



South coast of Devon Island, with Lancaster Sound in foreground, 24 April 1947.

ICE, OPEN WATER, AND WINTER CLIMATE IN THE EASTERN ARCTIC OF NORTH AMERICA: PART I*

By F. Kenneth Hare and Margaret R. Montgomery

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In the American Arctic, such open water surfaces have been described from Davis Strait, Baffin Bay, Hudson Strait, and Hudson Bay; for all these areas there is a scattered literature confirming the absence or the broken character of the winter sea-ice. The relative mildness of the winter climate of the West Greenland coast has often been ascribed to the influence of

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the nearby open water, and enterprising navigators have even used this hazardous channel to reach West Greenland ports in mid-winter. Less attention has been paid to the other two regions in recent years, though prolonged and acrimonious debate about the navigation season preceded

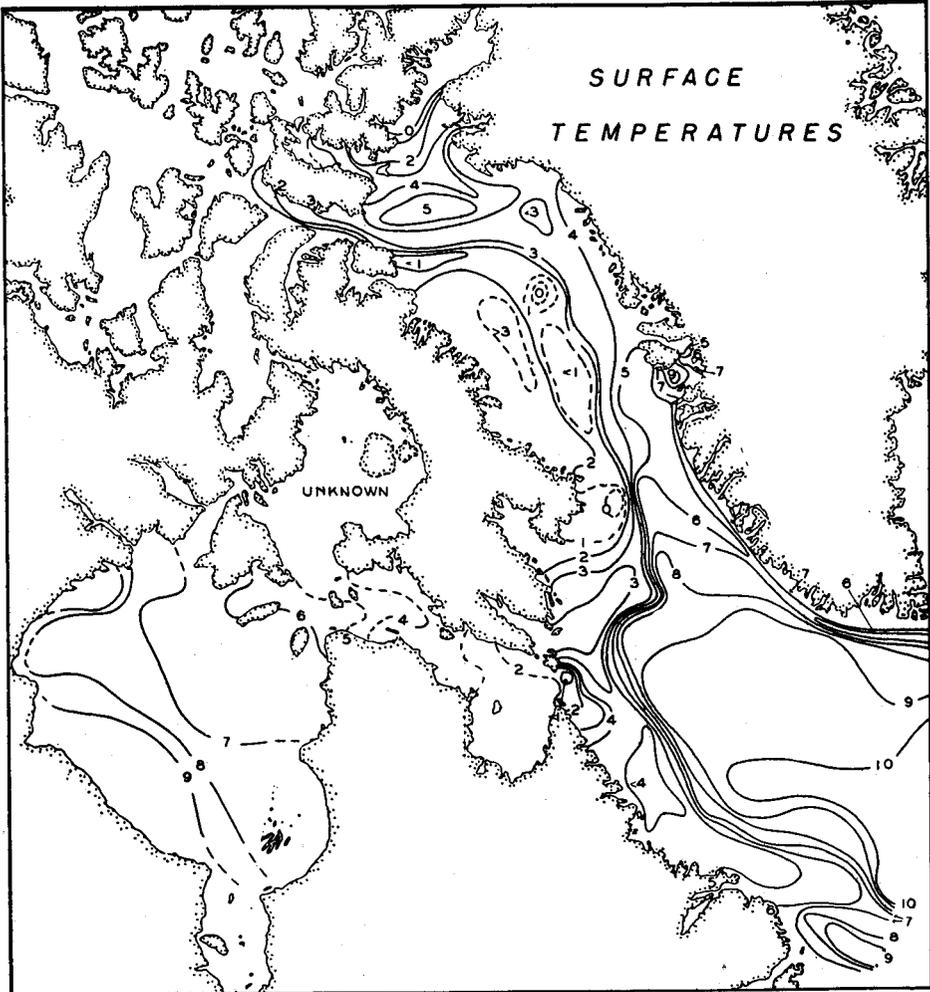


Fig. 1. Sea Temperatures over the Eastern Arctic in August and September (after M. J. Dunbar).

