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

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Abstract

Recorded marine climatic changes in Greenland, Iceland and the subarctic and Atlantic regions of eastern Canada are reviewed and compared. All regions show a rapid rise in temperature, strongest at the surface, from 1920 onwards. The peak temperatures in eastern Canadian waters occurred about 1950, some 10–20 years later than in Greenland and Iceland. A second peak occurred during the late 1950's to 1960 in Greenland and Iceland, but this was less marked in the Canadian region. The present trend is uncertain, but the general pattern on the longer (interglacial) time scale indicates a downward trend. The range of variation in temperature for all regions was, on the average, about 2° to 2.5°C.

Introduction

Although the patterns of change shown in this paper are for the most part generally known, the primary purpose is the bringing together of information from many regions of the Northwest Atlantic, from Baffin Bay to the Scotian Shelf and from West Greenland and Iceland to the Gulf Stream. The emphasis is on natural change, or properly the climatic change as observed. The change may in part be due to the effects of industrial man, but such possible effects are not considered here, because there is often no agreement among those researchers who are closely considering the subject. This does not mean that such effects can be ignored; on the contrary, they must be given urgent attention. 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 hydro-atmosphere is assuming alarming proportions (M.I.T., 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".

Mason (1976) concluded that the possible effects of man-made changes have been much exaggerated, a view with which the present author agrees. The scale of natural change appears to be such as to swamp that of recent or present manmade changes. The present cooling of the climate, since about 1940, has occurred impressively despite a continued rise in 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, MS 1960, MS 1962).

Climate 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 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 $0^{18}/0^{16}$ ratio, have drastically changed the interpretation of Pleistocene oscillation between glacial and interglacial periods (Emiliani, 1972). The period from peak to peak in the temperature curve (Fig. 1) is shown to be close to 50,000 years. The world now appears to be in an interglacial period and on the way toward the next glacial, perhaps a few thousand years from now.

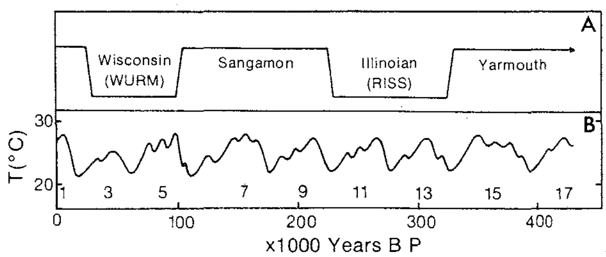

Fig. 1. Comparison of (**A**) the classical interpretation of the glacial cycle with (**B**) the paleotemperature curve based on oxygen isotope analysis of deepsea cones from the Carribbean and Atlantic. (From Emiliani, 1972.)

There is general agreement on the temperature history of the present interglacial period. Figure 2, from Wiseman (1954), shows the temperature change from the retreat of the last ice sheet to the middle of the 19th century, based on measurements of carbonate in Foraminifera skeletons in one of the Swedish *Albatross* long cores from the Atlantic. The hypsitherm of some 5,000–6,000 years ago and the gradual decline since then are well illustrated, the latter being interrupted by small-scale periods of warming. One of the most recent, and possibly the most extreme, of these warming interludes belongs to the present century.

Several authors have drawn attention to an apparent periodicity in these temporary warmings of 225–260 years. Scherhag (1937) ascribed the warming effect in Arctic seas to an increase in the strength of the atmospheric circulation between the tropics and the polar regions, and, from an examination of Easton's (1928) coefficients for West European winters since the year 1235, concluded that there seemed to have a secular period in the variation of atmospheric circulation of some 225 years duration, which apparently reached its maximum about 1937. Hammer *et al.* (1980), in describing the oscillation in northern hemisphere temperatures during 550–1950 A.D., showed that warmer periods occurred approximately every 200–250 years, with emphasis on the larger value. The Camp Century (Greenland) curve (Johnson *et al.*, 1969) from 1200 A.D. to the present is in good agreement with the general curve but shows subsidiary peaks within the 200–250 year rhythm. Aaby (1976) found a 260-year periodicity in his analysis of climatic variation over the past 5,500 years, derived from measurements in raised bogs. The smaller subsidiary periods, shown by Johnson *et al.* (1969) for Camp Century, agree with what is known about biological effects of climatic change in the sea, on Atlantic cod in particular and marine fauna in general (e.g. Jensen, 1939; Hansen and Hermann, 1965). The 225–250 year period appears to agree with what is known of the presence and absence of Atlantic salmon in Davis Strait waters (Dunbar and Thompson, 1979).

