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THE CLIMATE OF AUYUITTUQ NATIONAL PARK, BAFFIN ISLAND, NORTHWEST TERRITORIES

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ABSTRACT

Auyuittuq National Park covers approximately 25,000 km^2 in the mountainous Cumberland Peninsula of Baffin Island. This report describes the climate of the region with the main view of aiding visitors, managers and planners to better understand and cope with the rather capricious weather conditions occurring throughout the year.

The initial chapters I-IV describe the meteorological conditions generally, in terms of controls such as terrain, the sea, and storm tracks. Chapter V summarizes the principal climatic elements: temperature, wind, precipitation, cloud cover and sea ice. These are analysed by ordinary statistical techniques and illustrated graphically where possible.

The final chapters re-synthesize the data to arrive at a quality assessment of visitor activities, and the maintenance and development of the park. Data on which to base conclusions have many limitations; therefore a network of observing stations has been suggested in chapter VII. The terminating section of the report is an annotated bibliography.

SOMMAIRE

Le parc national Auyuittuq se situe dans la péninsule de Cumberland sur l'Île Baffin, et a une superficie d'à peu près 25 000 km^2. Cette étude, décrivant le climat de la région, a pour but principal, d'aider les visiteurs, et les responsables du parc à comprendre et à subir les temps souvent capricieux pendant l'année. En général, les conditions météorologiques ont été décrites dans les premiers chapitres en termes de contrôles, par exemple: le terrain, la mer et les trajectoires des tempêtes. Le chapitre V donne un sommaire des élements climatologiques principaux: les températures, le vent, les précipitations, les nuages et la glace marine. On a employé des méthodes statistiques simples pour l'analyse et des diagrammes explicatifs lorsque possible.

Les derniers chapitres expriment sur le plan climatique, une évaluation des activités des visiteurs, l'entretien et le developpement du parc. Puisque les conclusions sont tirées de données imparfaites, un réseau de stations d'observation à été suggèré (chapitre VII). Une bibliographie annotée conclue l'étude.

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THE CLIMATE OF AUYUITTUQ NATIONAL PARK

I. Introduction

On February 22, 1972, the Minister of Indian and Northern Affairs, the Honourable Jean Chrétien, announced the creation of Baffin Island National Park, later re-named Auyuittuq National Park. The objectives behind the establishment of this unique Park, the only national park located in an Arctic environment, include the preservation of regions containing particular geographical, geological, biological, historical, or panoramic significance which form part of our natural and cultural heritage for the benefit, instruction and enjoyment of the Canadian people. The climate of the region is one of the world's harshest. Well-being and survival of all living things are critically related to weather conditions. A good knowledge of the climate and the means to evaluate the significance of meteorological events is essential to those charged with managing this natural resource.

II. Geographic Complexity of Auyuittuq National Park Region

It must be initially emphasized that it is not feasible to describe a singular "climate" for Auyuittuq National Park at any given time. In spite of the limited areal extent of the Park in comparison with Baffin Island, weather conditions within its boundaries can vary tremendously from time to time and from place to place. These confront Park visitors with many problems including a struggle to find human comfort. The complex nature of the climate of the Cumberland Peninsula is largely related to certain geographical characteristics.

The landscape is mountainous, and processes of glacierization have left a terrain which is in the forefront of the most rugged surfaces of the world. Extending from the sea coast on the northern boundary of the Park,the land climbs steeply upward through the near-vertical slopes of fjord valleys to an ice-covered realm peaking above 2000 metres a.s.l. The classical climatic controls, i.e., latitude, altitude, distance from sea, topography and storm tracks, play, individually, very strong roles to define a most complex assemblage of climates varying enormously in a spatial sense, as well as with season. Offshore, open water is common in mid-winter, while no significant ablation takes place from the higher dome of the Penny Ice Cap in the summers of most years. Winds moving in from the sea, or streaming downslope from the ice-fields are channeled and accelerated by the deeply incised fjord-valleys giving local-scale howling gales while shelter and calm conditions are obtained only a few hundreds metres distant. The mountains rebuff and re-direct or fragment deep storm systems passing over the area. Thus cloudiness, humidity and precipitation are quite contrasting across the Park area, as are wind, temperature, visibility and other climatic criteria.

The areal contrasts and high incidences of storms and severe conditions provide most stimulating milieux for research climatologists to develop their skills, but these same factors are vexations to us who have to try and generalize patterns and provide sound recommendations.

Probably the best advice we can offer to Park Administrators, other personnel and visitors is to be very cautious regarding the weather when planning outdoor activities. Statistical summaries and printed "averages" of climatic conditions should be viewed skeptically, for the weather as measured at one site only applies in this type of country, to that specific site. Meteorological stations here are not very representative (for most elements) of extensive geographical areas. Persons operating out-of-doors quite often will develop a weather lore, and we would encourage this process, for people with good powers of observation can rationalize weather changes and climatic boundaries, and thereby interpret or interpolate weather station data to distant locations.

Auyuittuq Park is a most interesting area, scientifically. For some years now it has been considered to be a centre for the inception of continental glaciation, and of course much of its area has attracted many scientific field parties, particularly in the last 25 years, which have made important contributions to our knowledge of the area. Meteorological knowledge is very important, for the environment is a very delicate one where plants and animals survive and reproduce precariously. Bad years when the warm season becomes unusually short, or where storms, or inclement weather come at the time of calving, rutting, flowering, fruiting and other critical biological processes, not only occur frequently, but may re-happen over consecutive years. The area seems to have been subjected as well to more severe climatic fluctuations over the last few years than most other areas of the hemisphere.

Weather hazards in the form of severe turbulence over rough terrain for aviators, dense sea-ice in the shipping lanes, or cold precipitation, fog and strong winds bearing on overland travellers, are common, all-season events. The weather can only be "outwitted" by preparedness, sagacity as to weather behaviour, and always, prudence.

III. Data Sources and Problems

It bears repeating that users of data for Baffin Island are particularly cautioned that meteorological or climatic conditions may vary considerably over a short distance, and a single station represents only the immediate area about it. For example, the weather records being obtained in Pangnirtung Village do not indicate the presence of very strong fjord winds which are known to exist in the vicinity, and which can prove to be most dangerous for both air and ground travel. Failure to recognize and compensate for the spatial variation of weather conditions may seriously affect the comfort and safety of Park visitors. Station records are valuable, however, in that they provide a stable base to which measurements of regional variability may be related.

Table 1 provides a list of meteorological stations located on the Cumberland Peninsula, their period of record and type of observing programme. As indicated, only six stations are currently active; Broughton Island, Broughton Village, Clyde, Cape Hooper, Dewar Lakes, and Frobisher Bay Airport. Limited weather records have also been made available by members of expeditions doing research on the Penny Ice Cap and selected glaciers within Auyuittuq National Park.

Several important research projects in the Cumberland Peninsula have been described in the literature. Baird (1953) and Orvig (1955) of the Arctic Institute of North America measured several weather parameters from May through September, 1953, while attempting to delimit the firn area (accumulation zone) on the Penny Ice Cap. Coulcher (1967) carried out a general but extensive study of the synoptic climate of Baffin Island. In the early sixties the Geographical Branch of the Canadian Government studied the Barnes Ice Cap further north, adding to our knowledge of cold glaciers and glacierized terrain. During the 1970's, the Institute of Arctic and Alpine Research from the University of Colorado has conducted considerable research into the climate, past and present, of the Park region, and its effect upon glacier growth and annual amounts of snow accumulation (Andrews and Barry 1972; Jacobs, 1974; Jacobs, Barry, Bradley, and Weaver, 1974). In addition, officials of Auyuittuq National Park have operated a temperature and wind station at Pangnirtung, beginning in July 1973. Weather data from all of the above sources may be used to evaluate the effects of the climate on the delicate balance of floral and faunal ecosystems, on the frequency of suitable weather conditions for visitor outdoor activities and on the construction of permanent facilities within the Park limits.

IV. Climatic Controls

The climate of any region is brought about by a complex interaction of atmospheric and terrain factors. Some knowledge of the major influences is necessary to an understanding of the day-to-day weather and the planning of future activities. These major influences fall under the general headings of latitude, altitude, topography, distance from the coast, and atmospheric circulation.

Table 1

SELECTED METEOROLOGICAL STATIONS ON BAFFIN ISLAND

Station Name	Latitude	Longitude	Elevation (metres)	Period of Record		OBSERVING PROGRAM: Synoptic	Hourly Weather	Temperature	Precipitation	Wind Mileages	Sunshine	Upper Air	Snow Survey
Broughton Island	67° 31'	64° 03'	581	1956-06	1957-08		P						
				1957-09	1960-03			✓	✓				
				1960-03		✓	P	✓	✓				
Broughton Village	67° 33'	64° 02'	9	1972-01			P	✓	✓	✓			
Cape Dyer	66° 39'	61° 23'	723	1955-12	1957-09		P						
				1958-01	1959-07	✓	P	✓	✓				
Cape Hooper	68° 26'	66° 47'	401	1956-03	1956-12		P						
				1957-01	1957-04		P	✓	✓				
				1957-05	1957-06		P						
				1957-08		✓	P	✓	✓				
Clyde	70° 27'	68° 33'	3	1933-09	1933-12			✓	✓				
				1942-11	1943-09	✓	P	✓	✓				
				1946-02	1948-08	✓	P	✓	✓				
				1948-09	1954-09	✓	P	✓	✓			✓	
				1954-10	1959-09	✓	P	✓	✓	✓		✓	
				1959-10	1960-08	✓	P	✓	✓			✓	
				1960-09	1963-01	✓	P	✓	✓	✓		✓	
				1963-02	1963-10	✓	P	✓	✓			✓	
				1963-11	1965-01	✓	P	✓	✓	✓		✓	
				1965-02	1968-09	✓	P	✓	✓	✓		✓	
				1968-10		✓	P	✓	✓	✓	✓	✓	✓
Mid Baffin (name changed to Dewar Lakes)	68° 39'	71° 10'	518	1956-06	1958-01		P						
				1958-02	1960-12	✓	P	✓	✓				
				1961-01		✓	P	✓	✓				
Ekalugad	68° 43'	68° 33'		1956-08	1957-04		P						
				1959-01	1960-12			✓	✓				
				1961-01	1963-08			✓	✓				
Frobisher Bay A	63° 45'	68° 33'	21	1942-05	1945-12		P						
				1946-01	1950-08	✓	P	✓	✓				
				1950-09	1951-05	✓	P	✓	✓			✓	
				1951-05	1956-02	✓	✓	✓	✓			✓	
				1956-03	1964-10	✓	✓	✓	✓		✓	✓	
				1964-11		✓	✓	✓	✓		✓	✓	✓
Kivitoo	67° 58'	64° 55'	442	1957-03	1957-04		P						
				1959-08	1963-03			✓	✓				
Padloping Island	67° 06'	62° 21'	40	1941-12	1946-01			✓	✓				
				1947-10	1949-12			✓	✓				
				1950-01	1950-07	✓	P	✓	✓				
				1951-01	1955-03	✓	P	✓	✓				
				1955-04	1956-08	✓	✓	✓	✓				
Pangnirtung	66° 09'	65° 30'	13	1925-10	1926-07	✓	P	✓	✓				
				1930-09	1931-08	✓	P	✓	✓				
				1932-09	1942-12	✓	P	✓	✓				
				1943-01	1950-07	✓	P						

A. Latitude

Auyuittuq National Park is located between latitudes 66°33'N and 68°20'N. Figure 1 illustrates the annual variation of hours of sunlight for the Park region (List, 1963, p. 507). The most southerly portion of the Park receives two weeks of 24-hour daylight from mid-June to the first of July, while the northern regions receive up to six weeks. The energy received on a discrete flat surface of the earth is small because of the relatively low incident angle of the sun's rays. This is compensated for by the increased length of summer days, and by the fact that much energy received at maritime high latitudes throughout the year is sky (diffuse) radiation from clouds. As a result, the total incoming solar energy available during June and July is approximately equal to that of temperate latitudes. However, the high reflectivity of Arctic surfaces and associated cloud cover results in only a small percentage of this energy remaining to heat the earth and atmosphere. For example, the extensive cloud layers and ice-congested polar seas in summer reflect more than 50% of the incident radiation.

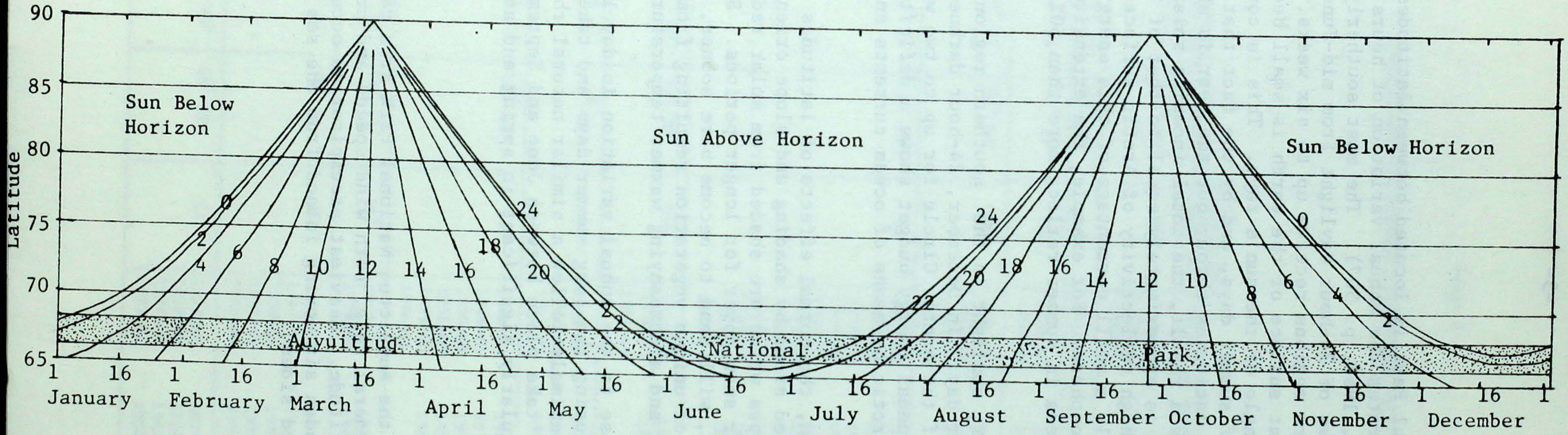
During the winter, sunlight in the southern regions of the Park lasts only a few hours per day. In December, 24-hour darkness occurs in the Park areas north of the Arctic Circle for up to two weeks. As a result of the long winter, the annual energy budget shows a deficit and energy must be transported into the Arctic by means of ocean currents and winds from the lower latitudes.

In uneven terrain, the normal effects of latitudes can be influenced in local, isolated areas by shading and slope orientation. For example, north-facing slopes which are shaded from solar radiation much of the time maintain their snow cover for longer periods. South-facing slopes, on the other hand, will tend to become bare sooner, and may even display one or two types of unique vegetation resulting from longer periods of direct solar radiation and accompanying warmer temperatures.

The human response to the annual variation in day length is to plan intensive activity during the long summer days and take rest in the dark season. Plants and animals follow a similar natural rhythm. Virtually all visitor activity will take place between June and September. Climatic constraints become particularly significant in spring and autumn.

B. Altitude

The altitude of the Auyuittuq National Park area ranges from sea level to 2100 m. As a general rule, both wind speeds and precipitation amounts tend to increase with altitude. Heaviest precipitation occurs on mountain slopes facing moisture-laden air moving inland from the sea while rain shadows may develop on the leeward sides.



Source: List, 1963

Figure 1:

Hours of Sunlight in Auyuittuq National Park

On a world-wide average, temperatures decrease with altitude. However, local conditions can be variable. On Baffin Island reverse gradients (temperature inversions) are widespread during certain times of the year and at night. These may persist over considerable periods.

Two types of temperature inversions are of common occurrence, but are different in formation and character. The nocturnal inversion forms on clear, calm nights when the air is relatively dry. With the sun below the horizon, the earth cools rapidly, particularly through the radiation of long-wave energy to space. This process is particularly effective over a snow-covered surface. The thickness and duration of the nocturnal inversion layer varies with season and topographic situation. Valleys and depressional areas trap cold air which has flowed by gravity from higher regions. In summer the thickness over a cold air "lake" might vary up to 100 m. In winter 300 m. inversions lasting several days are common.

Another type of inversion occurs along the sea coast. Cold water in spring chills the air heated by insolation over adjacent land surfaces. The layer of air above the ice-laden water is considerably cooler than warmer strata aloft. The duration of the marine inversion depends on the time taken for the water to warm up. During cooler years along the eastern coast of Baffin Island, the ice pack will remain close to the shore throughout the summer season, thus allowing the inversion to recur frequently.

If the air is sufficiently moist, for example, in a maritime situation, the top of the inversion may be seen to correspond with a layer of stratus or stratocumulus cloud. The cloud "tops" mark approximately the height at which the temperature gradient returns to a normal decline with elevation. Inversions are important features in that the air within them is very stable, and despite the cloud, precipitation will not occur. Stable air means it is not buoyant and air pollutants (in settled areas) may be trapped near the ground to the detriment of all living things in the region.

Another major effect of the inversion layer on Park visitors is the frequent presence of heavy fog particularly in early morning, although coastal regions may be blanketed with very cold air and dense fog all day which reduces visibility while areas at greater altitudes in the Park interior (i.e., above the cloud layer) may experience high temperatures and improved visibility. The subsidence of extremely cold air into valleys at night may also produce similar effects, though the nocturnal-type inversion is easily broken by moderate winds and strong sunlight.

Information concerning marine temperature inversions at Clyde has been tabulated by Bilello (1966) and is presented in Table 2. ~~Bilello~~ defined two types of inversions. From November through April Type 1 inversions, those with their bases on the ground, occur 63% of the time. The average thickness and temperature gradient of the inversion layer is

Table 2

TEMPERATURE INVERSIONS AT CLYDE, N.W.T.

A: Inversions with bases on ground surface

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
No. of Inversions	158	174	216	181	74	59	75	70	41	55	117	158	
Frequency Occurrence*	61	70	75	63	31	22	30	27	17	21	46	61	(Percentile)
Average Thickness	450	470	560	390	330	380	340	340	340	320	410	520	(m)
Average Temp. Gradient	1.6	2.2	2.0	2.2	1.4	.9	1.0	1.0	.8	1.1	1.4	1.7	(C°/100 m)
Average Temp. At Base	-29	-30	-28	-21	-9	3	6	5	- 1	- 8	-20	-26	(°C)

B: Inversions with bases above ground surface

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
No. of Inversions	82	67	64	90	115	130	113	103	63	79	111	84	
Frequency Occurrence*	32	27	22	31	49	49	44	40	26	30	44	32	(Percentile)
Average Thickness	520	500	490	450	400	370	320	350	340	320	380	470	(m)
Average Temp. Gradient	1.0	1.0	1.1	1.0	1.0	.9	1.1	.8	.9	1.2	1.0	1.2	(C°/100 m)
Average Temp. At Base	-27	-28	-24	-19	-10	- 3	0	- 1	- 7	-14	-20	-24	(°C)
Ave. Base Hght. Above Ground	630	550	570	660	680	590	490	640	960	940	680	600	(m)

C: All Inversions

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Frequency Occurrence*	93	97	97	94	80	71	74	67	43	51	90	93	(Percentile)

Source: Billelo (1966)

* Percentage frequency of all upper air soundings taken at 7 p.m., EST

Based on data January 1950 to April 1954 and February 1955 to December 1959.

470 m. and 1.9C°/100 m. respectively. During the warm half of the year, from May through October, Type 2 inversions, with their bases above the ground, occur more frequently than Type 1 inversions - about 40% of the time. The average height of the base of the inversion layer is 720 m. and the temperature gradient within it is 1.0C°/100 m.

C. Topography

Figures 2 and 3 illustrate the physiographic regions and the complex elevation contours of the Park respectively. Auyuittuq National Park is situated within the East Coast Mountain Range; and more specifically, in the Cumberland Peninsula where it occupies an area of 21,500 km^2. The juncture of the mountains with the sea is marked by steep, towering, headlands or deeply carved fjords which extend many kilometres inland. The coastal plain is very limited in areal extent. Entering the fjords are numerous, fast-flowing streams carrying melt-water in summer from the majestic ice fields at higher elevations. About 50% of Auyuittuq National Park is covered by glacier ice (Andrews and Dyke, 1974). The Penny Ice Cap is the principal body of permanent ice; it measures 6000 km^2 and sustains several radiating valley glaciers. Also present are many independent cirque and valley glacier systems - fed principally by moist air masses arriving from the east coast and the Davis Strait.

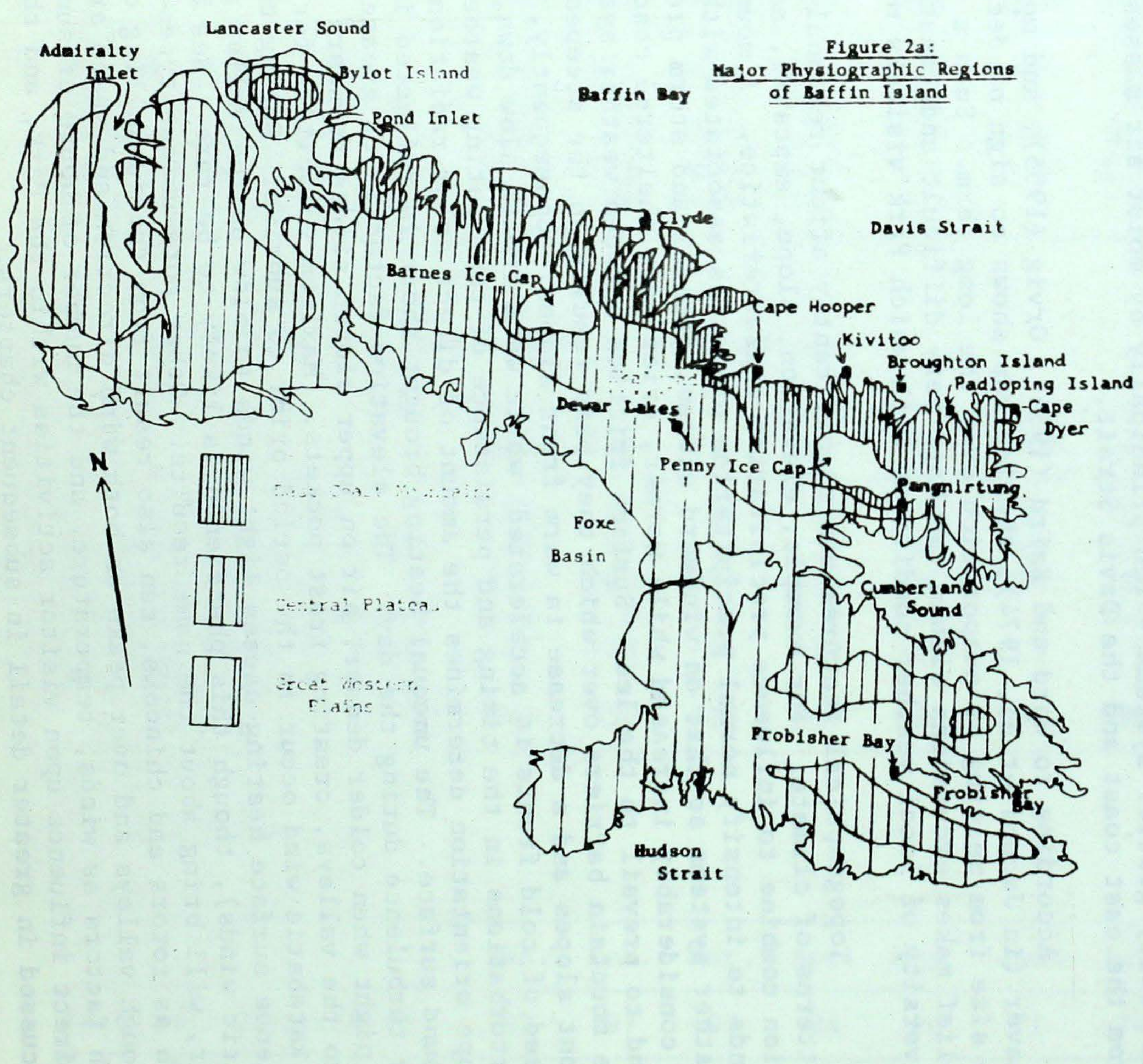
According to Ward and Baird (1954), Orvig (1955), and more recently Weaver (in Jacobs et al, 1974), the ice cap shows no sign of decreasing in size from melting or evaporation over the long term. Such a rugged relief makes excursions within the Park very difficult and creates a wide diversity of local weather conditions with which Park visitors must contend.

Topographical features can significantly affect regional and local patterns of climate. For example, elevation, slope, exposure, and orientation combine to influence precipitation characteristics. A mountain range tends to intensify normal precipitation processes associated with migratory weather systems so that on windward slopes, frontal and storm precipitation is considerably increased while warmer, drier more sheltered conditions tend to prevail to the lee. Surface friction between weather systems and the mountain barriers over which they pass results in the steepening of cold front slopes and a decrease in warm front slopes. Consequently, the travel speed of cold fronts is accelerated while warm fronts slow down, causing perturbations in the timing and persistence of contrasting weather situations. Slope orientation determines the amount of direct solar radiation received at ground surface. The unequal heating brought about is reflected in greater air turbulence during the day. The elevation factor is of greater importance at night when colder denser, air on upper slopes slides downward to settle into the valleys, creating frost pockets. Maximum velocities for downslope or katabatic wind occur in the period prior to sunrise. During the daytime, intense surface heating causes light winds to blow up the valley axes (anabatic winds), though this phenomenon is likely to be rare. Sea breezes, however, will bring about the same results. Other more unique types of winds, such as rotors and chinooks, can also result from the funnelling of winds through valleys and over peaks as both wind direction and speed are modified. Such factors as winds, temperature, and the number of hours of sunshine bear a direct influence upon visitor activities within the Park, and these will be discussed in greater detail in subsequent chapters.

FIGURE 2a:

Major Physiographic Regions of Baffin Island

and Permanent Glacier Ice on the Cumberland Peninsula



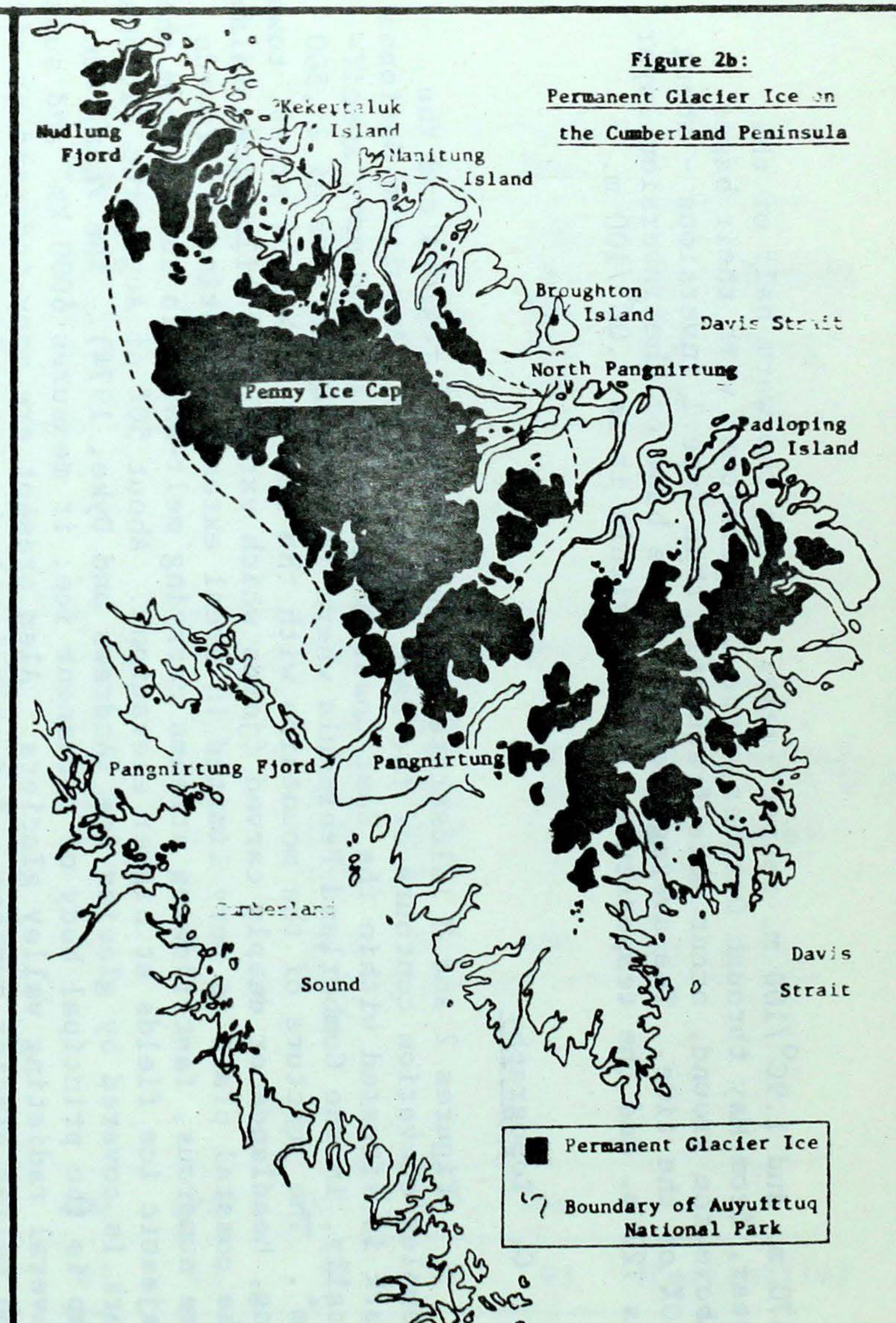
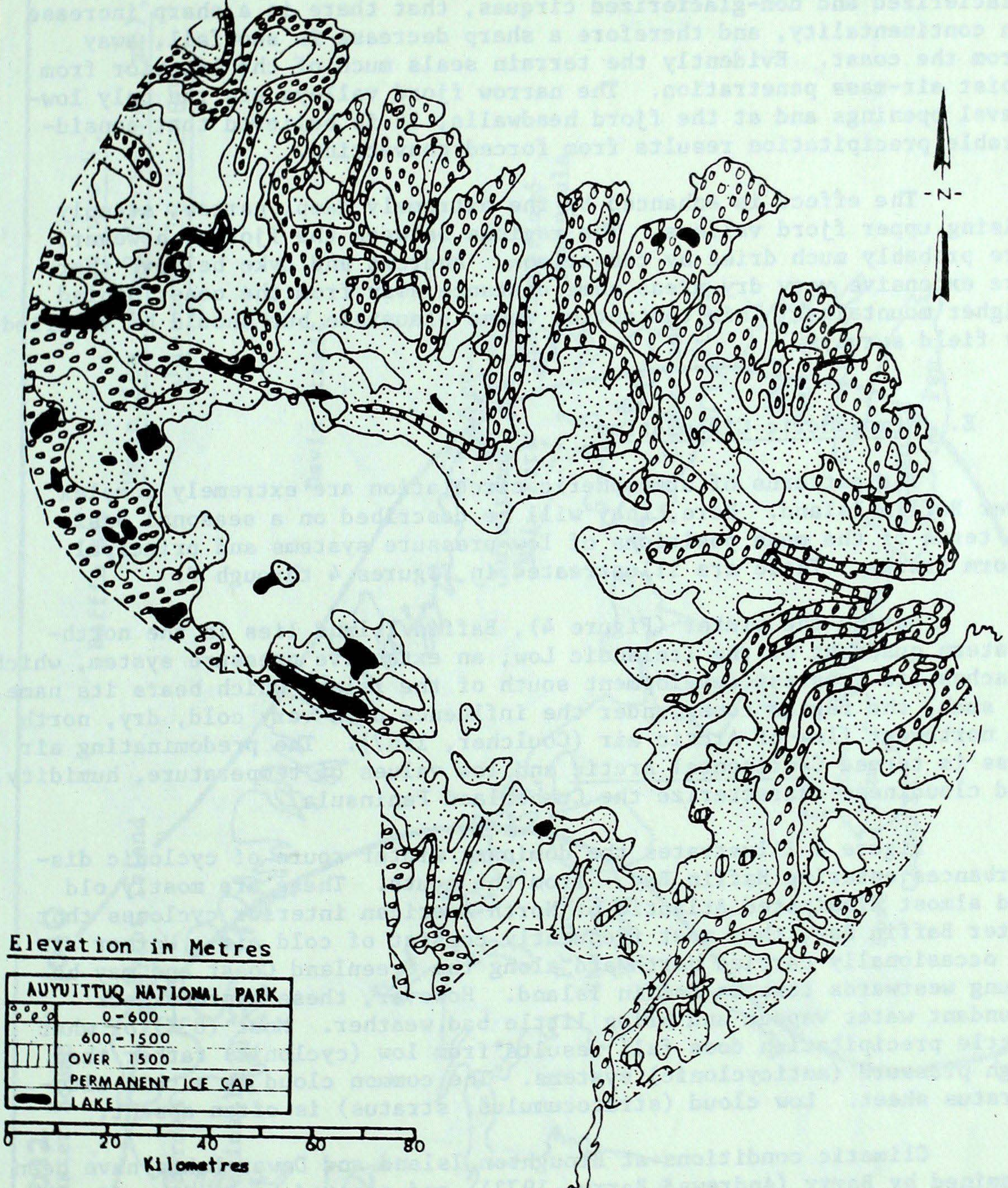


Figure 3:

Topography of Auyuittuq National Park



D. Distance From the Coast

The rugged physiography of the east coast of Baffin Island results in sharp contrasts between Park interior weather and that of the sea coast. Andrews and Dyke (1974) have suggested from a study of glacierized and non-glacierized cirques, that there is a sharp increase in continentality, and therefore a sharp decrease in snowfall, away from the coast. Evidently the terrain seals much of the interior from moist air-mass penetration. The narrow fjord valleys are the only low-level openings and at the fjord headwalls, it is believed that considerable precipitation results from forced convection.

The effect is enhanced by the extremely deep, narrow, steeply rising upper fjord valleys. The regions between the fjords, however, are probably much drier by comparison. Andrews and Dyke believe there are extensive very dry areas some distance away from the coast behind higher mountains. This contention seems plausible but should be verified by field surveys.

E. Atmospheric Circulation

The patterns of atmospheric circulation are extremely complex over Baffin Island. Here, they will be described on a seasonal basis in terms of the mean positions of low pressure systems and principal storm tracks. These are illustreated in Figures 4 through 7.

During the winter (Figure 4), Baffin Island lies in the northwestern quadrant of the Icelandic Low, an extensive pressure system, which reaches its greatest development south of the island which bears its name. As such, the region comes under the influence of a very cold, dry, north to northwest flow of Arctic air (Coulcher, 1967). The predominating air mass is termed Continental Arctic and low values of temperature, humidity, and cloudiness characterize the Cumberland Peninsula.

Figure 6 illustrates the dominant winter route of cyclonic disturbances entering Baffin Bay - from the south. These are mostly old and almost dissipated Atlantic or North American interior cyclones that enter Baffin Bay; they most frequently consist of cold air. Warmer air is occasionally carried northward along the Greenland Coast and may be swung westwards towards Baffin Island. However, these systems lack abundant water vapour and bring little bad weather. Most (83%) of what little precipitation does fall results from low (cyclonic) rather than high pressure (anticyclonic) systems. The common cloud is a thin altostratus sheet. Low cloud (stratocumulus, stratus) is often absent.

Climatic conditions at Broughton Island and Dewar Lakes have been examined by Barry (Andrews& Barry, 1972) and adapted by Bradley (Jacobs et al, 1974) to form a simplified classification of synoptic weather types. Figure 8 provides an illustration of the most frequently occurring pressure patterns and Table 3 provides a brief description of weather conditions (synoptic situation), the percentage of total precipitation resulting from each of these patterns, mean temperatures, and dominant wind directions.