In accordance with normal oceanographical practice, temperatures are given in degrees Centigrade. For rapid computation of degrees Fahrenheit note the following: $0^{\circ}\text{C.}=32^{\circ}\text{F.}$; $5^{\circ}\text{C.}=41^{\circ}\text{F.}$; $10^{\circ}\text{C.}=50^{\circ}\text{F.}$; any $1^{\circ}\text{C.}=9/5^{\circ}\text{F.}$

the opening of the Hudson Bay route from Churchill, Manitoba, to the Atlantic. The debate produced one unanimous verdict, from which few have dissented till recently: namely, that Hudson Bay does not freeze over in winter, being thereby established as by far the largest landlocked area of open water in the truly Arctic seas. With this verdict the authors disagree.

The Argument

An open water surface cannot cool below the temperature of the freezing point of sea-water, i.e. 29°F. Such open surfaces present uniform surface temperature to the air above, and in addition an important source of heat. Whenever cold, continental airstreams cross these natural thermostats, strong heating and moistening of the air proceeds from below; the airstreams are warmed up at a truly remarkable rate, and also become quite moist at low levels. It is characteristic of airstreams undergoing such modification that they become highly unstable, vigorous convection being set up in their lower layers, accompanied by much cumuliform cloud and wintry showers.

The most familiar case to North Americans is the persistent eastward flow of cold, continental airmasses across the warm North Atlantic Drift. Equally well-known to geographers is the change induced in the winter Asiatic monsoon as it flows southeast across the Japan Sea: cloudless, biting cold and bone-dry as it leaves the Russian or Korean coast, the monsoon appears over the northwest coast of Japan charged with an unbroken pall of thick cumulus cloud from which heavy and frequent showers of rain or snow occur.¹ The factor at work here is the relatively warm, unfrozen Japan Sea, which has added enormous stores of heat and moisture to the receptive monsoon. Since the Japan Sea and Hudson Bay have much in common, the case of Japan affords us a clue as to what an open Hudson Bay might do to the climate of Arctic Quebec and Labrador, where a similar cold "monsoon" blows in winter.

We may argue accordingly that open water surfaces must have striking effects upon the winter climatic maps of an arctic region: they must appear as gulfs of warmth, as areas of abnormal cloudiness and probably of unusually heavy precipitation. Conversely we may claim that the *absence* of these climatic anomalies argues strongly for the existence of a massive ice-cover. The permanent pack of the Arctic Ocean has a bitterly cold and snow-free winter, in which mean temperatures appear to be below -30°F. in January and February.² The ice effectively insulates the air from the warm water only a few feet below. Over these frozen seas the winter is almost, though not quite, as severe as over a continent. When, therefore, we find a sea area with a winter of great severity, we are on strong ground in assuming the existence of a thick and rigid insulating cover of ice.

An investigation along these lines of the winter climate of the eastern American Arctic appears to support these conclusions:—

¹'Meteorological Report on Japan'. Aviation Met. Rep. British Met. Off. Manual 365, No. 27, London, 1945.

²Sverdrup, H. U. "Klima des Kanadischen Archipels und Grönlands", in 'Handbuch der Klimatologie', ed. by Köppen, W., and Geiger, R. Vol. II, Pt. K, Berlin, 1935.

- (i) Over Baffin Bay, Davis Strait and Hudson Strait the winter climate shows clearly the influence of the proven open water; the latter is the main factor leading to the relative mildness of winter in these regions.
- (ii) Over Hudson Bay, the warming effect is very marked, but is confined to the early winter. All trace of warming disappears after December, and it is hence assumed that the Bay becomes covered by a consolidated ice cover early in January.

The Climatic Evidence

Temperature affords the easiest way of studying the effect of the water bodies. Cloud-formation and precipitation, though equally significant, require a more technical treatment than is possible here. F. E. Burbidge³ has carried out an elaborate study of the modification of cold winter airmasses over Hudson Bay; his results, to be published elsewhere, have been available to the authors, and confirm the findings of the present paper; his treatment has been largely concerned with cloud- and precipitation-formation.

Existing maps of air temperature over the Canadian and Greenland Arctic are unsatisfactory for the present purpose, as they are a little out-of-date, heavily generalised and as a rule cover only the month of January. Best available sources are those of Connor,⁴ Sverdrup,⁵ Petersen⁶ and the Meteorological Service of Canada.⁷

Since all of these except the last are pre-war, they were drawn without the valuable data that have accumulated in recent years. Accordingly it was decided that new maps would be needed, and those presented as Figs. 2-8 have been drawn afresh from data supplied from the following sources:—

- (a) The manuscript records of the Canadian Meteorological Service at Toronto; available to Dec. 1948 in most cases.
- (b) Abstracted records of United States stations maintained in Canada and Newfoundland since 1941.
- (c) Published records of the Danish meteorological services for Greenland, available only to 1939;⁸ with more scattered data from Greenland over the period 1940-48.