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

The Twentieth Century

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). Oceanographic measurements of the West Greenland Current and the inshore waters of Greenland by Danish investigators have been maintained constantly since the early 1900's, and there were some expeditions in the late 1800's whose results have been compared with later observations (Dunbar, 1946). Since the publication of Jensen's (1939) paper, the pattern of temperature change has been followed to the present time. The trend in sea-surface temperatures off West Greenland, based on records compiled by Smed (1947–62), was illustrated by Hansen and Hermann (1965) for the 1876–1960 period, and the records have been brought almost up to date in Fig. 3 (Denmark, 1977). The pattern of change and its apparent universality to sea and air temperatures in other regions of the Northwest Atlantic are discussed below.

Southern Canadian east coast waters

The data illustrated in Fig. 4 (from Lauzier, 1965) show essentially the same pattern for sea-surface and air temperatures over the whole region, based on air temperatures from 1874 at Halifax, Nova Scotia, and from 1891 at Sable Island on the Scotian Shelf and on sea-surface temperatures from 1906 at Boothbay Harbor, Maine, and from 1921 at St. Andrews, New Brunswick. there was a warming trend from the 1870's to about 1900, cooling from 1900 to the early 1920's, rapid

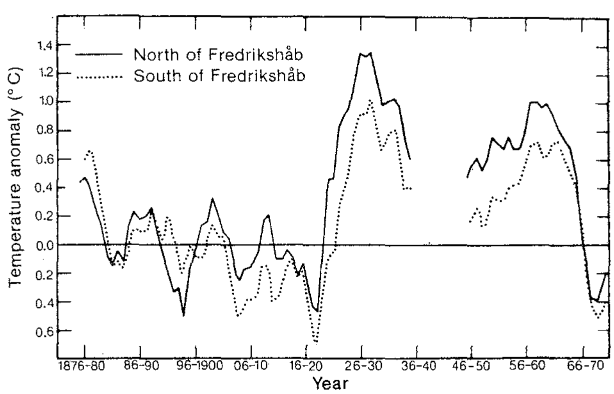

Fig. 3. Surface temperature anomalies (5-year running means) for West Greenland, 1876-1974. (From Denmark, 1977.)

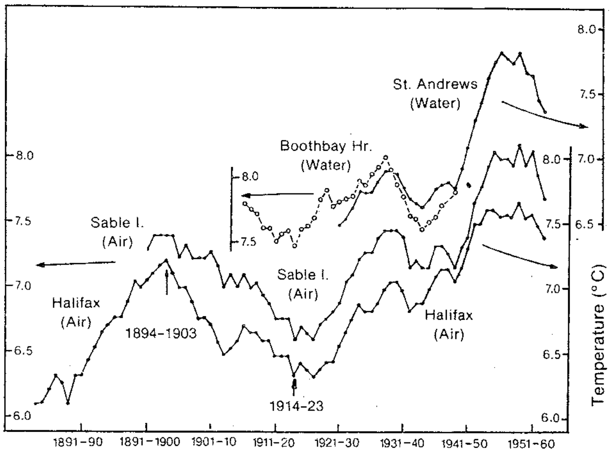

Fig. 4. Surface temperatures at St. Andrews and Boothbay Harbor, Maine, and air temperatures at Sable Island and Halifax, Nova Scotia (10-year running means assigned to the last year of the period). (From Lauzier, 1965.)

warming to a peak in the early 1950's and rapid cooling to 1962.

Sea-surface temperatures in the Gulf of St. Lawrence (Lauzier, 1972), where the records go back only to 1931 at Entry Island (Magdalen Islands) and to 1940 at Grande Rivière (Baie des Chaleurs, Quebec), show a pattern similar to that at St. Andrews, but the peak occurred somewhat later in the 1950's. Temperature changes at three depths in the Laurentian Channel (core water of the deep layer, and the 34 and 33‰ isohalines) (Fig. 5) parallel the surface temperatures at St. Andrews up to the peak, which, however, occurred later than St. Andrews, and the cooling after the peak is not pronounced, especially in the core water (Lauzier and Trites, 1958).

Bottom temperatures in the Bay of Fundy (Prince 5 Station) show the same general trend as the sea-surface temperatures at St. Andrews since the 1920's (Fig. 6). Also, bottom temperatures on the Scotian Shelf (Lurcher and Sambro Lightships, Emerald Bank, and Scotian Gulf between Sambro and Emerald Banks) during 1950–62 show a similar pattern of decline.

