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A PRELIMINARY ANALYSIS OF WEATHER AND WEATHER-RELATED FACTORS IN LANCASTER SOUND

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A PRELIMINARY ANALYSIS OF WEATHER AND WEATHER-RELATED FACTORS IN LANCASTER SOUND

1. Introduction

The objective of this study is to provide estimates of weather and weather-related factors that could have a significant effect on offshore drilling operations in Lancaster Sound. Winds, waves, visibility, and structural icing caused by freezing spray are described in terms of the average and extreme values that can be expected to occur during the part of the year in which the Sound is not ice covered. Where possible, values are compared with those from areas where offshore drilling has already taken place or is proposed.

It should be noted that exploratory drilling in Lancaster Sound is unlikely to pose any serious threat to the atmospheric environment. Weather and related factors, however, are important because of their potential impact on operations offshore, and in the event of an oil spill, on the motion of the oil and its containment. In addition, weather elements and their year-to-year variation need to be considered in the assessment of other aspects of the environment.

2. Area of Study

Lancaster Sound is located in the Eastern Canadian Arctic, bounded by Devon Island to the north and the north shore of Baffin Island to the south, see Figure 1. In this study the east and west boundaries have been arbitrarily located at 79° and 89° west longitude. The centre axis of the Sound is at approximately 74° N. latitude. Mountains capped by ice, marking the eastern end and opening to Baffin Bay attain an altitide of 1,524 metres. At the western end the Sound leads directly to Barrow Strait, between Somerset and Cornwallis Islands. The Resolute weather station is on the south side of Cornwallis Island. Except for a limited number of observations from ships, all observations of winds and air temperatures used in this project were taken from the records of this station.

The current station at Resolute is located in a flat valley about 61 metres above sea level. Hills rise to between 152 and 244 metres to the northeast, and to the southwest a hill rises to 183 metres about 3.2 kilometres away. The dome shape of Cornwallis Island reaches a maximum height of 305 metres near the centre. Although Resolute is over 300 kilometres from the centre of the study area, it was considered to have the best location for observations representative of Lancaster Sound.

3. Data Sources

Most of the wind and temperature values used were obtained from observations made at Resolute. Three-hourly observations were interpolated for the years 1954-1956 and 1959-1971. Hourly observations were available for the years 1957-1958 and 1972-1975. In addition, about 1,800 observattions from ships in Lancaster Sound obtained from the National

Oceanic and Atmospheric Administration (NOAA) were used. Most of the latter were made between 1947 and 1973, in either August or September.

Information regarding the ice cover in Lancaster Sound for the period 1959-1975 was taken from the historical charts of Ice Forecast Central (Atmospheric Environment Service) in Ottawa and from the United States Navy Hydrographic charts for 1954-1958.

4. Ice Cover

In the early stages of this project the importance of sea ice cover became evident. In addition to being the major determinant of the length of the drilling season, the presence of ice reduces the severity of waves and structural icing to a degree determined by its extent and location. In view of this, a few notes on ice behavior are included here.

Areas of open water usually developed in Lancaster Sound towards late June. These usually began as a patch just east of 85° west or as an open area at the eastern end of the Sound, and a tongue extending along the eastern shore of Devon Island. Often by the end of June the entire Sound was open but blocked by dense covers at each end. July was the most variable month. Often openings found in June closed as ice moved about the islands. When the sound was open, the most significant feature was the Baffin Bay ice pack which frequently extended across the fetch of easterly winds. ("Fetch" in this context means the distance along open water over which the wind blows. It is one of the factors that determine wave heights.) This ice pack frequently reduced fetch lengths during August in the wave hindcasting section of the study. At other times in August, however, when the Baffin ice pack drifted south, open water extended as far as the west coast of Greenland and fetches of 900 kilometres were observed. Ice drifted into the sound from around Cornwallis Island and Barrow Strait to block westerly fetches periodically throughout the season. The most consistently open period of the year was late August and early September. Limits to fetches at this time consisted of remnants of the Baffin ice pack or patches of ice that drifted south from Smith Sound and the northern reaches of Baffin Bay. The end of September frequently found the Sound covered with new ice. Only on rare occasions did significant open water exist past the second week of October. The general pattern was for temperatures to fall rapidly some time in September with new ice forming shortly thereafter. It was common for a completely open condition to exist one week and complete cover the next, in contrast to the gradual opening during June and July.

5. Wind

Values of offshore wind are needed to calculate waves and structural icing from freezing spray. In addition, very strong winds may directly disrupt offshore operations. A knowledge of the wind regime is also needed to assess the motion of spilt oil.

As mentioned previously, wind data are sparse in the Lancaster Sound area. The available ship observations are irregular in both space and time, and limited in number. The only long series of regular observations considered useful was that from Resolute. The ship data provide useful information regarding the "normal" distribution of offshore winds. However, it was necessary to use the Resolute observations to derive storm winds.

Various methods exist to estimate offshore winds from available meteorological data. The method used in this study was to adjust the coastal values observed at Resolute by use of the equation:

$$\frac{V_w}{V_l} = \left(\frac{Z_g}{10}\right)^N = R \qquad (1)$$

where V_w/V_l is the ratio of over-water to over-land winds, Z_g is the height in metres of the gradient level (level at which the wind becomes free of the influence of local topography), and N depends on the properties of the atmosphere and local topography. This is the same method used by Berry, et al (1974) in a study of Beaufort Sea winds. For a detailed discussion of this method, and the relative merits of several other methods the Beaufort Sea study should be consulted.

