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Lower Temperatures in the Labrador Current and in the Atmosphere During the Early 1970's and 1980's

by

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SPECIAL SESSION ON ENVIRONMENTAL CONDITIONS

Abstract

Unusually cold water in the Labrador Current in the early 1970s and 1980s appeared simultaneously with, and was presumably caused by, unusually cold air above the waters upstream of the Current. The abnormally cold air originates in the polar regions and is diverted southward from its usual westerly path by planetary waves in the circumpolar westerlies. These large-scale (10000km) long-period (>20 days) waves are a regular feature of the northern circulation pattern in the atmosphere but only rarely do they remain stationary for long enough and at the right time of year to produce large measurable effects in the ocean. Typically, the coldest weather occurs over the eastern arctic when the mean air flow is ≈30° more northerly than normal. In the middle of winter these conditions bring the temperatures 10°C below normal and the cloud amount 20% less than normal. The total cooling of the ocean by this cold and relatively clear northwest wind increases with the length of time that the wave remains stationary. In the years of greatest heat loss the anomalous condition begins in December and stays for at least two months.

Introduction

The Labrador Current, Fig. 1, flowing southeast over the continental shelves and slopes of Labrador and Newfoundland Canada, is one of a series of currents bringing cold, relatively fresh water south from the Arctic regions into the North Atlantic Ocean. It is usually said to begin near 60°N where the flow out of Hudson Strait joins the Baffin Island Current and the branch of the West Greenland Current which turns westward toward Baffin Island, and to end at the southern tip of the Grand Banks of Newfoundland at 43°N.

The main features of the temperature and salinity distributions across the Labrador shelf and slope at Hamilton Bank in early summer are illustrated in the vertical sections in Fig. 2 and in the temperature versus salinity (t-s) diagrams of Fig. 3. The water temperature over the continental shelf, moderately warm at ≅ 4°C near the surface, decreases at intermediate depths (50-150m) to values less than -1°C, and increases to values in the 0 → +1°C range at 200-250 m. The salinity of the waters over the shelf, in contrast to the temperature, always increases monotonically with depth from a salinity of 28 to 32, depending on the season and distance from shore, to about 33.5 at 100 m and to 34 at 250 m.

The cold intermediate layer, roughly defined as the water within the 0°C isotherm, is a regular feature over the shelf in spring and summer and is usually quite uniform across the shelf. Properties such as temperature, salinity and density, for example, exhibit only small horizontal gradients from one side of the shelf to the other. This uniformity, noted by Lazier (1982), is well illustrated in the diagrams of Figs. 2 & 3 which show almost no change in the relationship between temperature and salinity or between temperature or salinity and pressure across the shelf.

On the seaward side of the shelf a strong horizontal gradient in all properties is encountered over the continental slope where the shelf and oceanic waters meet in the front associated with the main branch of the Labrador Current. Temperature at 100 m increases across the front from ≅ -1°C over the shelf to 3.5°C on the seaward side, while salinity increases from ≅ 33.5 to 34.5. The cold intermediate layer, centered at a salinity of 33.0-33.5, rises and thins through the front to near extinction at the surface.

The cold intermediate layer is generally assumed to originate in winter with the loss of heat and consequent convection that mixes and deepens the surface layer. Observations of this process are almost non-existent in the Labrador Current, however convincing evidence of vertical mixing to 200m is contained in a profile obtained through the pack ice at 56°N 56°W by S. Prinsenberg (pers. comm.) in February 1987. The profile shows both temperature and salinity to be homogeneous from the surface to ≈200m, and although only one profile was obtained it probably represents typical conditions in the area as there are, as mentioned above, only small horizontal gradients in the temperature and salinity distributions over the shelf.

In spring, melting of sea ice and run off from the land alters the salinity distribution by lowering the near surface values at the time these surface waters are also increasing in temperature. This fresher and warmer surface layer is obvious in the early summer temperature and salinity distributions of Figs. 2 and 3. These effects of spring, limited to the upper few tens of metres, create a strong vertical density gradient that effectively cuts off vertical exchange between the atmosphere and the waters below the low density surface layer. In this way the winter-formed properties of the intermediate layer are preserved into summer and may, according to the flow of the water, be observed at locations far from the where the properties originated.

By these processes exceptionally cold winters over northeastern Canada in the early 1970s and 1980s caused the temperature of the intermediate layer in the Labrador Current to decrease far below normal. This report examines these events by comparing observations from the Labrador Current with meteorological observations over the eastern arctic. The unusually cold water is shown to follow the exceptionally cold winters and the cold winters in turn are shown to be characterized by a more northerly wind flow of clearer air. The anomalous conditions are produced by planetary waves in the atmosphere which create sustained deviations in the flow of the circumpolar westerlies.

The data are presented in four sections. First, are some continuous temperature measurements obtained intermittently at the base of the cold intermediate layer on the west side of Hamilton Bank Labrador between 1978 and 1987. These show the intermediate layer to be much colder for the two years between 1983 and 1985 than during the other years of the record. This cold period is then shown to also be present in the time series of measurements from the ocean station near St. John's Newfoundland known as, Station 27 (Fig. 1), and in the meteorological records from northeastern Canada. To look back further in time the thirty-two year temperature records from 1953 to 1985 obtained at Iqaluit and at Station 27 are examined to reveal another clear example of an extreemly cold and long lasting anomaly in both the air and water in the early 1970s. The fourth section contains a discussion of the surface and upper air meteorological measurements at Iqaluit.

Hamilton Bank - 200m temperatures 1978-1985

Starting in October 1978, an Aanderaa current meter capable of measuring water velocity, temperature and sometimes salinity has been moored 4m above the 200m isobath on the west side of Hamilton Bank, Fig. 1. The position of the instrument in relation to the early summer water mass distribution is indicated in Figs. 2 & 3. The monthly temperature anomalies which are the differences between each months average and the "normal" temperature or mean over all similar months in the record is presented in Fig. 4. The record is missing data between October 1980 and November 1982 except for three months in the summer of 1981, because of instrument failures.

The anomaly curve shows the temperature at the current meter between December 1982 and December 1985 to be roughly 1°C below the values found in the other years. The values during the period of missing data are of course, not known, but the short record during the summer of 1981 and the measurements during November 1982 are both higher than the normal values, suggesting that the lower than normal temperatures were confined to the period after December 1982.

For comparison with the current meter data, the temperature anomalies at ≥150m at Station 27 are also shown in Fig. 4. These data, obtained ≈700km to the south of Hamilton Bank, show a similar period of below normal temperatures from 1983-1985. The colder period lasts for about the same length of time and is roughly the same magnitude at both locations. The colder period begins about three months later at the southerly position which may reflect the southerly flow of the current. The water over the shelf moves at about 0.2m s^{-1} and would transport a signal over the intervening 700km in ≈40days. The fact that Station 27 is closer to shore than the current meter at Hamilton Bank and samples through a lower density part of the flow may also be a factor in the time delay.

Air Temperatures over eastern Canada 1978-1985

Air temperatures over much of the waters in or upstream of the Labrador Current are probably well represented by the air temperatures recorded at Cape Dyer, Iqaluit, Cartwright and St. John's, Fig. 1, as the prevailing winds at these sites are from the west or northwest; ie. from the land to the water. Monthly temperature anomalies, calculated the same way as the water temperature anomalies, for the four stations are given in Fig. 5. Two important features are immediately obvious. The winters of 1982/83 and 1983/84 were exceptionally cold at Iqaluit and Cape Dyer. The temperature anomaly reaching more than -10°C at Cape Dyer in January and December 1983 and January 1984. The mean anomaly for December, January and Febuary is -7°C in 1982/83 and -7.5°C in 83/84. The same pattern exists at Iqaluit except the anomalies are slightly less at -8.5°C in January 1983 and -8.0°C in January 1984. At Cartwright 1100 km south of Iqaluit the temperature anomalies are less and at St. John's no large anomalies are recorded.

