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The Climate of Northwestern Baffin Bay

by

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and

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ATMOSPHERIC ENVIRONMENT SERVICE

DOWNSVIEW, ONTARIO

1980

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THE CLIMATE

OF

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ABSTRACT

This report presents an assessment of the climate of the northwestern Baffin Bay area for the July-to-November portion of the year. The elements of the climate that are considered include climatic controls, wind, temperature, wind chill, precipitation, ceiling and visibility, aircraft icing, waves, structural icing, air pollution potential, and climatic variations. Analyses are generally presented in terms of means, extremes, percentage frequencies of occurrence, and design values. An extreme storm climatology and supporting case studies are also included.

RÉSUMÉ

Cette étude donne une évaluation du climat du secteur nord-ouest de la Mer de Baffin durant la période de juillet à novembre inclusivement. Les éléments climatiques qui sont considérés incluent les contrôles du climat, le vent, la température, la froideur du vent, les précipitations, le plafond et la visibilité, le givrage d'aéronefs, les vagues, le givrage de structure, le potentiel de pollution atmosphérique, et les variations climatiques. Les analyses sont généralement exprimées en fonction de moyennes, d'extrêmes, de fréquences en pourcentage des événements, et de valeurs de calcul. Une climatologie de tempêtes sévères et des études de cas typiques qui servent d'appui sont également inclues.

FOREWORD

The purpose of this study was to provide an analysis of the climatic and related factors that are important in the northwestern Baffin Bay area. The project was undertaken by the Arctic Meteorology Section of the Atmospheric Environment Service at the request of and under contract to Petro-Canada Exploration Inc. The latter intend to apply for permission to commence offshore drilling operations in the study area in the near future. As a result, the study was restricted to the July-through-November period which corresponds to the possible drilling season.

The project was divided into three sections, the first two of which the Arctic Section prepared or supervised internally, and a third which was carried out by the Arctic Weather Centre in Edmonton at the Arctic Section's request. The first two sections involved an assessment of the general (or "normal") climatic conditions to be expected in the area and an estimation of extreme conditions likely for winds, waves, and structural icing. The third section was an evaluation of extreme storm conditions possible and the various combined states of high winds, high waves, severe wind chill, low visibility, structural icing, etc., that could result.

Inevitably, such an approach leads to differences in style and overlap in content. Without getting involved in a large amount of rewriting or restructuring, an effort was made to meld the three sections into a cohesive whole, as represented by this final report. On the other hand, a certain degree of overlap has been retained so that each section may be read individually, if so desired.

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Downsview, Ontario,
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SECTION 1. GENERAL CLIMATOLOGY OF NORTHWESTERN BAFFIN BAY

1.1 Introduction

This first portion of the study is intended to provide an analysis of the "normal" climatic conditions of the northwestern Baffin Bay area during the July-to-November period of the year. This corresponds roughly to the possible offshore drilling season and the climatic elements (and analyses thereof) presented are those considered to be of prime importance to offshore drilling operations. Analysis of extreme storms and the extreme wind, wave, and structural icing climate appear in the following sections of this study.

1.2 Study Area and Available Data

The study area is the offshore region roughly bounded by parallels of latitude 71° and 76°N and meridians of longitude 70° and 81°W (Figure 1.1). Meteorological observations for this and adjacent areas are relatively scarce and those that do exist tend to suffer from one or more deficiencies.

The most directly applicable data are the marine observations taken by itinerant ships and research vessels either passing through or doing work in the general area. These data only amount to some 8000 observations taken principally during the 32 years 1947-1978 and spread over the months July through October, although 80 percent of the observations actually occurred in August or September. The data were summarized by four geographical areas called grid areas 7, 11, 12, and 18* and each group of summarized data was ascribed to roughly the midpoint of the appropriate area (Figure 1.1). The presentation of such data as representative of the area of interest assumes that no bias has been introduced into the data by the nature of the marine operations. Such a bias could result from ships attempting to avoid certain types of weather situations.

Several reporting stations located along island coasts skirting the area and which form part of the Atmospheric Environment Service's (AES) network have 3- or 6-hourly observing programs, but surface winds at these sites are not representative of the offshore areas due to local effects. At Clyde in the south, nearby hills result in recorded winds that are lighter than the expected wind flow. Winds at Pond Inlet suffer from channelling along Eclipse Sound and Pond Inlet itself. In the northeast, at Thule, winds are affected by outflow down the fiord as well as katabatic winds off the Greenland icecap. The nearest hourly observing station to the study area is Resolute, some 400 km to the west.

Data are also available from several other locations which have been part of the AES recording network, but which are no longer in operation. These include Arctic Bay, Carey Islands, Coburg Island, Craig Harbour, and Dundas Harbour, but the records are mainly short-term in nature and/or suffer from local effects again.

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* These numbers result from a pattern of marine grid areas covering the entire Canadian Arctic Islands and for which marine observations are available at AES.

During the July-to-October period of 1978, Petro-Canada supported radar installations at Hope Monument, Devon Island and Cape Fanshawe, Bylot Island - two land sites quite close to the anticipated offshore drilling area. Meteorological observations were taken by trained observers at these radar sites as well as with automatic recording devices at two nearby locations (Capes Sherard and Liverpool respectively). These data were of some assistance in this study, but they suffered from unrepresentative instrument siting and discontinuities in the record sequences. At Hope Monument, for example, the anemometer was located on a sharp ridge oriented from north to southwest which channelled the winds accordingly. The site at Cape Fanshawe was some 600 metres above sea level and also suffered somewhat from coastal channelling of the winds. There, wind data were missing from mid-August until almost mid-September.

In summary then, reliance was mainly placed on the marine observations, for this study; data from coastal locations were introduced for completeness where they were considered applicable. Table 1.1 summarizes the available data by location, type of observing program, and period of record. The deficiencies outlined in this section should be borne in mind when considering the data for the various climatic elements that are presented later.

1.3 Previous Studies

There have been no previous detailed studies on the climatology of the northwestern Baffin Bay area in question. Adjacent areas have received a fair amount of attention during this decade, however. Specifically, the "North Water" area of northern Baffin Bay has been examined closely in concert with extensive field work and documented in a series of yearly field reports, the most recent of which is Müller et al. (1978). Lancaster Sound has also been extensively studied in connection with recent applications for offshore drilling permits. Duck et al. (1977) prepared an analysis of the extreme wind, wave, and structural icing climate there. Prior to these studies, the general climatologies of the Canadian Arctic by Thompson (1965) and Department of Transport (1970) served as the basic references for all areas of the eastern Arctic.

Maxwell's (1980) handbook on the climate of the Canadian Arctic Islands and adjacent waters includes analyses of some of the available data in the northwestern Baffin Bay area and in an analysis of the climatic regions of the north, discusses the area's climate in comparison with adjacent regions of Baffin, Devon, and Ellesmere Islands.

Useful reference may also be made to short studies that have been done of the limited amounts of data available at several of the observing sites in the area, for example: Woodrow (1972, 1974) on Pond Inlet and Strathcona Sound, and Hill et al. (1978) on Cape Charles Yorke and several other sites along the eastern Parry Channel.

1.4 Climatic Controls

The climate of northwestern Baffin Bay depends primarily on the character of the solar energy input, weather systems, topography, and the nature of immediate and adjacent surfaces.

The study area lies at approximately the same latitude as Resolute, the nearest long-term radiation observing station. The mean monthly global solar radiation varies from zero in January during the polar night (the period of continuous darkness extending from early November to early February) to over 500 langleys/day in June. The mean annual net radiation experienced is near 10 kilolangleys resulting from mean monthly deficits of 20-45 langleys/day during the October-to-April period, but excesses of about 200 langleys/day in June and July.

Cyclonic activity is frequent in Baffin Bay throughout the year, but is most intense in winter. The preferred trajectory for most lows affecting the area is northwards through Davis Strait with the bulk of such systems being in the occluded phase by the time they affect northwestern Baffin Bay. Occasional systems tracking from the Keewatin over Baffin Island or from the west along Parry Channel also occur.

The topography of the islands bordering the study area is important. Devon, Bylot, and Baffin Islands are all mountainous along their eastern coasts and onshore flows forced aloft along those coasts result in greatly enhanced precipitation totals. Principally, however, the mountains tend to contain weather systems that have come north through the Davis Strait. The tendency for such systems to be occluded is mainly a result of the Greenland ice cap to the east which restricts the supply of warm air to the lows, a supply which would be necessary to deepen or at least maintain the lows' intensity. A second effect of the mountains is to act as a physical barrier to storms approaching the study area from the west or southwest.

The waters of northwestern Baffin Bay are influenced by sea ice for much of the year. Other than along the island coasts where fast ice occurs, moving first-year pack ice predominates during the winter and into May. With breakup, clearing develops during late May and June from the "North Water" area of thin ice/open water to the north and in Lancaster Sound to the west. The centre of the study area is in open water by early July usually. By September, northwestern Baffin Bay is subject to the presence of multi-year ice floes which have broken loose from Nares Strait to the north and also icebergs calved from Greenland and Ellesmere Island glaciers. Freeze-up in the centre of the proposed drilling area occurs in late October on the average.

A somewhat more detailed discussion of the sea-ice regime may be found in Section 3 of this study.

1.5 Climatic Elements

1.5.1 Wind

Wind is perhaps the most important climatic element to be considered because of its role in so many aspects of environmental conditions. Examples are the generation of waves which may restrict marine operations and cause damage to offshore installations, the development of freezing spray events (winds > 22 kt and air temperatures below the freezing point of sea water), severe wind-chill occurrence, and the movement of ice floes and icebergs.

Figures 1.2 to 1.5 are wind roses for each marine grid area showing the mean distributions of wind direction during each month of the July-to-October period. Figures 1.6 and 1.7 illustrate the prevailing wind directions during the same months both in the marine areas and for adjacent coastal stations. The variation in prevailing wind direction from location to location and during July to August is a reflection of the flat pressure gradient that exists in the Arctic during the summer (although there appears to be a tendency for a larger number of easterly to southeasterly winds then). Over all of Baffin Bay, for example, there is a very weak low pressure area which extends northward over Ellesmere Island. By early September, however, the strong northerly flow that is characteristic of the eastern and central arctic islands begins to be reestablished and northwesterly winds prevail over the study area from then on.

The percentage frequency of occurrence of hourly wind-speed classes is displayed in Figures 1.8 to 1.11 while Figure 1.12 shows the frequency of all winds at or exceeding 22 kt. The latter illustrates the trend to higher wind speeds during September and October, particularly at grid areas 12 and 18. This reflects the increase in cyclonic activity in the fall over the northwestern Baffin Bay area.

The nature of the marine observation records made a direct wind duration analysis impossible; however, the Resolute wind-speed regime was taken to be reasonably representative of the study area and therefore it was used to give an indication of durations to be expected (see, however, Appendix A) as it was based on a continuous hourly observing program. (In calculating the durations, no adjustments were made to Resolute wind speeds to account for coastal-offshore differences.) Table 1.2 indicates the number of duration events longer than 24 hours for and the maximum duration of winds greater than 17, 26, and 35 kts. Values are given for each month of the July-to-November period and are based on data collected during 1953-1972.

For an analysis of extreme wind speed over the study area reference should be made to Section 2 of this study; however, for completeness Table 1.3 shows the extremes that have been recorded at adjacent observing stations. The unrepresentativeness of most of these stations as discussed earlier should be remembered. In a recent study for Lancaster Sound (Duck et al., 1977), the maximum hourly wind speed for the July-to-October period with a 20-year return period was estimated to be 57 kt.

1.5.2 Temperature

Maps of the mean daily temperature for each of the months from July to October are presented in Figures 1.13 to 1.16. Particularly to be noted is the gradual increase in gradient over northwestern Baffin Bay. After July-August when mean temperatures of 3 to 4°C prevail over most of western Baffin Bay and the eastern Parry Channel, mean daily temperatures start to drop to near freezing in September with packing of the isotherms beginning over eastern Parry Channel. By October a strong gradient exists across the study area and into Lancaster Sound with mean temperatures decreasing westward from -5 to -10°C. This gradient is typical of the eastern arctic island nearshore waters in the fall as a result of increasingly intense outbreaks of cold air from the northwest spreading over the now relatively warmer waters of Baffin Bay.

The percentage frequencies of occurrence of various air temperature classes during the July-to-October period for each of the marine grid areas are shown in Tables 1.4 to 1.7. With the exception of grid area no. 11 in July, over 65% of all occurrences lie within the two temperature classes 0.1 to 2.2°C and 2.3 to 4.4°C in July and August. If a third class, 4.5 to 6.7°C, is included, over 85% of all occurrences may be found within the three classes. In September over 60% of all occurrences lie within the two temperature classes -2.1 to 0.0°C and 0.1 to 2.2°C for each grid area. By October, however, temperature occurrences are spread more evenly over four or more classes. For comparison, a similar presentation of data for Resolute is given in Table 1.8.

A summary of mean daily and extreme temperatures observed during the July-to-November months is given in Table 1.9 for both the marine grid areas and adjacent coastal stations. The values presented give a good picture of the temperature regime of the general area. The data from Resolute are drawn from the best records in the region in terms of continuity and frequency and as they represent a slightly colder temperature regime than that of the actual study area, design temperature values based on them provide useful conservative estimates for northwestern Baffin Bay. Figure 1.17 gives the appropriate design minimum temperatures for both the July-to-October and July-to-November periods.

1.5.3 Combined Wind-Temperature

The most frequently used combined wind-temperature index in meteorology is the wind-chill factor - a factor which represents a measure of how fast an exposed object cools. The actual calculation of the factor is based upon how fast water will cool with the combination of low temperature and wind, but it has been found to be equally applicable to the cooling effect experienced by the human body and by an inanimate object (AES, 1976). Wind chill is measured in units of watts/m^2; a value of 2700 watts/m^2, for example, indicates that exposed flesh is liable to freeze within half a minute for the average person.

A modified version of the standard wind-chill nomogram which divides the basic graph into seven comfort classes is shown in Figure 1.18.

The percentage frequencies of occurrence of these classes for the months of July, September, and November have been determined from Resolute and Dundas Harbour data and are shown in Table 1.10. These values would suggest that comfort class 6 is the most severe that is likely to be experienced in the study area, but probably no more than 5 to 10% of the time even in November. Desirable requirements for human activity during the occurrence of class 6 include: mandatory adequate face protection, no work or travel alone, and controlled exposure times of workers by careful work scheduling.

1.5.4 Precipitation

The annual precipitation over the study area is approximately 200 mm increasing along the adjacent island coasts to greater than 300 mm over eastern Devon and Ellesmere Islands. Slightly more than half of these totals falls during the July-to-October period with approximately 25 mm occurring per month increasing to 50 mm per month over the islands. The precipitation occurrence is spread over 10 to 15 days each month during the July-to-October period. During July and August, the majority of the precipitation is rain or drizzle, but by September, about two-thirds of the monthly total is snow on the average. In October, almost all precipitation is in the form of snow.

The contribution of freezing precipitation to possible superstructure icing of offshore marine structures and shipping is an important consideration. In the study area, however, the frequency of freezing precipitation is not unusually high, amounting to between 25 and 50 hours annually, over half of which occurs during September and October. (Such totals may be compared with the 50 to 100 hours that occur annually at the eastern entrance to Hudson Strait and the more than 175 hours that occur in the vicinity of Newfoundland each year on the average.) Offshore, in the autumn, most of the freezing precipitation is associated with frontal activity while along adjacent island coasts, onshore wind flows from open-water areas over snow-or ice-covered surfaces often bring localized freezing precipitation then.

A more significant contribution to severe superstructure icing, however, results from the occurrence of freezing spray. Reference should be made to Section 2 for an analysis of this aspect of the problem.

1.5.5 Ceilings and Visibility

Ceiling and visibility conditions greatly influence both flying and marine navigation. During the July-to-early September period, fog is the most important factor in causing reduced visibilities; thereafter, snow and blowing snow play increasingly significant roles.

Table 1.11 shows the percentage frequency of visibility by wind-speed classes for the marine grid areas. There appears to be a slightly greater tendency for low visibilities (<1 nm) to be associated with lower wind speeds than high visibilities (⩾ 5 nm), as would be expected. In the late summer and early fall, visibilities <1 nm tend to occur with winds from the north-to-east quadrant, switching to the north-to-west quadrant by October.

The percentage frequencies of occurrence of combined ceiling and visibility classes for the marine grid areas are given in Table 1.12. It should be noted that the reduced ceiling and visibility conditions of <150 ft and/or <50 yd are more frequent in July and August than in the later months when marine fogs occur less often and mean wind speeds are greater. For comparison, Resolute ceiling and visibility data are given in Table 1.13.

The importance of fog has been mentioned previously. In the study area, two types of fog are important during the July-to-November period. From July to September, advection-type fog is common. This forms when warm air masses penetrate the region from southern Canada and are cooled from below by ice-cold water. Such fog is widespread during the ice-melt period, but becomes patchy later in the season, tending to be frequent and dense only at the edges of drifting ice. From October on, fog formation that does occur is of the steam fog type. This is formed when very cold air passes over areas of open water. Often it is rather localized, not persisting more than a few kilometres downwind from the moisture source, but on occasion it can be more widespread during the occurrence of late season cold air flows over relatively warm, large open-water areas.

1.5.6 Aircraft Icing

No hard data are available on aircraft icing occurrence over the study area; however, an indication of its likelihood can be gained from the northern hemisphere aircraft icing climatology prepared by Heath and Cantrell (1972). That climatology considered only the occurrence of aircraft icing with no differentiation as to type or severity. Table 1.14, which is derived from that study, indicates the probability of encountering icing conditions over northwestern Baffin Bay at four levels of the atmosphere for each month during the July-to-November period. The values presented may be interpreted as percentage frequencies of occurrence; for example, the October probability of 0.05 for 100 kPa suggests an occurrence frequency of 5%.

Most apparent from this table is the gradual lowering of the altitude at which aircraft icing is most probable. The variation is from the 70-kPa level in July and August to 85 kPa in September and October to between 100 and 85 kPa by November. The highest probabilities (between 0.1 and 0.15) occur in September and October, at the 85-kPa level.

The icing frequencies of occurrence suggested in Table 1.14 appear to be somewhat lower than might be expected for the study area. During the summer particularly, arctic stratus can be a potential icing hazard especially for helicopter operations to drillsites. As low ceilings (less than 1,000 ft) are possible up to a third of the time and as freezing levels can be low in the arctic atmosphere at that time of year, it is likely that icing potential exists during a large proportion of the time that low ceilings are reported.

1.5.7 Waves

A detailed discussion of extreme wave heights to be expected in northwestern Baffin Bay is given in Section 2 of this study. For completeness, however, graphs showing the percentage frequencies of occurrence of observed wave heights for the marine areas have been prepared (Figure 1.19). Data for these graphs were only available in any significant amounts for the months of August and September. The expected increase in frequency of the higher wave heights during September over August is evident for each of the grid areas.

1.5.8 Air Pollution Potential

As in the case of aircraft icing, few specific data from the study area have been collected which would relate directly to air pollution potential. Several tentative conclusions can be drawn, however, based on knowledge of the weather systems affecting the area and from data collected at observing stations surrounding it. The characteristics of the study area in terms of air temperature inversion frequency, calm-to-light wind occurrence, and ventilation coefficients are of particular importance.

During July and August, surface-based temperature inversions occur 25 to 30% of the time with inversions based above but within 300 m of the surface occurring an additional 15% of the time. The marked increase in cyclonic activity in the fall results in a marked decrease in inversion frequency, particularly in September. Thereafter, the occurrence frequency increases to approximately 45% in November (plus another 5% for inversions above but within 300 m of the surface). Based on Resolute data, the surface-based portion of the inversions at this latitude have a fairly similar mean thickness throughout the July-to-October period (50 m) with maxima near 150 m. An increase towards the winter maximum in thickness is evident in November.

The occurrence and duration of calm or light (1 to 3 kt) winds are important factors in the persistence of pollution conditions. Such winds occur 10 to 20% of the time during the summer decreasing to 10% or less during September to November. These percentages are based on the rather limited data in the marine grid areas. Near-sea-level coastal stations in the eastern Arctic suggest that the frequencies are 15 to 20% higher there in both seasons. Such stations also suggest that maximum durations of such winds during July to-August are near 25 hours.

Ventilation coefficient is the term used to denote the product of the mixing height (atmospheric layer through which dispersion takes place) and the mean transport wind speed in that layer. It is usually expressed in m^2/sec; the higher the value the more able the atmosphere is to disperse pollutants. A threshold value of 6000 m^2/sec has been used as a relative indicator of low air pollution potential (Portelli, 1978). On that basis, it would appear that the northwestern Baffin Bay area is very pollution-prone during the summer and fall as monthly mean maximum ventilation coefficients are near 2000 m^2/sec in July and August and between 1000 and 1500 m^2/sec during the September-through-November period.

1.6 Climatic Variations

The data presented in this study are based on observations taken mainly during the past 30 years. The implications of possible climatic variations during the remainder of this century for the validity of the information presented here need to be carefully considered.

Climatic warming in the future mainly due to increased CO_2 levels in the atmosphere appears to be the most persuasive argument at present. The most likely results of this would be decreases in the thickness of first-year ice and in the concentrations of old ice that could affect the study area. A longer open-water season would also be expected. The latter would suggest that offshore drilling could be extended well into November on a regular basis; however, this could pose problems in that storm activity in November can be quite severe (see Section 3). Extended areas of open water would suggest also that a drilling operation would be prone to an increased frequency of severe high wave events as ice edges would no longer limit overwater fetches to the same extent.

Recently, Koerner and Fisher (1979) have suggested the alternative possibility of a climatic cooling extending into the next century, based on their analysis of ice cores from several locations in the Arctic Islands. The effects would likely include a shorter open-water season and a greater likelihood of experiencing old ice floes and icebergs in the study area.

Episodes of both cooling and warming will occur in the short term. The best evidence now available indicates the likelihood of a long-term warming trend resulting from increased atmospheric CO_2 levels, such that significantly warmer conditions will prevail in the Arctic, beginning in the first half of the next century. A more precise description of this trend and the relation between it and changes in the synoptic regime and ice cover requires further investigation which is beyond the scope of this study.

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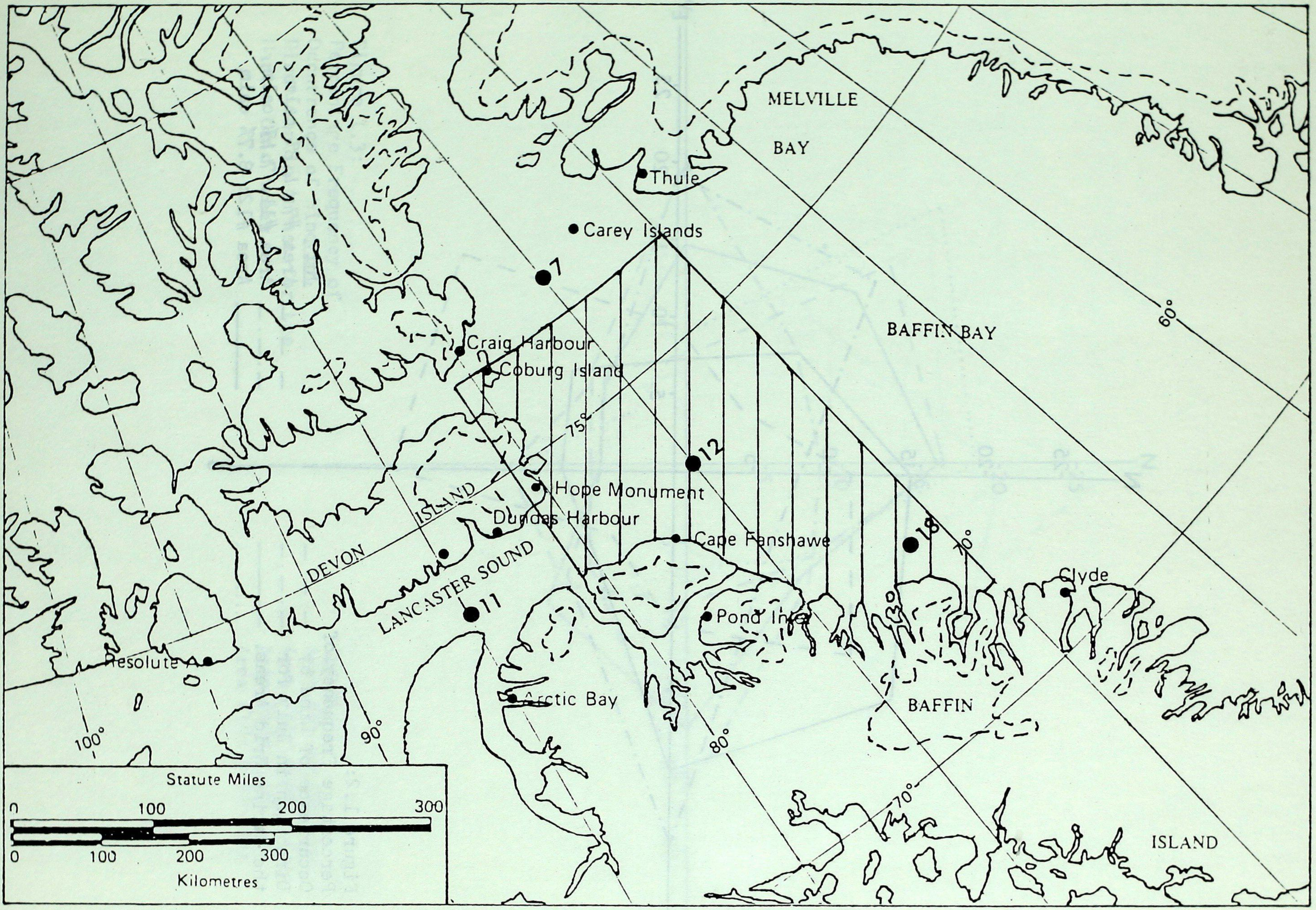

Figure 1.1 Map Showing the Northwestern Baffin Bay Study Area ▥ and Vicinity, 1,000 m Topographic Contours - - - -, and Locations with Available Meteorological Observations.

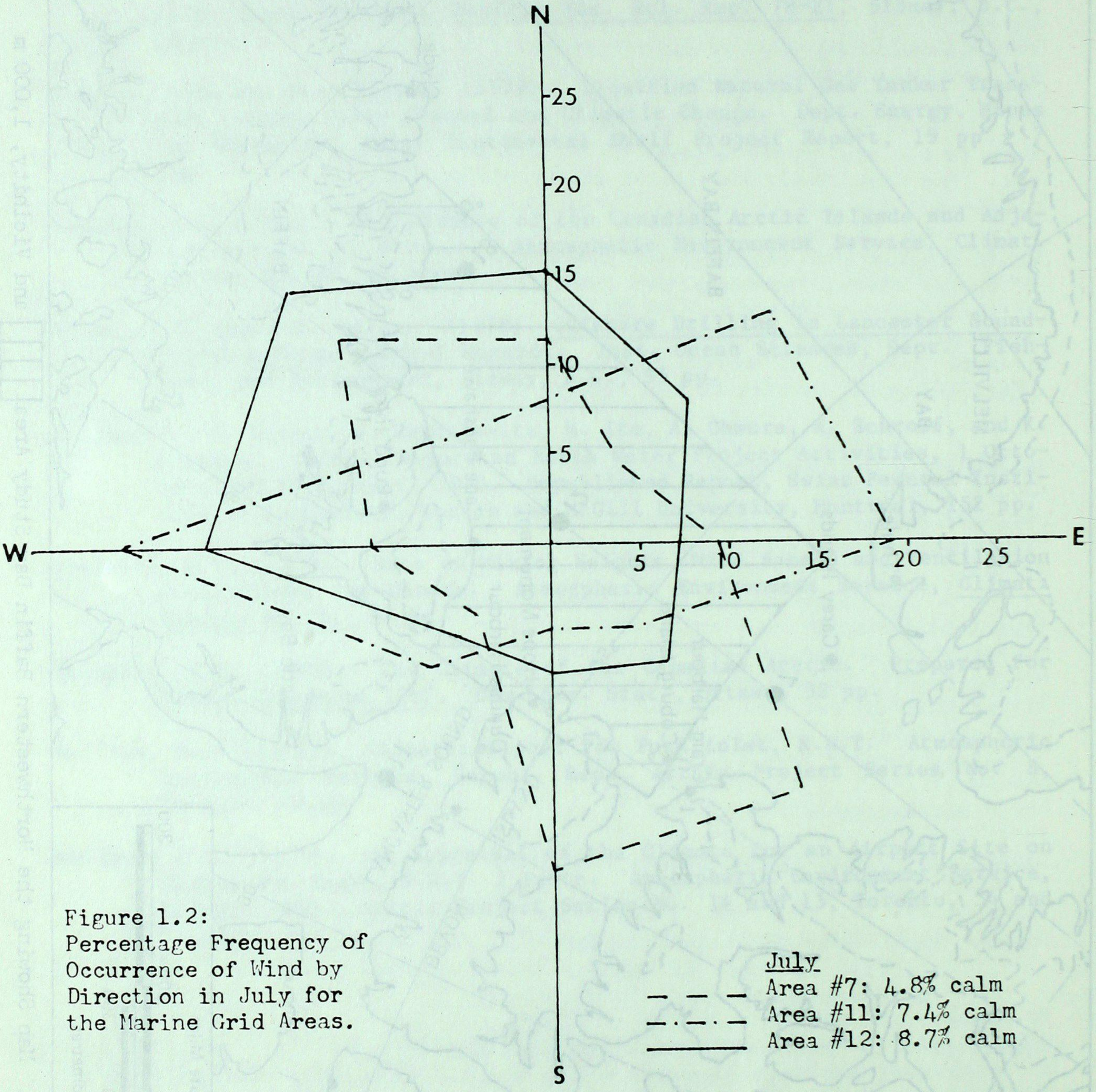

Figure 1.2:
Percentage Frequency of
Occurrence of Wind by
Direction in July for
the Marine Grid Areas.

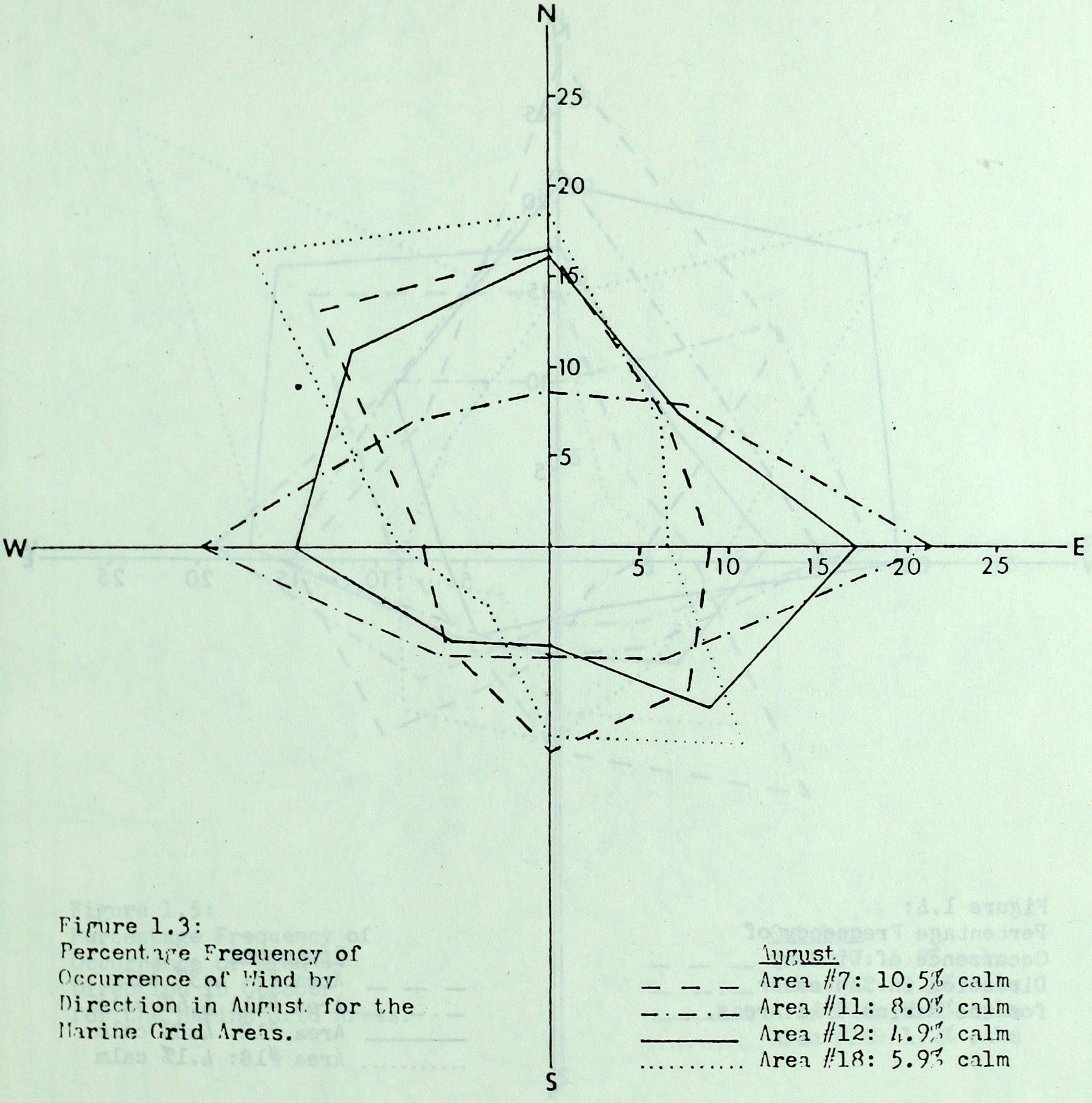

Figure 1.3:
Percentage Frequency of
Occurrence of Wind by
Direction in August for the
Marine Grid Areas.

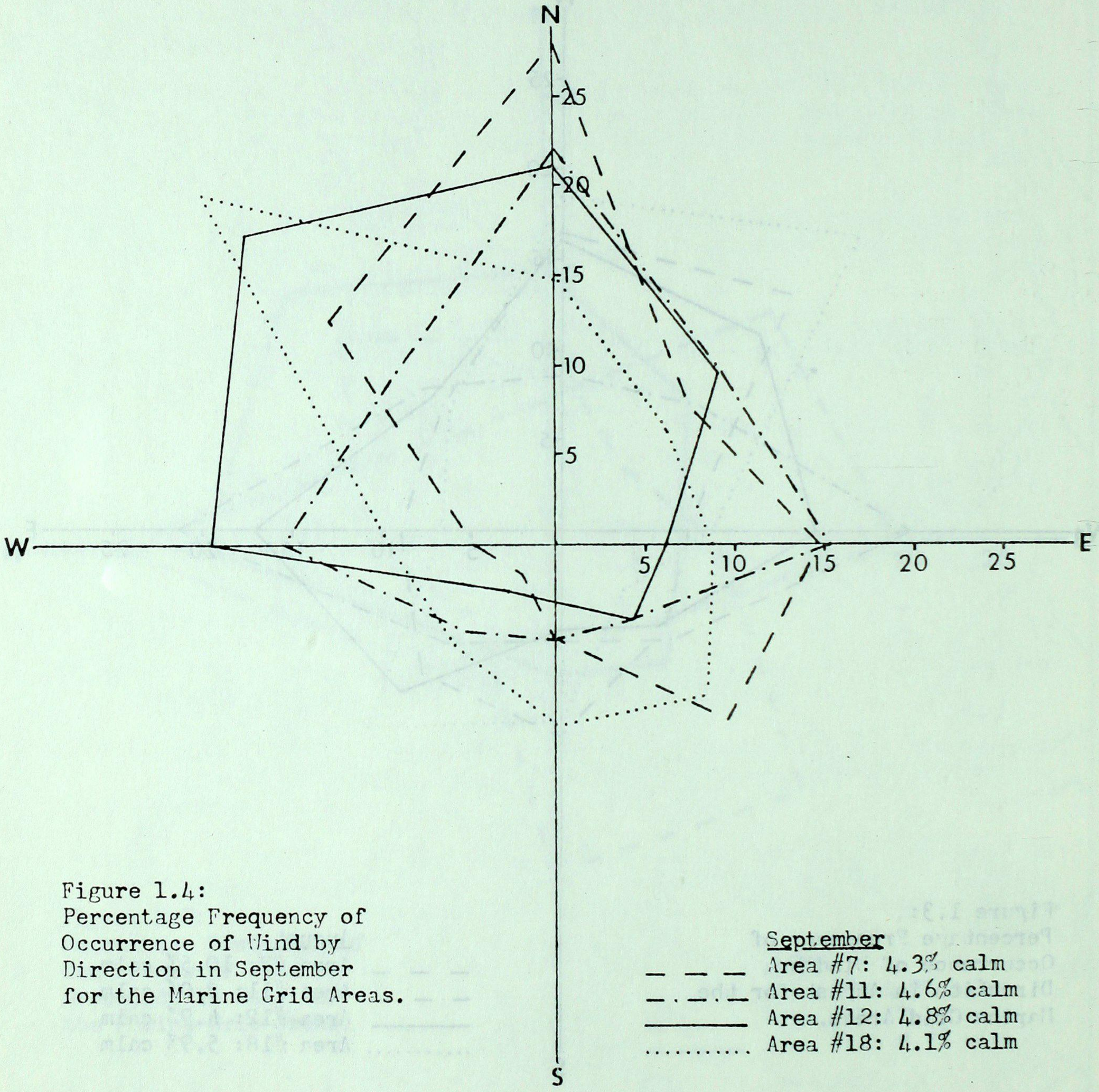

Figure 1.4:
Percentage Frequency of
Occurrence of Wind by
Direction in September
for the Marine Grid Areas.

