LANGARA, B.C.

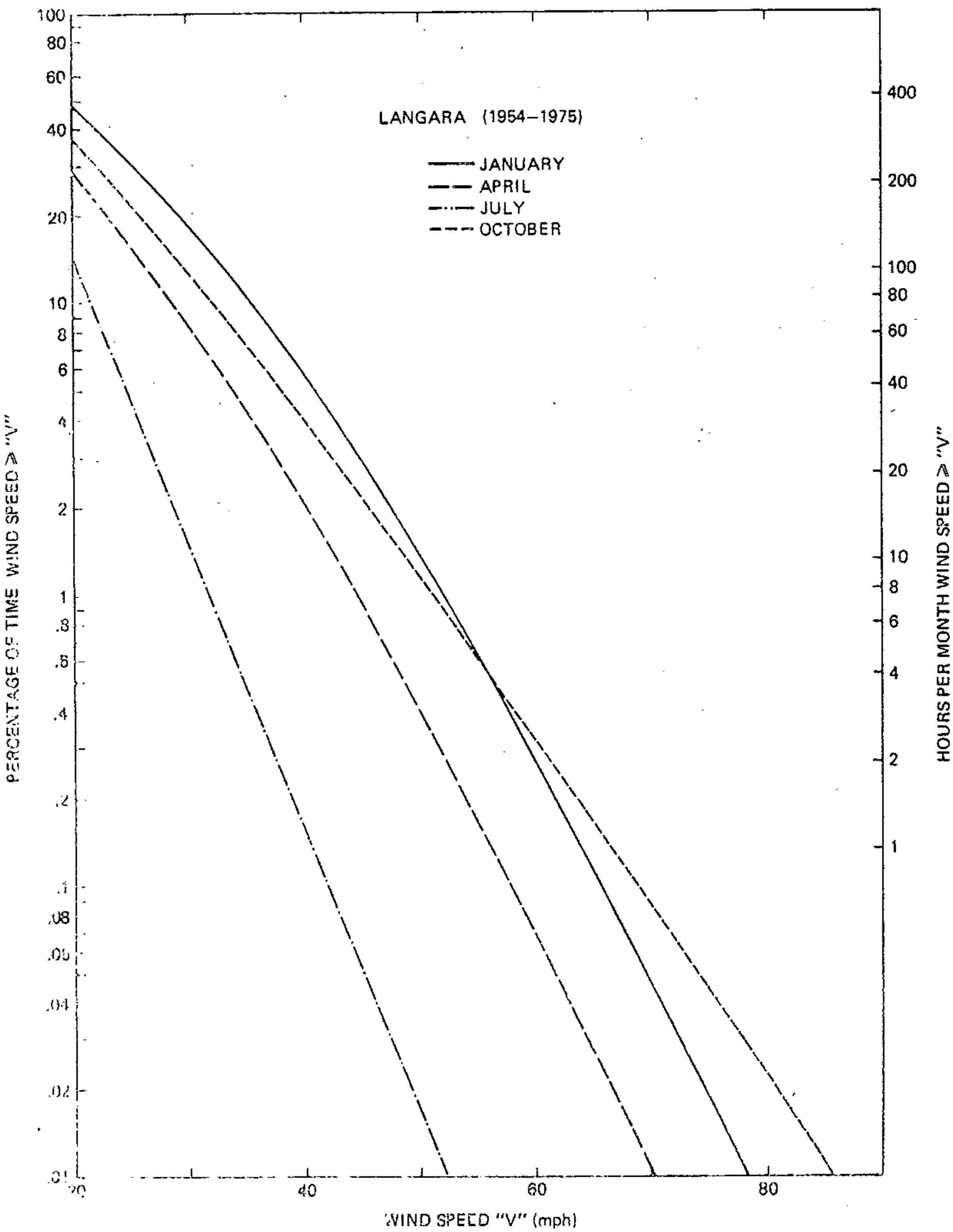


FIGURE 3b PERCENTAGE OF TIME AND HOURS PER MONTH WHEN WIND SPEED EQUALS OR EXCEEDS "V" AT MCINNES ISLAND, B.C.

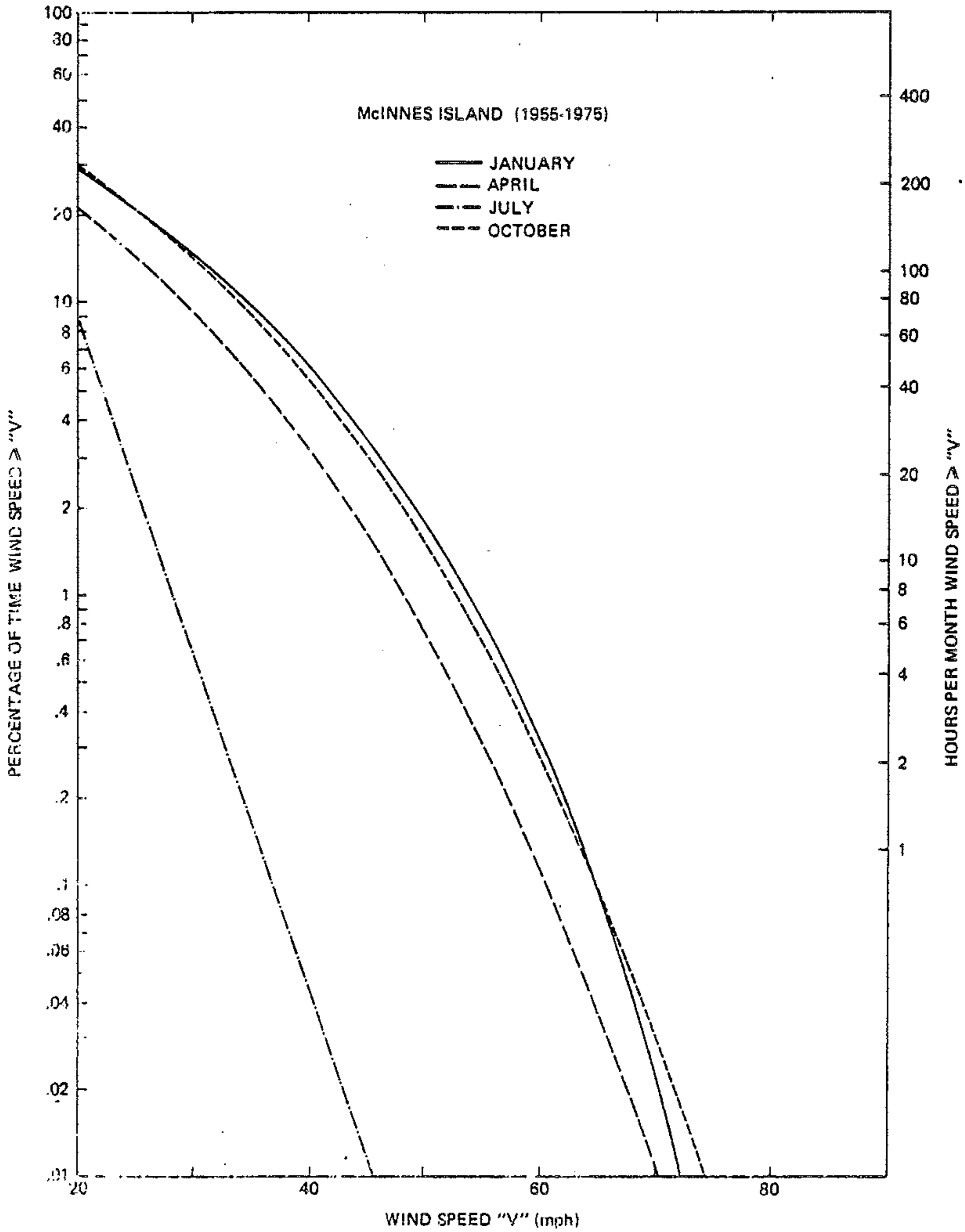


FIGURE 3c PERCENTAGE OF TIME AND HOURS PER MONTH WHEN WIND SPEED EQUALS OR EXCEEDS "V" AT ETHELDA BAY

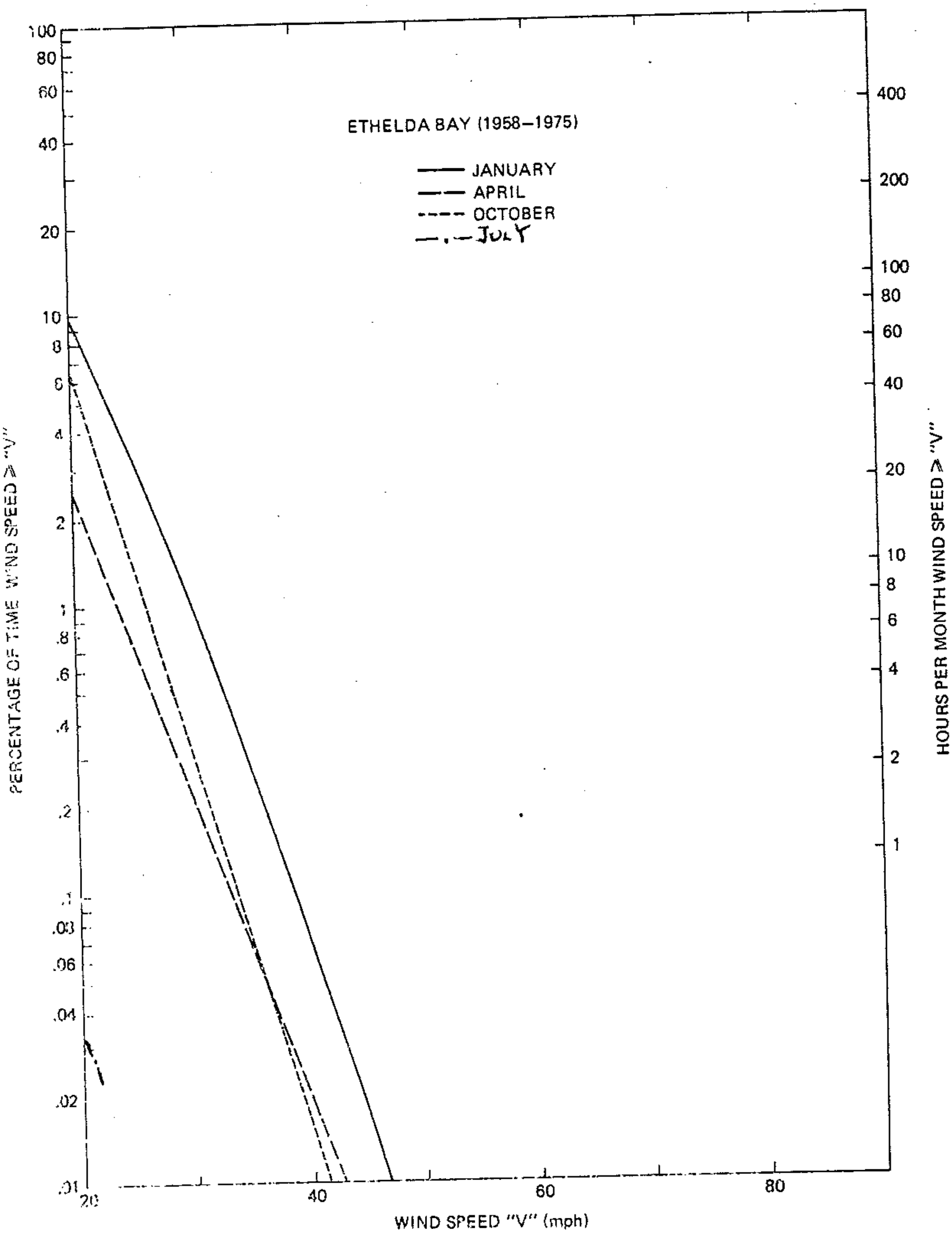


FIGURE 4 PERCENTAGE OF TIME AND HOUR PER YEAR WHEN WIND SPEED EQUALS OR EXCEEDS "V"

