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ARCTIC FJORD FLUSHING

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Authors who have investigated mid-latitude fjords consider the outflow of fresh and brackish water at the surface to be continually balanced by an inflow of more saline water beneath. The exchange of "basin" water, that is water below the fjord sill depth, tended to occur intermittently being related to the density of the water outside the sill and to eddy diffusivity processes causing a flux of salt upwards from the basin towards the surface. In Arctic fjords runoff from land is restricted to a comparatively short season of the year and in the absence of glaciers maybe half the annual total precipitation on the surrounding land finds its way into the sea in one week. Under these circumstances, the assumption of an inflow balanced to the outflow of surface waters will no longer be valid as the time taken for a water particle to move down the fjord is of the same order as the length of the runoff pulse.

Wind mixing, a common feature of surface waters in more southerly fjords, is reduced as one goes northwards according to the percentage of ice cover at any time of year. A fjord at 70° N. may, for example, be ice free for two months of the year with runoff reaching peak at the beginning of this period (Cambridge Bay, N.W.T.). At 80° N. the fjord may retain a proportion of its ice cover throughout the year with the major runoff occurring while the ice cover is still complete. The degree of wind mixing occurring during the summer determines the density structure at the time of freeze-up and the effects of one storm in late summer may be still evident nine months later.

As the sea ice sheet forms, salt is rejected at the ice/water interface causing vertical convective circulation down to a depth determined by the density profile in the underlying water. It has been found that the technique for calculating this depth due to Zubov (1943) gives a good approximation to nature. By the April of the following year, this convection will have caused thorough mixing of the water down to about 35 meters at 70° N. as shown in Figure 1 and as little as 1 meter at 80° N. (Figure 2). Figure 3 compares spring profiles in 1969 and 1970 at the 80° N. location, the former being preceded by an open water summer and the latter being after a summer when the ice cover was never completely removed.

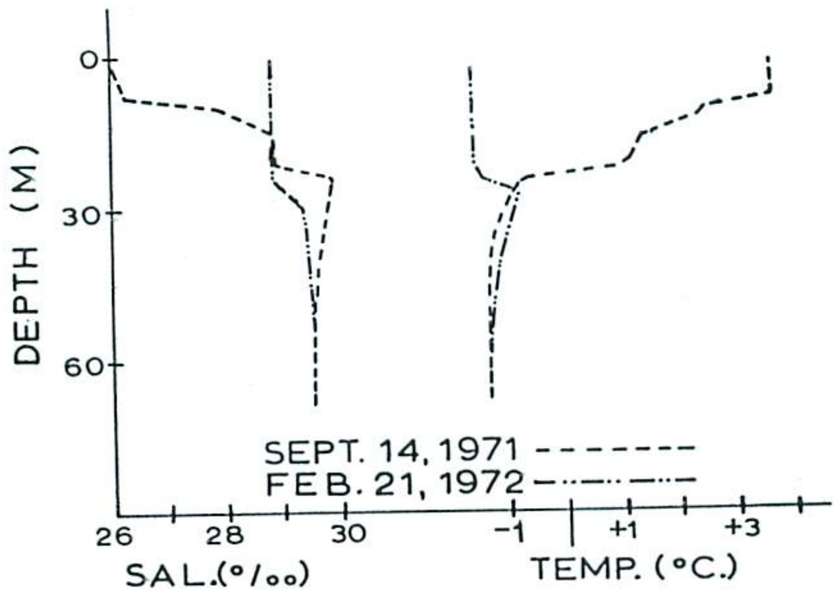

Fig. 1. Salinity and temperature profiles at Cambridge Bay, N.W.T. (69° 06' N., 105° 04' W.) at the end of summer and during the following winter. Convective mixing has occurred down to about 25 m. by February 21st.

