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Foreword

A Special Session on Ice, organized by the Environmental Subcommittee of the International Commission for the Northwest Atlantic Fisheries, was held on 1 June 1973 at Copenhagen, Denmark in connection with the Twenty-Third Annual Meeting of the Commission.

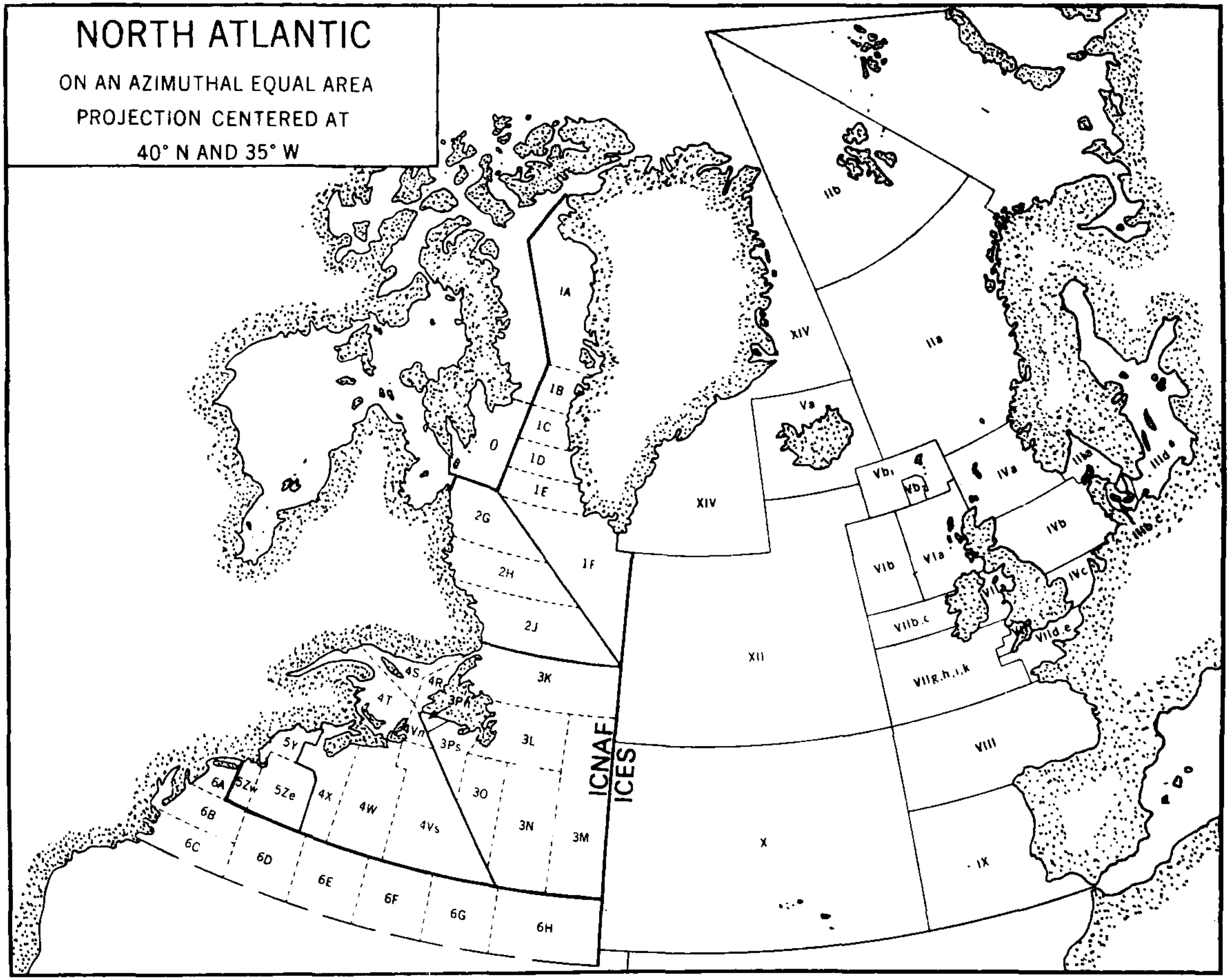
This special session was held as part of the continuing program of environmental studies within the ICNAF area. It was an outcome of the 1971 "Symposium on Environmental Conditions in the Northwest Atlantic, 1960-1969," at which the need for a more detailed examination of the sea ice problem was identified. In particular, considerable interest at the 1971 Symposium was expressed not only in the ice problem as it affects fisheries and fishing operations, but also in the possibility of using longterm historical trends in ice and iceberg forecasting.

Five papers were presented, four of which are reproduced here. Professor W. Dansgaard of Copenhagen University, who kindly presented an overview of the recent Danish studies on climatic change as reflected by examination of Greenland ice cores, preferred that his paper not be reproduced at this time. Mr Akagawa of Japan, in addition to presenting his paper, showed a most interesting film demonstrating the use of land-based radar to monitor sea ice movement.

The papers described ice research, ice forecasting techniques, and ice information services in several different geographical areas and from several different points of view. This interesting mix of material and emphasis stimulated a lively panel discussion following the papers, and it was obvious to all concerned that the session had achieved its goal of providing a fruitful exchange of ideas and information between ice scientists and forecasters.

N. J. Campbell,
Chairman, Environmental Subcommittee,
International Commission for the Northwest Atlantic Fisheries.

September, 1974



NORTH ATLANTIC
ON AN AZIMUTHAL EQUAL AREA
PROJECTION CENTERED AT
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XIV
XII
X
IIa
IIb
Va
Vb1
Vb2
VIa
VIb
IVa
IVb
IVc
VIIb,c
VIIg,h,j,k
VIId,e
VIII
IX
IIId

Contents

Polar Ice Variations Off The Greenland West Coast 1900-72

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Abstract

Polar ice, drifting with the East Greenland Current, extends northward along the Greenland west coast to a varying extent; Kangamiut at 65° 50'N being the northernmost settlement affected by this ice. The paper illustrates the variations in areal extent and in duration both with respect to year and to time of year as illustrated on Fig. 1, 2, 4 and 6. Various ice parameters are correlated with each other. It was found that the data on which the icebelt seasonally had advanced to pass Kap Farvel was rather strongly correlated with the length of the ice season (defined as presence of polar ice on the west coast) (Fig. 3).

Correlations of northernmost ice edge in 1 month with those of various other months are very weak or nonexistent (Fig. 7 to 10), so are the correlations between northernmost position of the ice and length of the ice season (Fig. 11 to 13).

The ice parameters were correlated with monthly mean air temperatures from Godthaab, Upernavik, Jan Mayen and Pt. Barrow up to 36 months before or after the ice data in question. The investigation revealed a possible, yet extremely faint, correlation between Jan Mayen air temperatures and ice conditions (Fig. 14 to 16); otherwise, the air temperature did not seem to be correlated with the ice data at all.

Introduction

The accurate prediction of sea ice conditions has obvious economic benefits. While several mathematical models have been developed for short and medium range ice forecasts, very little success has been gained so far concerning seasonal conditions, let alone conditions several years ahead.

It is a well known fact that the drift of pack ice is determined by wind and current. Further, it is obvious that the extent of the ice is determined by ice production, drift and melting. Air temperature is most likely the principal agent in ice production and melting processes. The influence of temperature on ice extent, if any, is of a much more indirect character and is not necessarily in phase with the influence on production and melting. Therefore, it should not be expected that a simple relation exists between air temperature and ice conditions. However, if it is true that air temperature follows a predictable cycle of several years, it is clear that it should be possible to find a connection between these climatic cycles and ice conditions. This concept is strengthened if the drilling cores from the Greenland inland ice do in fact provide a "thermometer" of historical time, since no similar record exists regarding wind and current.

The Danish Meteorological Institute has become involved in this problem in the Greenland waters for several reasons. To mention just one, accurate prediction of the severity of coming ice seasons would be extremely useful in planning the shipbuilding program. Will the next 30 years bring lighter ice seasons, or are the seasons, on the contrary, going to become worse? Is there any periodicity in the degree of severity? Is there any persistency, or, in other words, are severe seasons likely to occur in groups? Such questions have been raised, and the present paper will demonstrate that we are still unable to answer these questions with any reasonable degree of certainty.

The Concept of Severe Ice Seasons

One problem is how to define the degree of severity. Shall we define it according to information of (I) how the navigational conditions were or (II) according to amount of ice. Even if we could get sufficient information on (I), and in spite of the fact that the effect of the ice is what matters, we may reject (I) because even small ice occurrences may hamper navigation, if the ice locally is compacting, and also because the general judgment of ice conditions varies from shipmaster to shipmaster.

(II) the amount of ice adjacent to Greenland may be defined in several ways:

a) the sum of daily products of areal extent times concentration;

b) monthly or yearly maximum or mean areal extent times concentration;

c) monthly or yearly maximum areal extent;

d) the maximum (two-dimensional) extent of the ice along the coast ("the northernmost ice edge");

e) the length of period of ice being present within a given area.

Several other definitions could be put up, but it is obvious that a) and b) are the only ones which are "exact". However, even the last 10-15 years data which include air reconnaissance and satellite information do not supply us with sufficient information to enable us to define the season according to a) or b). Even definition c) demands more data than are available. The only usable definitions seem therefore to be d) and e) although these may not correctly reflect the degree of severity of the ice seasons.

Basic Material

Polar ice drifts southward from the polar basin along the Greenland east coast. The polar ice, mixed with thick first year ice formed off northern Eastgreenland, sooner or later in the season under the name of "Storis", passes around Kap Farvel and drifts northward into Davis Strait more or less along the west coast of Greenland.

Figure 1 depicts for the years 1900 - 1971 the approximate date on which the polar ice passed Kap Farvel*.

Figure 2 illustrates the length of the ice seasons off the Greenland west coast and refers, like all other information in the present paper, exclusively to "Storis", not to Baffin Bay ice or "Vestis" which, very occasionally, drifts into the area in question, i.e. the waters off the coast between Kap Farvel and a little north of Sukkertoppen.

*This diagram, is like some of the others, an updating and/or revision of diagrams given by J.S. Fabricius (1959) in "Betaenkning Nr. 227" concerning navigation in Greenland.

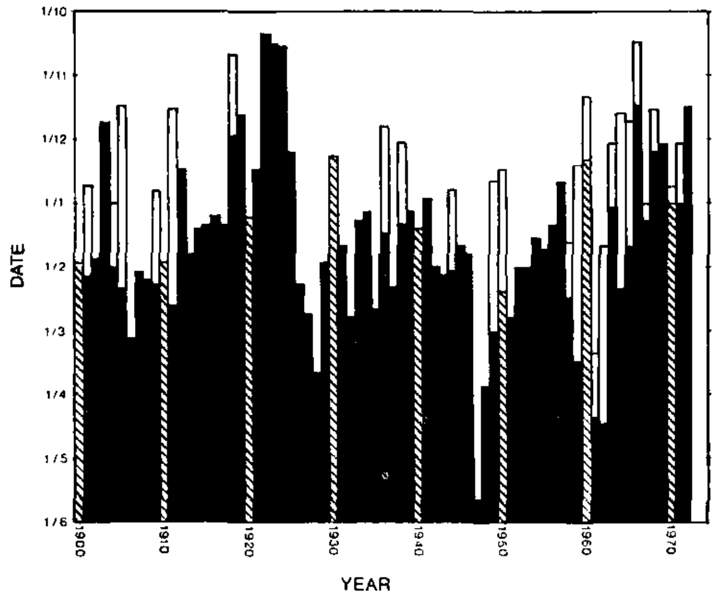


Fig. 1. Date of Polar Ice Passage at Kap Farvel, 1900-72. (Top of open section of columns indicates date of first reported "forerunners", while top of solid section indicates date of arrival of polar ice of more than 2 weeks duration.)

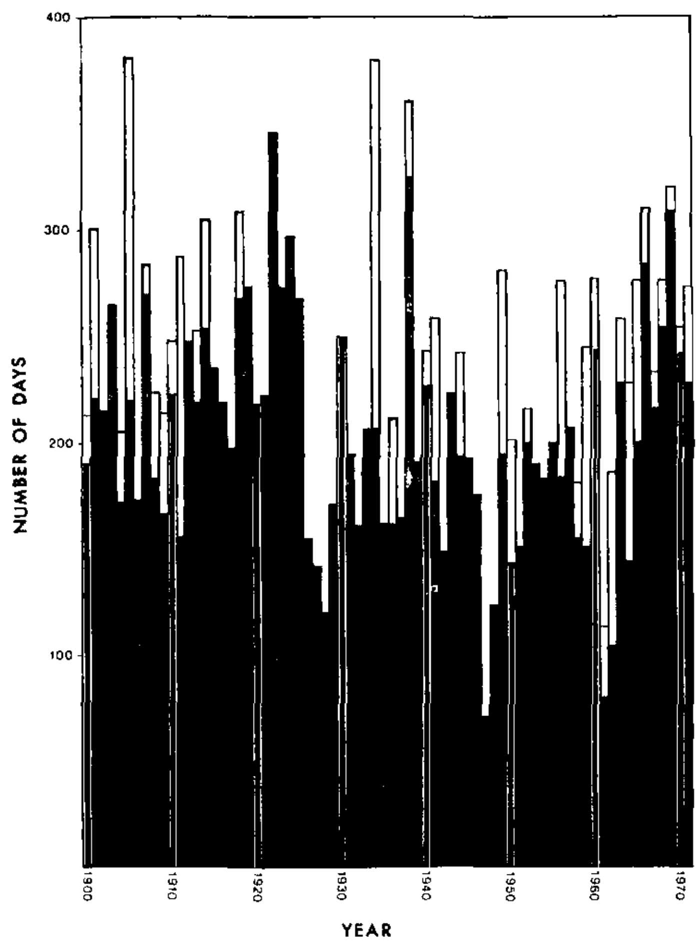


Fig. 2. Length of ice period, 1900 - '71. (Open section of columns indicates sporadic occurrences before and after the season.)

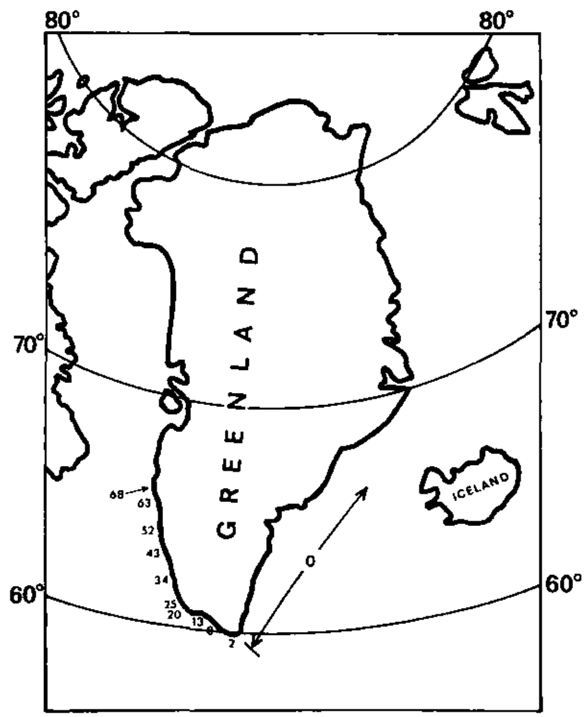
Figure 3 is a correlation diagram* of length of ice period in the area and date of passage of Kap Farvel. The scale of dates is given in Table I.

Table I. Numerical representation of dates.

Number on X-axis	Date of Passage	Number on X-axis	Date of Passage
0	30/9	243	31/5
31	31/10	273	30/6
61	30/11	304	31/7
92	31/12	335	31/8
123	31/1	365	30/9
151	28/2	396	31/10
182	31/3	426	30/11
212	30/4		

Table II. Numerical representation of northernmost position of the polar ice edge.

0	Not passed Kap Farvel
2	Kap Farvel
5	Frederiksdal
8	Nanortalik (Nan.)
11	Sydproven
13	Julianehaab
17	Qagssimiut (Qags.)
20	Nunarssuit
25	Arsuk
30	Narssalik
34	Frederikshaab (Fkb.)
36	Avaigat
38	Frederikshaabs Isblink
41	Ravns Storoe
43	Fiskenaesset (Fisken.)
47	Graedefjord
50	Faeringehavn
52	Godthaab (Godth.)
57	Atangmik
59	Napassoq
63	Sukkertoppen (Skt.)
68	Kangamiut



*On the correlation diagrams in asterisk indicates that two or more values are coinciding, while a plus sign indicates a single value.

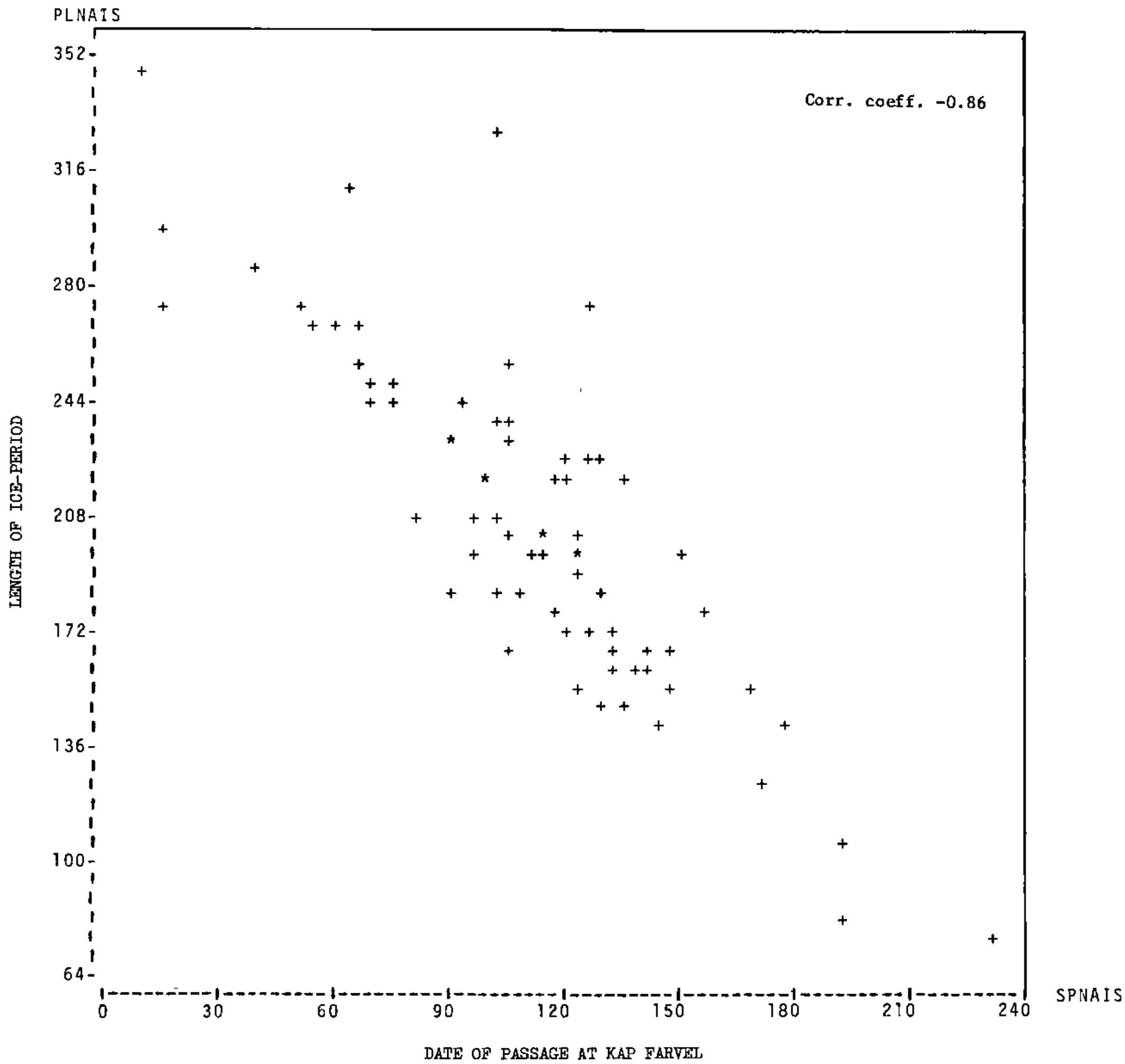


Fig. 3. Correlation diagram, length of ice period vs date of passage of ice at Kap Farvel

As the diagram may show there is a fairly good negative correlation (correlation coefficient -0.86) between passage date (start of season) and length of season, which seems to indicate that the starting date of the season varies much more than the termination date. Further it may allow us to concentrate on comparing length of period with other parameters which also may relate to the passage dates.

