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# Near Bottom Temperatures Over the Labrador Shelf, The Seasonal Cycle

by

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*Abstract*

Temperature and salinity data collected intermittently at 200 m with moored current meters between 1978 and 1986 over the Labrador Shelf demonstrate the existence of a seasonal cycle of almost 4 °C and 1.0 unit of salinity. The cycle is determined by a combination of vertical and horizontal processes. In late winter, vigorous mixing along the isopycnals which lie deep and horizontal over the shelf and which rise up to the surface in the front associated with the main branch of the Labrador Current, creates a uniform water mass described by a single temperature vs. salinity curve. The curve continues to define the water mass, in the intermediate and deep layers over the shelf, through the spring and summer as the increased vertical stratification in the surface layers inhibits exchange across the front and isolates the conditions determined in winter. In the autumn and early winter the surface layers increase in density which allows the rising isopycnals to again rise into the surface mixed layer and permits exchange across the front along isopycnals. The subsequent intrusions of near surface water into the intermediate and deep layers over the shelf cause the temperature and salinity profiles in these layers to be characterized by alternating values. The temperature and salinity signal at 200 m continues to be dominated by this cross shelf mixing until the mixed layer over the shelf gets deep enough, in the middle of winter, to dominate the conditions and drop the temperature and salinity at the current meter to the values of the mixed layer over the shelf. Continued exchange across the shelf along the isopycnals creates the water mass typical of the late winter.

SPECIAL SESSION ON DEEPWATER FISHES

*Introduction*

The Labrador Current, Fig. 1, flowing south-eastward over the continental shelves and slopes of Newfoundland and Labrador, brings relatively cold low-salinity water south from the Arctic regions into the Atlantic Ocean. Typical mid-summer sections of temperature, salinity and density across the current at Hamilton

Bank, Fig. 2, show a layer of moderately warm ( ≤ 6°C ) water in the top few tens of meters lying over an intermediate layer between 50 and 200 m of less than 0°C. Beneath this intermediate cold layer the temperature increases to about 1°C at 200 m. The salinity and density ($\sigma_t$) both increase monotonically through the water column, with near surface salinity values of 28-33 depending on distance from shore, and deep values of 34. Over the upper part of the continental slope a strong horizontal gradient, or front, separates these cold low-salinity waters from the relatively warm and saline oceanic waters. Across the front the temperature at 100 m, for example, rises from ≈ -1.0°C over the shelf to ≈ 3.5°C in the open ocean, while the salinity increases from 33.0 to 34.5 and the sigma-t rises by 1 kg/m$^3$.

The seasonal cycle of temperature and salinity at five depths over the Labrador Shelf, Fig. 3, was calculated by Lazier (1982) from all the archived bottle data obtained between 1935 and 1972. The temperature and salinity of the near surface layers vary instep with the seasonal heating and fresh water cycles and over the year the changes are adequately accounted for by vertical transfer processes. Below the cold intermediate layer the temperature changes in an unexpected manner. At 200 m it increases to its annual maximum in December-January, even though it lies below the colder water of the intermediate layer. This winter-time increase in temperature cannot be caused by vertical processes which would require that heat pass through, without affecting, the cold intermediate layer.

The purpose of this paper is to present some CTD data from across Hamilton Bank and multiyear records of temperature and salinity from a mooring maintained at 200 m over the Labrador Shelf to the west of Hamilton Bank, Figs. 1 and 2, to show that the seasonal variations in the temperature and salinity, at 200 m, are the result of both horizontal and vertical mixing. Vertical processes tend to dominate the upper layers while horizontal processes tend to control the temperature and salinity changes in the deeper water. The horizontal mixing occurs along the isopycnals which lie deep and nearly level over the shelf but which rise up to shallow depths in the front over the continental slope. Evidence of the mixing first appears in autumn and early winter when the surface layers increase in density.

In the following, the property distributions and the processes causing their change are described for each season, starting with winter, which is in some ways the simplest state.

*The Seasonal Cycle*

*Winter*

The temperature versus salinity (t-s) curves from a line of stations obtained across Hamilton Bank in February 1978 show, in Fig. 4, what are typical mid-winter conditions. The waters over the shelf lie between salinities of 33 and 34.4 while the stations in the deep water have salinities ≥ 34.5. The section of $\sigma_t$ based on these data is shown in Fig. 5.

The five t-s curves in Fig. 4 all lie more or less along the same line which means that at all positions along the section temperature and salinity on a specific density surface are constants. Thus, the density surface 26.8 in Figs. 4 and 5., lying deep and horizontal over the shelf rises up to the surface in the shelf break front and no horizontal gradients exists along it. This situation can only prevail if there is vigorous interchange along the isopycnals between the surface mixed layer and the deep waters. Under these conditions the properties of the deep waters over the shelf are determined in the surface mixed layer in the frontal region by horizontal exchange across the front and by vertical exchange through the mixed layer.Over the shelf, above this deep layer of offshore influence are the surface and intermediate layers which are vertically mixed to near homogeneity by the vertical fluxes through the local water column. The properties of the surface mixed layer over the shelf are reasonably constant at -1.6 °C, 33 in salinity and $\sigma_t \leq 26.8$.

