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OCEANOGRAPHIC CONDITIONS IN THE NEWFOUNDLAND REGION DURING 1995 WITH COMPARISONS TO THE 1961-1990 AVERAGE

by

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ABSTRACT

Oceanographic observations from St. Pierre Bank, Grand Bank, Flemish Cap, Northeast Newfoundland Shelf and Southern Labrador Shelf during 1995 are presented and referenced to the long-term (1961-1990) mean. At Station 27 water temperatures were normal during the winter months but had cooled to 0.5-1.0 °C below normal during the spring and early summer of 1995. By the fall temperatures were near normal over most of the water column. Salinities were near normal during early winter over the entire water column and from January to July near the bottom, but up to 1.0 psu fresher than normal in the upper water column during spring and summer. The cold-intermediate-layer (CIL) on the Newfoundland Shelf was above normal (by 20 %) along the Flemish Cap transect (Grand Bank), 28 % below normal along the Bonavista transect and 32 % below normal along the Seal Island transect. The cross-sectional area of sub-zero °C water except for the Grand Bank on the Newfoundland Shelf was the lowest in about 10 years. Minimum CIL core temperatures were above normal along the Seal Island transect, about normal along the Bonavista transect but still slightly below normal on the Grand Bank. Bottom temperatures on the shelf during the fall period increased significantly over previous years and were up to 0.5 °C above normal, except on St. Pierre Bank where significant negative temperature anomalies still exist. In general, the cold trends of the early 1990s have moderated during 1994 and 1995, however negative temperature and salinity anomalies were still present in the upper layers during the summer on the Newfoundland Shelf and during spring on St. Pierre Bank.

Résumé

Des observations océanographiques faites en 1995 sur le Banc de Saint-Pierre, sur le Grand Banc, sur le Bonnet Flamand, sur la partie nord-est du plateau de Terre-Neuve et sur la partie sud du plateau du Labrador, sont présentées et comparées à la moyenne à long terme (1961-1990). À la station 27, la température de l'eau était normale durant les mois d'hiver, mais elle est passée à 0,5-1,0 °C sous la normale au printemps et au début de l'été de 1995. À l'automne, la température s'était rapprochée de la normale dans presque toute la colonne d'eau. La salinité était près de la normale au commencement de l'hiver dans toute la colonne d'eau, et près du fond entre janvier et juillet, alors qu'elle était inférieure à la normale dans une mesure pouvant atteindre 1,0 PSU dans la partie supérieure de la colonne d'eau au cours du printemps et de l'été. Sur le plateau de Terre-Neuve, la couche intermédiaire froide (CIF) était supérieure à la normale (de 20 %) le long du transect passant par le Bonnet Flamand (Grand Banc), inférieure de 28 % à la normale le long du transect passant par Bonavista, et de 32 % sous la normale le long du transect passant par l'île Seal. Exception faite du Grand Banc sur le plateau de Terre-Neuve, la superficie en coupe transversale de la masse d'eau dont la température était inférieure à 0 °C était la plus réduite qu'on ait mesurée en une dizaine d'années. La température minimum dans le noyau de la CIF était plus élevée que la normale le long du transect passant par l'île Seal, à peu près normale le long du transect de Bonavista, mais encore légèrement sous la normale sur le Grand Banc. Sur le plateau, la température de l'eau de fond à l'automne s'est considérablement élevée par rapport aux années précédentes pour passer jusqu'à 0,5 °C au-dessus de la normale sauf sur le Banc de Saint-Pierre où règnent toujours des températures négatives anormales. En général, les eaux froides du début des années 90 se sont réchauffées en 1994 et 1995, mais on observait encore des salinités et des températures négatives anormales dans les tranches d'eau supérieures au cours de l'été sur le plateau de Terre-Neuve et au printemps sur le Banc de Saint-Pierre.

INTRODUCTION

This report presents an overview of oceanographic conditions in the Newfoundland region during 1995, with a comparison to the long-term average conditions based on historical data. The long-term mean was standardized to a base period from 1961-1990 in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council. Most of the averages computed for this report had good temporal coverage in the time interval except during the fall period for which most data is from the late 1970s to present. Much of the information presented here is based on oceanographic observations made at Station 27 and along standard cross-shelf transects (Fig. 1) during an annual oceanographic survey in July and August since 1946. In addition, all oceanographic observations made during the spring and fall pelagic and groundfish research surveys from the late 1970s to 1995 in NAFO Divisions 2J to 3NO and 3Ps are included. Data from all other sources in the area are also used to define the long-term mean.

DATA SOURCES AND ANALYSIS

Oceanographic data for NAFO Divisions 2J3KL, 3NO and 3Ps 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) to 1989 the bulk of these data were collected during the stratified random groundfish surveys using XBTs. Since 1989 conductivity-temperature-depth (CTD) recorders have replaced XBTs. Data in Subdivisions 3Pn and 3Ps are from the Canadian assessment surveys conducted in February, March and April mainly since 1973, however some historical data dating back to 1950 were available. Measurements of temperature and salinity were made using several models of CTD recorders including Seabird-911s, SBE-25s and SBE-19s. Data from the net-mounted SBE-19 CTDs are not field calibrated, but are checked periodically and are factory calibrated annually. The SBE-25 and 911s are field calibrated on each survey maintaining accuracies of 0.005 °C in temperature and 0.005 psu in salinity.

Time series of temperature and salinity were constructed at standard depths from Station 27 and temperature only on Hamilton Bank, in the Bonavista cod migration corridor and on the Grand Bank (Fig. 1 top panel, strata 206, 346 and 372) and from St. Pierre Bank (Fig. 1 bottom panel, Box B). The 1961-1990 data sets from these areas were sorted by day of the year to determine the annual cycle. Following the general methods of Petrie et al. 1992 and Myers et al. 1990, the seasonal cycle at the selected depths was removed by fitting a least squares regression of the form $\cos(\omega t - \phi)$ to the data. Unlike the time series of anomalies from fixed points like Station 27 these anomalies are based on data over larger geographical areas such as St. Pierre Bank and therefore may be subject to spatial biasing.

Temperature and salinity measurements made during the deployment of groundfish trawls are used together with other available data to determine the vertical temperature and salinity fields. Vertical cross-sections of the temperature and salinity structure during the fall along the standard Bonavista transect and across the 3Ps region in the spring were formed by averaging all observations within ± 15 minutes of latitude of the standard Bonavista line and in Box B in the 3Ps region shown in Fig. 1. The observations were then assumed to lie on a line joining the endpoints of the standard transect. The data were quality controlled and interpolated to 5.0 m depths intervals and averaged into 5.0 km bins along the line. During the calculation of anomalies an attempt was made to reduce temporal biasing by extracting historical data within 1 week on either side of the time period of the 1995 data collection.

Horizontal surface temperature maps are produced from all available data from 1961 to 1990 for a particular time and region of interest. The actual isotherms are derived from unweighted averages of all temperature profiles within a square grid projection of 0.25 degrees of latitude by 0.38 degrees longitude. Some temporal and spatial 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.

TEMPORAL ANOMALIES IN TEMPERATURE AND SALINITY

Station 27

Depth versus time contour maps of temperature and salinity and anomalies based on all XBT and CTD profile data collected at Station 27 during 1995, a total of 66 profiles, are plotted in Figs. 2 and 3. The cold isothermal water column during the winter months has temperatures ranging from -1.0 °C to -1.7 °C and remained less than -1.5 °C through to late summer at depths below 80 m. The time series shows upper layer (generally the 0 to 50 m depth range) temperatures decreasing from 0.0 °C in mid January to -1.5 °C by early March, and remained below -1.0 °C until early April, after which the surface warming commenced. By early May the upper layer temperature had warmed to above 0.0 °C and to above 10.0 °C by August at the surface after which the fall cooling commenced.

These temperatures were normal for January but had cooled to -0.25 °C below normal by late February to early March and to -0.5 °C by April in the upper water column. By mid July temperatures were -0.5 °C below normal near the surface. From 80 m depth to the bottom temperature anomalies remained up to 0.25 °C below normal until mid November after which conditions returned to near normal. Upper layer salinities were below normal by up to 0.8 psu from February to October. From 50 m to the bottom throughout the time series, salinities were slightly below normal, except during the fall when they were near to slightly above normal.

The annual time series of monthly temperature and salinity anomalies at Station 27 during 1995 at standard depths again referenced to a 1961 to 1990 average, are shown in Figs. 4 and 5. The large negative temperature and salinity anomaly in the upper water column during the summer returned to more normal values during the fall. In the depth range of 75 to 175 m there is evidence of summer heat propagating from the surface layers down into deeper water near the bottom with temperature rising to near normal values during late fall. Salinities were near to slightly below normal through the year in the depth range of 75-175 m.

