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Environmental Conditions During the Fall of 1993 in NAFO Divisions 2J3KL

by

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1. INTRODUCTION

This paper presents an overview of the environmental conditions in the Northwest Atlantic during late autumn of 1993. The information is based mainly on oceanographic data collected during the annual fall groundfish surveys in NAFO divisions 2J to 3NO. Data from other sources as well as all available historical data for the area are also included in the analysis. The horizontal, vertical and bottom temperature and salinity fields for the period of October 20 to December 7 (the time of the annual ground fish survey) 1993 are compared to a 1950-1990 average.

Dissolved oxygen data collected during early fall of 1992 and 1993 are presented and compared to all available historical oxygen data along the Newfoundland shelf.

The large upper level high pressure ridge over the north Pacific Ocean combined with a trough of low pressure over Atlantic and central Canada during most of the autumn period providing above normal temperatures (up to 2 °C) over northwestern Canada and up to 2 °C below normal over Atlantic Canada and the eastern Arctic (Fig 1). The below normal temperatures particularly in the eastern Arctic resulted in above normal ice cover by late November. In Baffin Bay and Davis Strait the ice edge was up to 300 km further south than normal by the end of November (Fig. 2) (Saulesleja, 1993). These conditions are again likely to result in above normal ice cover by the winter and spring of 1994.

The colder than normal air temperatures experienced over Eastern Canada since the late 1980s resulting in abnormal ice coverage during winter and spring have given rise to widespread negative water temperature anomalies and generally lower than normal salinities along Canada's Atlantic coast (Drinkwater et. al.,1992). These conditions contributed to large negative temperature anomalies over most of the water column in the fall of 1992 (Colbourne, 1993) and based on the present analysis again in the fall of 1993.

2. DATA SOURCES AND ANALYSIS

Oceanographic data for NAFO divisions 2J3KL and 3NO are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland. During the fall period since 1977 (in division 2J), and since 1981 (in divisions 2J3KL) the bulk of these data were collected during the stratified random groundfish surveys using XBTs. A location map showing all available temperature and salinity stations during the fall of 1993 is shown in Fig. 2a.

Since the fall of 1989 water temperatures during the groundfish surveys were measured using trawl-mounted Seabird 19 CTD systems. The extraction of the bottom temperature has changed from a single measurement at the bottom of the XBT trace (usually at the end of the tow) to a 10 to 20 minute horizontal average along the center portion of the tow. The temperature and salinity measurements made during the deployment of the trawl are used together with other available data to determine the temperature field over the water column. Data from the net-mounted CTDs are not field calibrated.

Horizontal maps of the average temperature and salinity at standard oceanographic depths are produced from all available data from 1950 to 1990 for a particular time and region of interest. The actual isotherms are derived from unweighted averages of all temperature and salinity profiles within a square grid with spacing of 0.25 degrees of latitude. The data were quality controlled and linearly interpolated to the standard depth of interest. No attempts were made to adjust the data for possible temporal or spatial biasing arising from this averaging procedure. Some temporal biasing may be present in the analysis given the wide time interval over which the fall survey is conducted plus the fact that this is a period when rapid cooling of the upper water column is taking place.

Horizontal bottom temperature maps were produced by contouring all bottom of the cast temperature values for the time and region of interest and rejecting values for which the cast depths were not within 5 % of the water depth. Time series of bottom temperatures were also produced from 1950 to 1993 for selected strata in 2J3KL.

Vertical cross-sections of the temperature and salinity structure were contoured by taking all observations within ± 20 minutes of latitude of the standard NAFO Bonavista and Seal Island transects. The observations were then assumed to lie on a line joining the endpoints of the standard transect. The data were then interpolated to 5.0 m depths intervals and averaged into 5.0 km bins along the line. The data were adjusted somewhat to reduce temporal biasing by extracting historical data within 1 week on either side of the time period of the 1993 data and not over the complete time period of the annual fall survey.

A description of the dissolved oxygen data collection, calibration and analysis is given in the last section of the paper.

3. HORIZONTAL TEMPERATURE FIELD

Figure 3a shows the average upper layer (10 m) temperature field for the October 20 to December 7 time period derived from all available data from 1950 to 1990 as described above. The average upper layer temperature ranged from 1 to 3 °C shoreward off the shelf break in NAFO divisions 2J3K and from 3 to 7 °C in division 3L (isotherms are -1,-0.5,0,1,2,4,6,8 and 10 °C, bathymetry lines are 300 and 1000 m). Figure 3b shows the upper layer temperature determined from all available data for the October 20 to December 7 1993 time period. The upper layer temperatures in 1993 ranged from approximately 1 to 2 °C in 2J3K, about normal near shore, and up to 1.0 below the 1950-1990 average further offshore. In division 3L the temperature ranged from 2 to 6 °C, again about 1.0 °C below the long-term average. During the fall of 1992 the surface temperature ranged from 1 to 2 °C below average during the same time period and near normal in 1991.

Figure 3c and 3d shows the average and the 1993 fall temperature at 75.0 m depth, near the center of the cold intermediate layer (CIL) (Petrie et. al., 1988) and near bottom over most of the Grand Bank. On average 0.0 °C water covers a large portion of the Grand Bank and part of the northeast Newfoundland shelf. The 2.0 °C isotherm follows the 1000 m isobath near the shelf edge. During 1993 0.0 °C water was much more extensive over the northeast Newfoundland shelf reaching further north and further offshore than the average. On average the temperature ranged from 1.0 to 2.0 °C below normal over most of the area, similar to 1991 and 1992.

Figure 4a to 4d shows horizontal maps of the salinity field at 10 and 75 m depth for the 1950-1990 average and for the fall of 1993. On average the salinity ranges from 32.0 along the coast, to 34.0 beyond the shelf edge at 10 m depth and from 32.5 near the coast and over most of the Grand Banks to 34.0 near the shelf edge at 75 m depth. During 1993 at 10 m depth the salinity ranged from 0.1 to 0.5 lower than average and up to 0.3 higher than average at 75 m depth.

4. BOTTOM TEMPERATURES

The average bottom temperature over various time ranges are shown in Fig. 5. and Fig. 6. The average bottom temperature over most of the northeast Newfoundland shelf (2J3K) ranges from 0.0 °C inshore, to 3.0 °C offshore at the shelf break. The average temperature over most of the Grand Banks varies from -1.0 to 0.0 °C and to 3.0 °C at the shelf break. In general bottom isotherms follow the bathymetry exhibiting east-west gradients over most of the northeast shelf. The bottom temperatures during the last 3 years have been significantly below those for any of the averaging periods presented here over most of the 2J3KL area. The percentage area of water less than -1.0 °C over the Grand Banks in 1990 to 1993 was significantly larger than the 1950-1990 average. In 1992 and 1993 the bottom temperature anomaly ranged from -0.25 to -0.75 °C over the northeast shelf and from -0.25 to -1.0 °C over the Grand Banks.

Figure 2b shows the approximate boundaries of selected strata (206,346 and 372) defined in NAFO divisions 2J3KL (Doubleday, 1981) for which time series of the bottom temperatures were examined in each division. These Strata were selected to show the bottom temperature time series at different depth ranges on the shelf and banks, from 80 m in 3L to 150 m in 2J and to 330 m in 3KL. Temperature profiles collected in the same stratum on the same day were averaged. The annual cycle was not removed from these time series since it was not statistically significant near the bottom. The time series plots of bottom temperature from 1950 to 1993 for the selected strata are shown in Fig. 7.

The time series in 2J shows a steady increase in the bottom temperature during the 1950s and through most of the 1960s, and a decreasing trend in the early 1970s, early to mid 1980s and since 1988 to the present. Temperature variations ranged from -0.5 °C in the early 1950s, mid 1980s and at present, to highs of 1.0 °C during the 1960s and late 1970s. Most importantly the bottom temperature in 1993 is continuing to decrease and is below that of 1990, 1991 or 1992.

The time series in divisions 3KL are bottom temperature from the deep trough between the Northern Grand Bank and the Funk Island Bank near the shelf edge in about 330 m of water. The temperature in this area remained at about 3.0 °C from 1950 to 1984 when it dropped to approximately 2.5 °C. The spike in 1992 may be the result of alaising of high frequency oscillations in the shelf/slope front which are present near the shelf edge, but more pronounced higher in the water column (Narayanan et. al., 1991).

In division 3L on the plateau of the Grand Bank the bottom temperatures remained relatively constant at approximately 0.0 °C from 1950 to the mid 1960s after which there was a weak warming trend. During the early 1970s and mid 1980s bottom temperatures decreased to near -1.0 °C and have remained below 0.0 °C since 1989.

5. VERTICAL TEMPERATURE FIELD

Figure 8 shows a contour plot of the temperature and temperature anomaly along the standard NAFO Seal Island transect in division 2J during the period of the annual fall groundfish survey. The seasonal warm upper layer has not completely cooled down, so the summer-like structure of the cold intermediate layer is still present. The surface temperatures ranged from 0.5 to 1.0 °C about 0.25 °C below normal. Mid depth temperatures are slightly above normal in the inshore portion of the transect and up to 1.0 °C below normal from mid-shelf to the shelf edge. In general, except for the thin layer at mid depth in the inshore region, the temperature was below normal everywhere along the Seal Island transect.

Upper layer salinities along the transect (Fig. 9) ranged from 32.25 inshore to 33.25 near the shelf edge, slightly lower than average. Near the bottom salinities ranged from 32.75 inshore to 34.75 on the shelf slope area, again slightly lower than average on the shelf and slightly higher beyond the shelf break.

The temperature structure across the northeast Newfoundland shelf along the standard NAFO Bonavista transect (Colbourne and Senciall, 1993) in the bottom layer is very similar to summer conditions (Fig. 10). For example the bottom position of the 2.0 °C isotherm is located shoreward of the shelf edge and the 3.0 °C isotherm is located near the edge of the shelf, about the same as the average summer positions. Again the seasonal warm upper layer has not completely eroded thus defining a CIL with a cross sectional area of about 25 km^2.

Upper layer temperatures were up to 0.25 °C warmer than average over the inshore portion of the continental shelf and up to 0.75 °C colder than average below 80 m depth. At mid shelf and further offshore, beyond the shelf edge, temperatures ranged from 0.25 to 0.75 °C below average.

Upper layer salinities (Fig. 11) off Cape Bonavista were very similar to values along the Seal Island transect 500 km to the north with values ranging from 32.25 near the coast to 33.5 near the shelf edge, slightly lower than average. Deep water salinities ranged from 33.5 to 34.5 near the shelf break, again slightly lower than normal.

6. THE FALL CIL

The 1980 to 1993 time series of CIL area less than 0.0 °C for the Seal Island and Bonavista transects during the fall survey period is shown in Fig. 12. The CIL area along the Bonavista transect shows similar trends as in the summer, however the average area has decreased from 33.0 km^2 during the summer to 24 km^2 in the fall as a result of summer heating and vertical mixing over the water column. The CIL area during the fall of 1993 was about 30.0 km^2 compared to an about 27 km^2 in 1992 and about 22 km^2 in 1991.

The Seal Island CIL area is more variable and smaller in average magnitude than the more southerly Bonavista transect, with some years when 0.0 °C water was completely eroded by fall convection. The average CIL area during the fall along this transect was about 13 km^2 with a standard deviation of about 11 km^2. The CIL area during the fall of 1993 along the Seal Island transect was about 16 km^2 compared to about 26 km^2 in 1992 and 11 km^2 in 1991.

