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Meteorological Conditions in the Decade 1970-79 and their Impacts over the Northwest Atlantic

by

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Introduction

The 1970's was a decade of remarkable weather extremes with devastating consequences for people around the world. Through television documentaries and news accounts, we witnessed the dramatic effects of unusual climate on the seas and in other lands such as in the Sahel and Bangladesh where one half million people died of famine following drought and floods. Most of us are aware of how poor harvest weather and droughts in the USSR, Australia and North America had a worldwide effect on food supply and hence on prices; of how an occurrence of unusually warm ocean water off Peru (El Nino) contributed to a reduction of the anchovy fishery from over 12 million tons in 1970 to 2 million tons in 1973; of how the 1976-77 winter's cold and snowfall in eastern North America and last year's Texas heat wave each caused a $20 billion loss to the North American economy.

The North Atlantic had its share of climate extremes during the past decade. Table 1 lists a few of the more newsworthy climate records.

The Northwest Atlantic is being submitted to many forms of exploitation. Fisheries thrive for many species and maritime nations are making a concerted effort to control and conserve this resource. In the future, offshore drilling, undersea mining and marine transportation of hydrocarbons and other products will become more frequent and widespread. Climate has significant social, economic and environmental impact on these and indeed on most coastal and offshore activities. Man's ability to forget the past when planning future activities makes a review of past decades or centuries climate, a prudent and worthwhile activity to engage in from time to time.

This paper will report on a selection of the significant meteorological events and climatological anomalies of the past decade. For a unified perspective, however, this review will begin with synoptic patterns - the movement and evolution of low andhigh pressure systems in the recent decade and the past. Following, will be a description of winds, precipitation and temperature patterns and their impacts.

Pressure Patterns

The area of horizontal air and water temperature gradients around the Gulf Stream from the Grand Banks to south of Cape Hatteras is a favoured spawning area for the development and intensification of low pressure areas, particularly in the winter months. There, systems tend to move in a north easterly direction over or to the east of the Atlantic Provinces of Canada. Many lows continue northward, either to Baffin Bay, or more frequently, to a position near Iceland where they weakenonly to be replaced by another centre. The Icelandic low is a semi-permanent feature and is sometimes called a "graveyard for Atlantic storms". The general movement, rapid development and intensity of migrating lows and the mean position and intensity of the Icelandic low have important implications for the regional climate of the Northwest Atlantic.

Particularly in winter, a relatively strong and persistent cold northly air flow transports cold water and pack ice down from the Arctic along the Labrador coast. Waves developed in strong northerly winds over the Labrador Sea progate southward as swell to mix with local wind seas east of Newfoundland. The confused pitching seas which can result are a serious problem to the mariner and to anyone who would develop this area's offshore mineral resources.

The intensity and movement of low and high pressure systems was investigated by Zishka and Smith (1980). Figures 1 and 2 are from their analyses showing the frequency, genesis and lysis (destruction or cessation) and relative variability of January and July 1950-77 lows analysed over a 2 degree quadrangle grid. The frequency maxima of the individual cyclone events shift northward in summer to follow the zone of strong horizontal air temperature gradient. The birth or genesis area for lows off the northeastern states is well marked in this analysis but the "graveyard" or lysis area for lows east of Greenland is not - quite likely, because it is just outside of the analysis area. Relative variability is the mean absolute difference between individual year event frequencies and the 28 year mean frequency divided by that mean. It gives some indication of interannual variability. Ziska and Smith have superimposed their analyses of a preferred track on this chart. Year to year variations in the number of and mean minimum pressure of January and July cyclones is plotted in Figure 3. While the number of lows has been decreasing, their central pressure have also been lowering. Another observation is that if central pressures are taken as a measure of storm intensity, the seventies have had fewer but more intense storms over North America.

In Figure 4, the areal distribution of cyclone events for the pentads, 1950-54 and 1970-74 is compared. While the number of cyclones has been decreasing through the seventies, it appears that the predominant cyclone track, if there is such a thing, has been displaced further south in the latter pentad, perhaps indicating a more southerly intrusion of Arctic air over the Scotian Shelf and Grand Banks in recent winters.

Storms and their behaviour are understandably of major interest to fishermen. There are direct impacts from winds, surface currents and waves but variations in productivity are also possible. Figure 5 shows the tracks of January lows obtained from Canadian analyses for decades ending in 1968 and 1978 respectively over the Northwest Atlantic and Canadian Arctic. These lows all attain a central pressure less than 98 kPa. In the period 1969-78 a majority of these lows migrated northeastward to become part of the Icelandic low. In the earlier decade, however, there were an approximately equal number of cases where the lows stalled over the northern Labrador Sea - Davis Strait area, an indication that a tendancy to blocking may have existed. In a blocking situation, a low would tend to persist in one area for a relatively long period of time. There are two other points. First, the notion of a predominant storm track is at best an idealization; and second, the Canadian analyses confirm the number of storms is fewer in the seventies decade than in the sixties.

Painting (1977) noted a marked decrease in the frequency of blocking anticyclones, particularly in winter, between the periods 1965-69 and 1970-74 at mid-latitudes between 10 E and 80 W. His analysis of the difference in averages of mean sea level pressure, Figure 6, shows the Icelandic low and Atlantic subtropical high to have intensified in winter, in the early seventies. Furthermore, his analysis showed that the median position of the Atlantic subtropical anticyclone was displaced northward by about 10 degrees latitude from the late sixties to eary seventies. As a result, there was an enhanced westerly flow over the open north Atlantic in the early seventies.

Winds

Changes in mean wind velocity are important in driving ocean currents and moving pack ice, and consequently are a factor in fish migration and productivity. Cushing (1980) argues that shifts in the mean position of the Icelandic low and consequently wind direction may have altered the strength of the Irmringer current and that these climate events lead to the rise and fall of the western Greenland cod fishery. The extremes of wind also have their impacts, particularly on fishing operations.

Long unbroken time series of winds over the oceans are hard to come by. In the Northwestern Atlantic, Sable Island, and until 1972 Weather Ship Bravo were a useful source of this information. The use of pressure gradients is a logical way of investigating the recent decadal variations in wind speeds. Figures 7 and 8 show the frequency distribution of geostrophic wind speeds by 5 m/s ranges over decades ending in 1968 and 1978 respectively for a selection of locations in the Northwest Atlantic. There is a consistent increase in the frequency of occurrence of higher wind speeds at most northern locations. Most currently available tables and atlases summarizing marine wind observations do not include data from more severe 70's. Design and strategy for offshore operations based on earlier climate normals may be insufficient if the more extreme climate continues.

Monthly vector mean geostrophic wind speeds were plotted for a point near the weather ship Bravo, Figure 9. These confirm the notion that winds in the seventies were stronger on the average than the sixties. Monthly mean speeds in the sixties did not peak as high in winter as in the seventies indicating lower than usual wind speeds in that area and/or winds which were more equally distributed with respect to direction in the sixties.

The frequency of strong winds has a considerable year-to-year variability for a particular point, as is evident in Figure 10 depicting the hourly frequency of gales at Sable Island by year (McKay, personal communication). Unlike the consistent pattern of increase over the northern parts of the North Atlantic the decadal frequency of gales does not appear to have changed much at Sable, but has exhibited more variability in the recent decade.

Precipitation

Precipitation measurements over ocean areas are very scarce. Only fixed ocean weather stations and occasionally research vessels measure precipitation. However, long-term seasonal and annual ocean precipitation patterns have been analysed from present weather and visibility groups as by Doman and Bourke (1980), Figure 11. However, their estimates appear 30-50% low when compared to Sable Island and other Canadian coastal stations. One suspects the frequency of fog to the north of the Gulf Stream may be partly responsible for the underestimate. Since precipitation at coastal stations is affected by orography and it is possible these stations may not be very representative of conditions offshore. They should give an indication of (year-to-year variations of) runoff into smaller estuaries.

The mean precipitation for a combined selection of stations including Montreal, Quebec and Saint John's is plotted in Figure 12. The graphs indicate that there has been a slow increase in annual precipitation over the last two decades - at least for eastern Canada.

Precipitation and consequently, streamflow, turbidity, sediment transport and estuary salinities have consequences for marine ecosystems. Heavy seasonal rainfall in part thanks to Hurricane David and Frederic caused excessive runoffs in rivers over much of Virginia in 1979 and the resulting low salinities threatened oysters in the James River area (Austin 1979). The drought of 1980 over the southeastern U.S., however, increased salinities but had negative side effects. It is feared (Austin 1981) that the preditor, oyster drill (Urosalpinix) which was flushed out of river tributaries by Hurricane Agnes in 1972 may recover.

Wet Year in Atlantic Canada

The decade ended with two consecutive wet years across the Atlantic region. In 1979, Saint John and Halifax reported record precipitation amounts of 1976 mm and 1671 mm, respectively. The year 1980 was particularly unkind to the people of Newfoundland. In that year, the Island suffered through its wettest, dullest summer on record. St. John's measured 450 mm of rain from June to August; an amount 500% of normal! Record low totals of sunshine were set in July and August when only 26% of possible sunshine was recorded. The wet weather was not just confined to summer; 1980 was the rainiest year at St. John's and Gander since records began in 1943. Both stations reported over

1400 mm of precipitation as well as 244 and 230 days with measurable precipitation, respectively.

The excessive wetness had a negative effect on agriculture, outdoor recreation and tourism and for the fishery it was a disaster! Nowak (1981) compiled an extensive list of socio-economic impacts on the Newfoundland fishery because of the prolonged wet spell. It was blamed for loss of wages by workers in fish plants and by crews on vessels. For the squid and salt-fish producers, the year was particuarly poor because there were no prolonged sequences of dry days. Throughout the months of August and October, there were no more than two consecutive days without precipitation at St. John's. Gander had an astonishing total of only 14 summer days without measurable precipitation. Squid production was down an average of 30 to 50% for the season. The summer had disasterous effects on other activities that provide incomes for the fishermen and their families. Local part-time farmers maintained that the wet weather caused garden produce to fail and problems arose in hunting as a result of the low incomes of the rural inhabitants.

Temperature

There is increased interest in global air temperatures. Why? - because our society is becoming increasingly technically advanced at the same time as the world is approaching the limits of its food supply. Variations in global temperature have an impact and threaten the food supply. We have also been alerted to the possibility that glacial episodes are initiated rather suddenly. On the other hand, man's influence on the global climate is suspected. It has been suggested that man's agricultural methods and other activities are contributing to a dust veil which could eventually set off another prolonged cold period. Ice core data from the Canadian Arctic and Greenland examined by Koerner and Fisher (1979) led them to suspect that this may already be happening, but not necessarily as a consequence of atmospheric turbidity. On the other hand, the global concentration of CO_2 has been observed to be increasing and at rates which suggest this is due to man's burning of fossil fuels. The extrapolation of current socio-economic trends and the results of climatic models suggests that there will be a global warming and and that this will be felt most strongly at high latitudes.

There are no clear cut predictions as to what will happen - one can only watch and wait. And it seems that we are definitely watching. Many analyses on local and global scales have been published, for example Brinkman (1976), Budyko (1977) and Yamamoto et al (1975, 1977). A recent paper by Yamamoto and Hoshiai applied the optimum interpolation method of Gandin (1963) to 370 stations for an analysis of trends in northern hemisphere air temperatures. Their results (Figure 13) indicate that temperatures appear to be slowly recovering from the successive cold episodes of the sixties. For the Northern Hemisphere, the temperature curves, Figure 14, of Jones and Wigley (1981) confirm a trend to warmer temperatures in all seasons.

During the seventies, however,several lengthy cold spells gripped parts of the north Atlantic. In 1972, strong cold air advection persisted over Canada most of the year. In 1976-77 eastern North America had the coldest winter on record and, in 1979, cold weather prevailed over most of northwest Europe throughout the year.

The difference in heights between the levels of the 50 kPa and 100 kPa pressure levels gives an indication of temperature within that layer. A useful approximation gives an increase of mean temperature of 1 degree C for an increase of 20 gpm in thickness. Analyses of the 1000-500 mb thickness have been made by Painting (1977), Dronin (1974), Kukla et al (1977), Harley (1980) and others. Painting's 1977 analysis (Figure 15) of the difference between thickness averages for winters between 1971-4 and 1961-70 indicates a significant cooling over Canada and the northwest Atlantic in winter and a warming in this season over Europe, but no significant changes when the annual differences are considered. Harley (1980) considered pentadal means of annual 1000-500 mb thickness over the northern hemisphere and also found no significant cooling or warming to have occurred over the 25 year period 1949-1973 in this area. However, when one examines his thickness differences between the period 1969-73 to the period 1974-78, Figure 16, the relatively large negative anomalies east of Newfoundland appear to be quite significant for this later period. The drop in thickness here and over eastern North

America might be taken as an indication of changes in the steering flow at 500 mb which seem to persist, particularly in the severely cold winters in the late seventies over eastern North America and the adjoining Atlantic.

The downward trend of air and sea temperatures between 1953 and 1968 as described by Perry (1974) was in evidence during the mid-1970's in the North Atlantic. For those years, when Ocean Weather Stations B, C and J were operating in the latitudinal zone around 55 N air and sea surface temperature were about 0.8 C and 0.5 C below normal, respectively.

Tables of water and air temperature were produced for the decade ending in 1979 for the SSMO Area 4, the Southeast Newfoundland coast (Figure 17). Air temperatures were -0.8 C cooler over the seventies decade relative to the period 1869-1971. On examining the monthly values it appears that the seasonal temperature cycle has a greater amplitude - warmer summer and colder winters. The latter trend is reflected in the decadal water temperatures, but there is only a small .1 C change in the annual means.

A plot of annual and five-year mean temperatures (Figure 18) for eastern Canadian stations (Montreal, Quebec and Saint John's) shows indications of a slight cooling trend into the seventies. A similar plot for Vestmanneyjar Iceland, Figure 19, shows the gradual cooling trend from the thirties onward. A little amelioration appeared there in the early seventies but the 1979 mean was the coldest on record.