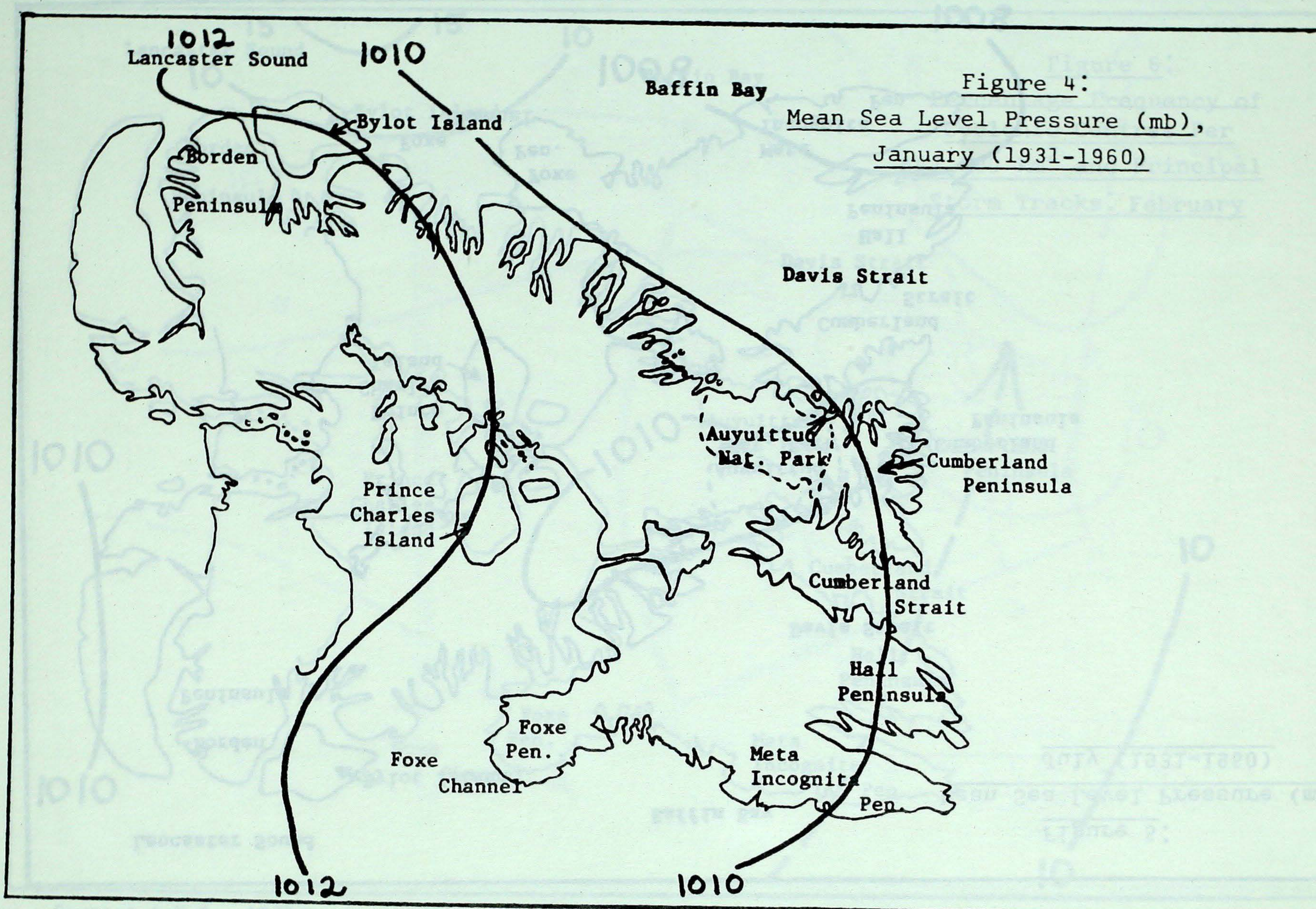


Figure 4:
Mean Sea Level Pressure (mb),
January (1931-1960)

Source: A.E.S., 1970a

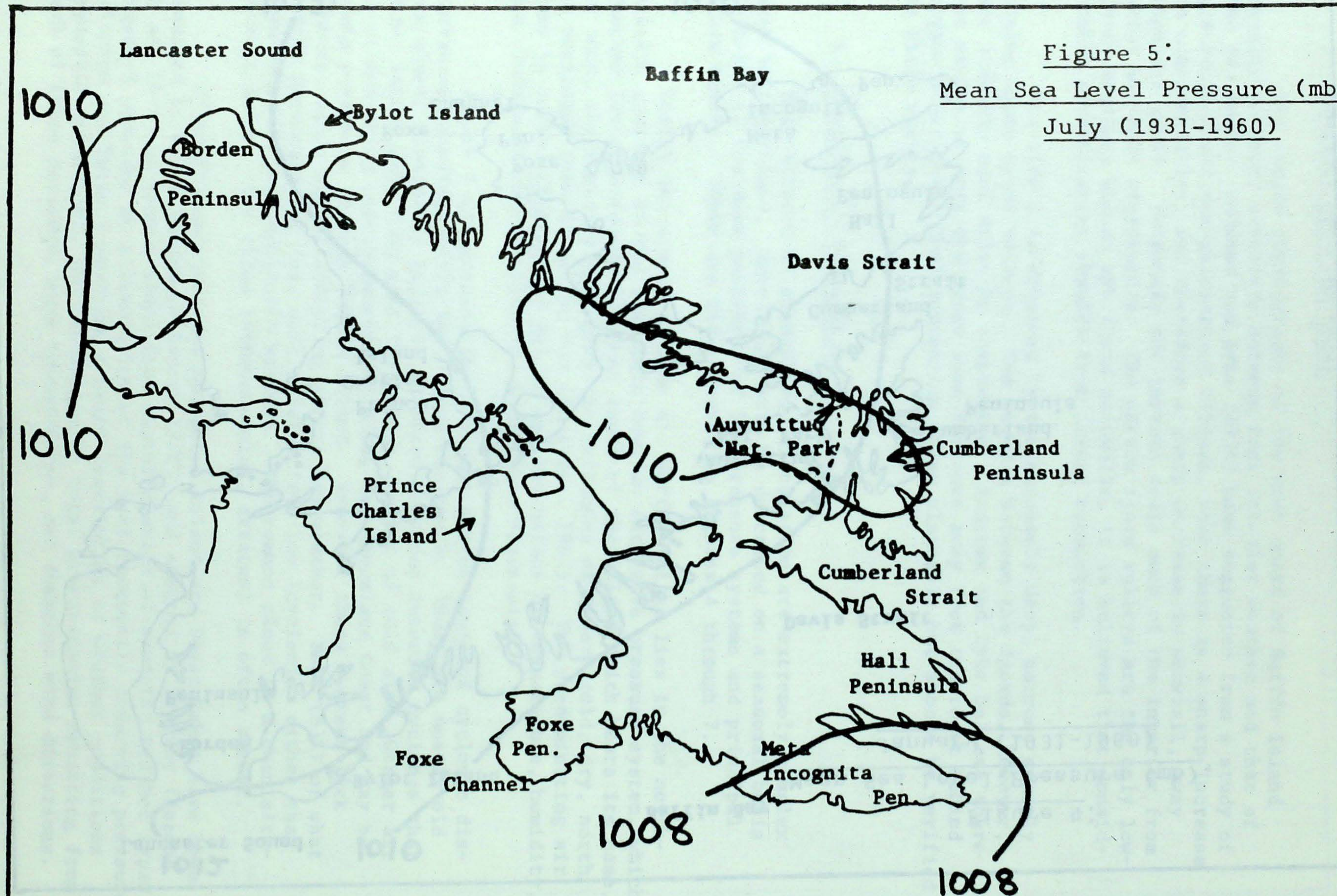


Figure 5: Mean Sea Level Pressure (mb) July (1931-1960)

Source: A.E.S., 1970a

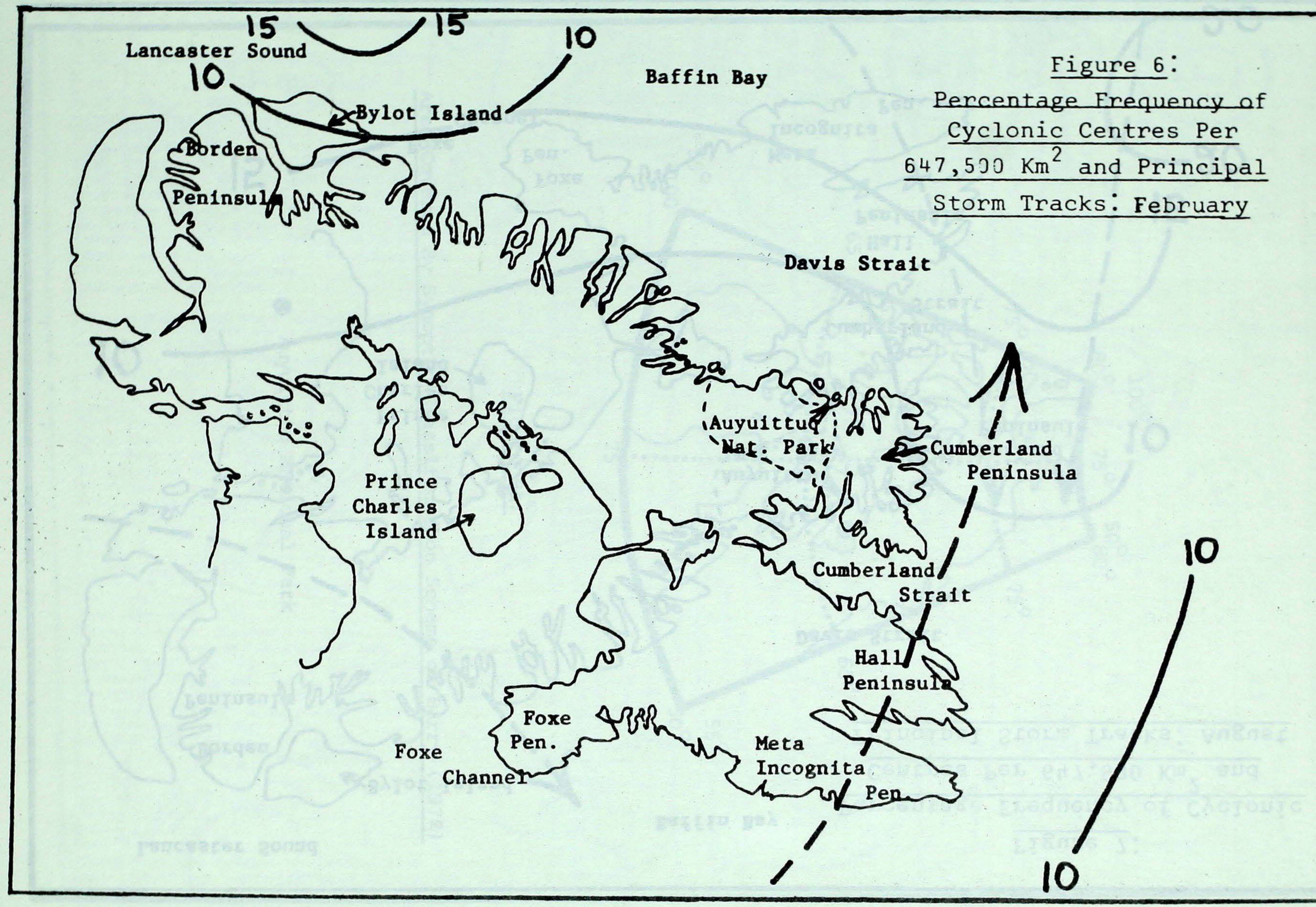


Figure 6: Percentage Frequency of Cyclonic Centres Per 647,500 Km^2 and Principal Storm Tracks: February

Source: A.E.S., 1970 a

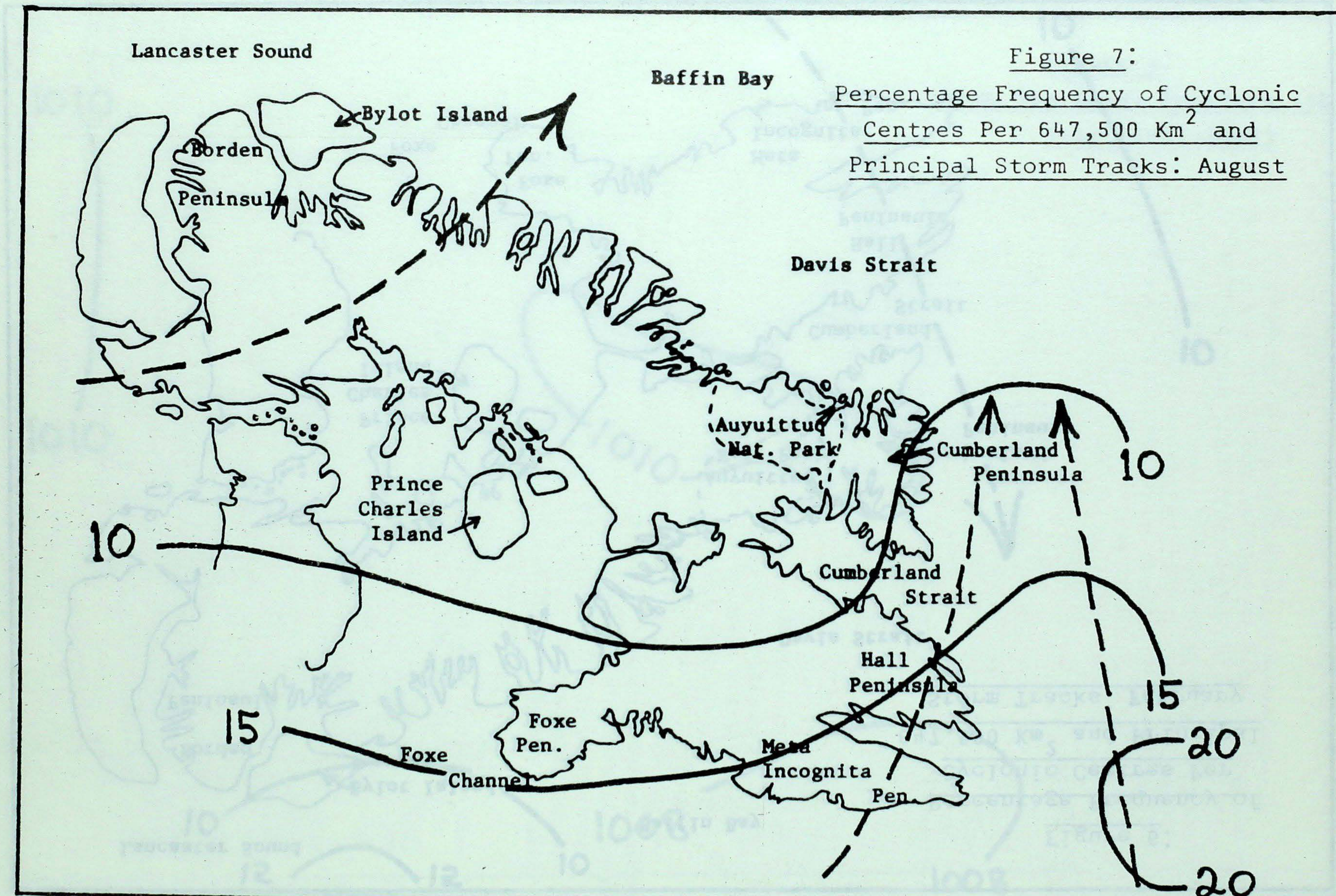


Figure 7:
Percentage Frequency of Cyclonic Centres Per 647,500 Km^2 and Principal Storm Tracks: August

Source: A.E.S., 1970 a

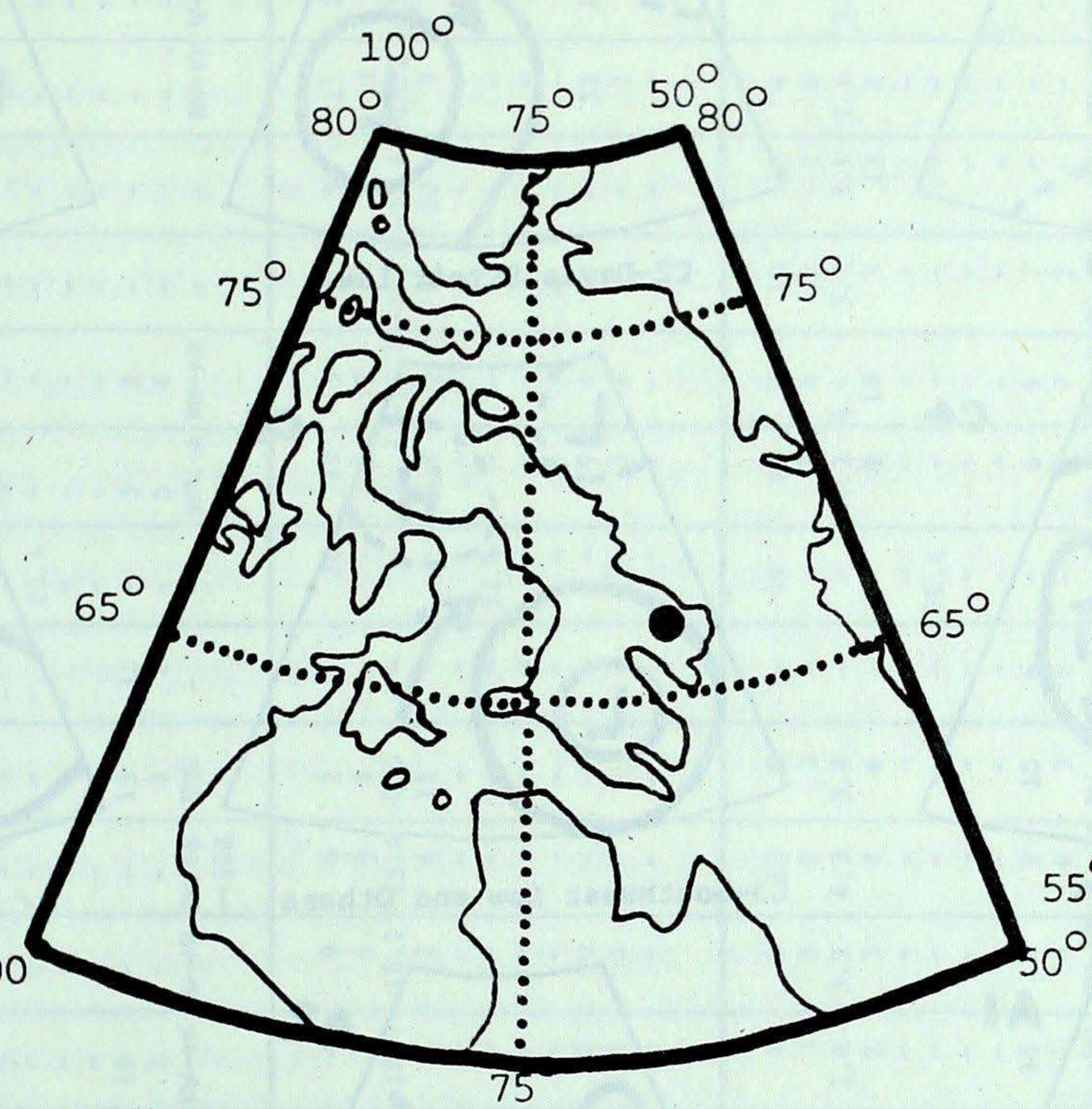


Figure 8A:

Area Covered By Synoptic Classification Scheme of Barry (1972)

● Auyuittuq National Park

Figure 8B:

Cyclonic and Anticyclonic Pressure Patterns Common to Baffin Island

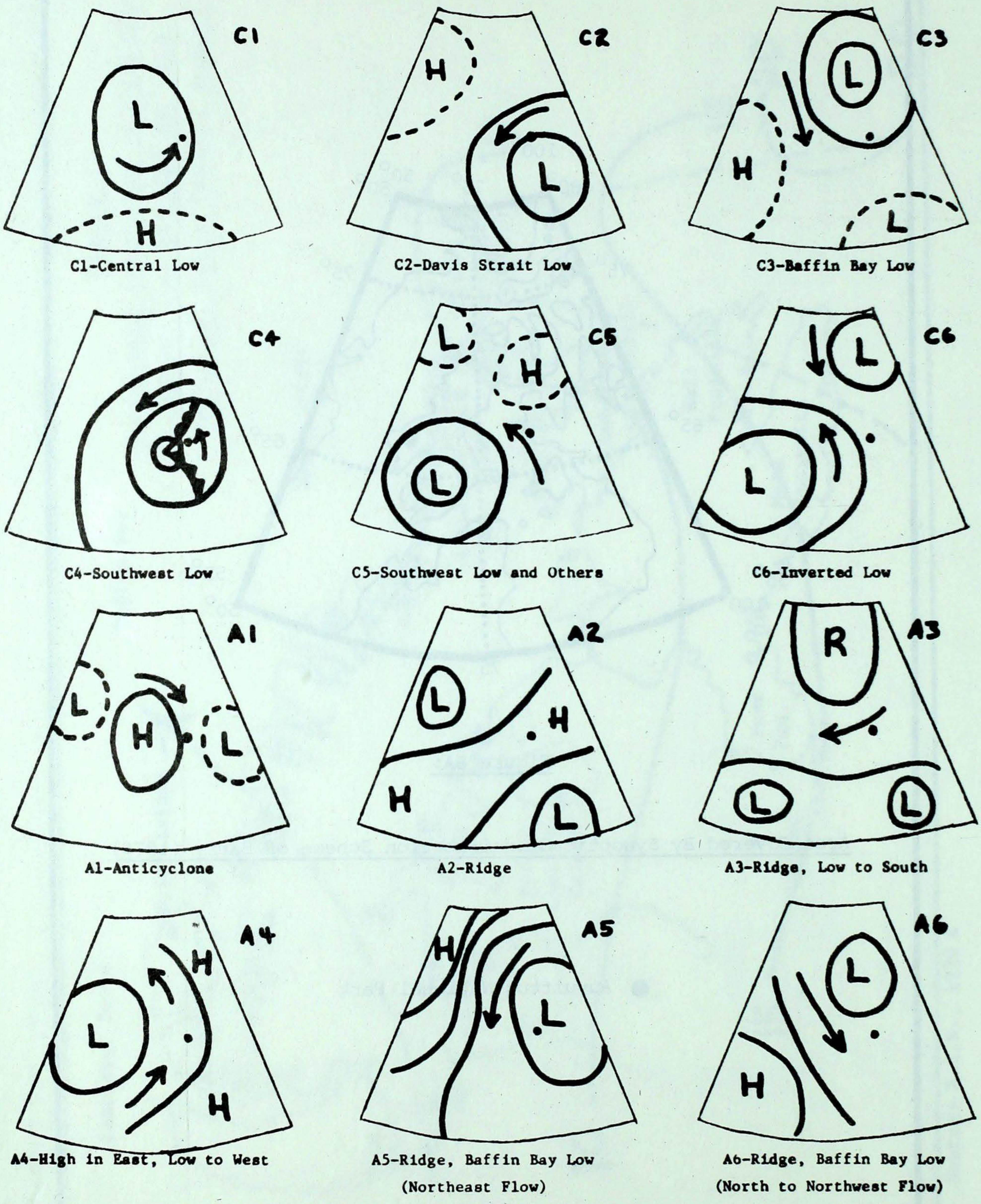


TABLE 3:

Characteristics of Pressure Patterns Common to Baffin Island

	Central Low C1	Davis St. Low C2	Baffin Bay Low C3	Southwest Low C4	Southwest Low and Others C5	Inverted Low C6	All C's	Anticyclone A1	Ridge A2	Ridge, Low to South A3	High in East, Low to West A4	Ridge, Baffin Bay Low, (NE Flow) A5	Ridge, Baffin Bay Low, (N NW Flow) A6	All A's	All C's & A's
January-February, 1961-1965															
Percentage Frequency of Occurrence	11	10	19	4	5	4	53	7	10	2	3	11	14	47	100
Occurrence Rank	3	4	1	7	6	7	-	5	4	9	8	3	2	-	-
Mean Temperature (°C)	-19.8	-25.4	-25.8	-23.3	-23.8	-13.1	-	-23.9	-25.7	-23.5	-19.9	-26.7	-27.1	-	-
Temperature Rank (Coldest 1 to Warmest 12)	11	5	3	9	7	12	-	6	4	8	10	2	1	-	-
Jan. & Feb. Precip. As Percentage of Total Annual Precip.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.4
Percentage of Jan. & Feb. Precip. From Cyclonic Patterns	-	-	-	-	-	-	83.4	-	-	-	-	-	-	-	-
Percentage of Jan. & Feb. Precip. Which Falls as Rain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Percentage of Jan. & Feb. Precip. Which Falls as Snow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Percentage Frequency of Jan. & Feb. Mean Precip.	18	18	-	-	13	32	-	5	8	-	-	-	-	-	-
Precipitation Frequency Rank	2	2	-	-	3	1	-	5	4	-	-	-	-	-	-
Dominant Wind Direction	NW→N →NE *	NW→N	NW→N	SW→S →SSE	NNW	-	-	NNW→ →N	NW→N	-	-	NW→N	W→N	-	-
* Northwest through North through Northeast															
April, 1961-1965															
Percentage Frequency of Occurrence	7	4	9	6	2	-	28	17	5	7	5	11	27	72	100
Occurrence Rank	5	8	4	6	9	-	-	2	7	5	7	3	1	-	-
Mean Temperature (°C)	-14.6	-18.7	-18.2	-15.4	-9.9	-	-	-14.1	-15.7	-16.3	-12.6	-13.2	-17.7	-	-
Temperature Rank (Coldest 1 to Warmest 12)	7	1	2	6	11	-	-	8	5	4	10	9	3	-	-
April Precipitation As Percentage of Total Annual Precip.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.8
Percentage of April Precip. From Cyclonic Patterns	-	-	-	-	-	-	52.6	-	-	-	-	-	-	-	-
Percentage of April Precip. Which Falls as Rain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Percentage of April Precip. Which Falls as Snow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Percentage Frequency of April Mean Precipitation	30	10	10	-	-	-	-	9	4	-	-	19	16	-	-
Precipitation Frequency Rank	1	4	4	-	-	-	-	5	6	-	-	2	3	-	-
Dominant Wind Direction	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
July-August, 1961-1965															
Percentage Frequency of Occurrence	16	9	5	10	9	-	49	10	8	10	10	4	9	51	100
Occurrence Rank	1	3	5	2	3	-	-	2	4	2	2	6	3	-	-
Mean Temperature (°C)	3.9	1.6	3.2	4.3	3.8	-	-	4.3	4.4	3.7	7.1	2.4	3.4	-	-
Temperature Rank (Coldest 1 to Warmest 12)	7	1	3	8	6	-	-	9	10	5	11	2	4	-	-
July-Aug. Precip. As Percentage of Total Annual Precip.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Percentage of July-Aug. Precip. From Cyclonic Patterns	-	-	-	-	-	-	78.4	-	-	-	-	-	-	-	-
Percentage of July-Aug. Precip. Which Falls as Rain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	62.5
Percentage of July-Aug. Precip. Which Falls as Snow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37.5
Percentage Frequency of July-Aug. Mean Precip.	38	15	-	9	10	6	-	6	4	7	-	-	-	-	-
Precipitation Frequency Rank	1	2	-	4	3	6	-	6	7	5	-	-	-	-	-
Dominant Wind Direction	S→SE→ →E	W→NW →N	NW→N	S→SE →E	NW→N S→SE →E	None	-	NW→N	NW→N	NW→N →NNE	S→SE →E	NW→N	NW→N	-	-
September-October, 1961-1965															
Percentage Frequency of Occurrence	15	14	13	6	9	-	57	8	6	3	7	5	14	43	100
Occurrence Rank	1	2	3	7	4	-	-	5	7	9	6	8	2	-	-
Mean Temperature (°C)	-2.8	-6.1	-5.6	-5.4	-5.2	-	-	-6.1	-6.8	-5.1	-4.3	-6.9	-8.5	-	-
Temperature Rank (Coldest 1 to Warmest 12)	11	5	6	7	8	-	-	4	3	9	10	2	1	-	-
Sept.-Oct. Precip. As Percentage of Total Annual Precip.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39.5
Percentage of Sept.-Oct. Precip. From Cyclonic Patterns	-	-	-	-	-	-	53.9	-	-	-	-	-	-	-	-
Percentage of Sept.-Oct. Precip. Which Falls as Rain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Percentage of Sept.-Oct. Precip. Which Falls as Snow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	97
Percentage Frequency of Sept.-Oct. Mean Precip.	12	13	18	-	9	-	-	4	12	5	4	-	16	-	-
Precipitation Frequency	4	3	1	-	5	-	-	7	4	6	7	-	2	-	-
Dominant Wind Direction	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

For example, during January and February from 1961 through 1965, the synoptic pattern producing the greatest amount of precipitation (C6 - an inverted low pressure system) occurred only 4% of the time while producing 32% of the precipitation. However, these two months are responsible for only 6.4% of the total annual precipitation. The table further denotes that of the most frequent pressure patterns influencing the Park region, the C6 cyclonic pattern is the warmest (an average temperature of $-13.1^{\circ}C$), and that there is no predominant wind direction because of the high frequency of calm conditions. Table 3 also contains information for the months of April, July and August, and September and October. Such data should assist Park visitors and personnel alike to anticipate possible weather conditions over a few weeks and plan accordingly. The percentages and other figures should in no way be construed as probabilities. There are too few data. However, they do suggest indications.

The spring season is the only time of the year when high pressure systems are significant to the climate of the Cumberland Peninsula, and these bring clear, cold, dry weather. During April there tends to be on the average a high pressure area to the west of Baffin Island. This means, of course, there is a lesser frequency of depressions bringing precipitation and cloud. While the percentage of precipitation originating from anticyclonic systems is much greater during April than in January and February, the absolute quantities remain relatively small. Dominant wind direction data were not determined by Bradley for April.

During the summer season, the paths followed by the low pressure centres are displaced well north of their winter routes. Although pressures have generally decreased in the Arctic areas they remain the same over the Park (Figure 5). The circulation is dominated by low pressure systems over Hudson Strait and a trough of low pressure extends northward. From June through September there is a sudden reduction in the frequency and intensity of the polar high pressure systems, and an increase in low pressure activity. From Alaska, the Mackenzie lowland, and the Beaufort Sea regions, many low pressure centres bring relatively warm and humid air (thick cloud and rain, at least in lower areas).

More than 50% of the precipitation of July and August results from C1 and C2 patterns which are accompanied most frequently by south to east and west to north winds respectively. Low cloud or sea fog occurs frequently (see Table 2). During the warmer hours of most summer days, convection and cumulus cloud formation occur inland. Low pressure centres moving northward towards Baffin Bay would seem to be a major source of moisture for at least the southern and eastern parts of Baffin Island.

Autumn is a brief transitional season. Wind speeds increase and at the time of freeze-up, extensive cloud and light snow occur regularly. The mean storm tracks move southward, and the approach of low pressure centres from the south becomes more significant to the daily weather of the Park region particularly as they deepen and become more vigorous. Almost 40% of the total annual precipitation occurs during September and October with just over half of that resulting from cyclonic disturbances. The warmest temperatures, however, are associated with certain anticyclonic pressure systems.

V. Pure and Applied Elements

A. Temperature

a) Daily Mean Temperature

Considered here is the temperature of the air measured at 1.2 m above the surface in a white louvred shelter.

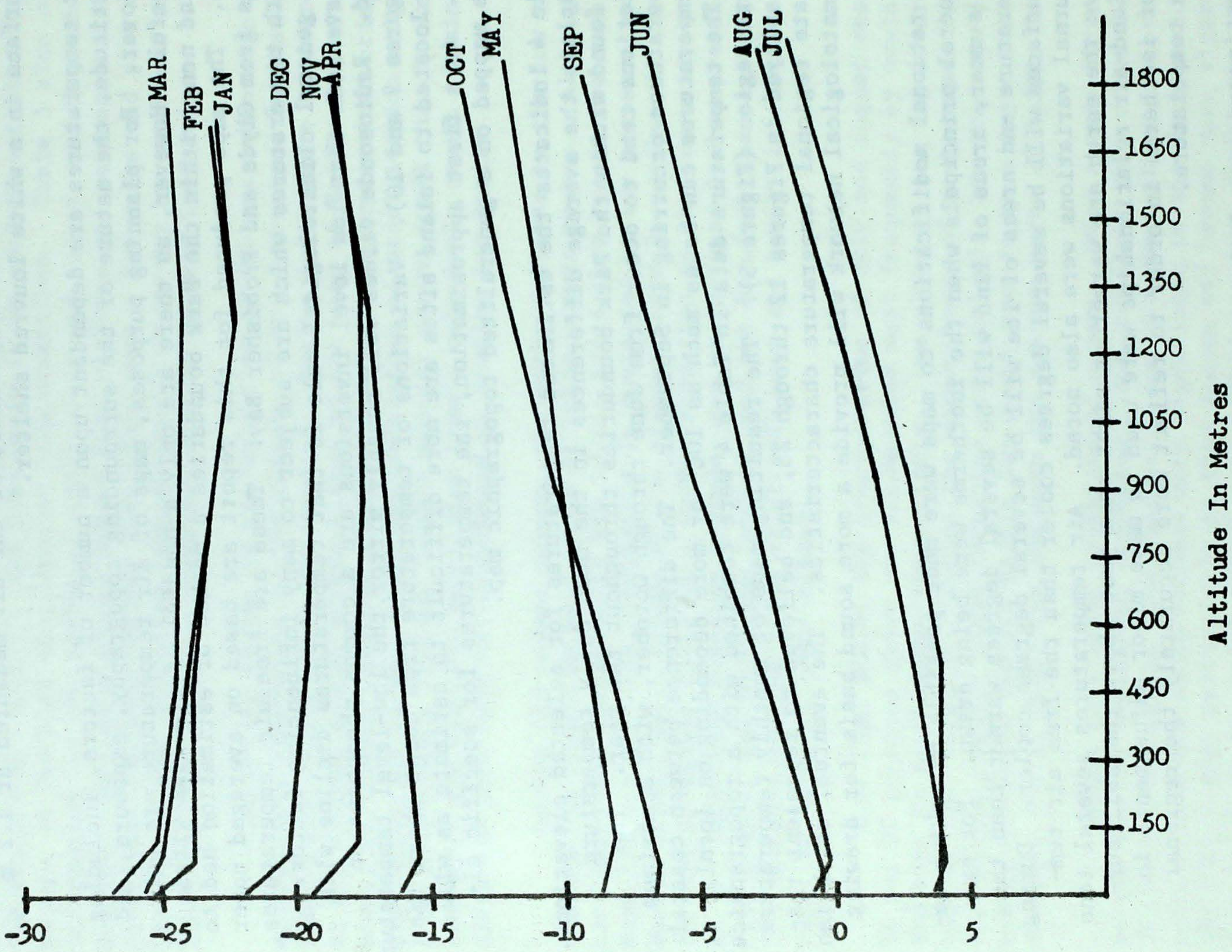
Air temperatures are dependent upon a number of factors, including latitude, altitude, the nature of the surrounding topography, exposure, and vegetative cover. For planning purposes, maps of air temperature are particularly useful. However, as there are only a handful of stations within the region and none within the Park boundaries a method of estimation had to be developed. The maps produced for this report are based on averaged upper air soundings from Clyde and Frobisher Bay. These are free air temperatures, not near-earth temperatures which are subject to many influencing factors. Although the general climatological rule is that temperatures decline with height, we have seen that low level inversions are a common phenomena on Baffin Island. Radiosonde values will roughly mirror the low-level temperature gradient (Figures 9 and 10). Variations of temperature from coast where the stations are located to inland sites are more difficult to estimate as will be discussed. As a first approximation, the temperatures for specific elevations were mapped on a generalized topographic map.

Table 4 indicates the estimated temperatures for selected elevations. Figure 11 displays the average differences in the mean daily temperature likely to be found within the Park boundaries throughout the year. The greatest variations tend to occur from June through October, with a maximum range of temperatures occurring in September. The difference between coastal and inland temperatures can be as much as 10C^{o} or more depending on local conditions. The temperature data in Table 4 were combined with a topographical map of the Park region (Figure 3). The resulting maps of monthly temperature trends are displayed in Figures 12 through 23, and believed to represent reasonably accurate regional temperature characteristics. The eventual establishment of a climatological network will provide a more sound basis for drawing maps.

Some rational modifications to maps were made possible by making reference to general principals when the isotherms were being drawn. For example, in the summer, areas of land will be several degrees warmer than the free air temperature and areas of ice will be several degrees cooler. During winter, all surfaces will be several degrees cooler than the free air temperature. Diurnal variations were also noted. Air temperatures several tens of metres above the earth are warmer at night than just above the soil surface. These land-air relationships were used to make minor adjustments in the location of isotherms in order to reflect more accurately the regional differences in temperature.

