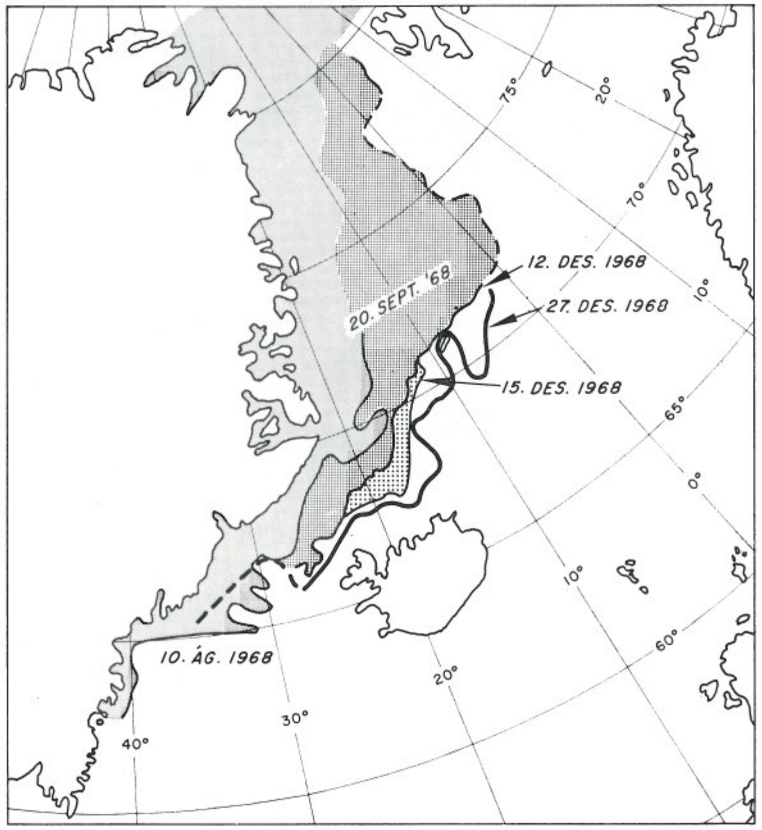

Fig. 10. The position of the ice edge is shown at several dates from August 10 to December 27, 1968. This composite picture is compiled from APT pictures and aircraft reports. The question is: will we be able to forecast the movement of the ice edge in the future?

snow from the land near the coastline will frequently show up as an apparent break in the icefield, while big leads (polynyas) in the ice-pack give evidence of great internal stresses, that are not easily explained. New and transparent ice is not discernible in the pictures. However snow that falls on top of ice of this kind will make it immediately visible. This can cause some confusion since the ice edge may seem to have advanced inexplicably far in a short time, and quite rapidly in spite of gentle wind speed. This kind of ice tends to break up easily and moves then much more rapidly than the main ice-pack.

Conclusion: By using APT pictures and mapping the position of the ice edge, whenever possible, and also using average monthly surface pressure maps, revised every 10 days or so, it should be possible to forecast the movement of the icefield 10 to 15 days ahead. These forecasts would be based upon Zubov's rule:

$$V = \alpha_1 \Delta p$$

where V is the drift of the ice in kilometers per month.

Δp is the pressure gradient in millibars per kilometer, calculated from an average monthly surface pressure map, and

α_1 is called the isobaric coefficient.

The rule is based on an empirical approach so one would probably have to find a new value for α_1. In the preliminary studies the value 13,000 was used.

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Winds and Ice Drift North of Iceland, Especially in the Year 1965

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ABSTRACT

The aim of the work presented here was to investigate whether the onrush of drift ice to the north coast of Iceland in February 1965 was caused chiefly by winds, and to study the correlation between the movement of the ice edge east of Greenland and the winds in these tracts.

Secondly it was the purpose to follow the movements of the ice in Icelandic waters after it had arrived and to find how its drift was related to winds.

INTRODUCTION

In the 19th century is was believed in northern Iceland that westerly winds increased the danger of ice. British meteorologists came to the same conclusion after their experience in Iceland during World War II, especially in the spring of 1944. *(British Hydrographic Dept.* 1946). Their research included seven years of the period 1931 to 1945 and showed that when southwesterly winds between Iceland and Greenland had lasted one to two weeks, one could expect drift ice near Straumnes, and after a duration of three weeks it would have passed Horn. The months August to November were excluded, because in these months drift ice near the Icelandic coasts is an exception.

