A NOTE ON CLIMATIC CHANGE IN THE SEA

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THE recent warming in the world's climate has been particularly striking in the North Atlantic region. An increase in solar heating would be expected to make itself apparent in increased circulation between the tropics and the poles in both atmosphere and hydrosphere, and there is ample evidence that it has occurred in both (1, 2, 3, 4). In the North Atlantic, it is in the Gulf Stream–North Atlantic Drift system that the change has been most violently manifested, involving an increase both in temperature and in water transport. The effect has been strongest in the northeastern part of the system (Iceland, Faeroes, Barents Sea, Svalbard) and in west Greenland, where the Irminger Current has been responsible for the change in marine climate.

In this process, as in most changes in nature, there has been an obvious element of self-regulation, or of a mechanism whereby the effects of the change are damped by processes set up by the change itself. An increased flow of Atlantic water northward to the Arctic Ocean requires an increased flow of polar water southward, so that the two areas most influenced by the polar outlets—east Greenland and the Canadian Eastern Arctic—would be expected to be buffered against the climatic change; and it is in fact in those two regions that the climate has changed least in the whole of the North Atlantic area in the past thirty-five years. Thus any warming effect in those two regions does not necessarily bear a simple or direct relation to the increased volume or velocity of the whole North Atlantic circulation.

This appears to have been demonstrated in the relative strengths of the increases in North Atlantic circulation in this most recent warming (1915 to the present, or more properly to about 1945) and in the short warm period before that, which occurred in the 1880's and perhaps in the late 1870's. The effect of the 1915–45 period has been most strong in Svalbard and in west Greenland, and comparatively unimportant in east Greenland and the Canadian Eastern Arctic. In the 1880's there is evidence that the effect was stronger in the "buffered" areas, at least as far as the Canadian Eastern Arctic is concerned.

The evidence for a short period of climatic "amelioration" in the decade of 1880 in west Greenland and in Svalbard is well known (2, 3, 5). Compared with the present effects there that warming was a mild affair. Although the Atlantic cod (*Gadus callarias*), which serves as a good indicator of warming marine conditions in the northern part of its range, did in fact appear in both Svalbard and west Greenland at that time, the invasions were insignificant

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compared with the present enormous populations there. But in the Canadian Eastern Arctic, as represented by Ungava Bay and possibly also Frobisher Bay, the story appears to have been different.

The existence during the 1880's of warmer conditions in Ungava Bay than prevail there today is indicated by the observations of Mr. Lucien Turner, who spent the period of 1882–4 at Fort Chimo on a commission from the U.S. Corps of Signals as one unit in the International Polar Year Expedition of 1882. Although there do not appear to be records of sea temperatures observed, Turner's manuscript report on the fishes collected (never published) records that the Atlantic cod was moving northward at that time "even to far north of Cape Chidley", and that the caplin (*Mallotus villosus*) was also moving northward year by year, and into Ungava Bay. On the subject of the caplin he writes: "Within Hudson Strait they had not been detected until several years ago when a few were seen in the neighboring waters of George's River. In the spring of 1884 they were observed in great numbers in that vicinity. On the 8th of August 1884 a school of several thousand individuals appeared four miles within the mouth of the Koksoak River. As many as were desired for specimens were secured by the hand as they swam near the shore . . . . This is the first instance known either to whites or natives of the appearance of the Capelin in the southern portion of Ungava Bay."[1]

During four seasons of intensive collecting in Ungava Bay from 1947 to 1950, the *Calanus* expeditions, using dredges, trawls, and hand-lines, took only two young specimens of the caplin, and none was found in the stomachs of seals or of Atlantic cod at Port Burwell (6). Moreover the temperatures measured in Ungava Bay were somewhat low for the normal caplin range, being never above 5.8°C at the surface nor above 2.5°C at 10 metres.