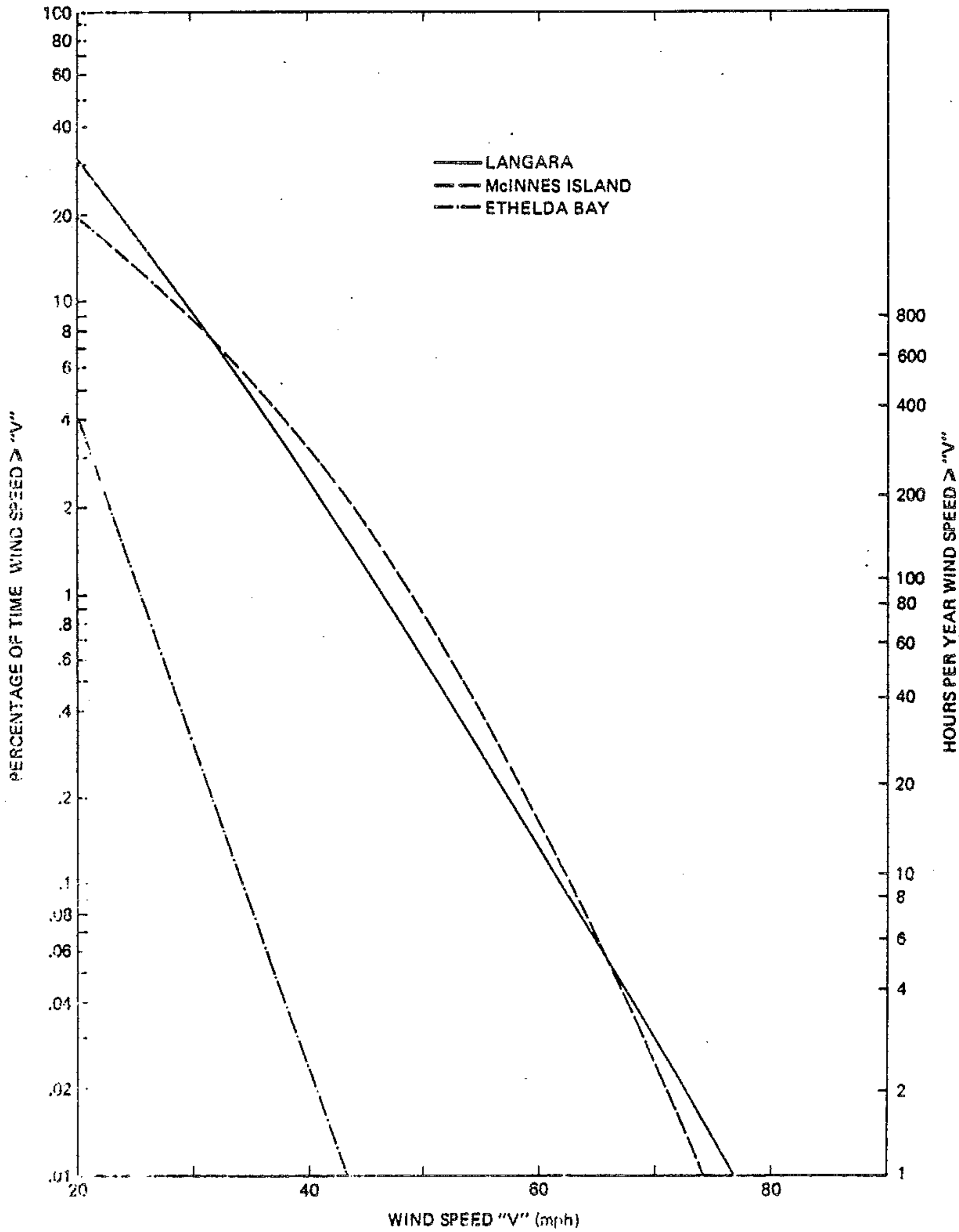


FIGURE 5a EXTREME WIND DURATION ANALYSIS FOR LANGARA

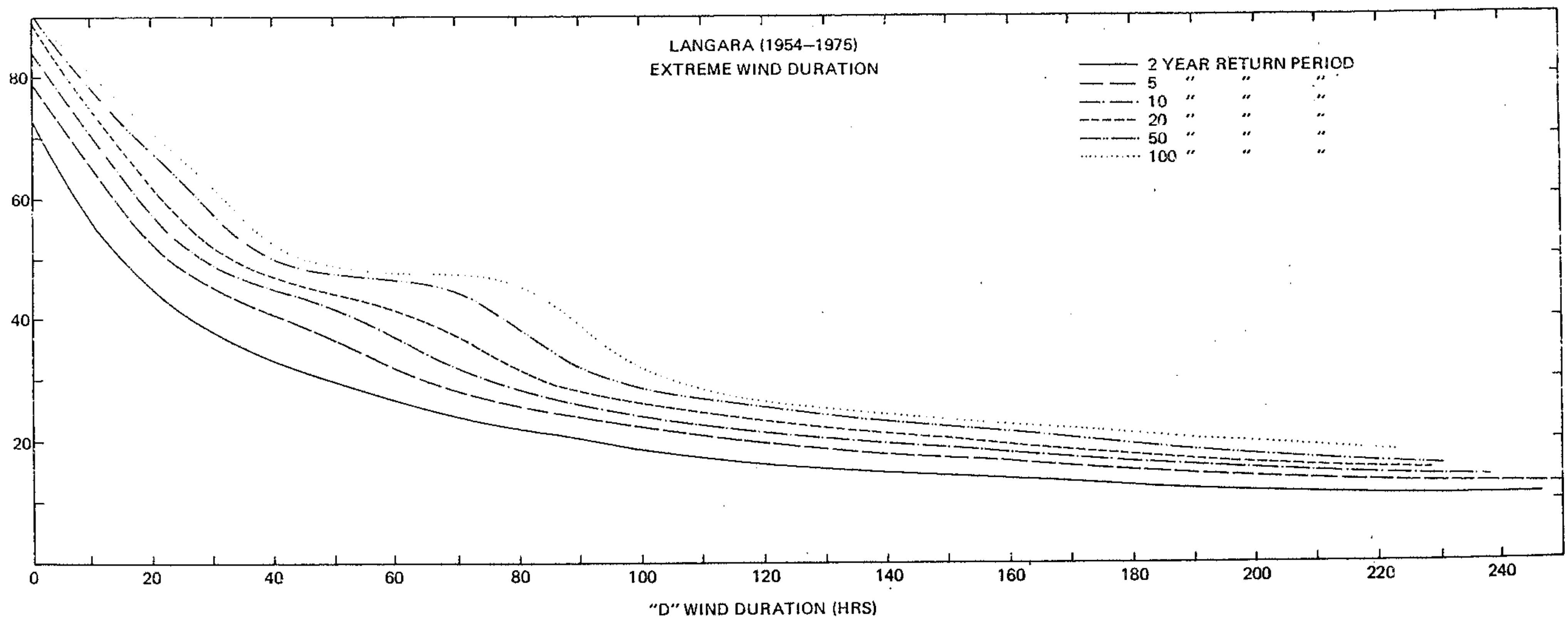


FIGURE 5b EXTREME WIND DURATION ANALYSIS FOR MCINNES ISLAND

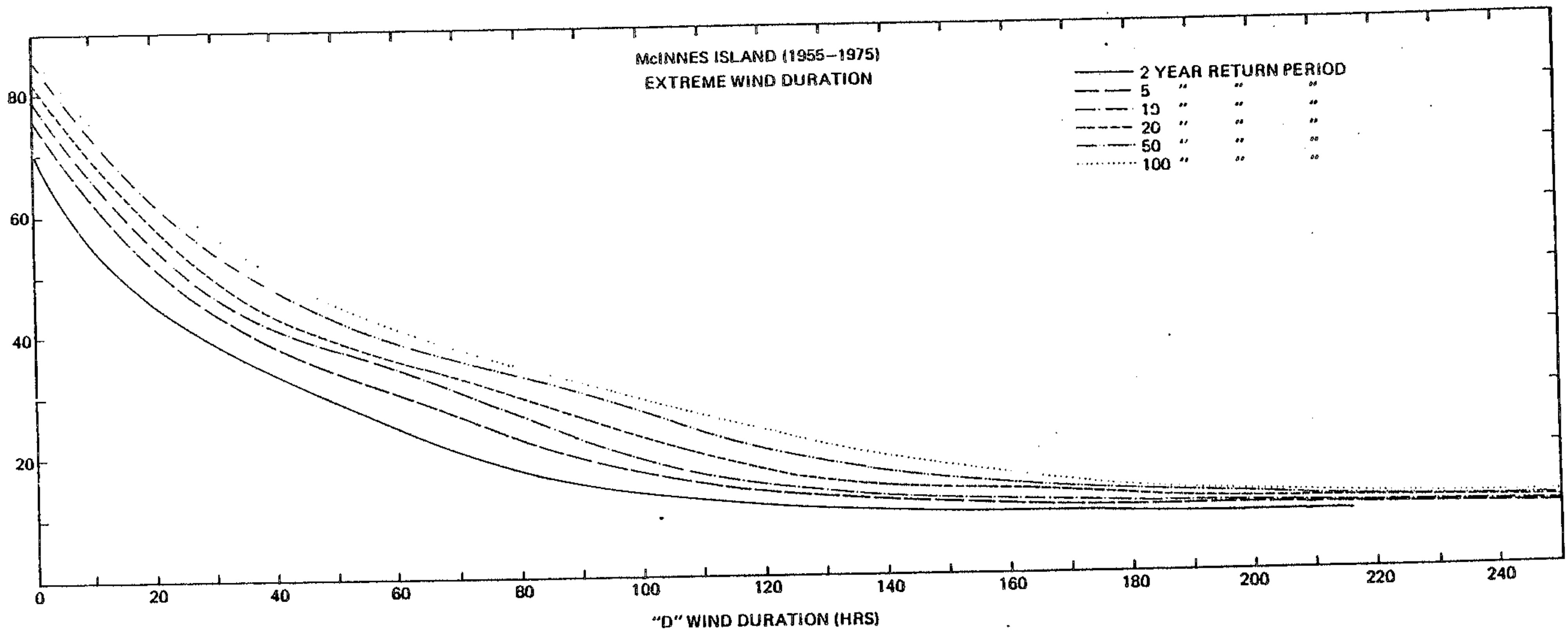


FIGURE 5c EXTREME WIND DURATION ANALYSIS FOR ETHELDA BAY

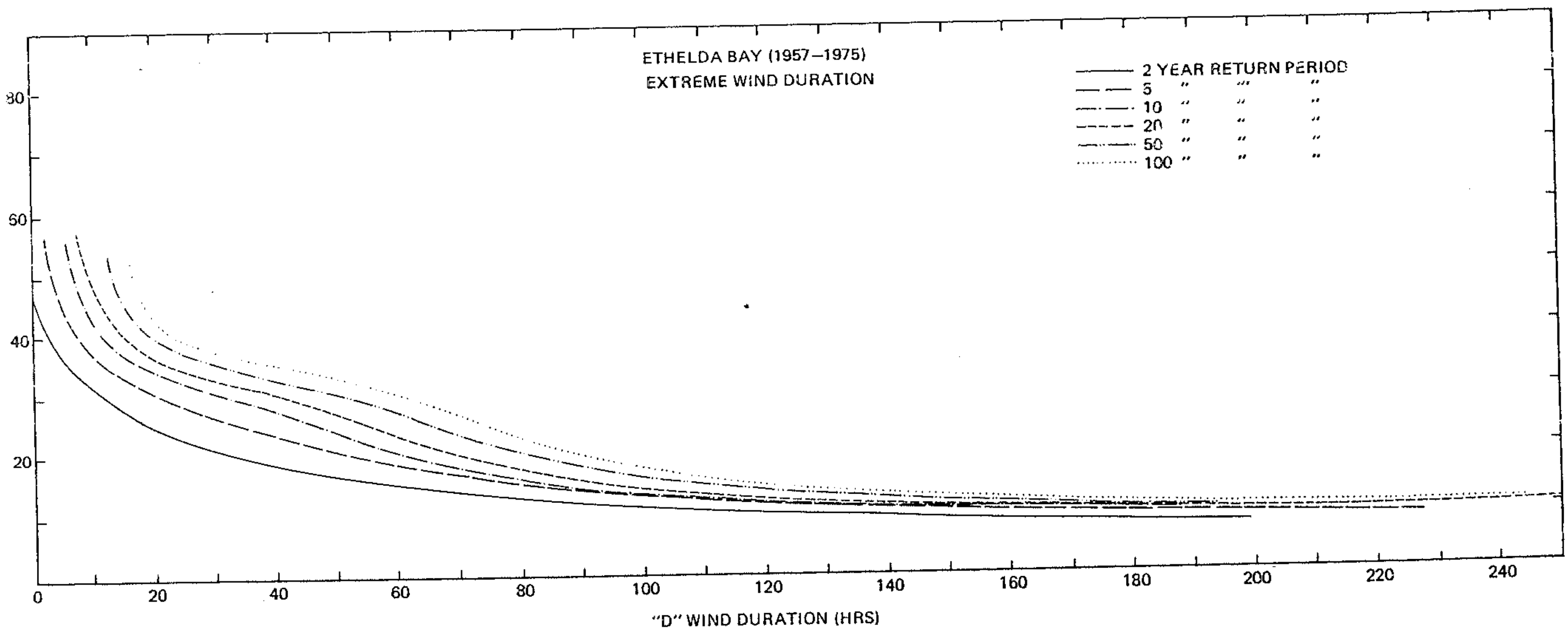