In the years 1951 to 1956 the author kept a record of wind components between Northwest Iceland and the Greenland coast. In these years no considerable ice occurred in Icelandic waters, so these observations were discontinued. They showed, however, that a few days of southwesterly winds always preceded ice occurrence at the coast of Vestfirðir.

It may seem more natural that northwesterly winds would bring ice to the coast. But due to the effect of Greenland northwesterly winds are an unstable phenomenon at the northwest coast of Iceland. Southwesterly winds can, however, last there for days, even weeks. Therefore, it becomes their role to bring in the ice to Vestfirðir, at least when the ice belt along Greenland is relatively narrow.

After a few days of unusually strong southwesterlies off the northwest coast, ice came in the proximity of Straumnes and Horn on the 9th and 10th of January, 1952. It was apparent from trawler reports that the ice edge had moved 80 miles* towards the coast. By assuming the surface wind to be 70% of the geostrophic one, it appears that the ice has drifted with the speed of 4–5% of the surface wind. This is about twice the speed *H. U. Sverdrup* (1942) reports from the Arctic. There he found that the thick April ice drifts with 1.4% of the wind velocity against 2.4% for the thinner August ice. Here off the northwest coast of Iceland, we have altogether different conditions. The floes at the ice edge are thin and will, therefore, drift with a higher percentage of the wind velocity than thicker ice. Secondly, in a southwesterly wind over the Greenland Sea in winter the air is in an unstable state, so the velocity of the air above is easily carried down to the surface. Such turbulence effect causing transport of momentum is always present over the partly open waters at an ice edge when the wind blows out from the solid or nearly solid, cold, main drift ice. This turbulence is probably the greatest factor in forming a belt of open drift and scattered floes along the edge of major drifts.

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*) Nautical miles are used throughout.

And, although it is not known to what an extent ocean currents may have effected the drift of the ice in the case above of Jan. 1952, one is led to believe that in some cases scattered floes can drift with as much or even greater speed than 4% of the wind velocity.

ICE AND WINDS EAST OF GREENLAND

Before considering the ice condition in the year 1965, some analyses of the average condition of winds and ice north of Iceland is necessary, because the ice that comes to the northeast coast of Iceland must originate there.

The winds have been divided into two components, one along the ice edge, the other perpendicular to it, or rather to lines selected close to its average position; Fig. 1. The ice edge is divided into three regions, each 300 miles in length, named region N, region M and region S. Monthly component values are found from the charts of the *German Weather Office* in Hamburg: Die Witterung in Übersee.

The position of the ice edge is taken from the monthly ice charts issued by the *British Weather Office* since March 1962. Fig. 2 shows the position of the ice edge in relation to the

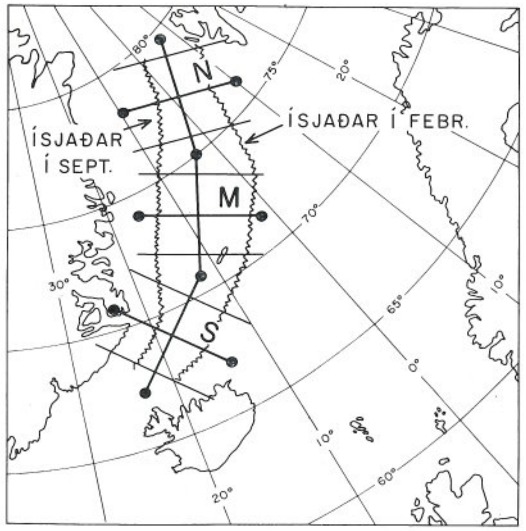


Fig. 1. The regions or lines from which the ice limit is measured and the wind components worked.

lines N, M and S. Each ice year is considered to begin in October and end with September, since then the ice is at its minimum as clearly appears in Fig. 4. It is obvious that the ice coverage is greatest in all the three regions at the end of February, but it decreases rapidly in March and April in regions N and M, whereas the decrease is much slower in region S between Jan Mayen and Iceland.

In order to get an oversight over the ice amount each year with respect to other years and to the average condition a graph has been made showing the position of the ice edge with respect to the monthly mean, Fig. 3. In region S the ice years 1965 and 1968 stand out, also 1967. Furthermore, there is quite apparent ice in this region in the falls of 1963 and 1967.