The low passed filtered time series of temperature and salinity anomalies at standard depths show three major cold and fresher than normal periods at near decadal time scales since the early 1970s (Fig. 6). At the surface and at 30 m depth the negative temperature anomalies that began in late 1990 and reached a peak in mid 1991 have moderated to above normal conditions by the summer of 1994 but returned to colder than normal by the summer of 1995. At the deeper depths of 100 and 175 m strong negative temperature anomalies have persisted since 1983 with a few periods of positive anomalies during the mid to late 1980s. During 1994 and 1995 bottom temperatures have been slowly returning to more normal values. Upper layer salinity anomalies shows the large fresher than normal anomaly that began in early 1991 had returned to near normal conditions by early 1993 but returned to fresher conditions by the summer of 1995. Other periods with colder and fresher than normal salinities particularly in the early 1970s and mid 1980s are associated with colder than normal air temperatures (Findlay and Deptuch-Stapf, 1991), heavy ice conditions and larger than average summer cold-intermediate-layer (CIL) areas on the continental shelf (Drinkwater 1994, Colbourne et al. 1994a).

The vertically averaged annual station 27 temperature (which is proportional to the total heat content of the water column, ie. $H/\rho C_p$) time series (Fig. 7a) show large amplitude fluctuations again at near decadal time scales with cold periods during the early 1970s, mid 1980s and early 1990s. The total heat content of the water column which reached a record low in 1991 has since recovered somewhat but remains well below the warm 1950s and 1960s. The 0 to 50 m vertically averaged summer salinity (Fig. 7a) shows similar behaviour as the heat content time series with large fresher than normal periods corresponding to the colder than normal conditions. The low salinity values of the early 1990s were comparable to values experienced during the 'Great Salinity Anomaly' of the early 1970s (Dickson et al. 1988). During 1993 summer salinities started returning to more normal values but have decreased again by the summer of 1995. The seasonal cycle of the vertically averaged Station 27 temperature for 1991 and 1995 are compared to a least squares fit to the historical data in Fig. 7b. The anomalous conditions in both the phase and amplitude of the temperature cycle during 1991 are clearly evident. During 1995 the below normal temperatures during spring and fall are clearly evident, however the phase was near normal.

Divisions 2J (stratum 206), 3K (stratum 346) AND 3L (stratum 372)

Figure 1 shows the approximate boundaries of strata 206, 346 and 372 in NAFO Divisions 2J, 3K and 3L (Doubleday, 1981) for which time series of near bottom temperatures were constructed. These strata were selected to show the variations in bottom temperature at different depth ranges on the shelf and banks, from 80 m in 3L to 150 m in 2J and to 330 m in 3K. 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 1995 for the selected strata are shown in Fig. 8.

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 from 1988 to 1994. Temperature variations ranged from -0.5 °C in the early 1950s, mid 1980s and early 1990s, to highs of 1.0 °C during the 1960s and late 1970s. Bottom temperatures during the fall of 1995 showed a significant increase from the low values experienced from 1991 to 1993 with temperatures reaching near 1.0 °C.

The time series in Divisions 3KL are bottom temperature of slope water 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 aliasing caused by high frequency oscillations in the shelf/slope thermal front which is 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 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, warmed to above zero values during the latter half of the 1980s and have shown a decreasing trend from 1989 to 1994. During 1995 near bottom temperatures increased significantly during the fall to near 1.0 °C.

St. Pierre Bank (Division 3Ps)

The time series of temperature anomalies from 1950 to 1995 from region B in Fig. 1 on St. Pierre Bank are shown in Fig. 9a at standard depths of 0, 20, 50 and 75 m. This time series was low pass filtered to suppress the high frequency variations at seasonal scales. Observations made during the same day appear as vertical lines and indicates spatial variability in the temperature over the bank at the same depth.

The time series is characterized by large variations with amplitudes ranging from ± 1.0 °C and with periods between 5 to 10 years with some higher frequency variations in the upper water column. The cold periods of the mid 1970s and the mid 1980s are coincident with severe meteorological and ice conditions in the Northwest Atlantic and colder and fresher oceanographic anomalies over most of the Canadian continental shelf. During the cold period beginning in 1984 temperatures decreased by up to 2.0 °C in the upper water column and by 1.0 °C in the lower water column and continued below normal until 1990. Since 1991 temperatures have moderated over the top 50 m of the water column but have remained well below average at 75 m depth. During 1992 to 1995 the sign of the temperature anomalies changed at 0 and 20 m depth but remained negative at the surface and at 75 m depth.

Flemish Cap (Division 3M)

The time series of temperature anomalies on the Flemish Cap at various standard depths down to at least 100 m (Fig. 9b) are characterized by 3 major cold periods: most of the 1970s, mid 1980s and the late 1980s to early 1990s. The cold period beginning around 1971 continued until 1977 in the upper layers, temperature anomalies in the 1970s near the bottom at 200 m were insignificant. From 1978 to 1984 the temperature anomalies showed a high degree of variability in the upper water column with a stronger tendency towards positive anomalies. By 1985 in the top 100 m of the water column, intense negative temperature anomalies had returned with peak amplitudes reaching near -3.0 °C to 50 m depth. This cold period moderated briefly in 1987 but returned again by 1988. By 1995 upper layer temperatures have moderated somewhat however below normal conditions still exist over most of the water column.

The time series of salinity anomalies (Fig. 9c) shows large fresher than normal conditions from 1971 to 1976 and from 1983 to 1986 in the upper 100 m of the water column with peak amplitudes reaching 0.5 psu below normal. Salinities during the early 1990s range from slightly below normal in 1992 (from 20 to 100 m) to slightly above normal in 1995. In general the temperature and salinity anomalies are very similar to that at Station 27 and elsewhere on the continental shelf over similar depth ranges (Colbourne 1993).

VERTICAL TEMPERATURE, SALINITY AND OXYGEN DISTRIBUTION

Vertical cross-sections of the temperature and salinity fields together with their anomalies along the standard Flemish Cap, Bonavista and Seal Island transects for the summer of 1995 are presented in Figs. 10 to 15. The anomalies were calculated from the mean of all available data for the transect from 1961 to 1990 during the time period of the 1995 survey. No attempts were made to adjust the mean for possible temporal biasing arising from variations in the number of observations within the time interval.

Flemish Cap (Grand Bank 47 °N, Summer)

The summer temperature along the Flemish Cap transect (Fig. 10) ranged from 10 °C near the surface to -1.0 °C below 75 m across the Grand Bank and about 3.0 °C over the Flemish Cap in the depth range from 80 m to the bottom. These temperatures were more than 1.0 °C below normal in the upper layer over the Grand Bank and about 0.5 °C below normal near bottom over the Grand Bank and Flemish Cap regions. Upper layer salinities (Fig. 11) were slightly fresher than normal over the Grand Bank to slightly saltier than normal over the Flemish Pass and Cap, while deeper (below 150 m) water salinities were normal.

Bonavista (Summer)

Temperatures along the Bonavista transect (Fig. 12) in the upper 50 m of the water column ranged from 0.0 °C to 8.0 °C near the coast and to 4.0 to 6.0 °C over most of the continental shelf. In deeper water (50 m to the bottom) temperatures ranged from -1.0 °C to -1.5 °C near the coast and to 0.0 °C to 3.0 °C further offshore near the edge of the continental shelf and beyond. The corresponding temperature anomalies ranged from 0.0 to -1.0 °C in the surface layer over the continental shelf and to 0.0 to 1.0 °C above normal over the water column from 50 m to the bottom across the shelf. Bonavista salinities (Fig. 13) ranged from 31.0 psu near the surface to 33.5 psu near the bottom over the inshore portion of the transect to 34.75 psu at about 325 m depth near the shelf edge. The corresponding salinity anomalies show fresher than normal conditions ranging from 0.1 to 0.9 psu below normal in the upper water column in the inshore region and from 0.1 to 0.6 psu above normal in the surface layers over the edge of the continental shelf and in the depth range of 100-300 m over the shelf.

Seal Island (Summer)

Temperatures along the Seal Island transect (Fig. 14) ranged from 2 to 6.0 °C in the upper layer and from -0.5 to 0.0 °C over most of the shelf below 50 m depth and about 3.0 °C beyond the shelf edge. Temperature anomalies along the Seal Island transect ranged from 0.0 to 1.0 °C above normal over the shelf and about 0.0 to -1.0 °C below normal in the offshore region beyond the shelf edge. Salinities along the Seal Island transect (Fig. 15) were generally 0.1 psu to 0.8 psu above normal over most of the shelf and normal in deep water at the shelf edge.

Bonavista (Autumn)

The vertical distribution of the temperature and salinity fields and anomalies along the standard Bonavista transect for the fall of 1995 are presented in Figs. 16 and 17. The fall temperature structure across the northeast Newfoundland shelf along the Bonavista transect in the bottom layer is very similar to summer conditions with temperatures ranging from subzero inshore to 3.0 °C near the edge of the continental shelf. The seasonal warm upper layer has not completely cooled down, so the summer-like structure of the cold intermediate layer (CIL) is still present.

Upper layer temperatures ranged from 3.0 °C near the coast to 2.0 °C offshore, about 1.0 to 2.0 °C warmer than average over the inshore portion of the continental shelf and from 0.5 to 1.0 °C warmer than average below 100 m depth. On the outer shelf and further offshore, beyond the shelf edge, temperatures were slightly above average in the upper layer and slightly below average in deeper water.

