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Temperature and Salinity Variability at Decadal Time Scales on the Scotian Shelf and in the Gulf of Maine: Some Initial Results

by

B. Petrie, K. F. Drinkwater and R. Pettipas

Department of Fisheries and Oceans, Physical and Chemical Sciences Branch
Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2

INTRODUCTION

The temperature and salinity characteristics of the waters on the continental shelves vary over a wide range of time and space scales. Of particular importance are interannual fluctuations which may affect fish distributions during annual stock-assessment surveys and longer-term changes which possibly affect recruitment and stock abundance. Renewed interest in such variability has been stimulated by both predictions of possible CO_2-induced climate change (Frank et al. 1990) and the recent decline in some of the important groundfish stocks.

In the report of the Scotia-Fundy Groundfish Task Force (Haché 1989), it was stated that large scale environmental factors are believed to be at least partially responsible for long-term fluctuations in groundfish abundance. They also noted a lack of any systematic long-term environmental monitoring program in the Scotian Shelf and Gulf of Maine and suggested that an investigation of current environmental data collection processes be undertaken to identify how best to provide a more comprehensive ocean monitoring program. In response to these recommendations, and with support from the Atlantic Fisheries Adjustment Program (AFAP), a working group was established at the Bedford Institute of Oceanography. This group has begun a study of the historical temperature and salinity data from the region with the following objectives: (1) to identify the dominant temporal and spatial scales of variability, (2) to establish time series of climatic indices, (3) to compare these indices with those from other regions in order to place Scotia-Fundy in the broader context of climate change in the Northwest Atlantic, (4) to identify the primary forcing functions controlling climate change in the region, (5) to initiate a monitoring program for climatic variability of temperature and salinity at some key locations on the Scotian Shelf and in the Gulf of Maine, and (6) to help fisheries managers, where feasible, to incorporate information on ocean climate variability into the estimates of fish abundance.

Previous studies of ocean climate in waters off Canada's east coast have largely focused upon sea surface temperature (SST) variability. The region from the mid-Atlantic Bight to the Grand Banks exhibits the highest interannual variability of SST anywhere in the North Atlantic Ocean (Weare 1977). Although the dominant mode of variability consists of uniform SST trends over the region (Hachey and MacLellan 1948, Lauzier 1965), there is a second mode having opposite changes of SST between the mid-Atlantic Bight and the Grand Banks with a nodal line across the middle of the Scotian Shelf (Trites et al. 1985, Thompson et al. 1988). The interannual SST variability has been attributed largely to changes in atmospheric circulation patterns (Bjerknes 1959, Rodewald 1963), in particular to the wind direction during the winter (Bunker 1980, Thompson et al. 1988). An offshore wind carries cold, dry air promoting heat loss from the ocean through latent and sensible heat fluxes. An onshore wind on the other hand carries warm, moist air which tends to inhibit oceanic heat loss.

Fewer studies have examined subsurface temperature changes. Lauzier (1965) noted that bottom temperature trends during the 1950s and early 1960s in the Bay of Fundy and at several locations on the Scotian Shelf paralleled those observed near surface. Colton (1968) found similar results for the deep waters (200 m) in the Gulf of Maine and attributed them to variations in the composition and volume influx of offshore Slope Water. Changes in the temperature of the deep water (>200 m) in the Laurentian Channel in the Gulf of St. Lawrence have been examined by Lauzier and Trites (1958) and Bugden (1991). Again similarity with sea-surface temperature trends was noted. The temperature fluctuations of these deep waters were attributed to temperature changes in the water at the mouth of the Channel and can be monitored by the position of the boundary between the shelf and Slope Waters (Bugden 1991).

As part of the AFAP climate program we have begun to determine more quantitatively the relationship between surface and subsurface changes and the spatial coherence of the subsurface variability. This paper presents some initial results of this study. In particular we have investigated the long-tern temperature trends throughout the water column in Emerald Basin (Fig. 1) on the Scotian Shelf from existing hydrographic data. These are compared to subsurface temperature trends at other shallower sites closer inshore as well as with surface temperatures at coastal sites for the Scotian Shelf and the Gulf of Maine and published subsurface temperatures in the deep waters of the Gulf of St. Lawrence. Long-term salinity data from a station near the mouth of the Bay of Fundy are also presented.

DATA AND METHODS

(1) Emerald Basin Temperature Data

Monthly means, maxima, minima, standard deviations and number of observations were obtained for a polygon which encloses Emerald Basin, a deep (291 m) geographic feature of the inner half of the Scotian Shelf (Fig. 1). These summary statistics covered the period 1946-88 and were based on the observed data interpolated to standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 225 and 250 m). The overall monthly averages and standard deviations were constructed from the individual monthly means in order to generate the annual cycle of temperature. These monthly averages were subtracted from the individual means to create a time series of temperature anomalies. Correlations of the temperature anomalies were calculated as a function of vertical separation in order to determine the vertical scales associated with the variability. In addition, autocorrelation functions were computed to give some indication of the frequency distribution of energy.

(2) Sambro Lightship Temperature Data

Monthly mean temperatures from near bottom (85 m) at the Sambro Lightship Vessel site (Fig. 1) were obtained from Lauzier and Hull (1969). These data were determined from twice daily bathythermograph casts and cover the period 1950-66. The Sambro Lightship was removed from service in October 1966.

(3) Lurcher Lightship Temperature Data

Lauzier and Hull (1969) also published monthly mean near-bottom temperatures (95 m) collected from the Lurcher Lightship Vessel. Data are available from August 1950 to October 1969 when the ship was decommissioned. The measurements were taken once per day using reversing thermometers.

(4) Prince 5 Temperature and Salinity Data

Monitoring of temperature and salinity at a station known as Prince 5 near the mouth of the Bay of Fundy have been conducted by the St. Andrews Biological Station since the 1920s. Data were collected once per month at 3 to 6 standard depths using reversing thermometers and water bottles. In the last couple of months of 1990 these have been replaced by a conductivity, temperature, depth profiler (CTD). Salinities were initially determined by titration and in more recent years with a salinometer. We obtained data from the early 1930s onwards from the combined archives of the Marine Environmental Data Centre in Ottawa and the St. Andrews Biological Station.

(5) Coastal SST Data

Sea surface temperature (SST) data are collected daily in Halifax Harbour, N.S., at St. Andrews, N.B., and at Boothbay Harbor, Maine (Fig. 1). These time series began in 1905 at Boothbay Harbor, in 1921 at St. Andrews, and in 1926 in Halifax. The monthly mean data were obtained up to 1969 from Lauzier and Hull (1969) and more recent data have been obtained from the Halifax Fisheries Laboratory in Halifax, the St. Andrews Biological Station, and the Marine Science Laboratory, in Boothbay Harbor.

Monthly averages for the period 1951-80 were calculated for Prince 5 and the SST stations. These averages were then subtracted from the original time series to produce monthly anomalies. For Sambro and Lurcher the anomalies were determined relative to 1950-66 and 1950-69, respectively, i.e. the full data set.

RESULTS

Emerald Basin

(1) Vertical structure of the annual cycle

The annual cycle of temperature shows a strong variation with depth (Fig. 2), having a range of about 15°C at the surface, falling to 10°C at 30 m, then rapidly decreasing to about 3.5°C and 0.9°C at 50 and 75 m respectively. For depths $\geq$ 100 m, a seasonal cycle is not evident.

(2) Time series of the temperature anomalies

A plot of the temperature anomalies (Fig. 3) for 0, 50, 100 and 250 m shows long period variability. We shall focus on the 100 m data where there is no seasonal cycle and where the annual mean temperature is 6.7°C. The late 1940s and early 1950s values are quite erratic but a temperature maximum of about 1°C above the mean was reached in 1952-53. A long period of temperature decline followed with values reaching a minimum of about 3°C below normal in the mid to late 1960s. A rapid temperature rise occurred over the next 2 years, followed by a slower increase to maximum values of 2°C above normal in the late 1970s. The slow decline into the 1980s have brought temperatures to near average values.

The same pattern is seen in the observations from the surface to the bottom, this in spite of the fact that the shallow waters are coastal in origin while the deeper waters originate offshore of the shelf break. At the surface, though, the pattern is less distinct, in part, because it is more affected by the rapidly varying patterns in the weather. On the other hand, at 250 m in the deepest part of the Basin, the pattern is easily seen since much of the high frequency variability associated with the atmosphere is filtered out.

The differences in the oceanic climate are illustrated (Fig. 4) by the comparison of hydrographic sections across the Scotian Shelf from the cold period (1966) and the warm period (1974). The most striking differences occur in the deep waters of Emerald Basin, where temperatures were 3-4.5°C in 1966 and 8-10°C in 1974, and over the Slope, where temperatures ranged from 5-8°C during the earlier section to 8-10°C during the later one. The changes are also reflected in the salinities where in 1966 they were about 1 psu (practical salinity unit) lower than in 1974. These sections indicate that the long period anomalies may be oceanic in origin.

Similar long term variability has been found in deep waters (200-300 m) of the Gulf of St. Lawrence (Bugden 1991). A temperature minimum of about 4.5°C (S = 34.4), similar to that found in Emerald Basin, occurred at the mouth of the Gulf in about 1966. The minimum occurred progressively later farther into the Gulf, again pointing to an oceanic origin of the anomalies. Over the next decade, the deep temperatures (salinities) in the Gulf rose by 1.5°C (0.3 psu).

(3) Frequency distribution of the variability

An irregularly spaced time series does not easily lend itself to spectral analysis which would define the frequency distribution of energy. It is evident (Fig. 3), however, that the higher frequency variability plays a greater role at the surface than at depth, where longer period changes increasingly dominate.

This distribution of energy can also be seen in the autocorrelation functions (Fig. 5). The rapid decrease of the function to values oscillating about zero (0 m) reflects the significance of the high frequency variability relative to low. However, with increasing depth, it is apparent that the influence of long period energy grows (50 m) and finally dominates (100 and 250 m).