In region M there has been an unusual amount of ice in the fall of 1967, the following winter and spring.

This excess of ice north of Jan Mayen in the early winter must be to a great extent responsible for the ice at the north and east coasts of Iceland in the spring of 1968. In the spring of 1965 there is a maximum in region M. This excess is due to unusually strong westerly winds in these tracts in February, the same winds as prevailed in region S and brought drift ice to the coasts of Iceland and will be discussed later. Considering region N, maxima appear both the winters 1965 and 1968; there is, however, no maximum in 1967. In the summer of 1962 a maximum appears also in region M. This excess lasted into the fall, and after a 7 knots geostrophic wind component out from the ice edge in January in region S, ice was seen off Horn the first days of February, 1963. But eastely winds in this region the following months kept the drift away the rest of the year.

Fig. 5 shows the average wind components east of Greenland the years 1962 to 1967. The most striking feature is the strong NE component along the ice edge in winter. There are 12 to 14 knots maxima in March and December but minima 0 to 2 knots in June. February reflects the exceptionally strong westerly winds in this month in 1965. The mean velocity in winter is 11 knots. One per cent of this, amounting closely to the Zubov's formula of ice drift, is some 2½ miles a day

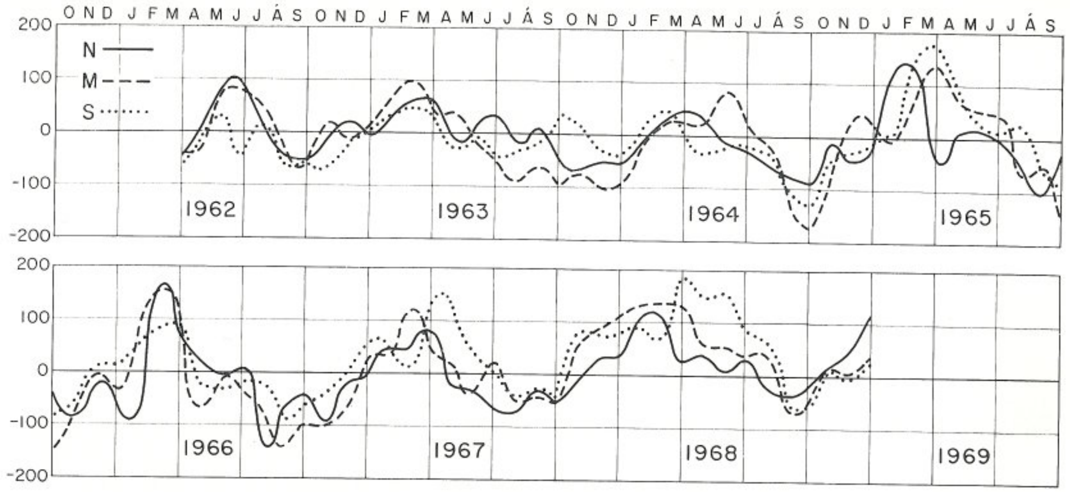


Fig. 2. The ice coverage east of Greenland. Distance from lines N, M and S in nautical miles.

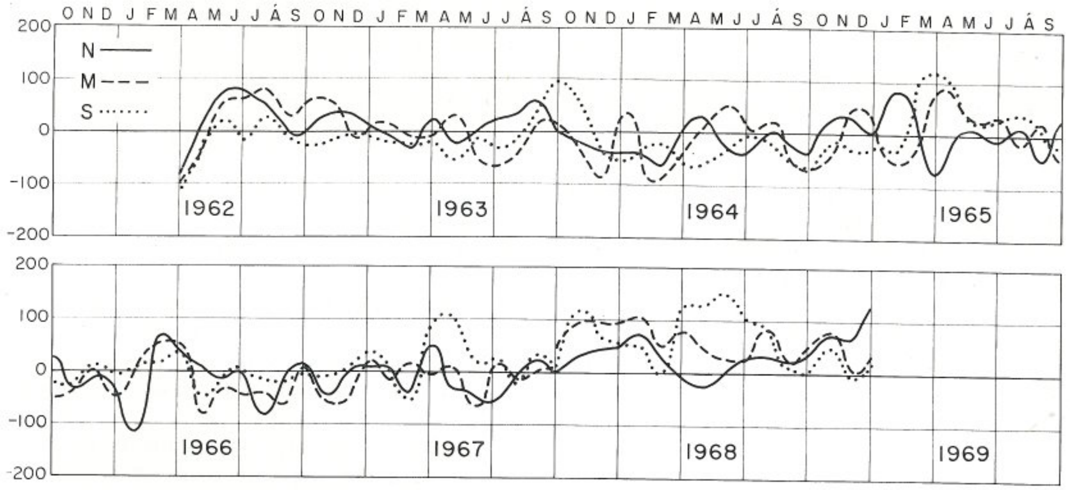


Fig. 3. The ice amount east of Greenland in excess of the 6 years mean for the month.