FIGURE 5d EXTREME WIND DURATION ANALYSIS FOR CAPE ST. JAMES

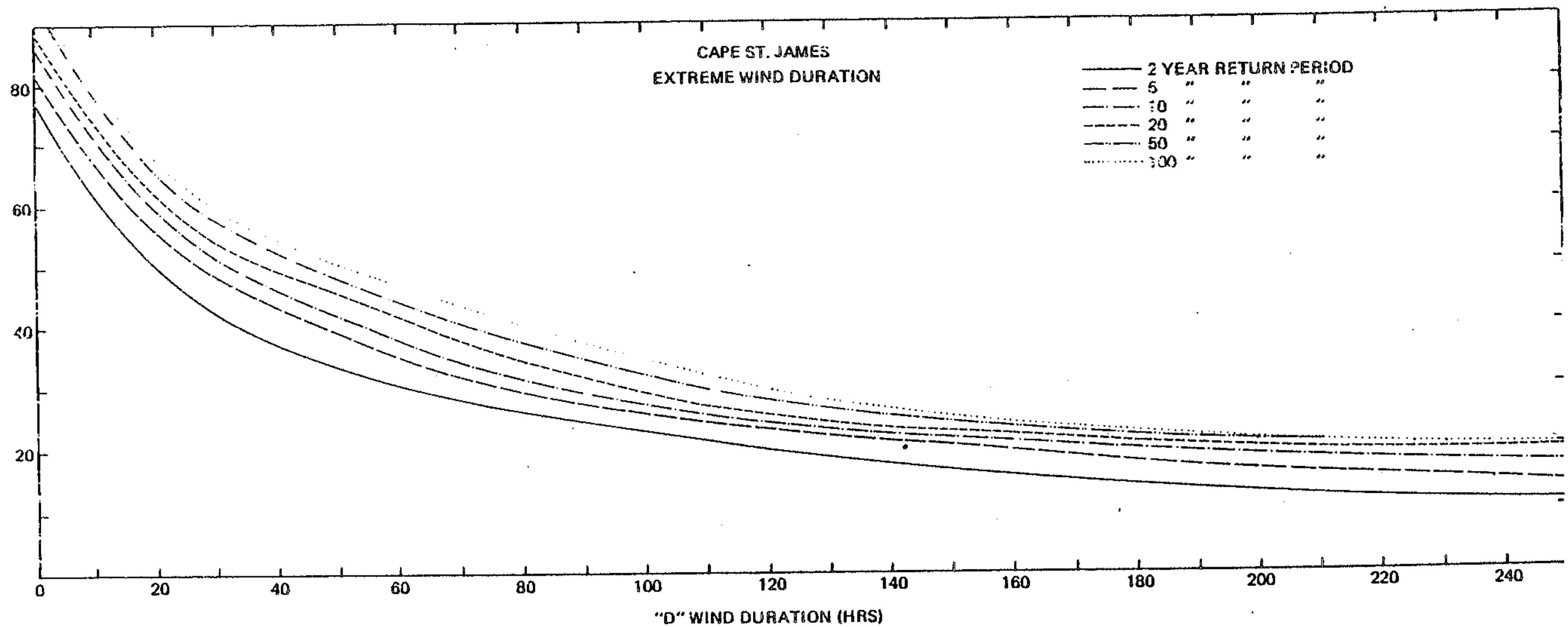


FIGURE 6a EXTREME VALUE ANALYSIS OF WIND SPEED AT BONILLA ISLAND

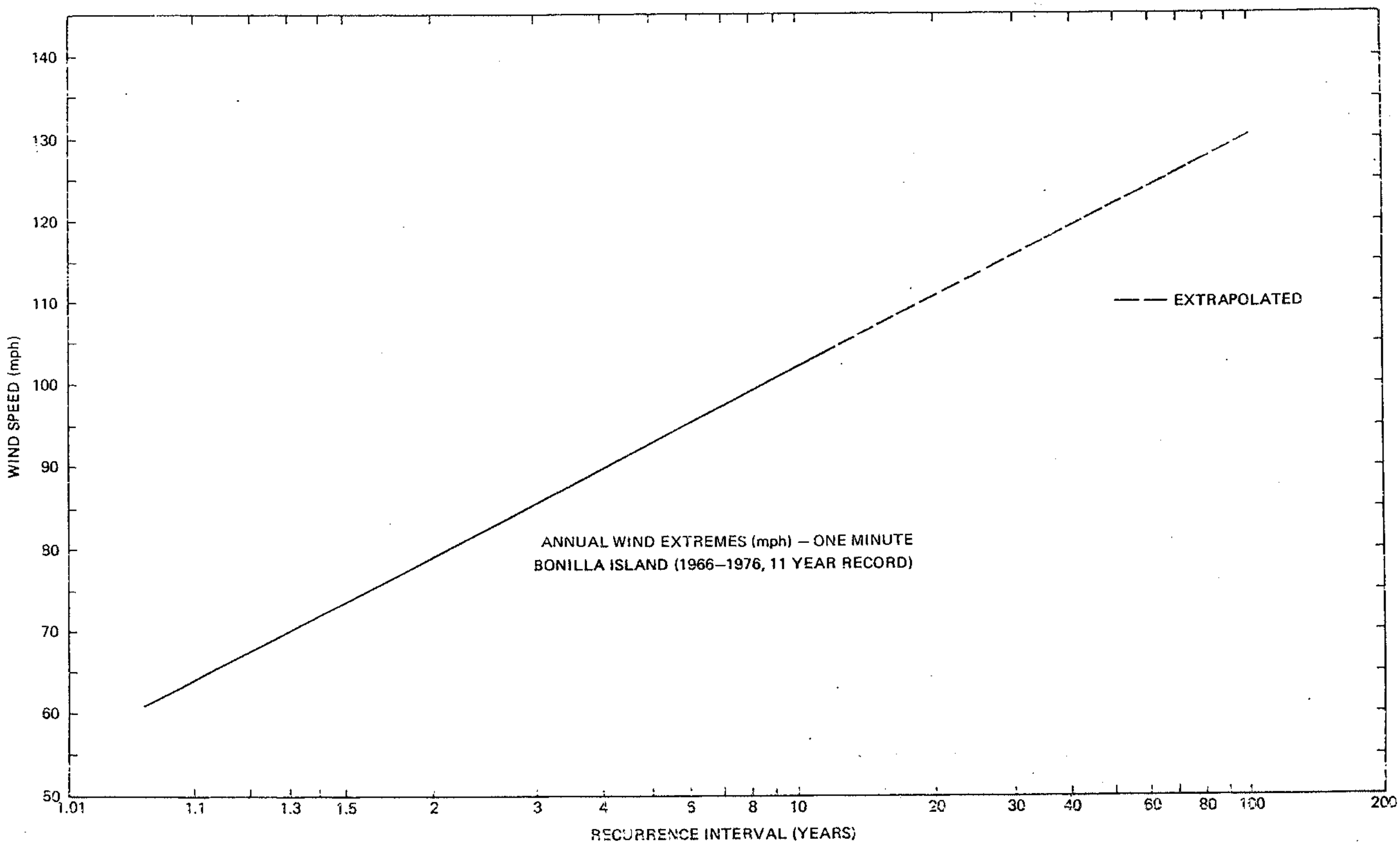


FIGURE 6b EXTREME VALUE ANALYSIS OF WIND SPEED AT MCINNES ISLAND

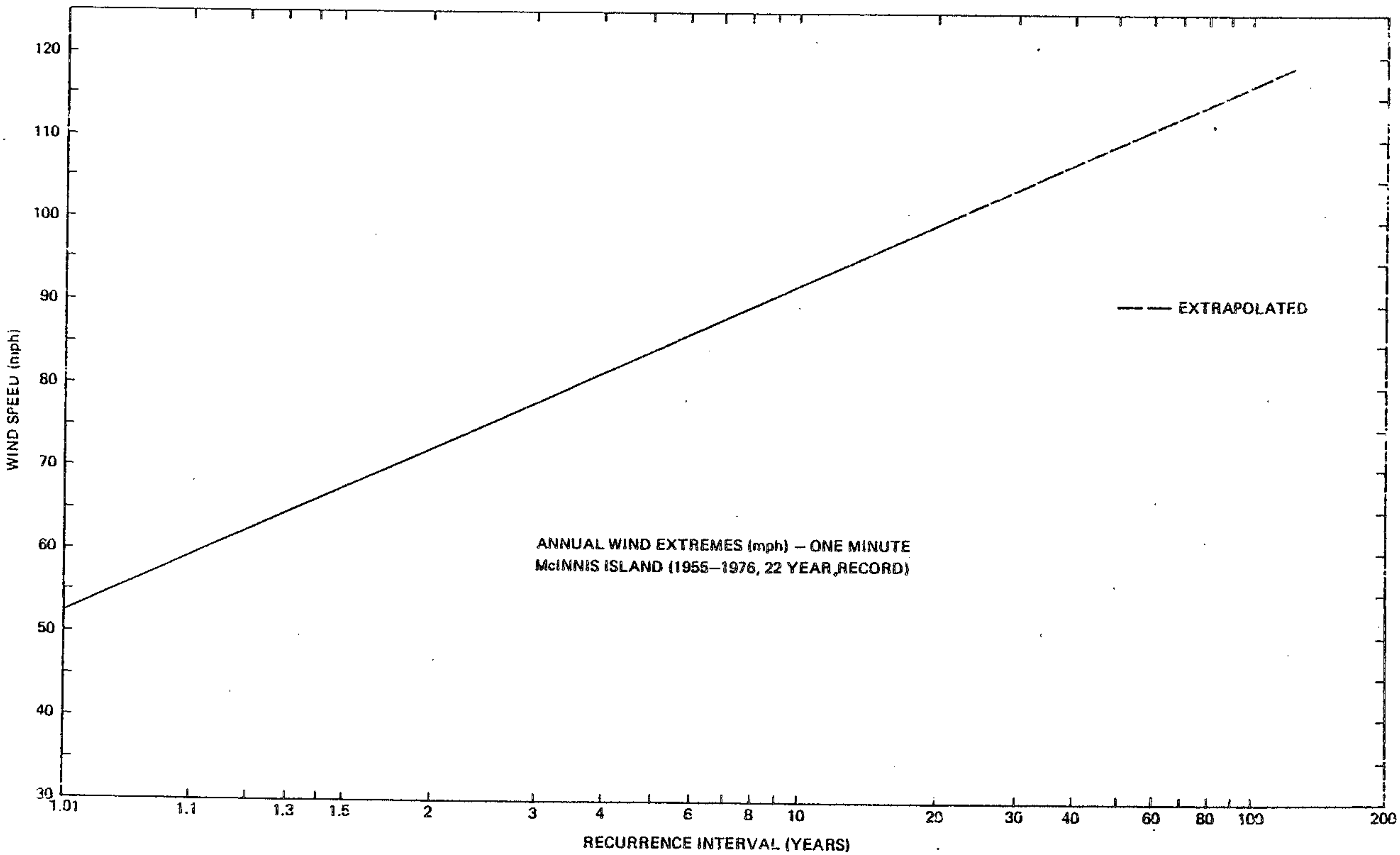


FIGURE 6c EXTREME VALUE ANALYSIS OF WIND SPEED AT CAPE ST. JAMES