Upper layer salinities off Bonavista (Fig. 17) during the fall ranged from 32.25 psu near the coast to 33.5 psu near the shelf edge. Deep water salinities ranged from 33.5 psu to 34.5 psu near the shelf break. Salinity anomalies were generally fresher than normal (0.1-0.4 psu) over the shelf in the upper layer and near normal over the rest of the area.

Bonavista Oxygen Distribution (Summer)

Dissolved oxygen data are now routinely collected along transects of Newfoundland on oceanographic research surveys. 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 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). The electronic measurements are then corrected from a least-squares linear regression of the titration measurements to the electronic sensor measurements. 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 historical oxygen data along the Bonavista transect together with data collected in July 1995 are shown in Fig. 18. The average dissolved oxygen distribution across the northeast Newfoundland shelf (Fig. 18) shows saturations ranging form 90 to 100 % in the surface layers to about 80 to 85 % over the shelf in the CIL and about 90 % in deeper water on the continental slope areas. During the summer of 1995 saturation levels ranged from 90 to 100 % from the surface to about 100 m depth over the shelf and to bottom near the shelf edge. Over the inshore portion of the shelf values ranged from 85 to 90 % from 100 m to the bottom. These values are very similar to 1994 during the same time period and show no evidence of oxygen depletion.

St. Pierre Bank 3Ps (Spring Temperature)

Vertical cross-sections of the average temperature field for April based on all available historical data from 1961 to 1990 and for April 1995 are shown in Fig. 19. Again no attempts were made to adjust this average for possible temporal or spatial biasing arising from variations in the number of observations within the time interval or within the area. An examination of the data indicates that the observations are well distributed geographically across the complete transect, however, temporally, most of the data have been collected since the early 1970s.

The average April temperature ranges from 1.0 °C to 2.0 °C near the coast and over St. Pierre Bank and beyond the shelf edge in the upper 100 m of the water column. In the deeper water of Burgeo and Hermitage Channels and on the continental slope region the temperature ranges from 2.0 °C at approximately 125 m depth to 5.0 °C to 6.0 °C near the bottom. Near the edge of the continental shelf on the Southwestern Grand Bank the temperature field is marked by a strong thermal front separating the warmer slope water from the Labrador Current water over St. Pierre Bank. In this region temperatures increase from 1.0 °C to 2.0 °C at 125 m depth to between 6.0 °C to 7.0 °C at about 175 m depth, a temperature gradient of 1.0 °C per 10 m depth change. In April 1995 temperatures ranged from less than 0.5 to 1.0 °C in the upper 100 m over Burgeo and Hermitage Channels, about normal, and from 0.0 °C to 0.5 °C over St. Pierre Bank, up to 1.0 °C below average over the central portion of the bank. Deep water temperatures on the continental slope in 1995 ranged from 4.0 °C to 7.0 °C, about normal.

THE COLD INTERMEDIATE LAYER (CIL)

Summer Area

As shown earlier in Fig. 12 the vertical temperature structure on the Newfoundland continental shelf is dominated by a cold layer of water, commonly referred to as the CIL (Petrie et al. 1988), trapped between the seasonally heated upper layer and warmer slope water near the bottom. For example, along the Bonavista transect during 1995 this cold layer extended offshore to about 200 km, with a maximum thickness of about 190 m corresponding to a cross-sectional area of about 19.7 km^2, compared to the 1961-90 average of 26.8 km^2. The area of the core of the CIL (temperatures less than -1.5 °C) during 1995 was very small along the Bonavista transect at only about 2 km^2, compared to an average of about 9 km^2 and non-existent along the Seal Island transect.

Figure 20 shows a time series of the CIL cross-sectional area for the Seal Island, Bonavista and Flemish Cap transects. In 1995 the CIL area off Bonavista was about 30 % below normal compared to about 7 % above normal in 1994, 28 % in 1993 and up to 68 % in 1991. The CIL area along the Seal Island transect was also well below normal (32%) during 1995 with a cross-sectional area of 19.2 km^2 compared to the 1961-90 average of 28.3 km^2. During 1994 the CIL along the Seal Island transect was 36 % above normal and up to 61 % above normal in 1991. Along the Flemish Cap transect the CIL remained above normal during the summer of 1995 at about 18 % (29.8 km^2) compared to 12 % in 1994 and to 48 % during 1991. In general, the total cross-sectional area of sub-zero °C water, except for the Flemish Cap transect, was the lowest in about 10 years.

The intensity or minimum core temperatures of the CIL for all three transects from 1948 to 1995 are shown in Fig. 21. The minimum temperature observed in the core of the CIL along the Seal Island transect was about -1.17 °C well above the normal of -1.57 °C. Core temperatures along the Bonavista transect were about normal at -1.63 °C and slightly below normal along the Flemish Cap transect at about -1.62 °C compared to the normal of -1.52 °C.

Autumn Area

The 1980 to 1995 time series of CIL area less than 0.0 °C for the Seal Island and Bonavista transects during the fall groundfish surveys are shown in Fig. 22. The CIL area along the Bonavista transect shows similar trends as in the summer, however the average area has decreased from 33 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 1995 was about 7 km^2 compared to 26 km^2 in 1994, 30 km^2 in 1993, 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 summer heating and 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 1994 was about 14 km^2 compared to 16 km^2 in 1993, 26 km^2 in 1992 and 11 km^2 in 1991. Data for the fall of 1995 was not available.

CIL Volume (Summer and Autumn)

The total volume of water on the Newfoundland and southern Labrador shelves shoreward of the 1000 m isobath and within NAFO divisions 2J3KL is approximately 2.0×10^{14} m^3. The calculation of the volume of sub-zero water overlying the continental shelf is described by Colbourne and Mertz, 1995. The spatial variation in the amount of subzero water on the shelf in different years is determined by contouring the thickness of the layer of water less than 0.0 °C on the Northeast Newfoundland Shelf in NAFO Divisions 2J and 3KL during the summer and fall periods. The isolines of CIL thickness show large variations from summer to fall of the same year and from cold years to warmer years (Colbourne 1995). The average thickness of the CIL is maximum (> 150 m) along the east coast of Newfoundland within 100 km of the shore and decreases to 0.0 m near the edge of the shelf, on the southern Grand Bank and on Hamilton Bank during warm years in the fall. During the summer and fall of 1995 the thickness of the CIL was significantly below average from the Grand Bank to Hamilton Bank (Fig. 23).

The time series of total volume of subzero water over the 2J, 3KL area (Fig. 24a) shows maximum values during the cold periods of the mid 1980s and early 1990s. The total volume of subzero °C water on the shelf increased from approximately 3.3 X 10^4 km^3 during the summer of 1989 to 5.6 X 10^4 km^3 in 1990 a 70 % increase. Since 1991 the volume of subzero °C water on the Newfoundland Shelf during summer and fall has been slowly decreasing, and by 1995 it has decreased to values of the early 1980s and from 1986 to 1989. The average volume of subzero °C water on the shelf during the summer is approximately 4.0 x 10^{13} ± 0.9 m^3 (40,000 km^3) roughly one-quarter of the total volume of water on the shelf. The time series during the fall shows similar trends but the total volume has reduced to 2.4 x 10^{13} ± 0.8 m^3 about one-half the summer values. Due to limited data sets the volume estimates were not calculated prior to 1980. The time series of the volume of subzero °C water over the 2J3KL area and the average CIL cross sectional areas along widely spaced transects (Seal Island, Bonavista and Flemish Cap) exhibits some differences but are highly correlated with correlation coefficients of 0.85 and 0.76 for the summer and fall periods respectively (Colbourne and Mertz 1995) (Fig. 24b).

HORIZONTAL TEMPERATURE AND SALINITY FIELD

Surface (Summer and Autumn)

Figure 25 and 26 shows horizontal maps of the average and the July 1995 near surface (10 m) and 75 m depth temperature and salinity fields in Atlantic Canada from all available data from July 15 to 31, 1961-90 and for 1995. These contours were derived from unweighted averages (ie. data for the entire time period are assumed synoptic) of all data in a square grid of 0.25 degrees. The normal sea surface temperature for this time period ranged from 12.0 °C over the Grand Bank to 5.0 °C off southern Labrador on Hamilton Bank. The surface temperatures during July 1995 ranged from 9.5 °C over the Grand Bank to about 4.5 to 5.0 °C on Hamilton Bank. In general the surface temperature over most of the surveyed area was up to 1.0 to 2.0 °C below the long-term average. Surface salinities show slightly fresher than normal conditions particularly along the coastal regions.

During the fall period the average near surface temperature have cooled down to between 1.0 °C to 1.5 °C in Division 2J3K and from 1.5 °C to 6.0 °C in Division 3L. During the fall of 1995 surface temperatures ranged from 0.0 °C to 2.0 °C in 2J3K and from 3.0 °C to 8 °C in Division 3L, up to 1.0 °C below average in north and up to 2.0 °C above average in the south (Fig. 27).

