Payne Bay, Ungava Bay, 1947. Waters from Hudson Bay, the Baffin Island Current and the West Greenland Current meet in Ungava Bay, which is highly sensitive to marine climatic change. Its living resources and ice conditions vary considerably with shifts in the climatic cycle.

Climatic Change and Northern Development

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INTRODUCTION

My approach to this subject is that of an oceanographer, not a meteorologist; but since much northern development, past, present, and future is closely related to the sea, it is not an inappropriate approach. The Eskimos, or Inuit, are fundamentally a coastal people, living largely on the products of the sea; whalers have used the northern waters extensively, traders have bought, and buy, sea mammal skins and oils, and the present industrial thrust is in part concerned with oil and gas from the northern sea floor or with mining close to the shore. The marine approach to the study of climate, however, may not seem so appropriate to many climatologists, for I have noticed that the literature on climatic change pays a great deal more attention to the atmosphere than to the hydrosphere, with important exceptions, such as Bjerknes (1974), certain publications of the International Committee for the Northwest Atlantic Fisheries (ICNAF), and the climatic theory of the Lamont-Doherty Geological Observatory (see Ewing and Donn 1956; Donn and Ewing 1966). And although the amount of heat transported from one point to another on the globe, in a given time, is far greater in the air than in the sea, the sea has the greater storage capacity and is probably a better guide to past history and present trends, since it manifests much less "noise", or variation over short time periods. Indeed, without the steadying effect of the sea, climatic change would be a sudden and rather violent affair.

Thirty years ago I suggested (Dunbar 1946) that there was evidence, from the study of the West Greenland Current, that the climatic warming of the nineteen twenties and thirties appeared to have reached a peak in the mid-thirties, and that there were indications of a weakening of the Atlantic, or warm water, influence in that region between 1942 and 1944. This has since been confirmed as a result of a great deal of more recent work, and by events in both Greenland and Canada, atmospheric as well as hydrospheric. It is with these recent events that I am most concerned in the present paper, and above all by what they imply concerning the immediate future, on the time scale of a few decades.

But first let me put these events in their longer-term framework. There are many different time scales in which it is useful to study climatic changes and climatic cycles, from the 225-250 million year amplitude involving ice ages in the Cambrian, Permian and present (Pleistocene) times, to the changes involving only a few years within a decade or two. The Pleistocene scale, the scale of the glacial-interglacial fluctuations, is the largest that need be of concern here. Large as that Pleistocene scale may appear to those concerned with immediate northern development, it is nevertheless highly relevant, for there is abundant and well-known

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evidence that the peak, or "optimum" of the present interglacial period has now been passed. Wiseman (1954), for instance, plotted the carbonate content, a measure of the concentration of Foraminiferan carbon, of one of the first long cores taken from the sediment of the North Atlantic — by the Swedish "Albatross" expedition (Pettersson 1954), showing a steady rise in surface temperature from some 15,000 years B.P. to 5000-6000 years B.P., and a subsequent decline. The symmetry of the curve is such as to suggest very strongly the expectation that the next glacial period will be well advanced in a few thousand years from now. The Wiseman curve also shows several unevennesses, or bumps, in the period since the maximum, which agree with evidence from other sources, including historical records, that there have been smaller climatic cycles or fluctuations since that time. Wiseman's analysis did not go beyond the mid-nineteenth century, because of surface disturbances in his core, but it is clear that the climatic upswing of the first half of the twentieth century was of wider amplitude in temperature than several that preceded it.

The glacial oscillation, according to several authorities, will probably be maintained as long as the geographic poles are approximately in their present positions, one in the Arctic Ocean and the other in Antarctica — a view which, I believe, was first put forward or implied by Ewing and Donn (1956), and developed in later papers (e.g., Donn and Ewing 1966). The present position, therefore, is that the climate is cooling on the glacial-interglacial scale, warm but cooling on the twentieth-century scale. And some evidence has been produced (e.g., by Lauzier 1972) that the cooling trend of the past 40 years has been reversed during the past five years, on evidence, *inter alia,* from the Gulf of St. Lawrence.