Sea Ice

The formation, state and movement of pack ice are governed by the interaction of wind current, air and sea temperatures and sea state. As atmospheric conditions vary considerably from year to year and month to month, so does sea ice. Figure 20 shows the end of the month distribution between past decade 1971 and 1980 of pack ice concentrations greater than 1/10th. Interannual differences are startling. The early seventies were bad ice years for the Canadian East Coast and western Greenland. Pack ice formed early in the year along the Gulf of the St. Lawrence, Newfoundland and Labrador coasts and stayed until late in the season. The year 1972 was a particularly bad ice year and record high freezing degree-day accumulations totalled about 40% above normal at coastal weather stations in the Maritimes (Markham 1980).

Further east, these analyses do not show the ice enroaching northern Iceland as frequently as was the case in the late sixties (Sigtryggsson 1969) but there is considerable year-to-year variation. Compare the end of July 1974 to July 1975. In 1974, the pack ice limit was 1000 km further north along the east Greenland shore than it was in 1975. That year the pack ice curled around Cape Farewell and a tongue from the pack extended 40 km further east toward Iceland. Ice conditions at the end of June were similar for both years but in 1974 an increased northerly flow and warm temperatures along the east Greenland coast contributed to the early breakup of ice. In 1975 decreased sea level pressures over Greenland and consequently an increase in the frequency of the southerly flows kept the pack ice intact along the coast of Greenland.

Record of Number of Icebergs - 1972, 1973 and 1974

Extensive sea ice and record numbers of icebergs occurred between Baffin Bay and Newfoundland in the springs of 1972, 1973 and 1974 causing millions of dollars damage to the East coast fishery. The combination of strong northwesterly winds, record low temperatures in the eastern Arctic, and cold sea temperature anomalies over the mid-latitudinal belt of the North Atlantic led to bergs much further south and east than normal.

An estimated 10,000 bergs break off the western Greenland glacier each year and begin a journey that may take 24 months to reach the Grand Banks. A yearly average of 280 make it below the 48th parallel based on figures from 1946 to 1973. The four seasons before 1972 were below normal years for icebergs (Mariner's Weather Log). In 1973 more than 1580 bergs were spotted south of St. John's, an all-time record with observations dating back to 1919. Airborne reconaissance of icebergs by the International Ice Patrol began about a month earlier than normal on February 29 and ended late on September 4. For the first time since 1959, . Coast Guard patrol boats were deployed to warn shipping of the dangers of bergs. In 1973, 847 bergs were spotted across the Grand Banks. In 1974 neary 1400 icebergs drifted into the Grand Banks between March and August. Over 300 icebergs made it as far as the 46th parallel and one reached the 42nd parallel. In the first week of July, over 250 bergs were driven onto the Newfoundland coast, a record for so late in the year.

Severe ice conditions present a great hazard to shipping and fishing along the eastern coast of Canada between mid-February and the end of April. During 1972, 1973 and 1974 and again in 1977, the threat was extended into May or June as record ice amounts combined with easterly winds, high tides and storms to push ice into bays and inlets along the coast of Newfoundland. Heavy damage was done to fishing vessels and equipment and lobster trips. In 1976-77 property damage and loss of revenue was in excess of $20 million (McKay, 1978).

Significant Climate Events and Storms

The Northwest Atlantic had its share of climatic anomalies or variations in the seventies. There were virtually limitless combinations of climate anomalies and consequences but prolonged cold and extensive sea ice, sustained drought, spells of wetness and devasting storms were the dominant problems. Figures 21 and 22 highlight a number of the significant storms and other climatic events that occurred in the North Atlantic basin during the 1970's.

Violent storms that claim lies and inflict extensive property damage are normal occurrences each year in the Atlantic. One only has to peruse the "Monster of the Month" feature in the Mariner's Weather Log to appreciate how regular fierce gales blow and how vulnerable man is to these whims of nature. On several occasions during the last years of the decade hurricane-force onshore winds coincided with the amplified, astronomically-influenced perigean spring tides. Tidal flooding and erosional damage to low-lying coastal regions was reported from Virginia to Nova Scotia and, quite intriguingly, on the opposite side of the Atlantic on the west and south coasts of Great Britain and along the North Sea coasts of France and West Germany. Damage to roads, fishing wharves, houses, and seawalls was extensive and on several occasions evacuations of thousands of persons was required. Of special significance, because of damage to property, was the tidal flooding on 11-12, January 1974 in the British Isles, 16-17 March, 1976 from Maine to Nova Scotia, 8-9 January, 1978 in New England, and on two occasions in February 1978, on the 11-12 in Great Britain and on 6-7 from New Jersey to Nova Scotia. Damage from two such storms in the winter of 1976 is described below:

1-2 January 1976

Described as the worse storm to strike northwest Europe in 29 years, the intense gale caused more than 100 deaths and inflicted a half billion dollars damage across most of northern Europe from Ireland to western parts of the Ukraine. Strong winds with gusts to 90 knots blew across countries bordering the North Sea. Waves 20 m high were reported along England's east coast. Flooding caused massive evacuations in Denmark and hundreds of ships were grounded or sank. The North Sea surge ruptured dykes in Belgium and flooded low-lying areas in England, Holland, Denmark and West Germany.

1-2 February 1976

A month later the infamous "Groundhog Day" storm raced up the Atlantic Seaboard causing extensive damage from Cape Hatteras to the northern tip of Labrador. Record or near-record low pressure occurred at several locations. Boston recorded their second lowest pressure of 964.4 mb and Caribou, Maine had a 957 mb reading, a record. Winds were from southeast to southwest at 30 to 50 kts or higher throughout the Maritimes. On Grand Manan Island, N.B. the wind averaged over 63 kts for 20 consecutive hours. At sea, ships measured hurricane-force winds and 12 m waves. For many communities in southwestern Nova Scotia and along the Fundy Coast the period of strong winds coincided with the rising tide resulting in exceptionally high water levels. Tide levels at Yarmouth and Saint John were 6 m and 8 m, respectively or 1.5 m above the predicted value - new records for both stations (Amirault and Gates, 1976).

Property damage was estimated at between $10 and $50 million in the

Atlantic Region (Tilley, personal communication). Many docks and water front structures were severely damaged. Several large freighters went aground and many collisons occurred.

Documenting newsworthy climate anomalies is much easier than reporting and interpreting the socio-economic disruption and losses associated with such events. Little reliable, long-term statistical information on economic loss values has been published. Fortunately in marine disasters, good loss estimates are available from such reputable groups as the Marine Safety Council, American Institute of Marine Underwriters, Lloyds of London and in Canada, the Fishing Vessel Insurance Plan operated by Canada Department of Fisheries and Oceans. Losses suffered by small fishing vessels (open boats or decked boats less than 20 m in length), because of storms and other adverse weather, grew steadily over the past decade. Since 1975, an average of 102 claims, out of a total of 378 were listed as weather-related casualties. This number does not take into account claims due to such causes as stranding and collision in which weather may have been a contributing factor. Settlements due to fires and explosions account for the greatest loss followed by weather, collision, stranding, flooding and mechanical. Almost 9400 fishing vessels are insured by the plan with more than 70% coming from the Atlantic region. Figure 23 shows the locations of casualties caused by capsizing, foundering, sinking and other heavy weather damage for the period 1963-1978.

Conclusion

The 1970's was a decade of conspicuous climate change in the northwest Atlantic. Stronger winds and devastating storms, colder winters, summers with either extensive wetness or dryness, and severe ice conditions occurred at times since 1972. The impacts of weather were staggering in terms of life, property and lost revenues. The loss of a North Sea platform in 1980 is estimated to have cost about $2 billion and took 123 lives. In 1977 ice damage to fishing gear and losses in revenue along the Canadian East Coast was in excess of $20 million and the winter of 1976-77 caused a similar loss in fishing revenue in the Atlantic States.

An important result of the growing consciousness over climate change and its impact in society has been the beginning of international and national climate programs. There have been world conferences on the environment, food, water and climate. The World Climate Program made a strong appeal to the global community to improve our understanding of climate and its impacts. In Canada, the Canadian Climate Program has been designed to help Canadians to respond better to climate variations, to predict climate and climate change and to better apply climate information for the management and wise use of our resources.

Understanding the role of the oceans in influencing climate is vital to defend against climate risks in offshore developments and capitalize on the economic opportunities provided by improving our knowledge of climate for managing our fisheries resource.

Whether the 1980's will be any different from recent years in the number of outstanding climate anomalies or in the magnitude of economic and social disruptions is difficult to determine. Let us hope, however, that the heightened awareness of the importance of climate will make us better able to cope with the surprises climate is sure to have for us.

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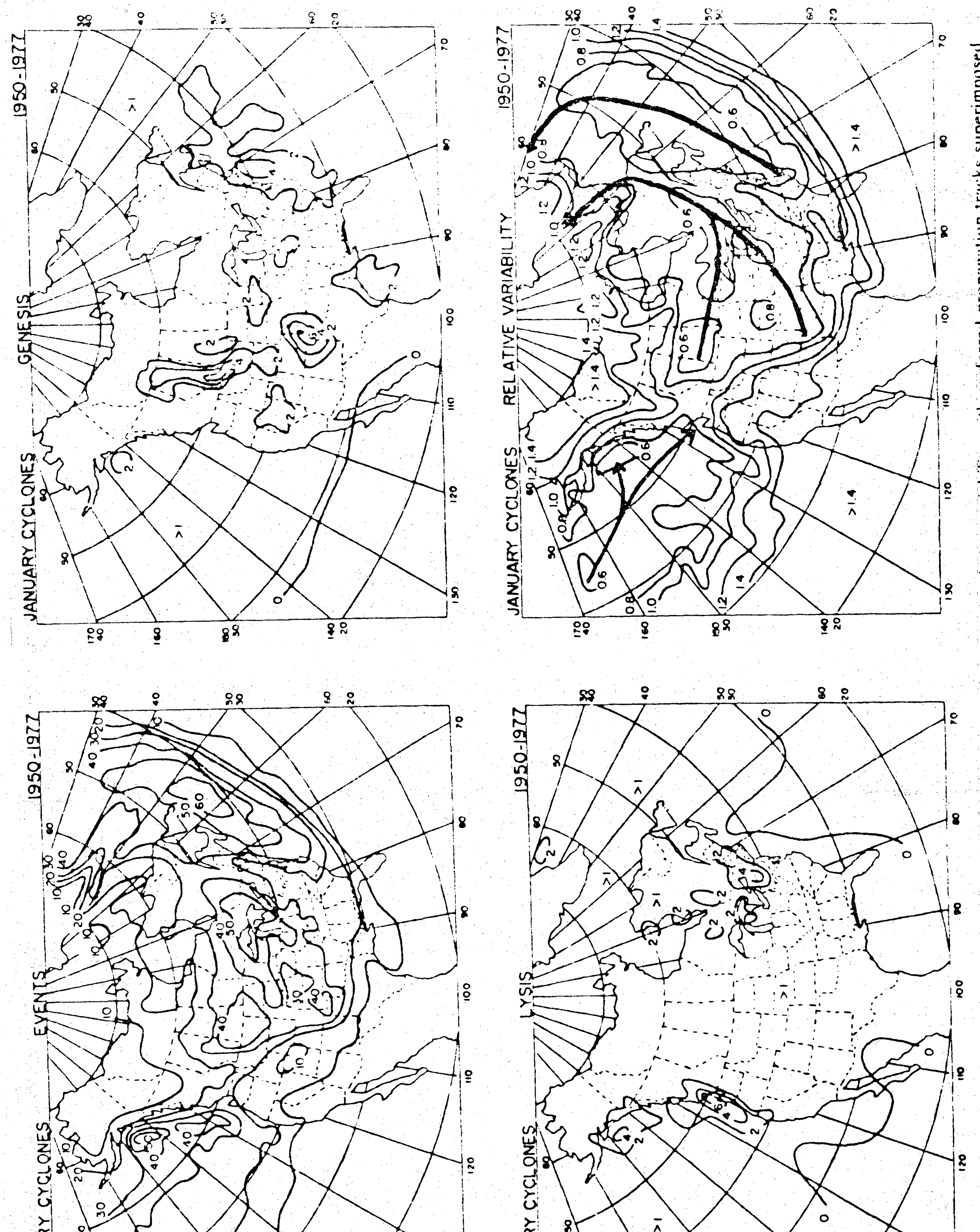
Table 1

North Atlantic Climate Records 1970-79

Date	Record
Sept - Dec. '71	- W. Norway stormiest in 30 yr; 75 days wind above force 8
1972	- Eastern Canadian Arctic mean annual temperature 4 deg C below normal
Fall '73*	- Shetland Is. stormiest in 40 yr
Summer '75	- Reykjavik, Iceland coldest since 1920
Summer '76	- record UK drought; warmest in 300 yr
February '76	- 95.70 kPa SLP at Caribou, Maine
January '77	- snow recorded in Bahamas - 94.02 kPa SLP at St. Anthony, Nfld; North American record
1978	- record high precipitation at Halifax, 1671 mm - W. Norway and Akureyri, Iceland - every month below normal temperature
1979	- record high precipitation at St. John's, 1976 mm - annual mean at Akureyri, Iceland 2.4 C below normal - annual sunshine total in Iceland, lowest since records started in 1880 - W. Norway coldest year since 1923 - S. Norway twice the normal number of gale-days



1950–1977 areal distributions of (a) events, (b) genesis, (c) lysis and (d) relative variability with preferred propagation tracks superimposed for January cyclones. Values represent 28 year totals. Areas in (b) and (c) in which individual quadrangles contain a frequency >1 but do not form centers defined by three contiguous quadrangles are designated by >1.