*Spring and Summer*

The temperature and salinty conditions across the shelf in mid-summer are shown in the t-s diagram of Fig. 6, which is based on the same data displayed in Fig. 2. The t-s curves and the sections show the property distributions to be much the same as in winter except for the warm and relatively fresh surface layer that lies on top of the distributions found in winter. The t-s curves illustrate the differences in properties of the surface layer between the shelf and the open sea. The upper shelf waters are at 4-6 °C and 31-32.2 in salinity while the surface layer to the east of the front is at 8-10 °C and 34.5. The t-s curves also demonstrate the large gradients of temperature and salinity that exists in summer along the isopycnals that lie deep over the shelf and which rise up into the near surface layers on the off-shore side of the current. The surface $\sigma_t = 26.8$ shown in Fig. 6 illustrates this change from the winter conditions. Over the shelf this isopycnal is found at -1.6 °C and 33.3 in salinity the same as in winter but on the other side of the front the isopycnal is in water of 8 °C and 34.4 in salinity. The winter situation of no gradients along isopycnals has changed. In summer there is a large temperature and salinity gradient along the isopycnals but there is no evidence that water is exchanged along the surfaces of constant density across the front as in winter.

One reason why interchange of water along isopycnal surfaces across the front is restricted in summer compared to winter is evident in Fig. 7 which is a detailed section of $\sigma_t$ across the front. The data, obtained in summer by a towed undulating CTD, or Batfish, shows isopycnals rising across the front from a region of low vertical gradient into a region on the open sea side of high vertical gradient. The increase in vertical gradient strongly affects the potential vorticity of the water column and increases the amount of energy required to move water from one side of the front to the other. For example, the layer $26.8 \le \sigma_t \le 26.9$ is about 20 m thick over the shelf but 2 m thick over the open ocean. The potential vorticity $(f+\zeta)/D$, where f is the coriolis parameter, $\zeta$ is the relative vorticity and D the thickness of the layer, is roughly $10^{-4}/20$ over the shelf and $10^{-4}/2$ in the region to the east of the front. This factor of 10 difference in the potential vorticity across the front strongly inhibits the flow of water across the front in summer, even though the water on both sides may be at the same density.

During the spring and summer the temperature and salinity, in and below the cold intermediate layer over the shelf, remain quite constant, except for the variations due to periodic oscillations such as internal waves. This is illustrated in the continuous plot of temperature vs. salinity, Fig. 8, obtained from the current meter mooring at 200 m over the shelf to the west of Hamilton Bank. The excursions of temperature and salinity during the winter to summer period lie approximatelyalong the t-s curve observed with the CTD. The structure of the water mass is clearly not changing nor is the t-s relationship but the position of the current meter relative to the water mass is oscillating with time. The mean water properties at the current meter are remaining virtually constant through the two seasons.

*Autumn and early winter*

In the autumn, cooling starts to increase the density and the depth of the surface mixed layers on both sides of the front. The isopycnals rising across the front start to encounter different conditions. The isopycnals that where imbedded in the pycnocline in summer begin, the least dense water first, to be part of the mixed layer. This drastically changes the potential vorticity distribution to the point where water can begin to move across the front in the surfaces of constant density. This is illustrated in Figs. 9a and 9b. Fig. 9a shows the approximate distribution of density in the autumn and shows the deepening mixed layers and the probable path of the water moving along isopycnals from the surface layer on the offshore side of the front to the deeper waters on the shelf side of the front. Fig. 9b shows the t-s relationships existing on each side of the front and in the centre of the front during the summer. As the surface layer deepens and water from offshore moves across the front to the shelf side, water characterized by higher temperatures and salinities appears over the shelf in intrusive layers. Examples of these intrusions are common in the vertical CTD profiles obtained in autumn as illustrated by the t-s curves obtained in October 1978 shown in Fig. 10. Compared to the uniform t-s curves of the earlier seasons, shown in Figs. 4 and 6, these autumnal profiles are characterized by alternate layers of relatively high and low temperature and salinity. The layered structure cannot be formed by vertical processes which would tend to homogenize the water, but must be created by water being exchanged across the front along density surfaces.

The effects of the cross shelf mixing are further illustrated in Figs. 8 and 11. Fig. 11 depicts the situation following that shown in Fig. 9a as the surface mixed layers continue to get denser as the winter progresses. The density of the offshore mixed layer increases, and its influence reaches to increasingly greater depths over the shelf. The current meter at 200 m is at first influenced by the intrusions occurring on isopycnals lying at depths shallower than 200 m. These early intrusions tend to decrease both the temperature and salinity at the current meter as is shown in the continuous plot of temperature vs. salinity in Fig. 8. As the density of the intrusions increase the density recorded at the current meter also increases, Fig. 8, with rises in both temperature and salinity.

The next step observed in mid-winter occurs when the mixed layer over the shelf increases in thickness to the depth of the current meter, Fig. 8, which quite suddenly records the lower temperatures and salinities of the mixed layer over the shelf. In Fig. 8, this stage occurs when the current meter is recording temperatures of -1.6 °C and salinities of 33.0.

The last phase in the annual variation is the re-establishment of the winter situation illustrated in Figs. 4 and 5 in which mixing along isopycnals occurs freely enough to keep gradients along the isopycnals small.

*References*

Lazier, J.R.N. 1982. Seasonal variability of temperature and salinity in the Labrador Current. J. of Marine Research, Vol. 40, Supplement.

