NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N434

NAFO SCR DOC. 81/IX/128

THIRD ANNUAL MEETING - SEPTEMBER 1981

Twentieth Century Marine Climatic Change in the Northwest Atlantic and Subarctic Region

by

M. J. Dunbar

McGill University, Institute of Oceanography
3620 University Street, Montreal, Canada H3A 2B2

Introduction

This paper is the result of a review of the literature; the patterns of change shown are for the most part generally known. The only virtue in the paper is the bringing together of information from many regions, Baffin Bay to the Scotian Shelf, West Greenland and Iceland to the broad northwest Atlantic, for general study. As will be seen, the trends of change have been similar in all regions, with local variations. The local variations should serve well as a basis for a more exhaustive study.

The emphasis is on natural climatic change, or properly the climatic change as observed. Part of the change may or may not be due to the effects of industrial man, but such possible effects are not considered here. This for good reason -- if there is one thing clear about the possible effects of man, it is that there is no agreement among those who are considering the subject most closely. This does not mean that such effects can be ignored; on the contrary, they must be given urgent attention, because we have little idea of what we may be doing. The situation is well described by Emiliani (1972):

> "Because the hypsithermals represent such a precarious climatic balance, the effect of man on the course of the present hypsithermal assumes critical significance. Beginning from the time of widespread deforestation and accelerating toward the present time of industrialization and global atmospheric pollution, man's interference with the heat budget of the hydroatmosphere is assuming alarming proportions (SMIC 1971; Matthews et al., 1971). Thermal, CO_2, and aerosol pollution produce contrasting effects, and so does urban development. Their relative magnitudes are poorly understood and the net effect is unknown, not only in magnitude but even in sign".

SYMPOSIUM ON ENVIRONMENTAL CONDITIONS

Mason (1976) concludes that the possible effects of man-made changes have been much exaggerated, a view with which I see good reason to agree. It appears that the scale of natural change is such as to swamp that of recent or present man-made changes. The present cooling of the climate, since about 1940, has occurred impressively despite a continued rise in the CO_2 content of the atmosphere, and even the possible effect of building a dam across Bering Strait seems to be quite small compared with the large change in the temperature of the West Greenland Current that has occurred during the present century (Dunbar 1960, 1962).

Climatic changes have occurred in the past in a considerable array of different time scales. Setting aside the periodicity of the major ice ages, a matter of 250-300 million years, and dealing only with the present glaciation, it has become apparent that new methods of dating and measuring temperature changes in the past, such as by C^{14} and O^{18}/O^{16} ratio, have drastically changed our interpretation of Pleistocene oscillation between glacial and interglacial periods (see, e.g., Emiliani 1972, from which Fig. 1 is reproduced here). The period from peak to peak in the temperature curve is now shown to be close to 50,000 years, and we are now in an interglacial and on the way toward the next glacial, perhaps a few thousand years from now.

There is general agreement on the temperature history of this present interglacial. Fig. 2 is taken from Wiseman (1954), showing the temperature change from the retreat of the last ice sheet to the mid-19th century, elicited from the measurement of carbonate in Foraminiferan skeletons in one of the Swedish "Albatross" long cores from the Atlantic. The hypsitherm of some 5-6000 years ago is well illustrated, and the gradual decline in temperature since that time, the decline being interrupted by smaller-scale periods of warming. One of the most recent of these warming interludes, and possibly the most extreme of them, belongs to the present century.

Several authors have drawn attention to an apparent periodicity in these temporary warmings in the range of 225 to 260 years. Scherhag (1937), describing the warming effect in Arctic seas, ascribed it to an increase in the strength of the atmospheric circulation between the tropics and the polar regions, and on the basis of an examination of Easton's

(1928) coefficients for west European winters since the year 1235, concluded "that it appears to be a question of a secular period in the variation of atmospheric circulation of some 225 years duration, which seems at this juncture (1937) to have attained its maximum". A recent publication from the Geophysical Isotope Laboratory, Copenhagen (Hammer et al., 1980), on the oscillation in northern hemisphere temperatures, 550 - 1950 A.D., shows warmer periods appearing approximately every 200 - 250 years, with emphasis on the larger value (Fig. 3). The Camp Century (Greenland) curve (Johnson et al. 1969), from 1200 A.D., is in good agreement with the general curve, but shows subsidiary peaks within the 200-250 year rhythm. Aaby (1976), describing variations in climate over the past 5,500 years derived from measurements in raised bogs finds a 260-year periodicity.

The shorter periods shown by Johnson et al. (1969) for Camp Century agree with what is known of biological effects of climatic change in the sea, in particular the Atlantic cod (Jensen 1939, Hansen and Hermann 1965, and many other papers), and the marine fauna in general (Jensen 1939 and elsewhere). The 225-250 year period appears to agree with what is known of the presence and absence of the Atlantic salmon in David Strait waters (Dunbar and Thomson 1979).

The twentieth century.

1. West Greenland

For the region from West Greenland eastward to Svalbard and Eurasia, the classic reference on climatic change and its marine biological effects is the study by Jensen (1939), which forms a baseline for the temperature history of the West Greenland Current. Oceanographic measurements by the Danes in the West Greenland Current and the inshore waters of Greenland in general have been maintained constantly since the early 1900's, and there were a few expeditions in the late 19th century whose results have been compared with later observations (Dunbar 1946). Since the publication of Jensen's paper, the pattern of temperature change has been followed to the present decade (Hansen and Hermann 1965, Greenland Fishery Reports, etc., to 1978). Hansen and Hermann (1965) published surface temperature records compiled by Smed (1947-62), reproduced here in Fig. 4. This covers the period from 1876 to 1960, for west and south Greenland. Fig. 5 shows a similar pattern for West

Greenland (Frederikshaab Sections) and brings the record almost up to date. The pattern of change, and its apparent universality for air and sea, Canada, Iceland and the North Atlantic in general, is discussed below.

2. Canadian east coast.

For the Gulf of St. Lawrence and the Scotian Shelf, the best starting point in the literature is Lauzier (1965), from which Figs. 6 to 9 have been taken. Sea surface temperatures and air temperatures over the whole region show essentially the same pattern: warming from the earliest recorded years (1874 for air temperatures at Halifax, 1891 for air temperatures at Sable Island, 1906 for SST at Boothbay Harbor, 1921 for St. Andrews) to about 1900, cooling from 1900 to the early 1920's, followed by rapid warming to a peak in the early 1950's, then rapid cooling to 1962. Information on sea surface temperatures from the Gulf of St. Lawrence (Lauzier 1972) shows that at Entry Island (Magdalen Islands) and at Grande Rivière (Baie des Chaleurs), where records go back only to 1931 and 1940 respectively, the pattern was similar to that at St. Andrews, but that the peak occurred somewhat later in the 1950's. For the deep water of the Laurentian Channel, Fig. 9 shows temperature changes at three depths, the core water of the deep layer, and the 34 and 33o/oo isohalines. Changes parallel the surface temperatures at St. Andrews up to the peak, which however occurred later than at St. Andrews, and the cooling after the 1950's is not marked, especially in the core water (Lauzier and Trites 1958).

Bottom temperatures for the Bay of Fundy (Prince 5 Station), Larcher, Sambro, "Scotian Gulf" (between Sambro and Emerald Bank, on the shelf), and for Emerald Bank, are shown in Fig. 8, compared with the St. Andrews surface temperatures. Again, the pattern is similar throughout.

3. Northern Canadian waters, Newfoundland to Baffin Bay.

Since 1950 regular monthly observations of temperature and salinity have been made at Station 27, east of St. John's, Newfoundland, $47^{\circ}31'50''$N, $52^{\circ}35'10''$W, in a depth of 1976 m. The results to 1962 have been consolidated by Templeman (1965) and to 1978 by Keeley (1981). Fig.

10, from Templeman, shows annual mean air temperatures for St. John's, and sea temperatures at several depths at Station 27. There is close agreement between air temperature and sea surface temperature. Templeman therefore published the air temperatures from 1872 onward (Fig. 11), from which it will be seen that the curve resembles strongly the sea surface temperatures (and air temperatures) from the Scotian shelf (Figs. 6 and 8), particularly in the case of the St. John's 11-year running means of temperatures from December to April. There is the same rise in temperature to the year 1900, a decline to the early 1920's, followed by a rise to the high point in the early 1950's. Keeley (1981) continues the series (Fig. 12), showing a fall in surface temperature after 1962 and again after 1970. Keeley also published the records for 20, 50, 70, 100, 150 and 170 m depth. Trends are less apparent below the surface, but the decline after 1970, and the suggestion of a rise in the second half of the past decade (1970's), are shown at all depths.

There is a manuscript by Riehl (1956), quoted by Templemen (1965) and others, which apparently gives "computed" surface temperatures for 5 degree (lat.-long.) squares for the North Atlantic, referred to again below, which shows, for the 45-50 degree square surrounding Station 27, the same general pattern as just described. Riehl's study stops at the year 1936.

It has been suggested (Dunbar 1955) that the region most sensitive to marine climatic change in our whole area is the West Greenland Current, because of the importance of the relative proportion of Arctic (East Greenland) water and Atlantic water (Irminger and Labrador Sea), which determines the nature of that current, and that change would be expected to be less marked in the waters of East Greenland on the one hand and the Canadian Eastern Arctic waters on the other, because of the buffering effects of the East Greenland Current and the Canadian Baffin Island current respectively, both of which carry water from the Arctic Ocean. Nevertheless temperature changes of some significance are apparent in the Labrador water and also in west Baffin Bay. Figs. 13 to 15, taken from Dunbar and Moore (1980), contrast the surface isotherms from the "Godthaab" and U.S. Coast Guard expeditions of 1928 and the isotherms derived from 1960 and 1961. 1928 was close to the maximum temperature condition reached in the West Greenland Current, and probably, in Baffin

Bay as a whole; it will be seen that 1960 and 1961 were considerably colder in the Canadian side of Baffin Bay. All three figures refer to the same period of the year (August - September).

We are at present compiling graphs of temperature changes in the Labrador Current area, but the full results are not yet available. Figs. 15A (1) to 15A (7) are inserted here for what they are worth, which is not much. They refer to Subareas 2H and 2J, and all that they show is that for the Atlantic component of the Labrador Current (15A (1), 15A (2), 15A (6) and 15A (7)), there is a decline in surface temperature after 1950, which is not shown by the inshore (cold component) curves.

Burmakin (1972) treated measurements along Section "8A" seaward from the coast of southern Labrador, coming out with a series of cycles of 3 and 4 years (Fig. 16). The datum points are means of temperatures in the 0-200 m layer. The inclusion of depths below the surface reduces the likelihood of the emergence of strong trends, but there is nevertheless an upward slope between 1950 and 1960 in the temperatures adjusted to 15 July, which agrees with the West Greenland record. The 3- and 4-year cycles are interesting, but at present little more can be said of them.

Lauzier and Campbell (1959) compared temperatures and salinities measured in the Labrador Sea and Davis Strait in 1928-1935 and 1950-1955. The surface waters in Baffin Bay, Davis Strait and the northern part of the Labrador Sea were cooler in the latter period than in the former. The southern part of the Labrador Sea, however, showed an increase in temperature. This is quoted from an abstract of a paper given at the New York Congress of Oceanography in 1959. No figures are given, and apparently the paper was never finally published.

4. Iceland.

The record of climatic change in Iceland is closely associated with the behaviour of sea ice in Icelandic waters; indeed the sea ice has played such an important part in the economic and social history of the country that it enters into the literature of the Icelanders, including their poetry, as a normal and decisive part of their environment. This accounts for the fact that the historical record of "severe years", involving starvation and other hazards, goes back to 976 A.D., and that of the number of days per year on which ice affected the coast to 1590

(Bergthórsson 1969a). By relating the mean air temperature to the ice cover for the years for which both are known (1846 to date), Bergthórsson calculated the air temperature back to 1590, shown in Fig. 17, and even, by using the "severe years" record, back to the year 976. The pattern shown in Fig. 17 resembles the West Greenland and Canadian curves in general. The peak occurs about 1950, resembling the eastern Canadian pattern rather than the West Greenland. On the other hand Sigfúsdóttir (1969), using the same records as did Bergthórsson (chiefly air temperatures measured at Stykkishólmur in west Iceland) shows winter temperatures reaching a peak in 1929-31, and again from 1938 to 1950. Bergthórsson used annual mean temperatures.

Sea surface temperatures from 1871 to 1970, measured at Grimsey and at other stations just north of Iceland, are published by Stefánsson (1969), from whose paper Figs. 18 and 19 are taken. Fig. 18 shows the annual mean SST, behaving in much the same way as the SST in the West Greenland region, and Fig. 19 shows the close inverse agreement between SST and the abundance of sea ice. Dickson et al. (1975) state that the cooling in the Greenland Sea came to an abrupt halt in the winter of 1970-71, and that the low point was the heavy ice year of 1967-68 (see below). Since 1970-71, a warming trend has set in, at least to 1974, north of Iceland. Such a trend is also shown west of Greenland (Fig. 5), at least a change from the former cooling. I have not seen the temperatures for the 1970's, but Smidt (Denmark 1977) reported that "after a series of cold years since 1968, there was a recognizable improvement with relatively warmer water in 1975 in Davis Strait, but in 1976 it was again colder as a result of a strong winter cooling of the surface water".