Northern Canadian waters, Newfoundland to Baffin Island

Regular monthly observations of temperature and salinity have been made since 1950 at Station 27 (47°31'50"N, 52°35'10"W) off St. John's, Newfoundland. The station is located in the core of the Labrador Current with a bottom depth of 176 m. The observations for 1950–62 were consolidated by Templeman (1965) and compared with mean annual air temperatures at Torbay near St. John's (Fig. 7). The results indicated reasonably good agreement between air and

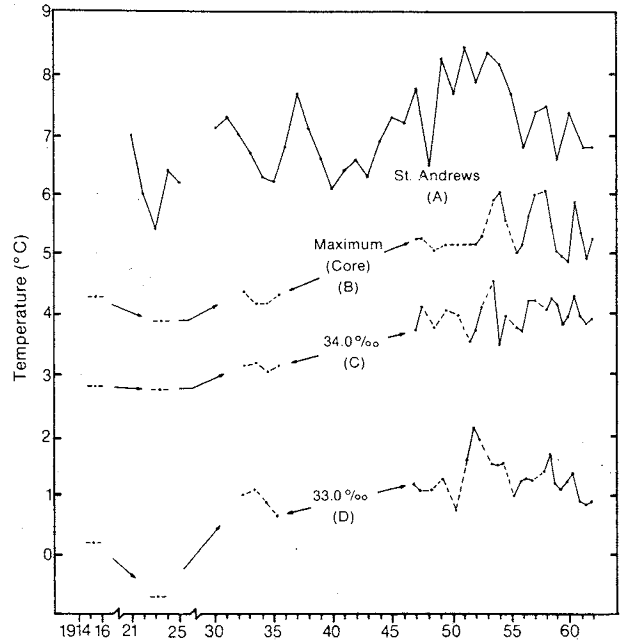

Fig. 5. Annual mean surface temperatures at St. Andrews, New Brunswick, and temperature trends at three levels in the deep water of the Laurentian Channel, 1915–62. (From Lauzier, 1965.)

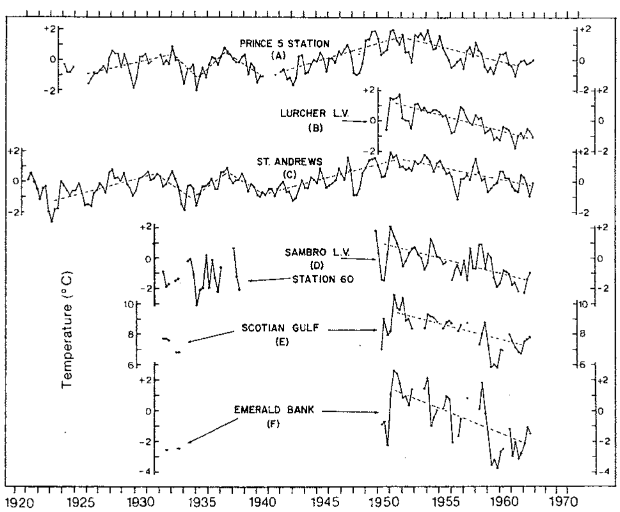

Fig. 6. Trends in (**A**) bottom temperature at Prine Station 5 in the Bay of Fundy, 1924–62, (**B**) bottom temperature at Lurcher Lightship off Yarmouth, Nova Scotia, 1950–62, (**C**) surface temperature at St. Andrews, New Brunswick, 1921–62, (**D**) bottom temperature at Sambro Lightship off Halifax, Nova Scotia, 1949–62, (**E**) maximum temperature of the bottom layer in the Scotian Gulf between Sambro and Emerald Banks, 1950–62, and (**F**) bottom temperature on Emerald Bank, 1950–62. (From Lauzier, 1965.)

sea-surface temperatures in the area, and Templeman (1965) then used the trends in air temperatures at Torbay from 1872 (Fig. 8) to describe long-term variation in environmental conditions. The pattern, particularly the 11-year running means of air temperatures in