Because of the effects of the terrain on the wind in the Resolute area, the application of equation (1) required that R be made a function of wind direction and atmospheric stability. The values used were the following:

Wind Direction (degrees true)	Atmospheric Stability		
	Unstable < -5.5 °C	Neutral -5 to +5 °C	Stable > 5.5 °C
050-110	1.10	.80	.70
010-040, 120-160	.90	.80	.90
170-360	1.40	1.20	.90

The temperature values used in the table represent the difference between air temperature and water temperature. Values of R were derived empirically, based on studies by Wilson (1959), Findlater, et al. (1966) and Richards, et al. (1966), supplemented by data prepared for this study. They cannot be used for wind speeds of less than 37 km/h (20 kts).

Estimated maximum offshore winds for various return periods and durations are given in Table 1. The values were derived by fitting a Gumbel (extreme-value) distribution to the data. The basic analysis was of hourly wind speeds, and is illustrated as Figure 2. Values for longer durations were based on adjustment factors from Draper and Wu (1969).

In this study it was not possible to provide an analysis of the directional frequency of strong offshore winds. However, consideration of the direction of winds over 63 km/h (34 kts) at Resolute, and from ship reports, suggests that thirty to fifty per cent of offshore winds of this strength will be from the east or northeast, but that they may occur from any direction.

When using these wind data the following points should be kept in mind.

- The analysis is based on 25 years of data. Wind values for return periods of length much in excess of this time period must be used with caution. This is reflected in the confidence intervals in Figure 2.
- The results are not applicable to areas where major topographic features may channel the wind. Locations near steep, high cliffs adjacent to the coast, and major valleys are examples. Evaluation of wind regimes in regions such as this requires a site-specific treatment.
- For adjustment purposes, in the July-to-October period, it is assumed the sea has the characteristics of open water.

Percentage frequencies of various wind-speed classes are given in Table 2 for Resolute and Lancaster Sound. The latter are based on ship observations. July and October are excluded because of an insufficient number of reports. For both Resolute and the Sound a normal distribution was fitted to the data to obtain the values in the table. It indicates that, for August and September, winds of 21-25 kts and above occur with about the same frequenty at Resolute as offshore.

Figure 3 gives directional frequencies of wind speeds for Resolute and Lancaster Sound. In this case, there is a substantial difference between the two areas, primarily because of terrain and sea- or land-breeze effects. The sharp increase in north and northeast winds in September at both locations is to be noted, however, as is the sharp decrease in westerly values.

6. Extreme Wave Study

Wave hindcasting has come to play an important role as man extends his world into the marine environment. In the design of coastal and offshore structures it is necessary to understand the stresses waves may exert during an extreme event. The object of this portion of the study is to develop an extreme deep-water wave climatology for Lancaster Sound using standard hindcasting techniques. A common method of wave hindcasting and one recommended by the United States Coastal Engineering Research Center when limited time and data are available is the Sverdrup-Munk-Bretschneider method. This method makes use of forecasting curves based upon empirical equations and the above reference is recommended for further detail (USCERC, 1973).

In order to use the SMB method some basic assumptions were applied to the Lancaster Sound situation. First no attempt was made to estimate the existing wave field; each event was assumed to start with a calm sea. Only those storms having wind directions within the bounds of 64° to 105° true, for easterly blows, and 250° and 286° for westerly storms were selected for analysis. These radials are based upon a reference point located in the middle of the sound at 84° west longitude. In this manner winds from other directions were eliminated on the assumption that short fetches limited the generation of waves significant to a study of extremes, and that the surrounding islands protect the Sound from direct contact with the wave field. For all events considered in this manner fetch was measured along the center radial of the corresponding sector. These were 84.5° true for easterly winds and 268° for westerly winds.

Wind observations at Resolute for the years 1954-1975 were searched to select potential extreme storms. For each month of each season four or five wind events were selected to cover the month's duration. This ensured that the worst storm was not likely to be overlooked and if ice was observed part of the month a storm had been selected for the open part of the month. Each storm was assigned a duration that would yield the maximum wave height. For example, if an event's average wind speed was 32 kilometres per hour for a 20-hour duration the hindcasting curve yields a wave height of 2.5 metres. However, if four hours of that duration produced an average wind speed of 64 kilometres per hour, the resultant wave height would be 2.5 metres and the shorter duration would be considered for the study. The list of storms was then compared with the ice charts; and the monthly extreme storm, during open water conditions at the reference point, was selected for analysis. Fetch for this storm would be measured from the reference point along the proper radial to the nearest shore or ice pack using the ice chart which corresponded to the dates of the storm.

Both values of fetch and duration were used to enter the Bretschneider curve and determine the significant wave height used in the extreme value analysis. A Gumbel analysis of season extreme storms was made using the most extreme event selected each year. It is important to note that the Bretschneider curves yield significant wave height and this is the value plotted for each storm in Figure 4. Significant wave height is the average height of the highest one-third of all waves observed. The highest wave is estimated to be 1.8 times this value (Thom, 1971).

Results

The highest wave height occurs in September at 5.5 metres. This suggests the occurrence of extreme waves in the order of 7.7 metres. Figure 4 indicates that the fifty-year event would produce a significant wave of 6.3 metres and hence an extreme wave of 8.8 metres.

7. Structural Icing

Structural icing has long been a menace to fishing fleets operating in waters where sub-zero air temperatures are frequently observed. Although freezing temperatures are an obvious requirement for icing to occur, to specify the precise meteorological conditions has proved to be a problem for researchers. Shellard (1974) provides a thorough review of the literature and discussion of the problems involved with estimating ice accretion. A basic problem is the difficulty of observing at sea a phenomenon that is purposely avoided by vessels. In addition, reports which are made may contain errors because of inexperienced observers, or the difficulties of making accurate observations in storms. In spite of these problems the icing environment has been studied and the conditions required for ice build up may be stated with some confidence.

For the purposes of this study structural icing in the marine environment has been separated into fresh-water icing and salt-water icing. The major differences between the two are the temperature at which each occurs and the moisture source.