5. Ice.

The Icelandic story serves as a proper introduction to the part played by sea ice in general in the pattern of climatic change. The causal relationship between sea ice, sea temperature, air temperature, wind and ocean currents cannot be discussed here, and as Markham (1976) has pointed out, the relationship is still not clearly understood, being in a state similar to (and associated with) that of ice forecasting, or as Markham puts its: "Long range ice forecasting is still an imperfect art. It is like going out on a limb even before the tree . . . is planted." Ice is in fact not a subject that can be tackled within the short scope of this review, but certain studies, relevant to the matter in hand, should be mentioned. Moira Dunbar (1972) has called attention to the increasing severity of ice conditions in Baffin Bay and Davis Strait between 1952 and 1970, during which period the ice remained progressively longer in the season. The classic study of Speerschneider (1931) on the state of the "Storis" on the West Greenland coast, has already been referred to. Valeur (1976) continued Speerschneider's study and brought the account of the variations of the Storis on the west coast of Greenland up to date. Valeur tested for significant correlation between the behaviour of the ice and the air temperature at Upernavik, Godthaab, and Point Barrow (Alaska), and found no correlation. He did not test for sea surface temperature, which Hansen and Hermann (1965) showed to be related both to the abundance of Atlantic cod and to the sea-ice record, shown here in Fig. 20, from the Hansen and Hermann paper. This graph is based on the original study by Speerschneider (1931).

For the extent of sea ice coverage in winter in Canadian waters, direct observations do not go back very far, but Markham (1976) points out that the air temperature is closely correlated to the degree of ice formation in situ, and infers that the air temperature record gives a good indication of variation in ice cover in the past. He used the same temperature records for St. John's, Newfoundland, as did Templeman (1965) already mentioned.

In Icelandic waters the abundance of sea ice increased very markedly in the 1960's. Sigurdsson (1969) writes that "more drift ice was observed in Icelandic waters 1967-68 than in any year since 1888. Some ice was reported near the coasts approximately 180 days and almost continuously from March 3 to July 25. The ice frequently impeded navigation and at times was completely blocking the northern and eastern coasts of the country". Sea surface temperatures were much lower than average.

Bergthórsson (1969b) offered a means of forecasting ice conditions each year off Icelandic coasts by means of the air temperatures at Jan Mayen. To quote from the abstract of his paper:

> "Considering the ocean currents north of Iceland the air temperature of the island Jan Mayen is thought to be of prognostic value for the ice conditions at Iceland approximately half a year in advance. This hypothesis is to some

> extent verified by an investigation showing that the summer and fall temperature at Jan Mayen is rather closely correlated with drift ice incidence at Iceland in the following winter, spring and summer. In this way it is possible to issue at the end of November an ice forecast for Iceland, valid until the end of September in the next year. During this period the forecast for the next month may at any time be amended according to the east wind component north of Northwest-Iceland during the last weeks."

6. North Atlantic Ocean.

Surface temperature measurements for the North Atlantic, between latitudes 57^{o} and 50^{o}, are available back to the year 1876; these have been brought together in a paper by Smed (1965), up to the year 1961. Smed writes:

> "For the various areas . . . a conspicuous feature . . . is the preponderance of positive anomalies from about the middle of the 1920's in all areas except the southeasternmost one, area N".

Fig. 21 shows the overall pattern in smoothed curves (overlapping 5-year means). Fig. 22 shows the areas considered. Not only is the warming since 1920 apparent, but also the cooling at the beginning of the 20th century to 1920. The agreement, however, is more marked in the western and northern part of the area studied by Smed (areas A to G) than for the southern and eastern areas H to N.

Smed's paper deals with the period up to 1961. Since that date there has been a significant decline in sea surface temperature, shown in Figs. 23 and 24, from Rodewald's (1967) review of Ocean Weather Ship records. Colebrook (1976), working on SST measurements in Marsden squares 182B and 145D (west of Iceland and west of France), shows the same pattern -- a low temperature trough at the end of the 19th century, down from a minor peak about 1885, and a high peak in the 1950-60 decade, followed by a decline to 1970. The same pattern is recorded by Martin (1972) for the waters northeast of Scotland. Other papers on the North Atlantic, not referenced here, show the same. Pocklington (1978) reports that the SST off Bermuda has decreased over 18 years (to date of publication) by 2-3% of the mean.

But the North Atlantic changes are not simple; they are not uniform over the whole area. This was pointed out by Rodewald (1967), and Zverev (1972), analyzing the long-term variations in the North Atlantic, 1948-68, using Ocean Weather Station data, concluded that "the phases of variation of water temperature anomalies in the western (Ocean Weather Stations B, C, D, E) and northern (Ocean Weather Stations A and I) region are 180^{0} out of phase with each other". This clearly needs further study, for it is not in agreement with other work reported here, for the northern part of the North Atlantic - Subarctic circulation.

7. Summary.

The range of variation, as shown by the smoothed curves (5- or 10-year means) is much the same throughout the regions discussed here, 2 to 2.5^{0}C. The year-by-year curves naturally show larger ranges, 4.5^{0} for Station 27 east of Newfoundland (Fig. 12), 3^{0} for St. Andrews, New Brunswick (Lauzier 1965, not shown here). All areas (Canadian waters, West Greenland, North Iceland, and the Atlantic in general, show temperature peaks in the 1930's and 1950's, but the second peak appears to have appeared later in West Greenland, in the early 1960's (Fig. 5). A minor peak is shown in all areas about 1900, and pronounced trough in 1920, except for the Icelandic record (Fig. 18) where the low temperatures appeared around the turn of the century and again about 1916, with a peak in between.

The rapidity of the rise in temperature in West Greenland waters from the 1920 low point is unmatched by the others. The 1930's peak in the Canadian and northern U.S. waters is the smaller of the two, whereas it is the larger in West Greenland and in Iceland. There are differences between all four areas in terms of the precise years of the maxima and minima.

8. Coda.

No review is offered here of the possible causes of climatic change that have appeared in the literature. It is a fascinating field of study, involving solar constants, sunspots, continental drift, volcanos, atmospheric pressure gradients, the Iceland low and the Azores high, zonal and meridional winds, interstellar clouds, oceanic circulation, terrestrial tilt. The literature is large. I would mention only two papers: one by Einarsson (1969), which summarizes very briefly the possible causes that have been suggested, and one by Schell and Corkum (1976) which discussed the thermal lag between atmosphere and ocean during periods of climatic change (which is more of less always).

The material reviewed here demonstrates the great value of regular monitoring of environmental factors. I have in the past urged many times, in print and in memoranda, that oceanographic monitoring should be maintained by Canadian ships in Canadian northern waters. This is now being done, but only very recently. It is maintained that the occupation of standard sections would be too expensive and would take up too much of the ship time available. That must depend on the importance placed upon monitoring. If Denmark (Greenland) and Iceland can monitor their waters for so many years in a row, surely we can do the same.

REFERENCES

Aaby, B., 1976. Cyclic climatic variations in climate over the past 5,500 years reflected in raised bogs. Nature, 263: 281-284.

Bergthórsson, P., 1969a. An estimate of drift ice and temperature in Iceland in 1000 years. Jökull, 19 ár: 94-101.

________, 1969b. Forecasting drift ice at Iceland by means of Jan Mayen air temperatures. Jökull, 19 ár: 44-52.

Burmakin, V.V., 1972. Seasonal and year to year variations in water temperature in the Labrador and Newfoundland areas. ICNAF, Spec. Publ., No. 8: 63-70.

Colebrook, J.M., 1976. Trends in the climate of the North Atlantic ocean over the past century. Nature, 263: 576-577.

Denmark, 1977. Referat af den Kongelige Grønlandske Handels Fiskerimøde, Mandag den 18 April 1977.

Dickson, R.R., H.H. Lamb, S-A Malmberg and J.M. Colebrook, 1976. Climatic reversal in the northern North Atlantic. Nature, 256: 479-482.

________ and A.J. Lee, 1969: Atmospheric and marine climate fluctuations in the North Atlantic region. In: Mary Sears (ed.), Progress in Oceanography, vol. 5: 55-65.

Dunbar, M.J., 1946. The state of the West Greenland current up to 1944. J. Fish. Res. Bd. Canada, VI(7): 460-471.

________, 1955. The present status of climatic change in the Atlantic sector of northern seas, with special reference to Canadian Eastern Arctic waters. Trans. Roy. Soc. Canada, Ser. III, 49: 1-7.

Dunbar, M.J., 1960. Preliminary report on the Bering Strait scheme. Unpublished report to the Department of Northern Affairs and National Resources, Committee on Northern Development, 25 pp.

________, 1962. Second report on the Bering Strait dam. Ibid, 23 pp.

________ and D.M. Moore, 1978. Marine life and its environment in the Canadian Eastern Arctic: a biogeographic study. M.S. report to Parks Branch, Department of Indian and Northern Affairs, Ottawa. 119 pp. and 33 charts. McGill University, Marine Sciences Centre.

________ and D.H. Thomson, 1979. West Greenland salmon and climatic change. Medd. om Grønl., 202 (4): 19 pp.

Dunbar, Moira, 1972. Increasing severity of ice conditions in Baffin Bay and Davis Strait and its effect on the extreme limits of ice. In: T. Karlsson (ed.), Sea Ice; Proc. Internat. Conf., NRC, Reykjavik, Iceland: 87-93.

Easton, C., 1928. Les hivers dan l'Europe occidentale. Leyde, E.J. Brill: 210 pp.

Einarsson, T., 1969. On climatic fluctuations and their possible causes. Jökull, 19 ár: 104-106.

Elizarov, A.A., 1962. On the interannual fluctuations of intensity in the Labrador and West Greeland currents and on the northwestern section of the Atlantic Ocean. Oceanology, 5:

Ellet, D.J., 1980. Long-term water variations in the northeast Atlantic. ICES, Hydrography Committee, CM 1980/c: 9, 11 pp.

Emiliani, C., 1972. Quaternary hypsithermals. Quat. Res., 2: 270-273.

Hammer, C.V., H.B. Clausen and W. Dansgaard, 1980. Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. Nature, 288: 230-235.

Hansen, P.M. and F. Hermann, 1965. Effect of long-term temperature trends on the occurrence of cod at West Greenland. ICNAF Spec. Publ. No. 6: 817-819.

Jensen, A.S., 1939. Concerning a change in climate . . . Det Kongelige Videnskabernes Selskab, Biologiske Meddelelser, XIV(8): 78 pp.

Johnson. S.J., W. Dansgaard, H.B. Clausen and C.C. Langway, 1969. Climatic oscillations 1200-2000 A.D. Nature, 227: 482-483.

Keeley, J.R., 1981. Temperature, salinity and sigma-t at Station 27 ($47^{0}33'N$, $52^{0}35'W$). An analysis of data. Canada, Fisheries and Oceans, Technical Report No. 8: 56 pp and microfiche.

Lauzier, L.M., 1965. Long-term temperature variations in the Scotia Shelf area. ICNAF, Spec. Publ. No. 6: 807-816.

________, 1972. Climatic change in the marine subarctic. Trans. Roy. Soc. Canada, Ser. IV, X: 297-307.

________ and N.J. Campbell, 1959. Comparison of some oceanographic features in the Labrador Sea and Davis Strait regions, 1928-35 and 1950-55. Int. Oceanogr. Congr., N.Y., Abstracts: 103. Woods Hole, Mass.

________ and R.W. Trites, 1958. The deep waters in the Laurentian Channel. J. Fish. Res. Bd. Canada, 15(6): 1247-2157.

Markham, W.E., 1976. Variability of ice season on the eastern Canadian seaboard. ICNAF, Spec. Publ. No. 9: 29-40.

Martin, J.H.A., 1972. Marine climatic change in the northeast Atlantic, 1900-1966. Rapp. Proc.-Verb., Cons. Perm. Int. Expl. Mer., 162: 213-229.

Mason, B.J., 1976. The nature and prediction of climatic changes. Endeavour: 35(125): 51-57.

Matthews, W.H., W.W. Kellog and G.D. Robinson, 1971. Man's impact on the climate. M.I.T. Press, Cambridge, Mass. and London.

Pocklington, R., 1978. Climatic trends in the North Atlantic. Nature, 273: 407.

Riehl, H., 1956. Sea surface temperatures of the North Atlantic 1887 - 1936. University of Chicago, 9 p. unpublished.

Rodewald, M., 1967. Recent variation of North Atlantic sea surface temperatures and the "type tendencies" of the atmospheric circulation. ICNAF Redbook 1967, Part IV: 6-23.

________, 1969. Temperature conditions in the north and northwest Atlantic during the decade 1961-1970. ICNAF Spec. Publ. No. 8: 9-33.

Schell, I.I., and D.A. Corkum, 1976. On a thermal lag in the North Atlantic Ocean during a climatic change. J. Phys. Oceanogr., 6: 125-129.

Scherhag, R., 1937. Die Erwärmung der Arktis. J. Du Conseil, 12: 263-276.

