ATVINNUDEILD HÁSKÓLANS
RIT FISKIDEILDAR 1954 — NR. 1

TEMPERATURE VARIATIONS
in the North Icelandic Coastal Area

by
UNNSTEINN STEFÁNSSON

Contents

1. *Introduction.*

Numerous records of the surface temperature in Icelandic waters have been published by the Danish Meteorological Institute since 1875. The bulk of this material has been collected by commercial vessels visiting Iceland or Icelandic waters. In the area north of Iceland (the Iceland Sea) the collection of material has mostly been limited to the summer season. During the other months of the year, particularly from November to March, restricted navigation has reduced the number of observations to only very few. Even during the summer months there are large tracts of the Iceland Sea where observations are very infrequent.

In the Nautical Meteorological Annual of the Danish Meteorological Institue for the year 1892 charts were published showing the mean sea surface

temperature, for the months April—September during the period 1876—1890. Since 1895 the observations have been published annually in the Annual except during the war years 1940—1944.

Chart giving the mean monthly isotherms of the Atlantic Ocean north of 50° N.Lat. based upon observations during the years 1876—1915, were prepared by *C. Ryder (1917)*. In drawing up these monthly charts *Ryder* used squares of one degree. First the mean temperature was computed for each year, and then monthly means were tabulated for each of the four decades 1876—1885, 1886—1895, 1896—1905 and 1906—1915, and finally from the mean figures of these, monthly mean values were computed for the entire period.

The anomalies of the surface temperature in the sea around Iceland during the years 1876—1939 and 1945—1947 have been worked out by *Smed (1947)*. He divided the sea around Iceland in two areas, *G:* 63°—67° N., 20°—30° W. and *I:* 63°—67° N., 10°—20° W. The temperature means for each month and each 1° square were compared with the grand monthly means of Ryder, and the anomalies computed in this way were then averaged over the entire area in question. In addition the corresponding anomalies were computed for the permanent meteorological stations situated at *Vestmannaeyjar, Stykkishólmur, Grímsey* and *Papey*. The temperature variations may be great in the above mentioned areas and governed by different factors, as within each of them we find water masses with entirely different characters. Thus in area G relatively warm Atlantic water will at all times be found in the southern part of the area, whereas in the northern part ice cold polar water will most often be met with. Besides, in this area most of the material has been collected from the southern part but very little from the north-western part. It is therefore somewhat doubtful whether the values of the computed anomalies, perhaps based upon relatively few observations, will truly represent the actual temperature fluctuations for such heterogeneous areas. It would seem more logical that division into areas for studies of temperature variations be made hydrographically rather than merely geographically to avoid having to deal with areas containing entirely different water masses.

2. *Normals.*

For evaluating the changes in the sea surface temperature of the North Icelandic coastal area from one year to another, both in connection with the biological investigations and for studying temperature variations within the latest decades, it was considered most natural to use as normals the temperature means for the period 1901—1930, in accordance with the resolution of the Conference of Meteorological Directors in 1935.

The normals used here are based entirely upon Danish material pub-

lished in the Nautical Meteorological Annuals, as material from other sources has not been available to the author. These other sources include the material collected by other than Danish and Icelandic ships, the material collected by the American and British Navy during the war and the temperature measurements made from Icelandic trawlers within recent years. It is to be hoped that all these data can be made available for study in near future.

On examining the Danish Nautical Meteorological Annuals, it soon became apparent that only from the Icelandic coastal area was the material extensive enough for computing reliable mean values. Furthermore, the normals have been worked out for the summer season only, as the collection of data has been very scanty from other months of the year.

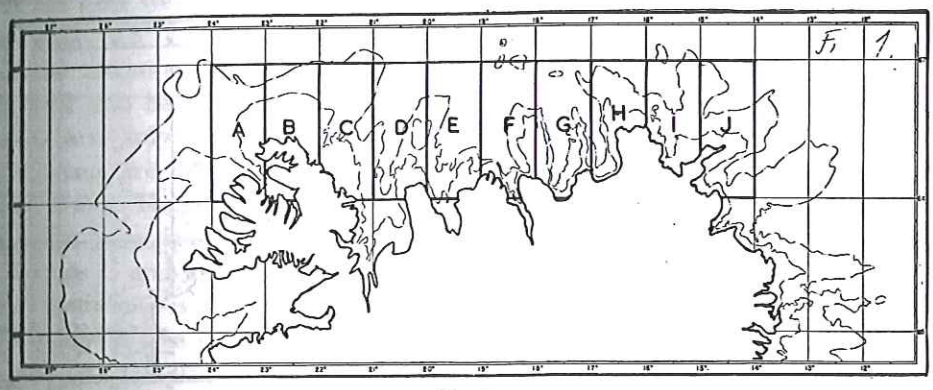


Fig. 1.
Areas where temperature variations were studied.

The temperature recorded in the the Annuals were averaged for each 1° square in the coastal area extending from 66° to 67° N. and 14° to 24° W. These ten areas are designated by A, B, C, etc. (Fig. 1). In the instances where observations were lacking calculated values were used. These were determined by comparison with the values of adjacent areas, or where these were missing, by comparison with the records from Grímsey. As regards the western coastal area (A—C), calculated values from *Suðureyri* on the northwest coast (where observations were begun in 1921) were also used. It was felt that more reliable results would be obtained by inserting these calculated values where observations were missing rather than averaging the available values only. It is even anticipated that no appreciable errors will be introduced by using the calculated values as in all cases a fairly good straight line relationship was found between the sea temperature measured in Grímsey and in the different areas. The number of years with observations made during the period 1901—1930, is shown in table *I*.

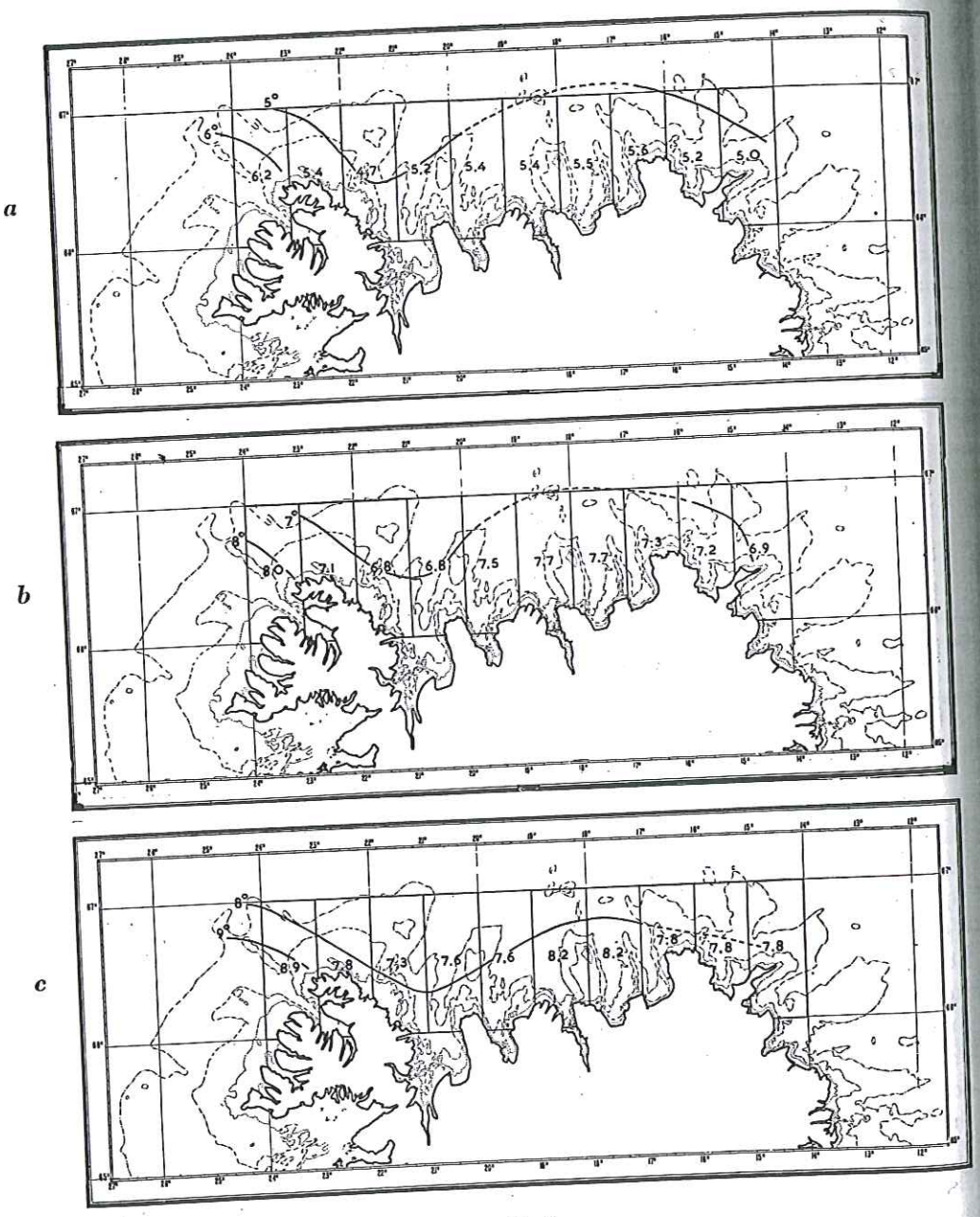
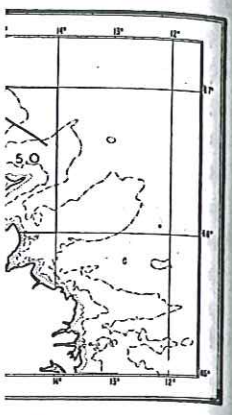
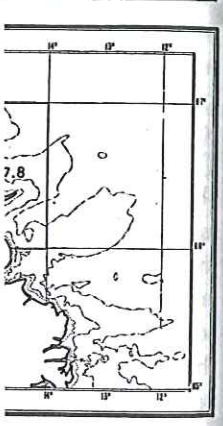


Fig. 2.
Normals for the sea surface temperature for the period 1901—1930.
a normals for June, *b* July and *c* August.





