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The classical methods of Physical Oceanography entail a number of bold assumptions, not the least of which concern the time relationship between observations. The distribution of physical variables is usually mapped as though all observations had been taken simultaneously, where, in reality, they are the results of a series of stations occupied by a single ship or, at the most, by a very few ships. The satisfactory results of patterns of water movement as inferred from physical variables observed in this way have justified the assumptions for most areas in the open ocean -- but the same cannot be said for observations in inshore waters, especially those exhibiting marked stratification.

Each such case must be considered separately to ensure that geographical variations are not being confused with short period temporal variations, and that the inferred movement patterns are not wholly, or in part, spurious.

There are a number of known mechanisms which may bring about short period variations in the vertical structure of a water mass. Changes in the pattern of atmospheric pressure over the oceans require a redistribution of mass in the underlying water in order that equilibrium be maintained. Wind stress may move the light surface layers away from a coast, requiring a compensating inflow of the lower and denser layers. The region near the boundary of well defined, intense ocean currents may appear unstable due to oscillations in the position of the boundary and small eddies may even be thrown off to form isolated patches with anomalous structure and closed circulation patterns. Tidal currents may produce confusing longitudinal shifts in the coastal water mass, or contribute the energy which sustains internal waves of tidal periods. Furthermore, in semi-enclosed areas, the lateral boundaries may give rise to favoured modes of oscillation, either of the whole body of water, or of internal waves. These periodic oscillations may be sustained by energy from random non-periodic disturbances.

The waters of the Gulf of St. Lawrence have, during the last five years, been subjected to systematic study by the Atlantic Herring Investigation Committee, the Atlantic Oceanographic Group, and the Canadian Naval Research Establishment. This report attempts to indicate the importance of the "Time" parameter in the treatment of the accumulated data.

An excellent study of the area was made in 1914-15 (Hjort et. al. 1919). The method employed for observations was the standard water bottle - reversing thermometer technique. Patterns of motion inferred from the gradients of isosters in profiles obtained in this manner may be qualitatively correct. The coarseness of the profile, however, both in horizontal and vertical spacing, tends to obscure any variations which would have indicated a fine structure of strong currents or short term variations in the vertical sections. The same is true of similar observations made since that time.

Bathythermograph observations made in the area prior to 1946, while not part of systematic investigation, aroused the suspicion thàt major changes in the vertical structure of the water mass might take place over very short distances or during comparatively short periods of time. This has been confirmed by bathythermograph sections made in 1947 and 1948. Figures 1 and 2 show sections taken along the Gaspe current by H.M.C.S. "Lloyd George", the 23rd and 24th of July, 1947, and by H.M.C.S. "New Liskeard", the 10th and 11th of June, 1948. The violent oscillations of the isotherms along these lines would indicate that there is either a very complicated horizontal movement or vertical fluctuations of considerable amplitude, or indeed both.

Lauzier (1947) has published data from a Station off Grand River, Quebec, which was occupied eighteen times between May and September, 1946. At the 20 metre, and more particularly at the 50 metre level, the fluctuations, from observation to observation, in both temperature and salinity are so extreme as to completely mask the seasonal trends. Some of the most violent changes take place between adjacent observations separated only by a few days. It is hardly conceivable that these changes are not due to some disturbance in the form of internal waves. His diagramatic presentation of the data is reproduced in Figure 3. Lauzier (1948) indicates that there is a correlation of these data with the stage of the tide, and his observations in 1947 bear this out. On July 21st and 22nd, 1947, the Station off Grand River and another on American Bank were occupied, the former six times during a twelve hour period and the latter four times during a similar period. These data, shown in Figure 4, indicate an internal wave of tidal period. Lauzier (personal communication) is of the opinion that this may be due to a tidal oscillation of the position of the Gaspe current, bringing it, with its deeper intermediate layer, inshore at these points during certain stages of the tide.