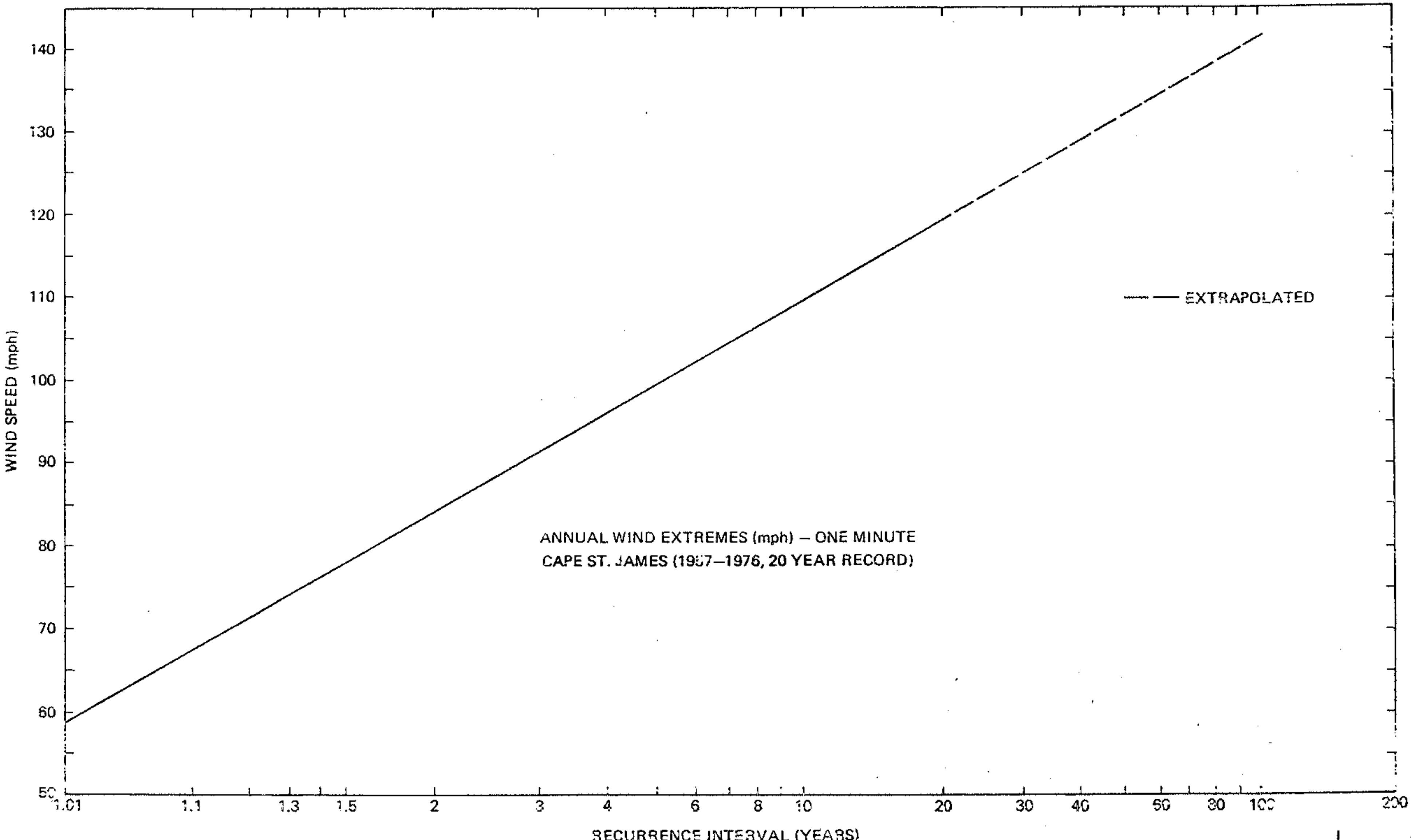


FIGURE 6d EXTREME VALUE ANALYSIS OF WIND SPEED AT KITIMAT 2

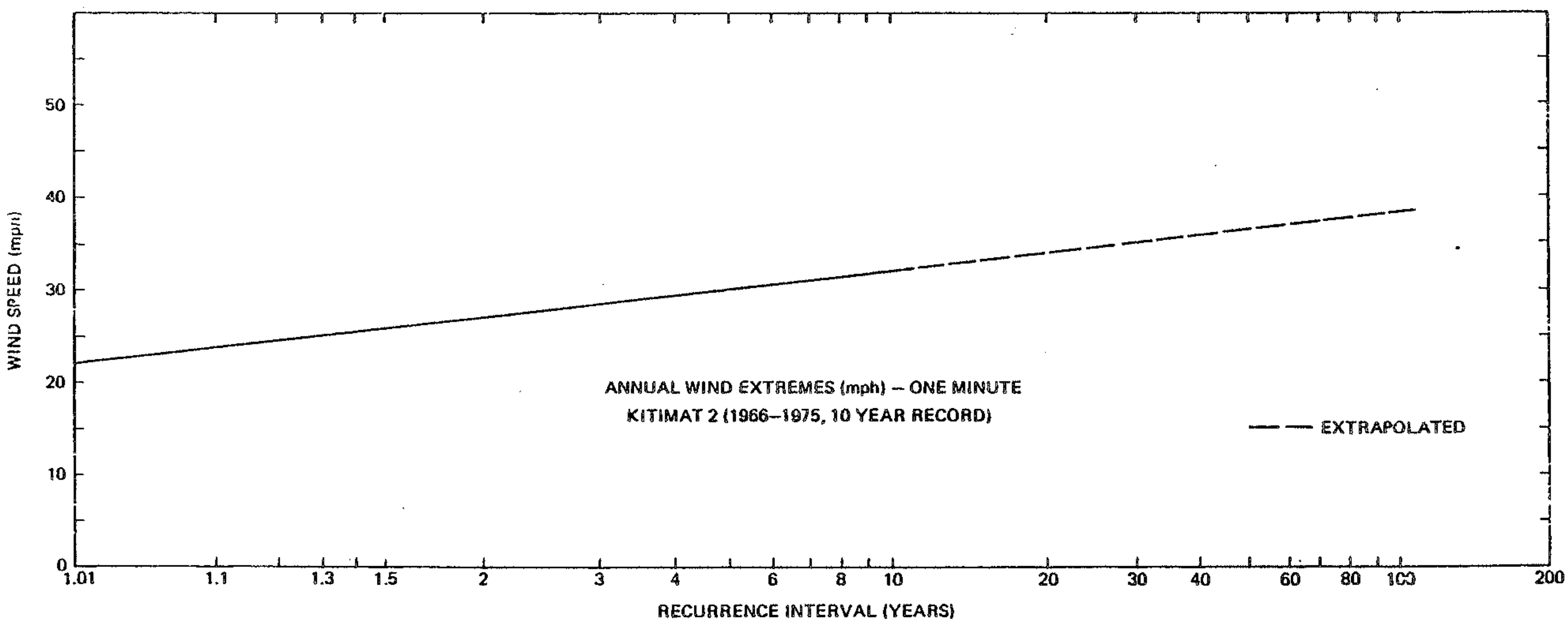


FIGURE 6e EXTREME VALUE ANALYSIS OF WIND SPEED AT PRINCE RUPERT

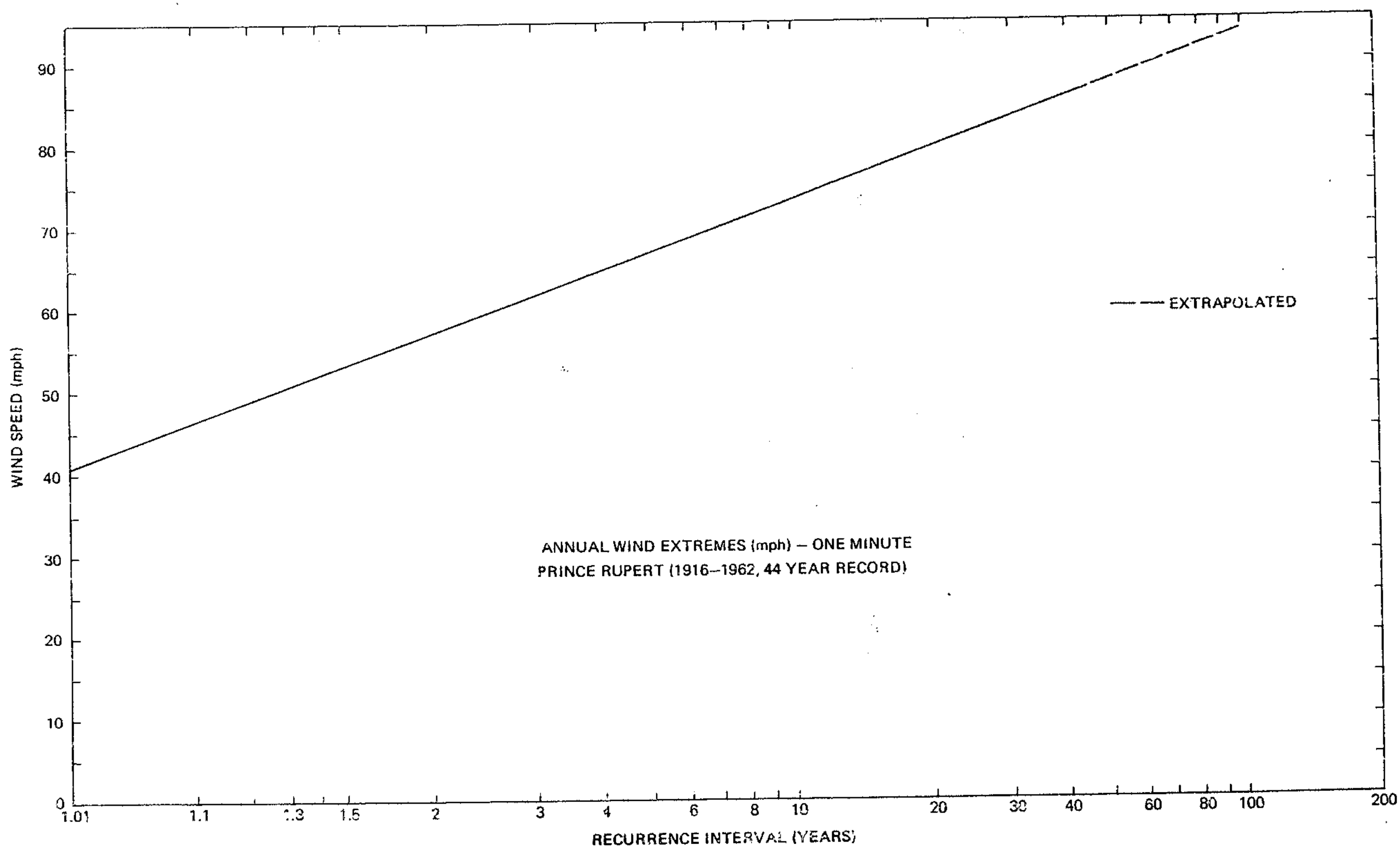


FIGURE 6f EXTREME VALUE ANALYSIS OF WIND SPEED AT ETHELDA BAY

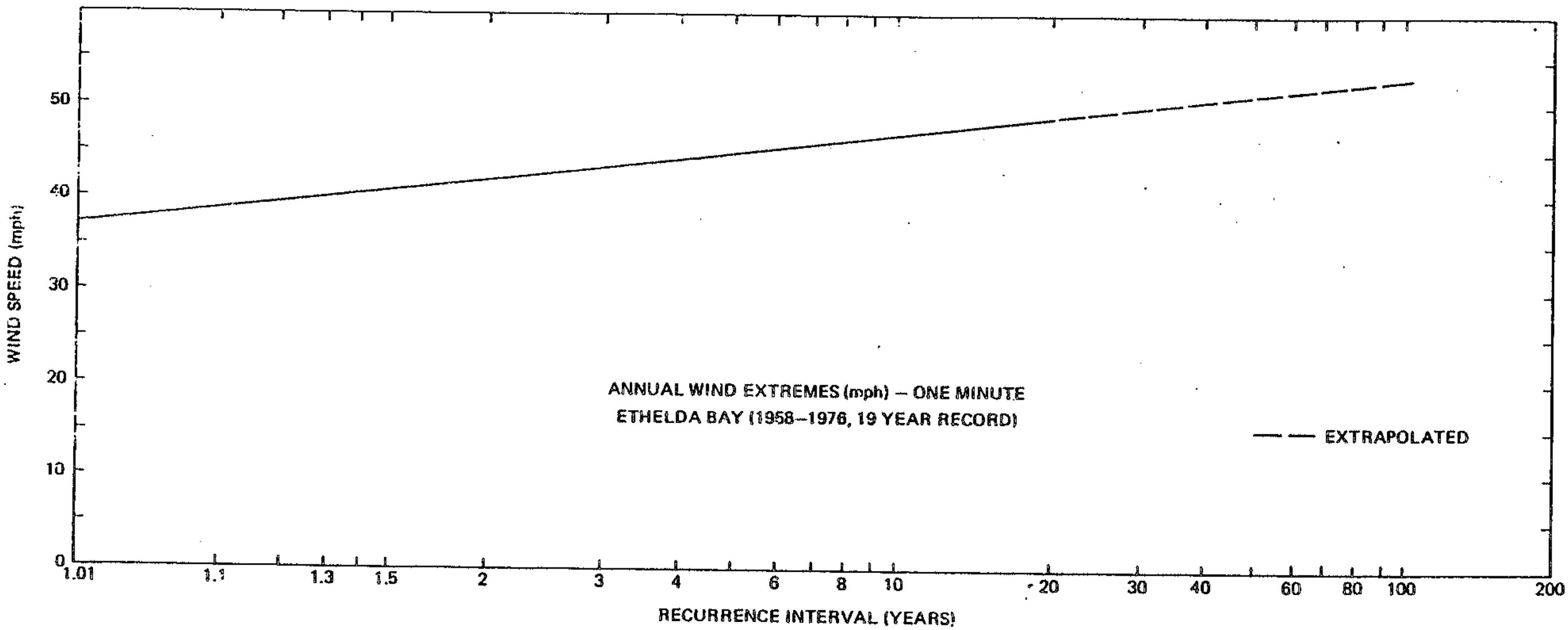