In the marine environment fresh water must come from the atmosphere. Fresh water ice accumulation occurs during incidences of supercooling of water in the atmosphere or the freezing of wet snow, and occurs at temperatures of 0^{o}C or below. The best known example of supercooled moisture is freezing rain. At higher latitudes, however, supercooled advection fog or steam fog (arctic sea smoke) can be a significant contributor to icing events. The former may arise when warm air flows over a cold sea surface or ice cover, the latter when water evaporated from a relatively warm sea surface condenses and is supercooled in cold air. Each of these conditions depends upon the air flow being able to maintain the temperature gradient between the sea and air.

Fresh water ice frequently forms a hard glaze which is difficult to remove but salt water ice, due to the nature and conditions of formation is considered to be the most hazardous. It usually occurs when supercooled spray strikes the superstructure of a vessel. This happens during storm conditions when spray is blown from wave crests and is generated by the impact of the waves against the vessel. In order for freezing spray to occur the air temperature must be below the freezing temperature of the salt water being converted to spray. The amount of spray generated by the vessel depends on the design of the craft with respect to shape, and ability to be oriented in the sea to minimize wave impact.

The extent of the icing hazard is evident in descriptions such as Hay (1956). A vessel's problems may multiply from difficulty in handling high seas to losses of balance and buoyancy. Freezing spray tends to accumulate ice above the center of gravity while those parts of the ship close to the water line remain ice free. At the same time, an increase of weight to the windward side leads to listing and ice accumulation in bow areas, causing greater plunging into the waves and hence more spray. Hay suggests that these conditions may progress to the point where the sail area, due to ice accretion, makes capsizing imminent if the vessel attempts to turn away from the winds.

Due to the dramatic circumstances and possible consequences of sea spray icing a study of the potential conditions in Lancaster Sound is an important part of this study. A set of conditions was selected to meet the requirements of sea spray icing. These are based upon the widely accepted nomograms developed by Mertins (1968) and shown here in Figure 5. The first requirement is a wind speed greater than 40 km/h corresponding to the lowest beaufort force on Mertins' diagrams. Whenever this condition was met the corresponding air temperature was examined and if Mertins' threshold of 2°C was met then a potential for sea-spray icing was assumed. Using this method the extreme storms for each year 1954-1975 were selected and hourly data for wind and temperature punched onto computer cards. The extreme storm consisted of a combination of longest duration, highest winds, and coldest temperatures relative to the other events each season. For a given year the season of potential icing was considered to end as soon as 25 per cent of Lancaster Sound was covered by at least three-tenths ice. The list of twenty-two storms was evaluated using Gumbel extreme-value analysis.

A second step in the procedure was to select all cases of severe icing for the period 1963 to 1974. These again were selected according to Mertins' wind and temperature criteria, differing from the extreme cases in that the threshold temperature was taken as -7°C and all events were included. These data were also transcribed onto computer cards.

The program used to convert the wind and temperature values into hourly icing rates was one used by A.E.S. for a similar problem in the Beaufort Sea (Berry at al., 1975). This program makes use of Mertins' nomograms to produce numerical relationships between the rate of ice accretion and each pair of wind and temperature values for a specified sea surface temperature. Examination of ship reports of sea surface temperature in Lancaster Sound resulted in using 0°C as a constant value of sea temperature when determining ice accretion rates.

Results

Figure 6 shows the return-period plot produced from the extreme icing events. The values plotted are total ice accreted for each of the 22 storms, and the dashed line is a best fit drawn by eye. Except for the most extreme storm all cases fall reasonably close to the line which yields a 50-year extreme storm totalling 15 cm of accreted ice.

Table 2 presents the results of the severe icing portion of the study. The first column presents rates of icing in cm/24hr by 5-cm increments. Seven cm/24hr is the first entry in the table because this is Mertins' threshold for severe icing as shown in Figure 18. To properly interpret the table the other three columns must be read as values at or greater than the specified rate. Consider the first entry. A rate of 7 cm/24hr is shown to have a maximum duration of 46 hours. This means that one event must have lasted 46 hours and although the rate may have been greater than 7 cm/24hr, it did not fall below that rate for the duration. The average duration of this condition was 7.4 hours, and the total number of hours at or above 7 cm/24hr is 265, from column four. Since

7 cm/24hr is the threshold for severe icing, column four for this entry displays the total number of severe icing observations during the 12-year period. This value divided by the number of years involved yields an average of 22.1 hours of severe icing per season, ranging from 8 to 77 hours. Using the period from the beginning of September to the time when ice inhibits spray formation as being on the average 986 hours long then severe icing may be estimated to occur 2.2 per cent of this time, mostly late September and October. It is important to keep in mind that the rates are expressed as cm/24hr and thus the single observation of 22.5 cm/24hr represents a total accumulation of .93 cm.

8. Visibility

It was necessary in this study to prepare estimates of visibility in Lancaster Sound from the limited number of ship reports available. There were enough observations in only August and September to allow estimates to be made, and even in these months the number available (1,142 and 507 respectively) did not permit a breakdown in terms of wind speeds, wind directions, or other parameters. Percentage frequencies of occurrence were as follows:

Visibility (nm)	< 1	< 5	≥ 5
(km)	< 1.6	< 8	≥ 8
August	9.7	19.0	81.0
September	3.4	15.0	85.0

9. Summary and Conclusions

It was not possible in this study to assess the effects of specific weather elements on the various components of an offshore drilling program, or on contingency plans. Some perspective, however, can be given to the data presented by comparing them with those from other areas where similar programs have been carried out or proposed, as in Table 4.