³Burbidge, F. E. "The modification of continental polar air over Hudson Bay". Thesis presented at McGill Univ., 1949. Results to be published later.

⁴Connor, A. J. (and Brooks, C. F.). 'Climatic maps of North America'. Cambridge, Mass., 1936.

⁵Sverdrup, H. U., *op. cit.*

⁶Petersen, H. "Klima der Küsten von Grönland", in 'Handbuch der Klimatologie', ed. by Köppen, W., and Geiger, R. Vol. II, Pt. K. II, Berlin, 1935.

⁷'Meteorology of the Canadian Arctic'. Air Services Branch, Met. Div. Canada, Toronto, 1944.

⁸'Nautisk Meteorologisk Aarbog', 1894 on. Danish Met. Inst. (Also contains annual ice summaries of great value).

The maps presented have been drawn for the period 1930-48, the longest period for which a respectable number of control stations is continuously available. In view of the remarkable climatic fluctuation in progress over the eastern Arctic and Greenland, longer term means lose some of the validity they possess in more stable regions. The scale of these changes, and their consequences on the human occupation, have been discussed elsewhere by Jensen⁹ and Oldendow,¹⁰ and they need no further discussion here. Their existence means, however, that there is an upper as well as a lower limit to the acceptable length of period for the determination of secular climatic means.

Many stations, including such vital points as Dundas Harbour (Devon Island) and Padloping Island (Baffin Island), are available for only a brief period. In general the following procedure has been adopted in these cases:—

- (i) Stations whose record is less than three years in length have not been used.
- (ii) Stations whose record is incomplete but which exceeds three years in length have been adjusted to the standard period 1930-48 by the anomaly extrapolation method,¹¹ using as control stations the long-term stations operating throughout the whole period. The adjustment of the Greenland observations to standard was impracticable; instead the period 1930-38 was adopted, as this period appears from the scanty observations available to duplicate almost exactly the longer period 1930-48.

One other source of observational material, the records of the Moravian mission stations in Labrador, has been consulted;¹² since the records of these stations are in all cases for periods far earlier than the standard period, they have been used as general guides only to the run of the isotherms.

The temperature distribution. The mean air temperature maps of the region, Figs. 2-8, cover the period from October to April inclusive. It is apparent at a glance that three conspicuous "gulfs" of warmth diversify the temperature distribution, corresponding roughly in position with known areas of open water. These gulfs occur:—