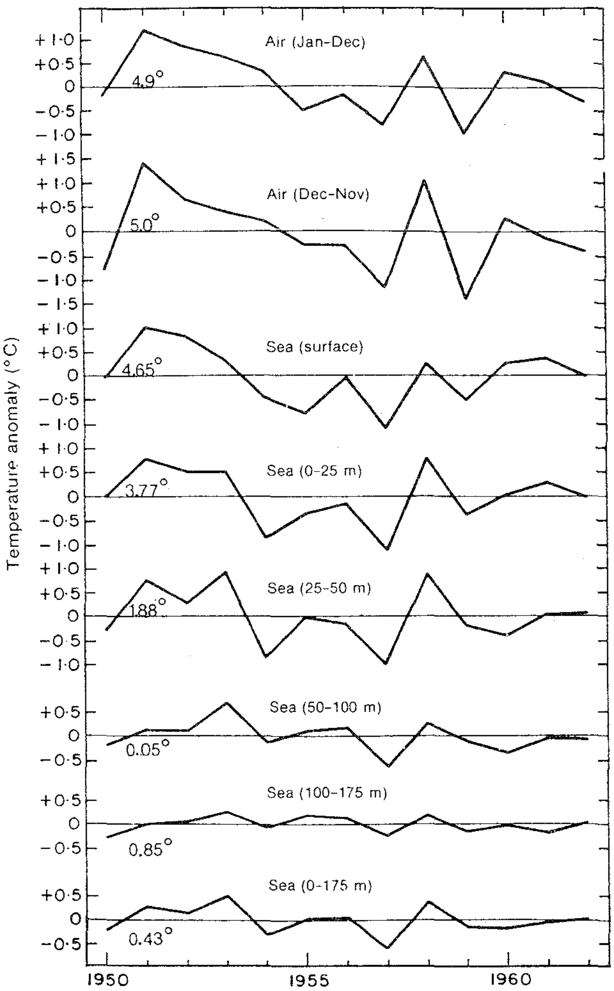

Fig. 7. Trends in annual average air temperature at Torbay-St. John's, Newfoundland, and water temperature at Station 27 off St. John's, 1950-62. (From Templeman, 1965.)

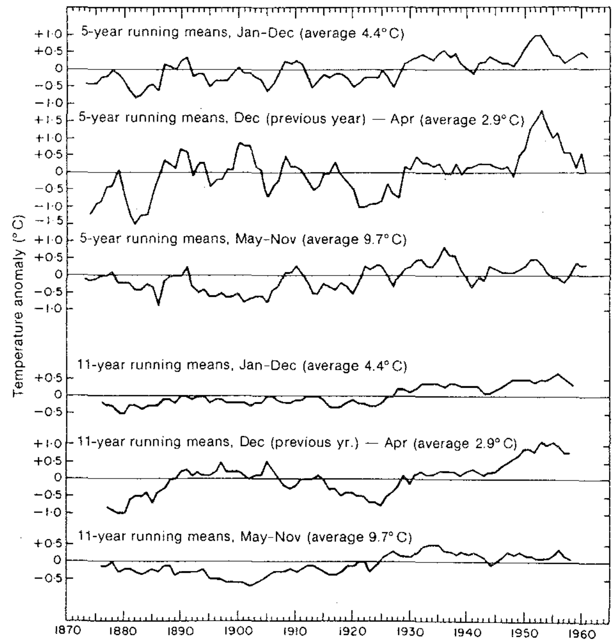

Fig. 8. Trends in air temperature at Torbay-St. John's, Newfoundland, 1875-1962 (5- and 10-year running means are assigned to the median year). (From Templeman, 1965.)

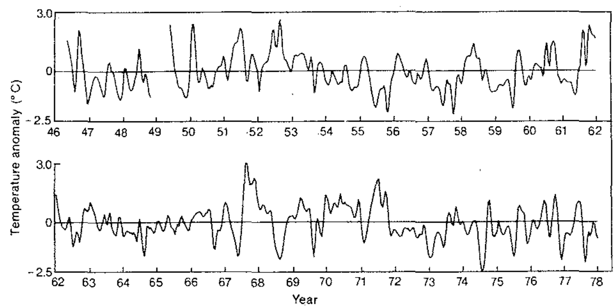

Fig. 9. Sea-surface temperatures at Station 27 off St. John's, Newfoundland, 1946-78. (From Keeley, 1981.)

December-April, closely resembles that for Halifax over the long-term and also the sea-surface temperatures at St. Andrews and Nova Scotia locations over shorter periods (Fig. 4, 6 and 7). There is the same rise in temperature to about 1900, a decline to a low in the 1920's, and an increase to a peak in the mid-1950's. Keeley (1981) updated to 1978 the Station 27 surface temperature series (Fig. 9) which shows declines after peaks were recorded in 1961, 1967 and 1971. Sea-surface temperatures during 1973-77 were generally below the long-term mean. Temperature trends at 20, 50, 70, 100, 150 and 170 m (Keeley, 1981) were less apparent, but the decline after 1971 and a slight indication of an increase after 1974 were evident at all depths.

Dunbar (1955) suggested that the region most sensitive to marine climatic change in the Northwest Atlantic is West Greenland, because the relative proportions of Arctic water (East Greenland Current) and Atlantic water (Irminger Current and Labrador Sea Water) are important in determining the nature of the West Greenland Current, and that change would be expected to be less marked in waters off East Greenland on the one hand and eastern Canadian Arctic waters on the other, because of the buffering effects of the East Greenland Current and the Baffin Island Current respectively, both of which carry water from the Arctic Ocean. Nevertheless, temperature changes of some significance occur in Labrador Current water and also on the western side of Baffin Bay, as indicated by surface isotherms from the "Godthåb" and U. S. Coast Guard expeditions of 1928 and from Canadian observations in 1960-62 (Fig. 10). Surface temperatures over the entire region were apparently considerably lower in August-September of 1961-62 than in the same months of 1928, when close to maximum temperatures were found in the West Greenland Current and probably also in Baffin Bay as a whole.

