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ARCTIC ICE FLUCTUATIONS IN JULIANEHAAB BAY 1901–1937

BY

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In the course of an investigation into the occupational developments in the Julianehaab District (Meddelelser om Grønland, Bd. 131, 7) it turned out that the conditions governing the occupations of the population varies considerably with the occurrence of arctic ice. It has therefore been a matter of much interest to Greenland's economy to endeavour to ascertain the causes of the great fluctuations in the occurrence of this arctic ice from year to year. We are aware that the solving of this problem is beyond our power, but believe that with the present investigation we have made a contribution which we hope others will improve upon.

For the purpose of the investigation we borrowed material from the Danish Meteorological Institute and from Captain W. NELLEMOSE (The International Council of Exploration of the Sea); we are grateful for this and for advice and guidance kindly extended to us by Mr. H. THOMSEN M.A. and Captain W. NELLEMOSE. Finally, we thank Mr. OLDENDOW, Governor of Greenland, for his interest and kindness with the aid of which we were able to complete the present report.

Copenhagen, April 1943.

I.

The arctic ice is formed in the polar basin, where the sea freezes over in winter, and the succeeding summer is not warm enough to thaw the enormous quantity of ice then formed. This ice lies in great floes or ice-fields and has been known to attain a thickness of up to 10 metres after the course of several winters. Some of this arctic ice drifts southwards with the East Greenland stream and in Denmark and Greenland is called "Storisen"[1]), and in Norway "Vestisen". It forms a belt along the east coast of Greenland, in widths that vary with time. As a consequence of the low temperature of the ice the climate on this coast is colder than in corresponding latitudes on the west coast (the annual average at Scoresby Sound is —7.0°, but at Godhavn —2.8°) (2). What arctic ice does not melt on its way along the east coast of Greenland goes with the Current round Cape Farvel and in the spring and summer months collects in Julianehaab Bay and its northerly surroundings, where a large part of it melts in summer.

The arctic ice is the home of large numbers of seals and also some polar bears, which by this means drift southwards with the ice from the breeding grounds in the northern regions. In this manner the arctic ice brings the hunting fields in the Julianehaab district additional game, and it also has considerable influence on the fisheries there.

II.

The oldest reports that have been preserved on the arctic ice date from about 1580 (3), but no regular observations on its occurrence are available until 1820, particularly the part of it that reaches Davis Strait.

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[1]) "Arctic ice", Danish "Storis".

This "Storis" is formed in the Polar Basin and, as a consequence of its being exposed to the frost of several winters, coupled with the thrusting of various floes one over the other in conjunction with falls of snow, it often acquires shapes and thicknesses that are beyond the power of even the strongest steady frost, as its melting from below will always prevent its thickness from increasing beyond a certain limit. The "Storis" encountered in Davis Strait will usually be at least two or three years old, having spent this period in drifting from its place of origin to the Strait (1).

These observations have been edited and published by Capt. C. I. H. Speerschneider on behalf of the Danish Meteorological Institute. In addition, every year the institute publishes a report on the ice situation in the polar basin and its surroundings, summarising all the available reports of the previous year. These publications have been used in compiling the following (4).

As it was a matter of great interest to follow the fluctuations of the occurrence of arctic ice, we have observed the quantities of it at a certain spot. We selected Julianehaab Bay for this purpose, conditions there being most perspicuous owing to the volume of traffic there being greater than anywhere else, with the result that most observations are taken there.

Since 1895 the Meteorological Institute's publications have every year contained five maps (one for each of the months of April, May, June, July and August) showing the quantity of ice. From these maps we have copied the outline of the ice on transparent paper (typewriting-paper), allowing the easterly limit to follow the meridian through Gape Farvel; the areas thus drawn were cut out, and all areas from the same year were weighed to an accuracy of $^1/_{10}$th milligram. The values found by weighing were employed as expressing the ice volume for the year and in Table 1 are shown in the first column for the period 1901 to 1938. It should be remarked that the arctic ice may be more or less closely packed within its limits, but this error was impossible to avoid and will scarcely have much bearing on the main result of the present investigation. In the second column of the same table we have introduced a sliding average for five years (the year in question, the two foregoing and the two succeeding years). This sliding average has been plotted into a coordinate system, in which the *X*-axis represents the period from 1901 to 1936 and the *Y*-axis the quantities of arctic ice.

Of these ice observations 80 per cent. lie within once the standard deviation, and 94 per cent. within twice; the year 1918, which lies outside three times the standard deviation, seems to be the exception, for conditions that year seem to have been particularly favourable to the arctic ice, or the ice was much scattered that year—the maps would seem to bear out the latter supposition. It may also be imagined that as the year 1917 was a disproportionately small ice year, most of the ice which should have gone adrift in 1917 was frozen up and did not break away till the following year; in that way 1918 received a correspondingly disproportionate quantity. Moreover, as 1917 according to the curve of averages should have been a year with an abnormally large quantity of ice, this explains the oscillation of the ice curve. This theory is supported by the fact that in that year Svalbard had an abnormally low mean temperature, —12.5°, compared with the normal of —6.0°

Table 1. Arctic ice in Julianehaab Bay. 1901 to 1938.

Year	Quantity of Arctic Ice	Quinquennial average	Year	Quantity of Arctic Ice	Quinquennial average
1901........	15.0	..	1920........	36.6	27.2
02........	29.4	..	21........	17.8	20.8
03........	20.5	19.7	22........	16.4	21.1
04........	13.5	20.3	23........	12.2	17.3
05........	20.3	20.5	24........	22.4	15.6
06........	18.0	19.8	25........	17.5	15.2
07........	30.3	21.4	26........	9.7	15.4
08........	17.0	21.6	27........	14.2	13.2
09........	21.3	20.0	28........	13.2	13.2
10........	21.4	18.0	29........	11.6	13.2
11........	10.2	18.6	30........	17.2	11.6
12........	20.0	18.3	31........	10.0	12.9
13........	19.9	16.0	32........	5.8	11.7
14........	19.8	16.3	33........	20.0	10.3
15........	10.2	13.6	34........	5.6	10.7
16........	11.4	18.5	35........	10.3	11.6
17........	6.7	18.7	36........	11.7	11.1
18........	44.4	24.0	37........	10.4	..
19........	20.8	25.3	38........	17.7	..

for the whole period. It is also a fact that North Norway (Ingøya) in 1917 had the lowest mean temperature for the year in the whole of the period under review. The relation between arctic ice and climate in the Arctic Ocean will, however, be discussed in a later chapter.

The first column of the table of ice values shows that there were relatively big ice-years in 1902, 1907, 1918, 1920, 1924 and 1933. If we look at the second column (the sliding average) we find that the figures rise steadily from 1902, reach the peak in 1907, then fall till 1915, whereafter they culminate again in 1920. From that point of time it seems as if unusual factors had exerted their influence, as the curve falls smoothly until 1936. If we compare the observations in Table 1 with Speerschneider's these unusual factors seem even more evident. Speerschneider points out that the quantity of arctic ice varies from maximum to maximum in a period of sixteen or seventeen years. This agrees fairly well with our figures in the first part of the period, but not in the latter.

III.

Various theories have been advanced as to the causes of the fluctuations in the occurrence of arctic ice in more southerly waters: the entire c e-cap has been considered to be one great floe which sometimes drifts towards the Atlantic and causes severe ice years there and less severe at the Bering Strait, to drift back to the other side after some years and bring about a preponderance of ice in the Bering Strait and less ice in the Atlantic. Another theory is that the fluctuations in the occurrences are the result of the northward penetration of the warmer water from the Atlantic.

To test the latter theory it would be of interest to ascertain the temperatures in the Gulf Stream as compared with the occurrences of arctic ice.

In this connection it should be remembered that the Gulf Stream comes from regions in the vicinity of the Equator and runs northwards along the coast of America almost as far as Cape Hatteras; there it bends more to the east, loses speed and gains in width, so that it ceases to be a stream in the proper sense of the word. If nevertheless we continue to call it the Gulf Stream in the following, it is meant in the popular sense. The warm water from the Gulf Stream continues its way across the Atlantic, passes north about Scotland, up along the coast of Norway and loses itself in the polar basin. It would thus seem to be fairly logical to connect the temperature of the water moving northwards with the quantity of arctic ice that moves southwards.

It is best to consider the temperatures at a place where the whole of the north-bound stream can be surveyed. This is most feasible in the waters between the Hebrides and the Faeroes, through which practically the whole of the stream passes; in addition, this is an area of much traffic and consequently the place where most observations are made. The observations employed in the present work were collected from a plethora of meteorological reports from ships, got together and worked up by Capt. W. Nellemose and kindly placed at our disposal for the purpose of our investigation. The waters in question are divided into eight single-degree areas between lat. 58° and 62° N. and long. 6° and 8° W. The temperatures are those of the surface water in Celsius degrees. All temperatures for the same year in all the areas are calculated together to find the mean; it should be stated, however, that the months of December, January and February are not included, as there is only very slight traffic, or none at all, in some of the areas. For the same reason we have excluded the area in lat. 61° N. and long. 7° W. During the war of 1914—1918 the areas in lat. 58° N. were closed, and therefore it has been necessary to leave out the corresponding areas to the north for those years in order not to upset the average too much. Accordingly the temperatures for this 1914—1918 period must be taken with some reserve. It should also be remembered that the "mean temperature" given is employed as a basis for comparison, and owing to the omitted months cannot, of course, be looked upon as a valid mean annual temperature.