Sigfúsdóttir, A.B., 1969. Temperature in Stykkishólmur 1849-1968. Jökull, 19 ár: 7-10.

Sigurdsson, F.H., 1969. Report on sea ice off the Icelandic coasts October 1967-September 1968. Jökull, 19 ár: 77-93.

Smed, J., 1947-62. Monthly anomalies of the surface temperatures in the sea. Ann. Biol., vols II to XVII.

________, 1965. Variation of the temperature of the surface water in areas of the northern North Atlantic, 1876-61. ICNAF, Spec. Publ. No. 6: 821-825.

Speerschneider, C.H.I., 1931. The state of the ice in Davis Strait, 1820-1930. Danish Met. Inst. Medd., 8: 1-53.

SMIC, 1971. Inadvertent climate modification. M.I.T. Press, Cambridge, Mass.

Stefánsson, U., 1969. Temperature variations in the north Icelandic coastal area during recent decades. Jökull, 19 ár: 18-28.

Templeman, W., 1965. Anomalies of sea temperature at Station 27 off Cape Spear and of air temperature at Torbay-St. John's ICNAF Spec. Publ. No. 6: 794-806.

Valeur, H., 1976. Polar ice variations off the Greenland west coast, 1900-1972. ICNAF, Spec. Publ. No. 9: 23 pp.

Wiseman, J.D.H., 1954. The determination and significance of past temperature changes in the upper layer of the equatorial Atlantic Ocean. Proc. Roy. Soc. London, Ser. A, 222: 296-323.

Zverev, A.A. , 1972. Water temperature variations in the North Atlantic in 1948-1968. Oceanology, 12(2): 182-186.

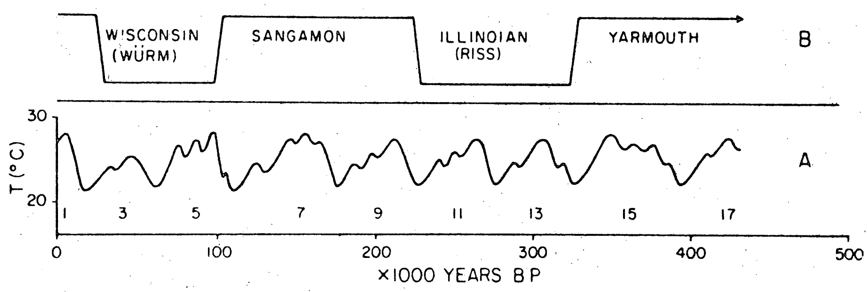


Fig. 1. Comparison of the classical interpretation of the glacial cycle (B) with the paleotemperature curve based on oxygen isotope analysis from deep sea cores, Caribbean and Atlantic. From Emiliani 1972.

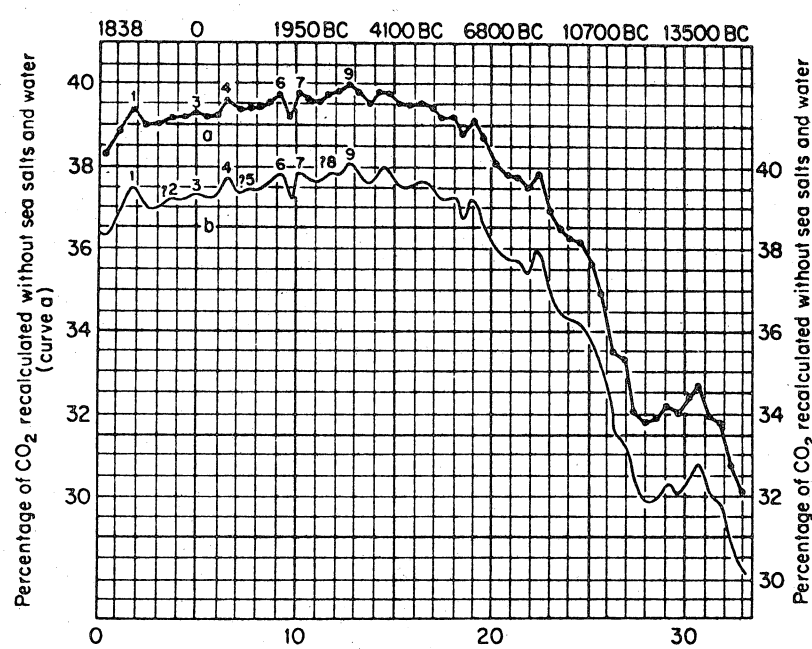


Fig. 2. Carbon dioxide measurements from sediment core taken in the Equatorial Atlantic by the Swedish "Albatross" Expedition. Redrawn from Wiseman (1954).

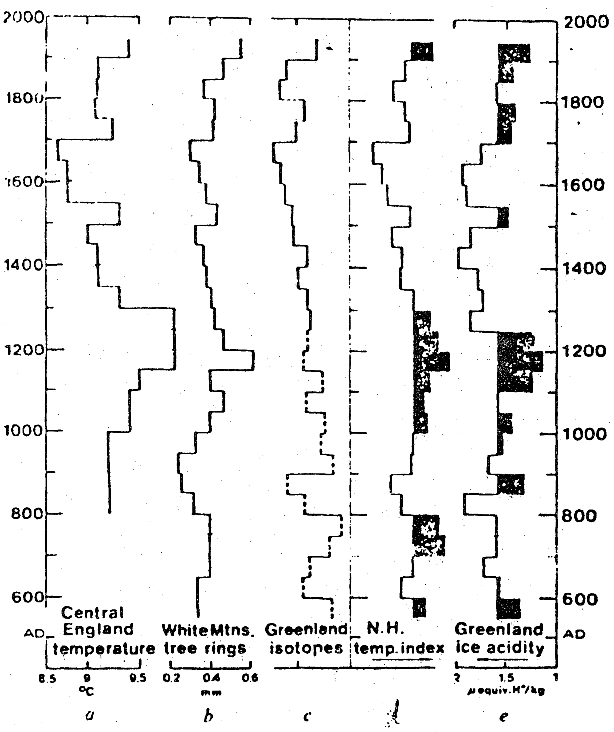


Fig. 3. Temperature variations measured by various methods (curves a, b, c, and summarized for the northern hemisphere (curve d). Curve e records volcanic activity. From Hammer et al., (1980).

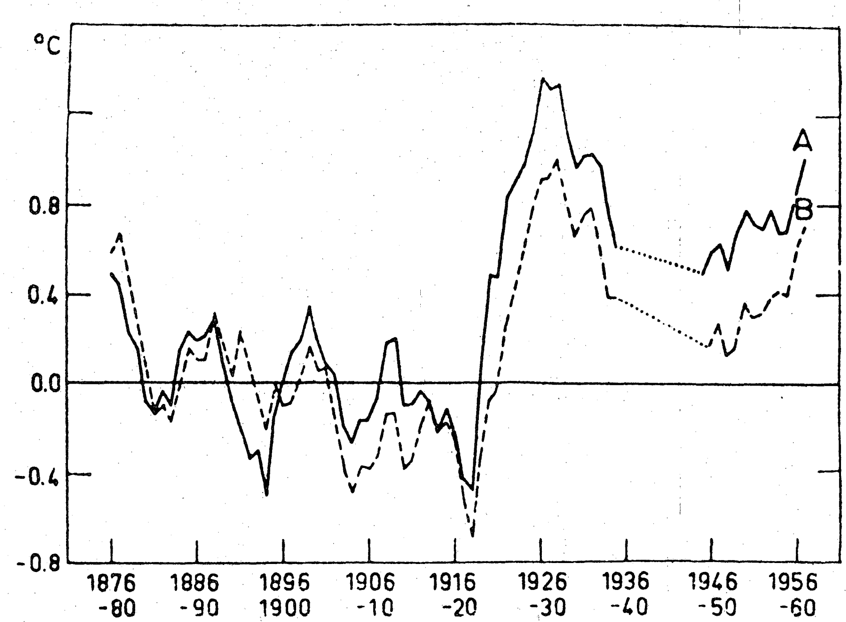
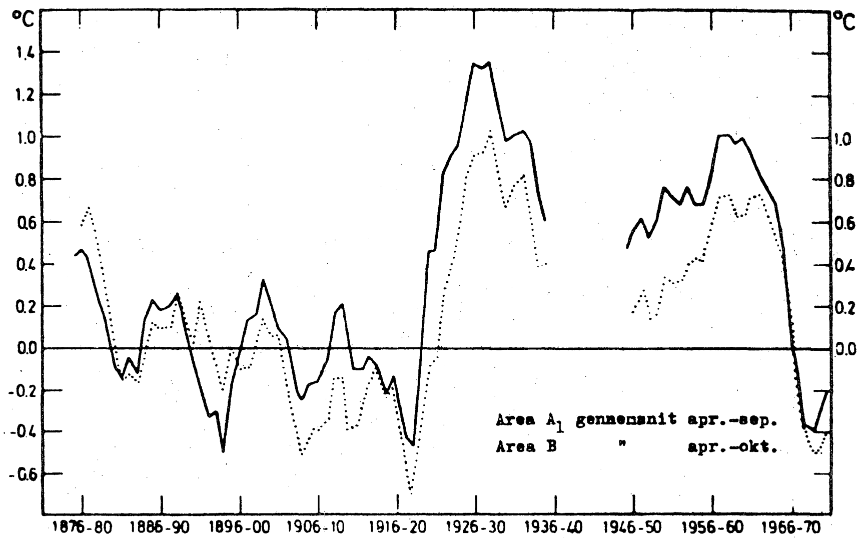


Fig. 4. Five-year running means, surface temperature, southwest Greenland. Curve A: Smed's area A_1 (west Greenland south of Disko Island); Curve B: Smed's area B (south Greenland round Cape Farewell). April to September (Curve A); April to October (Curve B). From Hansen and Hermann (1965).



Temperaturnomalierne for overfladevandet d.v.s. afvigelsen fra gennemsnittemperaturen for årene 1876-1915 (0-linien), angivet i 5 års glidende gennemsnit indtil 1974.
A_1 fuldt optrukken linie Vestgrønland (nord for Fredrikshåb Isblink), B punkteret linie Sydgrønland (syd for Fredrikshåb Isblink).

Fig. 5. Temperature anomalies, surface, five-year running means. Solid line: West Greenland north of Fredrikshaab "Ice-blink". Dashed line: west Greenland south of the "ice-blink". From Denmark (1977).

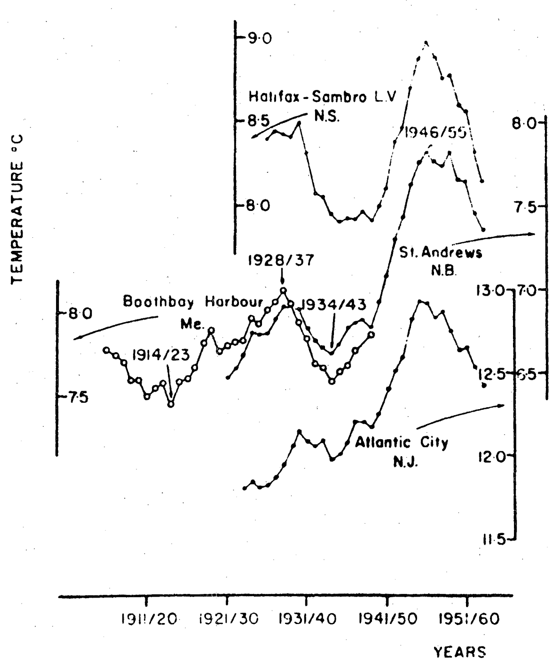


Fig. 6. Surface temperatures, eastern Canadian and U.S. seaboard. Ten-year running means credited to the last year of the period. From Lauzier (1965).

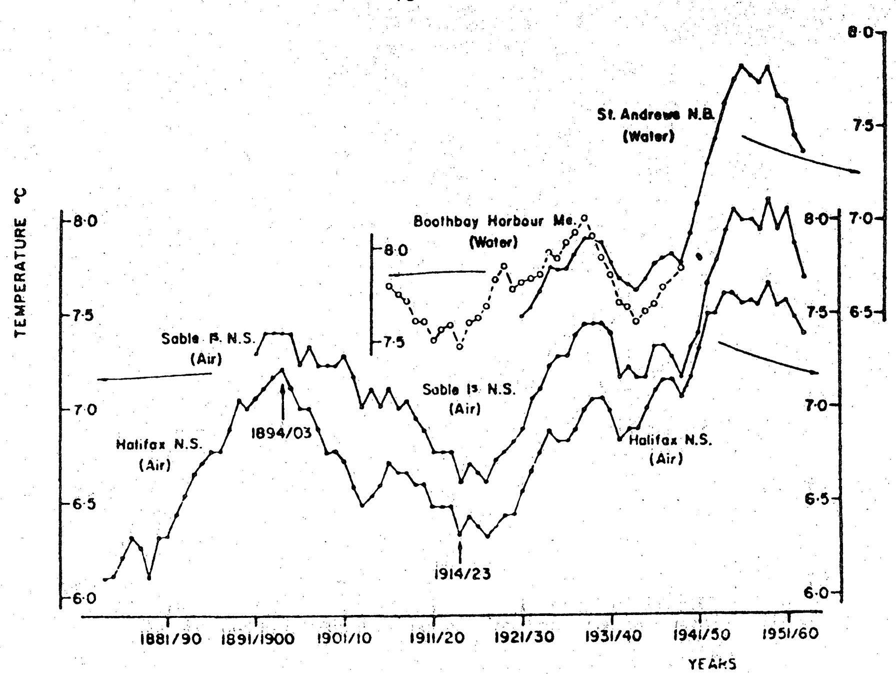


Fig. 7. Surface temperatures at St. Andrews and Boothbay Harbor. Air temperatures at Sable Island and Halifax. Ten-year running means credited to the last year of the period. From Lauzier (1965).