7. STATION 27 TIME SERIES

Time series of average fall (October-December) temperatures at Station 27 for the surface, 50 m and the bottom (175 m) are shown in Fig. 13. At the surface the average fall temperature from 1950 to 1993 was about 5.5 °C. At 50 m depth the temperature shows more variations with lower than average values since 1986 and 1991 being the only year in the record with negative fall water temperatures at 50 m depth. Near the bottom at 175 m depth temperatures average about -1.0 °C with a decreasing trend that started in the mid 1980s continuing into 1993. The general warming trend during the late 1950s and 1960s reached a peak in 1967. This was followed by a major cold period in the early 1970s and again in the mid 1980s.

Time series of the vertical temperature structure and anomaly at station 27 off St. John's for the fall of 1993 are shown in Fig. 14. The anomalies are calculated from the mean of all data collected on the station since 1950. The position of this station is such that the cold water (< 0.0 °C) that forms the core of the CIL is present year around in water depths from about 100 m to the bottom at 175 m. Hence this time series is invaluable in monitoring the variability in the seasonal upper layer as well as the core of the CIL, however it does not show the full vertical extent of the CIL over the continental shelf.

The time series show upper layer temperatures decreasing from 9 to 3 °C (up to 0.5 °C above average) during the annual fall survey, a cooling rate of approximately 0.1 °C/day. At depths greater than 70 m in early October and 120 m in early

December temperature remained below 0.0 °C with negative anomalies ranging from -0.5 to -1.0 °C. In 1992 upper layer temperatures for the same time period were up to 0.5 °C below average and about 0.5 to 1.0 °C below average at deeper depths, about the same as in 1993. The average bottom (175 m) temperature anomaly from October to December was about -0.5 °C compared to about -0.2 °C in 1992. Salinities at Station 27 were slightly above average during October and most of November over most of the water column (Fig. 15) and below normal by early December.

8. OXYGEN DISTRIBUTIONS

Dissolved oxygen data are now routinely collected along transects of Newfoundland on oceanographic research cruises. The measurements are made with a Beckman or YSI type polarographic element dissolved oxygen sensors with factory calibrated end-points at zero and 100 % saturated water oxygen levels. The sensors are interfaced to pumped Seabird-9 or 25 CTD systems. Field calibrations of the oxygen sensors were also carried out by taking water samples with Niskin bottles triggered at standard oceanographic depths during the CTD up cast. The average sensor oxygen values collected during each stop were compared to the titration values. The oxygen levels of the samples were determined by semi-automated analytical chemistry using a modified Winkler titration technique where the endpoint is detected photometrically (Jones et. al., 1992).

A total of 200 water samples were titrated during a cruise along the east coast of Newfoundland between September 24 to October 2 1993. A least-squares linear regression of the titration measurements to the electronic sensor measurements was then computed (Fig. 16 top panel). The corrected sensor readings were found to be related by a linear equation with a slope of 0.996 and an intercept of 0.166 (ie. corrected probe value = 0.996 x titration value + 0.166). These results indicate that the sensor was reading about 0.15 ml/l lower than the titrated values. The offset was near linear as indicated by the slope of the fitted line across the range of oxygen concentrations encountered (about 6.0 to 8.0 ml/l). Figure 16 (bottom panel) indicates that most of the scatter in the oxygen residuals (sample-sensor) occurs near the thermocline at about 30 m depth.

The oxygen concentrations in ml/l are converted to % saturation by dividing the measured oxygen concentration by the computed solubility of oxygen in sea water at the measured temperature and salinity (Weiss, 1970).

The depth versus horizontal distance of oxygen saturation along the Bonavista transect for late September of 1992 and 1993 are shown in Fig. 17. In both years the oxygen saturations ranged from about 80 to 100 % from the surface to about 50 m depth as a result of surface wave action. In the depth range from 50 to 300 m from the inshore areas to approximately mid shelf about 150 km offshore the oxygen saturation was about 70 to 75 % in 1992 and generally around 85 % in 1993. This area roughly corresponds to the cold Labrador current water (CIL, Fig. 10). Further offshore outside the CIL near the shelf edge saturations generally range from 75 to 80 % in 1992 and from 85 to 90 % in 1993. Near the bottom in about 300 to 350 m of water the oxygen saturation was near 70 % in 1992 and about 80 % in 1993. It should be noted that the 1992 data was not field calibrated, however based on experiments with different sensors and the 1993 calibration results the 1992 data is probably within 2-3 %.

Data collected in June and July of both 1992 and 1993 (not shown here) indicate bottom saturation values similar to the September values shown here, about 70 % in 1992 and 80 % in 1993. In 1992 the upper layer oxygen levels ranged from 80 to 100 % from 0 to 150 m in June, from 0 to 60 m in July and from 0 to 50 m by September. In 1993 both the June and July oxygen saturations ranged from 90 to 100 % from the surface to the bottom along the entire transect.

Further north along the Seal Island transect July oxygen saturation values ranged from 90 to 100 % in the upper 40 m of the water column, about 85 % in the CIL and from 90 to 95 % offshore of the shelf edge. In general the 1993 oxygen saturation values were up to 10 % higher than the 1992 values with no evidence of oxygen depleted water on the continental shelf off Newfoundland and Labrador.

The historical oxygen data along the Newfoundland shelf was sorted by day and the seasonal cycle determined by fitting a least-squares regression to the annual mean and a sum of 4 harmonics (Fig.18). The oxygen maximum corresponding to the spring plankton bloom occurs in early May near the surface to late June in deeper water.

The vertical structure of the oxygen level during September was then determined from the seasonal cycle and plotted with the September 1993 data (Fig.19a). This data indicates an oxygen maximum at about 50 m depth with the 1993 data higher than average below 50 m depth. Figure 19b shows a time series of oxygen anomalies at various depths determined from the seasonal cycle. In general oxygen values increased slightly during the 1960s, decreased during the early to mid 1980s and again in 1992. The recent data from 1993 indicated above average oxygen levels.

9. SUMMARY

The present analysis shows near normal upper layer temperatures near the coast of Newfoundland and from 0.25 to 1.0 °C below normal over the rest of the area during the fall of 1993 compared to 1.0 to 2.0 °C below normal in 1992 and near normal values in 1991. In deeper water (75 m) the 1.0 to 2.0 °C negative temperature anomalies that developed in 1991 are continuing into the fall of 1993. In 1993 upper layer salinities were lower (by about 0.1 to 0.5) than average and slightly higher (by about 0.3) at 75 m depth. As in 1991 and 1992 large areas of the continental shelf had below normal bottom temperatures (up to 1.0 °C below average).

The cross-sectional area of the CIL across the northeast Newfoundland shelf has increased from 22 km^2 in 1991 to about 30 km^2 in 1993 compared to the 1980-1993 average of 24 km^2. In area 2J across Hamilton Bank the CIL area had decreased from 27 km^2 in 1992 to about 16 km^2 in 1993.

The average fall bottom temperature at Station 27 continued a decreasing trend with values up to 0.5 °C below average. Station 27 temperature anomalies were slightly positive in the upper layer in 1993 slightly negative in 1992 and slightly positive in 1991. All three years saw strong negative temperature anomalies at mid-depths except towards the end of the fall survey.

Dissolved oxygen collected along transects show values ranging from 70 % saturation near the bottom to 75 % in the CIL to 100 % in the upper layer in 1992 and 80 % near the bottom to 85 % in the CIL and to 100 % in the upper layer in 1993.

The below normal air temperatures and above normal ice coverage during recent years have contributed to severe oceanographic conditions (low heat content) on the eastern Canadian continental shelf areas. The analysis presented here indicates a continuation of the most recent cold trend that began in the late 1980s. The 1993 oxygen levels however are above the average based on historical data from a large area of the Newfoundland shelf.

ACKNOWLEDGEMENTS

I would like to thank D. Senciall for computer software support and D. Foote for data processing and technical assistance in the preparation of this document. I would also like to thank the many scientists at the NAFC for collecting and providing much of the data contained in this analysis and to the Marine Environmental Data Service in Ottawa for providing most of the historical data.

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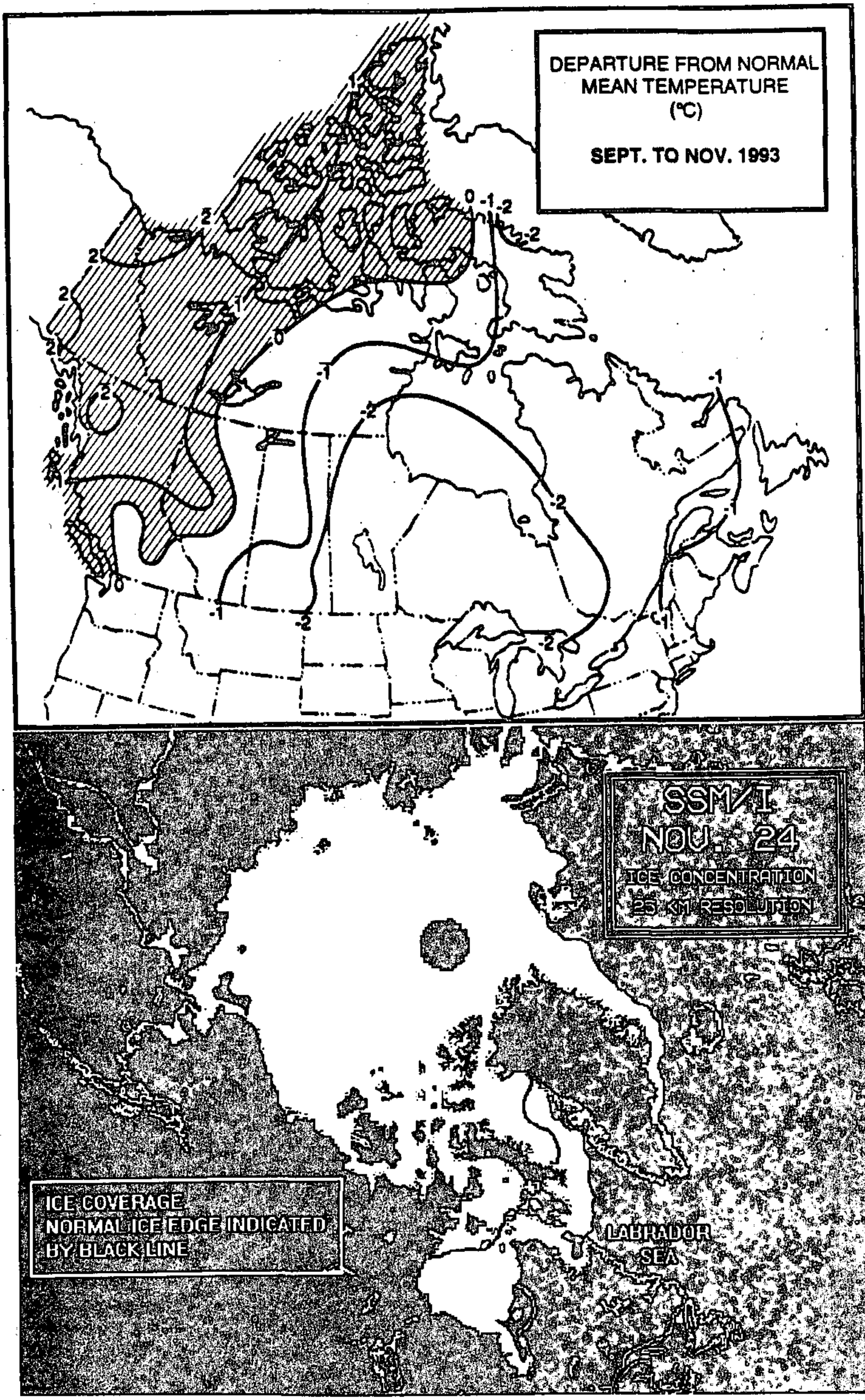

Fig. 1. The average fall air temperature over Canada (upper panel) and fall ice coverage (lower panel) from Climate Perspectives.