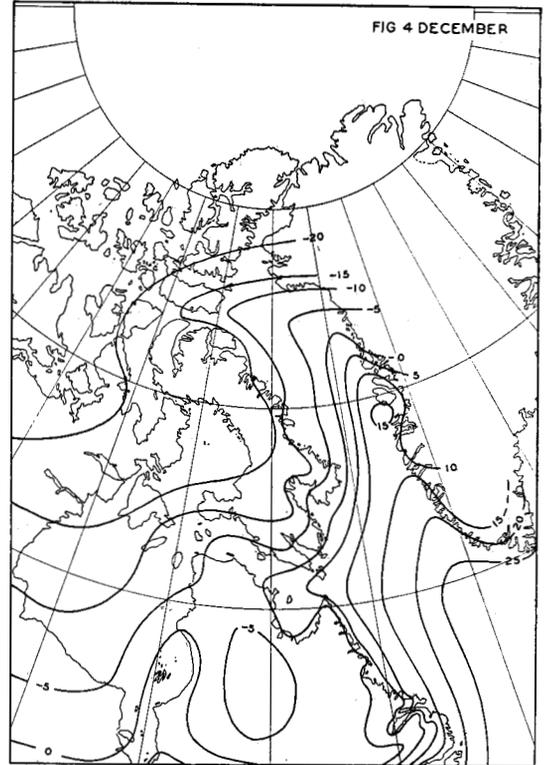
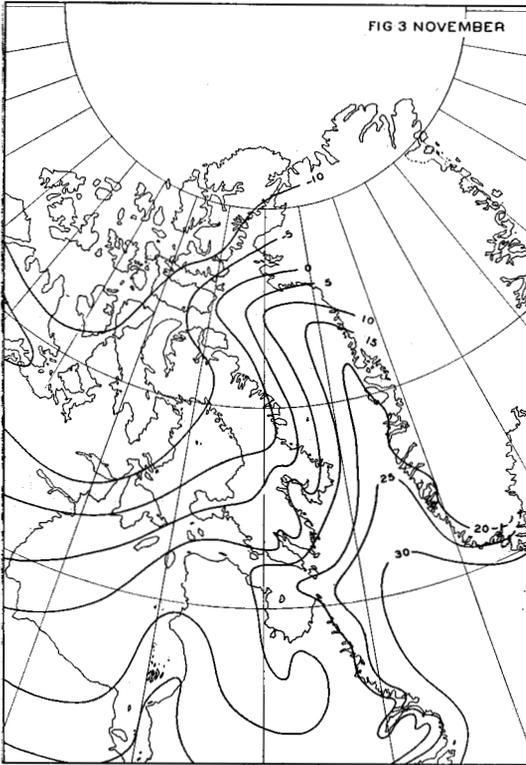
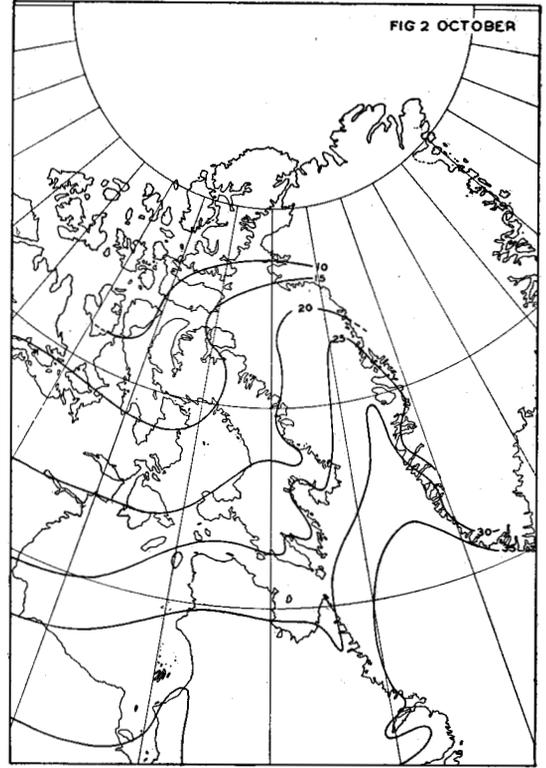
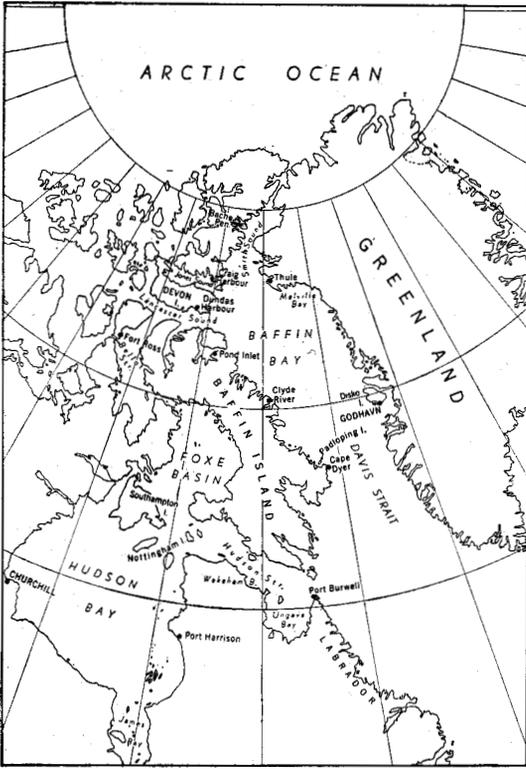
- (i) Over Davis Strait and Baffin Bay.
- (ii) Over Hudson Strait.
- (iii) Over eastern Hudson Bay.

⁹Jensen, Ad. S. "Concerning a change of climate, etc." *Det Kgl. Danske Vidensk. Selsk. Biol. Medd.* 14 (1939) pp. 1-76.