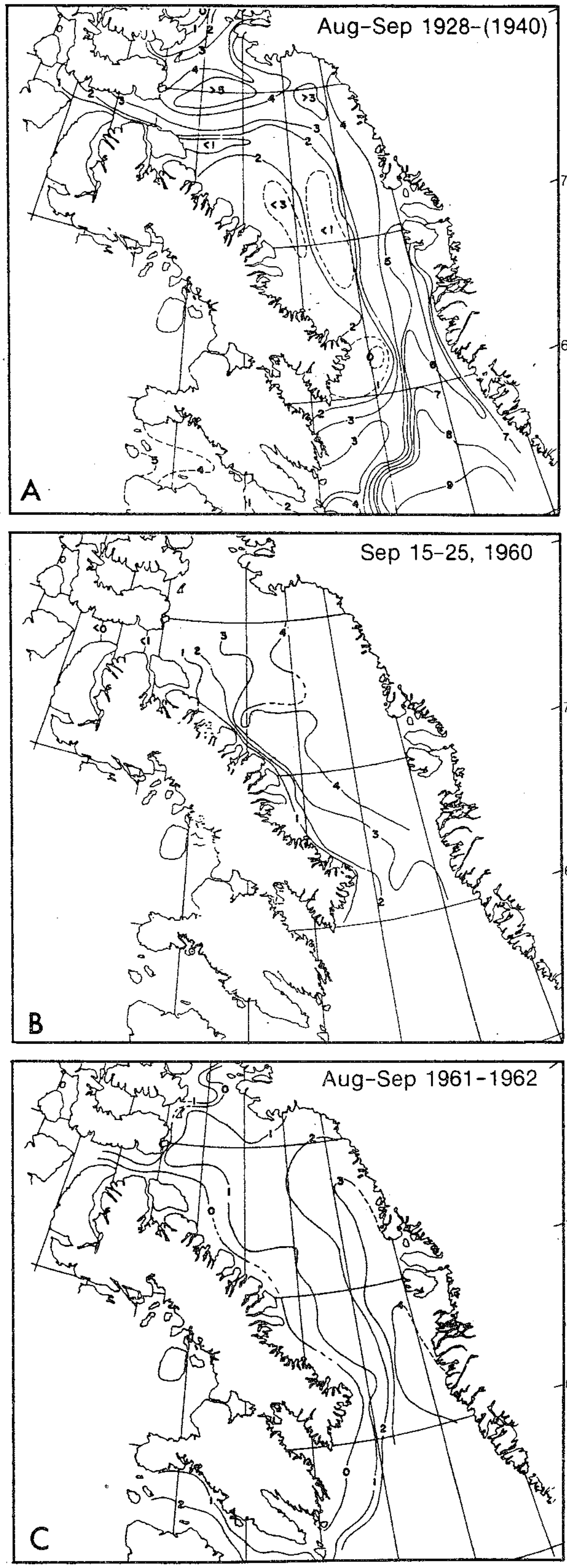

Fig. 10. Surface temperature pattern in Baffin Bay and the Labrador Sea during (**A**) August-September 1928-40, (**B**) September 1960, and (**C**) August-September 1961-62. (From Dunbar and Moore, MS 1980.)

Burmakin (1972) analyzed the available temperature measurements taken in the 0-200 m layer of the cold component of the Labrador Current at selected stations on USSR Section 8A which extends from southern Labrador northeastward across Hamilton Bank. He illustrated year-to-year fluctuations in mean temperature (adjusted to 15 July) of the 0-200 m layer (Fig. 11). The inclusion of sub-surface temperatures reduces the likelihood of the emergence of strong trends, but there is nevertheless an upward trend between 1950 and 1960 which agrees with the West Greenland record. The 3- and 4-year cycles are interesting but little can be said of them at present.

Lauzier and Campbell (1959) compared temperatures and salinities measured in the Labrador Sea and Davis Strait during the 1928-35 and 1950-55 periods. 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, whereas the southern part of the Labrador Sea showed an increase in temperature. These observations were noted in the abstract of their paper which was presented to the New York Congress of Oceanography in 1959. No illustrations were given, and the paper has apparently not been published.

Iceland

The record of climatic change in Iceland is closely associated with the behavior of sea ice in Icelandic waters; indeed, the sea ice has played such an important role in the economic and social history of the country that there are frequent references to it in the literature of the Icelanders, especially their poetry. Consequently, the historical record of "severe years", involving starvation and other hazards, goes back to 976 A.D., and records of the number of days per year when ice affected the coast goes back to 1590. By relating mean air temperature to ice cover for the years when both are known (1846 to date), Bergthórsson (1969a) estimated the annual mean air temperatures back to 1590 (Fig. 12). The pattern shown in Fig. 12 resembles the West Greenland curve (Fig. 3), with the peak around 1930, rather than the Canadian curve (Fig. 4).