The similarity between the anomalies of temperature displayed in Figs. 4 and 5, leads to the conclusion that the exceptionally cold temperatures over northeastern Canada during the winters of 1982/83 and 1983/84 are most likely the cause of the below normal water temperatures in the intermediate layer over Hamilton Bank and at station 27.

Iqaluit air and Station 27 water temperatures 1953-1985

The relationship between the atmospheric conditions in the north and the temperature in the Labrador Current is further explored in the plots of temperature from Iqaluit and from Station 27, between 1953 and 1985, presented in Figs. 6.

The oceanographic observations from Station 27, off St. John's Nfld., are the only records available to represent the conditions in the Labrador Current before 1978. Since the station is 1500 km south of Iqaluit and very close to shore, the data are probably not very representative of the conditions throughout the Current, but as shown above, the long lasting extreemly cold anomalies in northern air temperatures are reflected in lower than normal Station 27 water temperatures.

The two cold winters between early 1982 and 1984, at Iqaluit and the subsequent cold water at Station 27 are clearly evident in Fig. 6 as one of the major fluctuations in the time series. Another pair of anomalously cold winters occurred over Iqaluit during the winters of 1971/72 and 1972/73 and they too are followed by unusually cold water at Station 27. These are the two main cold periods between 1953 and 1985. At other times the air and water temperatures go below the long term averages but the connection between the two is never as obvious as during the big anomalies of the early 1970s and 1980s.

The two main cold periods in the early 1970s and 1980s are also marked by much larger than normal amounts of pack ice off Labrador as can be seen in the time series of ice cover in the Labrador Current shown in Fig. 6, (I. Peterson, pers. comm.). The increase in ice cover is also assumed to be a direct result of the anomalously cold flow of air over the ocean.

The correlation between the air temperatures at Iqaluit and Station 27 are examined further in Fig. 7, which displays the average air temperature anomalies over the months of December, January and February, at Iqaluit, against the water temperature anomalies at 150m at Station 27 over the same months. To make the correlation as high as possible the water temperatures are paired with the air temperatures from the previous winter. The delay improves the correlation slightly because the water moves south at $\approx 0.15 m\ s^{-1}$ taking about 150 days to travel from Iqaluit to St. John's Nfld. The scatter in Fig. 7 shows, as did Fig. 6, that in most years the connection between the northern air temperature and the southern water temperature is almost nonexistent. Only in the exceptionally cold periods is the signal large enough to rise above the backgroud noise to show a clear relationship.

That there is no clear relationship between the air and water temperatures except during long periods of very cold weather in the north reflects the fact that the temperature of the water is determined by a large number of factors. The temperatures of the waters that come together to form the Labrador Current influence the final temperature as does the vertical stability of the incoming waters and the atmospheric conditions above those flows. It is only when one of these factors gets far from its average value that it can be identified as having a significant effect on the final temperature. The abnormally high temperatures at Station 27, Fig. 6, between 1965 and 1970, for example, are not accompanied by a similarly large high temperature anomaly in the air temperatures in the north. The high water temperatures may have nothing to do with the atmospheric conditions over eastern Canada. They could be caused by any number of phenomena such as the lower than normal salinities and consequent higher vertical stabilities that were widespread in the area during the late 1960s, Lazier (1980).

Upper Air Observations over Iqaluit

In an attempt to better understand how abnormally cold winters develop over northeastern Canada, some of the data from the twice daily balloon ascents from Iqaluit and other nearby centres was examined. These data are better than the surface observations for this purpose because they are above the planetary boundary layer where the air flow direction is strongly influenced by the local terrain.

The purpose is to examine the data for evidence of low frequency oscillations in the atmosphere that may be responsible for the very cold, but rare, winters that have such a lowering effect on the temperature of the Labrador Current. The likely oscillations of interest are those associated with the planetary waves in the westerly flow of air around the globe in the northern hemisphere. These have been examined by Knox (1975), van Loon and Rogers (1978), Rogers and van Loon (1979) and Wallace and Gutzler (1981).

The long term average, or normal, height of the 50kPa pressure surface in the atmosphere during the winter months of December, January and February which is shown in Fig. 8 is derived from Knox (1975). It shows the flow of air around the northern hemisphere to be more or less parallel to the lines of latitude except for slight departures due to a permanent pattern of three low amplitude planetary waves around the globe. Over Iqaluit the diagram shows the normal flow of air to be from west to east.

The height of the 50kPa pressure surface is of course never in its normal state but is always distorted by waves of varying amplitude and duration. The distribution in Fig. 9 shows a pattern slightly different from normal. The flow over the North Atlantic Ocean is more southerly than normal while that over western Canada is more northerly than normal. These patterns change over many time scales as illustrated by the spectrum of the height fluctuations of the 70kPa pressure surface above Iqaluit between 1961 and 1986 (Fig. 10). The large peak at the annual period reflects the seasonal change in the height of the pressure surface caused by the seasonal change of temperature in the atmosphere. The smaller but broad peak centred at ≈20 days contains the fluctuations of interest in this study, ie the oscillations with periods that are long enough to have a significant impact on the weather over a month and longer. The high frequency or short period oscillations of less than ten days period are associated with the passing highs and lows of the baroclinic storms and are of too short a duration to be of importance in this study.

An example of the changes with time in the height of the 70kPa pressure surface above Iqaluit is given in Fig. 11. The data for this figure was first filtered to remove the fluctuations of less than 20 days and each point in the curve is the difference between the altitude on the date indicated and the normal height. The graph runs from the first of January 1967 for eighteen months and is typical of all the years examined in that it shows a continuous series of oscillations about the mean position of variable period and with an increase in amplitude from summer to winter.

That these fluctuations in the height of the pressure surface are not confined to the immediate area around Iqaluit is demonstrated by calculations of coherence between the various stations in the eastern arctic. The example given in Fig. 12 is typical of the calculation between the six stations at Kuujjuaq, Inukjuak, Iqaluit, Coral Harbour, Resolute Bay and Hall Beach (Fig. 1). The coherence tends to be above 0.8 for periods longer than 10 days and across 500km or less and drops off at higher frequencies and over longer distances. The coherences between Resolute Bay and Iqaluit which are ≈1500 km apart, for instance, are ≈0.7. Thus the low frequency oscillations of interest are large phenomena as shown in Figs. 8 & 9 and quite capable of influencing the weather over a large portion of northeastern Canada.

The main variable of interest with regard to this study of the cold winters is not the height of the pressure surfaces but is rather the temperature of the air being advected into the area. The coherence between the temperature and the height of the 70kPa pressure surface over Iqaluit is given in Fig. 13 which shows the two to be quite strongly correlated for fluctuations of 20 days or more. The correlation is not higher because the height is dependent on both temperature and humidity and fluctuations in the latter are not considered here. The temperature fluctuations at 70kPa are therefore not quite as accurate as pressure height fluctuations in determining variations in the flow field but they are a fair surrogate and certainly of more use in examining exchanges of heat. The correlation between the temperatures at 70kPa and at the earth's surface (not shown) is also high enough that the two can be used interchangeably.

The filtered temperature anomaly records obtained on the 70kPa pressure surface above Iqaluit during the three coldest winters between 1961 and 1986 are plotted in Fig. 14. These records have the same characteristics as the pressure height anomaly record shown in Fig. 11. They exhibit continuous changes throughout the year with various periods and amplitudes and the amplitudes of the fluctuations tends to increase from summer to winter. The fluctuations also appear to be random. No regular pattern from year to year is obvious to the eye. The three cold records have two features in common that are not shared with the other years. Each exhibits one or more large negative anomalies during the winter that last for at least two months and the cold period begins in December if not slightly before. But why only these three winters out of the twenty-five have these features is a mystery.