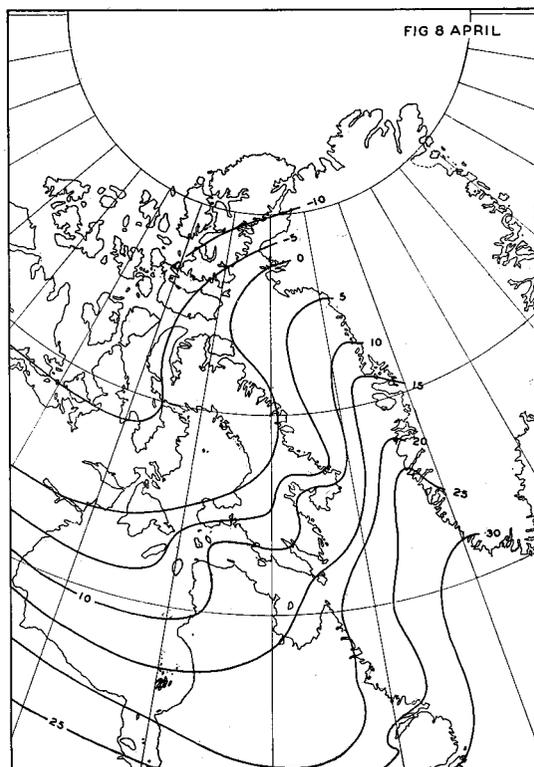
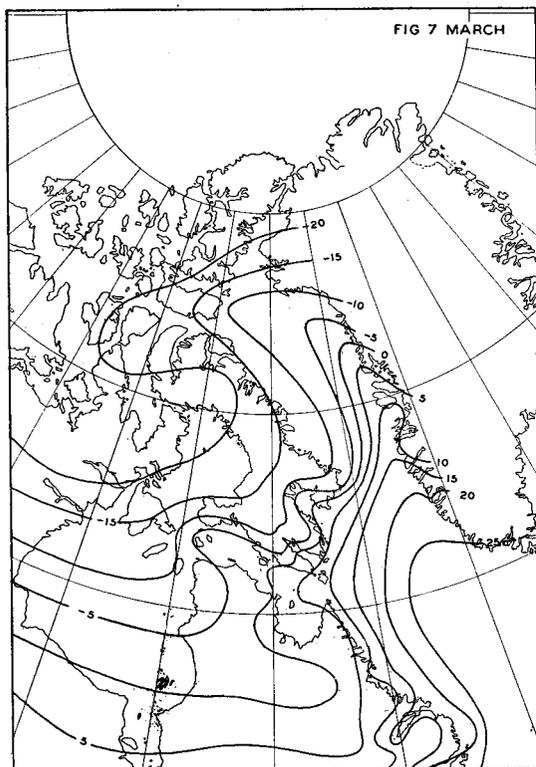
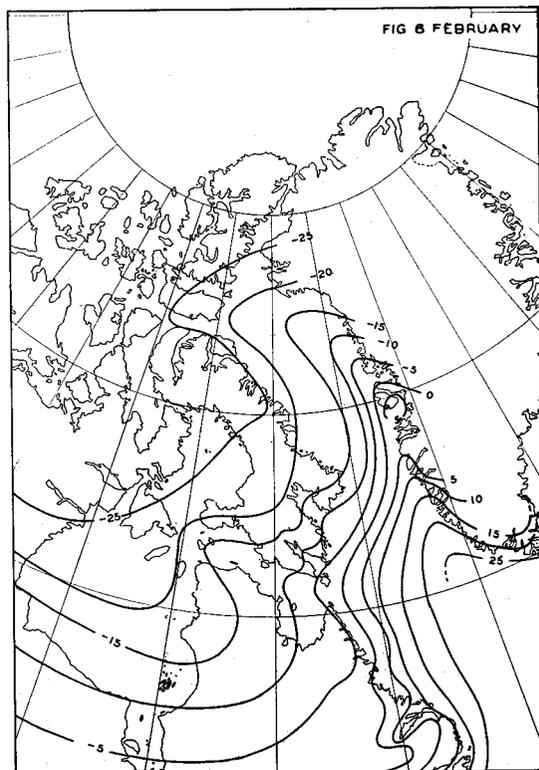
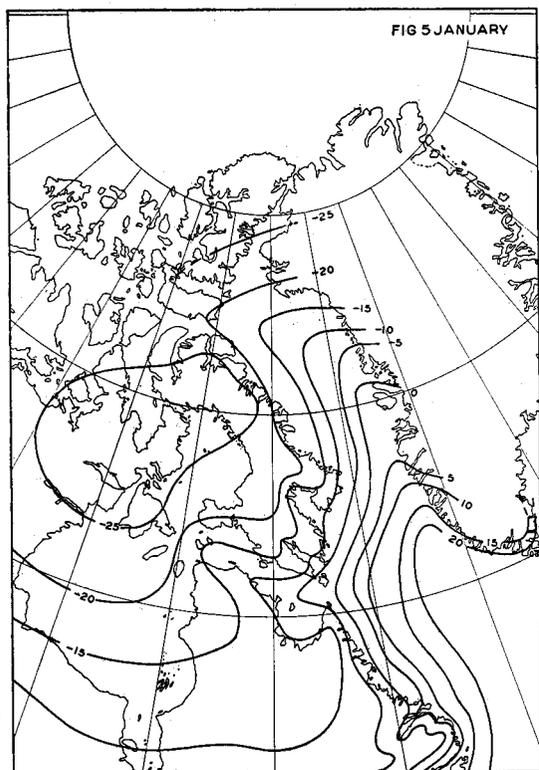
¹⁰Oldendow, K. "Landets Størrelse, Klima og Isforhold", *Beretninger vedrørende Grønlands Styrelse*, no. 1, 1942, Sammendrag af Statistiske Oplysninger om Grønland, I, pp. 390-405.