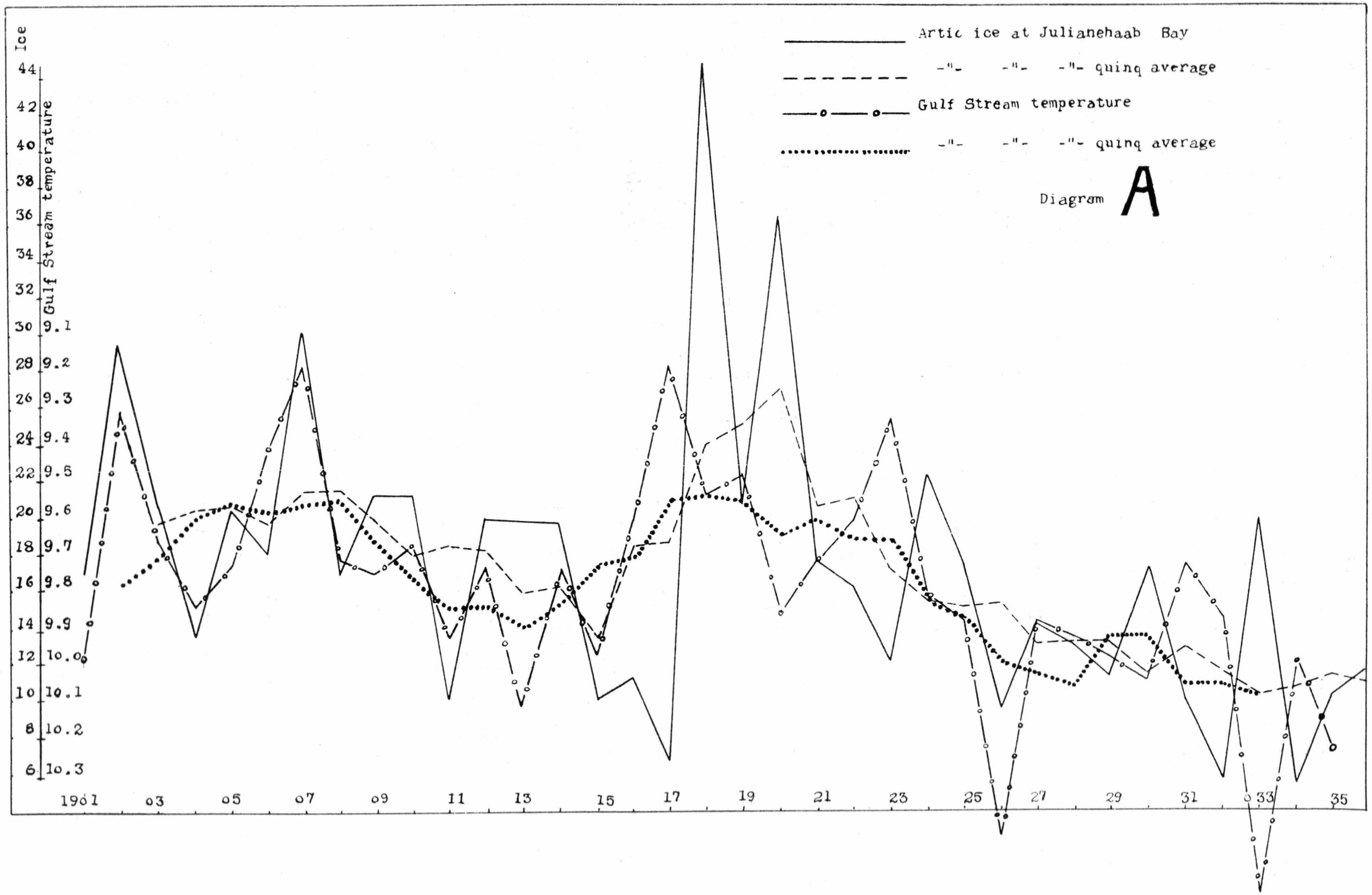
Table 2. Temperature of surface water between Hebrides and Faeroe Islands.

Year	Temperature	Quinquennial average	Year	Temperature	Quinquennial average
1900........	10.16	..	1918........	9.53	9.53
01........	9.98	..	19........	9.48	9.55
02........	9.32	9.79	20........	9.86	9.64
03........	9.67	9.71	21........	9.72	9.60
04........	9.84	9.60	22........	9.60	9.66
05........	9.73	9.57	23........	9.33	9.66
06........	9.43	9.58	24........	9.80	9.82
07........	9.18	9.56	25........	9.87	9.87
08........	9.72	9.55	26........	10.49	9.99
09........	9.76	9.65	27........	9.88	10.03
10........	9.67	9.76	28........	9.92	10.06
11........	9.92	9.84	29........	9.97	9.91
12........	9.73	9.83	30........	10.04	9.91
13........	10.11	9.89	31........	9.73	10.05
14........	9.74	9.83	32........	9.87	10.05
15........	9.97	9.72	33........	10.62	10.09
16........	9.60	9.70	34........	9.99	..
17........	9.17	9.55	35........	10.23	..

The temperatures are shown in the first column of Table 2, and from these we have worked out a sliding quinquennial average: Table 2, second column. Of these temperatures 74 per cent. are within once the standard deviation and 94 per cent. within twice.

IV.

If one would compare the observations comprised in Tables 1 and 2 it is best done by plotting the four columns in a diagram (Diagram A). In this diagram the X-axis expresses the individual years for all the figures, whilst the Y-axis, for the ice curve, shows the quantity of ice (the first column of measurements) and for the temperature curves, the temperature of the Gulf Stream when passing the line from the Hebrides to the Faeroes (the second column of measurements); it should be observed here that the temperatures have the lowest value uppermost (the curve is inverted).


Artic ice at Julianehaab Bay
-"- -"- -"- quinq average
Gulf Stream temperature
-"- -"- -"- quinq average
Diagram A
Ice
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
Gulf Stream temperature
9.1
9.2
9.3
9.4
9.5
9.6
9.7
9.8
9.9
10.0
10.1
10.2
10.3
1901
03
05
07
09
11
13
15
17
19
21
23
25
27
29
31
33
35

Whereas a comparison of the individual observations is somewhat difficult, a comparison between the quinquennial averages seems to reveal a distinct connection. This, however, becomes most clear when we compare the quantity of arctic ice in a year with the Gulf Stream temperature of the foregoing year. For both curves we find some increase in the first years, then a fall until about 1914, a rise until about 1919, whereafter both curves fall rapidly until the end of the period.

V.

These observations make it reasonable to essay a calculation of the connection between the two columns of figures.

For the purpose of determining the relation between the two groups of observations we have in Diagram B plotted points representing the relation between the Gulf Stream temperature (Y-axis) and the quantity of arctic ice (X-axis). As regards the correlation, the calculation has been made on the basis of the original annual values, the arctic ice of one year being placed in relation to the temperature of the previous year in the Gulf Stream. A direct observation seems to show that high temperatures in the Gulf Stream cause relatively small quantities of ice in the following year. If we try to calculate the relation as a straight line by the method of the smallest square we find according to the following equation:

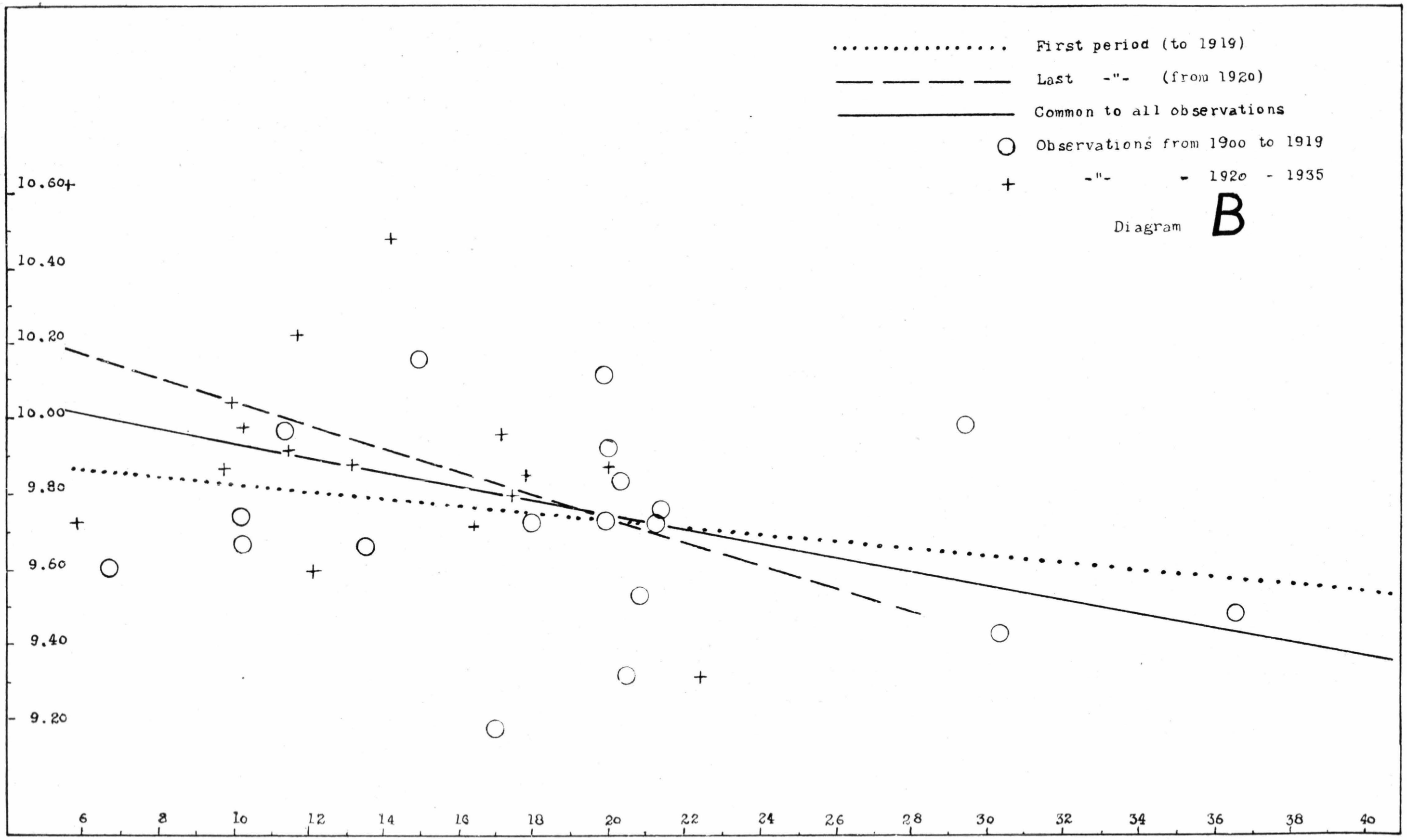
$$Y = \frac{X - 10.1248}{-0.01893};$$

where Y expresses the temperature observations and X the quantities of ice expected accordingly.

We then determined the expected quantity of ice in the year following a Gulf Stream temperature of 10° ($X = 6.6$) and following a temperature of 9.5° ($X = 33.0$). The line connecting these points is plotted in Diagram B as a continuous line. The correlation coefficient for this calculation is —0.43[1]).

However, it is not certain that the connection between the two sets of observations follows a straight line. As the relatively large quantities of ice occur in the first half of the period, we have in the same manner, as before calculated, the connection for both the first half (1901—1919, X_1 and Y_1) and the latter half (1920—1936, X_2 and Y_2).

[1]) Whereas the correlation coefficient above is calculated between the Gulf Stream temperature and the quantity of ice in the following year, we have also made a calculation for the same year; in this case the coefficient is —0.33.


First period (to 1919)
Last -"- (from 1920)
Common to all observations
Observations from 1900 to 1919
-"- - 1920 - 1935
Diagram B
10.60
10.40
10.20
10.00
9.80
9.60
9.40
9.20
6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

We have accordingly found the following points on the line for the first period:

$$Y_1 = \frac{X_1 - 9.9231}{-0.009481};$$

for $Y_1 = 9.85$ we have $X_1 = 7.7$ and
for $Y_1 = 9.6$ we have $X_1 = 34.0$.

For the last period we have:

$$Y_2 = \frac{X_2 - 10.3519}{-0.03057};$$

for $Y_2 = 10$ we have $X_2 = 11.5$ and
for $Y_2 = 9.5$ we have $X_2 = 27.8$.

On Diagram B the line for Y_1 (first half) is plotted as a dotted line and for Y_2 (last half) as a broken line.

On comparing the two lines it would seem as if the connection between the two sets of observations did not move as a straight line, but rather according to some logarithmic function. However, the observation material seems to be too slender to justify a logarithmic calculation.

The downward direction of the calculated lines indicates that, as suggested, there is fairly good inverted correlation. This seems to mean that there must be a connection between the Gulf Stream temperature observed and the quantity of ice in the subsequent year. Indeed, such a connection seems quite likely at first glance.

VI.

If we consider the two sets of figures in Tables 1 and 2 (first column) and the diffusion in Diagram B, it will seem reasonable to assume that the temperature of the Gulf Stream cannot be the sole cause of the fluctuations in the quantity of arctic ice; there must be other explanations. For example, the temperature of the air over the Arctic Ocean, wind conditions in the East Greenland stream (Arctic Current), the temperature of the Irminger Current, and finally, wind conditions in Julianehaab Bay.

Of these possibilities we have the means of examining the annual mean air temperatures for a number of years at several stations (5) on the edge of the Arctic Ocean and thus of making a comparison between these and the ice.

Furthermore, we have meteorological observations from Angmagssalik; but as that colony lies sheltered behind high mountains and in a deep fiord, the wind is subject to local influences; for this reason the observations are of little value for comparisons with the ice. On the other hand it is presumable that the wind conditions on the north coast of Iceland may provide some indication of the wind conditions in the area of the arctic ice. As regards the north coast of Iceland we have examined conditions on the island of Grimsey; for the Irminger Current we have observations made on the Selvogsbanki off Iceland (6); and for Julianehaab Bay we have meteorological observations at Nanortalik and Ivigtût. In the following four chapters we shall therefore examine the connection between the arctic ice, the mean temperature of the air in the Arctic Ocean, the wind at Grimsey, the temperature of the surface water at Selvogsbanki, and the wind at Nanortalik.

VII.

The air temperatures at the arctic stations are listed in the Norwegian meteorological annuals and have been lent us by the Danish Meteorological Institute. The temperatures at North Cape are shown

Table 3. Yearly average air temperature at North cape (Ingøya and Gjesværd).

Year	Average year temperature	Quinquennial average	Year	Average year temperature	Quinquennial average
1900........	0.9	..	1919........	1.9	2.12
01........	2.1	..	20........	3.7	2.68
02........	0.6	1.52	21........	2.7	2.86
03........	1.9	1.84	22........	3.3	3.06
04........	2.1	1.76	23........	2.7	2.86
05........	2.5	2.14	24........	2.9	2.74
06........	1.7	2.16	25........	2.7	2.56
07........	2.5	2.06	26........	2.1	2.60
08........	2.0	1.90	27........	2.4	2.54
09........	1.6	1.94	28........	2.9	2.66
10........	1.7	1.60	29........	2.6	2.80
11........	1.9	1.62	30........	3.3	2.86
12........	0.8	1.86	31........	2.8	2.92
13........	2.1	1.74	32........	2.7	3.20
14........	2.8	1.74	33........	3.2	3.12
15........	1.1	1.68	34........	4.0	3.14
16........	1.9	1.62	35........	2.9	3.40
17........	0.5	1.44	36........	2.9	..
18........	1.8	1.96	37........	4.0	..