Figure 4 depicts the yearly reported northern ice limit, while Fig. 5 gives the frequency distribution of this limit. The figures do not contain any information regarding the duration of the ice. Also, modest quantities of ice may have been present even further to the north without having been reported.

To combine extent and duration the matrix given in the appendix has been set up. The matrix gives the northernmost position of the ice edge month by month through the seasons 1899/1900 to 1971/72. The northernmost position is indicated no matter whether the ice remained at this position through the whole month or for a few hours only. The scale of the matrix is given in Table II and is roughly proportional to the distance from Kap Farvel along the outer coastline.

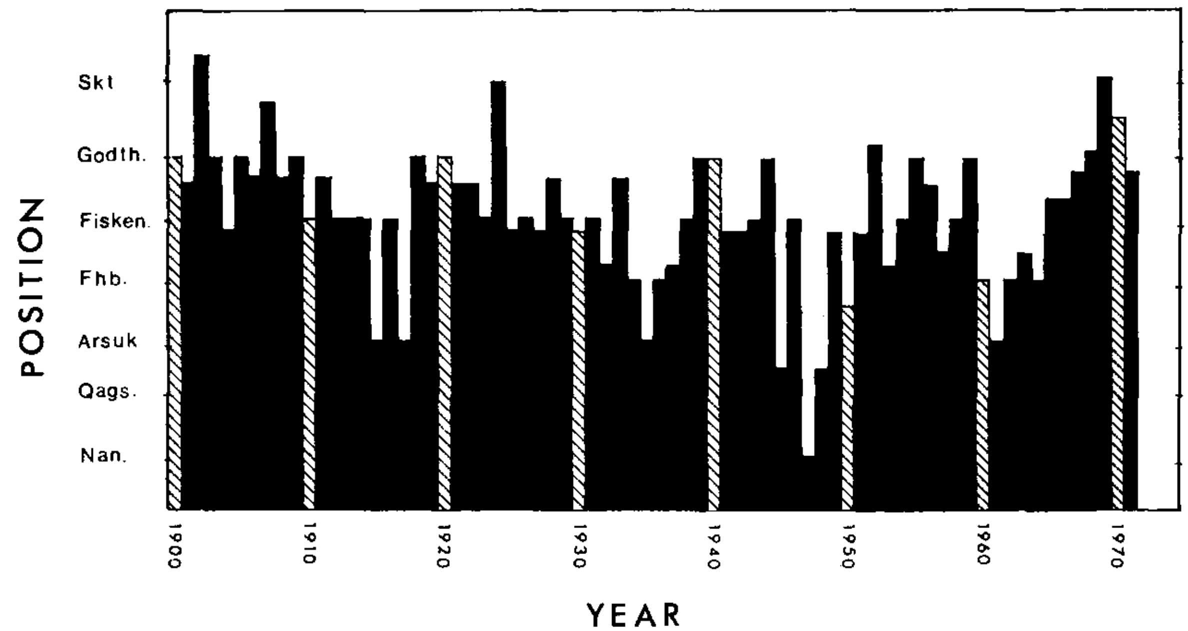


Fig. 4. Polar Ice, Northernmost ice edge, 1900 - 71. (The histogram indicates the northernmost position year by year of the polar ice edge off the Greenland West Coast.)

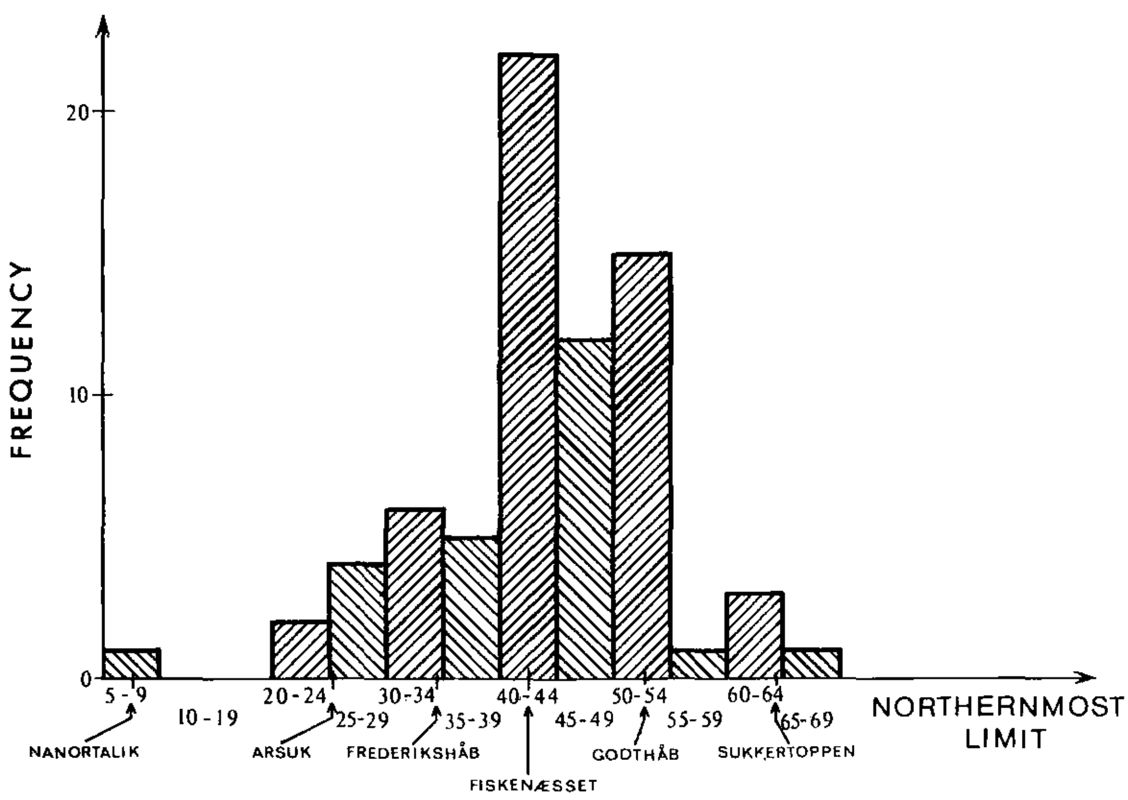


Fig. 5 Frequency of northernmost yearly limit of Polar Ice on the Greenland west coast 1900-71.

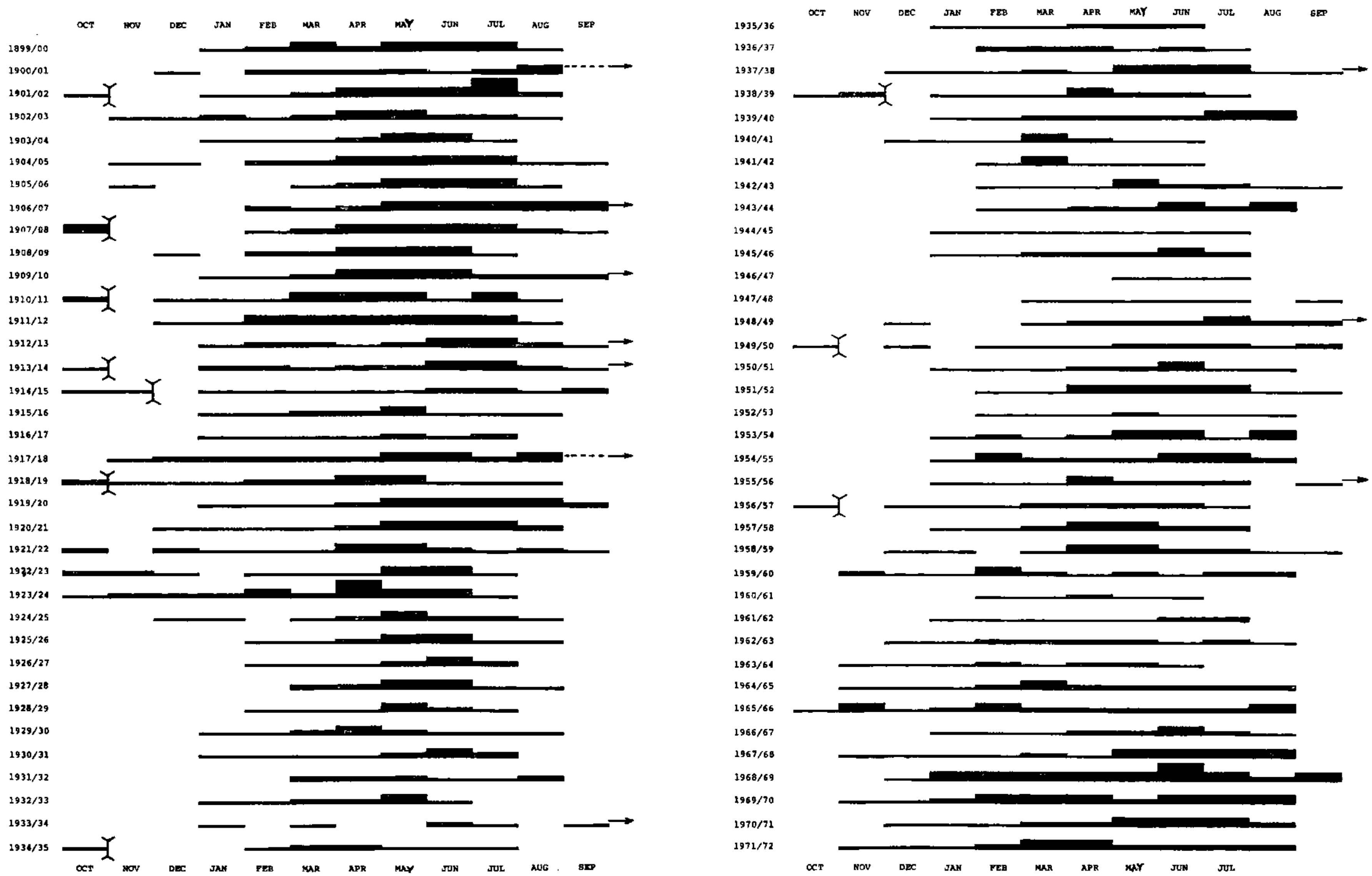


Fig. 6. Polar Ice, Greenland west coast, Northern Limit, month by month from 1899-1900 through 1971-72. (Top of white section of columns indicates date of first reported "forerunners", while top of black section indicates date of arrival of polar ice of more that 2 weeks duration.)

It would be desirable to extend the scale so as to include information of the southernmost ice edge on the east coast in the period(s) when the ice was not present west of Kap Farvel. However, the data from the east coast are far too sparse to allow this extension. Figure 6 is based upon this matrix and for the sake of clarity the dividing steps of the block height have been made logarithmic. No signature means that no polar ice was reported off the west coast; 1/2 mm. that the ice in the month concerned was present but not reported north of Nunarssuit (Table II, nos. 2-20); 1 mm. that ice was present north of Nunarssuit but did not extend to Ravns Storoe (Table II, nos. 21-40); 2 mm. that ice was present north of Ravns Storoe but did not extend to Napassoq (Table II, nos. 41-60); 4 mm. that ice was present even north of Napassoq at least once within the given month. All these diagrams illustrate how varying and obscure the ice conditions seem to be.

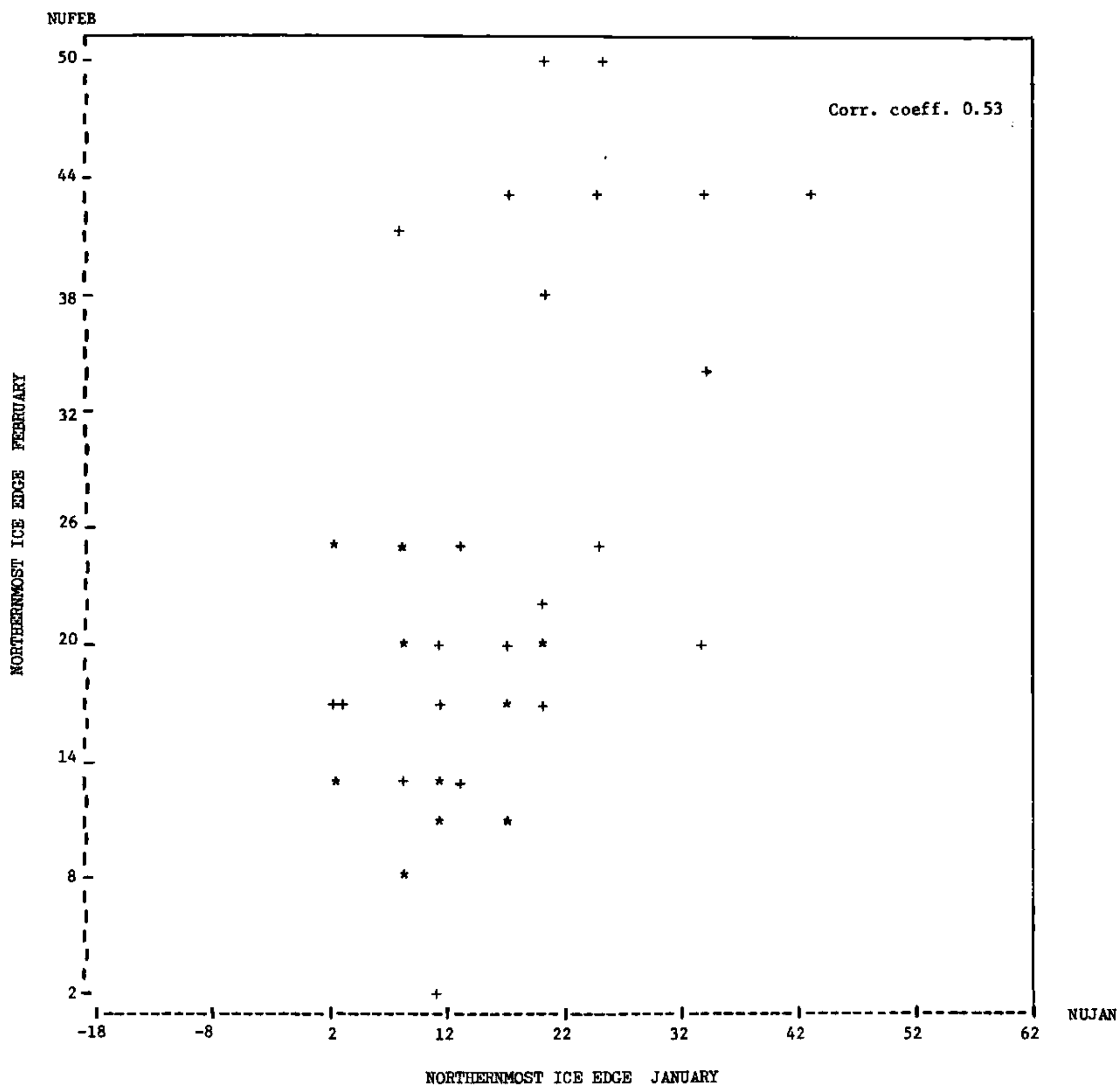


Fig. 7. Correlation diagram: Northernmost Ice Edge — January vs February.

Processing Results*

Are persistency correlations revealed by the data? In Fig. 7 the position of northernmost ice edge in January is correlated with its position in February. Although the correlation coefficient is only 0.53 it seems that a northerly position in January may have a tendency to be followed by a northerly position in February. However, it appears from Fig. 8 that this tendency has vanished already in March. Figures 9 and 10 give the same impression for the months May/June and May/August.