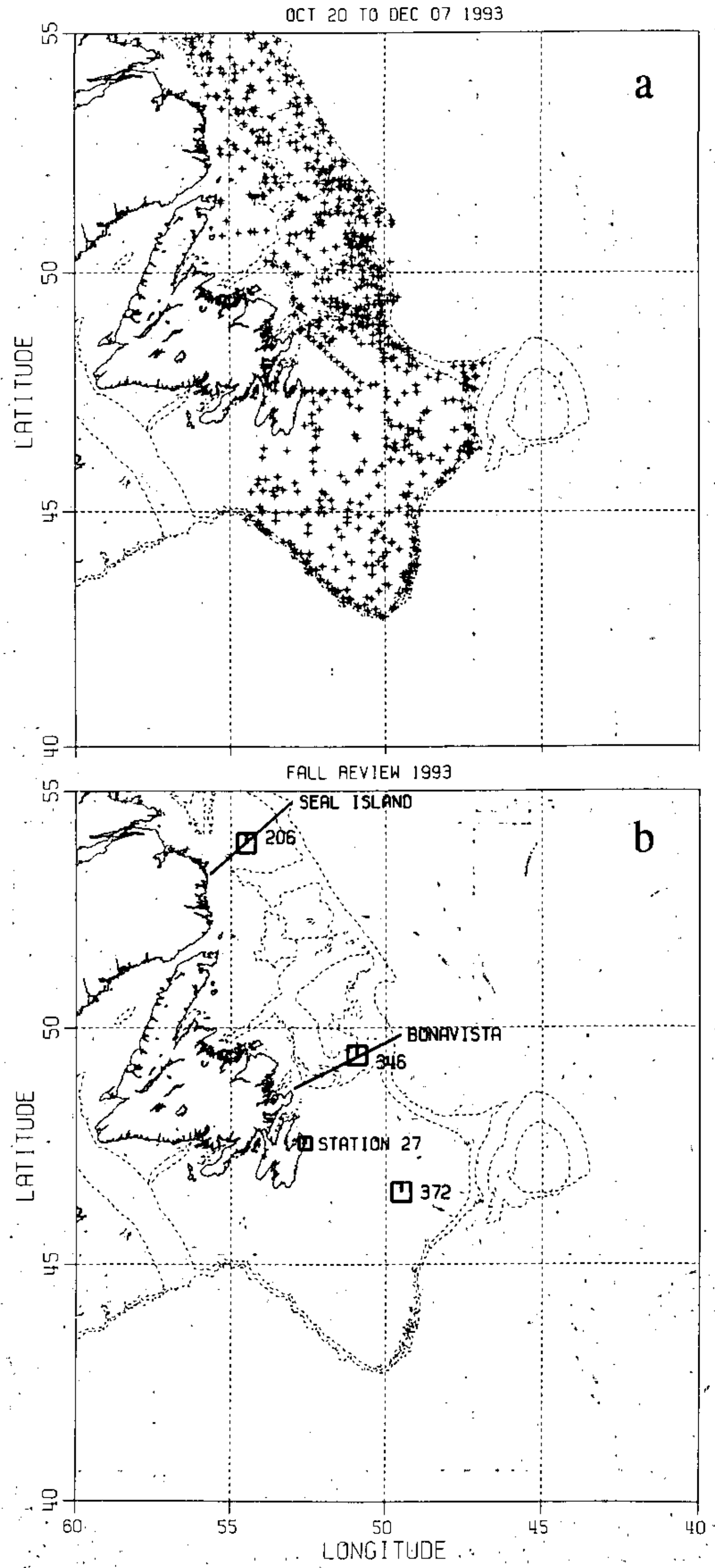

Fig. 2. (a) Location map showing set positions during the 1993 annual fall groundfish survey and (b) the location of the Seal Island and Bonavista transects.

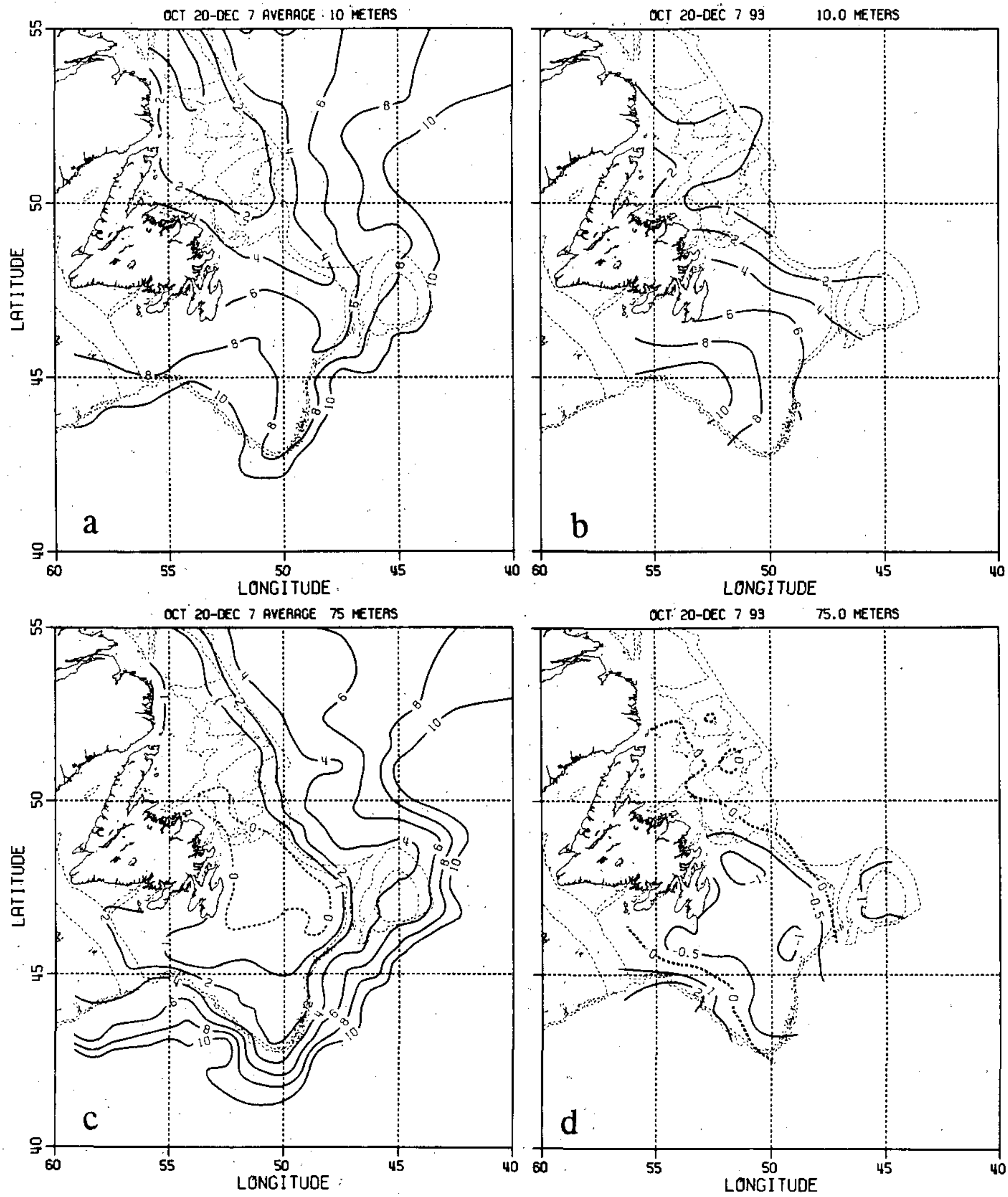

Fig. 3. Horizontal temperature maps for (a) fall average 10 m, (b) fall 1993 10 m, (c) fall average 75 m and (d) fall 1993 75 m, based on all available data.

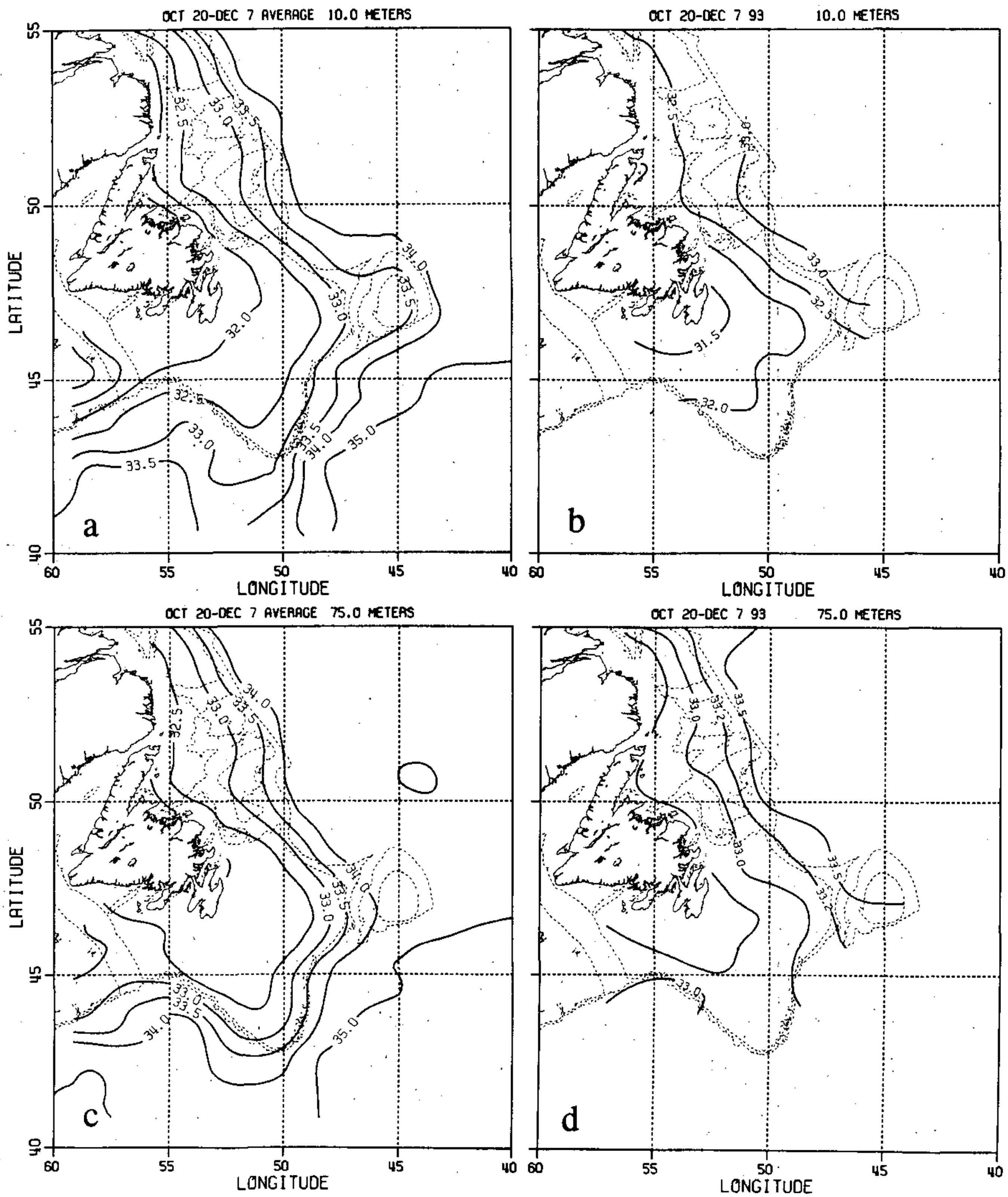

Fig. 4. Horizontal salinity maps for (a) fall average 10 m, (b) fall 1993 10 m, (c) fall average 75 m and (d) fall 1993 75 m, based on all available data.