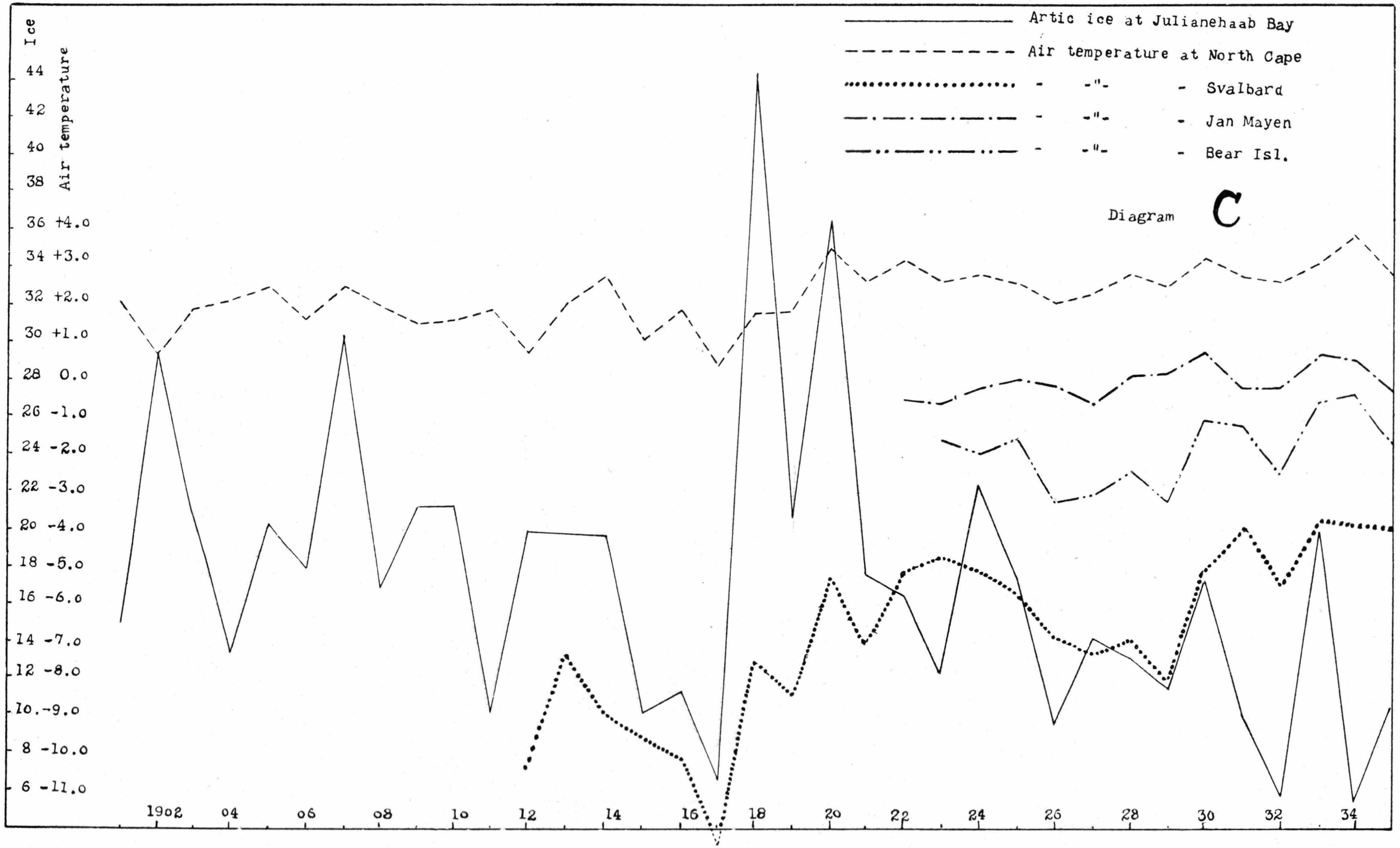

Artic ice at Julianehaab Bay
Air temperature at North Cape
- -"- - Svalbard
- -"- - Jan Mayen
- -"- - Bear Isl.
Diagram C
Ice
Air temperature
44
42
40
38
36 +4.0
34 +3.0
32 +2.0
30 +1.0
28 0.0
26 -1.0
24 -2.0
22 -3.0
20 -4.0
18 -5.0
16 -6.0
14 -7.0
12 -8.0
10.-9.0
8 -10.0
6 -11.0
1902
04
06
08
10
12
14
16
18
20
22
24
26
28
30
32
34

Table 4. Year's average air temperature at three meteorological stations in the Arctic Ocean.

Year	Svalbard		Jan Mayen		Bear Island	
	Year's average temp.	Quinquennial average	Year's average temp.	Quinquennial average	Year's average temp.	Quinquennial average
1912	—10.4	..	..	..	..	..
13	— 7.4	..	..	..	..	..
14	— 8.9	—9.28	..	..	..	..
15	— 9.6	—9.72	..	..	..	..
16	—10.1	—9.74	..	..	..	..
17	—12.6	—9.64	..	..	..	..
18	— 7.5	—8.78	..	..	..	..
19	— 8.4	—8.16	..	..	..	..
20	— 5.3	—7.46	..	..	..	..
21	— 7.0	—6.10	..	..	..	..
22	— 5.1	—5.44	—0.4	..	..	..
23	— 4.7	—5.52	—0.5	..	—1.5	..
24	— 5.1	—5.48	0.2	—0.14	—1.9	..
25	— 5.7	—5.92	0.1	—0.18	—1.6	—2.24
26	— 6.8	—6.36	—0.1	—0.04	—3.2	—2.42
27	— 7.3	—6.94	—0.6	—0.02	—3.0	—2.68
28	— 6.9	—7.02	0.2	0.12	—2.4	—2.56
29	— 8.0	—6.24	0.3	0.12	—3.2	—2.16
30	— 5.1	—5.88	0.8	0.22	—1.0	—2.06
31	— 3.9	—5.26	—0.1	0.32	—1.2	—1.68
32	— 5.5	—4.44	—0.1	0.38	—2.5	—1.10
33	— 3.8	—4.22	0.7	0.18	—0.5	—1.20
34	— 3.9	—4.32	0.6	0.06	—0.3	—1.28
35	— 4.0	—3.74	—0.2	0.10	—1.5	—0.76
36	— 4.4	..	—0.7	..	—1.6	..
37	— 2.6	..	0.1	..	0.1	..

in Table 3. Here the stations are Ingøya for the first period and Gjesværd for the latter, the meteorological station having been moved about 10 geographical miles. Both stations lie close to North Cape. Table 4 contains information from the stations at Svalbard (Green Harbour), Jan Mayen and Bear Island.

If now we compare the ice curve with the curves for the temperatures in the Arctic Ocean (Diagram C), we may first examine the extremes of the temperature curves and shall see that the years 1906, 1915, 1917, 1926, 1929 and 1932 had a low mean temperature and little ice. For all these years we are able to point out two more common features: all the years are followed by years with a higher mean temperature and with much ice in Julianehaab Bay; it should be noted, however, that the years 1902 and 1912 give the opposite picture. Again, 1919 and 1921 are different, but here we are in a period when the mean temperature for the localities examined is rising rapidly. Accordingly, for these years of 1902, 1912, 1919 and 1921 there must have been other causes having paramount influence on the quantity of ice. If we were to draw a conclusion from these observations, all we could say would be: When the mean annual temperature of the air in the Arctic Ocean is low, it is possible to some extent to reckon with small quantities of ice; if the temperature rises to any marked extent in the following year, a good deal of ice may be expected that summer. If, furthermore, we consider the oscillations of the ice curve in relation to the maxima on the temperature curve, we find that with one exception the years of much ice coincide with high average temperatures at the localities examined. This might also suggest that the quantity of ice which in a given year breaks loose and starts drifting, is in direct proportion to the temperature in the Arctic Ocean.

The series of mean temperatures in the Arctic Ocean also provide information as to a change in the climate[1]) which is relatively fairly considerable. For example, for North Cape (Table 3) we see that the mean temperature for the first five years is $+1.5°$ and for the last five years $+3.4°$. Here the mean temperature has risen by about 2 degrees between the two quinquennial periods. At Svalbard the same thing becomes still more evident, for the mean temperature for the first five years is $-9.28°$ and for the last five years $-3.74°$, which means a rise of 5.6 degrees for this locality between the two periods. If we take the value for the first decade to the last one the rise at the North Cape was 1.1 and at Svalbard 3.9 degrees.

The mean temperatures for Jan Mayen and Bear Island are also listed, but for a shorter period of years. For Bear Island the rise from the first to the last five year period is 1.4 degrees. For Jan Mayen it is 0.2°; this is too small to be of any significance, but taken along with the other rises it is not without value, as they all signify a considerable amelioration of the climate at these places. In the records of ice occurrences this milder climate is perceptible in reduced quantities of ice in Julianehaab Bay.

VIII.

For the purpose of learning something of the influence of the wind on the ice during its passage from the Arctic Ocean to Julianehaab Bay

[1]) Climate in this connection means the temperature within the period of the investigation. More profound researches into climatic changes have been made by several Danish and foreign authors (7).

we have examined the meteorological records for Grimsey Island (8) and the colony of Angmagssalik (9). The Icelandic island of Grimsey lies north of Øfjord and about 25 miles from land, so that it should be uninfluenced by local disturbances. Grimsey is about 150 miles from the Arctic Current and may be judged to have in part the same wind conditions as the locality in the Arctic Current that lies nearest the island. It may also be mentioned that in the principal ice months (especially May and June) the arctic ice sometimes spreads so much that the sea around the island is covered with it. Thus there seems to be a basis for a comparison between the wind frequency at Grimsey and the occurrence of the arctic ice.

The wind observations at the island's meteorological station are taken three times a day, or 1095 observations in the course of a year, the direction and strength being noted. From this material we have calculated the percentage of observations falling on north, northeast, east and southeast respectively, and also south, southwest, west and northwest. We consider the first group (from north to southeast) as being favourable, propitious, for ice drift and consequently for the quantity of ice in Julianehaab Bay, and the last group (from south to northwest) as unfavourable, inhibiting, or dispersing. The observations "calm" are considered as neutral in this connection. We have had to disregard the strength of the wind, as there is a period of eight years in which the strength was not recorded. For the years for which we have records, however, the mean wind force lies between 2.0 and 4.5 (Beaufort scale), one year 5.4 (1924). The results indicating the difference between the wind frequencies favourable and unfavourable to ice accumulation are shown in Table 5, second column; the quinquennial averages are given in the third column.