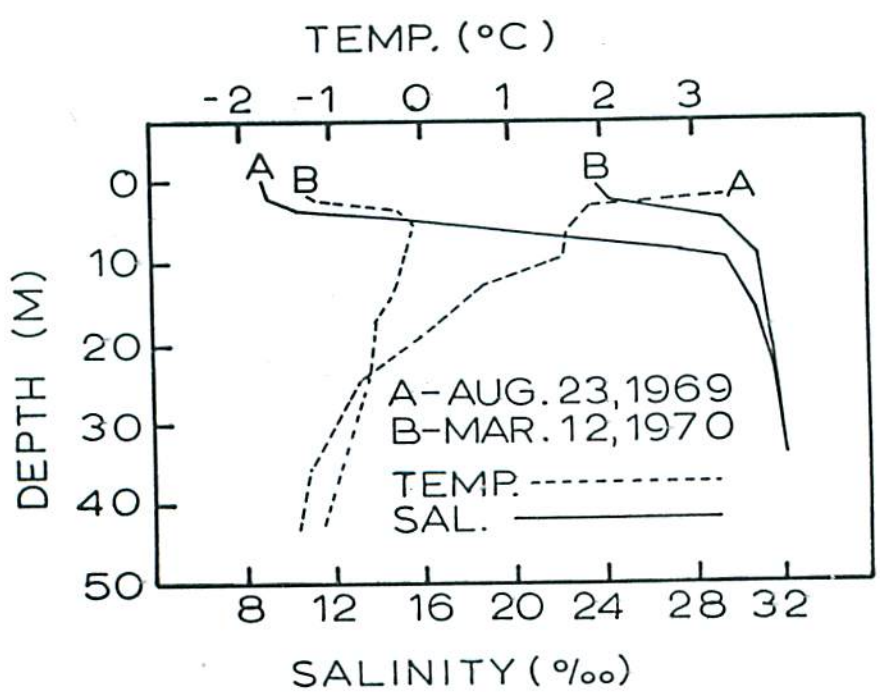

Fig. 2. Salinity and temperature profiles at d'Iberville Fjord, Ellesmere Island (80° 30' N., 79° 30' W.) at the end of summer and during the following winter. Convective mixing has occurred down to about 1 m. only by March 12th.

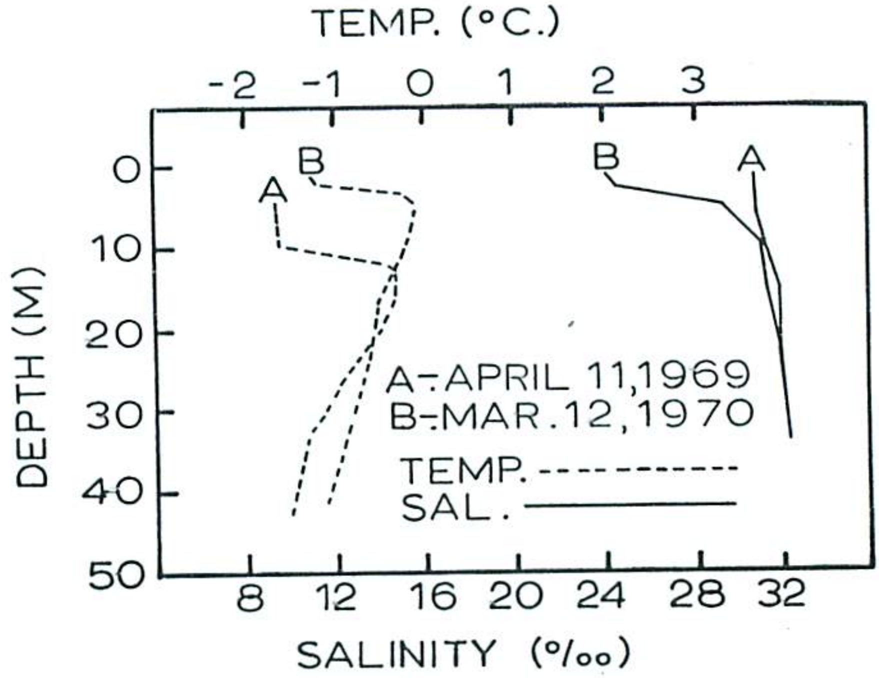

Fig. 3. Salinity and temperature profiles at d'Iberville Fjord during the late winter and spring of 1969 and 1970. Convective mixing reached 10 m. in 1969 but only 1 m. in 1970. The latter depth has been the more common over five years of observation.

Work on the runoff from Arctic streams is very limited but McCann et al (1972) showed that the major runoff pulse at 75° N. enters the sea before removal of the ice cover leading to a very highly stable water stratification under the ice. Figure 4 is from their paper. This fresh water is enhanced by the melting sea ice and a major seaward surge of waters helps to break up the ice sheet.