which is 80 miles a month or 5.7 cm/sec. We can, therefore, assume that so much of the southwestwards drift of the ice in winter is due to winds on the average. In some months the NE wind is twice as strong as the mean wind, and presumably the ice drift increases correspondingly. Preceding the arrival of the ice in 1968 the average speed of the NE wind components for the months January to March was 18 knots in region N, 17 knots in region M and 11 knots in region S.

The wind component perpendicular to the ice edge is much weaker and more irregular as shown in Fig. 4, especially in region M. The maximum SE wind occurs in spring, and the rapid recess of the ice at this time of the year must partly be due to this maximum. In region S the wind direction is from the SE all year around with maxima in the spring and fall. This inwards component is, at least in part, responsible in keeping the ice belt to the Greenland coast. It happens only when this component fails that the drift spreads out. And the danger of spreading out of the ice

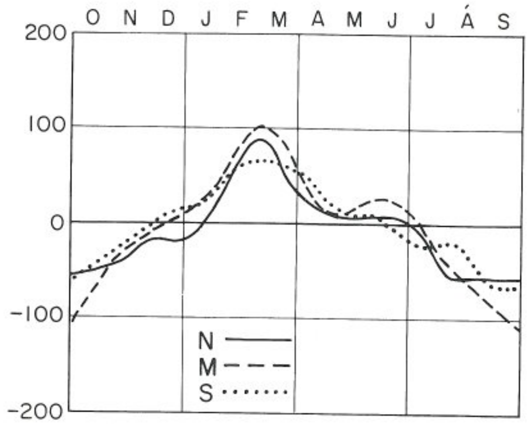


Fig. 4. The average distance of the ice edge from the lines N, M and S 1962–1968, measured in nautical miles.

belt becomes serious when northwesterly component sets in. This happened in the year 1965. In December the average outward component was 6 knots and again 9 knots in February, at the time of the year when the ice belt is widest.

Although one can point out different cases when the ice responds to the wind, the graphs of the wind component normal to the ice edge and the movements of the ice edge do not correlate closely. The correlation coefficient of these two factors was only 0.31 in region S and still smaller in the other regions. All cases, when the wind component perpendicular to the ice edge was 3 knots geostrophic or more, were taken separately and compared to the movement of the ice edge. Then the correlation coefficient in region N was 0.05, 0.24 in region M and 0.44 in region S. The poor correlation in the northern regions is no doubt due to various reasons: First, the period, a month, may be too long because of drift between regions; also the lines N, M and S do not always coincide with the moving ice edge. Secondly, the ice charts are inexact in these northerly tracts, especially in winter. In the third place, the main reason is probably that the movement of the ice edge is less dependent on winds in these regions than it is on the temperature and currents of the ocean.

The correlation coefficient 0.44 in region S is large enough to show that winds are to a considerable degree responsible for the movement of the drift ice there, although other factors also play their roles. They are sea currents, freezing in winter and melting in spring and summer. However, sudden outbreaks are no doubt due to winds. Two times during this period of six years the outward movement of the edge exceeded 100 miles in a month, in February 1965 and March 1967. In both cases the NW wind component was decisive.

As mentioned before, there is a small correlation between the movement of the ice edge in each region and simultaneous wind component alongside it. On the other hand there is a connection between the movement of the ice edge in region S and the difference between the strength of the NE wind there and in region M. The correlation coefficient is 0.46. This fact shows that when ice drift is greater through the northern limits of region S than the drift through the southern limits towards the southwest, the ice spreads out but is not entirely pressed together. This effect was present in 1968. Then the mean NE wind component for the months February and March was only 8 knots in region S compared to 15 knots in region M. The difference, 8 knots, is sufficient to account for a drift difference of 100 miles in these two months. Since the width of the ice belt was close to 300 miles at this time, the outward movement of the ice edge might have amounted to 100 miles due to this effect from the beginning of February to the end of March.