As indicated in the table, estimated wind and wave values for the Sound are substantially lower than those for most other areas listed. In the case of wind, this is primarily because the study was limited to the portion of the year when open water occurs; values computed on an annual basis would be considerably higher. To some extent the relatively lower wave values are a reflection of the lighter winds. However, the reduction in fetch by adjacent islands and by ice is also a factor. Low visibilities (as indicated by percentage frequency below 2 nm) are intermediate, being substantially higher than in southern areas like the Gulf of Mexico and South Coast of California, but lower than those off Newfoundland and in the Beaufort Sea. Ice accretion from freezing spray is estimated to be lower than in the Beaufort Sea, the only other area for which comparable data were available.

It should be noted, however, that an element-by-element comparison like the one above must be used with caution, since the simultaneous occurrence of two or more elements, not individually extreme, may pose a more serious hazard than the extreme occurrence of one. Furthermore, Lancaster Sound differs from most other areas where offshore exploration has occurred in that the presence of ice cover for most of the year severely limits the length of the open-water drilling season. In this regard, it should be noted that a combination of low temperatures, high winds and waves, and structural icing is most likely to occur in the latter part of the drilling season, and that consequently the date at which operations are to be terminated should be given careful consideration.

A better appreciation of offshore conditions would require the study of the relationships between, and variation in time of, weather, waves, and ice cover in individual synoptic events (such as storms).

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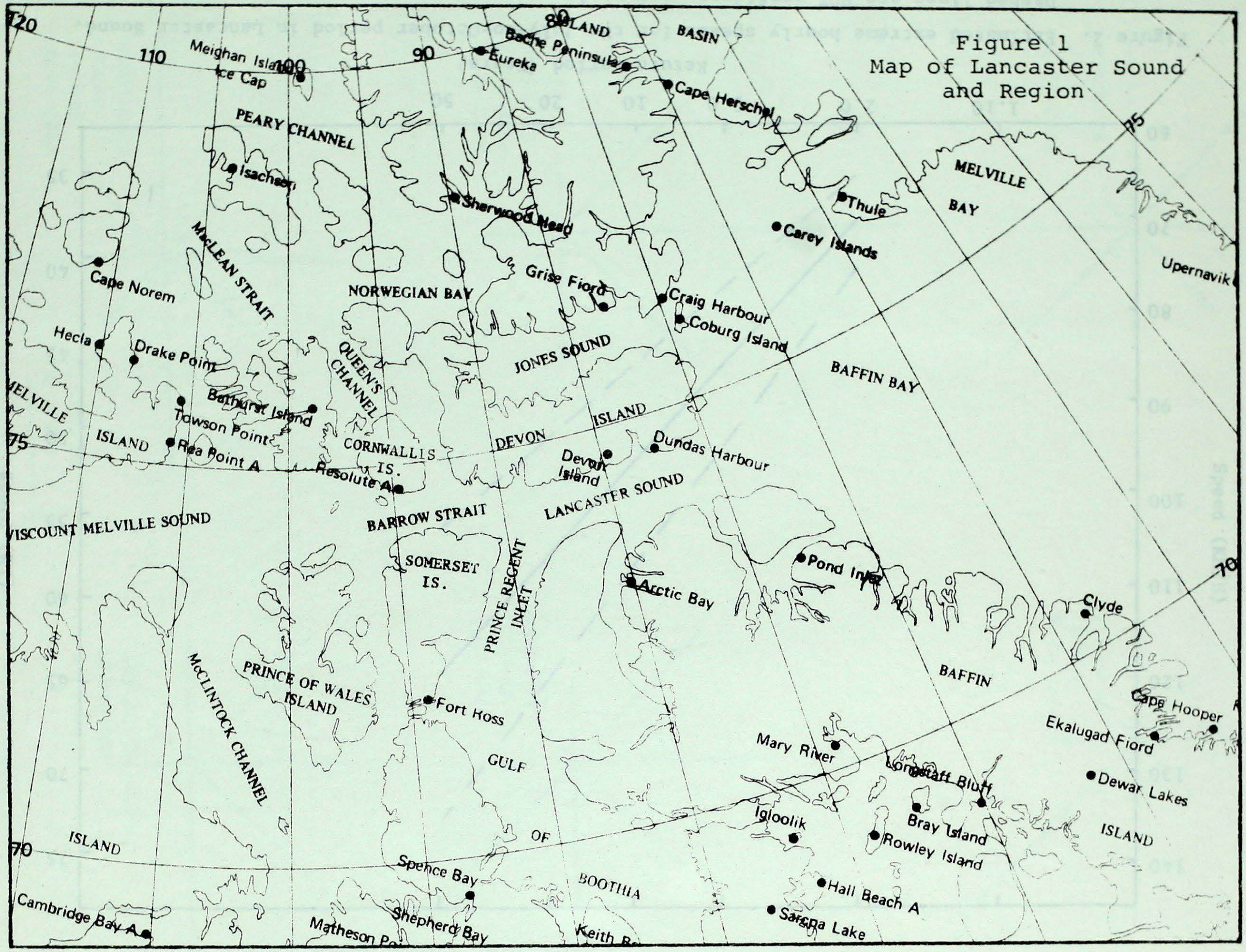
Figure 1
Map of Lancaster Sound and Region