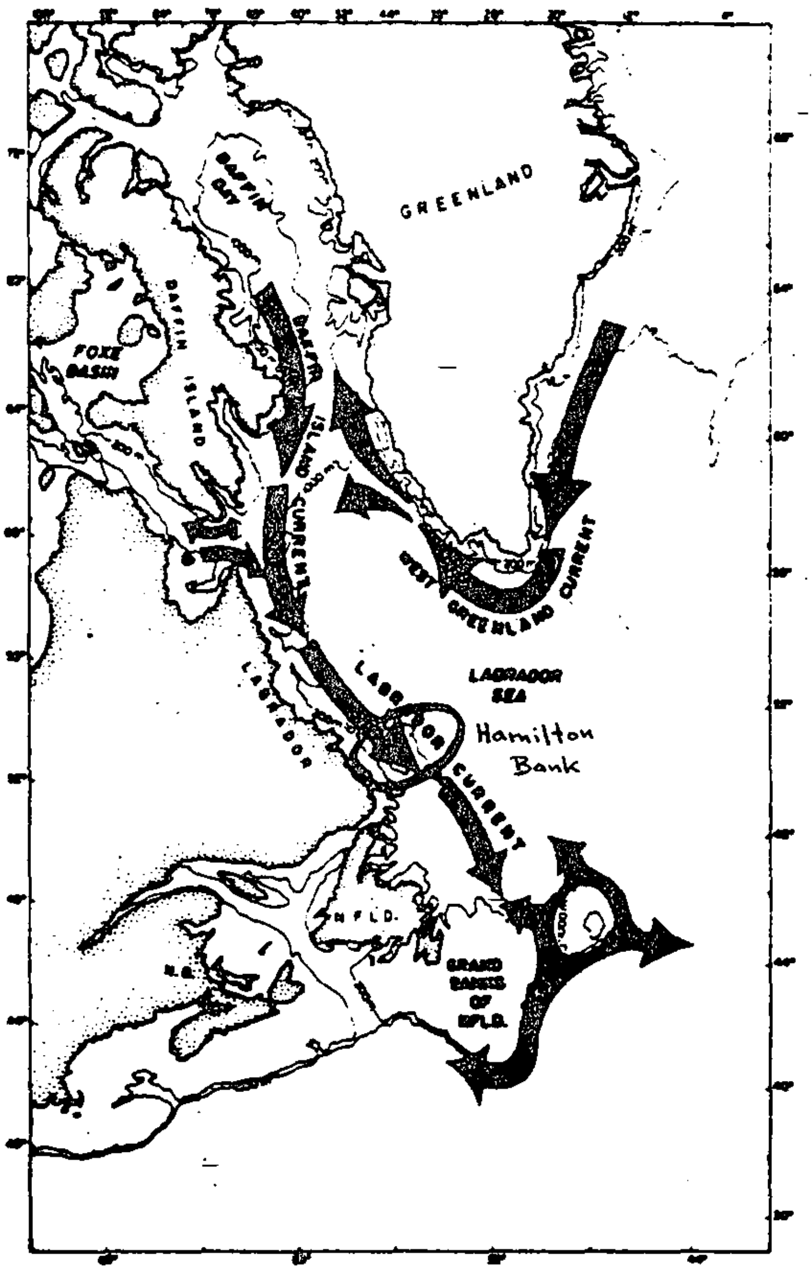



Figure 1 The Labrador and associated currents.