A number of studies; Knox (1975), van Loon and Rogers (1978), Rogers and van Loon (1979) and Wallace and Gutzler (1981) have examined these low frequency oscillations and have shown that they exhibit well defined standing waves. One of the best known is called the North Atlantic oscillation which was first observed as abnormally cold winters in Greenland concurrent with abnormally warm winters in Europe, and vice versa. The upper atmospheric pattern during the abnormally cold Greenland winter is similar to that shown in Fig. 9 in which the flow of air over the eastern North Atlantic Ocean is more southerly than normal and the flow over Canada is more northerly. This oscillation, being important and well known, has an index associated with it based on the atmospheric pressure difference between Iceland and the Azores and Myers, Akenhead and Drinkwater (1988) have used this index to show that almost 50% of the variation in the near bottom water temperature at Station 27 is associated with North Atlantic oscillation.

Figs. 15 and 16 illustrate two other characteristics of the colder winters. The first is a plot of the direction of the wind versus the air temperature. Each point in the plot represents the average conditions over the months of December, January and February for a particular year. It clearly shows that during the three coldest winters the wind definitely came from a more northerly direction than normal. For most of the other years the relationship between temperature and wind direction is indefinite. The points of Fig. 16 are again the average values over the winter months and show that there is quite a strong relationship between the air temperature at Iqaluit and the amount of cloud. The colder winters are clearer.

Summary and Conclusions

Data from moored instruments on Hamilton Bank and time series of station data off St. John's Nfld. show that temperatures in the Labrador Current were much below normal between 1972-74 and 1983-85. These unusually low temperatures were a wide-spread phenomenon and were noted by many observers from fishermen who blamed them for the low inshore cod catches to scientists who had trouble getting cold samples of water through the cold air into the warm laboratory before freezing. The extent of the ice off the coast of Labrador was also exceptionally severe during theses cold years.

Air temperatures from stations in northeastern Canada were anomalously low during the years that the Labrador Current was cold. This correspondance led to the conclusion that the cold years were, at least locally, an atmospheric phenomenon. Examination of the meterological observations at the 70kPa pressure surface above Iqaluit illustrated the nature of the low frequency fluctuations in the wind direction and temperature associated with the planetary waves in the circumpolar westerlies. The coldest winters seemed to appear because the planetary waves became blocked in just the right position at just the right time and stayed for long enough to inflict arctic air on unsuspecting southerners. This persistence of the planetary waves in some preferred position appears as a standing wave because higher than normal conditions at one place are mirrored by lower than normal conditions at some other place. These standing wave patterns have been thoroughly established in the literature but we still have very little understanding of the sequence of events which determines where and when they will be established.

The study also leads to the conclusion that careful monitoring of the meteorological conditions in the northeastern part of the country will lead to an ability to predict, in the obvious severe cases, that the temperature in the Labrador Current will be significantly below normal in the following spring and summer. It is only when one of the factors determining the properties of the water in the Labrador Current gets very far form its normal state that some predictive capacity exists.

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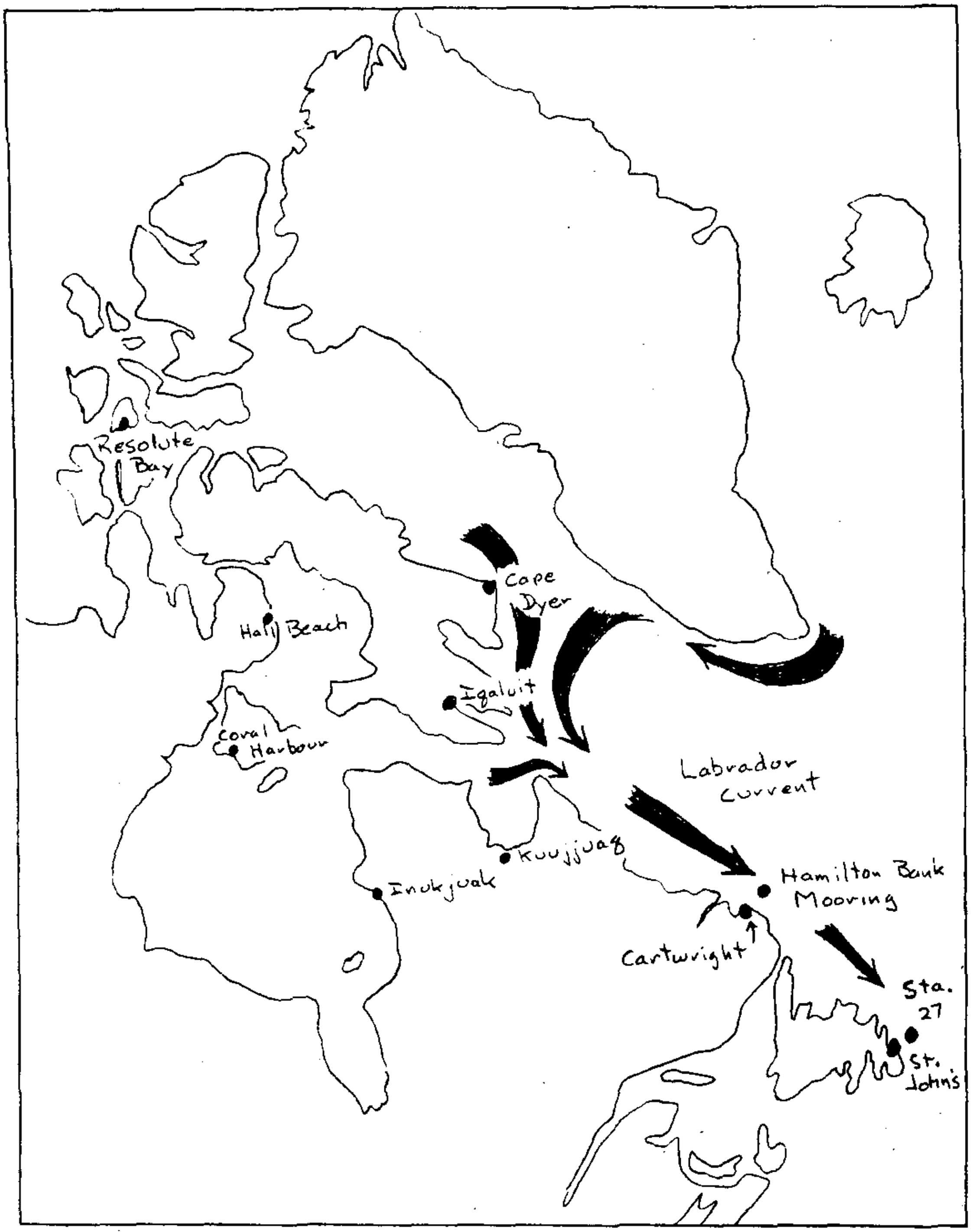

Figure 1 The Labrador and associated currents, meteorological stations, oceanographic Station 27, current meter mooring position and relevant geographic features.

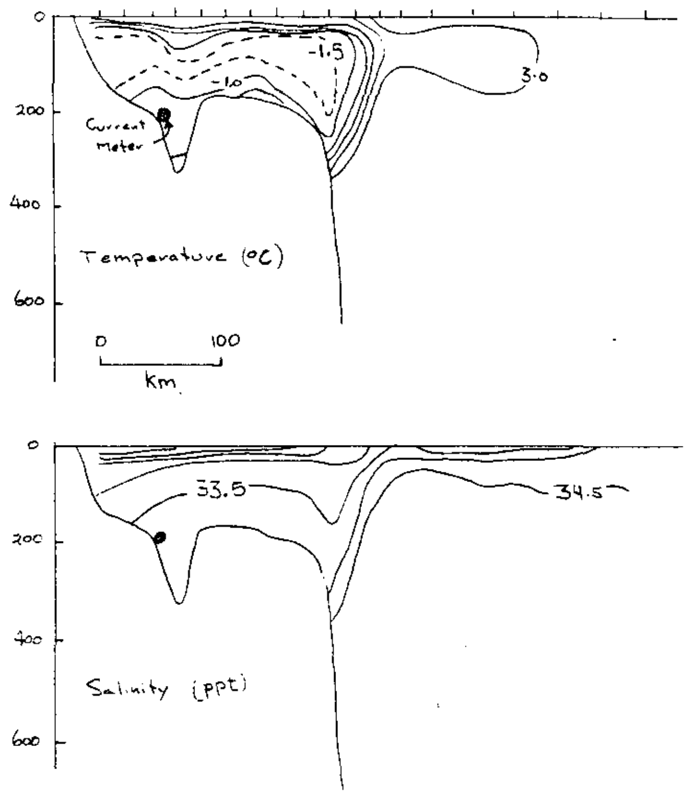

Figure 2 Vertical sections of temperature and salinity across the Labrador shelf and slope at Hamilton Bank, constructed from 20 CTD stations obtained in July 1986. The position of the current meter mooring over the 200 m isobath, to the west of the Bank is noted.