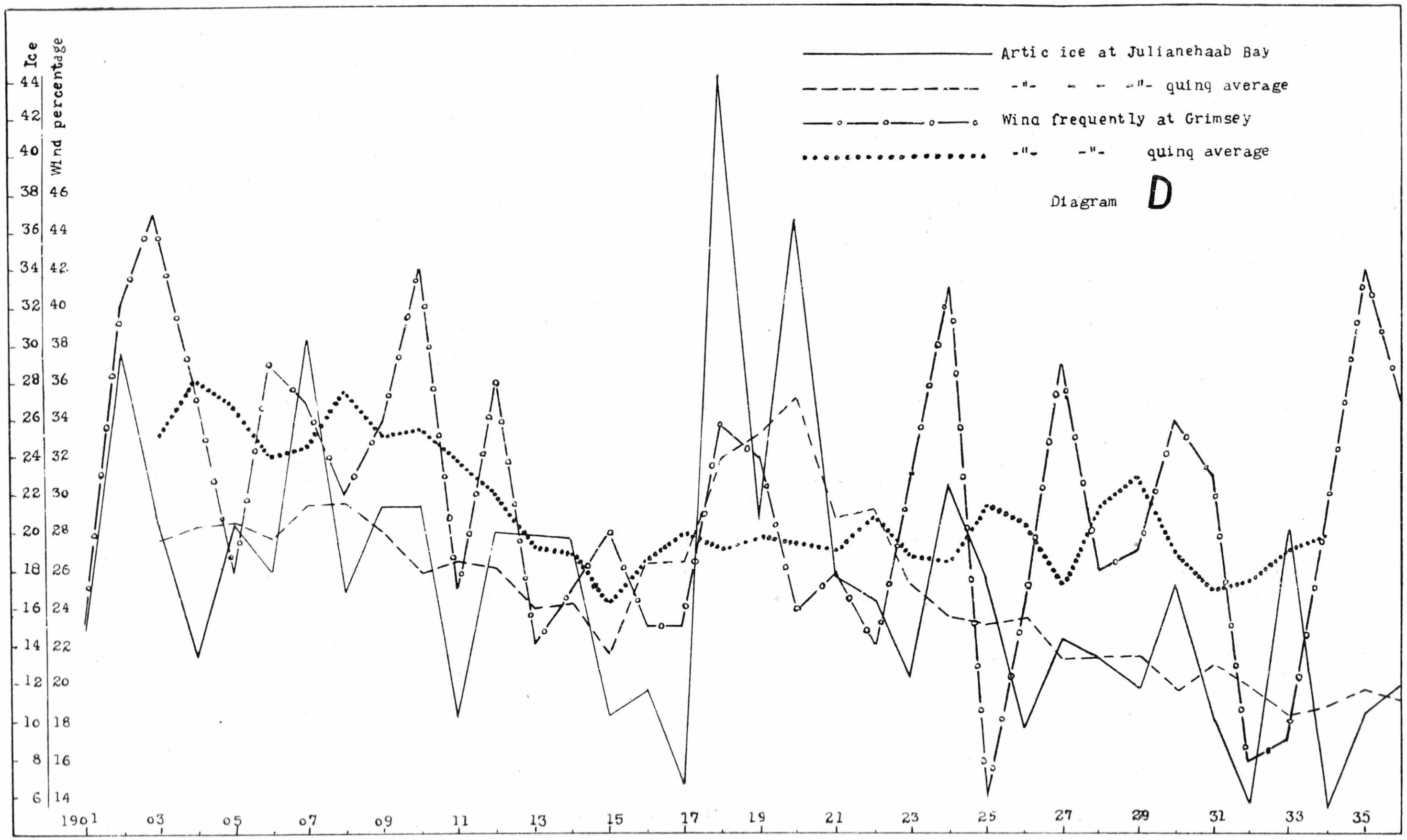
We have plotted the wind frequency and the quantity of arctic ice in Diagram D. It will be seen that the curve for prevailing favourable winds presents many features in common with the ice curve; in particular there is fairly good accord for the first half of the curves. It may be stated that in several cases the wind curves explain differences between ice and temperature, of which developments in the years 1905—06—07, 1914—15—16, 1921—22, 1925 and 1929—30 may be quoted here as examples.

There seems to be greater agreement between arctic ice and wind frequency at Grimsey in the first half than in the latter half of the period under review. The explanation of this may possibly be that the smaller quantity of ice observed in the last sixteen or seventeen years kept more within the Arctic Current and was not driven out of it by the wind, it being assumable that the ice inside the current is only little affected by the wind. We have calculated the correlation between wind

Table 5.

Wind conditions at Grimsey and Angmagssalik compared with the arctic ice at Julianehaab Bay. The figures indicate the difference between the winds favourable and unfavourable to the arctic ice in percentage of all observations at Grimsey and Angmagssalik respectively.

Year	Index for arctic ice at Julianehaab Bay	Grimsey		Angmagssalik	
		Wind frequency	Quinquennial average	Wind frequency	Quinquennial average
1901	15.0	23	..	— 1	..
02	29.4	40	..	— 4	..
03	20.5	45	33.2	—11	— 3.6
04	13.5	36	36.0	— 2	— 3.4
05	20.3	26	35.0	0	— 2.4
06	18.0	37	32.0	0	— 0.2
07	30.3	35	32.4	1	— 1.8
08	17.0	30	35.6	0	..
09	21.3	34	33.2	—10	..
10	21.4	42	33.4	..	..
11	10.2	25	31.8	..	..
12	20.0	36	30.0	— 8	..
13	19.9	22	27.2	3	..
14	19.8	25	26.8	— 4	— 5.6
15	10.2	28	24.2	—11	— 4.2
16	11.4	23	26.6	— 8	— 4.6
17	6.7	23	28.0	— 1	— 2.6
18	44.4	34	27.2	1	1.4
19	20.8	32	27.8	6	4.8
20	36.6	24	27.6	9	9.2
21	17.8	26	27.0	9	11.2
22	16.4	22	28.8	21	(12.5)
23	12.2	31	26.8	11	(11.2)
24	22.4	41	26.4	..	(14.0)
25	17.5	14	29.4	4	(12.0)
26	9.7	24	28.4	20	(13.8)
27	14.2	37	25.6	13	12.8
28	13.2	26	29.6	18	11.6
29	11.6	27	31.0	9	4.6
30	17.2	34	26.8	— 2	— 0.2
31	10.0	31	25.0	—15	— 4.8
32	5.8	16	25.4	—11	—10.0
33	20.0	17	27.0	— 5	—11.8
34	5.6	29	27.8	—17	—10.0
35	10.3	42	..	—11	..
36	11.7	35	..	— 7	..



Ice
Wind percentage
Artic ice at Julianehaab Bay
-"- -"- quinq average
Wind frequently at Grimsey
-"- -"- quinq average
Diagram D
1901
03
05
07
09
11
13
15
17
19
21
23
25
27
29
31
33
35

frequency and ice; as already appears from the foregoing it proves to be low, especially for the latter half of the period.

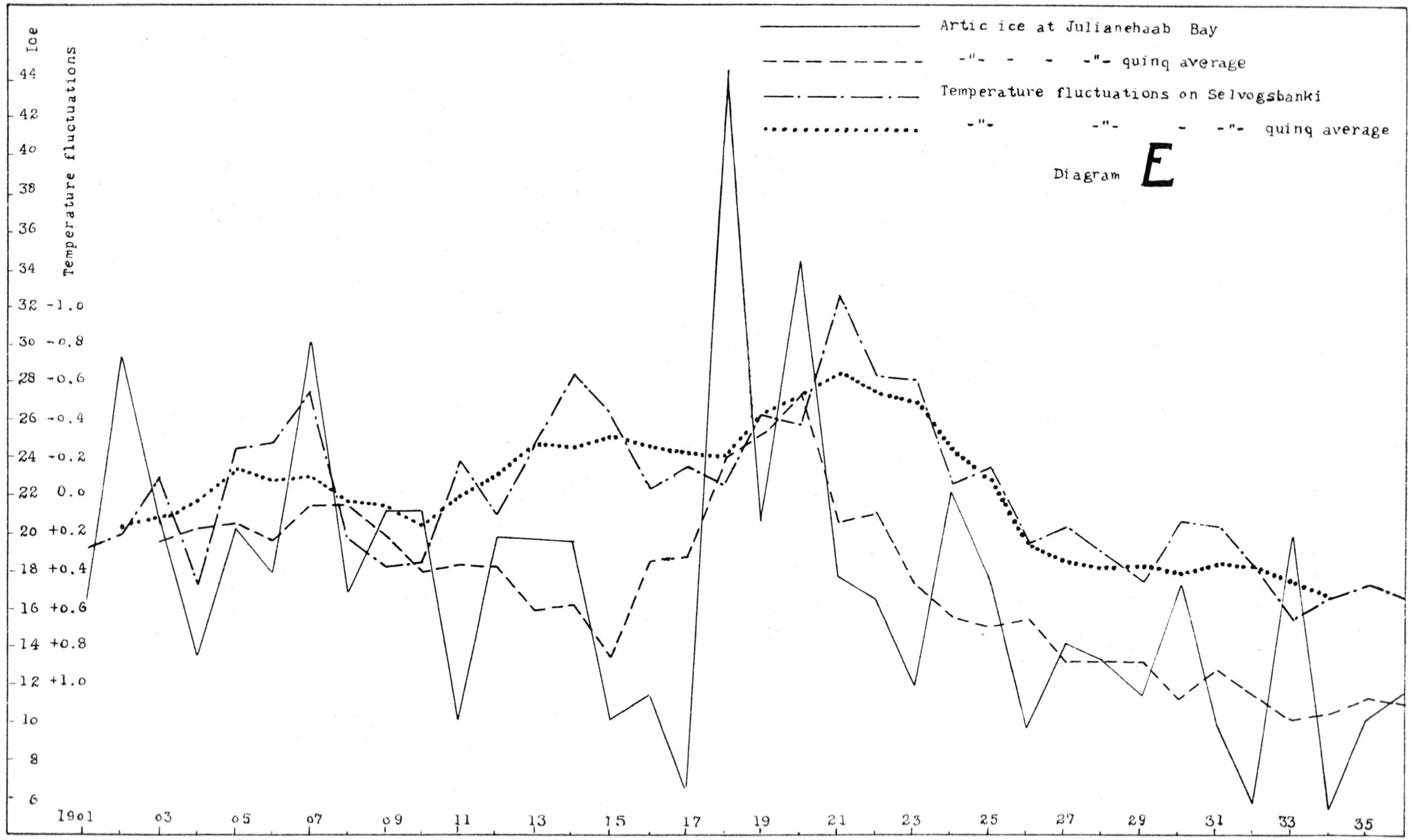
The last two columns in Table 5 represent a statistical treatment of the wind direction for Angmagssalik in the same manner as for Grimsey. On comparing these figures with those for the ice (the first column of the table) we find that there is no proportionality between the two. The explanation of this is that, as already stated, the winds at this colony are subject to special local influences. This is judged to be the reason why one cannot demonstrate a closer relation between the wind at Angmagssalik and the occurrence of arctic ice.