Figure 1 (after Zishka and Smith, 1980)

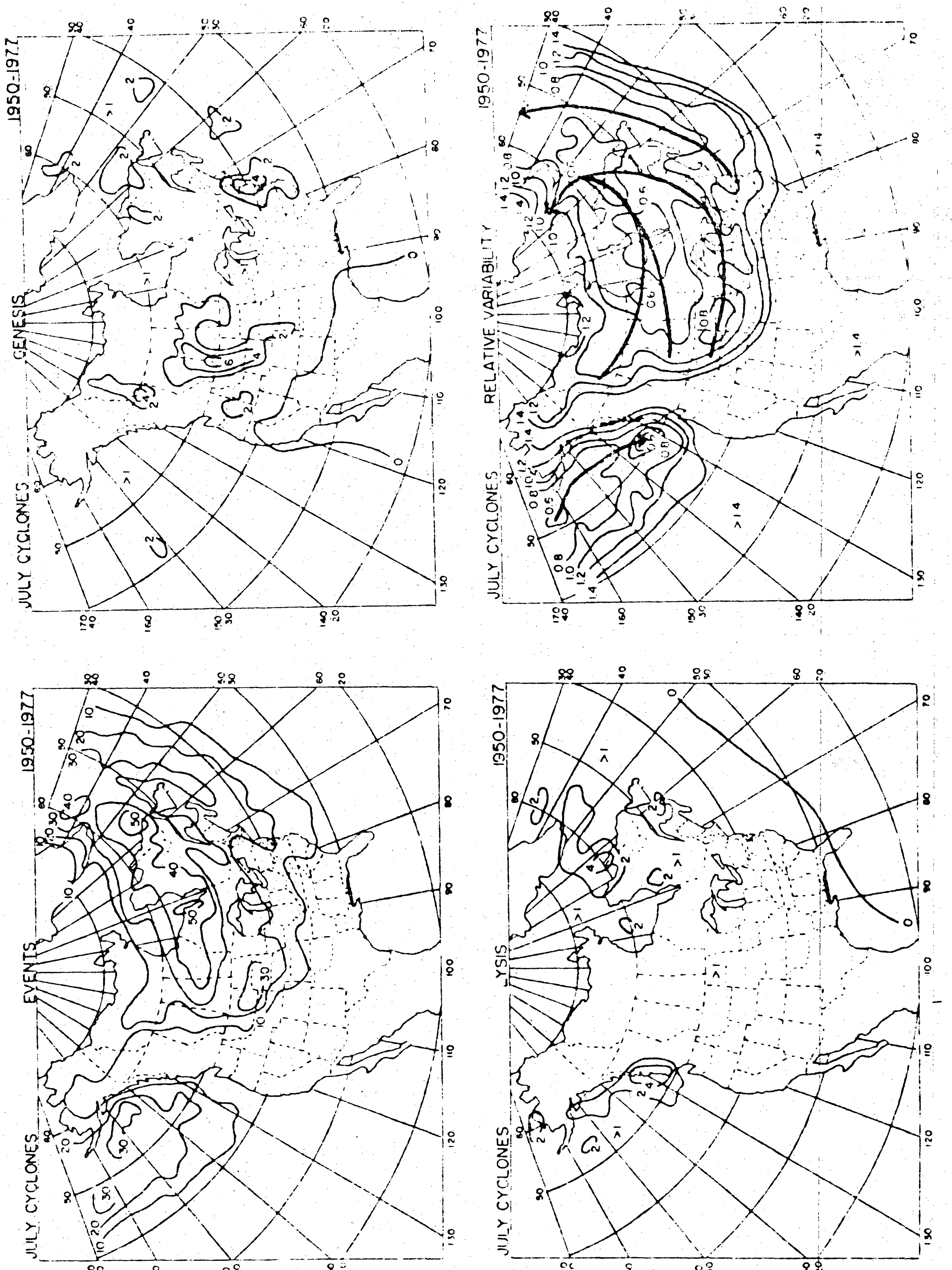
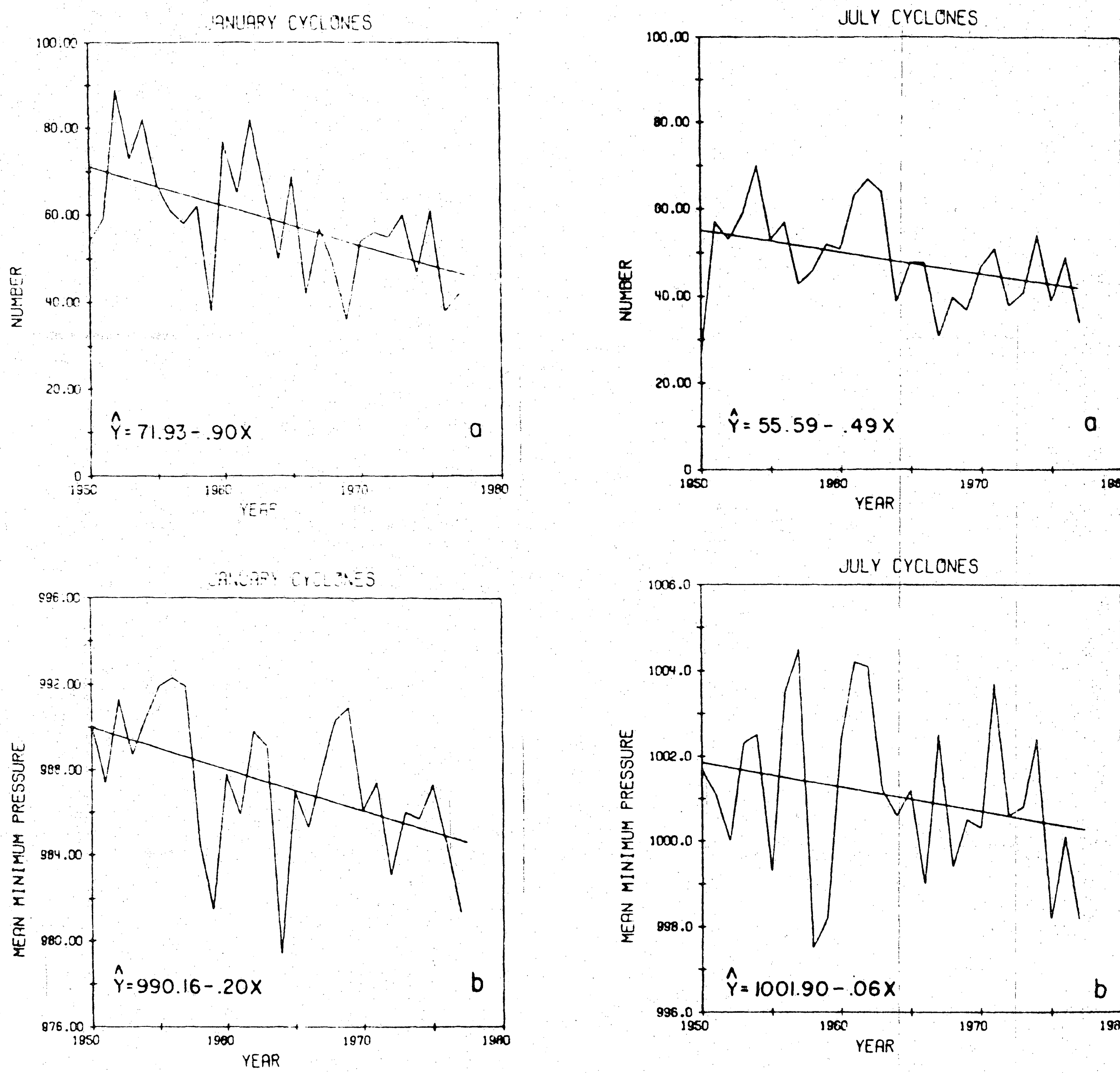


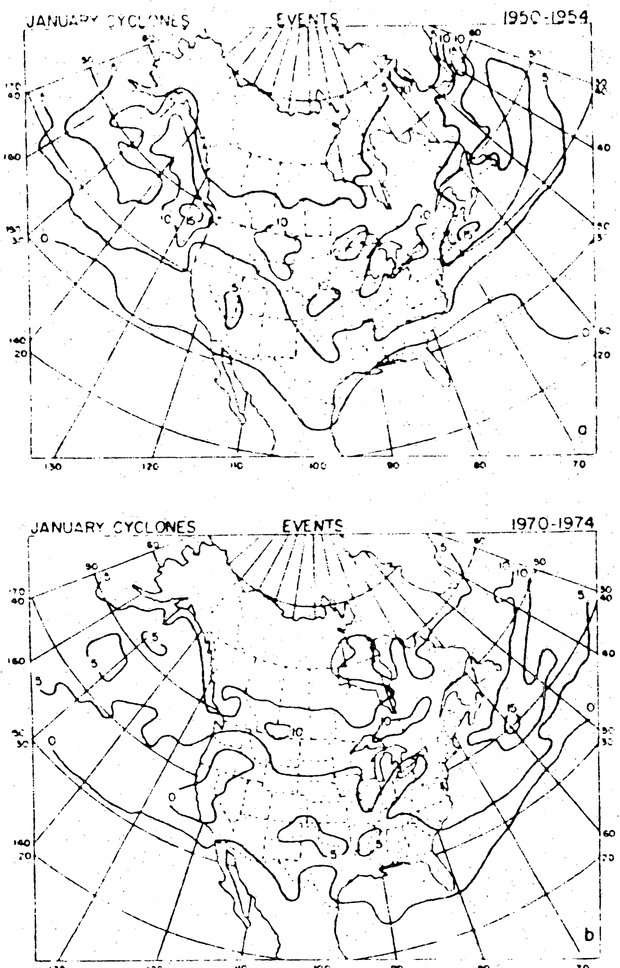
Figure 2 (after Zishka and Smith, 1980)



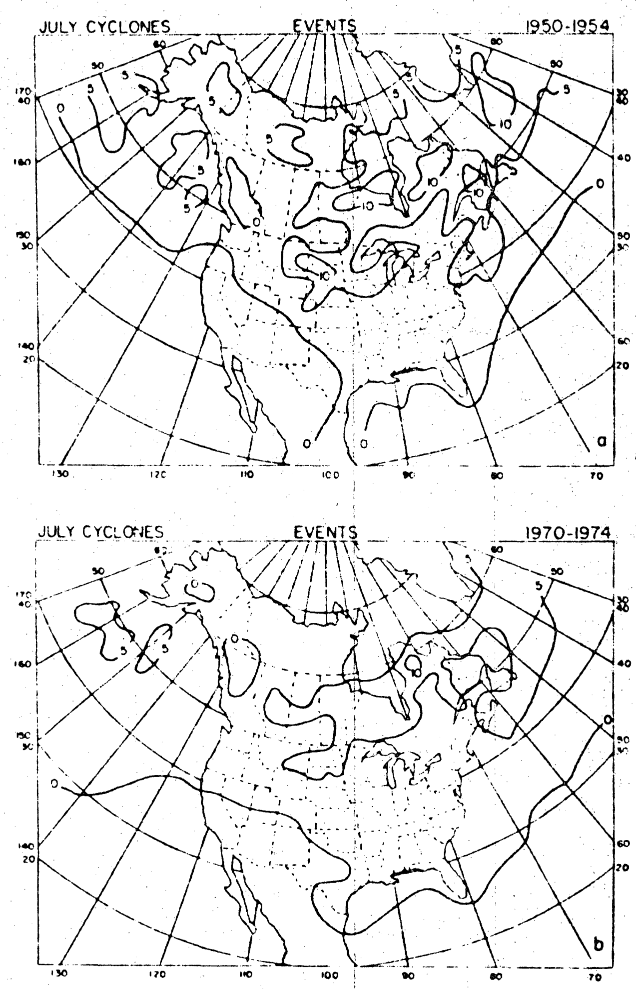
Yearly variations and corresponding linear regression lines of (a) number and (b) mean minimum pressure (mb) for January cyclones. $\hat{y}$ = number of cyclones or minimum pressure; X = year − 1950. Correlation coefficients of each line are: (a) $r = -0.54$, (b) $r = -0.47$.

July cyclones. (a) $r = -0.37$, (b) $r = -0.24$.

Figure 3 (after Zishka and Smith 1980)



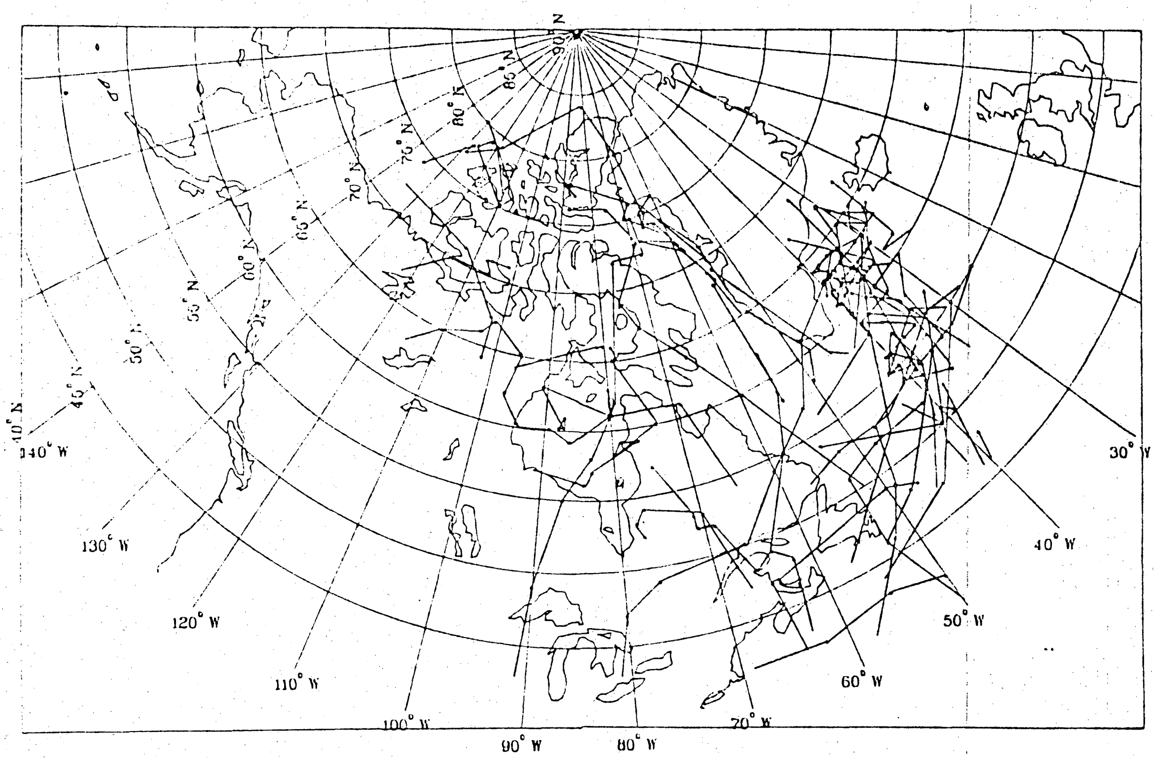
Areal distributions of January cyclone events for the subperiod (a) 1950–54 and (b) 1970–74. Values represent 5 year totals.