FIGURE 6g EXTREME VALUE ANALYSIS OF WIND SPEED ALONG NORTHERN BRITISH COLUMBIA COAST

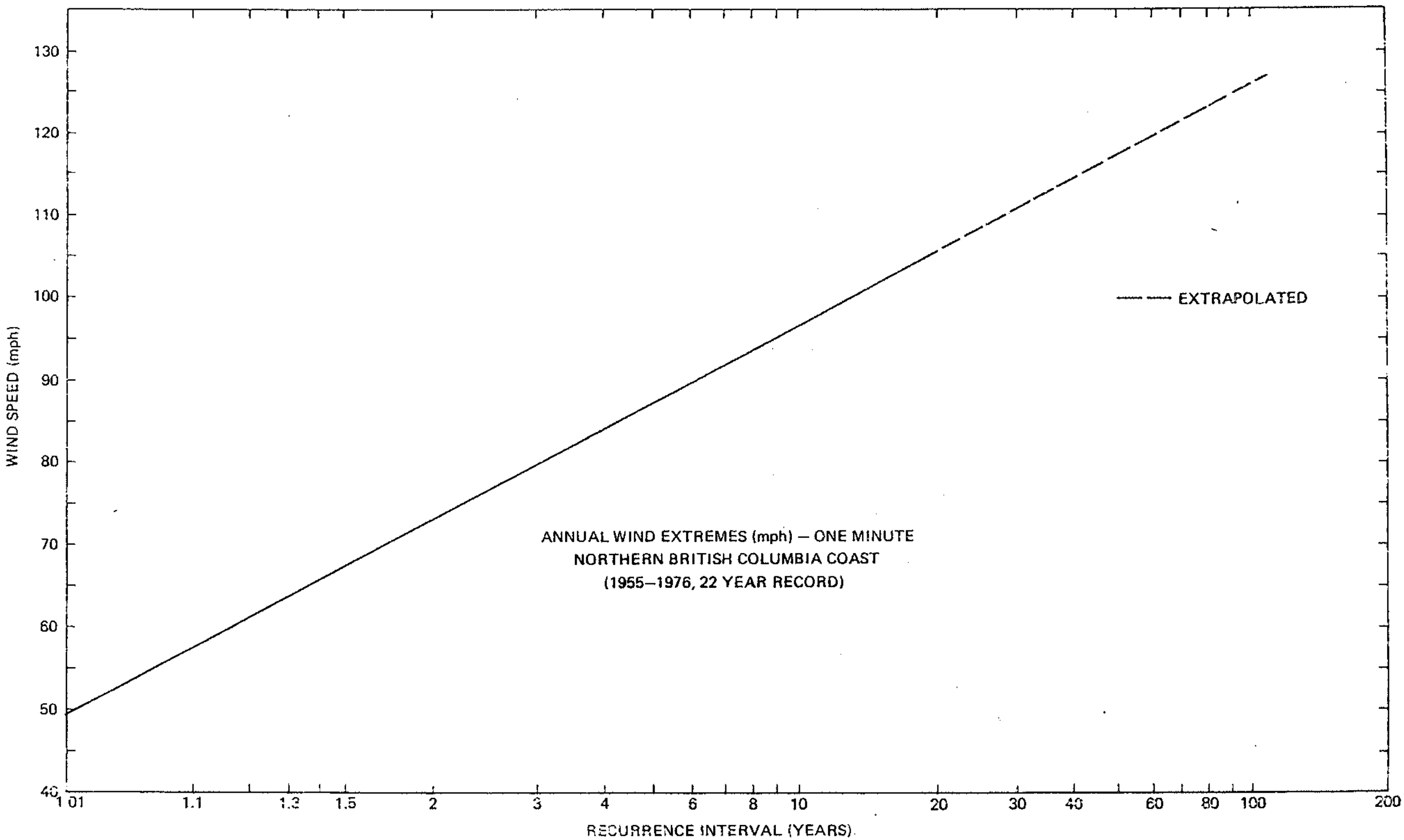
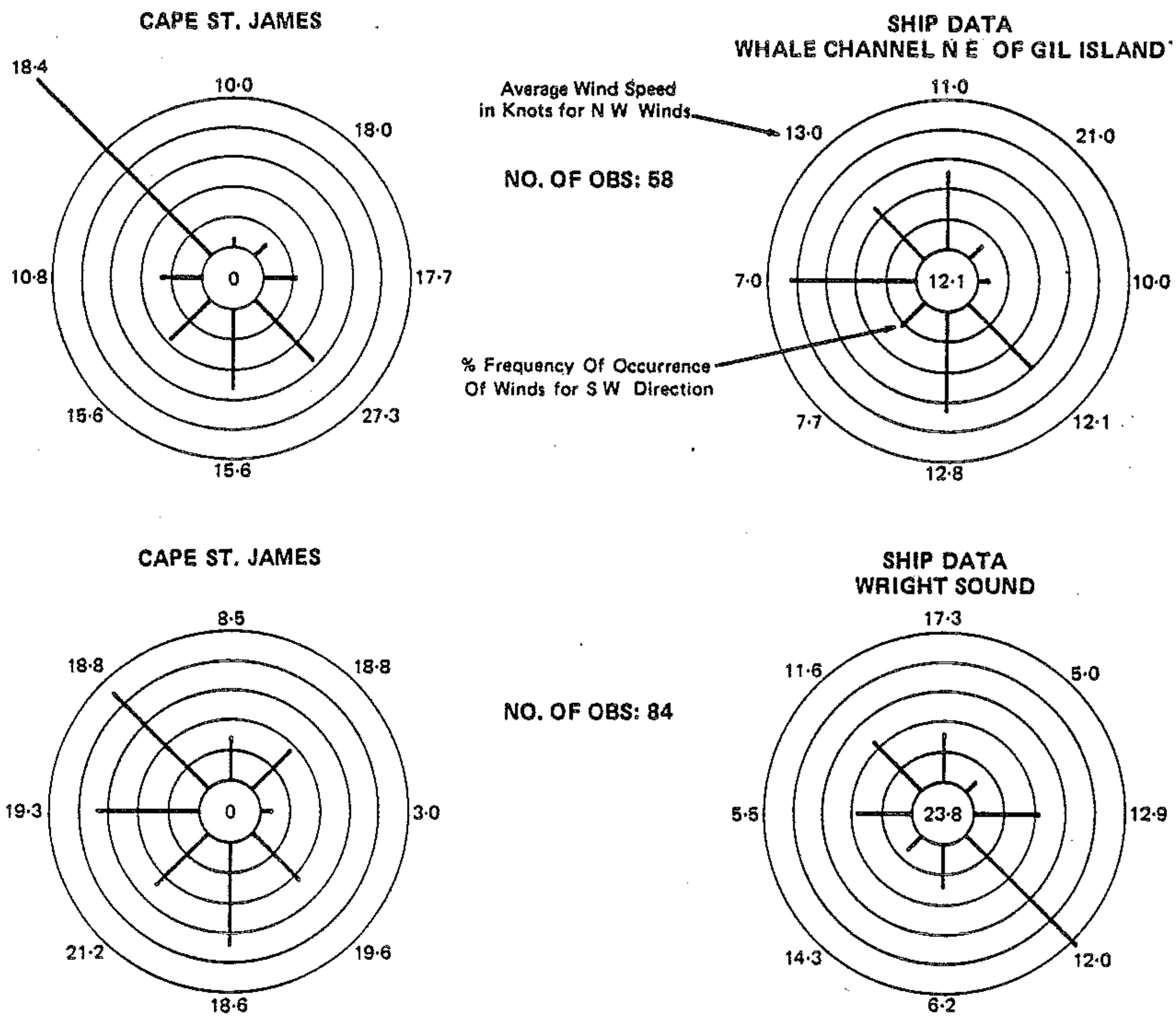


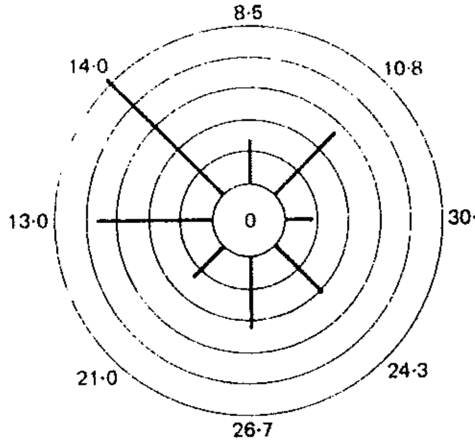
FIGURE 7a SIMULTANEOUS WIND ROSES BETWEEN SHIPS AND CAPE ST. JAMES



(Each concentric circle 5%; calm frequency (%) in centre of rose; windspeed in knots)