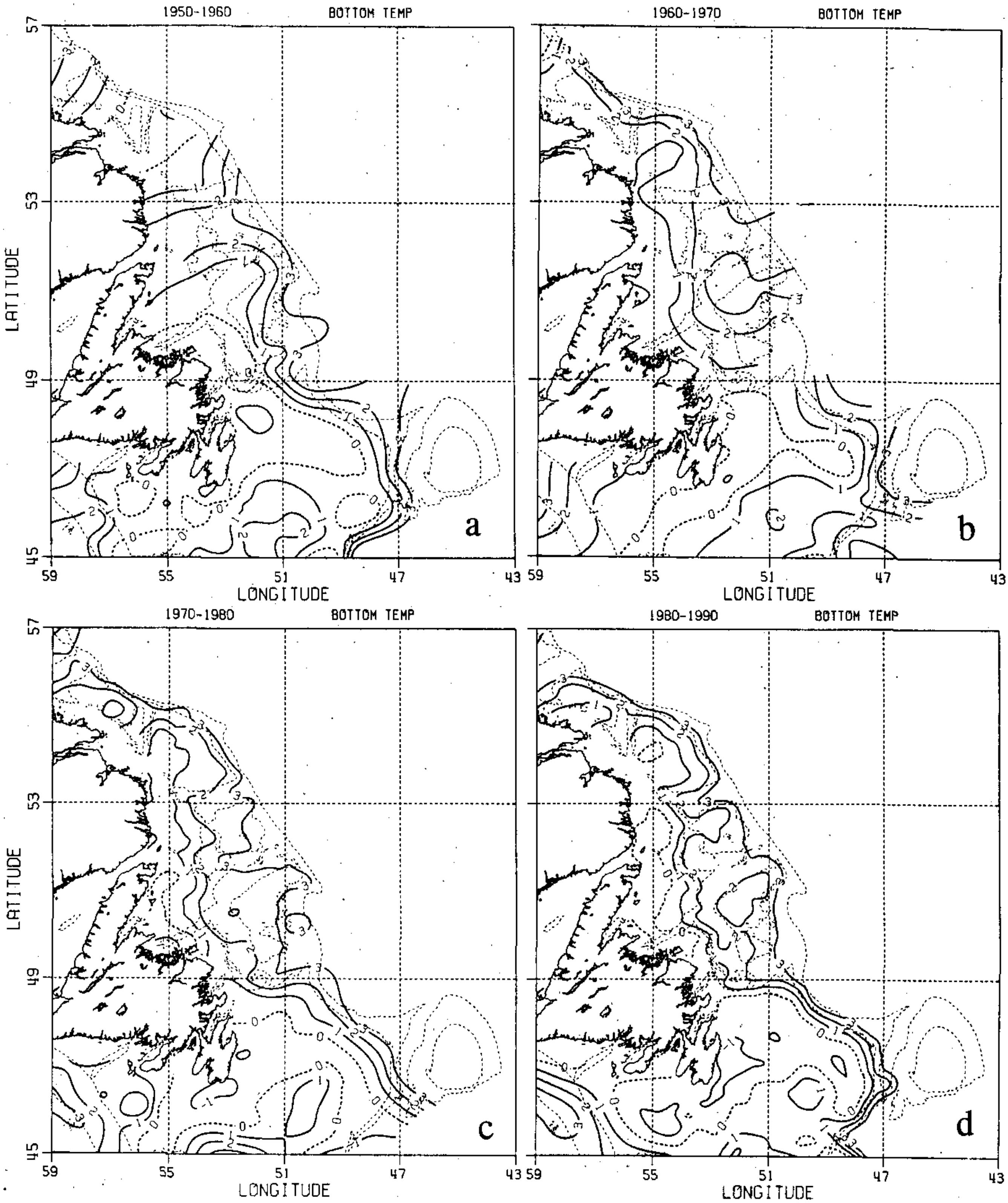

Fig. 5. Horizontal bottom temperature maps for (a) fall 1950 -1960 average, (b) fall 1960-1970 average (c) fall 1970-1980 average and (d) fall 1980-1990 average, based on all available data.

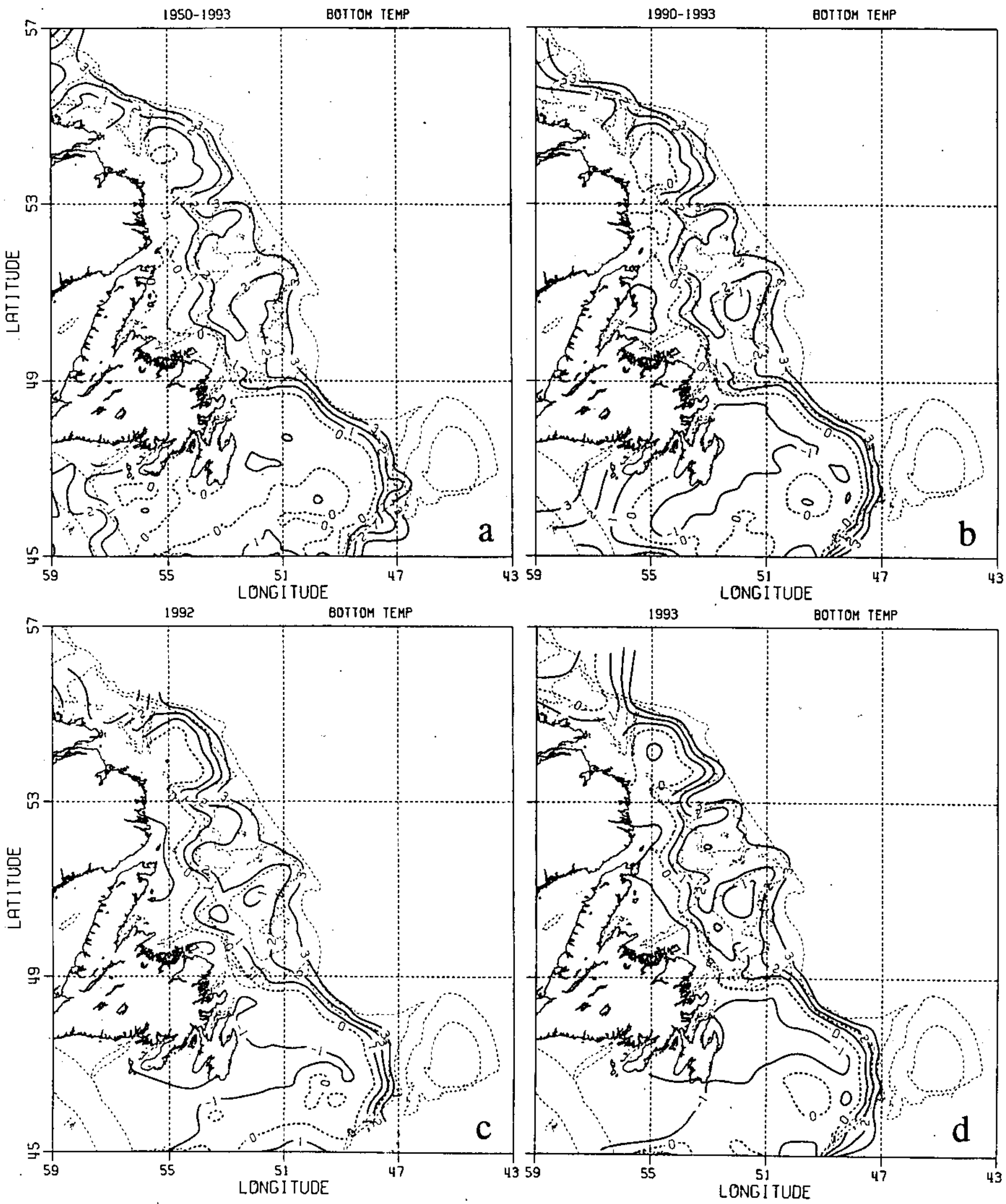

Fig. 6. Horizontal bottom temperature maps for (a) fall 1950 -1993 average, (b) fall 1990-1993 average (c) fall 1992 and (d) fall 1993, based on all available data.

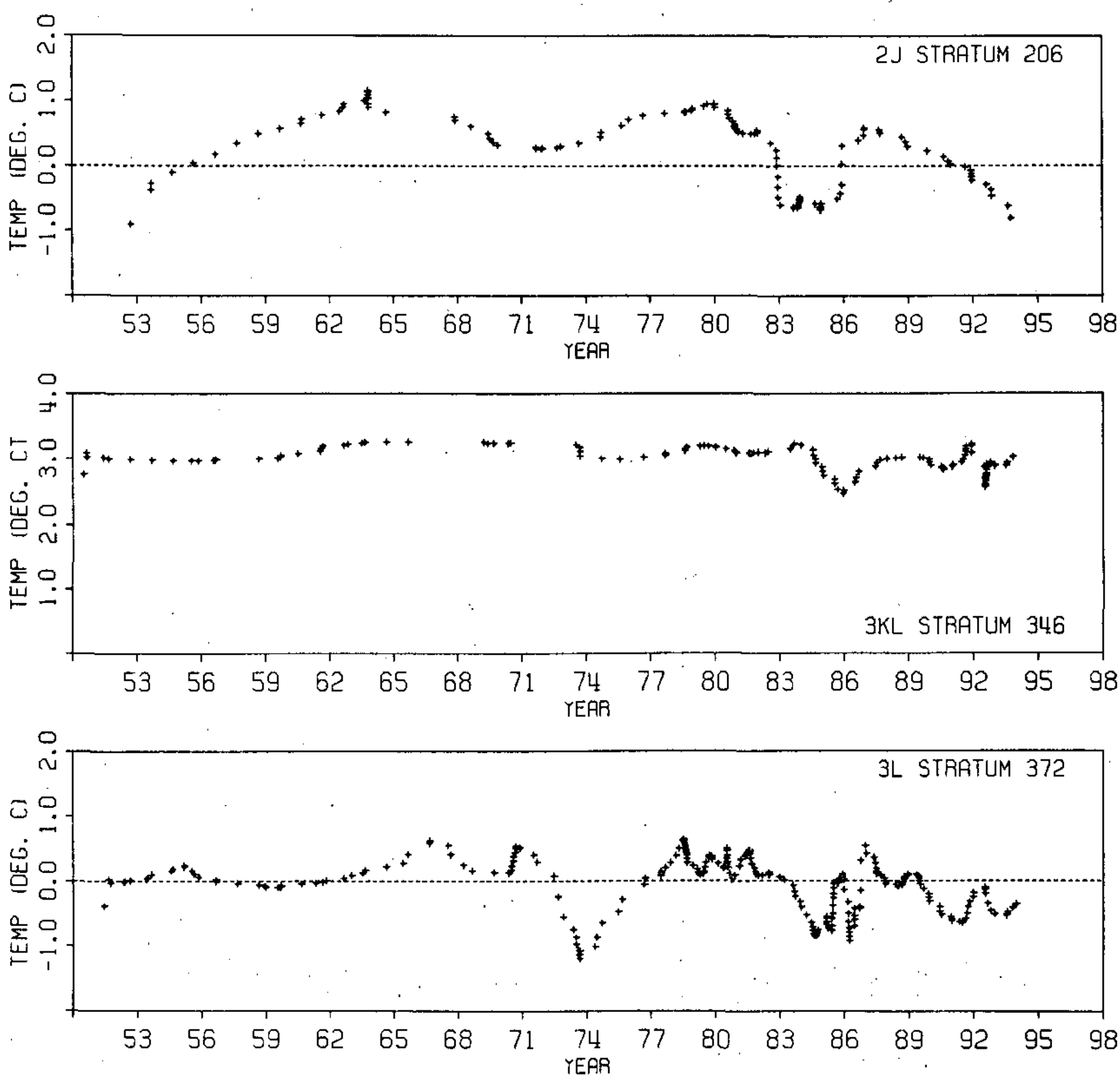

Fig. 7. Time series of bottom temperatures for strata 206 in NAFO Division 2J, 346 in division 3KL and 372 in division 3L.