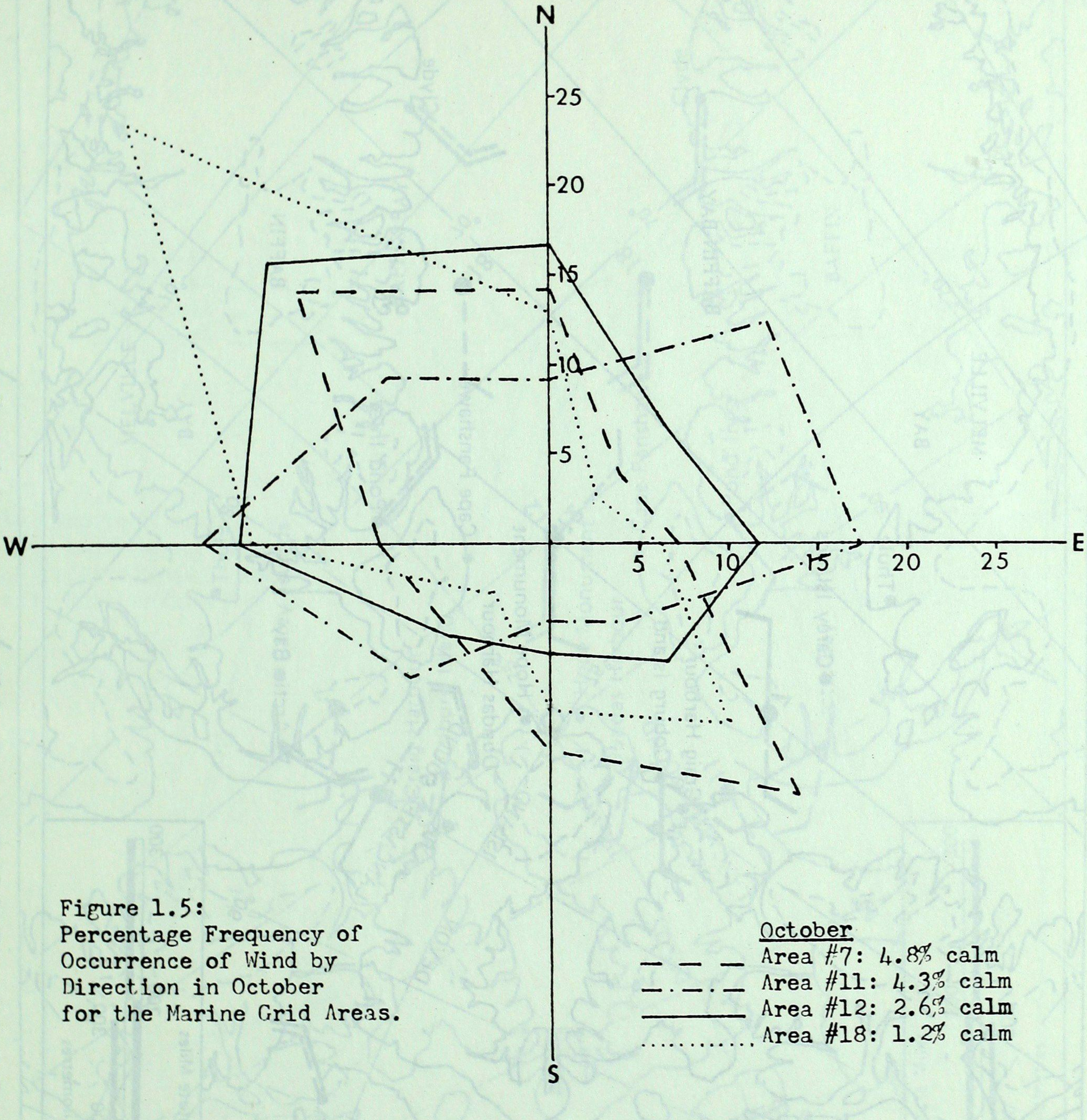

Figure 1.5:
Percentage Frequency of Occurrence of Wind by Direction in October for the Marine Grid Areas.

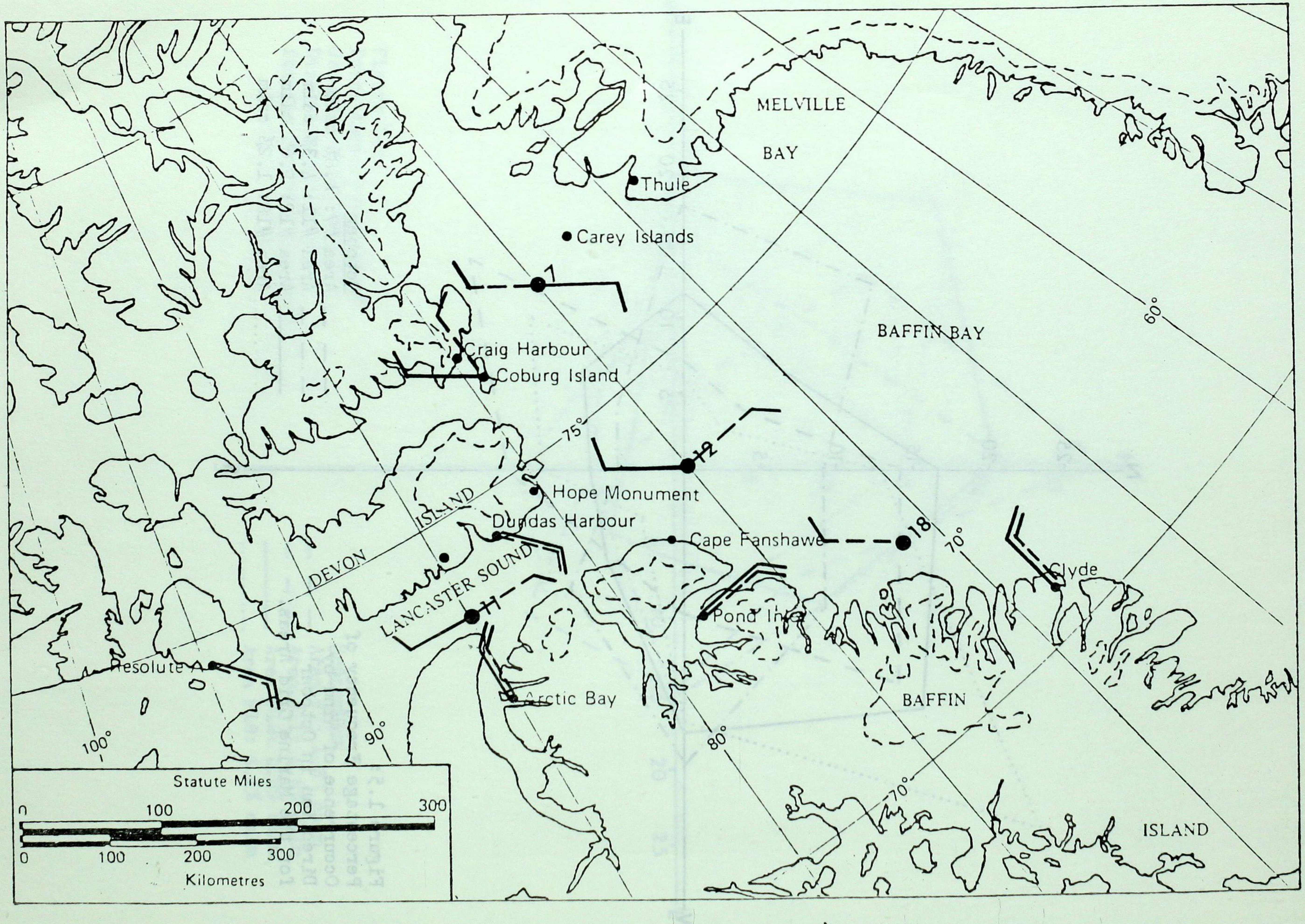

Figure 1.6 Prevailing Wind Direction in July ⌊___ and August ⌊_ _ _.

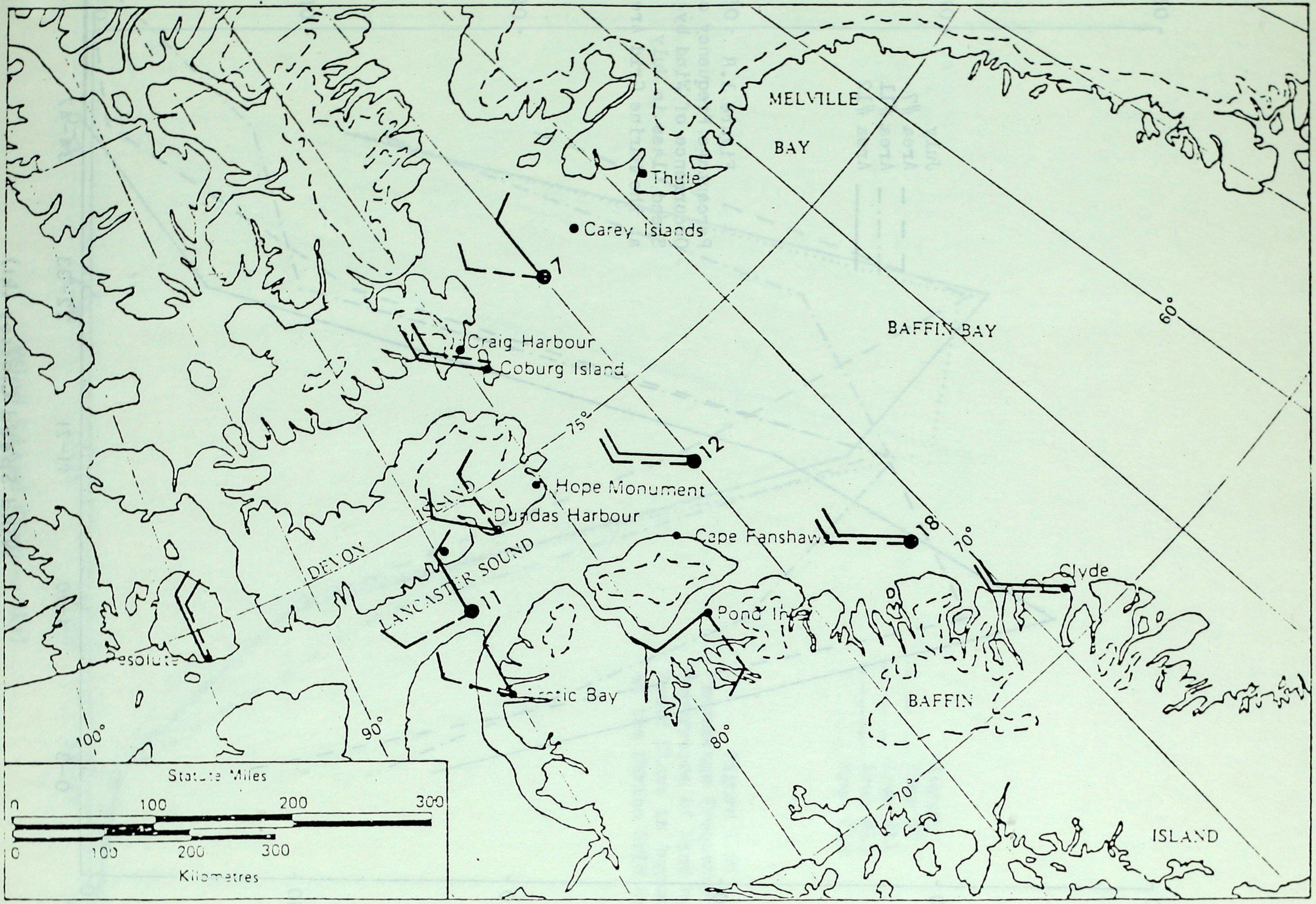

Figure 1.7 Prevailing Wind Directions in September ⌊____ and October ⌊_ _ _ .

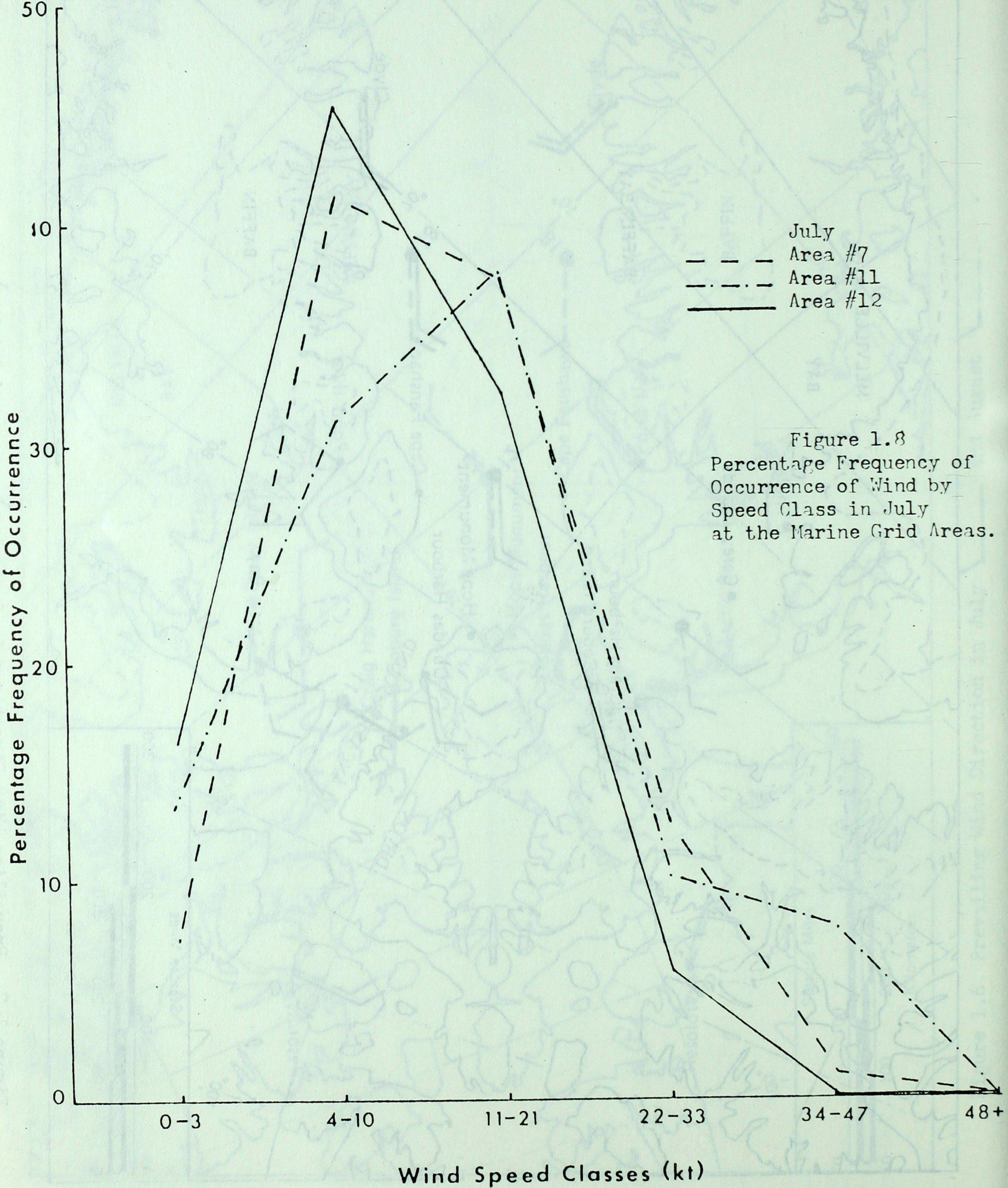

Figure 1.8
Percentage Frequency of
Occurrence of Wind by
Speed Class in July
at the Marine Grid Areas.

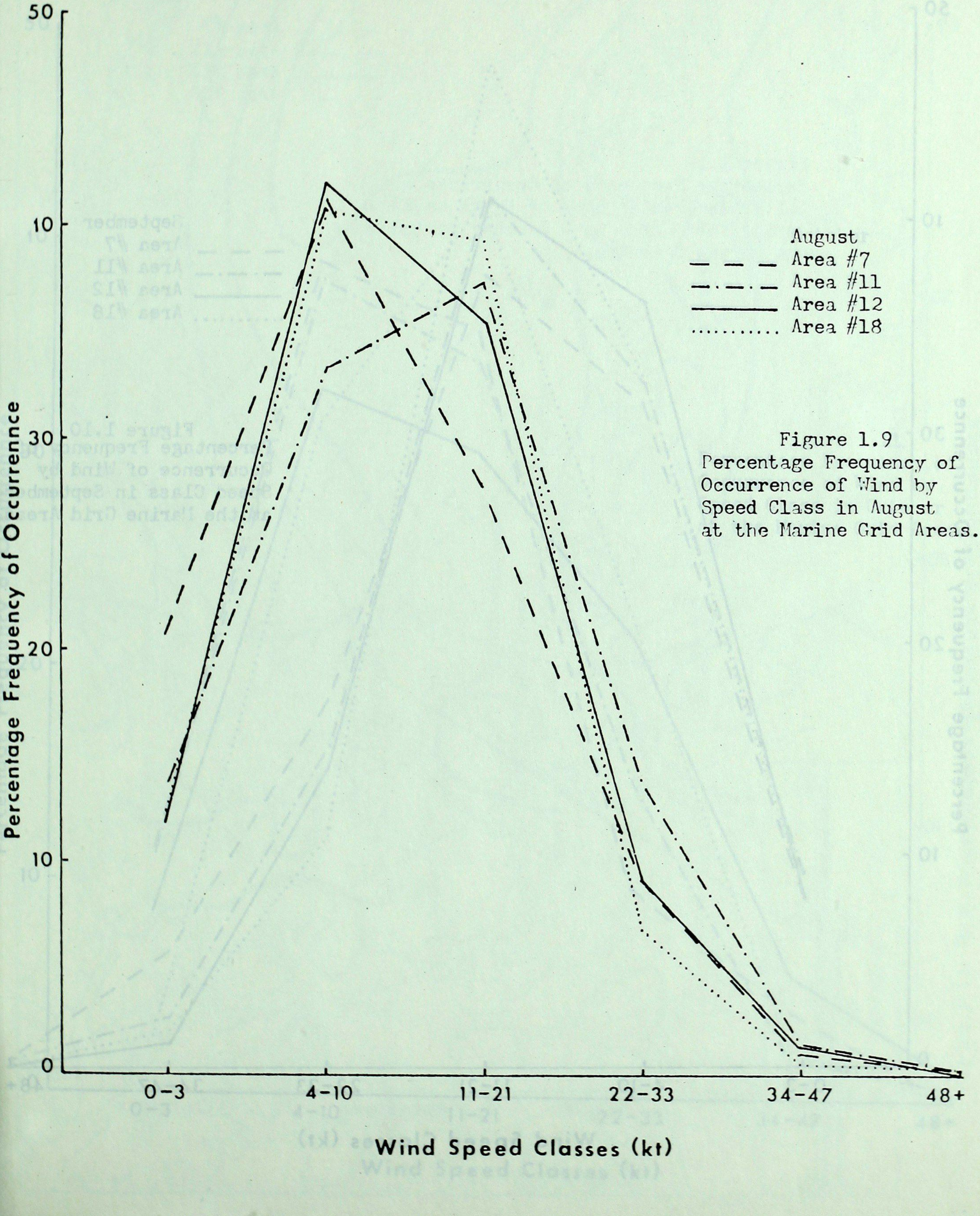

Figure 1.9
Percentage Frequency of Occurrence of Wind by Speed Class in August at the Marine Grid Areas.

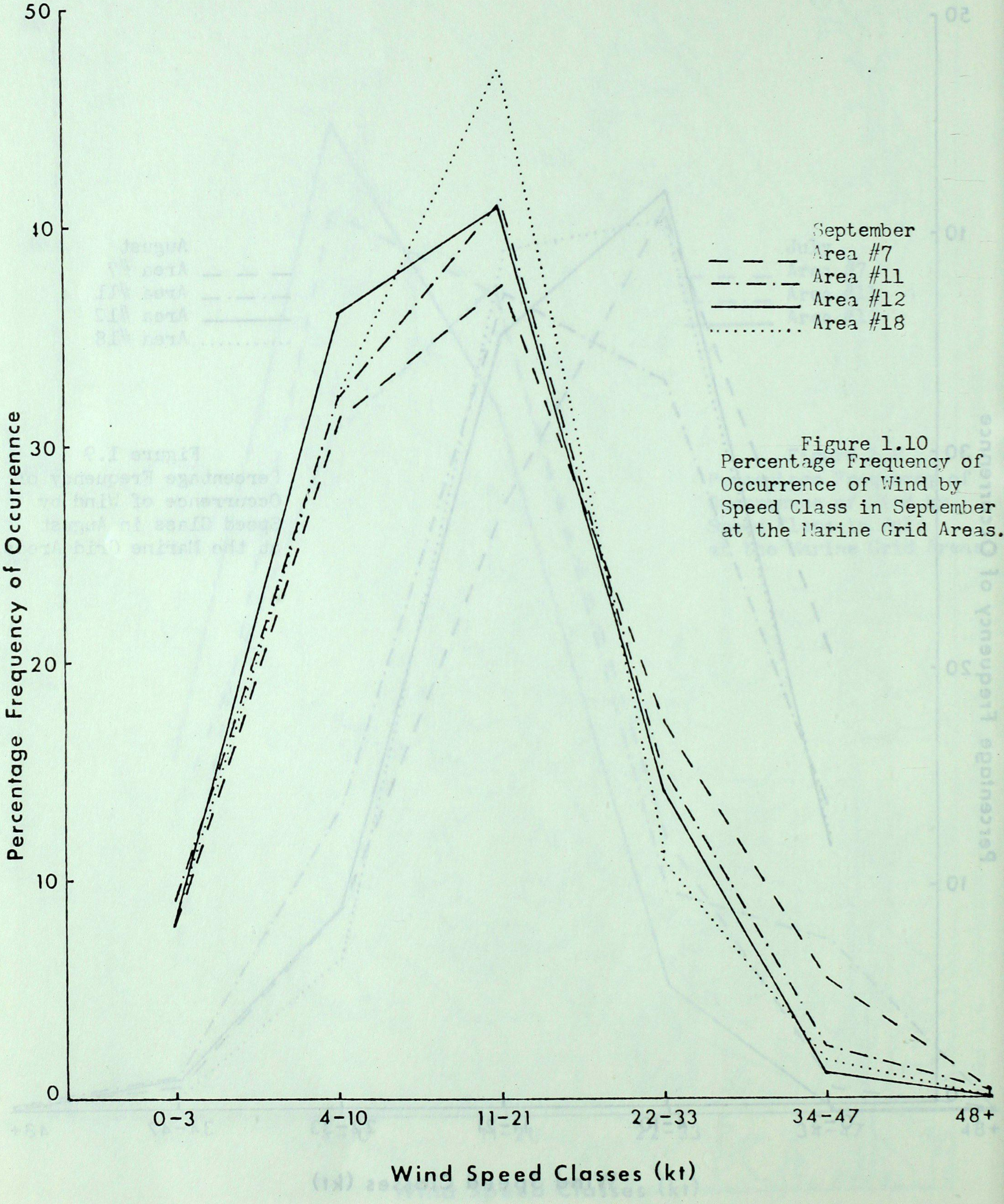

Figure 1.10
Percentage Frequency of Occurrence of Wind by Speed Class in September at the Marine Grid Areas.

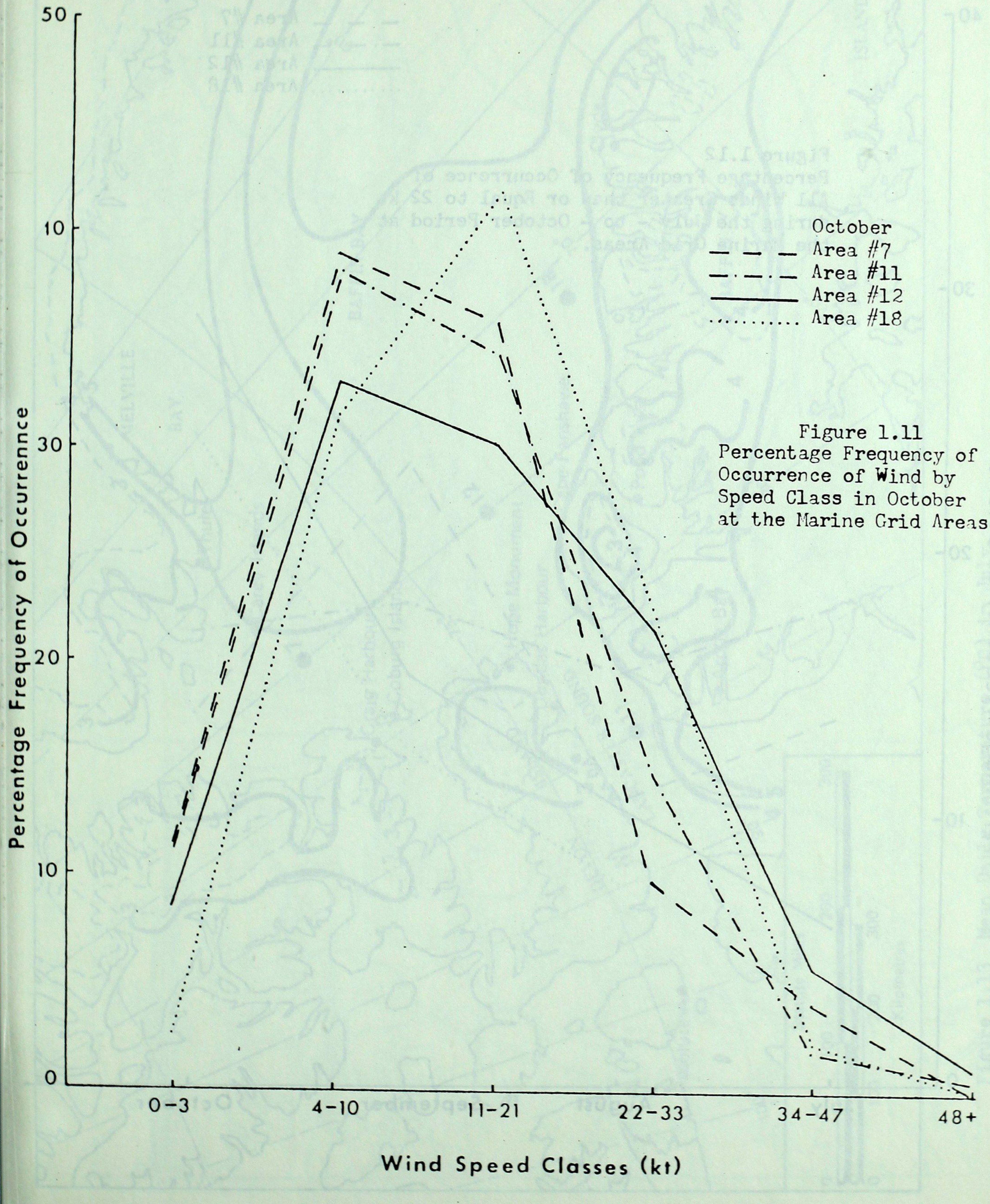

Figure 1.11
Percentage Frequency of Occurrence of Wind by Speed Class in October at the Marine Grid Areas.

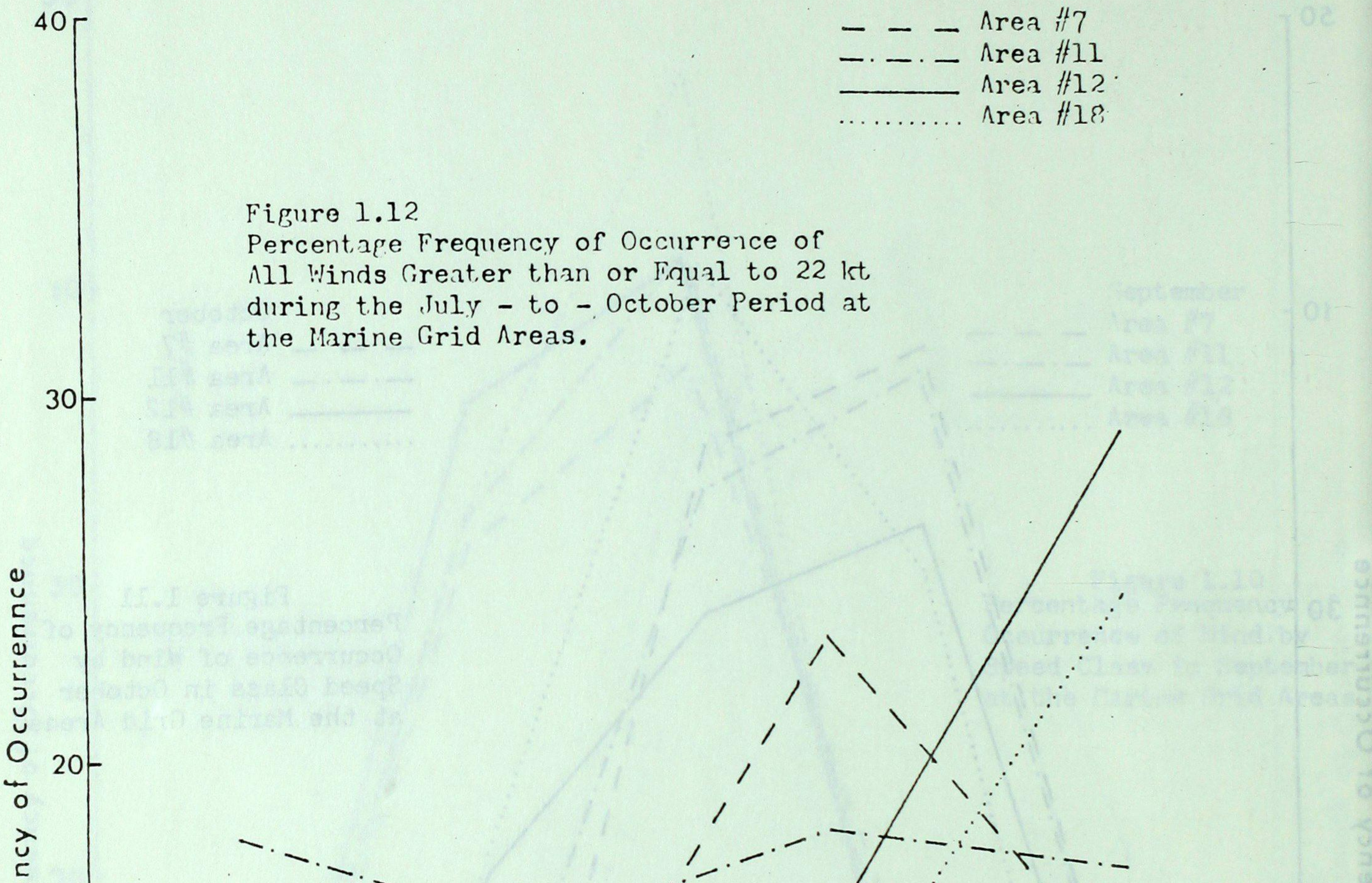

Figure 1.12
Percentage Frequency of Occurrence of All Winds Greater than or Equal to 22 kt during the July - to - October Period at the Marine Grid Areas.

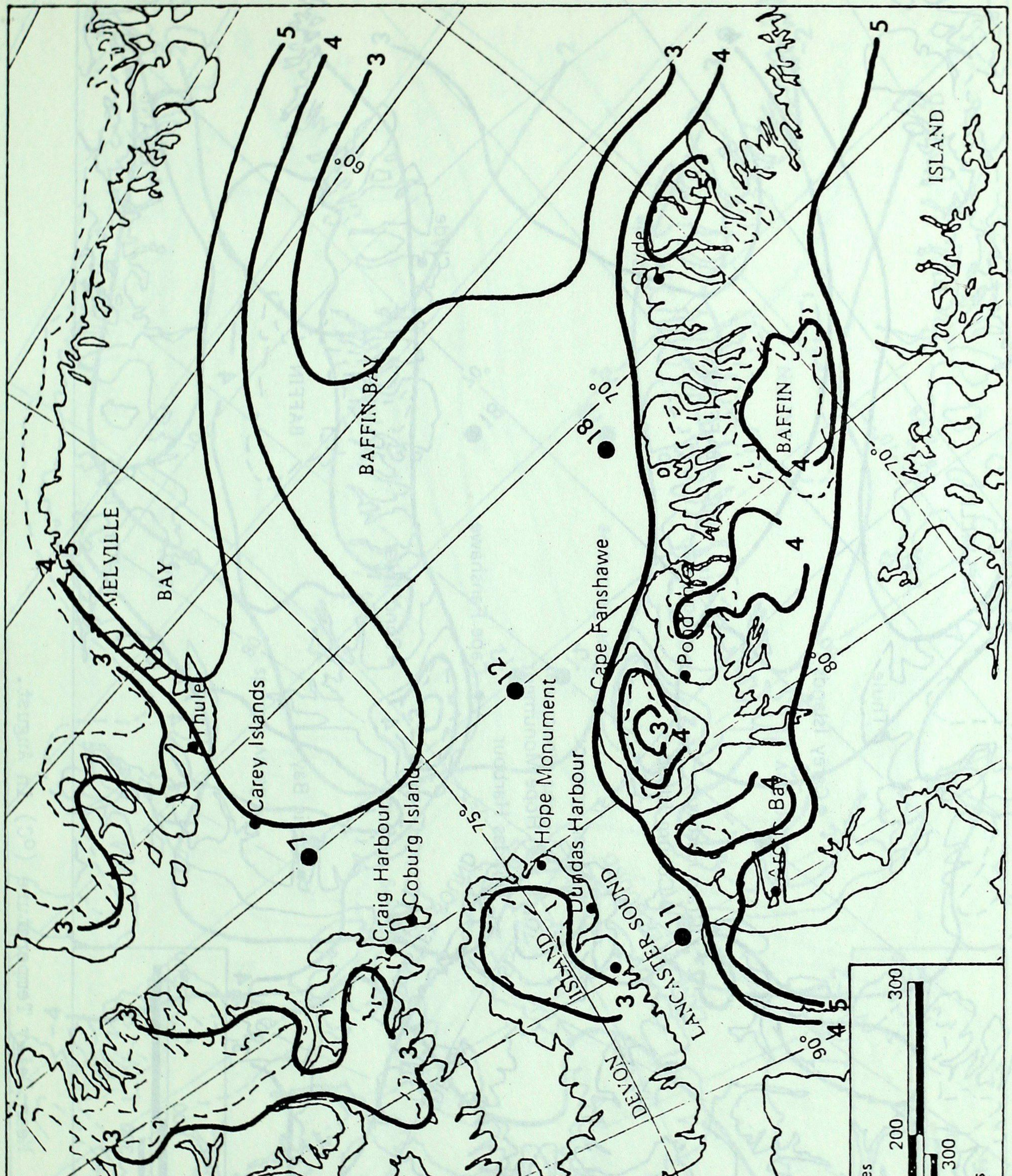

Figure 1.13 Mean Daily Temperature (°C) in July.