Annual mean sea-surface temperatures at Grimséy on the north coast of Iceland were reported by Stéfansson (1969) for the period from 1871 to the late 1960's (Fig. 13). The pattern is similar to that for West Greenland (Fig. 3). Stéfansson (1969) also found close inverse agreement between sea-surface temperatures at Grimsey and the incidence of drift ice in coastal waters (Fig. 14). Dickson *et al.* (1975) indicated that cooling in the Greenland Sea came to an abrupt end in the winter of 1970-71, the low point being the heavy ice year of 1967-68, and was followed by a warming trend, at least to 1974. The beginning of this warming trend

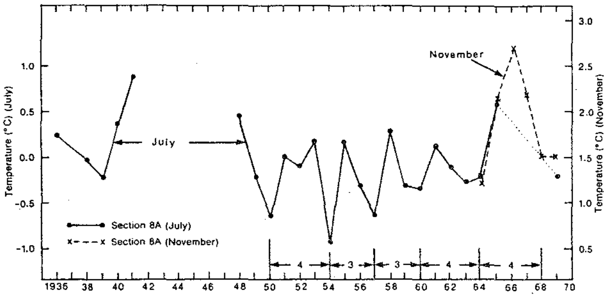

Fig. 11. Fluctuations in temperature of the 0–200 m layer of the cold component of the Labrador Current at selected stations on USSR Section 8-A off Labrador, 1936–69. (Redrawn from Burmakin, 1972.)

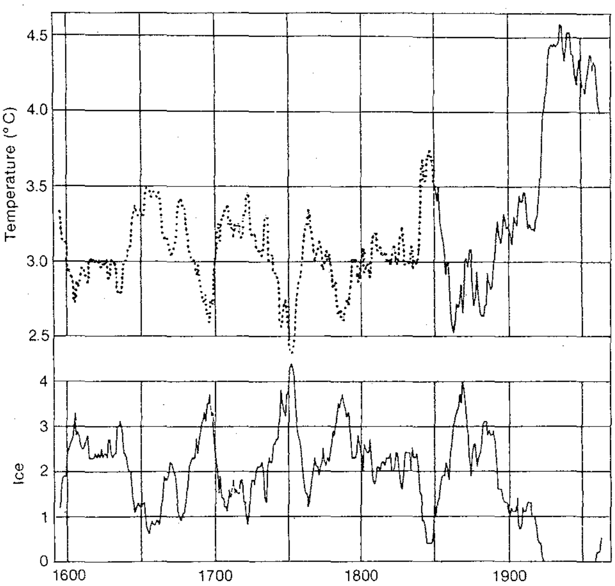

Fig. 12. Air temperature as 10-year running means (upper) estimated from ice incidence (lower) at Iceland, 1590–1968. (From Bergthórsson, 1969b.)

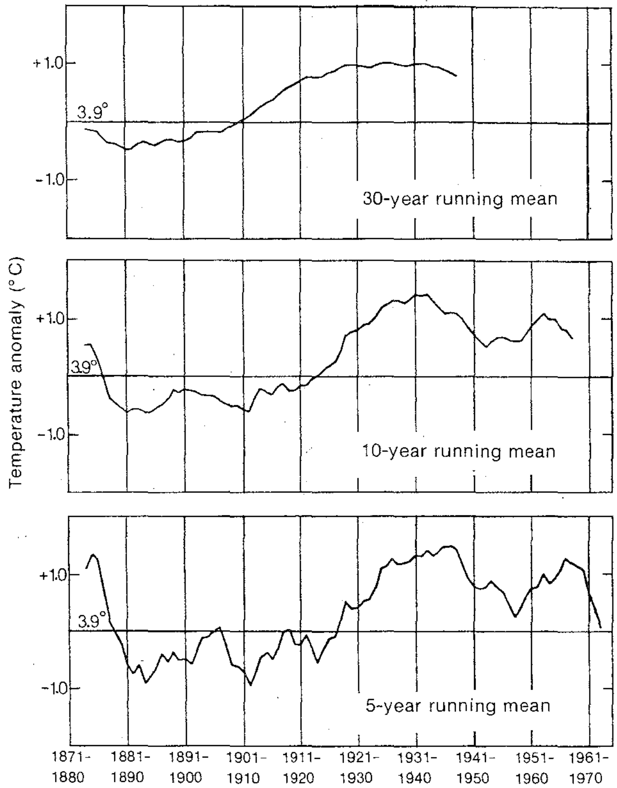

Fig. 13. Sea-surface temperatures at Grimsey, Iceland, 1871–1968 (expressed as 30-, 10- and 5-year running means. (From Stefansson, 1969.)

was also evident in West Greenland waters after about 1970 (Fig. 3). A recent report on conditions at West Greenland (Denmark, 1977) states 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".