IX.

On its further course southwards there should be a possibility of a connection between the quantity of arctic ice and the Irminger Current. For the latter we find particulars of the fluctuations in the temperatures of the surface water on Selvogsbanki off southwest Iceland in HELGE THOMSEN's treatise on this subject. In Table 6 we reproduce an extract of the annual observations and their quinquennial averages. In Diagram E

Table 6. Variations in surface temperatures on Selvogsbanki, Iceland, 1901—36.

Year	Year's average fluctuations	Quinquennial average	Year	Year's average fluctuations	Quinquennial average
1901........	0.28	..	1919........	—0.42	—0.42
02........	0.20	0.16	20........	—0.39	—0.52
03........	—0.10	0.12	21........	—1.07	—0.63
04........	0.43	0.01	22........	—0.65	—0.56
05........	—0.23	—0.15	23........	—0.62	—0.51
06........	—0.27	—0.08	24........	—0.08	—0.25
07........	—0.56	—0.10	25........	—0.14	—0.10
08........	0.21	0.02	26........	0.22	0.21
09........	0.37	0.04	27........	0.14	0.32
10........	0.35	0.16	28........	0.93	0.37
11........	—0.19	0.00	29........	0.43	0.35
12........	0.08	—0.13	30........	0.12	0.40
13........	—0.28	—0.29	31........	0.14	0.35
14........	—0.63	—0.27	32........	0.39	0.37
15........	—0.45	—0.31	33........	0.66	0.44
16........	—0.05	—0.27	34........	0.54	0.52
17........	—0.16	—0.23	35........	0.47	..
18........	—0.05	—0.21	36........	0.54	..



Artic ice at Julianehaab Bay
-"- - - -"- quinq average
Temperature fluctuations on Selvogsbanki
-"- -"- - -"- quinq average
Diagram E
Ice
Temperature fluctuations
44
42
40
38
36
34
32 -1.0
30 -0.8
28 -0.6
26 -0.4
24 -0.2
22 0.0
20 +0.2
18 +0.4
16 +0.6
14 +0.8
12 +1.0
10
8
6
1901
03
05
07
09
11
13
15
17
19
21
23
25
27
29
31
33
35

we have also plotted both the annual and the quinquennial averages for the temperature fluctuations on Selvogsbanki and for the occurrence of arctic ice in Julianehaab Bay.

An examination of the table and the curves seems to suggest a certain connection. There are relatively low temperatures and relatively much ice around 1907 and 1920. Between these years we have less ice and higher temperatures. After 1920 we observe a connection between the quantity of ice and rising temperatures.

We are also in a position to examine whether the observations provide any information as to the connection between the Irminger Current and the quantity of arctic ice. It seems possible to draw the direct conclusion that changes in the temperature of the Irminger Current follow after changes in the quantity of ice, so that it seems as if the latter affects the temperature of the stream more than vice versa.

We have therefore calculated the connection between the quantity of arctic ice and the variation in the temperature of the Irminger Current in the following year. By means of the usual calculation after the method of the smallest square we find that for observations the same year there is the following linear connection:

According to the equation $Y = -0.01477 \cdot X + 0.2598$ we have

for $X = 10$; $Y = +0.112$ and
for $X = 30$; $Y = -0.183$;

Y being the temperature variations on Selvogsbanki and X the quantity of arctic ice in Julianehaab Bay. In the second case (the connection between ice quantity and the following year's temperature deviations on Selvogsbanki) we get the following linear connection:

According to the equation $Y = -0.02406 \cdot X + 0.4088$ we have

for $X = 10$; $Y = +0.168$ and
for $X = 30$; $Y = -0.313$;

Y again being the temperature variations and X the quantity of ice in the previous year. We can further state that the coefficient of correlation in the first case (ice and temperature the same year) is $-0.27°$ and in the second case (the ice and the following year's temperature fluctuation) -0.37.

We have plotted the two curves on Diagram F, from which we see that the effects of the arctic ice seem to be greater in the following year. From this the conclusion may be drawn that the ice is of greater significance to the Irminger Current than vice versa.

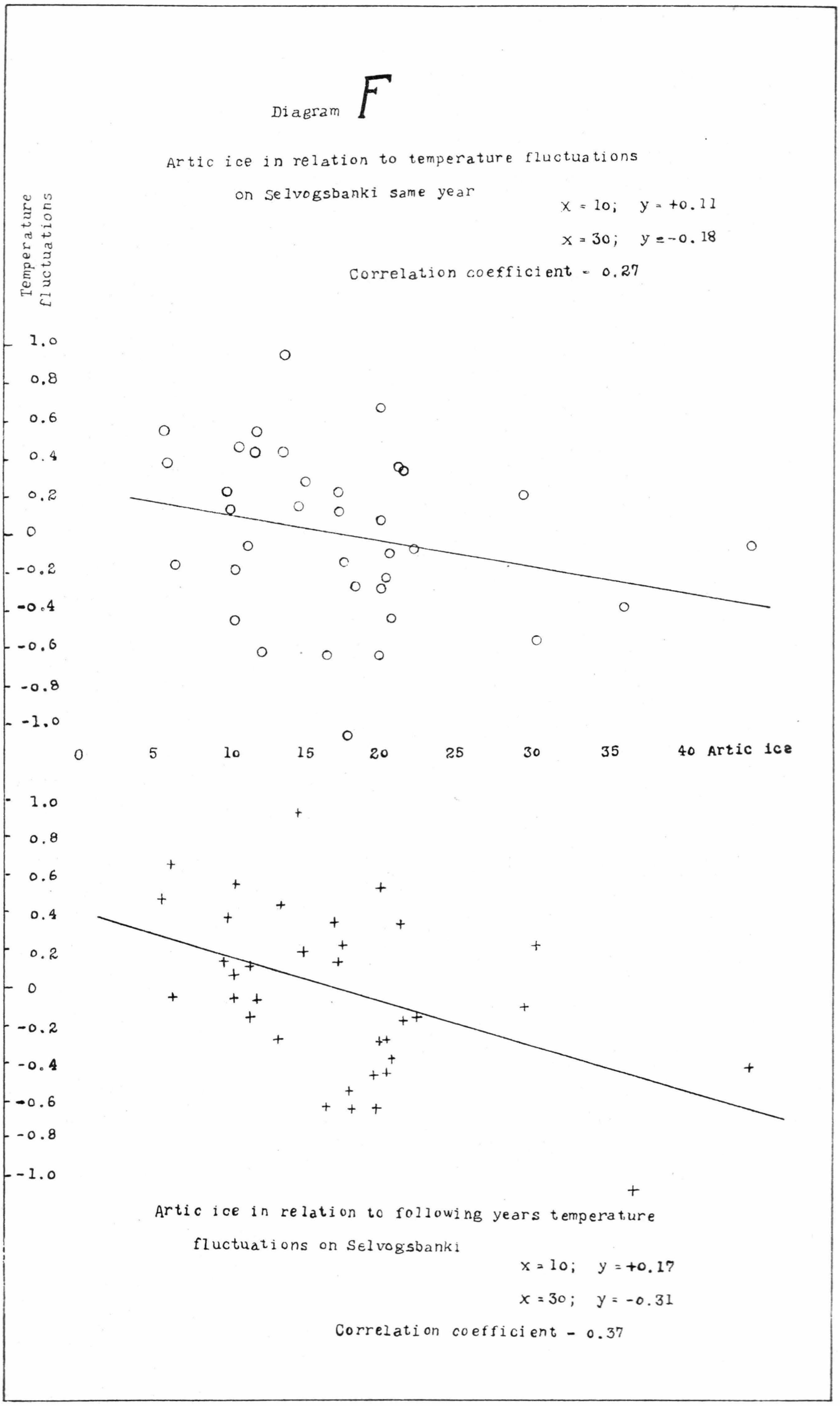


Diagram F
Artic ice in relation to temperature fluctuations
on Selvogsbanki same year
x = 1o; y = +0.11
x = 3o; y = -0.18
Correlation coefficient - 0.27
Temperature fluctuations
1.o
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.o
0
5
1o
15
20
25
3o
35
4o Artic ice
1.o
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
Artic ice in relation to following years temperature
fluctuations on Selvogsbanki
x = 1o; y = +0.17
x = 3o; y = -0.31
Correlation coefficient - 0.37