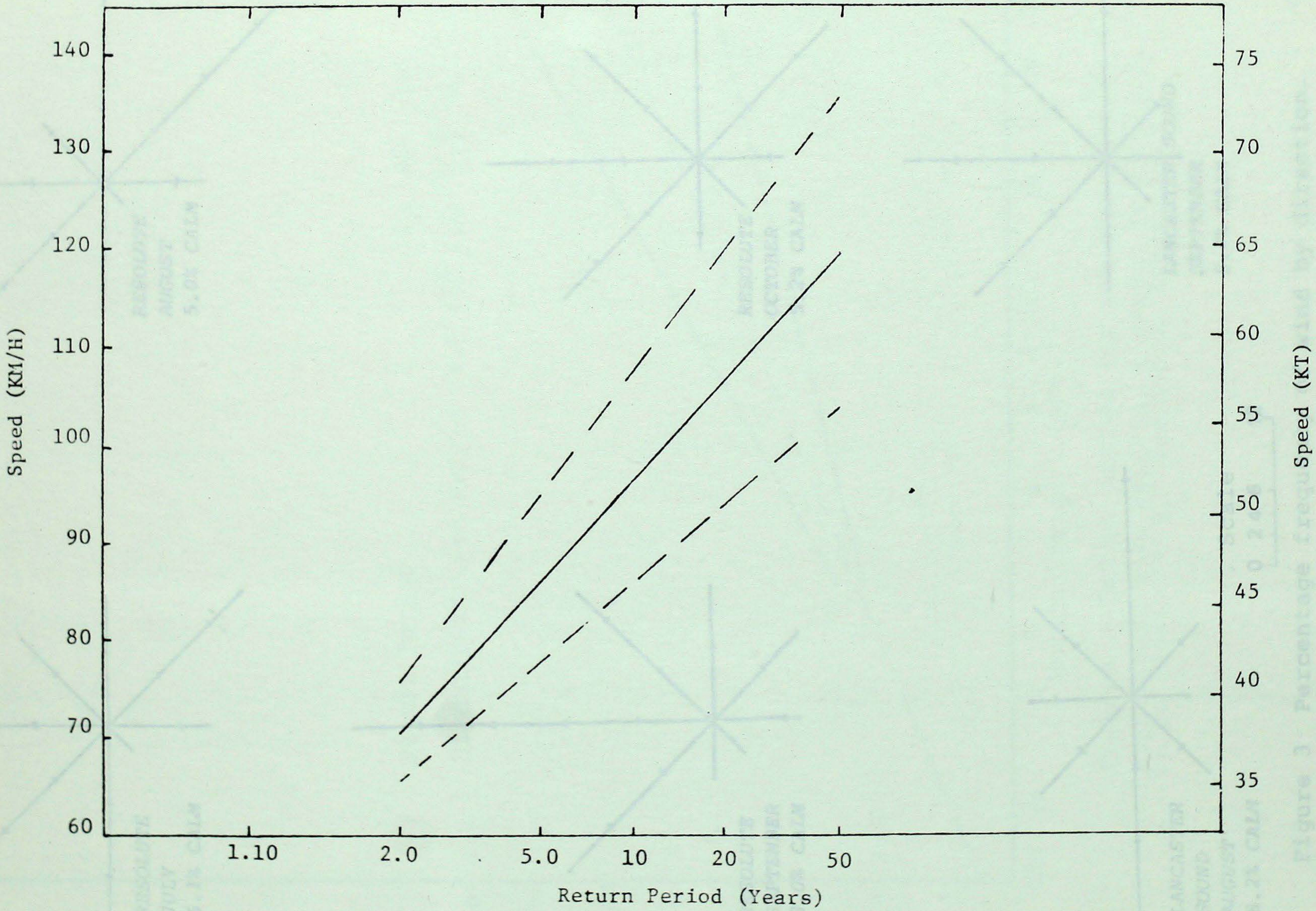


Figure 2. Estimated extreme hourly speeds for the July-to-October period in Lancaster Sound, Dashed lines are 90% confidence intervals.