(4) Vertical correlations

The vertical variations of the correlations between the anomaly time series relative to 0 and 250 m are shown in Fig. 6. The correlations referenced to the surface decrease more rapidly than do those referenced to the bottom. The e-folding scale of the former is about 55 m, whereas, it is approximately 200 m for the latter. This again illustrates the greater influence of high frequency variability at shallower depths.

Other Stations

(1) Time series of the temperature anomalies

The temperature anomalies for Sambro, Lurcher, Prince 5 (surface and 95 m) and the coastal sites at Halifax, St. Andrews and Boothbay Harbor are shown in Fig. 7 through 13. In each record the long period variability shows similar trends to those observed in Emerald Basin (Fig. 3). This includes warm temperatures during the 1950s, a decline through the 1960s, followed by a rise in the 1970s and a slight decrease or leveling off of temperatures during the 1980s. The amplitude of the decrease from the 1950s to the mid 1960s was typically 1-2°C at all sites. The anomalies at the surface and 90 m at Prince 5 are highly correlated, a result of the energetic tidal mixing in the Bay of Fundy. Similar results were found at Lurcher where tidal mixing is also important and the water column is relatively well-mixed (Garrett et al. 1978).

(2) Frequency distribution of SST variability

Power spectra were calculated for the average monthly temperature data from Halifax, St. Andrews and Boothbay Harbor. The root mean square amplitude of the temperature variability for periods of 3-21 y (Fig. 14) is nearly constant, ranging from about 0.23-0.36 °C. The annual cycle dominates the amplitude spectrum with values of 4.4, 5.0 and 5.3 °C for St. Andrews, Halifax and Boothbay Harbour, respectively.

(3) Time series of salinity anomalies at Prince 5

The salinity anomalies at Prince 5 at the surface and 90 m relative to the monthly averages for 1951-80 are shown in Fig. 15 and 16. In contrast to temperature, the salinity shows no long term trend over the entire length of the record. The strong negative salinity anomalies observed in the surface generally occurred during the spring and correspond in time to expected arrival of the effects of the peak freshwater discharge from the Saint John River in New Brunswick.

DISCUSSION AND CONCLUSIONS

A large component of the subsurface ($z \geq 50$ m) temperature variability in Emerald Basin occurs at very long periods (to 20 y) and has vertical scales comparable to the Basin depth. This indicates that the aliasing due to irregular sampling is not as important as previously thought (Mann and Needler 1967). Opportunistic sampling should provide adequate resolution of the low frequency temperature signal in the deep waters. This temperature variability observed in the deep waters extends to the surface but increasing high frequency energy and smaller vertical scales put different requirements on a sampling scheme to measure surface variability.

The temperature fields in Emerald Basin vary at long time periods in a like manner to those in the deep (200-300 m) Gulf of St. Lawrence, near bottom off Sambro (85 m), on the Lurcher Shoals (95 m) and at the mouth of the Bay of Fundy (90 m). Similar long-period variability are evident in the coastal SST sites in Nova Scotia, New Brunswick and Maine. These results indicate a broad scale, coherent ocean climate fluctuation in spite of differences in water mass characteristics. Moreover, the variations appear to be stronger in those water masses originating over the Slope, perhaps pointing to a largely oceanic origin of the low frequency anomalies. However, the actual extent of these changes and their causes must be established more rigorously. Future studies will include a statistical comparison of the temperature records. We also hope to obtain more temperature and salinity data covering a larger geographic region including stations in the deep basins in the Gulf of Maine and more on the Scotian Shelf.

REFERENCES

Bjerknes, J. 1959. The recent warming of the North Atlantic. p. 65-73. *In* B. Bolin [ed.], The Atmosphere and the Sea in motion (Rossby Memorial Volume), Oxford University Press.

Bugden, G.L. 1991. Changes in the temperature-salinity characteristics of the deeper waters of the Gulf of St. Lawrence over the past several decades. p. 139-147. *In* J.-C. Therriault [ed.] The Gulf of St. Lawrence: small ocean or big estuary? Can. Spec. Publ. Fish. Aquat. Sci. 113.

Bunker, A.F. 1980. Trends of variables and energy fluxes over the Atlantic Ocean from 1948 to 1972. Mon. Wea. Rev. 108: 720-732.

Colton, J.B. Jr. 1968. Recent trends in subsurface temperature in the Gulf of Maine and contiguous waters. J. Fish. Res. Board Can. 26: 2427-2437.

Frank, K.T., R.I. Perry, and K.F. Drinkwater. 1990. Predicted response of Northwest Atlantic invertebrate and fish stocks to CO_2-induced climate change. Trans. Am. Fish. Soc. 119: 353-365.

Garrett, C.J.R., J.R. Keeley and D.A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmosphere-Ocean 16: 403-423.

Haché, J.-E. 1989. Report of the Scotia-Fundy groundfish task force. Dept. Fish. Oceans, 86 pp.

Hachey, H.B. and H.J. McLellan. 1948. Trends and cycles in surface temperatures of the Canadian Atlantic. J. Fish. Res. Board Can. 7: 355-362.

Lauzier, L.M. 1965. Long-term temperature variations in the Scotian Shelf area. Int. Comm. Northwest Atl. Fish. Spec. Publ. No. 6: 807-816.

Lauzier, L.M. and J.H. Hull. 1969. Coastal station data temperatures along the Canadian Atlantic coast 1921-1969. Fish. Res. Board Can. Tech. Rep. 150: 25 pp.

Lauzier, L.M. and R.W. Trites. 1958. The deep waters in the Laurentian Channel. J. Fish. Res. Board Can. 15: 1247-1257.

Mann, C.R. and G. T. Needler. . 1967. Effect of aliasing on studies of long-term oceanic variability off Canada's coasts. J. Fish. Res. Board Can. 24: 1827-1831.

Rodewald, M. 1963. Sea-surface temperatures of the North Atlantic Ocean during the decade 1951-1960, their anomaly and development in relation to the atmospheric circulation. p. 97-107. *In* WMO-UNESCO Rome Symposium, Changes in Climate, UNESCO, Paris.

Thompson, K.R., R.H. Loucks and R.W. Trites. 1988. Sea surface temperature variability in the shelf-slope region of the Northwest Atlantic. Atmosphere-Ocean 26: 282-299.

Trites, R.W., D.R. McLain and M.C. Ingham. 1985. Sea-surface temperature along the continental shelf from Cape Hatteras to Hamilton Bank. NAFO Sci. Council Studies 8: 21-23.

Weare, B.C. 1977. Empirical orthgonal function analysis of Atlantic Ocean surface temperatures. Q.J.R. Meterorl. Soc. 103: 467-478.

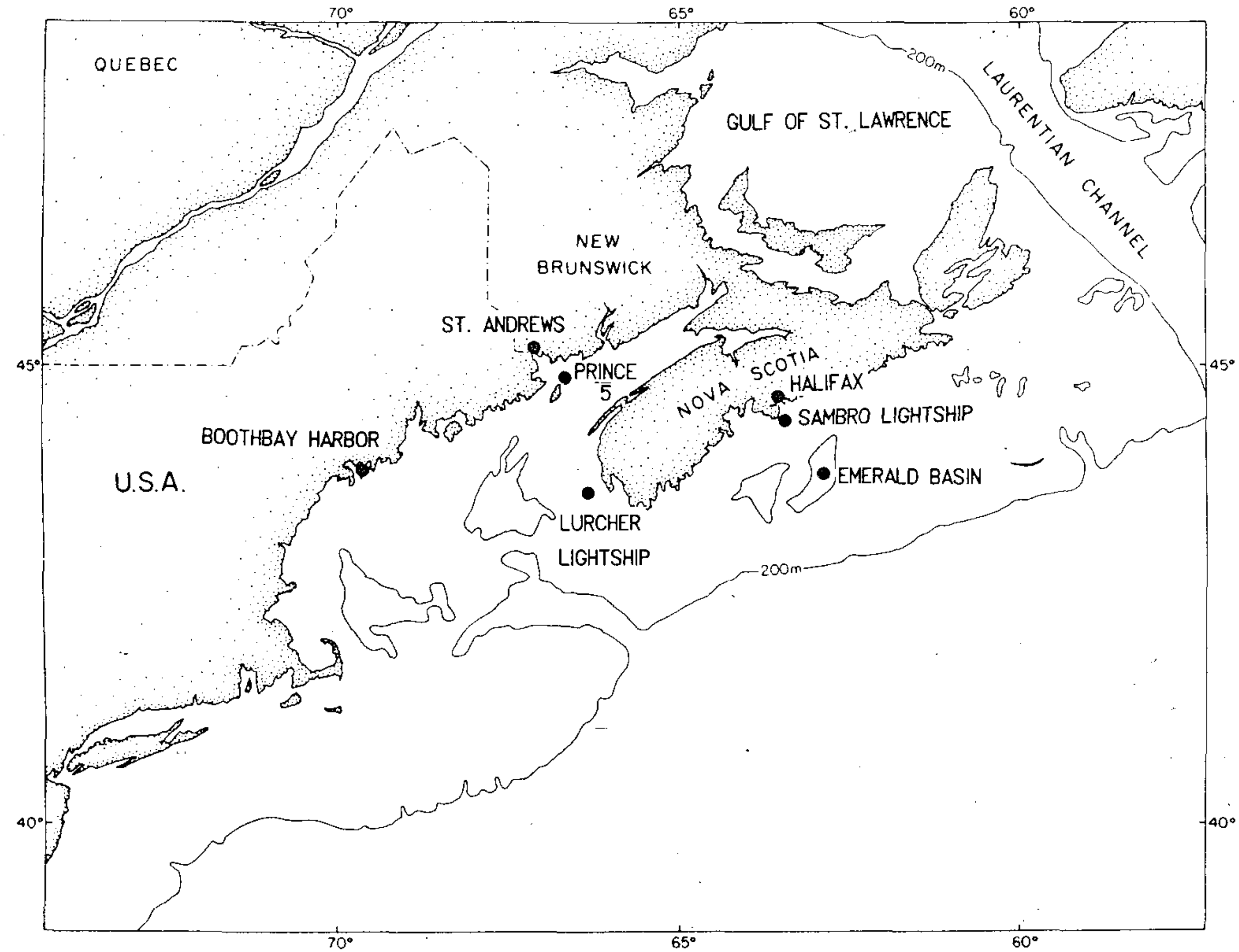

Fig. 1. Scotian Shelf and Gulf of Maine showing station locations.