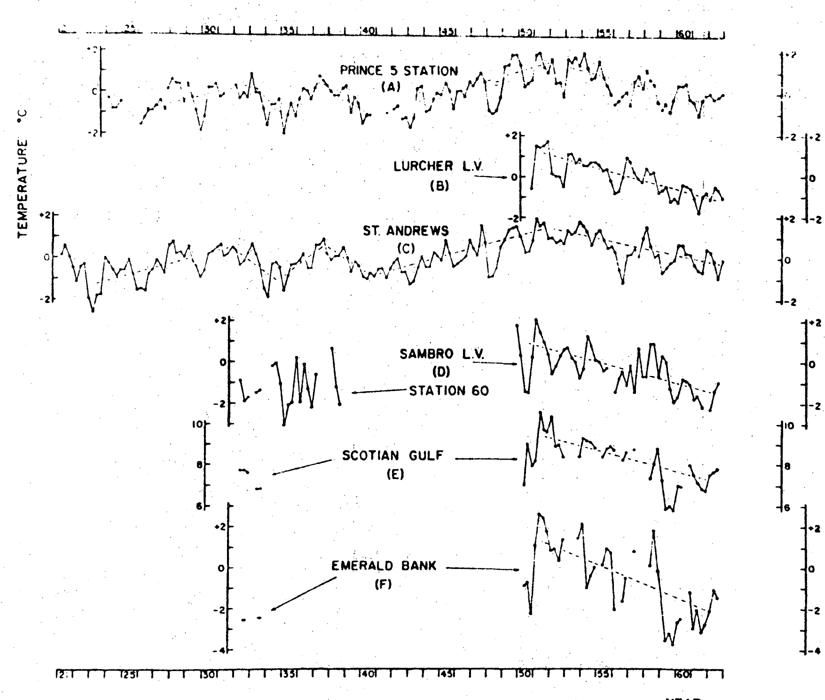


Fig. 8. Changes in water temperatures. (A) Prince 5 Station, bottom temperatures, averaged by quarter-years, 1924-1962. (B) Lurcher L-V, bottom temperatures, 1950-62. (C) St. Andrews, surface temperatures, 1921-62. (D) Sambro L-V, bottom temperatures, 1949-62. (E) Maximum temperatures within bottom layer, Scotian Shelf, 1950-62. (F) Emerald Bank, bottom temperatures, 1950-62. From Lauzier (1965).

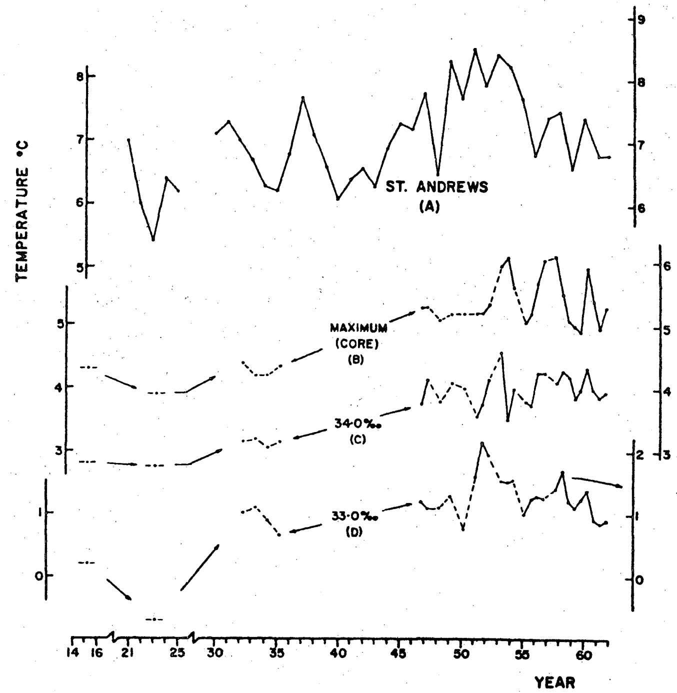


Fig. 9. Curve A: Surface temperatures, St. Andrews, annual means.
Curves B, C, D: temperatures in the deep layer in Cabot Strait, Laurentian Channel.
From Lauzier (1965)

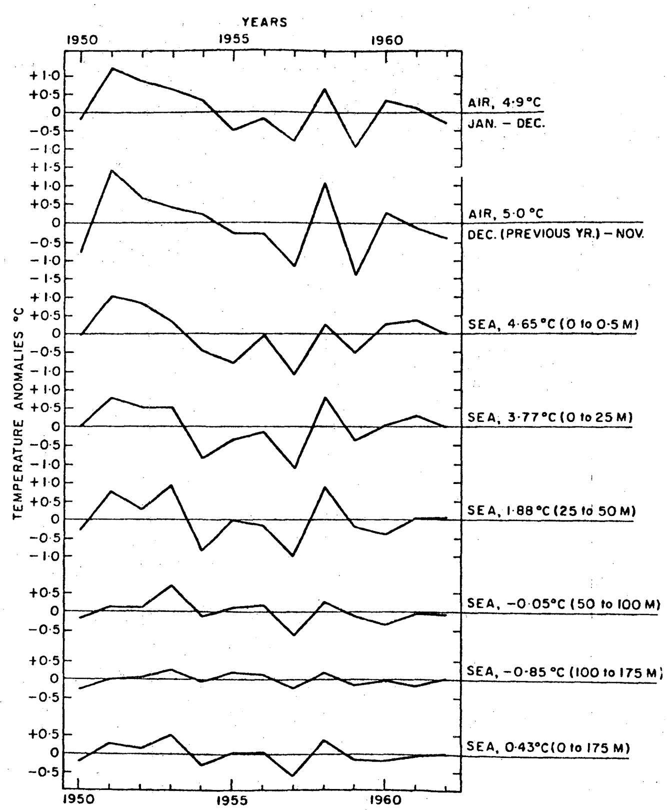


Fig. 10. Water column temperatures at Station 27, and air temperatures at Torbay-St. John's, Newfoundland. Annual averages. From Templeman (1965).

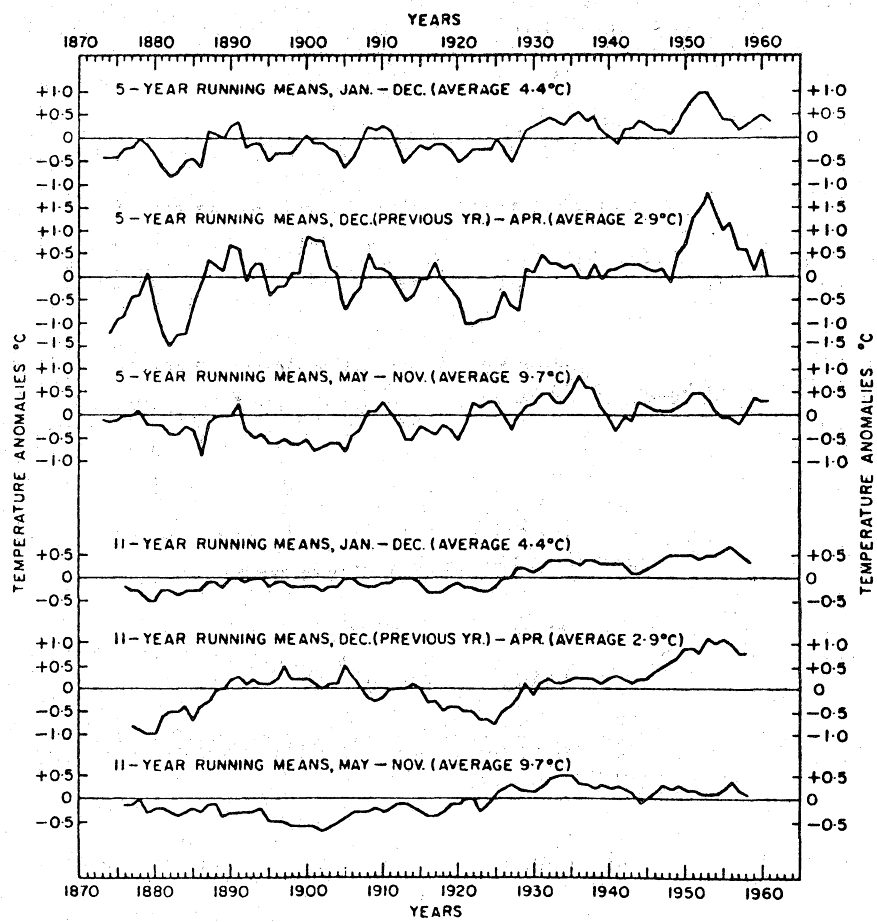


Fig. 11. Five-year and elevan-year running means of air temperatures at St. John's-Torbay. The running means are attributed to the median year. From Templeman (1965).

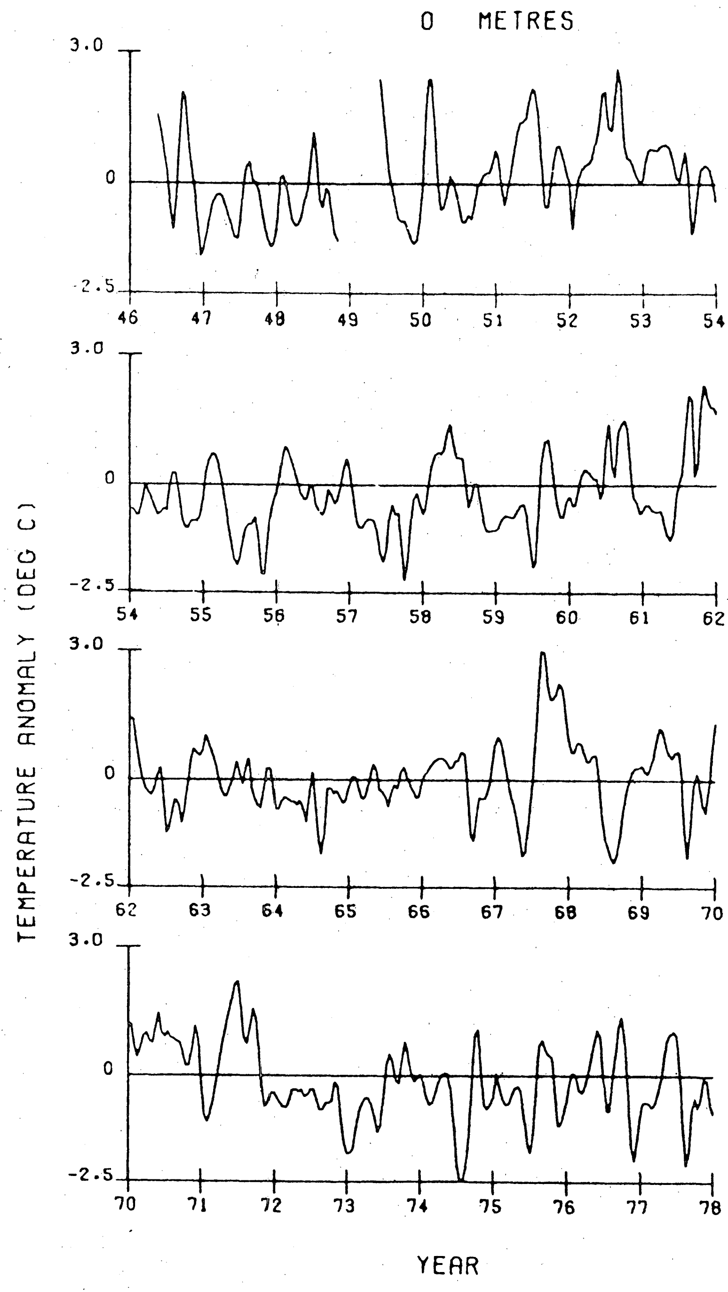


Fig. 12. Surface temperatures, Station 27, east of Newfoundland, 1946-78. From Keeley (1981).