¹¹See Conrad, V. 'Methods in Climatology'. Cambridge, Mass., 1944, pp. 129-149.

¹²'Deutsche Ueberseeische Meteorologische Beobachtungen'. Gesammelt und herausgegeben von der Deutschen Seewarte. 1883-1902 for all stations; 1883-1910 for Nain and Hebron.



Figs. 2-4. Mean air temperatures for winter months, 1930-48 (ground-level).



Figs. 5-8. Mean air temperatures for winter months, 1930-48 (ground-level).

The Davis Strait-Baffin Bay Gulf. The contrast in climate between the two sides of Davis Strait and Baffin Bay is well known, as it persists throughout the year, and makes the Greenland coast much more accessible and attractive for settlement than the Baffin Coast.

In summer the difference in climate arises from the contrast in sea-temperatures experienced on the two coasts. Off the Greenland coast a northward-moving stream of relatively warm water brings summer sea-temperature up to 40-48°F. (see Fig. 1 after M. J. Dunbar¹³) in many parts. Even in Melville Bay and the waters off Devon Island, temperatures are well above the freezing point. Along the Baffin coast, however, southward moving arctic water maintains near-freezing temperatures throughout summer. The result is that air temperatures on the Greenland coast are from 5 to 10 degrees Fahrenheit warmer than points in the same latitude on the Baffin coast.

It is at once apparent from Figs. 2-8 that this gulf of warmth is much more strongly developed in winter than in summer. The Baffin coast participates fully in the intense cold typical of the rest of Arctic Canada, but West Greenland continues to enjoy remarkable mildness. In December temperatures on Disko Island are some 25°F. higher than at Clyde River on the Baffin Coast, a staggering difference when one considers that the two shorelines are only about 375 miles apart. After this December peak, the "gulf" slowly diminishes in intensity, though it remains strong until April. There is evidence (inherent in the records at Godhavn, Jakobshavn and Holsteinsborg) that an enclosed area of greater warmth is situated near Disko Island, with somewhat cooler conditions in Davis Strait.

The northern apex of the gulf bends west across the region of the "North Water" to Devon Island. The records from Bache Peninsula and Craig Harbour on Ellesmere Island, from Dundas Harbour on Devon Island, and from Pond Inlet in north Baffin show that this is a persistent feature of the Arctic winter; in some months it appears that relative mildness extends even to Fort Ross on Bellot Strait. The general configuration of these cold season isotherms is astonishingly similar to that of the summer sea-temperature map. It suggests, incidentally, that the North Water occupies a relatively southern position. Kiilerich¹⁴ puts this body of largely open water—open all through winter (see Part II)—in Smith Sound, west of the Thule-Etah coast of Greenland. Since the prevailing winds over all this region are ENE in winter, the warmth of Dundas Harbour suggests that the open water lies in this direction from Devon Island, substantially south of Kiilerich's estimate. Recent flight

¹³Dunbar, M. J. Unpublished map: the authors are grateful for permission to reproduce it here.