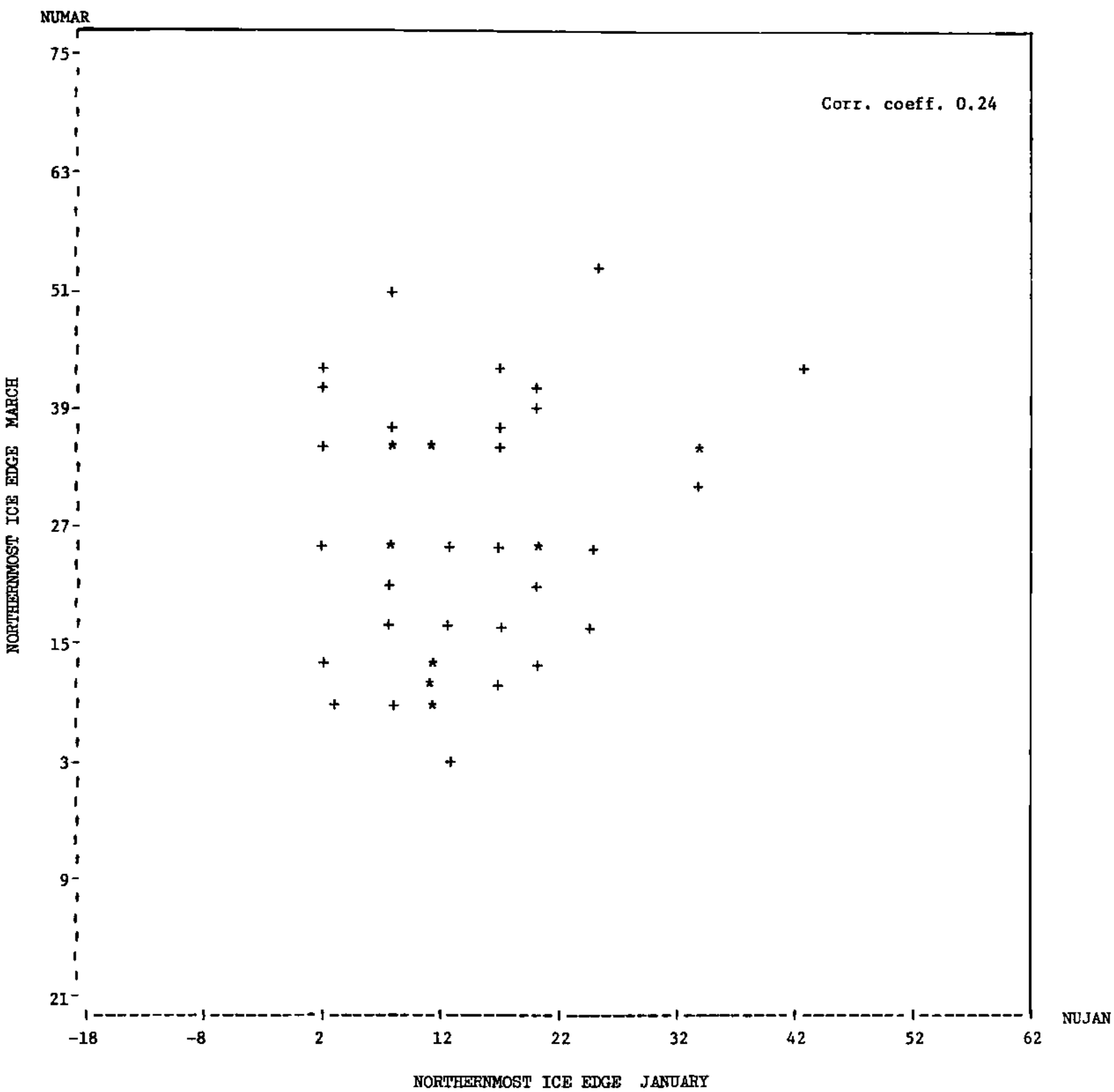


Fig. 8. Correlation diagram: Northernmost Ice Edge — January vs March.

*The computer program was set up and the processing executed at RECKU computer center by Mrs M. Lilholt. In all about 3,000 correlation diagrams were plotted.

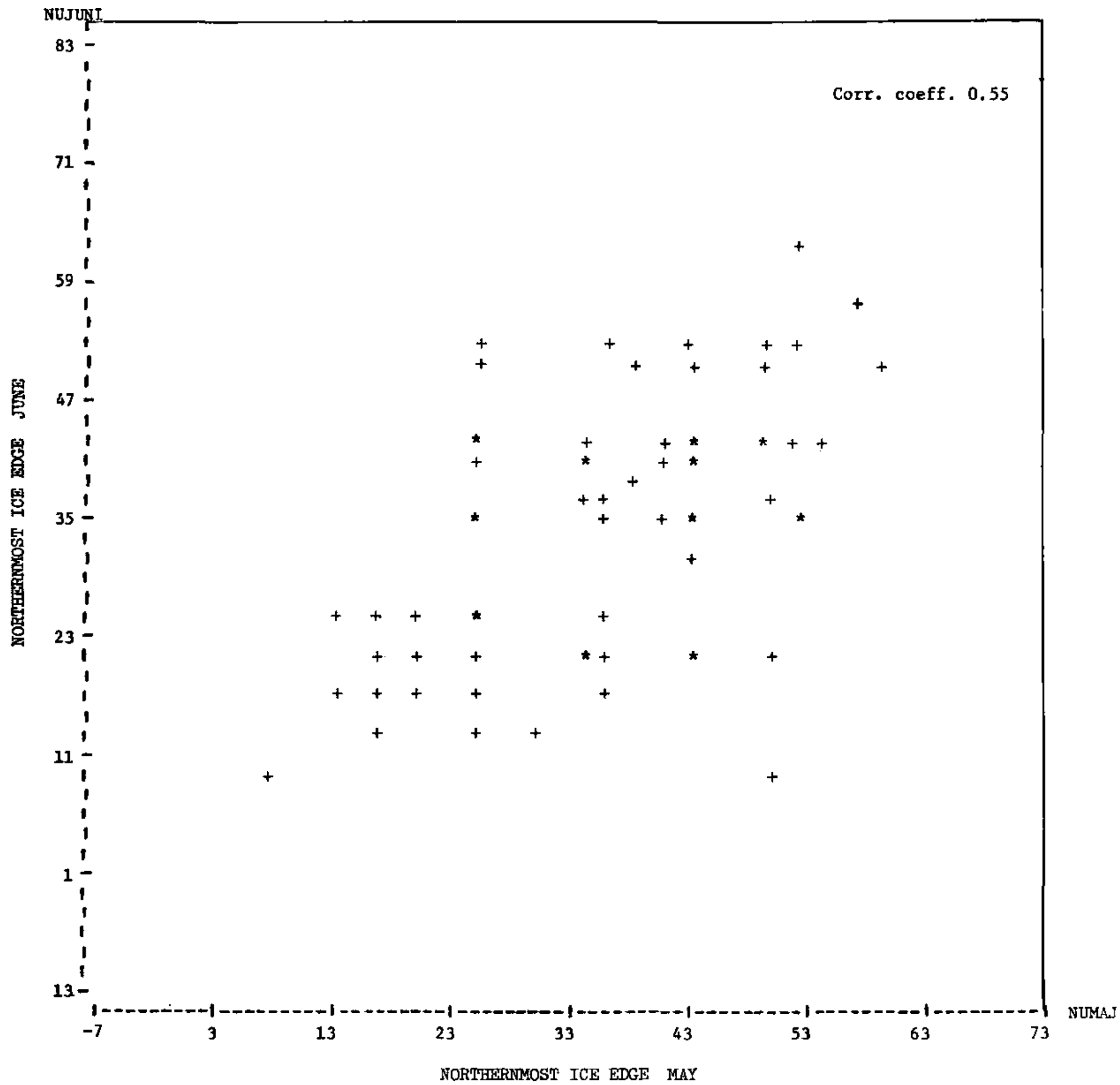


Fig. 9. Correlation diagram: Northernmost Ice Edge — May vs June.

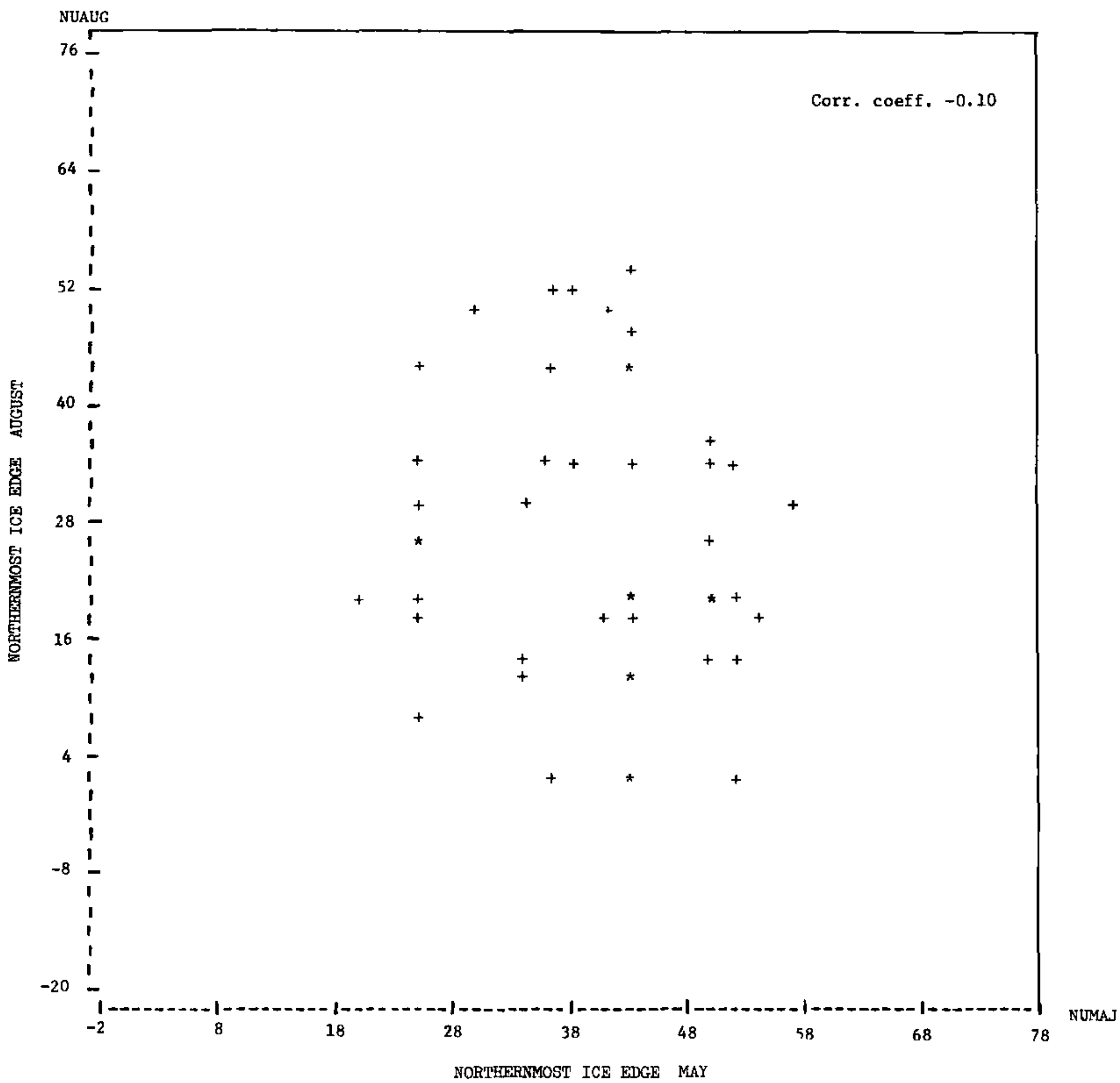


Fig. 10. Correlation diagram: Northernmost Ice Edge — May vs August.

How much can be concluded about the extension (NU) of the ice in the following season from data of ice extension in the present season? Very little; the best correlations seem to be NU May (year N) ⋆ NU April (year N+1) and NU May (year N) ⋆ NU May (year N+1) and NU June (year N) ⋆ NU April (year N+1) with correlation coefficients of 0.39 or lower! (⋆ defines "correlation with").

In conclusion, it may be said, that the tendency of ice extension may persist into the following month only. Very little, if anything, can be predicted from the present state of the ice concerning the ice conditions several months later in the season.

How much may be concluded from the length of a given ice season concerning the following season? Apparently nothing. Correlation coefficients between length of period (PL) year

(N) and length of period year (N + 1), (N + 2), (N + 3) respectively are 0.32, 0.23 and 0.28; and the correlation diagrams show circular clouds of dots.

Is there any significant correlation between the extent of ice and the length of the current ice period? Very little, if any. The best correlation is found between January extent and length of the ice period (Fig. 11). However, since the ice period frequently does not start until after January, this correlation is not surprising. Figures 12 and 13 concern themselves with the extent in April and May. Whereas ice extent in May may show some correlation with the period length, ice extent in all other months does not seem to be correlated with length of ice period in any way.

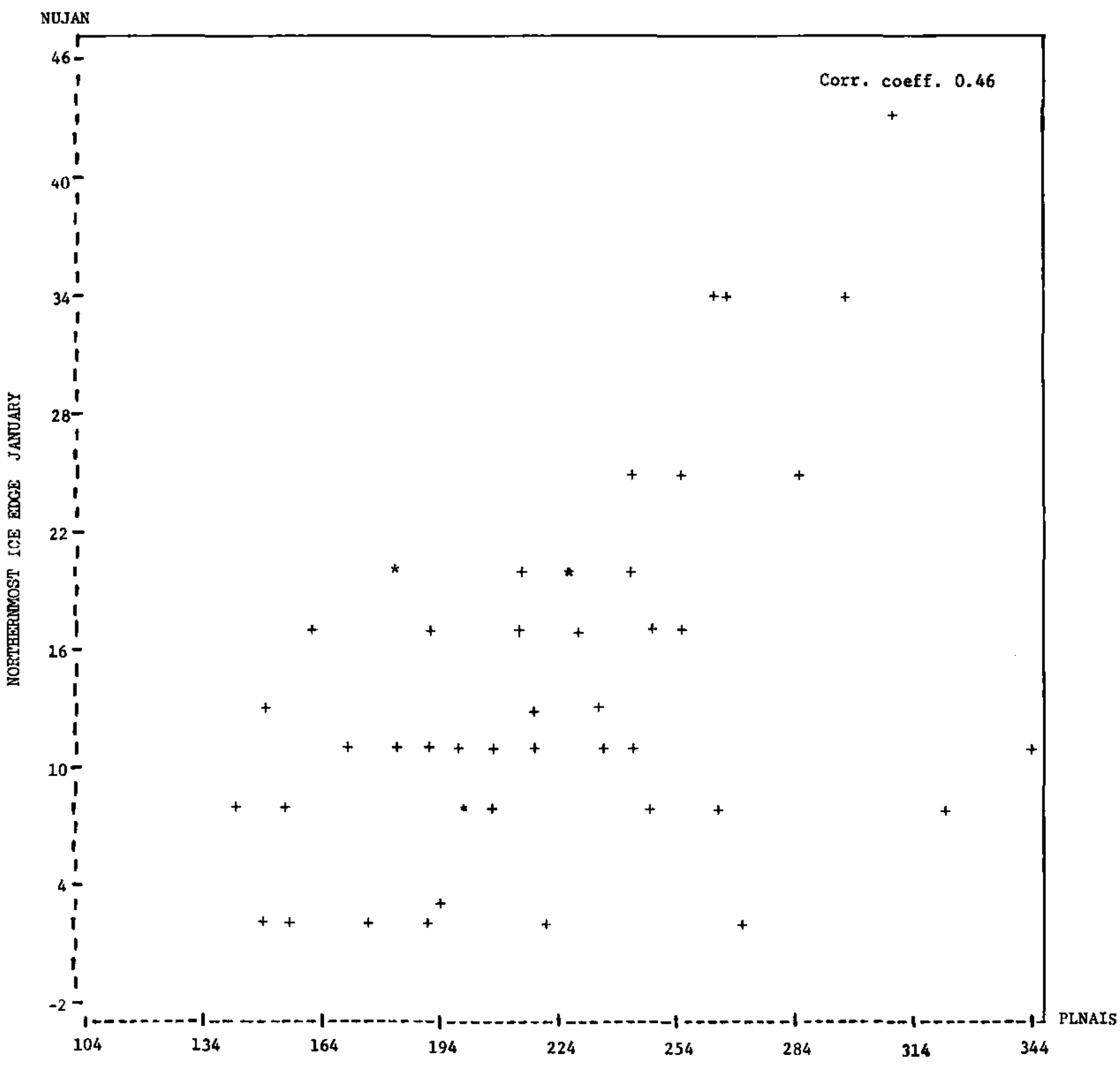


Fig. 11. Correlation diagram: length of Ice Season vs Northernmost Ice Edge in January

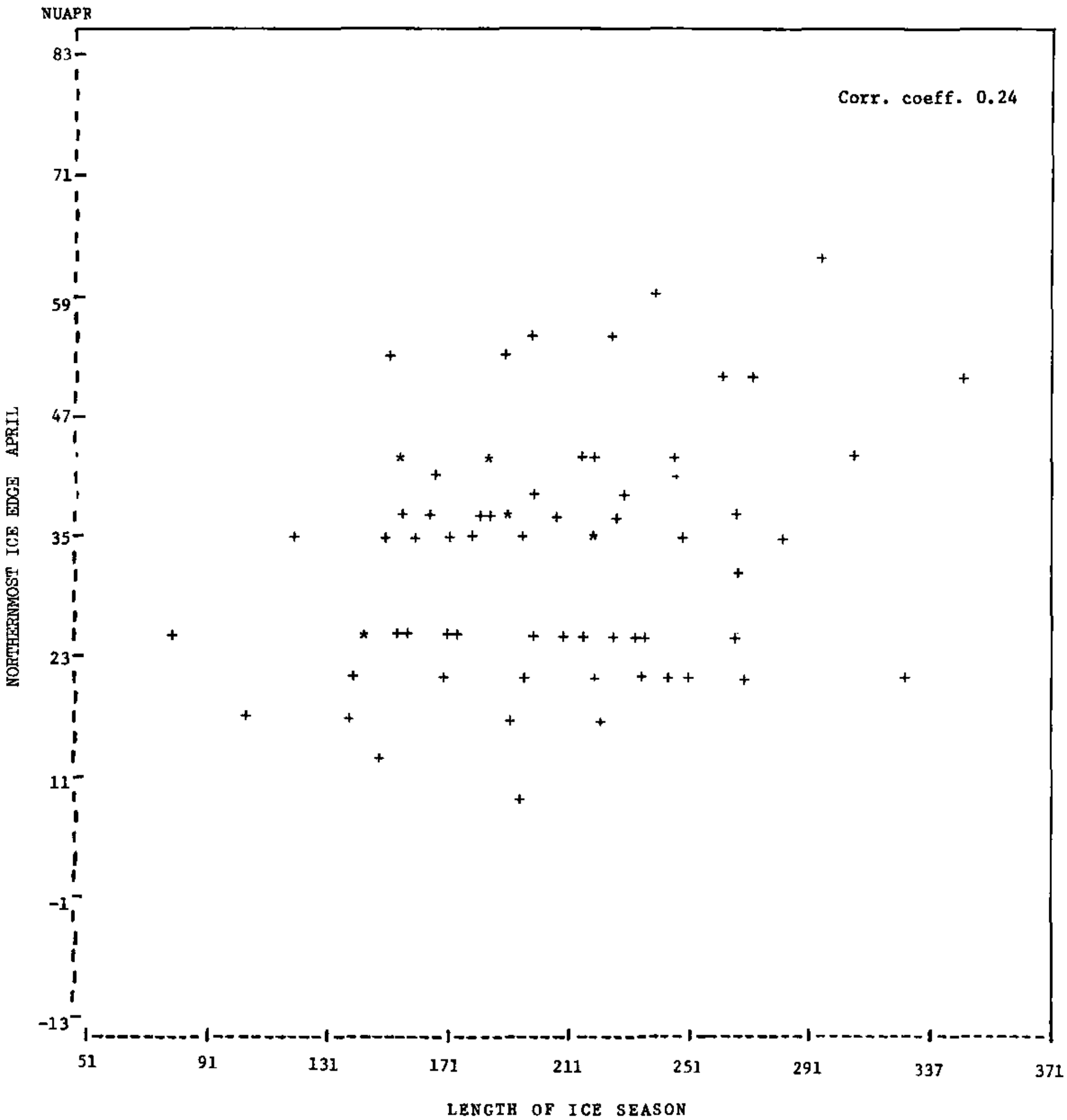


Fig. 12. Correlation diagram: length of Ice Season vs Northnmost Ice Edge in April