)1—1930.

TABLE I

The Number of Years with Observations During 1901—1930.

	A	B	C	D	E	F	G	H	I	J
June	25	22	17	20	13	20	18	16	16	18
July	26	23	23	25	23	26	21	15	18	20
August	28	25	23	26	26	26	20	19	16	20

On Fig. *2* a-c are inserted the normals for the sea surface temperature for the period 1901—1930. Differences between the squares are rather small as will be seen from the figures, with the exception of square A which shows higher values, no doubt on account of more pronounced Atlantic influence in the area west of Horn. Otherwise the values lie between 4.7° and 5.6° C. in June, 6.8° and 7.7° in July and 7.3° and 8.2° C. in August. The range of the temperatures is thus exactly the same (0.9° C.) in all three months. It will also be noticed that there is a 2° C. temperature difference between June and July and 0.5° C. difference between July and August. The mean isotherms are drawn on the basis of the inserted values and are shown on Fig. 2 a–c. These follow in the main a very similar course during the three months investigated. The most characteristic features are a southward bend in areas C and D and an upward sweep in areas F, G and H. This course of the isotherms is most likely caused by two factors: (1) a more pronounced influence of the drift ice in the area north of Húnaflói and (2) loss of heat in the surface layers in spring and summer due to greater vertical mixing in this area than farther east. In the area west of Húnaflói on the other hand, the surface layers will as a rule keep distinctly warmer on account of much stronger Atlantic influence.

3. *The Surface Temperature at Grímsey.*

Grímsey, 66° 32′ N., 18° 00′ W., is a small island on the arctic circle, about 23 nautical miles off the north coast. Measurements of the sea surface temperature have been carried out from this station since 1874. As a rule the sea temperature has been measured daily, so that on the whole the material is quite extensive. The water is fairly deep close to land where the temperature is measured, so that the influence from land and local conditions should therefore not affect the results seriously. Accordingly one should expect temperatures close to those of areas *F* and *G*. It is a disadvantage with this station, however, that the polar ice at times has surrounded the island, making observations impossible. There are, therefore, several months for which no observations exist and also where the observations have not been made every day. Furthermore, according to information received from the Icelandic Meteorological Office, there is reason to believe that the observations

after 1940 are less reliable than those of previous years. When the observations were missing, calculated values were used. These were found by comparison with the observations in *Papey* on the east coast.

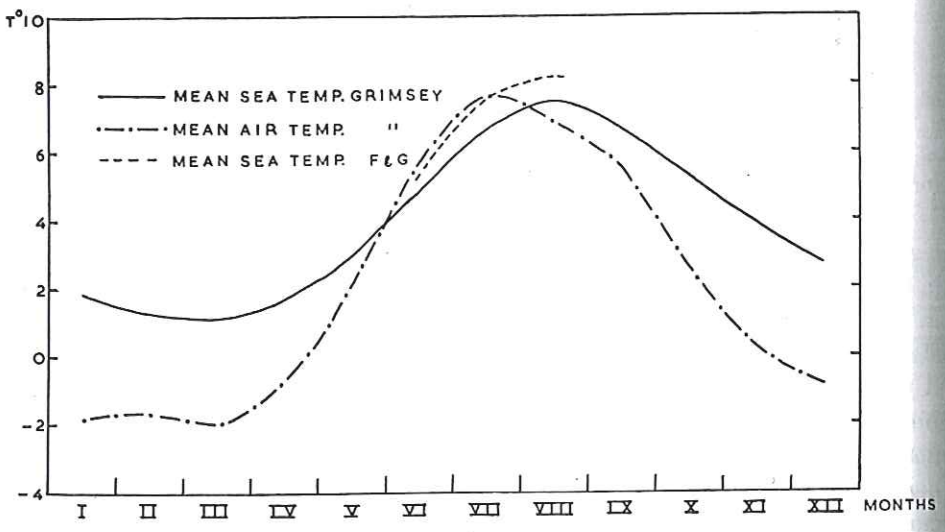


Fig. 3.
The mean annual sea and air temperature at Grímsey and mean sea surface temperature in area *F* and *G* for the summer season.

The mean annual temperature variation of the surface water at Grímsey for the period 1901—1930 is shown on Fig. 3. For comparison the mean sea temperature for June, July and August in areas *F* and *G* and the mean air temperature for Grímsey are also given. The winter sea temperature at Grímsey lies between 1.5° C. and 2.0° C. but rises from the last part of March until a maximum of 7—8° C. is reached in August. From then on a slow decline towards the winter temperature is experienced. The air temperature follows a similar course, but as seen from the diagram, the sea temperature is somewhat higher than the air temperature, especially during the winter months. The annual amplitude in the air temperature is about 3.5° C. in excess of that for the sea temperature. It is also of interest to note that the temperature maximum of the air temperature occurs in July, but that of the sea temperature in August. *Only in June and July does the air temperature exceed the sea temperature.*

As will be noticed from Fig. 3 the temperature values for the areas *F* and *G* during the summer are somewhat higher than the corresponding values in Grímsey. A possible explanation might perhaps be found in the position of the station. Grímsey is situated over 20 miles offshore, but the majority of the temperature measurements in areas *F* and *G* have probably been in that part of the areas which is closest to land. At Grímsey strong

tidal currents may also be prevailing, causing turbulent motion of the surface water, whereby its gets mixed with deeper water. In this case the surface temperature will be lowered in summer and raised in winter. This possibility could be tested by simultaneous observations in Grímsey and a few miles off the island.

On the whole we can conclude that the surface temperature at Grímsey will roughly represent the true temperature conditions in the middle part of the coastal area. Of more importance, however, is the fact (see p. 14) that the temperature fluctuations at Grímsey correspond very closely to those of the middle part of the coastal area.

4. *Variations in the Sea Surface Temperature.*

Recent investigations on meteorological conditions in the northern hemisphere indicate a general amelioration in climate during this century. Not only has the climatic improvement been apparent in an increase of the mean annual air and sea temperature, but it has also been characterized by an intensification of the atmospheric circulation, a recession of glaciers and a retreat of the polar ice.

The increase in temperature was particularily rapid after 1920 as shown by various investigators *(Scherhag 1937, Jensen 1939, Hesselberg and Birkeland 1943, Lysgaard 1948, Smed 1948)*, and it seems to have culminated in the thirties *(Erikson 1943)*. Concurrent with the hydrological and meteorological variations, great biological changes have also been found in northern regions, as shown by *Jensen (1939), Tåning (1948), Fridriksson (1948)* and others.

In Iceland and Icelandic waters similar changes have occurred. In his paper on "Probable Influence of Changes in Temperature on the Marine Fauna of Iceland" *(1932)* Dr. *Bjarni Sæmundsson* cites several examples of the increase in sea temperature since 1920 and the simultaneous changes in the animal life in the waters surrounding Iceland.

Thomsen (1937) has studied the variations in the surface temperature at *Selvogsbanki*, Iceland, during the years 1895—1936. His results show that the period 1895—1912 contains only three abnormal years, while otherwise cold and warm years alternate. The period 1913—1925 seems cold, with 6 of the years definitely cold, while the period 1926—1936 was warmer, with 6 of the years definitely warm.

In his studies of the monthly anomalies of the surface temperature around Iceland *Smed (1947)* finds a definite predominance of positive anomalies from about the middle twenties off the east and the southeast coast of Iceland. Off the west and southwest coast, however, the rise in temperature appeared to be only small.

The air temperature variations at 10 meteorological stations in Iceland have been studied by *Eyþórsson (1949)*. His results show that annual mean

temperatures smoothed by 30-year running means were below the normals in every thirty-year period before 1900, but from 1901/30 they were above normal. On the other hand, his 10-years running means, show a steady rise of the annual temperature at all stations from about 1916—1925 continuing until 1926—1935 when it becomes almost steady. *Eyþórsson* also studied the sea temperature at one station, viz. Papey off the southeast coast. The variations in the sea temperature at this station were seen to follow the corresponding air temperature variations very closely.

For studying the variations in the surface temperature in the North Icelandic coastal area the material used in the present account consists of temperature measurements for each 1° square between 66° to 67° N. and 14° to 24° W. collected and published by the Danish Meteorological Institute (cf. p. 3) and the observation material from Grímsey.