¹⁴Kiilerich, A. "Nordvandet. Forsög paa en Forklaring af det isfri Havomraade i Smith Sund". *Geografisk Tidsskrift* 36 (1933) pp. 53-61.

reports (unpublished) confirm this southern position, but the precise form of the North Water area remains unknown.

It cannot be assumed that this gulf of warmth—by far the most striking and persistent—is entirely an effect of the open water surface. It is certain, in fact, that dynamical influences contribute to the abnormal warmth. The air over the Baffin Bay region appears to be derived under normal conditions from subsiding currents from the Greenland ice cap; the low pressure which persists over southernmost Greenland throughout winter creates a pressure gradient over the Baffin Bay and Davis Strait regions for north-easterly circulation, which can only be derived by subsidence from the ice cap. Since subsidence raises air temperatures appreciably, we might expect the air over Baffin Bay to be considerably warmer than it would otherwise be. A variety of reasons leads us to reject the view that this is of more than secondary importance, however:—

- (i) In other regions subsidence is effective in raising temperatures only in middle and upper layers; the surface air over a cold radiating surface such as ice or snow is unhindered in its cooling, and becomes separated from the warm subsiding layer by a sharp inversion. There are no grounds for assuming that in Baffin Bay this general rule is broken, or that the subsidence extends to ground-level.
- (ii) Temperatures on the Greenland coast are higher in winter on the outermost islands and exposed coasts than they are in the heads of fjords: it is an obvious inference that the mildness of the outermost stations is due to their closeness to the open water.
- (iii) The high winter temperatures are by no means confined to situations where the air flows down off the ice cap. Deep, vigorous onshore currents, though rare, invariably show a rise of temperature as they approach the Greenland coast, to which onshore winds bring thoroughly maritime weather with high temperatures and cloudiness.

We see, then, that dynamical warming by subsidence is inadequate to account for the observed temperature distribution, and are forced to rely upon the presence of open water for our explanation.

The Hudson Strait Gulf. This gulf remains a pronounced feature of the map throughout the winter. As we might expect, the south shore is a little warmer than the Baffin coast, as the prevailing winds have a small component across the Strait from north to south. There are no grounds for assuming that either subsidence or the canalisation of warm airstreams can account for the warmth; winds are overwhelmingly directed *towards* the only warm source, the Atlantic, and the slow descent of air from the low plateaus of south Baffin can hardly be an appreciable warming agent. On the other hand, open water is known to persist in the Strait throughout

winter. Everything points, then, to the open water as the source of the anomalous warmth.

The Hudson Bay Gulf. Hudson Bay presents us with an entirely different picture. The October, November and December maps (Figs. 2-4) show a marked warm gulf over the eastern half of the Bay, flanked on the west by great cold over the west shore, and on the east by almost