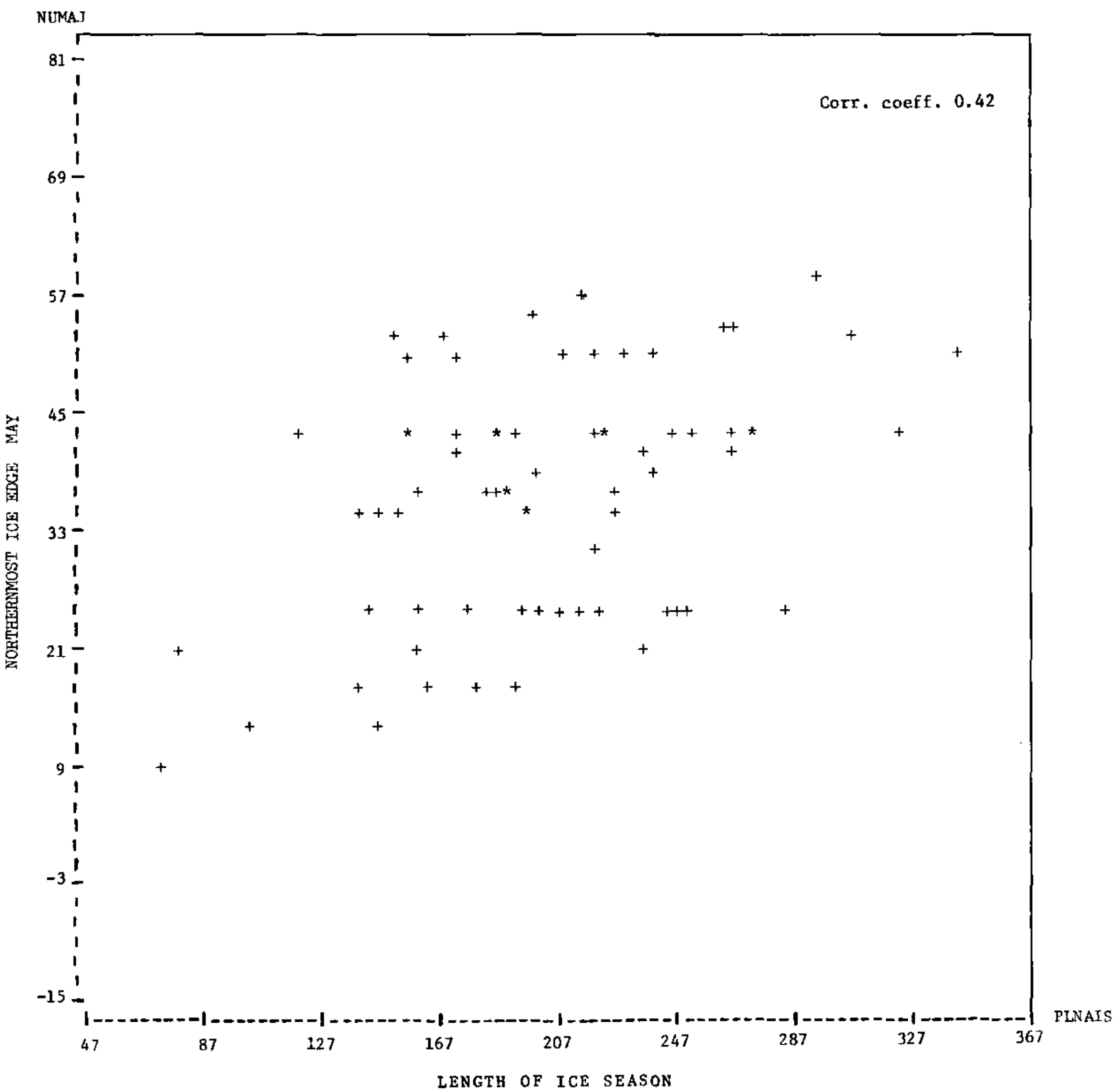


Fig. 13. Correlation diagram: length of Ice Season vs Northernmost Ice Edge in May

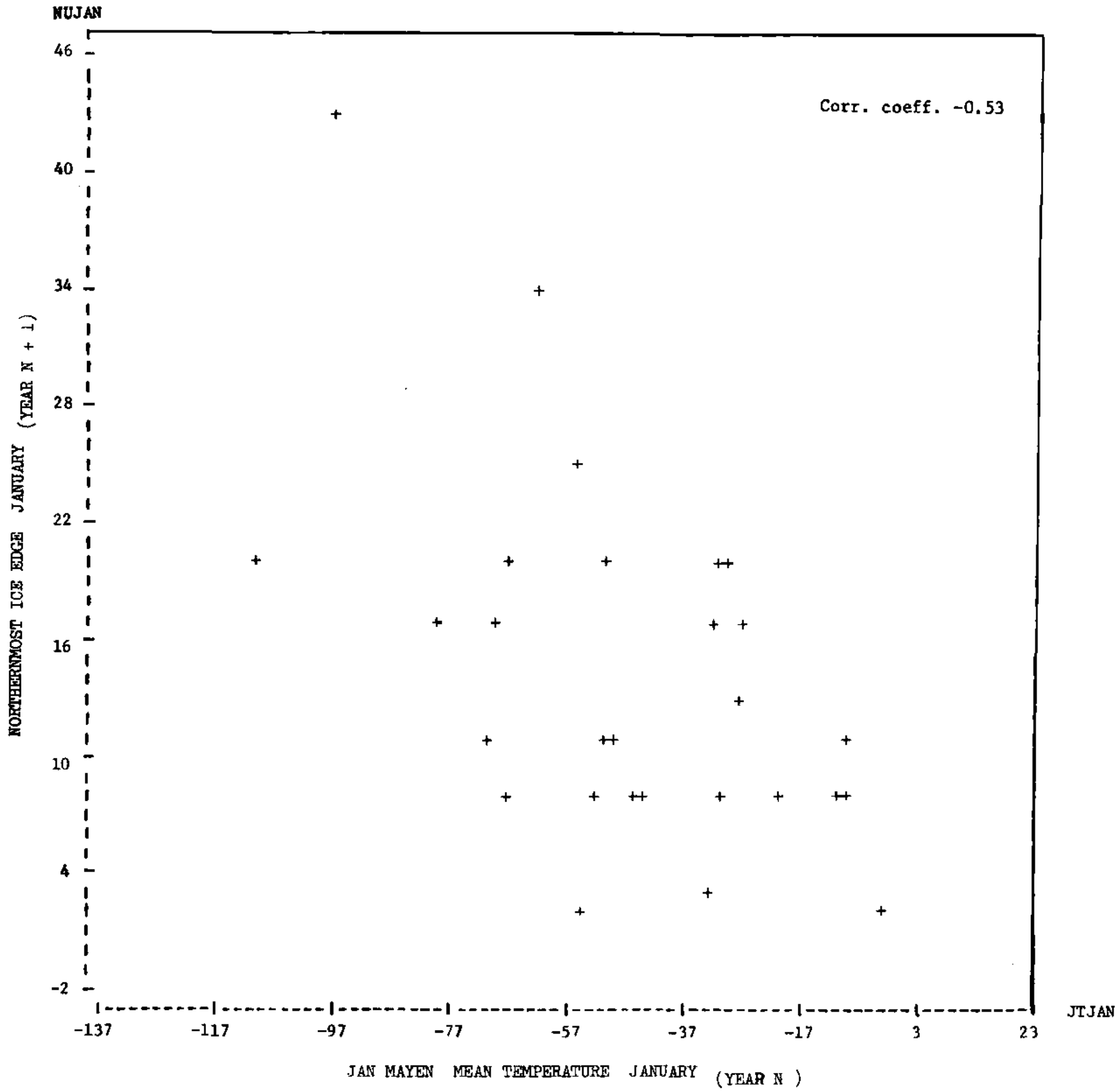


Fig. 14. Correlation diagram: Jan Mayen mean temperature January vs Northernmost Ice Edge in January of the following year

Is there any correlation between the extent of ice and the length of the following ice season? No significant correlation is apparent. The May diagram seems to indicate some correlation (c.c. 0.32); but this may have arisen by chance. Diagrams of all other months show no correlation at all.

Is there on the other hand any correlation between length of season and extent of ice the following ice season? The answer is, No.

Finally, is there any correlation between the date of polar ice passing Kap Farvel, i.e. date of initiation of the ice season and the extent of ice in that season? No.

This means that nothing can be predicted from the initiation date about the severity of the season with respect to the two-dimensional extent of the ice.

Correlation with Air Temperature

For the sake of elucidating possible connections between air temperatures and sea ice conditions the preceding ice data have been correlated with air temperature data. Unfortunately, only very few stations in or near the area have continuous or homogenized records through the whole period 1900-1971. The 4 stations Pt. Barrow, Jan Mayen, Godthaab and Upernavik fulfil the requirements and their data were correlated with length of ice period (PL) and ice extent off the Greenland west coast (i.e. the northernmost ice edge (NU)) 0, 1, 2 and 3 years later. No correlation was found between air temperatures at Pt. Barrow, Godthaab and Upernavik respectively and the ice data.

Jan Mayen air temperature (JT) seem to be correlated with the ice conditions to some extent. The correlations which on the diagrams seem to be best (and which with one exception had the highest correlation coefficients (c.c.)) are as follows:

JT * NU:	JT Nov. (year N)	* NU January (year N+2)	c.c.: -0.55
	JT Jan.$_N$	* NU Jan. (N+1)	c.c.: -0.53*
	-	* NU Feb. (N+1)	c.c.: -0.43
	JT May$_N$	* NU Jan. (N+1)	c.c.: -0.60*
	JT July$_N$	* NU Feb. (N+1)	c.c.: -0.41
	-	* NU Feb. (N+2)	c.c.: -0.49
	JT Sept.$_N$	* NU May (N+1)	c.c.: -0.29
	-	* NU May (N+2)	c.c.: -0.33
	-	* NU June (N+1)	c.c.: -0.29
	-	* NU June (N+2)	c.c.: -0.34
	-	* NU June (N+3)	c.c.: -0.44
	JT Oct.$_N$	* NU April$_N$	c.c.: +0.3
	-	* NU April$_{(N+3)}$	c.c.: -0.38
	-	* NU May$_N$	c.c.: +0.19
	-	* NU May (N+3)	c.c.: -0.43
JT * PL:	JT Sept.$_N$	* PL (N+1)	c.c.: -0.39
	JT Nov.$_N$	* PL (N+1)	c.c.: -0.60
	JT Sept.$_N$	* PL (N+2)	c.c.: -0.35

*The frequency distribution of NU Jan. is very skew whence the relatively high c.c. may be meaningless.

Three of the corresponding diagrams are shown: Fig. 14 seems to show some correlation between JT Jan.$_N$ and NU Jan.$_{(N+1)}$ which might indicate that the air temperature at Jan Mayen is reflected in the ice conditions off southwest Greenland one year later. This is a rather long delay compared with the generally assumed pack ice travelling time of about 6 months from the latitude of Jan Mayen to Kap Farvel.

On the other hand Fig. 15 may indicate a weak correlation between JT May and ice extent 8 months later. Finally, Fig. 16 indicates an extremely faint correlation between Jan Mayen temperatures in September and the length of following ice seasons in southwest Greenland.

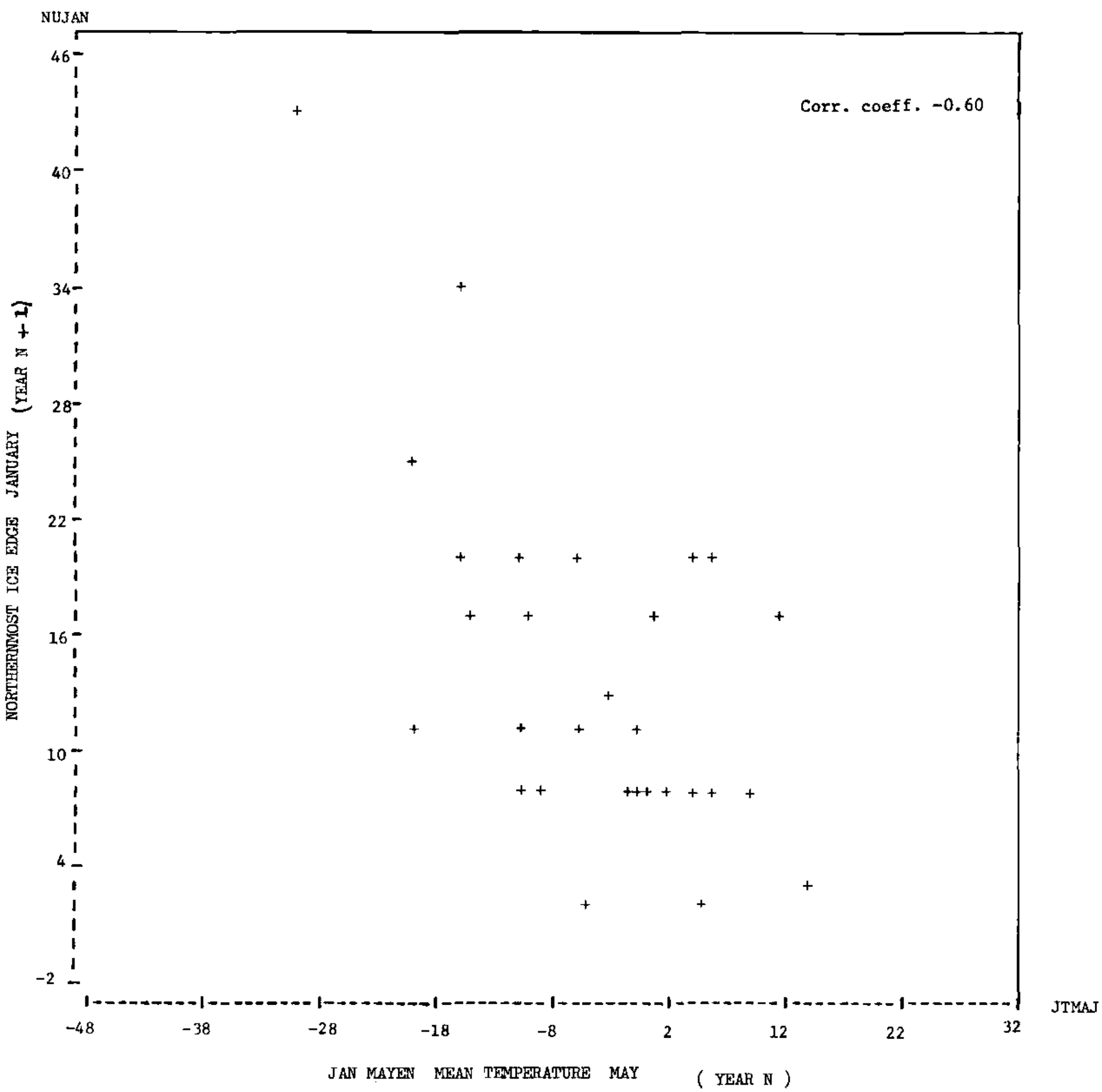


Fig. 15. Correlation diagram: Jan Mayen May mean temperature vs Northernmost Ice Edge in January of the following year

In conclusion, it may be said, that the temperature data do not seem to be of much help in predicting the severity of the ice seasons (as severity is defined in the present paper).

This rather discouraging conclusion corresponds well with the observed fact that the presence of atmospheric lows in Davis Strait frequently accelerates the penetration of the pack ice to the north, whence shortlasting "out breaks" of the ice are frequent.

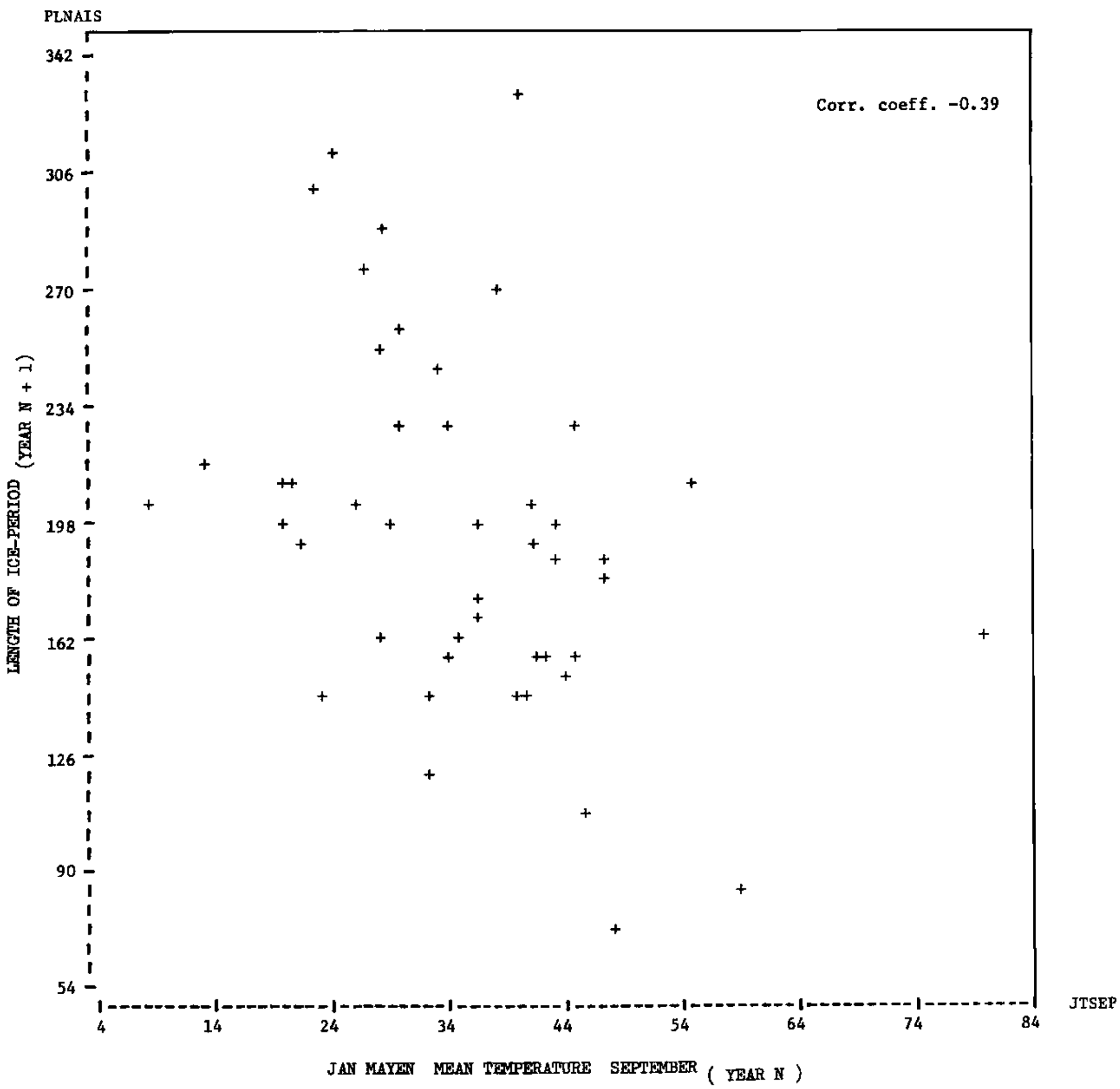


Fig. 16. Correlation diagram: Jan Mayen mean September temperature vs length of ice season in the following year