Keeping in mind the importance of using similar methods for compara-

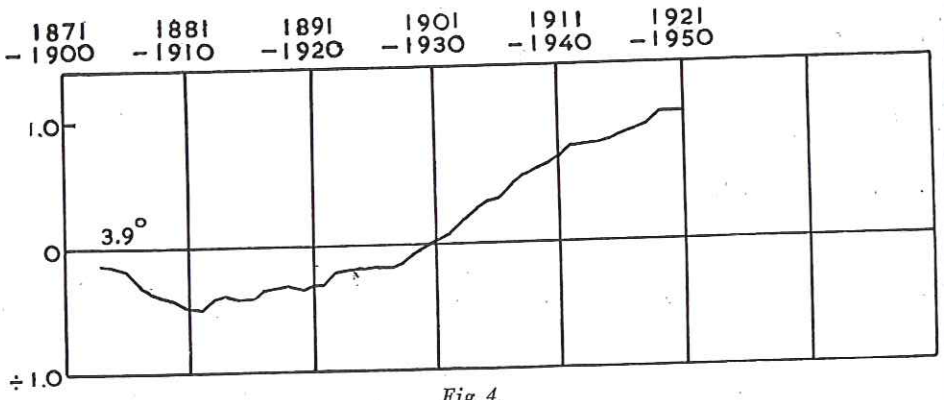


Fig. 4.
Variations of the annual mean sea surface temperatures at Grímsey, in consecutive 30 year periods.

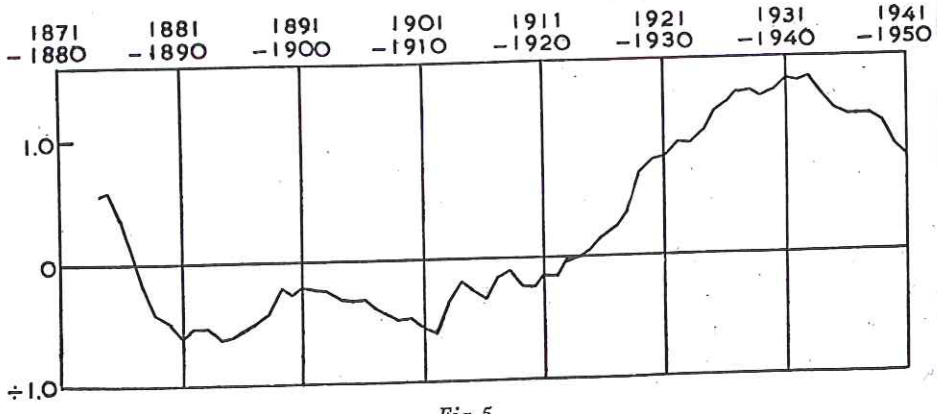


Fig. 5.
Variations of the annual mean sea surface temperatures at Grímsey, in consecutive 10 year periods.

tive studies of climatic variations, the method used here is that adopted by *Hesselberg* and *Birkeland (1940)* and later used by *Eyþórsson (1949)*.

a. *Variations at Grímsey.*

Fig. 4—5 shows the departures from normal of the annual surface temperature at Grímsey in consecutive thirty year periods and in consecu-

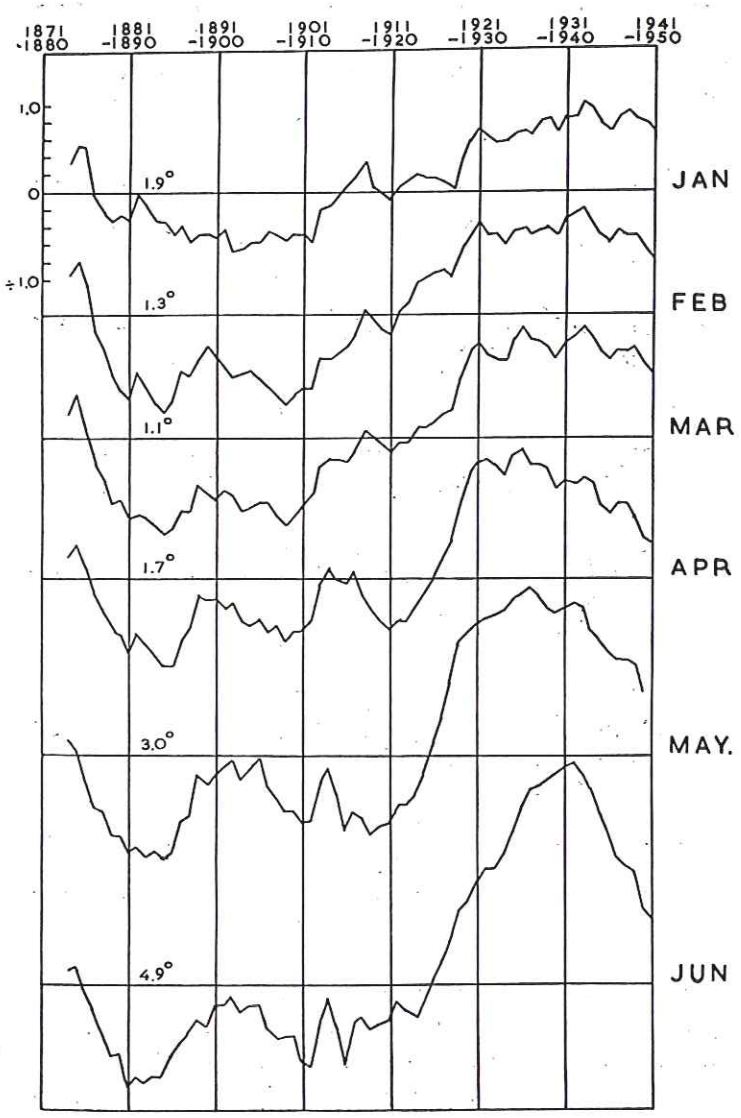


Fig. 6.
Variations of the monthly mean sea surface temperatures at Grímsey, January to June.

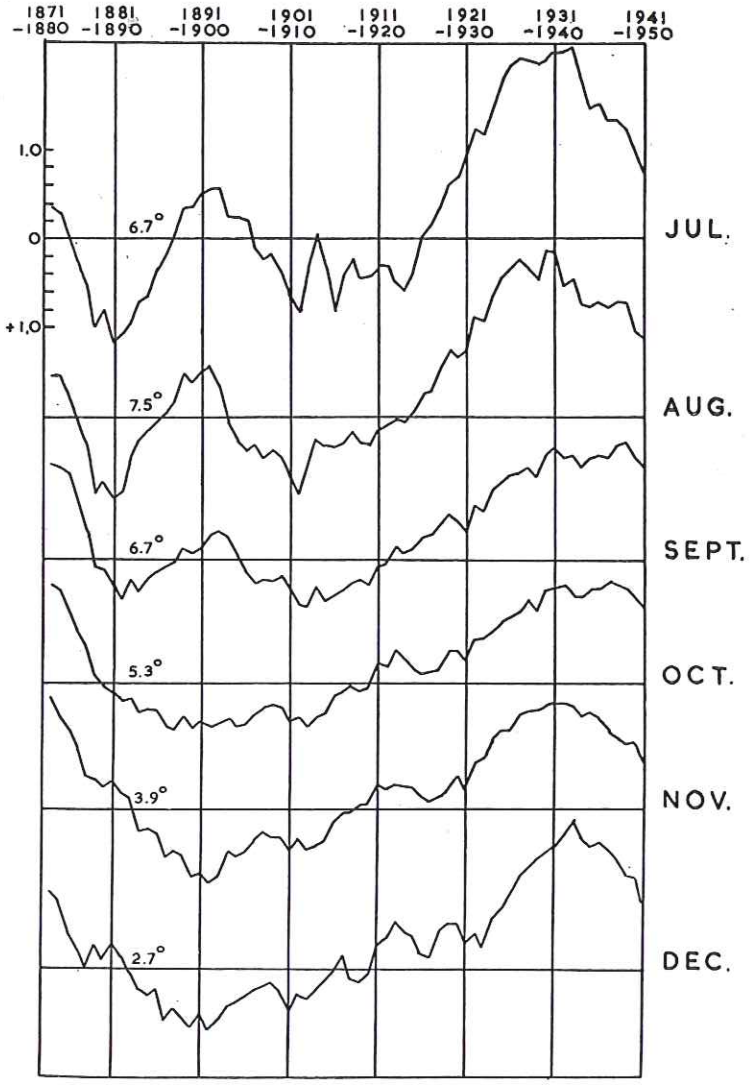


Fig. 7.
Variations of the monthly mean sea surface temperatures at Grímsey, July to December.

tive ten year periods. As seen from Fig. 4 the annual mean decreased from the period 1876/05 to 1881/10 when the lowest value of 0.48° C. below normal is reached. From then on it rises steadily to 1919/48 when a value of 0.98° C. above normal is reached. Fig. 5 shows that the temperature decreased until 1881/90, a temperature maximum is indicated around 1891/00, a temperature minimum around 1902/11, but from then on the temperature has increased, and it has risen particularly rapidly after 1911/20.