On September 7th and 8th of the same year, two time series were obtained with bathythermographs off the Gaspe Coast. H.M.C.S. "Lloyd George" occupied Station "A" (lat. 48°56'00"N, Long. 64°06'45"W) six miles off Cap de Rosiers, from 2030 hours. (G.M.T.) September 7th until 1000 hours September 8th when adverse weather forced abandoning the Station. The station was picked for ease of visual navigation day or night, and it is not likely that the positions of individual observations differ greatly. A standard hydrographic cast was made at 2030 hours, when the Station was first occupied but weather did not permit further observations of this nature. H.M.C.S. "New Liskeard" occupied Station "B" (Lat. 49°13'N, Long. 63°53'W), 21 miles from Station "A" on a line towards South-West Point, Anticosti Island, from 1715 hours September 7th to 1700 hours September 8th, keeping Station on a lighted buoy dropped for that purpose. Hydrographic casts were made at 1640 hours and 1830 hours, September 7th. Both ships made bathythermograph observations each hour when possible.

The results of these time series are shown in Figures 5 and 6. Both stations exhibit great variations in the depth of isotherms below the 35 degree F. isotherm. Here, where adjacent isotherms are separated by greater vertical distances, the almost vertical B.T. trace introduces the possibility of errors in reading, but this could not cause all the variations indicated. At Station "B" there was comparatively little oscillation of the intense thermocline, although just below it, the 35 degree isotherm fluctuated rather regularly with limits in depth of 75 and 110 feet. The variability continues to the full depth of observation, with rather more activity below the center of the cold water layer. The lower 31 degree isotherm ranges from 280 to 345 feet.

At Station "A" the situation was somewhat different. The 35 degree isotherm remained comparatively steady, while the water below was about as variable as that at Station "B". Here, moreover, there was a marked oscillation in the thermocline, the 45 degree isotherm ranging from 45 to 85 feet.

The depths of the 45 degree isotherm over the 14 hour period are plotted separately in Figure 7. The observed points are joined by the continuous straight lines. The dashed lines indicate the general trend of the isotherm, which is steadily downward with the suggestion of a rise towards the end of the series. The smooth curve (dot-dashed line) is drawn through the points, perhaps somewhat fancifully, to indicate a rough periodicity with period of approximately two and one-half hours. Little, if any, significance should be placed on this periodicity as the probability of its reality is slight. ("The number of maxima in a sequence of unrelated numbers is one-third the number of terms" (McEwen, 1949)).

The existence of this marked oscillation in the thermocline at Station "A", together with its absence at Station "B", points to its association with the Gaspe current. It might be caused by a lateral oscillation of the current transverse to its direction of advance (see recent studies of the Gulf Stream (Iselin and Fuglister, 1948)), or it may be the result of a system of internal waves at the boundary of the two bodies of water moving with different velocities and sustained by energy supplied from the differential motion.

Internal waves, or waves with their maximum amplitude within a fluid whose density varies with depth, have in recent years received considerable attention from oceanographers. The theory was first developed by Stokes (Lamb 1945 p. 370) for the simple case of two superposed fluids of different densities. Fjeldstad (1933) treated the general case where density is any function of depth. His results are strictly applicable only to waves of frequency which are low in comparison to the stability parameter N (Eckart, 1949). Ufford (1947) has applied Fjeldstad's results to explicit simple density gradients in order to treat with internal waves observed off the coast of California. (Ufford 1947a).

Eckart (1949) has dealt with the more general case, showing a dependence on the stability parameter "N". This parameter, attributed to Vaisala, is given as $N = \sqrt{\frac{g}{\varrho}\frac{\partial \varrho}{\partial z} + \frac{g^2}{c^2}}$ where ϱ is the density, z is the depth, c the velocity of sound and g the acceleration of gravity. It is closely related to the stability parameter "E", $E = -\left(\frac{\partial \varrho}{\partial z} + \frac{\varrho g}{c^2}\right)$, (Hesselberg and Sverdrup (1915)). N has the dimensions of a frequency ($sec.^{-1}$) and is the upper limit of permitted frequencies for internal waves of finite amplitude. $2\pi/N$ in minutes has been computed for a vertical section at station "A" 2030 hours 7th September, 1947, and is shown, together with the temperature and salinity distribution, in Fig. 8.

It would be of interest to make a thorough study of internal waves in this area. Fig. 8 indicates that one must be prepared for the observation of periods down to the order of two minutes. It is not to be expected that the disturbances will be of a simple nature, though the semi-enclosed nature of the area may impose lateral boundary conditions which favour a few discrete modes of oscillation.