75 Meters (Summer)

At 75 m depth, close to the bottom over most of the Grand Bank and about at the center of the CIL over most of the northeast Newfoundland Shelf, the average summer temperature ranged from 0.0 °C over the Grand Bank to about 3.0 °C along the continental slope and less than -1.0 °C over parts of the northeast Newfoundland and Labrador Shelves. The temperatures over the surveyed area in July 1995 ranged from -1.25 °C along the northeast Newfoundland coast to 3.0 °C at the shelf edge and from -1.0 to -1.25 °C over the Grand Bank. Except for the Grand Bank temperatures at 75 m depth were generally warmer than the long-term average. Salinities at 75 m depth were slightly saltier than normal in most areas (Figs. 25 and 26)

Bottom (Autumn)

The average (1961-90) and the 1995 fall bottom temperature for the 2J and 3KL area are shown in Fig. 28 (isotherms are -1, -0.5, 0, 1, 2, and 3 °C, bathymetry lines are 300 and 1000 m). The average bottom temperature over most of the northeast Newfoundland shelf (2J3K) ranges from less than 0.0 °C inshore, to 3.0 °C offshore at the shelf break. The average temperature over most of the Grand Bank varies from -0.5 °C 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 percentage area of water less than -0.5 °C over the Grand Bank and northeast shelf from 1990 to 1994 has been significantly larger than the 1961-1990 average. In 1992 and 1993 the bottom temperature anomalies ranged from -0.25 °C to -0.75 °C over the northeast shelf and from -0.25 °C to -1.0 °C over the Grand Bank (Colbourne 1994b). During the fall of 1995 bottom temperatures have moderated significantly over most areas on the Newfoundland Shelf with anomalies up to 0.5 °C above normal in many places. During 1995 the percentage area of water less than -0.5 °C on the Grand Bank was significantly below average.

3PS Bottom (Spring)

The 1961-90 average and the 1995 April bottom temperature maps for the 3Ps and 3Pn areas are shown in Fig. 29. In general the bottom isotherms follow the bathymetry around the Laurentian Channel and the Southwestern Grand Bank increasing from 2.0 °C at 200 m depth to 5.0 °C in the deeper water. The average April bottom temperatures ranged from 5.0 °C in the Laurentian, Burgeo and Hermitage Channels to about 3.0 °C to 4.0 °C on Rose Blanche Bank and on Burgeo Bank and from -0.75 °C on the eastern side of St. Pierre Bank to 2.0 °C on the western side. During April 1995 temperatures were about average over Burgeo Bank and Hermitage Channel and along the western side of St. Pierre Bank. On St. Pierre Bank temperatures ranged from 0.5 to 1.0 °C below average, similar to 1994 values.

SUMMARY

Time series of temperatures at Station 27 shows normal values during the winter of 1995 over all depth ranges. By the spring and summer however temperatures had decreased to about 0.5 to 1.0 °C below normal in the upper water column and remained slightly below normal in deeper water. By October temperatures had returned to near normal values over most depths. Salinities were significantly below normal in the upper water column during most of the year and near normal in deeper water.

Temperature anomalies on St. Pierre Bank show the cold period which started around 1984, continued to the spring of 1995 with temperatures up to 1.0 °C below average from 50 m to the bottom. Since 1991 temperatures have moderated over the top 50 m of the water column. Bottom temperatures on Hamilton Bank and the Grand Bank during the fall period of 1995 increased significantly over previous years and were up to 0.5 °C above normal. Deep water (>300 m) bottom temperatures in Bonavista Saddle area were near normal at about 3.0 °C.

Time series of temperature and salinity anomalies around the Flemish Cap area show similar to conditions on the adjacent continental shelf over the same depth ranges. The latest cold period which started around 1988 with temperature anomalies up to 2.0 °C below normal throughout the upper 100 m of the water column in 1993 show some moderation in the upper water column by the summer of 1995. The salinity time series show near normal conditions during the late 1980s and early 1990s compared to the mid 1980s when salinities were up to 0.6 psu below normal in the upper 100 m of the water column.

The summer 1995 area of the CIL was 20 % above normal on the Grand Bank, 28 % below normal off Bonavista and 32 % below normal on Hamilton Bank. During the fall the Bonavista CIL decreased from 26 km^2 in 1994 to 7 km^2 in 1995 compared to the 1980-1994 average of 24 km^2. Since 1991 the total volume of subzero °C water on the Newfoundland Shelf during summer and fall has been slowly decreasing, and by 1995 it has decreased to values of the early 1980s and from 1986 to 1989. The Newfoundland Shelf dissolved oxygen levels were near to slightly above average during the summer of 1995.

Surface temperatures during 1995 were below normal during the summer and above normal in the fall in southern regions of division 3L and below normal in northern regions of division 2J. During the fall of 1995 large areas of the continental shelf, particularly the Grand Bank, saw a significant increase in bottom temperatures (up to 0.5 °C above average) compared to values experienced during 1991-1994.

In general the cold trends established in the late 1980s, reached a peak in 1991 have moderated during 1994 and 1995. The analysis presented here shows conditions returning to more normal values over many areas however negative temperature and salinity anomalies were still present in the upper layers during the summer.

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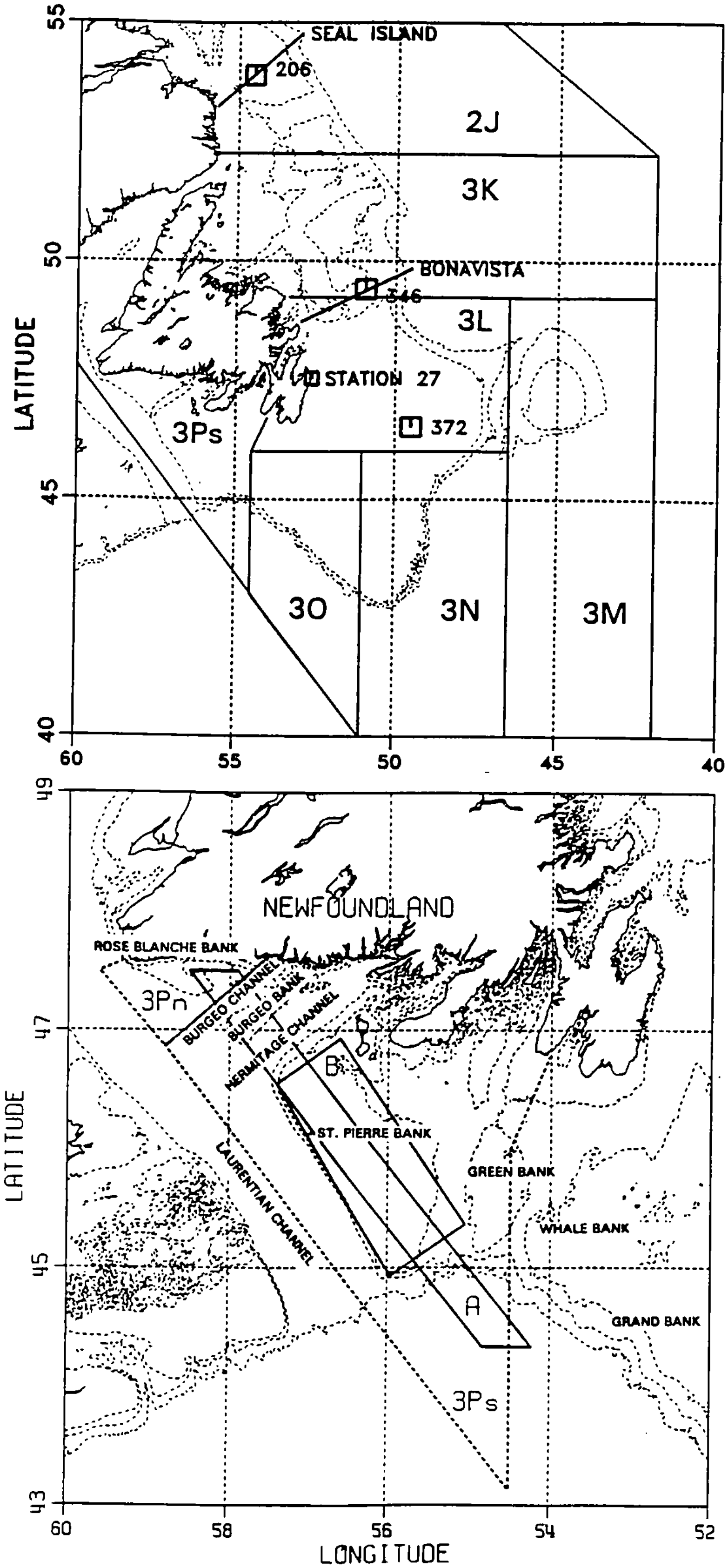


Fig. 1. Location maps showing positions of the Seal Island and Bonavista transects, Station 27 and the approximate positions of strata 206, 346 and 372 (top panel) and Subdivisions 3Pn and 3Ps and the areas A and B from which data were examined (bottom panel).