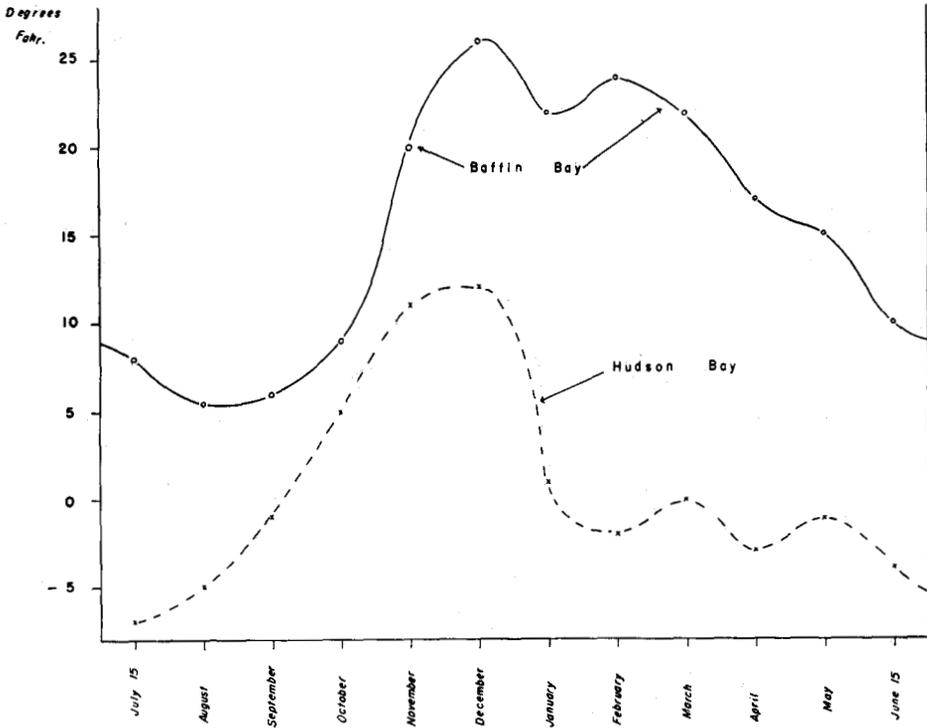


Fig. 9. Progress through the winter of the east-west temperature differential over Baffin and Hudson Bays.

The upper curve shows the variation of the temperature difference between the west (Baffin) and east (Greenland) coasts, exemplified by Clyde River and Godhavn respectively. The difference remains high throughout the winter.

The lower curve shows similar differences between the west and east coasts of Hudson Bay, positive when the east coast is the warmer. The stations used are Churchill and Port Harrison. The warmth of the east coast abruptly ceases in January.

equally severe conditions in Ungava. The warm gulf is most marked in November. By January (Fig. 5) it has disappeared, and cannot be detected on any subsequent monthly maps. We may note in passing that a similar sequence of events affected the distribution of precipitation. In November and December there is heavy precipitation on the Ungava coast south of Portland Promontory, whereas the interior of Ungava-Labrador is dry at this season. In January, however, the heavy precipitation on the coast abruptly ceases, and for the rest of the winter coast and interior

are much alike. Burbidge¹⁵ ascribes this autumnal precipitation to convection set up in westerly airstreams by the warm open water. The prevailing winds are between west and north, i.e. onshore.

These facts suggest that Hudson Bay is largely an open water surface in the fall and early winter, but freezes over completely early in January. Fig. 9 gives the evidence for this dating. The two curves show the difference in temperature between west and east coasts of Baffin Bay and Hudson Bay during the winter months:—

- (i) The curve for Baffin Bay shows the progress of the temperature difference between Clyde River (Baffin) and Godhavn (Disko Island). Though highest in December, the difference remains large throughout the winter, pointing to the continued existence of the open water.
- (ii) Over Hudson Bay, the curve represents the temperature difference between Churchill and Port Harrison, roughly on a parallel of latitude. In October, November and December, Port Harrison is much warmer than Churchill, pointing to marked warming of the prevailing northwesterly winds as they cross the Bay. By January the east coast appears to have cooled to the Churchill level, and for the rest of the winter the Port Harrison coast is the colder. Evidently the source of heat is cut off quite sharply at about the New Year.

It was this abrupt retirement of Hudson Bay as a warm influence in mid-winter that first suggested to the authors that it froze over. Since this view conflicted with so much published opinion, direct photographic evidence was desirable. Several other interested organizations and individuals were also anxious to observe the Bay directly, and in 1948 a programme of aerial reconnaissance was inaugurated by the Royal Canadian Air Force, an effort which was continued in the winter of 1948-49. The evidence from these flights will be reviewed in Part II of this paper. It is sufficient to note here that they have completely confirmed the deductive conclusions drawn from the climatic evidence.

The results described above and in Part II of this paper form part of the research of a group working at McGill University on the climatology of eastern Canada. The authors have depended primarily on the purely climatological evidence, whereas the meteorological analysis has been largely due to Mr. F. E. Burbidge, who is also a meteorologist in the Department of Transport. In the course of co-operative research it is sometimes difficult to sort out the parentage of a given idea. The authors therefore wish to emphasize the great debt they owe to Mr. Burbidge, who is entitled to a large share of the credit for the results presented here.

¹⁵Burbidge, F. E. *op. cit.*