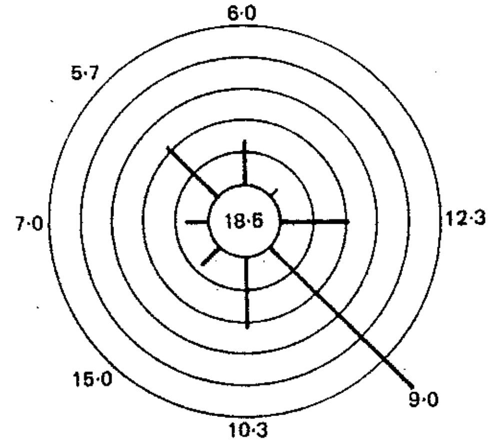
FIGURE 7b SIMULTANEOUS WIND ROSES BETWEEN SHIPS AND CAPE ST. JAMES

CAPE ST. JAMES

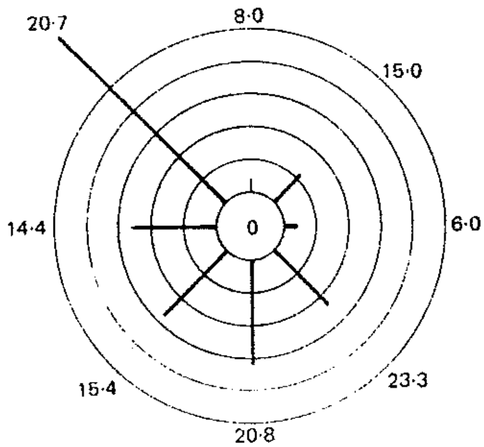


NO. OF OBS: 27

SHIP DATA
DOUGLAS CHANNEL

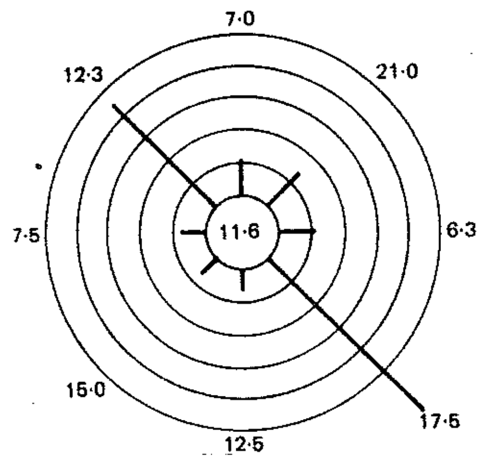


CAPE ST. JAMES

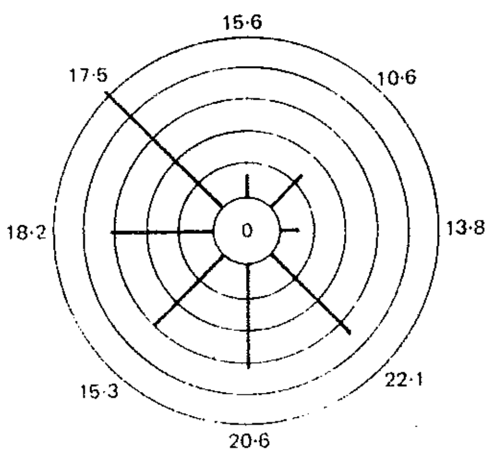


NO. OF OBS: 52

SHIP DATA
PRINCIPE CHANNEL



CAPE ST. JAMES



NO. OF OBS: 240

SHIP DATA
GRENVILLE CHANNEL

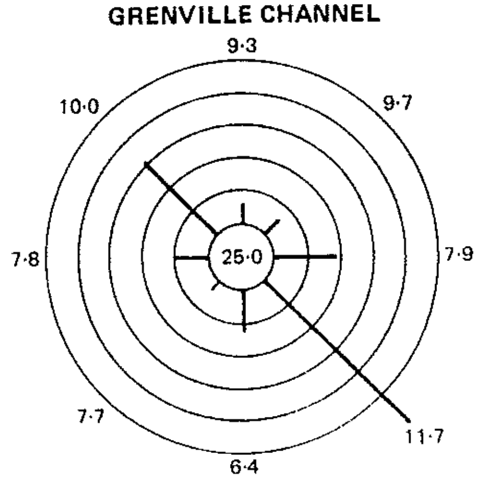


FIGURE 8 PERCENTAGE FREQUENCY OF OCCURRENCE OF SIGNIFICANT WAVE HEIGHT

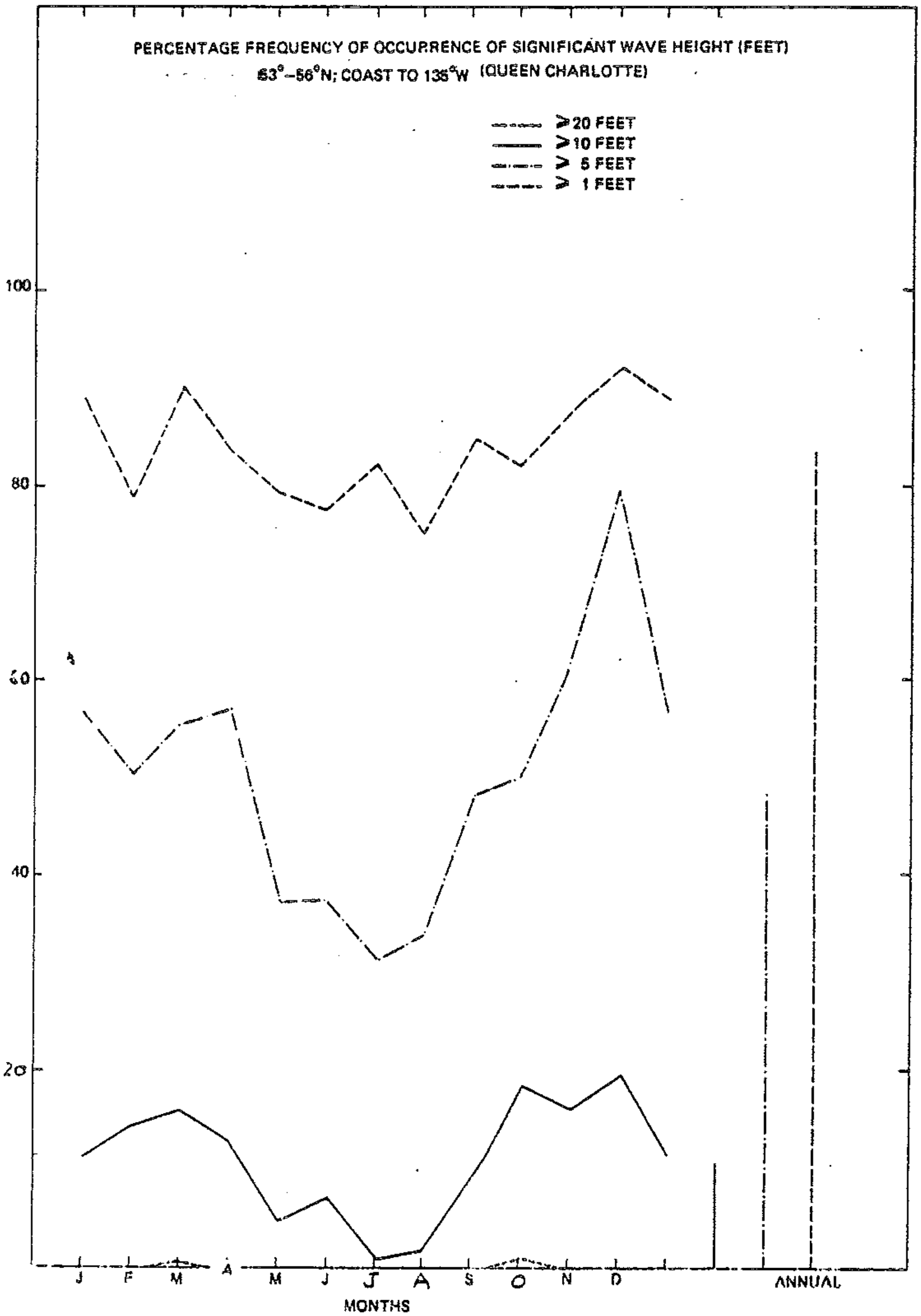


FIGURE 9 EXTREME VALUE ANALYSIS OF SIGNIFICANT WAVE HEIGHTS NEAR CAPE ST. JAMES

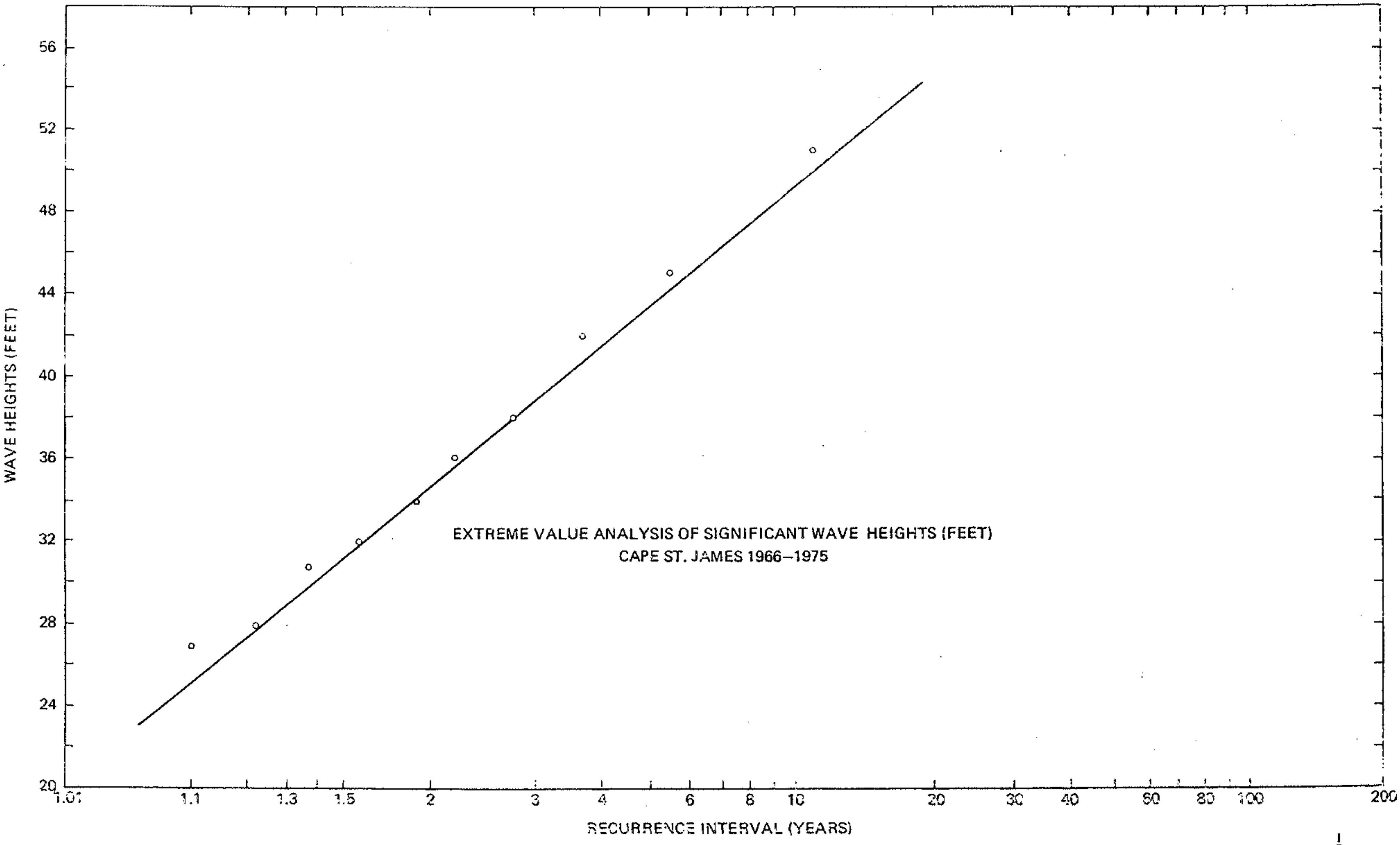


FIGURE 10a PERCENTAGE FREQUENCY OF OCCURRENCE BY WIND DIRECTION OF OBSERVATIONS WHEN VISIBILITY IS ½ MILE OR LESS FOR JANUARY