APPENDIX

POLAR ICE, GREENLAND WEST COAST, NORTHERN LIMIT

(ref.: Table II)

	O	N	D	J	F	M	A	M	J	J	A	S
1899/1900				2	25	41	36	43	41	52	20	
1900/1901			8		34	34	34	30	13	34	50	
1902				17	11	25	43	57	57	68	30	
1903		8	2	34	20	(30)	50	52	34	36	20	
1904				11	20	11	25	41	41	20		
1905		13	13		30	25	43	50	50	52	20	13
1906		13				11	35	50	43	41	20	
1907					25	13	30	43	52	59	43	54
1908	46				13	25	43	43	41	50	34	8
1909			11		25	25	41	52	43	20		
1910				2	13	25	54	43	43	34	34	25
1911	25		2	2	13	43	43	50	20	43	13	
1912			17	17	43	43	43	43	43	43	20	
1913				13	25	25	20	25	43	41	30	20
1914	2			25	25	17	34	25	41	43	34	8
1915	11	11		13	13	17	20	20	25	25	20	25
1916				11	2	34	34	43	20	17	2	
1917				11	11	11	20	25	17	25		
1918		2	25	34	34	34	36	52	52	34	43	
1919	30	2	13	2	25	34	50	43	20	11	2	
1920				11	13	8	25	41	43	52	50	34
1921			11	11	13	13	25	50	43	43	25	
1922	25		25	11	11	13	50	50	36	17	36	11

ref.: Table II (continued)

	O	N	D	J	F	M	A	M	J	J	A	S
1922/1923	25	34	8		2	17	20	43	43	13		
1924	8	25	30	34	43	34	63	59	50	20		
1925			11	8		17	25	41	34	25	17	
1926					8	8	25	43	41	8	11	
1927					8	11	20	34	41	36		
1928						25	34	43	50	11	11	
1929					8	13	20	43	34	20		
1930				8	8	25	41	25	20	17	17	
1931				13	17	8	8	34	43	34		
1932						36	36	36	17	8	34	
1933				8	20	34	36	50	8			
1934				11		8			34	17		11
1935	2				8	25	25	20	20	13		
1936				17	11	11	34	25	25			
1937					25	36	36	17	25	17		
1938			2	8	13	25	20	43	43	43	20	17
1939	11	25		11	17	17	52	36	34	17		
1940				17	17	36	36	36	36	52	52	
1941			8	20	17	41	34	17	17			
1942					17	41	13	13	17			
1943					8	8	17	43	30	25	17	8
1944					20	8	36	36	52	36	43	
1945				17	17	17	17	17	20	20		
1946				2	17	25	25	25	43	34		
1947								8	8	8		
1948						2	2	17	13	20		2
1949			8			17	25	34	36	41	30	36

ref.: Table II (continued)

	O	N	D	J	F	M	A	M	J	J	A	S
1949/1950	(2)		2		8	20	20	25	25	30	8	34
1951				2	13	13	25	34	41	17	11	
1952					8	20	41	54	43	43	17	13
1953					2	13	20	36	20	8	2	
1954				20	22	20	25	43	41	20	43	
1955				8	41	36	34	25	52	52	25	
1956				11	13	8	50	36	25	34		5
1957	11		2	11	11	34	25	25	34	17		
1958				8	20	34	43	43	34	25		
1959			5	13		2	52	52	34	34	2	2
1960		25	20	20	50	25	20	25	13	25	25	
1961					17	17	25	20	17			
1962				8	8	8	17	13	25	34		
1963			2	20	38	25	25	34	20	25	13	
1964		17	13	8	25	20	25	34	20			
1965		8	8	8	25	50	38	38	38	34	34	
1966	2	50	20	25	43	25	34	25	34	34	43	
1967				20	20	13	25	25	50	25	20	
1968		2	13	17	20	34	20	43	43	52	47	
1969			13	43	43	43	43	52	63	60	34	43
1970		8	13	25	50	52	58	38	50	52	52	
1970/1971			13	20	20	38	38	50	52	52	34	
1971/1972		20	13	17	25	43	41	34	34	22	34	

Variability of Ice Seasons on the Eastern Canadian Seaboard

by

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Abstract

Based on systematic ice reconnaissance flights during the past 15 years, mean ice conditions at the end of January, February and March are presented. The variability of ice conditions in late March in a mild winter such as 1960 compared to those of a cold one such as 1973 is discussed and explained in the light of mean airflow during the winter months.

Mean winter air temperatures at St. John's and Belle Isle are examined and although a cooling trend in the 10-year running mean is apparent it is pointed out that this represents averages only and means nothing on a year-to-year basis. From the discussion of ice conditions that are known to exist, it would appear that winter fishing on the offshore banks of northern Newfoundland could be further developed.

Introduction

The key factors which affect the severity of ice seasons on Canada's east coast are air temperatures, winds and water currents. Air temperatures dictate whether ice will form, how thick it will become and when freezing will give way to melting conditions. To this one must add the windflow which may break-up and spread the ice, leave it intact or compress it strongly against the shore. Temperature and wind are somewhat interdependent. Obviously, below normal temperatures would be unlikely in this area with southerly winds but mild northeast winds are as possible as cold ones. Similarly, westerly winds can be cold or mild depending on their upwind source; so the whole regional pressure situation must be examined in conjunction with temperatures.

In taking water currents into consideration as a factor, we are in general concerned more with water temperatures and their variability than with the currents themselves. For example, in the early part of 1973, waters in the southward-flowing Labrador current were abnormally cold chiefly because the arctic summer of 1972 was particularly cool. Thus, the water flowing past the Newfoundland-Labrador coast early in 1973 was much cooler than normal which permitted more ice to form and permitted it to form earlier than would have been the case after a mild preceding summer in the north.

As mentioned previously, the regional atmospheric pressure pattern exerts a controlling influence over the ice season. Figure 1 is a summation of the mean monthly pressure maps for January, February and March. Notice that the Icelandic low is centered east of Kap Farvel. A moderate north to northwest air flow extends from Baffin Island across Quebec and Labrador into the

Newfoundland and Grand Banks area where the flow becomes west to northwest. Under this southward flow of cold air, surface temperatures generally diminish with increasing latitude. For example, freezing normally begins at Cartwright on November 5 at St. Anthony on November 17 and at St. John's on December 10. At the end of March the cumulative freezing degree day totals at these three locations are normally 2370, 1685, and 740 respectively. However, freezing conditions have sometimes ended at St. John's before the end of March.

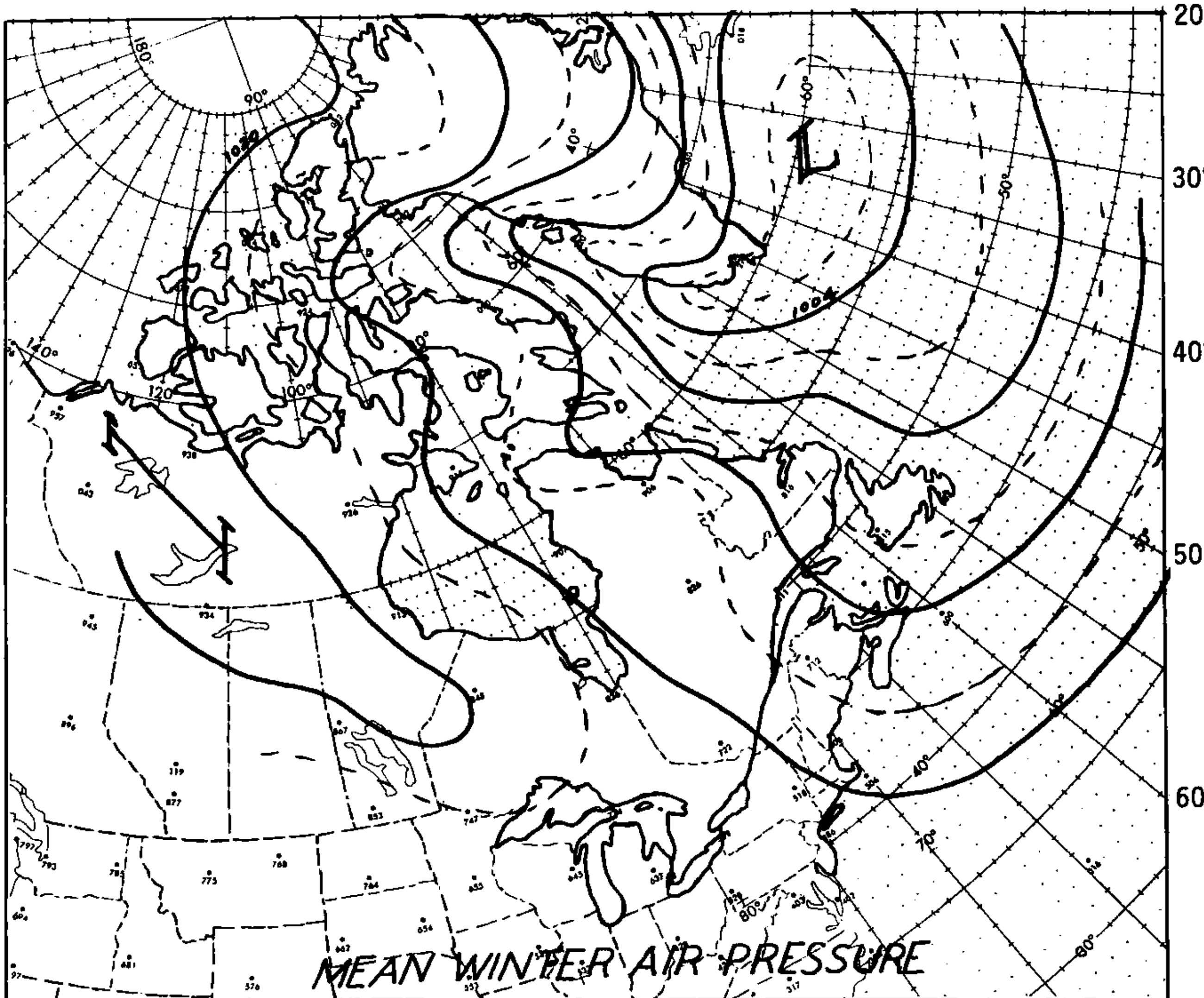

Fig. 1. Mean winter air pressures for January, February and March 1973

Normal Ice Conditions

Systematic reconnaissance flights of ice conditions on Canada's eastern seaboard have been carried out throughout the ice season for the past 15 years. Figures 2 - 4 are composites of the conditions which have been observed at the end of January, February and March respectively over the 13 year period ending in 1971. No distinctions have been made in the diagrams for age of ice.

At the end of January (Fig. 2) ice may reach as far south as Cape Bonavista; the 50% probability line is just north of latitude 50°. Even in the mildest years the ice reaches Belle Isle Strait. If 1972 and 1973 were included the ice limit would extend as far south as St. John's and eastward to the edge of the chart, but the 50 and 75% probability would advance only slightly.

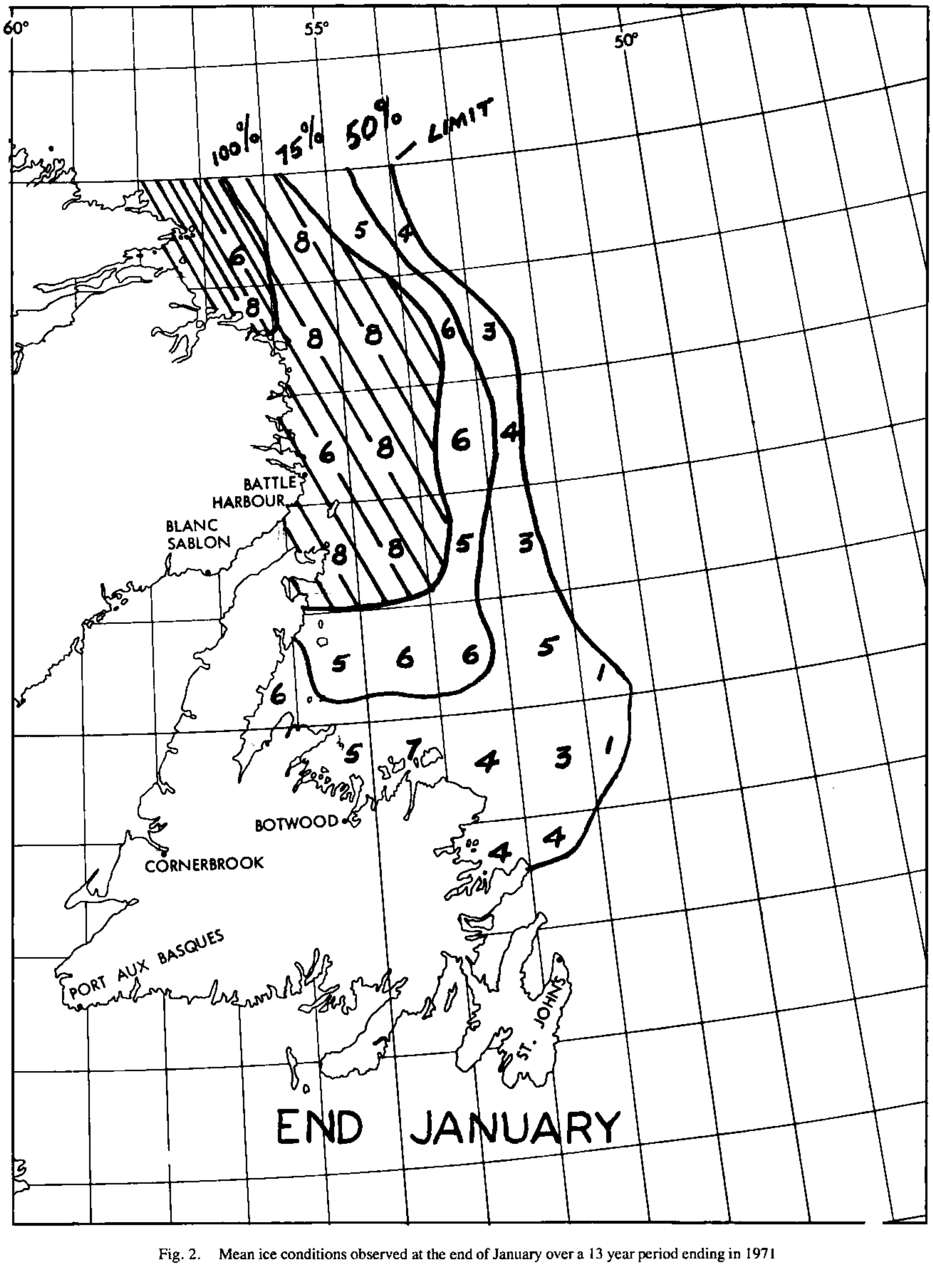

Fig. 2. Mean ice conditions observed at the end of January over a 13 year period ending in 1971

At the end of February (Fig. 3) the ice limit has reached Cape Race and the 75% probability line has reached Cape Freels. Again we are looking at a 13 year mean but recent conditions would not alter the chart significantly because it already includes some rather unusual seasons that were late in developing.

At the end of March (Fig. 4) there is even a further southward extension of the ice limit, but the 75% line is not greatly altered. The ice apparently can surround Newfoundland but in fact when ice extends eastward from Cabot Strait it never rounds Cape Race and vice versa so there is always some ice free routes into the island. If recent years were included in this summation there would be considerable eastward extension of the ice limit south of latitude 49° for this was a feature of this past ice season.

Extreme Ice Conditions (Favourable and Unfavourable)

It is interesting also to look at a "good" season and a severe one. 1960, although not the warmest winter on record ranks fairly high in the years for which we have ice data. The mean for the three winter months at St. John's was 26.8°F whereas the long normal is 25.9°F.

The mean pressure chart for the year (Fig. 5) reveals that Icelandic low is displaced southward, the airflow is from Denmark Strait and Kap Farvel towards Newfoundland and as a result the ice cover is quite restricted (Fig. 6). The ice, although relatively high in concentration, never did pass south of Cape Freels. An even lighter ice season probably occurred in 1958. Then, the winter mean was 30.3°F, the fourth warmest in 100 years, and the ice at its greatest extent probably did not reach Cape Freels. However the amount of ice data was quite limited because the reconnaissance program was still in its infancy.

The winter of 1973 was one of the coldest on record in Newfoundland and the ice conditions show it. The mean at St. John's from January 1 - March 31 was 20.9°F, the coldest in about 30 years, and the sixth coldest in the past 100 years. There may, however, have been another colder winter during a data gap in the 1930's as we will see, so perhaps we should say the seventh coldest in 100 years.

Figure 7 is the mean air flow for the 1973 winter. It is not vastly different from the normal as the flow is still from the Baffin Island area. But note that there is a more northwesterly component - the air source is more in the western Foxe Basin - Hudson Bay sector than from Baffin Bay and, because of its more continental origin, the resulting air is colder. Also, there is a definite offshore trend between 45° and 50°N. latitude. This is revealed on the ice conditions chart (Fig. 8) where close pack ice extends to the eastern edge of the Grand Banks in fact almost as far east as 45°West longitude.

Indications of Trends

After two cold winters like 1972 and 1973 the question in many peoples minds is what is the trend for coming winters and what is the future as far as winter fishing operations are concerned? Long-range ice forecasting is still an imperfect art. It is like going out on a limb even before the tree that will grow the limb is planted. However, the next two graphs may be of interest. Figure 9 is a plot of the mean winter temperatures at St. John's. Note that there is a gap from the early 1920's until the mid 1930's and that we have shown the curve for Belle Isle through this period, adjusted upwards by 10° to bring it more in line with St. John's. 1934 is the cold year that was mentioned previously for which no figures exist for St. John's.