The estimated mean daily temperatures do correspond reasonably well with the limited, short-term data that does exist for areas inside the Park. For example, Orvig (1955) established a station at an elevation of 2050 m. (65^{o}59'N and 65^{o}28'W) on the Penny Ice Cap. A comparison of estimated long-

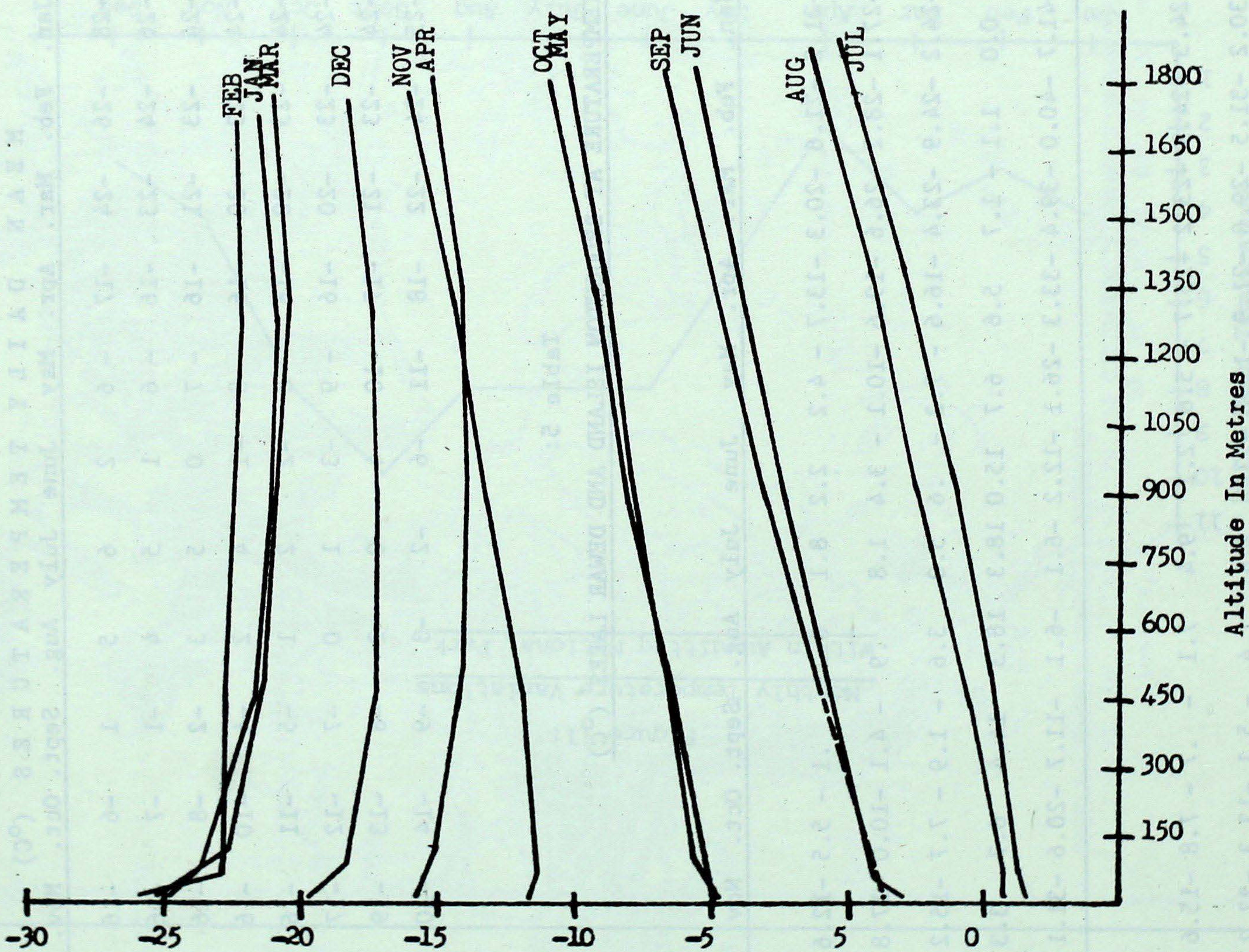
Figure 9: Free Atmospheric Temperature Variation With Altitude at Clyde



Based on 1961-1970 data

Source: Titus, 1973

Figure 10: Free Atmospheric Temperature Variation With Altitude at Frobisher Bay



Based on 1961-1970 data

Source: Titus, 1973

Table 4:

ESTIMATED TEMPERATURE VARIATIONS WITH ELEVATION

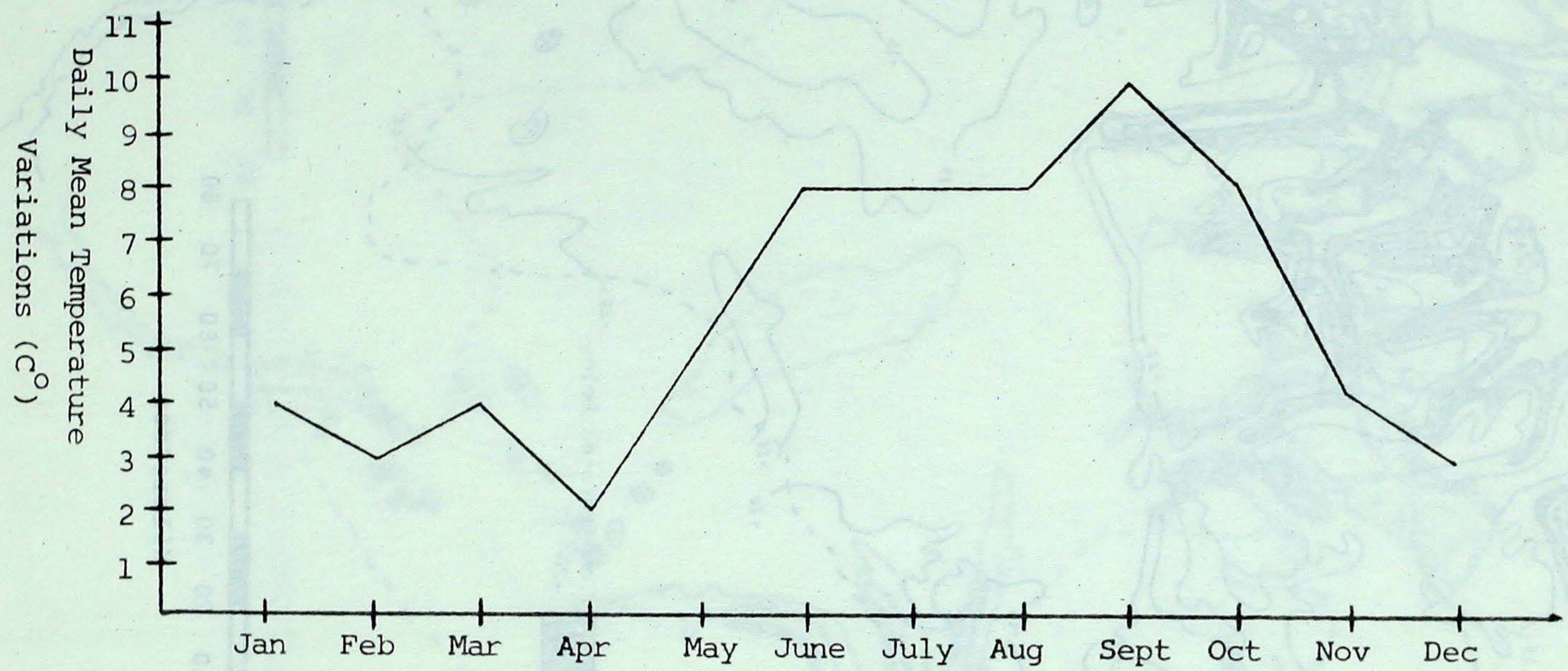
Elev. (m)	MEAN DAILY TEMPERATURES (^oC) Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Surface	-28	-26	-24	-17	- 6	2	6	5	1	-6	-16	-24
300	-26	-24	-23	-16	- 6	1	5	4	-1	-7	-16	-22
600	-24	-23	-21	-16	- 7	0	5	3	-2	-8	-16	-21
900	-24	-23	-20	-16	- 8	-1	4	2	-4	-10	-16	-21
1200	-24	-23	-20	-16	- 8	-2	2	1	-5	-11	-16	-21
1500	-24	-23	-20	-16	- 9	-3	1	0	-7	-12	-17	-22
1800	-24	-23	-21	-17	-10	-4	0	-2	-8	-13	-19	-22
2100	-25	-24	-22	-18	-11	-6	-2	-3	-9	-14	-20	-23

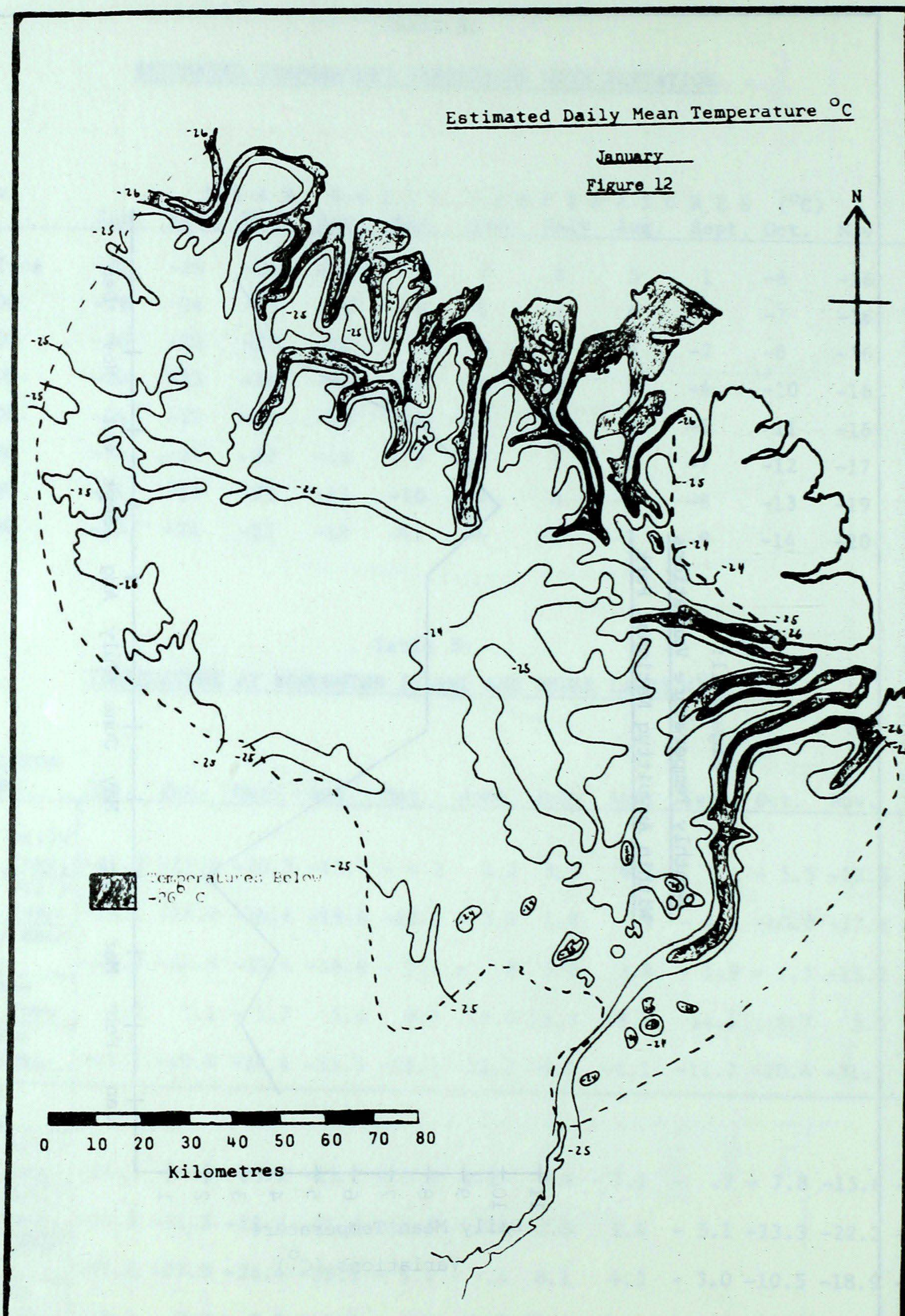
Table 5:

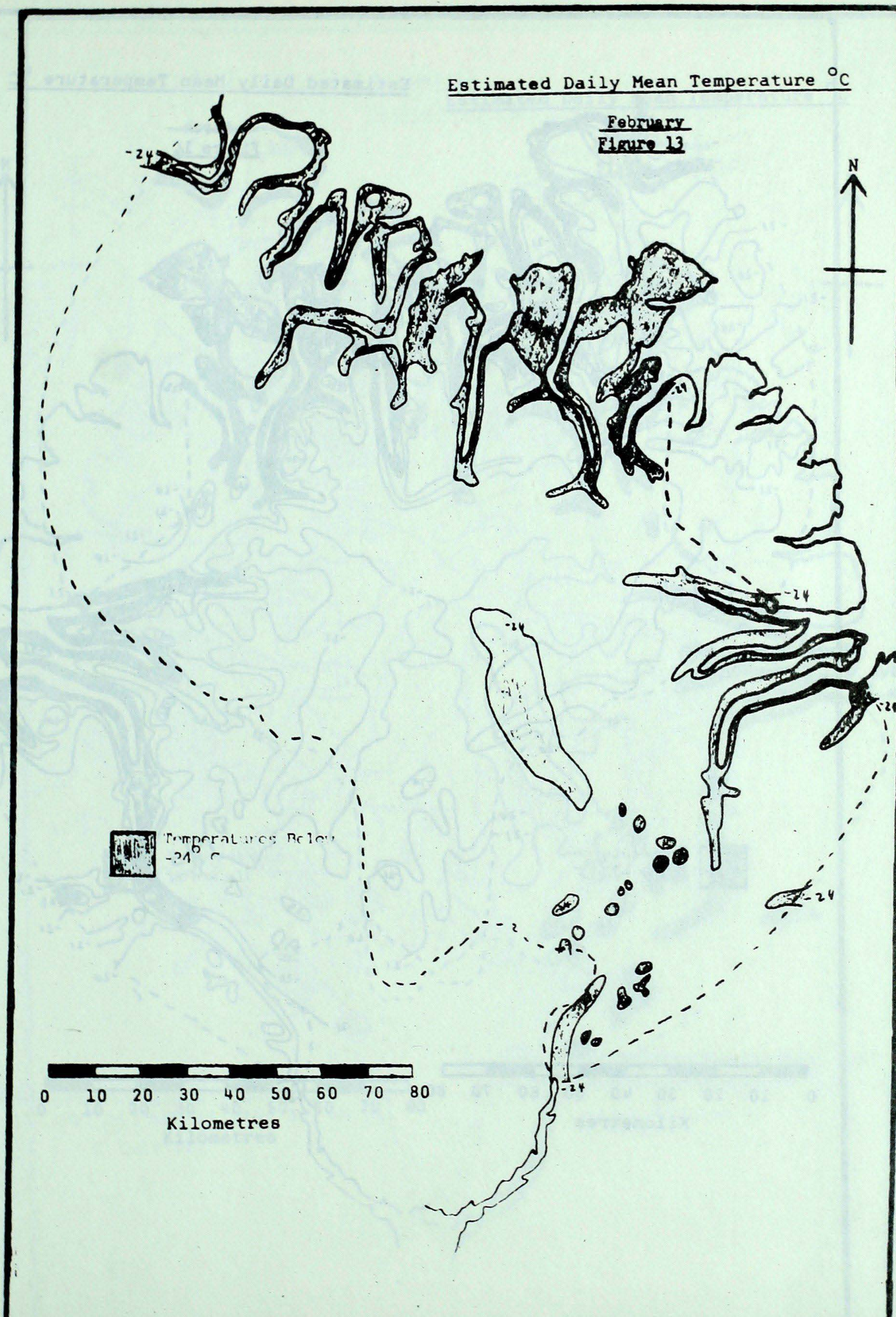
TEMPERATURE AT BROUGHTON ISLAND AND DEWAR LAKES (^oC)

BROUGHTON ISLAND	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Daily Max. Temp.	-21.2	-21.6	-20.3	-13.7	- 4.2	2.2	8.1	6.2	.1	- 5.5	-12.6	-18.5
Mean Daily Min. Temp.	-27.1	-28.2	-26.6	-19.6	-10.1	- 3.4	1.8	.9	- 4.1	-10.0	-17.8	-24.1
Daily Mean Temp.	-24.2	-24.9	-23.4	-16.6	- 7.2	- .6	5.0	3.6	- 1.9	- 7.7	-15.2	-21.3
Extreme Max. Temp.	0.0	1.1	- 1.7	5.6	6.7	15.0	18.3	18.3	14.4	6.7	3.3	5.0
Extreme Min Temp.	-41.7	-40.0	-39.4	-33.3	-26.1	-12.2	-6.1	-6.1	-11.7	-20.6	-31.1	-37.2
DEWAR LAKES												
Mean Daily Max. Temp.	-24.3	-24.3	-23.2	-15.7	- 5.6	2.2	9.4	7.1	- .7	- 7.8	-15.6	-21.7
Mean Daily Min. Temp.	-30.2	-31.5	-29.6	-21.9	-11.2	- 3.1	2.8	1.4	- 5.1	-13.3	-22.2	-27.3
Daily Mean Temp.	-27.2	-27.9	-26.4	-18.8	- 8.4	- .4	6.1	4.3	- 3.0	-10.5	-18.9	-24.5
Extreme Max. Temp.	- 3.3	0.0	- 3.3	- 1.1	6.1	11.7	20.0	20.6	11.1	3.3	- .6	.6
Extreme Min. Temp.	-46.7	-45.6	-48.3	-38.9	-29.4	-17.2	-3.3	-7.2	-17.2	-30.0	-40.6	-45.0

Figure 11:
Monthly Temperature Variations
Within Auyuittuq National Park



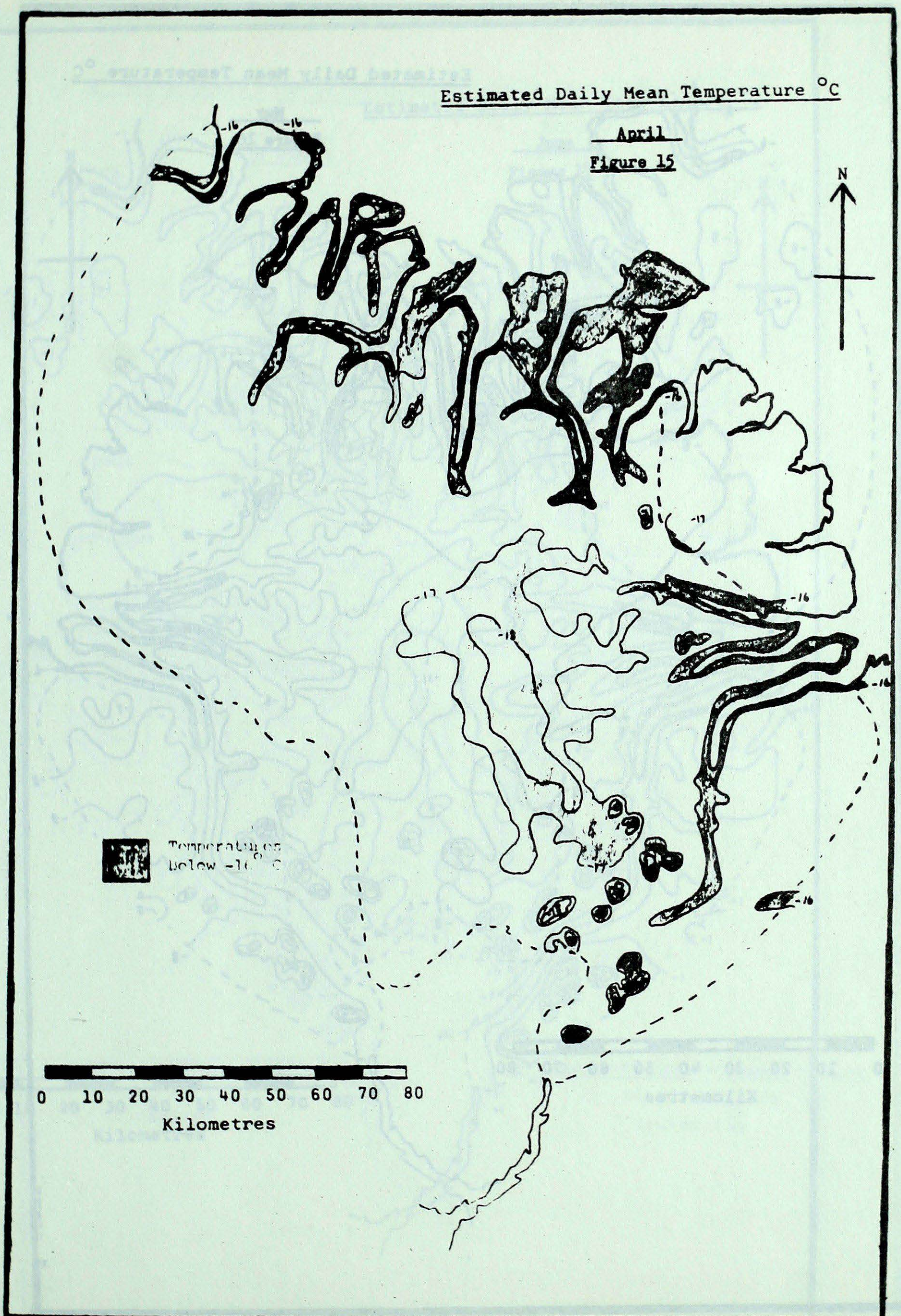

Estimated Daily Mean Temperature °C
January
Figure 12
N
Temperatures Below
-26° C
0 10 20 30 40 50 60 70 80
Kilometres

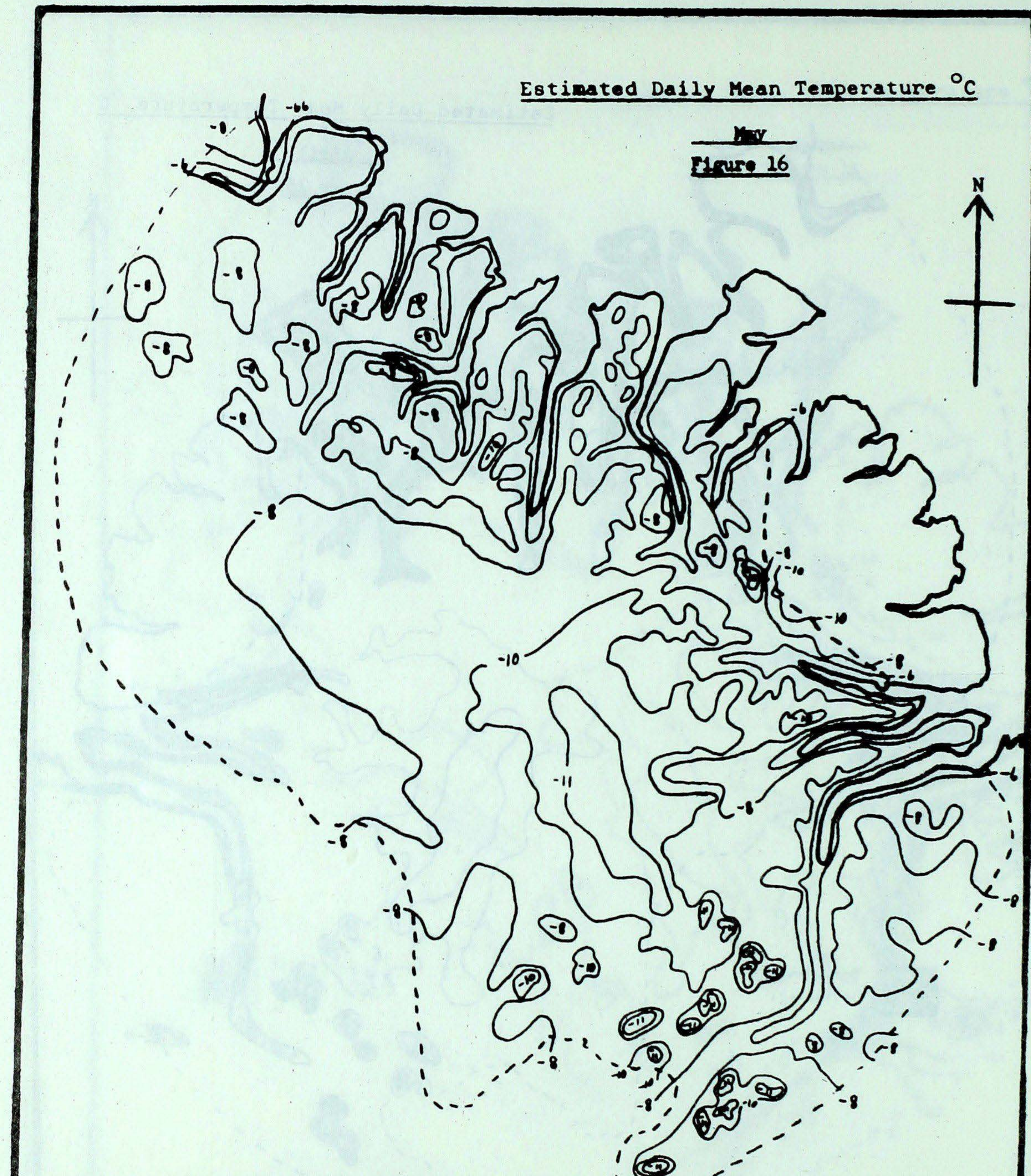

Estimated Daily Mean Temperature °C
February
Figure 13
N
Temperatures Below -24° C
-24
0 10 20 30 40 50 60 70 80
Kilometres

Estimated Daily Mean Temperature °C

~~March~~

Figure 14

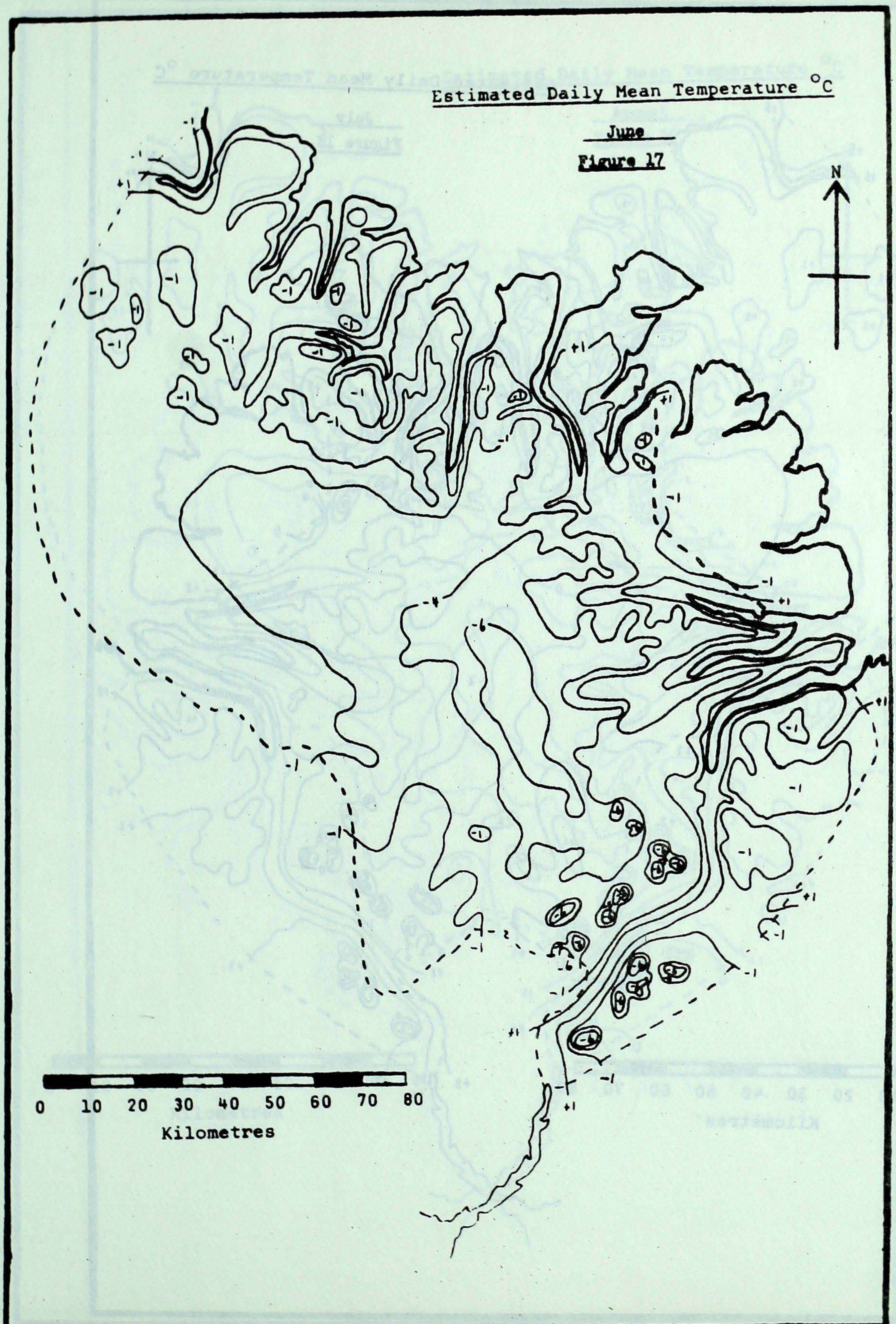

Estimated Daily Mean Temperature °C
April
Figure 15
N
-16
-17
-18
Temperatures Below -16 °C
0 10 20 30 40 50 60 70 80
Kilometres

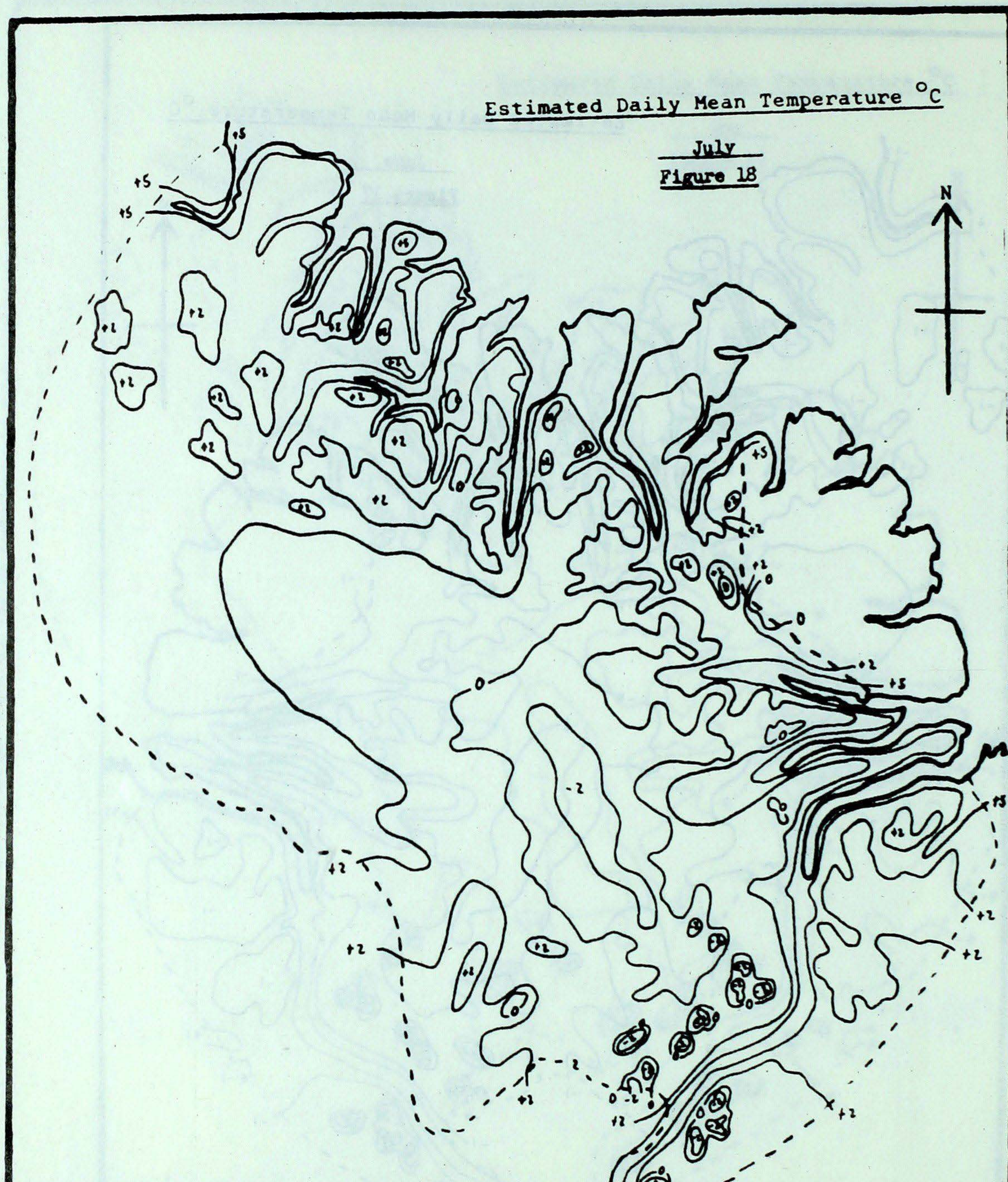


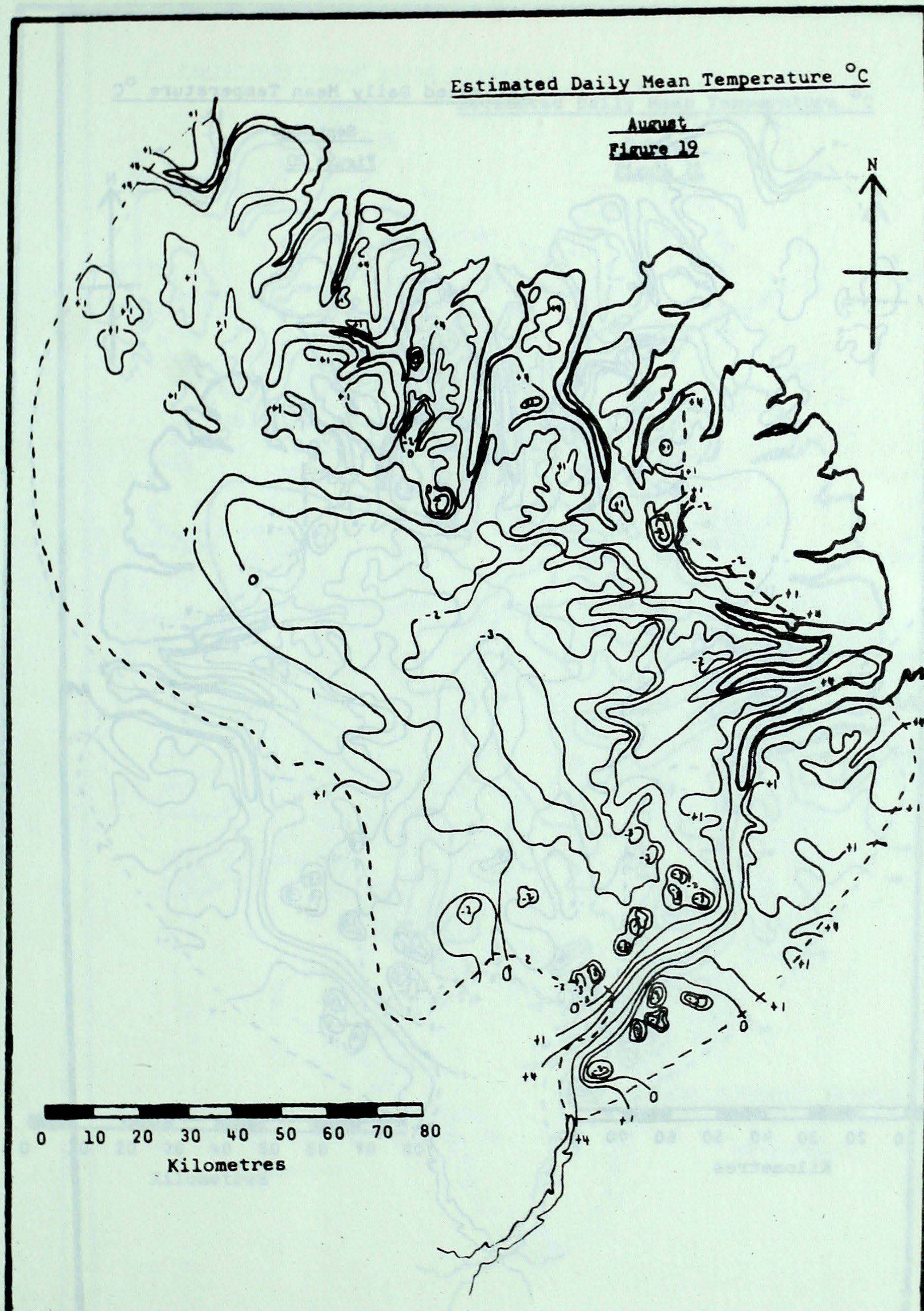
Estimated Daily Mean Temperature °C

May

Figure 16


Estimated Daily Mean Temperature °C
June
Figure 17
N
0 10 20 30 40 50 60 70 80
Kilometres

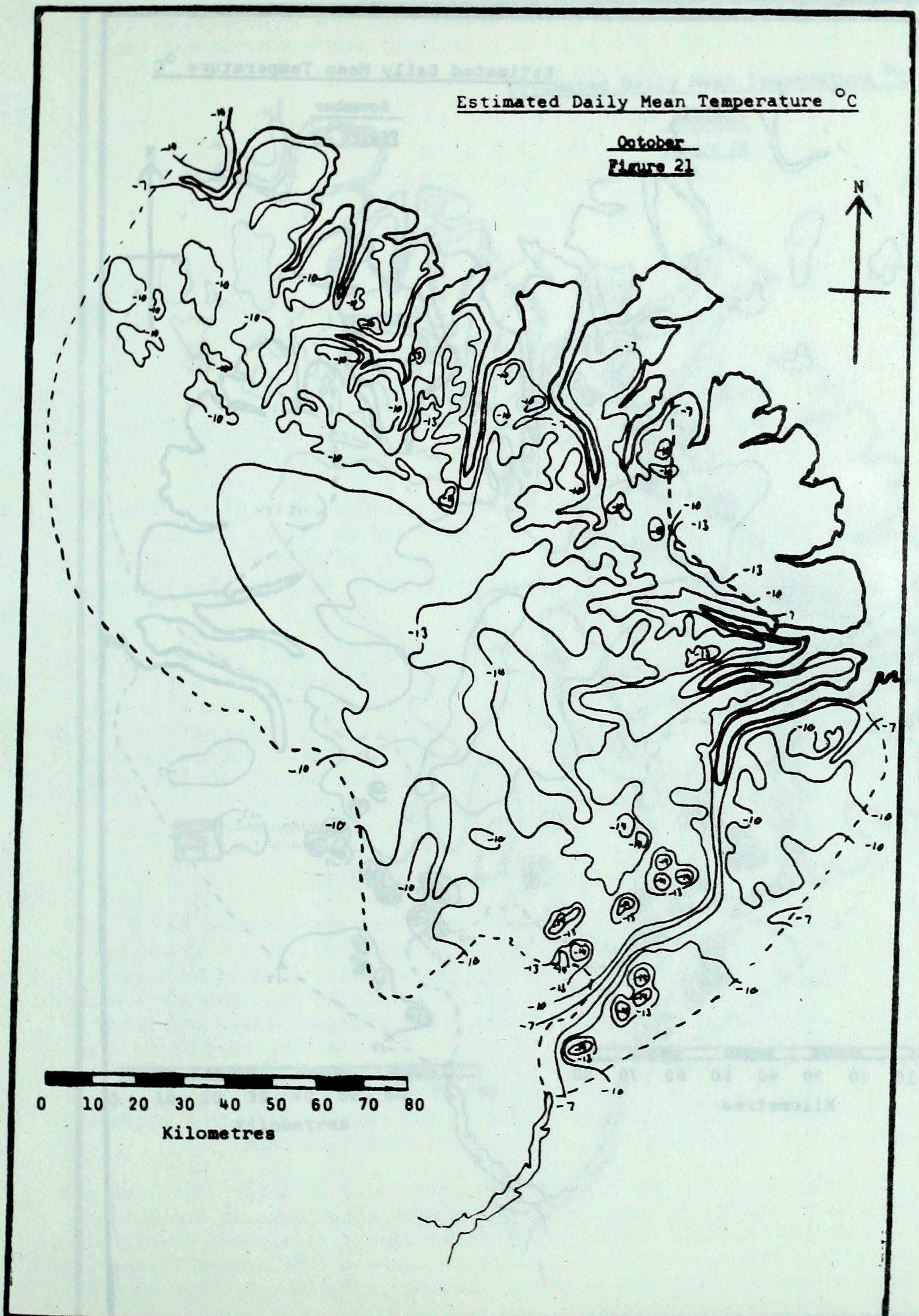

Estimated Daily Mean Temperature °C
July
Figure 18
N
0 10 20 30 40 50 60 70 80
Kilometres

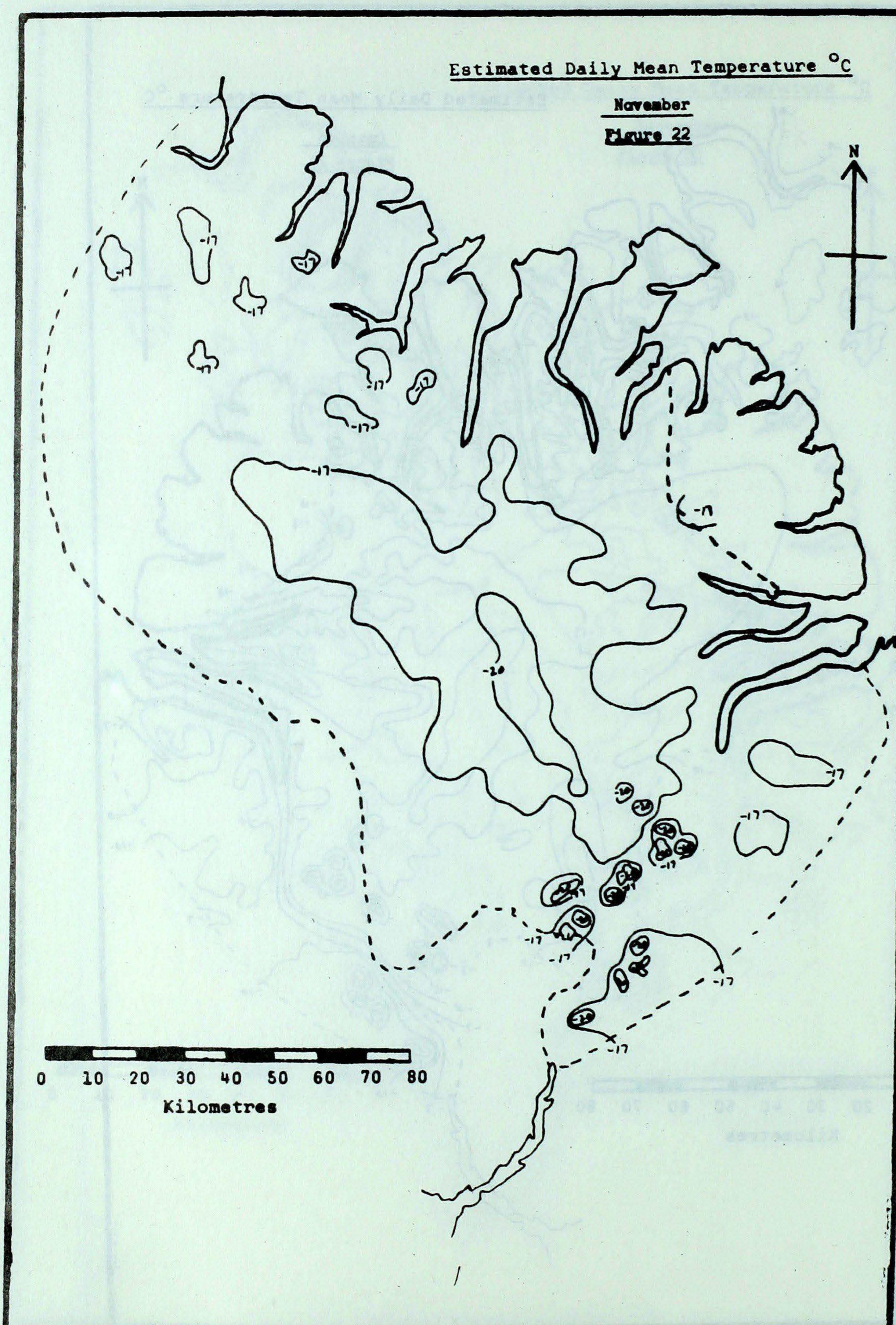

Estimated Daily Mean Temperature °C
August
Figure 19
N
0 10 20 30 40 50 60 70 80
Kilometres