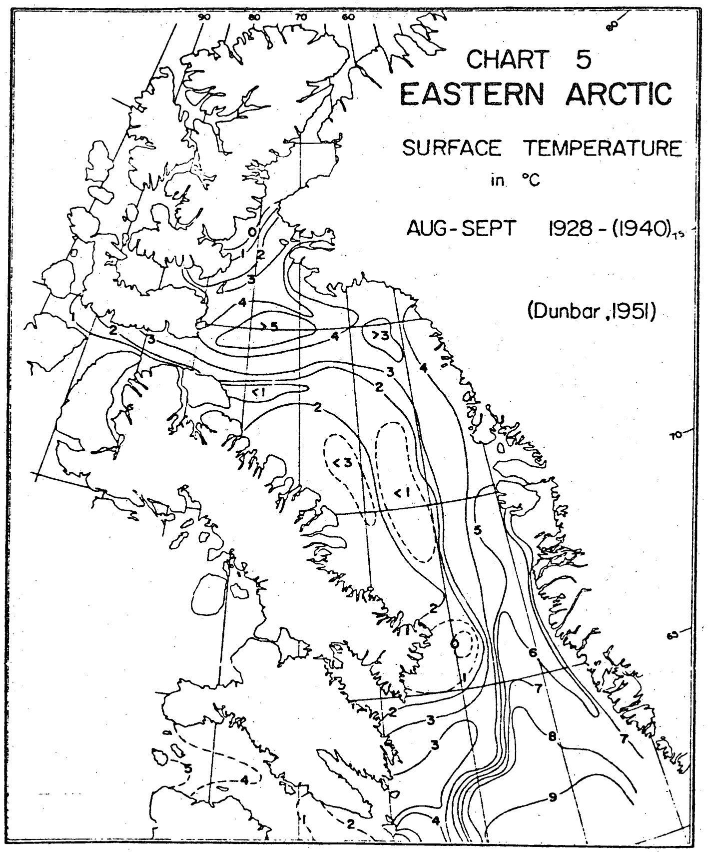


Fig. 13. From Dunbar and Moore (1980)

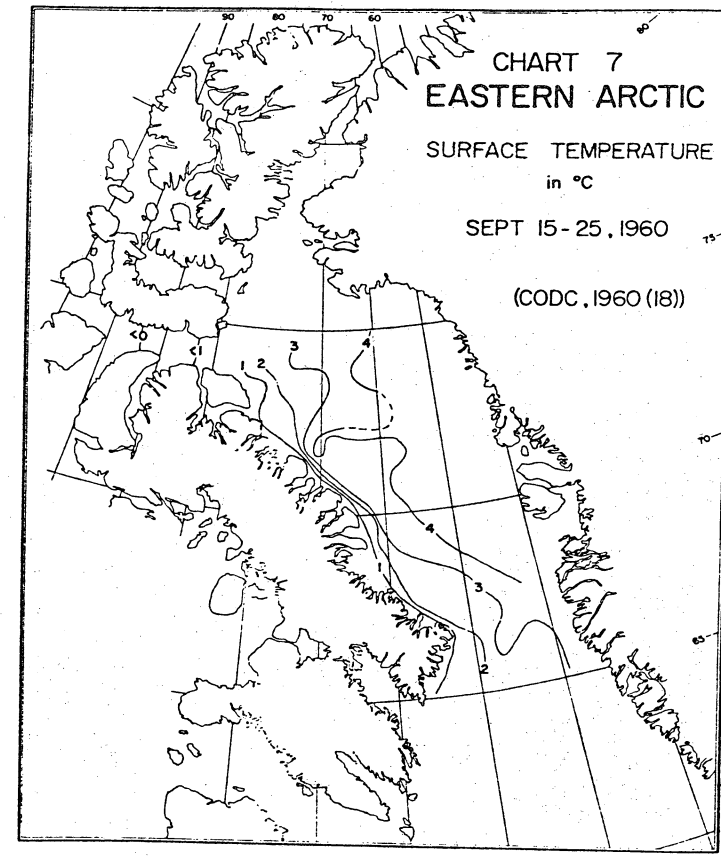


Fig. 14. From Dunbar and Moore (1980)

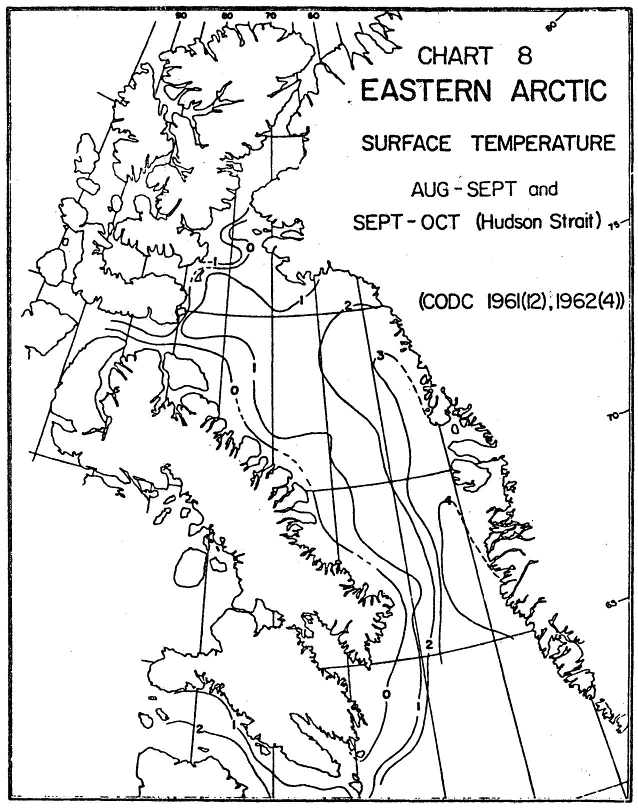


Fig. 15. From Dunbar and Moore (1980)

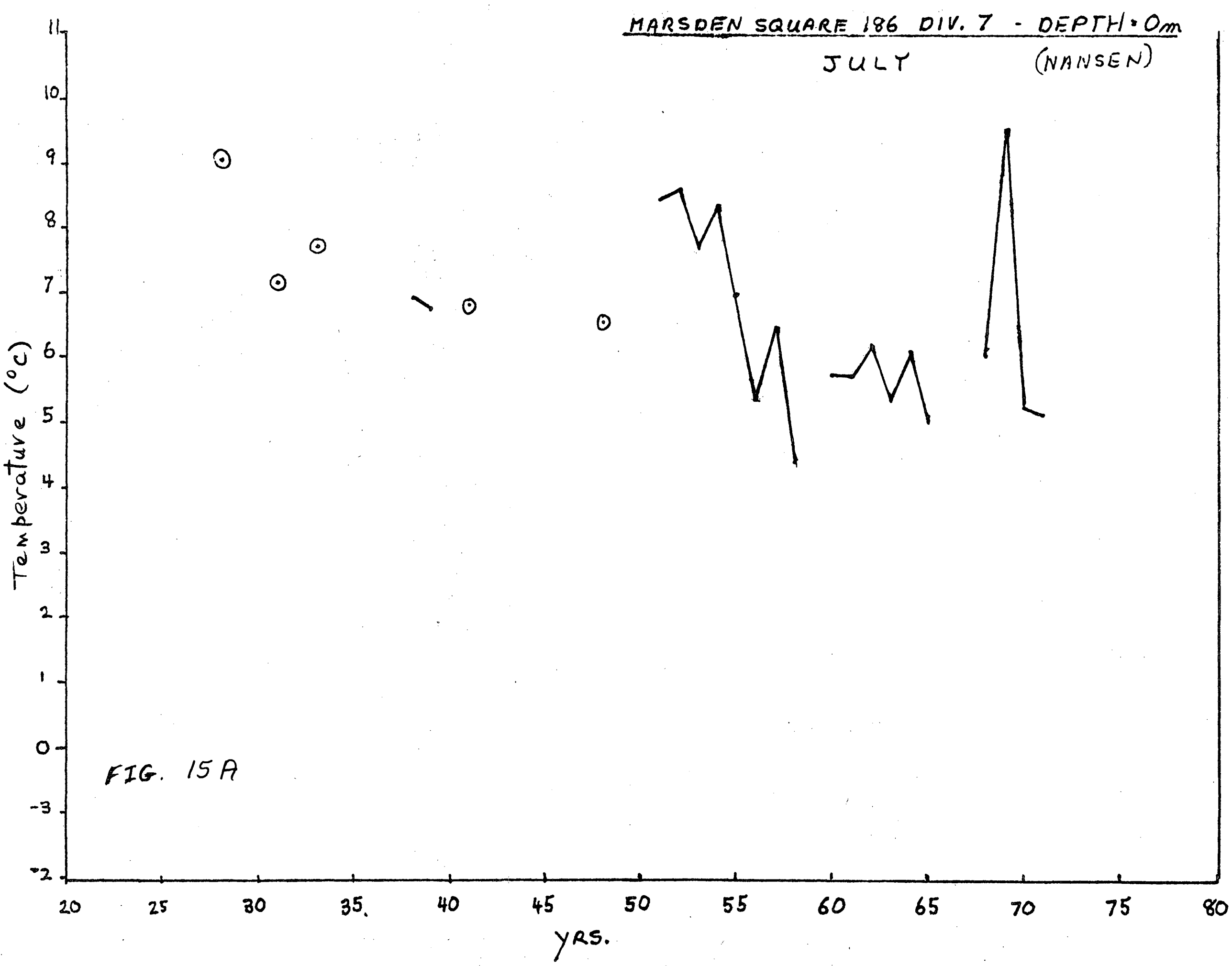


FIG. 15A

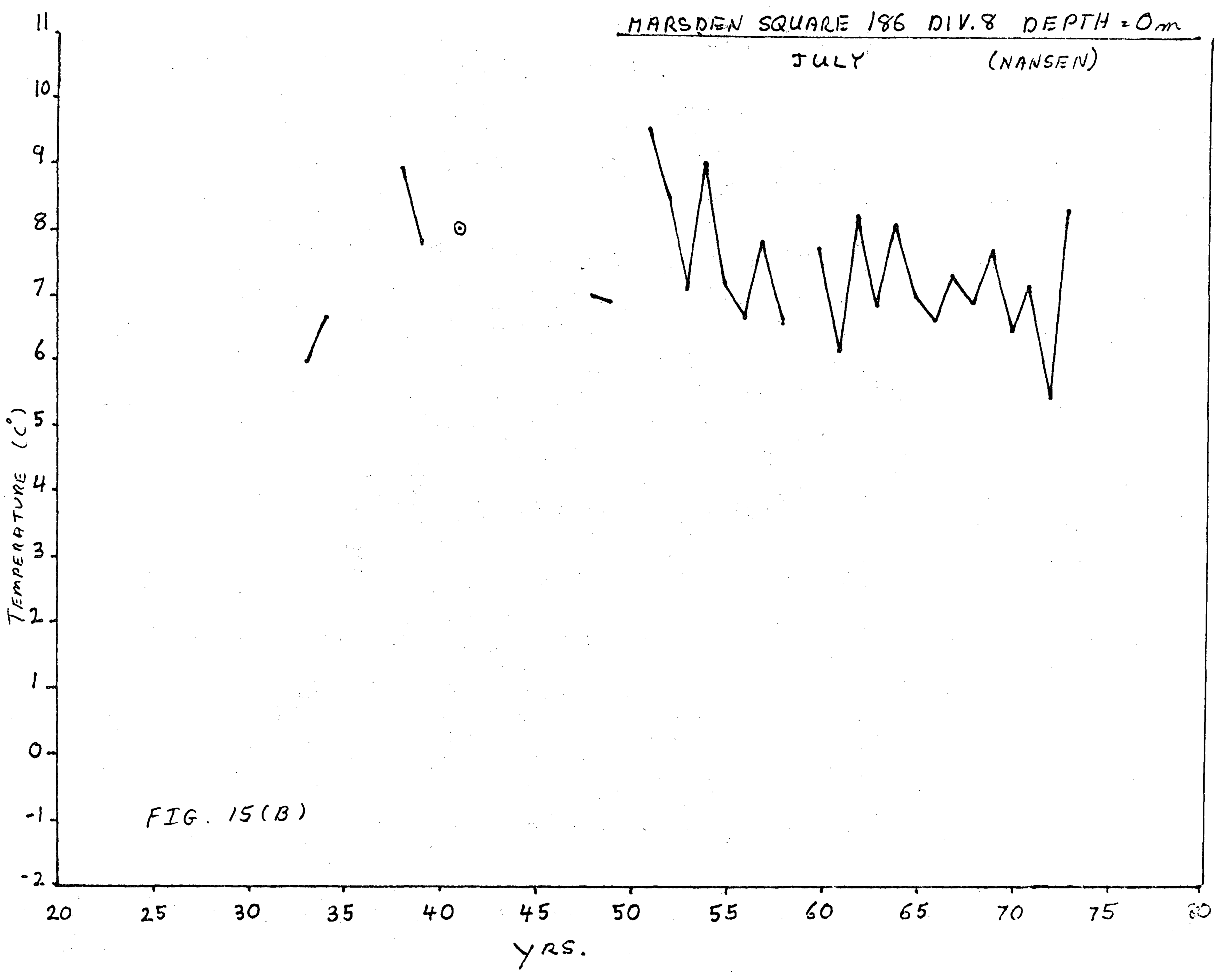


FIG. 15(B)