In recent years very cold outbreaks of arctic air south along the east coast of Greenland have been more frequent than before. And it is mainly due to these outbreaks that the

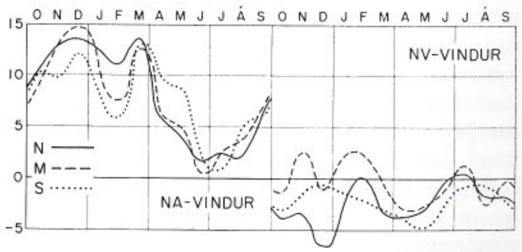


Fig. 5. The average wind components east of Greenland for the years 1962–1968. Geostrophic wind in knots.

TABLE 1

Mean winter winds east of Greenland in degrees true and knots geostrophic.

	Region N	Region M	Region S
1956–1961	060 – 13	045 – 11	065 – 12
1962–1967	040 – 13	040 – 11	060 – 10

TABLE 2

Mean geostrophic wind component in knots across and along the average ice edge east of Greenland for the years 1956 through 1967

	Region N		Region M		Region S	
	SE	NE	SE	NE	SE	NE
January	4.8	12.2	0.5	12.4	1.2	10.8
February	3.0	11.1	– 1.2	9.8	0.7	8.3
March	4.2	14.1	0.2	10.9	3.8	11.4
April	5.5	8.4	2.2	9.1	2.7	10.4
May	2.6	5.1	1.3	5.2	3.0	6.1
June	0.4	2.6	0.1	3.0	1.9	3.8
July	0.0	1.6	– 0.9	2.4	0.8	2.0
August	2.1	2.3	2.3	4.8	0.6	5.3
September	2.1	5.0	1.3	5.0	2.4	5.2
October	5.2	9.1	1.5	8.8	3.5	9.8
November	5.4	10.1	0.0	10.5	2.3	9.9
December	7.2	12.3	2.5	13.3	2.6	13.3

winter temperature of Iceland has lowered considerably these latest years. Comparison of the mean winds for the months October through March for the period 1956–1961 to the ones in 1962–1967 shows a tendency towards more northerly wind direction. The difference appears as a 2½ knots decrease in the SE wind component for all three regions. The difference is greatest farthest north. See Table 1.

Besides the change of direction the wind speed in region S has decreased, indicating a recess in the Iceland low. The change of wind direction in region N is bound to result in strengthening of the East Greenland Current and also an increase in ice drift south through the strait between Northeast Greenland and Svalbard. Farther south the wind change makes it easier for the ice belt to broaden, and the filling of the Iceland low results in retardation of the ice flow towards the southwest between NW Iceland and Greenland. All these factors relating to wind changes east of Greenland are probably the prime factors causing the increase of ice in Icelandic waters in the latest years.

THE ICE IN 1965

The first months of the winter 1964–1965 nobody even thought of ice in Icelandic waters. However, in region N the amount of drift ice was greater than usual in October and November. Similar increase appeared about a month later in region M, as can be seen in Fig. 3. And near Jan Mayen some ice was observed in November. In region S the ice edge was 20 to 40 miles nearer the Greenland coast than normally until the end of January. At that time a maximum that had appeared in region M in December had disappeared and a minimum come in stead. The reason for this change is obviously the fact that southeasterly wind component had prevailed most of January as seen in Fig. 6.

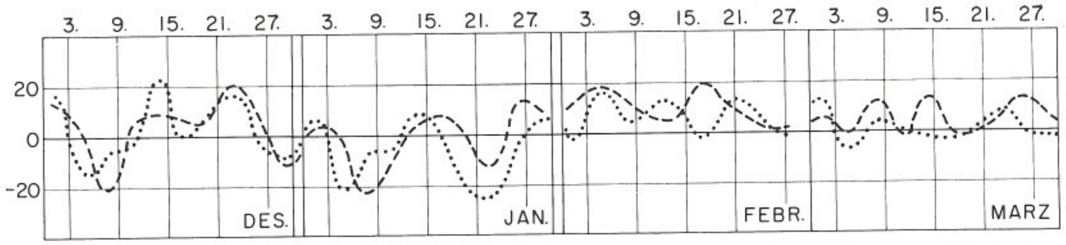


Fig. 6. Geostrophic wind component out from the ice edge in the winter 1964 to 1965. Broken lines in region M, dotted lines region S. — Note the strong outwards wind in Dec. and Feb.