It is with this twentieth century scale that I am concerned here, and especially with the biological effects of it and its implications for industrial and other development in northern Canada. The crux of the matter is prediction, and it is for this reason that the setting of this period within larger time-scales is important.

THE PRESENT CYCLE AND ITS BIOLOGICAL EFFECTS

The most complete record of the twentieth-century warming and subsequent cooling, more especially in its biological effects, is to be found in West Greenland, for two good reasons. First, the Danish authorities in Greenland started early in the century to explore that region for immediately-exploitable animal resources. They did so with great success, for there are oceanographic and biological records which go back to the turn of the century, and also, with lesser coverage, into the nineteenth; and second, the West Greenland Current is peculiarly sensitive to oceanic climatic change. It is composed of water from three sources: the Arctic Ocean (East Greenland Current), the Irminger Sea (Atlantic Drift water), and the Labrador Sea. Variations in the proportions of these three water types largely determine the temperature of the West Greenland Current. Moreover, the position and intensity of the Icelandic Low, which vary in a secular manner, also influence the composition of the current. The state of the climate of the whole North Atlantic – Subarctic area, therefore, is reflected in the West Greenland Current, and the current in turn influences the atmospheric climate.

The best starting point in describing this present marine climatic cycle is the now-classical paper of Adolf Jensen (1939) on climatic change during recent decades from Greenland to Eurasia. Jensen was in charge of investigation into the fisheries of Greenland, beginning in 1908, and was able to follow, and to exploit, the remarkable changes in distribution and abundance of the sea fauna, notably the Atlantic cod *(Gadus morhua),* which began in the second decade of the century to move into the West Greenland area from Iceland, and to establish a breeding stock there. By 1917 the cod were to be found in the southwest, in the latitudes of Julianehåb (61°N) and Frederikshåb (62°N); and by 1919 they had penetrated northward to Godthåb, and by 1927 to Holsteinsborg. By 1931 they were well into Disko Bay, and were found also at Umanak. By 1940 they were known in small numbers at Upernavik (nearly 73°N). During this time, from 1908 to 1940, the temperature in the core of the West Greenland Current had risen by more than 2°C, which represents an enormous increase in total heat transport. There was a very cold year in 1938, when many codfish were found dead at the surface in various parts of West Greenland, and since the nineteen forties the temperatures, and the codfishery take, have been declining. The faunal changes were of course general, since what was happening was a migration northward and then southward, of whole ecosystems. The cold water forms, such as the beluga and the ringed seal, etc., retreated northward during the warming period, and the Atlantic cod were accompanied by the full Subarctic-Atlantic community, details of which can be found in Jensen (1939), and elsewhere.

Among the faunal elements concerned, and of special interest, is the Atlantic salmon *(Salmo salar),* which since 1960 has been fished commercially in West Greenland waters and in the Labrador Sea. Of this species Jensen (1939) wrote:

> The Salmon *(Salmo salar)* was previously only known and only in small numbers at two places, namely, Kapisigdlit in Godthaab Fjord and Amerdlok Fjord near Holsteinsborg. But towards the end of the twenties the observation was made, that in the autumn (October and November) a migration of large salmon takes place in the Sukkertoppen district, though not very near the coast. Later, especially in 1935 and 1936, the salmon occurred in numbers from October and on into December at several places in the Sukkertoppen district, at the dwelling place Ikerasak and in fjords round about as also at the outpost Napassok and the dwelling place Agpamiut. In the autumn of 1935 about 200 of this stately fish were caught at Ikerasak. In September 1936 a number of salmon were caught at Lichtenau, in 1935 in October several salmon were noticed at Fiskenaesset, and in September 1938 a salmon was caught in the Tasermiut Fjord.