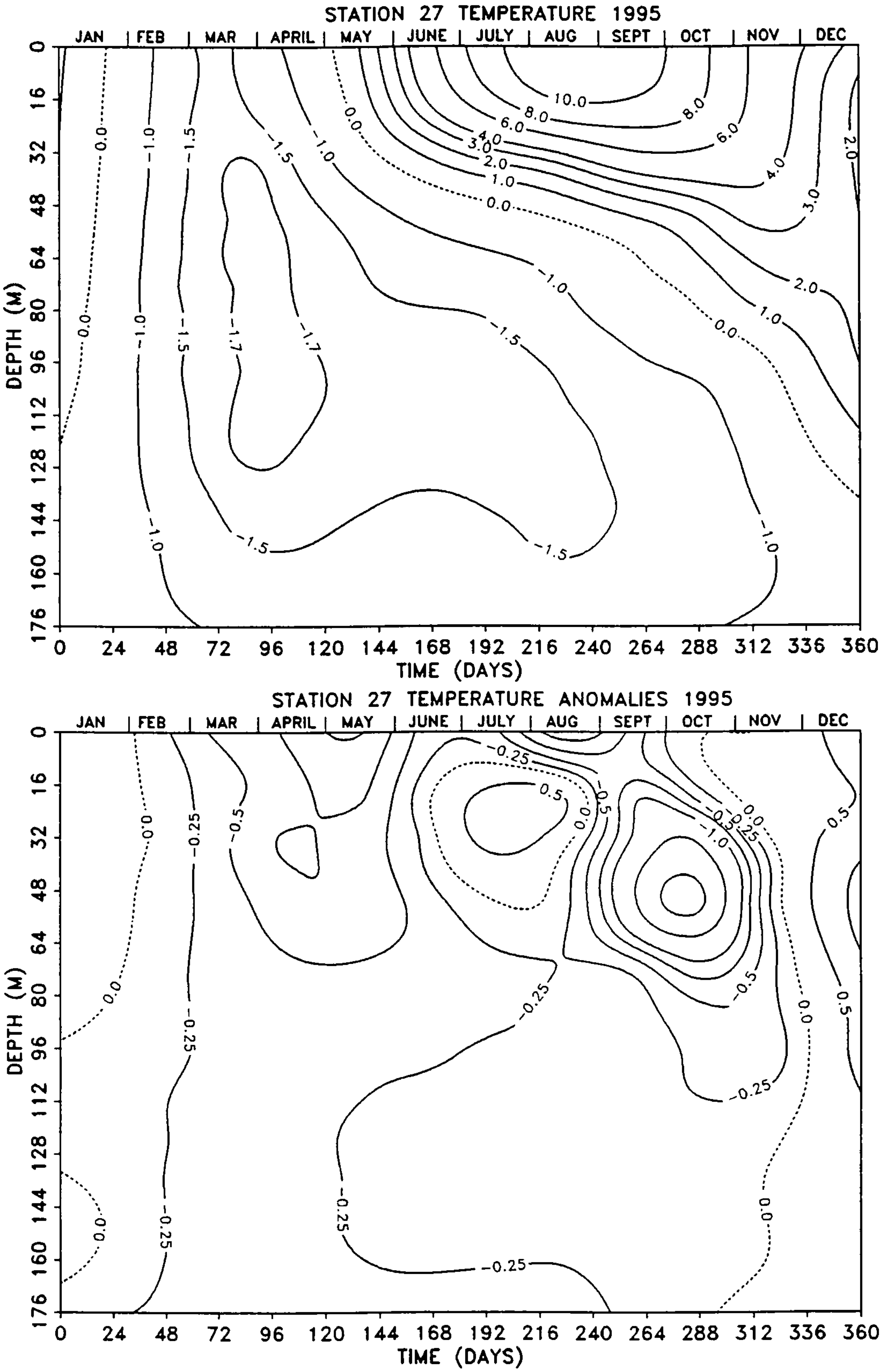


Fig. 2. Depth versus time contour plots of temperatures and anomalies at Station 27 for 1995.

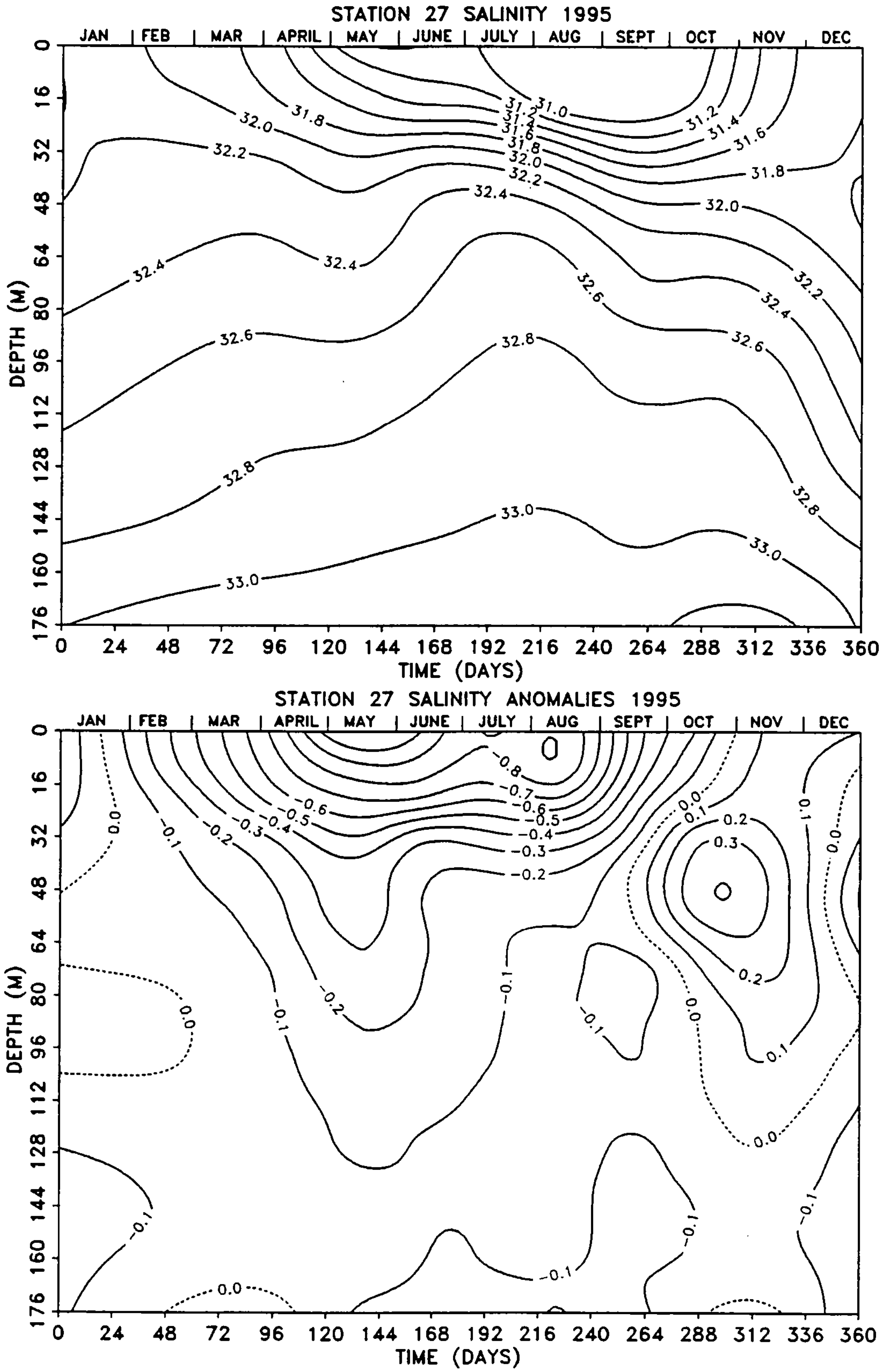


Fig. 3. Depth versus time contour plots of salinity and anomalies at Station 27 for 1995.