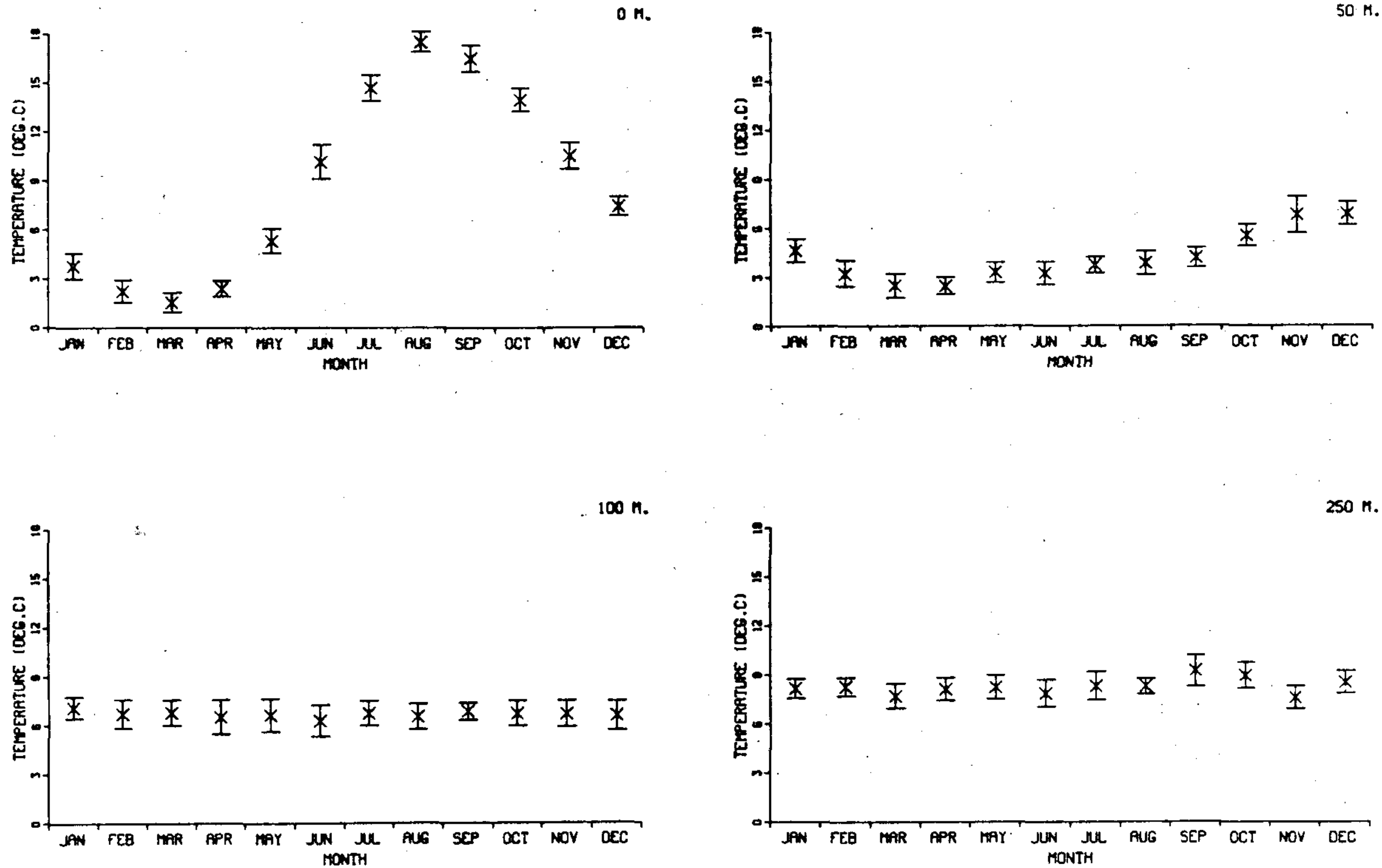

Fig. 2. Monthly average temperatures and standard deviations at 0, 50, 100 and 250 m in Emerald Basin.

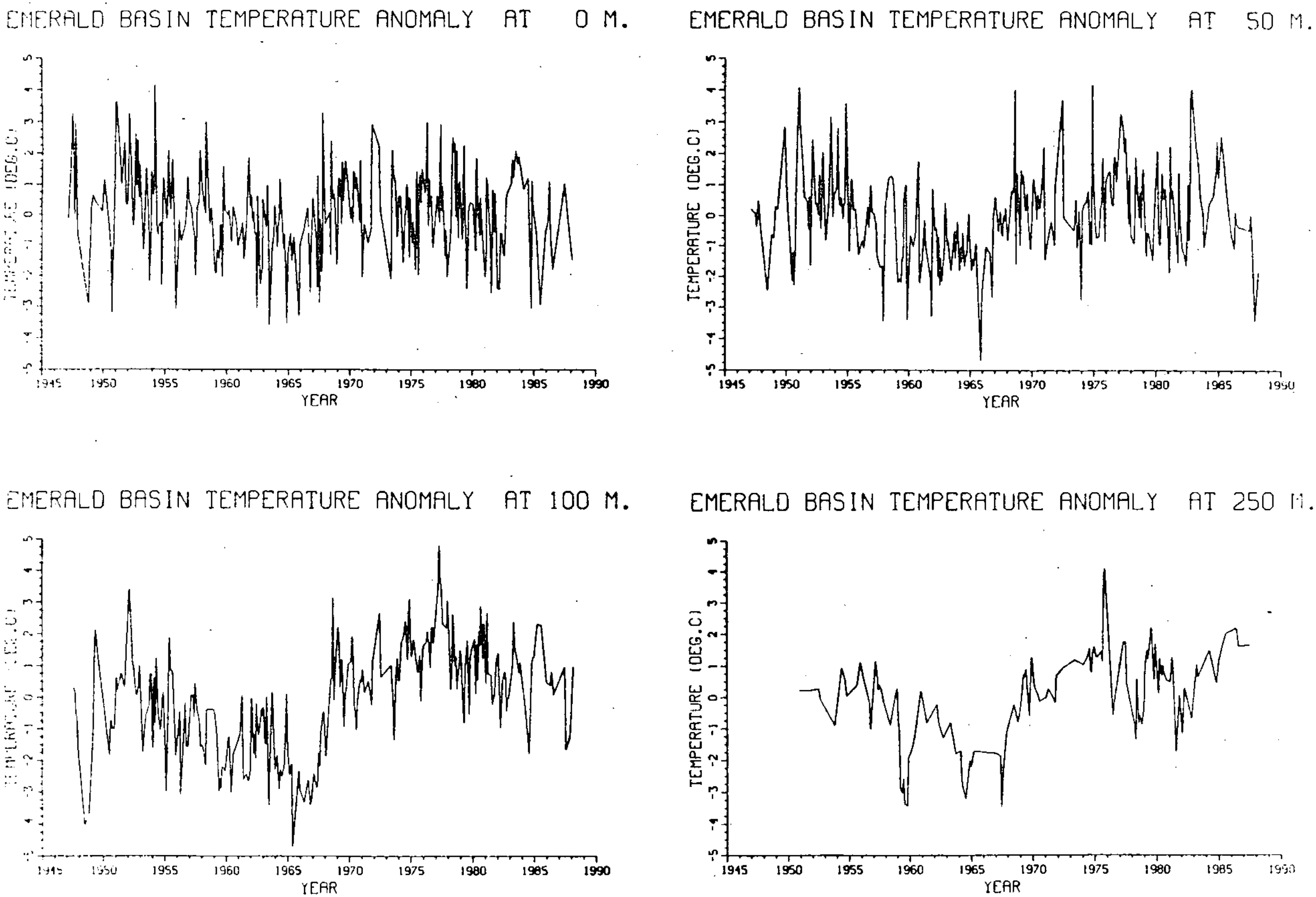

Fig. 3. Temperature anomalies for Emerald Basin at 0, 50, 100 and 250 m for the period 1946-88.