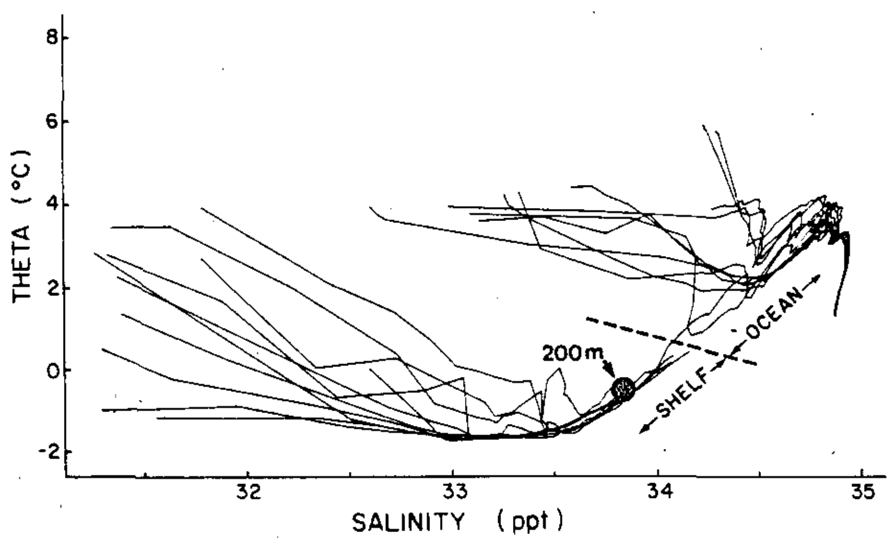

Figure 3 Temperature versus salinity curves from the twenty CTD stations obtained across the shelf and slope at Hamilton Bank in July 1986. The mean values of temperature and salinity obtained by the current meter at 200 m is marked as is the approximate position of the front which separates the shelf water from the ocean water.

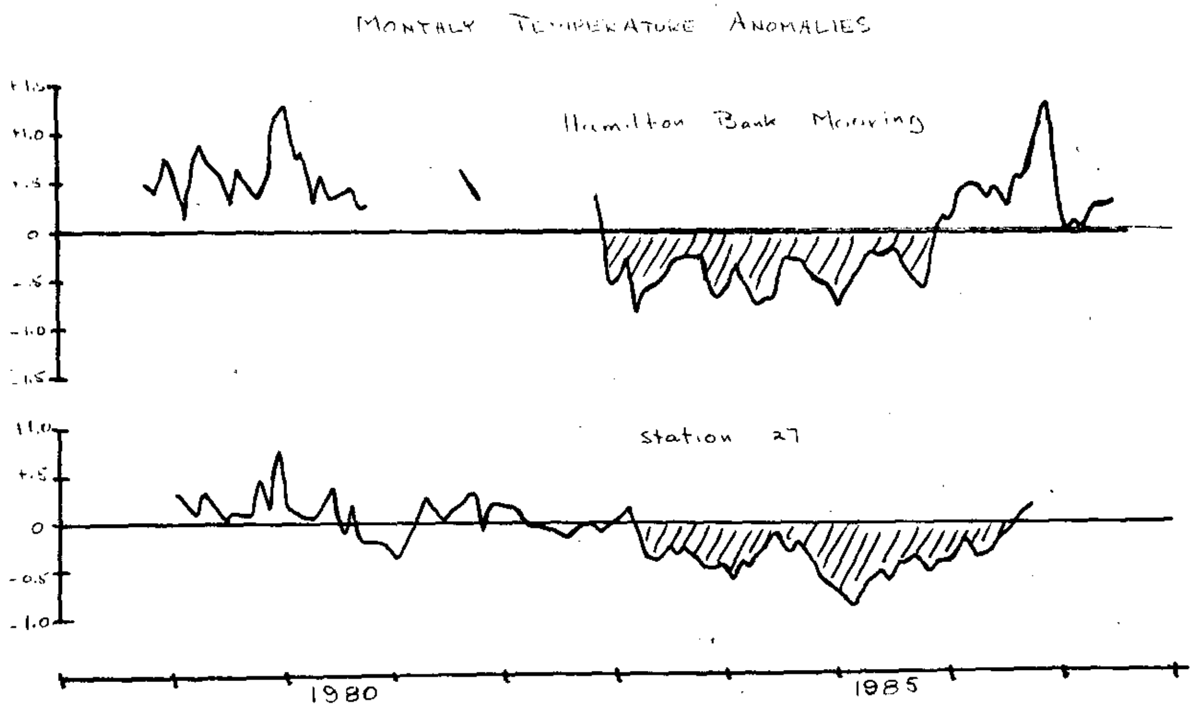

Figure 4 Monthly temperature anomalies (a) at 200m depth west of Hamilton Bank obtained from a current meter moored between 1978 and 1987 and (b) from 150m at Station 27 near St. John's Nfld.

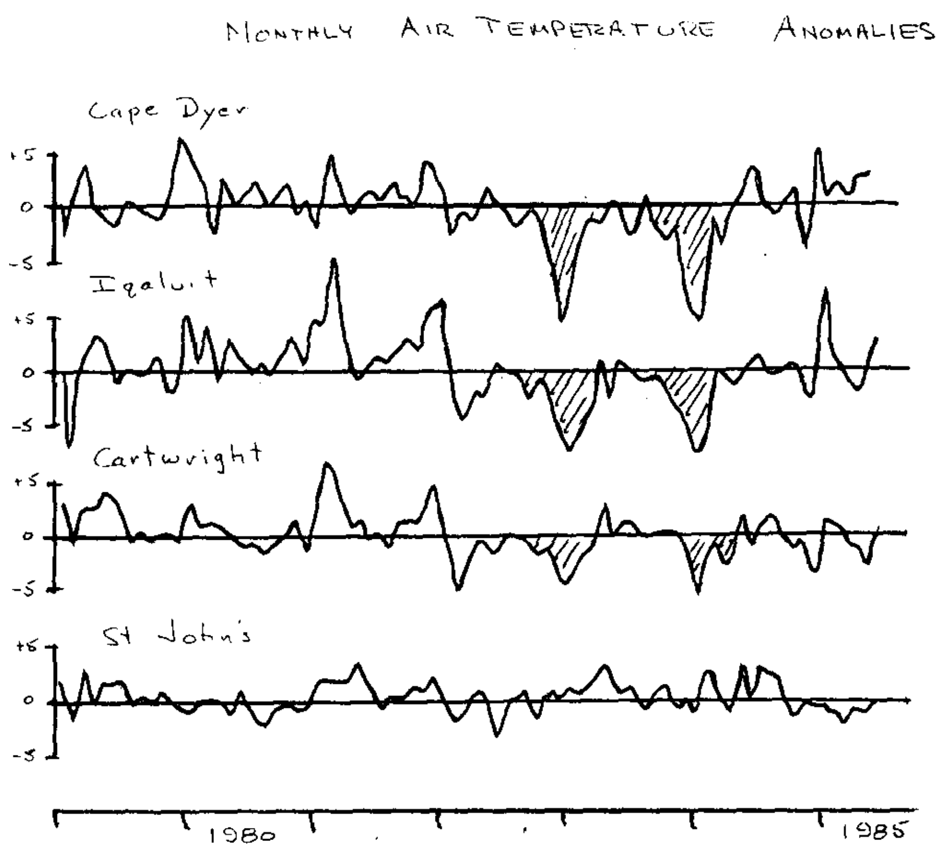

Figure 5 Monthly air temperature anomalies between 1979 and 1985 at Cape Dyer, Iqaluit, Cartwright and St. John's.