A maximum in the 10 year annual mean is attained around 1932/41 when it has a value of 1.4° above normal. Then the annual mean decreases again and in the period 1941/50 it is only 0.7° above normal.

Fig. 6—7 gives the temperature variations for each month smoothed by 10 year means. In the main they resemble the annual variations. Thus the temperature decreased from 1875/86 to 1881/90 and after 1920 the temperature increased in all months. In the months February to September

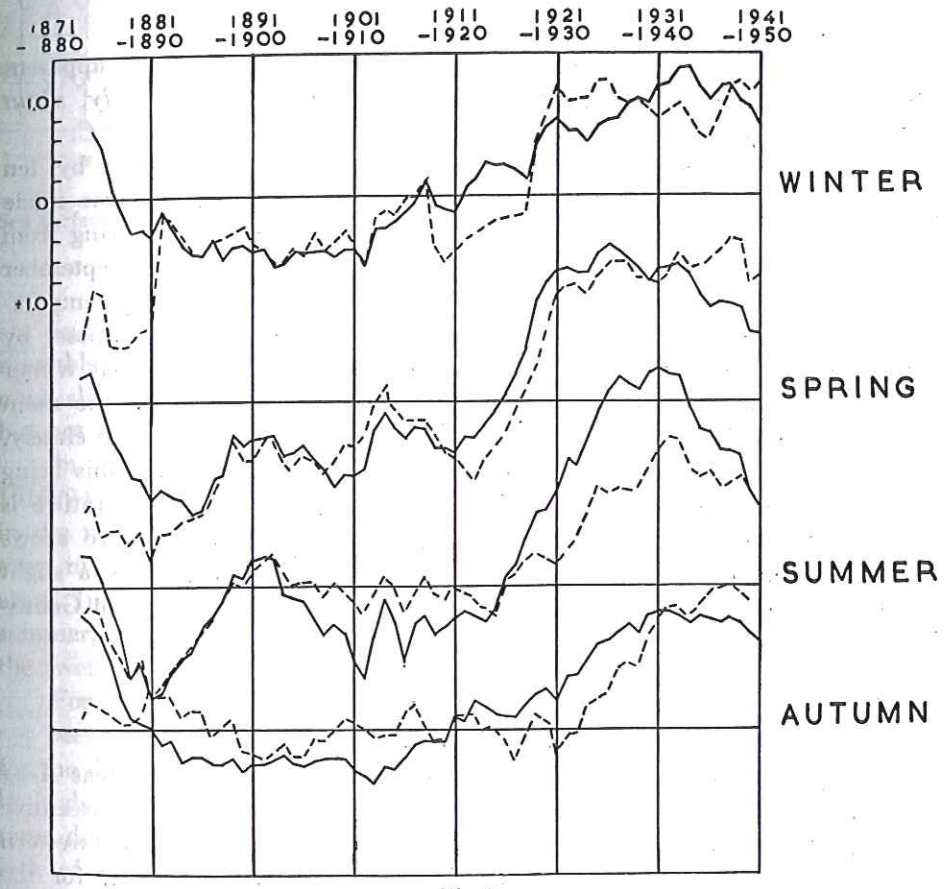


Fig. 8.
Variations of the seasonal mean temperatures at Grímsey.
Solid line sea surface temperature, broken line air temperature.

a temperature maximum is indicated around 1891/00. In the remaining four months no such maximum is seen. This maximum is particularly conspicuous in July and August, where the mean was about 0.5° above normal. In April another distinct maximum appears a few years after the period 1901/10. In the twenties all the months show a marked increase in temperature culminating in the period 1931/40 or a few years later. From

the period 1911/20 to the period 1931/40 the temperature gain for the various months was as follows:

January	0.95	July	2.43
February ...	1.36	August	1.95
March	1.30	September ..	1.31
April	1.69	October	0.87
May	2.43	November ..	0.89
June	2.87	December ..	1.13

From an inspection of the curves and the figures above, it is apparent that *the temperature rise has been greatest in May, June and July, about 2.5° above normal, but least in October—January or less than 1.0° C.*

Fig. *8* shows the seasonal temperature fluctuations, smoothed by ten year consecutive means. The division of the year into seasons was made here in the usual way, viz. winter from December to February, spring from March to May, summer from June to August and autumn from September to November. For comparison the corresponding curves for the air temperature are also shown. These were kindly placed at the author's disposal by Mr. *Eyþórsson*. It will be noted as regards the sea temperature that winter and autumn show similar features as do spring and summer. In the main the temperature variations of the air follow those of the sea rather closely, especially in spring and summer. In winter they differ somewhat, this being the season when the value for the difference sea minus air temperature is greatest. It will further be noted that whereas the sea temperature shows a distinct fall after about 1931/40, the air temperature shows only a slight tendency to decrease. Lastly we see that the rise in air temperature at Grímsey is greatest in spring and least in winter.

b. *Variations in the Coastal Area.*

The temperature variations during the period 1896—1939 in areas *A—J* (Fig. *1*) were studied in the same manner, i. e. by forming consecutive 10-year means. The fluctuations were averaged for areas A—C (western area), D—G (middle area) and H—J (eastern area). The results for the three summer months, June, July and August are shown in Fig. *9* a–c.

In June the sea surface temperature fluctuated in a similar manner in the middle and the eastern area, viz., irregularly until about 1911/20, then it increased rapidly and in 1930/39 it was 1.5° above normal in the middle area and 2.0° above normal in the eastern area. In the western area the fluctuations were somewhat different. There the temperature increased from 1895/04 until 1904/13 by about 0.7° C., falling again abruptly to 1.2° below normal in 1915/24. Then it rose rapidly and reached 1.0° above normal around 1925/34.

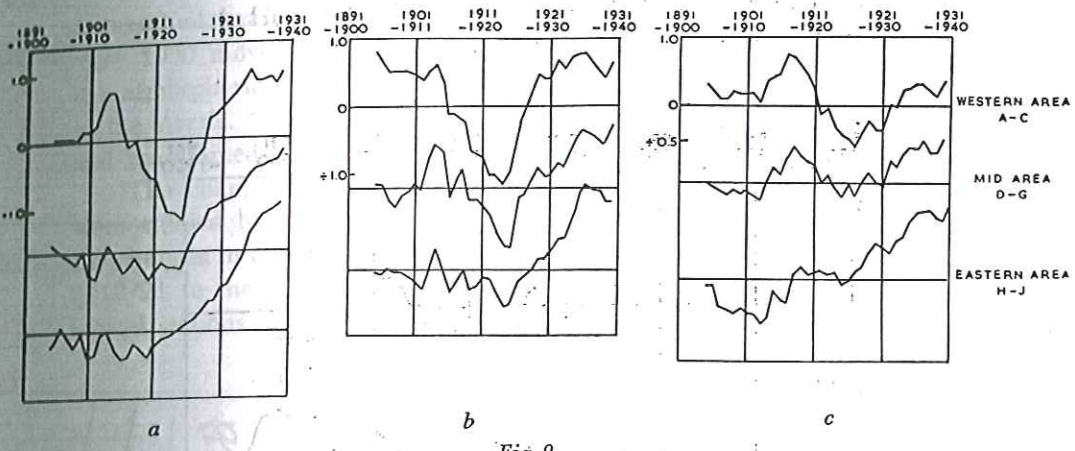


Fig. 9.
Sea surface temperature variations in western (A–C), mid (D–G) and eastern (H–J) area, *a* in June, *b* in July, and *c* in August.

In July the temperature fluctuations of the middle and the eastern area resembled more those of the western area. This time the temperature minimum shortly after 1911/20 also appeared in the middle and the eastern area, but not as distinctly as in the western area.

In August the temperature minimum of the western area (around 1915/24) was much less conspicuous than in the other two months and in the middle area it was only slightly indicated. In this month the variations in the eastern area differed considerably from those of the other two areas. In all the areas the temperature rise was least towards the end of the summer, particularly in the western area the temperature rise beginning in the twenties was only very slight.

For the period 1876—1895 the temperature values for these areas have not been published for individual years, but *Ryder (1917)* gives the means for the decades 1876—1885 and 1886—1895. These values appear surprisingly high for the western part of the area considering the severe ice conditions during the last decades of the 19th century. However, on account of lack of the original data, a further discussion on this matter will here be omitted.

In Fig. *10* the fluctuations in sea surface temperature in area *F* and *G* for the summer season are compared to those at Grímsey. It appears that these three curves show a close correlation as was to be expected. It should be noted, however, that the temperature increase is distinctly greatest at Grímsey. This is probably caused by the fact that the majority of the measurements from areas F and G have been made close to land. At Grímsey the effect of the ice on the surface temperature has been greater, and as will be discussed later, the decreasing extension of drift ice during recent

decades is most likely one of the main reasons for the marked temperature increase at Grímsey during the summer months.