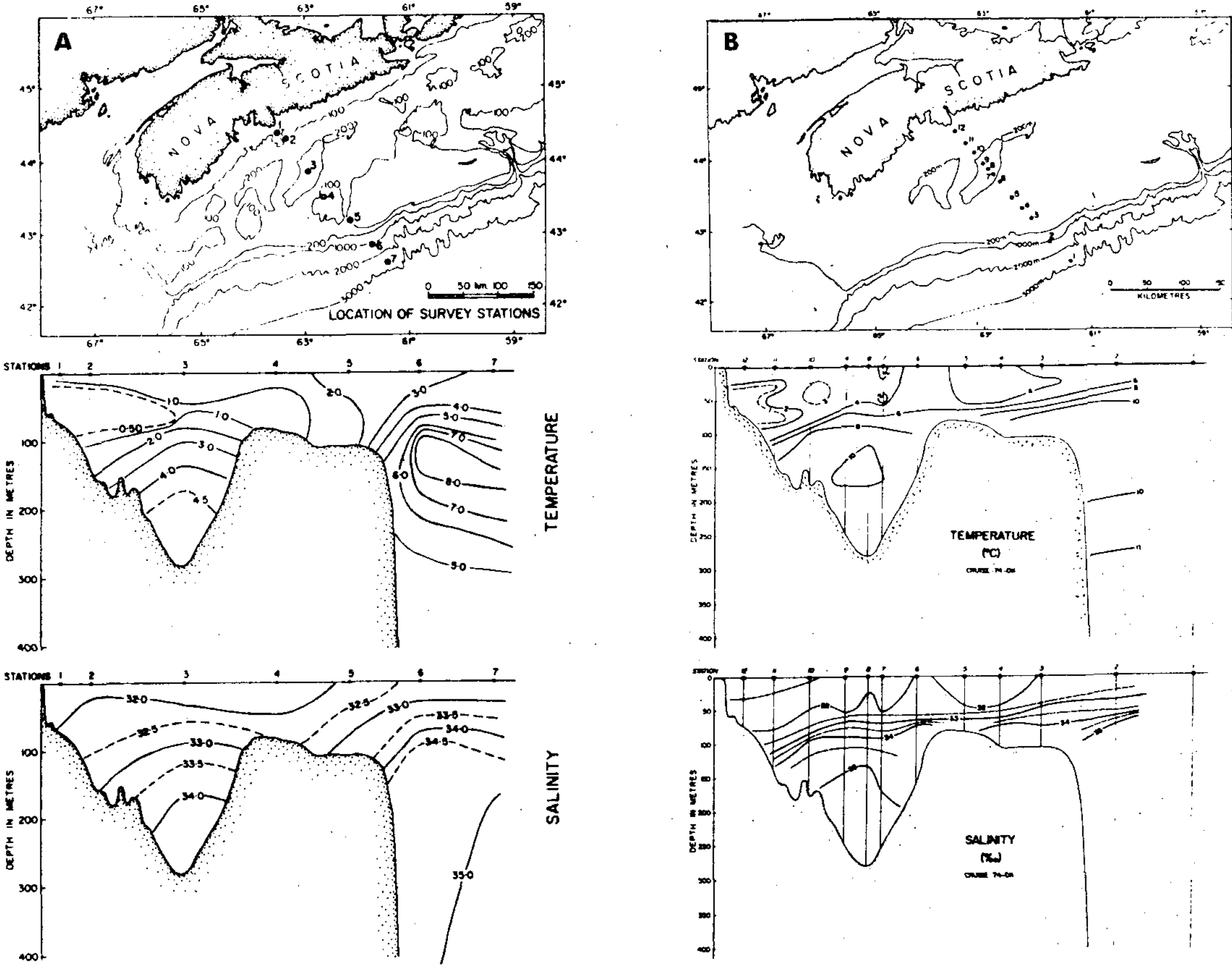

Fig. 4. Temperature, salinity and density from the Halifax Section A) 12-13 April, 1966; B) 30 April-3 May, 1974.

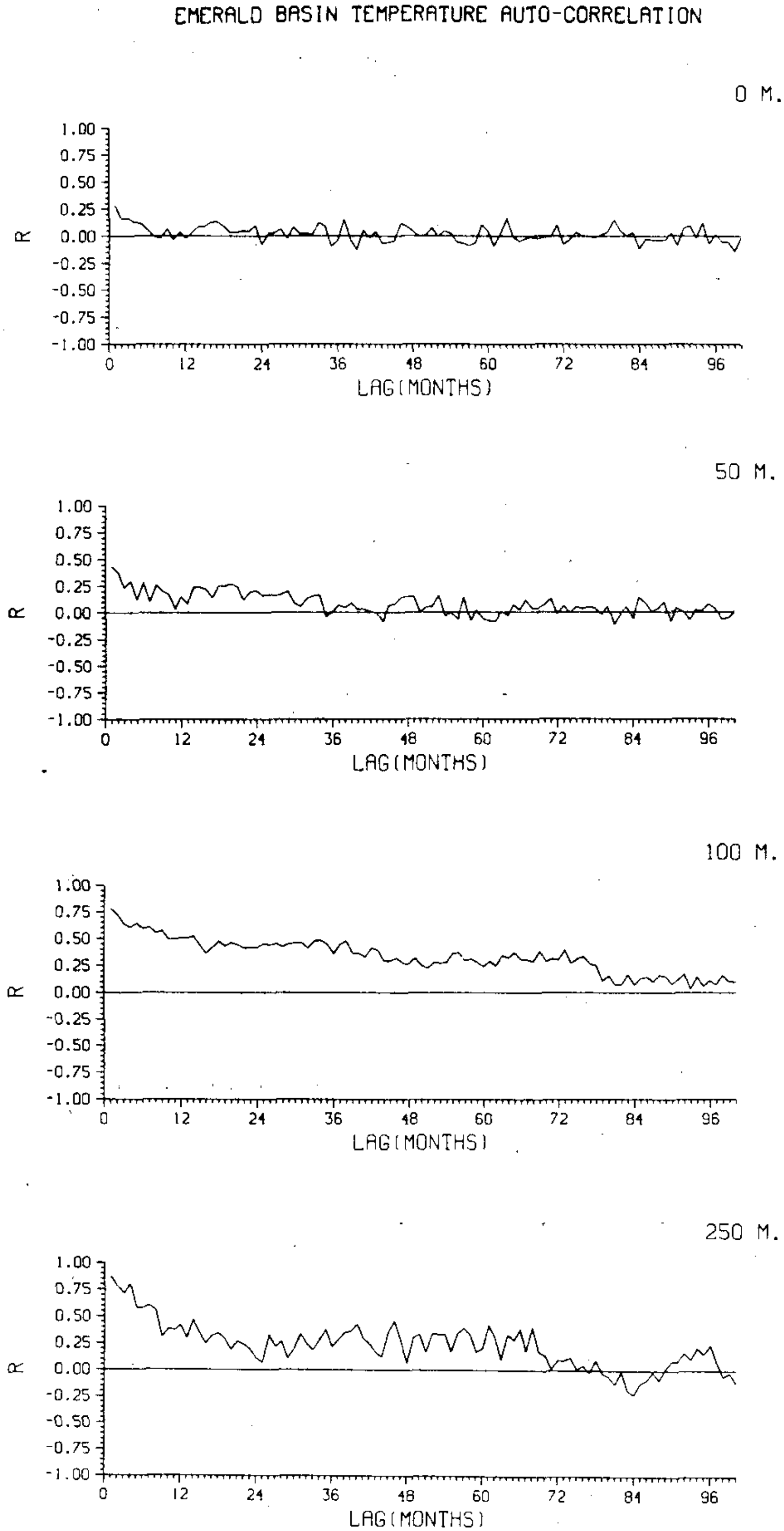

Fig. 5. Autocorrelation functions of temperature anomalies for 0, 50, 100 and 250 m in Emerald Basin.

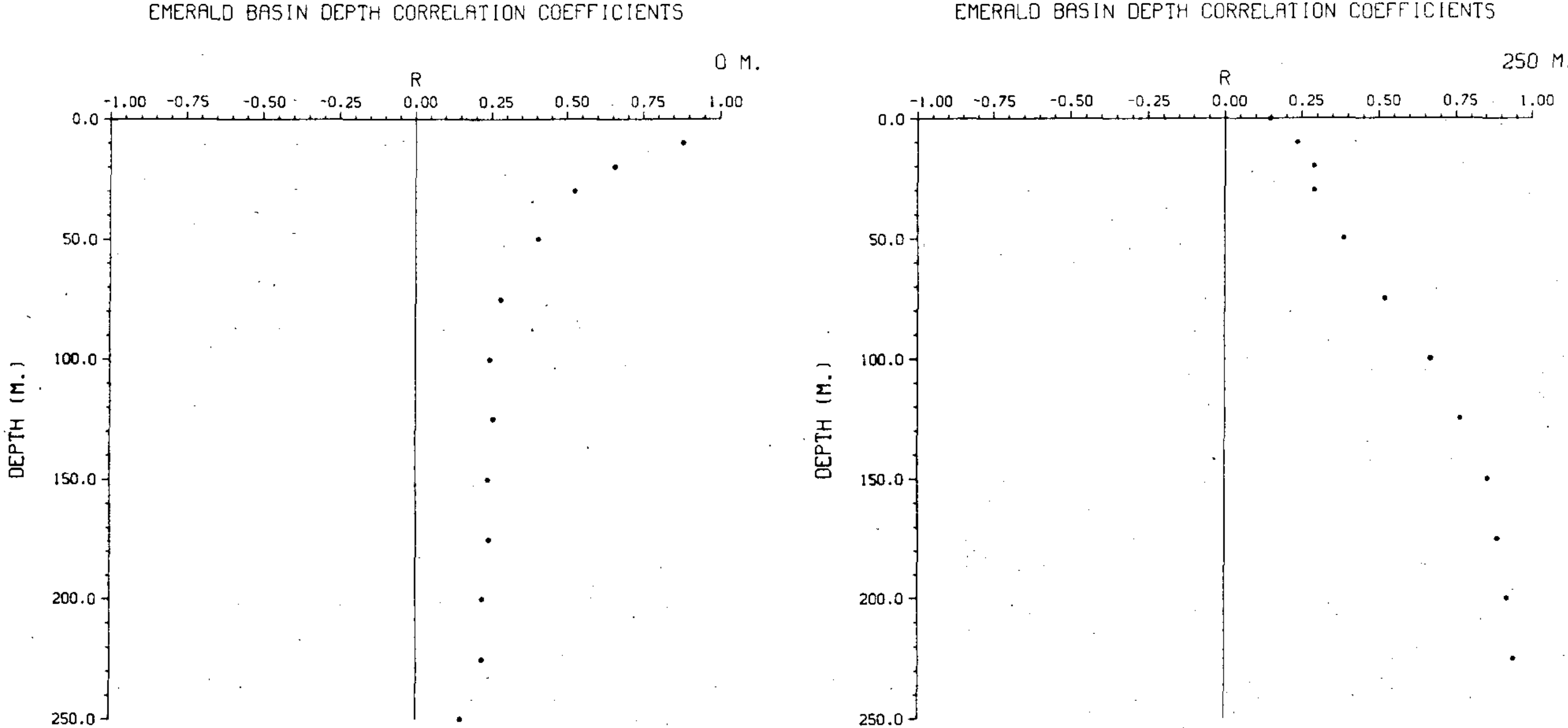

Fig. 6. *Correlations of temperature anomalies relative to* the 0 and 250 m time series for Emerald Basin.