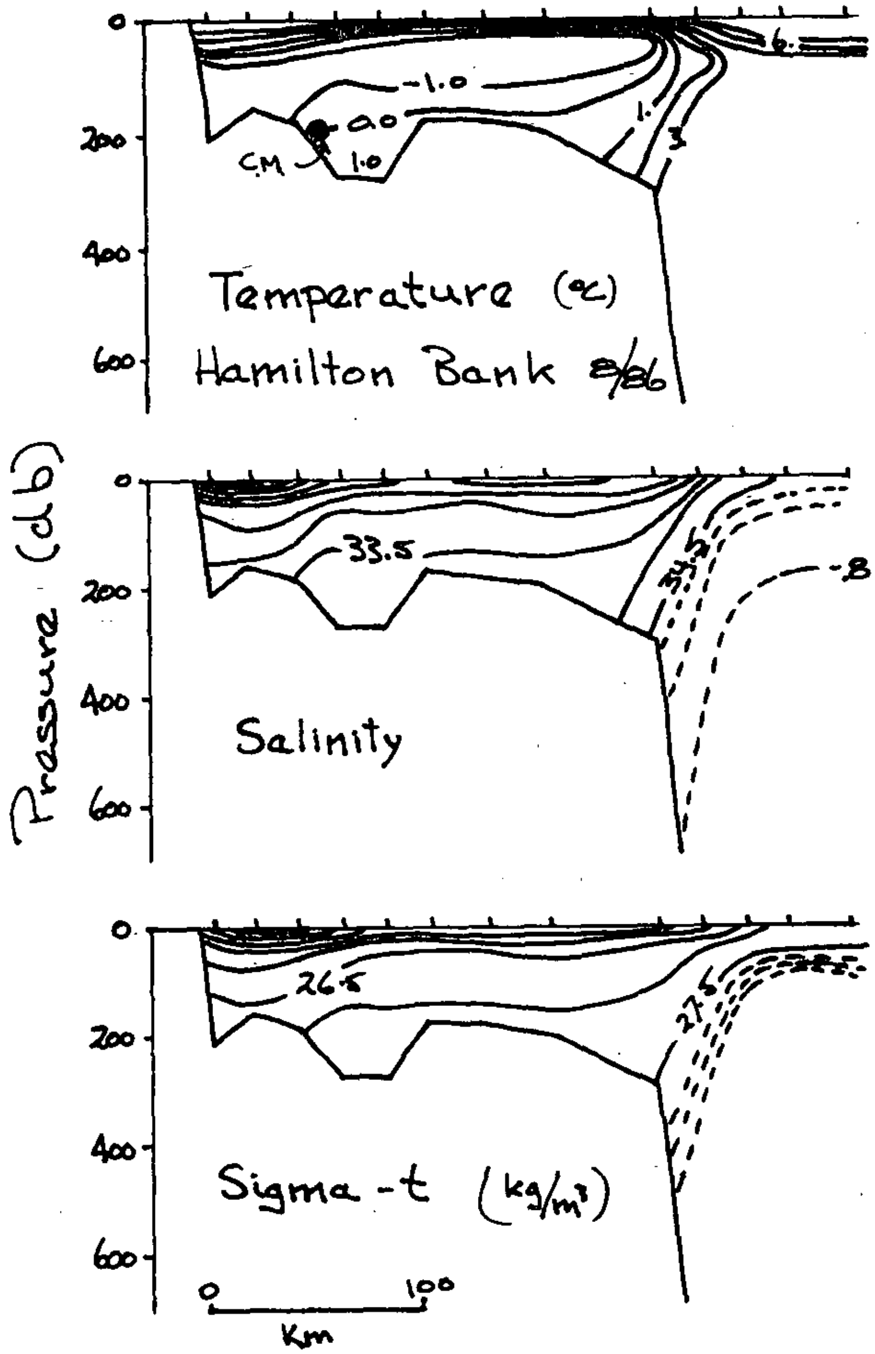



Figure 2 Sections of temperature, salinity and sigma-t constructed from CTD profiles obtained across Hamilton Bank in August 1986.

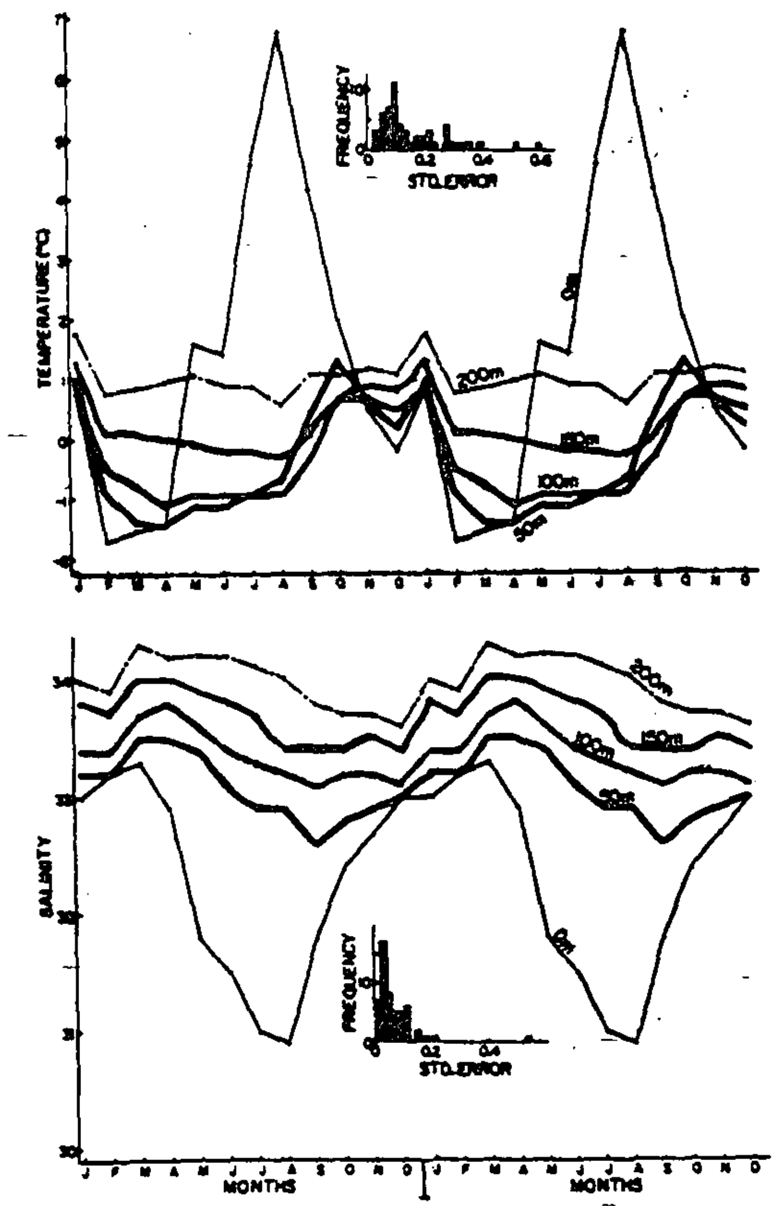



Figure 3 Monthly averages of temperature and salinity at five depths over the Labrador shelf calculated from archived data.