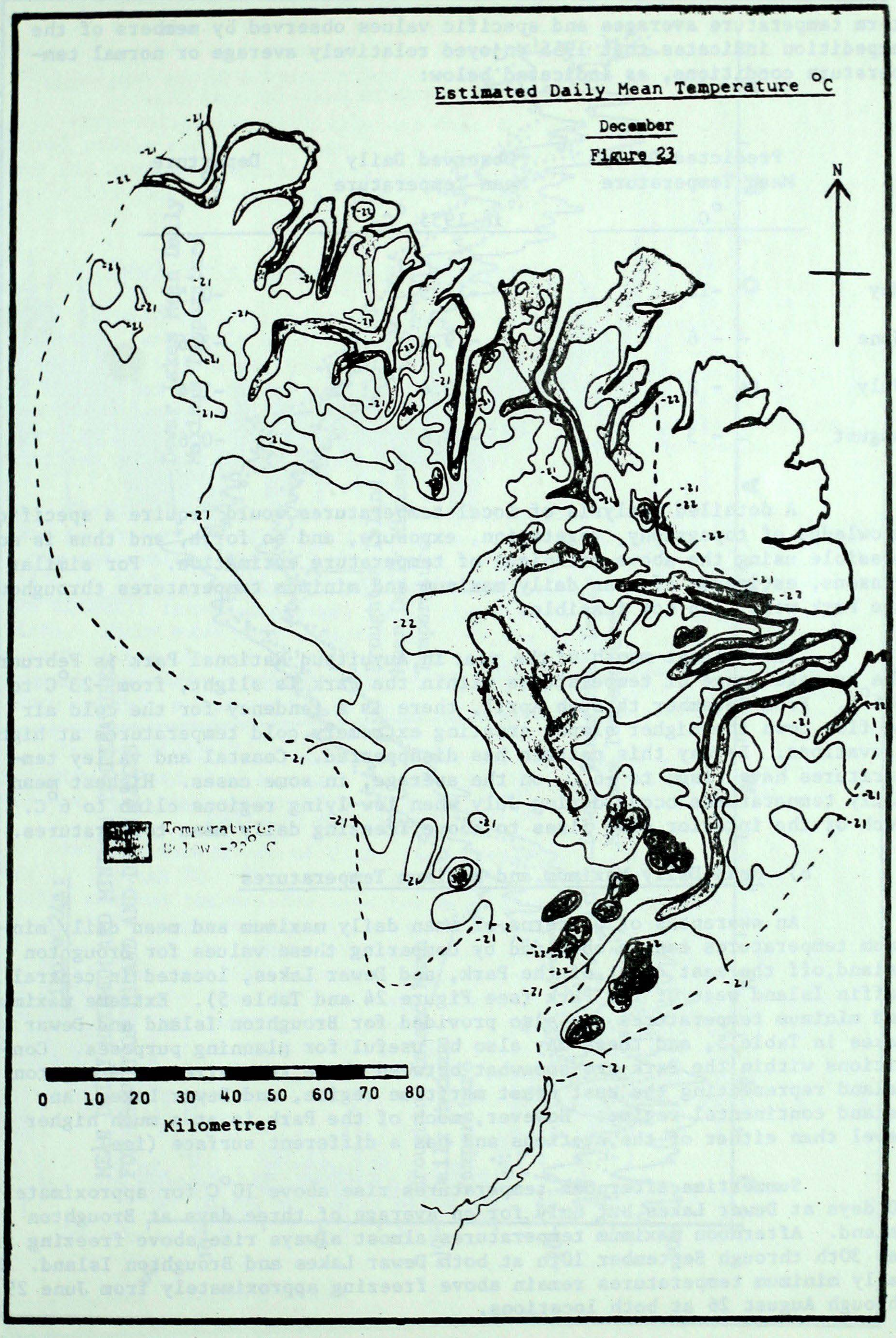
Estimated Daily Mean Temperature °C

September

Figure 20


Estimated Daily Mean Temperature °C
October
Figure 21
N
0 10 20 30 40 50 60 70 80
Kilometres


Estimated Daily Mean Temperature °C
November
Figure 22
N
-17
-20
0 10 20 30 40 50 60 70 80
Kilometres


Estimated Daily Mean Temperature °C
December
Figure 23
N
Temperatures
Below -22° C
0 10 20 30 40 50 60 70 80
Kilometres
-21
-22

term temperature averages and specific values observed by members of the expedition indicates that 1955 enjoyed relatively average or normal temperature conditions, as indicated below:

	Predicted Daily Mean Temperature °C	Observed Daily Mean Temperature in 1955 °C	Departure C°
May	-11	-11.5	-0.5
June	- 6	- 9.6	-3.6
July	- 2	- 3.4	-1.4
August	- 3	- 3.6	-0.6

A detailed analysis of local temperatures would require a specific knowledge of topography, vegetation, exposure, and so forth, and thus is not possible using the above technique of temperature estimation. For similar reasons, estimates of mean daily maximum and minimum temperatures throughout the Park were also not feasible.

The coldest month of the year in Auyuittuq National Park is February. The average range of temperatures within the Park is slight, from -23°C to -26°C. From December through April, there is a tendency for the cold air to flow down the higher slopes creating extremely cold temperatures at higher elevations. By May this pattern has disappeared. Coastal and valley temperatures have risen to -6°C, on the average, in some cases. Highest mean daily temperatures occur during July when low-lying regions climb to 6°C. Much of the interior also rises to above freezing daily mean temperatures.

b) <u>Mean Daily Maximum and Minimum Temperatures</u>

An awareness of patterns of mean daily maximum and mean daily minimum temperatures can be obtained by comparing these values for Broughton Island, off the east coast of the Park, and Dewar Lakes, located in central Baffin Island west of the Park (see Figure 24 and Table 5). Extreme maximum and minimum temperatures are also provided for Broughton Island and Dewar Lakes in Table 5, and these may also be useful for planning purposes. Conditions within the Park are somewhat between these two extremes, Broughton Island representing the east coast maritime regime, and Dewar Lakes, an island continental regime. However, much of the Park is at a much higher level than either of the stations and has a different surface (ice).

Summertime afternoon temperatures rise above 10°C for approximately 10 days at Dewar Lakes but only for an average of three days at Broughton Island. Afternoon maximum temperatures almost always rise above freezing from May 30th through September 10th at both Dewar Lakes and Broughton Island. Mean daily minimum temperatures remain above freezing approximately from June 29 through August 26 at both locations.

Figure 24a:

MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURES
FOR BROUGHTON ISLAND AND DEWAR LAKES

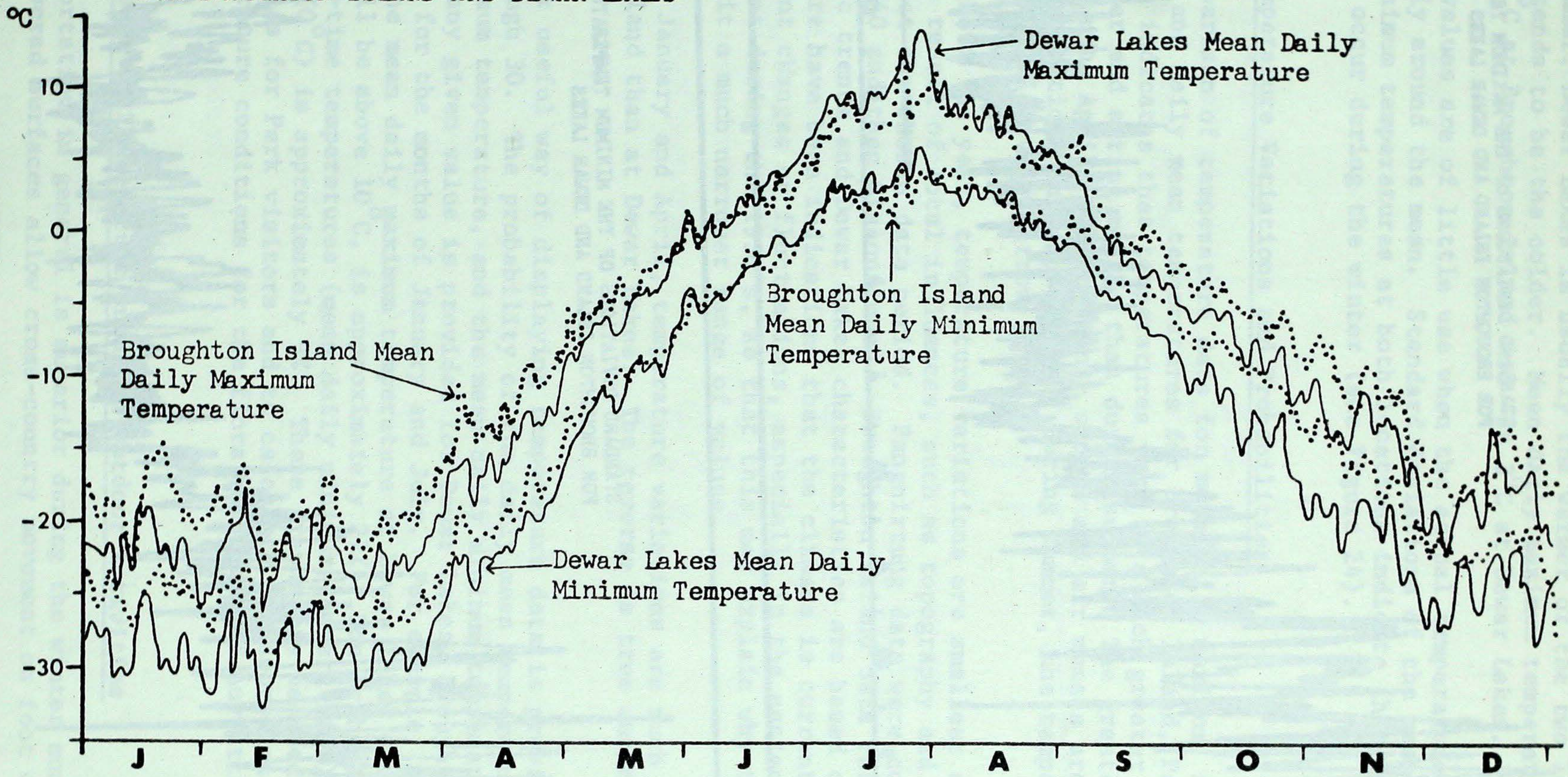
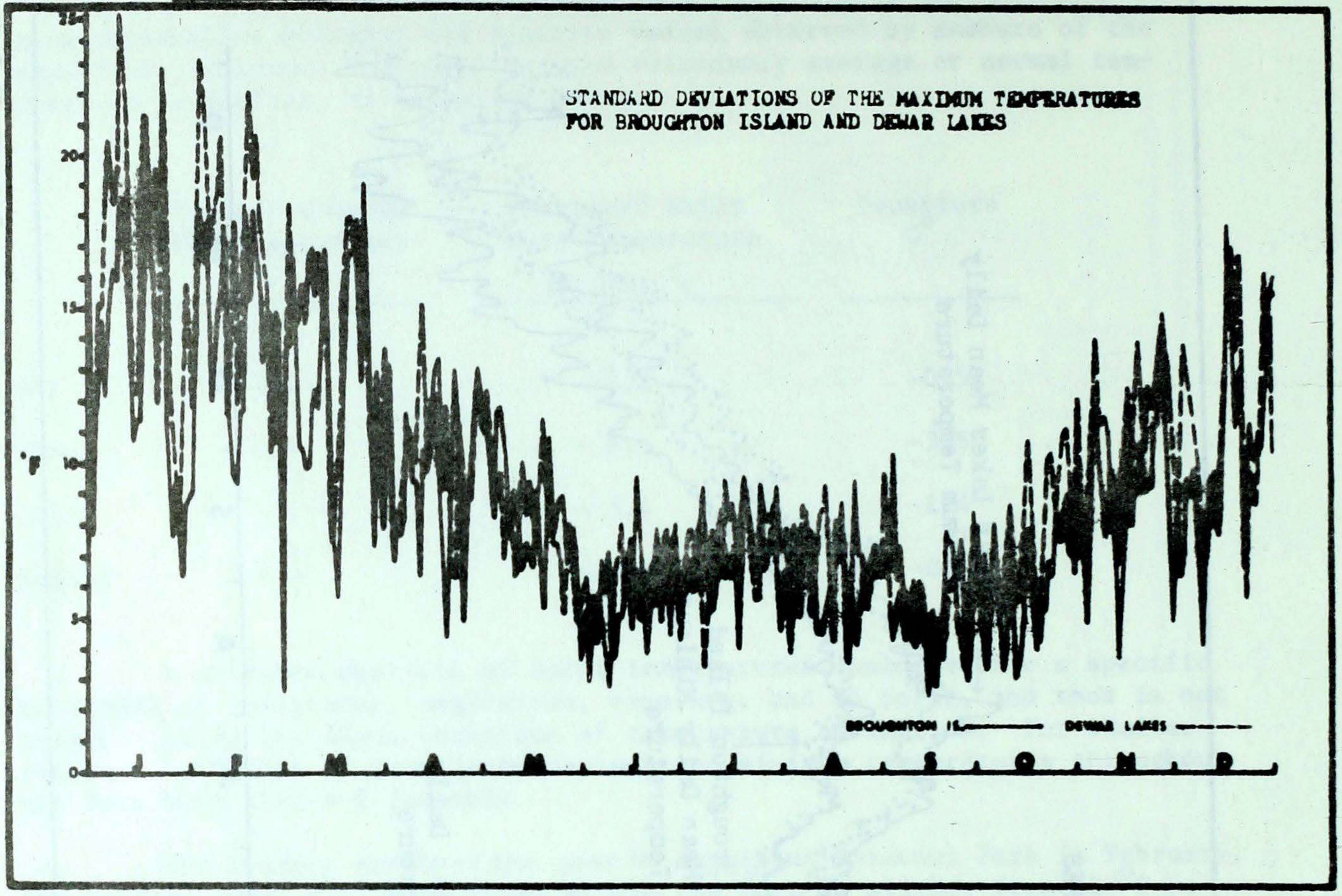
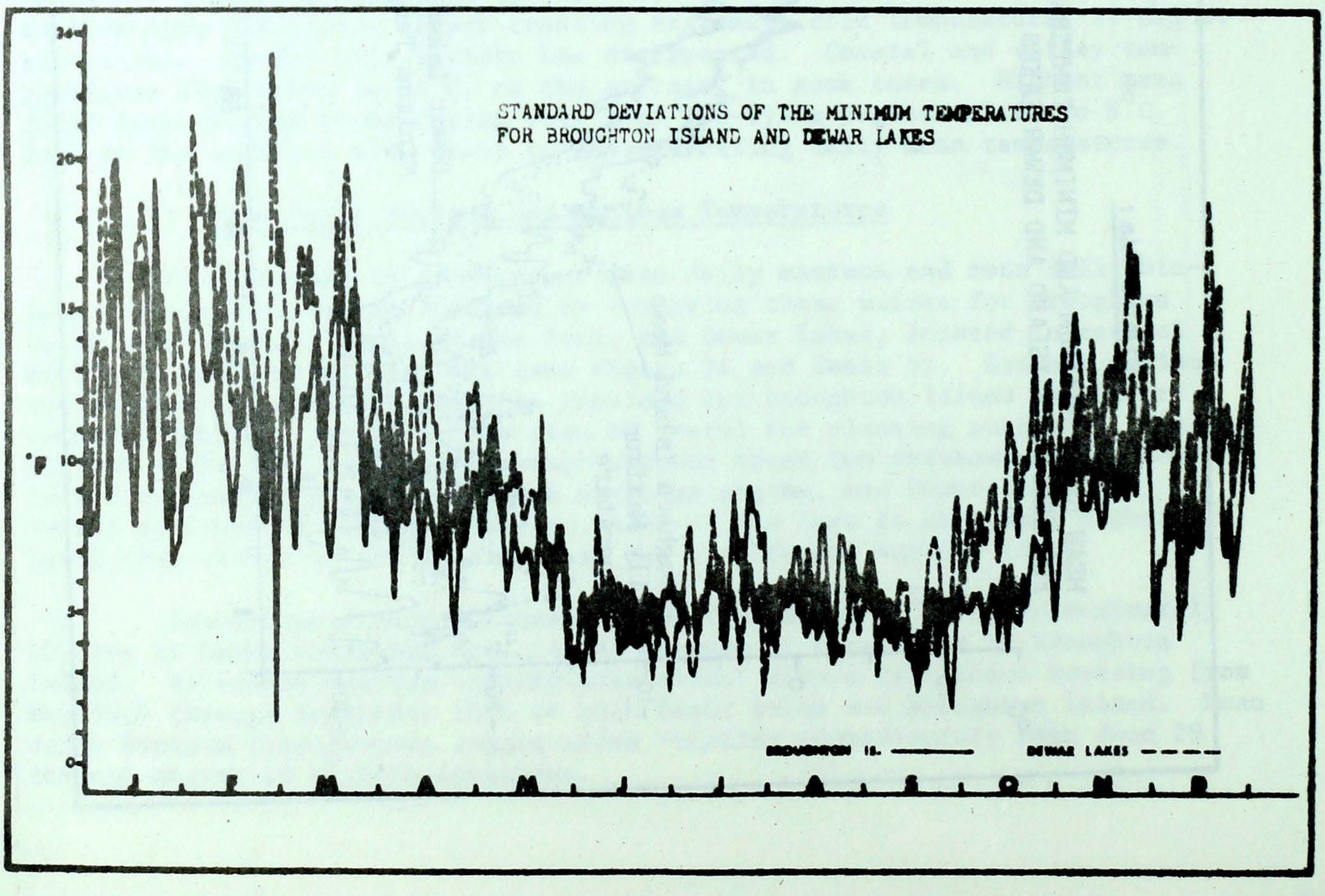


Figure 24b:
Standard Deviations of the Mean Daily Maximum and Minimum Temperatures for Broughton Island and Dewar Lakes





In summer, Dewar Lakes is usually the warmer of the two locations. In winter, it tends to be the colder. Mean daily maximum temperatures average only -21.6°C at Broughton Island and -24.3°C at Dewar Lakes.

Mean values are of little use when the actual temperatures are scattered widely around the mean. Standard deviations of the mean daily maximum and minimum temperatures at both locations indicate that the greatest variations occur during the winter (see Figure 24).

c) Temperature Variations and Probabilities

A comparison of temperature data for mean daily maximum, mean daily minimum, and daily mean temperatures for Broughton Island, Pangnirtung, and Dewar Lakes indicates that temperatures vary to a much greater extent during the winter and spring months than during summer. The greatest differences occur during April, when cyclonic storms and air masses are migrating, causing wide fluctuations in temperature. During summer, the temperatures are confined to a relatively narrow range.

Throughout the year, temperature variations are smallest at Pangnirtung. This may be the result of local influences, such as topography and exposure or it may reflect the chosen data period. Pangnirtung data were collected from 1931 to 1940 and then discontinued. Broughton Island data reflect 1959 to 1974 climatic trends and Dewar Lakes characteristics are based on 1960 - 1974 data. There have been indications that the climate is currently undergoing significant changes or fluctuations, especially in the eastern Arctic. These were absent during the 1930's, so that this may explain why the Pangnirtung data exhibit a much narrower range of values.

During January and April, temperature variations are much greater at Broughton Island than at Dewar Lakes. The reverse is true during July and October.

Another useful way of displaying temperature data is provided in Figures 25 through 30. The probability of the daily mean temperature, the mean daily maximum temperature, and the mean daily minimum temperature being above or below any given value is provided for Dewar Lakes, Broughton Island, and Pangnirtung for the months of January and July. For example, the probability that the mean daily maximum temperature at Dewar Lakes during July (Figure 26B) will be above 10°C, is approximately 27%. The probability or risk that night-time temperatures (mean daily minimum temperatures) will be below freezing (0°C) is approximately 9%. These graphs may be used to plan outdoor activities for Park visitors and to calculate the approximate chance of severe temperature conditions for the flora and fauna of Auyuittuq National Park.

d) Effects of Temperature on Human Outdoor Activities

Transportation in general is superior during the winter months when snow and ice-covered surfaces allow cross-country movement on foot or snow-

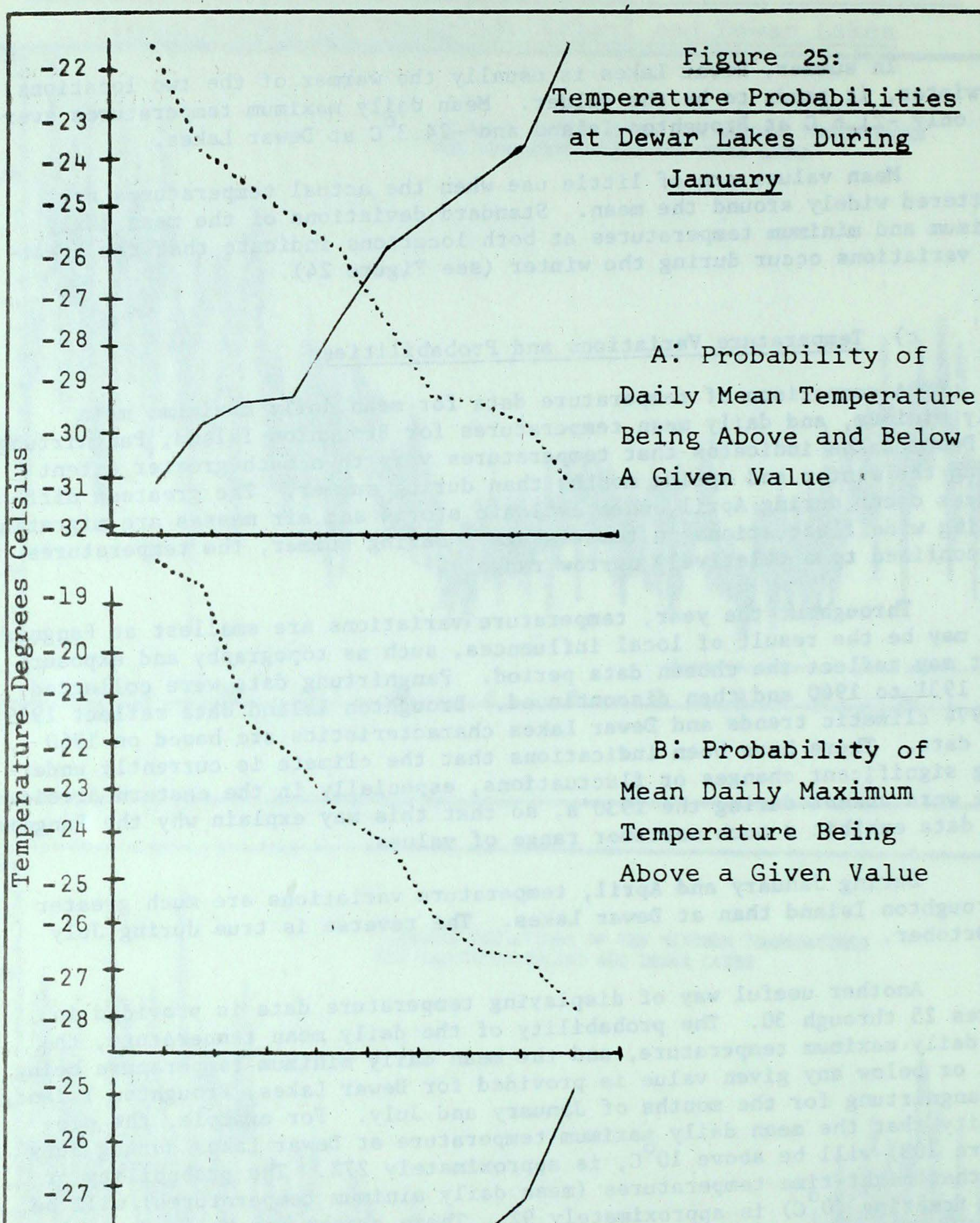


Figure 25:
Temperature Probabilities
at Dewar Lakes During
January
A. Probability of
Daily Mean Temperature
Being Above and Below
A Given Value
B. Probability of
Mean Daily Maximum
Temperature Being
Above a Given Value
C. Probability of
Mean Daily Minimum
Temperature Being
Below a Given Value
(Based on 1962-1971
Data)
Temperature Degrees Celsius
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31
-32
-19
-20
-21
-22
-23
-24
-25
-26
-27
-28
-25
-26
-27
-28
-29
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.9
1.0

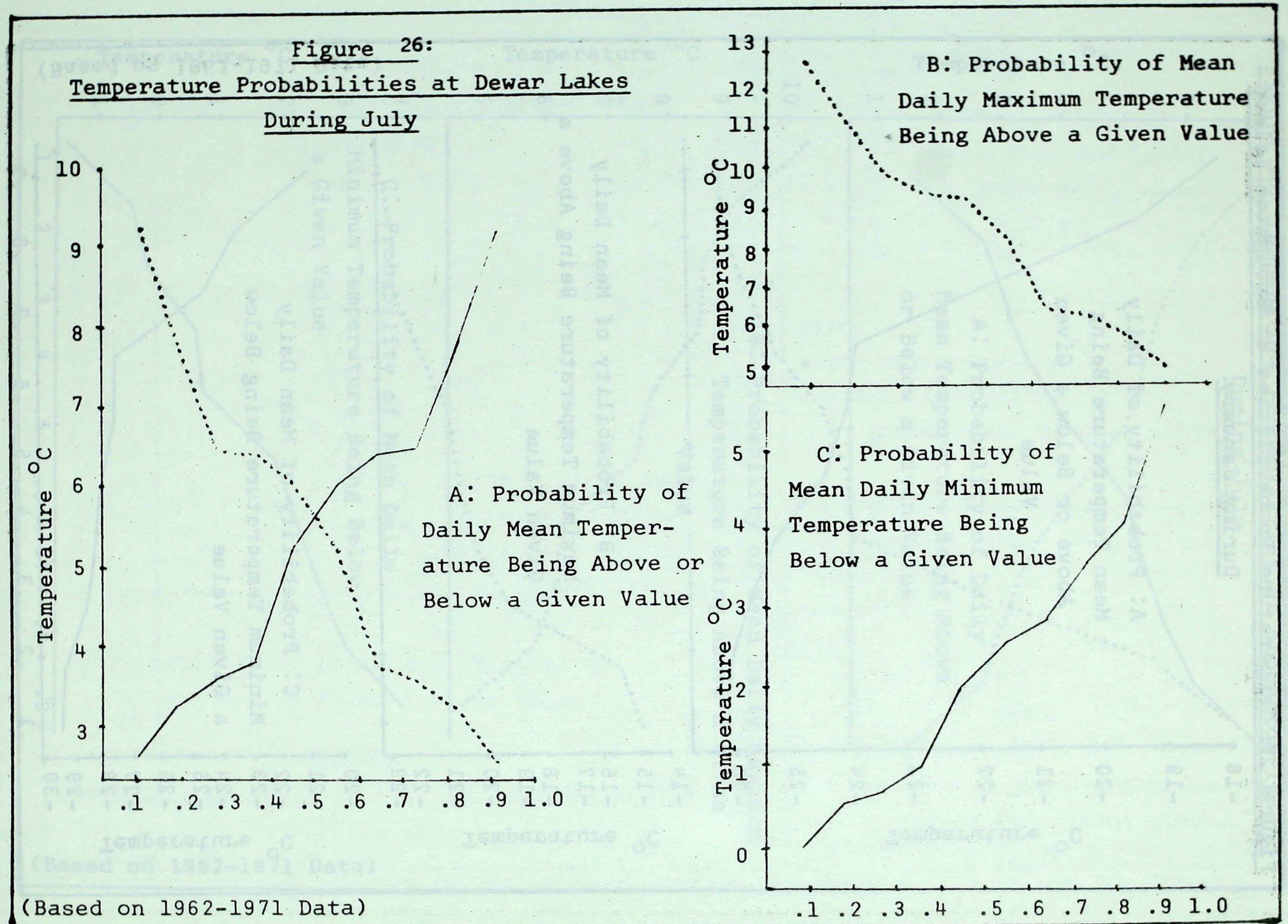


Figure 26: Temperature Probabilities at Dewar Lakes During July

Figure 27: Temperature Probabilities at Broughton Island During January

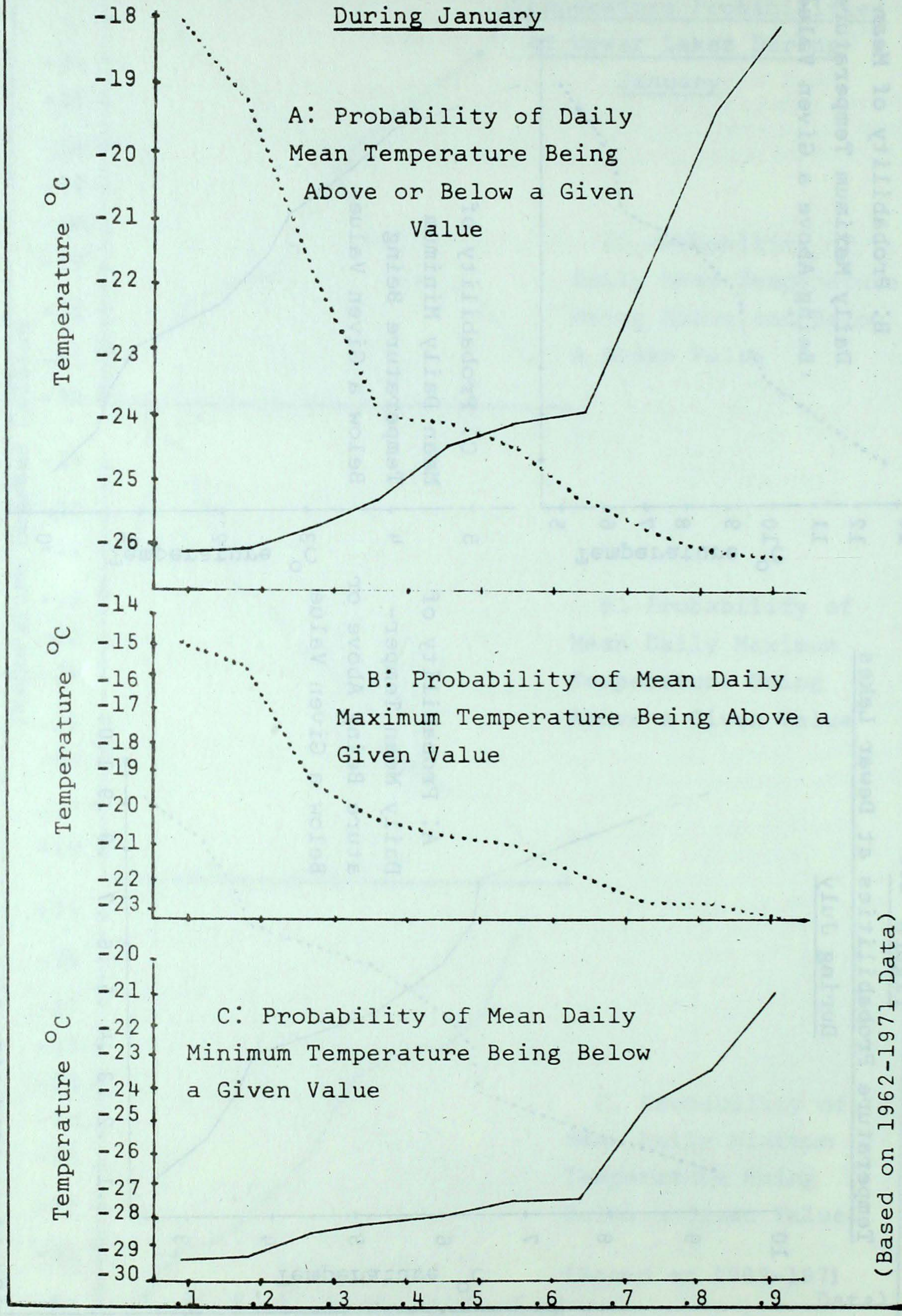


Figure 28: Temperature Probabilities at Broughton Island During July

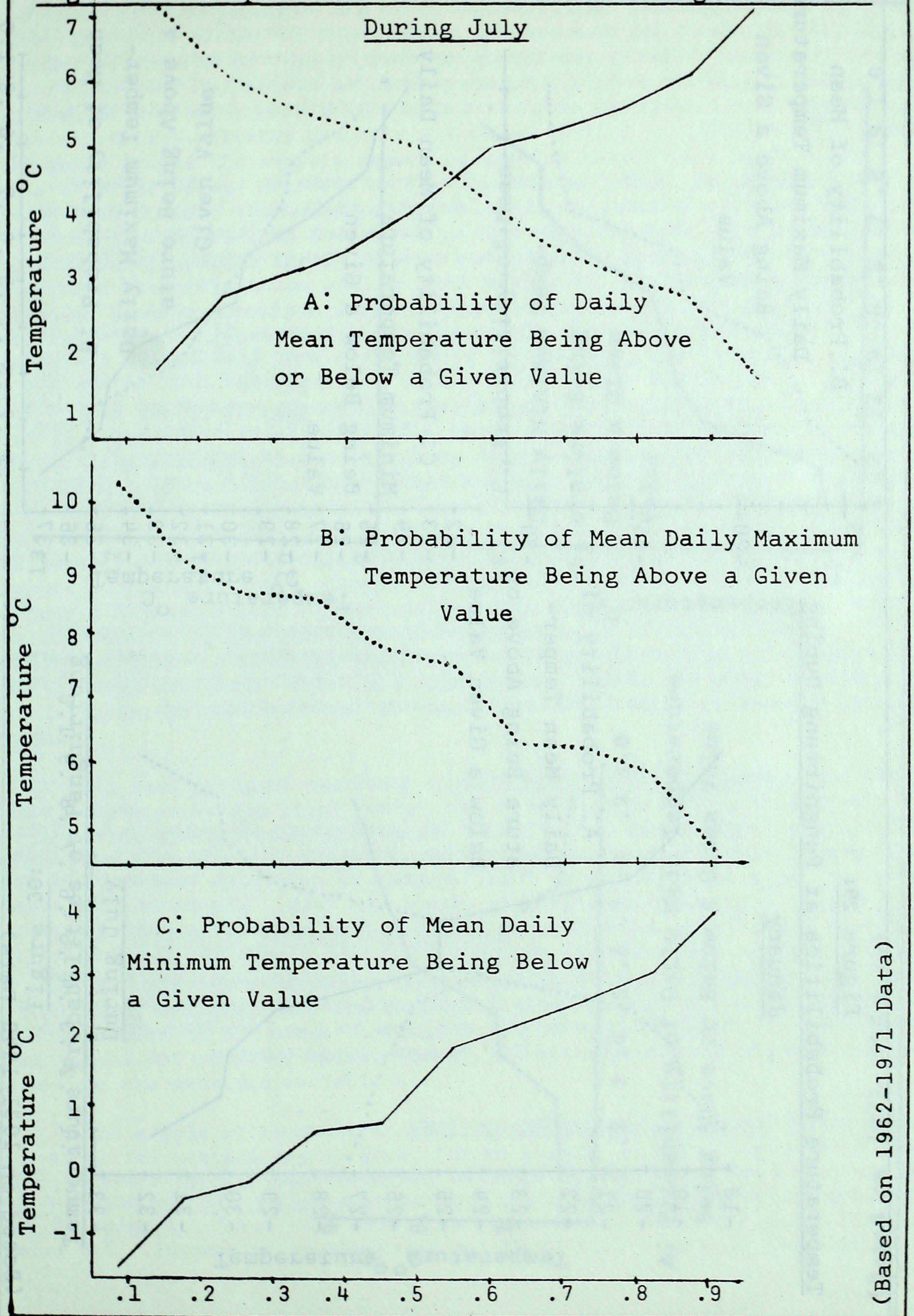
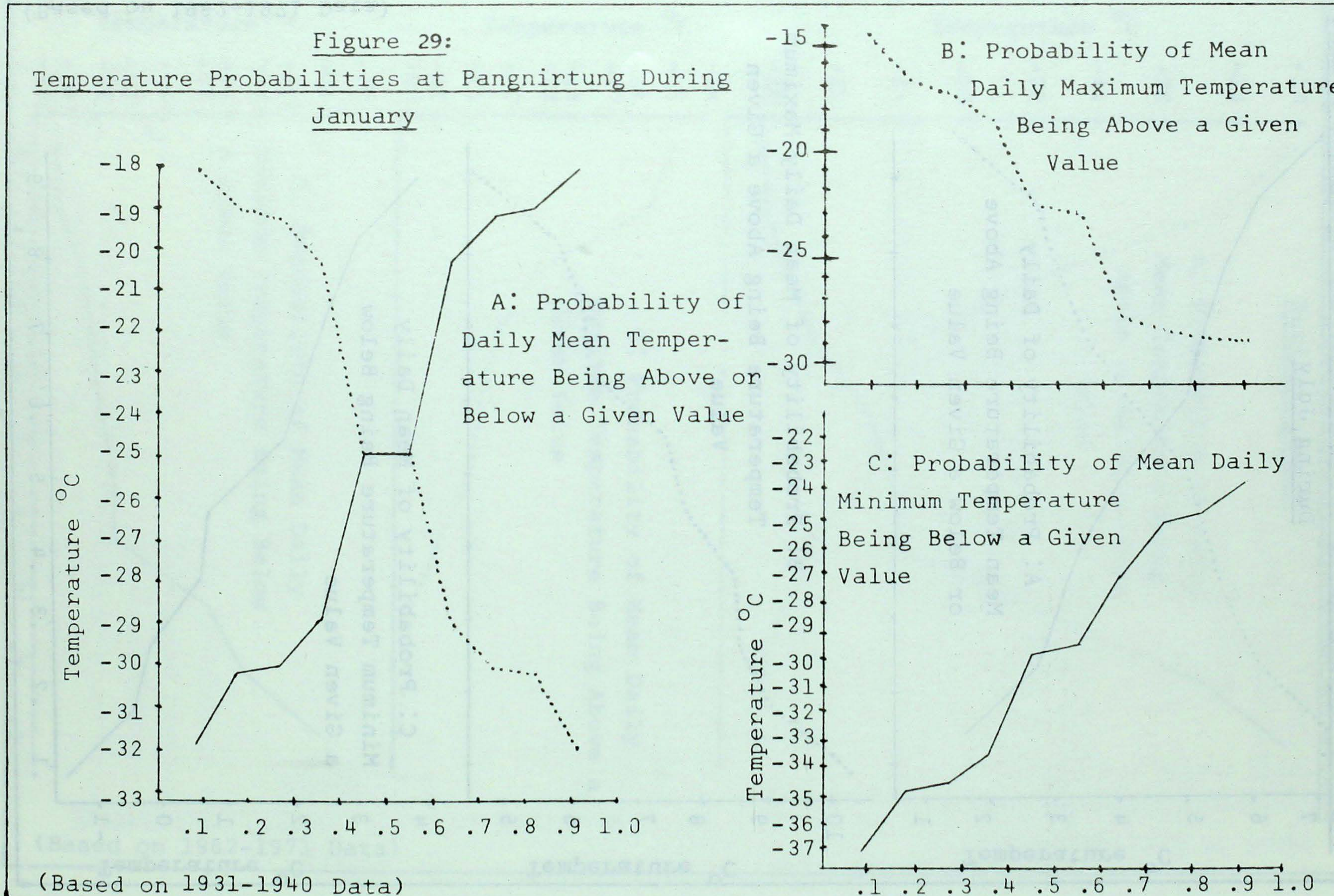