The presence of Atlantic cod in Ogac Lake, a saltwater lake on the shore of Frobisher Bay (7), may also be relevant to this matter. The locality lies over one hundred miles from the northernmost present occurrence of the cod (Resolution Island), and the cod is not found in the waters of Frobisher Bay itself. The Ogac Lake cod must therefore have reached the lake during a former period of warmer climate. The 1880 period is the most likely, for the lake is very small and the survival of an isolated cod population in so confined a habitat for longer periods of time is not probable.

Other relics of warmer climate at present alive in the Canadian Eastern Arctic may perhaps be less valuable as indicators in this particular context, but they should be mentioned here. The eel-grass (*Zostera marina*) has been recorded in southern Hudson Bay and in James Bay (8). It appears to have been known in Hudson Bay, however, as early as the time of Rae (9), and moreover there is the possibility that it dispersed there from the Gulf of St. Lawrence by way of a post-glacial marine connection (10), or by the agency of birds. The copepod *Acartia clausi* is known from James Bay and southern Hudson Bay, but is elsewhere known from Atlantic areas (southern Labrador, Gulf of St. Lawrence, southern Iceland, Norwegian coast, and southwards

[1] I am indebted to the Smithsonian Institution for the loan of Mr. Lucien Turner's manuscript on the fishes of Ungava Bay, and of his caplin specimens.

to west Africa (11)). It is not recorded from west Greenland. The caplin, again, is common in Hudson Bay but rare, as has been mentioned, in the region of Hudson Strait. As in the case of the Atlantic cod in Ogac Lake, Frobisher Bay, and setting *Zostera* aside as a more doubtful example, it is questionable whether these marine animals could reasonably be supposed to have survived several thousand years since the last major climatic maximum in Hudson Bay; it is more likely that they are relics of a much more recent warming.

The inference is that the warming of the marine climate in Ungava Bay and probably in the Eastern Arctic generally in the decade of 1880 was of greater power than any that may be occurring there now; yet the present warming in west Greenland is undoubtedly of far greater extent than that of the 1880's.

The reason for this is possibly to be found in the relative volume transports and velocities of the Atlantic Drift system in the two periods. A large increase in flow, such as has been stimulated in the present or recent warm period, would have two important secondary effects: a) the flow out of the Arctic Ocean would be increased, as mentioned above (and it is to be noted that the thickness of the polar water layer in the Arctic Ocean has decreased considerably during recent decades (12)); and (b) the Canadian Arctic Current and the West Greenland Current, the latter with a large proportion of Atlantic (Irminger) water, would be pressed with greater force against the coasts of Baffin Island and west Greenland respectively, since the Coriolis force is proportional to the mass and the velocity of the moving body. This would have the effects of forcing more arctic water from the Canadian Arctic Current into Hudson Strait and Ungava Bay, and of minimizing the westward flow of West Greenland water over to the eastern end of Hudson Strait. It has in fact been established (2) that the extent to which the West Greenland Current holds close to the Greenland coast is proportional to the transport of the current, which varies from year to year.

If it is assumed that the warming of the 1880's involved a much lesser increase in current transport than did the 1915–45 period, which is a reasonable assumption, it follows that the effect in the Canadian Eastern Arctic may have been greater then than now, owing to the much lesser buffering effect of the Canadian Arctic Current and the lesser value of the Coriolis force acting upon the West Greenland Current. And since there is good evidence that the recent warm period has reached its maximum, at least temporarily (4, 5), we may expect, as the transport in the current system relaxes, that the cooling effect will be most noticeable in west Greenland and in the northeast Atlantic area, and that the Canadian Eastern Arctic region, probably at least as far south as the Gulf of St. Lawrence or Nova Scotia, may go through a further period of warming before the general cooling takes effect.

If the present apparent relaxation of the Atlantic circulation gives place in due course to an increased circulation again, which is probable, giving a northward transport of heat to a degree greater than during the recent warm period, then we should perhaps look forward to a time when the cold upper

layer of polar water in the Arctic Ocean is finally "flushed out". If and when that happens, the climate of the north will no doubt become suddenly considerably milder, and moister.

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