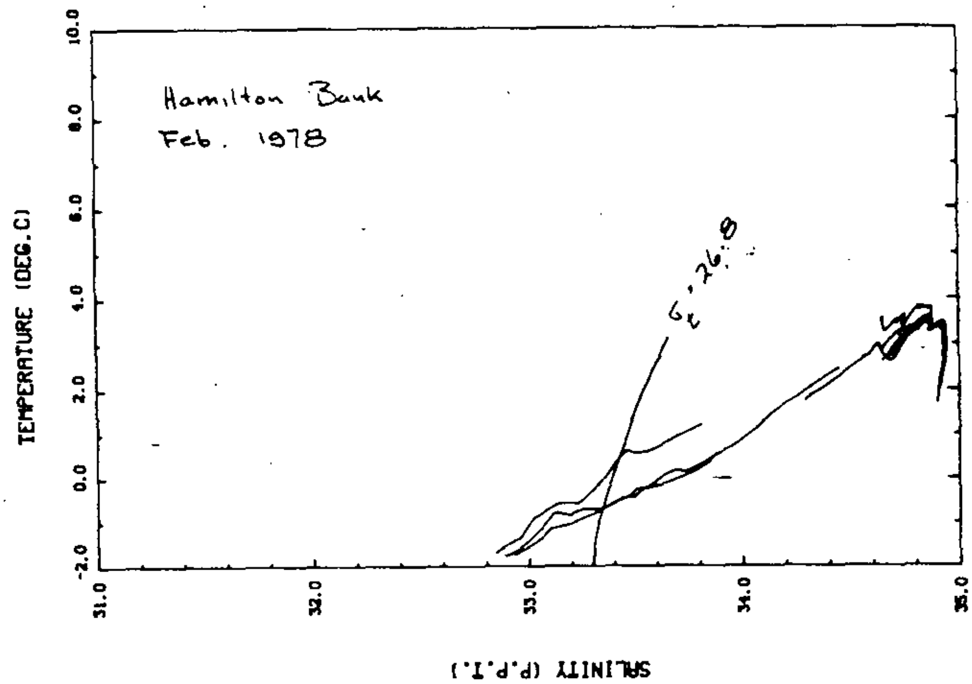



Figure 4 Temperature vs. salinity curves from 7 CTD stations obtained across the shelf and slope at Hamilton Bank in February 1978.

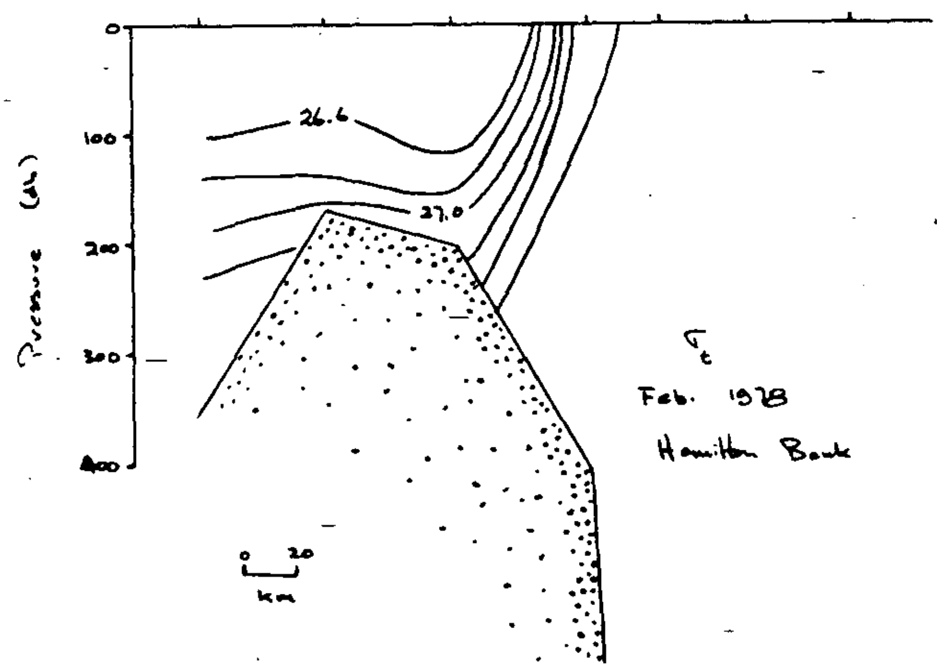



Figure 5 Section of sigma-t across Hamilton Bank based on CTD stations obtained in February 1978.