Figure 29:

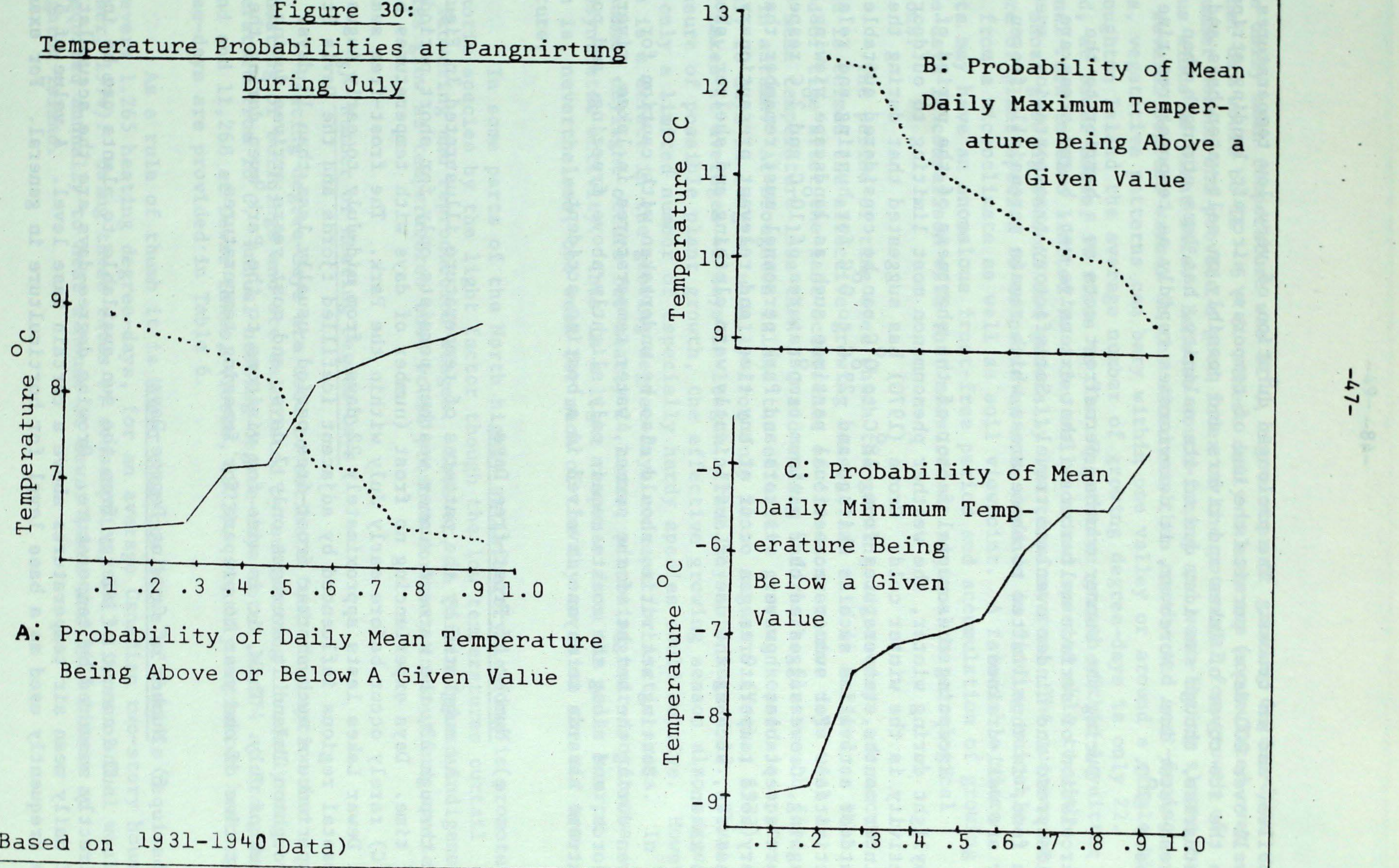
Temperature Probabilities at Pangnirtung During January



(Based on 1931-1940 Data)

Figure 30:

Temperature Probabilities at Pangnirtung During July



(Based on 1931-1940 Data)

mobiles, and in trucks. The prolonged duration of very low temperatures (well over 200 days) permits the use of temporary aircraft landing strips on the ice cover of lakes and rivers and possibly on salt-water bays and estuaries, though sea ice, due to its salinity, has less strength than fresh-water ice. Moreover, it deteriorates rapidly as temperatures rise above -7°C.

During the summer months, permafrost acts as a barrier to the percolation of surface meltwater so that extensive wet, boggy areas are widespread and hinder overland travel. Satisfactory transportation, even on foot, is thus limited to those areas which remain perennially frozen or are well-drained.

Excepting the crucial factor of the shortness of the period of daylight during winter, the weather phenonmenon most limiting to outdoor activity is the winter cold. Crowe (1970) has suggested that during the winter months, temperatures from -18°C to 0°C can be considered suitable for outdoor activities such as skiing, and -29°C to 0°C for hunting and related activities. For summer recreational pastimes such as landscape viewing and angling, Crowe suggested that minimum temperatures of 10°C and 2°C respectively were acceptable; however, visitors and Park personnel must remember that very cold temperatures can occur at any time, and relevant precautionary measures, such as the use of sufficiently warm clothing and shelter, should be taken.

Boating activities should also be undertaken with caution for even during the height of the summer, water temperatures in lakes, rivers, fjords, and along the coasts remain only slightly above freezing, and pose extreme hazards to anyone involved in a boating accident.

e) Number of Frost-free Days

As suggested by the patterns of temperature illustrated in Figures 12 through 23, the warmest summer weather persists only for short periods of time. Days experiencing no frost (number of days with temperatures below 0°C) rarely occur before early July within the Park. The frost-free season at Dewar Lakes lasts approximately 22 days, from mid-July to early August. Coastal regions influenced by adjacent icefilled fjords and the Davis Strait experience a much shorter frost-free period, usually less than 10 days. At Broughton Island it averages only 7 days, and most years arrives during the third week of July. Thus, it is wise for visitors to the Park even during the warmest time of the year to prepare for freezing temperatures.

f) Number of Growing Degree-Days

The amount of energy from the sun available to plants can be indirectly measured by temperature. Growing degree-days are the accumulation of daily mean air temperatures above a certain base level. A value of 5°C is frequently used as a base level for horticulture in general. For example, if the daily mean temperature was 11°C, the number of growing degree-days for that day would be 11 - 5 = 6. These daily values are accumulated over the summer season and provide a good index of the potential for growth of various kinds of plant life. Because south-facing and west-facing slopes tend to be several degrees warmer in the afternoon than north- and east-facing slopes, vegetative patterns can bary within one valley or around a single hill. At Broughton Island the average number of growing degree-days is only 22. Inland, at Dewar Lakes, it rises to 51. Vegetative growth within Auyuittuq National Park is thus limited to a few well-adapted species able to withstand short growing seasons and generally low temperatures. The success or failure of plant species to colonize an area depends on finding suitable sites from a microclimate as well as soil viewpoint. A favourable microclimate may have an anomalous frost-free period and accumulation of growing degree-days in comparison with that measured at regional meteorological stations.

The period of time over which the growing degree-days are accumulated is termed the effective growing season, and this is defined as that period of time after the last occurrence of five consecutive days with a daily mean temperature less than 5°C and ending before the first such five days in autumn. At Broughton Island the effective growing season is approximately 20 days in length, usually from July 21 to August 9 (Yorke, 1972). At Dewar Lakes it averages 46 days in length, from July 4 to August 18. Thus, as a measure of possible plant growth, the effective growing season also suggests that only a limited number of especially hardy species could survive. However, there is a defect in the growing degree-days concept for Arctic areas. In mid-summer daylight occurs for nearly 24 hours, promoting near-continuous photosynthetic activity. This is a light response from the solar source which is, nevertheless, too weak for much of the day to raise the air temperature.

In some parts of the North highly satisfactory leafing is promoted in exotic species by the light factor though the low temperatures curtail the flowering and reproduction stages. However, on Baffin Island indigeneous species grow at temperatures that would promote dormancy in southern species.

g) Number of Heating Degree-Days

Heating degree-days are used to estimate fuel consumption for the heating of buildings and are calculated by subtracting the daily mean temperature from 18°C. Annual heating degree-days total 10,574 at Broughton Island and 11,268 at Dewar Lakes, (Yorke, 1972). Monthly estimated heating degree-days are provided in Table 6.

As a rule of thumb it is known that one litre of fuel is required for every 1.265 heating degree-days, for an average Canadian two-story house (Webber, 1974). Using these rates of consumption, 8913 litres of fuel would be required annually to heat a house at Dewar Lakes and 8404 litres at Broughton Island.

Table 6

ESTIMATED HEATING DEGREE-DAYS BELOW 18^{o}C

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Broughton Is.	1262	1227	1313	1031	821	507	404	439	582	819	989	1180
Dewar Lakes	1385	1303	1401	1116	819	555	361	427	644	905	1084	1268

Source: Yorke, 1972

Data averaged from 1959 to 1967 for Broughton Island and

from 1958 to 1967 for Dewar Lakes.

Table 7

ESTIMATED FREEZING AND THAWING DEGREE-DAYS

		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Broughton Is.:	FDD	749	725	709	482	269	55	0	0	76	243	447	622	4377
	TDD	0	0	0	0	0	32	160	112	23	0	0	0	301
Dewar Lakes :	FDD	864	794	778	560	279	36	0	0	123	334	528	713	5009
	TDD	0	0	0	0	0	49	203	124	14	0	0	0	390

FDD = Number of Freezing Degree-Days
TDD - Number of Thawing Degree-Days

Source: Boyd, 1973 (converted to metric units)

h) Number of Freezing and Thawing Degree-Days

Freezing and thawing degree-days give a measure of the occurrence of below- and above-freezing mean daily temperatures. Accumulated freezing degree-days can be used to estimate the date of formation of lake and river ice in the autumn and the thickness of lake ice at a particular time (Burns, 1974). In the same manner, accumulated thawing degree-days can be used to calculate the spring date of snow melt and ice break-up. Boyd (1973) has suggested that the yearly cycle of the two indices can be related to heat loss and gain in the soils of an area and, thus, can be correlated with the depth of frost in the ground and the depth of thawing in a permafrost region. Freezing and thawing degree-days for Broughton Island and Dewar Lakes are provided in Table 7. In addition to the very severe nature of the climate, the figures indicate the continentality of the Dewar Lakes region, which has the greater number of both freezing and thawing degree-days.

B. Wind

a) Local Topographical Effects on Wind

The lower layers of air in motion come into contact with the ground surface, and both the speed and direction of these surface winds are modified. In order to obtain a more complete awareness of how local physiography and vegetation influences wind patterns, a brief description of three selected areas; Broughton Island off the east coast of Baffin Island; Pangnirtung; and Dewar Lakes in central Baffin Island is provided below and illustrated in Figure 31. Mean wind directions and speeds are located in Tables 8 and 9 respectively.

The Pangnirtung Fjord is 48 km long and 3 km wide. The cliffs on each side rise from sea level to as much as 900 m. The meteorological station is located 13 km from the mouth of the fjord. Because the fjord runs northeast to southwest, there is a prevalence of northeast and southwest winds. As a result of the funnelling action of airflow in the valley, there is rarely a lull in the steady, but not necessarily strong, northeast and southwest winds, which come with almost equal frequency (Baird, 1953). The high percentage of calm conditions recorded in Table 8 does not reflect this situation again emphasizing how localized winds can be. Occasionally, an easterly or westerly wind is experienced. These winds blow down the courses of two rivers that empty into the Pangnirtung Fjord at the location of the meteorological station. The weather in the fjord is quite variable and changes very quickly. High winds are quite common particularly where the valley narrows. During 1971, southerly winds of 160 km/hr were registered (Parcs Canada, 1972). Winds of 40 km/hr in this and similar valleys can make the air circulation uncomfortable, and they very often prohibit small boats from travelling into the fjords. Thus, the Pangnirtung weather station measures conditions existing in one specific location in the valley. The observations do not necessarily represent upper winds blowing above the valley, across the plateaus and peaks.

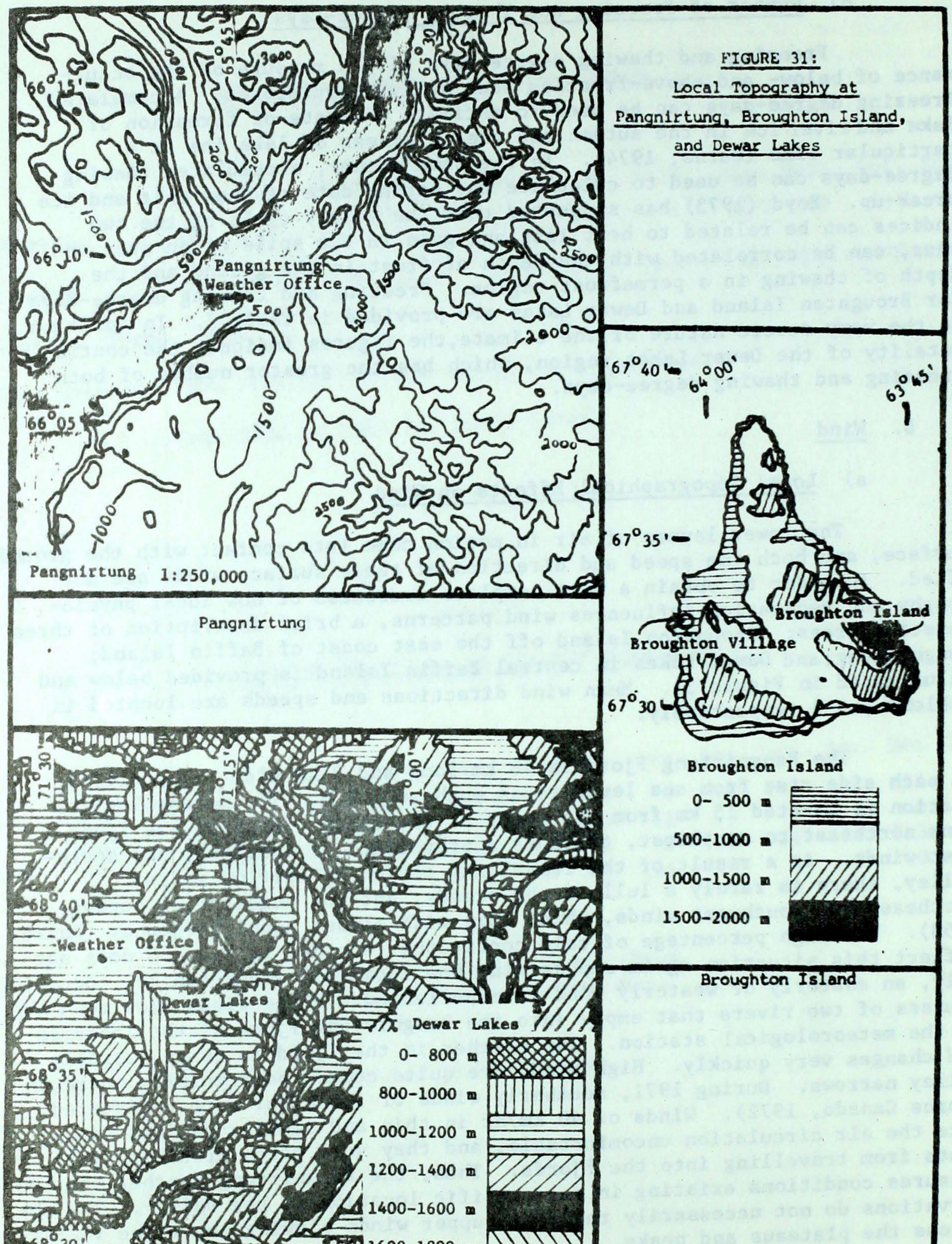


FIGURE 31: Local Topography at Pangnirtung, Broughton Island, and Dewar Lakes

TABLE 8:

Wind Direction for Selected Months
In Percentages

Station	Observation Period	Month	N	NE	E	SE	S	SW	W	NW	CALM
Broughton Island	1961-66	Jan.	9.4	2.4	5.7	5.7	7.5	4.5	8.3	18.8	36.9
	1960-66	April	16.0	1.4	1.3	8.0	6.2	1.2	4.0	20.2	41.0
	1960-66	July	14.9	2.6	2.9	7.3	5.8	1.8	7.3	14.2	43.4
	1960-66	Oct.	9.0	3.1	5.3	8.0	4.1	4.9	11.6	18.7	35.2
Cape Dyer	1959-66	Jan.	5.4	13.6	9.4	9.3	8.1	7.2	14.6	12.7	19.6
	1959-66	Apr.	6.4	12.8	9.6	5.4	7.3	7.1	14.4	14.8	22.4
	1958-65	July	8.7	7.1	6.0	6.1	10.2	16.0	19.2	7.8	19.2
	1959-66	Oct.	9.2	9.1	9.1	4.8	6.4	5.5	25.7	14.7	15.6
Cape Hooper	1958-66	Jan.	9.1	11.4	7.4	6.6	2.6	7.6	22.1	9.0	24.4
	1958-66	Apr.	11.5	10.9	6.1	7.2	2.4	7.4	20.3	5.3	28.9
	1958-66	July	8.5	7.3	7.7	14.5	5.8	9.3	14.6	10.0	22.4
	1958-66	Oct.	13.8	12.3	9.6	9.0	4.4	10.0	24.0	8.2	8.7
Dewar Lakes	1958-66	Jan.	5.5	17.5	26.1	8.7	11.0	7.0	7.1	2.9	13.2
	1958-66	Apr.	9.6	10.4	25.0	10.3	8.3	8.0	9.7	8.9	10.9
	1958-66	July	3.8	7.1	32.2	8.8	11.2	13.6	10.6	7.2	5.8
	1958-66	Oct.	13.5	18.5	22.8	7.4	6.3	5.1	8.9	6.5	11.3
Padloping Island	1942-56	Jan.	22	5	4	2	2	2	11	42	10
	1942-56	Apr.	28	6	6	4	2	1	7	32	14
	1942-56	July	17	5	8	14	10	5	7	22	12
	1942-56	Oct.	22	8	5	5	8	8	13	26	5
Pangnirtung	1930-42	Jan.	2	15	7	4	6	13	10	1	42
	1930-42	Apr.	2	19	10	3	5	17	10	1	33
	1930-42	July	1	5	7	1	2	49	21	1	13
	1930-42	Oct.	8	21	9	7	4	16	8	5	22

Source: Coulcher, 1967, p. 89

TABLE 9:

Wind Speeds for Selected Months
at Selected Locations

Station	Observ. Period	Mon	Calm	Percentage Observations (km/hr) 1-20	21-60	≥61
Broughton Island	1961-66	Jan	36.9	31.6	30.6	.9
	1960-66	Apr	41.0	46.7	12.3	0
	1960-65	July	43.4	50.8	5.8	.2
	1960-65	Oct.	35.2	48.4	16.2	.2
Cape Dyer	1959-66	Jan.	19.6	36.7	35.8	7.9
	1959-66	Apr.	22.4	49.8	25.6	2.2
	1958-65	July	19.2	58.2	22.1	.5
	1959-66	Oct.	15.6	46.2	36.2	2.0
Dewar Lakes	1958-66	Jan.	13.2	50.1	32.5	4.2
	1958-66	Apr.	10.9	60.9	27.7	.5
	1958-66	July	5.8	48.1	45.2	.9
	1958-66	Oct.	11.3	57.2	28.1	1.4
Cape Hooper	1958-66	Jan.	24.4	37.6	32.0	6.0
	1958-66	Apr.	28.9	45.0	22.4	3.7
	1958-66	July	22.4	57.7	18.8	1.1
	1958-66	Oct.	8.7	44.4	42.5	4.4

Source: Coulcher, 1967, p. 90

The area surrounding the Dewar Lakes observing office is extremely hilly and rocky, with numerous lakes and fast flowing streams. Again, the data represent the weather at one location only, and especially in hilly areas they should not be considered necessarily representative of the surrounding region. Instrument exposure is considered excellent, however, and the control of the physiography on winds is much less significant than at Pangnirtung.

Broughton Island is 19 km long and 13 km wide. The observing station is situated 800 m from the Island's east shore and the general terrain is quite mountainous and rocky. Large valleys between the highest elevations could induce local weather effects. All instruments are well-exposed, however, and the meteorological measurements are considered valid and useful for our purposes of suggesting probable Park conditons along the Eastern coast. Distinct differences can be noted between coastal and inland areas of Broughton and other islands, as well as the coastal regions of Baffin Island itself.

b) Seasonal Wind Patterns

During the winter season, winds blow from the east and northeast at Dewar Lakes, and at a much greater speed than those at Broughton Island. In the Pangnirtung Fjord, winds are funnelled by the steep walls so that northeast and southwest directions are most frequent. The strongest winds come from northerly directions. These occur frequently and can continue for several days.

At Broughton Island, winter winds from the northwest continue through the spring, decreasing slightly in speed. Northerly winds occur more frequently. Dewar Lakes winds also decrease somewhat and become more northerly and northwesterly. The local northeast and southwest winter winds at Pangnirtung continue to prevail during the spring.

In summer, winds at Broughton Island blow predominantly from the north and northwest, and are generally light. At Dewar Lakes, prevalent winds blow from the east and southwest. Approximately 48% of these winds have speeds from 1 to 20 km/hr and 45% from 21 to 60 km/hr, even greater than those during winter. Summer winds in the Pangnirtung Fjord prevail from the southwest and west. Only during certain times of the year do easterly or westerly winds occur, and then they blow down the courses of the two rivers that empty into the fjord.

During the transition period from summer to winter, Broughton Island winds swing somewhat westward and prevail from the northwest and west, decreasing in speed. In the Dewar Lakes region winds shift slightly northward and prevail from easterly and northeasterly directions, decreasing slightly in speed. In the Pangnirtung Fjord, winds are once again funnelled by the fjord walls, and northeast and southwest winds occur most frequently.

c) <u>Wind Chill</u>

The most important weather factors affecting human comfort out-of-doors in Auyuittuq National Park are temperature and wind speed. Heat is lost from the skin and lungs by radiation, convection and evaporation. With a decline in temperature, an increasing proportion of human energy is required to decrease the loss of heat from the body and to cope with the additional weight and restriction to movement incurred by the layers of protective clothing. Cold, dry air is heated and saturated in the lungs, resulting in important heat and water losses. This effect of low air temperatures upon heat and water balances in the body is further augmented by wind, which increases the rate of heat loss and dehydration.

An index measuring the convective cooling effect of varying combinations of low temperature and wind on dry exposed skin was designed by Siple and Passel (1945), and offers a reasonable indication of the degrees of discomfort and tolerance of man in a cold climate. The correlation between relative human comfort and atmospheric cooling is indicated in Table 10.

Figure 32 is a wind chill nomogram from which one may determine the equivalent wind chill temperature from the ambient air temperature and wind velocity. It is applicable to instantaneous values of wind speed and air temperature. For example, if the air temperature is $0^{o}C$ and the wind speed averages 10 km/hr, the wind chill is slightly above 800 kgcal/m^2/hr, metric units, watts/$metre^2$ are obtained by dividing the number of kgcal/m^2/hr by .8601. According to Table 17, a value of 800 kgcal/m^2/hr is considered borderline between comfortable and uncomfortable. However, if the wind continues to blow at 10 km/hr and the temperature drops to $-20^{o}C$, perhaps at night-time, the wind chill increases to 1300 kgcal/m^2/hr. If the wind increases in speed to 30 km/hr, the wind chill rises to over 1600 kgcal/m^2/hr, at which point exposed flesh will freeze very quickly, and travel becomes difficult, if not dangerous. The equivalent wind chill "temperature" in the above conditions ($-20^{o}C$, 30 km/hr wind) is $-45^{o}C$.

Figure 33 can be used to estimate the probability of a specified level of wind chill if the mean monthly wind speed and air temperature are shown. For example, the mean daily maximum temperature at Dewar Lakes in January is $-24^{o}C$, and the strongest winds average 35 km/hr. The wind chill at Dewar Lakes thus averages 1800 kgcal/m^2/hr in January. Sometimes it will rise above 1800 and occasionally it will fall below. The right-hand chart indicates (by following the 1800 curve until it crosses the 2000-line) that the wind chill will exceed 2000 kgcal/m^2/hr (the point at which exposed flesh freezes) more than 70% of the time.

Figure 34 is a modification of Figure 32 and is used by the United States Air Force under Arctic conditions. The basic nomogram is divided into seven chill classes which are accompanied by a description of the degree of discomfort and necessary precautionary measures.

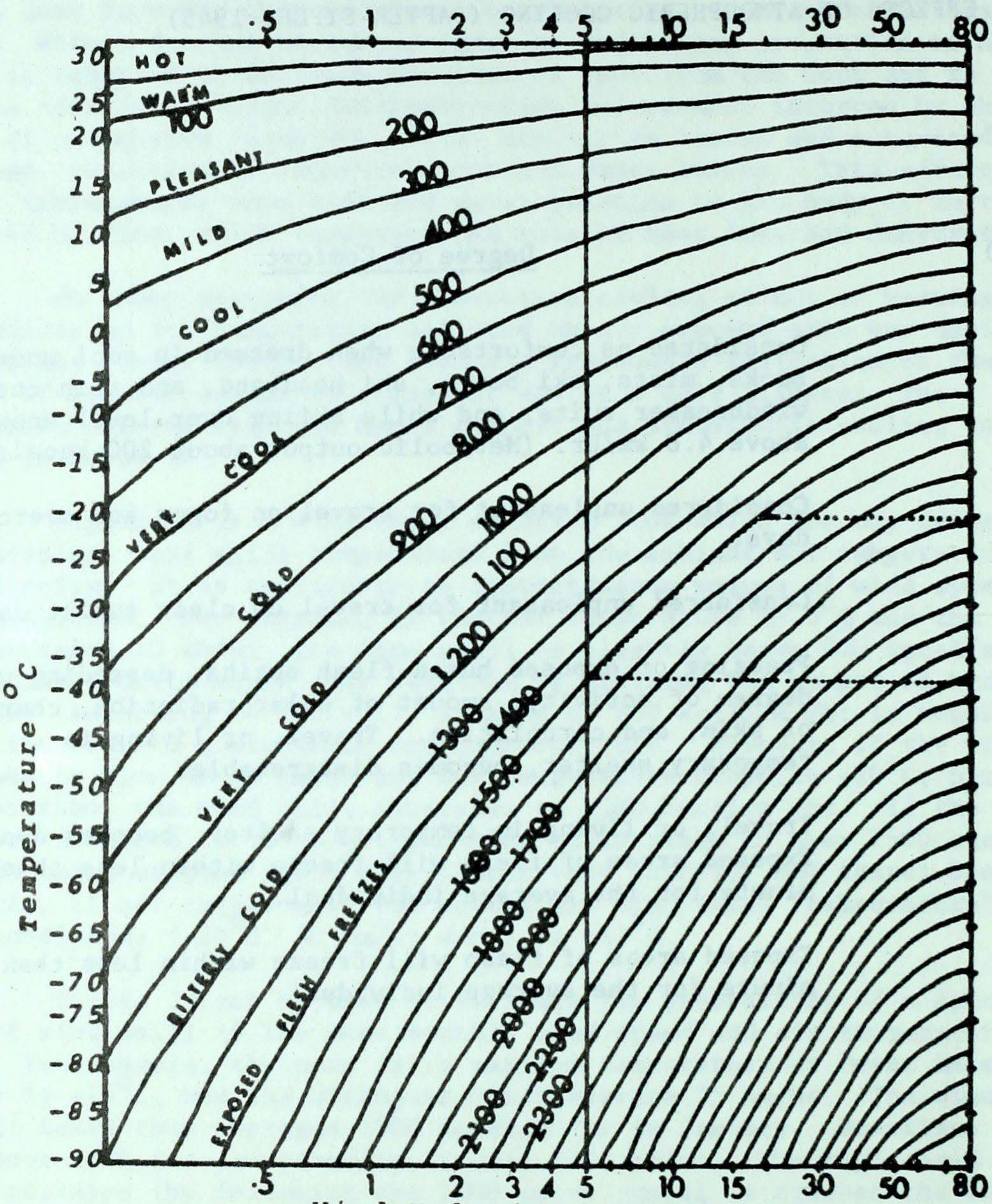
Table 10:

STAGES OF RELATIVE HUMAN COMFORT AND ENVIRONMENTAL EFFECTS OF ATMOSPHERIC COOLING (AFTER SIPLE, 1945)

Wind-Chill ($kgcal/m^2/hr$)	Degree of Comfort
600	Considered as comfortable when dressed in wool underwear, socks, mitts, ski boots, ski headband, and thin cotton windbreaker suits, and while skiing over level snow at or above 4.8 km/hr. (Metabolic output about 200 $kgcal/m^2/hr$).
1000	Considered unpleasant for travel on foggy and overcast days.
1200	Considered unpleasant for travel on clear sunlit days.
1400	Freezing of exposed human flesh begins, depending upon degree of activity, amount of solar radiation, character of skin, and circulation. Travel, or living in temporary shelter, becomes disagreeable.
2000	Travel, or living in temporary shelter, becomes dangerous. Exposed areas of flesh will freeze within less than one minute for the average individual.
2300	Exposed areas of flesh will freeze within less than ½ minute for the average individual.

Figure 32:

Wind Chill Nomogram



Cooling is expressed in kilogram calories per square metre per hour for various temperatures and wind velocities. The cooling rate is based upon a body at a neutral skin temperature of 33°C. When dry cooling rate is less than the rate of body heat production, excess heat is removed by vaporization. Under conditions of bright sunshine cooling is reduced by about 200 calories. Expressions of relative comfort are based upon an individual in a state of inactivity.

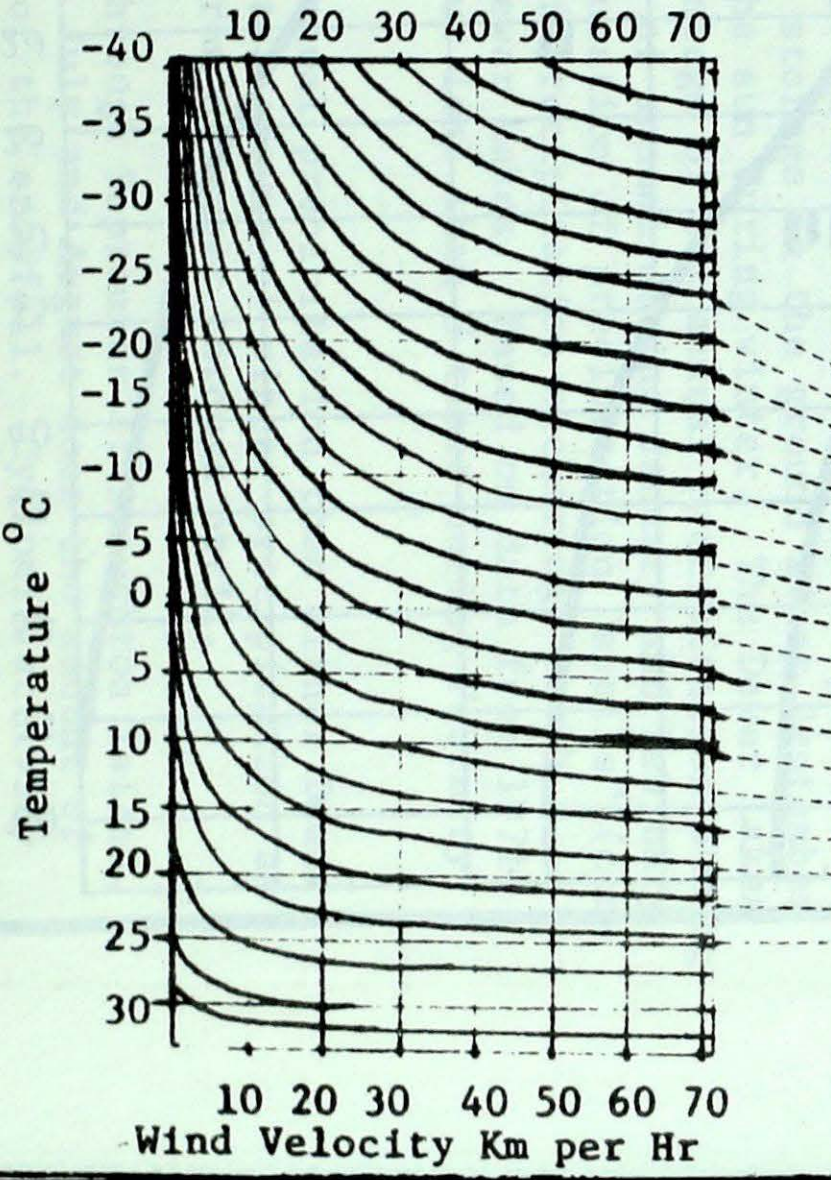
To obtain equivalent wind chill temperature values, select the current temperature value (C°) at the side of the curves; move horizontally to the left to a point vertically below the current wind velocity (km per hr); follow to the left and downward to the nearest parallel line until you intersect the 5 km per hr vertical line; go back to the right and read off the equivalent wind chill temperature.

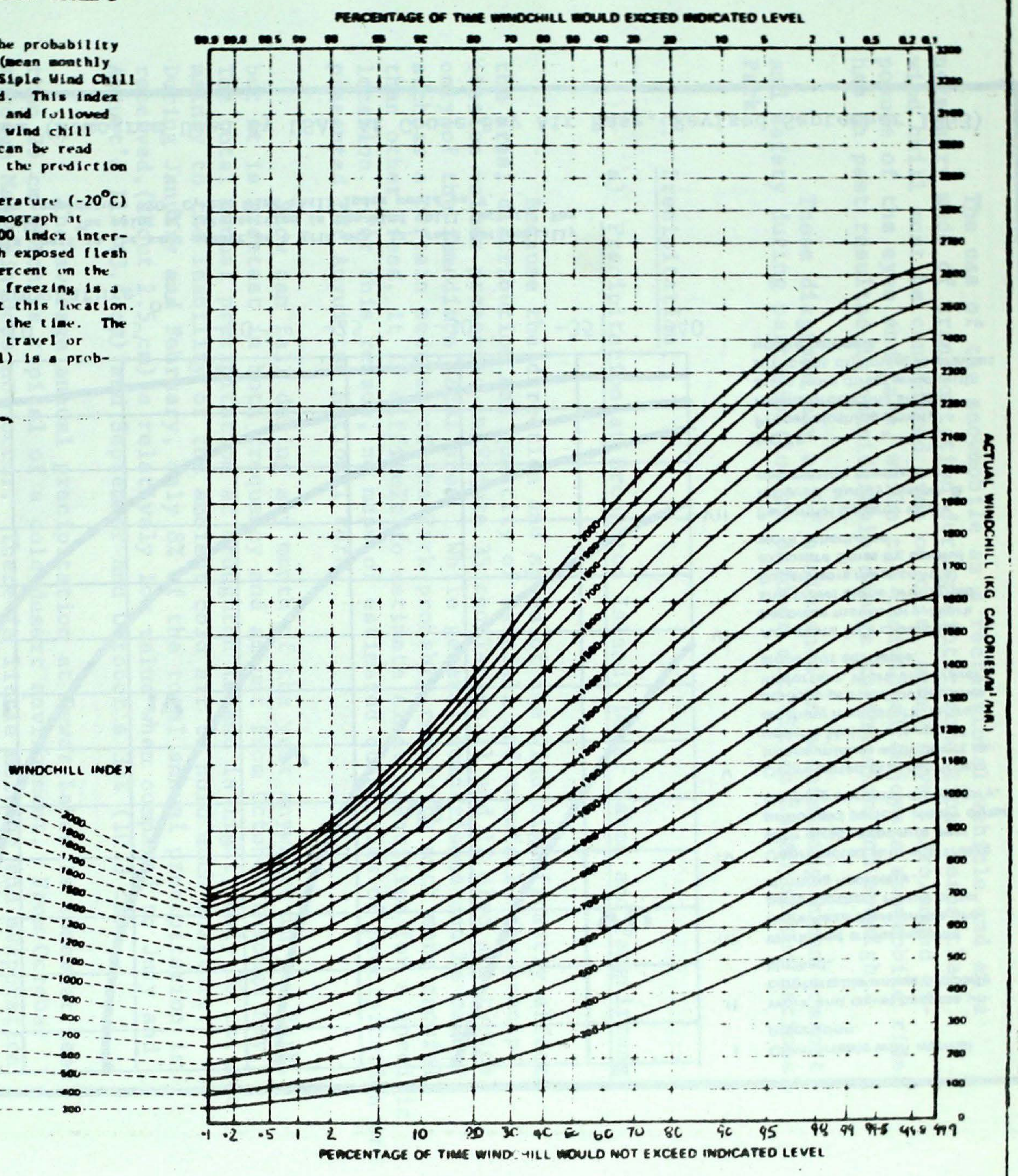
Example: At -20°C with a 20 km per hr wind, the equivalent wind chill temperature would be -38°C.