This history, as I have pointed out elsewhere (Dunbar 1975), effectively disposes of the myth, recently promulgated, that the sea-life region of the Atlantic salmon was discovered by a U.S. nuclear-powered submarine to be in the West Greenland area. It also raises the question of what precisely has caused the presence of the salmon in those waters, for they appear to have become abundant there during a cooling, not a warming, period. The fishery began, in the first half of the nineteen sixties, mainly inshore, later spread to the Store Hellefiske Bank, off Holsteinsborg. In 1966-67 the fishery spread further north, to Disko Bay. Since

1969 there appears to have been a trend toward a more southerly distribution (Christensen and Lear 1974).

When the commercial fishery began, it was assumed by most of those involved in the study of these salmon that they had always been in the West Greenland region during their sea-life, and that this was the long-sought feeding area of the salmon from both the North American and the European coasts (salmon from both coasts are indeed found there, most of them one-year sea-life fish; there are no grilse). This seems extremely unlikely. The salmon swim very close to the surface and are taken in surface drift nets. The West Greenland waters have been fished and hunted for some four centuries. The whalers sailed up the West Greenland coast regularly during the nineteenth century and into the twentieth; and the Greenlanders themselves are a watchful and enterprising people. The "Tjalfe" Expeditions of 1908 and 1909 (see Jensen 1939) worked in southwest-Greenland waters specifically with the purpose of exploring for possible fisheries to develop, to be followed by many similar operations. It is entirely unreasonable to believe that, had the salmon been in those waters during so long a time, they would not have been discovered long since. It is also quite unreasonable to suppose that the rules that apply to the Atlantic cod, the Atlantic halibut, and indeed to the whole faunal population of the West Greenland Current, should not apply also in like strength to the salmon. It has been suggested as a result of recent research (Dunbar and Thomson 1977) that salmon were present in these waters in at least two periods in the past, about 1600 and again about 1810, and that during both periods there occurred a cooling of the climate from a preceding short warming phase.

Concerning the effects of the twentieth-century cycle in Canada: as in most changes in nature, there is a mechanism of regulation here whereby the effects of the change are damped by processes set up by the original event itself. The intensification of the pressure gradient between the Iceland Low and the Azores High increases the velocity and transport of the Gulf Stream system, including the North Atlantic Drift as a whole, the Irminger current — the Atlantic Drift water current which turns westward southwest of Iceland, and enters the Labrador Sea — and the entry of Atlantic water into the Arctic Ocean in the northwest-Svalbard region and the Barents Sea. An increased flow of Atlantic water northward to the Arctic Ocean requires an increased flow of polar (Arctic Ocean) water southward, unless all of the Atlantic increase turns at once and flows back into the Greenland Sea, for which there is no evidence at present. This means that the two regions most influenced by the polar outlets, East Greenland and the Canadian eastern Arctic, will be buffered against the climatic warming in the sea. This is no more than an extension to the marine environment of the phenomenon of intensified circulation already described for the atmosphere by Vize (1935), Scherhag (1937) and others. It is in fact in East Greenland and in the Canadian Arctic and Subarctic seaboard that the climate has changed least in the whole of the North Atlantic region. Thus any warming effect in those two regions would not be expected to bear a simple relation to the increased velocity, transport and temperature of the Atlantic Drift circulation, as appears to be the case in West Greenland.