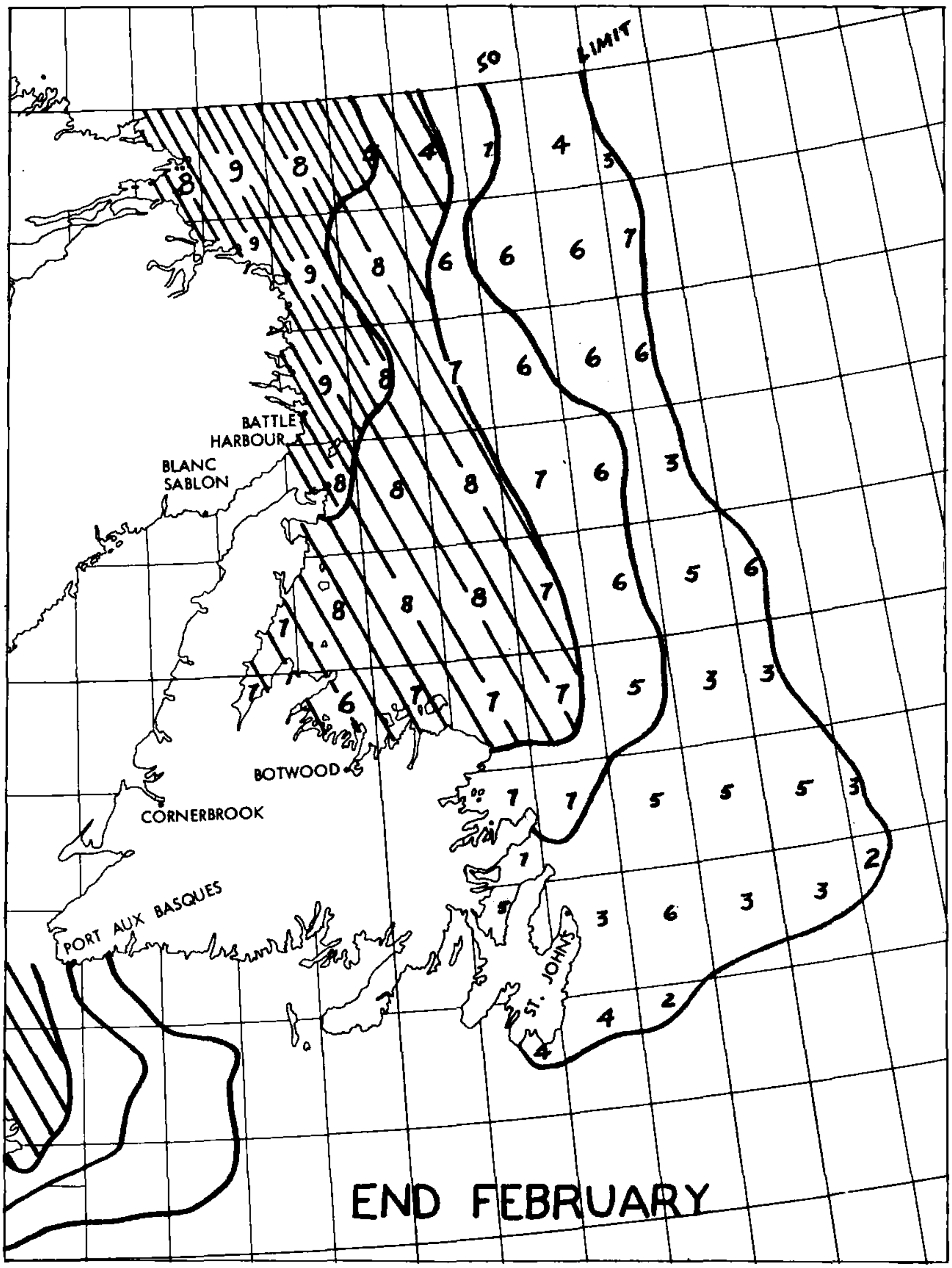

Fig. 3. Mean ice conditions observed at the end of February over a 13 year period ending in 1971.

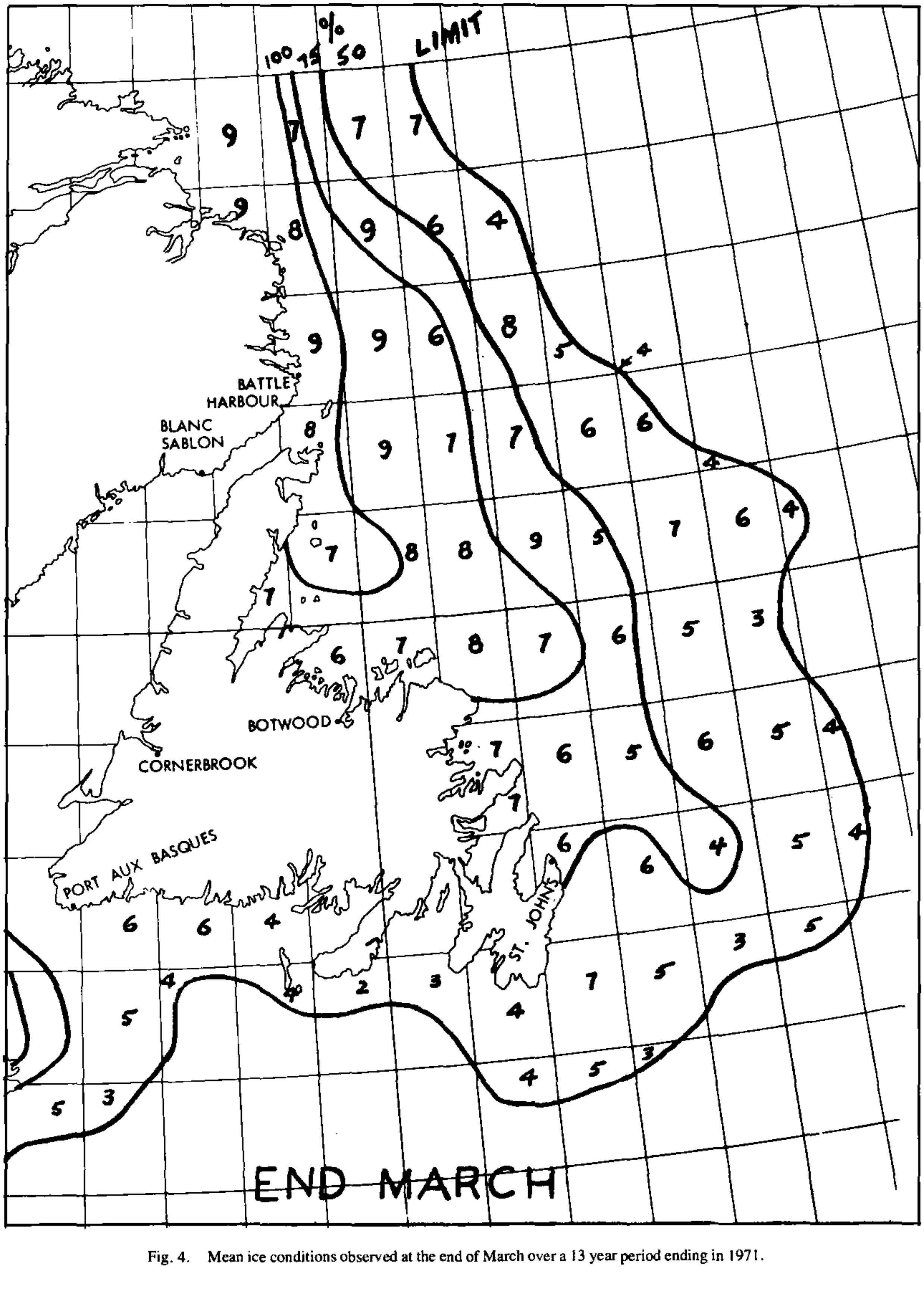

Fig. 4. Mean ice conditions observed at the end of March over a 13 year period ending in 1971.

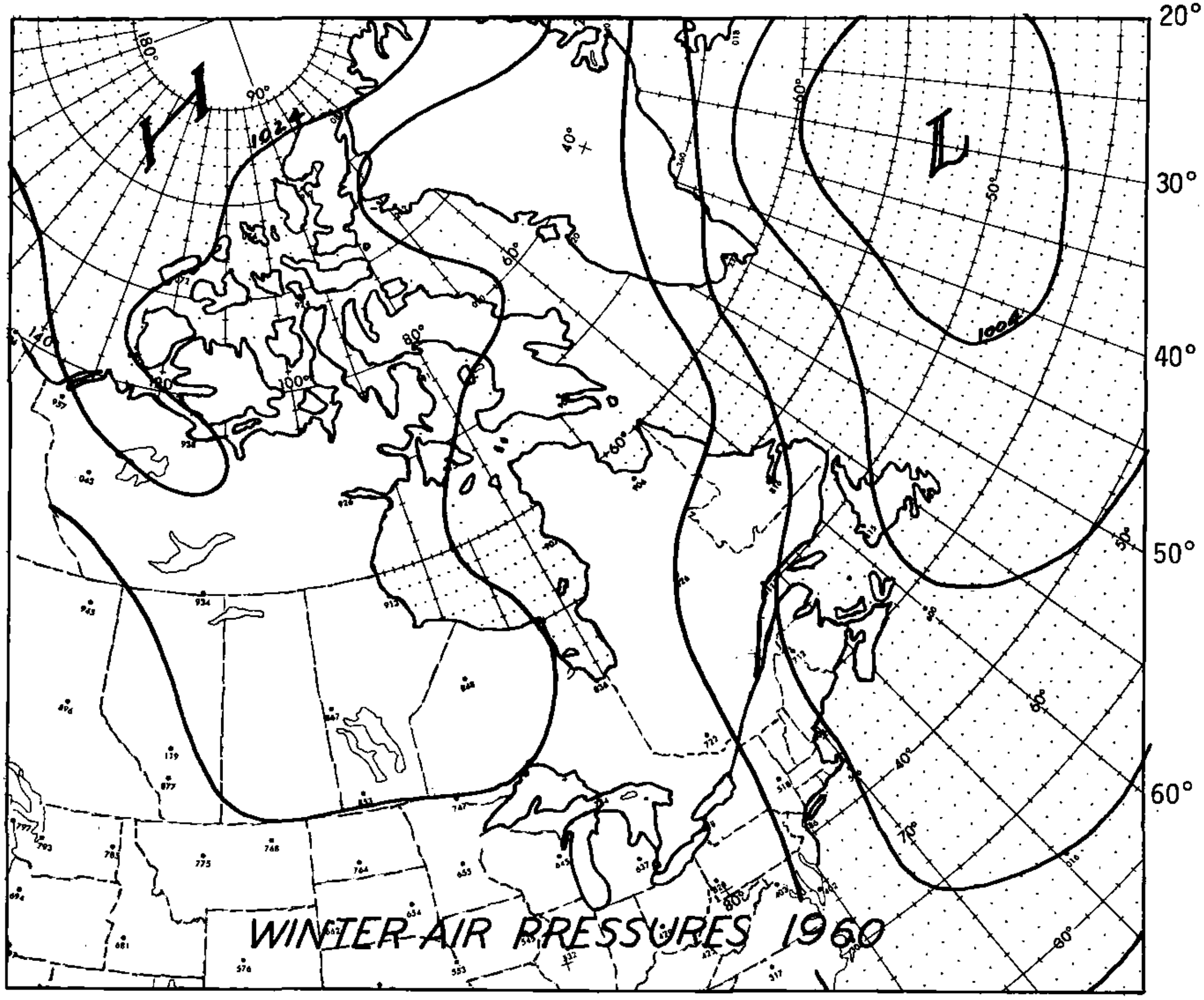

Fig. 5. Mean winter air pressures in 1960.

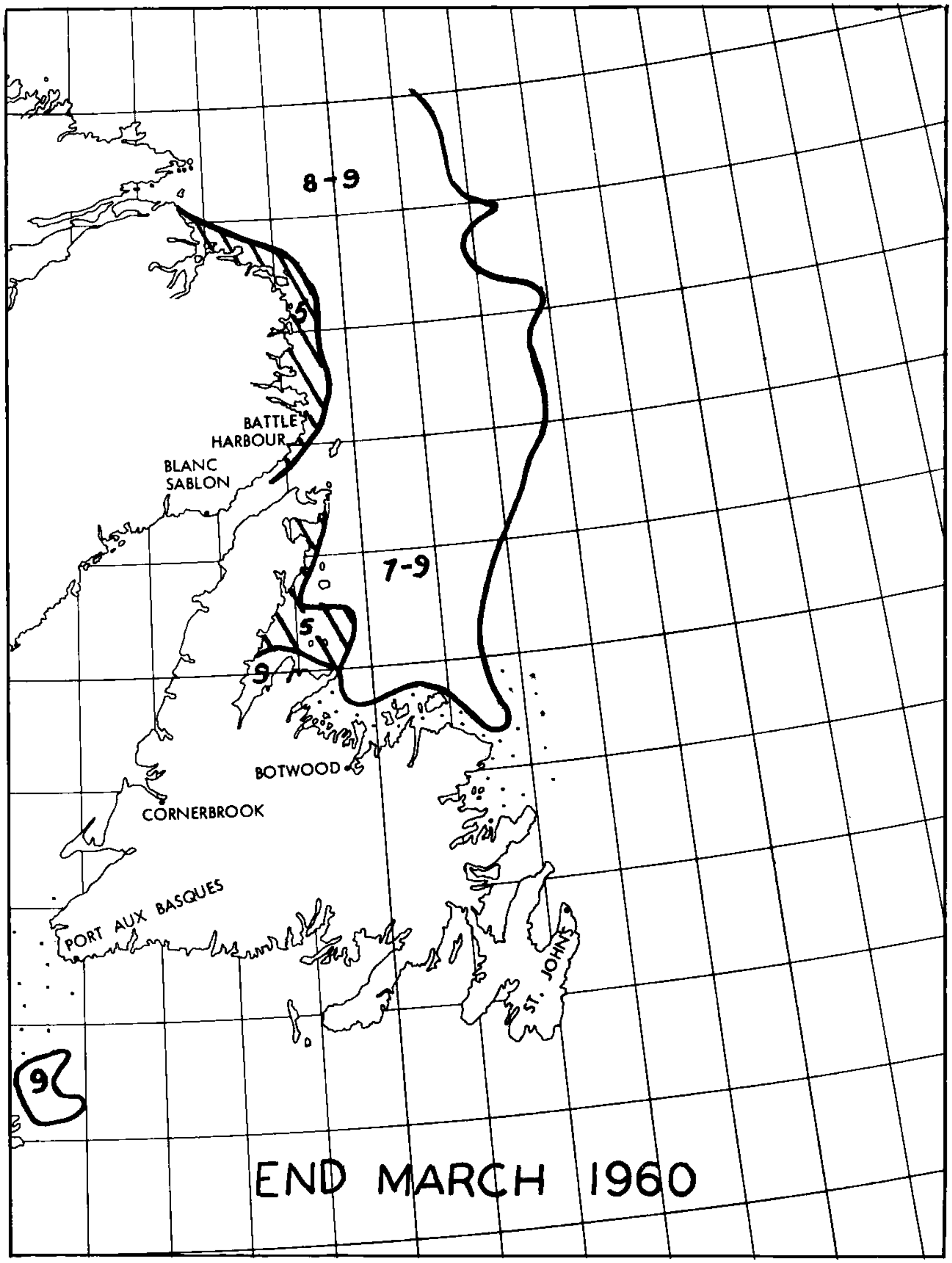

Fig. 6. Ice conditions at the end of March 1960.

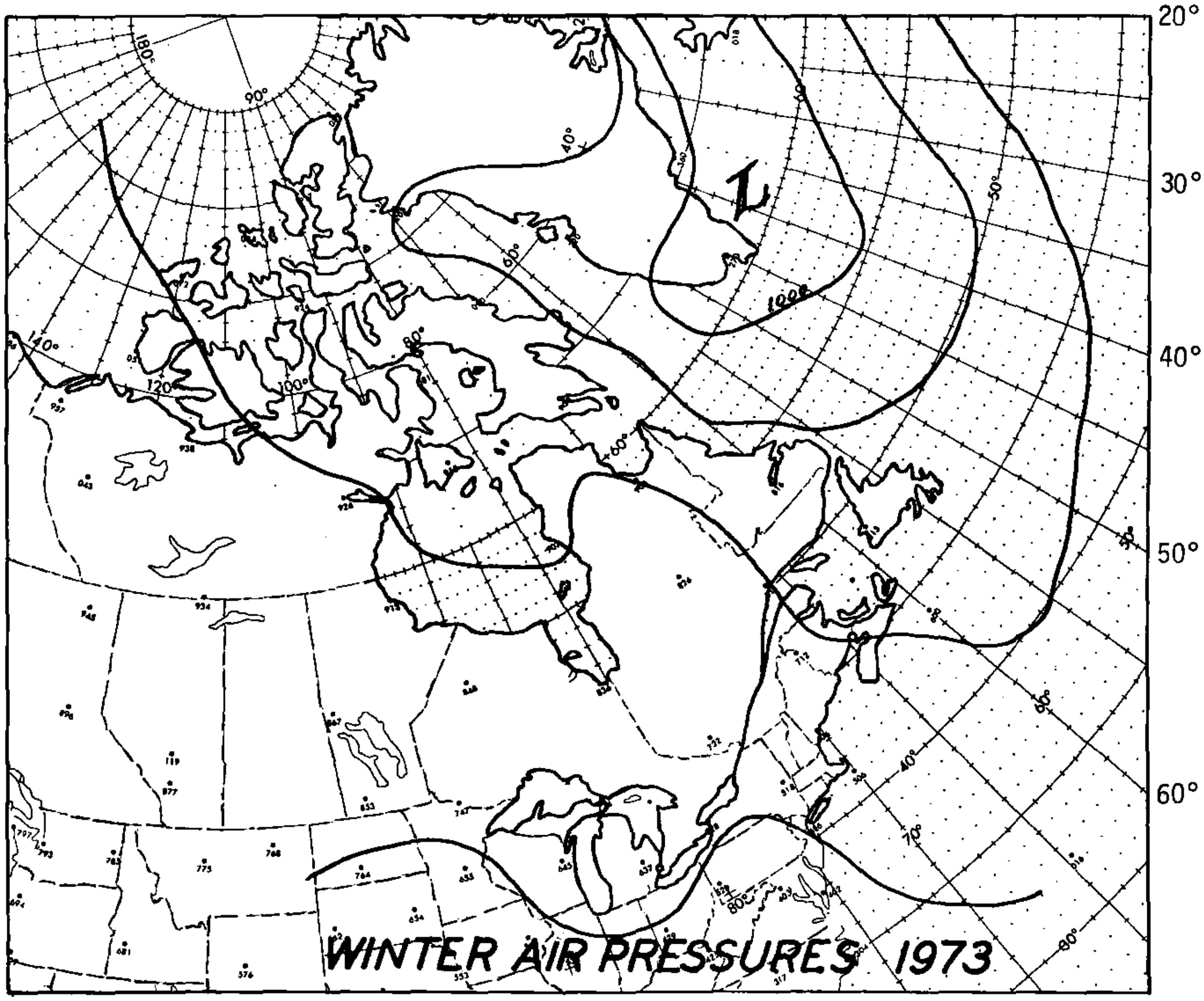

Fig. 7. Mean winter air pressures in 1973.