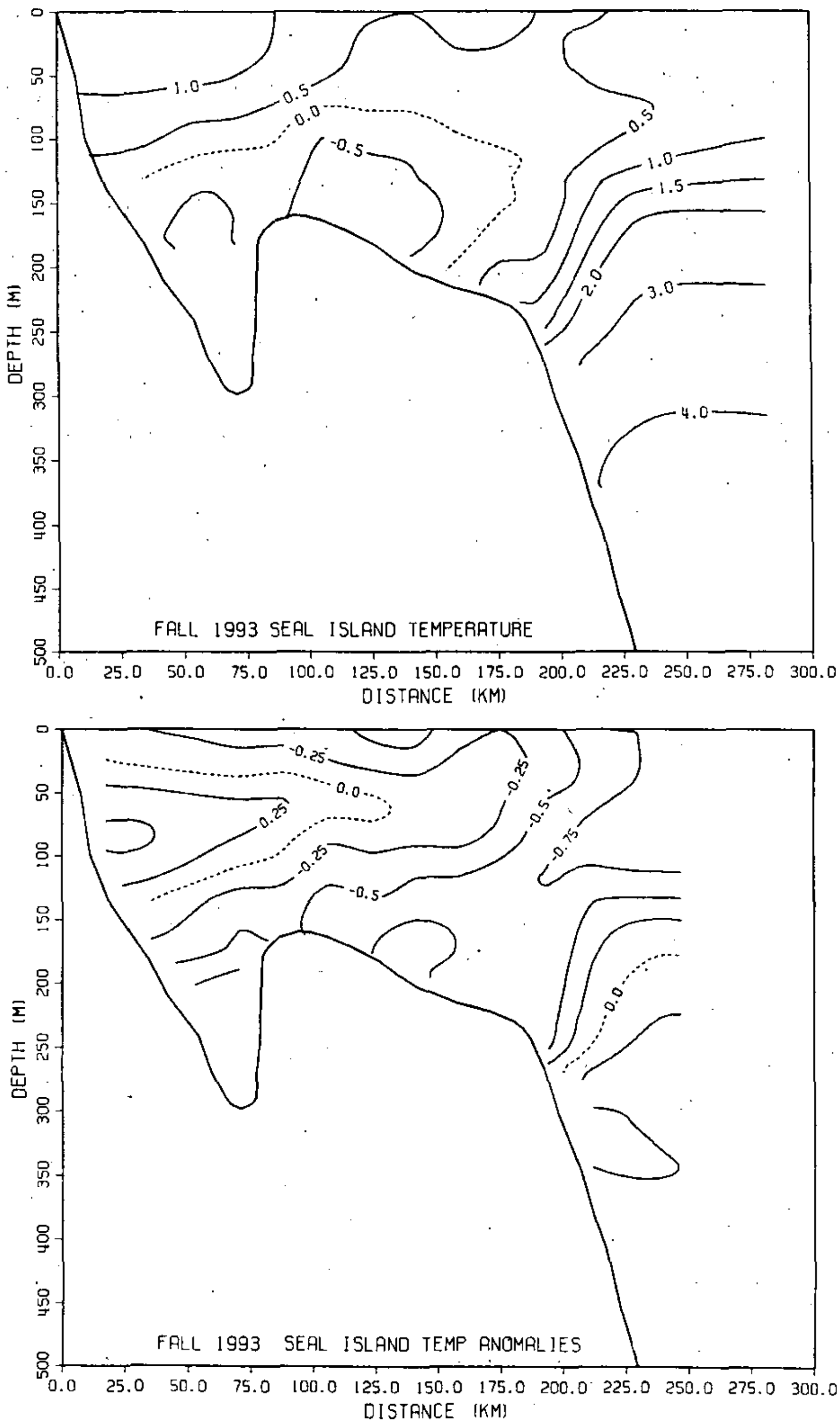

Fig. 8. The 1993 fall temperature (top panel) and temperature anomaly (bottom panel) vertical cross section for the Seal Island transect.

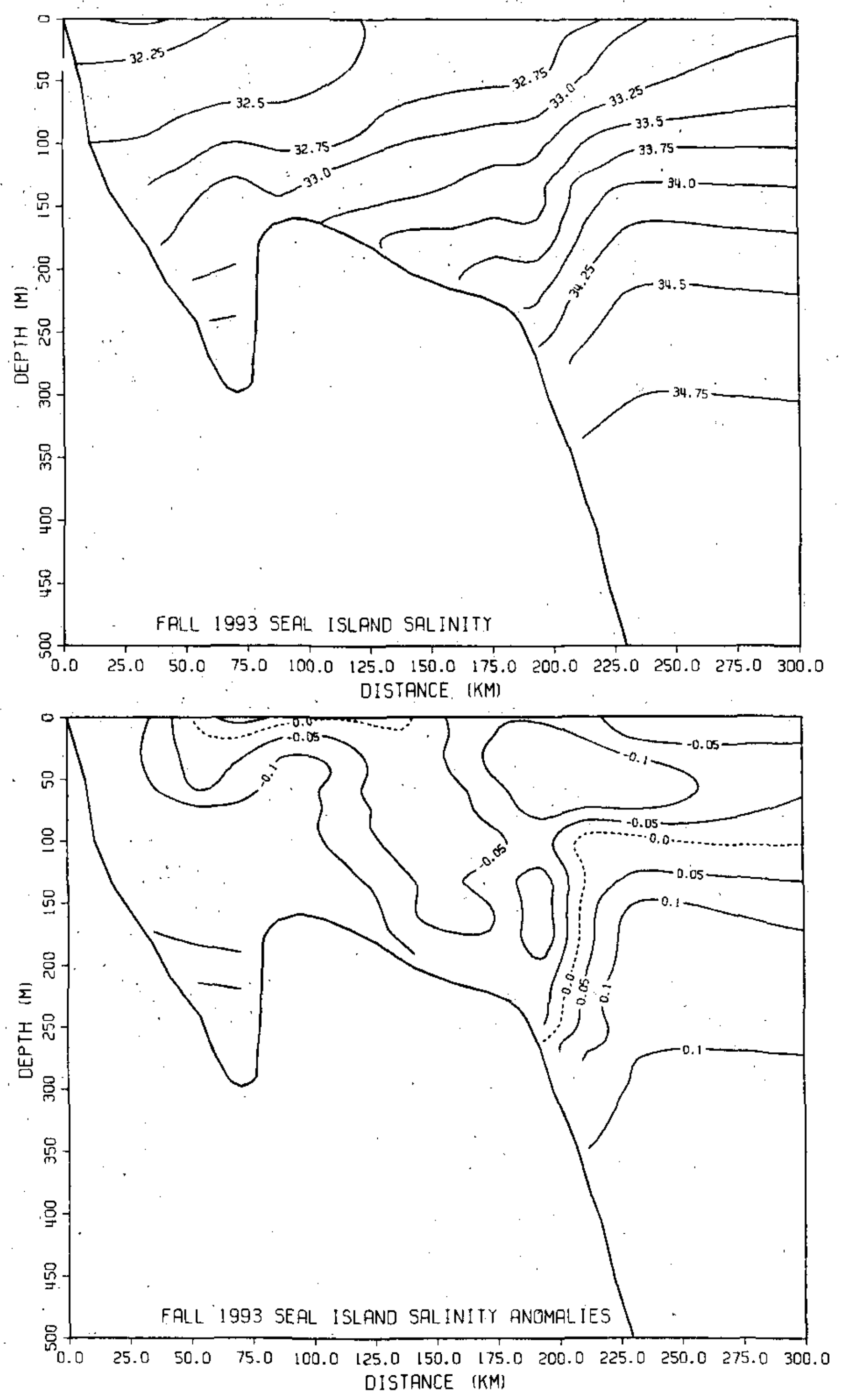

Fig. 9. The 1993 fall salinity (top panel) and salinity anomaly (bottom panel) vertical cross section for the Seal Island transect.

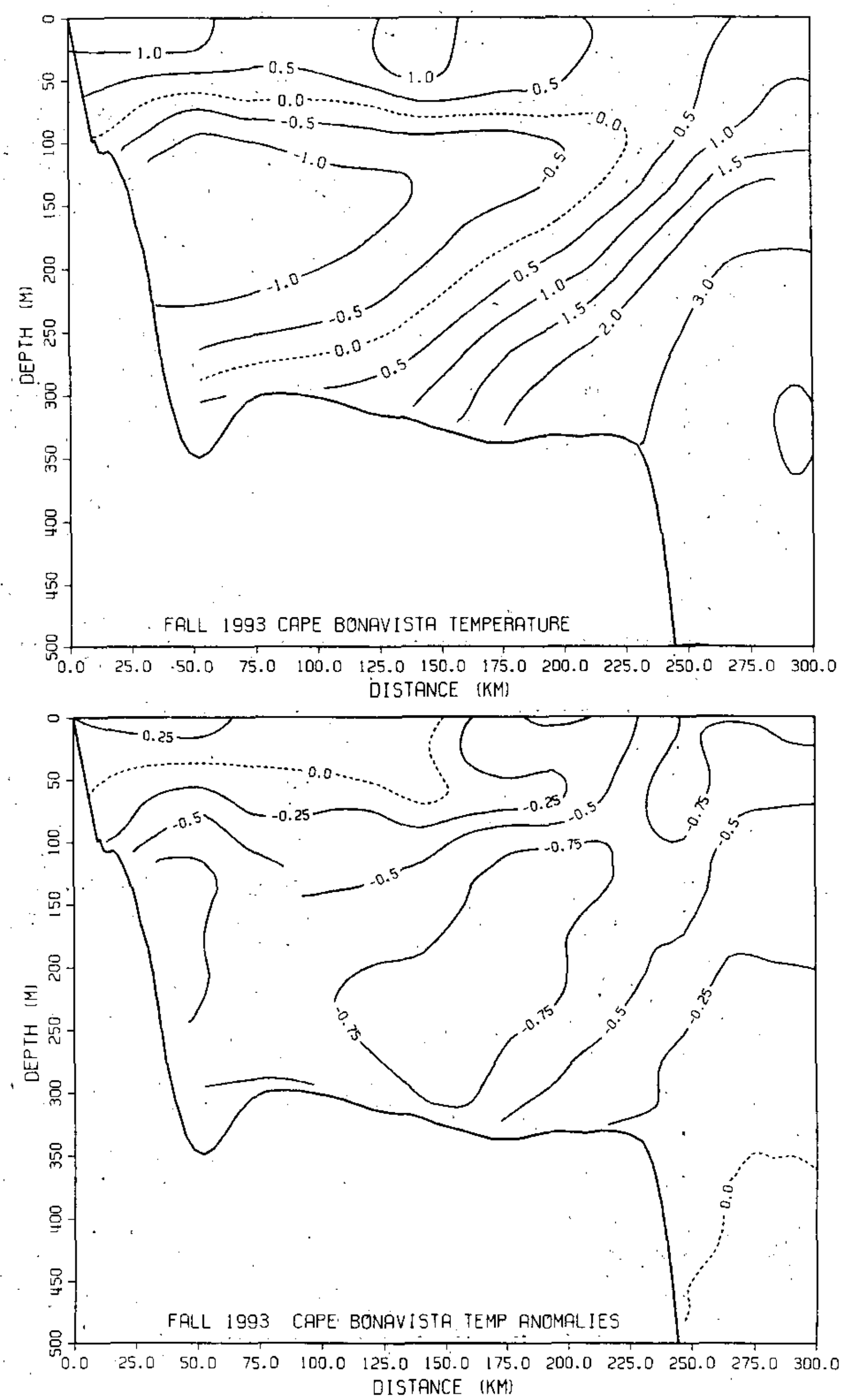

Fig. 10. The 1993 fall temperature (top panel) and temperature anomaly (bottom panel) vertical cross section for the Bonavista transect.