The positive relation of the East Greenland Current to the Atlantic inflow to the Arctic Ocean was shown by Berezkin (1937), who reported that an increase in flow in the Atlantic current of the eastern Greenland Sea is accompanied by, or followed very shortly by, an increase in the flow of the Arctic water of the East Greenland Current. There is also, according to Berezkin, a negative relation between the temperature change in the two water bodies. In the years 1933-35, 1933 and 1934 were years of less intense circulation in the Greenland Sea than was 1935, and in a section along the eightieth parallel the Atlantic water was 0.4°C to 0.5°C higher in 1935 than in the two preceding years, while the East Greenland water was 0.5°C to 1.0°C lower. There was also a slight increase in the salinity of the Atlantic water in 1935, and a decrease in salinity in the East Greenland water. Summing up these observations, Berezkin writes (as quoted in Dunbar 1955):

> Assuming that the quantity of the water masses in the Polar Basin remains constant from year to year, it may be inferred that an increase in the intensity of the Atlantic Drift would inevitably bring about a similar increase in the Polar Current that runs counter to it, and vice versa. As a result, the whole circulation process of the waters of the Polar Basin is expressed more intensely . . . increased temperature of the North Cape Current in August of any year is reciprocated by a greater amount of ice in the Greenland Sea in July of the following year.

The latter result of Berezkin's study is a highly practical one of prediction.

An important point which Berezkin does not mention is that as the velocity of the East Greenland Current increases, so does the Coriolis effect working up it, so that it will be pressed more strongly to the west, against the East Greenland coast, thus further strengthening the buffering effect. The principle applies to the Canadian eastern Arctic, where the Atlantic component is the Atlantic water in West Greenland Current and the Arctic outflow is the Canadian or Baffin Island current along the east coast of Baffin Island, which picks up more Arctic water from Hudson Strait and forms part of the Labrador Current. The East Greenland component of the West Greenland Current varies considerably; it was large in 1935, and following years, possibly in response to the large flow in northeast Greenland reported by Berezkin. It was also large in the nineteen fifties (Alekseev *et al.* 1972; Soule *et al.* 1950; Moynihan and Anderson 1969).

The interplay between the water types present in the eastern Arctic is not at all well understood, but an understanding is going to be necessary if there is to be any hope of being able to predict climatic change in that region, and such prediction will be of considerable value, as is shown by the case of the capelin in Ungava Bay.

The capelin *(Mallotus villosus)* is a small smelt-like fish of Subarctic (mixed water) distribution. It is normally absent or rare in Ungava Bay, abundant on the Labrador coast, especially the southern part of that coast. During four seasons of field work in Ungava Bay from 1947 to 1950 by the "Calanus" expeditions of the Fisheries Research Board of Canada, which used dredges, trawls, handlines and large plankton nets, only two young specimens of capelin were taken, and none was found in seal stomachs; nor were any seen inshore or on the beaches, where they can be extremely numerous within their normal range (Dunbar and Hildebrand 1952). But they were present in large numbers in 1884 and again in 1959 and later, years when there happened to be someone in the area who recorded them (Dunbar 1955; Lejeune 1959). The presence of this species in Ungava Bay can be explained only on the basis of change in the currents, that is, marine climatic change, and since the capelin is the basis for the subsistence of other species (it is itself of increasing commercial importance today), prediction of these resources in the Ungava Bay area will depend on understanding the hydrographic and atmospheric mechanisms involved in the changes.

It is only in these marine regions peripheral to the Arctic Ocean itself, however, that climatic change can have any significant marine effect in terms of living resources. These peripheral seas are Baffin Bay, Hudson Strait, the Labrador Sea, and the southern Beaufort Sea. Over the rest of the Canadian North the water is strictly Arctic, that is, of Arctic Ocean upper water origin, and it cannot be expected to change significantly within the time scale being considered in the present paper. Ice conditions, of course, do change from year to year in this Arctic water, mainly under the influence of the wind system, and are discussed below.