On the 13th of February open pack ice was reported at the northwest coast where it remained the following weeks. At the same time the pack ice approached land farther east, and on the 24th of February the first floes hit the coast. The following day a tongue of ice had passed to the south of Langanes and continued on its southwards course the following days. See Fig. 8.

Great changes have taken place since the beginning of the month. In region S the ice edge mowed 90 to 210 miles towards the southeast, the average being some 140 miles. See Fig. 7. The reason is clear. In stead of east-northeast geostrophic wind of 10 to 12 knots, which is the mean winter wind here, a due west wind of 13 knots is now the average for February. All inward thrust by the wind

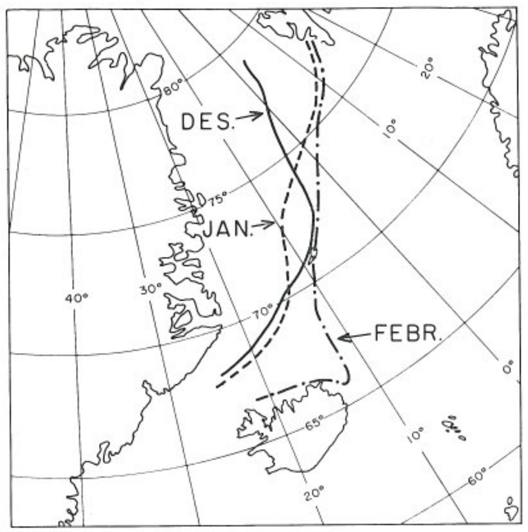


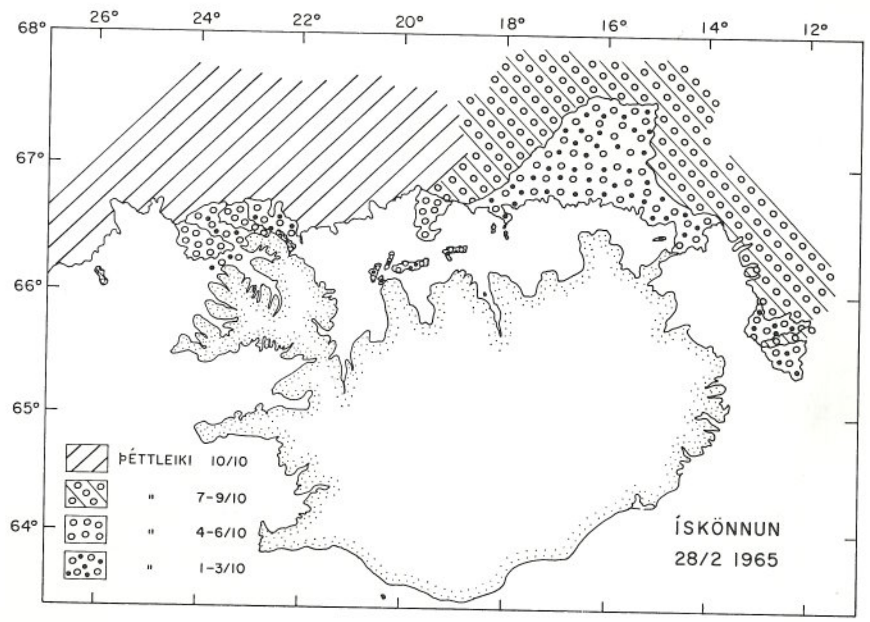
Fig. 7. The ice edge at the end of the months December, January and February, 1965.

is gone and a strong outward push has taken its place. Actually, the outward movement of the ice seems greater than to be caused by the wind alone, especially where the ice tongue extends south along the east coast. This is only natural, because it is here the East Icelandic Current would be expected to play its greatest role.

After the arrival of the ice to the coasts its movements can be followed from day to day. It becomes apparent that besides tidal currents the wind is the major factor in moving it about. Fig. 9 shows graphs of the north and west wind components at the northeast coast of Iceland where the mid point is at 66.5° N and 16° W. The graphs are drawn from three days means, and one can almost use them as a diary on the movements of the ice. With the February graphs there is also drawn the west wind component between the stations Galtarviti in Northwest Iceland and Cape Tobin in Northeast Greenland. The great similarity between this curve and that for the west wind at the coast of Northeast Iceland shows that a good estimate of the winds north of Iceland can be formed by measuring the gradient off the northwest coast.