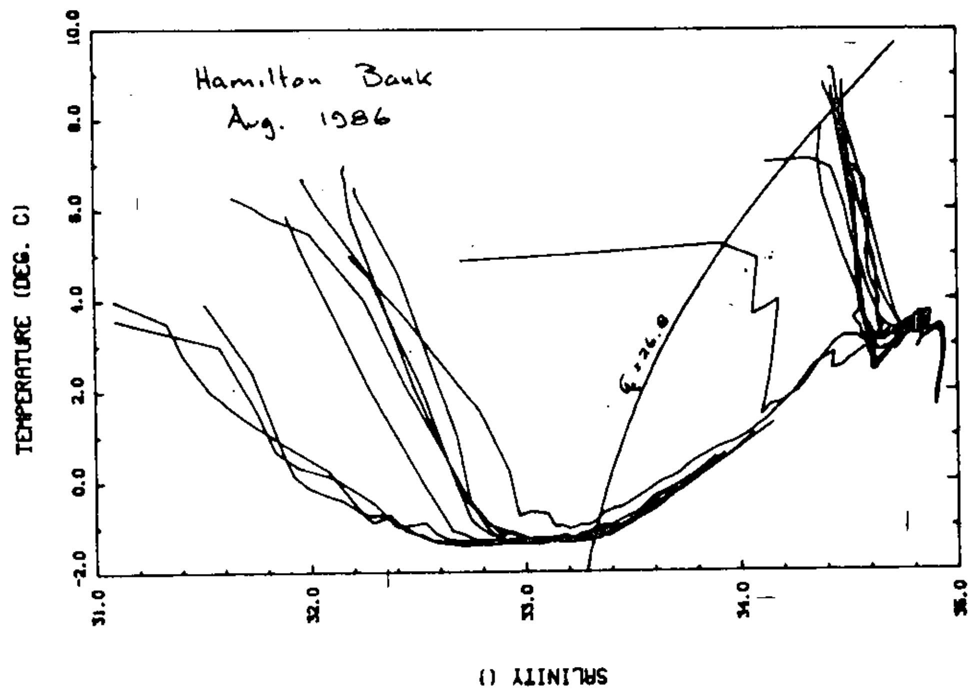



Figure 6 Temperature vs. salinity curves of nineteen CTD stations obtained across the shelf and slope at Hamilton Bank in August 1986.

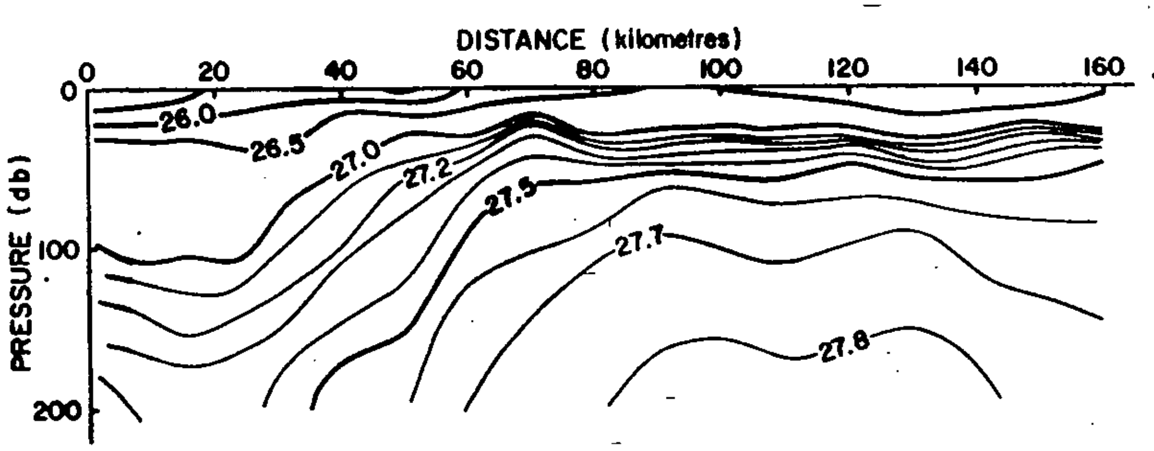



Figure 7 A section of sigma-t across the front associated with the main branch of the Labrador Current obtained with Batfish in August 1986, south of Hamilton Bank.