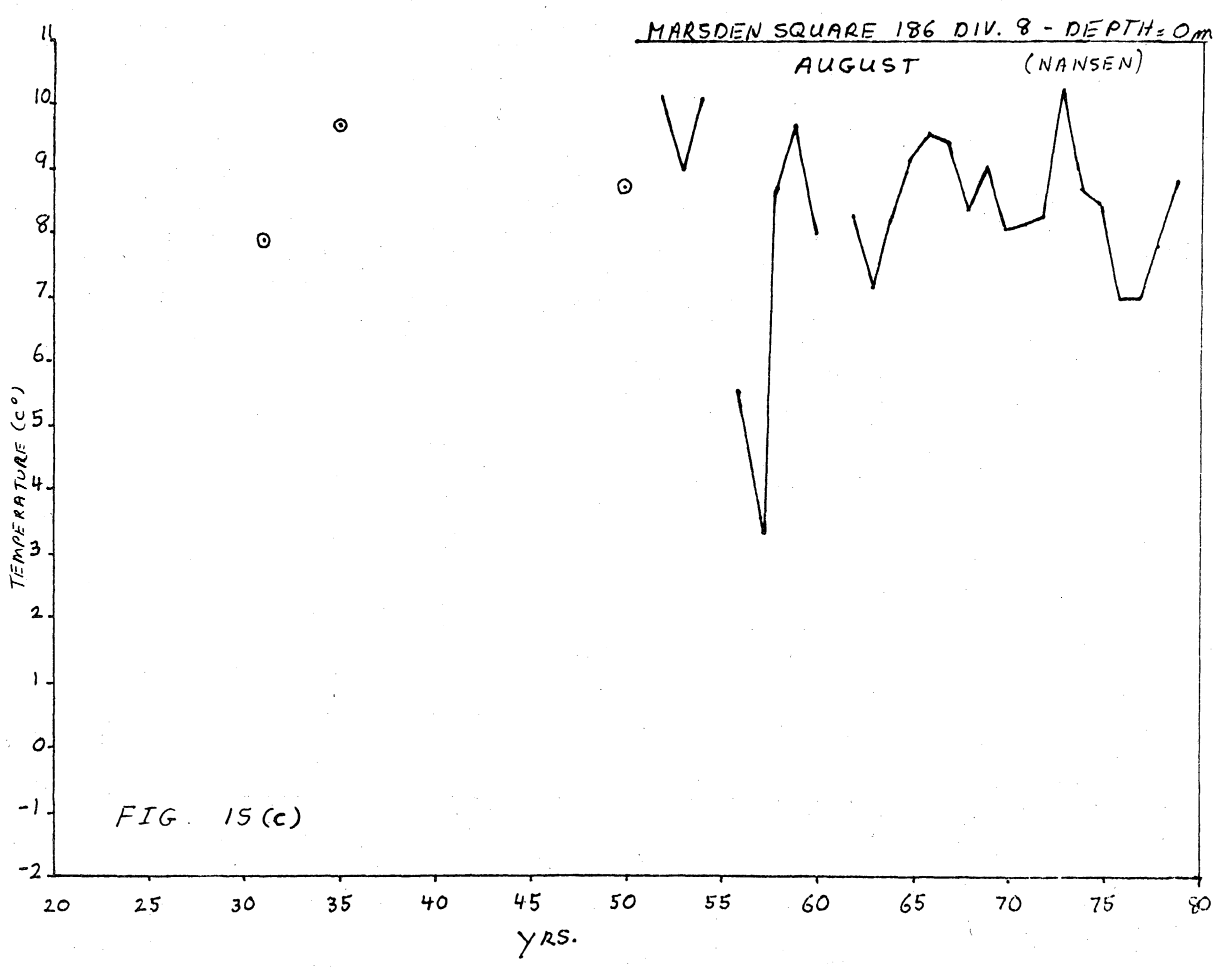


FIG. 15(c)

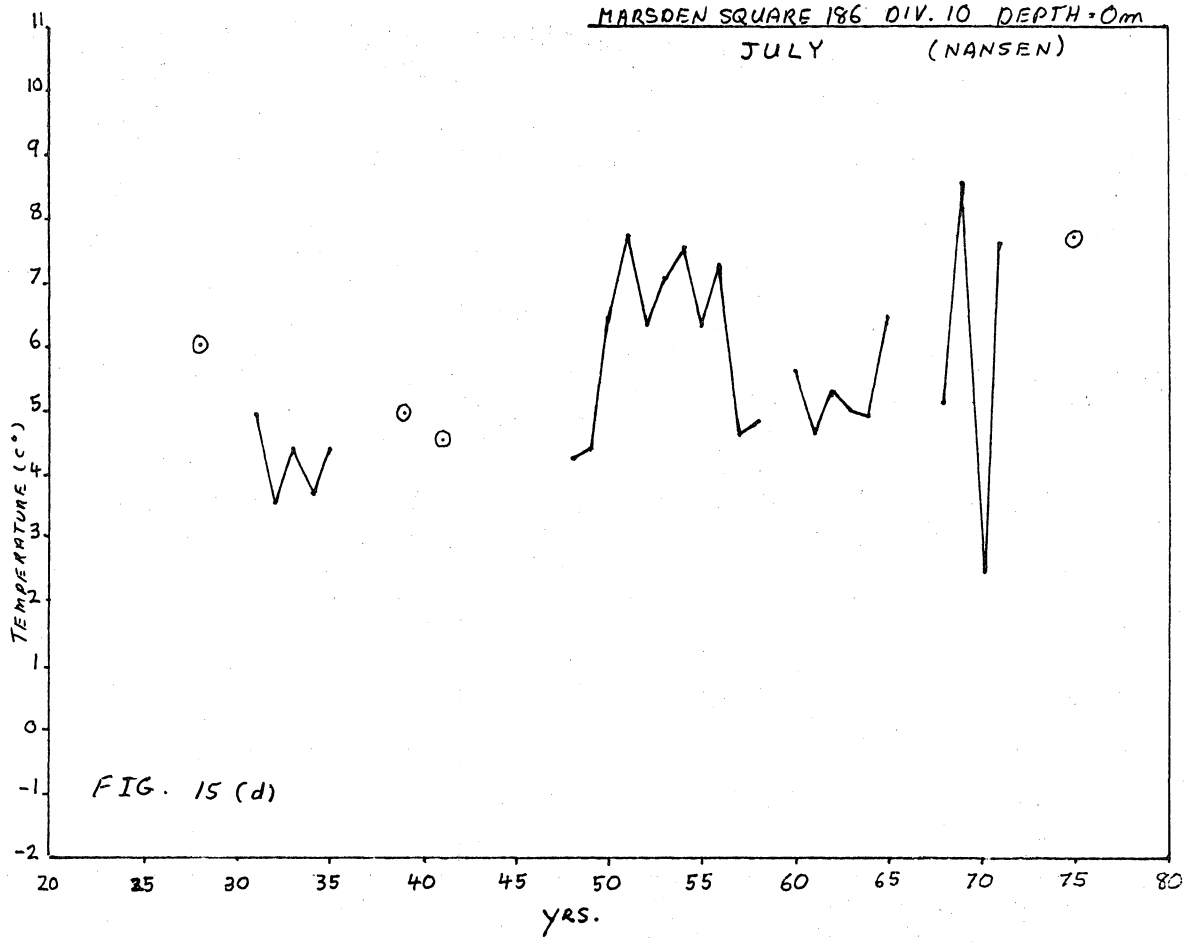


FIG. 15 (d)

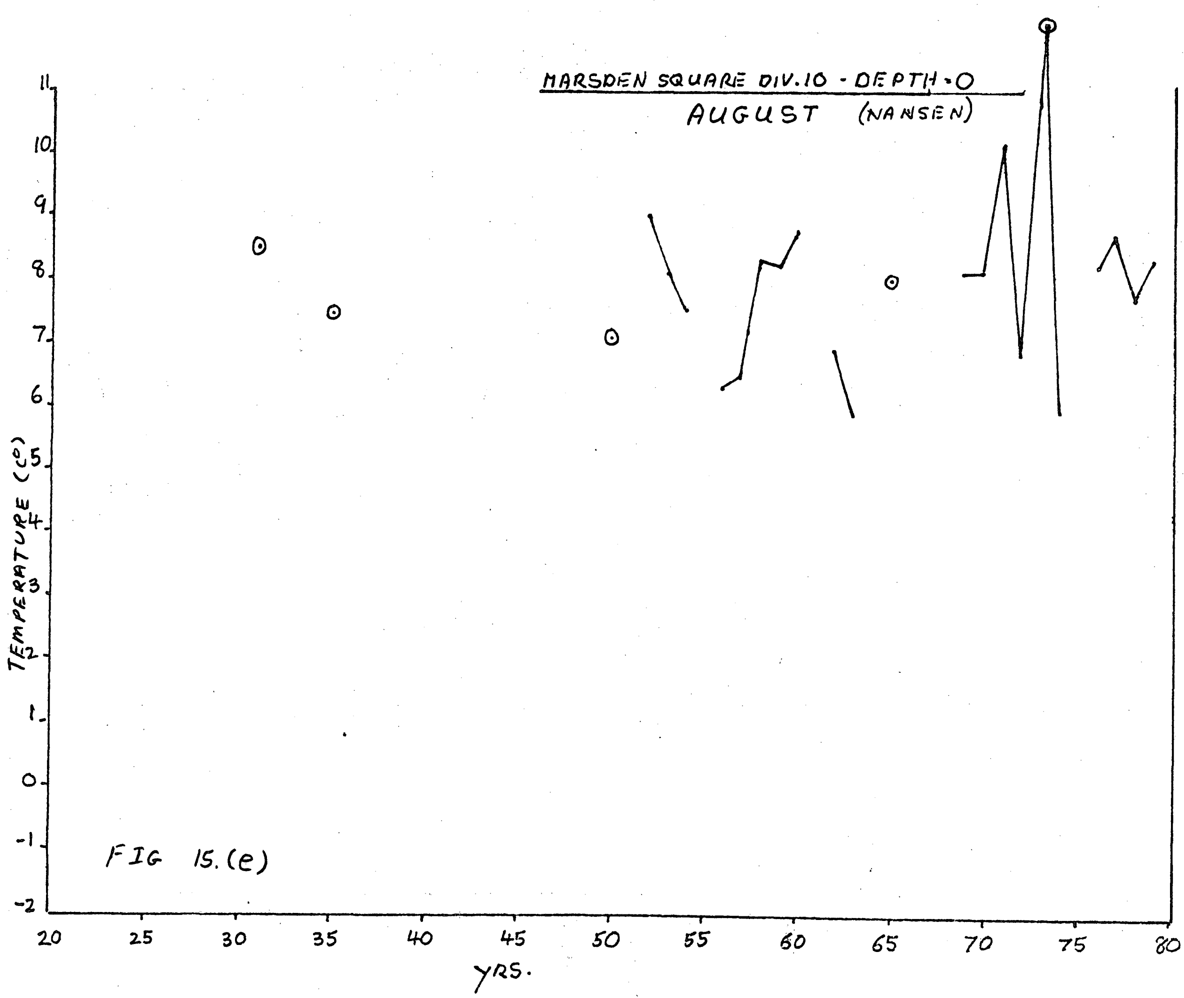


FIG 15. (e)

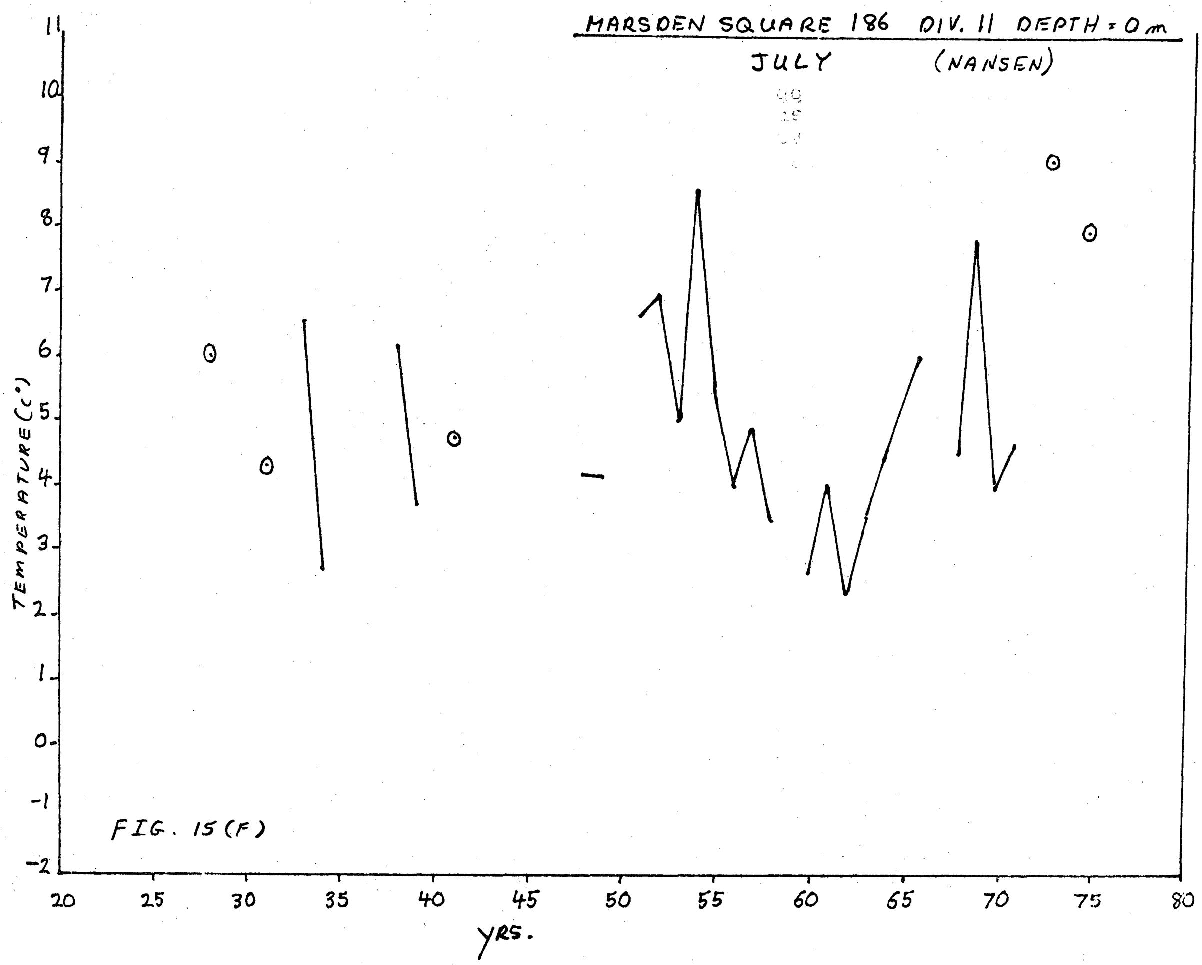


FIG. 15 (F)