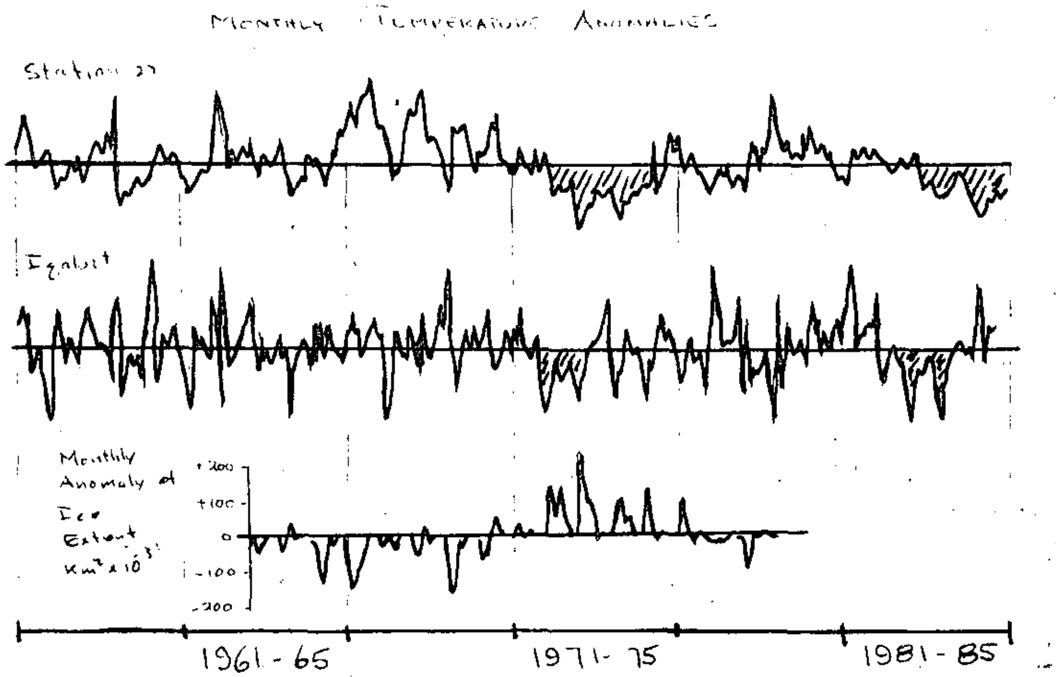

Figure 6 Monthly water temperature anomalies at 150m at Station 27 and monthly air temperature anomalies at Iqaluit between 1953 and 1985 plus monthly anomalies of the amount of pack ice south of 54°N, between 1953 and 1985 in thousands of km^2, (I. Peterson, personal communication)

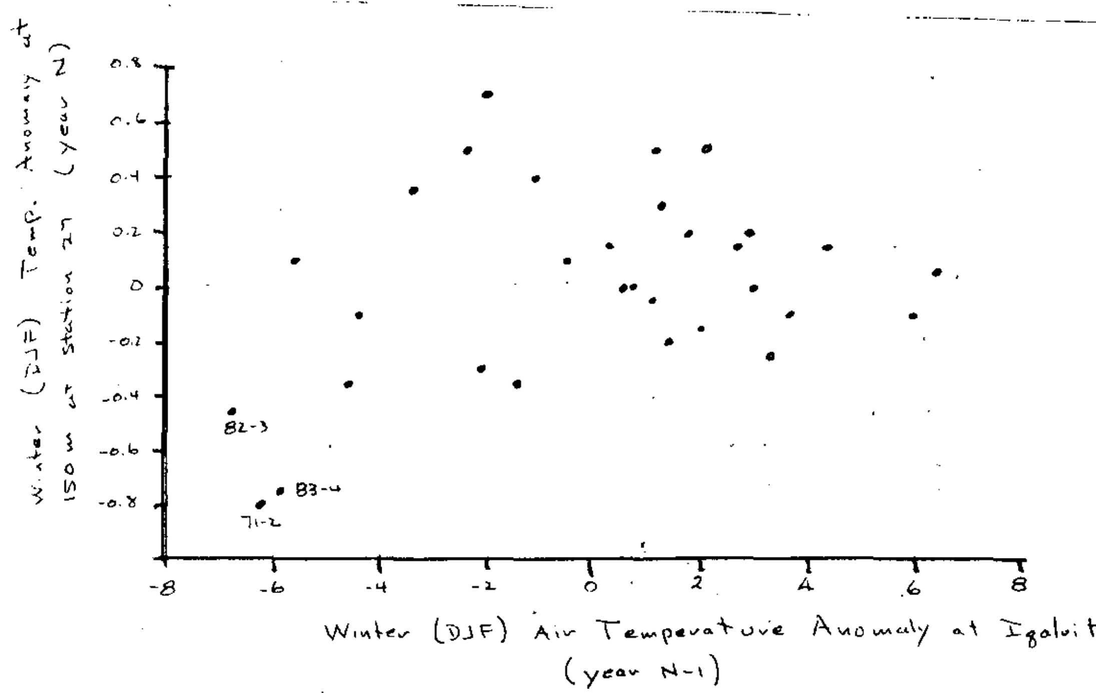

Figure 7 Anomaly of air temperature averaged over December January and February, at Iqaluit, versus the anomaly of water temperature at 150 m depth at Station 27 averaged over the same months for the winters between 1953 and 1985. The data for year N at Station 27 is paired with that for year N-1 at Iqaluit to allow for a possible phase lag due to the speed of the current.

Figure 8   Normal geopotential height of the 50kPa pressure surface in units of dynamic metres (dm) for winter, adapted from Knox (1975). The contour interval is 12dm.

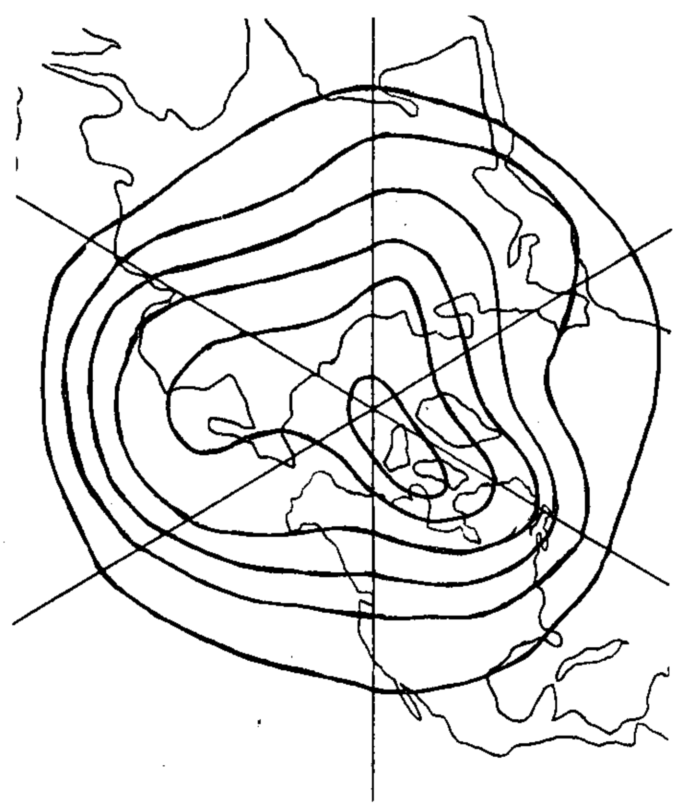

Figure 9   Geopotential height of the 50kPa pressure surface for a situation favouring more northerly winds over central Canada and more southerly winds over the eastern North Atlantic Ocean with the same contour interval as in Fig. 8, from Wallace and Gutzler (1981).