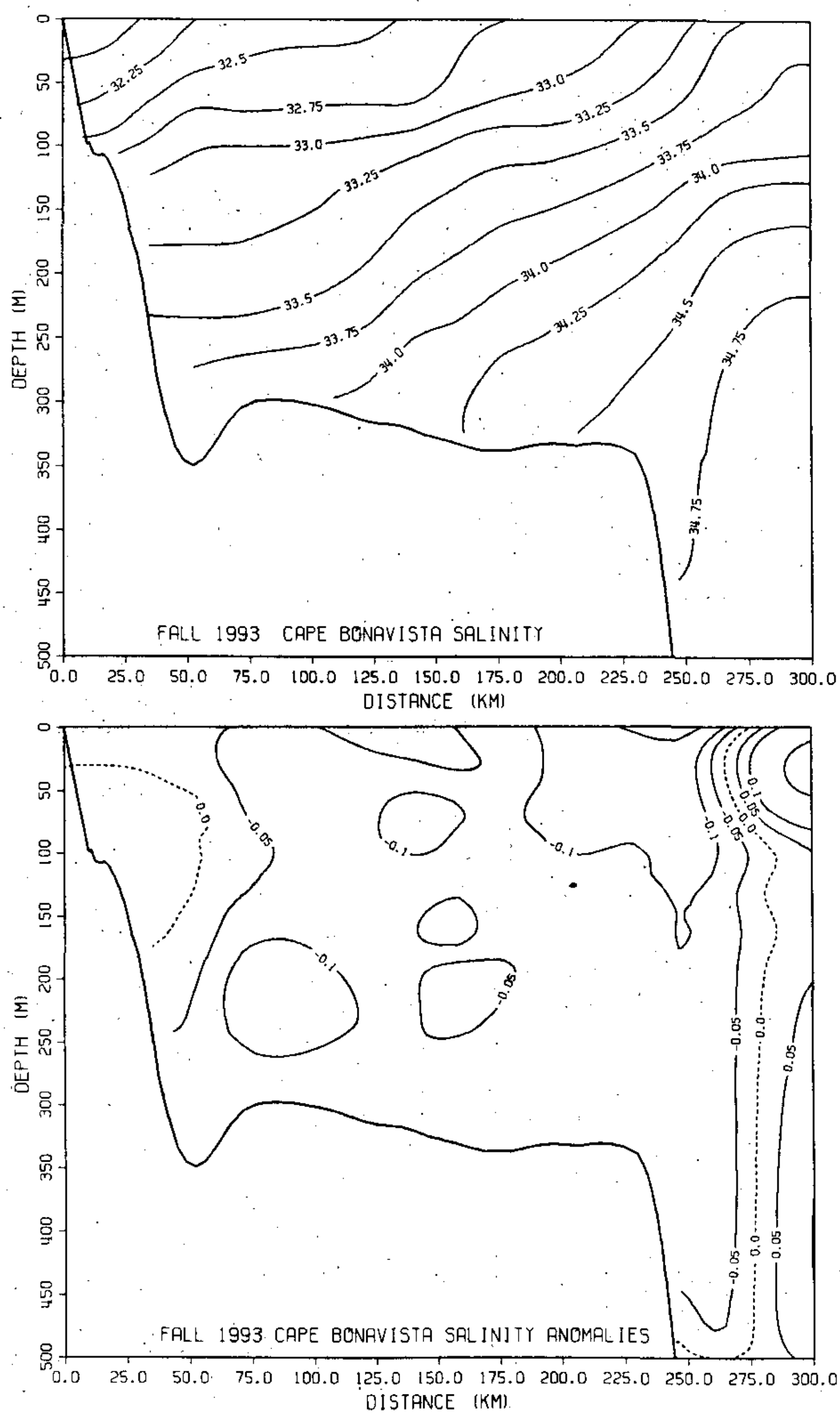

Fig. 11. The 1993 fall salinity (top panel) and salinity anomaly (bottom panel) vertical cross section for the Bonavista transect.

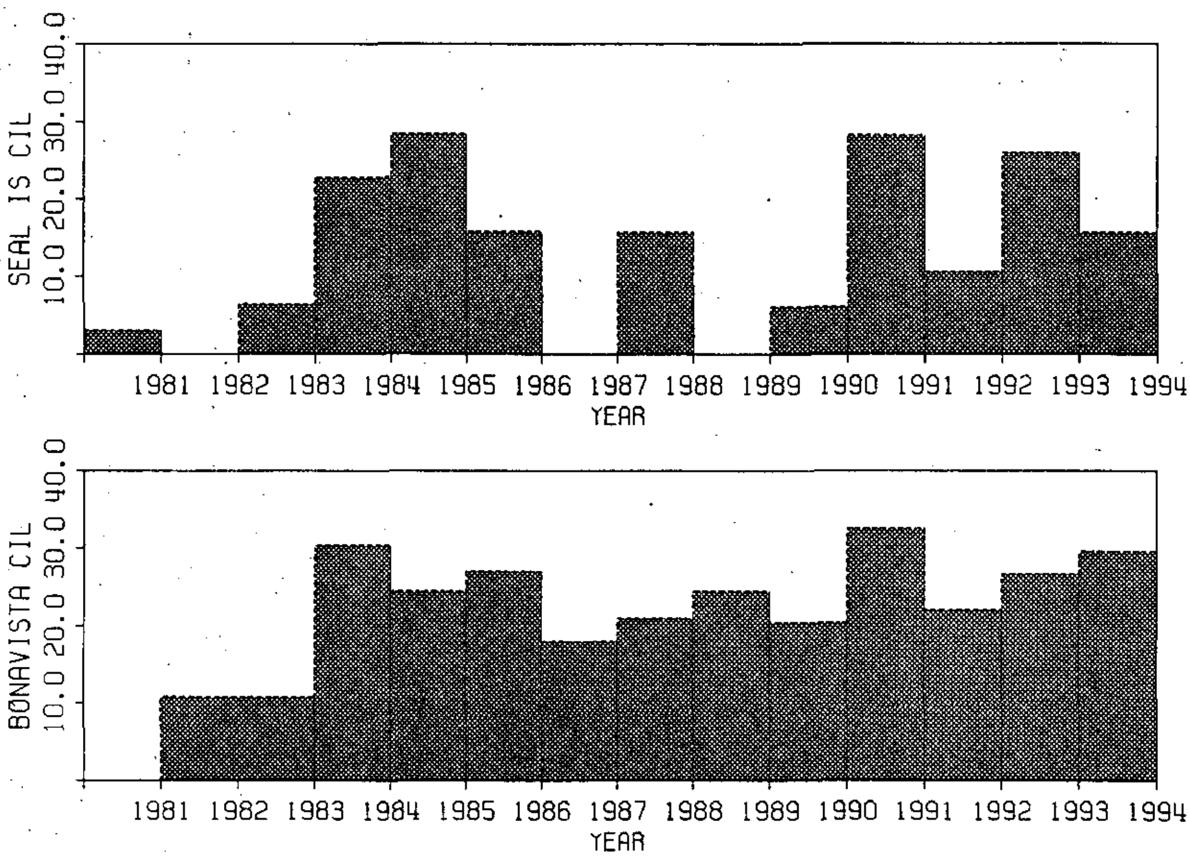

Fig. 12. Time series of CIL cross sectional area less than 0.0 °C during the fall for the Seal Island (top panel) and for the Bonavista transect (bottom panel).

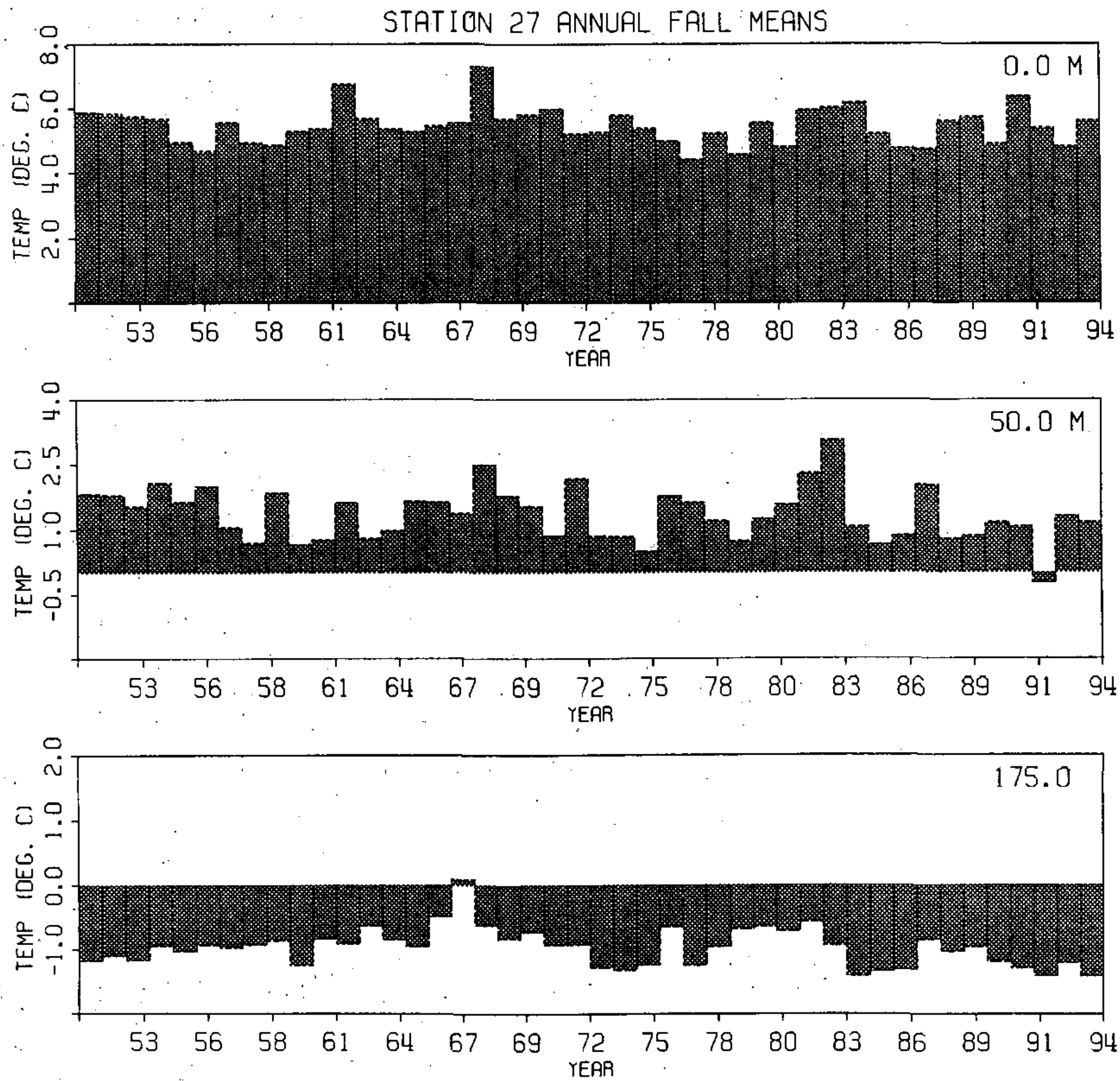

Fig. 13. Time series of Station 27 average fall temperatures at 0.0, 50.0 and 175.0 m depth.