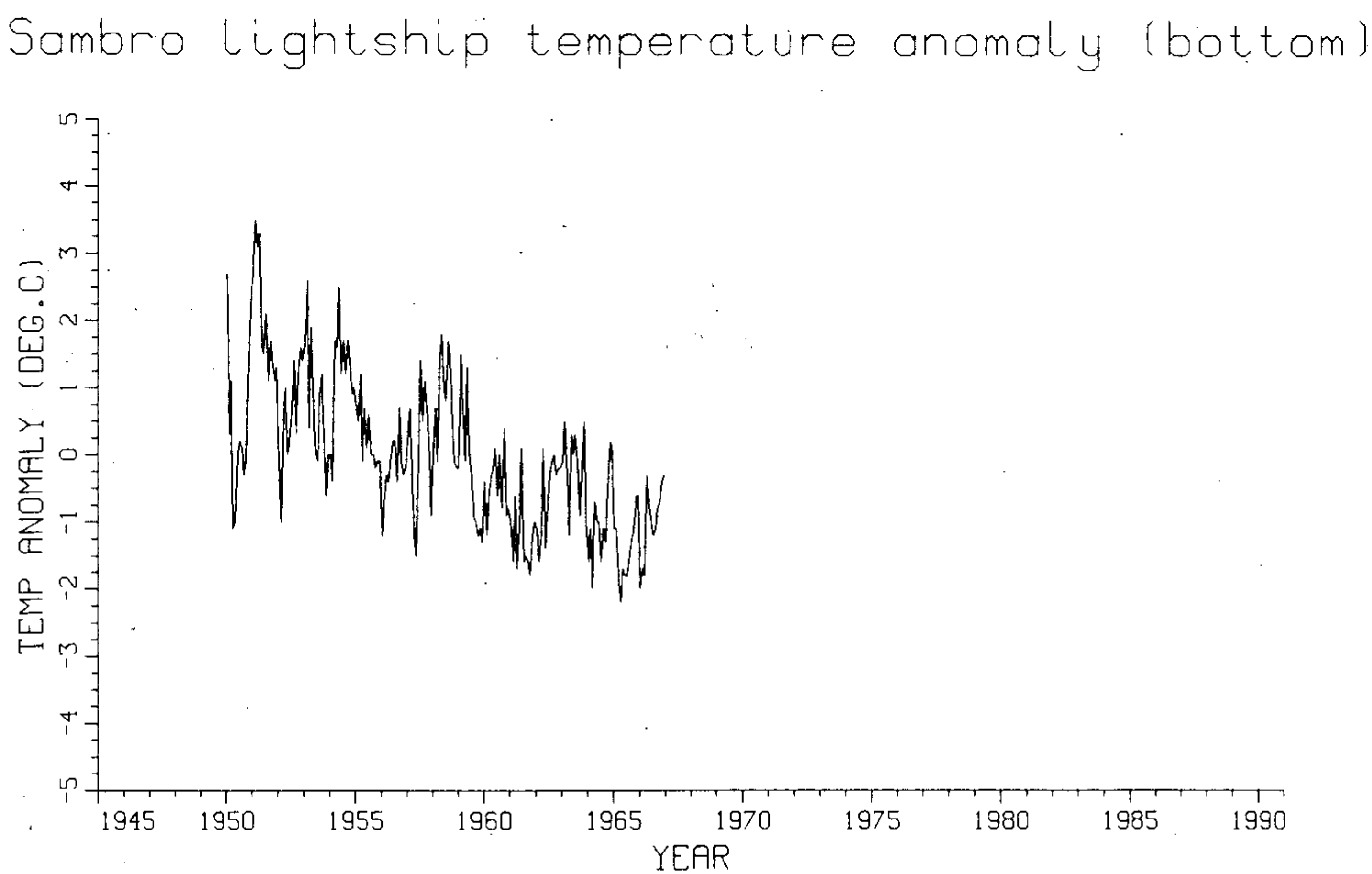

Fig. 7. Temperature anomalies in the near-bottom (85 m) waters from measurements taken aboard the Sambro Lightship Vessel relative to long term average (1950-66).

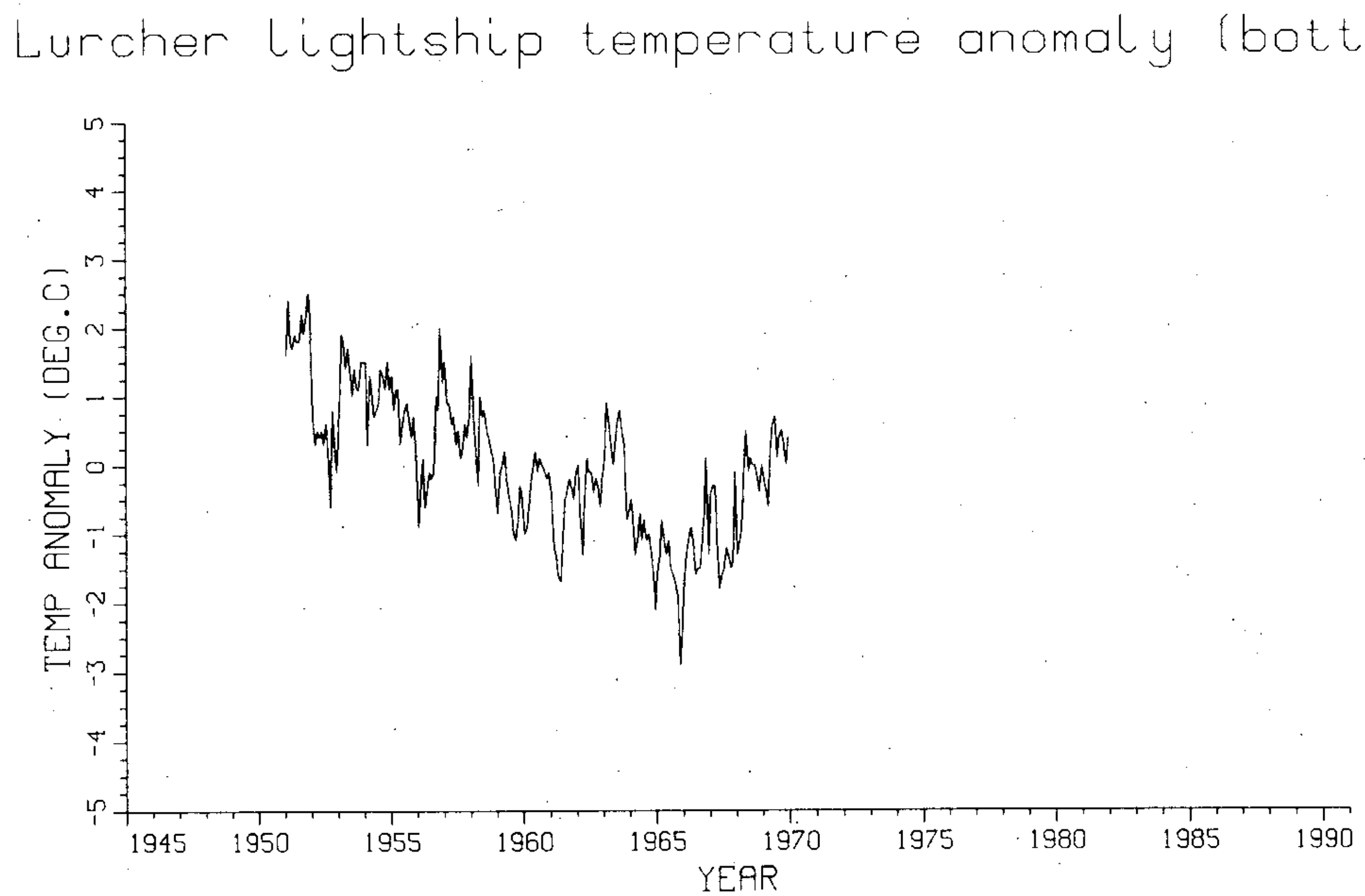

Fig. 8. Temperature anomalies in the near-bottom (95 m) waters from measurements taken aboard the Lurcher Lightship Vessel relative to long term average (1950-69).