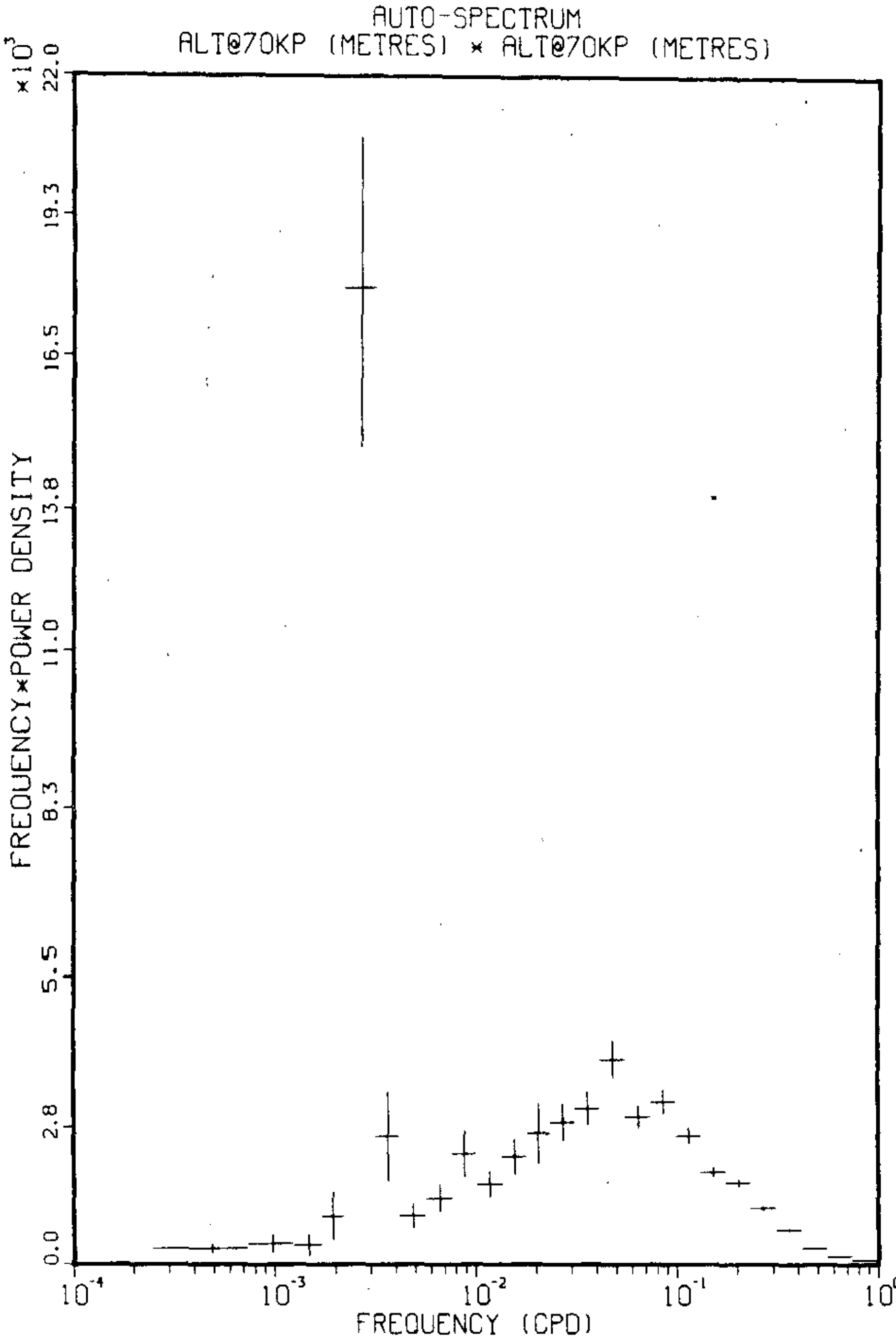

Figure 10 Spectrum of vertical oscillations in the height of the 70kPa pressure surface above Iqaluit, based on twice daily balloon ascents from 1961 to 1987.

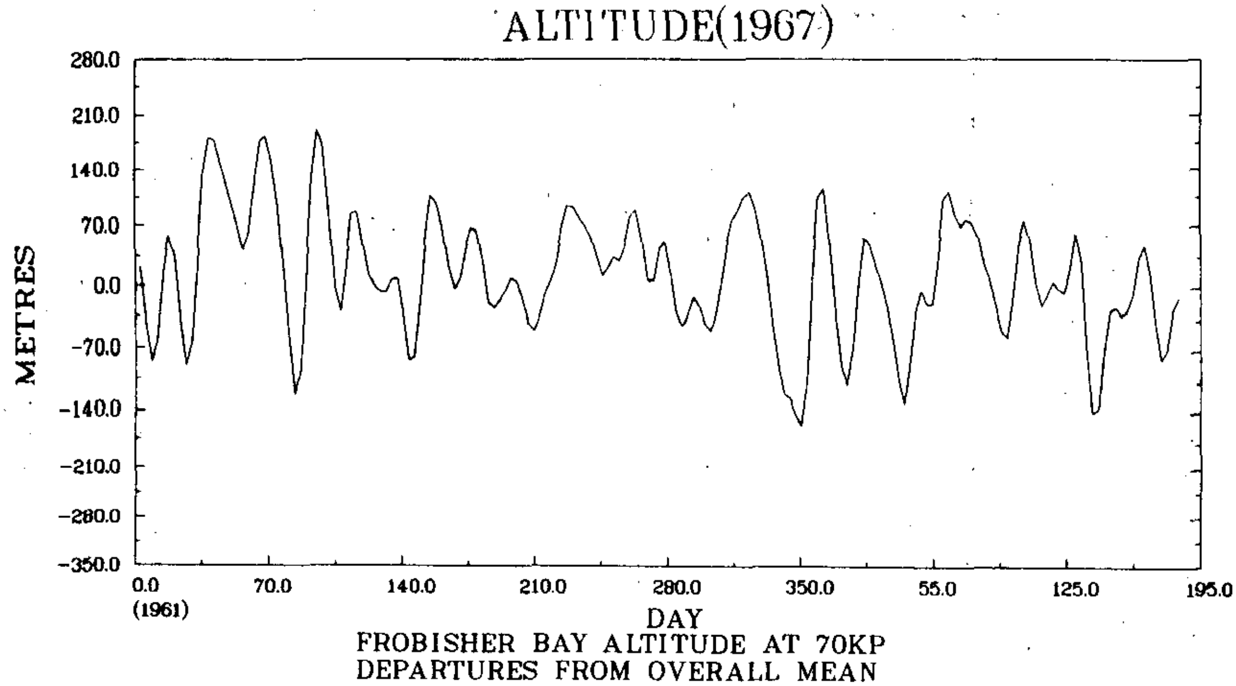

Figure 11 Departures in the height of the 70kPa pressure surface from the long term mean from January 1967 to July 1968, over Iqaluit. The data has been smoothed with a filter to remove the oscillations at periods less than 20 days.