Sea ice and climate change

The Icelandic story is an interesting example of the part played by sea ice in the pattern of climatic change. Markham (1976), however, pointed out that the relationship between sea ice and such factors as sea temperature, air temperature, winds and ocean currents are not clearly understood. Ice is, in fact, not a subject that can be tackled within the scope of this short review, but certain studies 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 this study and brought the account of variations in the "Storis" at West Greenland up to date. He found no correlation between the behavior of the ice and air temperatures at Upernavik and Godthåb (West Greenland) and Point Barrow (Alaska). He did not test for sea-surface temperature, which Hansen and Hermann (1965) showed to be related to the abundance of Atlantic cod and to the sea-ice record, the latter (Fig. 15) being based on the study initiated by Speerschneider (1931).

Direct observations on the extent of ice coverage in the Labrador-Newfoundland area go back only to the late 1950's. Markham (1976), from his analysis of ice conditions up to 1973, pointed out that air temperature is closely related to the degree of ice formation *in situ* and that a good indication of variation in ice cover in the past could be inferred from the winter air-temperature records. He used the same temperature records as did Templeman (1965) for Torbay-St. John's, Newfoundland.

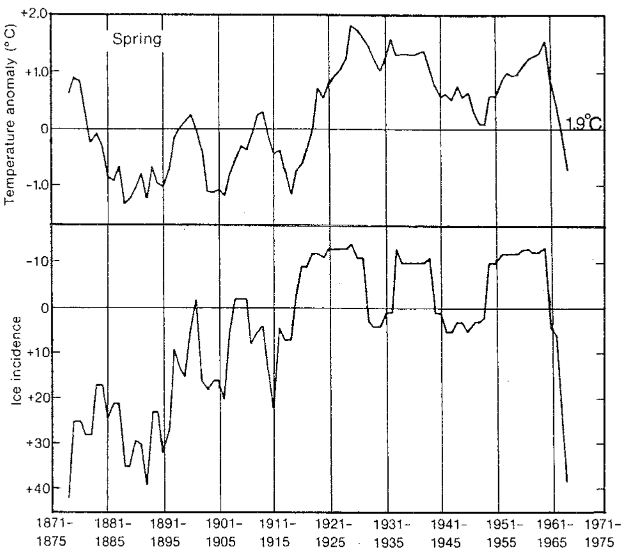

Fig. 14. Sea-surface temperatures at Grimsëy (upper) and the incidence of drift ice in Icelandic coastal waters (lower) during March-May, 1871-1968. (From Stefánsson, 1969.)

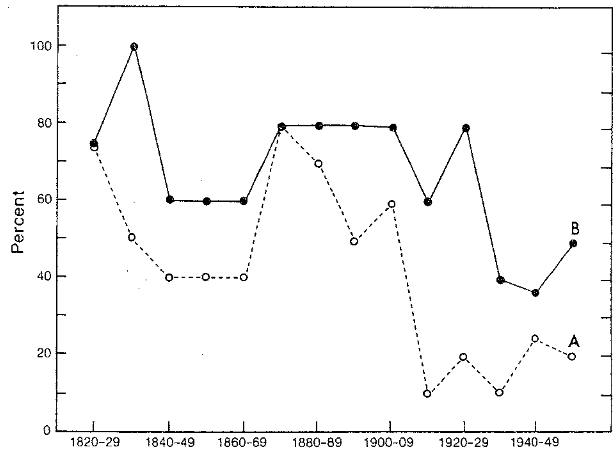

Fig. 15. Frequency of years in which drift ice reached as far north along West Greenland as (**A**) Gődthab and (**B**) Fiskenaesset. (From Hansen and Hermann, 1965.)

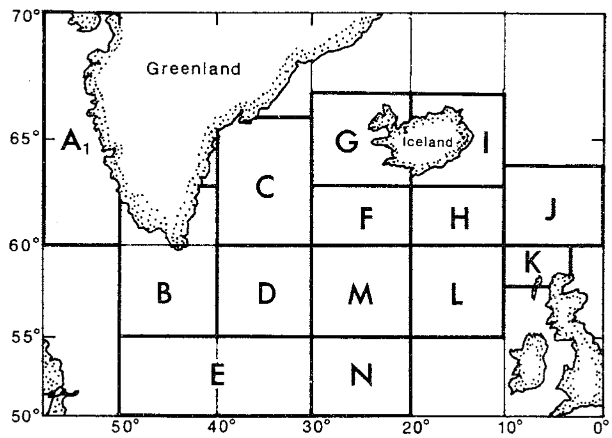

Fig. 16. The North Atlantic areas referred to in Fig. 17. (From Smed, 1965.)