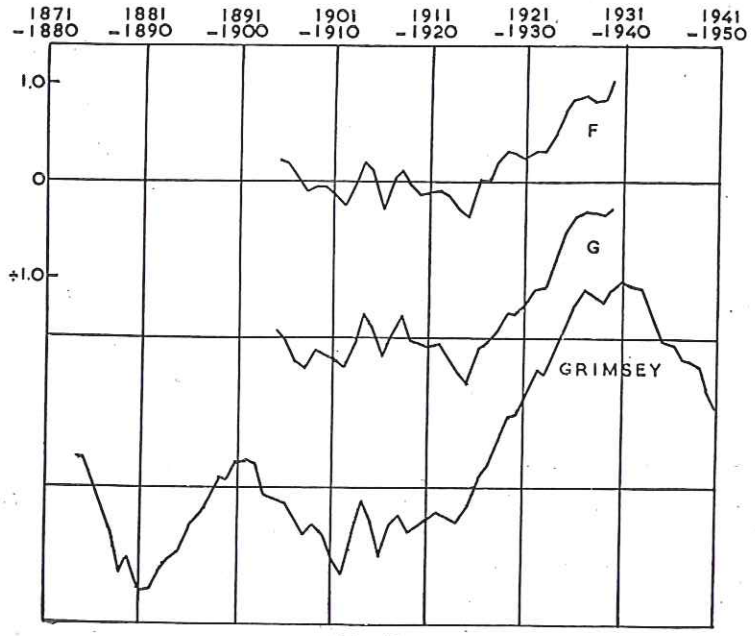


Fig. 10.
Sea temperature variations for the summer season in area *F*, *G* and at Grímsey.

5. *Possible Causes of the Observed Temperature Fluctuations.*

In attempting to explain the observed variations in the surface temperature a number of possibilities will have to be examined. As regards Icelandic waters with their changeable hydrographical and meteorological conditions, this problem will be a very complex one. In this case, therefore, we can not expect to find a straight-forward correlation between the fluctuations and say one single meteorological phenomenon. More likely we will have to consider the interplay of many factors, most of which may again be governed by some general cause. Some of these factors will now be discussed.

a. *Changes in the Atmospheric Circulation.*

Extensive literature on changes in the meteorological condition has been published by *Helland-Hansen* and *Nansen (1916)*, *Defant (1924)*, *Wagner (1929)*, *Hesselberg* and *Birkeland (1940—43)*, *Rubinstein (1946)* and others, the main conclusions being that the principal reason for climatic changes in the arctic regions is the change in the atmospheric circulation. Also, accord-

ing to *Eriksson (1943)* the low pressure area in the north Atlantic which after 1920 moved abnormally far northwards has changed the direction of the atmospheric pressure gradient so as to increase the flow of warm air to the Arctic. "This increased flow of heat," Eriksson states, "has produced and maintained a strong positive anomaly of temperature."

The changes of air pressure in the North Atlantic, including Iceland, were studied by *Hesselberg* and *Birkeland (1943)*. Their charts illustrating the changes in air pressure at sea level for the various seasons from the period 1912/21 to the period 1926/35 make use of the records from two meteorological stations in Iceland, viz. *Stykkisholmur* and *Vestmannaeyjar*.

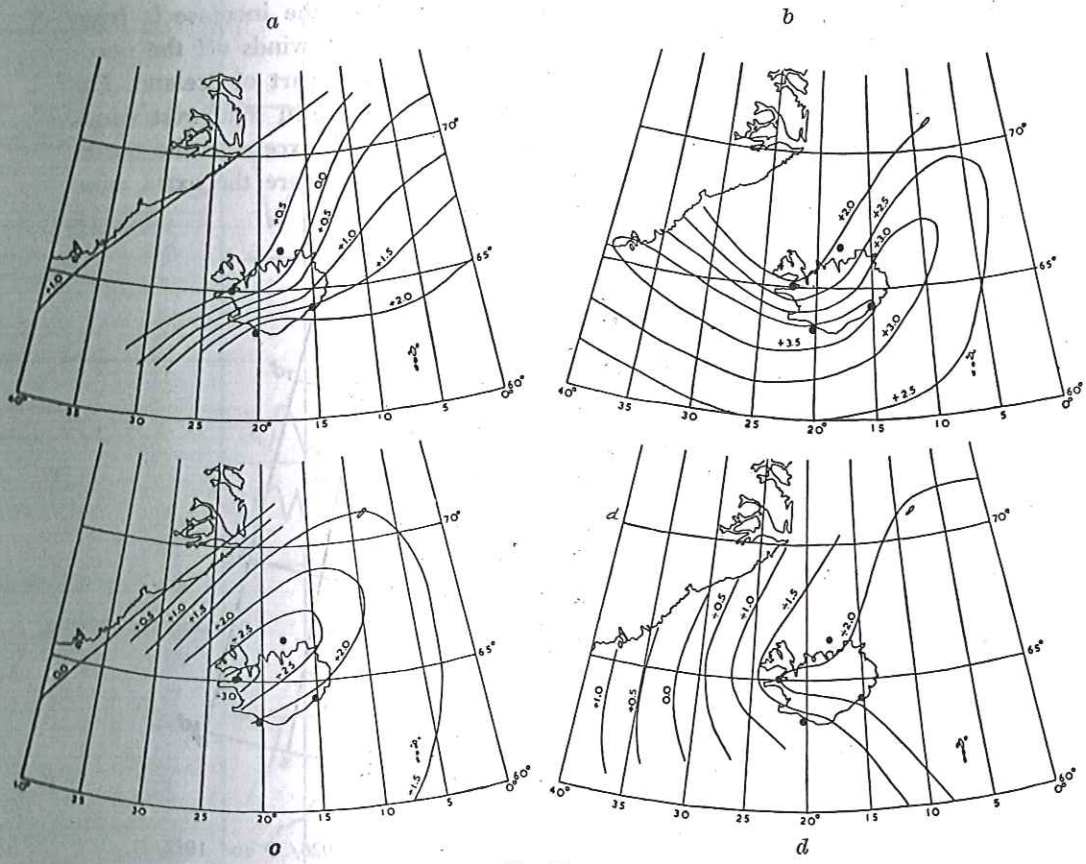


Fig. 11.
Difference in the seasonal air pressure between the period 1926/35 and the period 1912/21, *a* winter, *b* spring, *c* summer, *d* autumn.

In order to make these charts more detailed as regards the area around Iceland, the values for the stations *Grímsey* and *Berufjordur* have been calculated and are here (Fig. *11* a–c) inserted on the charts. Besides, slightly different values for Stykkisholmur are also used to correct for height of

the station since found to be somewhat different according to Mr. *Hlynur Sigtryggsson* of the Icelandic Meteorological Office.[1])

These modified charts of the pressure difference between the periods 1912—1921 and 1926—35 show, however, no appreciable difference from those of Hesselberg and Birkeland. In looking at the charts it becomes at once apparent that in *winter* there has been a great increase in SW-winds in Iceland, especially in the southern and the eastern part of the country. In *spring* there is an increase in westerly winds in the southern and western part of the country and southwest winds off the north coast. In *summer* there is an increase in south winds in most part of the country, except in the northwest part and off the northwest coast where the increase is from northeast. In *autumn* there is a slight increase in north winds off the north coast and in west or northwest winds in the southern part of Iceland. For the *year* as a whole (Fig. 12) there has been an increase in southwest winds in Iceland and over Icelandic waters during this period, except in the northwest part of the country and off the northwest coast, where the extra wind component has been from the north or northeast.

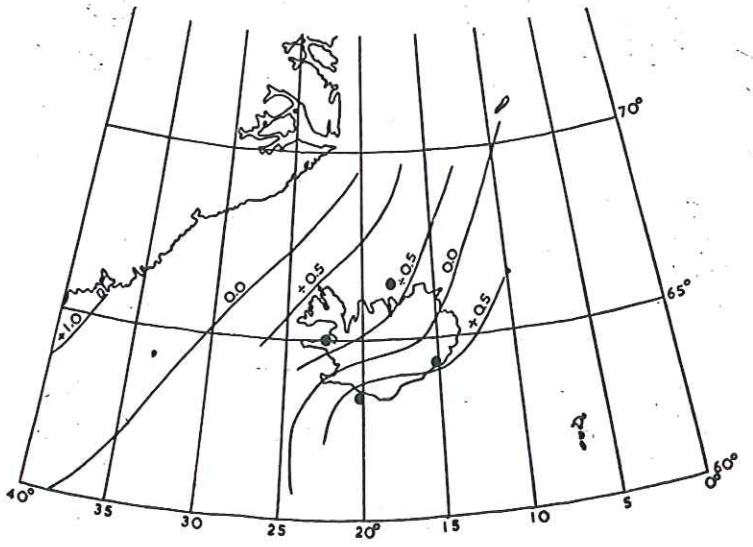


Fig. 12.
Difference in the annual air pressure between the period 1926/35 and 1912/21.

Deviations in the frequency of SW-winds at Grímsey expressed by 10-year moving summations for the various seasons are shown in Fig. *13*. The fluctuations observed are seen to fall in line with the changes in pres-

1) The true heights were:

1907—1919 H = 17.8 m
1920 H = 16.2 —

sure distribution as shown on Fig. *11–12*. Especially noticeable is the great increase in SW-winds in winter beginning around 1920. However, in summer and fall there has not been an increase in SW-winds around 1920, but for the year as a whole they have increased to a small extent.