July cyclones.

Figure 4 (after Zishka and Smith 1980)

LOW PRESSURE CENTRES : < 980 MB : JANUARY 1969-1978



LOW PRESSURE CENTRES : < 980 MB : JANUARY 1959-1968

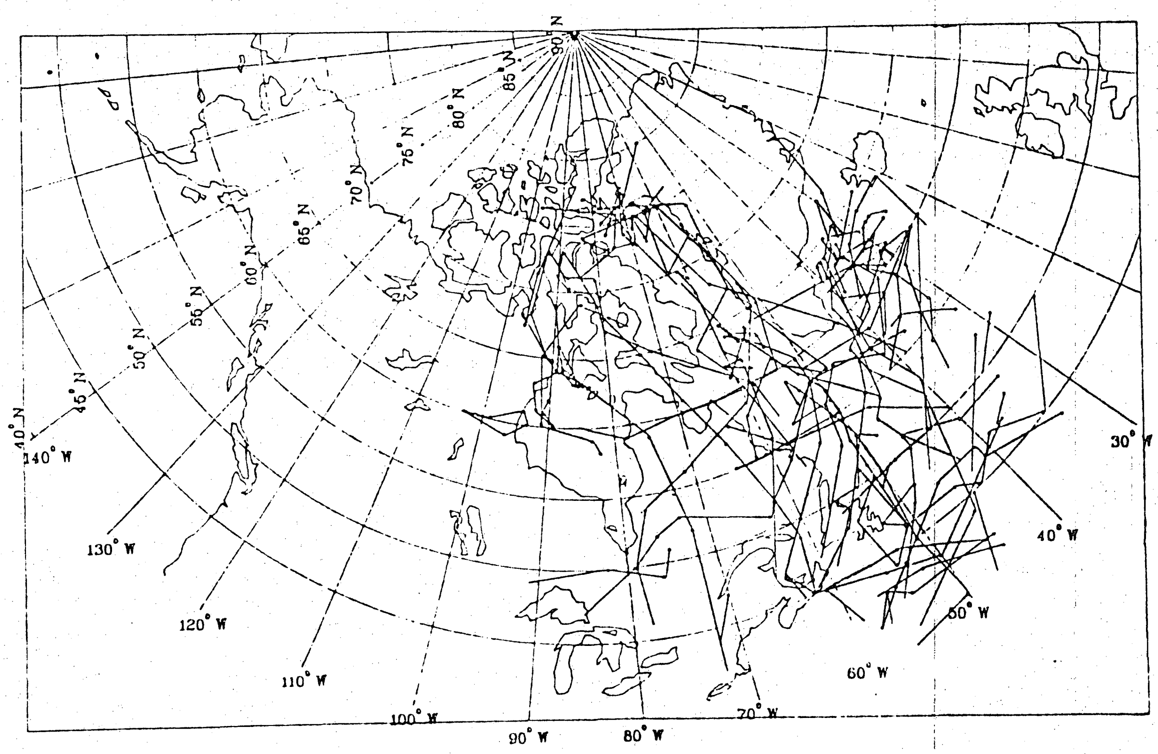
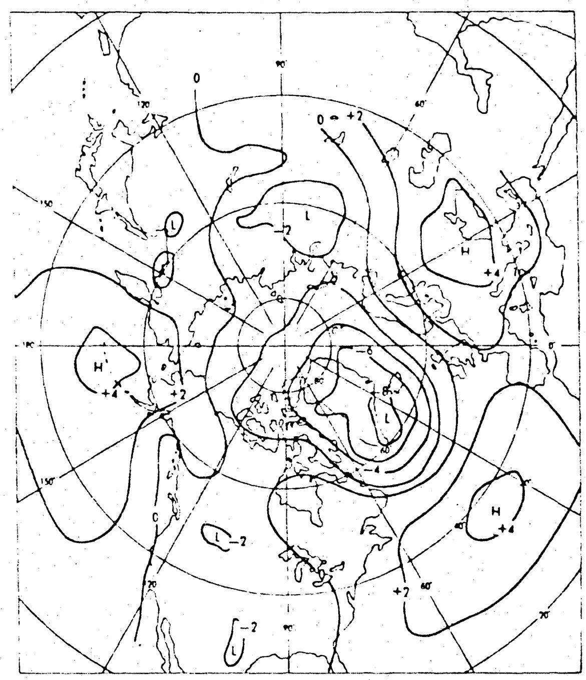


Figure 5



Mean-sea-level-pressure. Winter.

Difference of averages, 1971-4 minus 1961-70, (mb).

Figure 6 (after Painting 1977)

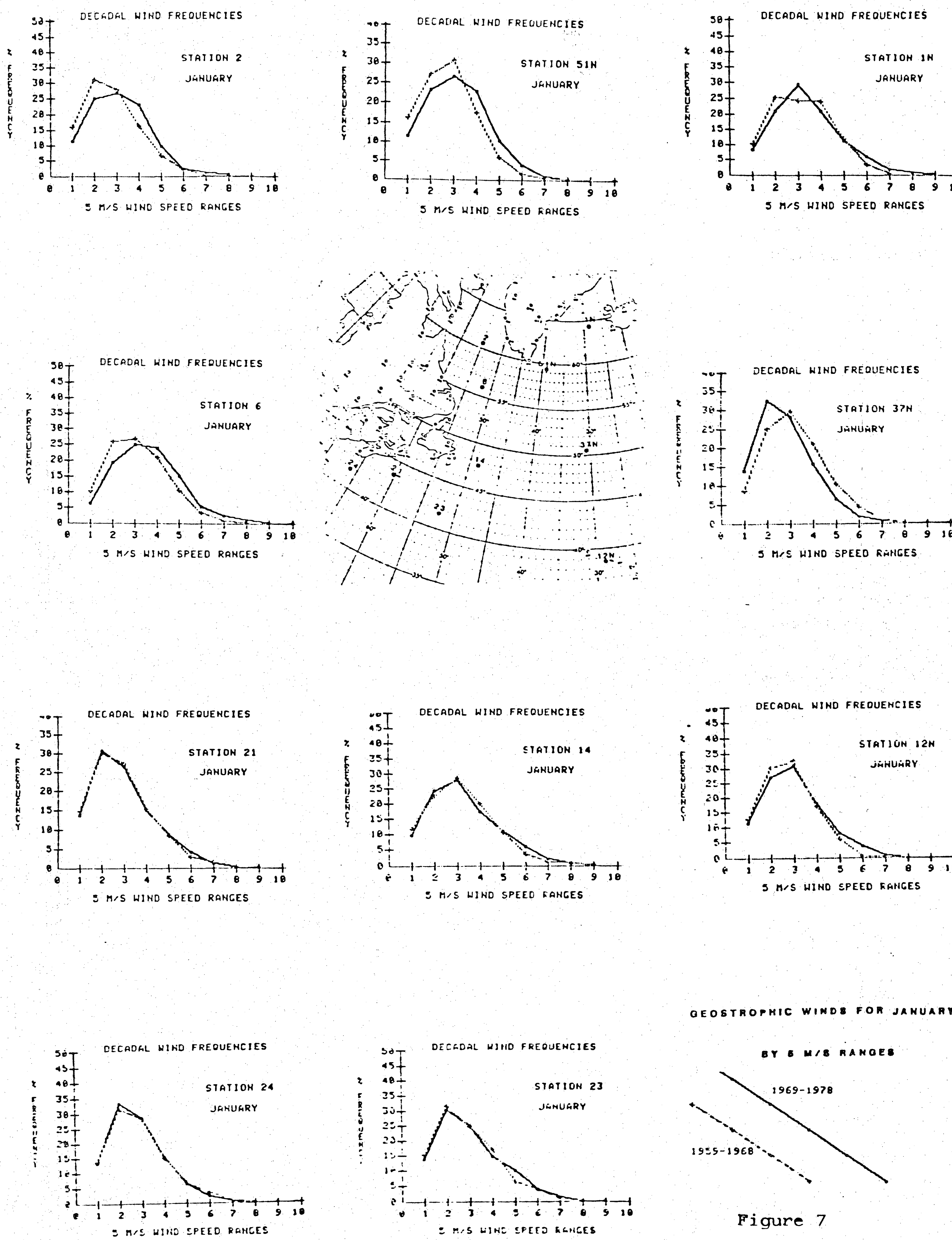

DECADAL WIND FREQUENCIES
STATION 2
JANUARY
STATION 51N
JANUARY
STATION 1N
JANUARY
STATION 6
JANUARY
STATION 37N
JANUARY
STATION 21
JANUARY
STATION 14
JANUARY
STATION 12N
JANUARY
STATION 24
JANUARY
STATION 23
JANUARY
% FREQUENCY
5 M/S WIND SPEED RANGES
GEOSTROPHIC WINDS FOR JANUARY
BY 5 M/S RANGES
1969-1978
1959-1968

Figure 7

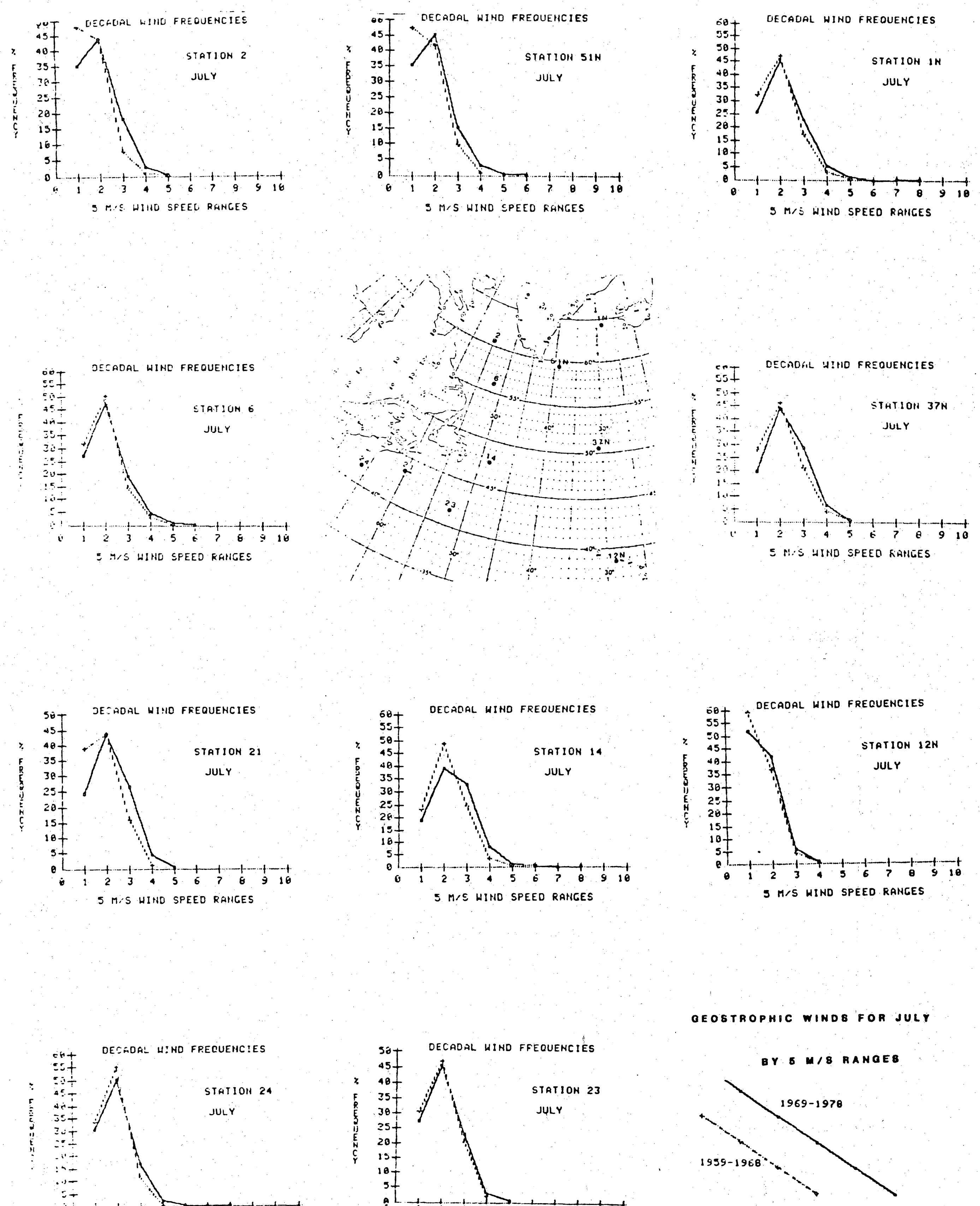

DECADAL WIND FREQUENCIES
STATION 2
JULY
DECADAL WIND FREQUENCIES
STATION 51N
JULY
DECADAL WIND FREQUENCIES
STATION 1N
JULY
DECADAL WIND FREQUENCIES
STATION 6
JULY
DECADAL WIND FREQUENCIES
STATION 37N
JULY
DECADAL WIND FREQUENCIES
STATION 21
JULY
DECADAL WIND FREQUENCIES
STATION 14
JULY
DECADAL WIND FREQUENCIES
STATION 12N
JULY
DECADAL WIND FREQUENCIES
STATION 24
JULY
DECADAL WIND FREQUENCIES
STATION 23
JULY
% FREQUENCY
5 M/S WIND SPEED RANGES
GEOSTROPHIC WINDS FOR JULY
BY 5 M/S RANGES
1969-1978
1959-1968