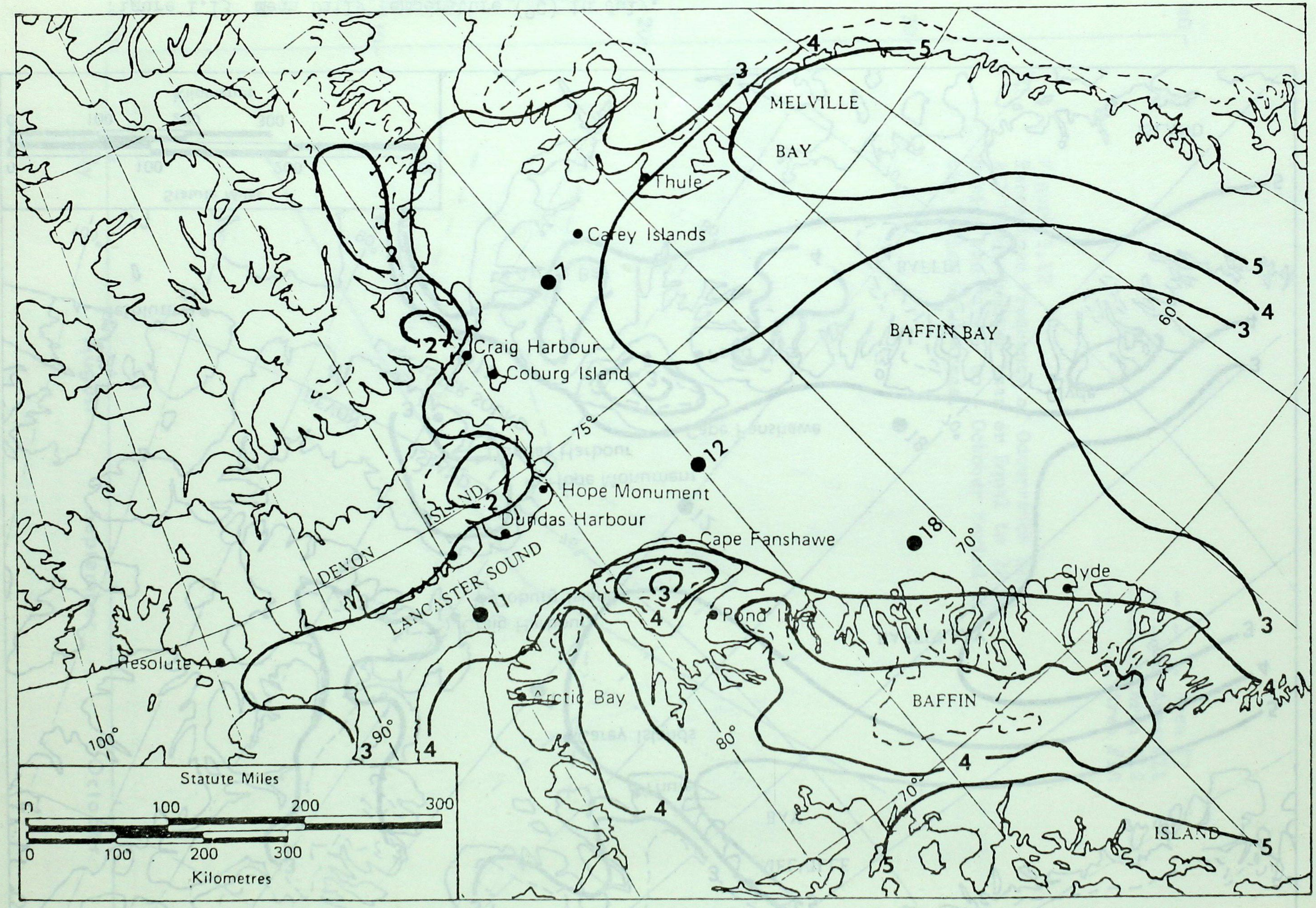

Figure 1.14 Mean Daily Temperature (°C) in August.

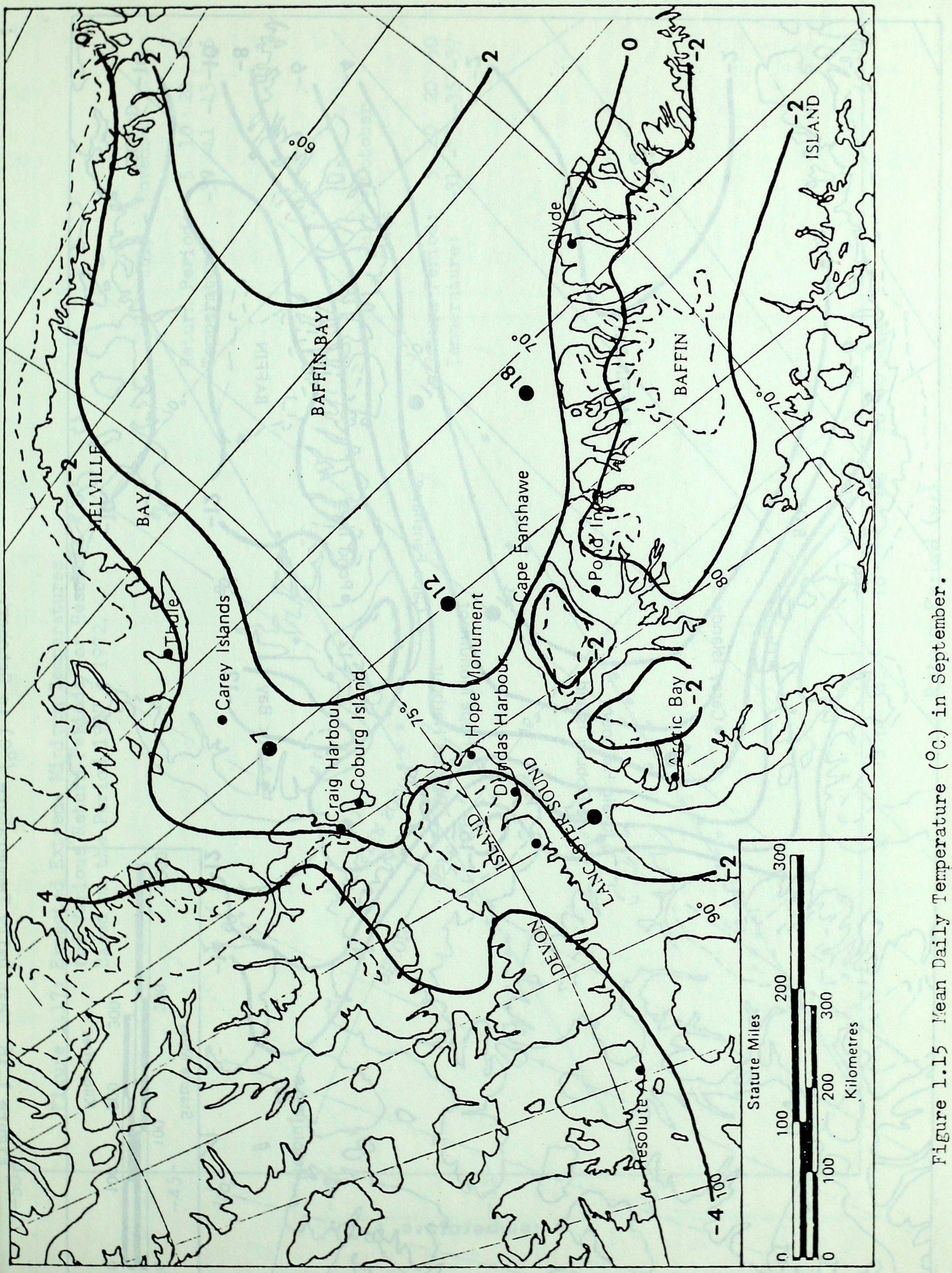

Figure 1.15 Mean Daily Temperature (°C) in September.

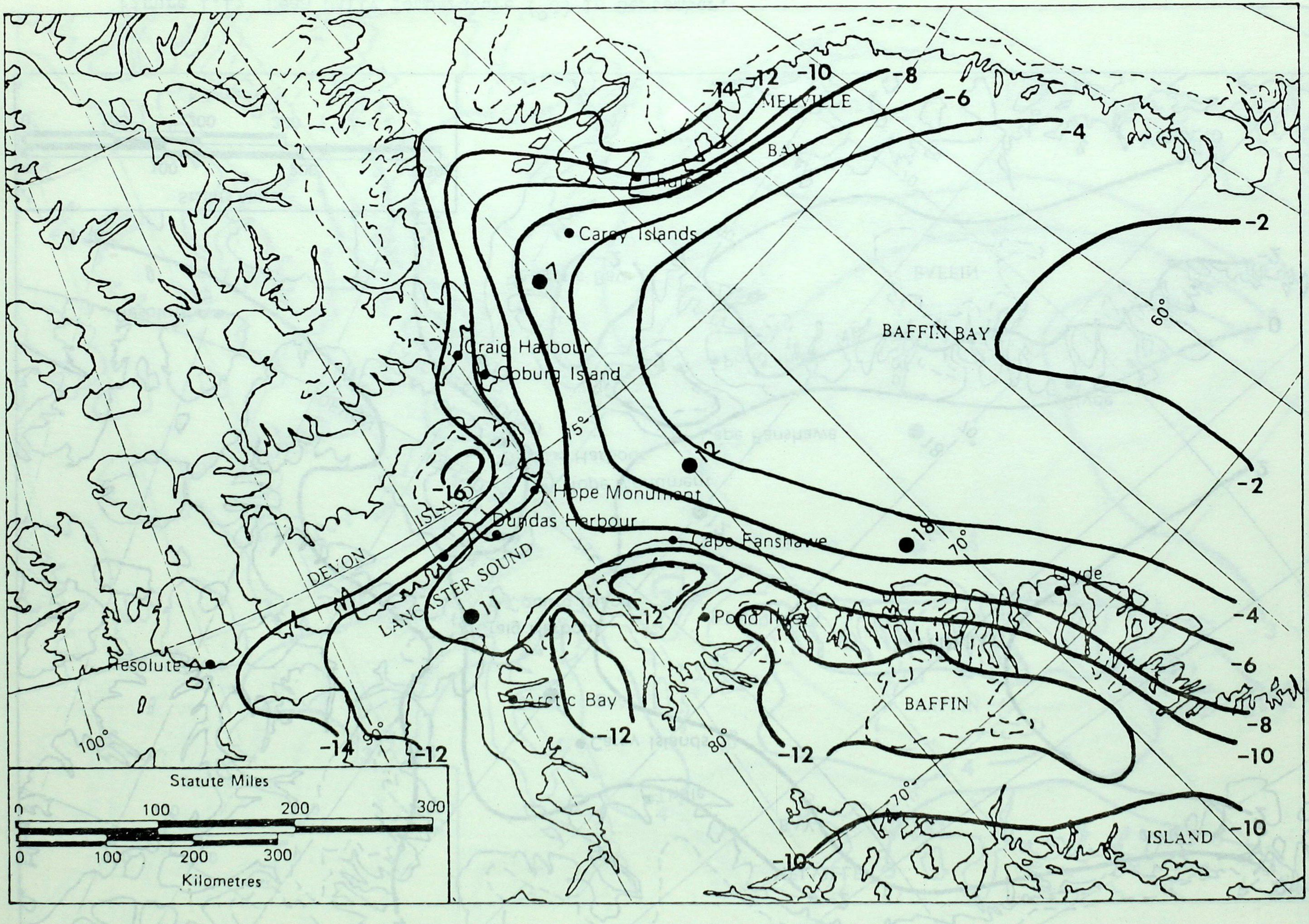

Figure 1.16 Mean Daily Temperature (°C) in October.

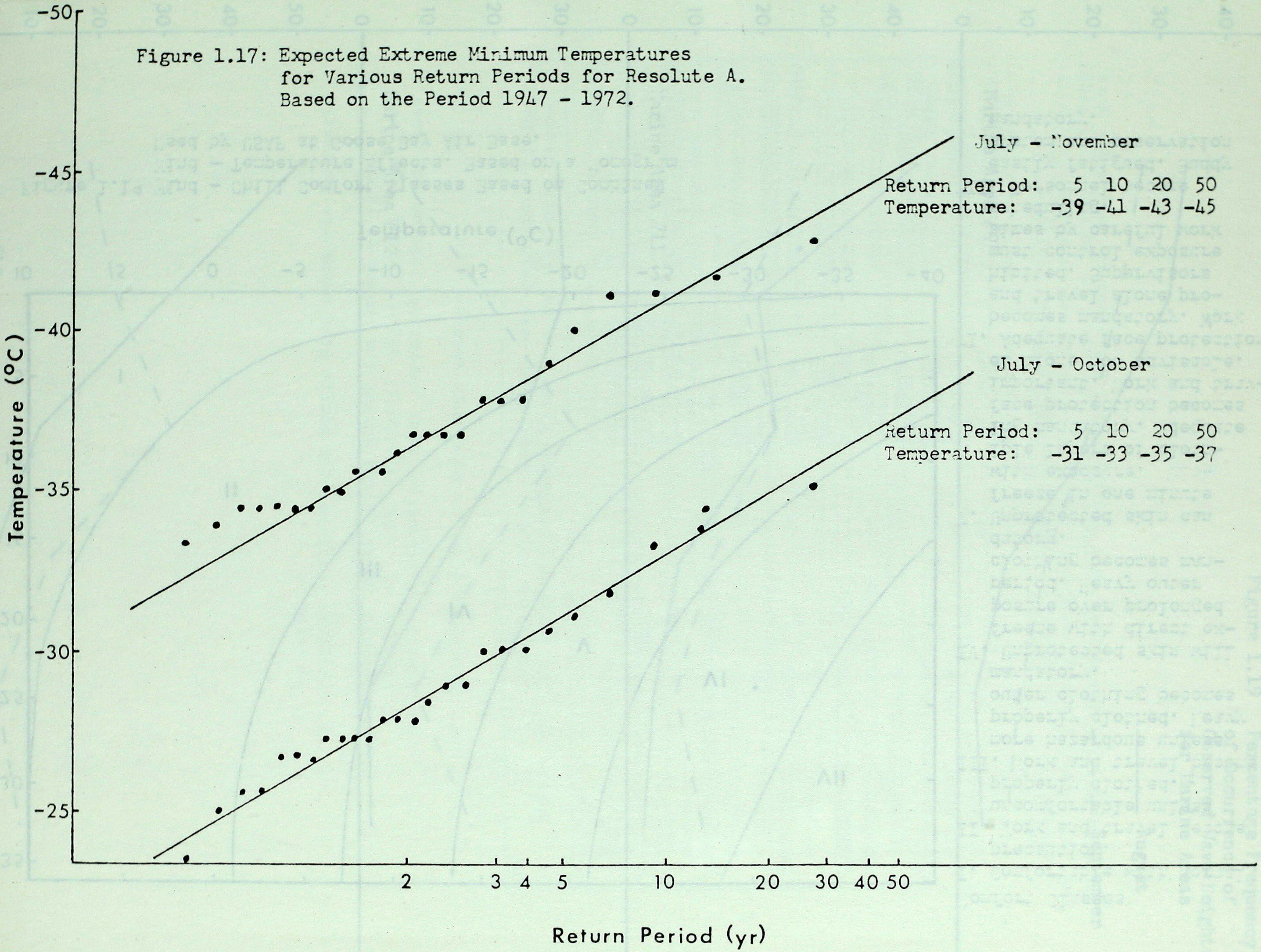

Figure 1.17: Expected Extreme Minimum Temperatures for Various Return Periods for Resolute A. Based on the Period 1947 - 1972.

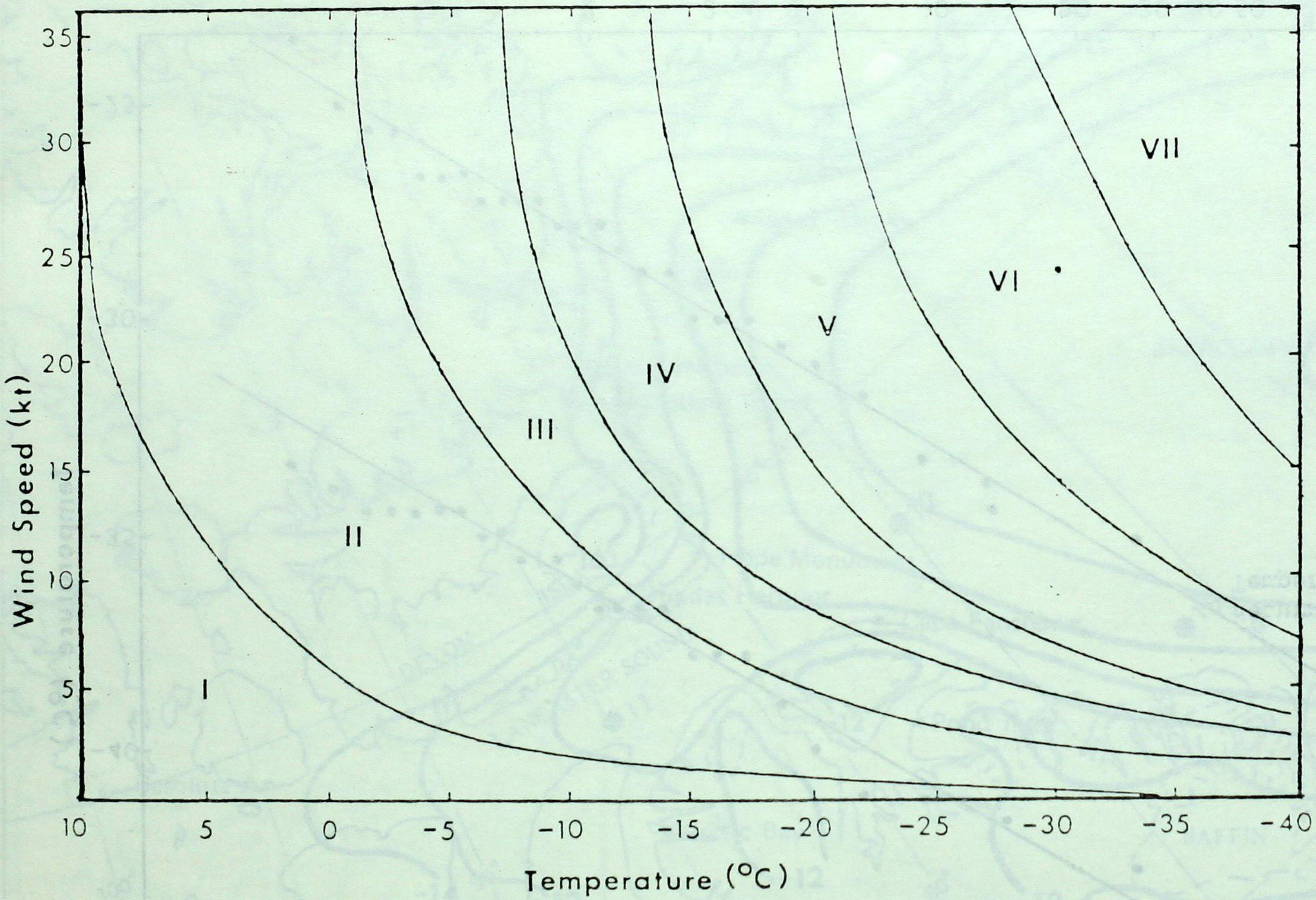

Figure 1.18 Wind – Chill Comfort Classes Based on Combined Wind – Temperature Effects. Based on a Nomogram Used by USAF at Goose Bay Air Base.

Comfort Classes

I. Comfortable with normal precaution.

II. Work and travel become uncomfortable unless properly clothed.

III. Work and travel become more hazardous unless properly clothed. Heavy outer clothing becomes mandatory.

IV. Unprotected skin will freeze with direct exposure over prolonged period. Heavy outer clothing becomes mandatory.

V. Unprotected skin can freeze in one minute with exposure. Multiple layers of clothing mandatory. Adequate face protection becomes important. Work and travel alone not advisable.

VI. Adequate face protection becomes mandatory. Work and travel alone prohibited. Supervisors must control exposure times by careful work scheduling.

VII. Personnel become easily fatigued. Buddy system and observation mandatory.

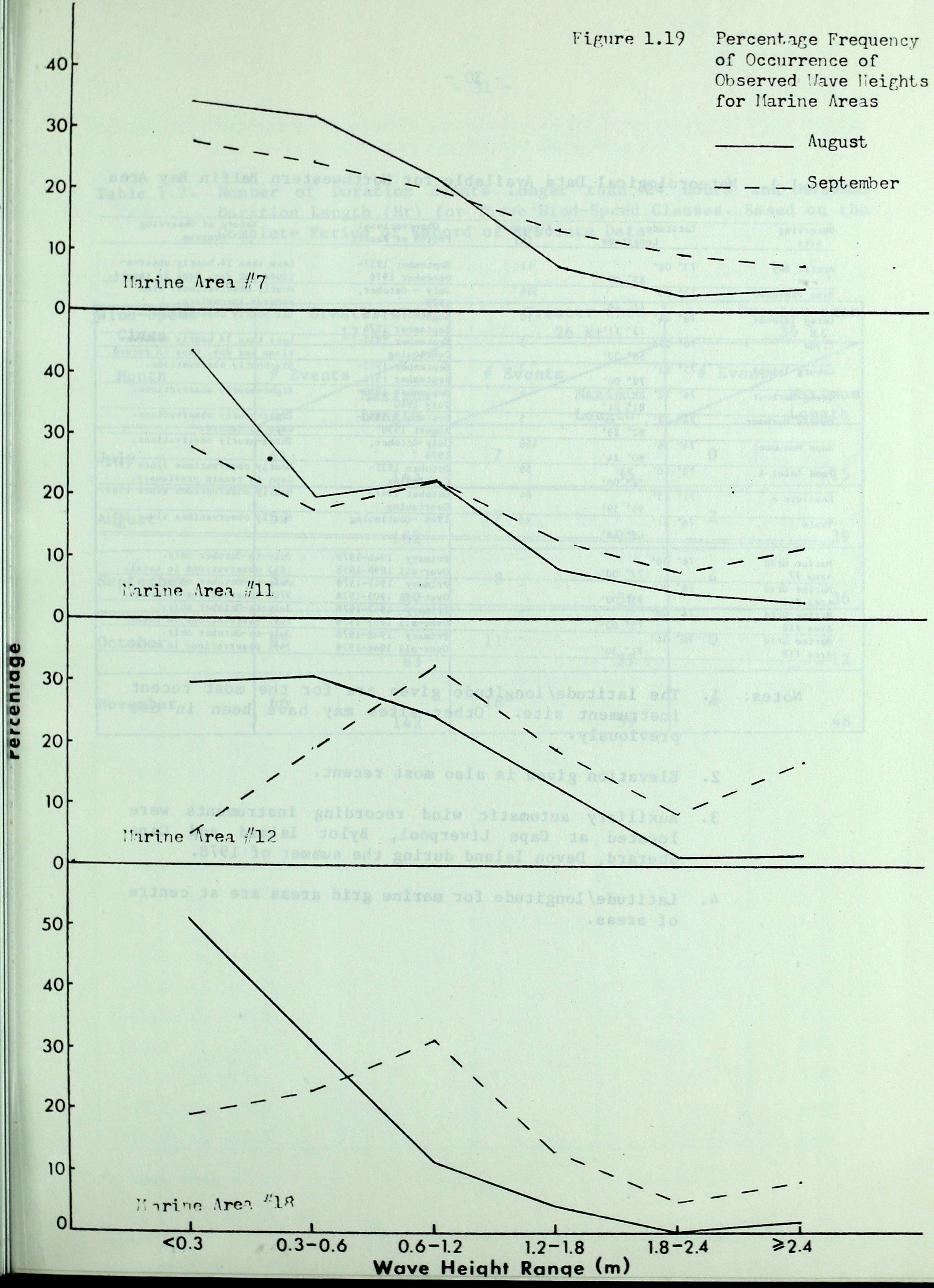

Figure 1.19 Percentage Frequency of Occurrence of Observed Wave Heights for Marine Areas

Table 1.1. Meteorological Data Available for Northwestern Baffin Bay Area

Observing Site	Latitude	Longitude	Elevation (m)	Observational Period of Record	Nature of Observing Program
Arctic Bay	73° 02'	85° 09'	11	September 1937-December 1976	Less than 24 hourly observations per day. Gaps in record.
Cape Fanshawe	73° 33'	77° 26'	596	July - October, 1978	Hourly observations. Wind records incomplete.
Carey Islands	76° 44'	73° 11'	10	August 1973-September 1974	Six-hourly observations.
Clyde	70° 27'	68° 33'	3	September 1933-Continuing	Less than 24 hourly observations per day. Gaps in record.
Coburg Island	75° 55'	79° 00'	3	September 1972-September 1976	Six-hourly observations.
Craig Harbour	76° 12'	81° 01'	4	September 1933-July 1940	Eight-hourly observations.
Dundas Harbour	74° 32'	82° 23'	5	September 1930-August 1950	Eight-hourly observations. Gaps in record.
Hope Monument	74° 36'	80° 24'	450	July-October, 1978	Three-hourly observations.
Pond Inlet A	72° 40'	78° 00'	59	October 1921-Continuing	Hourly observations since 1974. Gaps in record previously.
Resolute A	74° 43'	94° 59'	64	October 1947-Continuing	Hourly observations since 1962.
Thule	76° 31'	68° 48'	80	1946 -Continuing	Hourly observations since 1951.
Marine Grid Area #7	76° 30'	75° 00'	-	Primary 1946-1978 Over-all 1898-1978	July-to-October only. 1865 observations in total.
Marine Grid Area #11	74° 00'	85° 00'	-	Primary 1947-1978 Over-all 1903-1978	July-to-October only. 3700 observations in total.
Marine Grid Area #12	74° 00'	75° 00'	-	Primary 1947-1978 Over-all 1903-1978	July-to-October only. 1097 observations in total
Marine Grid Area #18	70° 30'	71° 30'	-	Primary 1948-1978 Over-all 1946-1978	July-to-October only. 1491 observations in total.

Notes:

1. The latitude/longitude given are for the most recent instrument site. Other sites may have been in use previously.
2. Elevation given is also most recent.
3. Auxiliary automatic wind recording instruments were located at Cape Liverpool, Bylot Island and Cape Sherard, Devon Island during the summer of 1978.
4. Latitude/longitude for marine grid areas are at centre of areas.

Table 1.2. Number of Duration Events Longer than 24 Hours and Maximum Duration Length (Hr) for Three Wind-Speed Classes. Based on the Complete Period of Record of Resolute Data.

Wind-Speed Class	Greater than 17 kt		Greater than 26 kt		Greater than 35 kt	
Month	# Events	Maximum Length	# Events	Maximum Length	# Events	Maximum Length
July	61	145	7	35	0	15
August	53	162	17	75	2	39
September	53	87	8	56	4	36
October	95	83	11	37	0	12
November	66	142	18	59	4	48

Table 1.3. Extreme Hourly Wind Speeds (Kt) Recorded at Coastal Stations in the Vicinity.

Station and Period of Record Used	July	August	September	October	November
Arctic Bay (1953-1964, 1971)	28	28	26	39	22
Clyde (1953-1972)	37	35	52	43	43
Dundas Harbour (1930-1933, 1945-1950)	7*	9	9	8	9
Pond Inlet (1940-1954)	39	35	35	39	30
Resolute A (1953-1972)	46	48	57	50	77

* Dundas Harbour winds were recorded in Beaufort Force numbers. These numbers refer to the following wind-speed ranges: Force 7: 28-33 kt, Force 8: 34-40 kt, Force 9: 41-47 kt.

Table 1.4. Percentage Frequency of Occurrence of Temperature Classes during the Period of Record for Marine Grid Area # 7.

Temperature (°C)	Percentage Frequency			
	July	August	September	October
6.8 to 8.9	6.9	1.9		
4.5 to 6.7	9.5	17.2	0.3	
2.3 to 4.4	39.2	47.6	2.6	
0.1 to 2.2	33.3	28.3	22.5	1.3
-2.1 to 0.0	8.5	5.0	38.3	27.8
-4.3 to -2.2	2.6		19.5	27.8
-6.6 to -4.4			14.2	35.4
-8.8 to -6.7			2.6	5.1
-11.0 to -8.9				2.5

Table 1.5. Percentage Frequency of Occurrence of Temperature Classes during the Period of Record for Marine Grid Area #11.

Temperature (°C)	Percentage Frequency			
	July	August	September	October
13.4 to 15.6		0.1		
11.2 to 13.3	0.4	0.5		
9.0 to 11.1	2.8	1.3	0.1	
6.8 to 8.9	12.1	5.6	0.1	
4.5 to 6.7	24.5	14.0	2.3	
2.3 to 4.4	38.9	39.2	11.4	0.3
0.1 to 2.2	19.0	34.8	34.3	1.4
-2.1 to 0.0	2.3	4.5	32.8	10.7
-4.3 to -2.2		*	11.8	16.8
-6.6 to -4.4			4.0	22.3
-8.8 to -6.7			1.7	19.0
-11.0 to -8.9			1.1	12.5
-13.2 to -11.1			0.4	8.0
-15.5 to -13.3				5.8
-17.7 to -15.6				2.6
-19.9 to -17.8				0.6

* Less than 0.05

Table 1.6. Percentage Frequency of Occurrence of Temperature Classes during the Period of Record for Marine Grid Area #12.

Temperature (°C)	Percentage Frequency			
	July	August	September	October
9.0 to 11.1	1.1	0.9		
6.8 to 8.9	5.3	3.0		1.5
4.5 to 6.7	24.5	24.1	1.2	7.6
2.3 to 4.4	31.9	40.3	10.8	13.6
0.1 to 2.2	35.1	29.4	28.3	8.4
-2.1 to 0.0	2.1	2.3	40.8	22.0
-4.3 to -2.2			12.0	14.4
-6.6 to -4.4			5.1	14.4
-8.8 to -6.7			1.7	3.8
-11.0 to -8.9			0.3	4.5
-13.2 to -11.1				3.8
-15.5 to -13.3				1.5
-17.7 to -15.6				4.5

Table 1.7. Percentage Frequency of Occurrence of Temperature Classes during the Period of Record for Marine Grid Area #18.

Temperature (°C)	Percentage Frequency			
	July	August	September	October
11.2 to 13.3	Insufficient Data	0.2		
9.0 to 11.1		2.4	0.2	
6.8 to 8.9		8.5	2.9	1.8
4.5 to 6.7		21.1	5.8	4.1
2.3 to 4.4		44.0	21.6	2.4
0.1 to 2.2		22.3	39.8	21.7
-2.1 to 0.0		1.5	21.6	14.3
-4.3 to -2.2			7.9	15.7
-6.6 to -4.4			0.2	21.2
-8.8 to -6.7				9.2
-11.0 to -8.9				6.9
-13.2 to -11.1				1.8
-15.5 to -13.3				0.9

Table 1.8. Percentage Frequency of Occurrence of Temperature Classes during the Period 1957-1966 for Resolute A.

Temperature (°C)	Percentage Frequency				
	July	August	September	October	November
13.4 to 15.6	0.1				
11.2 to 13.3	0.2				
9.0 to 11.1	1.4	0.2			
6.8 to 8.9	5.8	3.1			
4.5 to 6.7	19.8	10.7	0.2		
2.3 to 4.4	27.3	29.0	1.6		
0.1 to 2.2	35.4	34.2	6.2		
-2.1 to 0.0	9.8	17.2	17.7	0.2	
-4.3 to -2.2	0.2	5.1	22.3	2.6	0.2
-6.6 to -4.4		0.5	17.5	3.5	0.8
-8.8 to -6.7			14.0	9.0	1.8
-11.0 to -8.9			8.8	9.6	3.3
-13.2 to -11.1			6.4	12.3	3.7
-15.5 to -13.3			3.6	13.2	3.5
-17.7 to -15.6			1.3	12.6	4.4
-19.9 to -17.8			0.3	11.1	7.8
-22.1 to -20.0			*	9.3	9.8
-24.3 to -22.2				6.9	10.3
-26.6 to -24.4				4.7	15.1
-28.8 to -26.7				3.3	14.5
-31.0 to -28.9				1.3	10.8
-33.2 to -31.1				0.3	9.0
-35.5 to -33.3				0.1	3.4
-37.7 to -35.6					1.6

* Less than 0.05

Table 1.9. Summary of Monthly Mean and Extreme Temperature Values

Station	Mean Daily Temperature (°C)					Extreme High Temperature (°C)					Extreme Low Temperature (°C)				
	July	Aug.	Sep.	Oct.	Nov.	July	Aug.	Sep.	Oct.	Nov.	July	Aug.	Sep.	Oct.	Nov.
Arctic Bay (1938-1965)	5.8	4.8	-1.6	-11.1	-21.1	23.9	18.3	13.3	6.7	2.2	-5.6	-4.4	-15.0	-32.2	-41.1
Clyde (1946-1970)	4.6	4.0	-0.1	-6.6	-16.9	22.2	20.0	12.8	6.1	6.7	-5.6	-5.6	-16.1	-25.6	-35.0
Coburg Island (1972-1974)	3.9	3.1	-3.1	-10.2	-19.6	12.2	13.9	7.2	0.0	1.1	-2.2	-3.9	-15.0	-25.6	-35.6
Craig Harbour (1934-1940)	5.0	3.3	-2.2	-11.1	-20.6	16.1	11.1	7.2	4.4	1.1	-1.7	-5.6	-10.6	-23.3	-35.0
Dundas Harbour (1930-1933,1945-1950)	5.6	4.3	-1.0	-9.1	-15.4	17.8	17.1	11.1	2.2	2.4	-2.2	-3.1	-14.0	-23.9	-35.0
Pond Inlet (1922-1960)	5.1	4.7	-1.1	-10.3	-21.2	20.0	17.2	15.6	7.2	3.9	-6.1	-3.3	-17.8	-28.9	-46.1
Resolute A (1947-1970)	4.3	2.7	-4.9	-14.7	-24.2	18.3	15.0	8.9	0.0	-2.8	-2.8	-8.3	-20.6	-35.0	-42.8
Marine Grid Area # 7 (1947-1972)	2.9	3.2	-1.4	-4.2	-	10.0	8.9	5.6	1.6	-	-3.3	-1.7	-8.3	-12.2	-
Marine Grid Area #11 (1947-1972)	4.4	3.4	0.1	-5.8	-	8.3	12.8	6.7	2.8	-	1.7	-1.7	-9.4	-15.0	-
Marine Grid Area #12 (1947-1972)	3.8	3.6	-0.3	-5.2	-	8.3	11.1	6.1	1.1	-	-1.7	-1.1	-7.2	-16.7	-
Marine Grid Area #18 (1949-1972)	-	3.8	-1.6	-4.3	-	-	11.1	10.0	2.2	-	-	-1.1	-3.9	-13.3	-

Table 1.10. Percentage Frequency of Occurrence of Wind-Chill Comfort Classes*

Station Month	Comfort Class I	II	III	IV	V	VI	VII
Dundas Harbour							
July	72	28					
September	35	53	10	1			
November	4	34	23	17	18	4	
Resolute A							
July	42	53	2				
September	13	58	21	7	**		
November	3	16	19	21	26	14	1

* Comfort Classes defined on Figure 1.18.