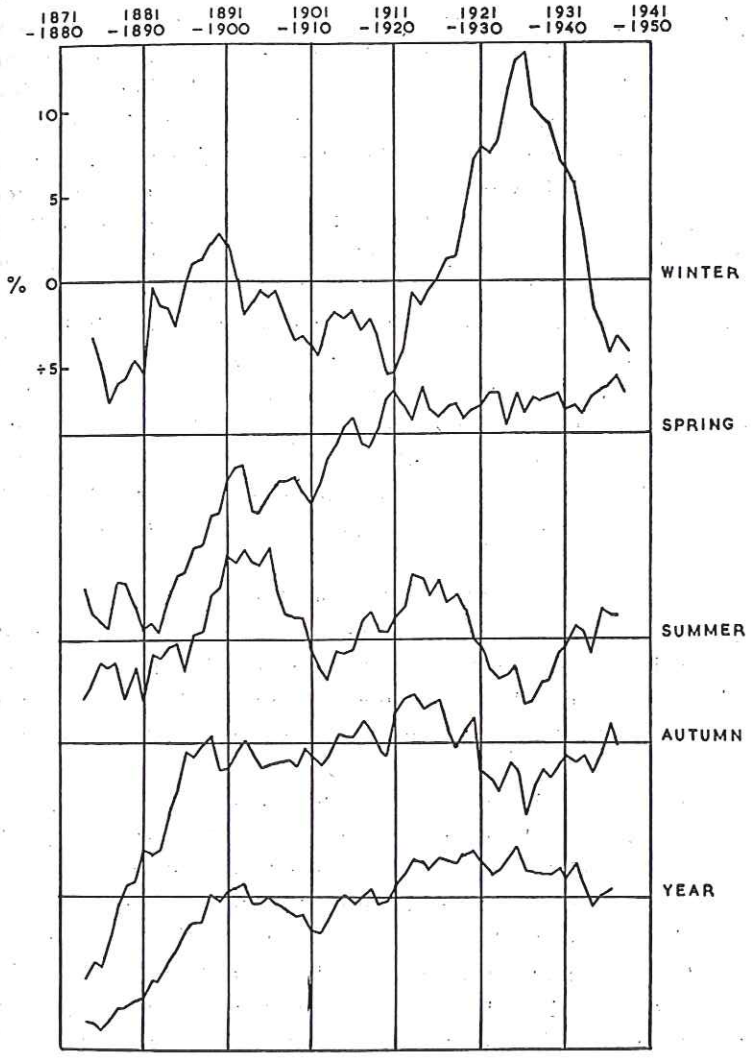


Fig. 13.
Deviations from mean in the frequency of south-west winds expressed as the difference between the south-west and the north-east wind component.

As previously mentioned the main conclusions of *Eyþórsson's* investigations of the air temperature variations were, first that the temperature increased rapidly after 1920 and secondly that the increase in air tempera-

ture has been greatest in winter, and least in summer and fall. His results are therefore in good agreement with the changes in air circulation thus illustrating clearly *the causal connection between the variations in air circulation and air temperature.*

Also the variations in the sea surface temperature of the North Icelandic coastal area are seen to correlate to some extent with the corresponding variations in wind frequency. Thus the increase in sea temperature after 1920 coincides with the maximal increase in SW-winds. However, the records from Grímsey show some discrepancies in this respect. To begin with the increase in sea temperature at this place has been greatest in summer, and smallest in autumn and winter while the air temperature has shown the greatest increase in winter and the smallest in summer and fall. Furthermore, the correlation between the variations in air and sea temperature is less at Grímsey than at Papey on the southeast coast. Farther west in the area the correlation between air and sea temperature is still less as would be apparent, if we compared the variations in sea temperature in the western area with the corresponding variations in air temperature at *Bolungavík* on the northwest coast (see *Eyþórsson 1949*, p. 52). This indicates that *other factors besides changes in the wind frequency alone are responsible for at least some af the fluctuations in sea temperature in the North Icelandic coastal area, especially as regards the western part of the area.*

b. *Changes in Wind Force.*

In any detailed study of meteorological conditions, changes in the wind strength as well as the direction of the winds will have to be taken into account. Thus increased SW-winds during winter will be more effective in bringing warm air to the area than in summer, when the mean wind force is less.

In this paper we will only consider the *mean wind force.* Such a mean may of course sometimes be misleading, but as a rule it should together with the deviations in wind frequency, give a rough idea of changes in air transport. Furthermore, we must keep in mind that the estimations of wind force at a place like Grímsey where an anemometer has never been available, may not be too dependable and are apt to be somewhat subjective. The possibility was considered that the observed variations in wind force might to some extent be due to change of observers at this station. But it so happens that from 1895—1936 the meteorological observations were carried out by the same person *(Matthías Eggertsson)* and within this period the greatest variations occurred.

The fluctuations in wind force by means of 10-year moving averages for the different seasons are shown in Fig. *14*. All the curves show a distinct decrease in the mean wind force, beginning around the middle of the twenties, i. e. roughly at the time when the temperature curves began to rise.

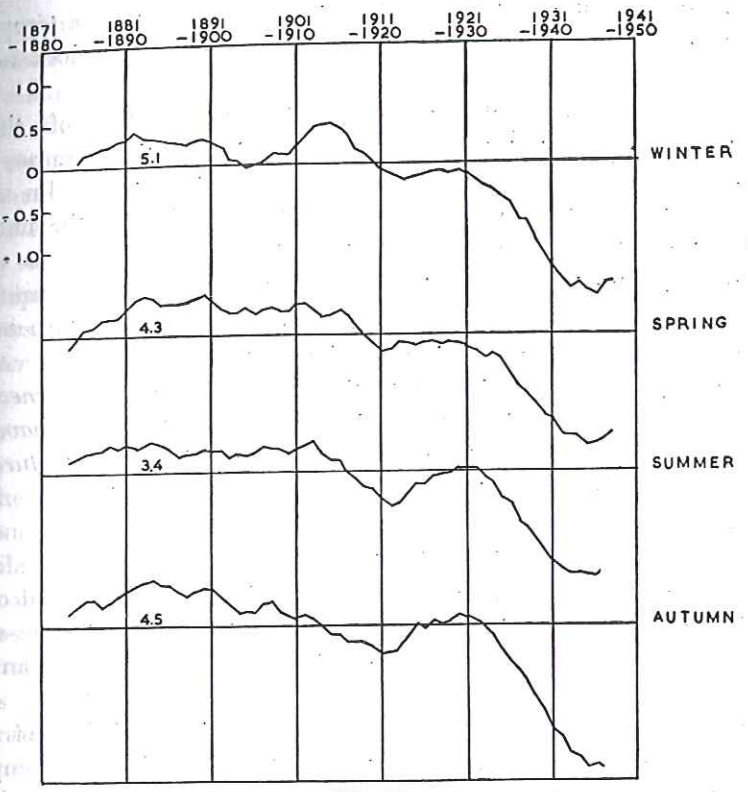


Fig. 14.
Seasonal variations in wind force at Grímsey in consecutive 10 year periods.

In Fig. *15* a comparison is made of the inverted curve showing the 30-year moving averages of the mean annual wind force and the corresponding averages in the annual sea temperature. As seen from the figure, there appears

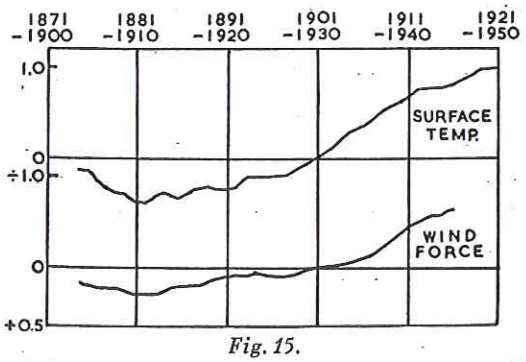


Fig. 15.
Comparison of the variations in sea surface temperature and wind force, the inverted curve showing the 30 year moving averages of the mean annual wind force.

to be a negative correlation between the wind force and the sea temperature. As regards the individual seasons, however, the agreement does not seem to be too good.

It would seem logical that the sea surface temperature off the north coast is increased by diminishing wind force during the summer season, as a sharper thermocline will be formed if the weather stays calm and thus less heat will be lost from the surface layer in mixing with the underlying water. In winter, however, the diminishing wind velocity would be expected to have the opposite effect. This influence of the wind velocity on the surface temperature will not as a rule be as apparent off the south and west coasts where the water column is more homogeneous.

On the whole we can thus state that *the decrease in the mean wind velocity which took place about the middle of the twenties, may have contributed somewhat to the great increase in the sea surface temperature of the North Icelandic coastal area in summer.*

c. *Variation in the Ocean Currents.*

The sea surface temperature will naturally be much dependent on changes in the currents conveying warm or cold water masses to the observed field. Such changes will have a stronger influence on the sea than the air temperature.