Figure 33: Wind Chill Prediction Chart

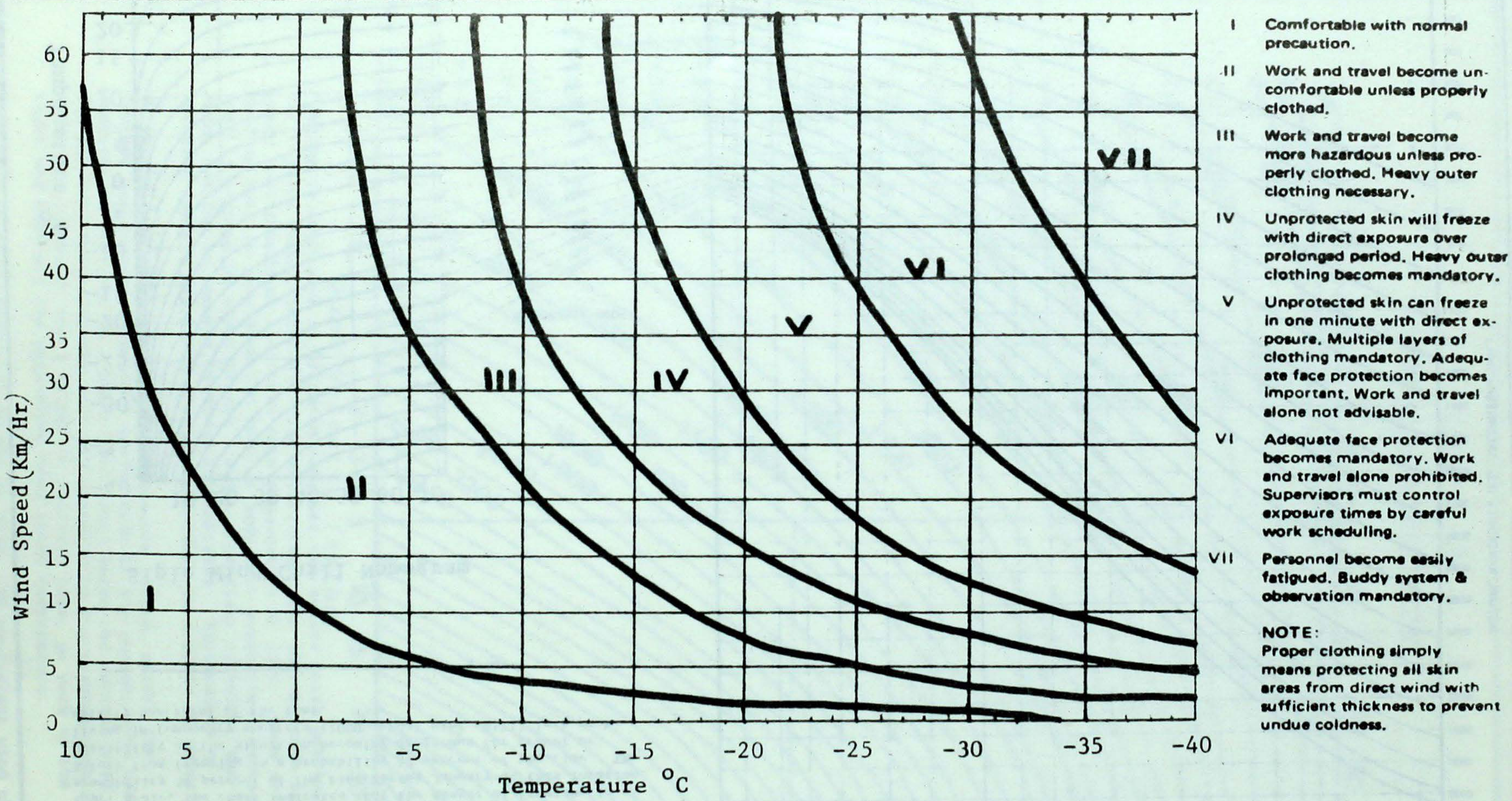
By a simple technique, it is possible to estimate the probability of a specified level of wind chill. Data required (mean monthly air temperature and wind speed) are entered in the Siple Wind Chill Nomogram at the left and a wind chill index obtained. This index is transferred to the prediction chart at the right and followed to the pre-determined level desired (read on actual wind chill scale at the extreme right). Percentage frequency can be read on the probability scale at either top or bottom of the prediction chart.

Example: At a given location the January mean temperature (-20°C) and wind speed (25 km per hr) are entered in the nomograph at the left and give a 1600 wind chill value. This 1600 index intersects the 1400 actual wind chill (condition at which exposed flesh freezes). At 58 percent on the upper scale or 42 percent on the lower scale, the chart indicates that the danger of freezing is a probability 58 percent of the time during January at this location. Safety from freezing is a probability 42 percent of the time. The possibility of the situation becoming dangerous for travel or living in temporary shelters (2000 actual wind chill) is a probability 6 percent of the time.





Source: Lackey, 1958



How to read the Wind Chill Chart: Use this chart in the same manner as a grid map, ie. read horizontally the temperature and the wind speed vertically. The point of intersection is the wind chill factor. For example, if the wind were 40 km hr and the temperature -20 °C, the wind chill index would be V.

Figure 34: Temperature/Wind Chill Index (Nomogram Used By USAF At Goose Bay Air Base, Revised September 1963)

The use of the snowmobile as a recreational vehicle and as a necessary mode of transportation during winter conditions means that wind chill must be considered even on calm, sunny days. Prolonged exposure of the eyes and face, while the individual enjoys a snowmobile ride, has in past resulted in considerable damage to the skin and eyesight.

These diagrams may be of assistance in maintaining human comfort and safety during participation in outdoor activities in Auyuittuq National Park.

C. Precipitation

a) Precipitation at Broughton Island, Dewar Lakes and Pangnirtung

Because the direction and speed of the wind significantly affects the areal distribution and quantity of rainfall and snowfall, the precipitation values presented in Figure 35 and Tables 11 and 12 also are typical only of the immediate local area. While general comparisons can be made, such as a certain section of the Park probably receiving much more snowfall than other areas, it is difficult to estimate exact quantities for a specific location. For this reason, no maps of estimated quantities of precipitation are presented for Auyuittuq National Park.

Snow can fall during any month of the year anywhere in the Park, but it is greatest in both frequency and amount from October through May. The total annual precipitation at Broughton Island is light, only 30 cm, due mainly to the inability of the ambient cold air to hold much moisture. During January and February, only 8% of the total annual precipitation is received,(about 2.5 cm) a relatively low value when compared to July and August's 11% (3.4 cm) and September and October's 34% (10.3 cm).

The average annual precipitation at Dewar Lakes is somewhat less than 25 cm which is typical of a cold desert environment. From October through May rain does not occur. There is little melting and evaporation of the snow cover due to limited heat storage in the ground after September as well ineffective insolation from the sun during winter. The Dewar Lakes region receives an even smaller percentage of its annual precipitation during winter than does Broughton Island (4% of annual during January and February, or 0.8 cm). Both the frequency and duration of precipitation "spells" (consecutive days with at least a trace of precipitation occurring) reach a minimum during the winter season at Dewar Lakes. Based on data from 1971 through 1975 precipitation spells occur less than 3 times during February and last only a day or two.

Pangnirtung has a greater annual precipitation than either Dewar Lakes or Broughton Island, and a greater amount of winter precipitation as well. No rain falls at Pangnirtung from November through April.

Rain falls only from June through September at Broughton Island, but snow is also common. Only during July and August does the amount of rainfall exceed the water equivalent of the snowfall. Cyclonic activity reaches a peak in the summer, and rainfall increases towards the southern

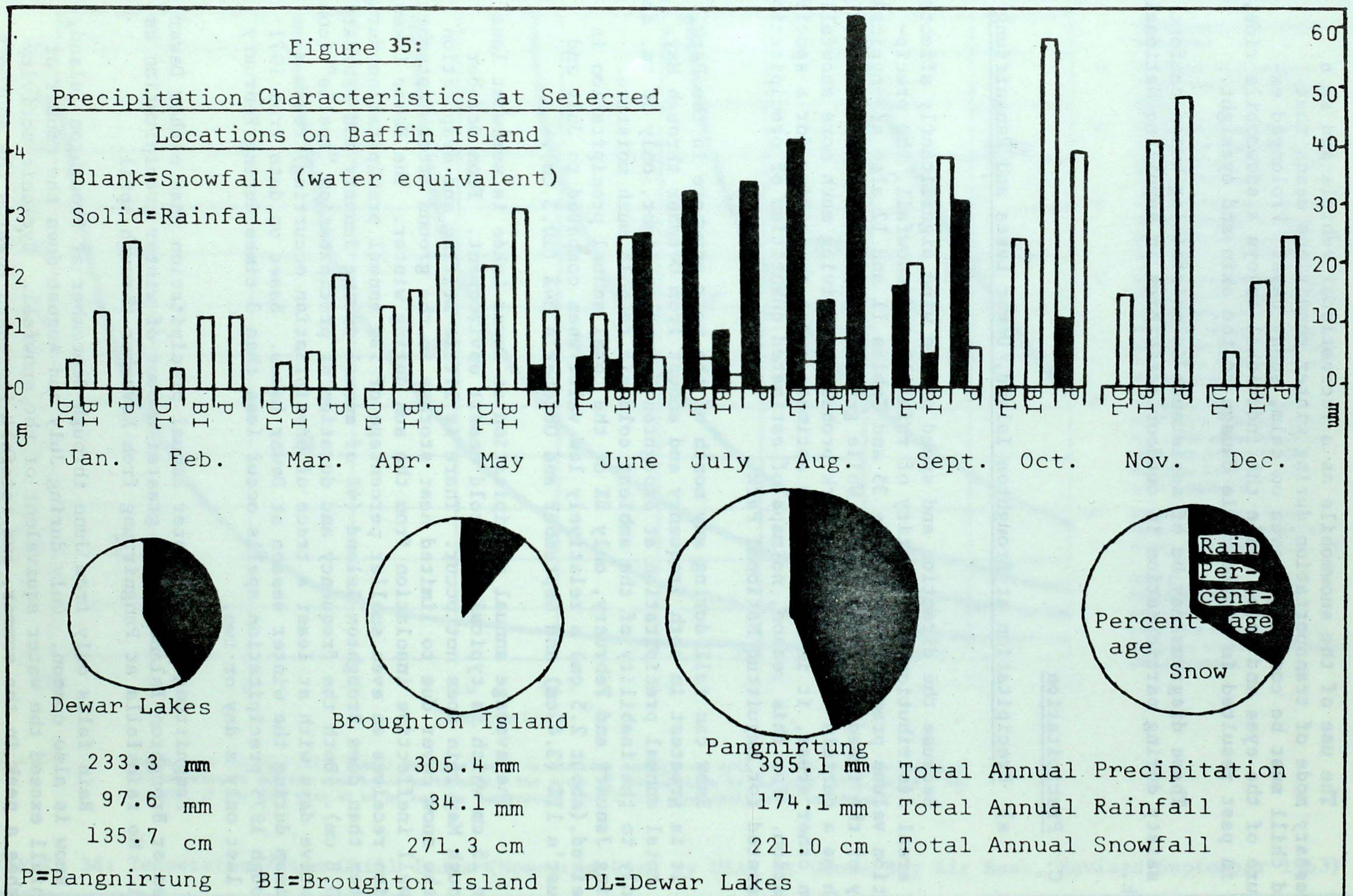


Figure 35: Precipitation Characteristics at Selected Locations on Baffin Island

Table 11:

PRECIPITATION AMOUNTS AT SELECTED LOCATIONS ON BAFFIN ISLAND

Snowfall measured in centimetres; Rainfall and total precipitation measured in millimetres.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
BROUGHTON ISLAND													
Mean Rainfall	–	–	–	–	–	4.8	9.4	14.5	5.1	.3	–	–	34.1
Mean Snowfall	12.9	12.2	6.1	16.5	30.5	25.7	2.3	7.9	38.6	59.2	41.9	17.5	271.3
Mean total Precip.	12.9	12.2	6.1	16.5	30.5	30.5	11.7	22.4	43.7	59.5	41.9	17.5	305.4
CAPE DYER													
Mean Rainfall	.3	.5	–	T	.5	7.4	27.4	52.1	17.8	3.6	1.5	.3	111.4
Mean Snowfall	71.9	77.0	26.9	37.6	49.0	36.3	4.8	10.9	57.9	99.3	76.3	71.4	619.3
Mean total Precip.	72.2	77.5	26.9	37.6	49.5	43.7	32.2	63.0	75.7	102.9	77.8	71.7	730.7
CAPE HOOPER													
Mean Rainfall	–	–	–	–	–	5.3	14.0	16.0	11.4	.8	–	–	47.5
Mean Snowfall	9.9	16.0	7.9	21.6	32.8	22.3	5.1	10.4	29.0	34.5	36.1	14.5	240.1
Mean Total Precip.	9.9	16.0	7.9	21.6	32.8	27.6	19.1	26.4	40.4	35.3	36.1	14.5	287.6
DEWAR LAKES													
Mean Rainfall	–	–	–	–	.3	5.6	32.8	41.9	17.0	T	–	–	97.6
Mean Snowfall	4.6	3.3	4.6	14.2	21.1	12.7	4.6	4.3	20.6	24.6	15.5	5.6	135.7
Mean total Precip.	4.6	3.3	4.6	14.2	21.4	18.3	37.4	46.2	37.6	24.6	15.5	5.6	233.3
EKALUGAD LAKES													
Mean Rainfall	.3	–	–	–	–	.3	29.0	7.4	–	–	–	44.9	
Mean Snowfall	6.9	6.4	1.5	9.4	10.9	10.9	.8	11.4	23.4	33.5	18.3	1.3	134.7
Mean total Precip.	7.2	6.4	1.5	9.4	10.9	11.2	29.8	18.8	31.3	33.5	18.3	1.3	179.6
PADLOPING ISLAND													
Mean Rainfall	T	.8	–	–	T	6.1	19.3	8.9	10.2	.5	T	–	45.8
Mean Snowfall	16.0	15.2	6.6	5.3	14.2	9.1	2.5	4.8	16.8	38.9	34.5	13.5	177.4
Mean total Precip.	16.0	16.0	6.6	5.3	14.2	15.2	21.8	13.7	27.0	39.4	34.5	13.5	223.2
PANGNIRTUNG													
Mean Rainfall	.3	–	1.0	1.0	4.1	26.4	35.1	63.3	31.2	11.4	.3	–	174.1
Mean Snowfall	24.6	12.4	19.8	25.1	12.7	5.1	.3	.3	6.4	39.1	49.5	25.7	221.0
Mean total Precip.	24.9	12.4	20.8	26.1	16.8	31.5	35.4	63.6	37.6	50.5	49.8	25.7	395.1

Source: Yorke, 1972

Table 12:

WINTER SNOWFALL AVERAGES AND EXTREMES (CM) AT PRINCIPAL CLIMATOLOGICAL STATIONS ON BAFFIN ISLAND

	Average Snowfall	Period	Heaviest		Lightest		RECENT Total Snowfall		
			Snow	Winter	Snow	Winter	1969-70	1970-71	1971-72
Broughton Island	271.3	1960-72	409.1	69-70	145.3	65-66	409.2	196.3	199.1
Cape Dyer	619.3	1959-72	886.0	68-69	273.1	71-72	630.2	700.3	273.1
Cape Hooper	240.1	1958-72	487.7	69-70	82.0	60-61	487.7	240.9	248.2
Clyde	152.9	1944-72	359.2	50-51	44.5	46-47	139.2	203.0	298.5
Dewar Lakes	135.7	1958-72	170.4	58-59	76.0	65-66	138.7	159.5	148.8
Frobisher Bay	246.9	1942-72	478.8	57-58	49.0	42-43	292.4	209.8	202.2
Padloping Island	177.4	1951-56	272.3	55-56	155.7	51-42	-	-	-

Source: Manning, 1973

end of the east coast of Baffin Island. During July and August, Broughton Island receives 13% of its total annual precipitation (just over 4 cm), slightly more than during January and February. Rime, hoarfrost and fine drizzle frequently occur also. Precipitation spells of 2 to 3 days occur, on the average, 5 times during July and September, and just under 4 times in August. At Dewar Lakes, rain can fall from June through September, but the greatest amounts, 43% of the total annual precipitation (8.4 cm), fall during July and August. Summer precipitation at Dewar Lakes is three times that of Broughton Island and the east coast. Summer weather in Pangnirtung Fjord is quite variable and changes rapidly. The greatest amount of precipitation at Pangnirtung is received during the summer months, exceeding that of both Broughton Island and Dewar Lakes. Pangnirtung experiences a much larger percentage of its total annual precipitation as rainfall than either of the other two locations.

The largest amount of total annual precipitation at Broughton Island falls during the autumn (34%, or 10.3 cm, occurring during September and October alone). October, at Dewar Lakes and Broughton Island, provides more days with precipitation than any other month; more than 19 at the former, and just under 18 at the latter. During September, Broughton Island experiences the least amount of rainfall and the greatest amount of snowfall of the three areas. This trend is also reflected in the total annual snowfall figures: Broughton Island receives 18% more snowfall (5 cm more) than Pangnirtung and double the amount at Dewar Lakes. At Pangnirtung, a mixture of both rain and snow fall during September, October and November with increasing amounts of snowfall as winter approaches.

b) Precipitation and related factors on the Penny Ice Cap

On the Penny Ice Cap, weather patterns vary considerably from those of the east coast and inland non-glacierized regions. Precipitation falls as snow throughout most of the year. The generally low wind speeds and the rugged relief permit a deep and more reliable snow cover. In the most rugged regions in the southern end of the Park, snow accumulation far exceeds 200 cm in some areas. In the far northwest it decreases to less than 125 cm and in the interior basins it is less than 75 cm. Orvig (1955) at his camp in the Penny Highlands above the Pangnirtung Fjord (elevation 2050 m) measured the annual snow at between 81 cm and 107 cm. In the most exposed areas, and especially in summer on the Ice Cap, drifting snow can become a problem to hikers.

At the highest regions of the Penny Ice Cap there is little or no melting of the surface layers of snow, and the temperature of the underlying ice remains below freezing (Coulcher, 1967). What ablation does occur usually lasts only a few hours at a time for a few weeks. Strong solar radiation can promote sublimation without raising the air temperature.

The many smaller glaciers present in the Park may advance or retreat from time to time. Bradley and Miller (1972) note that in recent years, winter temperatures have risen slightly, resulting in large increase in winter precipitation. At the same time, summer temperatures have decreased, as reflected in the larger quantities of snowfall remaining throughout the warm-weather period.

These conditions retard ablation (melting and evaporation) rates during summer and encourage moderate snow accumulation during winter, which eventually help to stimulate glacier growth. However, many cases of glacier movement have no climatic relation whatsoever, and result from hydrodynamic processes within the ice mass. "Surging" glaciers sometimes occur in response to these internal physical factors.

Park visitors travelling on the Ice Cap must be prepared for the variety of snow and ice conditions they are likely to encounter. Clothing and shelter must be just as suitable for rain as it is for snow, especially in the lower regions of the Ice Cap. Valleys located adjacent to the Ice Cap frequently experience cold winds which descend, often leaving the higher slopes warmer than the lowest part of the valleys. During cooler summers, lakes and small bodies of water which are normally ice-free contain large quantities of ice or remain entirely ice-covered throughout the year. Conversely, normally continuously frozen water bodies may melt during abnormally warm summers, thus changing transportation patterns for boats and persons on foot. Prolonged periods of cool summers and increased precipitation or the inverse also effect important changes in local plant and animal populations and the territories they occupy.

c) <u>Blowing Snow</u>

One major winter hazard to human and animal life is blowing snow, briefly defined as "snow particles raised by the wind to sufficient heights so as to diminish visibility at eye level to 10 km or less" (Atmospheric Environment Service, 1971 p. 35). It is a major cause of restricted visibility during the Arctic winter, and can greatly deter overland travel. Snow distribution is also significantly influenced by wind. Exposed areas may be swept bare of snow by the wind, while valleys, ravines and smaller depressions become filled with snow, and snow drifts of ten metres or more can be formed.

Especially in Arctic regions, local topographical effects can have a dominating influence on the occurrence of blowing snow at any given location. Because it is a surface-based phenomenon, blowing snow rarely occurs above 50 m. As the wind increases in speed, it picks up particles of snow lying on the ground and carries them great distances, greatly obstructing visibility. Blowing snow can also be very abrasive and damaging to plants. The duration of blowing snow is related to the wind speed, the supply of snow available to be transported and the temperature of the air if conditions are near the freezing point.

Snow is essential to the survival of all floral and faunal life; however, either too much snow, or not enough, can result in high mortality rates for certain animals. A snow cover of sufficient depth acts as a protective blanket to plants and to many types of small animals that burrow and build nests, and use the snow as their source of water. Rikhter (1963) has estimated that optimal snow depths for plant growth are about 50 to 60 cm.

Scouring and filling processes can result in a varied snow cover with differing densities and numerous exposed areas and drifts. Kensall, 1968, and Henshaw, 1968, have stated that caribou and reindeer will not feed and dig for lichens in snow depths greater than 50 to 80 cm, or when a strong durable crust forms on top of the snow with a density exceeding 0.5 m/cm^3. Thus, in mild, snowy winters, the animals are more likely to die of starvation. Caribou calves can become marooned in excessively deep snow, while on ice they may be unable to stand during strong winds. Such conditions rapidly weaken young animals, and they may become unable to stay with the herd for protection. Thus, in colder drier winters exposure is of greatest danger to the herds. The thermoregulatory systems of young caribou especially, cannot compensate for prolonged exposure to low temperatures and strong winds.

The removal and redeposition of the snow cover by wind is also of considerable significance to ground temperatures and the occurrence and depth of thaw during the summer, and also to the growth or decline of the Penny Ice Cap and the many smaller glaciers and permanent snow banks present within the Park.

In eastern Baffin Island, blowing snow decreases in frequency until May, when it reaches a minimum, and increases from September through January. Kruger (1960) has estimated visibility for several classes of wind speed, as seen below:

Wind Speed (km/hr)	24-31	32-39	40-47	48-55	>55
Visibility in blowing snow (km)	not reduced	3-5	>3	1	0.8-0

The frequency of blowing snow during February is 12% and during May 2% depending upon local conditions. It is most often associated with northwest winds. The highest frequencies within Auyuittuq National Park are probably confined to the more exposed stations along the outer coasts and to sites in the interior where natural obstructions are few. More sheltered locations will naturally experience lower frequencies of blowing snow.

D. Cloud Cover

a) Clouds

Due to difficulties encountered by observers when recording cloud cover during the long Arctic night and also as a result of the generally short duration of records, the cloud statistics for the Park region are less than ideal. Those records that do exist suggest that maximum cloud cover occurs in the late spring and early autumn (Coulcher, 1967, p.43). During May and June, melting ice and snow provide large quantities of available moisture for cloud formation. Also, water vapour-saturated air beneath the marine inversion will condense out into fog and stratus cloud when uplift is stimulated by turbulence or orography.

During July, cloud amounts are at a minimum. In-coming radiation has melted or evaporated much of the snow and ice. Air currents rising from the warmed ground surface destroy the overlying inversion along the coasts. During September, the approaching winter is preceded by the southward penetration of cold, Arctic air. The temperature gradient between the overlying air and the relatively warm water bodies becomes quite steep, creating turbulence as the warmer air rises and the cooler air sinks. Extensive cloud and snow showers follow. As the winter becomes more severe, the inversion slowly re-establishes itself over the land areas. Ceilings of stratocumulus clouds are common over land. Over open water, cumulus clouds are more frequently seen. Once the freeze-up is complete, the amount of moisture available to the air is greatly reduced, which is marked by a decrease in cloud cover. Table 13 provides data related to cloud amounts at Cape Dyer, south of Auyuittuq National Park, and Clyde, to the north. Both represent coastal areas adjacent to large supplies of available moisture. Inland locations, such as Dewar Lakes and the inland areas of the Park, will experience greater differences between winter and summer cloud amounts (see Table 14). This is probably a result of an ice-cover in January over the extensive water bodies forming the "lake district" of Dewar Lakes. Coastal areas, of course, have open water areas even in mid-winter.

b) Fog and Low Cloud

During winter, periods of low cloud (ceiling less than 120 m) and poor visibility (less than 2 km) are usually accompanied by northwest winds. During summer, this poor weather is associated with southeast or south-southeast winds, and reaches a maximum during July. Low ceilings and visibility rarely accompany a northwest circulation in summer, as an offshore flow is usually accompanied by favourable weather. In areas which are frequented by fog, a recurring pattern of diurnal variation persists (Coulcher, 1967, p.74). Figure 36 displays the generalized pattern of fog frequency throughout the day.

According to Coulcher, the greatest density of fog develops around 3 a.m., the time of maximum cooling. The presence of this fog hinders or curtails outgoing radiation from the surface, causes temperatures to rise slowly, and the fog to dissipate somewhat. Cooling sets in once again, and a second period of dense fog becomes established around 7 a.m. As the day progresses, radiation from the sun warms the air and the fog disappears. Minimum fog frequencies occur around 3 p.m., the time of maximum heating. In spring and summer the addition of moisture to the air from day-time evaporation, when combined with gradually cooling temperatures after 3 p.m., results in fog appearing just prior to 6 p.m. Between 6 p.m. and 7 p.m., the fog curtails the cooling process, condensation of water vapour ceases, and the fog dissipates. After 7 p.m., radiational cooling encourages fog formation until approximately 11 p.m. By this time, the fog has reached a density sufficient to negate the cooling process and cause a second dissipation of fog. However, dropping temperatures again prevail and the fog increases in density until it reaches its daily maximum around 3 a.m.

Table 13

CLOUD COVER AT CAPE DYER AND CLYDE

Cape Dyer	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Mean Cloud (Tenths celestial dome)	5.6	5.3	3.8	4.6	7.4	6.5	6.3	6.8	7.4	6.9	5.7	5.5	6.0
Percentage Freq. of 8/10 - 10/10	46	43	26	32	67	54	49	55	66	60	48	45	49
Percentage Freq. of 3/10 - 7/10	21	21	23	22	19	24	29	26	22	22	19	20	22
Percentage Freq. of 0 - 2/10	33	36	51	46	14	22	22	19	12	18	33	35	29
Clyde													
Mean Cloud (Tenths celestial dome)	4.8	4.4	3.7	4.4	6.9	6.6	6.9	7.6	8.2	7.4	5.9	4.4	5.9
Percentage Freq. of 8/10 - 10/10	41	37	31	35	62	57	60	69	76	67	54	36	52
Percentage Freq. of 3/10 - 7/10	14	15	15	18	15	18	21	16	13	14	12	15	16
Percentage Freq. of 0 - 2/10	45	48	54	47	23	25	19	15	11	19	34	49	32

Source: AES, 1968

Table 14

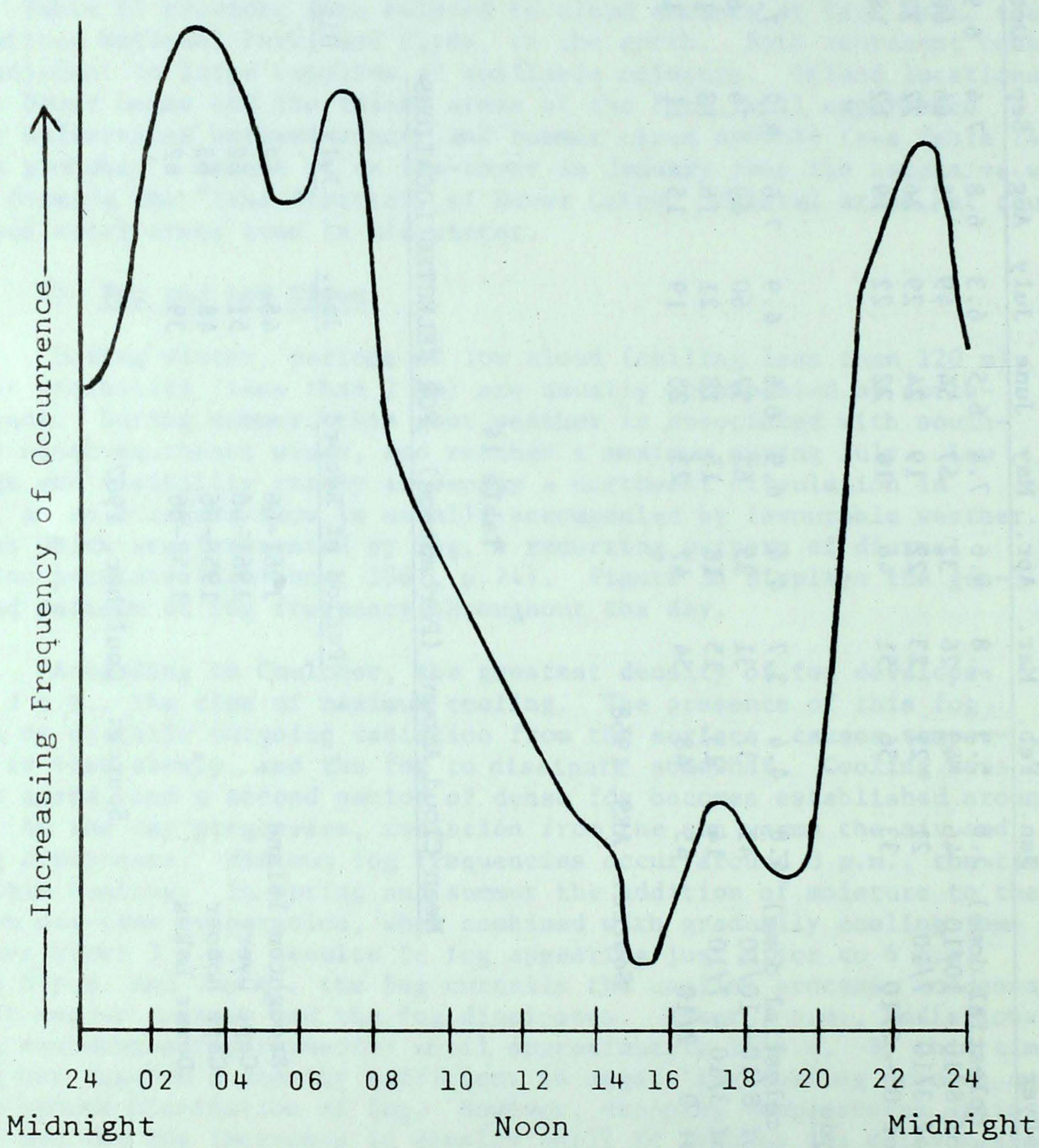
Mean Cloud Amount (Percentage) FOR SELECTED LOCATIONS

	Period of Record	Jan.	July	Difference
Broughton Island	1961-66	45	62	17
Cape Dyer	1961-66	51	62	11
Cape Hooper	1958-66	48	63	15
Dewar Lakes	1958-66	39	62	23

Source: Coulcher, 1967

Figure 36:

Generalized Pattern of the Diurnal Frequency of Fog



Source: Coulcher, 1967

c) Ice Fog

During January and February, periods of very cold weather with calm or light winds may be characterized by the formation of ice fog when there is some water vapour present. Also, a well-developed temperature inversion with cloudless skies is usually associated. Ice crystals are created by the rapid freezing of super-cooled water droplets, and the presence of numerous hygroscopic nuclei trapped beneath an inversion facilitates ice-crystal formation. Condensation nuclei are also produced in abundance by exhausted hydrocarbons from aircraft, making airports a favoured location for ice fog. Topographic depressions where cold air drainage accumulates during this nocturnal inversion are also suitable.

d) Effects of Low Cloud and Fog on Human Outdoor Activities

All of the above variations of cloud can severely restrict access to and movement within Auyuittuq National Park by visitors. Aircraft flights from exterior and interior points within the Park are frequently delayed or re-scheduled due to the presence of fog or low cloud. Visitors occasionally are required to spend an extra day or two in one of Baffin Island's villages awaiting the arrival of acceptable flying weather. Enjoyment of the scenery by hikers and snowmobilers within the Park can also be dampened while the low cloud persists. While some measures can be taken to offset the discomfort or dangers arising from other weather parameters, such as suitable clothing and shelter for extremes of temperature and precipitation, nothing can be done to alleviate the inconvenience of low cloud or fog conditions, and the visitor must be prepared for such an event.

E. Sea Ice

a) Ice Cover Along the Eastern Coastline

The presence of adjacent ice-laden waters significantly influences the climate of the Park region. In summer, the water temperatures are only slightly above the freezing point and the air immediately above the ice remains chilled. The cold surface air penetrates deeply inland by way of the fjords, profoundly altering the local climate by prolonging low temperatures and inducing widespread stratus and fog occurrences. However, cooling is also retarded in autumn.

A colder than normal winter in Baffin Bay (adjacent to northern Baffin Island) results in more ice drifting southward and affecting the coastal regions of Auyuittuq National Park. Wind direction affects the extent to which the pack and fast ice are held along the coast (Jacobs et al, 1974).

The dates of ice break-up and freeze-up are discussed below and provided in Table 15 (Allen and Cudbird, 1971). Unfortunately, information is lacking for Cumberland Sound or the Pangnirtung Fjord.

Table 15:

ICE COVER BREAK-UP AND FREEZE-UP

		DATE OF				DATE OF		
		First Permanent Ice Cover	Complete Freeze-Over	Safe Ice Traffic	Maximum Thickness (in.)	Unsafe Ice Traffic	First Ice Deterioration	Water Clear of Ice
Broughton Island	Earliest Date	Sept. 23	Nov. 1					
	Latest Date	Nov. 15	Dec. 5					
Cape Dyer	Earliest Date	Oct. 14	Oct. 28		30		June 2	
	Latest Date	Dec. 12	Dec. 16		60		June 28	
Cape Hooper (Home Bay)	Earliest Date	Oct. 25	Nov. 19				June 15	
	Latest Date	Dec. 1	Dec. 23				June 9	
Cape Hooper (unnamed Lake)	Earliest Date						June 28	
	Latest Date						July 10	
Clyde (Patricia Bay)	Earliest Date	Oct. 17		Sept. 15	56	May 31	June 8	July 2
	Mean Date	Nov. 6			65		July 6	Aug. 1
	Latest Date	Nov. 24		Dec. 10	78	July 20	July 26	Oct. 2
Frobisher Bay (Koojesse Inlet)	Earliest Date	Sept. 20	Nov. 2	Oct. 2	53	May 31	May 22	June 28
	Mean Date	Oct. 18			62		June 16	July 15
	Latest Date	Nov. 12	Nov. 27	Nov. 13	69	July 10	July 7	July 28
Frobisher Bay (Sylvia Grinnel R.)	Earliest Date	Oct. 15					May 30	June 21
	Latest Date	Nov. 10					June 10	July 10

Source: Allen and Cudbird, 1971

At Broughton Island, ice begins to form during late September through mid-November. Freeze-up is usually completed during November or early December.

Farther north, freeze-up at Cape Hooper in Home Bay usually begins in late October or November, and reaches 100% coverage in the latter half of November or early December.

In Sunneshine Fjord, at Cape Dyer, ice begins forming from mid-October to early December. The process is usually completed in November or early December.

Initial break-up of the ice in Davis Strait begins in June or early July. Dates pertaining to the elimination of all ice are not available. Large icebergs can be seen floating in the Strait during any month of the year. Ice break-up is dependent upon a number of factors. Air temperature and wind speed and direction are most important early in the summer season. After puddles have formed on the ice surface more solar radiation can be absorbed by the ice; radiation and cloudiness therefore become important too.

During the 1969-70 winter, mean sea level pressure remained slightly below normal as the result of a separate component of the Icelandic low pressure cell being located over Baffin Island in February, and over Newfoundland in March. Because of this, the drift was westward or southwestward in Baffin Bay and Davis Strait instead of the usual southward drift. The pack ice was therefore much heavier than normal. Break-up occurred later than predicted.

In spite of the prolonged presence of ice cover along the eastern coastline of the Park, a definite maritime, moderating influence exists. During summer, temperatures remain within several degrees of freezing as a result of the presence of ice packs and lack of strong solar heating. During winter, the transfer of heat through the ice prevents temperatures from falling to very low levels, as indicated in Figures 12 through 15 and 23.

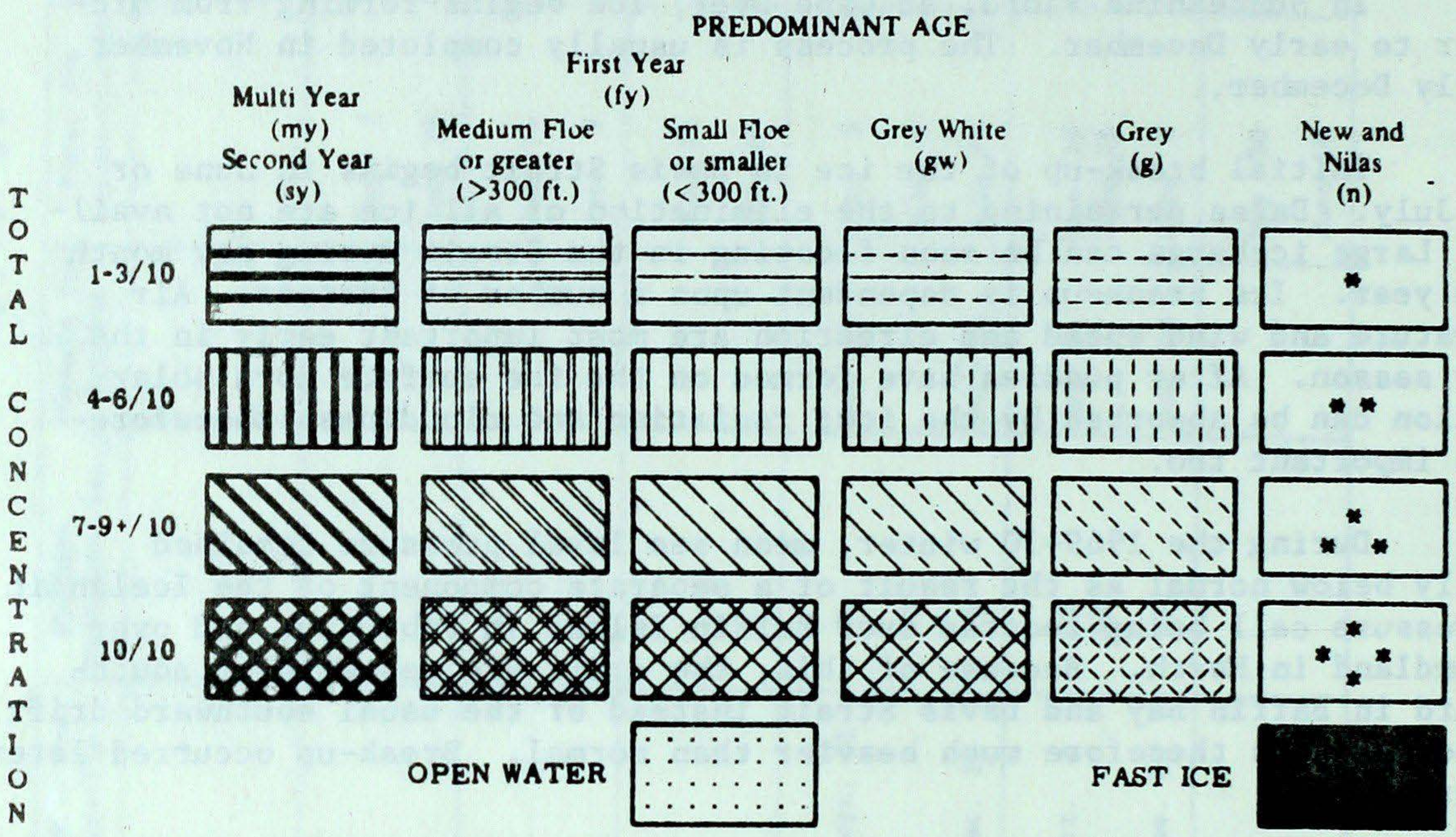
b) Effects of Sea Ice on Human Outdoor Activities

In ice-laden waters transport by boat or canoe becomes extremely dangerous because of the chance of an upset. Fishing and sight-seeing along the coast is risky or even foolhardy during certain periods. In thick ice no ships are able to move; hence supplies from southern Canada are restricted to what can be brought in by aircraft.