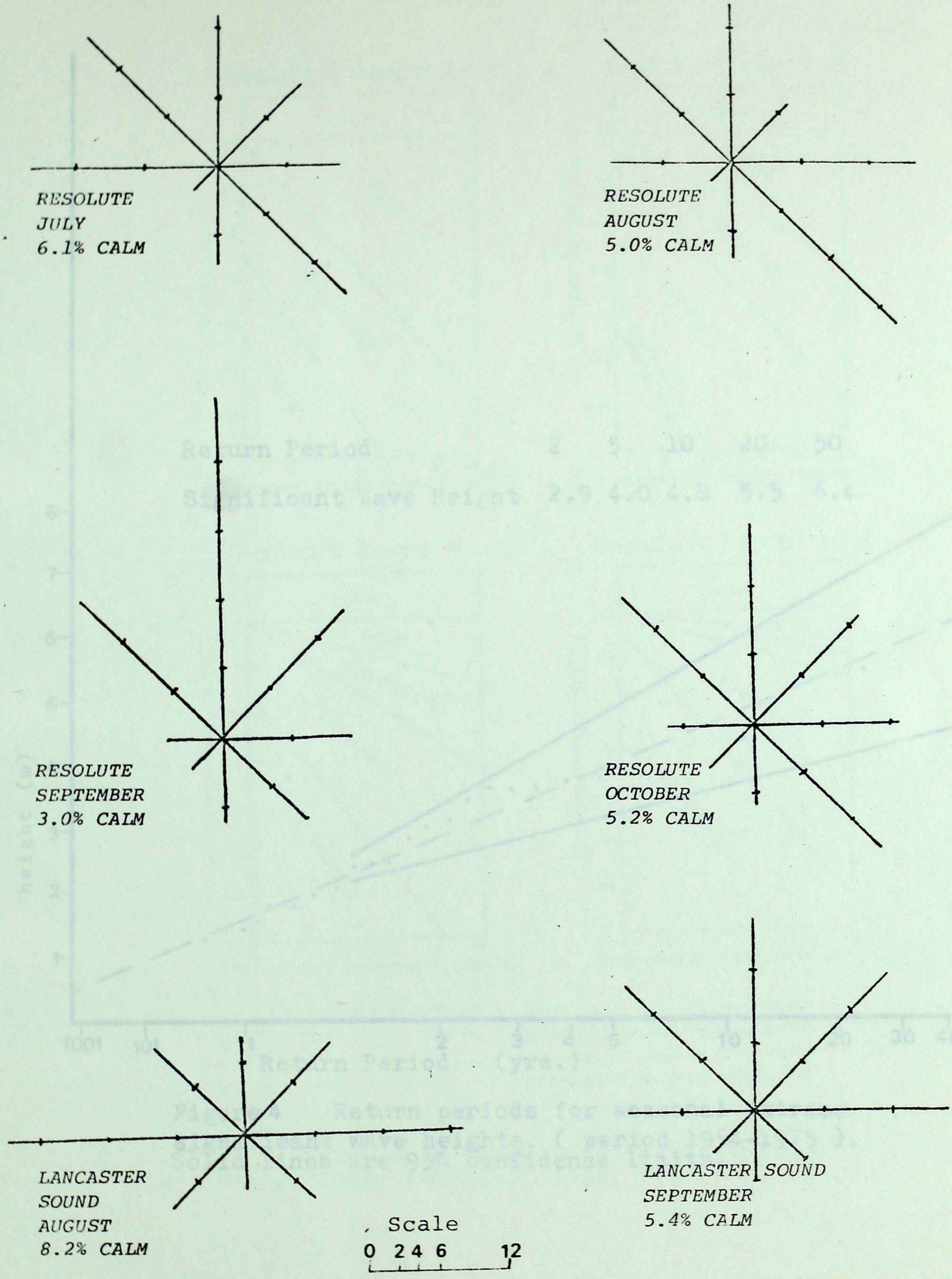


Figure 3 Percentage frequency of wind by direction.

Return Period	2	5	10	20	50
Significant Wave Height	2.9	4.0	4.8	5.5	6.4

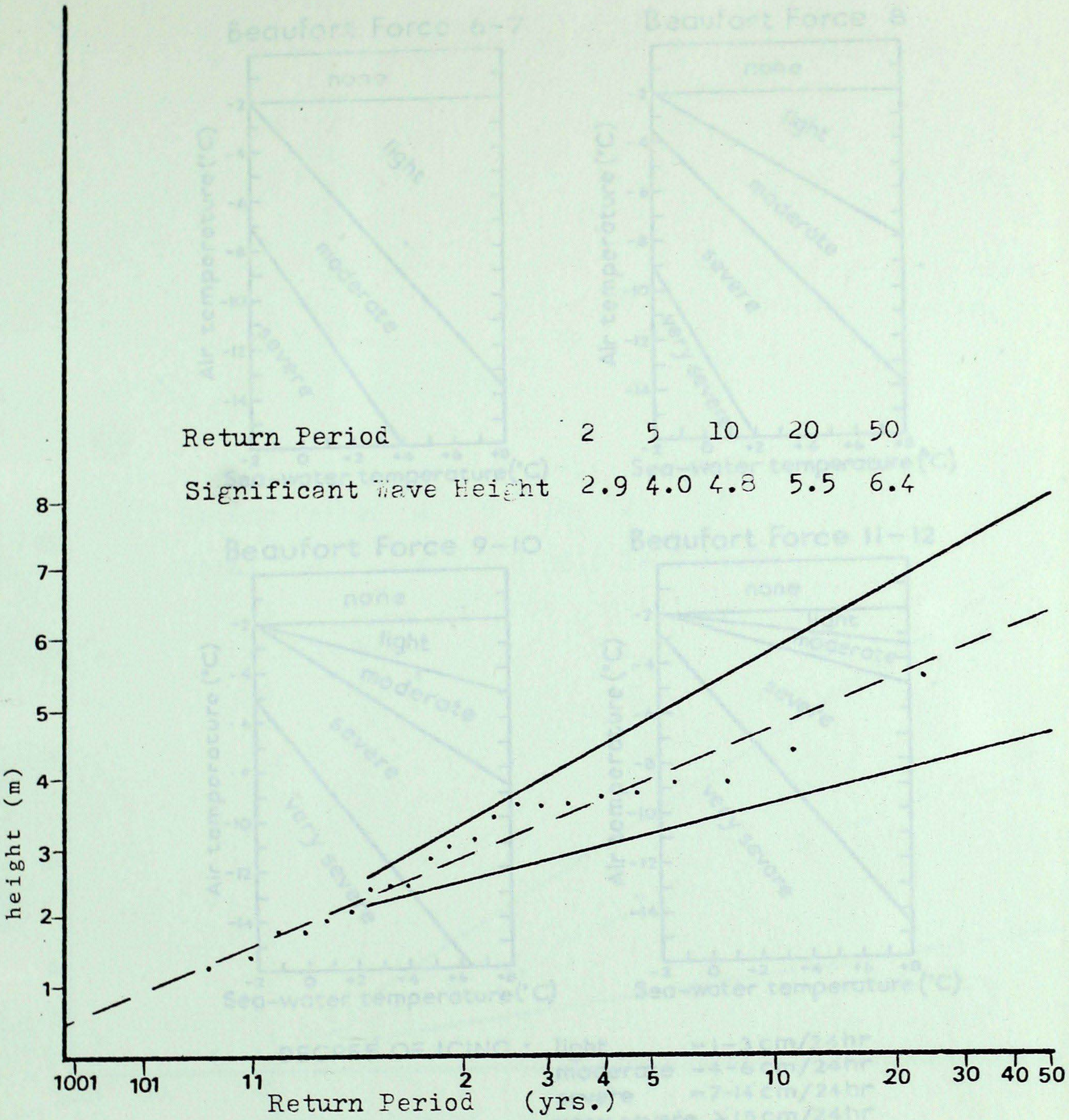


Figure 4 Return periods for seasonal extreme significant wave heights, (period 1954-1975). Solid lines are 95% confidence limits.