In the North Icelandic coastal area variations in the influx of Atlantic water will greatly effect the surface temperature provided the temperature of this water mass be higher than that of the water already present in the area it invades. The heating effect will thus be greater, if the influx takes place in the early spring before the summer warming has started. In the winter season, when Atlantic water is present in the westernmost part of the area, at least occasionally, the surface temperature will increase rapidly offshore, as was the case in February 1948. In the summer season, however, when the heating of the sun has already warmed up the top layer and complete stratification has been attained, continued influx of Atlantic water with similar temperature will not be of any appreciable effect on the surface temperature in this area. Thus in early July 1948, late July 1949, August the same year and in the beginning of August 1950 only small variations were found in the coastal area south of 67° N. In other cases, such as in August 1948, the surface temperature, showing little gradient from west to east, has been found to decrease much more rapidly away from the coast. The fall in temperature from near the coast to 67° N. may be up to 2 to 3° C. But this has no relation to the Atlantic influx.

Changes in the extension of the East Greenland Polar Current and the East Icelandic Current will have great influence on the temperature conditions in the Icelandic coastal area. But we know very little about year to year fluctuations in these currents because of insufficient data. It should be

kept in mind, however, that probably no independent effect on climate can be ascribed to changes in the currents since they are governed by changes in the atmospheric circulation. It would therefore be expected that coincident with the increased SW-winds in the twenties, due to the changes in the low pressure area of the North Atlantic there was an increase in the Atlantic current which again would strengthen the influx of this water to the North Icelandic coastal area. But we can not prove this on account of the scarcity of hydrographical observations. However, as will be discussed in a later paper, investigations of the sections off *Melrakkasletta* and between *Langanes* and *Jan Mayen* seem to indicate *increasing amounts of cold arctic water in the area off northeast Iceland in the most recent years.*

d. *Variations in the Extension of the Drift Ice.*

The occurrence of polar ice at the coasts of Iceland has for centuries been one of the most serious concerns of the people living in the country, particularly on the north and northwest coasts. In heavy ice years all navigation along the north coast is hampered and farming may suffer greatly. The possibilities for civilized life in Iceland are therefore highly dependent upon nature. The influence exercised by the drift ice on the climate in Iceland is tremendous. In heavy ice years the climate actually changes from temperate to arctic. In exceptional ice years also the temperature at the east or even south east coast of Iceland is lowered. In ordinary years, however, the influence of drift ice is most apparent off the northwest coast and then usually in the spring and the early summer.

As appears from the numerous papers on drift ice published within the last 10—20 years, the ice conditions in northern waters have greatly improved as the result of the increased flow of heat to the Arctic. Since the beginning of the century, ice conditions at Iceland have been improving. This is clearly seen from the graphical representation of the occurrence of ice recorded in a paper by *Thorarinsson (1941)*. During the last decades drift ice has only very rarely been observed near the coasts of Iceland.

In Fig. *16–17* the seasonal and annual variations in the frequency of drift ice are expressed by 10-year moving summations. The graphs are inverted with frequencies higher than normal shown below the line and vice versa. The calculated values are based upon Thoroddsen's ice chart *(Thoroddsen, 1917)* for the period prior to 1916, and after that time on ice reports published in the *Danish Meteorological Annual* and *Veðráttan*. As seen on the figures the mean values of the frequency of ice for the period 1901—1930 are as follows: winter 6 days, spring 14 days, summer 7 days, and the entire year 27 days. Spring is thus by far the heaviest ice season. In autumn ice occurs only very rarely at the coasts of Iceland. All the curves indicate an improvement in ice conditions after 1881/90. In winter

ice conditions have been gradually improving and since 1920 ice has occurred only rarely during the winter months. In spring there was a distinct improvement in ice conditions from the nineties to about 1921/30. In summer

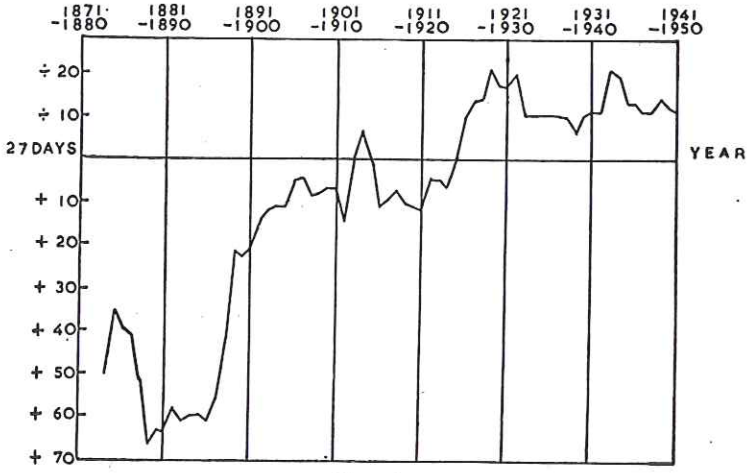


Fig. 16.
Annual variations in the frequency of drift ice expressed by 10 year moving averages.

the inverse ice curve rises sharply from 1882/91 to 1889/98. Then follows a period of about 15 years with practically no ice. Next comes a period with heavier ice years. Finally the curve rises again shortly after the period 1911 /20, and for the last 20 years ice has only very seldom been observed during the summer months.

The curves shown on Fig. *16–17* must be taken with some reservations. They are primarily indicative of ice at the northwest coast where it is most often first observed and occurs more frequently than farther east. Furthermore, only the number of days with ice has been taken into consideration. The curves give no information regarding how much of the shore was in contact with the ice. Therefore, the values for the heavy ice years tend to be uninformative as to the quantity of ice present along the coast (cf. *Koch, 1945*, p. 236—238). Also drift ice may often extend into the coastal area without being observed from land. Lastly, ice reports from Iceland may not be too dependable, especially in the past, when the ice observing stations were fewer than they are now, so that scattered ice floes are undoubtedly more likely to be reported now than they were in the past. The great change in the extension of ice in the area north of Iceland and between Iceland and Greenland after 1920 will therefore appear more distintly if we examine the actual ice maps.

At the bottom of Fig. *17* (the dotted curve) comparison is made of the variation in the ice frequency and the temperature in the western area

during the summer season. As seen, there exists a close negative correlation between the sea temperature and the ice frequency, and thus we have an explanation of the marked temperature minimum which was found in the western area between 1910 and 1920.

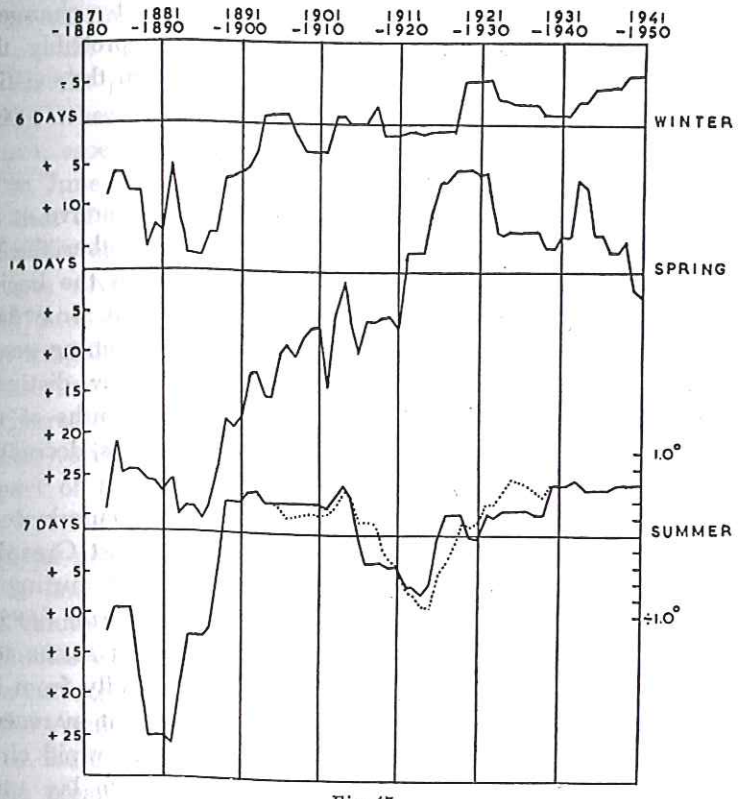


Fig. 17.
Seasonal variations in the frequency of drift ice.
Dotted line shows temperature variations in the western area in summer.

In spite of the fact that the extension of ice must primarily be considered the effect rather than the cause of the climatic change, one must keep in mind that the drift ice may exert great local influence by cooling limited areas. It would therefore be expected that at the north and the northwest coast of Iceland such local influence would be greatest. The cooling effect would, however, be much less in winter when the surfae temperature in the area is already quite low (2—3° C. or less). But in spring or summer when the surface layers have warmed up, this influence may be of great consequence. Besides, the drift ice occurs more frequently in spring and early summer than in other seasons.

The ice maps published in *Koch's* work on the East Greenland polar ice

(1945), show distinctly how the ice conditions at Iceland have greatly improved since 1920, particularly in the middle and the eastern area. But doesn't this suggest that the great increase in sea surface temperature at Grímsey after 1920 during spring and summer is to some extent due to the decreased extension of drift ice? In the area around Grímsey and farther east the temperature change is no doubt largely caused by changes in air circulation, whereas in the western area the drift ice is probably the main factor. These arguments seem to get their full support from the existing data.

e. *Concluding Remarks.*

At this point it would seem most desirable if we could arrive at a logical conclusion as to what we may expect in coming years, whether the sea temperatur in near future will fall or remain unchanged. On the basis of the material here discussed, we can not do any forecasting, but some data seem to indicate that we are in for a more severe climate in the coming years. Thus the curves giving the temperature variations at Grimsey show distinctly that the sea surface temperature has been decreasing in all months of the year during the last decade. However, the air temperature has decreased only slightly during the last 10—15 years.