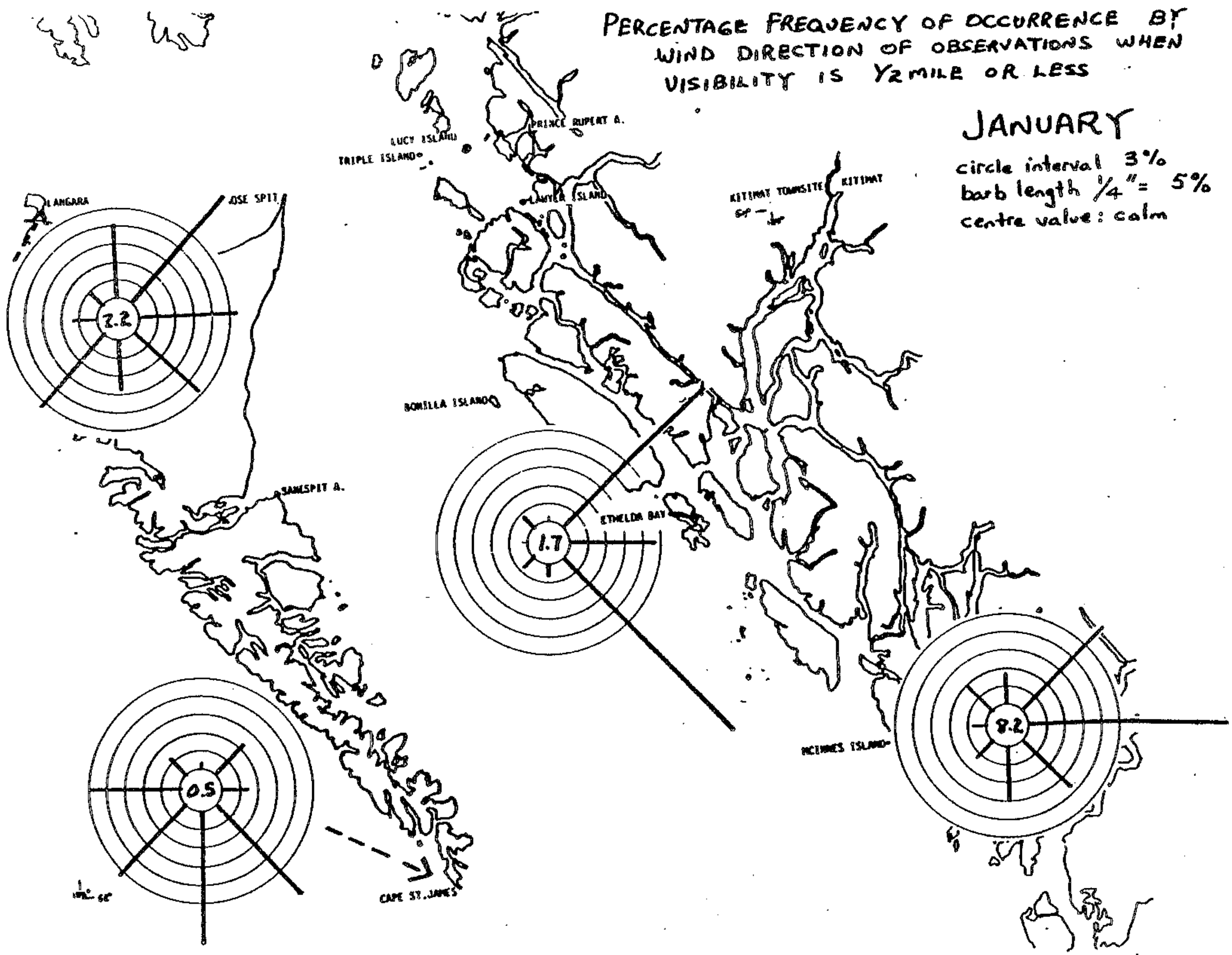


FIGURE 10b PERCENTAGE FREQUENCY OF OCCURRENCE BY WIND DIRECTION OF OBSERVATIONS WHEN VISIBILITY IS ½ MILE OR LESS FOR APRIL

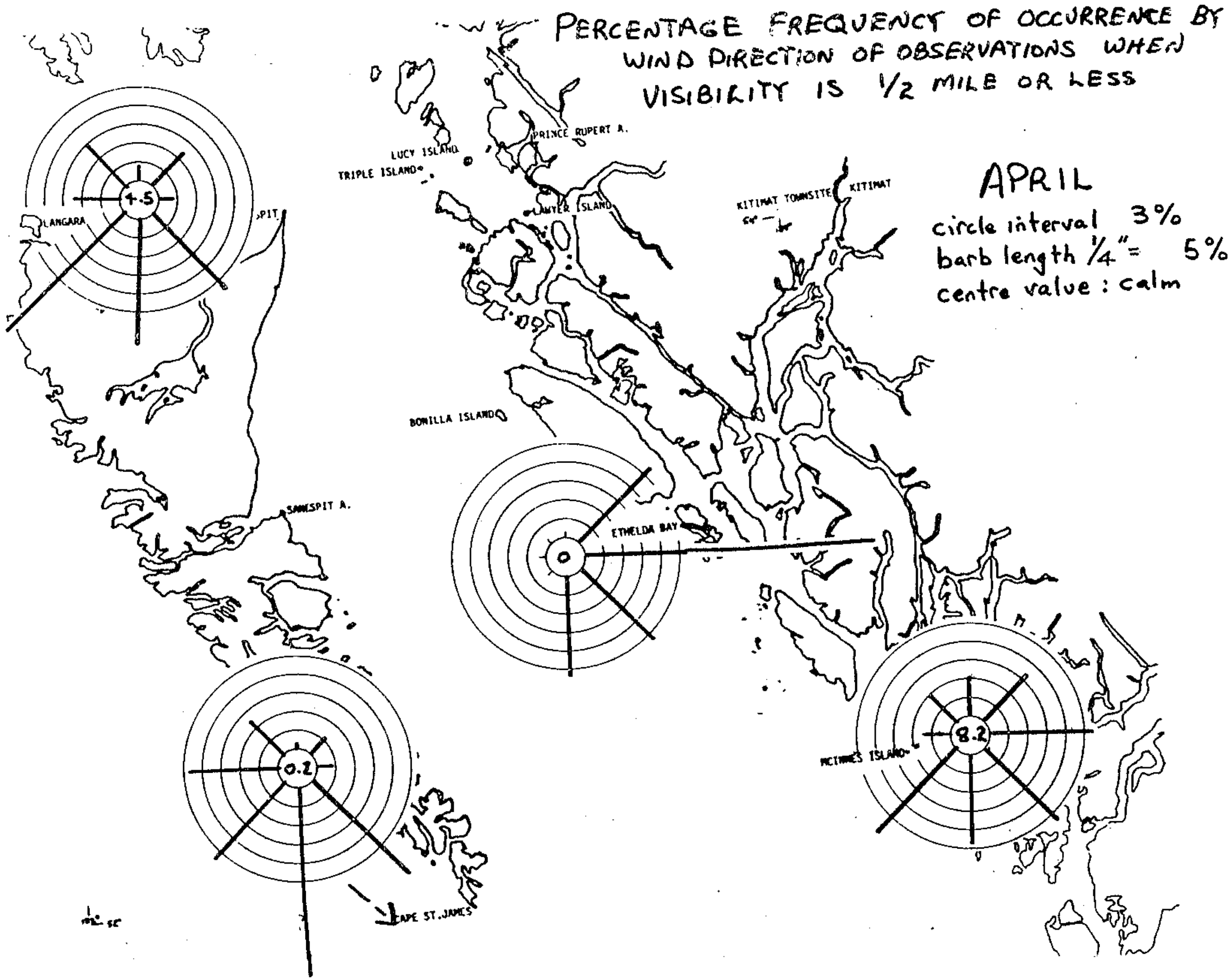


FIGURE 10c PERCENTAGE FREQUENCY OF OCCURRENCE BY WIND DIRECTION OF OBSERVATIONS WHEN VISIBILITY IS ½ MILE OR LESS FOR JULY

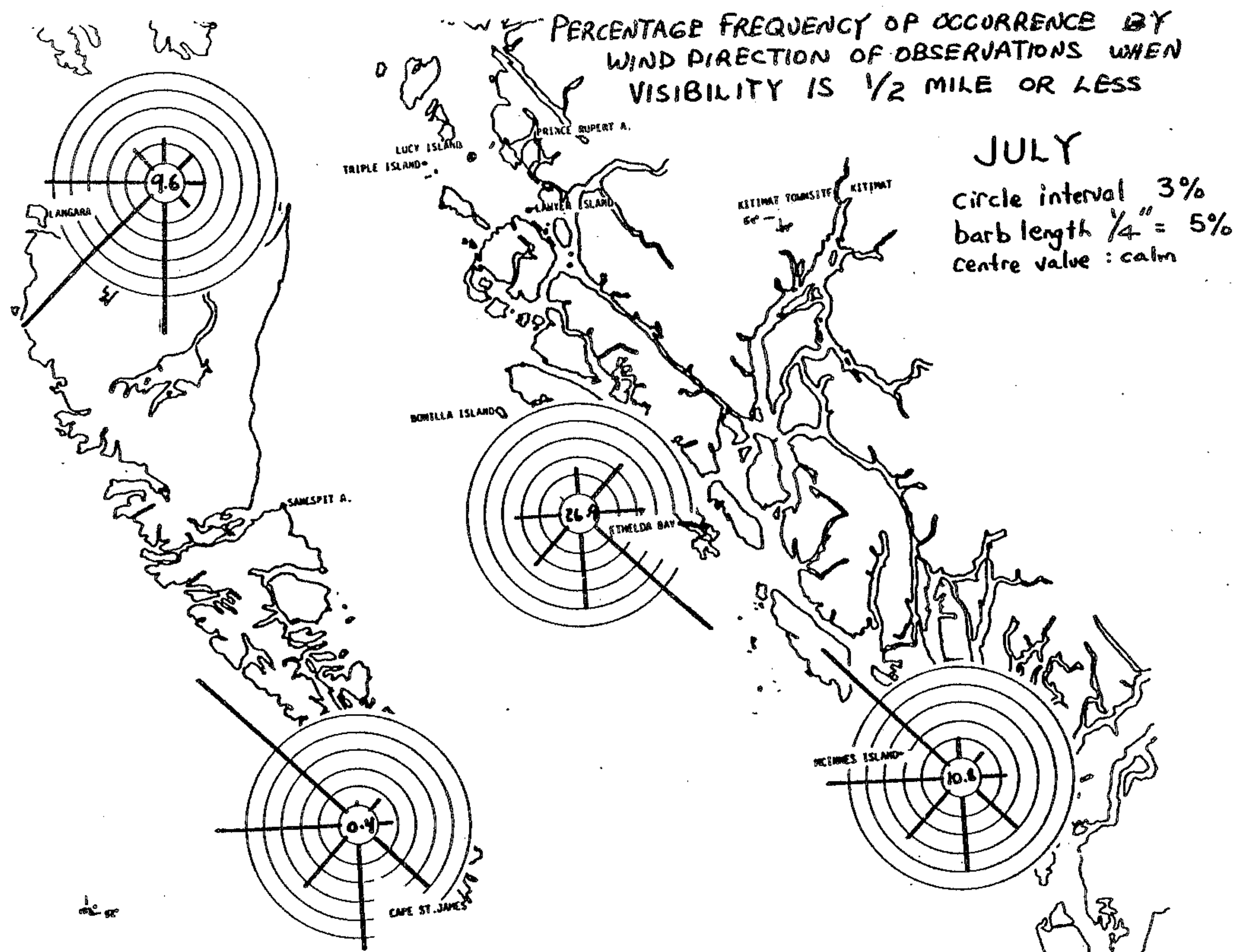


FIGURE 10d PERCENTAGE FREQUENCY OF OCCURRENCE BY WIND DIRECTION OF OBSERVATIONS WHEN VISIBILITY IS ½ MILE OR LESS FOR OCTOBER