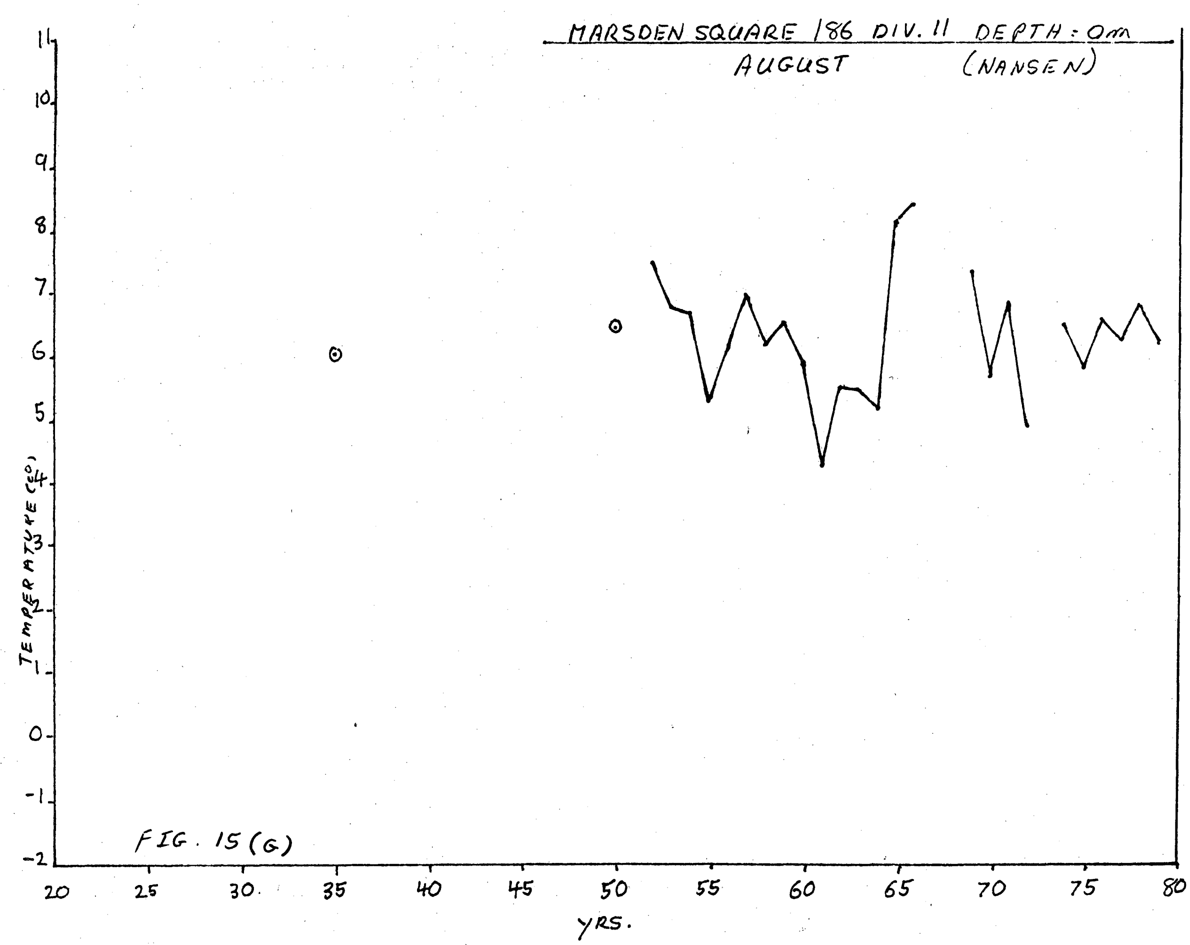
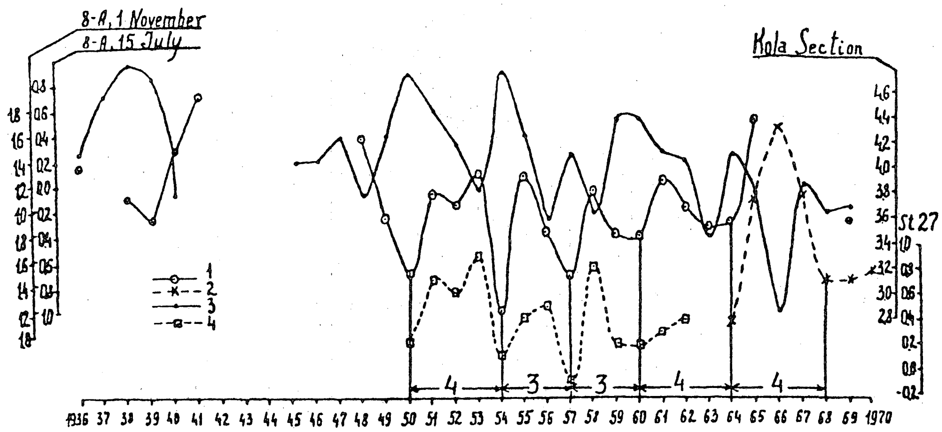


FIG. 15 (G)



Year to year fluctuations of temperature of the 0- to 200-m layer:
1) of the cold component of the Labrador Current on section 8-A, adjusted to 15 July for 1936, 1938-41, 1948-64, 1969;
2) adjusted to 1 November for 1958, 1962, 1964-70;
3) the mean annual temperature on section "The Kola Meridian" in the Barents Sea for 1936-40, 1945-69;
4) the mean annual temperature on station 27 and off Newfoundland for 1950-62.

Fig. 16. From Burmakin (1972)

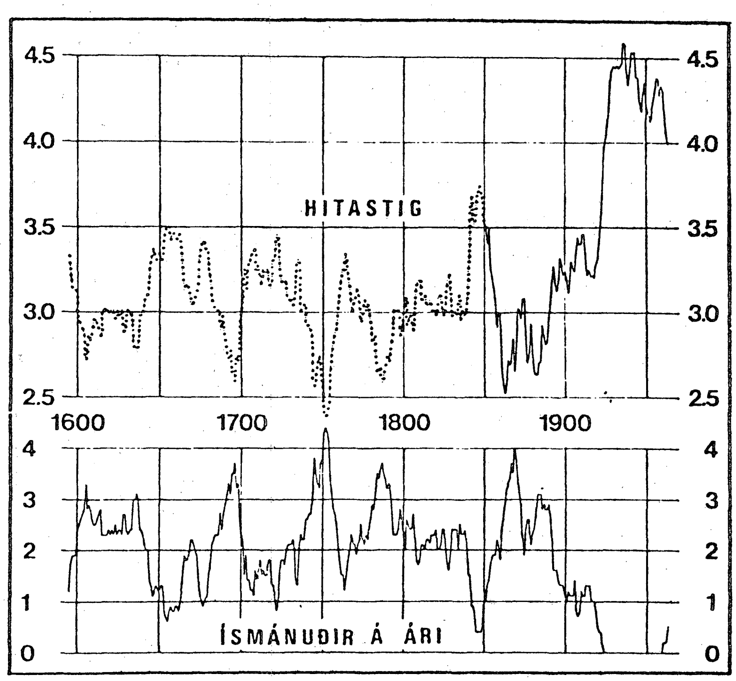


Fig. 17. Ten-year running means of air temperature (upper curve) and of ice incidence in months per year (lower curve). Air temperatures are ~~the means of measur~~ estimated from the ice conditions (see text). From Bergthórsson (1969a). Iceland.

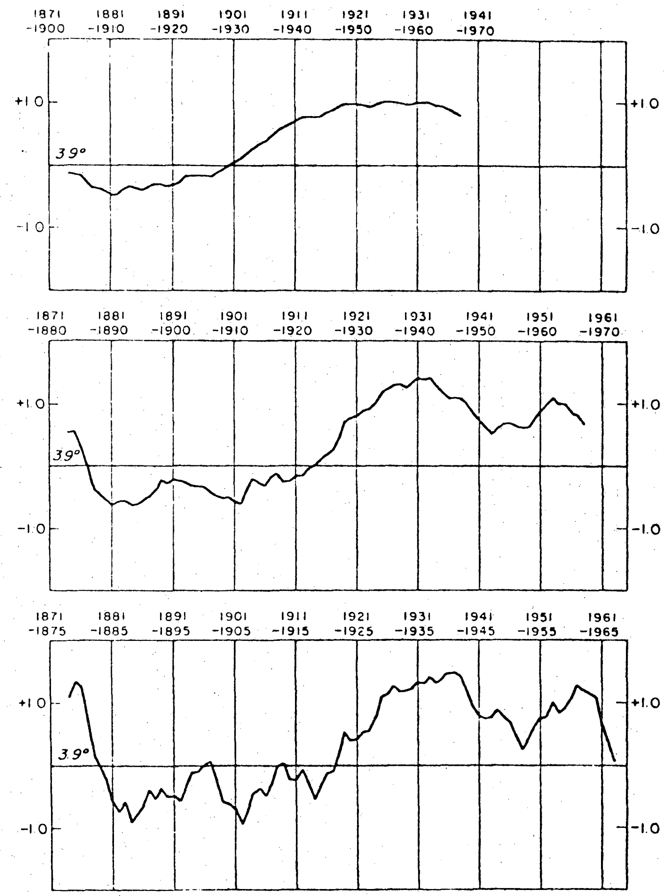


Fig. 18. Sea surface temperatures at Grímsey, Iceland, expressed as 30-, 10- and 5-year running means. From Stefánsson (1969).

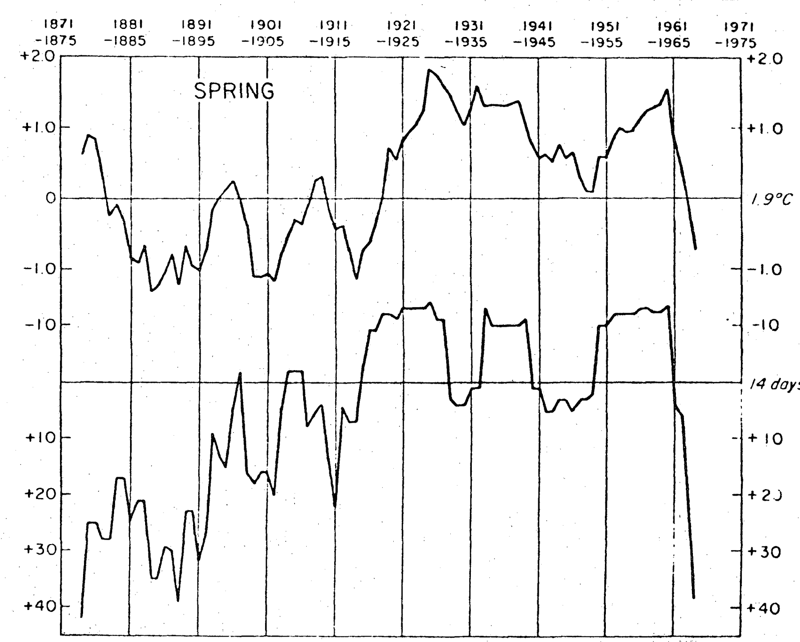


Fig. 19. Variations in the incidence of drift ice in the Icelandic coastal area in March-May; and sea surface temperatures at Grímsey, March-May. From Stefánsson (1969).