The history of marine climatic change (by which is meant subsurface, or hydrospheric, climatic change) is very poorly known in the Beaufort Sea compared with that of the Eastern Arctic – Greenland region. The Pacific inflow into the Arctic Ocean through Bering Strait, however, is small (about 1 sverdrup averaged over the year) compared with the Atlantic inflow of about 6 sverdrups (one sverdrup equals 1 million cubic metres per second). The interplay between Arctic and non-Arctic water, therefore, is less important than in the east in determining climatic change. Moreover, the Pacific water enters from the Bering Sea, itself a cold-water region, and it tends to form a subsurface layer of water (as the Atlantic water does within the Arctic Ocean), and not to influence surface conditions so much as the Atlantic water (Irminger, Labrador Sea water) influence the upper water in the eastern Arctic and Subarctic. There is therefore little to be said about the effects of climatic change on the renewable resources of the Beaufort Sea.

ICE

Ice conditions each year are recorded by the Atmospheric Environment Service of Canada, and have been for some years now. Within a short term of years, it is known which have been heavy ice years (1964, 1965, 1974), and which light ice years (1966, 1969). It must however be admitted that much research will have to be done before it will be possible to forecast ice conditions, rather than just to guess that a cold summer will probably lead to heavier ice conditions the following year, and that to the extent the strength and direction of the wind can be forecast, one has some knowledge of ice movements a few days ahead. Neither of these small abilities deals with climatic change, but only with short-term weather conditions. On the larger scale, it is known that during the recent warming trend the southern limit of sea ice in the Svalbard – Jan Mayen region retreated some 200-300 km northward between 1928 and 1936, and that it moved south again during the cooling period. It is also reported in the Russian literature that the thickness of the cold upper (Arctic water) layer in the Arctic Ocean had decreased from 200 to 100 metres from the days of the "Fram" expedition (1893-96) under Fridtjof Nansen to the nineteen thirties. This applied to the Eurasian Basin, and is very interesting. No such information is available for the Canada Basin, where the upper layer appears to be between 200 and 250 metres thick at present. It is also reported that the thickness of the ice itself, in the Arctic Ocean, decreased from some 360 cm average to about 215 cm between 1893 and 1940; again, this is from Russian sources (see Schokalsky 1936).

No records are available from which to elicit comparable information for Canadian Arctic waters, and one can only insist that full records be kept from now on, as a routine matter, in order to build up information upon which to base prediction. The importance of this information to northern industrial development is clear, and is something that is at present neglected entirely in the contemporary flood of "impact studies". Even the Beaufort Sea Project, which was a good model of an impact study, made no effort to predict climatic change, nor was the subject mentioned in the final report (D.O.E. n.d.). But it is obviously important. The time required to exhaust the oil and gas reserves in the southern Beaufort Sea is, by present estimates, of the order of 30 years; in 30 years the cooling of the present climatic cycle may well have progressed so far as most significantly to change the local ice and weather conditions for the worse, hampering both the extraction of the oil and making the repairing of damage due to blow-outs increasingly difficult. This applies also to mining operations on Arctic coasts, and to transportation in general, everywhere.

In the peripheral seas of the eastern Arctic, ice conditions are highly sensitive to climatic change, most sensitive in West Greenland but also very appreciably on the Canadian side of Baffin Bay and the Labrador Sea (see, for instance, Moira Dunbar 1972). This applies to oil and gas extraction, and mining operations, in Ungava Bay and on the Labrador coast. In the latter region there is the additional hazard of icebergs. The need for means of prediction is becoming acute, but it is very difficult to convince governmental bodies of this fact, or of the necessity of regular monitoring of water conditions and the behaviour of currents in the key sections — such as Baffin Bay, Hudson Strait, Ungava Bay, the Labrador coast, Cape Farewell (Greenland) and Denmark Strait. This has been recognized at the international level, and is one of the objectives of the "Polex" operation, but Canadian scientists seem to have been slow to realize the importance of the matter.

In short, there is little more to be said on ice conditions than has already been said in the Phase I report of "Living with Climatic Change" (Beltzner 1976), which of necessity discusses weather variation in the short term, rather than climatic change as such.