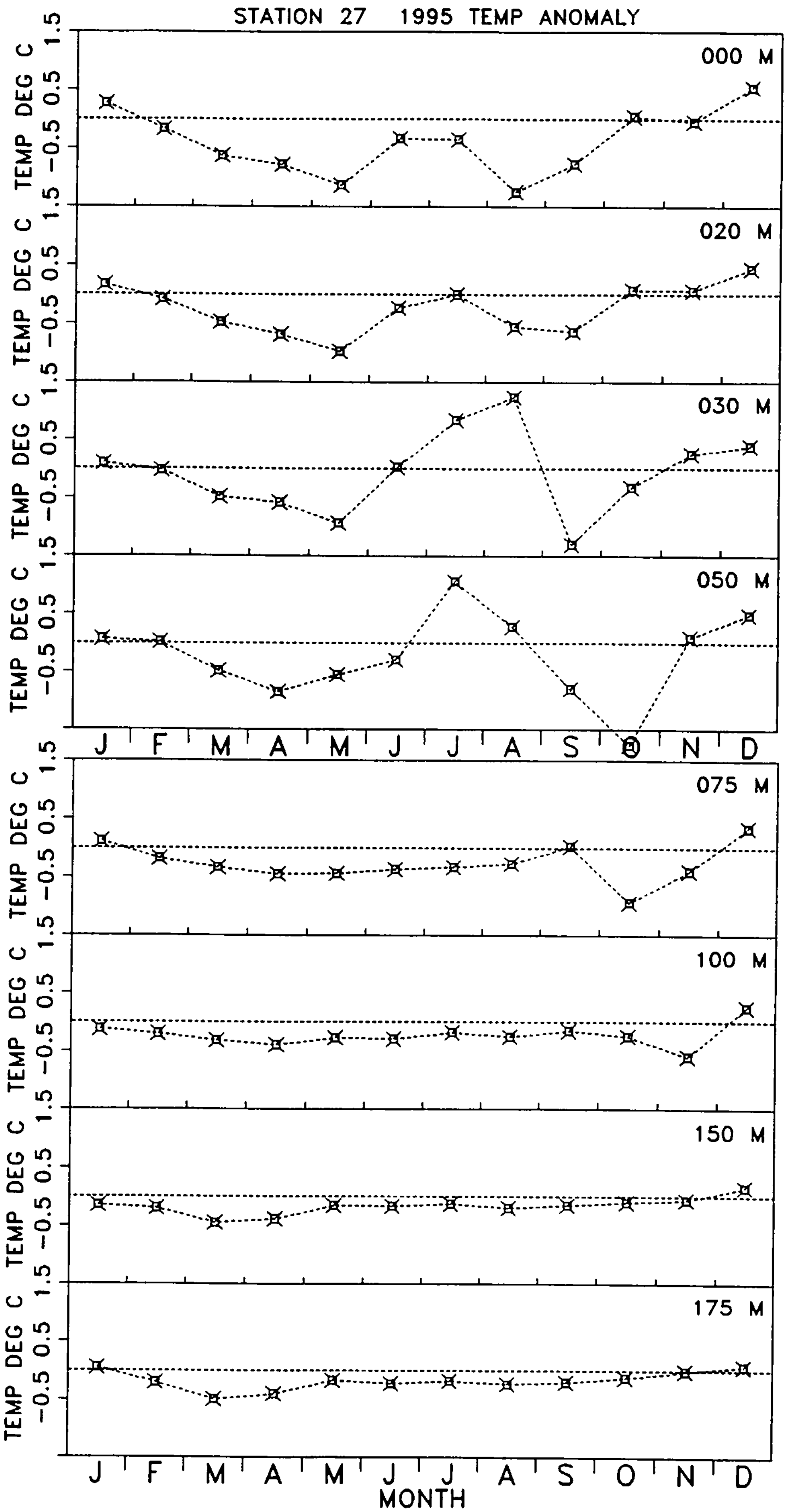


Fig. 4. Time series of monthly temperature anomalies at Station 27 at standard depths during 1995.

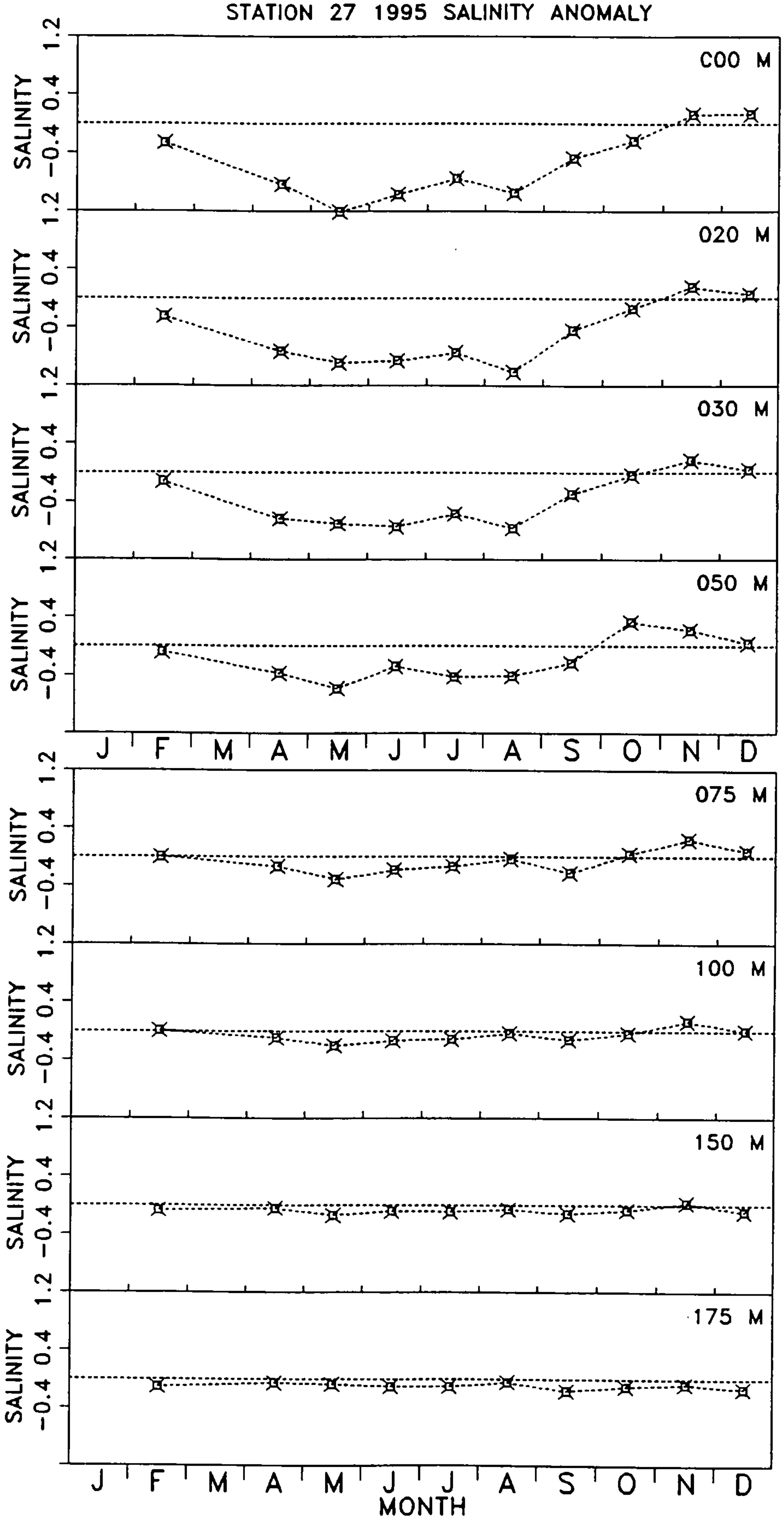
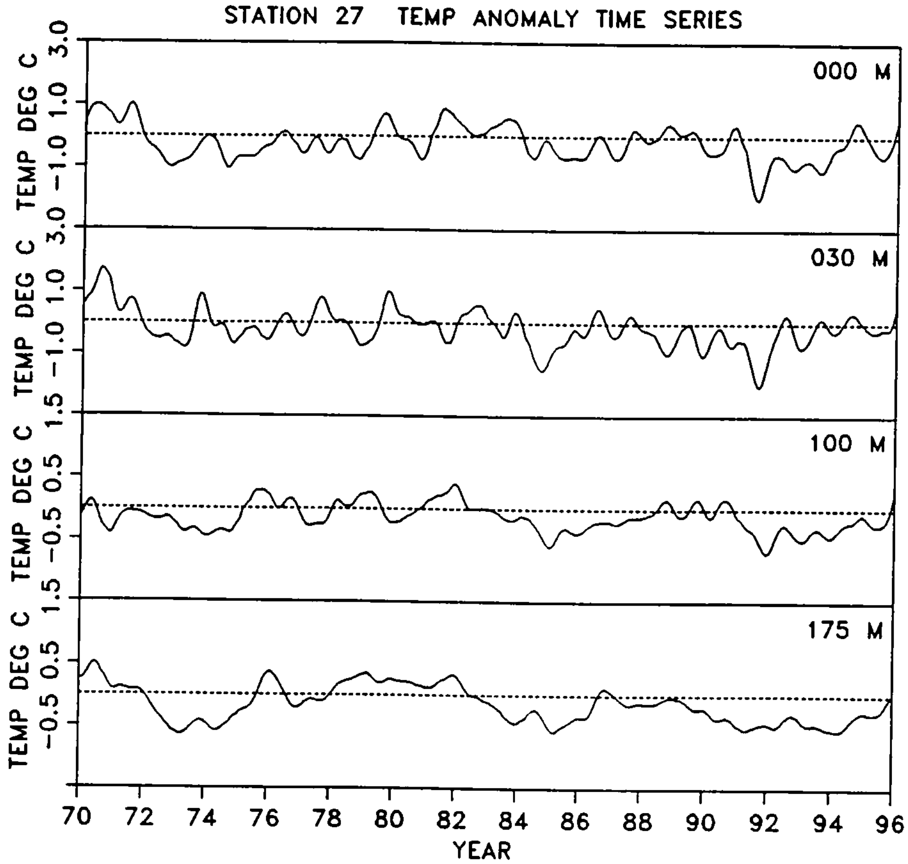


Fig. 5. Time series of monthly salinity anomalies at Station 27 at standard depths during 1995.