Figure 8

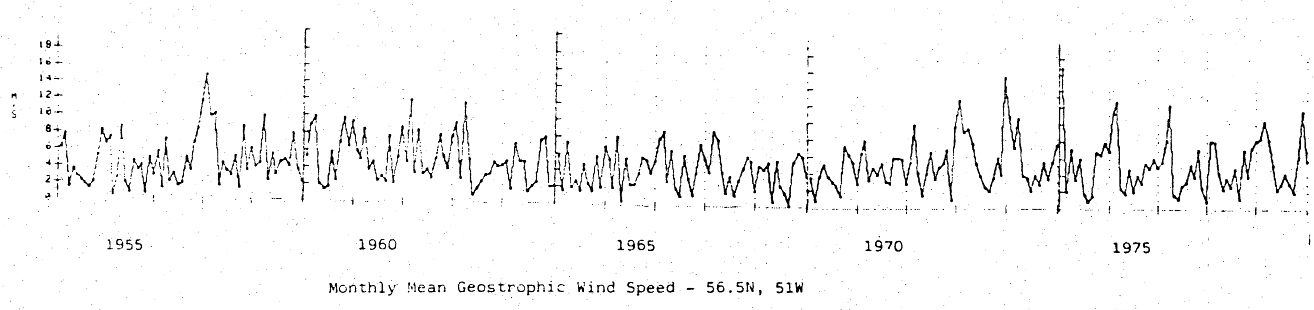
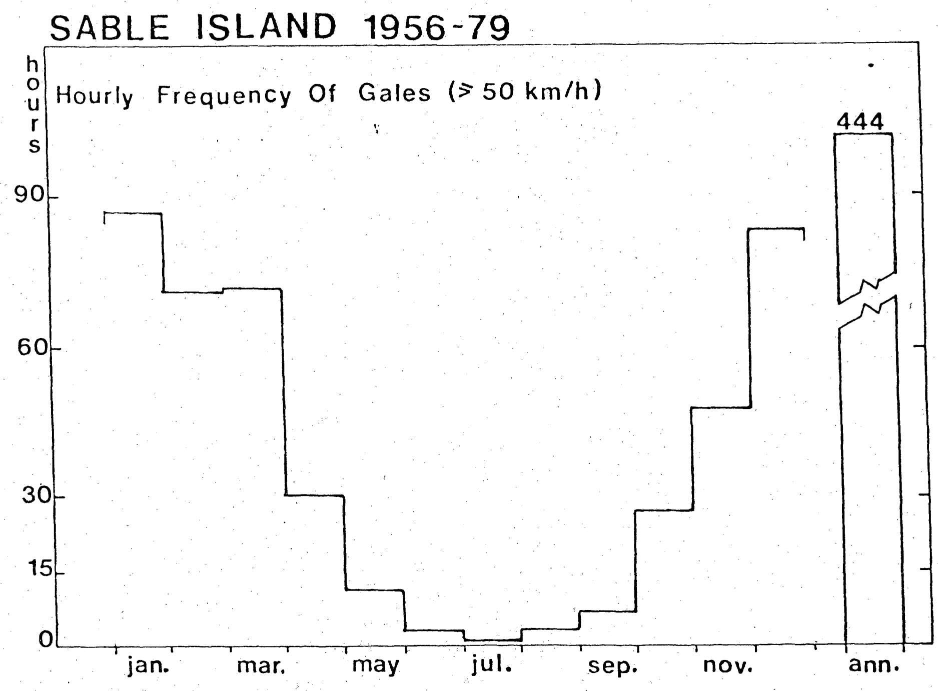

1955
1960
1965
1970
1975
Monthly Mean Geostrophic Wind Speed - 56.5N, 51W

Figure 9


SABLE ISLAND 1956-79
hours
Hourly Frequency Of Gales (≥ 50 km/h)
444
90
60
30
15
0
jan.
mar.
may
jul.
sep.
nov.
ann.

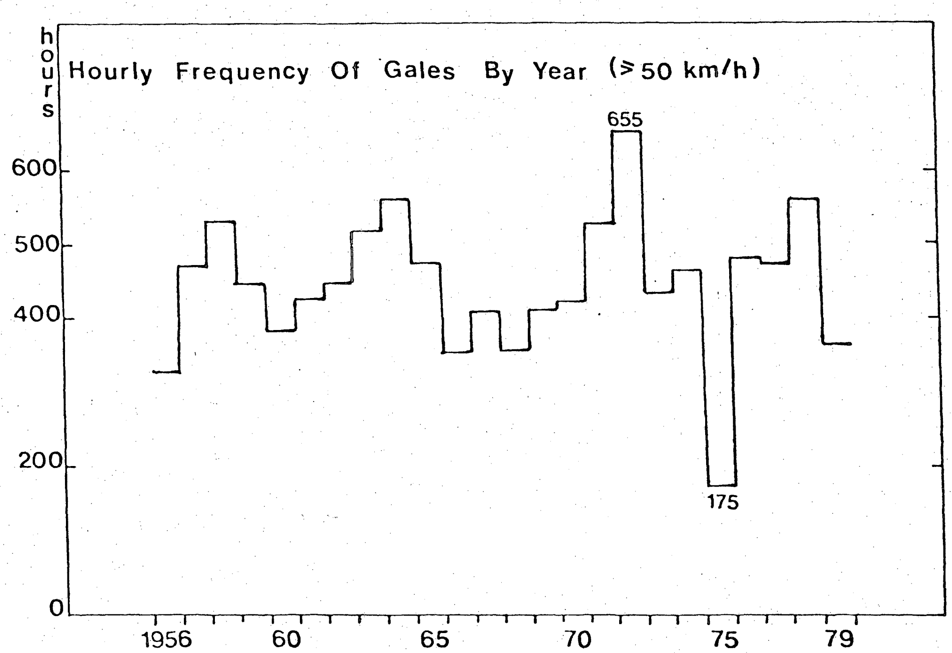
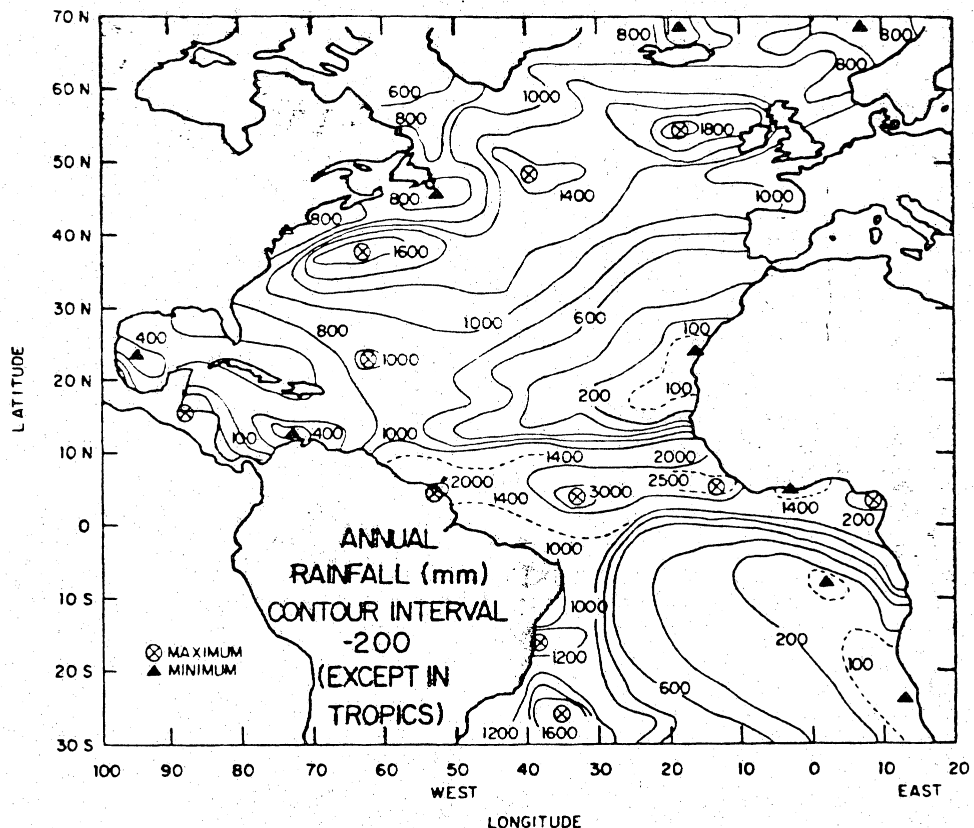

hours
Hourly Frequency Of Gales By Year (≥ 50 km/h)
655
600
500
400
200
175
0
1956
60
65
70
75
79

Figure 10



Mean annual rainfall over the Atlantic Ocean between 30°S and 70°N.

Figure 11 (after Dorman and Bourke, 1980)

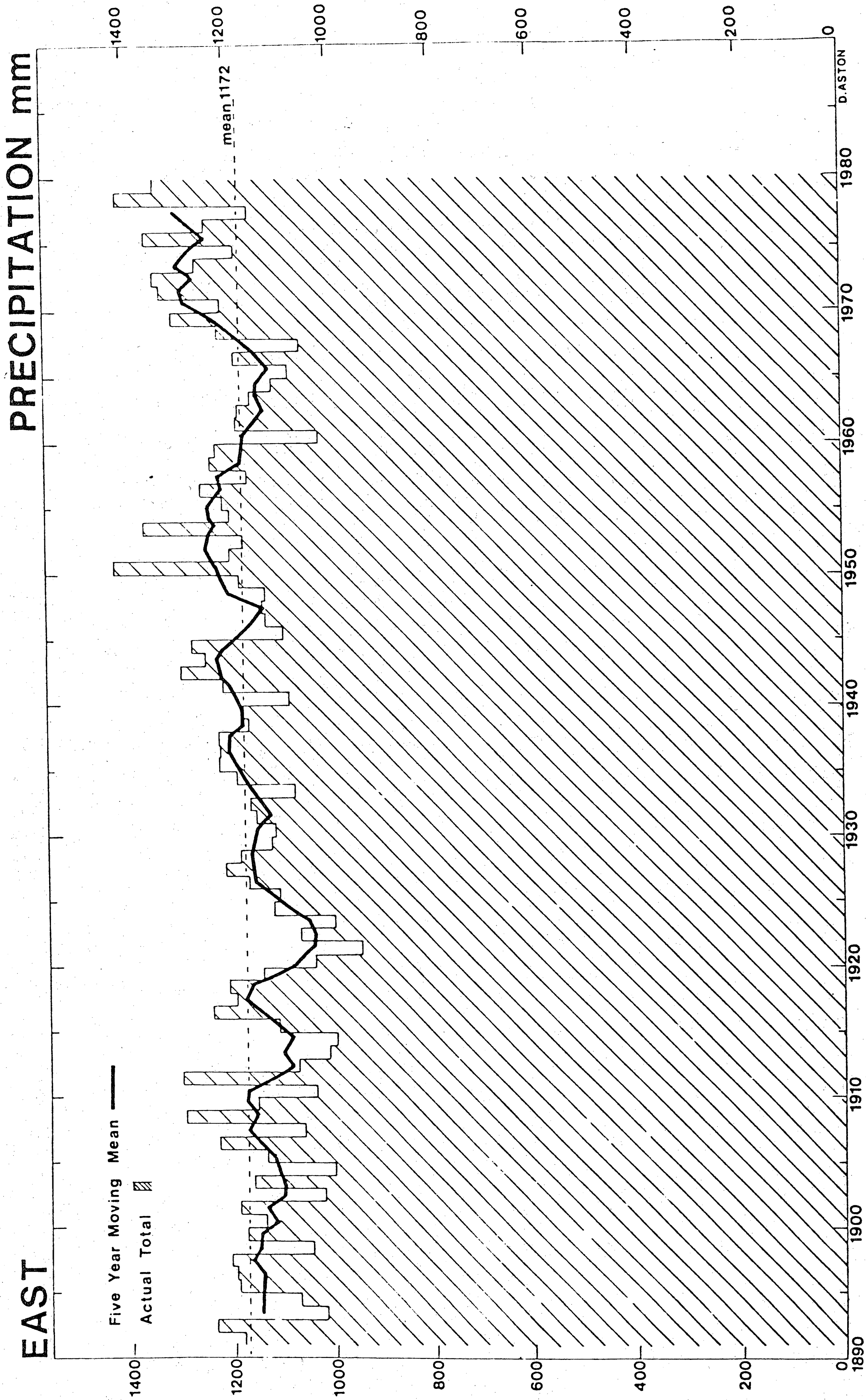
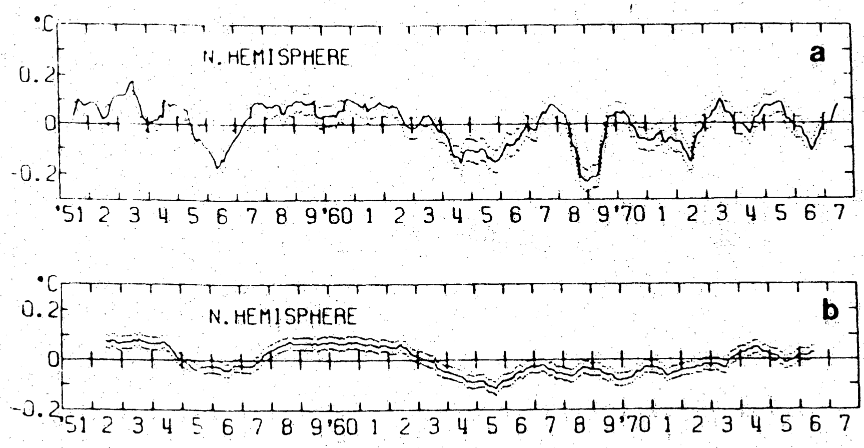

EAST
PRECIPITATION mm
Five Year Moving Mean
Actual Total
mean 1172
D.ASTON
0
200
400
600
800
1000
1200
1400
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980

Figure 12



12-month (a) and 36-month (b) running means of the surface air temperature deviations averaged over the Northern Hemisphere (full curves). The two dotted curves represent the 95% confidence limit for the error.