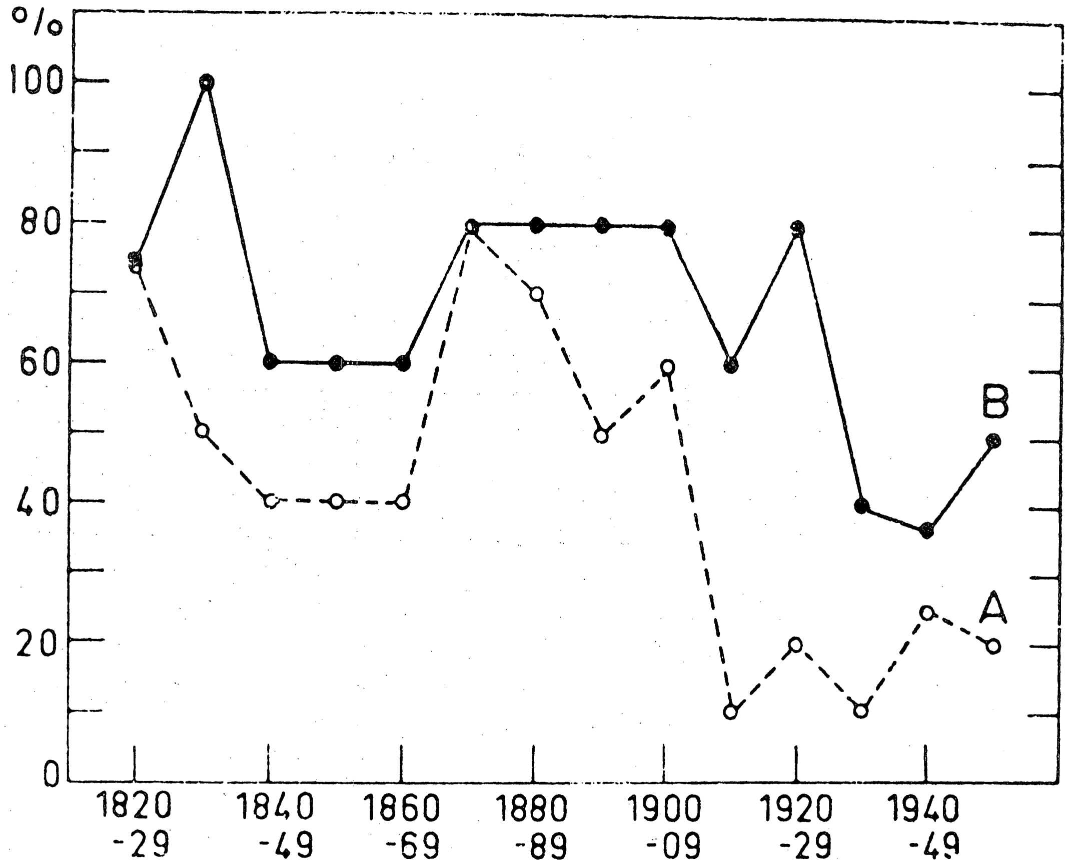


Fig. 20. Frequency of years in which the Storis reached as far north as Godthaab (A), and Fiskenaesset (B). From Hansen and Hermann (1965).

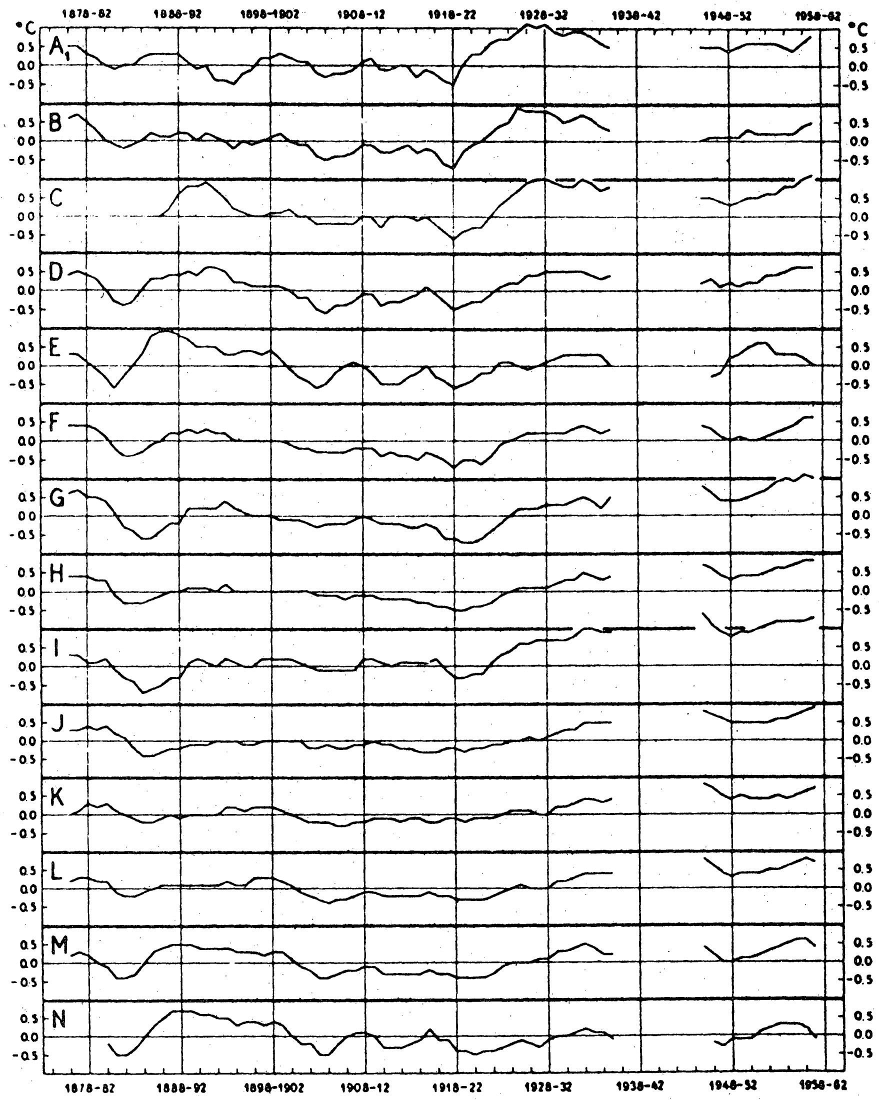


Fig. 21. Overlapping 5-year means of anomalies of sea surface temperature in the areas A_1 to N. From Smed (1965). See Fig. 22 for the areas concerned.

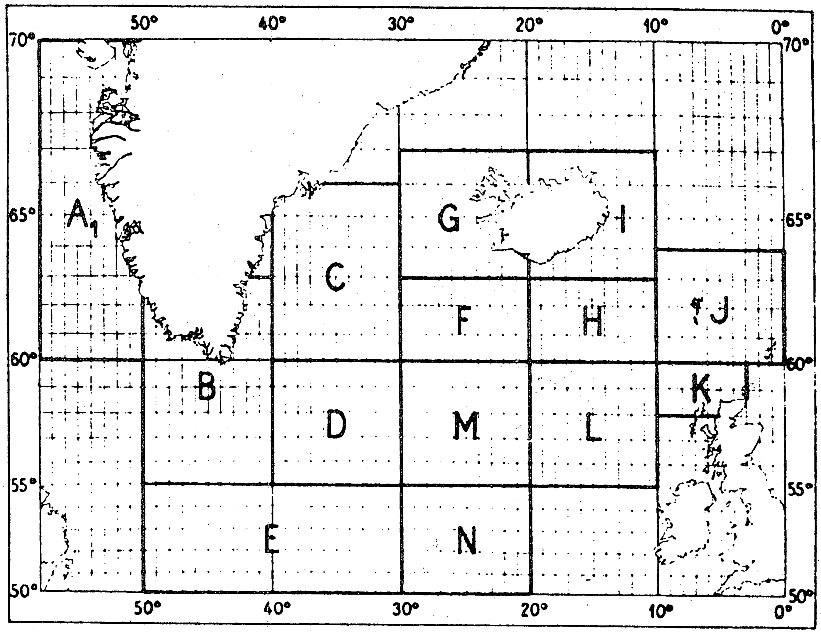


Fig. 22. North Atlantic areas referred to in Fig. 21. From Smed (1965).

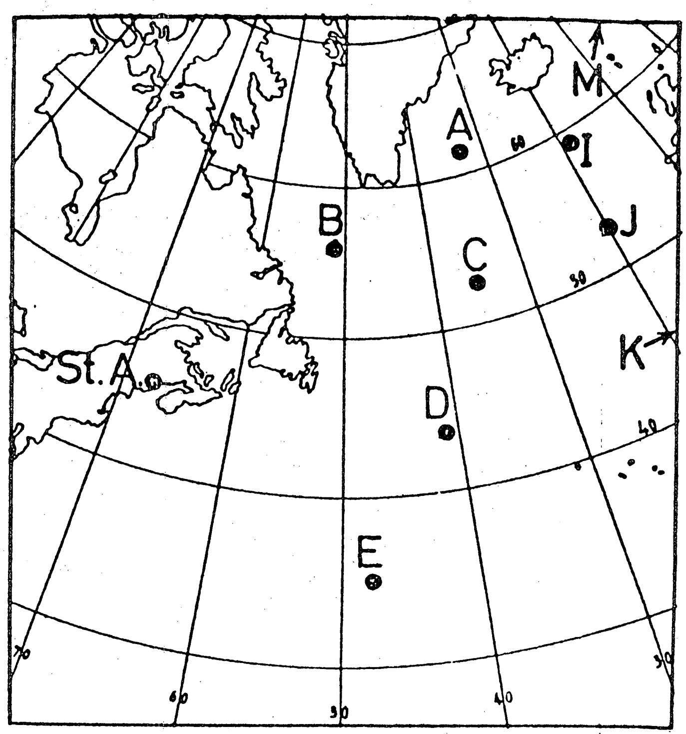


Fig. 23. Ocean weather ship positions. From Rodewald (1967).

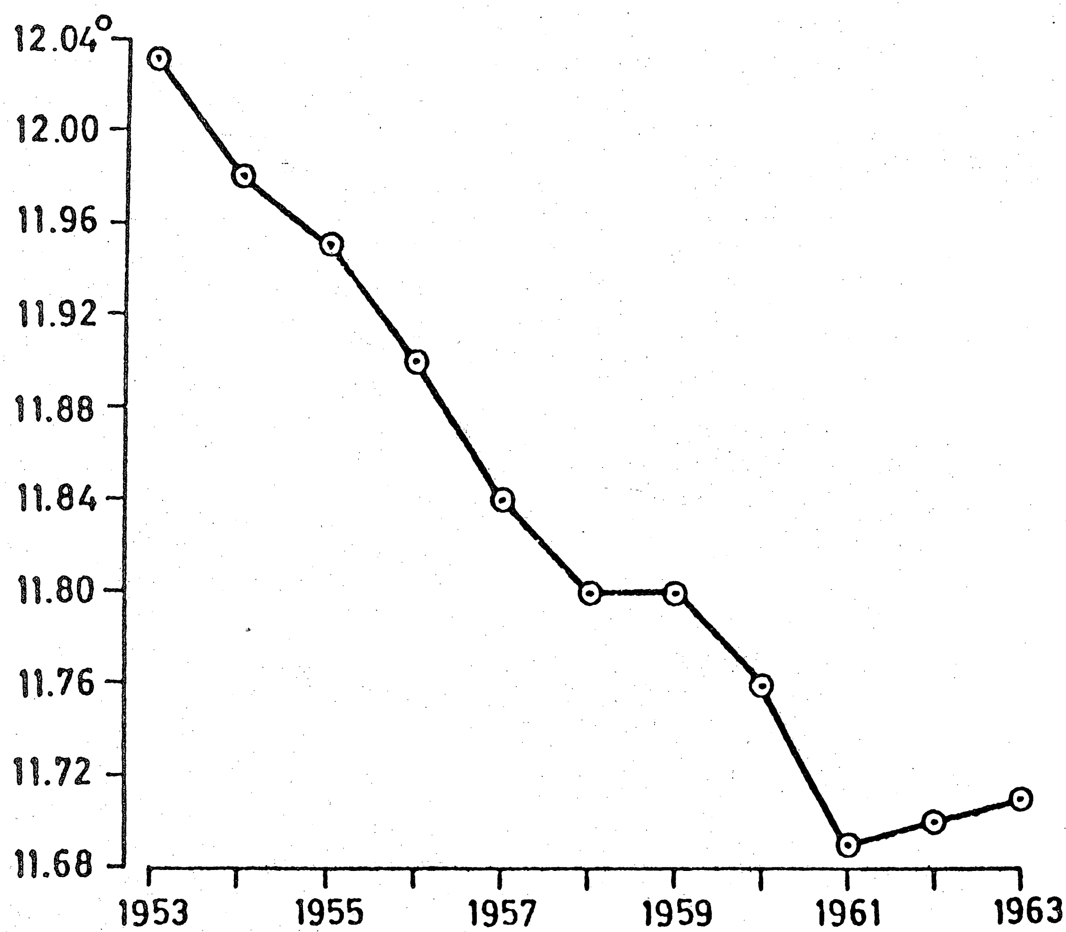


Fig. 24. Temperature changes (surface) for the North Atlantic; means of measurements at the Ocean Weather Ships (see Fig. 23 for positions). From Rodewald (1967)