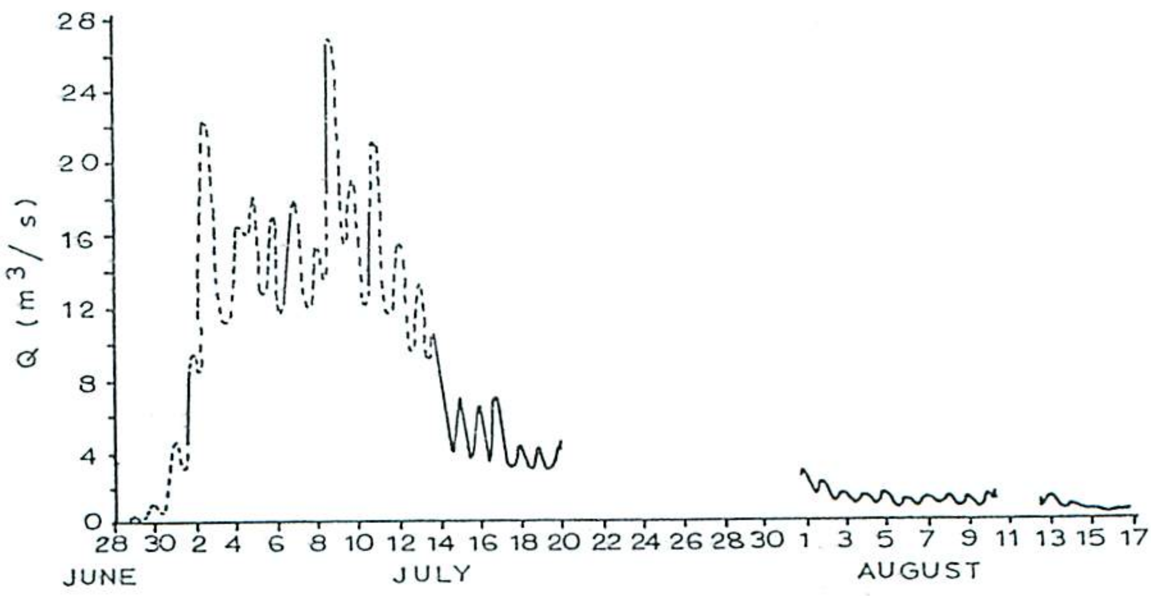

Fig. 4. Runoff from River Mecham near Resolute Bay (74° 43' N., 94° 59' W.) in 1970. The catchment area is about 140 sq. Km.

Figure 5 shows the output from a stream running into d'Iberville Fjord (80° N.). Temperature and salinity profiles taken offshore as the runoff proceeded showed that the fresh water remained essentially unmixed immediately beneath the existing sea ice where it added to melt water from the superincumbent snow. Figure 2 shows that this stratification can persist into the following spring when the ice cover remains throughout the summer. Other measurements made in the spring along d'Iberville Fjord and into Greely Fjord having a horizontal extent of 150 Km. show that blobs of fresh water can still be detected just below the ice, but records of temperature fluctuations with time at depths of 2.5, 5, and 7.5 meters shows little if any correlation. In a

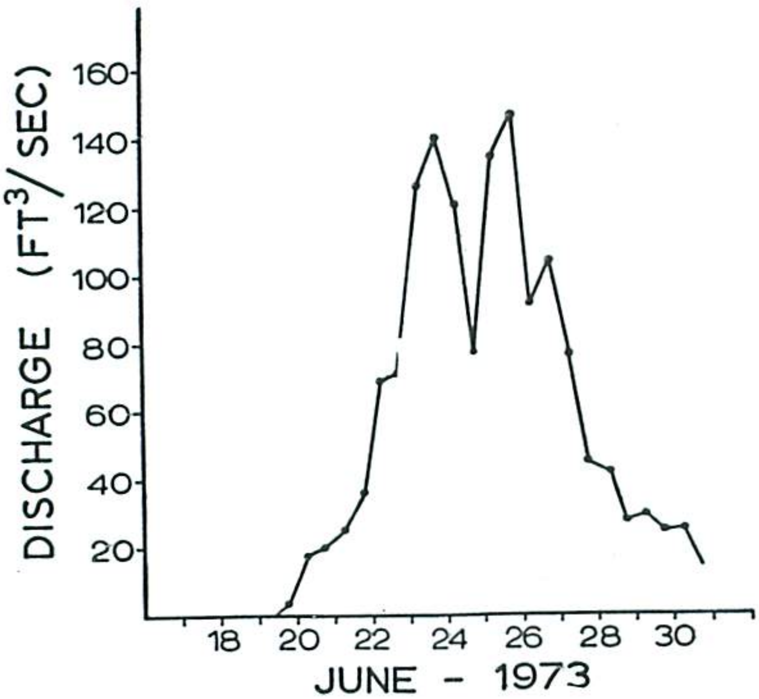

Fig. 5. The output from "weir river", d'Iberville Fjord (80° 30' N. 79° 30' W.).

complex system such as the Canadian Arctic Archipelago, one is tempted to make an analogy with a propagation of pulses in a similarly complicated transmission line, each channel, bay, etc. being described in terms of an "impedance" at its entrance in a network analysis.

In Arctic fjords with shallow sills, it appears that the return flow of saline water to compensate for the outflow of entrained salt occurs late in the season after the main runoff has passed (Gade et al, 1973). In deeper silled fjords one would anticipate that some return flow would occur almost immediately. Exchange of basin water has not received any study but the situation should be comparable to mid-latitude fjords.

The present work serves to define the limits of ignorance on a subject where far more information is required before waste products can be disposed of safely from industrial structures built in or around Arctic waters. The difference between 70° N. and 80° N. for potential pollutant dissipation is most marked, largely due to the presence and absence of wind mixing respectively.

Studies of the dissipation of pollutants in Arctic fjords will require:-

1. Tidal studies.
2. Measurement of water profiles in summer.
3. Estimates of air/ocean heat flow from meteorological parameters applied to a Zubov calculation.
4. Measurements of local runoff from snow pack and glaciers giving rate of discharge as well as total discharge in relation to radiation input.
5. Measurements of the response of the surface waters of the system to the fresh water discharge pulse.
6. Numerical modelling of complex flow systems.

References

Gade, H. G., R. A. Lake, E. L. Lewis and E. R. Walker. (1973) "The oceanography of an arctic bay", Unpublished manuscript, Frozen Sea Research Group.

McCann, S. B., P. J. Howarth and J. G. Cogley. (1972) "Fluvial processes in a periglacial environment", Transactions of the Institute of British Geographers, No. 55, pp. 69-82.

Zubov, N. N. (1943) "Arctic Ice" (English translation) U.S. Navy Electronics Lab., San Diego, 491 pp.