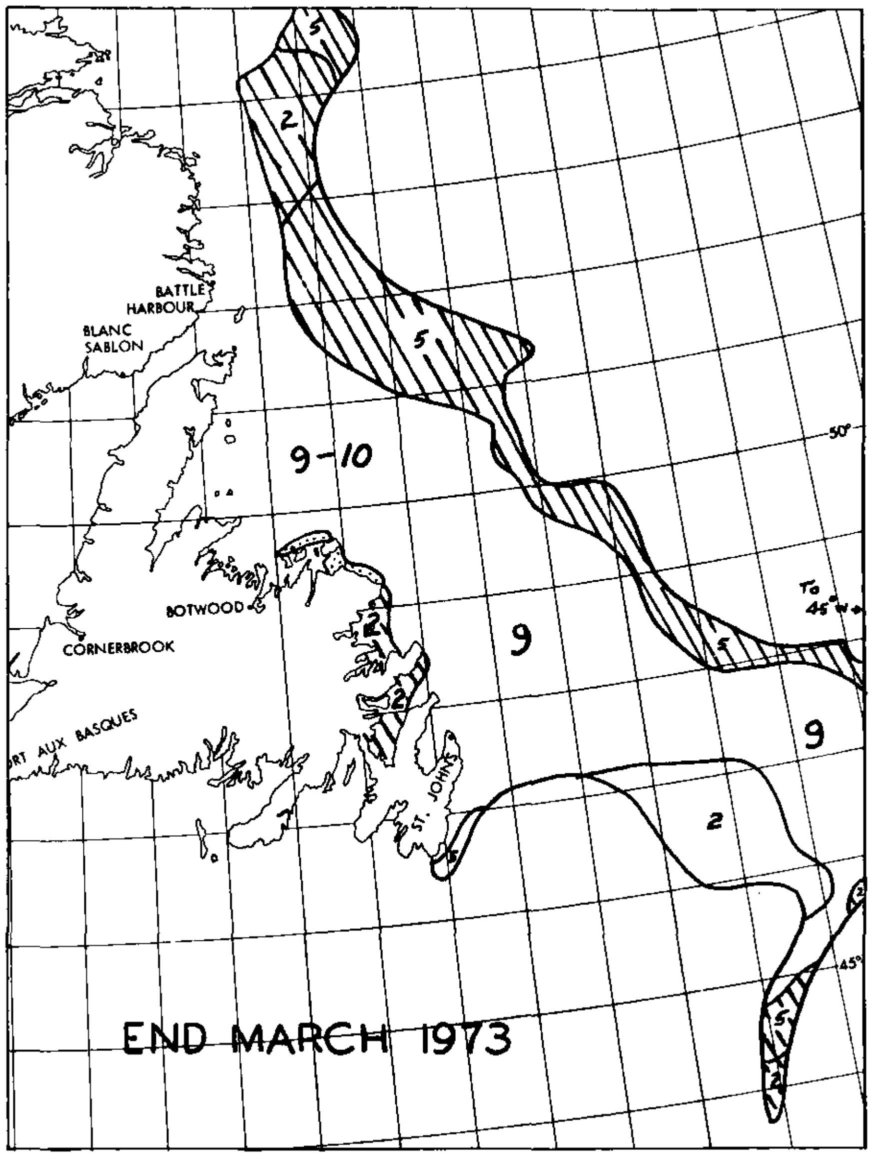

Fig. 8. Ice conditions at the end of March 1973.

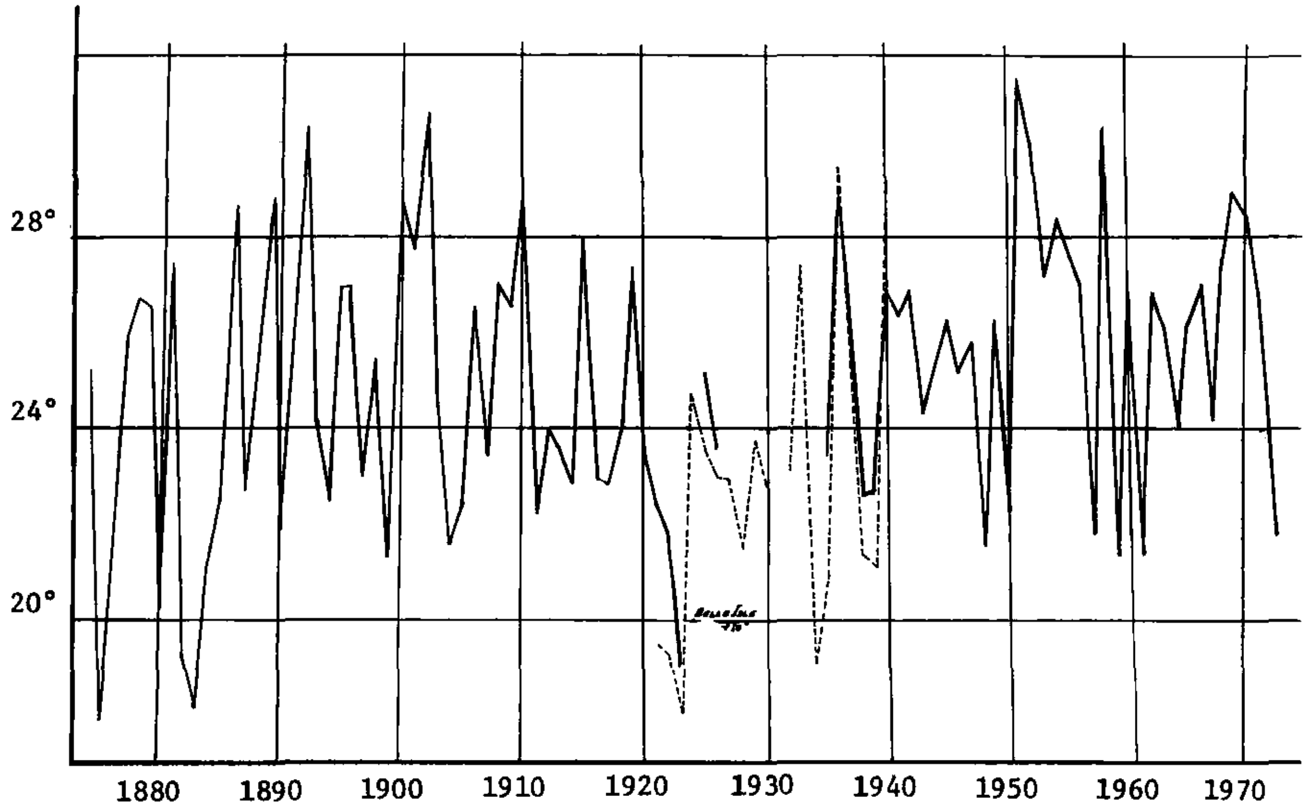

Fig. 9. Mean winter temperatures at St. John's, Newfoundland from 1 January to 31 March.

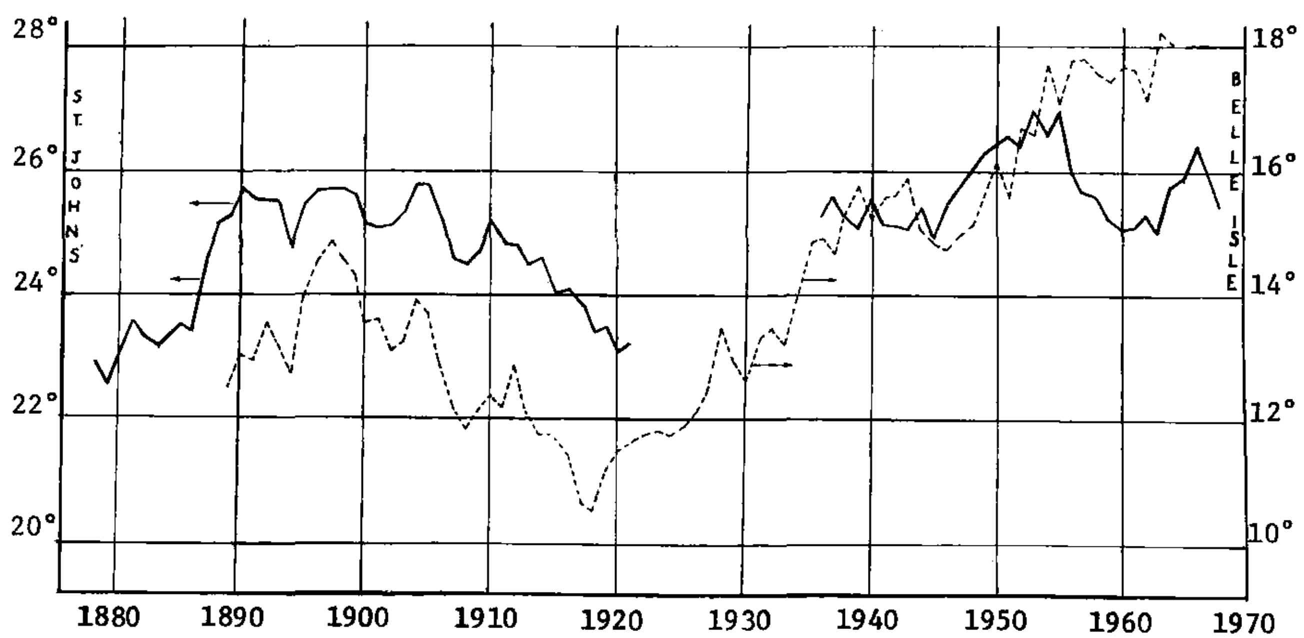

Fig. 10. Ten year running mean of winter temperatures from 1 January to 31 March.

A curve of this nature is very much a hodgepodge of spikes and valleys and it is difficult to detect any trends. To overcome this, running 10 year means have been calculated. On Figure 10 the resultant means are plotted with each plot being the mid point of each 10 year period. The solid curve is St. John's, the dashed is Belle Isle adjusted upwards by 10°F.

The trends are quite clear and quite similar - a cold period in the 1880's and another in early 1920's, then a rise until the mid 1950's and now in recent years a trend downwards again. At Belle Isle the minimum was reached earlier but the most recent drop had only just begun when the station was closed in 1970.

What then for the future? From the last peak to the subsequent trough there was a 20 - 25 year interval and on this basis one might (and the word "might" cannot be emphasized enough) expect a downward trend until about 1980, 20 - 25 years after the peak in the mid 1950's. But note that the warming trend on the preceding cycle took 20 years whereas the last one took 35. Does this mean a downward trend for the next 35 years? To predict either would be shear speculation. Cycles are interesting to examine but they are notorious failures in forecasting.

One final comment, however, on the question of trends (and for this one must return to Fig. 9). Note that even in the 1920's when the running means were near their minimum there can still be winters like 1919 which was even warmer than 1960 which was given as an example of a good winter.

Relationship Between Ice Cover and Fishing Operations

As stated previously, Fig. 4 is a mean ice chart showing percent of time the ice is present at the end of March over a 10 - 12 year period. On Fig. 4 ice concentrations are also noted - the black figures in the center of each square. If it is feasible to fish in an ice cover of 5 - 6 tenths and if one can plan to operate in areas where there is only a 50% probability of encountering ice, then the limit of operations remains well to the north of Newfoundland. Even in March the outer limits of the pack can nearly always be penetrated and fishing is rarely as restricted as Fig. 4 would lead one to believe.

A point related to ice concentration is that when the pack is diverging because of offshore winds, its concentration in the outer edges is usually in the 4 - 7 tenth range. On the other hand, when it is converging and is compressed against the shore by east and northeast winds, although concentrations are very high, most of the northern fishing banks are completely outside the ice. It would seem, therefore, that fishing off Newfoundland's east coast in winter requires sturdy vessels operated by men who have an understanding of ice behaviour and who keep up to date with ice and weather forecasts so that they can determine how the wind and temperature will affect the ice in their own area. In conclusion, it would appear that some form of winter fishing operation should be possible in what are normally taken for granted as being ice-covered waters.

Notes on the Time-Space Variations in the Features and Dynamics of the East Greeland Pack Ice

by

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Abstract

A classification scheme is presented to describe the southward moving East Greenland pack ice regime. Zone I, the outermost, is defined as the most dynamic. Here alternate offshore winds, quiescent periods, onshore winds, fragmentation by swells, melt by advection into warmer waters and vertical motions between the cold Arctic and warm Atlantic water masses cause highly variable pack ice features. Vast quantities of ice are frequently created by deformation resulting from violent onshore winds following the quiescent periods when large scale new ice formation has occurred. On the other hand, following periods of offshore winds, equally vast (thousands of square miles) quantities of ice are melted by advection into warm water, thus profoundly affecting the density structure of the water mass. A second, middle zone, represents the more normal southward, and accelerating, velocity field of predominantly multi-year ice emanating from the distant central portions of the Arctic Ocean. Movements along this "Zone II" path have been demonstrated by the manned drifting stations SP-1 (USSR) and ARLIS II (US) trajectories years ago. The final major zone is that near the coast line. It is usually characterized in summer by largely ice free shore leads; in the winter relatively flat fast ice, attached to the shore, prevails. Scattered throughout this innermost zone is a relatively high frequency of icebergs and glacial fragments. Along the edges of the major zones areas of strong shear evidenced by much deformed ice and fracturing are frequently apparent.

Finally if ice forecasters are drawing composite maps of surface atmospheric pressure averaged over several days a "col" situation sometimes occurs. Such an occurrence in the velocity field interrupts the normal north to south drift, and east-west oriented leads up to 10 miles wide may result.

Introduction

The East Greenland pack ice, for many reasons, is considered unique and singularly important among those ice regimes that comprise the sea ice of the Arctic Basin and its marginal zones. This area, at the season of maximum coverage, stretches from the Greenland Sea between northeastern Greenland and West Spitzbergen, along the entire eastern coast of Greenland, reaches the southernmost tip of Kap Farvel and continues beyond for as much as several hundred miles upward along the southwestern coast. Here, documented speeds in the flow of ice are up to four, and more, times greater on the mean than is the case in the Central Arctic Basin waters. From a global heat balance point of view, this drift stream of ice and Arctic surface water represents the major efflux zone of water, ice and heat outward from the central polar pack ice regions.

The East Greenland Pack Ice Regime

Figure 1 presents schematically the unique aspects of the East Greenland ice regime. In Fig. 1, three major zones are described. Zone I represents the most dynamic of the three, especially from the point of view of its being subject to nearly instantaneous response to wide variations in wind speed and direction. Its width varies in direct proportion to changes in the intensity of the offshore and onshore components of the prevailing northeasterly winds. The width of Zone I is between 0 - 120 nautical miles; usually, however, it ranges between 20 to 30 (see below). Zone I may be thought of as an "Ice Factory". With offshore winds huge quantities of new, first-year and sometimes, multi-year ice are advected into warmer waters where they are very quickly melted. This destruction is believed to be brought about primarily by the warm water masses that usually lie in direct juxtaposition to cold masses along the ice edge, line AA^1.

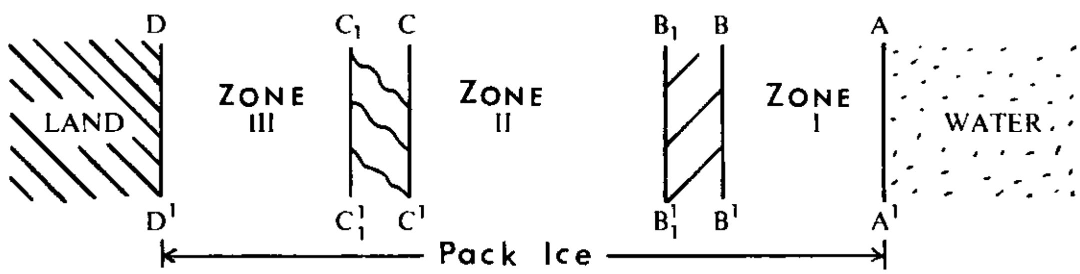

Fig. 1. Schematic diagram of East Greenland pack ice

The normal storm track trajectory in the area is northeastward running parallel to the ice edge. Frequently sharp reversals in wind direction are interspersed with one to three day periods of relatively stagnant or motionless conditions from the point of view of air stress. In such quiescent periods, ice forms quickly in the very shallow, cold, low salinity surface water layer caused by the previously described meltings. Thus in the mid-winter months (December - March, inclusive) thousands of square miles of new ice are frequently formed. If, following the quiescent period, sharp increases in the onshore components of ice drift occur, compaction, crushing and deformation of this new ice results. Consequently the ice edge is moved toward or into the position BB^1.

Numerous sporadic occurrences of this phenomenon in any month where air temperatures are below the freezing point of sea water (Approximately 28.5°F) result in a secondary belt or zone represented in Fig. 1 by the parallel lines BB^1 and $B_1B_1^1$. This region of intensively ridged and hummocked ice has only recently been recognized as an important occurrence which may have profound effects on acoustical propagation and ambient noise as well as upon surface ship sea ice penetration. This BB^1 - $B_1B_1^1$ zone varies widely in time and space throughout the East Greenland regions from a few to ten or more miles across; a modal width however is probably between one and three miles. Thus, after intensive, sustained onshore ice drift, Zone I might be completely obliterated and vessels approaching the ice would encounter a sharp boundary comprised of heavy, densely concentrated ice.

Another mechanism, not present in the Central Arctic Basin, must be described. In Zone I long-period swells often occur. These are generated by the cyclones described above and follow a fetch directly into the pack. It is possible that they contribute significantly to the confused surface topography of the ice in the zone represented by BB^1 - $B_1B_1^1$. These swells not only play a very important part in breaking the new Zone I ice into pancake and other small ice forms but, at the same time, they contribute significantly to the severe noises which so frequently have been reported by submarines traversing this region. The exact physical understanding of this mechanism is only now being studied, mainly through the ARPA sponsored marginal ice zone work under the direction of Dr W.K. Lyon, Arctic Submarine Laboratory, Naval Underwater Center, San Diego (ASLNUC). In any evaluation work of weapons systems, the fetches and durations of swells affecting Zone I and the other components of the East Greenland Drift Stream can be documented and studied much more readily then is the case in the central Arctic Basin or other marginal seas. This is so because of the excellent network of surface air pressure reporting systems located at 150 mile intervals along the entire East Greenland coast and by the relatively good coverage provided by stations on Spitzbergen, Jan Mayen, Iceland and the ocean weather station, ALFA.

Zone II, in Fig. 1, represents the generally widest and most easily described feature of this regime. In this area the predominantly multi-year ice floes move steadily southward. Mean monthly velocities are approximately 8nm/day in the northernmost portions of the Greenland Sea and increase gradually to a mean monthly velocity of 11nm/day in the vicinity of the Denmark Straits. Daily speeds of ice drift in Zone II have been known to reach 1-1/2 knots (30nm/day). The zone frequently displays widths of 150 - 200, or more, nautical miles.