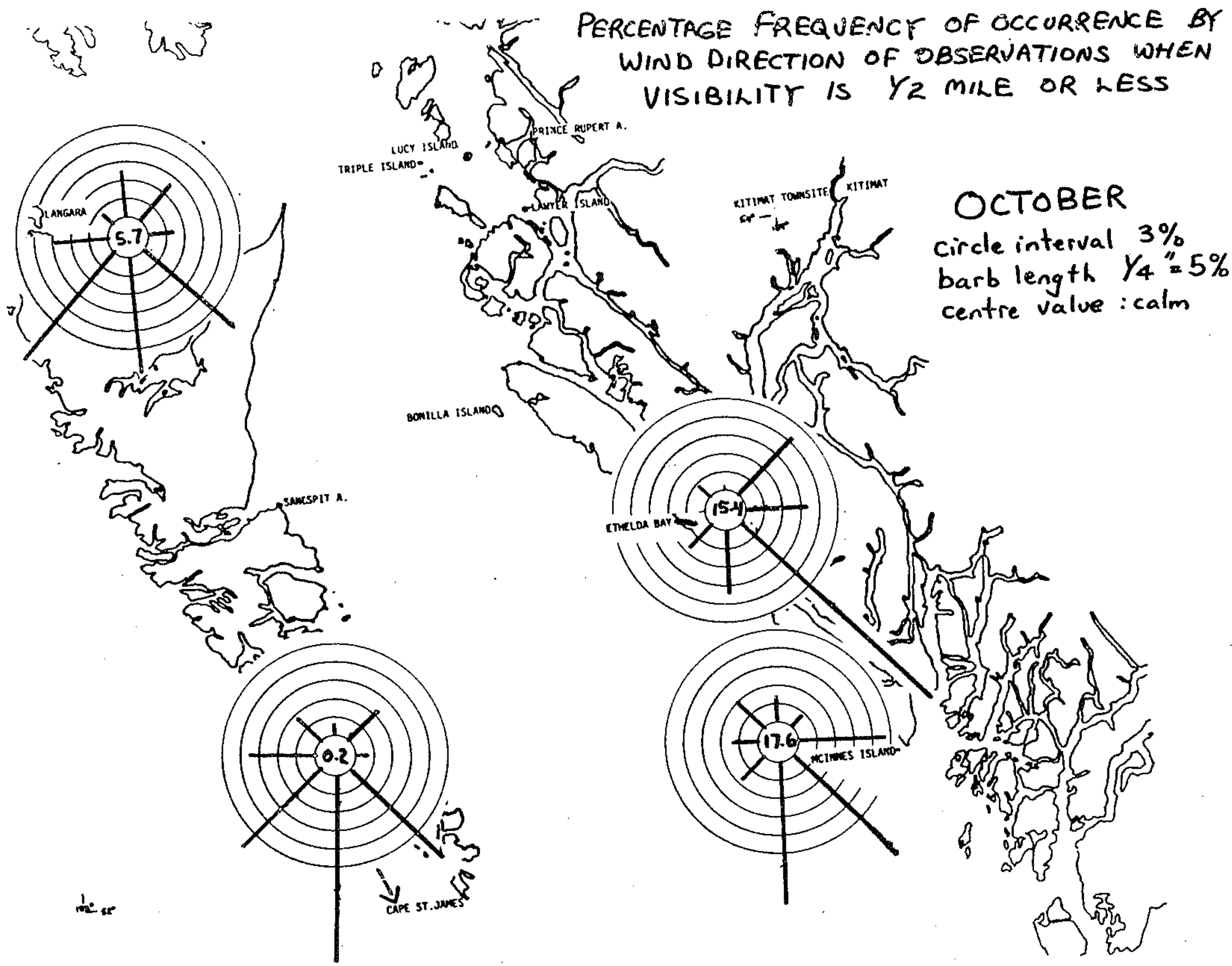


FIGURE 10e PERCENTAGE FREQUENCY OF OCCURRENCE BY WIND DIRECTION OF OBSERVATIONS WHEN VISIBILITY IS ' MILE OR LESS

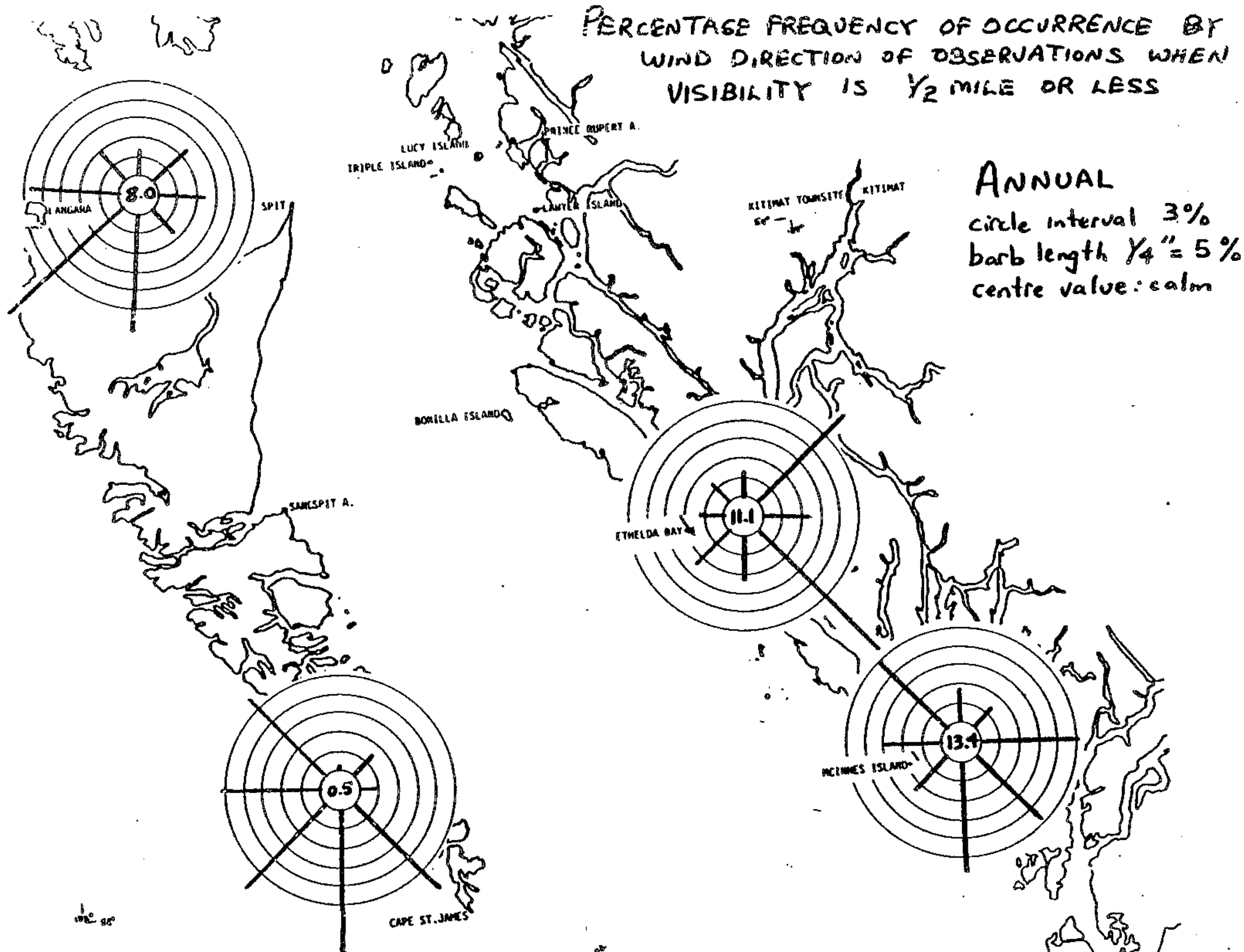


FIGURE 11 SHORT DURATION RAINFALL INTENSITY-DURATION-FREQUENCY DATA FOR KITIMAT 2

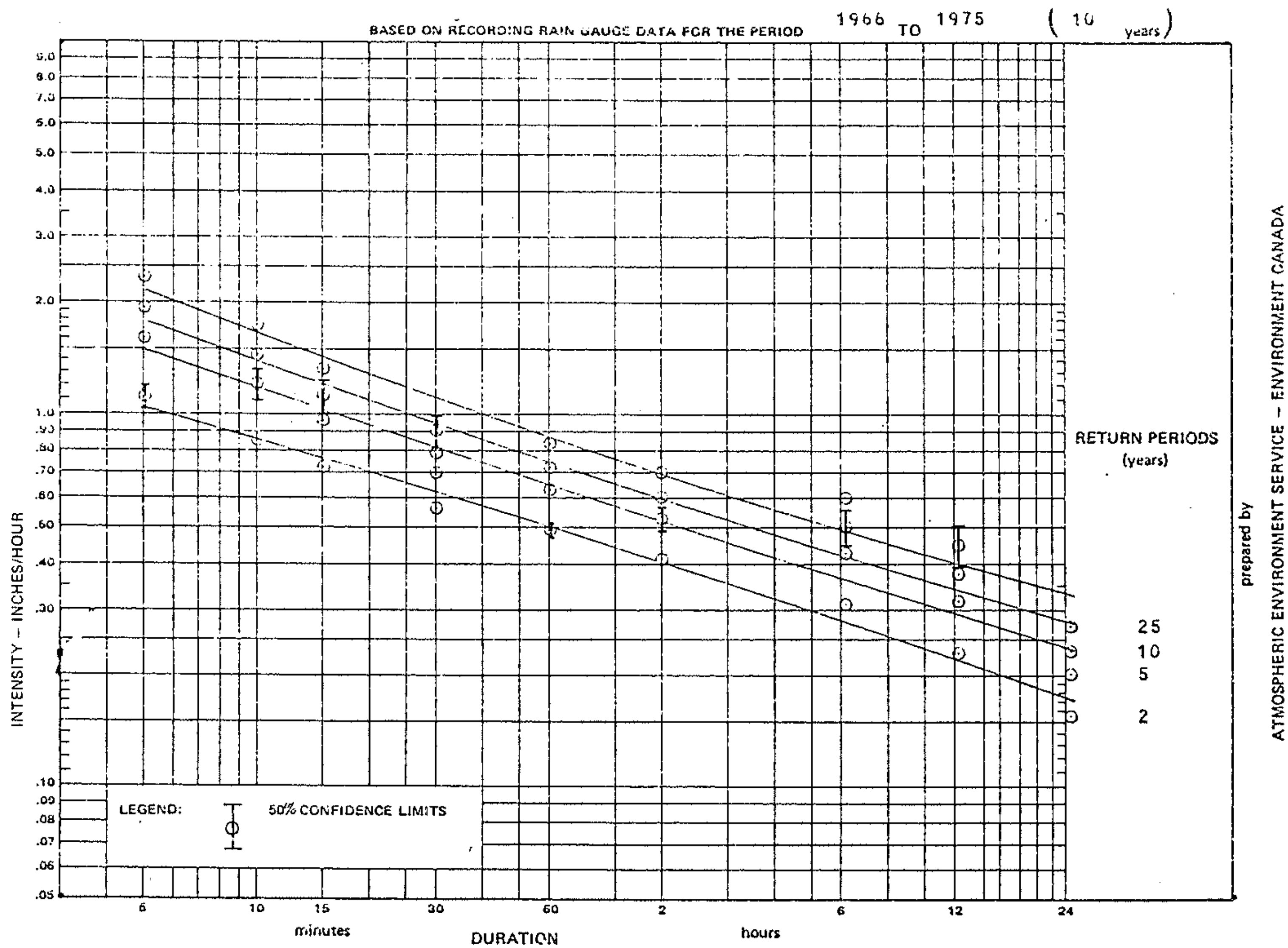


FIGURE 12 PERCENTAGE FREQUENCY OF OCCURRENCE OF GOOD SHIPPING WEATHER