In conclusion, this study indicates that internal waves, or other short period fluctuations in the vertical structure of the water mass must be thought of as being quite general in the Gulf of St. Lawrence. Seasonal cycles, patterns of movement, or other phenomena inferred from widely spaced hydrographic observations, must recognize the possibility of short period internal disturbances of up to twenty metres amplitude, unless they treat with regions shown to be free from such disturbances.

The problem requires further intensive study, and the implications should be thoroughly explored.

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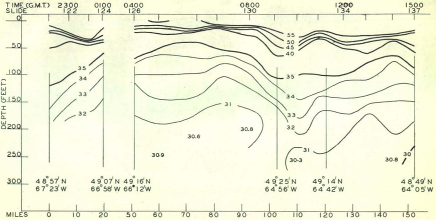

Figure 1

Bathythermograph Section along the Gaspe Current. July 23rd and 24th, 1947 Temperatures in degrees Fahrenheit.

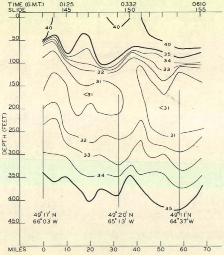

Figure 2

Bathythermograph Section along the Gaspe Current. June 10th and 11th, 1948. Temperatures in degrees Fahrenheit.

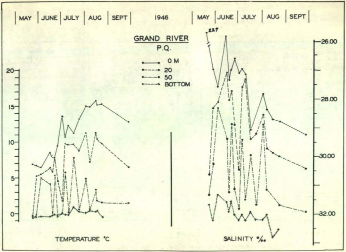

Figure 3

Temperature and Salinity Observations at a Station off Grand River, Quebec. May to September, 1946. Reprinted from Atlantic Herring Investigation Committee Report 1947.

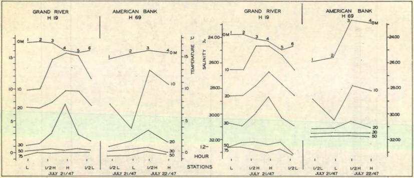

Figure 4

Temperature and Salinity over a twelve hour period at Stations off Grand River and on American Bank. July 21st and 22nd, 1947. Reprinted from Atlantic Herring Investigation Committee Report 1948.

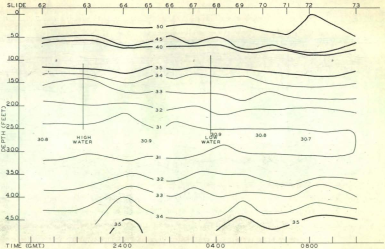

Figure 5

Bathythermograph Time Series, Station "A", Lat. 48°56'00"N. Long. 64°06'45"W. 2030 hrs. (G.M.T.), September 7th, to 1000 hrs. September 8th, 1947. Temperature in degrees Fahrenheit.

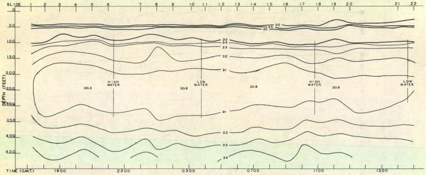

Figure 6

Bathythermograph Time Series, Station "B", Lat. 49°13' N. Long. 63°53' W. 1715 hrs. (G.M.T.), September 7th, to 1700 hrs. September 8th, 1947. Temperature in degrees Fahrenheit.

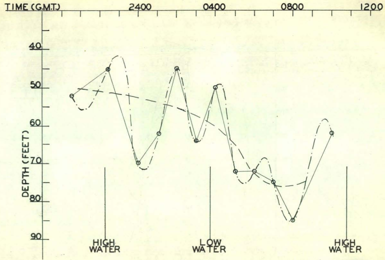

Figure 7

Variation in Depth of the 45 Degree Fahrenheit Isotherm at Station "A", 2030 hrs. (G.M.T.) September 7th to 1000 hrs. September 8th, 1947.

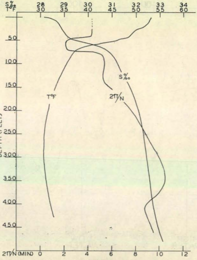

Figure 8

Temperature, Salinity, and Stability Parameter 2π/N at Station "A", 2030 hrs. September 7th, 1947.