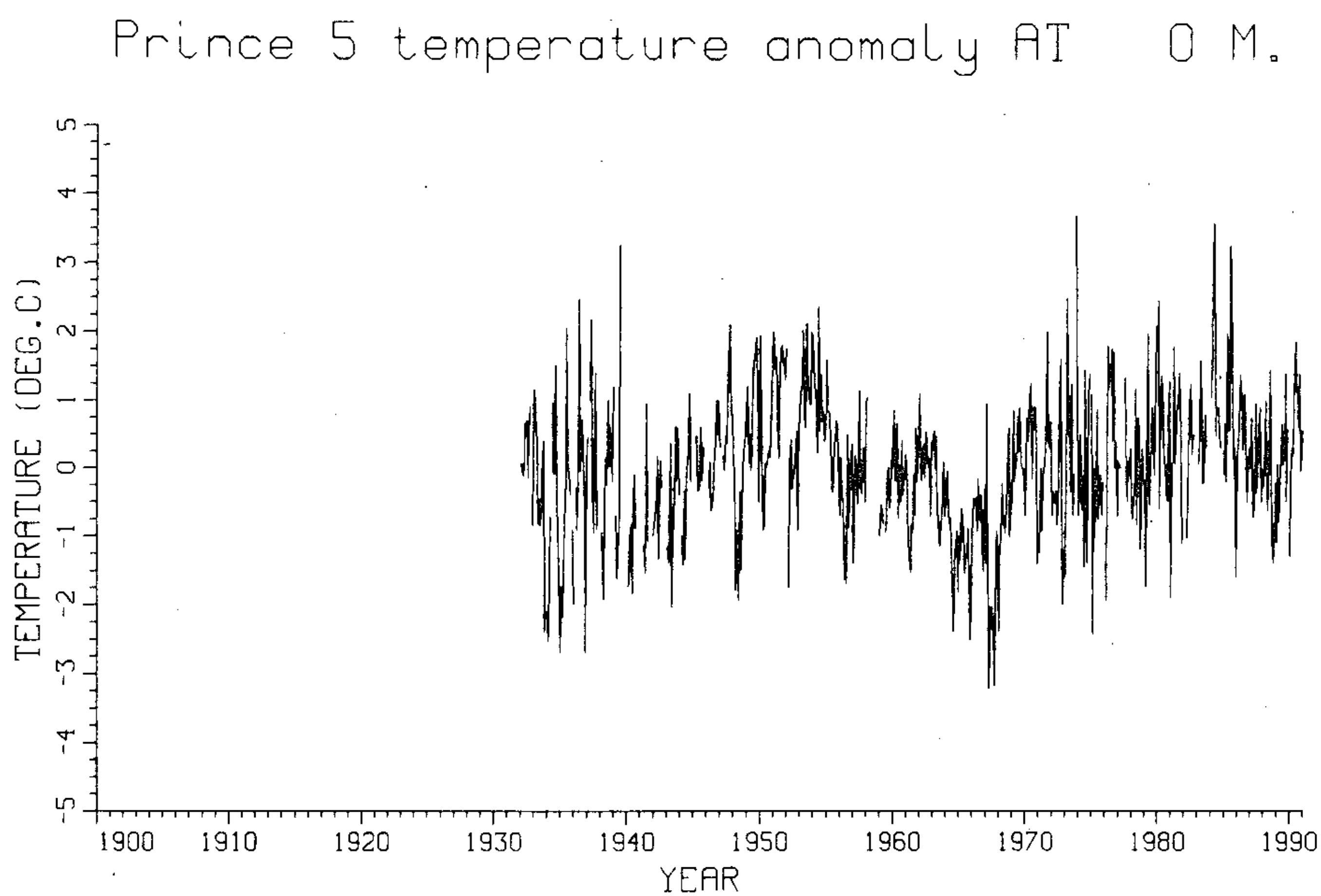

Fig. 9. Temperature anomalies in the surface waters at the Prince 5 Station at the mouth of the Bay of Fundy relative to long term average (1951-80).

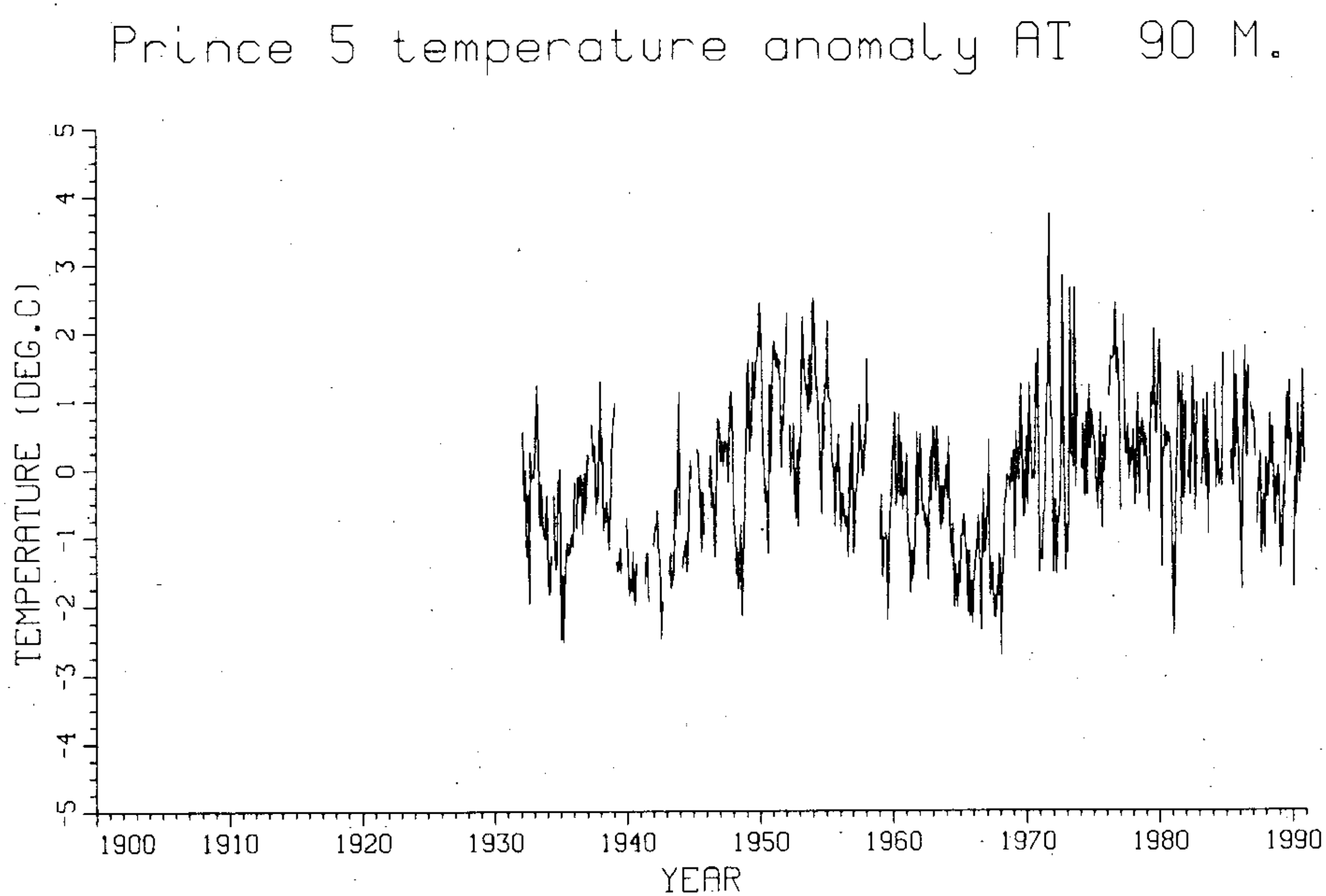

Fig. 10. Temperature anomalies in the near-bottom (95 m) waters at the Prince 5 Station at the mouth of the Bay of Fundy relative to long term average (1951-80).

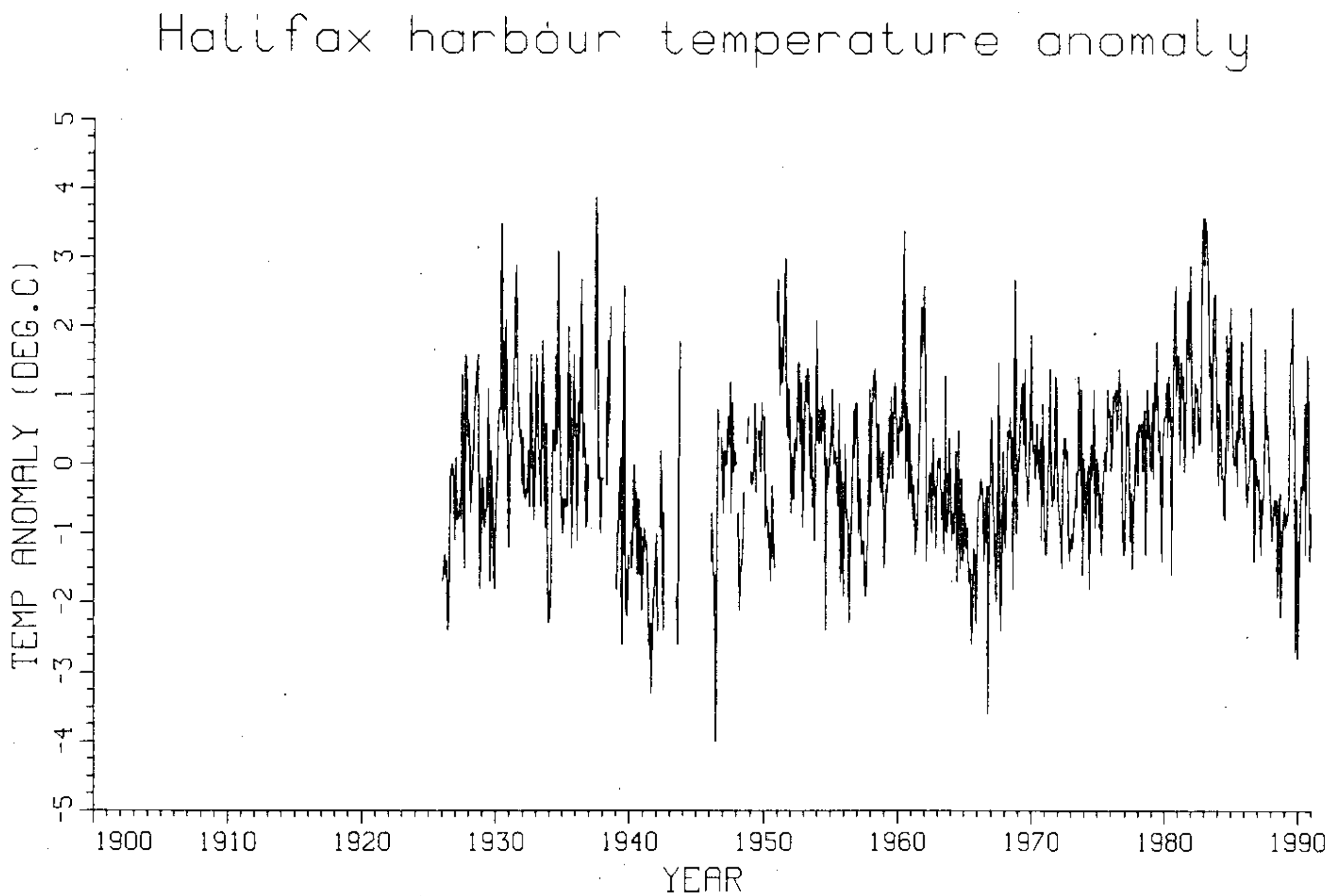

Fig. 11. SST anomalies at Halifax relative to long term average (1951-80).