Figure 13 (after Yamamoto and Hoshiai 1980)

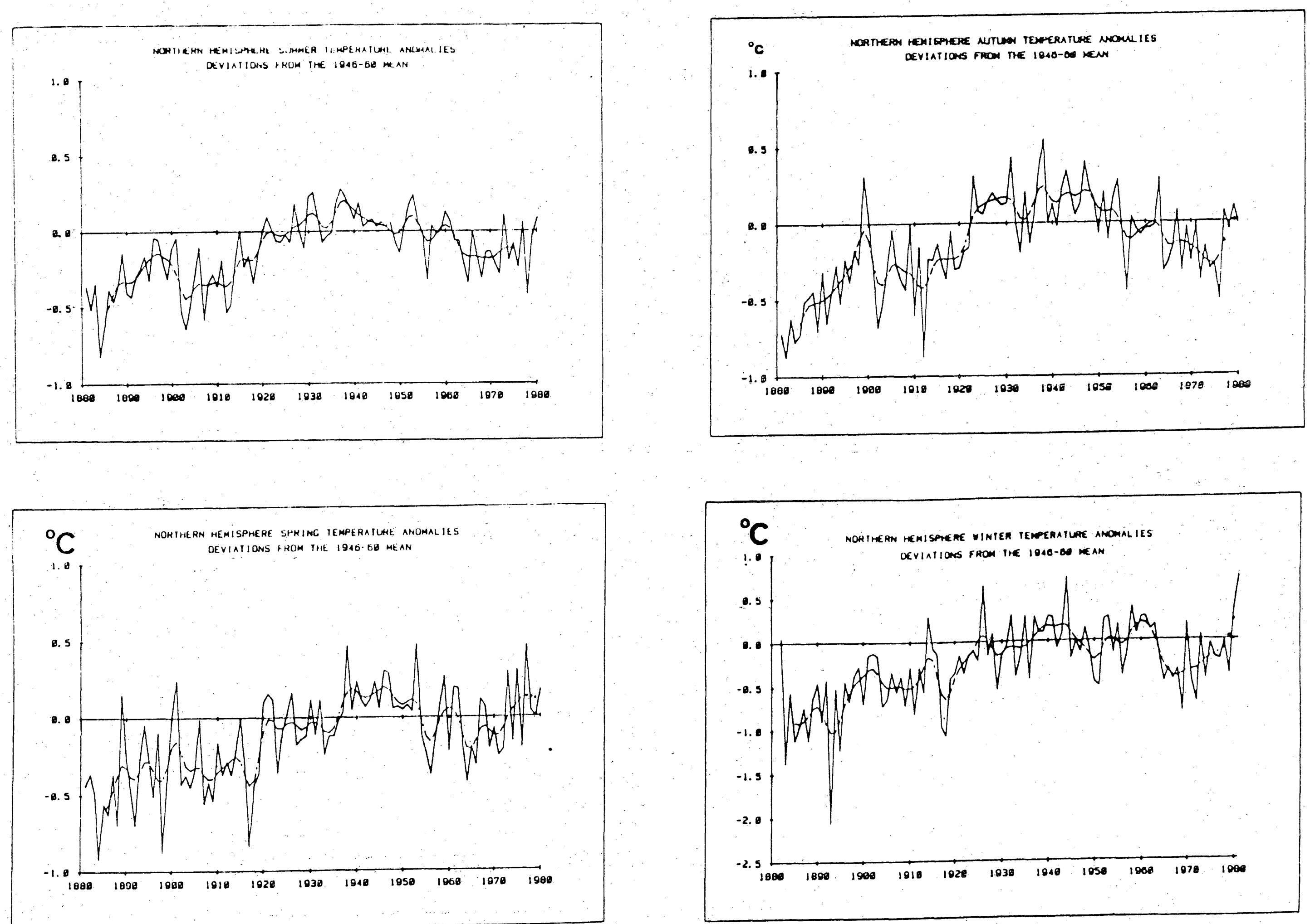
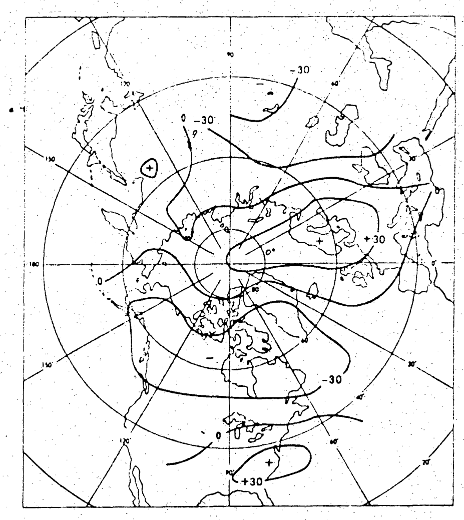
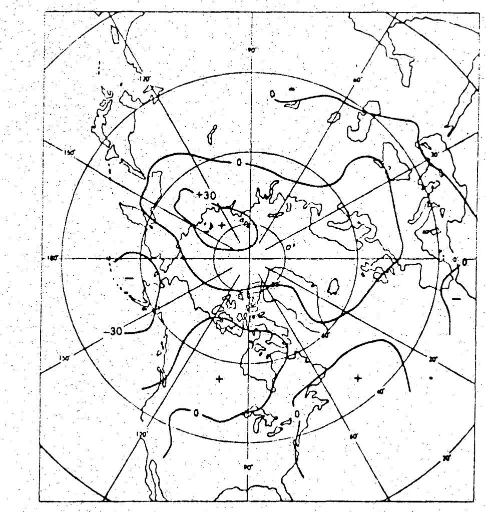


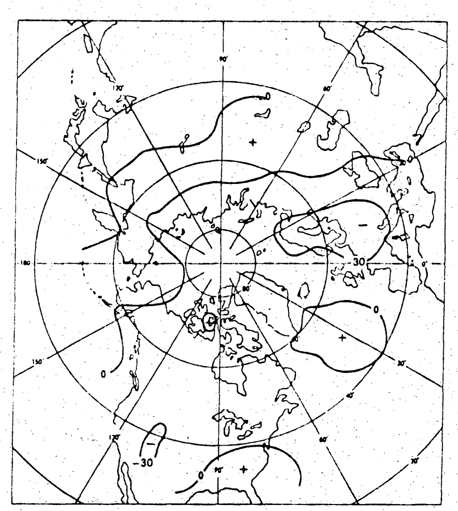
Figure 14 (after Jones and Wigley, 1980)



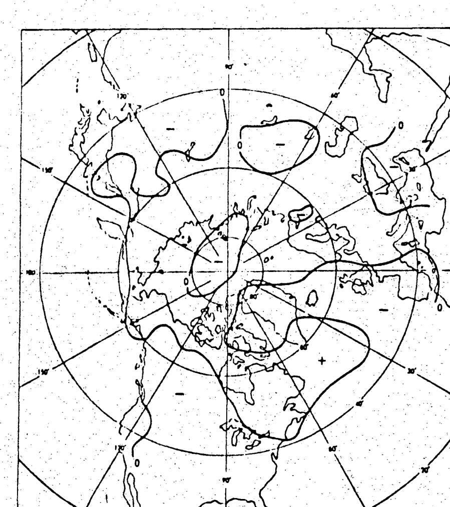
1000-500 mb.thickness. Northern Hemisphere. Winter. Difference of averages, 1971-4 minus 1961-70, (gpm).



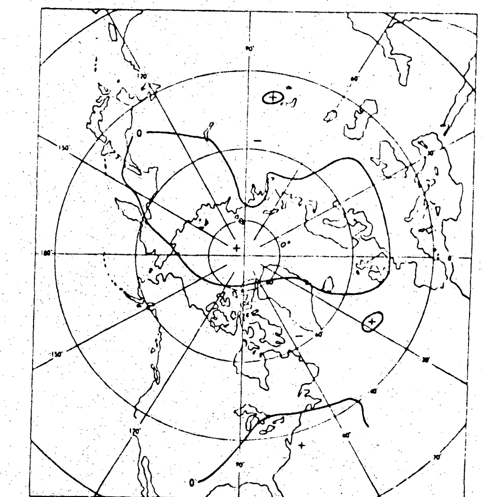
1000-500 mb thickness. Northern Hemisphere. Spring. Difference of averages, 1971-4 minus 1961-70, (gpm).



1000-500 mb thickness. Northern Hemisphere. Autumn. Difference of averages, 1971-4 minus 1961-40, (gpm).

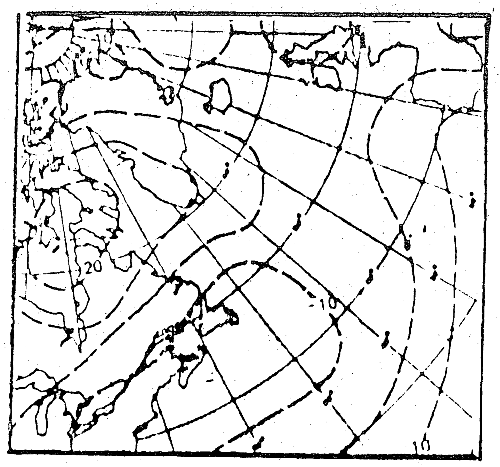


1000-500 mb thickness. Northern Hemisphere. Summer. Difference of averages, 1971-4 minus 1961-70, (gpm).

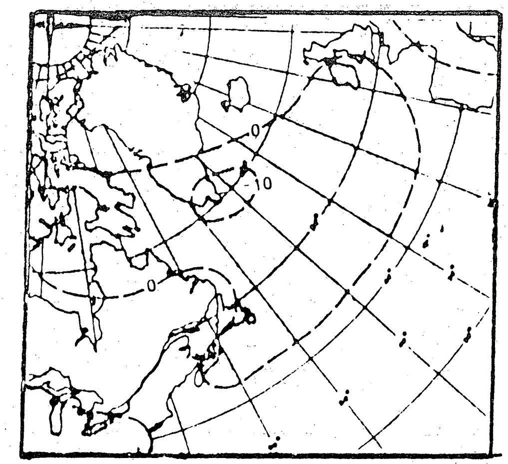


1000-500 mb thickness. Northern Hemisphere. Year. Difference of averages, 1971-4 minus 1961-70, (gpm).

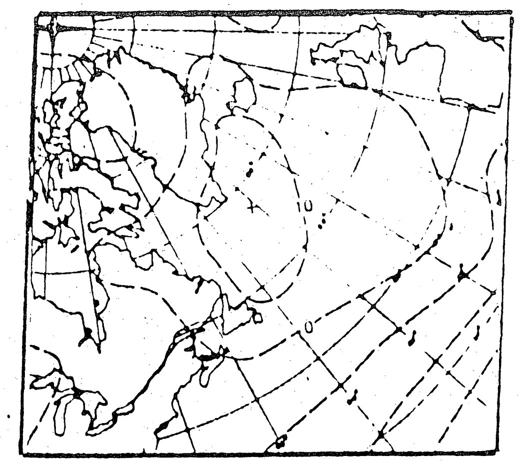
Figure 15 (after Painting 1977)



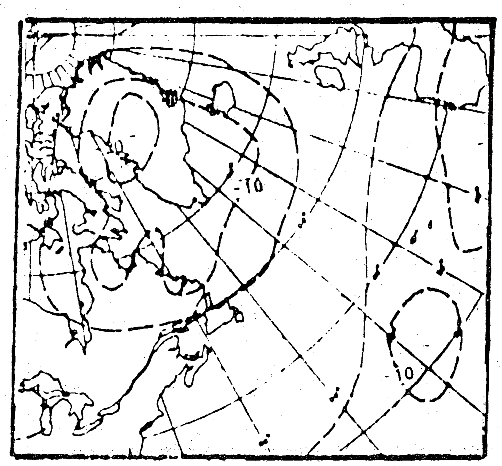
1949-53 to 1954-58



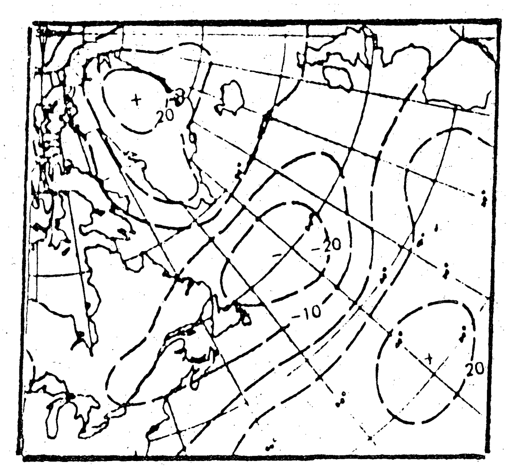
1954-58 to 1959-63



1959-63 to 1964-68



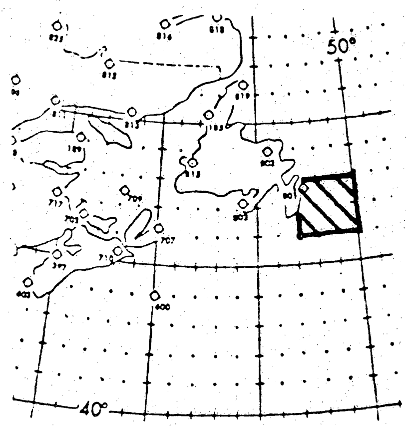
1964-68 to 1969-73



1969-73 to 1974-78

Five-year mean 1000-500 mb thickness change. (After Harley 1980)