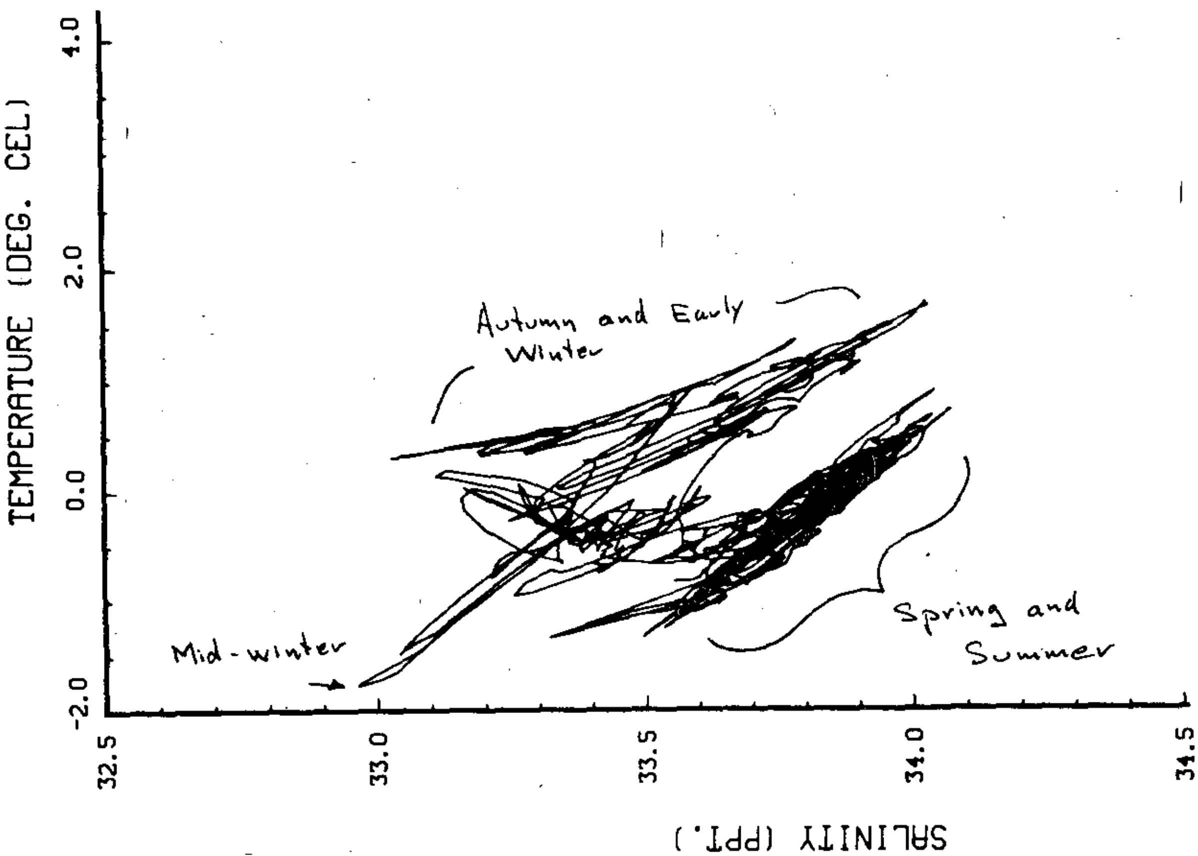
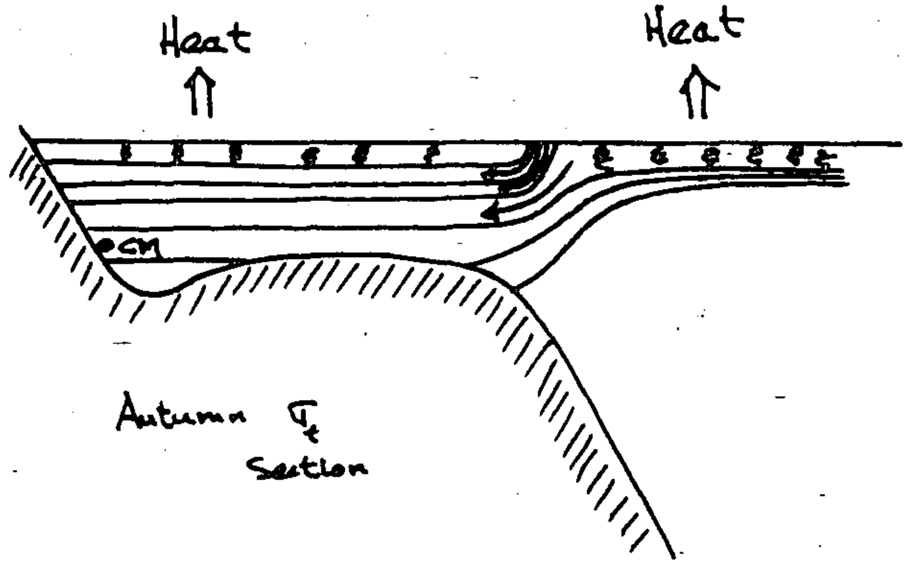



Figure 8 A plot of temperature vs. salinity obtained by the current meter moored at 200 m depth to the west of Hamilton Bank, between October 1978 and August 1979.



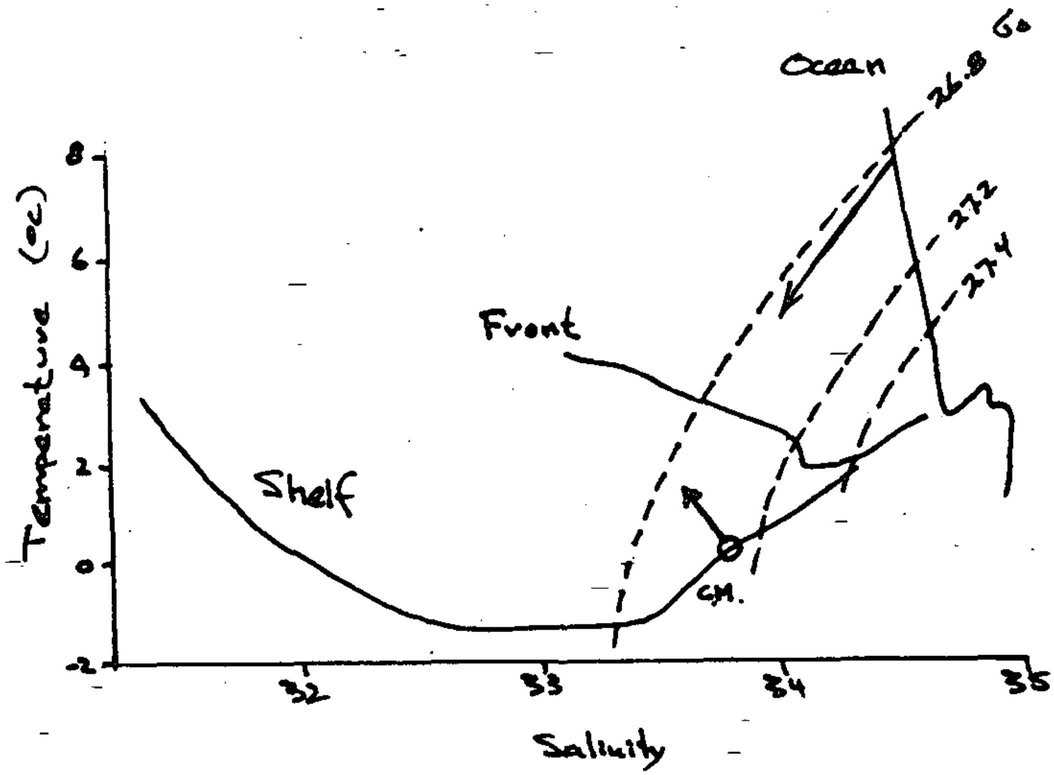




Figure 9a A schematic section of sigma-t across Hamilton Bank in the autumn, showing the deepening mixed layer and the probable path of the near surface water that intrudes across the front on isopycnal surfaces.