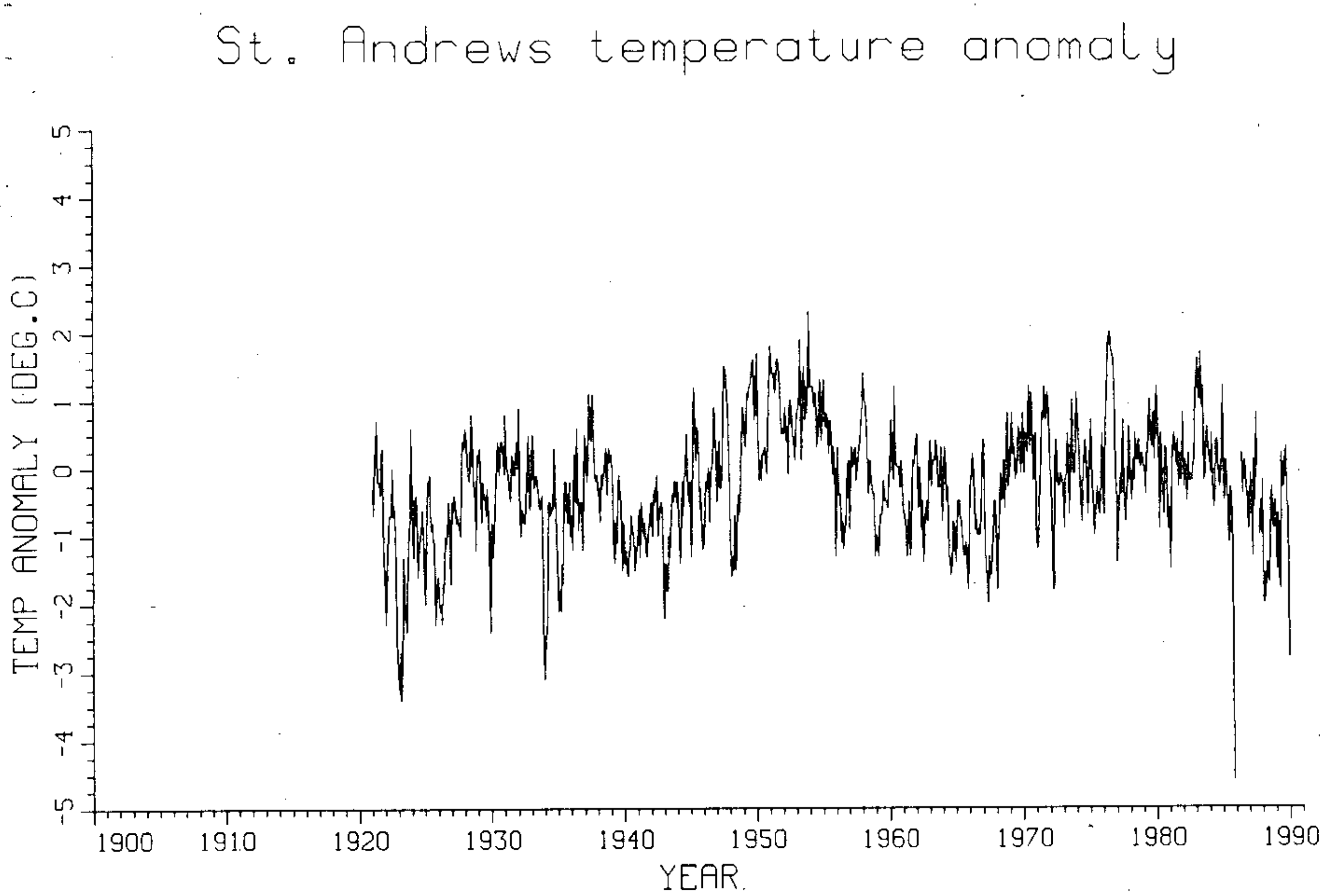

Fig. 12. SST anomalies at St. Andrews relative to long term average (1951-80).

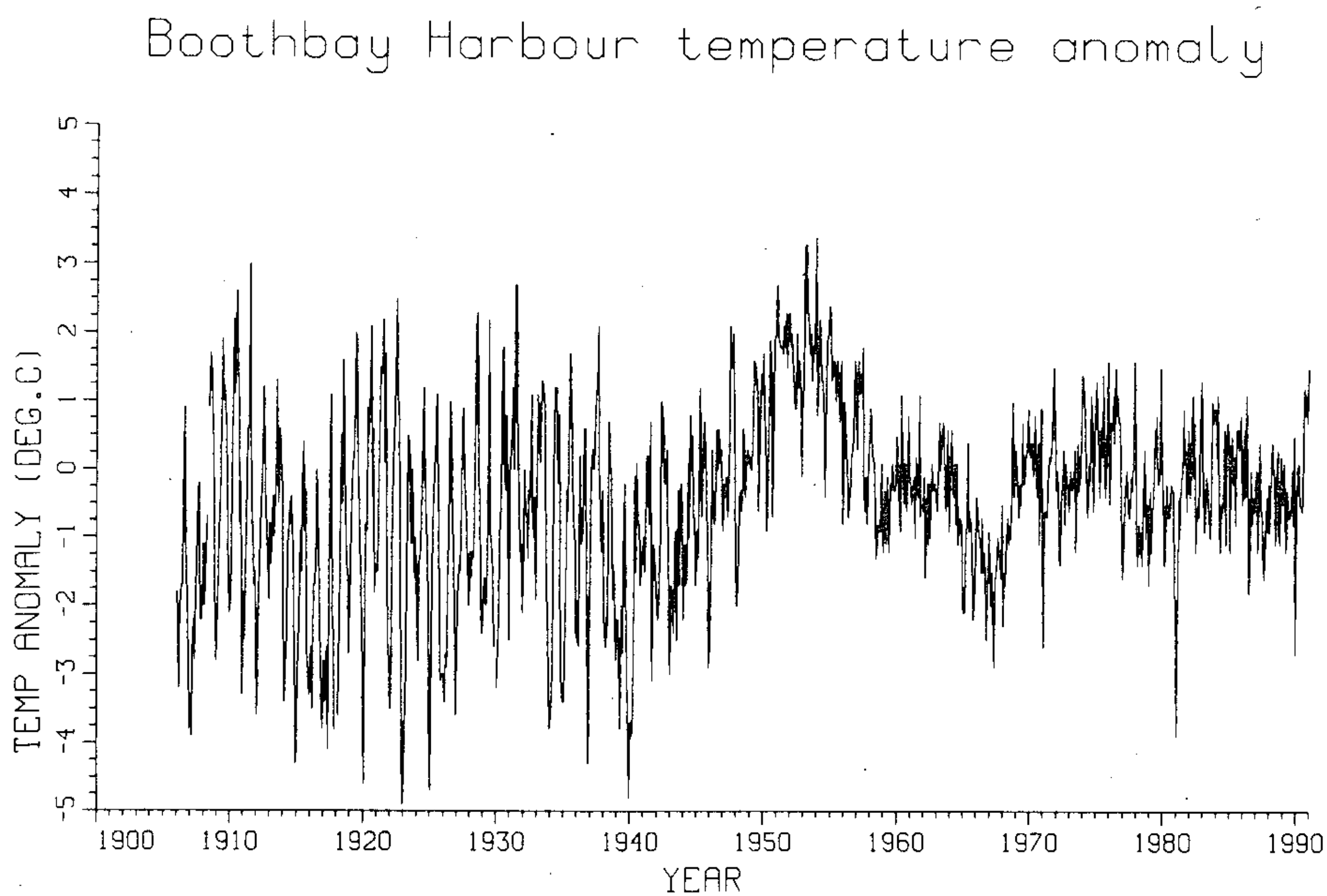

Fig. 13. SST anomalies at Boothbay Harbor relative to long term average (1951-80).