In terms of comfort, a wind off ice-covered water in summer is unpleasant though it will drive away insects. The ice near shore of course is a traditional transportation highway during winter.

Figure 37:

Key to Ice Symbols



CONCENTRATION AND SIZE BY AGE

$\frac{\text{Tenths of Each Age}}{\text{Tenths of Mdf. or Greater}}$ $\frac{(C)}{(N)}$ Mdf. is Medium Floe – >300 ft.

$\frac{C_{my}\ C_{sy}\cdot C_{fy}\ C_{gw}\ C_g\ C_n}{N_{my}\ N_{sy}\ N_{fy}\ N_{gw}\ N_g\ N_n}$ Example $\frac{20.3410}{1\quad 23}$

(Where N is in Tenths)

$\frac{2}{1}$ 2/10's Multi-Year Ice of which 1/10 (Half) is Medium Floe or Greater Size

0 No Second-Year Ice

. Decimal Point

$\frac{3}{2}$ 3/10's First-Year Ice of Which 2/10's is Medium Floe or Greater Size

$\frac{4}{3}$ 4/10's Grey-White Ice of Which 3/10's is Medium Floe or Greater Size

1 – 1/10 Grey Ice, No Medium Floe or Greater Size

0 – No New Ice or Nilas

ICE OF LAND ORIGIN

△ – (n) Icebergs

TOPOGRAPHY

$\frac{\wedge\wedge}{(n)}$ Rafting/extent

$\frac{\wedge\wedge\wedge}{(n)}$ Ridging/extent

$\frac{\frown\frown}{(n)}$ Hummocks/extent

$\frac{\text{Pd}}{(n)}$ Puddling/extent

Source: A.E.S., 1970b

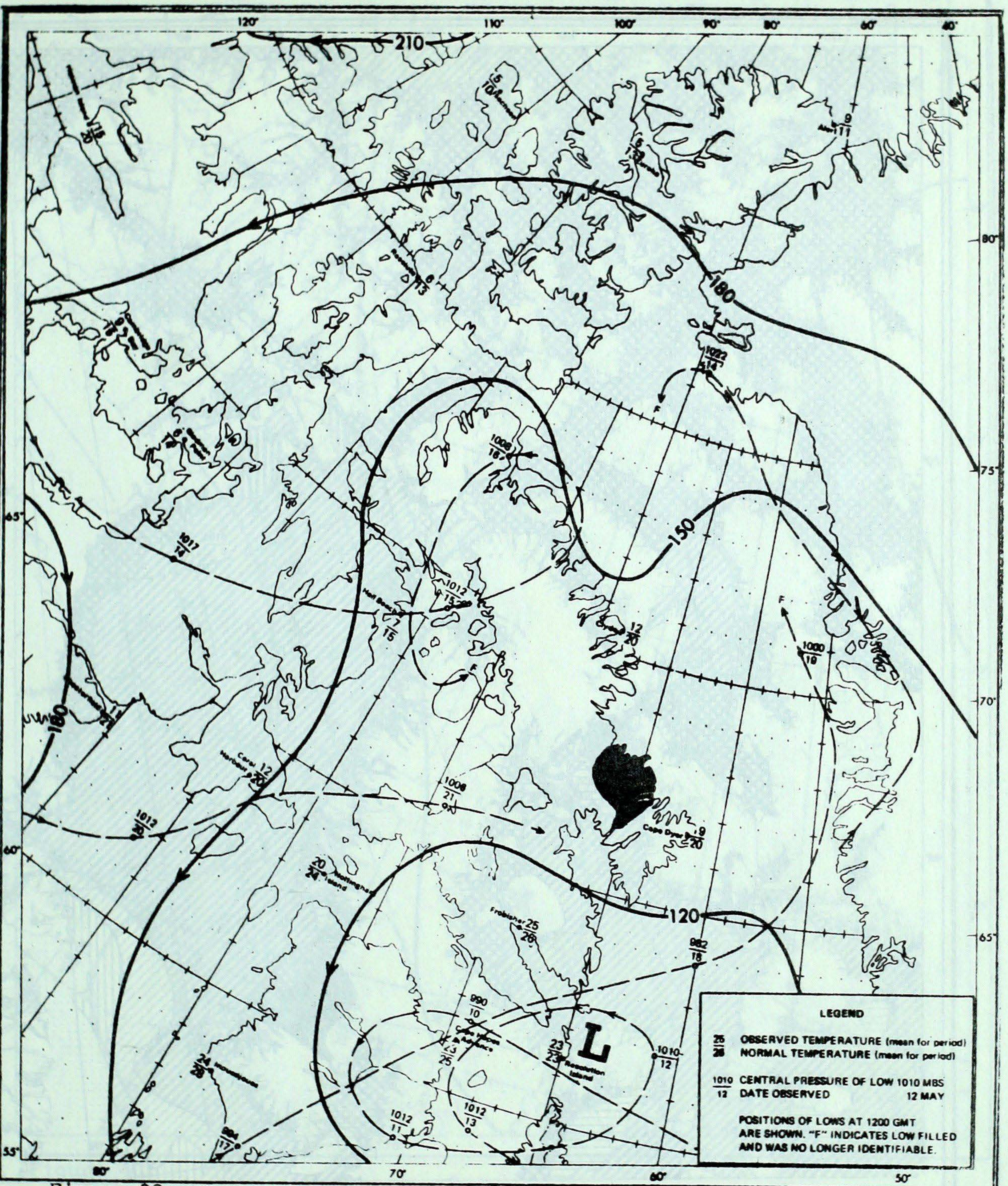


Figure 38:

MEAN TEMPERATURE AND WIND CHART FOR THE PERIOD 8–21 MAY 1970

From a low centered near Resolution Island a troughline lay northwestward toward Barrow Strait. This maintained a light on-shore drift pattern along the coast from Cape Dyer to Bylot Island and a southward drift trend in eastern Parry Channel. Temperatures north and west of Cape Dyer averaged well below normal.

Source: A.E.S., 1970b

Figure 39:
ICE CONDITIONS ON 21 MAY 1970

Openings were developing along the fast ice on the west coast of Greenland. Development of the North Water area was continuing and loosening was beginning in eastern Lancaster Sound. The Hall Beach polynya was well developed. Most of the ice remained quite heavily snow-covered.

Source: A.E.S., 1970b

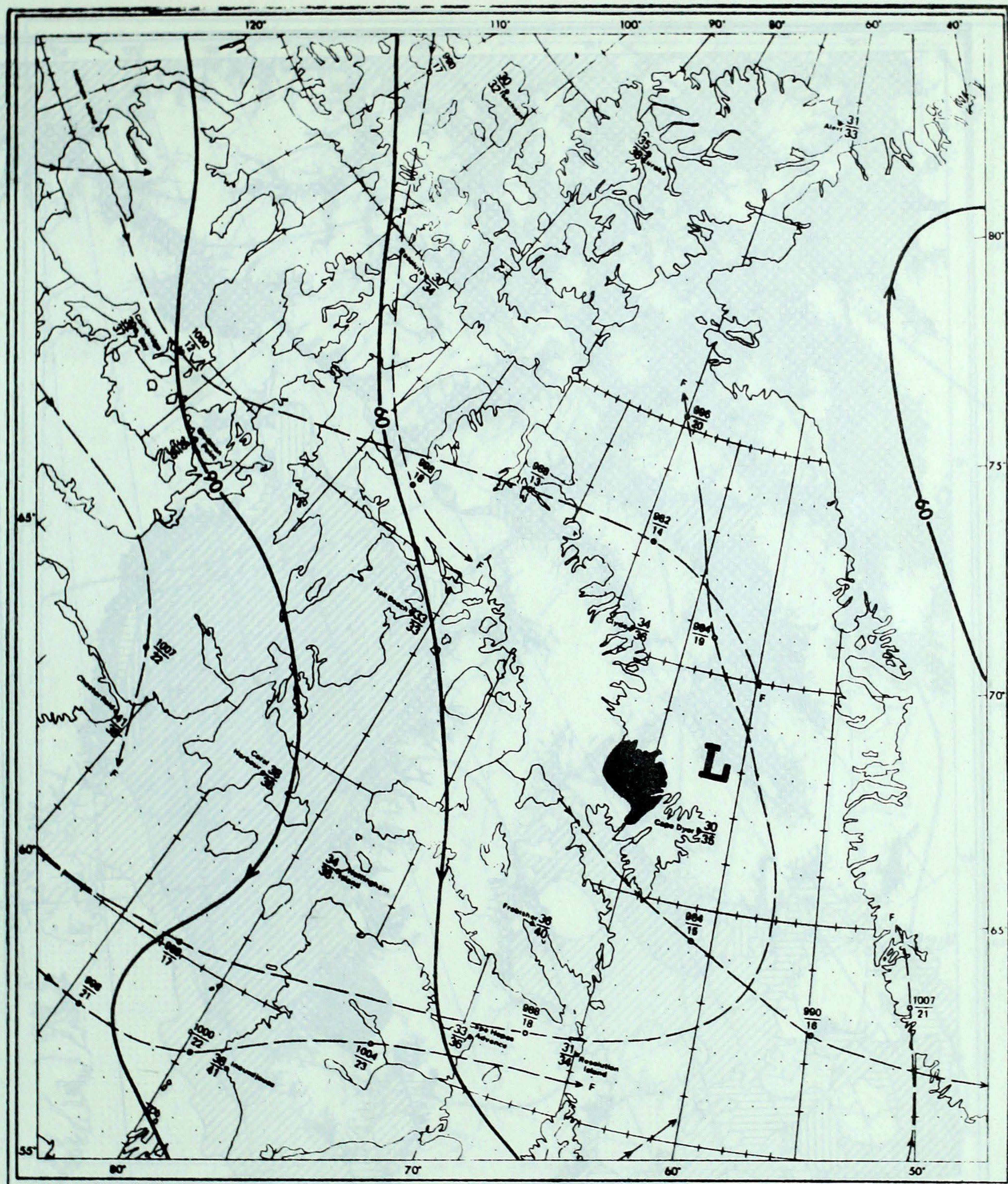


Figure 40:

MEAN TEMPERATURE AND WIND CHART FOR THE PERIOD 12–25 JUNE 1970

A weak trough persisted over Davis Strait and Baffin Bay and across Ellesmere Island. The number of migratory low pressure areas increased as did their intensity. Only over Foxe Basin and the Gulf of Boothia were resultant winds relatively strong. Average temperatures over the eastern Arctic were near or above normal, but at several locations remained below the melting point.

Source: A.E.S., 1970b

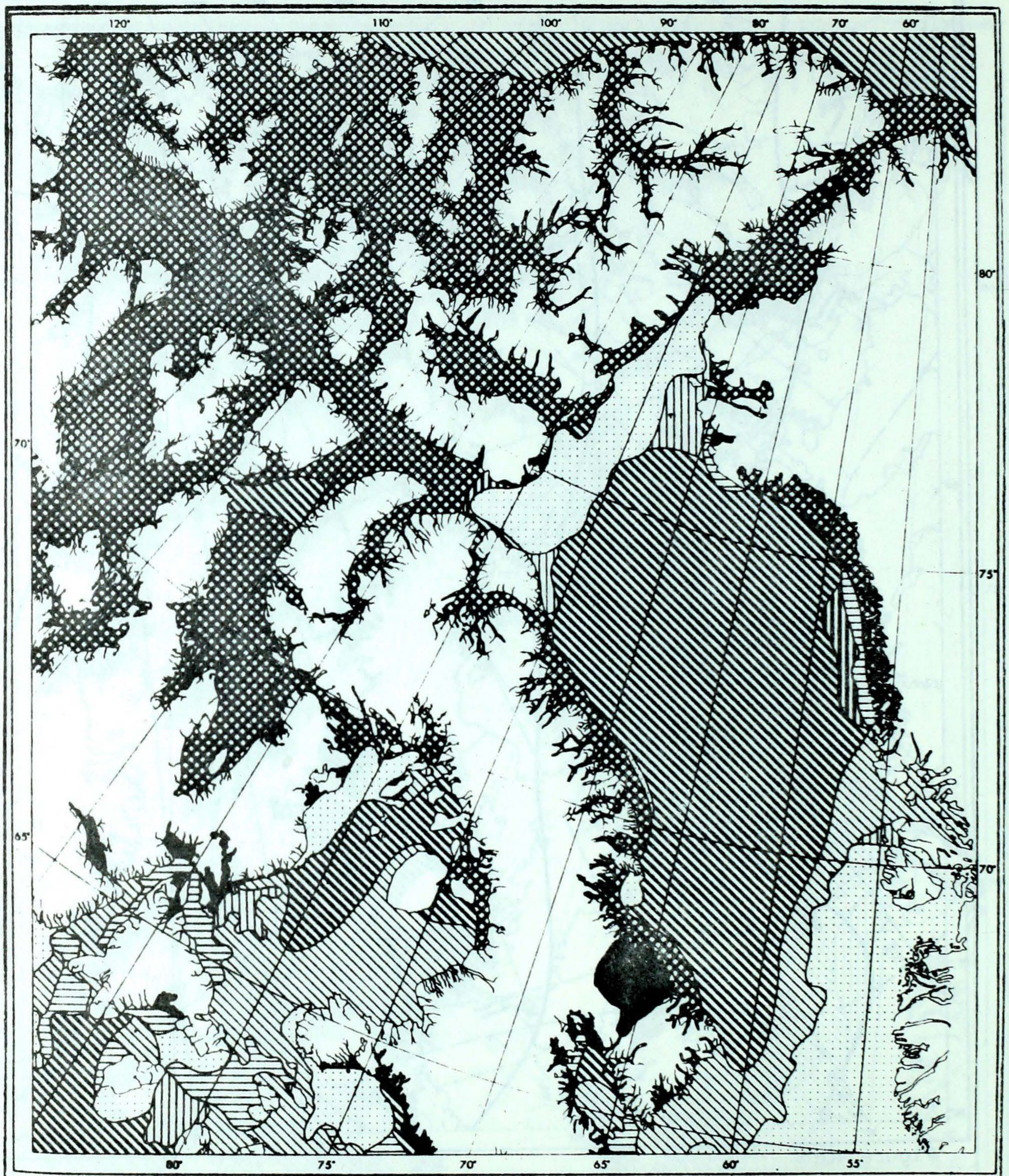


Figure 41:

ICE CONDITIONS ON 25 JUNE 1970

The break-up process accelerated along the west coast of Greenland and the Hall Beach polynya expanded in response to prevailing winds. Although the North Water expanded at the entrance to Lancaster Sound the ice from Barrow Strait to Eureka Sound remained consolidated.

Source: A.E.S., 1970b

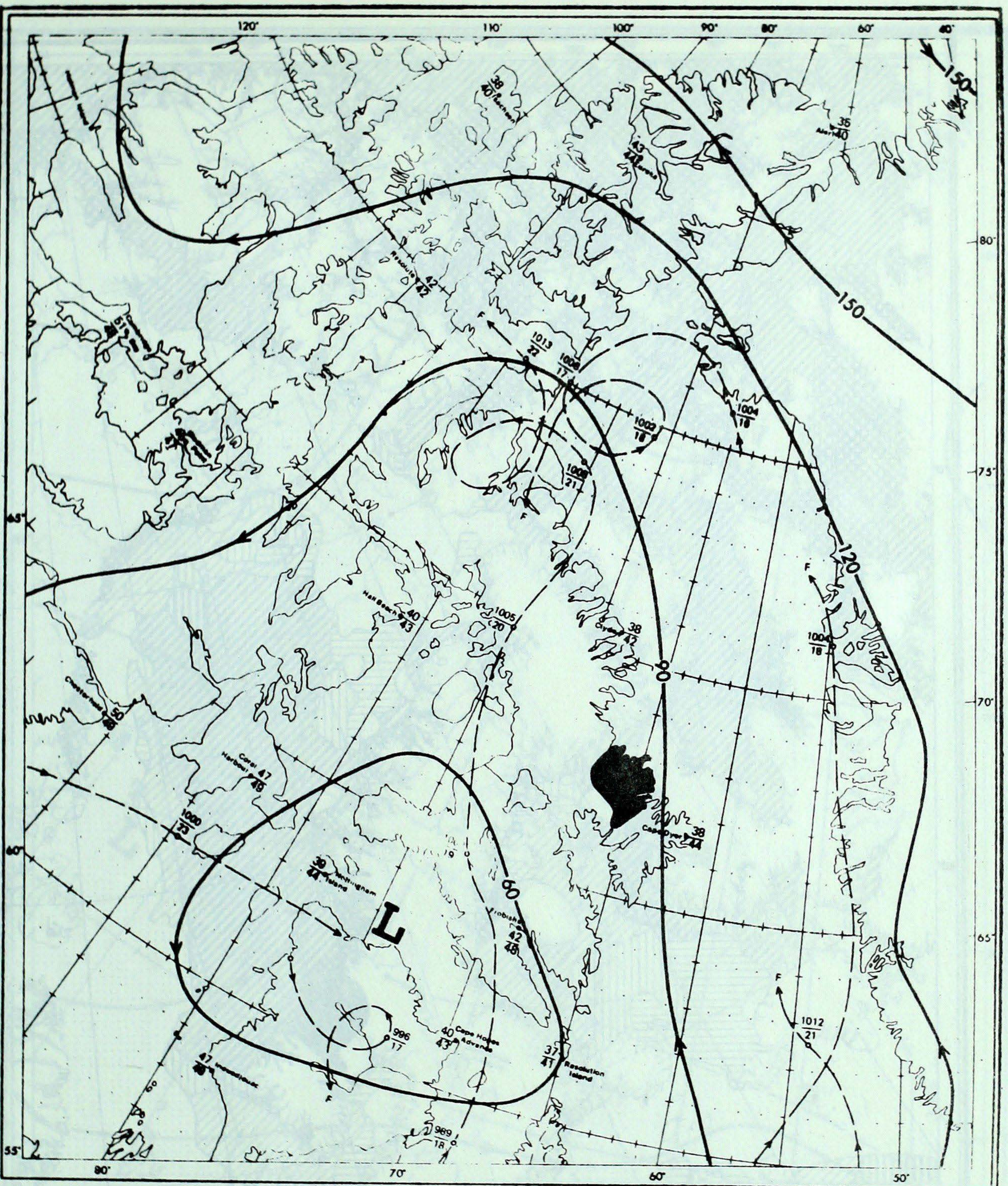


Figure 42:

MEAN WIND AND TEMPERATURE CHART FOR THE PERIOD 17–23 JULY 1970

With a low centered near Nottingham Island and a trough across Foxe Basin to Eureka, gradients were somewhat stronger with mean southeasterly winds over Baffin Bay, easterly winds over Lancaster and Jones Sounds and northeasterlies over the central Arctic. The temperature pattern reverted to generally below normal through the eastern Arctic.

Source: A.E.S., 1970b

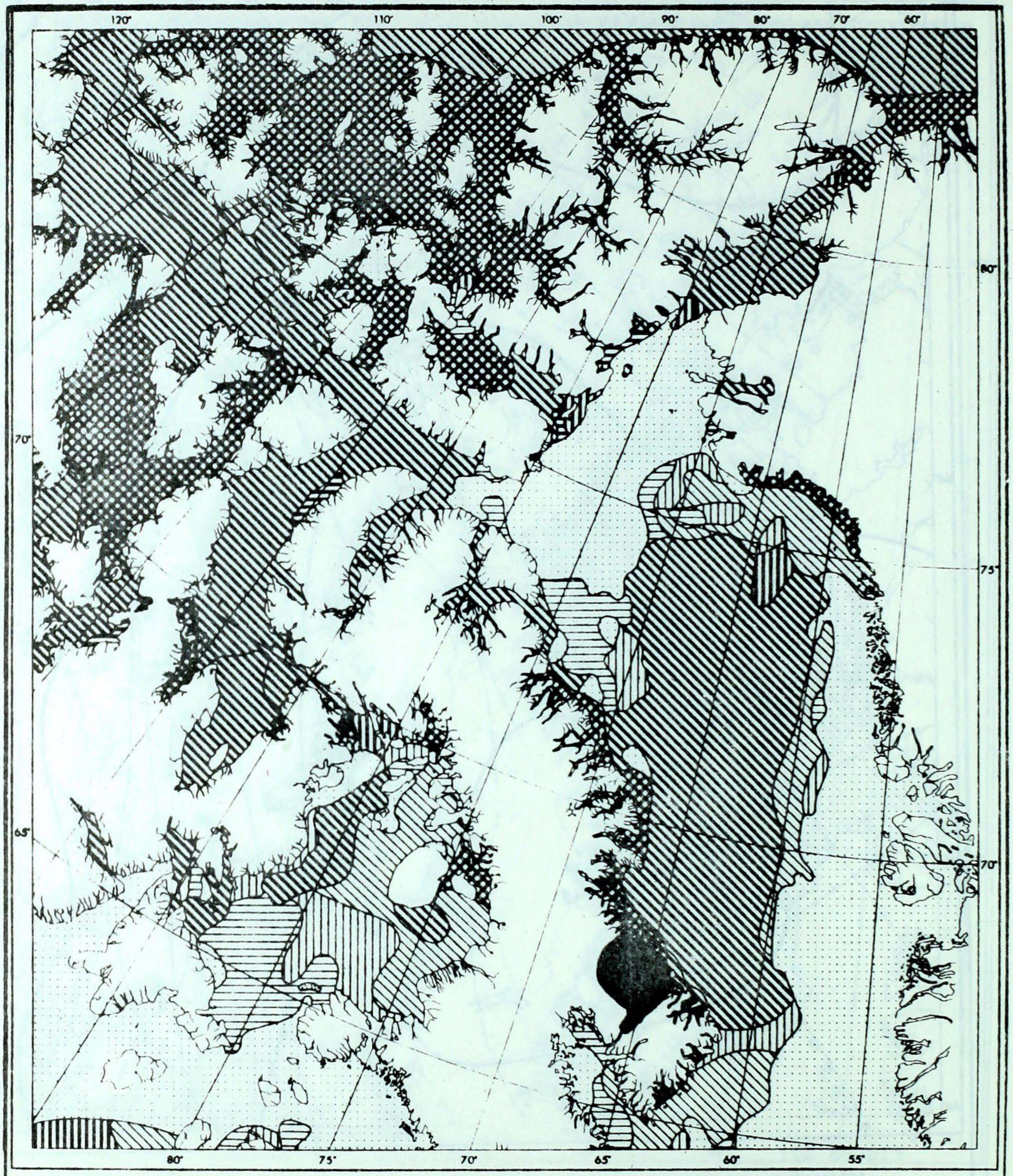


Figure 43:

ICE CONDITIONS ON 23 JULY 1970

The west Greenland coastal lead opened to near 75°N as the ice drifted northwestward in northern Baffin Bay. The Pond Inlet Eclipse Sound Navy Board Inlet area reduced to close pack ice. The band of consolidated ice along the northeast coast of Baffin Island was also breaking. Initial break-up occurred in Eureka Sound, Greely Fiord, southern Norwegian Bay and eastern Barrow Strait.

Source: A.E.S., 1970b

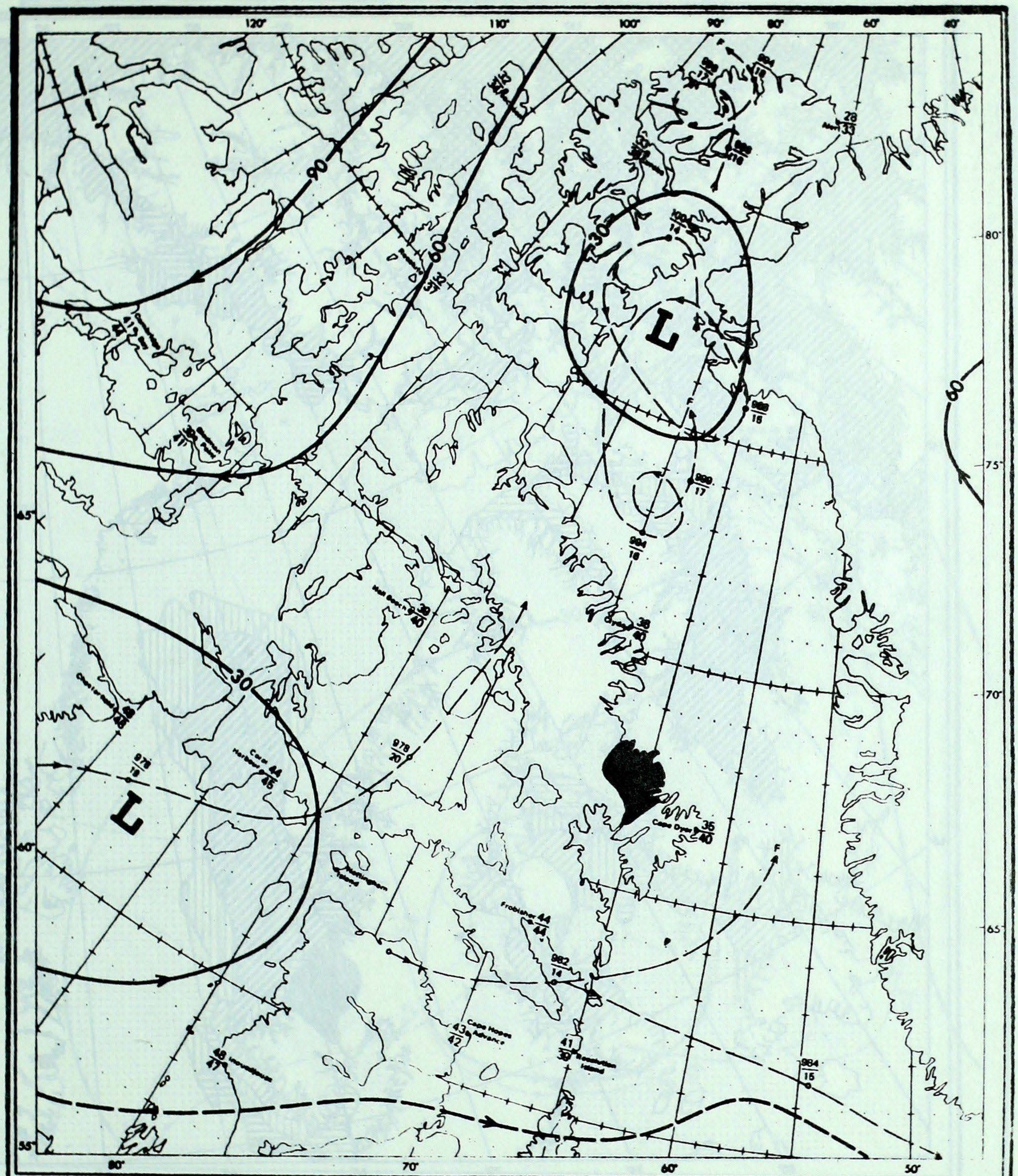


Figure 44:

MEAN TEMPERATURE AND WIND CHART FOR THE PERIOD 14–20 AUGUST 1970

The gradient remained weak over Davis Strait – Baffin Bay and over Foxe Basin. A stronger gradient over Queen Elizabeth Islands gave moderate northwest winds over central Parry Channel. Temperatures across the eastern Arctic were below normal and had dropped below the freezing point in the extreme north.

Source: A.E.S., 1970b

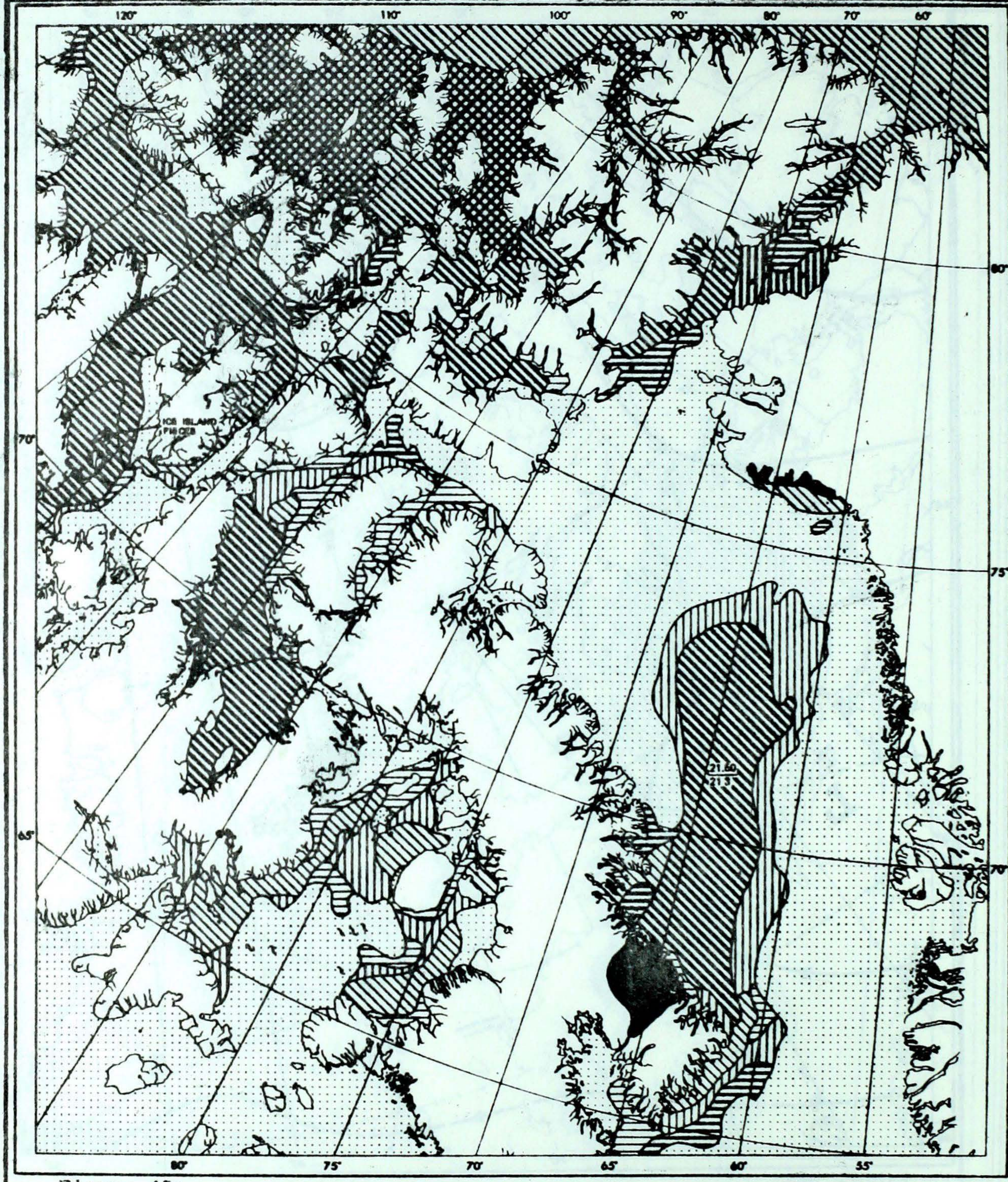


Figure 45:

ICE CONDITIONS ON 20 AUGUST 1970

Heavy congestion persisted in much of Home Bay and close pack ice remained in the approach to Cape Dyer as well as through central Baffin Bay. Increased loosening and efflux of ice from Kane Basin occurred. Conditions in Eureka Sound had improved as had those in Lancaster Sound and Barrow Strait but the major change was the clearing in Parry Channel west of Resolute and the drift of old ice through Penny Strait.

Source: A.E.S., 1970b

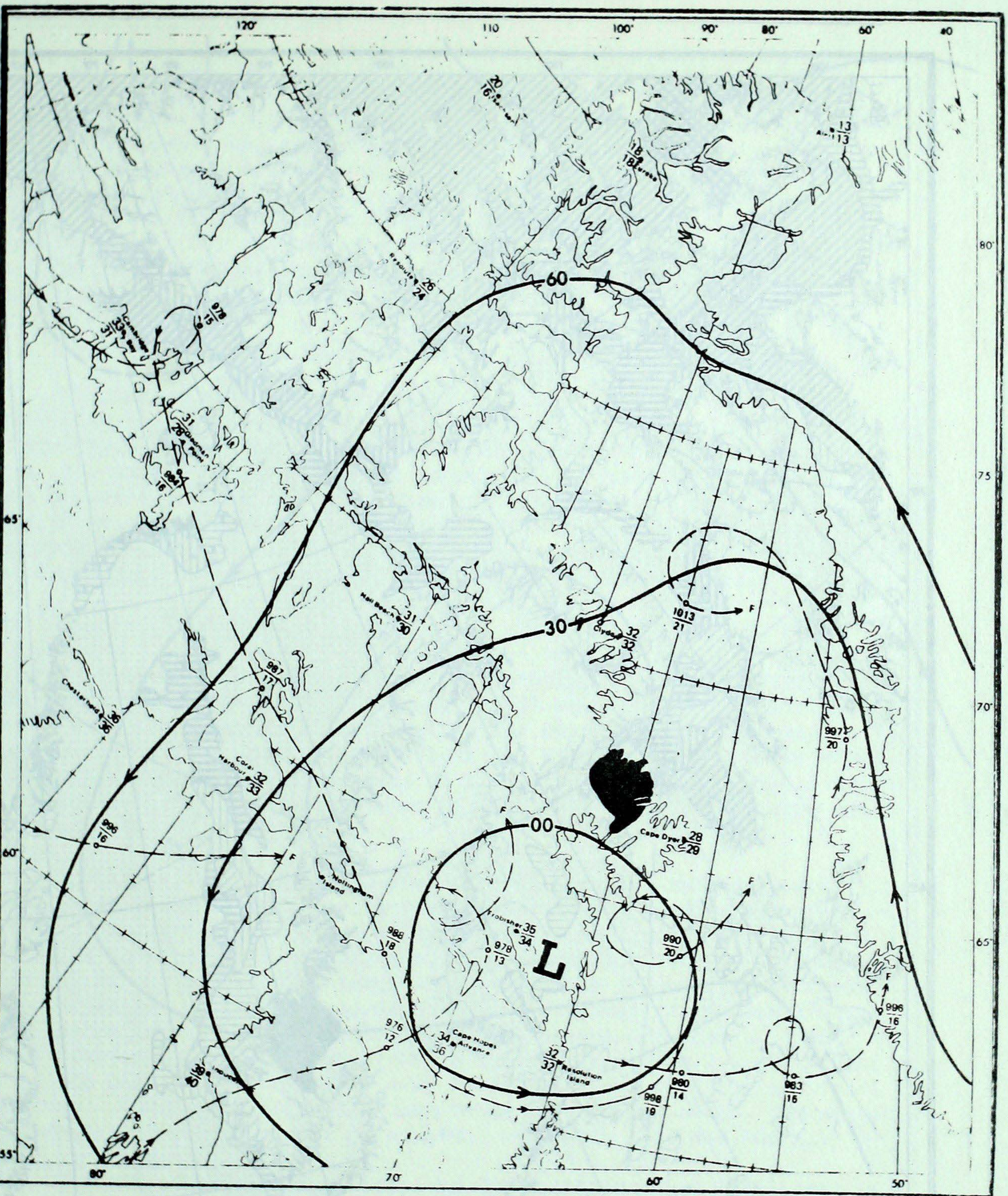


Figure 46:

MEAN TEMPERATURE AND WIND CHART FOR THE PERIOD 11–24 SEPTEMBER 1970

A series of migratory lows resulted in a mean low centered near Frobisher with resulting on-shore winds along the east Baffin coast and northeast winds over Foxe Basin and eastern Parry Channel. The seasonal decline in temperatures was evident throughout with mean temperatures at or below the freezing point over Foxe Basin and the east Baffin coast.

Source: A.E.S., 1970b

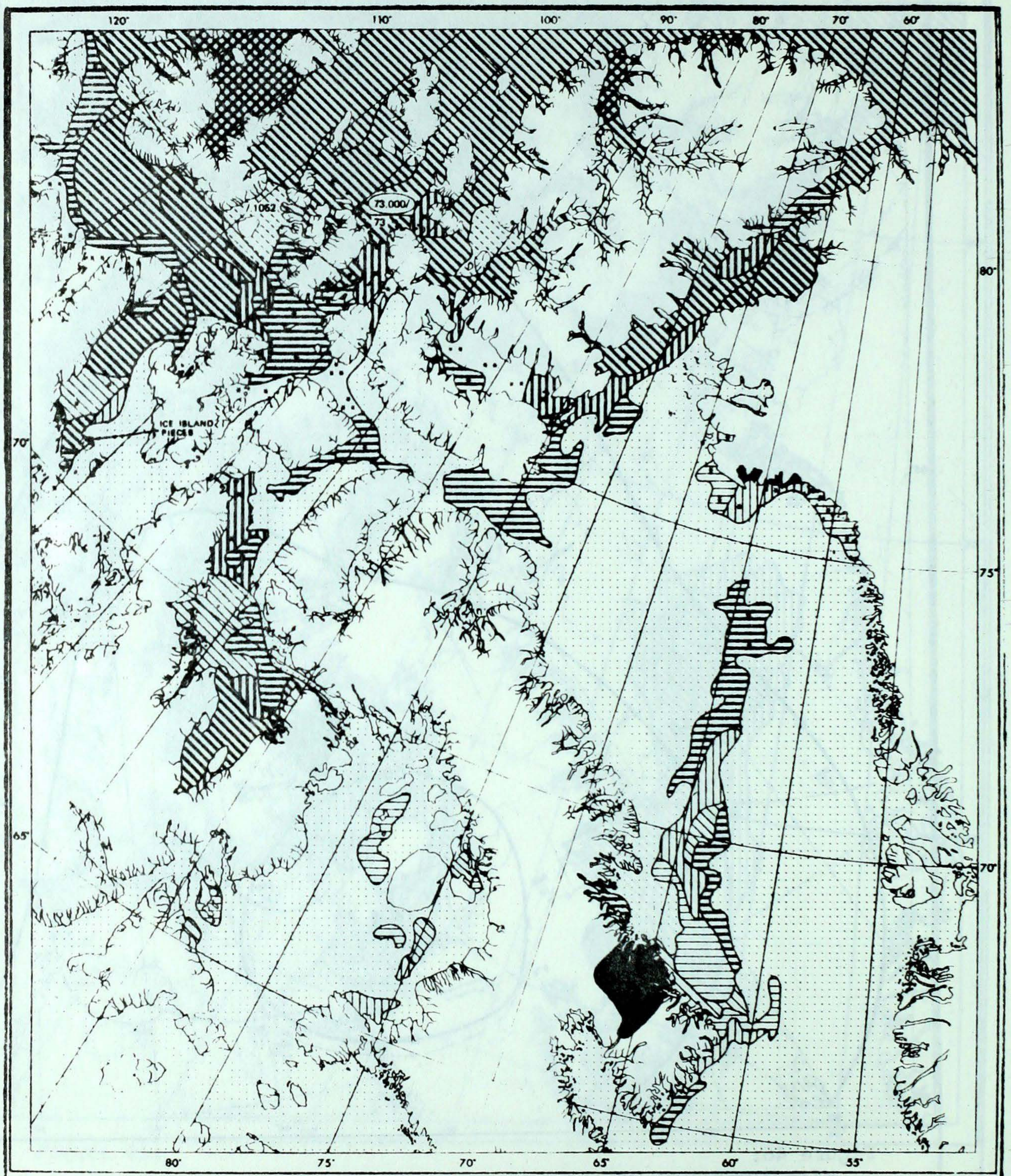


Figure 47:

ICE CONDITIONS ON 24 SEPTEMBER 1970

A narrow belt of ice remained through central Baffin Bay and in the approach to Cape Dyer but gradual disintegration was continuing. Ice growth accelerated in Nares Strait and the northern islands where transformation to Grey-White and First Year ice was evident. Little growth had yet occurred in eastern Parry Channel, while in Foxe Basin melting had further reduced the existing ice areas.