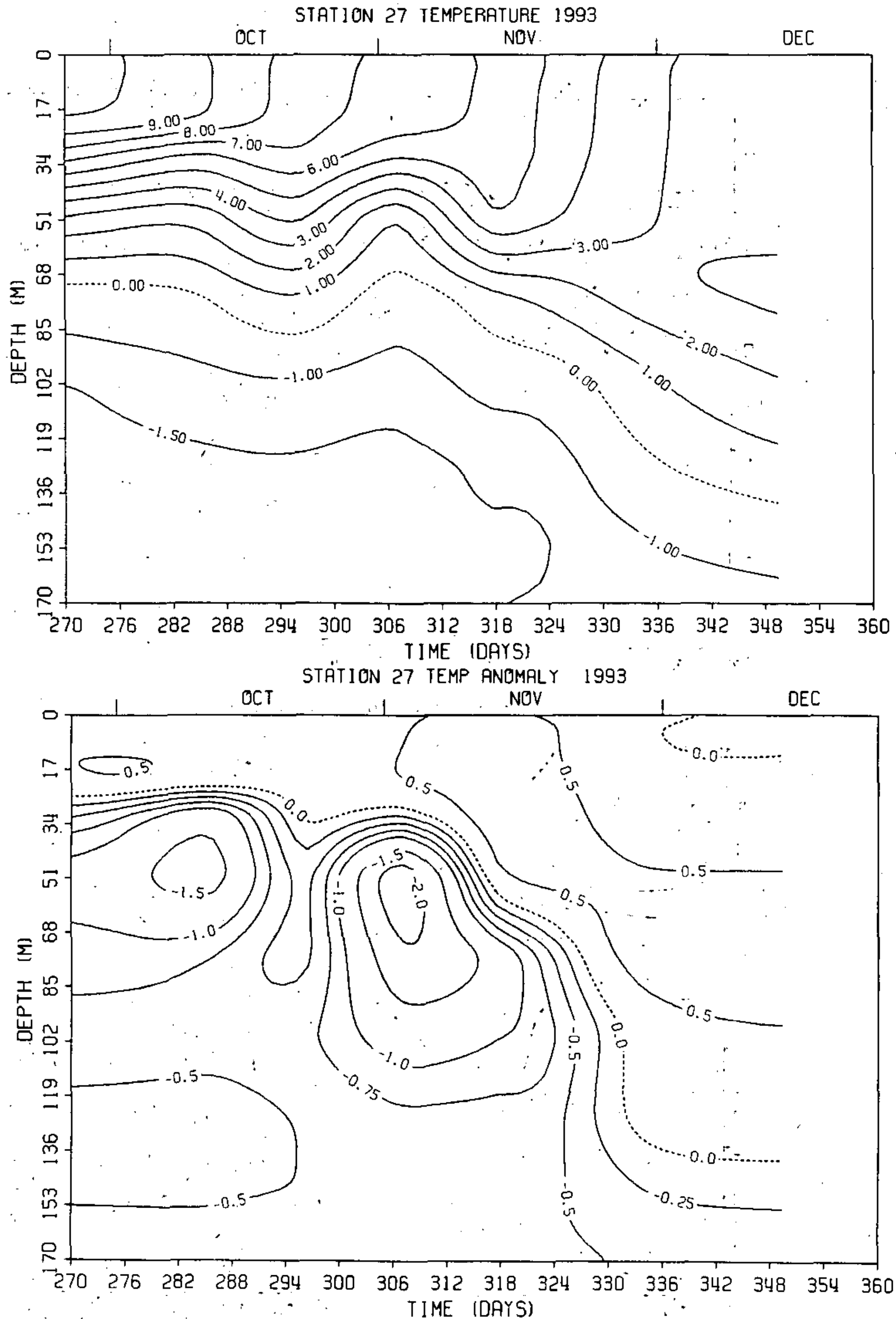

Fig. 14. The fall time series of temperature and anomaly versus depth at station 27 for 1993.

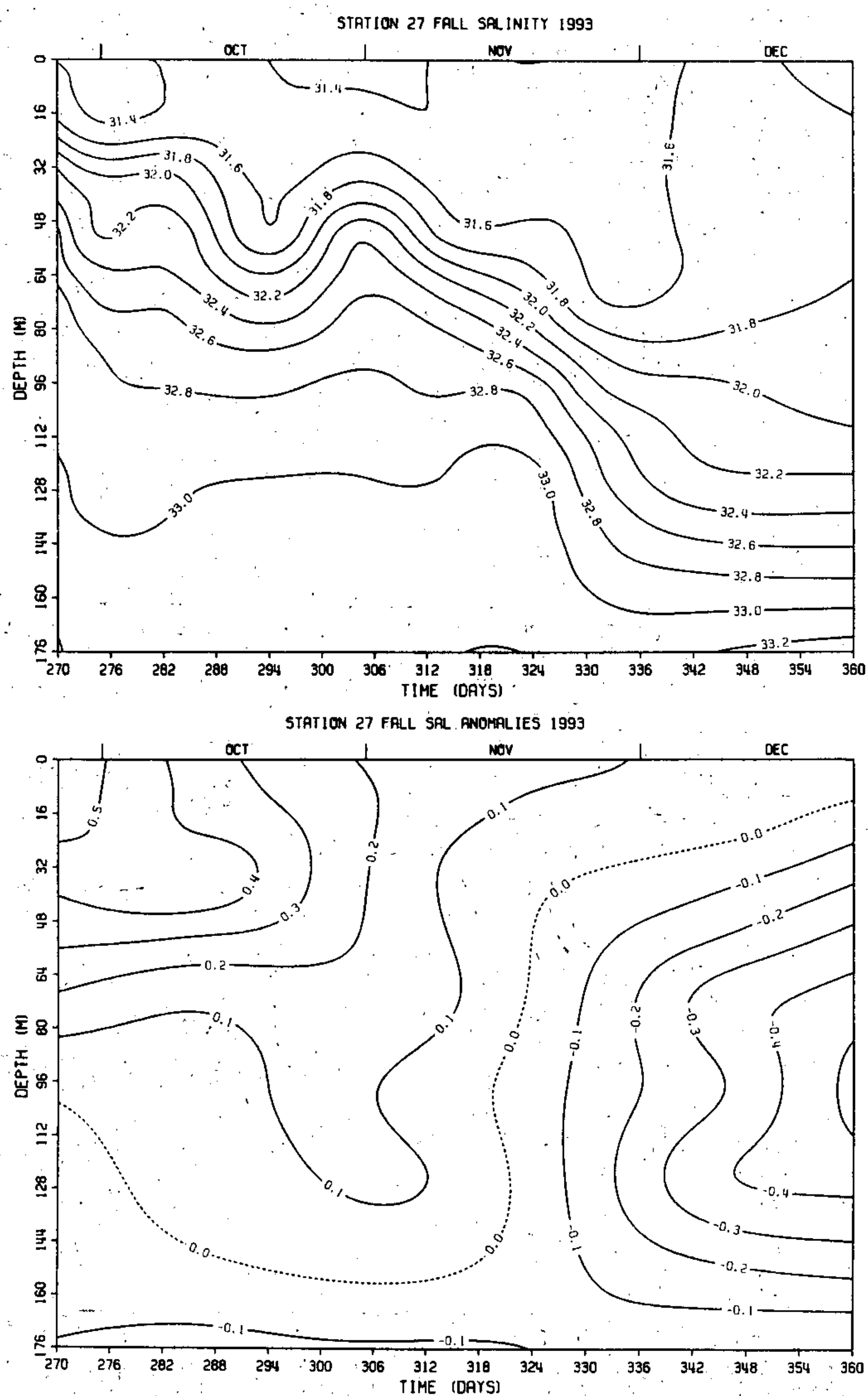

Fig. 15. The fall time series of salinity and anomaly versus depth at station 27 for 1993.

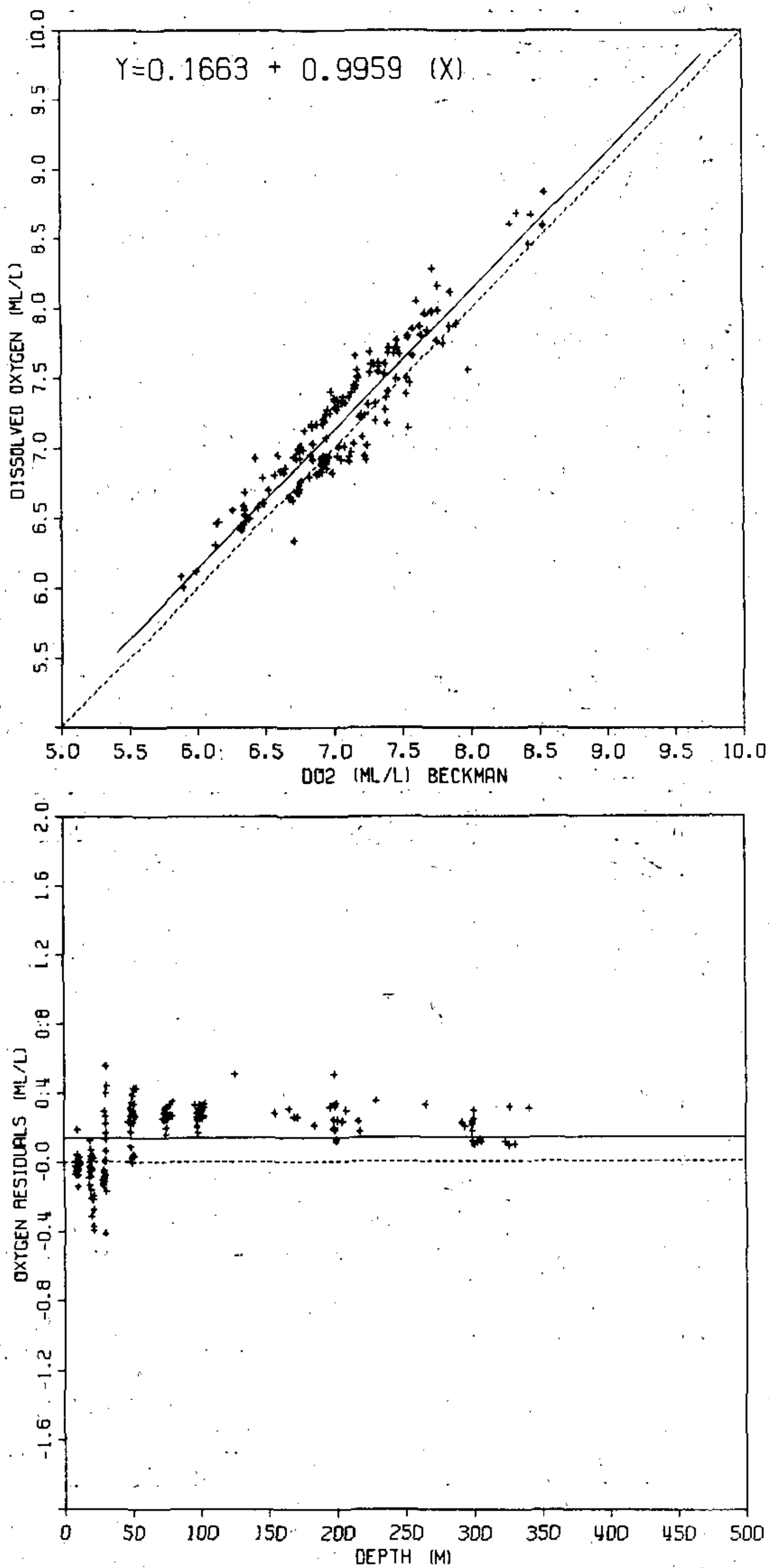

Fig. 16. A least-squares linear fit of the titrated oxygen samples to the electronic probe measurements (top panel) and the oxygen residuals (sample-sensor) versus depth (bottom panel).