** Less than 0.5%.

Table 1.11. Percentage Frequency of Occurrence of Visibility by Wind-Speed Range for the Marine Grid Areas

Grid Area	Visibility Range (nm)	Wind-Speed Classes (kt)																			
		July					August					September					October				
		0-3	4-10	11-21	22+	All	0-3	4-10	11-21	22+	All	0-3	4-10	11-21	22+	All	0-3	4-10	11-21	22+	All
# 7	Visib. <1	1.6	12.2	9.0	1.6	22.4	2.2	5.9	1.9	0.7	10.7	0.5	1.4	1.1	0.6	3.6	0.0	0.8	2.4	0.0	3.2
	1 ≤ Visib.<5	1.0	3.2	1.6	2.1	7.9	0.4	2.6	3.4	1.6	8.0	0.8	4.1	5.0	3.5	13.4	5.7	3.3	6.5	3.2	18.7
	Visib. ≥ 5	4.8	25.9	27.0	10.0	67.7	13.0	33.7	25.2	9.4	81.3	6.6	25.8	31.2	19.4	83.0	5.7	35.0	26.8	10.6	78.1
#11	Visib. <1	0.9	2.3	4.2	2.8	10.2	1.7	2.3	3.3	2.1	9.5	0.7	2.0	2.0	1.5	6.2	0.3	3.2	2.4	1.6	7.5
	1 ≤ Visib.<5	0.5	3.2	3.2	0.9	7.8	0.7	2.3	3.9	2.4	9.4	1.4	3.6	4.6	2.5	12.1	2.1	6.2	5.9	5.0	19.2
	Visib. ≥ 5	12.0	25.3	30.4	14.3	82.0	11.1	28.7	30.5	10.8	81.1	5.7	25.4	34.6	13.9	81.7	8.5	28.8	26.1	9.9	73.3
#12	Visib. <1	2.3	6.0	4.4	0.5	13.2	0.3	2.6	1.1	1.7	5.7	0.5	2.7	2.1	2.7	8.0	4.9	10.7	1.9	0.0	17.5
	1 ≤ Visib.<5	0.7	3.9	5.1	2.3	12.0	0.0	3.6	4.6	2.3	10.5	1.1	9.0	5.3	9.6	25.0	2.9	1.9	2.9	0.0	7.7
	Visib. ≥ 5	7.6	32.3	27.0	7.9	74.8	7.7	29.9	34.8	11.4	83.8	6.8	21.3	22.9	16.0	67.0	8.6	33.0	27.2	5.8	74.8
#18	Visib. <1						1.2	5.4	3.2	0.9	10.7	1.4	3.0	3.3	0.8	8.5	0.0	2.1	3.2	2.1	7.4
	1 ≤ Visib.<5			Insufficient			1.0	5.1	6.3	0.9	13.3	1.1	4.2	7.2	3.8	16.3	0.4	5.0	10.7	7.9	24.0
	Visib. ≥ 5			Data			10.0	30.3	29.9	5.8	76.0	5.5	24.6	36.8	8.3	75.2	2.1	24.4	28.1	14.0	68.6

Table 1.12. Percentage Frequency of Occurrence of Combined Ceiling and Visibility Classes for the Marine Grid Areas

Grid Area	Combined Ceiling (C) and Visibility (V) Classes	Percentage Frequency			
		July	August	September	October
# 7	C <1000' and/or V < 5 nm	36.6	23.2	19.9	38.6
	C < 600' and/or V < 1 nm	27.3	14.5	8.5	16.7
	C < 150' and/or V < 50 yd	13.7	7.8	4.5	1.5
#11	C <1000' and/or V < 5 nm	12.0	20.9	18.6	22.3
	C < 600' and/or V < 1 nm	6.2	12.0	7.4	8.5
	C < 150' and/or V < 50 yd	3.8	3.8	0.9	3.5
#12	C <1000' and/or V < 5 nm	Insufficient Data	30.6	23.3	36.4
	C < 600' and/or V < 1 nm		20.6	9.3	19.0
	C < 150' and/or V < 50 yd		10.5	3.5	6.2
#18	C <1000' and/or V < 5 nm	Insufficient Data	29.1	25.4	34.0
	C < 600' and/or V < 1 nm		15.4	10.3	12.8
	C < 150' and/or V < 50 yd		7.5	2.4	3.2

Table 1.13. Percentage Frequency of Occurrence of Combined Ceiling and Visibility Classes for Resolute A. Based on the Period 1957-1966.

Combined Ceiling (C) and Visibility (V) Classes	Percentage Frequency				
	July	August	September	October	November
C <1000' and/or V < 3 mi	27.1	30.1	27.9	24.0	14.1
C < 500' and/or V < 1 mi	18.8	18.8	10.0	9.0	5.2
C < 200' and/or V < 0.5 mi	10.3	7.6	4.2	3.8	1.8

Table 1.14. Probability of Encountering Aircraft Icing over the Northwestern Baffin Bay Area.

Constant Pressure Surface (kPa)	Corresponding Mean Altitude MSL (m)	Probability (P)				
		July	August	September	October	November
100	100	$P < 0.025$	$P < 0.025$	$0.025 < P < 0.05$	$P \sim 0.05$	$0.05 < P < 0.1$
85	1400	$0.025 < P < 0.05$	$P \sim 0.05$	$0.1 < P < 0.15$	$0.1 < P < 0.15$	$0.05 < P < 0.1$
70	2900	$p \sim 0.05$	$0.05 < P < 0.1$	$0.05 < P < 0.1$	$0.05 < P < 0.1$	$P \sim 0.05$
50	5300	$0.025 < P < 0.05$	$0.025 < P < 0.05$	$P < 0.025$	$P < 0.025$	$P < 0.025$

Derived from: Heath and Cantrell, 1972.

SECTION 2. EXTREME WIND, WAVE, AND STRUCTURAL ICING OCCURRENCE IN NORTHWESTERN BAFFIN BAY

2.1 Introduction

The purpose of this second section of the report is to provide an analysis of extreme meteorological and related events in the study area. As in Section 1, the analysis was restricted to the possible offshore drilling season. The results presented here are based on analyses of the magnitudes of observed and hindcast occurrences of the events. Careful attention should be paid to the assumptions built into the hindcasting techniques used.

2.2 Study Area and Data Used

The general study region, as described in Section 1, is that area of northwestern Baffin Bay located off the eastern and southeastern coasts of Devon Island and the northern and eastern coasts of Baffin and Bylot Islands. These adjacent land masses include mountainous terrain with permanent icefields at altitudes extending beyond 1500 metres ASL. The rest of Baffin Bay lies to the north, east, and southeast and Lancaster Sound penetrates the Arctic Islands to the west. Sea depths in the area range from 400 to 600 metres.

For this portion of the study, it was necessary to select a reference point and area within the general study region (see Figure 2.1) for the wave and structural icing analyses. The reference point (74.5°N 78.0°W) was used for determining the fetches for the wave analysis and the reference area (74 to 75°N, 76 to 80°W) for determining sea-ice cover conditions for the wave and structural icing analyses.

The bulk of the data used in this study was extracted from the weather records of Resolute which is located approximately 400 km to the west on Cornwallis Island. Resolute was selected for use in this study as its wind speed regime was considered to be reasonably representative of the general study area (see Appendix A). As such, it provided a long-term, continuous series of hourly weather observations.

Sea-ice cover information required was taken from the historical charts (1959-1977) of the Ice Climatology Section of AES in Ottawa. The latter also supplied United States Navy Hydrographic ice charts to cover the 1953-1958 period.

2.3 Sea-Ice Cover

Sea ice is one of the physical factors which dominate offshore activity in the Arctic. It not only controls the length of the active shipping season, but also in many areas poses a constant danger to activities during that season. The extent of the ice cover may also have an important influence on the occurrence and magnitude of events such as the wave and spray icing conditions examined in this study. The brief overview of the behaviour of the ice cover during the period of concern which follows pertains to the reference area of Figure 2.1 previously mentioned.

The normal pattern of ice clearing begins in June with open water extending westward and southward, from the "North Water" area of northern Baffin Bay, along the eastern shore of Devon Island. Some open water may also occur within Lancaster Sound at this time. These areas usually unite, by mid-July, into one area of open water extending from Smith Sound in the north to a line running from Lancaster Sound and the north shore of Bylot Island across the northwestern end of Baffin Bay to the Cape Athol area of the Greenland coast. The study area may be affected by ice at any time during the open-water season, however, due to ice-drift from one or all of Smith, Jones, and Lancaster Sounds. Frequently, for example, sea ice drifts southward along the northwest coast of Baffin Bay from Smith Sound, remaining along the Devon coast well into August. Significant to this study is the potential for this ice to move southeastward from Devon Island in high concentrations and into the study area at times when open water is the dominant condition elsewhere in northwestern Baffin Bay.

During July and August, another important feature is the "middle ice" of Baffin Bay to the southeast of the study area. This pack usually separates from the west coast of Greenland and the northeast coast of Baffin Island by the middle of July. This leaves a very broad band of ice in varying concentrations across the middle of the Bay from Baffin Island to Melville Bay centred roughly on 65 degrees west longitude. This "middle ice" may recede from Melville Bay forming a broad tongue extending from the east coast of Baffin Island. When this pattern occurs, fetches for easterly winds affecting northwestern Baffin Bay gradually increase over the summer as the tongue recedes further towards Baffin Island. Alternatively, the "middle ice" may also erode along its eastern and western edges leaving a narrowing band of ice along the axis of the Bay mentioned above. When this pattern occurs, the pack will break up along this band leaving patches of ice and eventually open water allowing increasingly long southeasterly wind fetches, though much later in the season than for the previous pattern. The complete clearing of Baffin Bay permits the greatest fetch length for wave development used in this study, extending almost 800 kilometres to the Greenland coast to the southeast. The end of the open-water season is usually heralded by new ice forming about the second week in October. For the years examined, ice covers significant to offshore operations developed as early as mid-September and as late as the final week of October.

2.4 Wind

A key meteorological parameter for all portions of this section of the study is the strength of the offshore wind. Ship observations may provide an impression of the distribution of these winds, but they are irregular both in time and space, thus precluding an in-depth statistical analysis. It was, therefore, necessary to use long-term, continuous records from Resolute for extensive and event-specific analyses. Values extracted from this coastal station had to be adjusted in order to be representative of over-water conditions. In this study, all Resolute wind speeds were adjusted using the formula:

$$V_w = R\ V_l$$

where V_w is the over-water wind speed,

V_l is the land-based wind speed as reported at Resolute, and

R is a value for the ratio V_w/V_l based on Resolute data for July through October and for winds greater than or equal to 20 knots.

Table 2.1 displays the values of R used in this study (see Appendix A). It must be noted that the adjustments apply to the period of open water and for areas free of topographic influences and should not be trusted in locations or at times when such conditions do not apply.

Figure 2.2 indicates the results of an extreme value analysis of Resolute extreme hourly wind speed data which have been adjusted as above. The analysis follows the Gumbel technique (Kendall, 1959). Table 2.2 gives corresponding values determined for several durations according to Draper and Wu (1969). Return periods for intervals greater than the length of the initial data base should be used with caution.

It has not been possible within this study to provide information on the directional distribution of extreme offshore winds, but in Section 3, it is suggested that winds 35 knots or stronger and lasting at least six hours are predominantly northwesterly or southeasterly.

2.5 Wind Waves

The approach taken in this study was to hindcast annual extreme wave events using the Sverdrup-Munk-Bretschneider method as outlined by the United States Coastal Engineering Research Centre (1973). This method requires event duration, mean wind speed over the same time period, and fetch length. These values are used to enter a nomogram which provides a significant wave height for the conditions specified. It should be noted that in interpreting the results, the significant wave height is the average height of the highest one-third of all waves observed. The maximum wave height would be higher. (A factor of 1.8 has been suggested by Thom, 1971.).

The analysis presented here is based on a reference point (see Figure 2.1) in northwestern Baffin Bay opposite Lancaster Sound and Devon Island. Synoptic observations of wind for Resolute were examined for conditions greater than 20 knots which might be significant to a study of extremes. For each year from 1953 to 1977, a number of storms for the period July to October were selected. The selection of an event was dependent upon certain direction, duration, and velocity criteria.

Wind direction was used to eliminate storms from the sectors 164°T to 220°T and 266°T to 330°T due to fetch-restricting land masses. This restriction applies to a study of seasonal extremes and is not meant to disregard the potential for moderately high waves to be generated by winds from these directions. If an event satisfied the direction restriction, it was selected as a potential extreme event based on its having a mean velocity and/or long duration high relative to other events during the given season. Once selected, an event was fitted to its respective fetch class depending on the dominant wind direction throughout its duration. These classes, shown in Table 2.3, are based upon the significant coast lines which limit fetches for the study area.

The selected storms were compared to the ice-cover charts corresponding to their dates and eliminated if open water did not exist in the reference area. Otherwise, the wind fetch was measured as the distance along the centre radial of the respective fetch class until pack ice or land intervened. Wind speeds were adjusted as previously described and the nomogram was used to hindcast the maximum possible significant wave height developed during the event. The maximum obtained for each season was used in the extreme value analysis. Among the seasonal extremes found, the maximum significant wave height was 8.8 metres, produced by a storm occurring in 1962 for which the wind averaged 26 knots over a duration of 36 hours. (This event also took place under conditions favouring moderate-to-severe structural icing.)

The results of the extreme wave analysis are shown in Figure 2.3. For a 20-year return period, the estimated extreme significant wave height is 8.1 metres. Under this condition, an extreme wave height of 14.7 metres may be expected (1.8 times the significant wave height). These values are almost double those found for nearby Lancaster Sound (Duck et al., 1977) and are mainly due to the greater range of potential fetches significant to extremes at the location considered in this study.

2.6 Structural Icing

An important aspect of meteorology in cold regions is the potential for ice to form on structures exposed to the weather. This problem is even more severe in offshore regions of the Arctic where air temperatures may drop well below the freezing point of sea water before surface sea-ice cover restricts marine activities. The estimation and prediction of such icing is important for dealing with the severe working conditions, mechanical complications, and decreased vessel stabilities that may be expected at this time of year. A useful review of the literature and the problems of estimating ice accretion is provided by Shellard (1974). In light of the significance of this type of event, a section of this study has been devoted to determining the past occurrences of extreme and severe structural icing events due to sea spray in northwestern Baffin Bay.

The procedures followed here were the same as those used by Berry et al. (1975) and Duck et al. (1977). Events were selected for analysis on the basis of weather criteria set out in the nomograms produced by Mertins (1968), as shown in Figure 2.4. From these diagrams, a computer program using air temperature, sea-surface temperature, and wind velocity was developed to linearly interpolate ice accretion rates between the boundaries of the indicated severity classes (Berry et al., 1975). Extreme events for each year during the period 1953-1977 were selected from Resolute data on the basis of the annual event which contained the most hazardous conditions of wind and cold temperatures relative to other events occurring in the same season. In selecting the events, it was assumed that the icing season extends from the time when sea-ice cover is reduced to a maximum of three-tenths concentration covering 25 percent of the reference area in the summer until the same cover has reformed in the fall. The severe icing portion of the study includes an analysis of only those events for which the ice accretion rate was greater than or equal to 7.0 centimetres per 24 hours and includes all such events for each season from 1963 to 1974. Before ice accretion rates were determined, the winds were adjusted to the over-water condition. During the calculation of ice accretion, a sea-surface temperature of +1°C was used for September events and 0°C for those occurring in October.

The results of the extreme value analysis are shown in Figure 2.5. The total amount of ice accreted for each annual extreme event is shown along with the line of best fit. The extreme event of those on which the analysis is based had the potential to produce 18.7 cm of ice. For a 20-year return period, the expected extreme event is estimated to produce 18.2 cm of ice.

The results of the analysis of the severe icing events are displayed in Table 2.4. Increments of ice accretion rates are given in the first column of this table while average and maximum durations of these rates are provided in the second and third columns. The rates in column one must be read as equal to or greater than such that for the first increment, an ice accretion rate of at least 7.0 cm/24 hr appears to last for an average duration of 4.5 hours. One such event, however, lasted as long as 38 hours. In the same example, column four indicates that there were 374 hourly observations in the data set for which the ice accretion rate was equal to or greater than 7.0 cm/24 hr. Since this rate is the threshold for severe icing it may be said that over the period examined this condition or worse averaged 31.2 hours per year (374 divided by 12 years), ranging from zero to 102 hours for any given year.

The results reported here show durations of events and amounts of ice accreted, but this should not be read directly as the only significance of the events. A severe icing event includes the occurrence of cold temperatures combined with high winds. Wind and waves serve to generate spray from both wave crests and vessel movements while the air temperature serves to rapidly cool droplets and structures such that freezing of spray takes place on contact or shortly thereafter. In effect, spray icing is a consequence of several hazardous meteorological conditions occurring simultaneously. Hence the amount indicated must be used also to infer the existence of such conditions for the duration of the event.

It should be noted that the information provided here does not indicate the likelihood of events to follow in close sequence.

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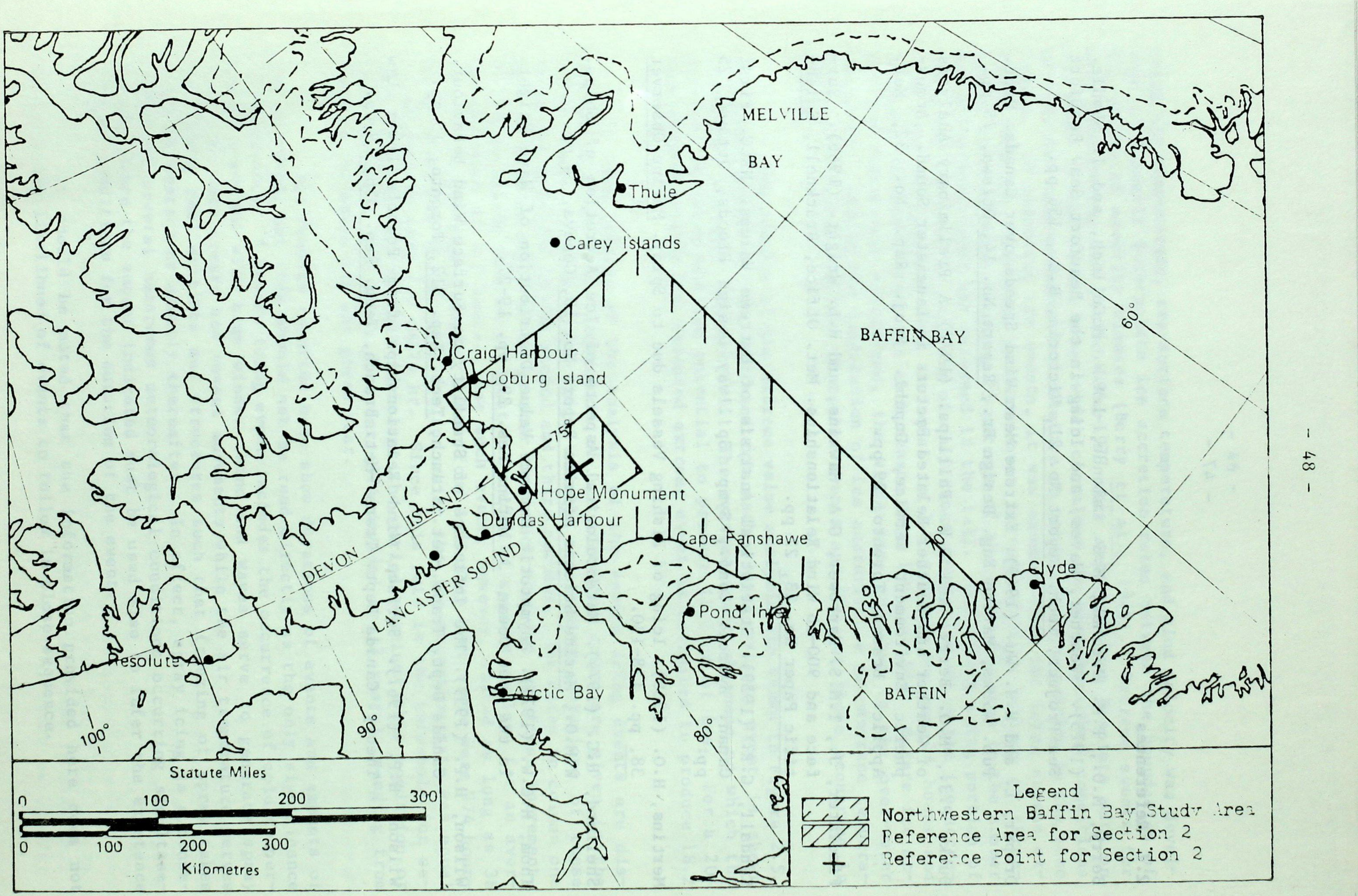
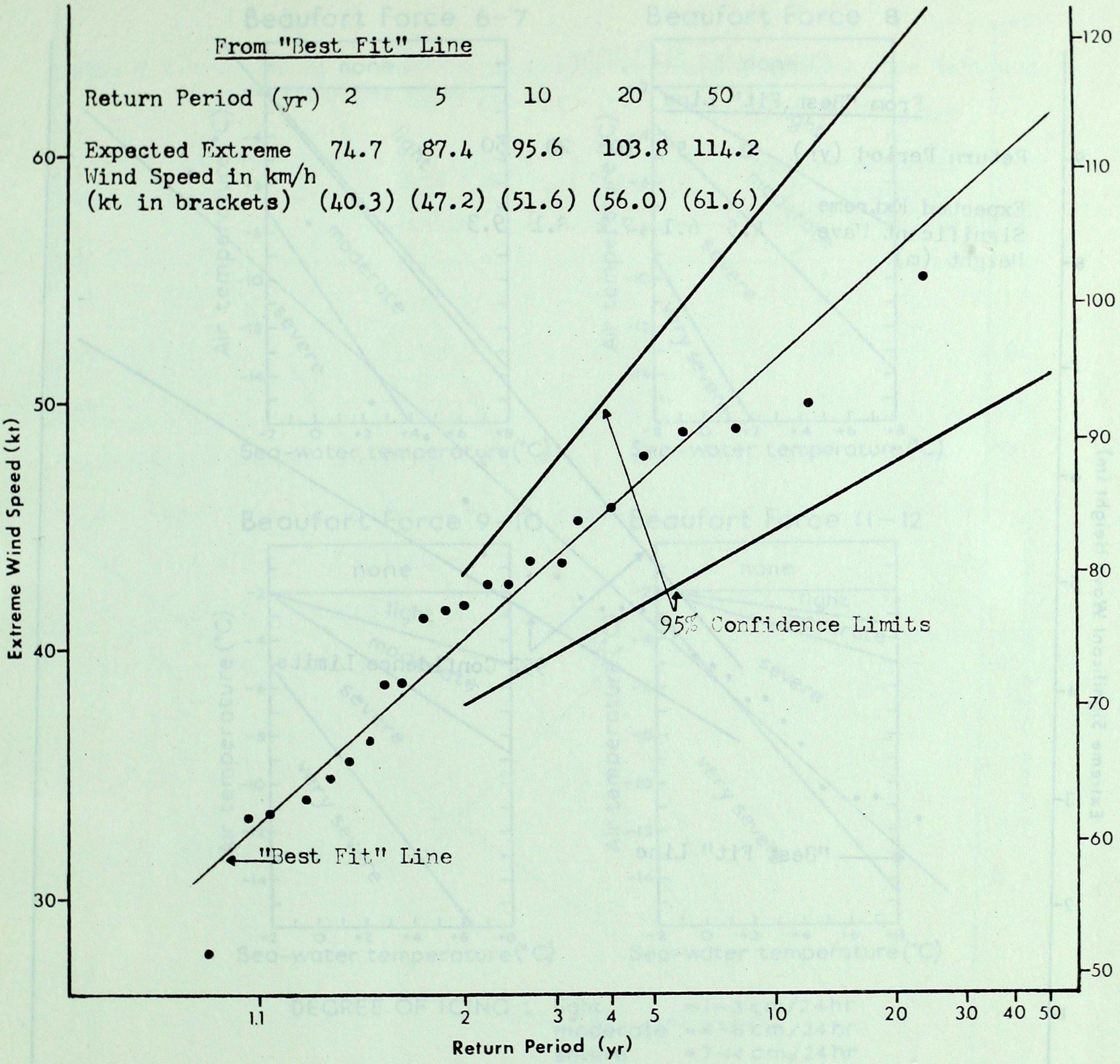


Figure 2.1. Map Showing the Northwestern Baffin Bay Study Area and the Reference Point and Area Used in Section 2 of the Report.



From "Best Fit" Line

Return Period (yr)	2	5	10	20	50
Expected Extreme Wind Speed in km/h (kt in brackets)	74.7 (40.3)	87.4 (47.2)	95.6 (51.6)	103.8 (56.0)	114.2 (61.6)

Figure 2.2. Expected Extreme High Hourly Wind Speed for July-to-October Period in Northwestern Baffin Bay.

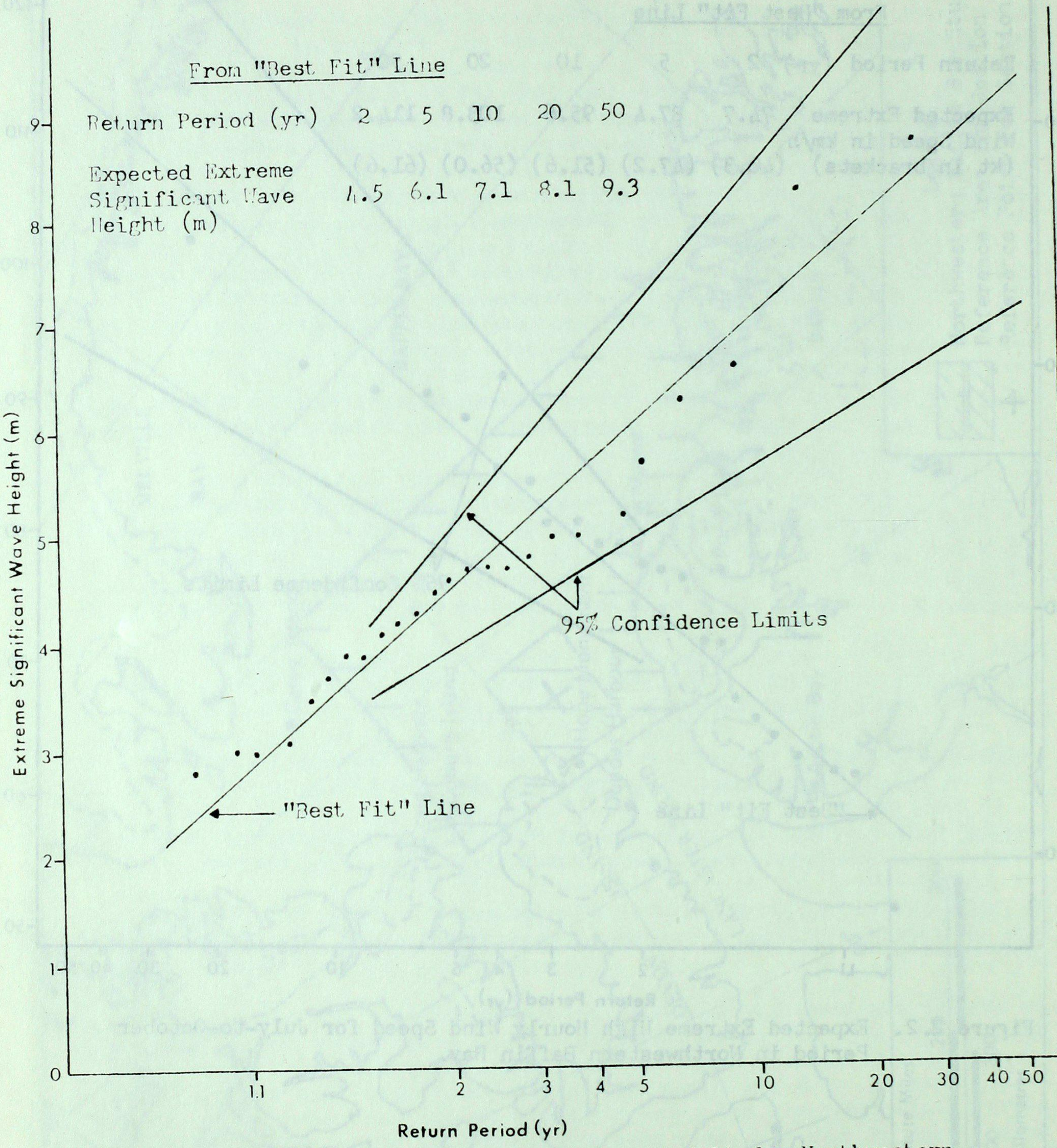


Figure 2.3. Expected Extreme Significant Wave Height for Northwestern Baffin Bay.

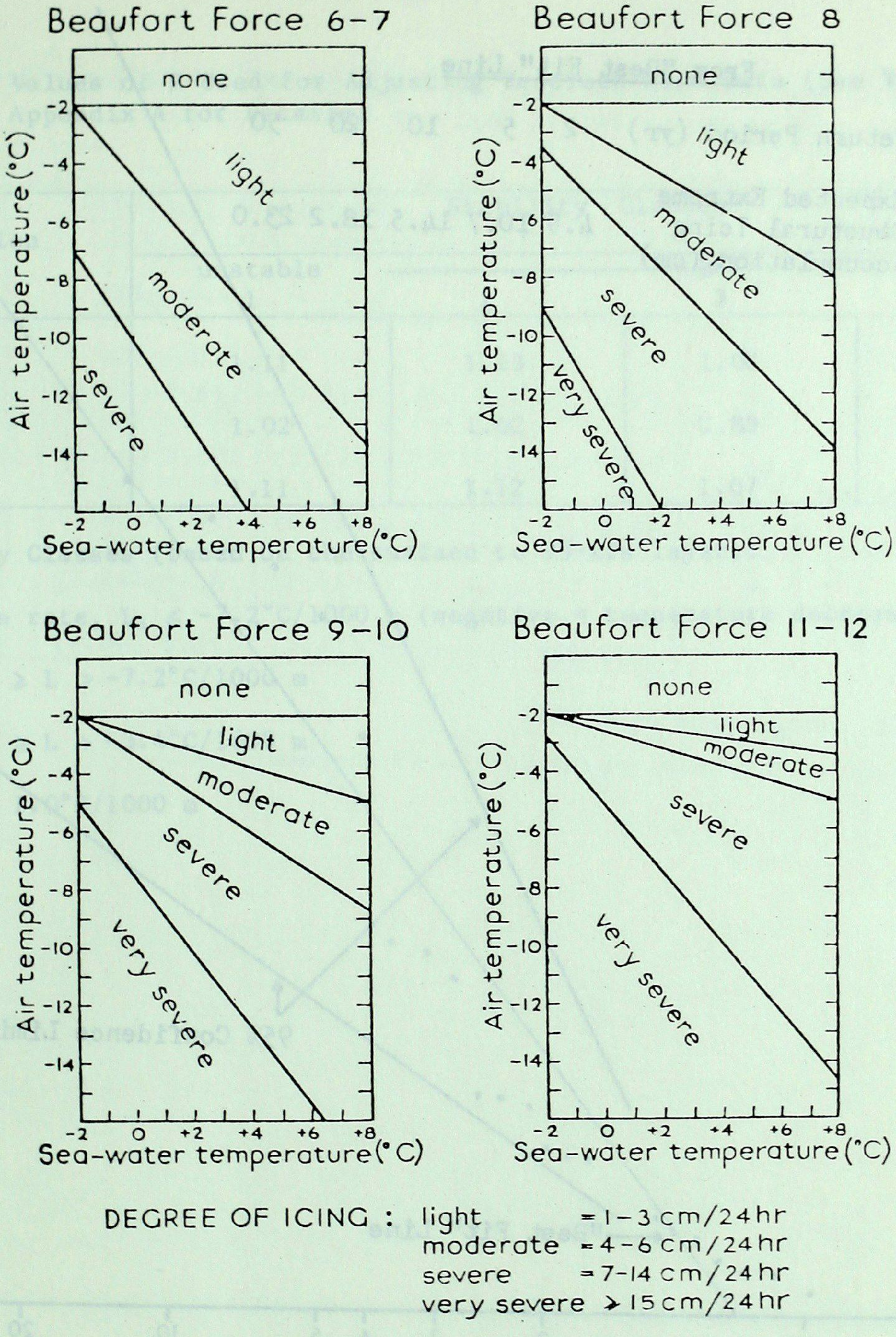
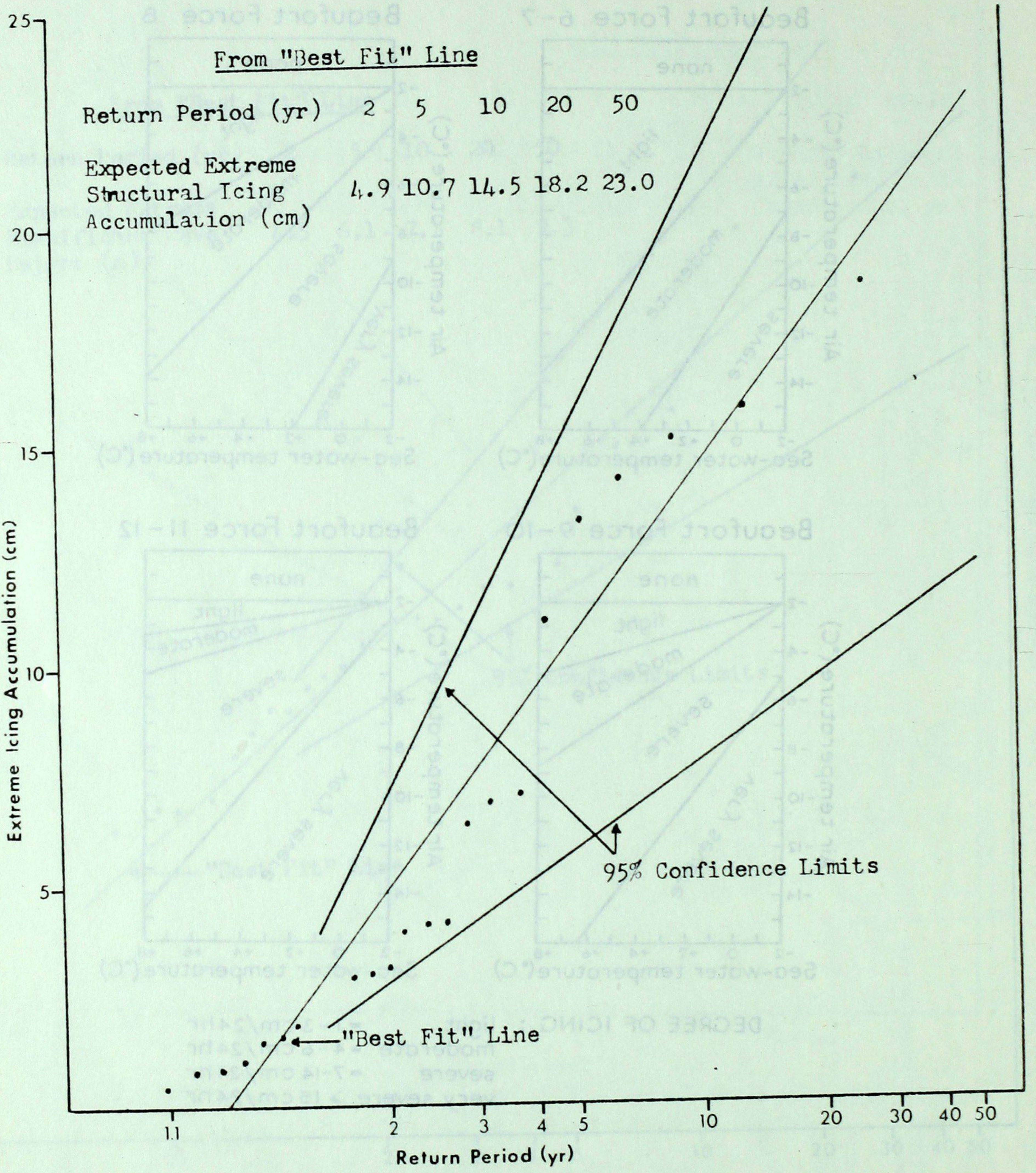


Figure 2.4. Conditions for Sea Spray Icing (Mertins, 1968).



From "Best Fit" Line

Return Period (yr)	2	5	10	20	50
Expected Extreme Structural Icing Accumulation (cm)	4.9	10.7	14.5	18.2	23.0

Figure 2.5 Expected Extreme Structural Icing Events for Northwestern Baffin Bay.