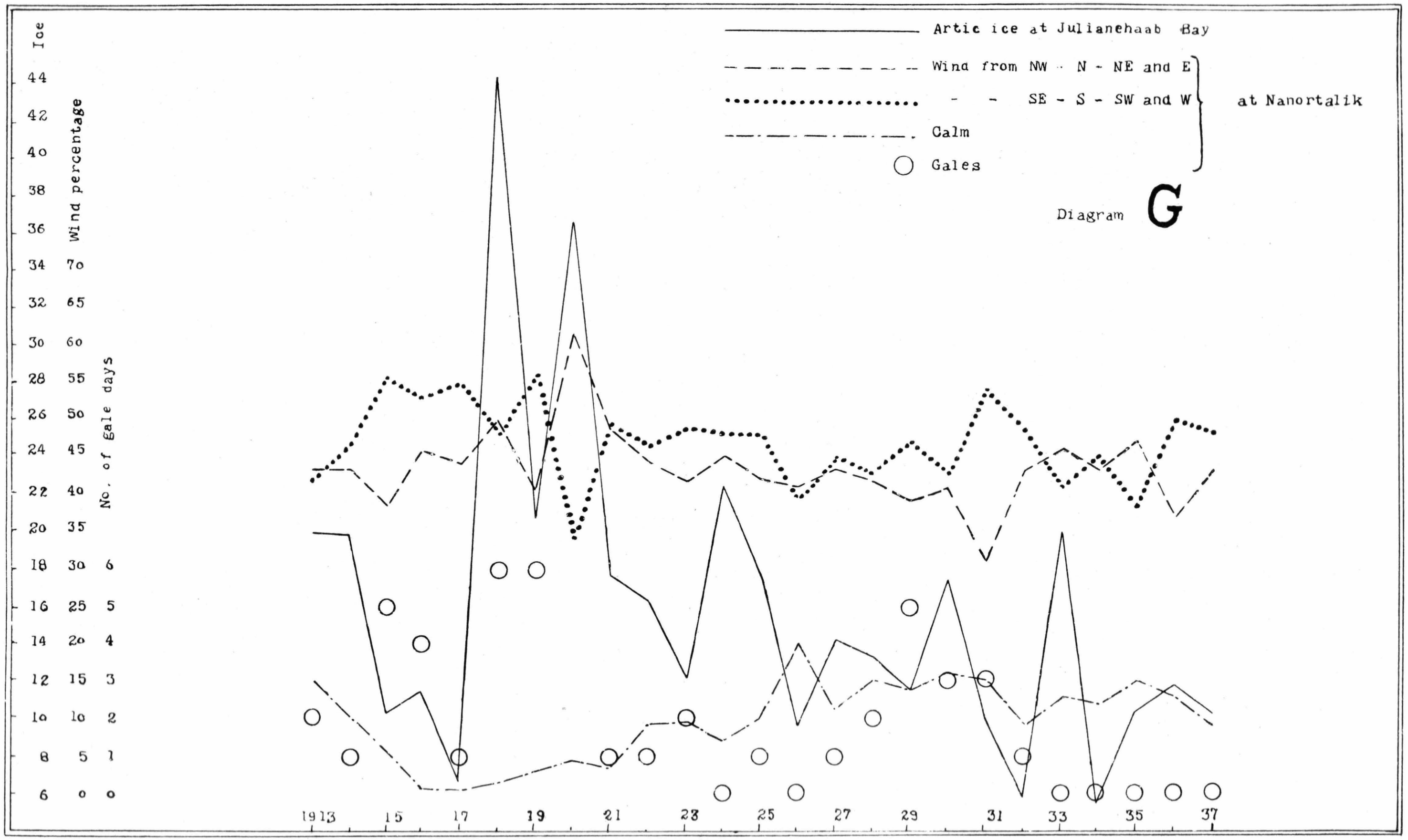
X.

Finally, it is possible that there may be a certain connection between the quantity of ice in Julianehaab Bay and the direction of the wind (or gales) in the same place in those months when the ice appears (April, May, June, July and August). To elucidate this question we have meteorological observations from Nanortalik (from 1913 to 1937) in the southern part of the Julianehaab district, and from Ivigtut, which lies in the southern part of the Frederikshaab district.

From the observations at Nanortalik we have in Table 7 for the months of April to August entered the number of observations (these are taken three times a day) with a wind blowing from NW., N., NE. and E. in the first column, and those with a wind blowing from SE., S., SW. and W. in the second column. The third column indicates the

Table 7. Wind conditions at Nanortalik in the years from 1913 to 1937. For the wind the figures indicate the percentage of all observations for the directions shown. For gale days the number of whole gale days.

Year	Winds from			Calm	No. of Gale days
	NW-N-NE-E	SE-S-SW-W	E-SE-S		
1913	43	42	23	15	2
14	43	47	23	10	1
15	38	56	30	6	5
16	46	53	31	1	4
17	44	55	32	1	1
18	50	48	27	2	6
19	41	56	37	3	6
20	62	34	18	4	—
21	48	49	28	3	1
22	44	47	13	9	1
23	42	49	9	9	2
24	45	48	8	7	0
25	42	48	10	10	1
26	41	39	12	20	0
27	43	45	9	12	1
28	42	43	7	15	2
29	39	47	7	14	5
30	41	43	8	16	3
31	31	54	9	15	3
32	43	48	16	9	1
33	46	41	11	13	0
34	43	45	8	12	0
35	47	38	13	15	0
36	37	50	10	13	0
37	43	48	12	9	0



Artic ice at Julianehaab Bay
Wind from NW - N - NE and E
- - SE - S - SW and W
Calm
Gales
at Nanortalik
Diagram G
Ice
Wind percentage
No. of gale days
44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6
70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
6 5 4 3 2 1 0
1913 15 17 19 21 23 25 27 29 31 33 35 37

number of observations from E., SE. and S. In the fourth column are the observations with calm, and the last column shows the number of days with gales in the months mentioned.

All the values of the table, together with the quantity of arctic ice, are plotted on Diagram G. From the figures in the table and Diagram G we see that, there seems to be no connection between the number of calm days and the quantity of arctic ice.

Whereas one might presume a priori that there was some connection between the northerly and easterly winds which should check and spread, and a small quantity of ice, we find that the opposite is the case. When northerly and easterly winds have prevailed, in seven out of eight cases there is more ice[1]) compared with the foregoing and the following year. As for the southerly and westerly winds, we see that where these prevail there is, in three out of four cases, less ice than before and after. From this it would be reasonable to assume that the wind observations at Nanortalik are of less significance to the ice conditions in the immediate vicinity of that place. One might be tempted to utilize the direction of the wind at Nanortalik as expressing that the wind conditions would be similar east of the adjacent Cape Farvel. In that case it seems likely that northerly and easterly winds give more ice, and southerly and westerly winds less.

Finally, one might think that when there are gales the ice is washed away more, so that many stormy days give a small quantity of ice. A comparison between the values in Table 7 and Diagram G does not seem to show any connection in that direction.

XI.

In Table 8 and Diagram H we have similarly examined whether there is any connection between the direction of the wind at Ivigtŭt and the quantity of ice.

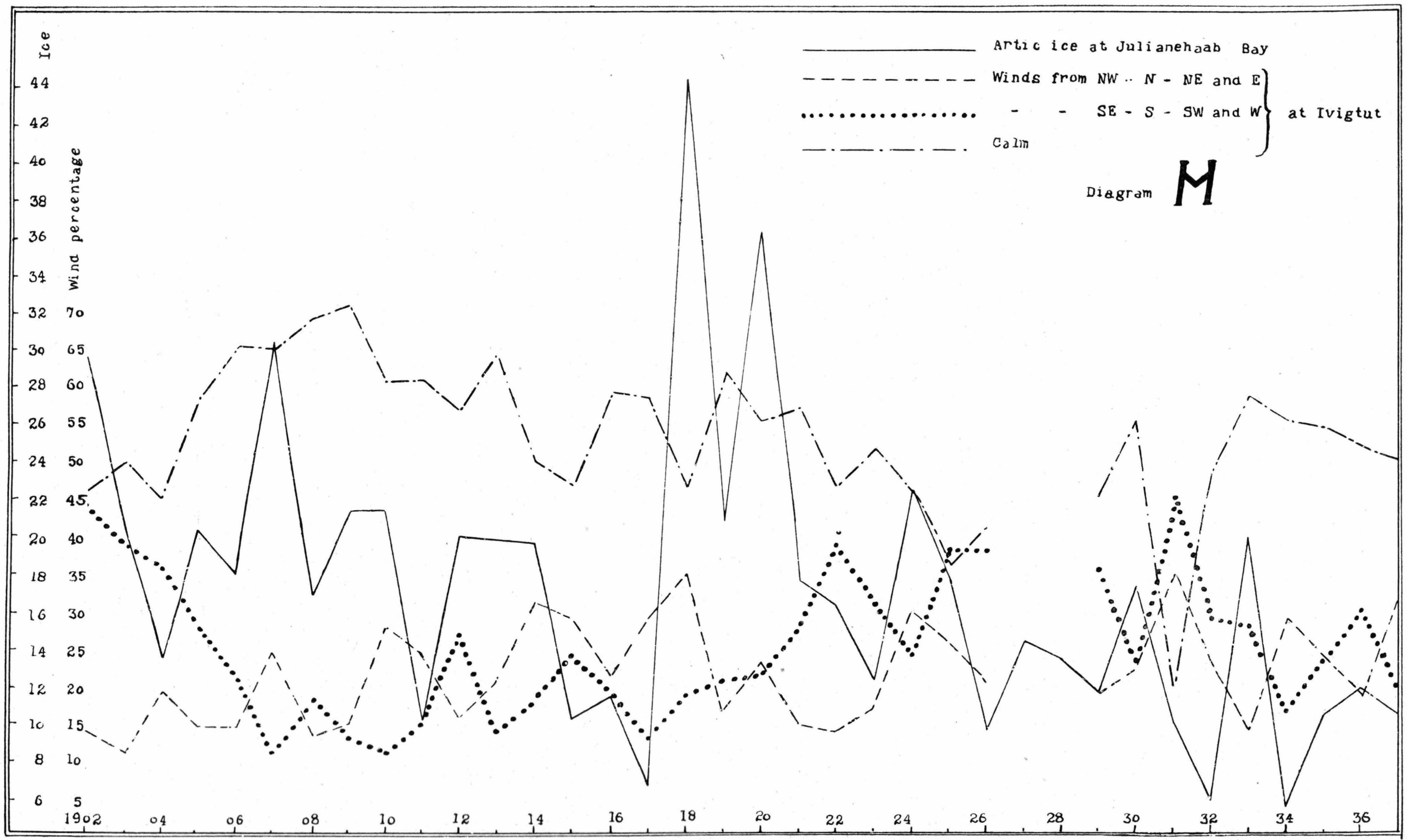
Judging from the table and the diagram there is no connection. As in the case of Nanortalik Table 8 contains wind observations for the months of April to August only. If we take the SE., S., SW. and W. winds, the curves oscillate to the same side for 13 years and to the opposite side for 18 years. Winds from NW., N., NE. and E. oscillate to the same side for 16 years and to the opposite side for 15 years. In "calm" we have oscillations for 13 years to one side and for 15 years to the other. Nor is there any connection for E., SE. and S. winds, for