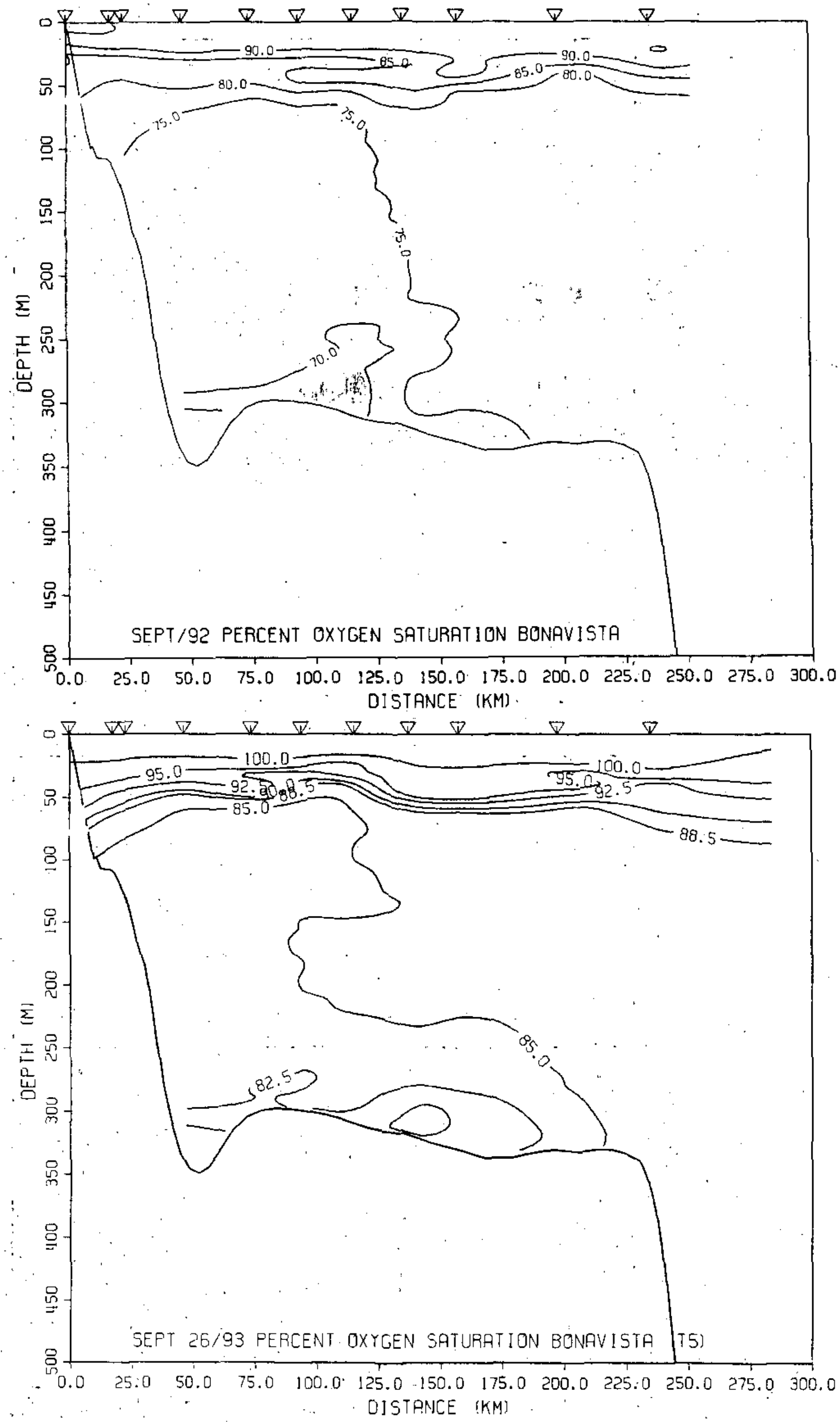

Fig. 17. The 1992 (top panel) and 1993 (bottom panel) September dissolved oxygen saturation vertical cross section for the Bonavista transect.

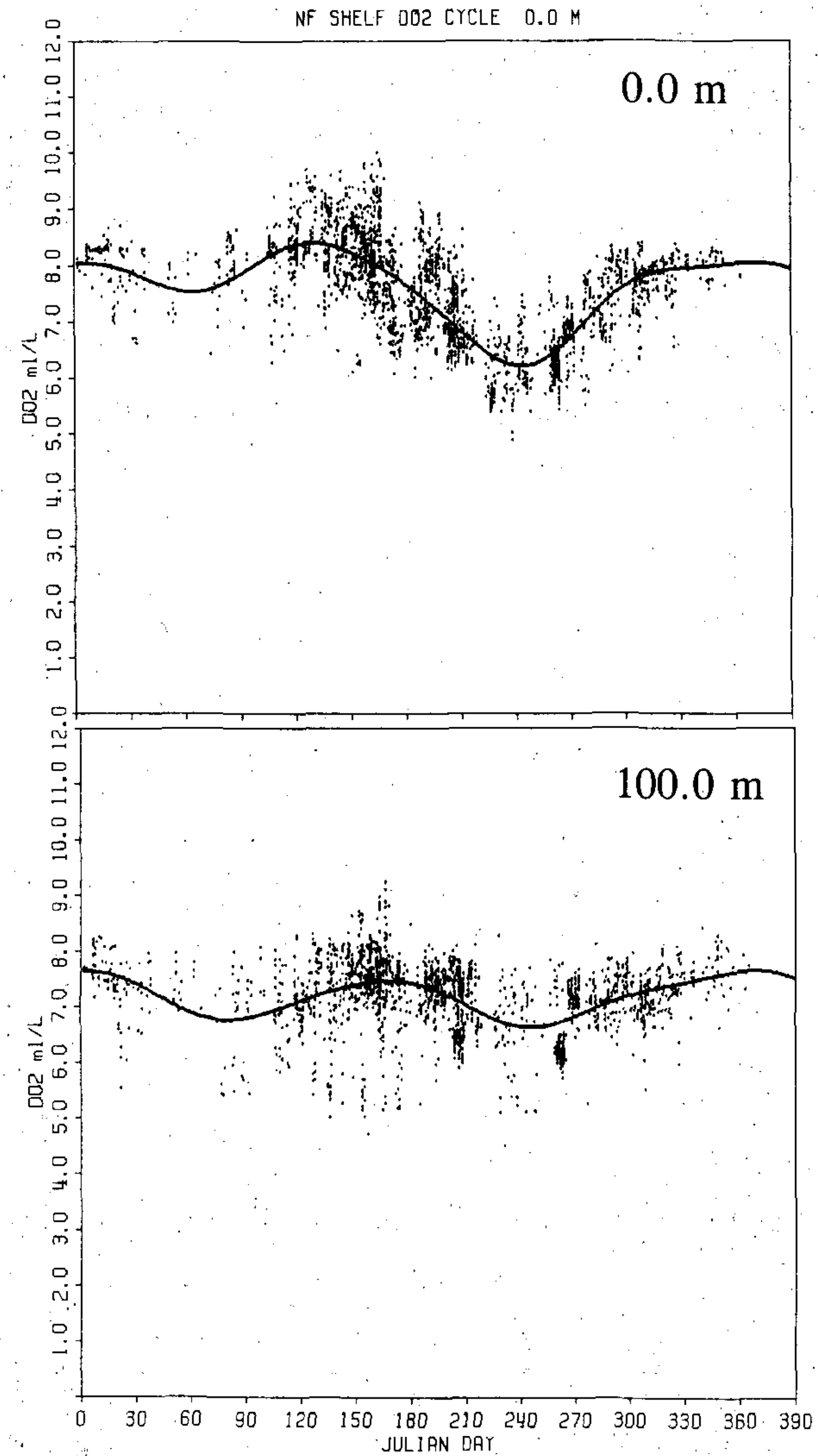

Fig. 18. Dissolved oxygen seasonal cycles at 0 and 100 m depth with the fitted harmonic regression curves based on all data available on the Newfoundland shelf.

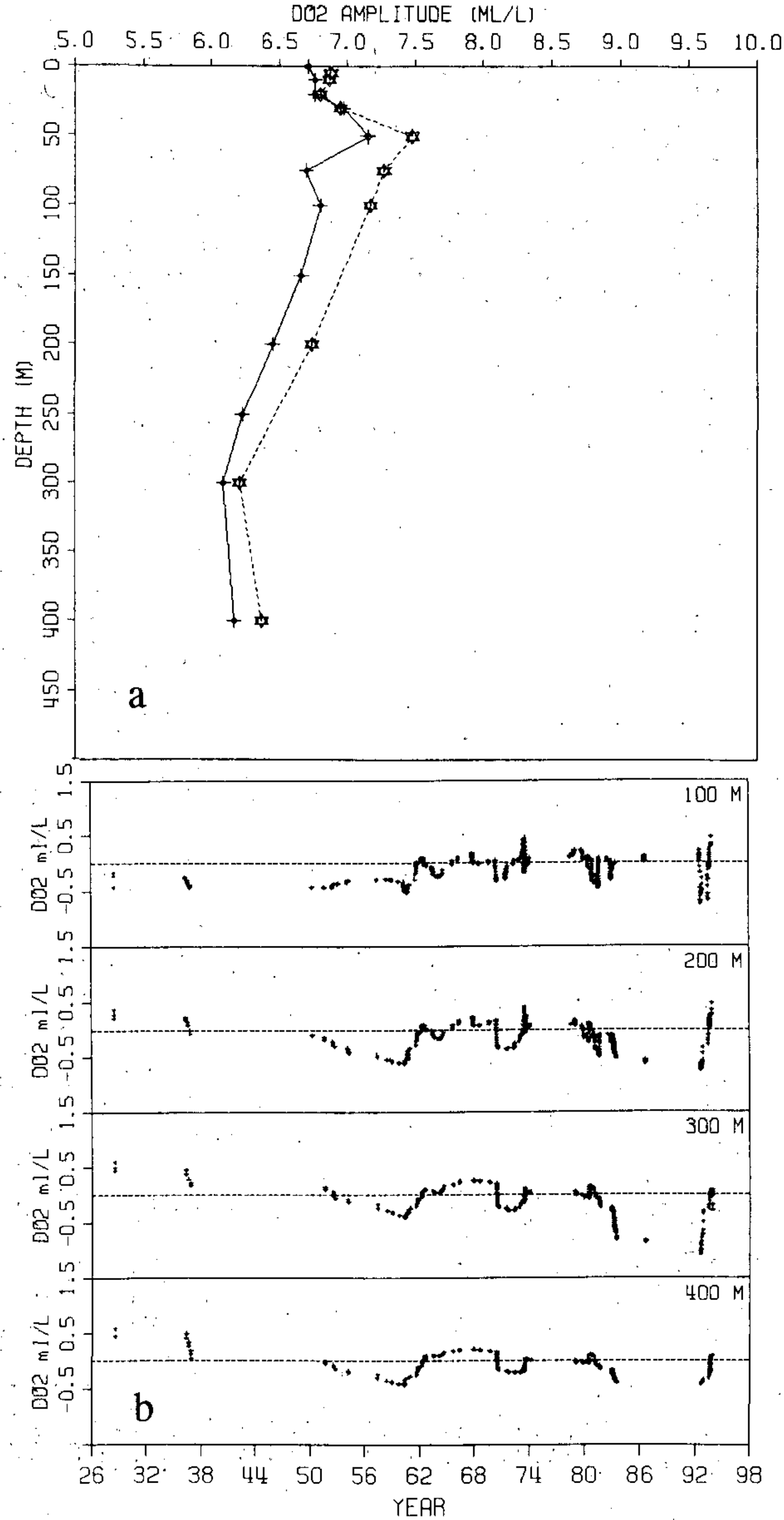

Fig. 19. (a) The September 1993 (dashed line) and the average (based on the regression of all data, solid line) dissolved oxygen amplitude on the Newfoundland shelf. (b) Time series of dissolved oxygen anomalies.