Table 2.1. Values of R Used for Adjusting Resolute Wind Data (See Text and Appendix A for Details)

Wind Direction	Stability Classes*			
	unstable 1	2	3	stable 4
260 - 020	1.11	1.13	1.08	1.17
020 - 140	1.02	1.02	0.89	0.85
140 - 260	1.11	1.12	1.07	1.15

* Stability Classes (based on the surface to 95-kPa layer):

1: Lapse rate, L, $\leqslant -7.2^\circ\mathrm{C}/1000$ m (negative = temperature decrease)

2: $-3.4 \geqslant L > -7.2^\circ\mathrm{C}/1000$ m

3: $1.0 \geqslant L > -3.4^\circ\mathrm{C}/1000$ m

4: $L > 1.0^\circ\mathrm{C}/1000$ m

Table 2.2. Expected Extreme High Wind Speeds for the July-to-October Period in Northwest Baffin Bay, for Various Durations

Duration (hr)	Adjustment Factor*	Wind Speed (km/h)			
		Return Period (yr)			
		2	5	20	50
1/60	1.25	** 93.4 (50.4)	109.3 (59.0)	129.8 (70.0)	142.8 (77.1)
1	1.00	74.7 (40.3)	87.4 (47.2)	103.8 (56.0)	114.2 (61.6)
6	0.87	65.0 (35.1)	76.0 (41.0)	90.3 (48.7)	99.4 (53.6)
12	0.79	59.0 (31.8)	69.1 (37.3)	82.0 (44.3)	90.2 (48.7)
24	0.73	54.5 (29.4)	63.8 (34.4)	75.8 (40.9)	83.4 (45.0)

* From: Draper and Wu (1969)

** Values in brackets represent the wind speed in kt.

Table 2.3. Fetch Classes Used in the Analysis of Waves

Class	Limits (°T)	Width (degrees)	Centre Radial (°T)
1	330 - 020	50	360
2	020 - 058	38	039
3	058 - 140	82	099
4	140 - 164	24	152
5	220 - 266	46	243

Table 2.4. Severe or Worse Structural Icing in Northwestern Baffin Bay. Based on 12 years Data for the Period 1963 to 1974

Ice Accretion Rate (cm/24 hr)	Average Duration (hr)	Maximum Duration (hr)	Occurrences ≥ Indicated Rate over the 12 Year Period
7.0	4.5	38	374
7.5	4.4	33	347
8.0	4.3	29	316
8.5	4.3	28	293
9.0	4.3	21	268
9.5	4.2	21	263
10.0	4.2	18	242
10.5	4.1	17	215
11.0	3.8	15	190
11.5	3.6	15	171
12.0	3.4	13	146
12.5	3.3	13	130
13.0	3.1	13	108
13.5	2.9	13	89
14.0	2.7	10	78
14.5	2.3	6	55
15.0	2.1	6	47
15.5	2.1	5	41
16.0	2.0	5	34
16.5	1.8	5	29
17.0	1.7	4	19
17.5	1.5	4	15
18.0	1.5	4	15
18.5	1.3	2	10
19.0	1.5	2	6
19.5	1.3	2	4
20.0	1.5	2	3
20.5	1.0	1	1
21.0	0.0	0	0

SECTION 3. EXTREME STORMS IN NORTHWESTERN BAFFIN BAY

3.1 Introduction

This portion of the report provides an investigation of extreme storms in northwestern Baffin Bay during the possible offshore drilling season (July to November). The general study area was that region used in the previous sections of the report.

For purposes of this investigation, a storm was defined to be any occurrence of gale force winds 65 km/h (35 kt) or stronger for a period of at least 6 hours. When such a storm was identified, its history was recorded to develop a brief synoptic climatology of the area. This climatology was extracted from the five seasons 1974-1978. For the most severe of these storms, a more detailed approach was taken. Where the winds were extreme, waves, sea ice, superstructure and aircraft icing as well as ceilings, visibilities, and wind chill were examined to demonstrate the worst environmental conditions to be expected in the study period.

3.2 Data Extraction and Analysis

Arctic Weather Centre (ARWC) maps were used exclusively for the synoptic portion of this study. Some ship data (principally those collected by Petro-Canada in 1978) were used to supplement the maps and allowed, in a few cases, their re-analysis thus giving a better depiction of the synoptic situation in northwestern Baffin Bay.

The data deficiency in the study area has been previously discussed in this report. To overcome this deficiency at least partially, the following method was used. Four points, considered to be fairly representative, were chosen in the study area. These are indicated in Figure 3.1. At each of these points, geostrophic winds were measured on the ARWC surface analyses using a standard geostrophic wind scale. The relationship between geostrophic level and surface winds will be discussed later.

Waves in this study were determined using Bretschneider's nomogram (1966). Superstructure icing was determined using the criteria developed by Mertins (1968) and the wind-chill rate was calculated following AES (1976).

3.3 General Synoptic Climatology of the Area

Baffin Bay has been aptly referred to as a graveyard for cyclones because of the high frequency of occluded lows affecting the area. Lows track to Baffin Bay in all months but are more frequent and intense in winter. Almost always, lows are in the occluded phase by the time they reach the area of interest in western Baffin Bay (Fraser, 1973).

The topography of Baffin Island and Greenland gives an important clue to this tendency for lows to fill in Baffin Bay. For a low to maintain its depth or deepen, a well-developed 50-kPa trough is required (often referred to as the nebulous "good upper support"). As well, an injection of cold air behind the low enhances the cyclonic circulation and warm air advection ahead of the low. This warm-cold contrast (baroclinicity) is required to supply energy to the system which maintains or deepens the low. For lows heading northwards across northern Quebec, Labrador, or the Atlantic Coast, this supply of warm air is physically removed by the ice cap on Greenland. Hence without the supply of warm air ahead of it the low fills as it moves northwards into Davis Strait and Baffin Bay. Similarly, for a low tracking northeastwards across the Keewatin towards Baffin Island, the mountains of Baffin Island act, much like the Rockies in the west, as a physical barrier to the passage of a low. Some lows that are supported by well- developed upper troughs manage to cross the mountains to, or redevelop over, Baffin Bay. Once over Baffin Bay, however, the lack of good thermal contrast (in the low levels) causes the low to fill. This simplistic approach to synoptic development gives some insight into the reasons for cyclolysis in Baffin Bay.

The synoptic regime of northwestern Baffin Bay suggests that the offshore drilling season may be divided into two parts - the Summer season and the Autumn season. In this study, the division between these two seasons was based on a low-level air stability criterion. This was derived by subtracting the sea temperature from the air temperature as done by Hasse and Wagner (1971) in determining the surface winds from the geostrophic winds in the German Bight. Values of -3°C or higher were considered stable while values below -3°C were deemed unstable. The value of -3°C was chosen in agreement with Hasse and Wagner (1971) who used -2.7°C as the division between neutral and unstable. In mid-summer, air temperatures often rise to 8°C while sea temperatures are 2°C which gives a stability factor of 6°, considered quite stable. In mid-autumn, air temperatures can be -10°C compared to sea temperatures of -2°C, giving a stability factor of about -8°, considered quite unstable. The transition between Summer and Autumn occurs in the latter half of September or early October and is so used in this study.

This stability criterion was used in the reduction of geostrophic winds to MSL. For the unstable case (stability factor less than -3°), a reduction factor of 0.85 was used to reduce geostrophic winds to sea-level. For the stable case (stability factor greater than or equal to -3°), a reduction factor of 0.65 was used. Due to the inaccuracies in assessing stability, a neutral classification was not used.

In support of this approach, a storm in late September, 1978 was examined. Eight ship reports were available in the area and when these were compared to measured geostrophic winds, a reduction factor of 0.64 with a standard deviation of 0.23 was found.

As well as the reduction in wind speed from the geostrophic level to the surface, there is also the well-known cross-isobar flow into lows to be considered. Using the same eight ship reports noted above, the wind was found to back 20° from the geostrophic wind level to the surface, in good agreement with the 24° found by Albright (1971).

Before considering the Summer and Autumn seasons in more detail, a short review of sea-ice conditions is appropriate.

3.3.1 General Sea-Ice Conditions

To understand the sea-ice conditions in Davis Strait and Baffin Bay, a brief consideration of the water circulation is required. Movement and structural irregularities of the ice are due chiefly to the geographical location of these waters and their circulations.

The Baffin Bay-Davis Strait water system is quite complex. Warm, slow currents off the southwestern Greenland coast flow northwards to Disko Island and beyond. Cold waters from Lancaster, Jones, and Smith Sounds flow into northwestern Baffin Bay. From there the waters flow southward along the coasts of Baffin Island and Labrador. A great eddy-current is formed in Baffin Bay. A slow drift of warm waters in the east contrasts to more swiftly moving cold waters in the west markedly influencing the formation of ice on the sea.

Based on the past fifteen years (1964-78) of data, a typical ice year is summarized here. Baffin Bay and all its inlets are covered with consolidated first-year ice in May. One important exception to this is the North Open Water which is located at the southern entrance to Smith Sound. This expands southwards and southwestwards in May and June. At the same time, a shore lead opens northwards along the west coast of Greenland.

Lancaster Sound becomes free of ice between the middle and end of June. The open water area in western Baffin Bay expands southwards and southeastwards along northeastern Baffin Island while the west Greenland shore lead expands northwards. The northern half of the study area is usually in open water by early July. The earliest date for this occurrence was June 25 while the latest was August 20 with the median being July 2.

The steady northward extension of the west Greenland lead to near 74°N combined with the southward expansion of the North Open Water results in an open-water route to Lancaster Sound from the west Greenland lead by about July 20. Pond Inlet, Milne Inlet, Eclipse Sound, and Navy Board Inlet usually clear by mid-August. Open water in Baffin Bay normally occurs by the end of August and by early September, sea ice has retreated to its northernmost limits. By early September, multi-year ice is breaking loose from Nares Strait and presents a hazard to shipping in northwestern Baffin Bay until the end of the season.

The presence of icebergs in the concession area is also of great concern to both the drilling program and shipping. The principal source region for icebergs (Fenco Consultants Ltd. et al., 1978) is the west Greenland coast between latitudes 67°N and 72°N. These bergs break off of glaciers and are carried northwards then westwards finally traversing Baffin Bay in a cyclonic path. Ocean currents in the area dictate the motion of the icebergs. Flights over the concession area by the International Ice Patrol from the years 1963 to 1977 indicate that an average of 380 icebergs were observed through a 40 to 50 day period from mid-September to the end of October. The data are, however, very limited providing only a first approximation of the berg concentrations in the proposed drilling area for one particular time of the year.

Freeze-up is confined to a much shorter time frame than break-up. Freeze-up in the center of the study area occurs during the last two weeks of October with October 8, the earliest; October 29, the latest; and October 22, the median.

3.3.2 The Summer Season

The Summer season is typified by the lack of real storms. The warmest air temperatures prevail. Sea-surface temperatures struggle up to the 2 to 3°C range which, when combined with warm air temperatures, result in a fairly rapid retreat of sea ice. With warm air temperatures (4 to 6°C being typical) and relatively cool sea temperatures, the atmosphere is considered quite stable. The large expanse of open water in Baffin Bay in early September allows long fetches for waves to build.

It is probable that flying conditions are poor for a considerable portion of the summer. This is inferred from two observations. Firstly, Broughton Island, off the northeast coast of Baffin Island, receives considerable stratus and fog in the summer months. Secondly, satellite photos for the 1978 season were examined over the study area. It was found that six to nine-tenths of low cloud (stratus and/or fog) covered the drill area on an average of twelve days per month in July, August, September, and the first half of October. This corresponds to the open water season in the area.

The stratus and/or fog is produced by two mechanisms. With a northwesterly flow, cold air passes over a relatively warm sea surface producing 'Arctic sea smoke'. With a southeasterly flow, relatively warm air is advected over a cold sea surface and eventually the temperature of the air in the low levels is lowered to its dew point and low cloud results.

Numerous small areas of low cloud on the satellite photos which might only cover one or two tenths of the total study area, indicate that at a specific site, such as that occupied by a drill ship, ceilings and visibilities might be poor. While visibilities cannot be determined from satellite photos, it is suggested that ceilings below 1000 ft occur at least one-third of the time over the study area during the summer season.

3.3.3 The Autumn Season

During the Autumn season, the frequency and intensity of cyclogenesis increases. Sea ice has retreated to its northermost limits. Air and sea temperatures are decreasing. Early in autumn this combination of more intense lows, increased fetch, and decreasing air and sea temperatures increases the possibility of aircraft icing, freezing spray and superstructure icing. As the autumn season progresses, ice begins to form on the sea surface and gradually thickens. Although the storms encountered in late autumn are likely to be more intense than earlier in the season, ice will cover the sea surface and thus the sea state will not be a factor affecting the drilling process. The strong winds from an intense storm would then only produce poor flying and working conditions due to blowing snow along with severe wind chill.

From mid-October to the end of November broken low cloud occurs on only eight days over the study area indicating that this low cloud is now associated with synoptic scale systems rather than with air-sea temperature differences.

3.4 Summary of Storms of the Five Seasons 1974-1978

During the five seasons 1974-1978, 29 storms (as defined earlier) affected the study area. Of these, nine were considered to be of the summer variety with the remainder (20) occurring in autumn.

There are only two storm tracks of consequence that affect Baffin Bay. The first of these (Type A) is the situation where a low from Hudson Bay, northern Quebec, or the Atlantic Ocean moves into the Brevoort Island area east of southern Baffin Island. Usually the low splits here with the main upper support going east over Greenland, and a sharp trough develops along the west Greenland coast, giving northwesterly winds to the study area. Frequently a low pressure centre will develop in the trough, then move northward and produce strong northwesterlies over the study area. Twenty- two of the 29 storms were of this type. It was possible to break down this category into subsections based on the initial source region of the low, but this was not considered instructive and hence was not attempted.

The second principal storm track (Type B) results from having an upper level low or trough over the Keewatin District and possibly a surface low pressure centre associated with it. The upper level low or trough and associated warm air advection moves northeastward across Foxe Basin and Baffin Island and develops a trough in the lee of Baffin Island. This type produces strong southeasterlies across the drill area. Five of these storms were identified during the past five seasons.

Of the two remaining storms, one tracked due eastward across the Arctic Islands (Type C) producing moderate southeasterlies ahead of it and strong northwesterlies behind it (see Figures 3.8 and 3.9).

The other storm was interesting because of the manner in which it developed. A 50-kPa low over the Boothia peninsula generated an upper level southwesterly flow across northern Baffin Island (see Figure 3.11) and caused lee cyclogenesis in Baffin Bay (see Figure 3.12). This was labelled type D and produced very strong northwesterlies over the study area.

The intensity and frequency of the storms increase as the season progresses from summer to autumn. Over the five-year study period, 9 storms occurred in the summer season. Only 4 cases were found during July and

August, and these were just intense enough to qualify as storms. Four storms occurred in September and one in October, with the strongest winds produced being 85 km/h (46 kt) from the September storm of 1978.

Most of the storms studied (20) occurred in autumn with 10 in October and 10 in November. The most severe of these occurred in November with four of the storms producing recorded winds in excess of 110 km/h (59 kt). In comparison, the four strongest storms in October produced recorded wind in excess of 93 km/h (50 kt).

From a study of geostrophic winds over the period 1946 to 1971 (A. Saulesleja, personal communication), many of the observations made above are confirmed. Through this twenty-five year period there is a noticeable increase in strong wind occurrences from July to November with the strongest average surface wind of 65 km/h (35 kt) in November. Surface winds exceeding 60 km/h (32 kt) occurred as follows:

MONTH (1946 - 1971)	OCCURRENCE OF WIND (greater than 60 km/h)
July	0
August	2
September	7
October	10
November	13

The strongest surface wind analyzed appears in November of 1966 with a speed of 93 km/h (50 kt). The above information is taken from a numerical analysis using a 381 km grid. The actual grid point used here was located at 73.5°N 73.7°W. Cases studied usually included two analyses per day for the twenty-five year period; however, for some years, only daily data were available. It is felt that the analyzed data provides a good representation of geostrophic winds over the concession area; however, awareness of the short-comings of this type of analysis should be noted.

3.4.1 Summer Storms (July - September, 1974-1978)

In the past five years nine storms occurred over the study area in the Summer season. Of these nine storms four were type A, four were type B and one was type C. It is expected that Type B storms occur more frequently in the warm season because warm advection into Baffin Bay is much more likely at that time.

Reasons for this small number of storms must be examined. Two things appear to be essential for cyclonic development in this area: (1) a sharp upper-level trough or low centre, and (2) low-level warm advection. With only one condition present, development is either weak or of short duration.

Many of the synoptic patterns studied showed early indications of development. An upper-level southwesterly to westerly flow across northern Baffin Island frequently caused troughing and occasionally the development of a low in the lee of Baffin Island. Without simultaneous low-level warm air advection into Baffin Bay, major cyclogenesis did not occur, however. When southerly to southwesterly upper-level flows developed across the southern Baffin Island and Brevoort areas, they advected warm air into Baffin Bay causing cyclogenesis with the subsequent development being intense but brief.

Another common occurrence lends credence to the above hypothesis. This is the situation where two upper-level lows move from west-to-east across the Arctic. One of the upper-level lows moves across the Arctic Islands with a similar system moving with it on a more southerly track. The warm air advection normally is associated with the southern system causing the development of a low center in the Davis Strait or Brevoort Island areas. This surface feature then fills as it moves northward into Baffin Bay and the upper support drifts eastward across Greenland.

3.4.2 Autumn Storms (October - November, 1974-1978)

In the past five years 20 autumn storms have occurred; 18 type A, one type B, and one type D. The type B storm occurred in early autumn while the one type D storm occurred in late November. The west Greenland trough and associated lows occurred throughout the autumn season. Two of these storms (one in late November, 1976 and the other in late November, 1978) produced extended periods of winds in excess of 90 km/h (49 kt) with a peak estimated wind near 130 km/h (70 kt) for both storms. Both lasted in excess of thirty hours.

3.5 Extreme Storms

Several individual storms will now be considered. Those selected had the most severe weather conditions found in the 1974-1978 five-year period. These should provide some idea of the worst environmental conditions experienced in northwestern Baffin Bay.

3.5.1 Extreme Storm Case 1 (August 21-22, 1978)

The most severe storm found to affect the study area during the months of July and August in the five years occurred on the 21st and 22nd of August, 1978. This was a type A storm causing strong northwesterly winds. A low, with a frontal wave associated with it, moved from northern Manitoba eastwards across Hudson Bay. While the storm moved towards Baffin Island, extensive low-level warm air advection occurred well in advance of the low centre. As the weather system moved through northern Quebec, the frontal wave occluded and the warm air and supporting upper trough moved eastward with the upper flow across southern Greenland (see Figure 3.2).

At 1200 GMT 20 August, the low centre had deepened to 98.8 kPa and was located 190 km southwest of Frobisher Bay. The circulation from the storm extended approximately 550 km in all directions giving winds of 66 to 74 km/h (36 to 40 kt). Rain which was also reported in this area turned to snow over more northerly sections. The low continued northeastward at 25 km/h (14 kt) until 0000 GMT 21 August when a second low was spawned at 65°N 59°W. This break in the circulation was caused by the eastward movement of the dynamic support. The two lows continued their northerly course with the new low moving at almost 74 km/h (40 kt) and no change in its central pressure. The original low moved northeastward and began filling by 1200 GMT on the 21st with only a trough from the main low remaining by 1800 GMT on the 21st (see Figure 3.3). This system maintained a cyclonic circulation in Baffin Bay for the next twelve hours.

As this was a summer situation, geostrophic winds were reduced to sea level using a reduction factor of 0.65. With this reduction factor, the strongest winds at 74°N 75°W (the "drill site") were northerly 72 km/h (39 kt) at 0000 GMT 22 August. Very shortly thereafter, the winds decreased as the surface low filled rapidly.

At this time a considerable amount of sea ice still persisted in Baffin Bay. On 20th August the drill site was essentially in open water that extended southeastwards at least 190 km; however, the edge delineated by the boundary of ice concentrations greater than 5/10ths was within 16 km to the northwest and northeast. With a northeasterly wind becoming established on the 21st, the ice pack would be expected to move southwards towards the drill site. The winds shifted to the northwest on the 22nd causing the ice to move further southwards and by the 23rd the drill site was in ice concentrations greater than 5/10ths. Since 1/10th of this ice was large multi-year floes, it is likely that a drill ship would have been hard-pressed to stay on location during this storm.

One important aspect of ice coverage is that it will limit the fetch distance in which waves could develop. With the 5/10ths ice edge in the immediate vicinity throughout this storm, the fetch would have been negligible. Hence, waves would have been suppressed, which would also have eliminated the risk of superstructure icing even though sea temperatures in the 1 to 2°C range and air temperatures below freezing were common throughout the storm.

The structure of this disturbance was such that very little vertical motion occurred over the study area. Most of the moisture at mid-levels moved eastward over southern Greenland. These two factors sharply reduced the amount of weather over the study site. Precipitation in the form of snow was confined mainly to coastal areas giving visibilities as low as 1 km. Here the onshore flow was the main mechanism producing the weather.

Fog areas were observed over eastern Lancaster Sound and Western Baffin Bay as the disturbance approached, but they cleared again as the winds shifted to northwesterly.

3.5.1.1 Meteorological Extremes

The peak wind during the August storm was estimated to be northwesterly at 72 km/h (39 kt) with the sustained mean wind being northwesterly at 56 km/h (30 kt) lasting for 12 hours. Air temperatures during the storm fluctuated very little from 0°C and, combined with the wind, produced wind-chill values of 1340 W m^{-2}. Translation of this value to human activity indicates that any outdoor activity would no longer be pleasant even with appropriate clothing.

As mentioned earlier, the growth of waves and production of freezing spray were mostly suppressed by the presence of ice. It is interesting to note, however, that if no sea ice had been present and the above meteorological conditions had been unchanged, significant wave heights of 5 m would have developed.

3.5.2 Extreme Storm Case 2 (September 25-27, 1974)

One of the most intense storms to affect the study area in the five years occurred in late September 1974. This was one of the type B storms which advect warm air into Baffin Bay and produce strong southeasterly winds. The storm is all the more significant since at the time Baffin Bay was ice-free which allowed a long fetch length (840 km) for waves to build.

A deep cold low with its associated surface feature remained quasi-stationary over the Boothia Peninsula during the initial stages of this storm with a trough extending southwards to western Hudson Bay (see Figure 3.4). The trough rotated around the upper low and moved a surface low rapidly northeastwards (see Figure 3.5) to combine with the deep surface low over Boothia Peninsula to form an even deeper low over Melville Peninsula. Within 250 to 300 km ahead of the upper-level trough, a trowal extending from the Brodeur Peninsula southeastward continued to move northeastwards (see Figure 3.6). Strong southeasterly winds were blowing over the drill area all day on the 25th. The trowal continued to move northeastwards as the surface low remained over the Gulf of Boothia. The cold low and its associated surface low began moving slowly northwestwards on the 25th.

The strong southeasterlies ahead of this system persisted over the study area. With the trowal continuing slowly northeastwards, a surface low eventually developed northeast of Clyde River over Baffin Bay by 0000 GMT on the 27th and moved northwestward (see Figure 3.7). This further tightened the gradient in the drill area with storm force northeasterlies being experienced over the northwestern section of the drill site. The low moved northwestwards on the 27th, lost its thermal support, and filled.

3.5.2.1 Meteorological Extremes

This system produced winds in excess of 55 km/h (30 kt) for 30 hours. Southeasterly winds greater than 70 km/h (38 kt) were reported for 6 to 12 hours. One ship report in the northwest section of the study area had northeasterly winds of 100 km/h (54 kt).

Waves reached a significant wave height of 6 m with a period of 12 sec along with a peak wave of 8 m and a period of 13 sec. This was principally due to the extended period of strong winds combining with a long fetch.

The occurrence of freezing spray was not reported during this storm. The sea surface temperature was 0°C while the air temperature was near -1°C. With these conditions no superstructure icing was indicated; however, if the air temperature had been 2°C lower, then severe superstructure icing would have been expected. The temperature actually did fall towards the end of the storm, but no superstructure icing was experienced possibly because the winds also diminished.

Visibilities were generally good throughout the storm although snow flurries frequently lowered visibilities to 8 km. Along the Baffin Island coastline and in Lancaster Sound, snow flurries reduced visibilities to 5 to 10 km with one report of a 1-km visibility in snow.

The wind chill was 1375 W m^{-2} increasing to 1475 W m^{-2} by the end of the storm when the temperature dropped. This gives conditions when outdoor activities are no longer pleasant.

3.5.3 Extreme Storm Case 3 (September 17-19, 1978)

This was an example of a severe summer storm resulting from a low crossing the Arctic Islands from west to east. It was classified as a type C storm. This meteorological situation was unique, being the only type C storm which developed gale force winds in the five seasons. This occurred during September 17th to 19th, 1978.

An upper trough extending from northern Greenland southwestward to Banks Island on the 17th of September (see Figure 3.8) was moving slowly southeastwards. This upper trough supplied the dynamic support for a surface low and frontal wave that was tracking eastward along 74°N towards Lancaster Sound (see Figure 3.9). Temperatures in the warm sector of the wave were near 5°C while in the cold air, temperatures hovered near freezing. Well to the east of the low and to the east of the concession area, light to moderate southeasterly winds prevailed.

As the low and frontal wave moved eastward into Lancaster Sound, a trough developed to the lee of Baffin Island. A moderate to strong southeasterly flow developed over central and eastern Baffin Bay, but only light winds were analysed over the drill area.

Northerly winds strengthened to gale force by 0000 GMT on the 18th of September as this disturbance moved eastward across the proposed drill area. The gales continued for about twelve hours before slowly subsiding. The strongest winds over the concession area were northwesterly at 85 km/h (46 kt) except for an outflow wind of westerly 93 km/h (50 kt) reported by a ship just off the northeast coast of Baffin Island.

The main upper support for the surface low moved southeast of the area with an upper low forming over central Baffin Bay. The surface low was captured by this upper feature and both slowly filled after 1200 GMT on the 18th of September.

In advance of the low a large area of snow spread eastwards with reports indicating visibilities near zero in heavy snow and fog. Visibilities in snow were less than 5/8 of a kilometre for twelve consecutive hours at the MV Theron (one of Petro-Canada's field ships). Low ceilings and visibilities in snow continued until after 1200 GMT 18th September, then slowly improved as the northerly winds brought colder air over the concession area. The Theron also reported 2-metre waves in the comparatively light winds; however, with a fetch of approximately 220 km, swell waves were able to build from the northeast. The waves were reduced somewhat by patches of ice in the immediate area of the ship. With the light winds, freezing spray was not likely.

Several characteristics of this storm should be emphasized. Well-developed lows seldom cross the Arctic Islands from west to east as this one did. The warm air associated with such a low can produce extended periods of snow with accompanying low ceilings and visibilities. Northerly winds to the west of the low do have a reasonably long fetch allowing waves to build. The northerly flow will transport cold air into the area which in September and October, combines with cold sea temperatures to enhance the risk of freezing spray.

3.5.3.1 Meteorological Extremes

With strong northerly winds for a period of at least twelve hours, waves in excess of 5 metres were possible over the proposed drill area. Water temperatures near 0°C and air temperatures in the -5°C to -7°C range, would have produced moderate to severe superstructure icing. Wind-chill values of 1500 $W\ m^{-2}$ could have been expected in the northerly flow, indicating conditions no longer pleasant for outdoor activity.

3.5.4 Extreme Storm Case 4 (November 23-25, 1976)

Storms that occur in November in Baffin Bay are likely to be more intense than earlier in the season due to the greater temperature contrast between air masses. This is the time of year when the proposed drill area is completely ice covered and the likelihood of a drill ship being on station is not great; however, other related operational activities may very well be continuing.

This basically type A storm developed from the 23rd to 25th of November, 1976. A major low over Labrador at 1200 GMT on the 23rd of November extended from the surface to 50 kPa and was moving slowly northeastwards. Another 50-kPa low was centred over the Boothia Peninsula and remained quasi-stationary. A ridge extending from central Greenland to Southampton Island separated the two lows (see Figure 3.10). As the Labrador low moved southeastwards, a sharp surface trough developed along the west Greenland coast northwards into Baffin Bay (see Figure 3.11). Gale force northwest winds began over the proposed drill area around 1200 GMT on the 23rd of November.

By 0000 GMT on the 24th, it became apparent that the main Labrador Sea low was going east of Greenland. A sharp trough remained along the west

Greenland coast maintaining gale force northwesterlies over the drill area. At 50 kPa, the upper system supporting the Labrador Sea low moved slowly east-northeastward. The Boothia Peninsula low remained quasi-stationary producing a southwesterly upper flow over northern Baffin Island. A thrust of milder air (0°C to 5°C) along the west Greenland coast contrasted sharply with the minus 25°C temperatures over northwestern Baffin Island. This southwesterly flow aloft combined with the push of warm air in the low levels enhanced the development of a surface low in the trough over Baffin Bay on 24th November (see Figure 3.12). Northwest winds in excess of 100 km/h (54 kt) continued for approximately the next 12 hours before diminishing after 0000 GMT on 25th November.

3.5.4.1 Meteorological Extremes

Steady winds of 74 km/h (40 kt) and air temperatures below minus 20°C gave cooling rates of 2400 W m^{-2}. These extremely cold conditions would have caused exposed flesh to freeze within one minute making outdoor human activity extremely difficult. As the area was completely ice-covered, waves and freezing spray were of no concern. Problems in flying weather would have been encountered near open water where fog and low cloud could produce very low ceilings and poor visibilities. Visibility restrictions would also have been expected in blowing snow where actual 'white-out' conditions might also have occurred.

3.5.5 Extreme Storm Case 5 (November 27-29, 1978)

The second of the November cases studied is a very good example of a type A storm. A deep surface low developed east of the Labrador coast with a sharp trough northward along the western Greenland coast. This situation produced a long duration of north to northwesterly winds over the concession area as minor impulses rippled northwards to eastern Baffin Bay enhancing the already deep surface trough.

At 0000 GMT on 27th November, the 50-kPa analysis placed a 498 dam low centre just west of Inoucdjouac. To the east of this low was a well developed south-southeasterly flow extending from the Labrador Sea northwards to southern Baffin Bay (see Figure 3.13). Embedded in the upper flow was a small disturbance which supported a 99-kPa surface low south of Disko Island. The main 96.2-kPa surface low and frontal wave was much further south under the support of an upper vorticity centre (see Figure 3.14). The Disko Island low continued to move rapidly northwards tightening the pressure gradient to the west of the trough and producing gale force northwesterly winds over the concession area by 1200 GMT on the 27th.

The surface trough continued to deepen over Baffin Bay as warm air from the frontal wave moved quickly northwards. Temperatures in the cold air ranged from minus 30°C to minus 35°C while values in the warm sector were above freezing. This strong temperature gradient is common for this time of year with a southerly flow aloft and usually causes rapid deepening of low centres in the trough.

The southerly flow aloft over Davis Strait continued, but the split in the 50-kPa pattern over Baffin Bay transported most of the warmer air and other dynamic upper support eastwards over northern Greenland. The surface trough was maintained by injections of warmer air transported by a series of impulses moving northwards along the western Greenland coast (see Figure 3.15). This synoptic pattern maintained northwesterly gales for 54 hours over the concession area with a peak wind estimated at 125 km/h (68 kt). After mid-day on the 29th, the flow at 50 kPa and the anchoring upper feature weakened. This caused the surface low and trough in northern Baffin Bay to fill, bringing an end to the northwesterly gales.

The combination of the time of year and the southerly flow aloft created a strong temperature gradient over the area making this particular storm the most severe case studied. The very strong thermal contrast maintained and deepened the surface lows and trough which in turn strengthened the gales while prolonging their duration. With the concession area completely ice-covered, blowing snow became a real hazard to outdoor activity, especially aviation. The orientation of the surface trough produced an intense isallobaric field strong enough to induce high speed outflow winds along the northeastern coast of Baffin Island.

3.5.5.1 Meteorological Extremes

Northwesterly gales persisted for 54 hours with peak winds analyzed near 125 km/h (68 kt). It is expected that outflow winds would have been even stronger. This wind field created extremely poor visibilities in blowing snow with near zero conditions reported by coastal locations for two consecutive days. The bitterly cold temperatures and gale force winds produced a cooling rate of 2300 W m^{-2} completely stopping outdoor activity. Waves and freezing spray were not a problem at this time of year; however, severe aircraft icing in the vicinity of frontal waves was expected to have been a very real hazard.

3.5.6 Summary of Meteorological Extremes for the Five Case Studies

The following table summarizes the extreme occurrences of six meteorological or related elements for the five case studies discussed.

Table 3.1 Summary of Meteorological Extremes

Elements	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5
Duration of Storm (hr)	12	30	6	30	54
Maximum Wind Speed (km/h)	72	72	85	125	125
Maximum Significant Wave (m)	Nil	6 to 8	2	Nil	Nil

Table 3.1 Summary of Meteorological Extremes (Cont'd)

Elements	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5
Structural Icing Rate (cm/24 hr)	Nil	Nil	7 to 14	Nil	Nil
Structural Icing Duration (hr)	N/A	N/A	3	N/A	N/A
Aircraft Icing Potential	Light	Moderate	Moderate	Light	Moderate to Heavy
Lowest Expected Visibility (km)	1	5 to 8	0.5	0	0
Maximum Wind Chill ($W\ m^{-2}$)	1340	1475	1500	2400	2300

3.6 Scenario of an Extreme Storm

The preceding discussion of extreme storms has considered all the meteorological factors which were present. Unfortunately, no single storm was found in the past five years which adequately depicted the worst environmental conditions possible in the study area. Hence, it was thought necessary to attempt to outline the worst possible environmental conditions possible in the case of a deep low in Baffin Bay in early autumn.

The extreme storm to be discussed below is fictitious only in that it was not observed. All of the meteorological parameters used and their values are realistic for the study area.

Open water is needed to create the most extreme overall conditions for the drilling operation. Therefore, a time period from late September to early October is considered since this is the time of year when sea ice has retreated to its northernmost limits. At this time of the year the sea temperature is near 0°C with the air temperature below freezing, but highly dependent on the air trajectory and source region. Temperatures below -2°C are of concern with respect to both structural icing and windchill. It is for this reason that winds from the northern quadrant were chosen. Temperatures in a northerly flow frequently reach values below -10°C at this time of year. As was shown in previous discussions, storms lasting 36 hours with peak winds in excess of 100 km/h (54 kt) are possible in the concession area. The above environmental parameters describe a storm which will produce the most extreme conditions under which offshore drilling could be forced to operate.

Winds from the north at 100 km/h (54 kt) will generate waves in excess of 10 to 12 m in height. A northerly flow brings air from frozen snow surfaces giving temperatures in a range from -5°C to -15°C during a 36-hour storm. Under these conditions, structural icing would occur at the rate of 7 to 14 cm/day increasing to over 15 cm/day as the air cooled to below -8°C. Human activity would be severely limited with wind-chill values in excess of 1575 W m^{-2}. When the air temperature drops below -10°C wind-chill values approaching 1750 W m^{-2} would cause exposed flesh to freeze. As the cold air continues pouring out over the warm water, extensive stratus and fog will lower both vertical and horizontal visibilities to near zero km. Severe icing conditions in the stratus could also be expected. Low-level flying for any reason would have to be curtailed. Now perhaps the most severe danger occurs. Without areal reconnaissance the flow of multi-year ice or icebergs from the north cannot be properly monitored. Radar could be used to identify these destructive floes of ice. Unfortunately the ice could be very close before corrective measures are taken and with very poor weather conditions, problems with evasive action are seriously increased.

It is considered that the above storm is a realistic fabrication of meteorological parameters over the study area. A study by A. Saulesleja (personal communication), which included a statistical analysis of the period 1946 to 1971, indicated that the return period of such a storm would be 20 to 25 years. In the author's opinion a storm as indicated above would cause serious problems to the drilling operation, both human and mechanical.