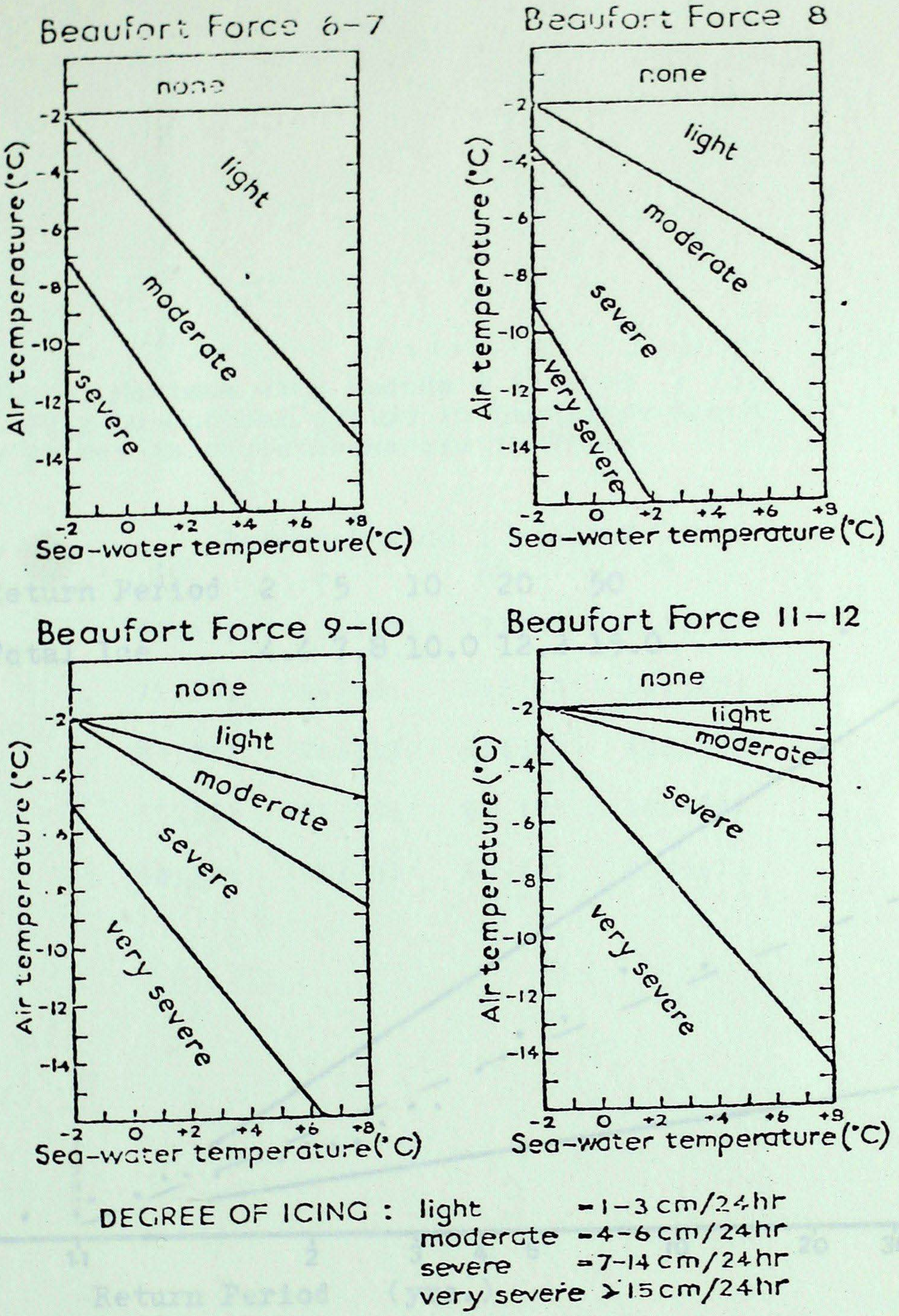
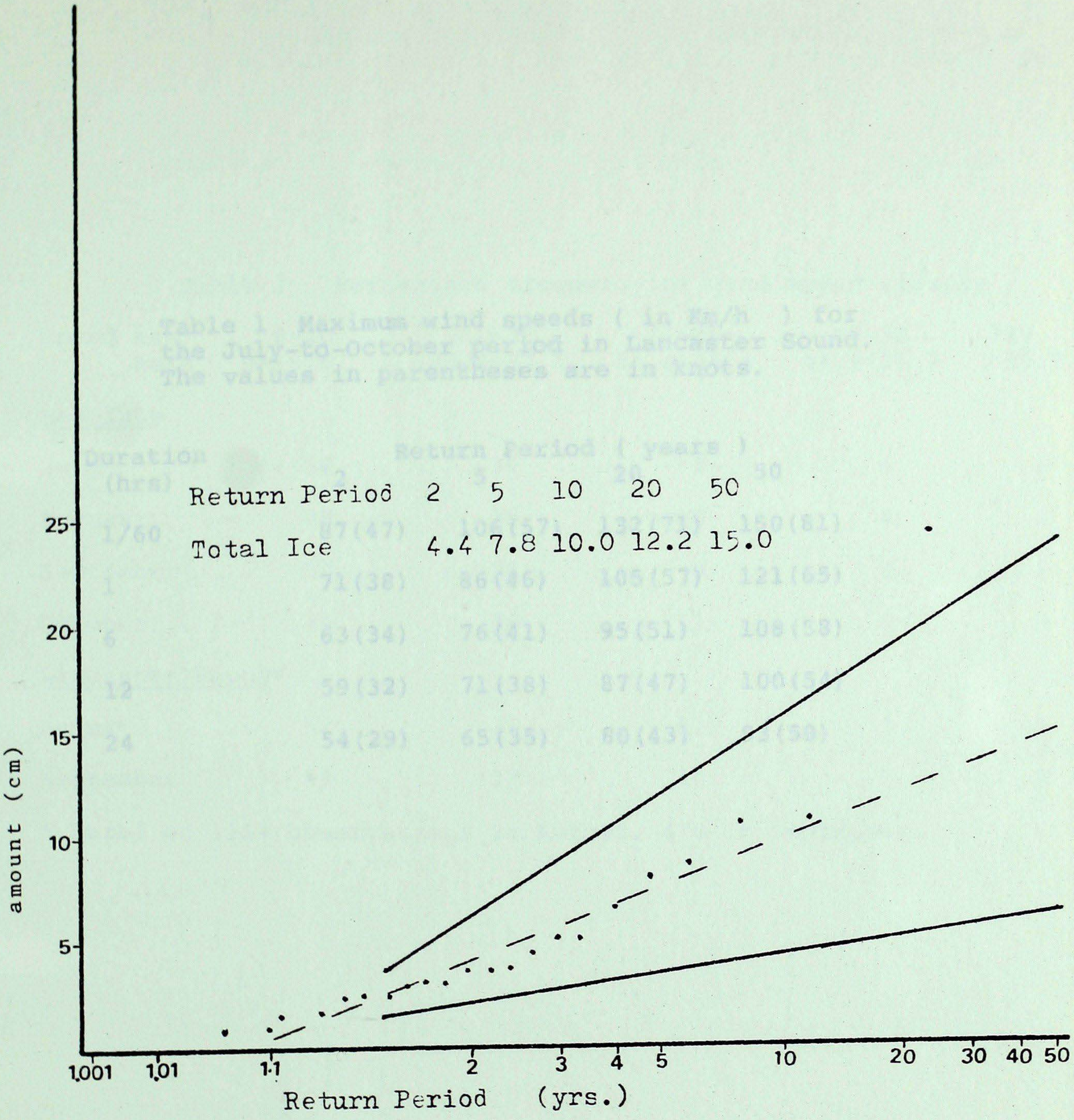