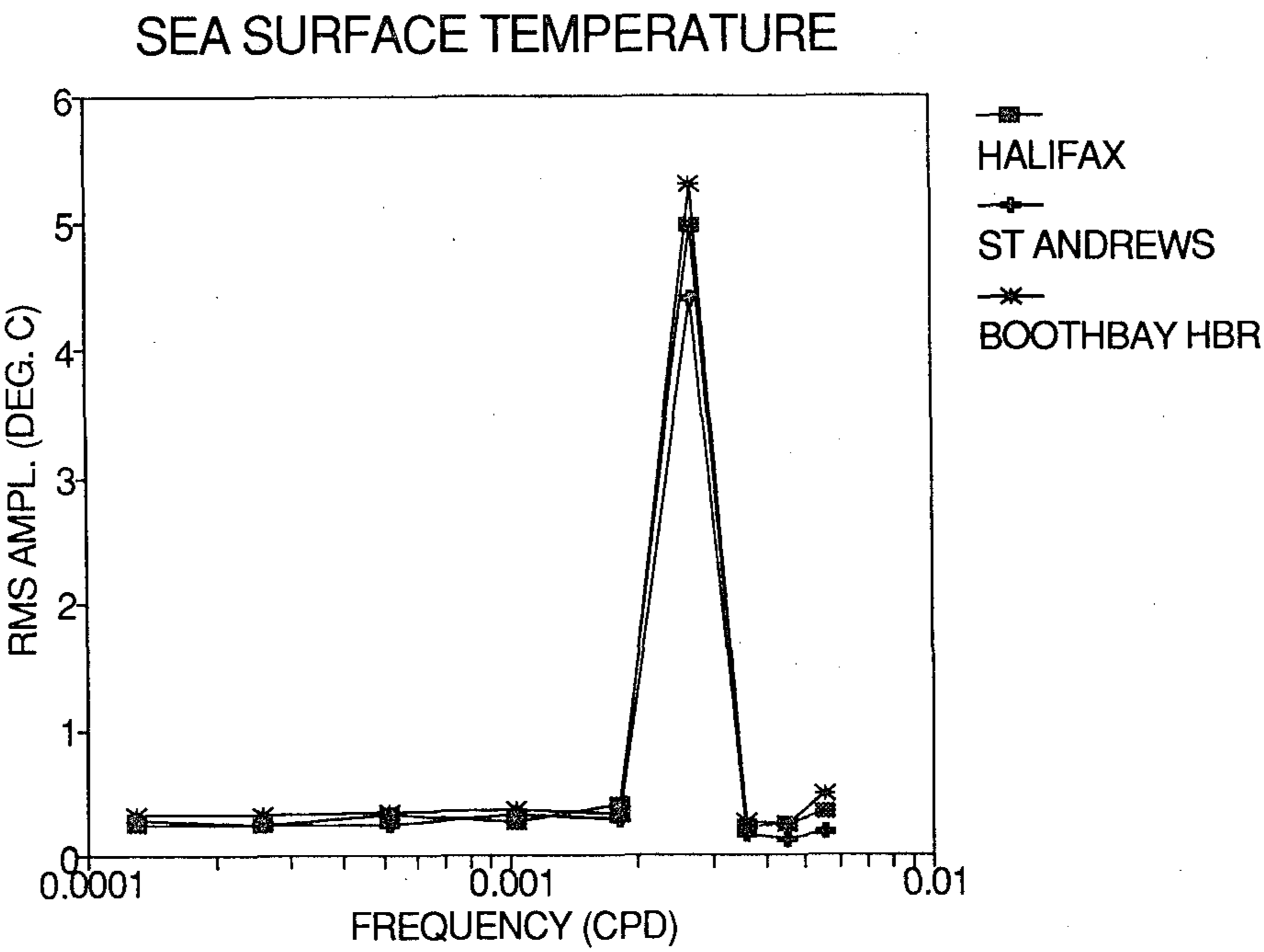

Fig. 14. Root mean square (RMS) amplitudes derived from the power spectra of sea surface temperature at Halifax, St. Andrews and Boothbay Harbor.

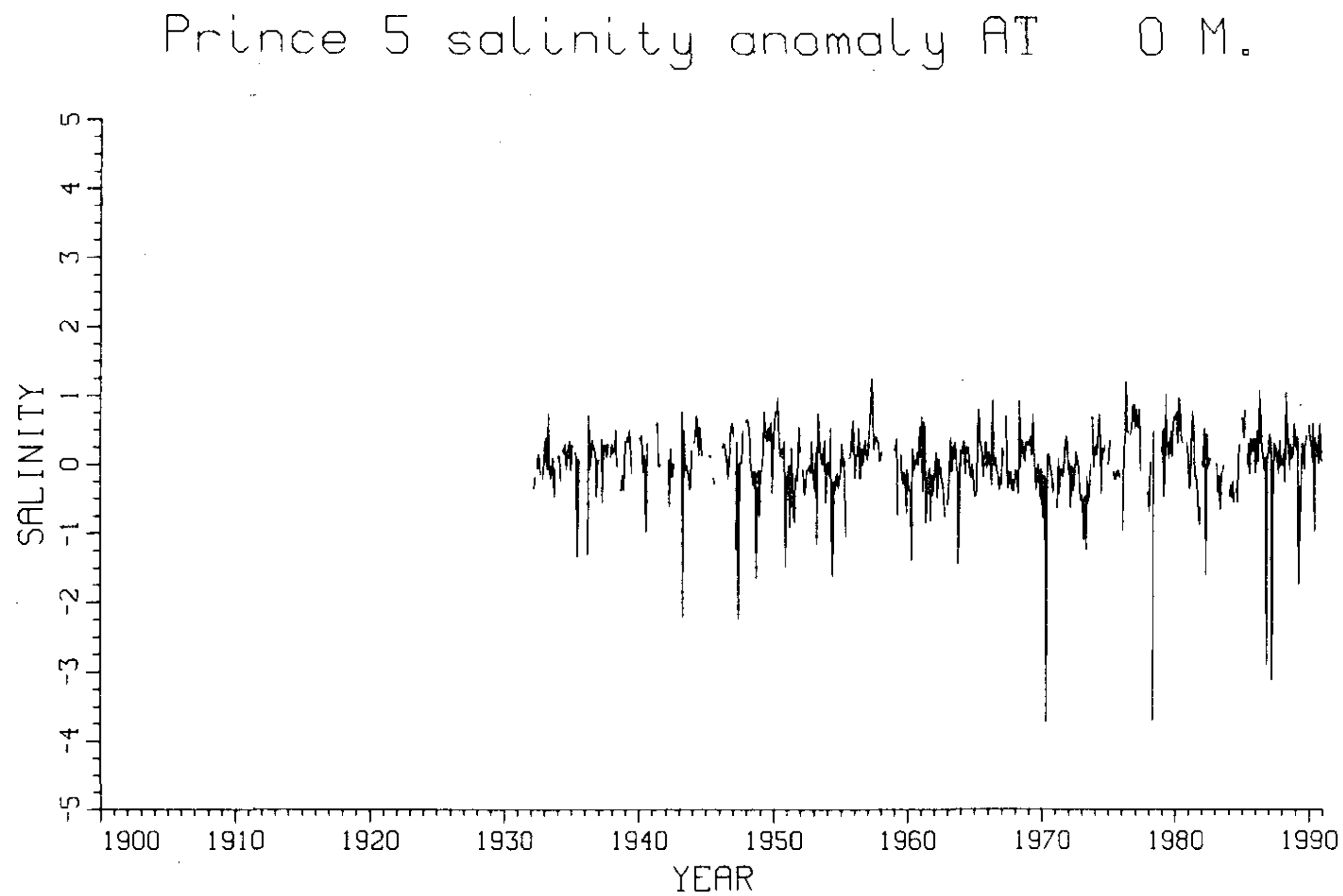

Fig. 15. Salinity anomalies in the surface waters at the Prince 5 station relative to long term average (1951-80).

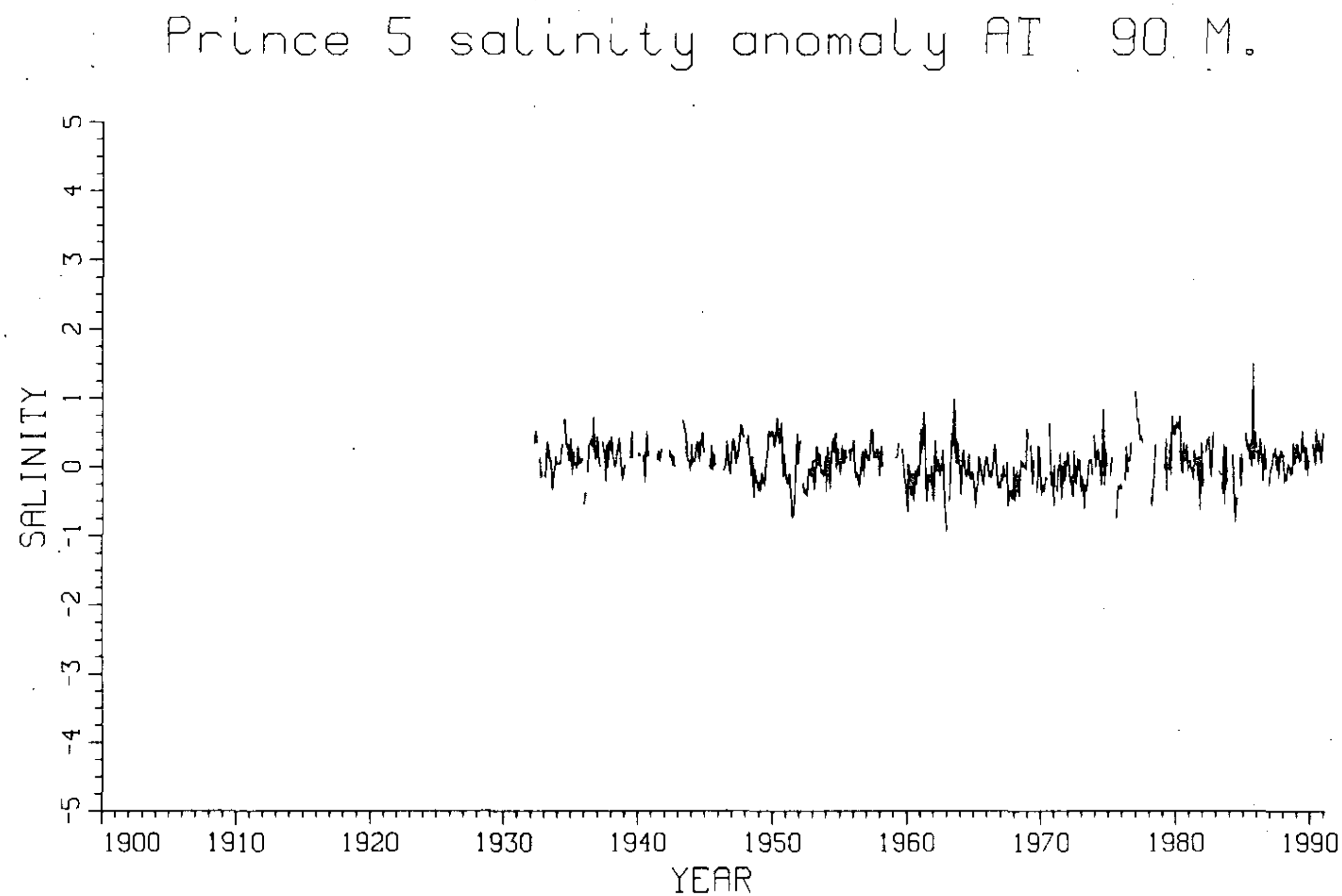

Fig. 16. Salinity anomalies in the near-bottom waters at the Prince 5 station relative to long term average (1951-80).