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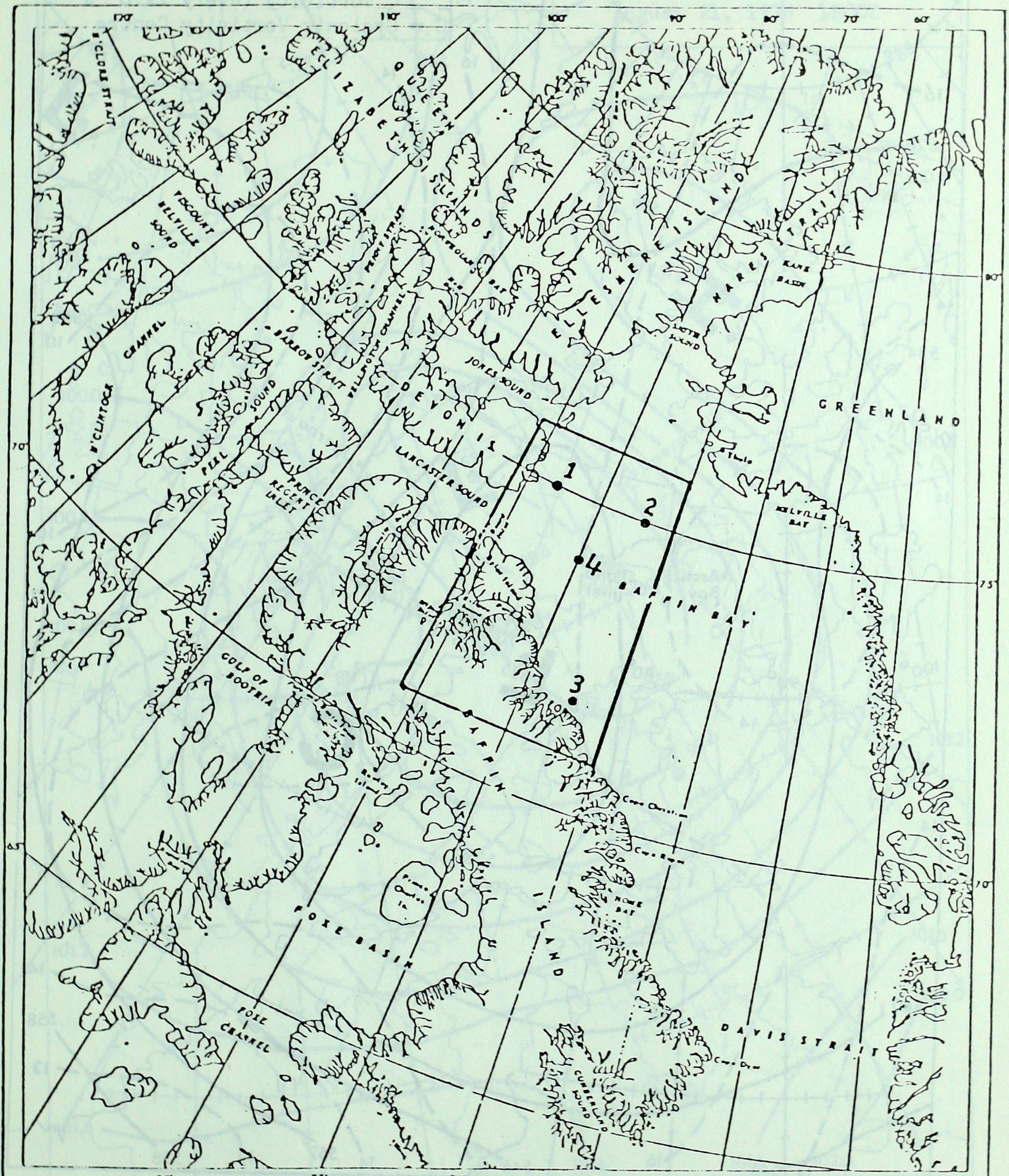


Fig. 3.1. Geographical Reference Chart

Legend: ☐ Study Area

● Points at which geostrophic winds are measured.

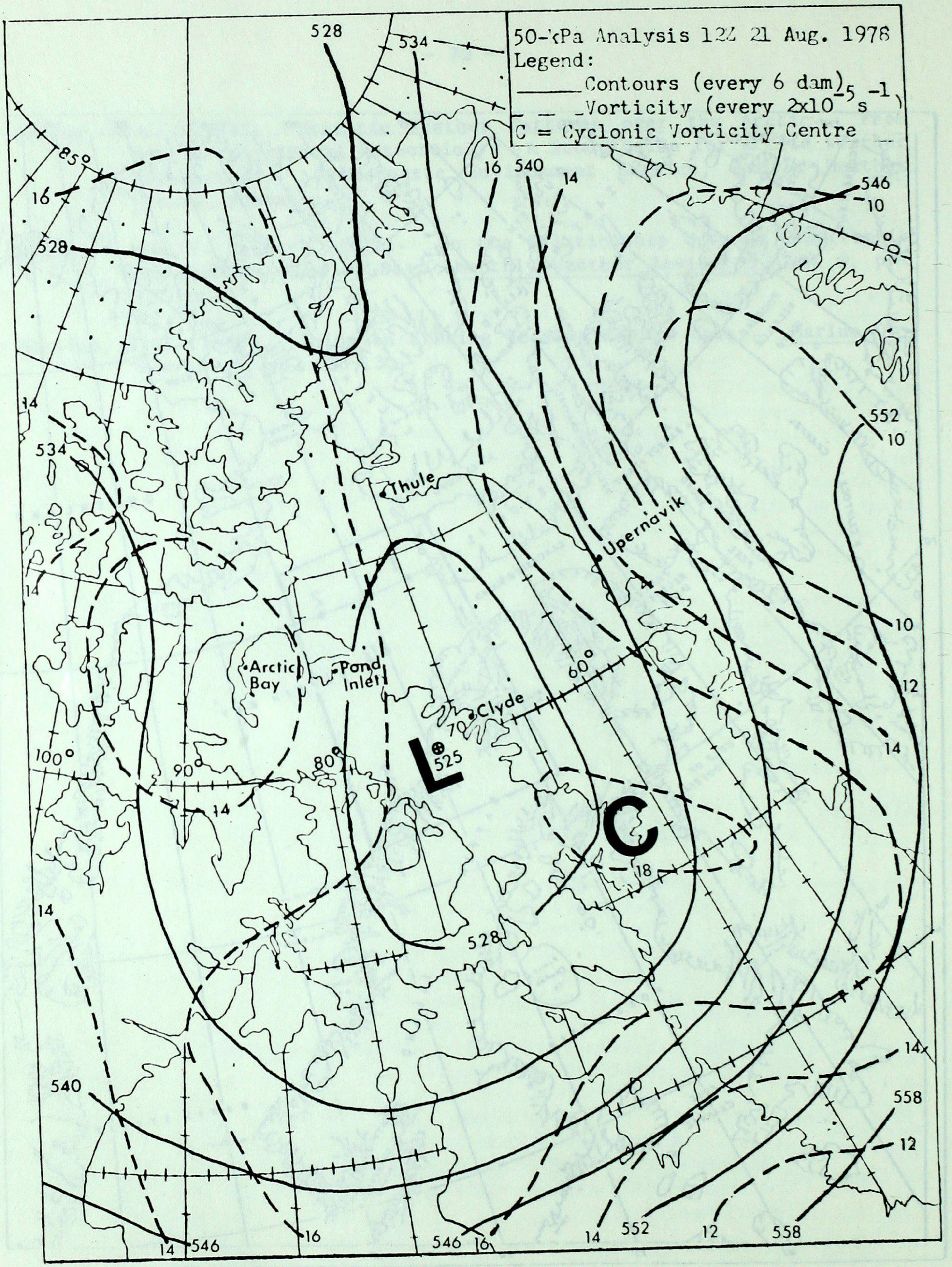


Fig. 3.2. 50-kPa Analysis showing a low over central Baffin Island and a trough southeastward across Davis Strait and southern Greenland.

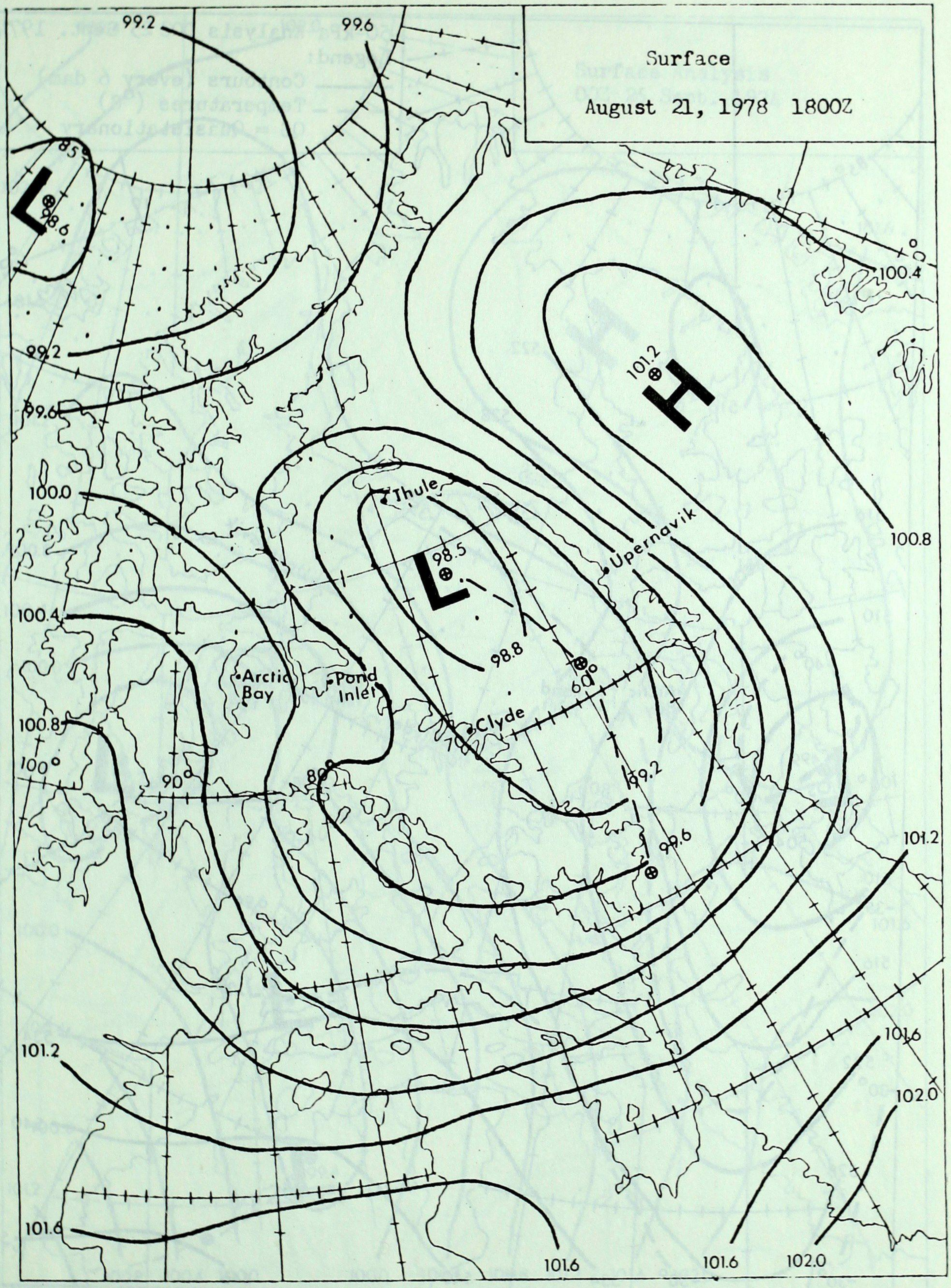


Fig. 3.3 Surface Analysis showing a 98.5 kPa low in Baffin Bay with a trough southwards and a northwesterly flow over the study area.

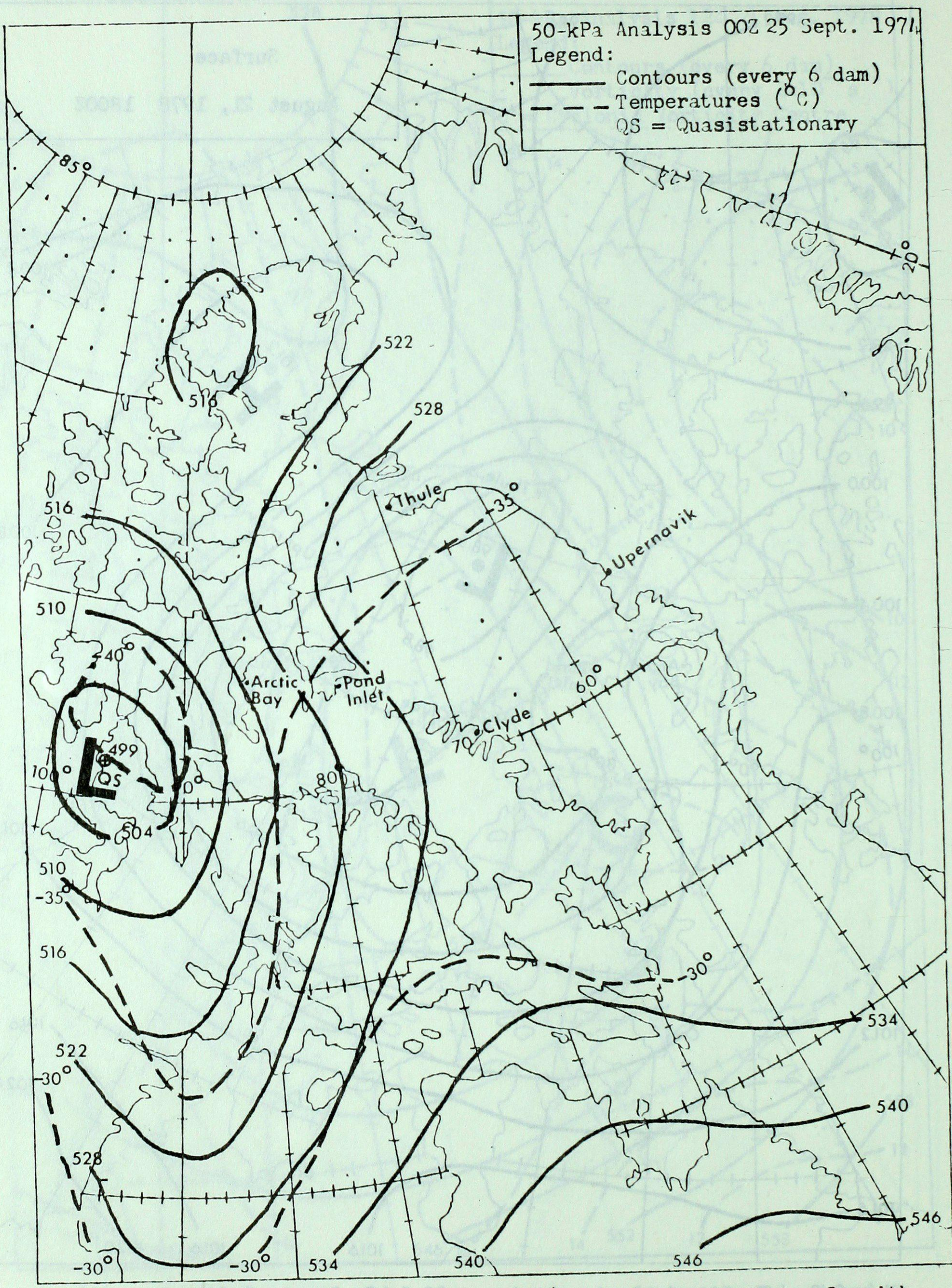


Fig. 3.4 50-kPa Analysis showing a cold low over Boothia Peninsula with a trough southward into Hudson Bay.

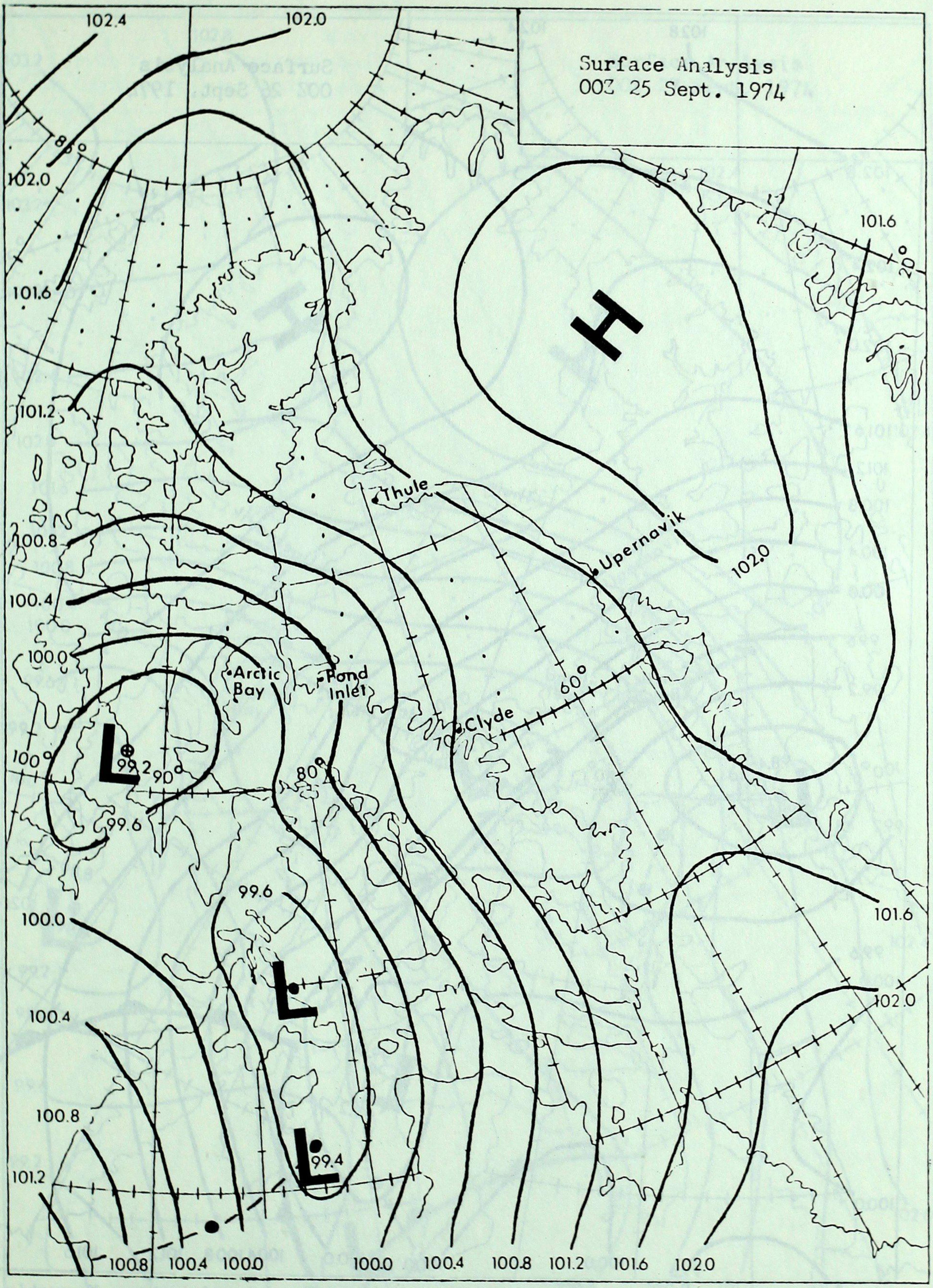


Fig. 3.5. Surface Analysis showing a 99.2 kPa low over Boothia Peninsula with a trough to a second double-centered low.

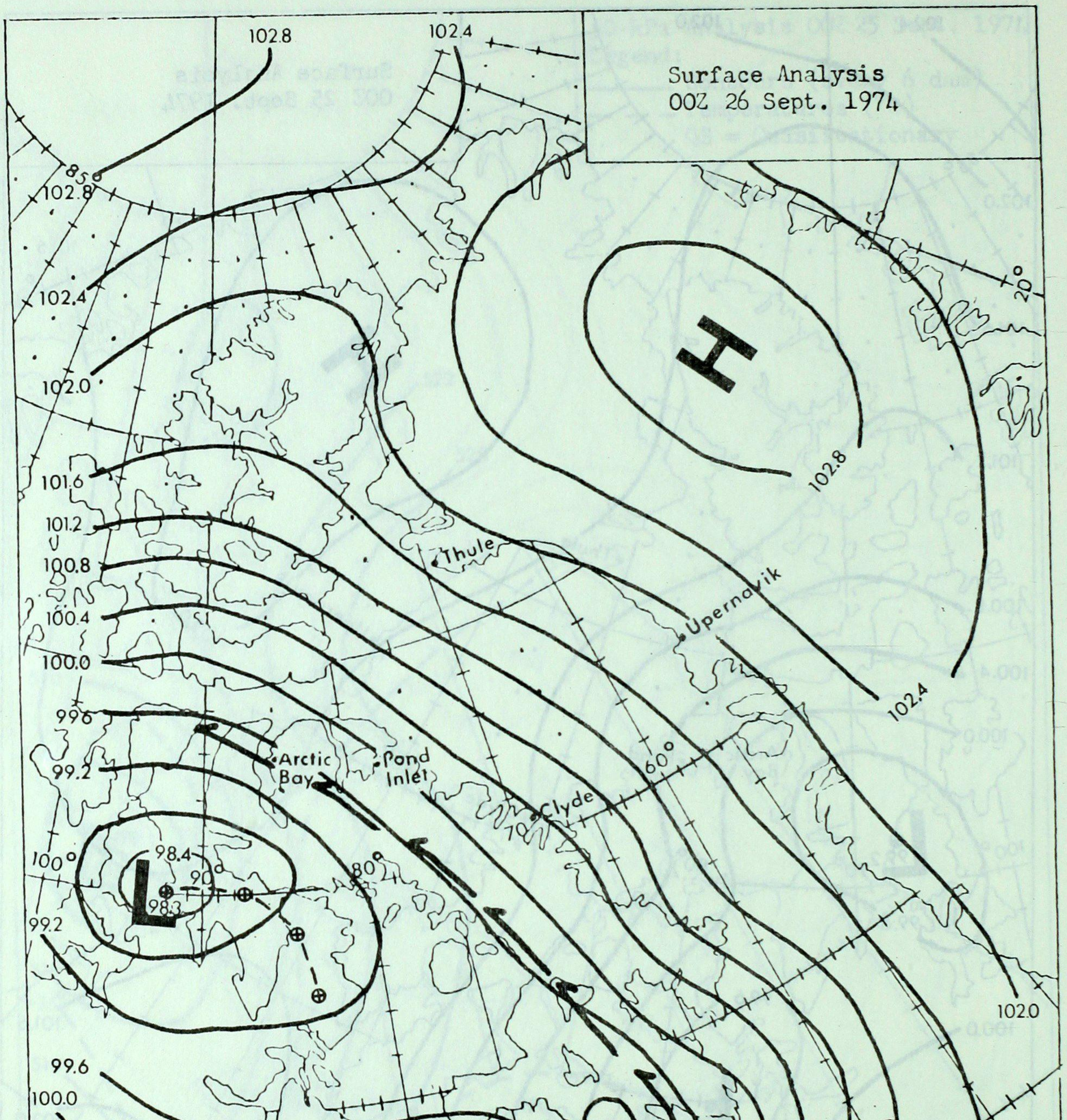
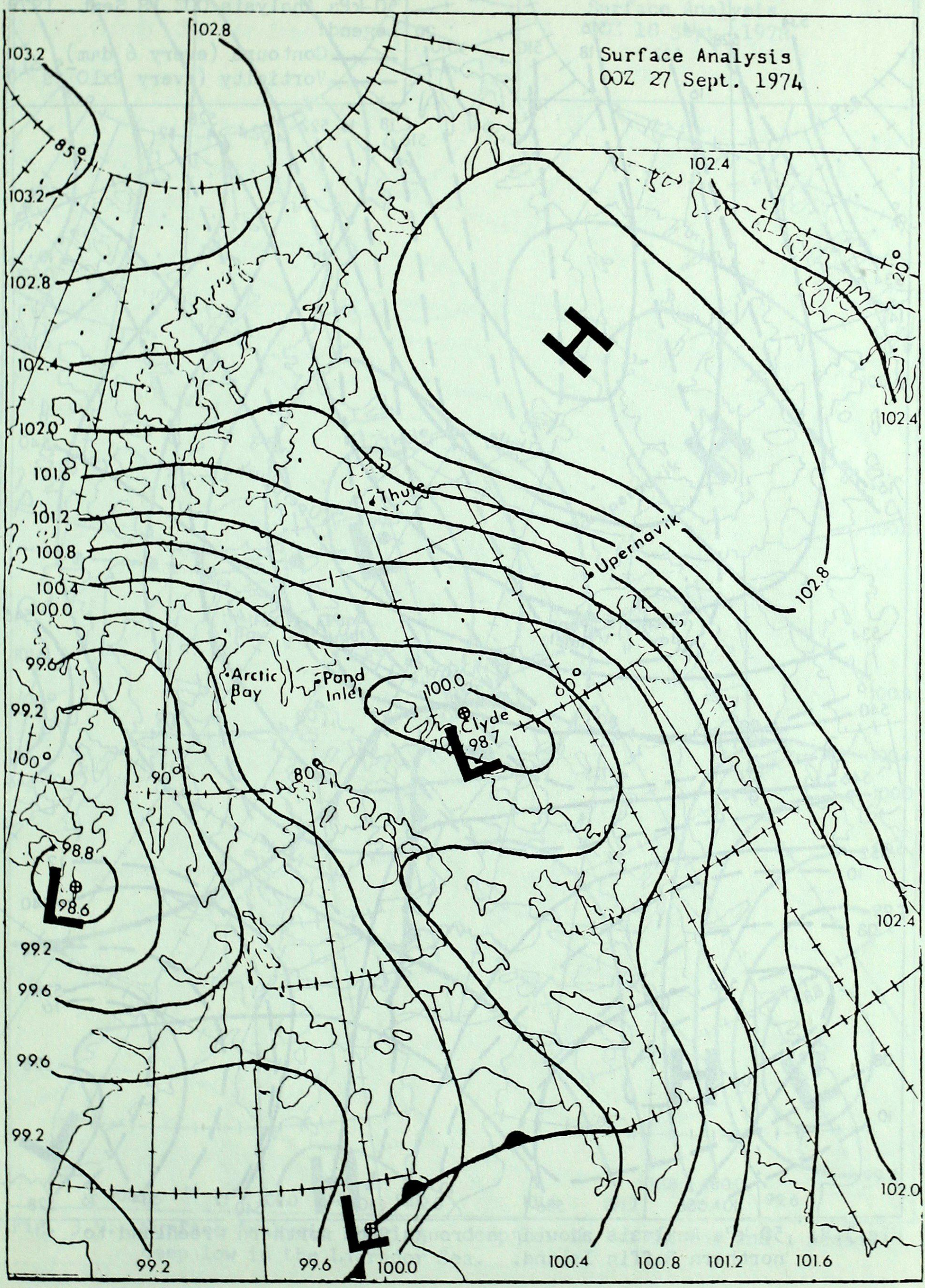


Fig. 3.6 Surface Analysis showing a deep low over northeastern Keewatin District moving northwestward with a trough to a second low moving rapidly northwards to southern Baffin Island. Trowal remains to northeast of lows.



Surface Analysis
00Z 27 Sept. 1974

Fig.3.7. Surface Analysis showing a deep low over the northwestern Keewatin District with a second low just northeast of Clyde River.

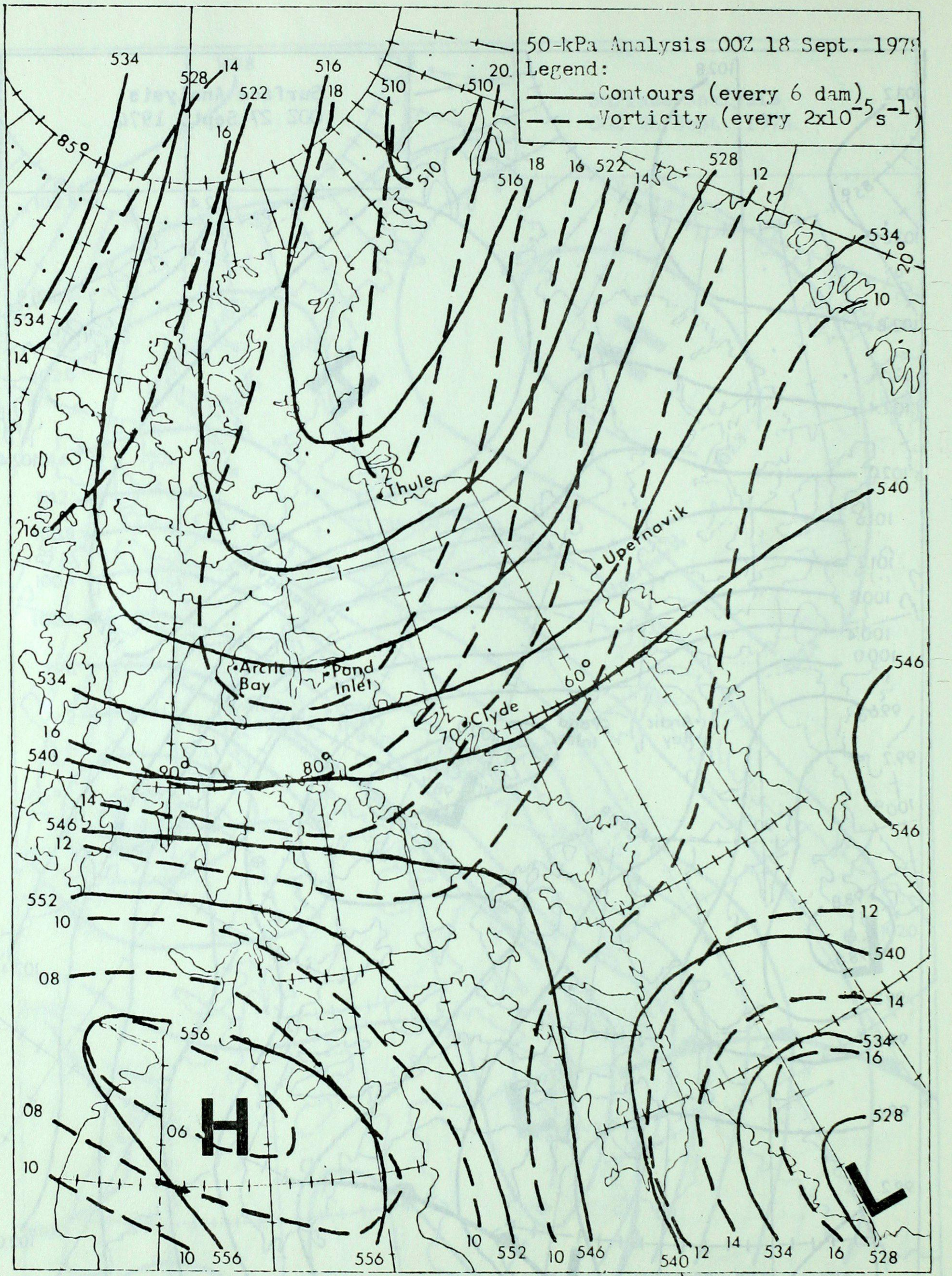


Fig.3.8. 50-kPa Analysis showing a trough from northern Greenland to northern Baffin Island.

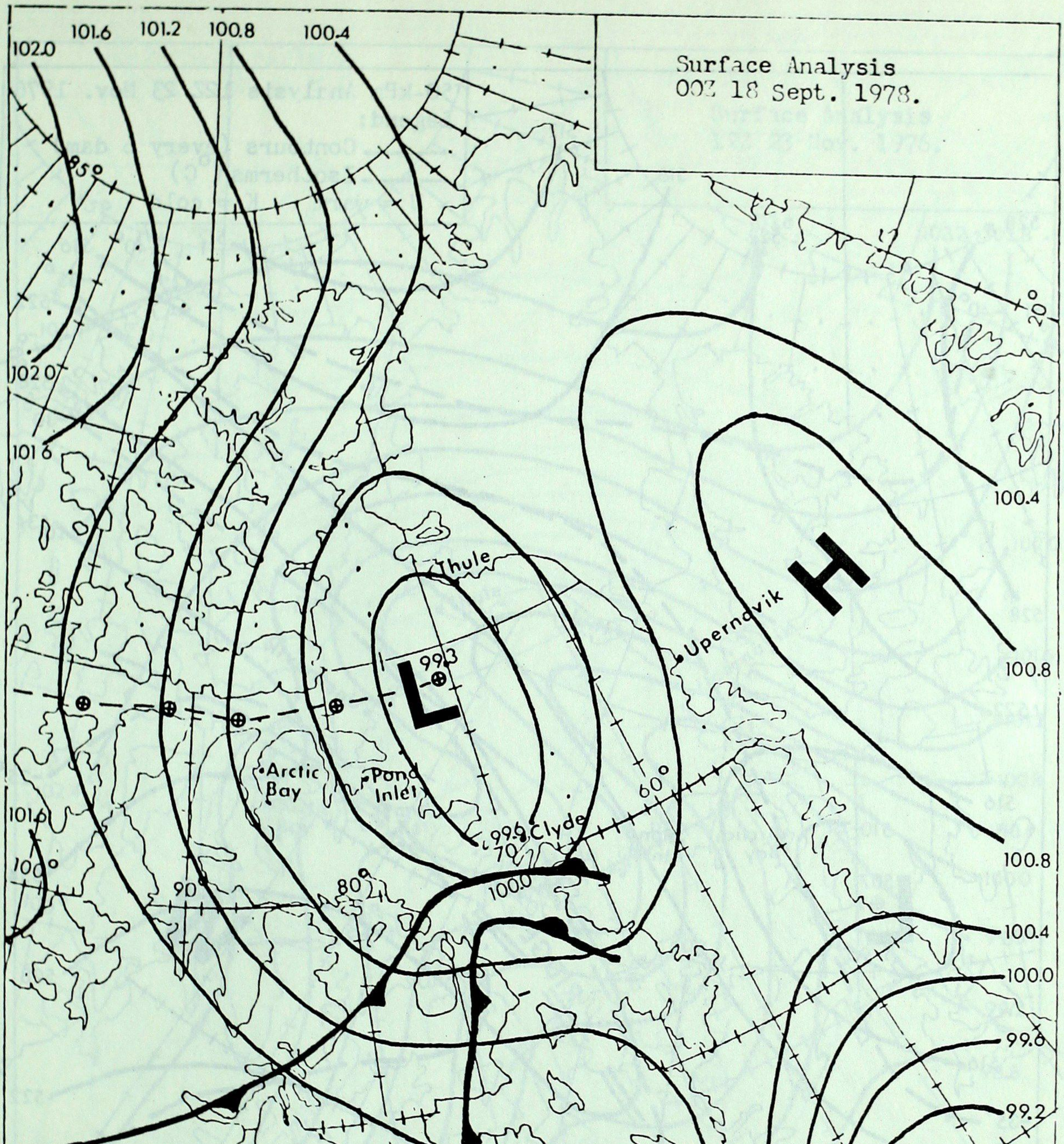


Fig. 3.9. Surface Analysis showing a deep low in Baffin Bay and a second deep low in the Labrador Sea.

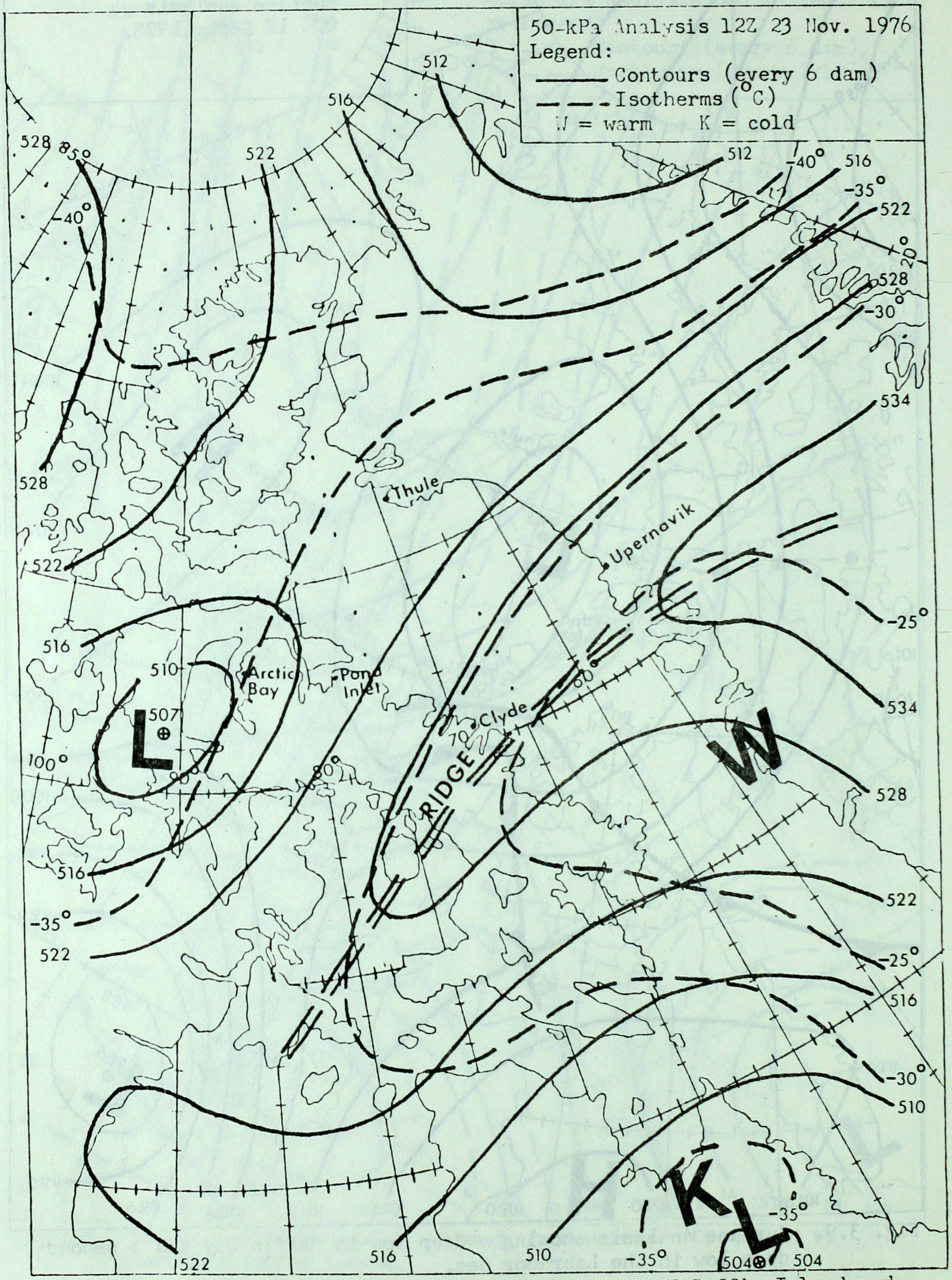


Fig. 3.10. 50-kPa Analysis showing a low just west of Baffin Island and a ridge extending from central Greenland to Foxe Basin.