It appears that the improvement of the ice conditions culminated in the thirties. Thus 1938 was one of the heavier ice years at East Greenland. At Iceland greater quantities of drift ice have been observed during the last decade than during the preseding decade. *Jensen* and *Fristrup (1950)* state that the thickness of the drift ice off the Greenland coast seems to be diminishing, indicating that the ice is now moving more rapidly from its place of formation to the East Greenland pack ice. They feel that in recent years the greater quantities of drift ice are the result of a more rapid circulation of the ice, and that great quantities of ice which hitherto lay untouched are now broken off and carried to the drift ice belt. They believe that this will cause a more than normal frequency of drift ice for some years. In a paper by *Rasmussen (1950)*, on the other hand, it is stated that the drift ice along the coast of Greenland in 1949 was unusually thick and heavy. This indicated, according to *Rasmussen*, that it was not only ice frozen in one winter which had broken up, but that areas which had not been touched by the summer breakup in 1948 had broken up in 1949. *Rasmussen* considers it possible that the increased flow of ice was caused by the Atlantic water having penetrated unusually far towards north in the Spitsbergen area during spring and summer.

Summary.

1. The 1901—1930 normals for the north Icelandic coastal area were calculated for the summer months, the observation material for other seasons being considered insufficient. The 1901—1930 normals of the sea temperature as measured at the meteorological station *Grímsey* were calculated for each month. Comparison of the mean annual cycle of the surface temperature for the period 1901—1930 with the corresponding air temperature reveals that whereas the sea temperature is generally higher than the air temperature, especially in winter, the air temperature exceeds the sea temperature in June and July. The temperature maximum of the air occurs in July but that of the sea in August.

2. Studies of the temperature variations at Grímsey by means of moving averages reveal that in all months the temperature decreased from around 1875 to shortly before the turn of the century. Then it fluctuated somewhat irregularily until in the twenties when all the months show a marked increase in temperature, culminating between 1930 and 1940. This temperature increase is found to be greatest in late spring and early summer.

3. The variations during the period 1896—1939 in the middel and the eastern part of the coastal area in summer are seen to resemble those at Grímsey, but in the western part they are somewhat different. In this part of the coastal area a distinct fall in the sea surface temperature occurs between 1910 and 1920. In general the temperature rise of the twenties shows increased values to the east.

4. Studies were made of the main causes of the observed fluctuations in the sea surface temperature. Whereas the changes in air and sea temperature in the Arctic in general are considered to be primarily the result of changes in the air circulation, other factors such as changes in wind force and in the ocean currents and the extension of drift ice may be of local importance in the North Iceandic coastal area.

5. Charts illustrating the change in air pressure at sea level between the periods 1912—1921 and 1926—1935 indicate an increase in SW-winds in Iceland, especially in the southern and the eastern part of the country. In the North Icelandic coastal area the changes have been such that the increase has been greatest in the eastern area, less in the middle part, whereas in the western part there has been only a slight increase or even a decrease in SW-winds. The changes have been greatest in winter.

6. Deviations in the frequency of SW-winds at Grímsey expressed by 10-year moving summations also show a marked increase in SW-winds in winter beginning around 1920. In other seasons the increase in southerly winds has been very slight.

7. Examination of the variations in wind force at Grímsey indicates a distinct decrease in the mean wind force around the middle of the twenties.

8. Variations in the influx of Atlantic water into the North Icelandic coastal area will affect the surface temperature, especially if the influx takes place in the early spring before the summer warming has started.

9. Although the drift ice is not a primary climatic factor, it may have great local effect in cooling limited areas. This will particularly be true off the north west coast of Iceland. The cooling effect of the ice is greatest in late spring and early summer. Thus at Grímsey the relatively great rise in temperature in spring and summer can be attributed to the combined effect of changes in the atmospheric circulation and the improved ice conditions. In the western part of the coastal area where the influence of the drift ice is greatest and the increase in SW-winds least, the extension of drift ice is the dominating factor. In this area a distinct negative correlation exists between the surface temperature and the extension of ice.

Acknowledgements.

The author wishes to express his thanks to the director of the Icelandic Meteorological Office, Mrs. *Theresia Gudmundsson*, for placing the meteorological data at his disposal. Thanks are also due to Mr. *Jón Eyþórsson* of the Icelandic Meteorological Office for his criticism, valuable suggestions and genuine interest in the work. Further the author wishes to thank his assistant, Miss *Sigþrúður Jónsdóttir*, who has tabulated the data, carried out many of the calculations and made nearly all the drawings. Lastly, thanks are due to Messrs. *Joseph Chase* and *Irving Schell* of the Woods Hole Oceanographic Institution for amending the English text.

REFERENCES

1. *Defant, A.* (1924): "Die Schwankungen der atmosphärischen Zirkulation über dem Nordatlantischen Ozean im 25-jährigen Zeitraum, 1881—1905". Geogr. Ann. *6.*
2. *Eriksson, B. E.* (1943): "Till kännedomen om den nutida klimatändringen inom områdena kring nordligaste Atlanten." Geogr. Ann. *25.*
3. *Eyþórsson, J.* (1949): "Temperature Variations in Iceland." Glaciers and Climate, Geogr. Ann. *1949.* H. 1–2.
4. *Fridriksson, Á.* (1948): "Boreo-tended Changes in the Marine Vertebrate Fauna of Iceland during the last 25 Years." Rapports et Procès Verbaux des Réunions, *CXXV.*
5. *Helland-Hansen, B. and Nansen, F.* (1916): "Temperatur-Schwankungen des Nordatlantischen Ozeans und in der Atmosphäre." Videnskapsselskabets Skrifter *I.* Mat.-Naturv. Klasse. No. 9.
6. *Hesselberg, T. and Birkeland, B. J.* (1940—44): "Säkulare Schwankungen des Klimas von Norwegen." Geophys. Publ. *14,* 4, (1940), *14,* 5, (1941), *14,* 6, (1943) and *15,* 2, (1944).
7. *Jensen, Ad. S.* (1939): "Concerning a Change of Climate during Recent Decades in the Arctic and Subarctic Regions." Kgl. Dansk Vid. Selsk., Biol. Medd., *14.*
8. *Jensen, Ad. S. and Fristrup, B.* (1950): "Den arktiske klimas forandring og dens betydning, særlig for Grönland." Geografisk Tidskrift, *50.*
9. *Koch, L.* (1945): "The East Greenland Ice." Medd. om Grönl., *130,* No. 3.
10. *Lysgaard, L.* (1948): "Recent Climatic Fluctuations." Rapp. et Proc.-Verb. *CXXV.*
11. *Danske Meteorol. Institut:* Nautical Meteorological Annual, 1892 and 1895—1939.
12. —— Meteorological Annual 1876—1920.
13. *Rasmussen, B.* (1950): "Notes on the Ice Conditions in Greenland Waters in 1949." Ann. Biol. *VI.* (1949).
14. *Rubinstein, E.* (1946): "K probleme izminenija klimata." Sci. Res. Dept., Ser. Hydro-Meteorol. Serv. U.S.S.R.
15. *Ryder, C.* (1917): "Monthly Mean Temperatures of the Surface Water in the Atlantic, North of 50° N.Lat." (App. to Naut.-Meteor. Annual). Copenhagen 1917.
16. *Sæmundsson, B.* (1934): "Probable Influence of Changes in Temperature on the Marine Fauna of Iceland." Rapp. et Proc.-Verb. *LXXXVI.*
17. *Scherhag, R.* (1937): "Die Erwärmung der Arktis." Journ. du Cons. *12,* 3.
18. *Smed, J.* (1948): "The Increase in the Sea Temperature in Northern Waters during Recent Years." Rapp. et Proc-Verb. *CXXV.*
19. —— (1949): "Monthly Anomalies of the Surface Temperature in the Sea around Iceland during the Years 1876—1939 and 1945—1947." Ann. Biol. *IV.*, (1947).
20. *Tåning, V.* (1948): "On Changes in the Marine Fauna of the North-Western Atlantic Area, with Special Reference to Greenland." Rapp. et Proc.-Verb. *CXXV.*
21. *Thomsen, H.* (1937): "Variations of the Surface Temperature at Selvogsbanki, Iceland, during the Years 1895—1936." Rapp. et Proc.-Verb. *CV.*
22. *Thorarinsson, S.* (1941): "Mot eld och is." *Ymir* 4.
23. *Thoroddsen, Th.* (1917): "Árferði á Íslandi í þúsund ár." Copenhagen, 1916—17.
24. *Veðurstofan, Reykjavík:* Íslenzk Veðurfarsbók, Reykjavík 1921—1923.
25. —— Veðráttan, Reykjavík, 1924—1948.
26. *Wagner, A.* (1929): "Untersuchungen der Schwankungen der Allgemeinen Zirkulation." Geogr. Ann. *11.*