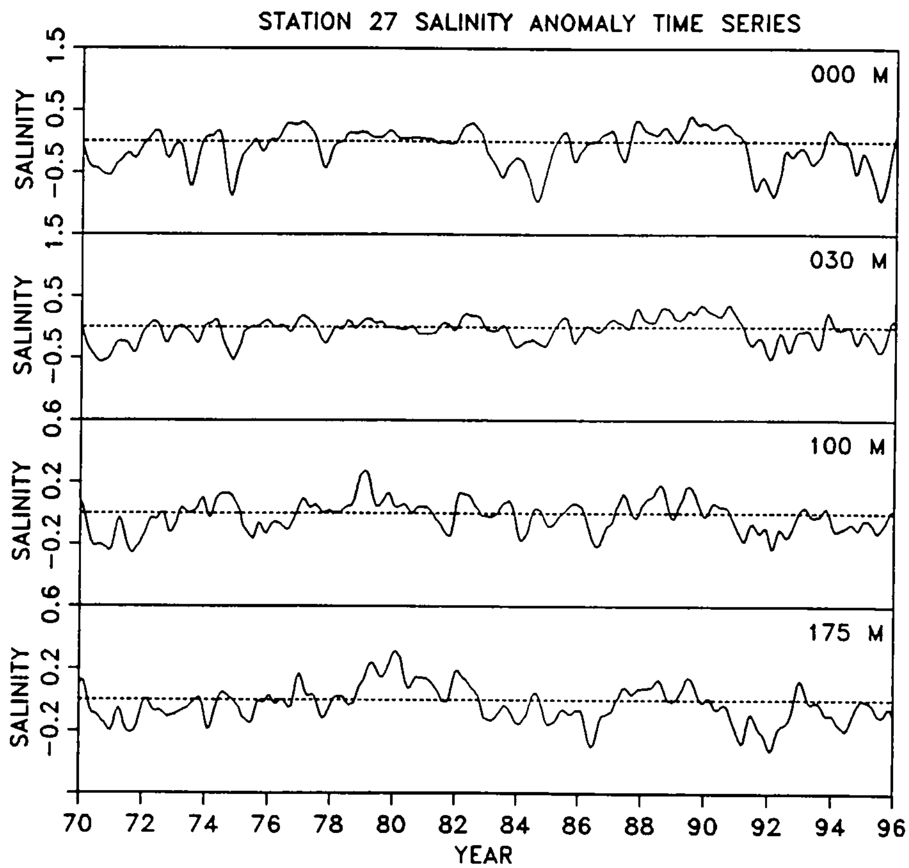


Fig. 6. Low passed filtered time series of temperature and salinity anomalies at Station 27 at standard depths from 1970 to 1995.

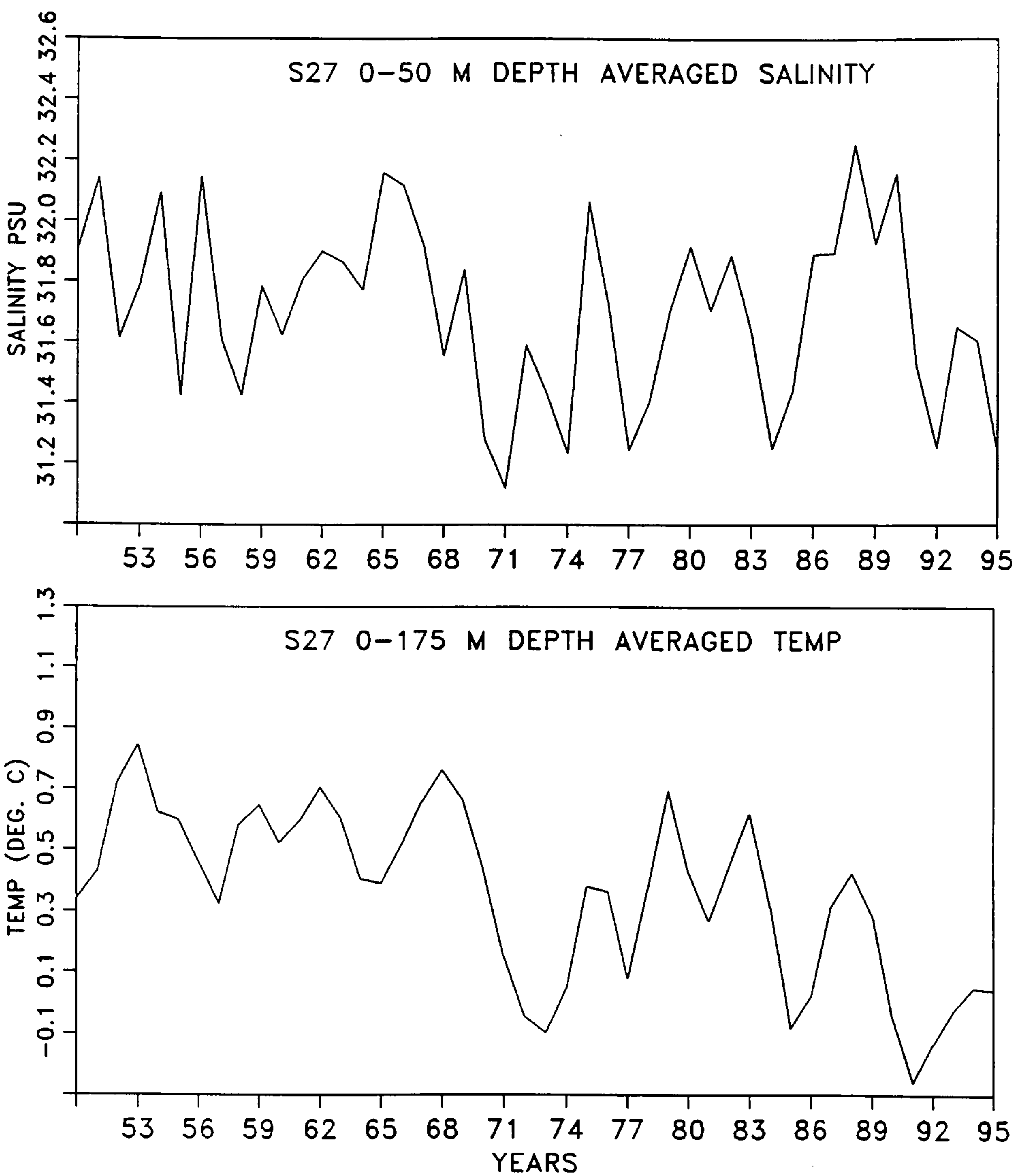


Fig. 7a. Time series of the vertically averaged (0-176 m) Station 27 temperature and the vertically averaged (0-50 m) summer (July-Sept.) Station 27 salinity.

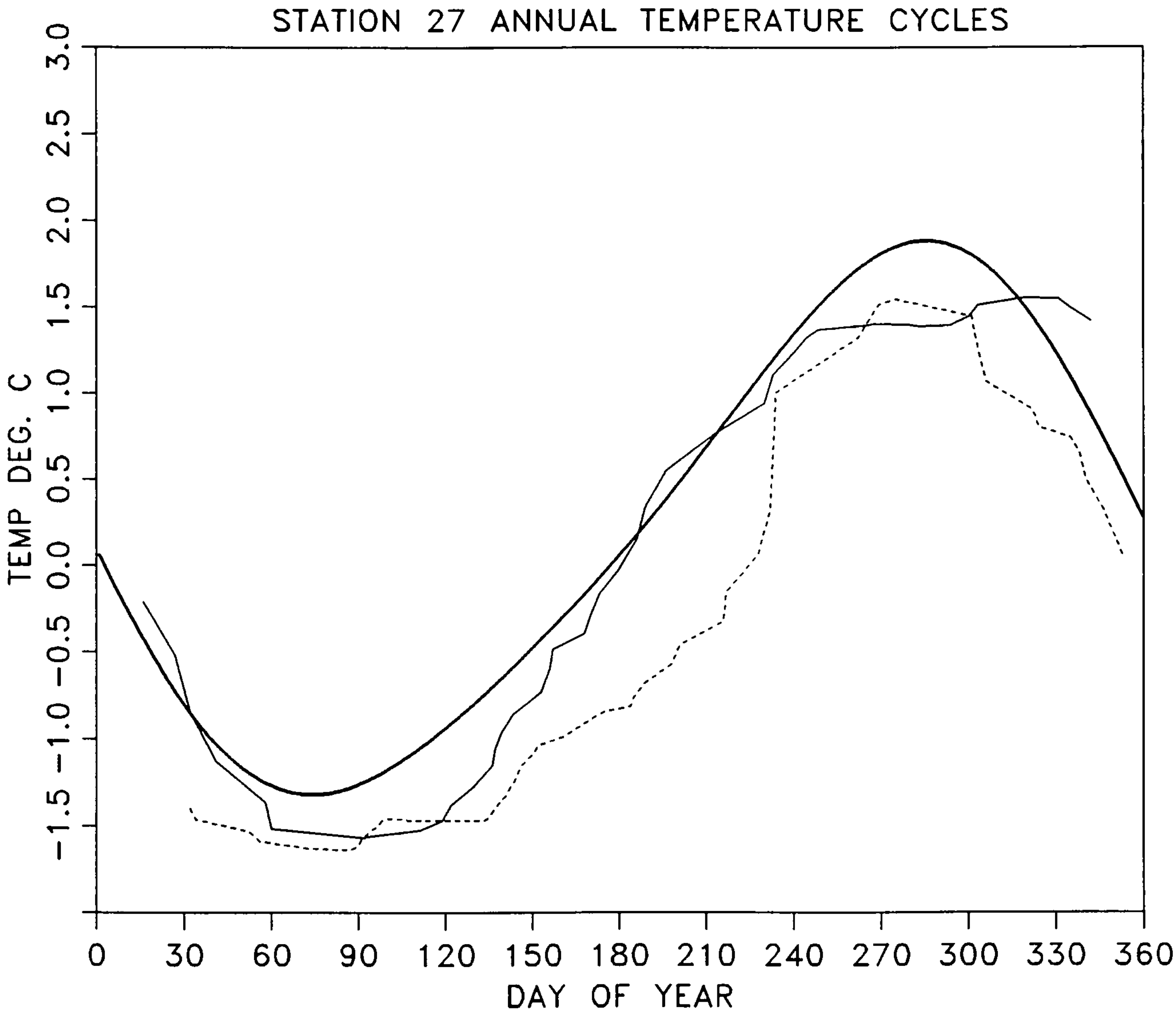


Fig. 7b. The vertically averaged (0-176 m) Station 27 seasonal temperature cycle. The heavy solid line represents the 1961-1990 average, the dashed and solid lines are the 1991 and 1995 cycles respectively.