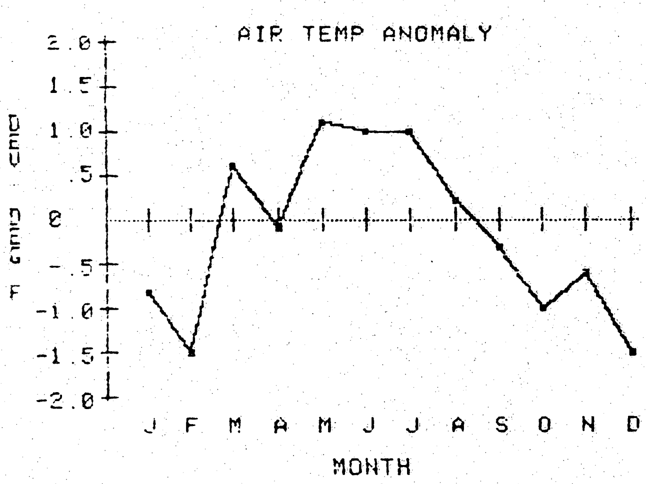
Figure 16



Temperature Anomalies- SSMO Area 4

SE Newfoundland Coast

1970-79 minus 1869-1971 (normal)



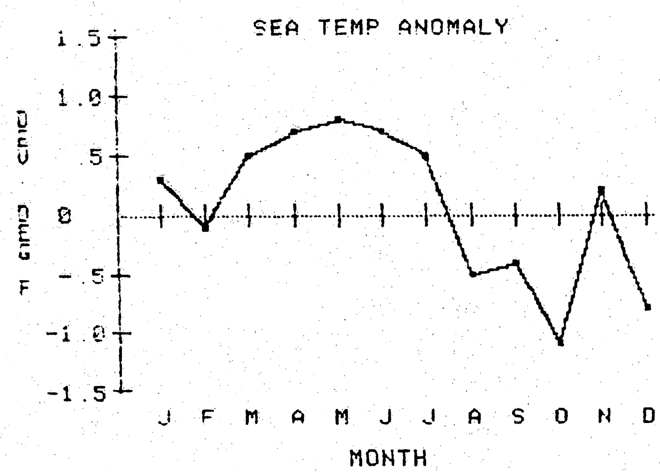


Figure 17

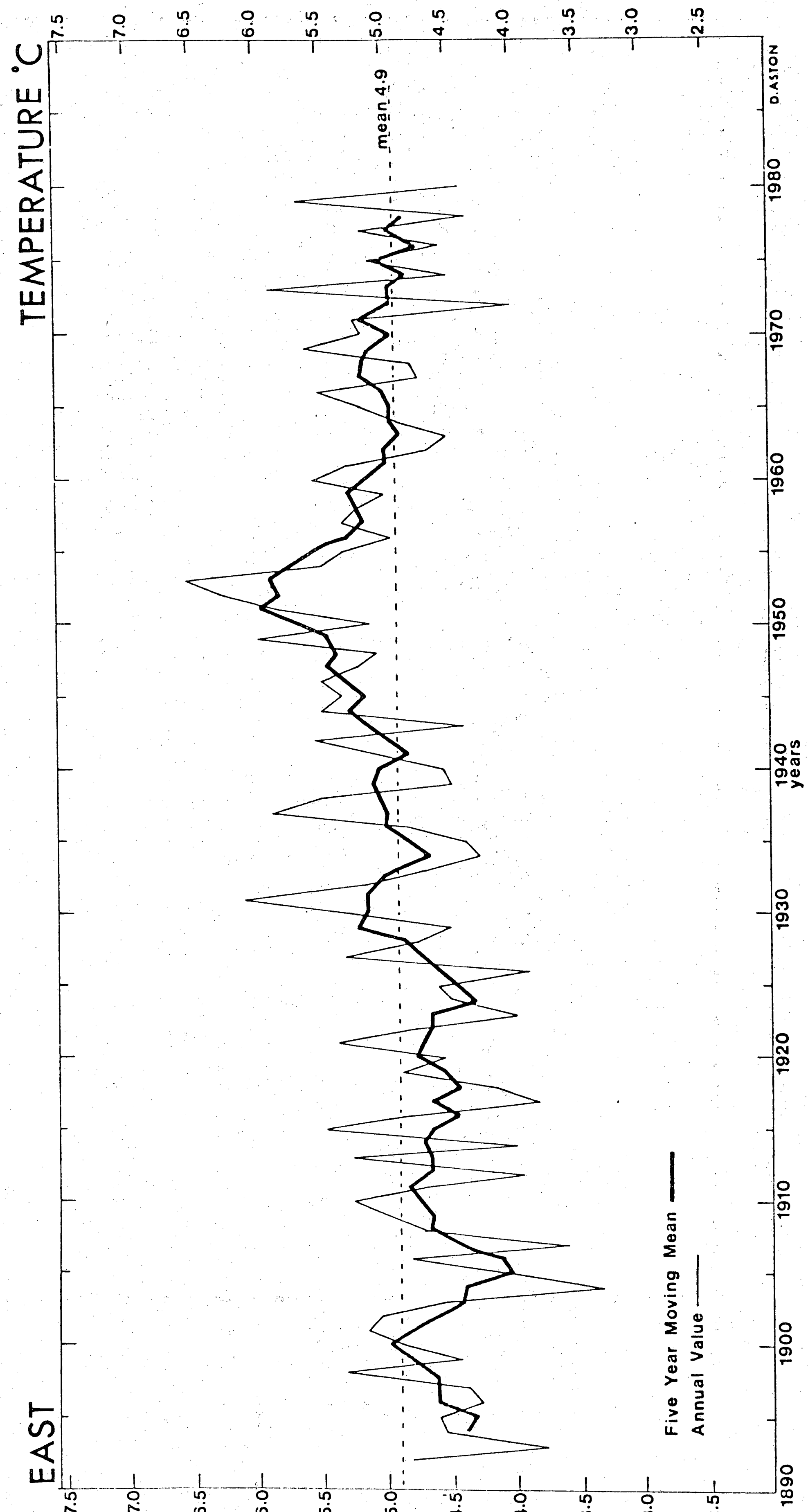

EAST
TEMPERATURE °C
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
mean 4.9
1890
1900
1910
1920
1930
1940
years
1950
1960
1970
1980
Five Year Moving Mean
Annual Value
D.ASTON

Figure 18

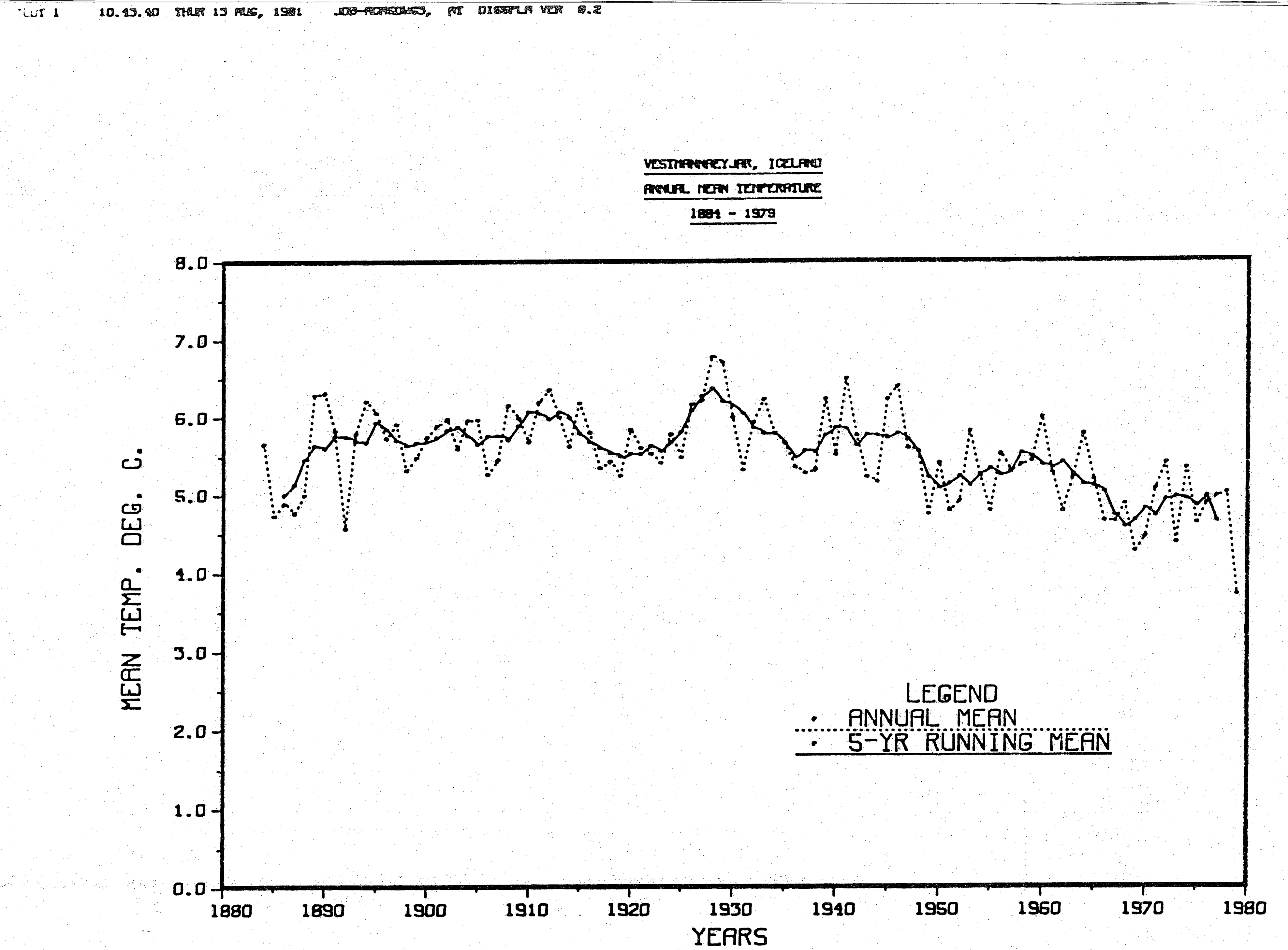
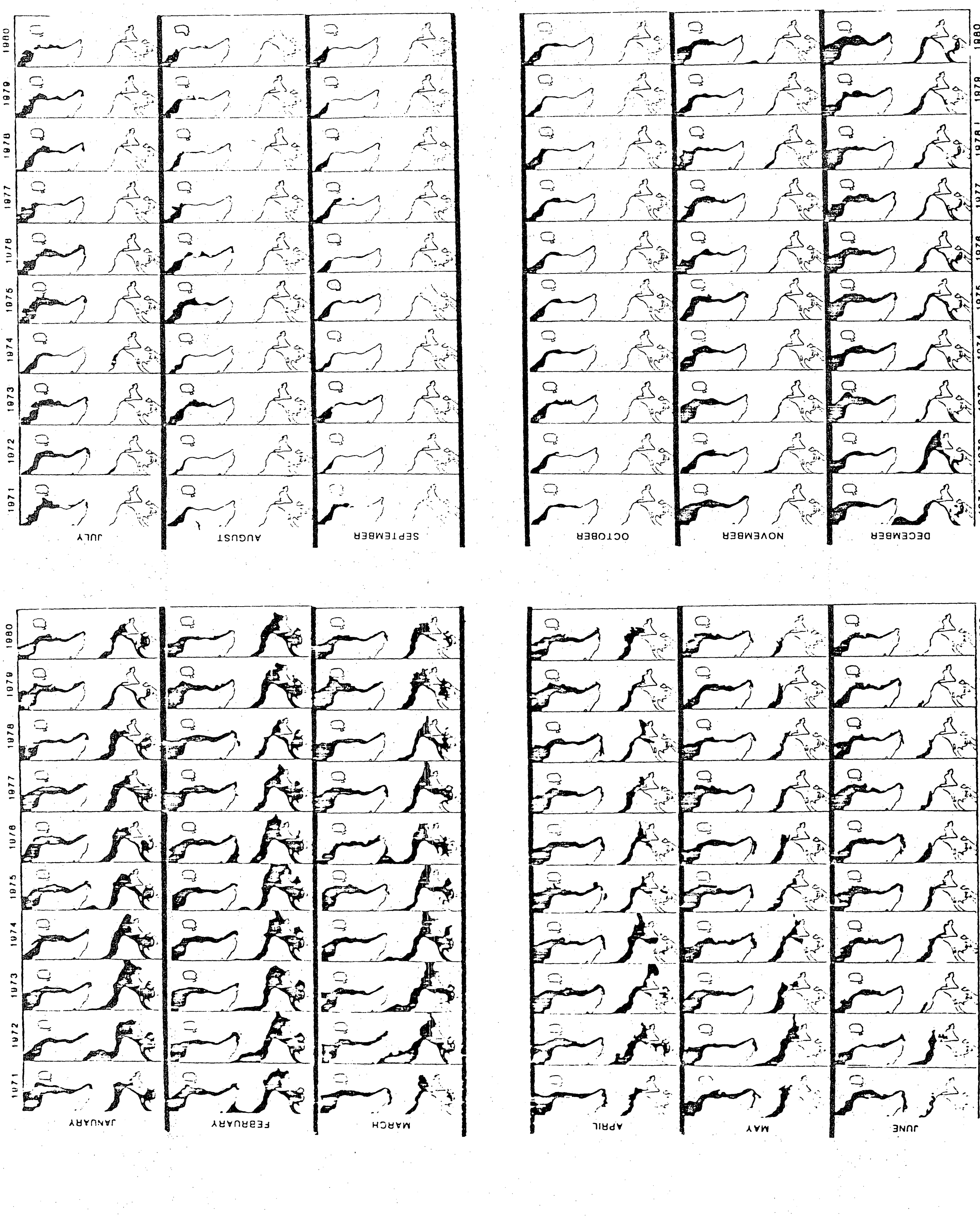

PLOT 1 10.43.40 THUR 13 AUG, 1981 JOB-ACRSOWES, AT DISSPLA VER 8.2
VESTMANNAEYJAR, ICELAND
ANNUAL MEAN TEMPERATURE
1884 - 1979
MEAN TEMP. DEG. C.
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEARS
LEGEND
ANNUAL MEAN
5-YR RUNNING MEAN