Figure 5 Conditions for Sea Spray Icing (Mertins, 1968)



Return Period	2	5	10	20	50
Total Ice	4.4	7.8	10.0	12.2	15.0

Figure 6 Return periods for extreme spray icing events, (period 1954-1975). Solid lines are 95% confidence limits.

Table 1 Maximum wind speeds (in Km/h) for the July-to-October period in Lancaster Sound. The values in parentheses are in knots.

Duration (hrs)	Return Period (years) 2	5	20	50
1/60	87(47)	106(57)	132(71)	150(81)
1	71(38)	86(46)	105(57)	121(65)
6	63(34)	76(41)	95(51)	108(58)
12	59(32)	71(38)	87(47)	100(54)
24	54(29)	65(35)	80(43)	93(50)

Table 2 Percentage frequency of wind speed classes

Speed kts km/h	0-10 0-18.6	11-20 20.4-37.1	21-25 39.0-46.4	26-30 48.2-55.7	>30 >55.7
Resolute					
July	54	32	8	4	2
August	48	36	10	4	2
September	50	35	9	4	2
October	44	36	11	6	3
Lancaster Sound*					
August	52	31	11	3	3
September	49	33	10	5	3

* Based on 1114 observations in August, 478 in September.

Table 3 Ice accretion from freezing spray in Lancaster Sound. Based on 12 years of data for *September* and October, see Section 7 for details.

Rate cm/24hr	Average Duration (hours)	Maximum Duration (hours)	Occurrences ≥ rate
7.0	7.4	46	265
7.5	6.8	45	239
8.0	7.0	44	224
8.5	7.3	40	203
9.0	7.2	36	173
9.5	6.3	25	150
10.0	6.1	23	134
10.5	5.6	19	122
11.0	5.3	14	105
11.5	4.7	10	94
12.0	4.8	9	77
12.5	4.8	9	72
13.0	4.7	8	66
13.5	4.3	8	60
14.0	3.5	6	46
14.5	3.6	6	32
15.0	3.6	6	29
15.5	3.6	6	25
16.0	3.5	5	21
16.5	2.8	4	17
17.0	2.0	4	12
17.5	2.0	4	8
18.0	1.7	3	5
18.5	2.0	3	4
19.0	1.5	2	3
19.5	1.5	2	3
20.0	1.5	2	3
20.5	1.5	2	3
21.0	1.0	1	1
21.5	1.0	1	1
22.0	1.0	1	1
22.5	1.0	1	1
23.0	0.0	0	0

Table 4 Estimated values of weather and related parameters for selected offshore areas. Sources: Quayle and Fulbright (1975), Berry, et al. (1975), and summaries of ship observations from the U.S. Navy, N.O.A.A., and the British Meteorological Office.*

Area	25-year return periods of extreme:			Percent frequency of occurrence of visibility <3.7k
	1-hour wind (km/h)	Significant wave (m)	Accreted ice (cm)	
Lancaster Sd.	109	5.8	13	12.2
Beaufort Sea	113	6.5	28-39	18.3
Gulf of Alaska	169	15.5	n/a	n/a
Sern. Nfld.	171	18.0	n/a	35.7
Nern. North Sea	n/a	n/a	n/a	11.0
Western Baffin Bay	n/a	n/a	n/a	25.2
South Coast Calif.	113	11.6	n/a	5.5
Gulf of Mexico	156	13.8	n/a	0.4

* Visibilities are for July, except for the Beaufort Sea and Lancaster Sound, which are for August. Wind and wave values are annual, except for the Beaufort Sea and Lancaster Sound, which are for the open-water season.