Here the movements of the ice at the shores of Iceland will not be followed closely. It wandered away with offshore winds and came in again with onshore winds. After a few days of northeasterly winds in March it reached its southernmost position at the east coast due east of Berufjörður. It blocked the way for all navigation at Langanes from the 18th of March to the 22nd of April. Off Cape Horn navigation was never hindered for any length of time but sailing was often difficult in Húnaflói. In May the wind remained easterly

Fig. 8.
Drift ice off the north coast of Iceland on February 28, 1965. The Icelandic Coast Guard reconnaissance flight.
Þéttleiki = Degree of ice coverage.



most of the time and drove the main bulk of the ice away towards the west and northwest. See Fig. 10. Only on the east coast of Vestfirðir and in the fjords of the northeast coast ice remained pressed to the shores by the wind and a few harbours were closed for this reason. This ice drove off to sea with great rapidity as the wind turned into the west the last days of May. Thereby the ice was gone for good this year except for scattered growlers and floes which remained in Hrútafjörður and Miðfjörður until the latter part of June. But still the after effects of the ice were felt in the low temperature of the surface waters of the sea, which caused considerable lowering of the mean summer temperature in Iceland, especially in the northern and eastern districts.

SUMMARY

The observations made here are strongly in favor of the opinion that the ice in Icelandic waters in 1965 was due to unusually strong westerly winds north of Iceland in February that year. Such has undoubtedly often been the case in past centuries. However, it must not be ignored that the amount of ice present in the tracts east of Greenland must also be a deciding factor. It may be pointed out that the two months preceding the arrival of the ice in 1968 there was no westerly wind north

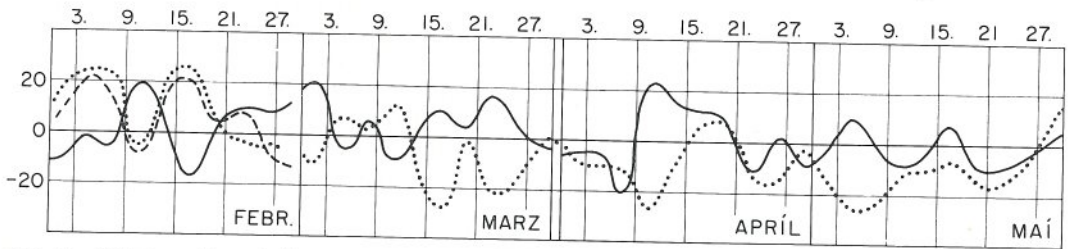


Fig. 9. Geostrophic wind components near Rifstangi on the northeast coast of Iceland in 1965. Continuous line N wind, dotted line W wind. Broken line shows the west wind between NE Greenland and the NW coast of Iceland. The curves are worked from three days means.

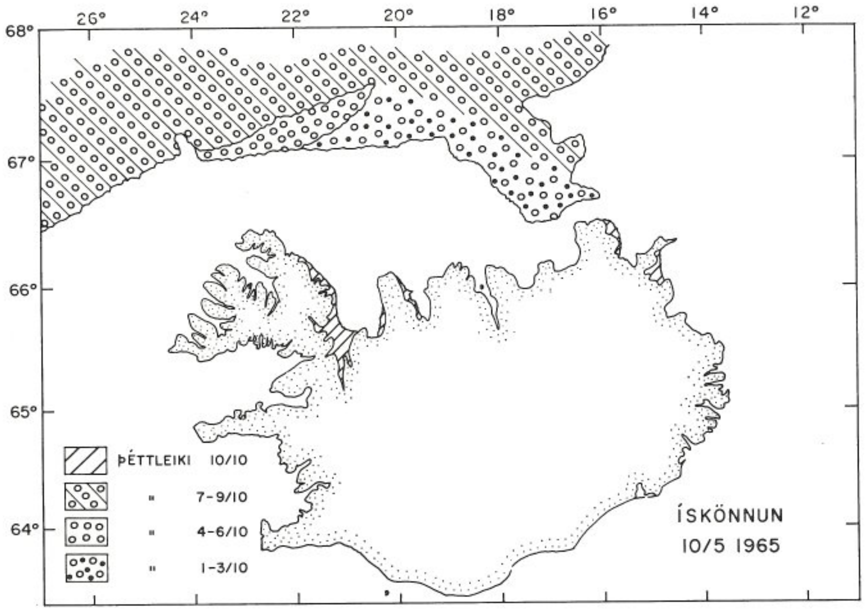


Fig. 10. Drift ice off the north coast of Iceland on May 10, 1965, after a period of three weeks of easterly winds. The Icelandic Coast Guard reconaissance flight.