Figure 19

Figure 20
Ice concentration
greater than 1/10
at the end of
months 1971-1980



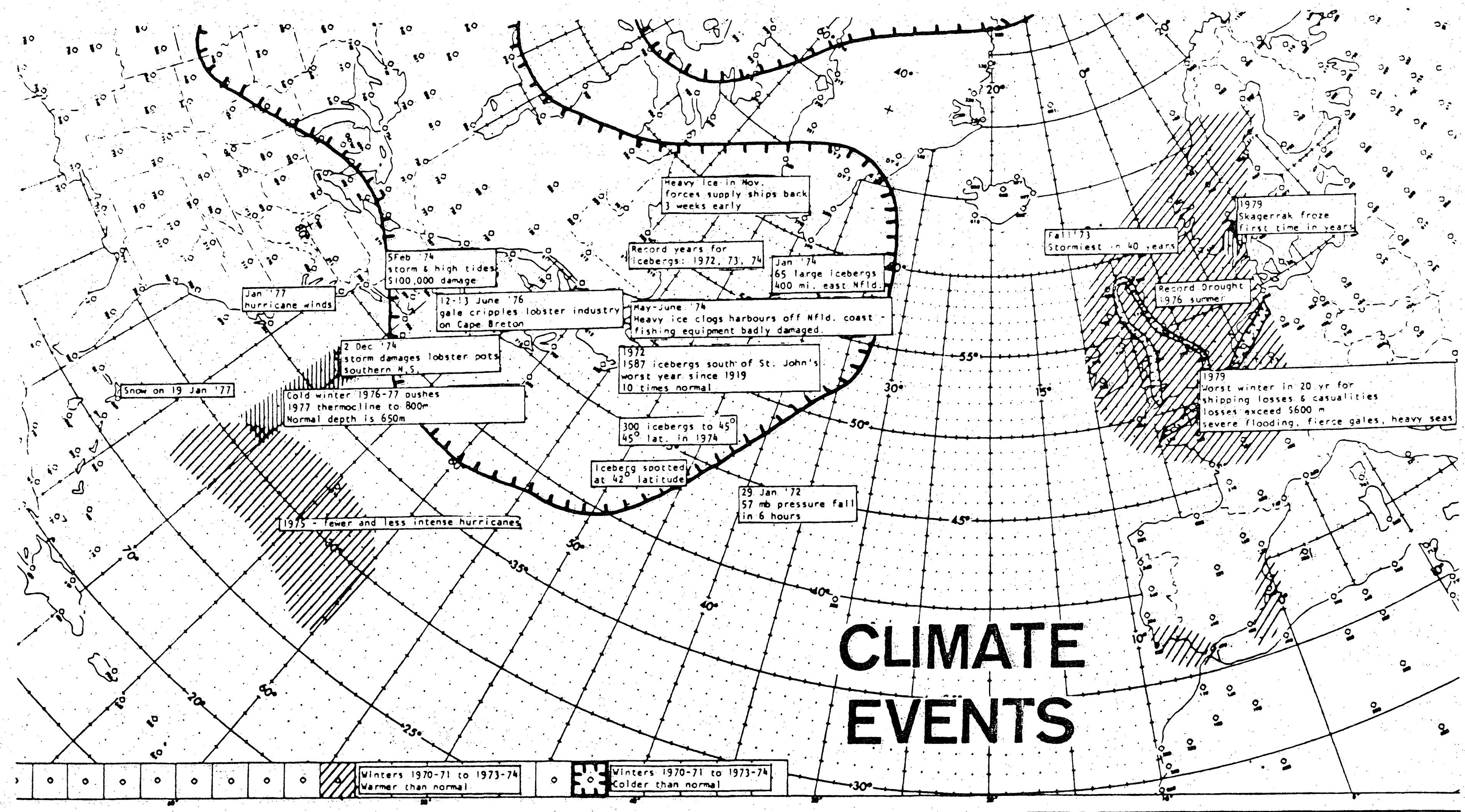

CLIMATE EVENTS
1979 Skagerrak froze first time in years
Fall '73 Stormiest in 40 years
Record Drought 1976 summer
1979 Worst winter in 20 yr for shipping losses & casualities losses exceed $600 m severe flooding, fierce gales, heavy seas
Heavy ice in Nov. forces supply ships back 3 weeks early
Record years for icebergs: 1972, 73, 74
Jan '74 65 large icebergs 400 mi. east Nfld.
May-June '74 Heavy ice clogs harbours off Nfld. coast - fishing equipment badly damaged.
1972 1587 icebergs south of St. John's worst year since 1919 10 times normal
300 icebergs to 45° 45° lat. in 1974
Iceberg spotted at 42° latitude
29 Jan '72 57 mb pressure fall in 6 hours
5Feb '74 storm & high tides $100,000 damage
12-13 June '76 gale cripples lobster industry on Cape Breton
Jan '77 hurricane winds
2 Dec '74 storm damages lobster pots Southern N.S.
Snow on 19 Jan '77
Cold winter 1976-77 pushes 1977 thermocline to 800m Normal depth is 650m
1975 - fewer and less intense hurricanes
Winters 1970-71 to 1973-74 Warmer than normal
Winters 1970-71 to 1973-74 Colder than normal

Figure 21

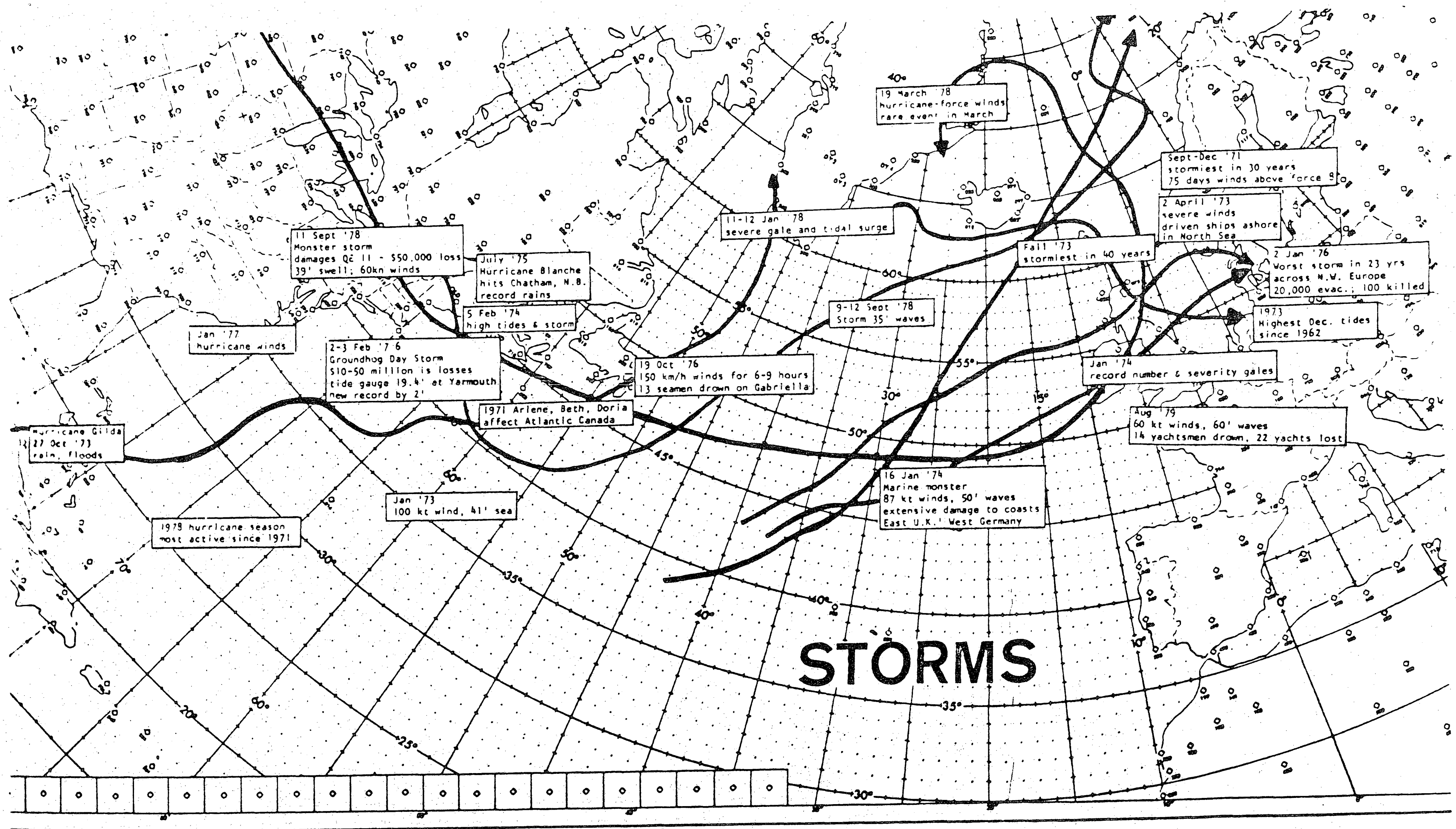

STORMS
19 March '78
hurricane-force winds
rare event in March
Sept-Dec '71
stormiest in 30 years
75 days winds above force 9
2 April '73
severe winds
driven ships ashore
in North Sea
2 Jan '76
Worst storm in 23 yrs
across N.W. Europe
20,000 evac., 100 killed
1973
Highest Dec. tides
since 1962
11-12 Jan '78
severe gale and tidal surge
Fall '73
stormiest in 40 years
11 Sept '78
Monster storm
damages Qc 11 - $50,000 loss
39' swell; 60kn winds
July '75
Hurricane Blanche
hits Chatham, N.B.
record rains
5 Feb '74
high tides & storm
9-12 Sept '78
Storm 35' waves
Jan '77
hurricane winds
2-3 Feb '76
Groundhog Day Storm
$10-50 million is losses
tide gauge 19.4' at Yarmouth
new record by 2'
19 Oct '76
150 km/h winds for 6-9 hours
13 seamen drown on Gabriella
Jan '74
record number & severity gales
1971 Arlene, Beth, Doria
affect Atlantic Canada
Aug '79
60 kt winds, 60' waves
14 yachtsmen drown, 22 yachts lost
27 Oct '73
rain, floods
16 Jan '74
Marine monster
87 kt winds, 50' waves
extensive damage to coasts
East U.K.' West Germany
Jan '73
100 kt wind, 41' sea
1979 hurricane season
most active since 1971

Figure 22

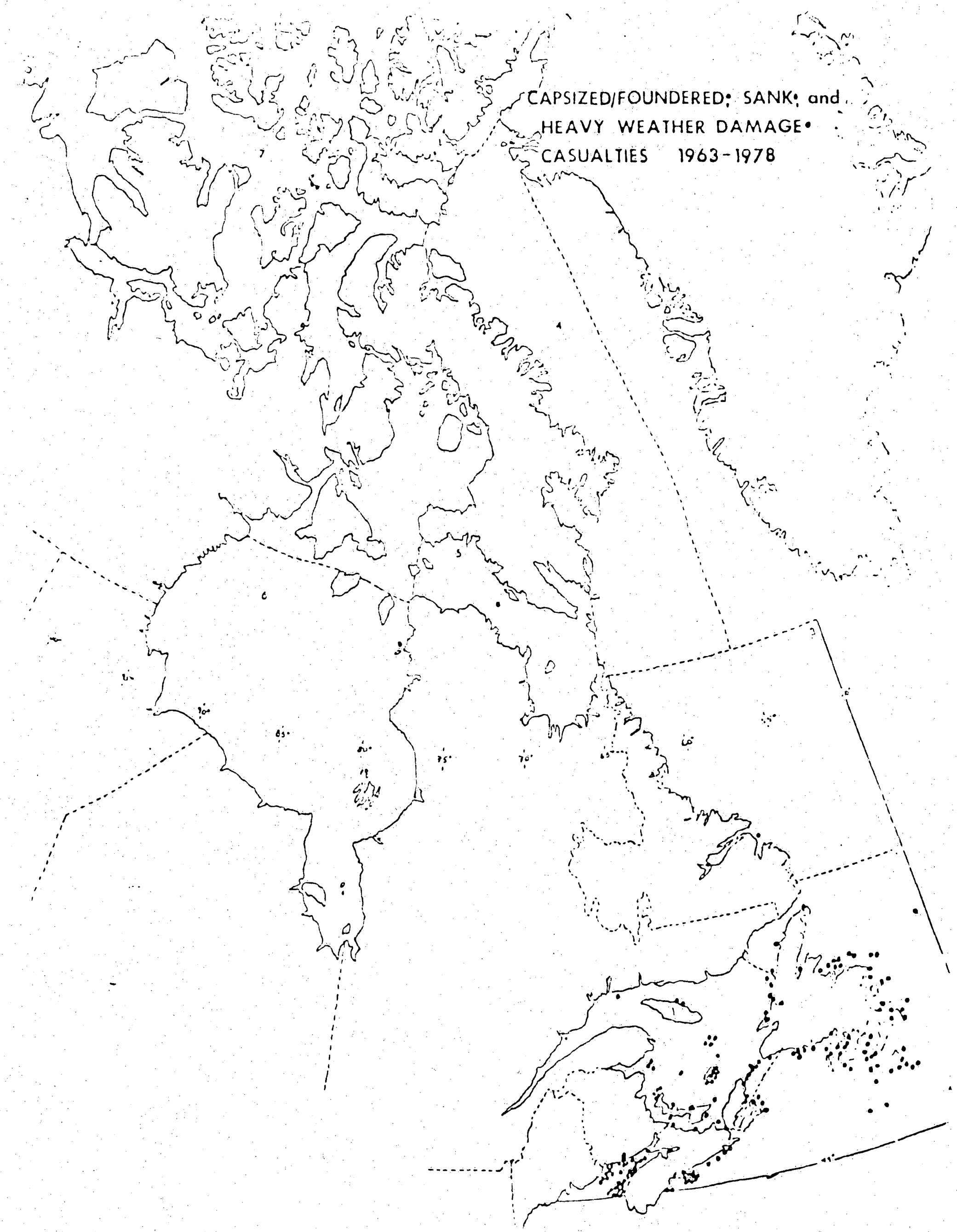

CAPSIZED/FOUNDERED; SANK; and
HEAVY WEATHER DAMAGE•
CASUALTIES 1963-1978

Figure 23