Source: A.E.S., 1970b

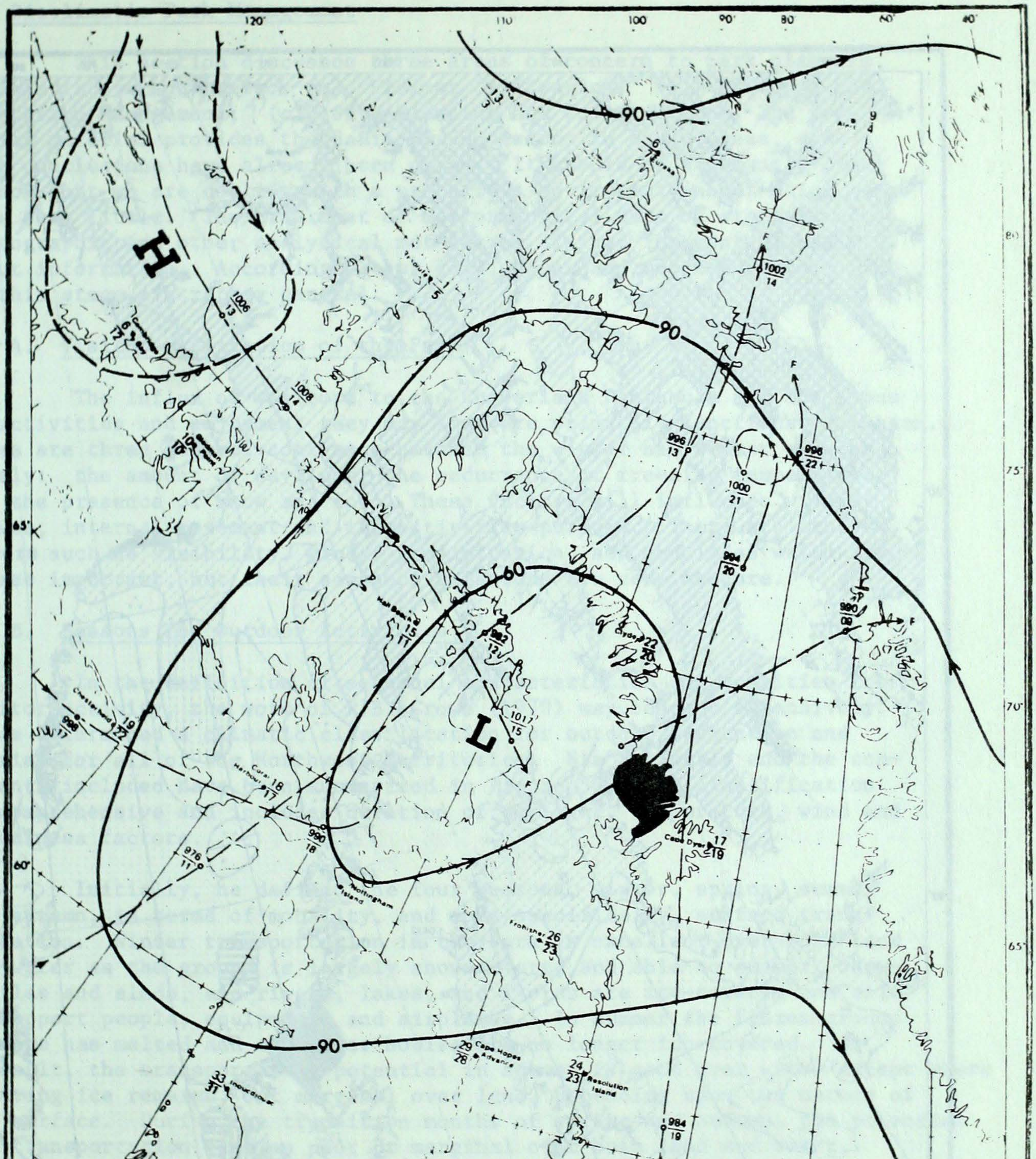


Figure 48:

MEAN TEMPERATURE AND WIND CHART FOR THE PERIOD 9–22 OCTOBER 1970

Again, several low pressure systems crossing the area gave a mean low centered over eastern Foxe Basin. Gradients were moderate except over Queen Elizabeth Islands. The seasonal temperature decline continued with greatest decreases in the north, and the general pattern showing both above and below normal values.

Source: A.E.S., 1970b

Figure 49:

ICE CONDITIONS ON 22 OCTOBER 1970

Significant areas of ice remained south of Cape Dyer and the new season's ice growth was advancing rapidly across northern Baffin Bay. Through the northern islands and eastern Parry Channel ice growth reached the close pack to consolidated ice state with much of the ice in the First Year stage. Ice growth covered northern Foxe Basin.

Source: A.E.S., 1970b

VI. Bicolimatic Park Management

This section discusses three areas of concern to park planners, administrators and users: (a) Visitor Utilization; (b) Wildlife and Vegetation Management; (c) Site Planning and Construction. The preceding material provides the basis for decisions in these areas, and some conclusions have already been drawn. It should be abundantly clear by now that we are dealing with a precarious environment about which we know very little. The treatment of meteorological data by statistical, cartographic and other analytical methods is limited for want of basic input information. Accordingly, our conclusions and recommendations even at this stage are rather general.

A. Visitor Utilization of the Park

The influx of visitors to the Cumberland Peninsula and the types of activities and enjoyment they may find are primarily functions of season. There are three general contrasts between the winter and summer seasons, namely: the amount of daylight; the occurrence of freezing temperatures; and the presence of snow and ice. These factors will influence visitor access, internal movement and the activities pursued. There are other factors such as visibility, winds, precipitation, and sunniness which are of course important, but their seasonal relations are more obscure.

B. Seasons for Outdoor Activities

In the definition of seasonal characteristics and qualities for visitor activity, the work of R.B. Crowe (1970) may be used extensively. Crowe determined a climatic classification for outdoor recreation and tourism for all of the Northwest Territories. His rationale and the components included have been summarized in Figure 50. The classification is comprehensive and includes duration of daylight, temperature, wind and cloudiness factors.

Initially, he defined the four seasons, winter, spring, summer and autumn, in terms of mobility, and more specifically, surface transportation. Winter transportation in the Park is excellent over both land and water as the ground is largely snow-covered and able to support snowmobiles and sleds, and rivers, lakes, and fjords are ice-covered and able to support people, equipment, and airplanes. In summer the frozen ground surface has melted and the water bodies are no longer ice-covered. As a result, the transportation potential in summer is good over water except where floating ice remains, but marginal over land, depending upon the nature of the surface. During the transition months of spring and autumn, the potential for transportation remains poor or marginal over both land and water.

The winter season, as defined by Crowe, begins when the ground is snow-covered and lakes, rivers, and fjords are fast-frozen. It ends when the snow cover has melted or with the initial breaking up of the ice in water bodies. In Auyuittuq National Park, winter generally persists from the end of October through early June.

Summer is said to begin when lakes, rivers, and fjords are ice-free (excepting floating ice which lingers in the Davis Strait) and the ground is

FIGURE 50:

Climatic Potential For Outdoor Recreation

And Tourism In Auyuittuq National Park

(Derived From R. B. Crowe, 1970)

Winter Factors

1.) Length of Sunlight Plus Civil Twilight → > 12 hr. = Ideal; 6–12 hr. = Marginal; < 6 hr. = Sub-marginal

2.) Temperature (Mean daily maximum temperature) → > -18°C = Ideal; -18 to -26°C = Marginal; < -26°C = Sub-marginal

3.) Wind → < 16 km/hr = Ideal; 16–24 km/hr = Marginal; > 24 km/hr = Sub-marginal

Summer Factors

1.) Temperature → ≥ 10°C = Ideal; < 10°C = Marginal

2.) Cloud Amount → < 50% = Ideal; 50–70% = Marginal; > 70% = Sub-marginal

3.) Wind → < 16 km/hr = Ideal; ≥ 16 km/hr = Marginal

	January 1	January 15	February 1	February 15	March 1	March 15	April 1	April 15	May 1	May 15	June 1	June 15	July 1	July 15	August 1	August 15	September 1	September 15	October 1	October 15	November 1	November 15	December 1	December 15
Winter Grade	D	D	D	C	C	B	A	A	A+B	B	B	A+B	TR	TR	······	······	······	······	TR	TR	C	C	D	-D
Summer Grade	······	······	······	······	······	······	······	······	······	······	······	······	TR	TR	B	B	B	B	TR	TR	······	······	······	······

Daylight: —S-m→ (January) ← Marginal → (February – mid-March) ← Ideal → (mid-March – September) ← Marginal → (October) ← Sub-marginal – (November – December)

Seasons: ← WINTER → (January – mid-June) | Transition (mid-June – July 1) | ← SUMMER → (July – September) | Transition (October) | ← WINTER → (November – December)

Winter Recreation-Tourism Classification

Grade	Factor Combinations	Capability for Recreation and Tourism
A	Ideal all factors	Excellent for non-residents and residents. No significant restrictions
B	Two ideal, one marginal	Generally satisfactory for non-residents and residents. Length of daylight and civil twilight plus wind chill may approach lower limits for comfort and safety.
C	Two ideal, one marginal, or one ideal, two marginal	Generally unsatisfactory for non-residents but considerable activity possible by residents in local areas
D	One ideal, one marginal, and one sub-marginal, or more than two marginal, or more than one sub-marginal	Highly unsatisfactory for non-residents and extremely restrictive for residents.

Summer Recreation-Tourism Classification

Grade	Factor Combinations	Capability For Recreation and Tourism
B	Two ideal, one sub-marginal, or one ideal, two marginal	Generally satisfactory for non-residents. Reasonably good for residents in local areas.

Symbols

TR = Transition period from one season to another

Daylight = Sunlight plus civil twilight

> Greater Than

< Less Than

≤ Equal to or less than

no longer snow-covered (excepting perennial ice- and snow-fields). It ends with the arrival of the first autumn snow cover or with the first appearance of the ice in the lakes, rivers, fjords, whichever is earlier. In Auyuittuq National Park summer begins around mid-July and ends during the last half of September.

C. Weather Quality for Outdoor Activities

Those activities which may be practised at a given time of year are indicative of the season quality. The climate may be described in terms of the opportunities and constraints it presents for each type of activity.

Some of the outdoor recreational activities that may be enjoyed by Park visitors during the winter months include snowmobiling, skiing, snowshoeing, ice fishing, landscape and nature viewing, and photography. Crowe has suggested that three factors are most responsible in determining how suitable the weather is for these activities; duration of daylight, temperature, and wind.

The duration of daylight includes the number of hours of sunlight, e.g. when the sun is above the horizon; and the duration of civil twilight, e.g. the time when the sun is just below the horizon but still providing the sky with enough light to permit people to continue their outdoor activities. In the most northerly regions of the Park, where the sun remains below the horizon for up to two weeks during the winter season, civil twilight does break the continuum of total darkness for an hour or two each 24-hour period. However, a minimum of six hours of daylight is considered necessary by Crowe for outdoor activities to be worthwhile, and this condition is not met from early November to the end of January (Figure 1). Six to twelve hours are "marginal" while more than twelve hours of daylight are "ideal". The average durations of sub-marginal, marginal, and ideal conditions for Auyuittuq National Park are also shown in Figure 50. The daylight quality is considered ideal from mid-March through September.

The temperature factor used is mean daily maximum temperature, as most recreational activities will be engaged in at the time of day when the temperature is highest. The ideal, marginal, and sub-marginal classes of temperature are listed in Figure 50.

The wind factor used is mean monthly wind speed, and the wind classes are also provided in Figure 50.

Some of the outdoor recreational activities that summer visitors to the Park may enjoy include landscape and nature (e.g. wildlife and vegetation) viewing, photography, hiking, mountain climbing, and fishing, the latter especially off the coasts of Baffin Island near Pangnirtung and Broughton Island and at the mouths of rivers. Those weather factors considered most important to summer outdoor recreation include temperature, cloud amount, and wind. Precipitation varies considerably over short distances because of topographic diversity, and was not included by Crowe in his analysis. Cloud cover in combination with wind, however, does give a reliable estimate of the general frequency of storms passing through the area.

The frequencies of the different factor classes were combined to determine a classification of weather potential for both winter and summer outdoor recreational activities. It can be seen in Figure 50 that the weather is at least generally satisfactory (with few or no weather restrictions) for winter activities from mid-March through all of June, and ideal from early April through the first of May. On the average, generally satisfactory weather conditions for summer outdoor recreational activities begin in early August and linger through late September.

Thus, August and September weather is the most suitable for outdoor recreational activities during summer, and April weather is best suited for winter past-times.

D. Visitor Access

Conditions of internal accessibility have already been suggested to some extent. There are significant frequencies of severe inland weather in all months to persuade the visitor to remain vigilant, cautious and prepared for eventualities. Overland travel in winter is facilitated by snow and ice surfaces, though there is always a risk of cold injury, and navigation during heavy precipitation or blowing snow is difficult. Summer travel is of course slower over rough or wet land surfaces, though lakes and coastal waters are at time helpful, particularly when ice and fog are absent. The transition periods, as identified by Crowe possess the most undesirable aspects of the cold and warm seasons.

In terms of access from the exterior, travellers by air can have their voyage halted or changed on short notice due to bad weather at any time of the year, but in particular during late autumn and winter. For example, the months of October, December, January, February and May at Frobisher Bay Airport have more than 50 hours, respectively, with ceilings and visibilities below the visual flight rules. The worst month is February with nearly 70 hours below VFR, while June and September have less than 40 hours (Yorke 1972).

The main impediment to surface access from outside is ice, which has been illustrated geographically and synoptically by Figures 37-49. August and September are the most ice-free months.

E. Wildlife and Vegetation Management

For natural reasons the Park does not have a large wildlife population. There is virtually no food to be obtained from the ice-field region, and the extensive areas of rock outcrop are not amenable to herbivorous animals. The climates of these areas are, therefore, of limited importance in this context. More critical here are those local zones and niches where plants and animals establish inter-dependent communities. Such milieux are very sensitive to inadvertent site modifications brought about for example, by too many visitors travelling over the tundra. The prosperity or decline of a particular ecosystem may often be related to micro-climatic factors for which we have very limited information. However, life zones are sporadically distributed throughout the region below the permanent ice, and weather changes documented by well-positioned climatological stations should have important general implications. For example, there are certain critical periods of the year for the larger mammals, particularly ruminants which do not have shelter in caves or burrows with favourable micro-climates. These are: (a) the rutting periods in fall, late October, early November, when the intense activity weakens the males, and (b) the calving period in spring when mortality rates are high among the young and the females. Debilitating conditions would be chilling or freezing rains with wind and falling temperatures when the young or weakened animals fail to adjust their body heat to combat the cooling of the air. Snow cover is also important to grazing animals, as discussed under "Blowing Snow". Depths of less than 10 cm present few problems for feeding, particularly if there are no ice crusts. Muskoxen are less tolerant than caribou to snow cover over their rangeland. As well, deep snow or moderately deep layers with thin crusts that long-legged animals may break through can be hazardous.

In an attempt to relate specific climatic dangers to wildlife, a comparison of snow cover depths at Broughton Island and Dewar Lakes was made for the 1961-70 period. It is noted that a particularly heavy snowfall was received over the winter and continuing into the summer of 1962-63 at both stations, but at Broughton Island severe winters also occurred in 1967-68 and 1969-70. Years having 5 months or more with above-normal snowfall include 1963 and 1970 at Dewar Lakes and 1961, 1963, 1964, 1967, 1968, 1969 and 1970 at Broughton Island between 1961-1970.

An analysis was made of the continencies of debilating weather conditions during the critical calving and rutting periods. These times were defined as May 15 - June 15 and October 15 - November 15, respectively. The factors assessed were: (a) high snowfall amounts (b) occurrences of freezing rain or rainfall followed by cold temperatures, (c) the incidence of wind chill values exceeding 1100 $kgcal/m^2/hr$. This refers to an incidence of one or more mean hourly wind speeds on any day of the month > 1100 $kgcal/m^2/hr$. The data are summarized in Table 16.

Important contrasts between the stations may be noted. Broughton Island has a higher incidence of heavy snowfall during the critical periods, but significantly fewer wind chill episodes. (The table of course does not show the duration of wind chill episodes but these are, in general, longer at Dewar Lakes). Wet, cold periods are frequent during calving time at Dewar Lakes, but in the rutting season such conditions are less common at both stations, with a slightly greater risk at Broughton Island.

F. Site Planning and Construction

The construction of Park facilities such as camping sites, sewage disposal systems, and emergency huts in remote locations can be most

Table 16

Incidence of Debilitating Weather during the Calving and Rutting Seasons

Year	DEWAR LAKES Incidence Hvy Snowfall		Rain & Cold		Wind Chill		BROUGHTON ISLAND Incidence Hvy Snowfall		Rain & Cold		Wind Chill	
	C	R	C	R	C	R	C	R	C	R	C	R
1961	X	*	2	0	23	32	X		0	0	9	17
1962			4	0	17	26		X	0	0	16	15
1963	X	*	1	0	21	24	X	*	0	2	0	11
1964			0	0	16	30		X	2	2	7	19
1965			2	0	15	30	X		0	0	7	23
1966		X	0	0	17	27	X	X	0	0	9	14
1967	X	*	6	0	23	30	X	X	2	(A)	0	18
1968	*	X	5	0	19	18	X		0	0	11	8
1969	X	X	0	0	17	32	X	X	0	0	6	15
1970	X	X	1	0	23	26	X	X	0	(A)	14	19

C = Calving season R = Rutting Season

X Above normal snowfall in May - June or October - November

* Above normal snowfall in April or September

(A) 2 or more occurrences in September

difficult, time-consuming, and expensive as a result of the severity of the weather. The problem is two-fold: the weather affects the performance of men involved with construction work, as well as that of the materials and machinery they use. The most detrimental weather parameters include low temperature, precipitation, winds and combinations of wind and temperature (chill factor).

Working out-of-doors in an Arctic environment, especially during the long winter season, can influence the worker both psychologically and physiologically. Even the thought of being exposed to such unpleasant conditions can result in below normal production and performance.

On the physiological level, the working efficiency of those involved in outdoor construction declines with decreasing temperatures, poor lighting conditions, and heavy snowfall. Whereas the working efficiency is considered 100% when the air temperature is 10°C, it declines to 97% at 0°C, to 87% at -10°C, and to 39% at -30°C (Havers and Morgan, 1972)

Lighting conditions at the construction site are also important. Working efficiency is considered 100% under indirect sunlight. Under Arctic winter twilight conditions, however, it drops to 56%. Artificial lighting will probably be required if construction is to continue into the winter season.

Light snow only slightly hinders the working efficiency of workers. Heavy snow, however, can decrease efficiency to about 41%.

Thus, combined effects of low temperature, poor natural lighting, and heavy precipitation can significantly deter construction. Park management personnel are therefore strongly advised to make as much use as possible of the long hours of sunlight during the summer season when the frequency of these detrimental weather parameters is at a minimum.

Most of the weather-related damage incurred by materials and machinery results from extremely low temperatures. Rubber, for example, becomes very stiff; bending will cause it to break. At -49°C rubber loses its elasticity and at -51°C becomes as brittle as glass. Rubber-tired vehicles are therefore limited in their use. Such extremely low temperatures are not unknown to Auyuittuq National Park and indeed have been recorded at Dewar Lakes. Some data on low winter temperatures are indicated by Figure 29. As the percentage humidity content of the air approaches zero (with freezing temperatures), wood dries out and becomes severely warped. Canvas becomes stiff and difficult to fold, while glass, because it is a poor conductor of heat, will crack if exposed to any sudden crack in sub-zero temperatures. Concrete that is allowed to freeze soon after being poured will gain very little strength and some permanent damage is likely to occur.

The fuel used in various types of engines does not freeze when exposed to extreme cold, but becomes very difficult to vaporize. Very low temperatures cause oils to become thick, thus retarding the flow to vital parts of the engine needing lubrication. At -51°C standard lubricating oils solidify into a buttery type of substance.

Thus, if construction is to continue into the colder seasons in Auyuittuq National Park, steps must be taken to protect materials and machinery from break down. Heaters may be required to set cement and to liquify engine lubricants. Special cold-temperature fuels, lubricants and tempered metals may become a necessity. Such measures will add to the expense, but may be considered necessary if breaking ground and construction work must continue into the autumn and winter seasons.

If a particularly costly construction venture is planned for the future, it would be useful to start obtaining site climatological measurements as soon as practicable.

G. Winter Clothing Requirements

Warm, protective clothing is essential to the comfort and safety of visitors to Auyuittuq National Park. Havers and Morgan (1972) have indicated how proper clothing, when worn correctly protects the body against cold, repels snow or rain, and reduces the effects of the wind. Basic principles of dressing adequately are provided below, followed by a more quantitative analysis of required clothing protection.

Generally speaking, clothing should be lightweight, totalling less than 1.5 kg (three pounds) to facilitate movement. The air trapped between several layers of clothing acts as an insulator, helping to keep in the warmth of the body. Also, perspiration, which fills the air spaces of clothing materials and reduces their insulating effect, can be kept to a minimum when different layers of air are present to provide ventilation. For these reasons, several light layers of clothing are preferable to one heavy layer. Also, layers of clothing can be removed one at a time when milder conditions occur.

Fasteners should be strong and easy to use. Clothing design should avoid loose flapping cuffs and hems.

In 1973 Auliciems, de Freitas, and Hare completed a study of winter clothing requirements throughout Canada, based on approximate energy expenditures for selected activities, heat exchange processes between a human body and the surrounding microclimate, average weather conditions, and the degree of protection afforded by various types and layers of clothing. Table 17 consists of a list of various activities, the amount of energy expended while participating in them, and the degree of heaviness or lightness of the activities. It may seem too vague to equate the activities listed in Table 17 with individual recreational and other outdoor activities likely to be undertaken by visitors and an average level of exertion and energy expenditure. For example, depending upon its nature, construction work may be classified as "light", "moderate", or "heavy", and the energy expenditure can be estimated within a range of values. Figure 51 provides a graph of clothing requirements from September through April at Frobisher Bay for several levels of energy expenditure. It is likely that conditions within Auyuittuq National Park will be even more severe than those at Frobisher Bay.

Table 17

APPROXIMATE ENERGY EXPENDITURES FOR SELECTED ACTIVITIES

Activity		Energy Expenditure ($kcal/m^2/hr$)	Classification of Work
Sleeping		35	
Sitting		50	light
Strolling	1.5 mph	90	
Walking	2 mph	100	Activity
Canoeing	2.5 mph	100	
Walking	3 mph	155	
Field march		183	Light work
Walking	1 mph, 20 kg. load	210	
Walking,	3 mph, 20 kg. load	360	moderate work
Walking	3.5 mph, on hard snow	714	
Walking	2 mph, with snowshoes on soft snow	828	Heavy work
Walking	2 mph, 20 kg. load on soft snow	1242	

Source: Auliciems et al., 1973, p. 5

Table 18

A CLOTHING ASSEMBLY FOR COLD WEATHER

Layer	Items	Approximate Clo Value
1	Heavy underwear, woolen socks	.5
2	Woolen shirt and trousers (and shoes)	1.0
3	Woolen coveralls, gloves, and cap	1.0
4	Hooded parka, mittens, and fur-lined boots	1.5
	Total Clo Value	4.0

Source: Auliciems et al., 1973, p. 14

In Table 18, the requirements are interpreted in terms of types of clothing garments. For any outdoor activity, warm layers of protective clothing are essential to the well-being of people out-of-doors during the winter months. In addition to clothing requirements, climate will also dictate the duration of time spent outside. Under severe discomfort and visibility conditions, outdoor activity may be permitted for only a short period of time and in the presence of at least one other person; or, it may be forbidden completely, until the weather improves.

VII. Meteorological Station Network

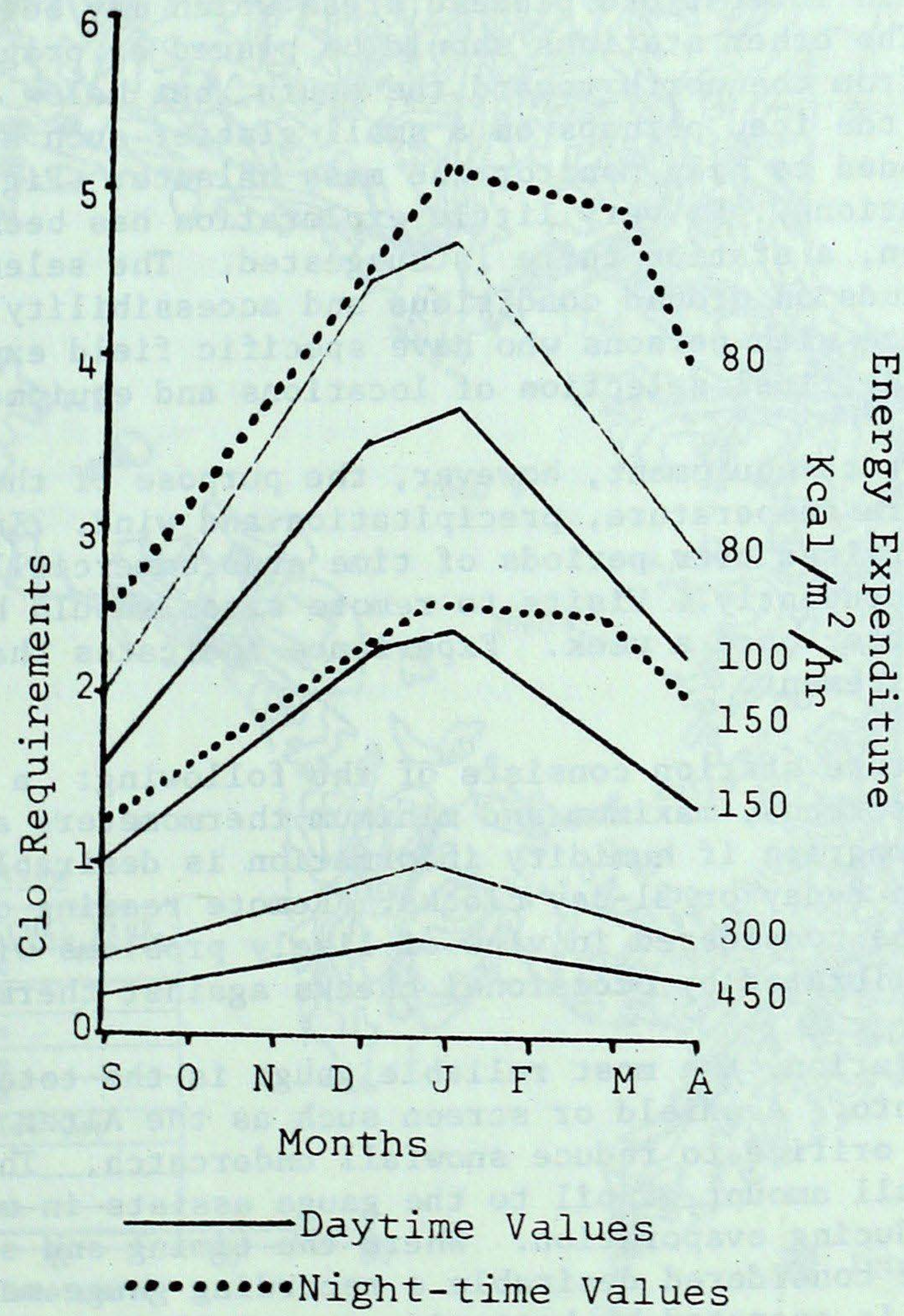
A. Need for Data

The creation of a small network of simple climatological stations within Park boundaries would provide useful information for many activities and operations, as well as to resolve speculations and controversies over regional climatic characteristics.

Data acquired from short-term stations established by the Institute for Arctic and Alpine Research (INSTAAR) verify that there is a considerable spactial variation to be eventually documented. Work by scientists in remote areas has led to impressions that certain districts require instrument surveys in the near future in order that ecological and geomorphological processes may be better understood. Andrews and Dyke (1974), for example, have drawn attention to apparently dry areas located short distances inland from the sea for which we have no information.

Indeed, one of the attractions of the Cumberland Peninsula to visitors is the realization that this was a point of initiation for Pleistocene continental ice sheets, and the Penny Ice Cap represents today a relic of that age. The apparent stability of the ice cap and the interesting observations of Andrews and Barry (1972) pertaining to the close proximity in elevation of active and relic cirques emphatically suggest that renewed glacierization could be accomplished by minor declines in temperature. During the 1960's it was noted from the observations at Broughton Island station that the climate was becoming cooler and snowier. Andrews and Barry calculated that a decline in the mean daily July temperature of about 3C^{o} could re-establish firn in the now-dormant cirque basins, 150-200m below the present mountain glaciers. This was estimated to be the catalyst of a full-scale glaciation of the Park area and covering as much as 70% of the Cumberland Peninsula. Of course, a warm summer such as that of 1974 eliminates the small accumulations on the glaciers made in previous years (Miller and Bradley, 1975). In the preparation of this report it became apparent that the cooler snowier conditions of the '60's pertained more to the Broughton Island - North Coast region than to interior locations such as the Dewar Lakes. This supports the now popular concept that climatic fluctuations are often very local in a geographical sense, being related to small perturbations in the atmospheric circulation. As the climate of Baffin Island is very strongly influenced by the influx of storms (in comparison with many other areas), a month-to-month and year-to-year variability factor will have large terms. The idea of a "normal" or average climate is difficult to establish in this area. It follows that it is dangerous to compare conditions from place to place using records from different time periods. Thus, the record from Pangnirtung during the '30's, for example, has a limited utility when used with Broughton Island and Dewar Lakes data to make areal comparisons.

Figure 51:
Clothing Requirements For
Five Rates of Energy Expenditure At
Frobisher Bay



Source: Auliciems et al, 1972

B. Number and Type of Stations

For reasons of economy a network of no more than five or six stations should be considered initially. It is important to establish one high quality station measuring temperature, precipitation, wind and sunshine among other parameters, presumably near the Park Headquarters where it may be monitored daily. This station should be considered semi-permanent and the site should not be disturbed once established. Eventually a stable bank of data will be established which can be treated statistically, and which will form a reference for all other stations established for particular purposes in the Park.

A secondary network will indicate regional variation. There is a need to document the weather at the headwalls of fjords where conditions may be severe, and in inter-fjord plateau areas which may be important for animal life. The other stations should be placed at progressively higher elevations from the north toward the south, but below the ice cap. A station sited on the ice, perhaps on a small glacier such as the Boas Glacier is recommended to help monitor the mass balance. Figure 52 indicates some suggested locations. As very little exploration has been done in the northwestern section, a station there is suggested. The selection of specific sites depends on ground conditions and accessibility. It would be useful to collaborate with persons who have specific field experience in the area to determine the final selection of locations and equipment.

With respect to equipment, however, the purpose of the secondary network is to measure temperature, precipitation and wind. Instruments which will operate unsupervised over periods of time are commercially available but should be used prudently. Visits to remote sites should be made regularly once a month, or better once a week. Experience indicates that this should be the minimum requirement.

The temperature station consists of the following: a thermometer shelter (Stevenson screen), maximum and minimum thermometers and a thermograph (or hygrothermograph if humidity information is desirable). Thermographs may be obtained with 8-day or 31-day clocks. Remote reading or distance thermographs might be considered in view of likely problems with blowing snow. Charts should be calibrated by occasional checks against thermometer readings.

For precipitation, the most reliable gauge is the totalizing type such as the Sacramento. A shield or screen such as the Alter shield should be fitted about the orifice to reduce snowfall undercatch. The addition of antifreeze and a small amount of oil to the gauge assists in measuring the accumulation and reducing evaporation. Where the timing and storm amounts of precipitation are considered desirable a recording gauge may be installed. Here, the mechanism is operated by batteries especially manufactured and installed to function in cold weather. Recording gauges are of course more expensive (by a factor of 8 or 10).

Run of wind (average wind speed over a period) may be simply measured with a totalizing cup anemometer. To measure direction as well as speed a recorder is required. Sometimes event recorders are used which

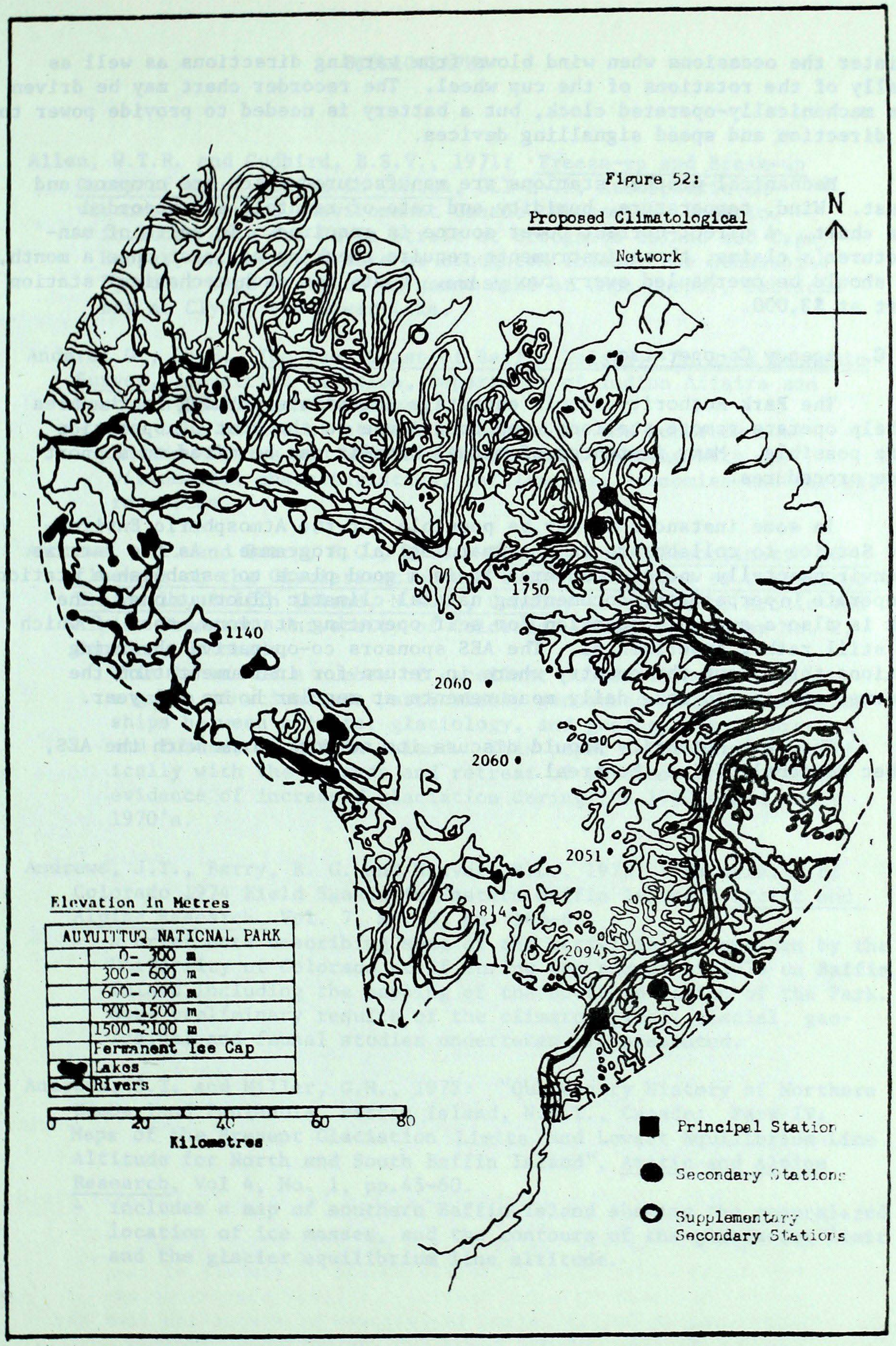


Figure 52: Proposed Climatological Network

register the occasions when wind blows from varying directions as well as a tally of the rotations of the cup wheel. The recorder chart may be driven by a mechanically-operated clock, but a battery is needed to provide power to the direction and speed signalling devices.

Mechanical weather stations are manufactured which are compact and robust. Wind, temperature, humidity and rate of rainfall are recorded on a chart. A direct-current power source is required. In spite of manufacturer's claims, these instruments require checking at least once a month, and should be overhauled every two years. Costs for each mechanical station start at $3,000.

C. Agency Co-operation

The Park Authority should encourage scientists working in the area to help operate remote stations, and contribute to the cost of operation where possible. Many instances of mutual benefit can be cited to support these procedures.

In some instances it may be possible for the Atmospheric Environment Service to collaborate in a climatological programme. As the Park is an environmentally undisturbed area it is a good place to establish a station to operate in perpetuity, documenting natural climatic fluctuations. The park is also a suitable location for self operating stations, most of which are still rather experimental. The AES sponsors co-operative observing stations throughout the country where in return for instrumentation the observer agrees to make daily measurements at regular hours all year.

The Park Authority should discuss its network plans with the AES, Quebec Regional Office, Montreal.

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