[1]) It is possible that northerly and easterly winds produce a spreading of the ice, so that according to our procedure it occupies a larger area though the actual quantity need not be larger.

Table 8.

Wind conditions at Ivigtût in the months of April, May, June, July and August from the year 1900 to 1937. For the wind the figures indicate the percentage of all observations for the directions shown. For gale days the number of whole gale days.

Year	Winds from			Calm	No. of Gale days
	NW-N-NE-E	SE-S-SW-W	E-SE-S		
1900...........	17	45	22	38	0
01...........	—	—	—	—	—
02...........	13	41	24	46	0
03...........	11	39	13	50	0
04...........	19	36	14	45	4
05...........	14	28	20	58	0
06...........	14	21	16	65	0
07...........	24	11	11	65	0
08...........	13	18	16	69	1
09...........	15	13	9	72	0
10...........	28	11	8	61	0
11...........	24	15	11	61	3
12...........	16	27	19	57	3
13...........	21	14	14	65	0
14...........	32	18	12	50	0
15...........	29	24	12	47	0
16...........	22	19	8	59	0
17...........	29	13	7	58	0
18...........	35	18	9	47	4
19...........	17	21	7	62	0
20...........	23	22	10	55	0
21...........	15	28	16	57	3
22...........	14	39	13	47	0
23...........	17	31	16	52	1
24...........	30	24	13	46	0
25...........	26	38	26	36	1
26...........	21	38	26	41	0
27...........	—	—	—	—	—
28...........	—	—	—	—	—
29...........	19	33	29	45	1
30...........	22	23	15	55	0
31...........	35	45	38	20	4
32...........	23	29	18	48	1
33...........	14	28	15	58	0
34...........	28	17	15	55	1
35...........	23	23	17	54	0
36...........	18	30	19	52	0
37...........	31	19	13	50	1


Artic ice at Julianehaab Bay
Winds from NW - N - NE and E
- - SE - S - SW and W
Calm
at Ivigtut
Diagram M
Ice
Wind percentage
44
42
40
38
36
34
32 70
30 65
28 60
26 55
24 50
22 45
20 40
18 35
16 30
14 25
12 20
10 15
8 10
6 5
1902 04 06 08 10 12 14 16 18 20 22 24 26 28 30 32 34 36

here there are oscillations to the same side for 14 years and to the opposite side for 14 years. Thus from these observations we can find no connection between the wind at Ivigtŭt and the ice in Julianehaab Bay.

This observation seems quite reasonable when we consider the geographical conditions at Ivigtŭt. It lies among high mountains, and there is no direct reason for assuming that there is any real connection between that spot and Julianehaab Bay. The wind conditions at Ivigtŭt are of a pronouncedly local character.

XII.

We have now endeavoured to analyse the causes of the fluctuations in the occurrence of arctic ice in Julianehaab Bay and have had to confine ourselves to the observations that are accessible or those that have been lent to us. On the basis of this analysis we feel justified in concluding that there is no single cause, but that the fluctuations are due to the interaction of a number of factors.

The most important of these factors seems to be the temperature of the Gulf Stream (measured between the Hebrides and the Faeroes) in the previous year. It seems possible to demonstrate a statistical connection between the decreasing quantity of arctic ice and the rising temperature in the Gulf Stream, and this connection stands out most clearly when we consider the quinquennial sliding averages.

On observing the annual variations we find very considerable differences between the Gulf Stream temperature and the quantity of arctic ice. Most of these differences can be explained by information as to air temperatures in the Arctic Ocean. When it has been a particularly cold year in the Arctic, it would seem that the ice freezes together' with the result that in the first year relatively small quantities of ice come into Julianehaab Bay, but much larger quantities the following year.

On its way along the east coast of Greenland the quantity of ice is affected to some degree by the prevailing winds. We assume that the effect is greatest when the wind drives the ice out of the southward-bound arctic current and into the warmer water, where melting can proceed more rapidly.

When it reaches Denmark Strait the arctic ice meets the Irminger Current; it would seem that this contact has more effect on the temperature of the Irminger Current, i. e. the temperature fluctuations are affected by the quantity of ice.

Round Cape Farvel the arctic ice again comes under the influence of the wind to some extent, and the investigation shows that it is the northerly and westerly winds that are of particular significance to the occurrence of arctic ice.

As stated at the beginning, we are well aware that in making this investigation we have merely raised the question and set up a preliminary working hypothesis which later workers may be able to amplify or alter. For example, to understand more about the subject it will be necessary to have a continuous series of observations for a long period from several places. We hope that when these observations become available the connections to which we have referred may be expanded or explained.

In conclusion we would say that the connections indicated in themselves can only be of statistical character. Whether they again are the expression of a causal relation or whether the correlation observed between the phenomena are all effects of quite other causes which have escaped our attention, we are unable to say.

LITERATURE

1. V. Garde: Vejledning til Besejling af Kolonierne i Vestgrønland. Copenhagen 1895, p. 8—9.
2. Sammendrag af statistiske Oplysninger om Grønland I, 1942, p. 393.
3. C. Speerschneider: The state of the Ice in Davis Strait 1820—1930. Copenhagen 1931.
4. Det danske meteorologiske Instituts Aarbog: The state of the Ice in the arctic seas and the surface temperature of the sea in the northern Atlantic-Ocean and in the Davis Strait. 1900—1937.
5. Det norske meteorologiske Instituts Aarbog 1900—1937.
6. H. Thomsen: Variation of the surface temperature at Selvogsbanki, Iceland 1895—1936.
Extrait au Rapports et Procès-Verbaux, Vol. CV. Copenhagen 1937.
7. Einar Sagen: Dei sista vitane. Militært Tidskrift for Ingeniørvaabnet 1934.
B. J. Birkeland: Temperaturvariationen auf Spitzbergen. Meteor. Zeitschr. 1930.
Th. Hesselberg: Klimavariasjoner i Norge i vår tid. Nordiska Naturforskermøtet i Helsingfors 1936.
A. Wagner: Untersuchung der Schwankungen der allgemeinen Zirkulation Geografiska Annaler IX, 1929.
Osc. V. Johansen: Die abnehmende Kontinentalität in Europa. Mitteilungen des Meteorologischen Instituts der Universitet No. 13. Helsingfors 1929.
J. B. Kincer: Is our Climate changing? A study of longtime temperature Trends. Monthly weather Review 1933.
Helge Petersen: Klima der Küsten von Groenland. Handbuch der Klimatologi von W. Køppen und R. Geiger, Band 2, Teil K. Berlin 1935.
C. E. P. Brooks: The Change of Climate in the British Isles. Meteorological Magazine 70. 1935.

R. SCHERHAG: Die Zunahme der atmosphärischen Zirkulation in den letzten 25 Jahren. Annalen der Hydr. und Mar. Met. 1936.

LEO LYSGAARD: Ændringer i Danmarks Klima i den nyeste Tid. Geografisk Tidsskrift, København 1937.

K. KIRDE: Change of Climate in the Northern Hemisphere. Scientific Papers of the Meteorological Observatory of the University Tartu, No. 2. Tartu 1938.

H. W:SON AHLMANN, J. W. SANDSTRÖM, A. ÅNGSTRÖM: Den paagaaende Klimatændring. Ymer 1939.

B. J. BIRKELAND: Mittel und Extreme der Lufttemperatur. Geofysiske Publikasjoner Vol. XIV, No. 1. 1936.

TH. HESSELBERG und B. J. BIRKELAND: Säkulare Schwankungen des Klimas von Norwegen. Geofysiske Publikasjoner Vol. XIV, No. 4. 1940.

8. Det islandske meteorologiske Instituts Aarbog 1918—1936.
9. Det danske meteorologiske Instituts Aarbog II. 1900—1937.

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