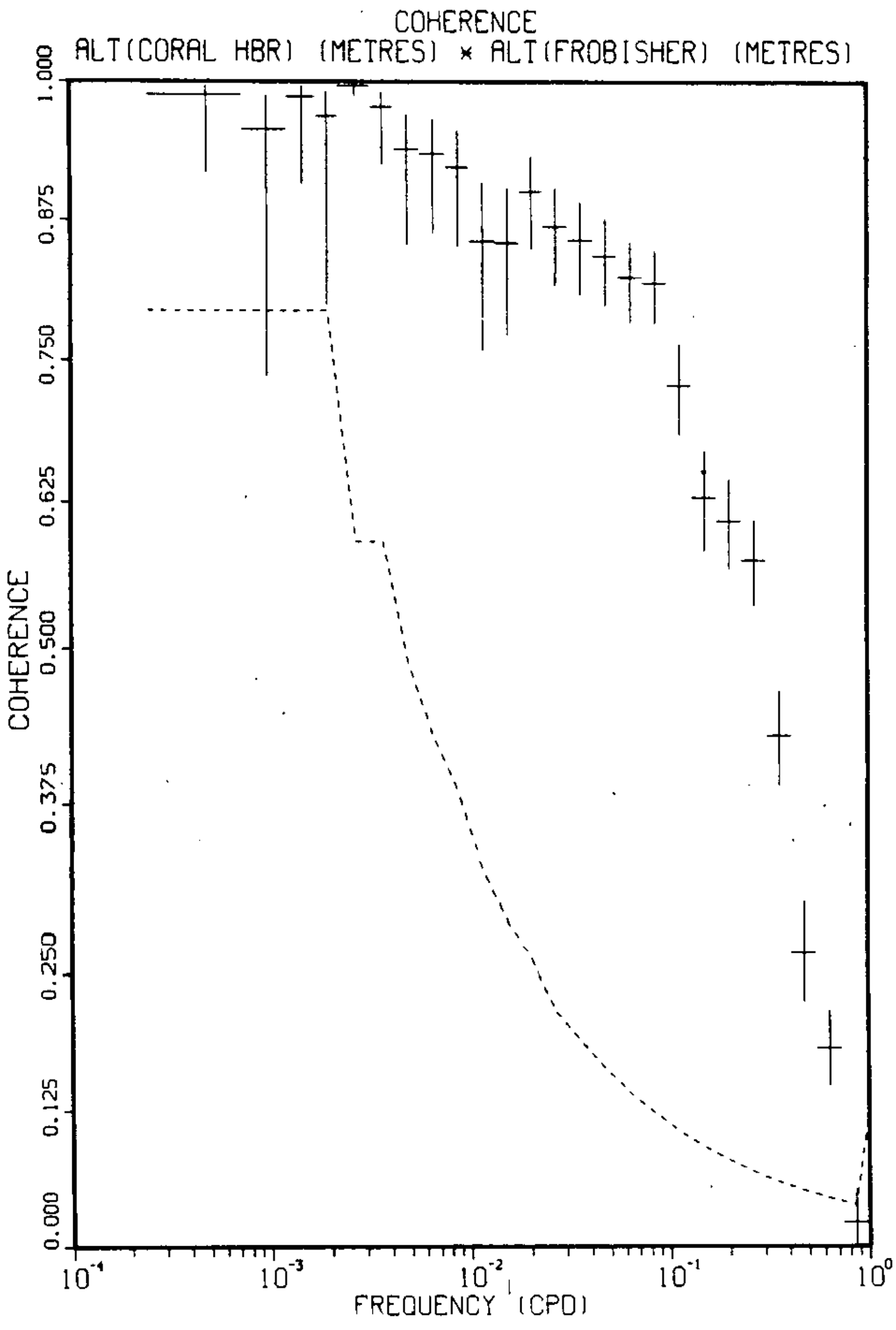

Figure 12 Coherence between Iqaluit and Coral Harbour in the height of the 70kPa pressure surface. The dashed line is the coherence between random signals.

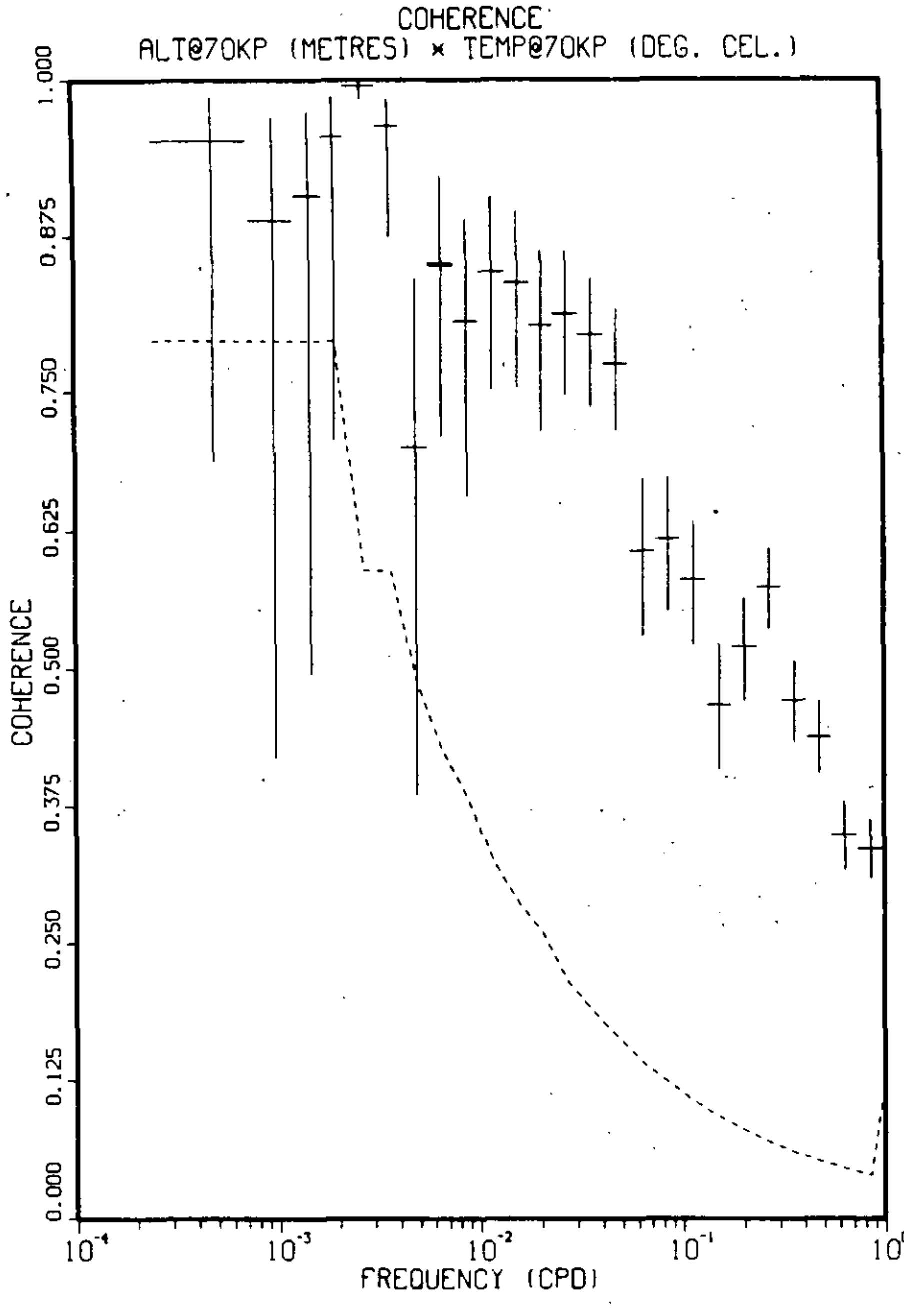

Figure 13 Coherence between the height of the 70kPa pressure surface above Iqaluit and the temperature at that surface. As in Fig. 12, the dashed line gives the coherence between random variations.