CLIMATIC CHANGE AND THE RESOURCES OF THE LAND

So far I have dealt entirely with marine conditions and marine resources. On land, the past history of the present interglacial has been much the same as in the sea, predictably. The trend since the climatic maximum of 5000 years B.P. has been downward, involving a retreat southward of the treeline by some 500 km, a global drop in mid-latitude air temperatures of some 2.5°C, and increasing aridity in the tropics (Fairbridge 1972). And there has been the same recent upswing to 1940 and same subsequent cooling to about 1970, followed by the suggestion of a reversal of the cooling trend in the past five years, possibly or probably a temporary reversal only.

Faunal changes have also been recorded during the present century. In Iceland, a country drastically affected by these changes, the avifauna has virtually changed twice: first the arrival of new breeding bird species from Europe during the warming, to be followed by the disappearance of these novelties and the establishment of breeding birds from the north (Watson 1975). In Canada there is documentation of northward dispersal of both birds and mammals during the warming period, including moose, red fox and coyote. An interesting discovery some years ago was the presence of red fox fleas on arctic foxes in Baffin Island — evidence no doubt of more than just a northward movement of the red fox.

Much more important for northern development, however, than the response of wildlife to climatic change are the concomitant changes in the potential for agriculture, aquaculture and stock breeding. On this subject there is very little information. Much experimentation has been done on the breeding of cold-resistant plants and cereals of short-growing-season requirements, and on the possibilities of reindeer-, muskox- and sheep-farming, and the breeding of specially adapted hybrids. But none of it has amounted to a direct attack on the problem of the implications of future environmental change. Here again, therefore, the matter rests; meteorologists have some ability to predict short-term weather conditions, whose effects on living populations are fairly well known, but have little or no ability to deal either with longer term predictions of environmental change, or with its effects on stock or plant production under northern conditions. As to other technologies, such as housing, sewage disposal and mining, it is improbable that conditions on land will change within the next few decades sufficiently to affect them significantly. In this the land differs from the sea, where ice conditions are of dominant importance.

MAN-MADE CHANGES

I find it difficult to believe that either carbon dioxide in the atmosphere, water vapour, freon, or any other substance, produced by man's efforts, is going to compete seriously with Nature in changing our climate. The literature on these matters is conflicting, each new paper claiming to contradict the one before it. Has any explosion so far rivalled, or surpassed in violence or in climatic effect, the Krakatoa volcanic eruption of 1883? On the subject of carbon dioxide production by the combustion of fossil fuels, there is a paper by Hutchinson (1948), which seems to have escaped the attention of the climatologists. It is established that the carbon dioxide content of the atmosphere has risen, perhaps from 290 to 320 parts per million within the past hundred years, an increase which is not enough, however — by a factor of two or three — to account for all the fossil fuel burned during that time; and it is clear that there are natural reservoirs for carbon dioxide, in changes in vegetation and probably also in the sea, which are capable of absorbing surpluses of it. Hutchinson (1948) puts the matter as follows:

> The true interpretation . . . would appear to be a slight change in the distribution of stationary concentrations of CO_2 passing through the system, rather than a static accumulation of the gas . . . There must be sinks as well as sources in the atmospheric circulation of the gas. If, as seems probable, the sinks are local areas of ocean surface, they have not yet been discovered on a scale commensurate with what is required. Meanwhile, it seems far more likely that the observed increment in the carbon dioxide of the air at low levels in both Europe and eastern North America is due to changes in the biological mechanisms of the cycle rather than to any increase in industrial output. It is quite probable that the net effects of the spread of the technological cultures of the North Atlantic basin has been to decrease the photosynthetic efficiency of the land surfaces of the earth. Though the most productive agricultural land . . . can have a photosynthetic efficiency greater than that of the best temperate forest, it is very unlikely that, in general, cleared farm land is as biologically productive as virgin forest.