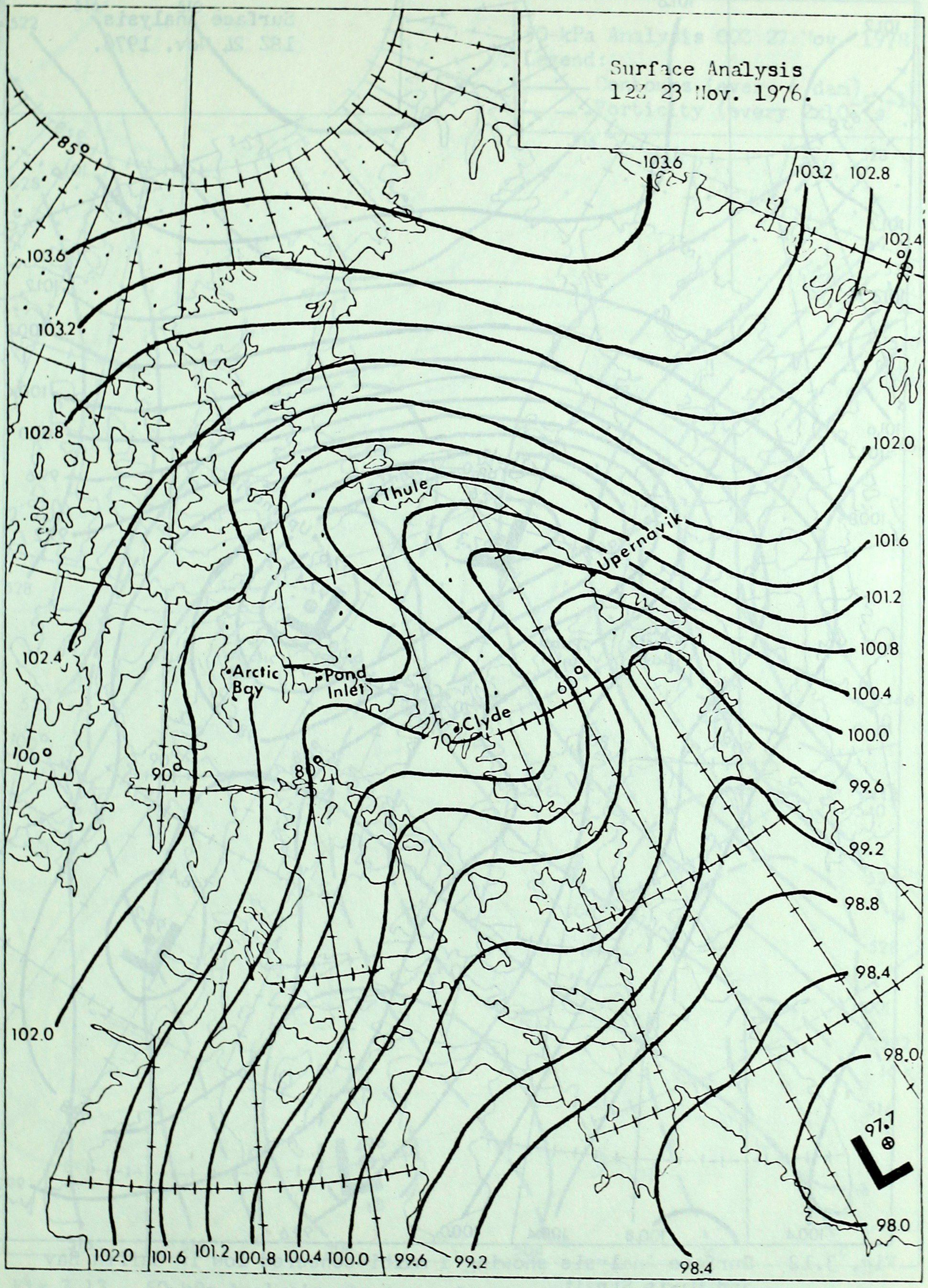


Fig. 3.11. Surface Analysis showing a deep low in the Labrador Sea with a sharp trough extending up the west Greenland coast.

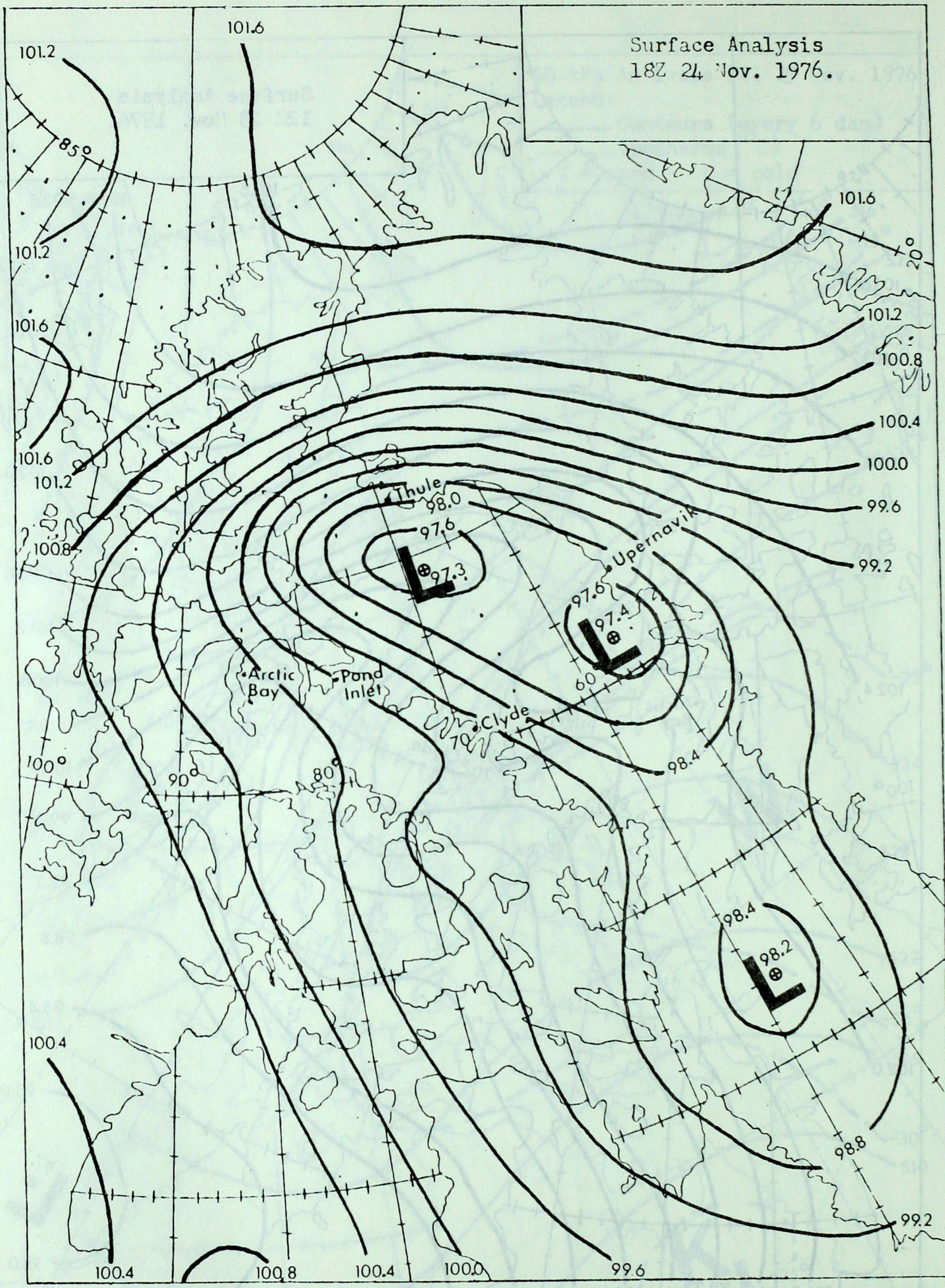


Fig. 3.12 Surface Analysis showing a multi-centered low in Baffin Bay and Davis Strait.

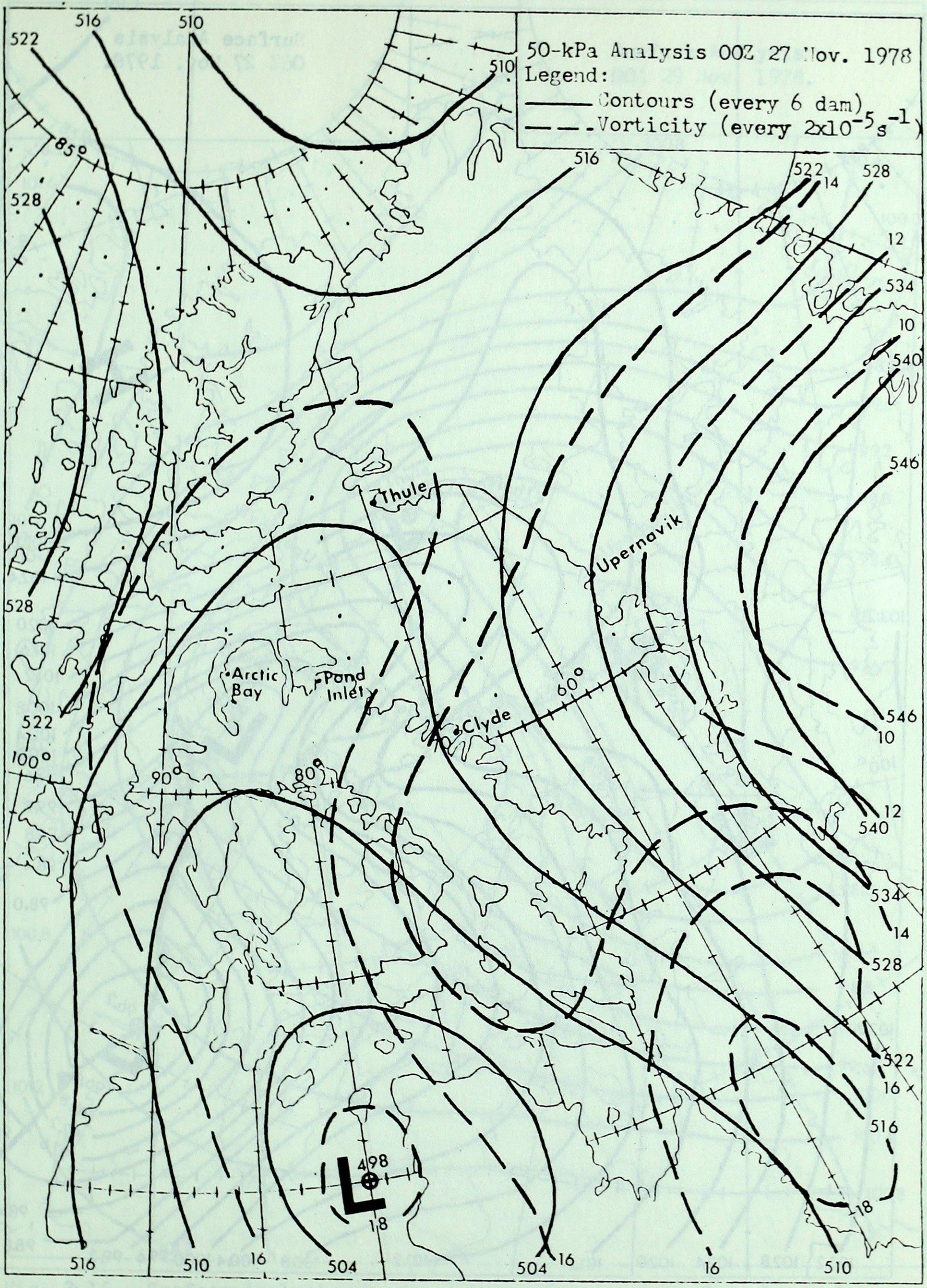


Fig.3.13. 50-kPa Analysis showing a low to the west of Inoucdjouac, a well-established south-southwesterly flow through Davis Strait, and a short-wave trough over southern Greenland.

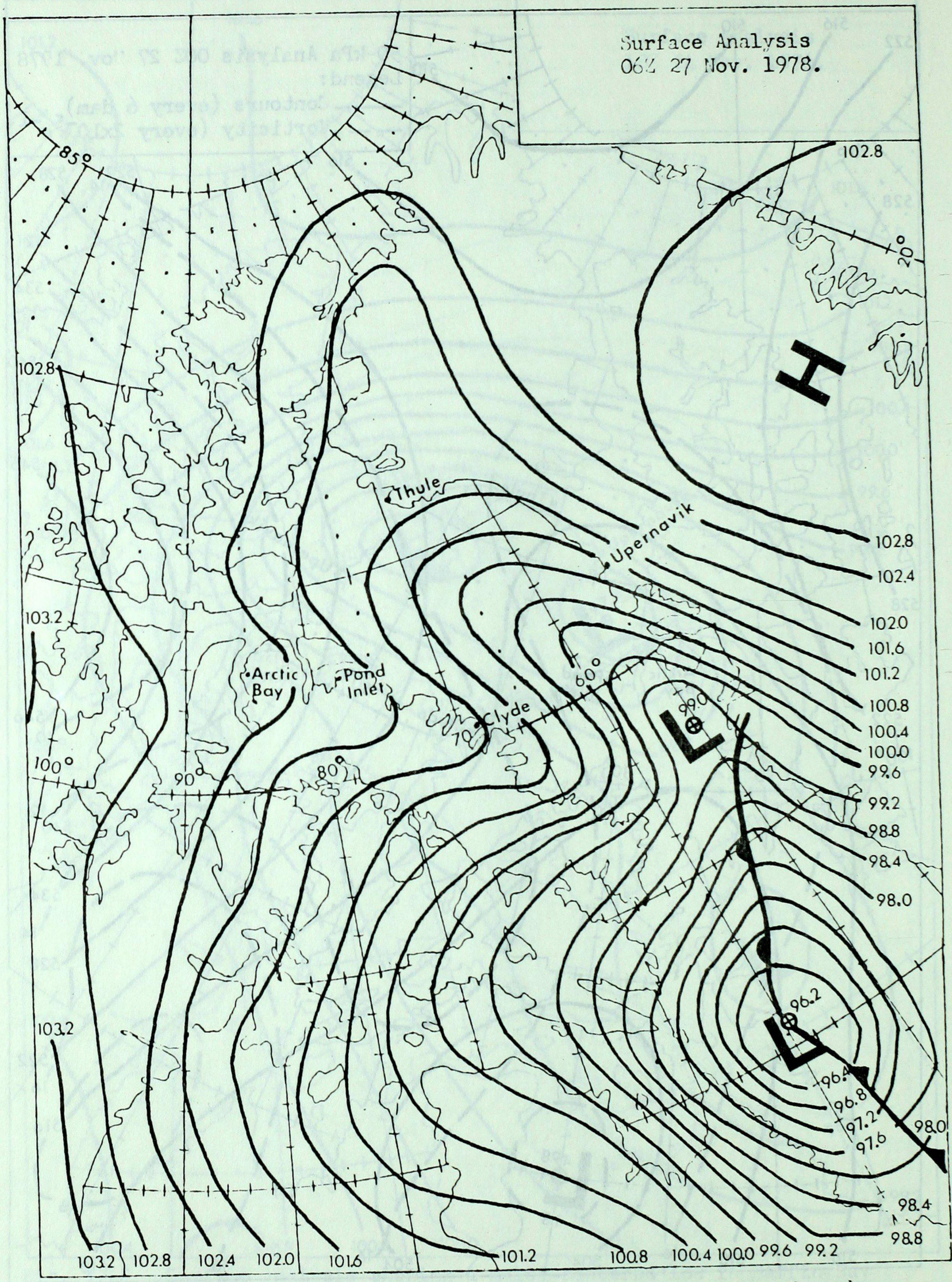


Fig 3.14. Surface Analysis showing a sharp trough extending northwards along western Greenland. A secondary low near Disko Island lies to the north of the main low centre and frontal wave at 60.5°N 59.5°W.

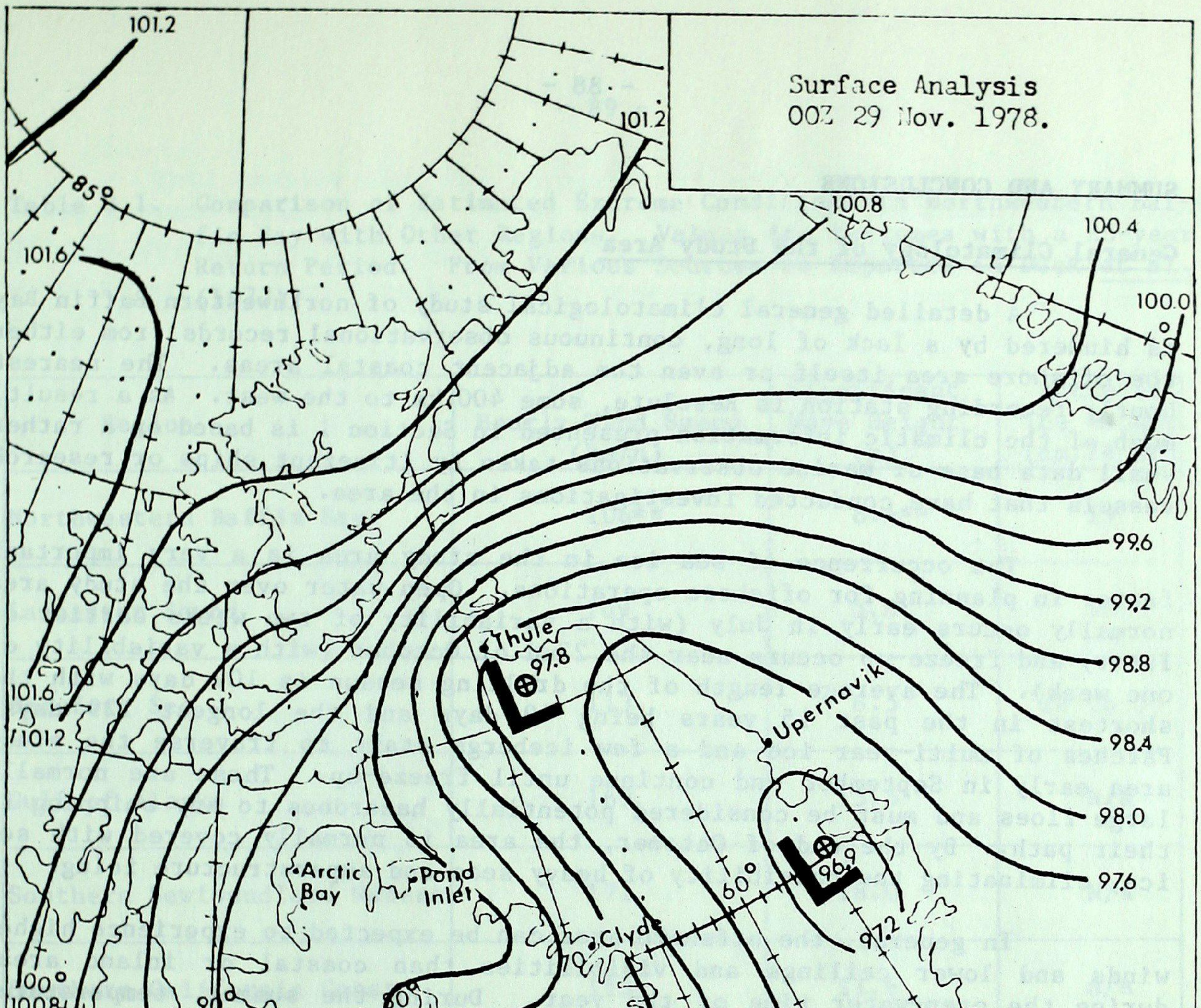


Fig. 3.15. Surface Analysis showing trough along western Greenland with two lows tracking northwards along the coast. Quasistationary low northern Baffin Bay.

SUMMARY AND CONCLUSIONS

General Climatology of the Study Area

A detailed general climatological study of northwestern Baffin Bay is hindered by a lack of long, continuous observational records from either the offshore area itself or even the adjacent coastal areas. The nearest hourly recording station is Resolute, some 400 km to the west. As a result, much of the climatic information presented in Section 1 is based on a rather small data base of marine observations taken by itinerant ships or research vessels that have conducted investigations in the area.

The occurrence of sea ice in the study area is a very important factor in planning for offshore operations. Open water over the study area normally occurs early in July (with a variability of two weeks earlier or later) and freeze-up occurs near the 22nd of October (with a variability of one week). The average length of the drilling season is 102 days with the shortest in the past 15 years being 49 days and the longest 129 days. Patches of multi-year ice and a few icebergs start to traverse the study area early in September and continue until freeze-up. These are normally large floes and must be considered potentially hazardous to any shipping in their path. By the end of October, the area is normally covered with sea ice, eliminating the possibility of heavy seas and superstructure icing.

In general, the offshore area can be expected to experience higher winds and lower ceilings and visibilities than coastal or inland areas during the open-water time of the year. During the summer, temperatures over the water are also several degrees cooler. Means and percentage frequencies of occurrence presented in this study do not suggest unusually harsh conditions in this area in comparison with other areas of the eastern Canadian Arctic; however, storm activity in the fall can be severe and extremes of winds, waves, and structural icing could be damaging to offshore structures and vessels.

Extreme Winds, Waves and Structural Icing

The following table compares northwestern Baffin Bay with other regions where offshore activity is occurring or is proposed, in regard to extreme winds, waves, and structural icing. The values for arctic regions, except for accreted ice, are apparently less severe than for more southerly regions. Although this may be true for wave heights (due to sea-ice covers), the values for winds would be higher if computed on an annual basis for the Arctic. The analysis for northwestern Baffin Bay does yield an extreme significant wave height greater than either Lancaster Sound or the Beaufort Sea. It is probable that this is due to the more open nature of the study area as the extreme winds for the open water season are similar. (Here, "more open nature" implies longer over-water fetches during the open-water season.)

Extreme amounts of accreted ice appear to be twice as great for the Beaufort Sea as for Lancaster Sound and northwestern Baffin Bay.

Table S.1. Comparison of Estimated Extreme Conditions in Northwestern Baffin Bay with Other Regions. Values Are Extremes with a 25-year Return Period. From Various Sources as Reported in Duck et al. (1977)*.

Region	Hourly Wind Speed (km/h)	Significant Wave Height (m)	Accreted Ice Amount (cm/24 hr)
Northwestern Baffin Bay	106**	8.4**	19
Lancaster Sound	109	5.8	13
Beaufort Sea	113	6.5	28 to 39
Gulf of Alaska	169	15.5	N/A
Southern Newfoundland Waters	171	18.0	N/A
Southern California Coast	113	11.6	N/A
Gulf of Mexico	156	13.8	N/A

* Duck, P.J., M.O. Berry, and D.W. Phillips. (1977). A Preliminary Assessment of Weather and Weather-Related Factors in Lancaster Sound. AES, Unpubl. Proj. Rep. No. 32, Met. Applic. Branch, Toronto, 29 pp.

** Wind and wave values are annual except for northwestern Baffin Bay, Lancaster Sound and the Beaufort Sea where the values apply to the open-water season only.

Extreme Storm Occurrences

In the five seasons 1974-1978, twenty-nine storms affected the study area. Twenty-two of these were classified as Type A - a low or trough in Baffin Bay giving strong northwesterlies over the drill area. Five lows were labelled Type B and resulted from an upper low being anchored over the northeastern Keewatin District and producing warm air advection over Baffin Bay and resulting southeasterly winds. The other two storms were different from either of these two types. Nine of the storms occurred in the summer and twenty in the autumn.

Meteorological conditions in northwestern Baffin Bay in July and August of the past five years were seldom severe enough to generate strong winds. Gale force winds in July and August occurred over the study area on an average of less than once per season. The gales were equally likely to be southeasterly as northwesterly.

The frequency and intensity of storms increased in September with one storm expected per season. Two or three storms per year occurred in each of the months of October and November. The stronger winds were associated with the later storms. In October one storm per season can be expected to have winds stronger than 90 km/h (49 kt) while in November one storm per season is likely to have winds in excess of 110 km/h (59 kt). In spite of the stronger winds in November, the October storms are likely to be more significant because of the likelihood of heavy seas and superstructure icing.

The northwestern Baffin Bay area has a lower potential for extreme storm development than the Beaufort Sea or Brevoort (Southern Davis Strait) areas. This is basically due to two factors. The latter two areas both lie under mean storm tracks and both have potential to develop baroclinicity. This is not true of northwestern Baffin Bay.

The main storm track over eastern Canada lies to the south of Baffin Bay. Low pressure areas moving from the west or southwest seldom reach the higher latitudes. Usually they track eastward towards southern Greenland where a minor impulse will split and propagate northward along the western Greenland coast as the main system continues eastward. When the upper flow does shift to lie through Baffin Bay, systems in this stream have an unfavourable trajectory over rugged terrain with very little low-level energy input.

Formation of storms in the southern Beaufort Sea and Brevoort areas is possible with both regions having perpetual baroclinic zones in the vicinity whose energy is easily tapped. In the Baffin Bay area, air and sea temperatures do not contrast strongly enough to form the necessary thermal gradients for storm development. The Greenland ice-cap is a constant source of cold air as are the rugged peaks of northern Baffin, Devon and southeastern Ellesmere Islands. Water temperatures cooler than those in the Beaufort Sea and Brevoort areas further weaken temperature gradients.

This implies that the formation of a low in Baffin Bay requires strong dynamic support aloft. After the low or trough has formed, development or intensification is severely limited by this lack of baroclinicity.

The above comments are borne out by the much higher frequency of storms in the Beaufort and Brevoort drilling areas. In this study, the most severe storm resulted from a type A pattern where warm air was advected over the area by a strong upper circulation. Dynamic support aloft was available and yet the low pressure centres weakened rapidly when the upper flow changed only slightly. The northwestern Baffin Bay area does not have a large potential for generating extreme storms.

Climatic Variations

The validity of the type of analyses presented in this study requires that variations or trends in climate not be of sufficient magnitude to make the historic period used significantly unrepresentative of the future. As mentioned in Section 1, the best presently available information indicates a warming trend which would be accompanied by changes in the synoptic and sea-ice regimes. This trend is expected to be gradual, however, and is unlikely to produce significant changes for at least the next 15 years. Shorter-term trends could produce periods of cooler or warmer conditions.

Planning and assessment of offshore operations must, therefore, be carried out bearing in mind that there is a finite chance that future weather events will fall outside the limits given in these analyses, but that the possibility of this happening will increase with time. It follows that in the case where operations are to continue over a period in excess of a few years, monitoring to detect trends is essential, and that analyses should be revised when this monitoring indicates significant changes have occurred. It also follows that parts of an offshore program particularly vulnerable to weather or sea-ice should be designed with a safety margin, and that the need for this increases with the length of time the component is expected to be needed.

APPENDIX A. USE OF RESOLUTE WIND REGIME

Resolute-Northwestern Baffin Bay Wind Regime

The use of Resolute wind data to determine wind and wind-based statistics for the study area of northwestern Baffin Bay requires some explanation. To derive meaningful statistical analyses for such meteorological and related elements as winds, waves, and structural icing, a record of weather observations both continuous over a long period of time and preferably hourly in observing frequency is desirable. There is no such program of observations at any location in either northwestern Baffin Bay or on adjacent islands. The nearest possible source is the Resolute observing station, some 400 km to the west on Cornwallis Island. (Two other possible stations located at similar distance from the study area, Clyde to the southeast and Thule to the northeast, were judged to be unacceptable due to marked local influences on their wind regimes.)

Weather observations have been taken at Resolute since it was first established in 1947. Until 1949, the program consisted of four observations per day. Then the program was upgraded to eight observations per day and remained so, with occasional variations, until 1962. Since then, an hourly program of observations has been in effect.

The Resolute observing station is about 65 m above sea level and is situated in a fairly flat valley which falls off towards Resolute Bay, about 3 km to the southeast on the south side of Cornwallis Island. The valley, which is oriented roughly northwest-southeast, is flanked on the northeast side by hills lying less than 2 km distant and rising to between 150 and 250 m ASL. On the southwest side, a hill on Cape Martyr reaches 150 m, about 3 km distant.

The surface wind direction regime for the July-to-October period at Resolute, shown in Figure A.1, reflects the slight channelling effect of the valley in which Resolute is situated. In July and August, the prevailing winds are southeasterly due to frequent onshore flows from Barrow Strait due to the differential heating of land and water at that time of year. Even so, however, northerly and northwesterly winds are frequently observed and the dominance of such winds becomes increasingly apparent in September and October with the reestablishment of the northerly surface air flow that is typical of much of the east-central arctic during the fall-winter-spring period.

Gale force and higher winds (> 34 kt) and extreme winds are generally associated with northerly through southeasterly directions not only during the July-to-October months, but throughout the year also. An important phenomenon at Resolute is the occurrence of extremely unsteady surface winds during periods of moderate northeasterly flow aloft. Strong north-north-easterly to east-southeasterly surface winds are sometimes interrupted by calms which begin and end so abruptly as to present a hazard to aviation (Fraser, 1959; Burns, 1976). The implications of such activity are important for duration analyses of high winds, for example. The applicability of such analyses to offshore areas is somewhat suspect as duration lengths might be underestimated where they are based on time series that contain short calms that occur only at Resolute and not generally over the rest of the region.

Figures A.2 to A.9 compare the Resolute wind regime with that of the northwestern Baffin Bay area as characterized by the marine observations available for marine grid area #12. With regard to the directional regimes (Figures A.2 to A.5), there is quite good agreement between the respective wind roses considering the distance between the two locations, the effects of surrounding topography, and the small number of observations available for the marine area. Two points may be noted. Firstly, southeasterly winds are up to 10 percent more frequent at Resolute in July and August, reflecting the channelling and differential heating factors mentioned above. Otherwise, there is markedly close accord between the two wind regimes. Secondly, in September and October with wind speeds becoming higher on the average, westerly winds are 10 to 12 per cent more frequent at the marine grid area. This is most likely a reflection of wind channelling in the east-west direction along Lancaster Sound, as grid area #12 extends to the mouth of that water body. During these two months, though, northerlies or northwesterlies are the prevailing winds at both locations.

The "normal" wind speed distributions are indicated in Figures A.6 to A.9. During July, August and September, there is little significant difference between the two locations. Higher wind speeds (those $\geq$ 22 kt) are slightly more frequent at Resolute during the first two months, but by September, such winds become more frequent in the marine area. This trend to more frequent high winds over the water than at Resolute is more noticeable on the October graph.

The comparison of the speed and directional components of the wind regimes at Resolute and northwestern Baffin Bay based on summaries of the long-term records of both (bearing in mind athe rather fragmentary nature of the data base of marine area #12) suggests that the use of the Resolute wind data base to provide statistical estimates of normal conditions over the northwestern Baffin Bay study area is not unreasonable. The preparation of statistical estimates of extreme conditions is somewhat more complex. Generally, surface wind speeds over marine areas are expected to be somewhat higher than adjacent coastal locations due to lesser surface frictional effects over water. This is apparent in the present analysis from the speed regimes of September and October. In order to account for this difference in coastal-offshore winds and to still use the Resolute wind records for reliable statistical estimation of extreme conditions applicable to northwestern Baffin Bay, a set of adjustment factors for wind speed was developed.

Determination of Adjustment Factors

The method used to develop the wind speed adjustment factors made use of information on the relationship between surface and gradient level winds previously derived for a selection of Canadian upper-air stations.

The information was in the form of ratios of surface to gradient level wind speed based on various low-level air stability classes and surface wind directions.

The following equation was used:

$$\frac{v_w}{v_1} = \frac{v_w}{v_{95}} \cdot \frac{v_{95}}{v_1} \text{ or } R = R_1 R_2$$

where $\frac{v_w}{v_1}$ is the ratio, R, between offshore surface wind speed (v_w) and coastal surface wind speed (v_1) at Resolute;

$\frac{v_w}{v_{95}}$ is the ratio, R_1, between offshore surface wind speed and offshore gradient level (95 kPa) wind speed; and

$\frac{v_{95}}{v_1}$ is the ratio, R_2, between gradient level wind speed and surface wind speed at the coast.

The gradient level wind speed was assumed to be the same over coastal and nearby offshore areas.

In determining values of R for this particular study, the ratio of surface to gradient level wind speed for marine areas (R_1) was taken to be independent of geographical location and to vary only because of differing air stability conditions, time of year, and sea state conditions (as reflected by wind speed). Accordingly, the values of R_1 used were taken from Pacific Ocean Weather Station "Papa" (50°N, 145°W) for the period July to October and for surface winds greater than or equal to 20 knots. These values were compared with earlier ones determined by Findlater et al. (1966) from two Atlantic Ocean Weather Stations and, within the limits of comparison, were found to agree reasonably well. The ratios of gradient to surface level wind speed at the coast (R_2) were taken from Resolute upper air data and were dependent on air stability and wind direction. They also were for the period July to October and for winds greater than or equal to 20 knots.

The values of R so derived are shown in the following table:

Low-Level Air Stability → Surface Wind Direction ↓	$L \leqslant -7.2$°C/km *	$-3.4 \geqslant L > -7.2$°C/km	$1 \geqslant L > -3.4$°C/km	$L > 1$°C/km
260-020	1.11	1.13	1.08	1.17
020-140	1.02	1.02	0.89	0.85
140-260	1.11	1.12	1.07	1.15

* $L \leqslant -7.2$°C/km indicates a lapse rate (L) in which the air temperature decreases more than 7.2°C/km. Thus, the table represents increasing low-level air stability from left to right.

These values were utilized in Section 2 of this study to estimate offshore wind speeds at the time of extreme Resolute wind speed occurrences and so to determine the various extreme wind, wave, and icing statistics for northwestern Baffin Bay.

References

Burns, L.M.D. (1976). Pressure Jump at Resolute Bay. Atmospheric Environment Service, Unpubl. Rep., 12 pp.

Findlater, J., T.N.S. Harrower, G.A. Hawkins, and H.L. Wright. (1966). Surface and 900-mb Wind Relationships. Met. Office, Bracknell, Scientific Paper No. 23, 22 pp.

Fraser, D.B. (1959). Unstable Character of Northeasterly Winds at Resolute, N.W.T. Dept. Trans.-Met. Branch, Tech. Circ. 300, Toronto, 14 pp.