of Iceland. The southeasterly wind component was zero both these months, and one can argue that a mean wind thrust onto the ice edge to keep it in the East Greenland current is missing. It has also been pointed out that the turbulence over partly open water at an ice edge is bound to cause scattered floes to drift considerably faster than the main ice and that their speed is likely to be as great as 4% of the wind speed, or even greater. It has been shown that the northeasterly wind along the east coast of Greenland takes a good part in the ice drift southwards in winter and that this part varies greatly from month to month.

It appears that the ice drift is more dependent on winds in the region between Iceland and Jan Mayen than it is farther north. Also the fact stands out that the past six years the winter winds are more northerly than the six years before, thus explaining, at least partly, the increasing amount of ice in Icelandic waters.

Finally I want to stress the need of close watch of winds and pressure pattern north of Iceland not only monthly but daily, if one is to attempt the forecasting of ice arrival at the north coast of Iecland. It is also necessary to keep track of the ice edge as far north as to Jan Mayen. This may possibly be done by the use of satellite pictures, but weekly reconnaissance flights are to be recommended.

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Report on Sea Ice off the Icelandic Coasts October 1967 to September 1968

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More drift ice was observed in Icelandic waters than in any year since 1888. Some ice was reported near the coasts approx. 180 days and almost continuously from March 3rd to July 25th. The ice frequently impeded or closed navigation and at times it was completely blocking the northern and eastern coasts of the country.

The number of ice messages received by the Icelandic Meteorological Office greatly exceeded that in all previous years. Messages from ships and meteorological stations cover 232 pages in the ice journals of the office. Of these 36 pages were for March, 65 pages for April and 81 pages for May. For comparison can be mentioned that ice reports from the year 1966–'67 cover 41 pages, from 1965–'66 12 pages and from the year 1964–'65 which also was a severe ice year, 36 pages.

The year was considerably colder than normal, deviations of yearly means ranging from – 0.8° C in the extreme south and southwest to – 2.3° C in the extreme north. The first nine months from October to June were colder than normal on practically all stations, and on a few stations on the northern promontories and on the east coast even all months of the year were below average. On most stations however July and September were above normal.

Sea temperatures were also mostly lower than average with deviations of yearly means ranging from – 0.4° C at Stykkishólmur to – 1.6° C at Raufarhöfn and – 2.3° C at Teigarhorn.

Below are quoted monthly means of air temperature and deviations from normals at Hornbjargsviti, Stykkishólmur and Raufarhöfn.

Hornbjargsviti 66°25′ N, 22°23′ W, 26 m above M.S.L.

	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Year
Means 1967–'68 .	1.6	– 0.1	– 2.3	– 4.6	– 3.6	– 6.0	– 1.6	1.1	4.0	9.0	8.0	5.9	0.9
Deviations	– 2.1	– 2.0	– 2.5	– 3.8	– 2.5	– 5.6	– 2.0	– 2.8	– 2.6	0.8	– 0.2	– 0.7	– 2.2

Stykkishólmur 65°05′ N, 22°44′ W, 17 m above M.S.L.

	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Year
Means 1967–'68 .	2.4	– 0.0	– 1.4	– 2.7	– 2.7	– 2.5	0.7	4.1	7.0	10.9	9.6	8.5	2.8
Deviations	– 2.1	– 2.2	– 1.8	– 1.9	– 1.8	– 2.7	– 1.1	– 1.6	– 1.7	0.5	– 0.4	0.6	– 1.4

Raufarhöfn 66°27′ N, 15°57′ W, 5 m above M.S.L.

	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Year
Means 1967–'68 .	1.4	– 0.9	– 2.8	– 4.3	– 4.7	– 6.1	– 2.8	0.1	4.8	8.3	8.5	5.8	0.6
Deviations	– 1.9	– 2.0	– 2.3	– 2.9	– 2.8	– 5.2	– 3.1	– 3.9	– 2.1	– 0.6	– 0.3	– 1.0	– 2.3