Moreover, the measured increase in carbon dioxide in the atmosphere, according to the most recent computations, would not be enough to have any measurable climatic effect. Rasool and Schneider (1971) conclude that an increase in the carbon dioxide content of eight times the present level would produce an increase in surface temperature of less than 2 °C, and that if the concentration were to increase from the present level of 320 parts per million to about 400 by the year 2000, the predicted increase in surface global temperature would be about 0.1 °C. One of the natural processes that must have a most significant effect on the atmospheric carbon dioxide is the alternation of glacial and interglacial periods; for extensive glaciation, by removing the plant cover from large areas, reduces total photosynthesis and therefore must increase the steady-state concentration of atmospheric carbon dioxide. It is a pity, in fact, that man's combustion efforts will not have a significant climatic effect; it might have been enough to delay or reduce the extent of the next glaciation!

The possibility of changing the climate by the manipulation of ocean currents has always had a fascination for humanity, especially non-oceanographic humanity. Russian engineers have several times since the eighteen eighties suggested the closing of Bering Strait, with or without the pumping of water through it in either direction, and Russian oceanographers have just as often denied the feasibility of such schemes, on very reasonable grounds. The Strait of Belle Isle (between Newfoundland and Labrador) has been a favourite target, and there has been consideration of Fury and Hecla Strait (between western Baffin Island and the mainland of Canada). But I think, for the purposes of this paper at least, all of them can be ignored.

ON PREDICTION

Climatologists and other scientists are understandably reluctant to predict climatic change, and indeed, on the basis of present knowledge cannot in fact do so. But prediction is the crucial need in the whole argument; prediction is, after all, one of the paramount objectives of all science, climatology not excepted.

There are two ways in which some power of prediction could be achieved, one much better than the other. The first is the obvious one, the understanding of the rules, that is, the causative chain or web of events that determines the course of climate. The other is the dogged maintenance of routine observations of the relevant variables as the years go by, in order to build up a pattern of past change from which intelligent guesses may be made about the future. Such routine observations are now well established on a world-wide basis in the atmosphere, but not by any means in the hydrosphere. This dull building up of records has not appealed to oceanographers, except perhaps to the Russians, who have so many research vessels that they have to find work to keep them occupied. Canadian oceanographers point out that adequate coverage would keep the whole of the Canadian research fleet occupied full time, at great expense and to the detriment of oceanographic research as a whole. But remote-sensing ability of some refinement is now available, and the technology of moored instruments is advancing rapidly, so that much of the necessary monitoring can be done without the full-time use of ships. At all events, in support of such a system of marine monitoring, I quote here from an earlier paper of mine (Dunbar 1972):

> The nations of the world have organized among them, during the past 50 years, an efficient system of weather observation, reporting, and synopsis, upon which is based weather forecasting for all regions. If there had been a similar organization to deal with the hydrospheric climate over the same period of years we would now know a great deal more about the changing marine climate, and would have the beginnings at least of a means of forecasting it; and the marine subarctic, as the region most sensible to climatic change, is the logical region in which to start. . . . There is a need for a program of routine hydrographic measurement, organized internationally, of temperatures and salinities in certain key sections such as Hudson Strait, Davis Strait, the Labrador Sea, Denmark Strait, over the Wyville Thompson Ridge between Iceland and Scotland, and in the Barents Sea and Svalbard areas; between Northeast Greenland and Svalbard.

A few very tentative predictions, on the shorter time scale, are being made. For instance Johnsen *et al.* (1969), on the basis of ice-cap measurements in Greenland, expect the present cooling trend to continue for one or two decades with subsequent warming reaching a maximum in about 40 or 50 years. Winstanley (1973) does not expect a change in the cooling trend for another 60 years. Very probably the rules governing the shorter-term changes or cycles, of the scale of the present twentieth century events, which are the most important in the present context, will turn out to be more difficult to understand than those governing the larger-scale cycles; such as the glacial-interglacial. At least it will be more difficult to gauge whether hypotheses concerning the larger time scale are correct or not, for it will take several millennia to find out.

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