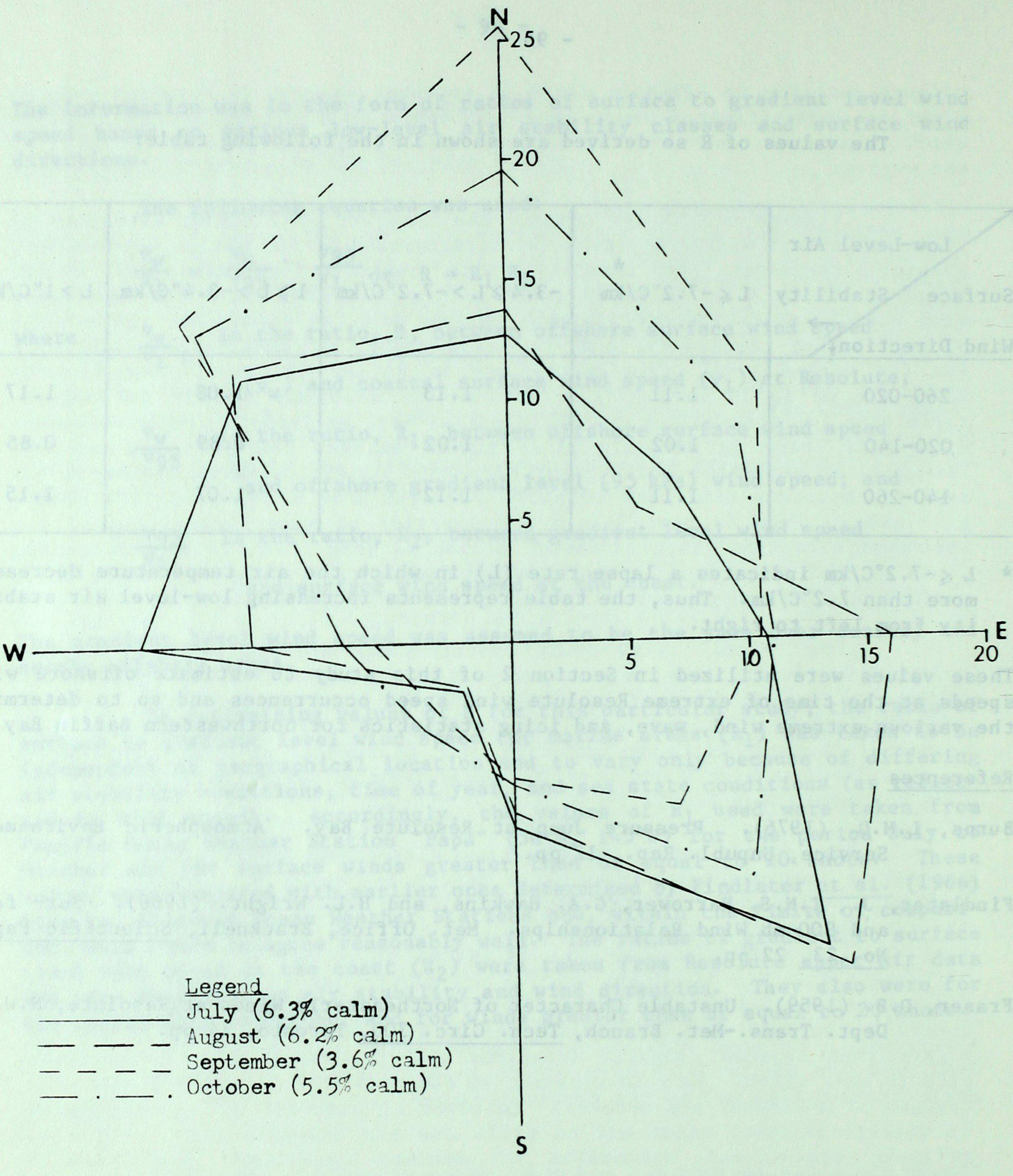


Figure A.1. Percentage frequency of occurrence of wind by direction for Resolute during the July-to-October period.

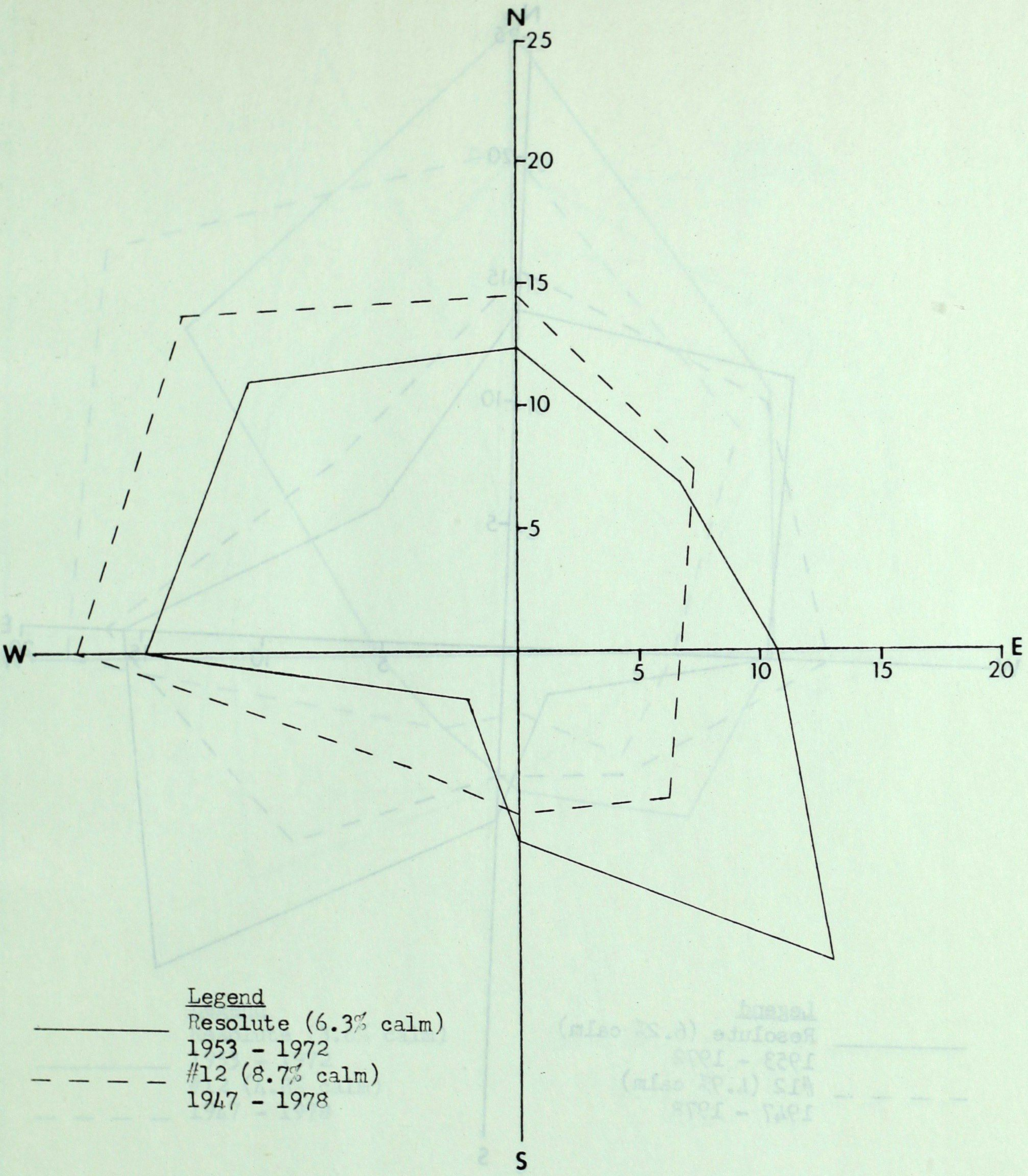


Figure A.2. Percentage frequency of occurrence of wind by direction for Resolute and marine grid area #12 in July.

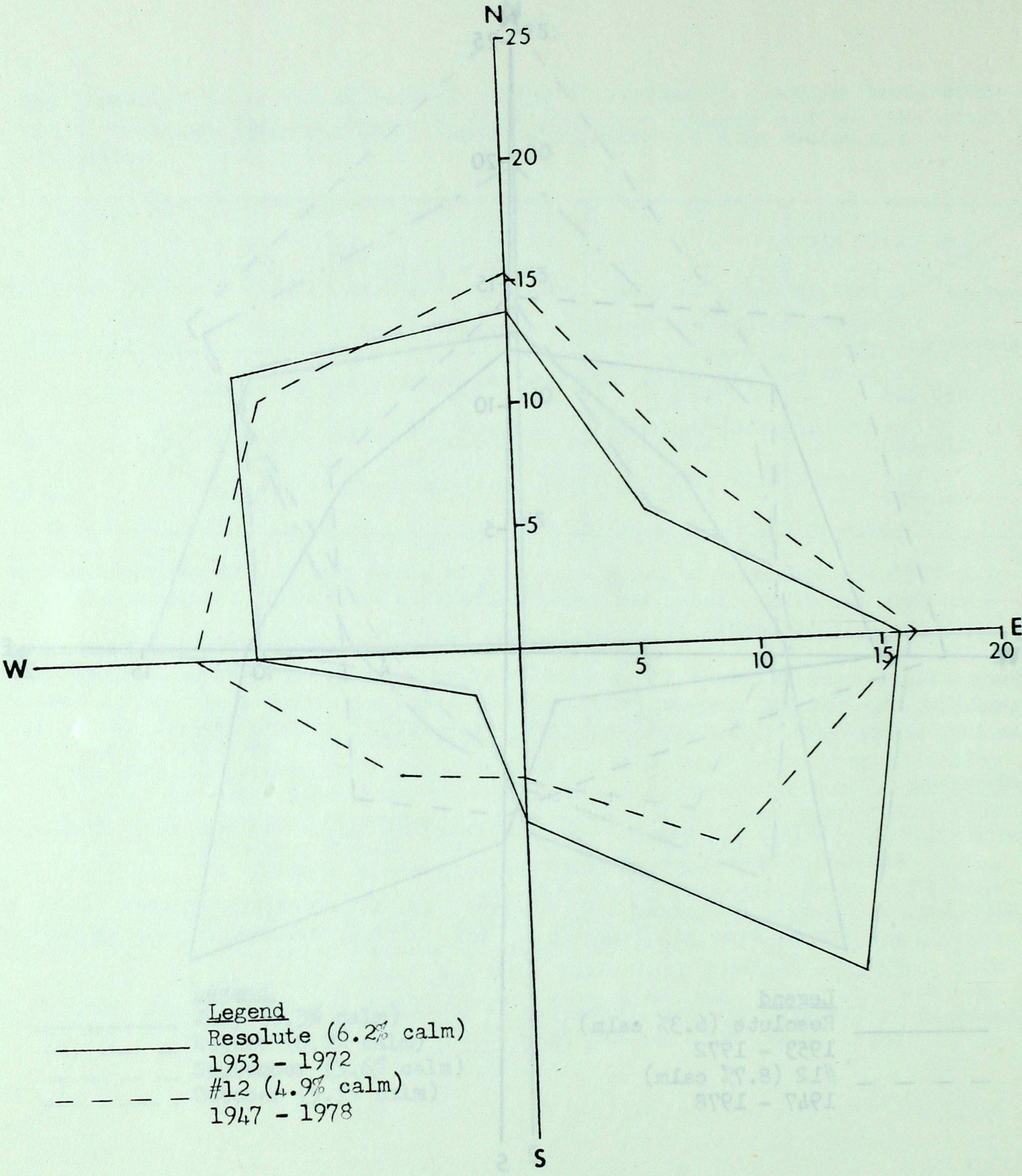


Figure A.3. Percentage frequency of occurrence of wind by direction for Resolute and marine grid area #12 in August.

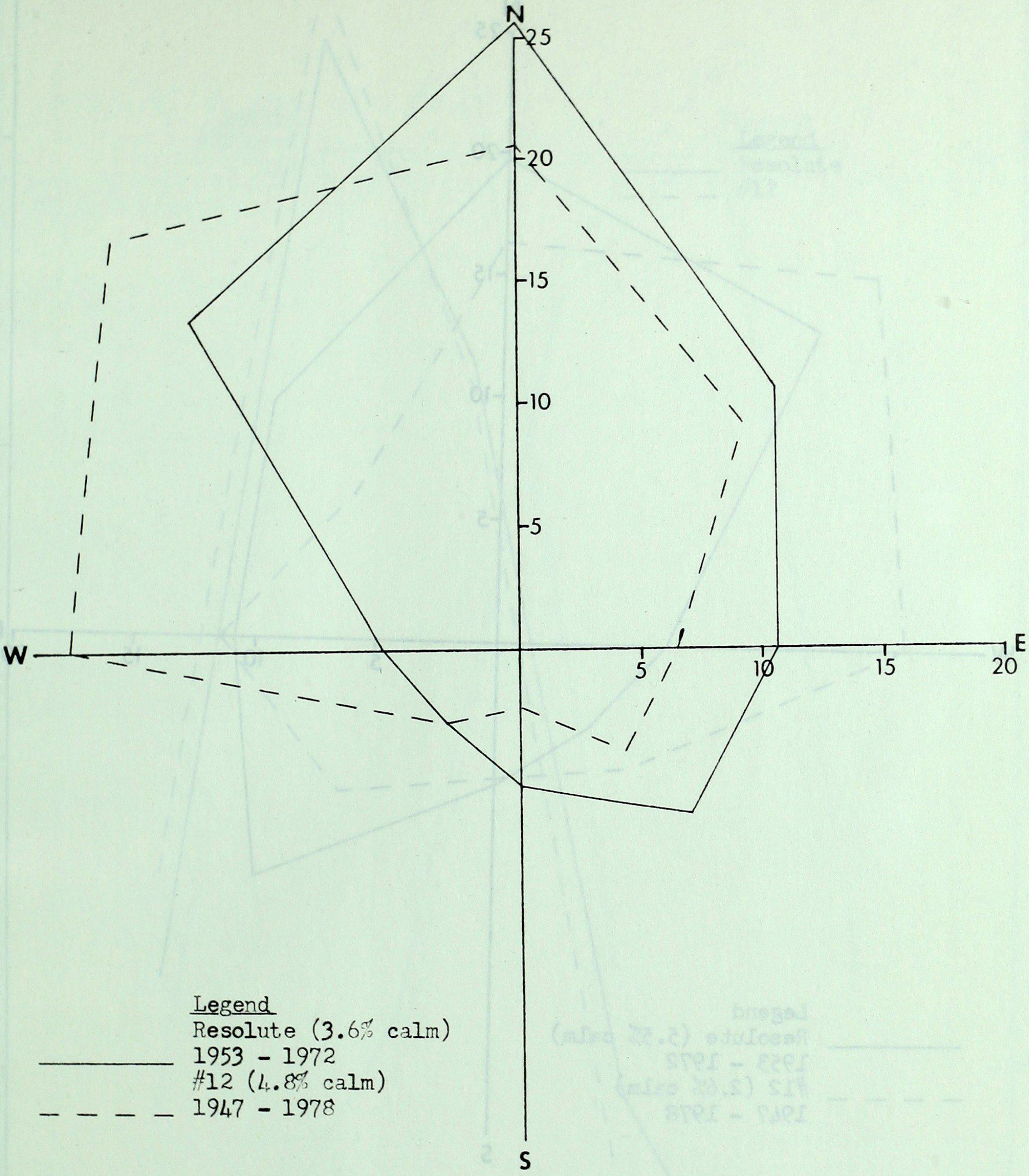


Figure A.4. Percentage frequency of occurrence of wind by direction for Resolute and marine grid area #12 in September.

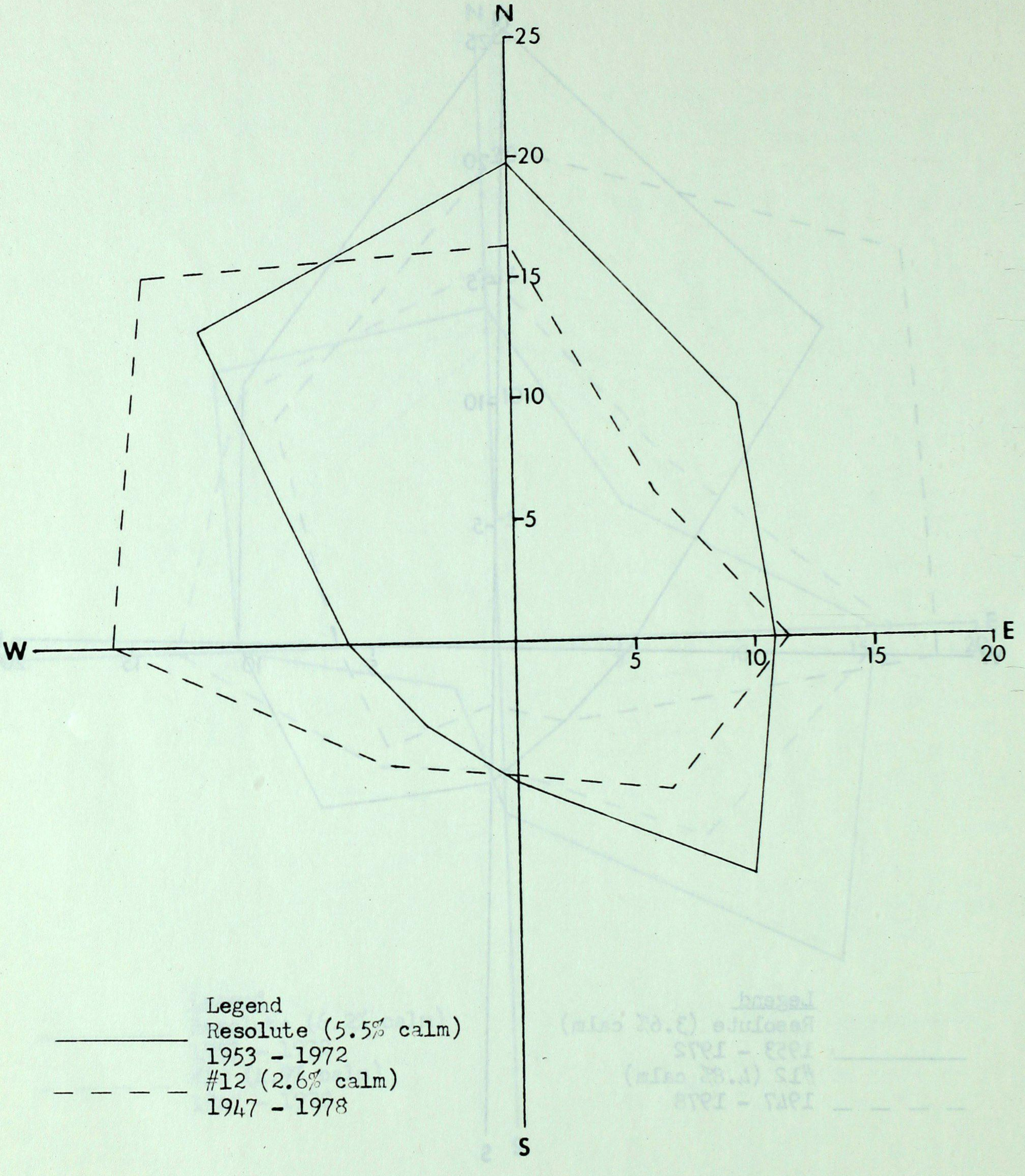


Figure A.5. Percentage frequency of occurrence of wind by direction for Resolute and marine grid #12 in October.

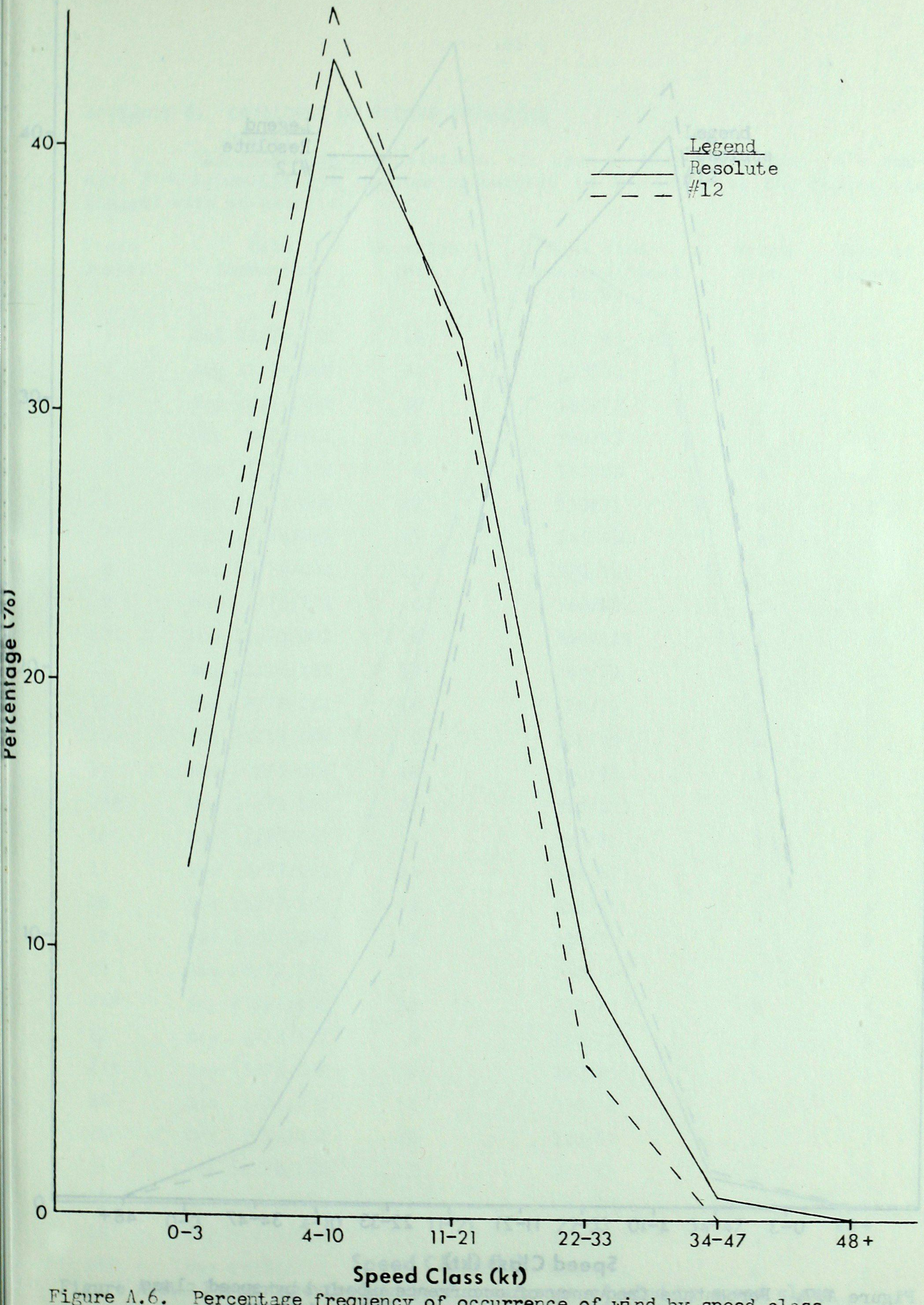


Figure A.6. Percentage frequency of occurrence of wind by speed class for Resolute and marine grid area #12 in July.

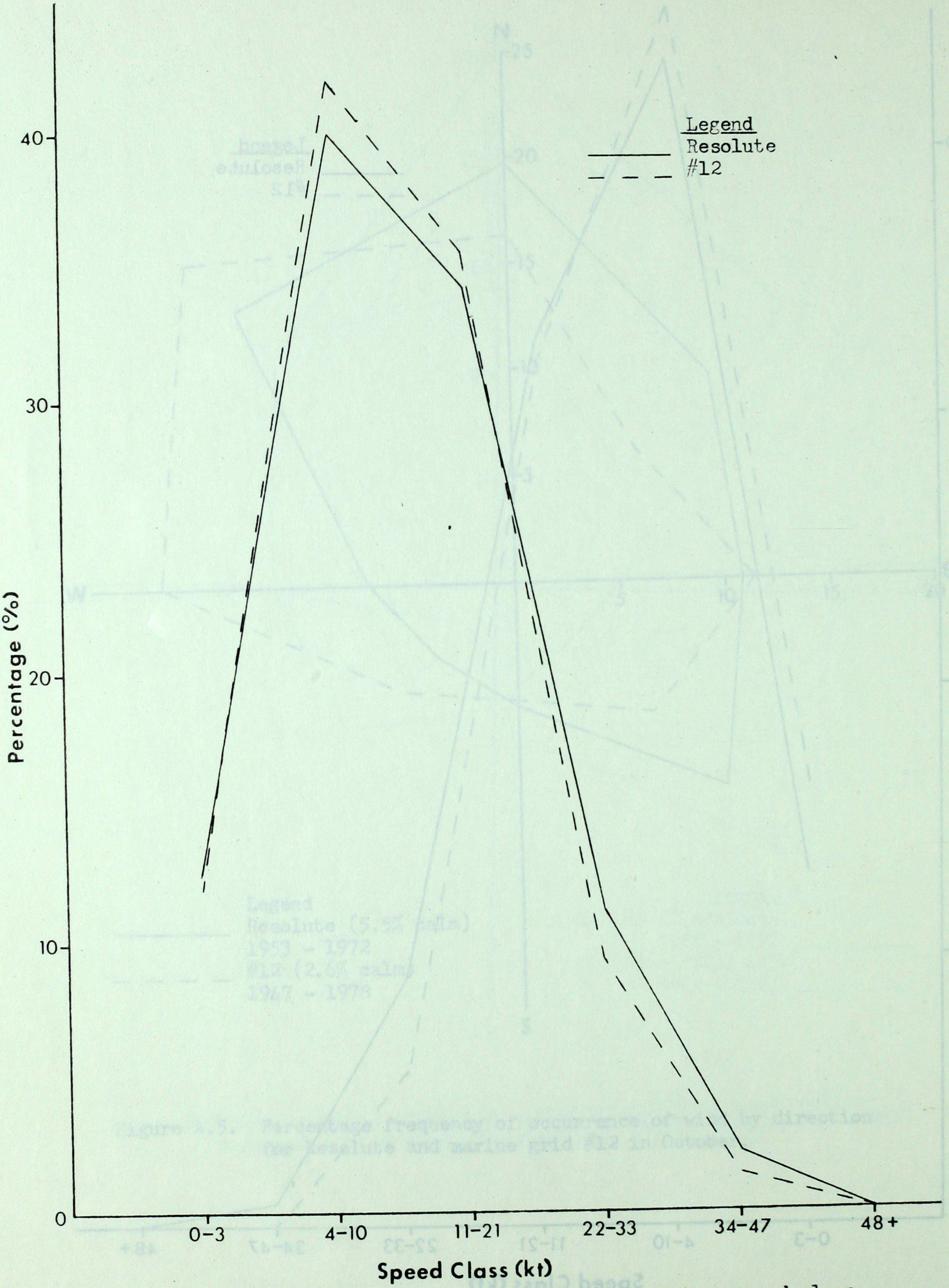


Figure A.7. Percentage frequency of occurrence of wind by speed class for Resolute and marine grid area #12 in August.

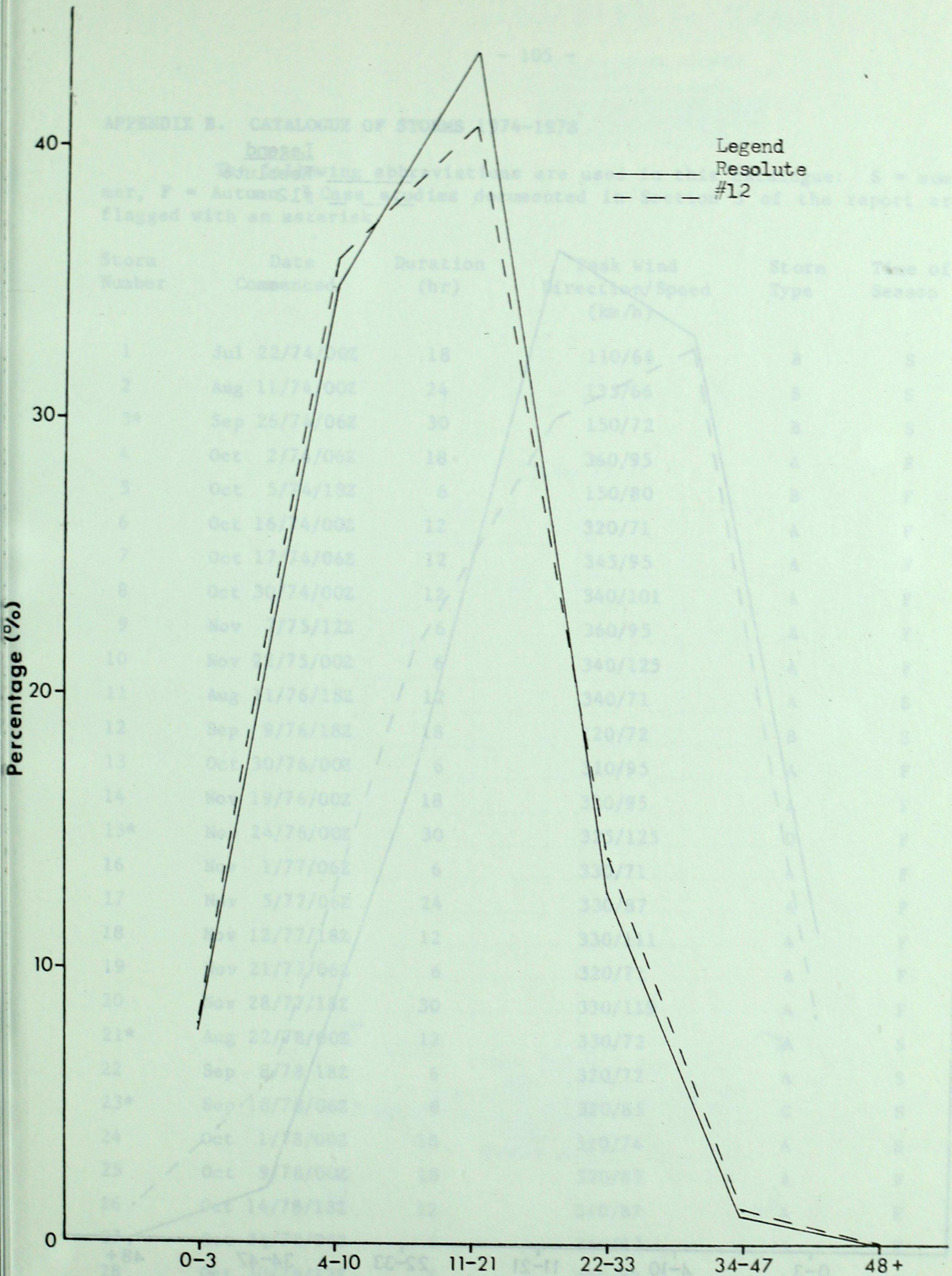


Figure A.8. Percentage frequency of occurrence of wind by speed class for Resolute and marine grid area #12 in September.

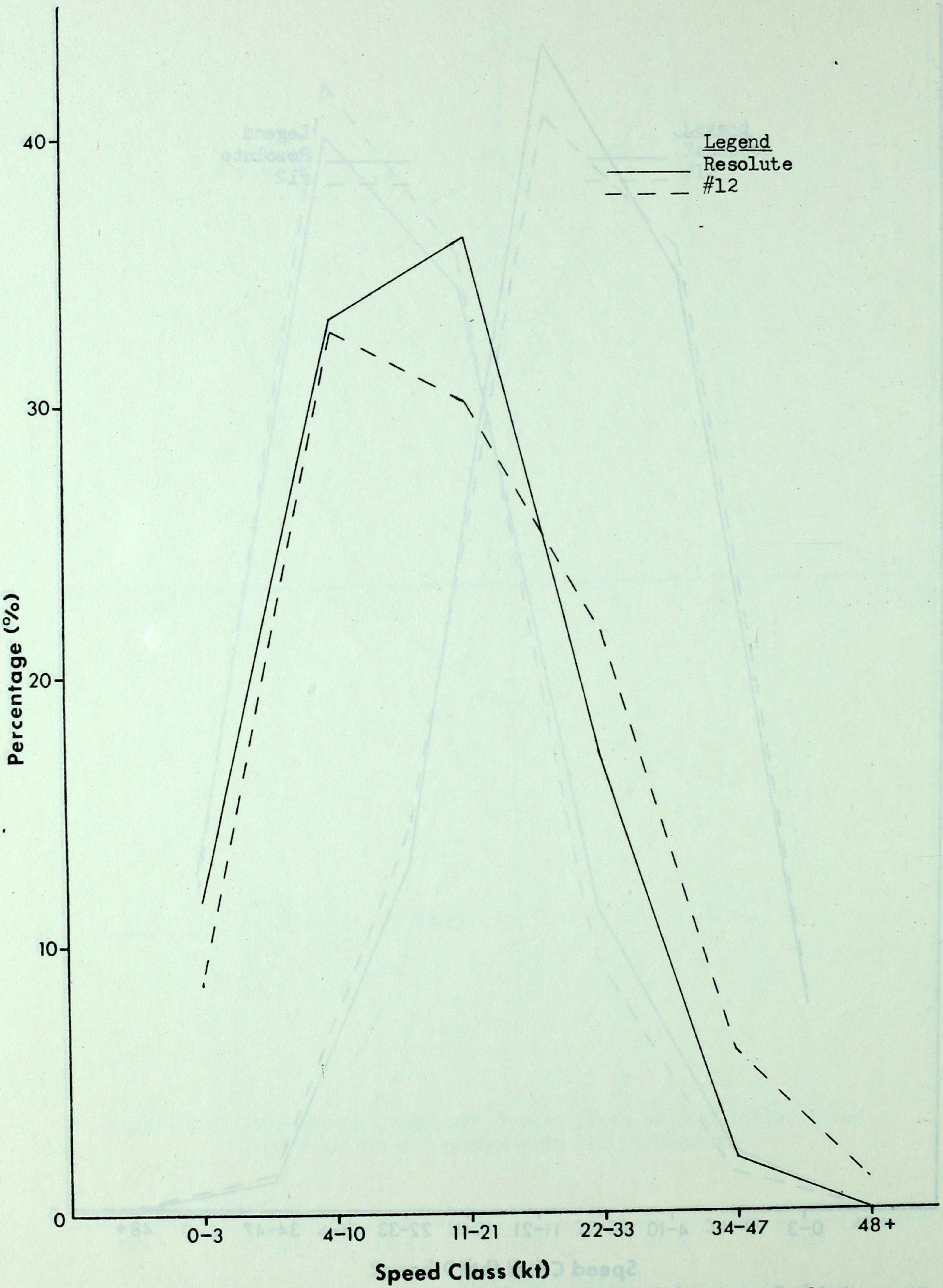


Figure A.9. Percentage frequency of occurrence of wind by speed class for Resolute and marine grid area #12 in October.

APPENDIX B. CATALOGUE OF STORMS 1974-1978

The following abbreviations are used in this catalogue: S = summer, F = Autumn. Case studies documented in Section 3 of the report are flagged with an asterisk.

Storm Number	Date Commenced	Duration (hr)	Peak Wind Direction/Speed (km/h)	Storm Type	Time of Season
1	Jul 22/74/00Z	18	110/66	B	S
2	Aug 11/74/00Z	24	135/66	B	S
3*	Sep 26/74/06Z	30	150/72	B	S
4	Oct 2/74/06Z	18	360/95	A	F
5	Oct 5/74/18Z	6	150/80	B	F
6	Oct 16/74/00Z	12	320/71	A	F
7	Oct 17/74/06Z	12	345/95	A	F
8	Oct 30/74/00Z	12	340/101	A	F
9	Nov 7/75/12Z	6	360/95	A	F
10	Nov 22/75/00Z	6	340/125	A	F
11	Aug 11/76/18Z	12	340/71	A	S
12	Sep 9/76/18Z	18	120/72	B	S
13	Oct 30/76/00Z	6	310/95	A	F
14	Nov 19/76/00Z	18	330/95	A	F
15*	Nov 24/76/00Z	30	325/125	D	F
16	Nov 1/77/06Z	6	330/71	A	F
17	Nov 5/77/06Z	24	330/87	A	F
18	Nov 12/77/18Z	12	330/111	A	F
19	Nov 21/77/06Z	6	320/71	A	F
20	Nov 28/77/18Z	30	330/119	A	F
21*	Aug 22/78/00Z	12	330/72	A	S
22	Sep 8/78/18Z	6	320/72	A	S
23*	Sep 18/78/06Z	6	320/85	C	S
24	Oct 1/78/00Z	18	320/74	A	S
25	Oct 9/78/00Z	18	320/87	A	F
26	Oct 14/78/18Z	12	340/87	A	F
27	Oct 21/78/06Z	6	340/87	A	F
28	Oct 30/78/12Z	6	320/87	A	F
29*	Nov 27/78/12Z	54	330/125	A	F