Figure 9b Temperature vs. salinity curves representing the conditions over the shelf, in the centre of the front, and in the deep sea to the east of the front. The proposed flow of water across the front along isopycnals is indicated, as is the location of the current meter and the change of properties observed at the current meter.

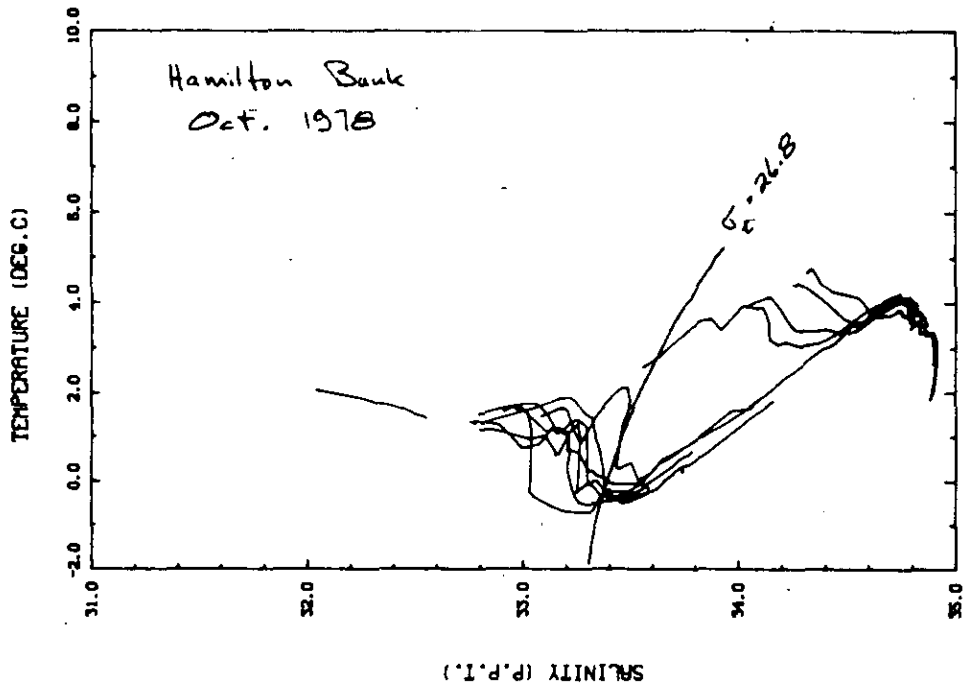



Figure 10 Temperature vs. salinity curves obtained across Hamilton Bank during October 1978 showing the effect on the t-s profiles over the shelf of the intrusions of near surface water crossing the front.

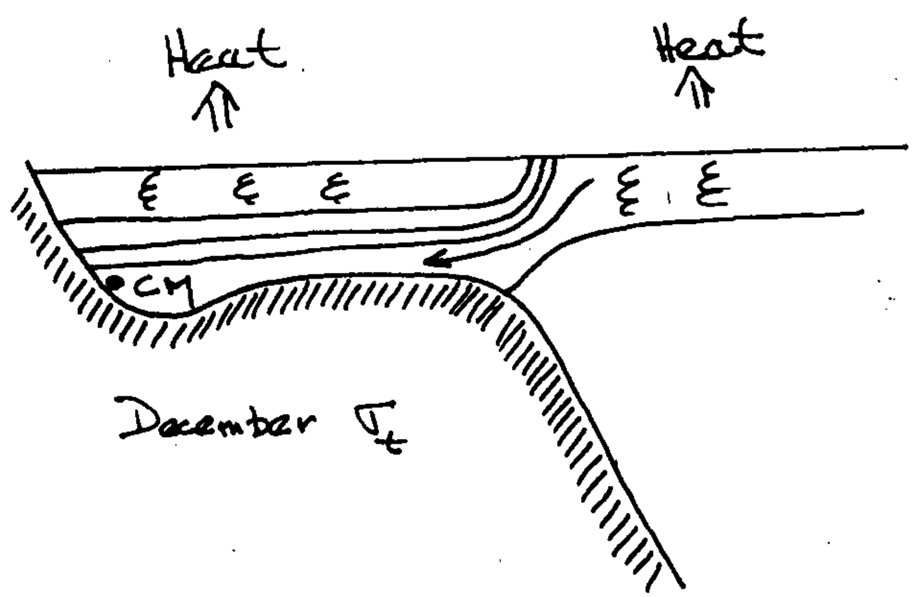



Figure 11 A schematic section of sigma-t representing the situation in December when the density of the offshore intrusions has increased to the mean value observed at 200 m over the shelf.