In Icelandic waters, the abundance of sea ice increased markedly in the 1960's. Sigurdsson (1969) stated that "more drift ice was observed in Icelandic waters in 1967-68 than in any year since 1888. Some ice was reported near the coast approximately 180 days and almost continuously from 3 March to 25 July. 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 Iceland approximately half a year in advance by considering the ocean currents north of Iceland and the preceding autumn air temperatures at Jan Mayen.

North Atlantic Ocean

Surface temperatures for several areas of the North Atlantic between latitudes 50° and 67° N (Fig. 16) have been compiled and analyzed by Smed (1965) for the period from 1876 to 1961 (Fig. 17). Not only is the warming since 1920 apparent but also the cooling from about 1900 to 1920. The pattern is more marked in the western and northern parts of the region (areas A_1 to G) than in the southern and eastern parts (areas H to N). Colebrook (1976), using sea-surface temperatures for Marsden squares 182B and 145D (west of Iceland and west of France respectively), showed a minor peak in temperature about 1885, a low temperature trough at the end of the 19th century and a high peak during 1950-60, followed by a decline to 1970. The same pattern was reported by Martin (1972) for the waters northeast of Scotland. Pocklington (1978) reported that the sea-surface temperature off Bermuda has decreased continuously since 1960.

Marine climatic changes in the North Atlantic are not simple to explain, because they are not uniform over the whole area. This was pointed out by Rodewald (1967), and Zverev (1972), using Ocean Weather Station data for 1948-68, concluded that the phases of variation in water temperature anomalies in the western and northeastern regions of the North Atlantic are 180° out of phase with each other. This clearly needs further study, as it is not in agreement with other studies reported here for the northern part of the North Atlantic-Subarctic circulation.

Concluding Remarks

The range of variation in temperature, as shown by smoothed curves (e.g. 5- or 10-year means) is much the same throughout the regions considered here, 2° to 2.5°C. The year-by-year curves naturally show

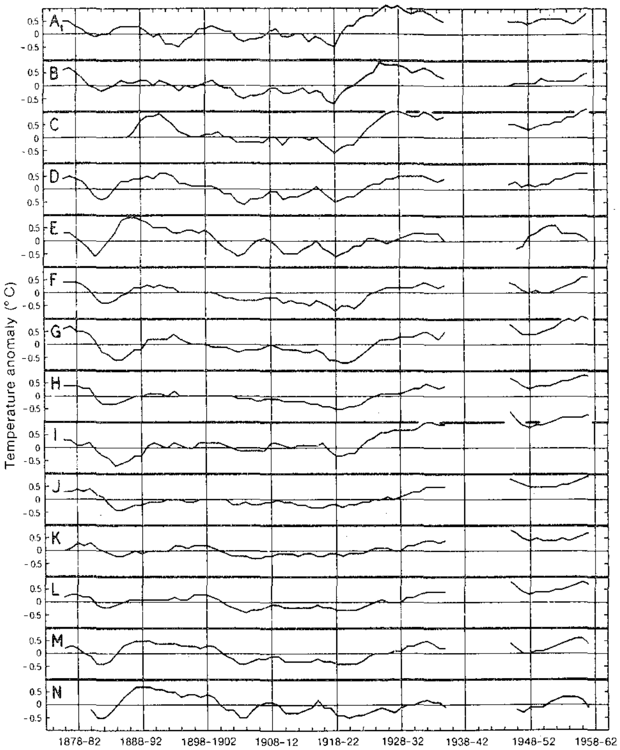

Fig. 17. Overlapping 5-year means of anomalies of sea-surface temperature in areas A_1 to N shown in Fig. 16. (From Smed, 1965.)

larger ranges, 4.5° C for Station 27 off St. John's, Newfoundland, and 3° C for St. Andrews, New Brunswick. All areas (Canadian waters, West Greenland, Iceland, and the North Atlantic in general) show temperature peaks in the 1930's and 1950's, except that the latter peak occurred later (1960's) in West Greenland. In the Northwest Atlantic, a minor peak is shown for all areas around 1900, followed by a trough about 1920. At Iceland in the Northeast Atlantic, low temperatures occurred around 1900 and again about 1916 with a peak in between.

The rapidity of the rise in temperature at West Greenland from the low in 1920 was unmatched in other areas. The peak temperature of the 1930's in eastern Canadian and northeastern United States waters was lower than those of the 1950's, whereas at West Greenland and Iceland the earlier peak was higher than the later one. There are differences between all four regions in terms of the precise years of maxima and minima.

No review is offered here of the possible causes of climatic changes that have been reported 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 meridianal winds, interstellar clouds, oceanic circulation and terrestrial tilt. The literature is large, but only two papers are noted here: one by Einarsson (1969) which briefly summarized the possible causes that have been suggested, and the other by Schell and Corkum (1976) which discussed the thermal lag between atmosphere and ocean during periods of climatic change. The material reviewed in the preceding sections of this paper demonstrates the great value of regular monitoring of environmental factors.

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