Zone II has ice characteristics that are very similar to those prevailing in the Central Arctic Basin with a few exceptions. Because of the natural divergence caused by increased velocities as one proceeds southward, large leads and polynyas exist with a much greater frequency than in the central Arctic Basin. These features frequently display diameters on the order of magnitude of miles - and even ten's of miles.

Documented proof of the character of Zone II has been provided by the Russian station SP-1 and the USN station ARLIS II as well as by the earlier observations of buoys, ship wreckage, etc. Southward of Scoresby Sound, latitude 70°, the summer East Greenland ice in Zone II is quite different from that found in most of the central arctic regions. The only ice that survives the July - September period of melting is a mixture of fragmented remnants of severely ridged pressure ice from zones $BB^1 - B_1B_1^1$ and $CC^1 - C_1C_1^1$ and hummocked remnants of multi-year ice from zone II. The first year ice and level portions of multi-year floes have completely disintegrated at this time leaving only the thickly compacted pressure ice. In the southern Greenlandic coastal waters this ice has been uniquely termed "Storis".

Zone III is characterized by, in the winter months from December through April inclusive, relatively flat shore-fast ice extending from the coast seaward approximately to the ten fathoms line. Interspersed within this ice are significant numbers of icebergs, bergy bits and growlers. Data on which to base any quantitative description of the occurrence of these relics from the Greenland ice cap are much too sparse. It can only be said that the northeasterly winds and prevailing currents keep those bergs and glacial fragments confined generally to Zone III. However, a sprinkling of these glacial phenomena occurs also in Zones I and II and, on occasions, for distances of many hundreds of miles to the seaward of the ice edge, line AA^1. The frequency of iceberg calving and their presence in Zone III increases markedly at the time following the spring freshet. After September a gradual lessening in the number of icebergs within Zone III occurs.

In the June period the fast ice zone, which, because of the bathymetry, varies between 5 - 40 miles, generally disintegrates quickly as a result of the warming influences caused by the "spring freshet" along the edge of the ice-cap-dominated Greenlandic coastal regions. By mid-July Zone III, which in winter consists mainly of first-year ice, is usually obliterated.

The same - but with lesser intensity and frequency - factors of alternate offshore-onshore wind stress discussed earlier result in another severely ridged zone characterized by $CC^1 - C_1C_1^1$ in Figure 1. When the onshore component occurs in all but the summer seasons, compacted, ridged and hummocked ice forms result. With offshore stresses this same region is marked by a "flaw lead". This lead varies from series of tiny cracks to completely open or newly refrozen regions having a width of up to ten or more miles.

The Wind Stress Pattern

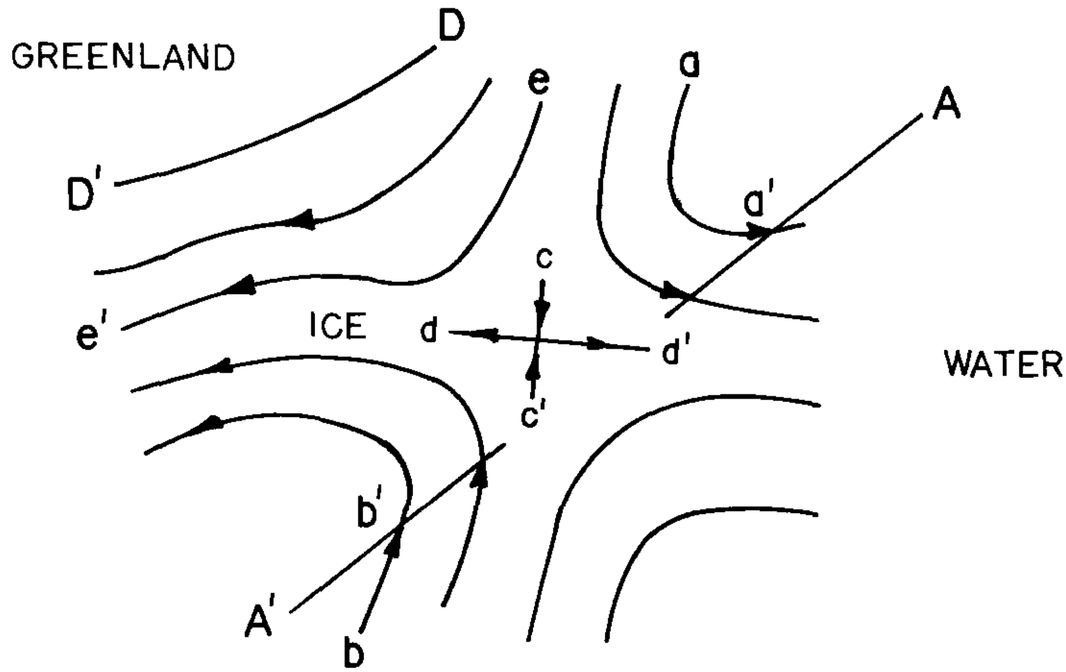

Fig. 2. Schematic wind stress pattern on East Greenland pack ice

Figure 2 describes a typical situation which characterizes the wind stress field of the East Greenland Drift Stream. It also serves to illustrate various types of situations that sequentially occur in the East Greenland Drift Stream. In this figure AA^1 again represents the outer ice pack edge and DD^1 represents the coastal boundary. The offshore winds that cause large scale melt and disintegration are represented by the stream line aa^1; the onshore stream lines at the outer pack edge and in the coastal shore are represented by bb^1.

The col situation, as illustrated in the center of Fig. 2, occurs frequently. In a case such as this, near zero motions occur in areas ten's of square miles between regions displaying the offshore and onshore drift. Effectively, a complete separation of the normal southernly flow of pack ice may thus result. In Fig. 2. cc^1 and dd^1 represent conditions in this col area where convergence exists along one axis and divergence along the other; at the same time strong southward drift, ee^1 is occurring in Zones II and III while weak variable motions are found along the outer ice pack edge, ff^1. Sequential examination of daily weather maps will reveal a variety of the components of the situation shown in Fig. 2. happening alternately.

Not shown but frequently occurring in the East Greenland Drift Stream is the situation created by intensive storms. These storms sometimes produce hurricane force winds with accompanying motions and deformations in the ice of an intensity rarely experienced in the central Arctic Basin and many of the other marginal seas. Since small floes get into equilibrium motion with the wind much more quickly than larger floes, speeds of 2 knots, (48nm/day) and more may result from these hurricane-speed winds; no measurements of such Zone I type movements have ever been reported in East Greenland waters. Soviet, Japanese and Canadian investigators on the other hand have measured such individual floe movements in low ice concentrations by coastal radar, but only in the marginal seas, not east of Greenland.

Conclusion

In conclusion, the ice in the East Greenland Drift Stream is probably the most dynamic of all Northern Hemisphere ice regimes. Experiments in its dynamic behaviour must take this variability, together with exceptionally adverse weather conditions, into account.

Outline of Present Sea Ice Services in Japan

by

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Abstract

It is well known that the Northwest Pacific Ocean and the Okhotsk Sea are good fishing grounds. On the other hand, fisheries in these sea areas are affected by the tendency to form sea ice in the winter season.

A brief outline of the present sea ice services in Japan are presented including observation systems, ice information messages and assessment of user requirements for ice data.

Introduction

In the seas neighbouring Japan, sea ice occurs in the Okhotsk Sea, the Northwestern Pacific Ocean and the Northern Japan Sea. The Okhotsk Sea coast of Hokkaido is icebound every winter and shipping ceases. The period from December to May is the normal ice season. It is interesting that this sea ice phenomenon occurs in such a middle latitude area and it owes its presence to the winter monsoon circulation working in combination with cold seas of low salinity.

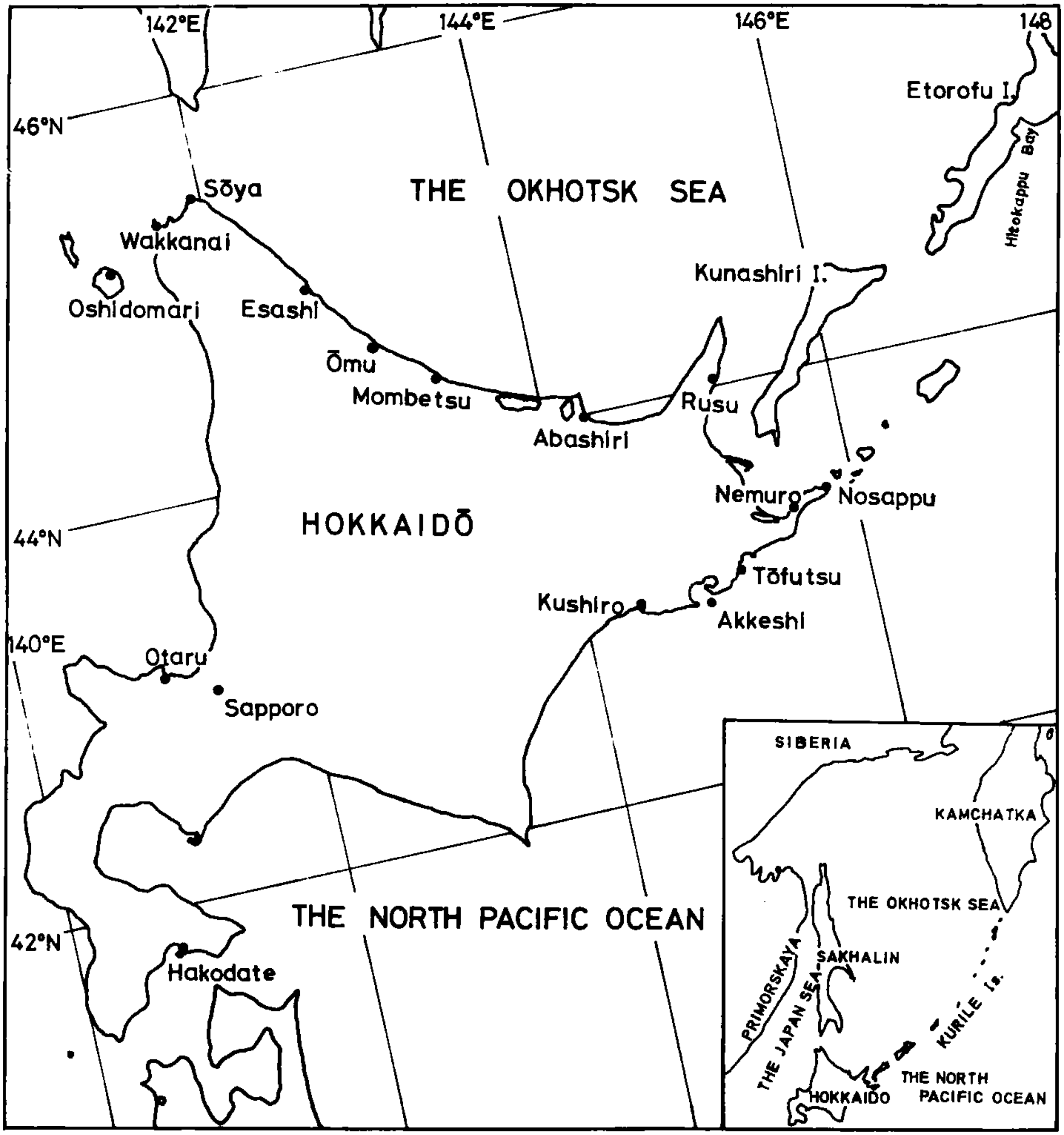
Growth of fast-ice on the coast of Hokkaido is not extensive. Therefore pack ice is the predominant feature.

Daily ice observations have been carried out by shore stations under the control of two governmental agencies: the Japan Meteorological Agency (J.M.A.) and the Maritime Safety Agency (M.S.A.) of the Ministry of Transportation. In addition, several patrol ships of M.S.A. take part in the observational program and aerial ice reconnaissance flights are carried out by the J.M.A. in co-operation with the National Defence Agency (N.D.A.) as well as by M.S.A. alone in particular circumstances. Also, the Institute of Low Temperature Science of Hokkaido University established a "Sea Ice Research Laboratory" which set up a radar observation network at Mombetsu in 1967.

Routine Coastal Observation

There are seven weather stations of J.M.A. taking ice observations at 1000 JST (Wakkanai, Kitamiesashi, Omu, Mombetsu, Abashiri, Nemuro, Kushiro). Eleven Maritime Safety stations and lighthouses of M.S.A. take observations at 0900 JST (Oshidomari, Wakkanai, Soyamisaki, Mombetsu, Notoromisaki, Abashiri, Nemuro, Nosappumisaki, Rausu, Tofutsumisaki, Akkeshi).

The ice data are transmitted by teletype or telephone to the Sapporo District Meteorological Observatory (S.M.O.), the Hakodate Marine Observatory (H.M.O.) and the 1st Regional Maritime Safety Headquarters (M.S.H.).



Map showing locations refered to in text.

Observations from Ships

Patrol ships of M.S.H. cruise in the neighbourhood of ice areas and observations of ice conditions are transmitted to the Maritime Safety stations by wireless. The two Japanese icebreakers Fuji and Soya, are not available for ordinary ice observations.

Aerial Observation

Ice reconnaissance in co-operation with J.M.A. and N.D.A. is carried out as follows:

Flights of Neptune P2V,J (Maritime Self-Defence Force) are made about 25 times in a season. The flights follow three courses: a) northeast of Hokkaido and east of Sakhalin, in the periods of pack ice approach and retreat, b) southeast of Hokkaido and the southern Kuril Islands, in periods when pack ice drifts into the North Pacific Ocean, and c) around Hokkaido, in the dominant periods. Flights of jet aircraft (Air Self-Defence Force) and Cessna (Land Self-Defence Force) are made about 8 and 10 times. The jet flights cover the Okhotsk coast of Hokkaido and the Cessna, the eastern coast of the island. During these reconnaissance flights, sea ice charts are made by sketching, photogrammetry and radar observation from the air. Additionally, as the need arises, M.S.A. carries out aerial ice observations using Beachcraft and YS-11 aircraft.

Other Services of Ice Data

APT data from the USA meteorological satellite ESSA and NOAA, data from broadcasts of USSR coastal hydrographic observations and maritime meteorological observations received by J.M.A. are used to provide information on sea ice conditions in the Okhotsk Sea, the Northern Japan Sea and the Bering Sea.

Ice Information Messages

Local meteorological offices issue sea ice forecasts or sea ice information daily or on special occasions for the sea area under their respective responsibility. The messages are based on ice data collected from various sources. In addition, the messages are transmitted to the general public and ships by commercial television and radio stations and by the fishery radio stations.

In 1971, J.M.A. began a facsimile broadcast of 5-day mean sea ice charts based chiefly on the APT data from ESSA-8. Included on the charts is the surface temperature distribution of the Okhotsk Sea and ice data from the radar network at Mombetsu, Abashiri and Esashi.

The ice information of M.S.A. is issued by the Ice Information Center of M.S.H. and is also transmitted to ships from fishery radio stations and from the standard broadcasting stations. The information center is located in the 1st Regional Maritime Safety Headquarters.

In Japan the service of long range sea ice forecasting was started in 1960 on trial by H.M.O. and since 1966 has been carried out as routine work in co-operation with H.M.O. and S.M.O. It predicts the time of arrival or departure and the expected conditions of sea ice in the Okhotsk Sea.

Sea Ice Studies

Detailed analyses are made of ice in the Okhotsk Sea and its annual variation. The interaction between sea ice and meteorological and oceanographical phenomena are studied by research workers of J.M.A. In 1970, for example, work began on a project named "Large-Scale Sea-Ice, Sea Temperature, Salinity, and Weather Interrelations and their Significance for Long-Range Forecasting" under the Japan-U.S. Co-operation Science Program.

Members of the Institute of Low Temperature Science carry out research on the physical and chemical properties of sea ice and observe natural phenomena in shore-fast ice. Their studies of sea ice movement using a radar network are noteworthy.

It should be recognized that Japan also participates in sea ice studies in the Antarctic.

Ship Damage by Sea Ice

A summary of ship damage by sea ice in recent years is provided below. The summary is based on data obtained from the 1st Regional Maritime Safety Headquarters.

Years	1966	1967	1968	1969	1970
Number of ships[a]	22	19	7	6	18
Total tonnage	647	1492	257	234	2265
Beset	14	15	2	3	14
Holed	2	1	0	0	0
Propeller trouble	3	1	1	1	2
Engine trouble	1	0	2	0	0
Stranded	0	0	0	0	0
Persons died or lost	0	0	0	0	0

[a] The ships are mostly small or medium size

Assessment of User Requirements for Ice Data

Present ice message services from the J.M.A. and the M.S.A. are considered adequate for users operating in the Hokkaido vicinity. But in recent years the number of fishing vessels and other ships navigating far from Japan in the waters affected by sea ice is increasing. For example, there are increased numbers of cod fishing boats in the seas around the Kuril Islands and the Kamchatka Peninsula, of herring fishing boats in the northern part of the Okhotsk Sea, of crab fishing boats in the waters west of the Kamchatka Peninsula and in the eastern part of the Bering Sea and of lumber carriers on the Sakhalin or the Primorskaya route. The sea ice information services for such areas are not sufficient, because ice observations are insufficient in these areas. Further the transmission system of the information has not been established.

Unfortunately, in March 1972 a tragic shipwreck caused by pressure of pack-ice occurred in Hitokappu Bay of Etorofu Island. Eight cod fishing boats were sunk and 30 persons died. This incident aroused public opinion which demanded an improvement in the sea ice observation programme and information services. As a result, the area and frequency of aerial ice reconnaissance has been extended and careful consideration is being given to finding ways to improve the sea ice forecasting system.

Long range sea ice forecasting services provided by the Hakodate Marine Observatory and the Sapporo District Meteorological Observatory are proving to be useful for navigation, fisheries and their related industries. Continuation of these services is demanded.

Publications

Over the years, Japan has published a great deal of sea ice information. A sample of the types of publications available is given below. Japan is willing to make these publications available for users in various fields and hopes that the international exchange of operational messages and ice data for research purposes will quickly develop.

1. *Outline Report of Sea Ice Conditions* (issued every ten days by H.M.O.)

2. *Ten-Day Report of Sea Ice* (issued by 1st R.M.S.H.)
   The two above are regular brief reports of sea ice conditions in waters near Hokkaido.

3. *Technical Report of the J.M.A.* (special editions of sea ice)
   Detailed ice conditions until 1965 are described and papers for study of sea ice are included.

4. *The Results of Marine Meteorological and Oceanographical Observations* (issued yearly by J.M.A.)
   Brief reports of ice conditions after 1966 are described with ice charts and results of coastal sea ice observations are tabulated.