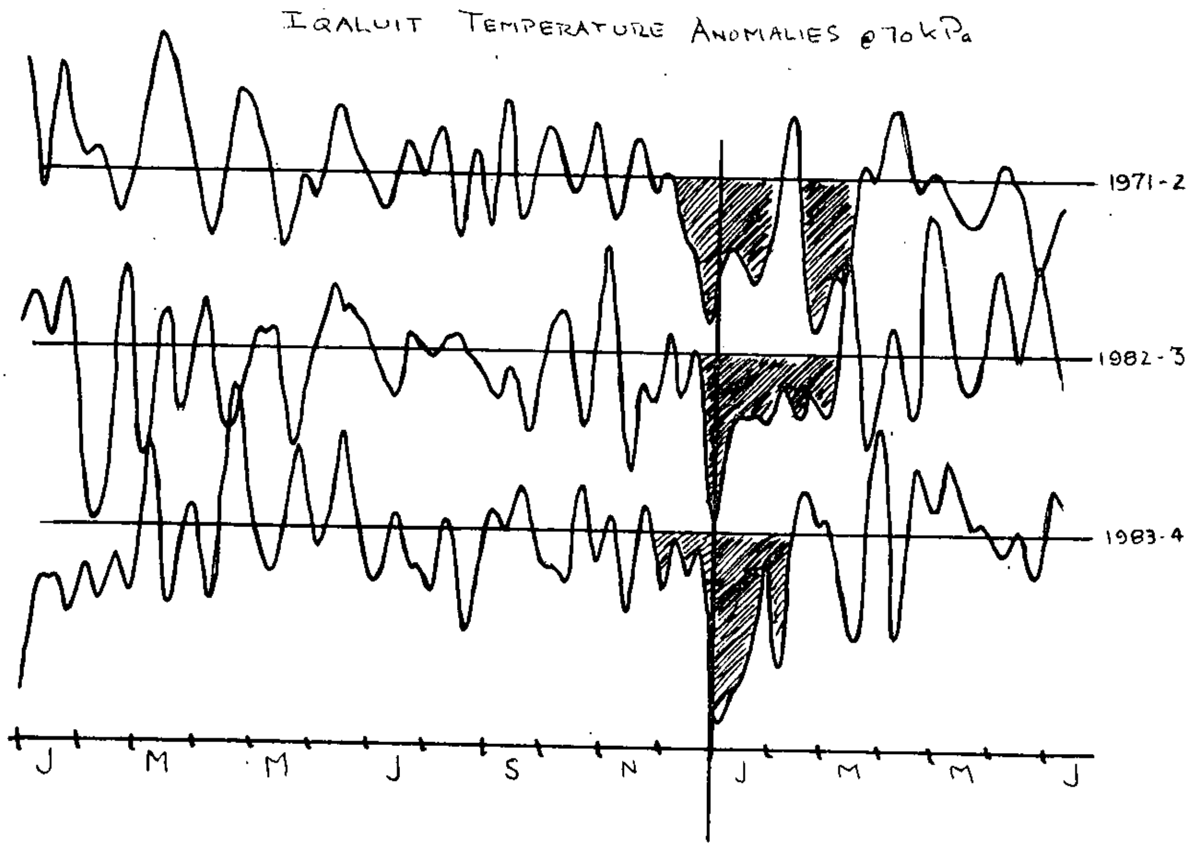

Figure 14 Eighteen month records of temperature anomalies at the 70kPa surface above Iqaluit spanning the three most severe winters between 1961 and 1987.

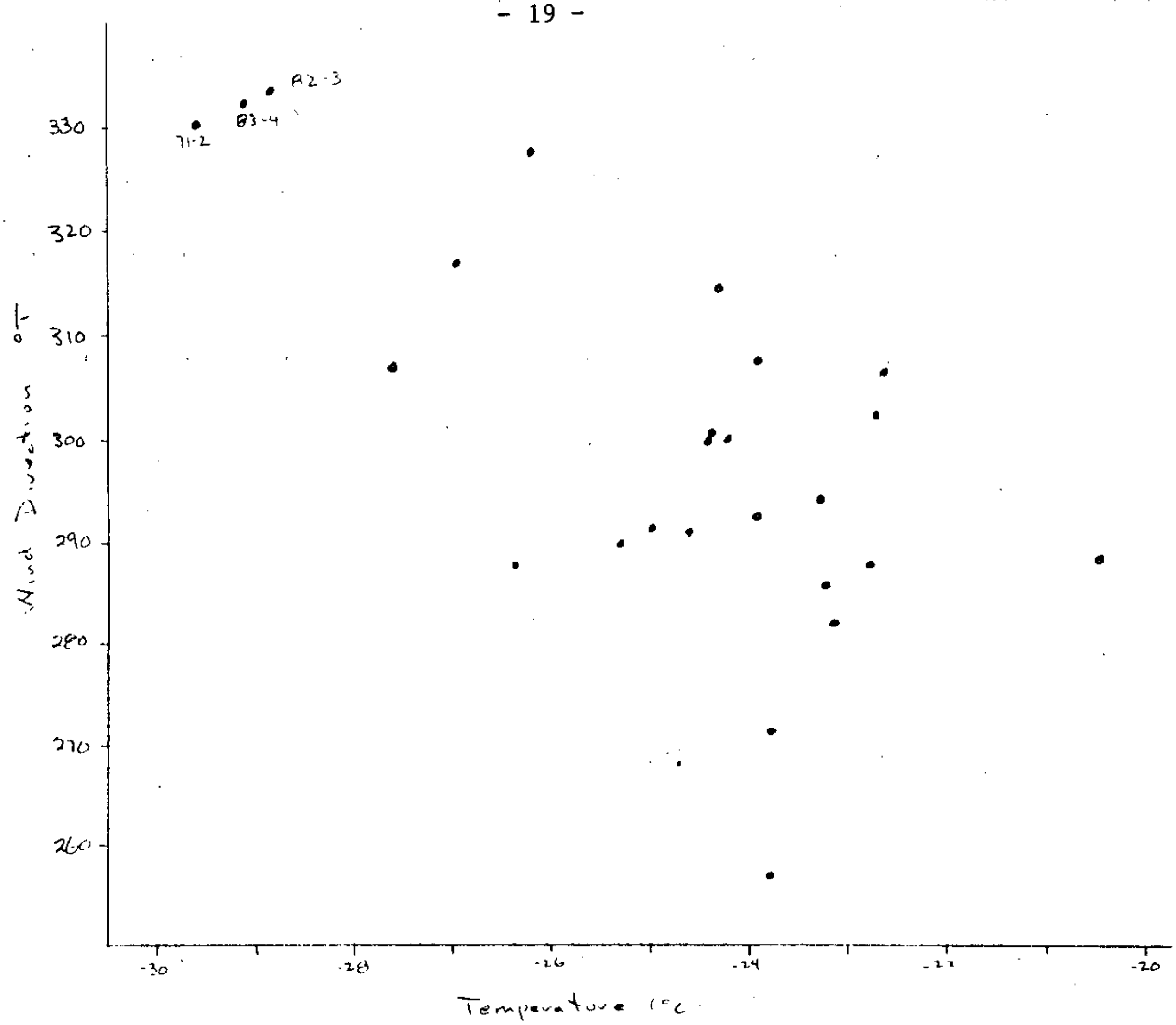

Figure 15 Scatter plot between the wind direction and temperature obtained at the 70kPa pressure surface over Iqaluit. Values are averages over the winter months; December, January and February.

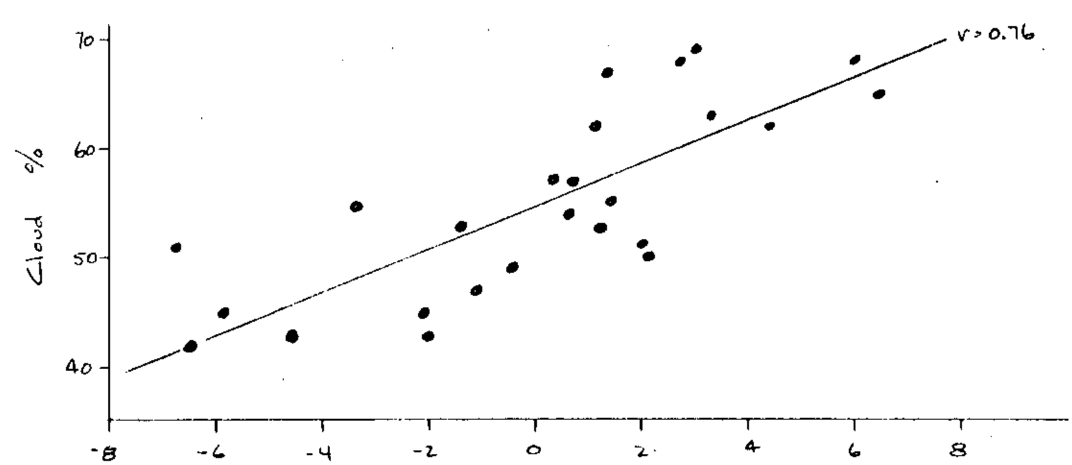

Figure 16 Winter air temperature as a function of the cloud cover at Iqaluit.