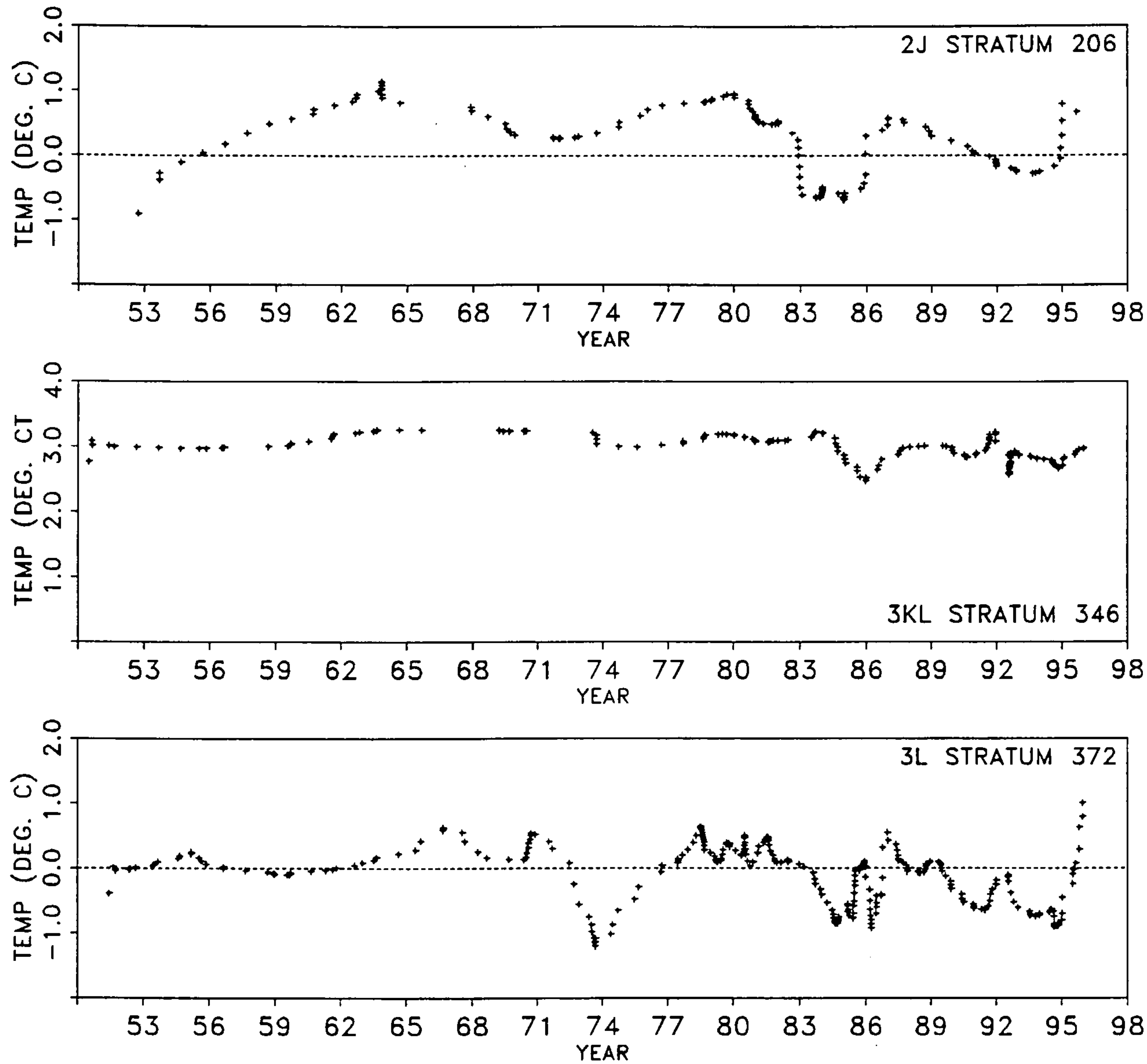


Fig. 8. Time series of bottom temperatures for strata 206 in NAFO Division 2J, 346 in Division 3KL and 372 in Division 3L, the locations of which are shown in Fig. 1.

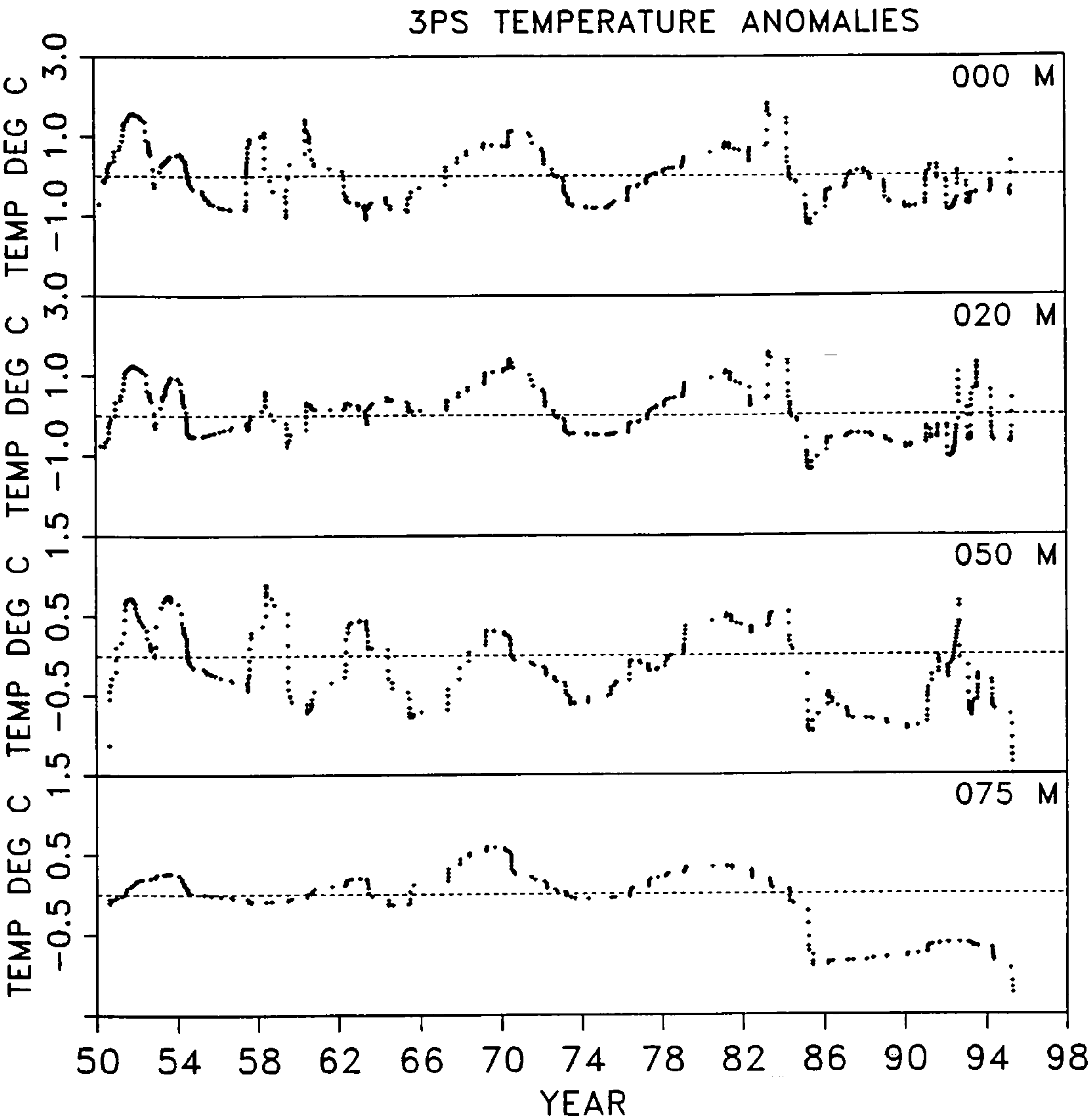


Fig. 9a. Time series of temperature anomalies at standard depths of 0, 20, 50 and 75 m for box B in Subdivision 3Ps shown in Fig. 1.

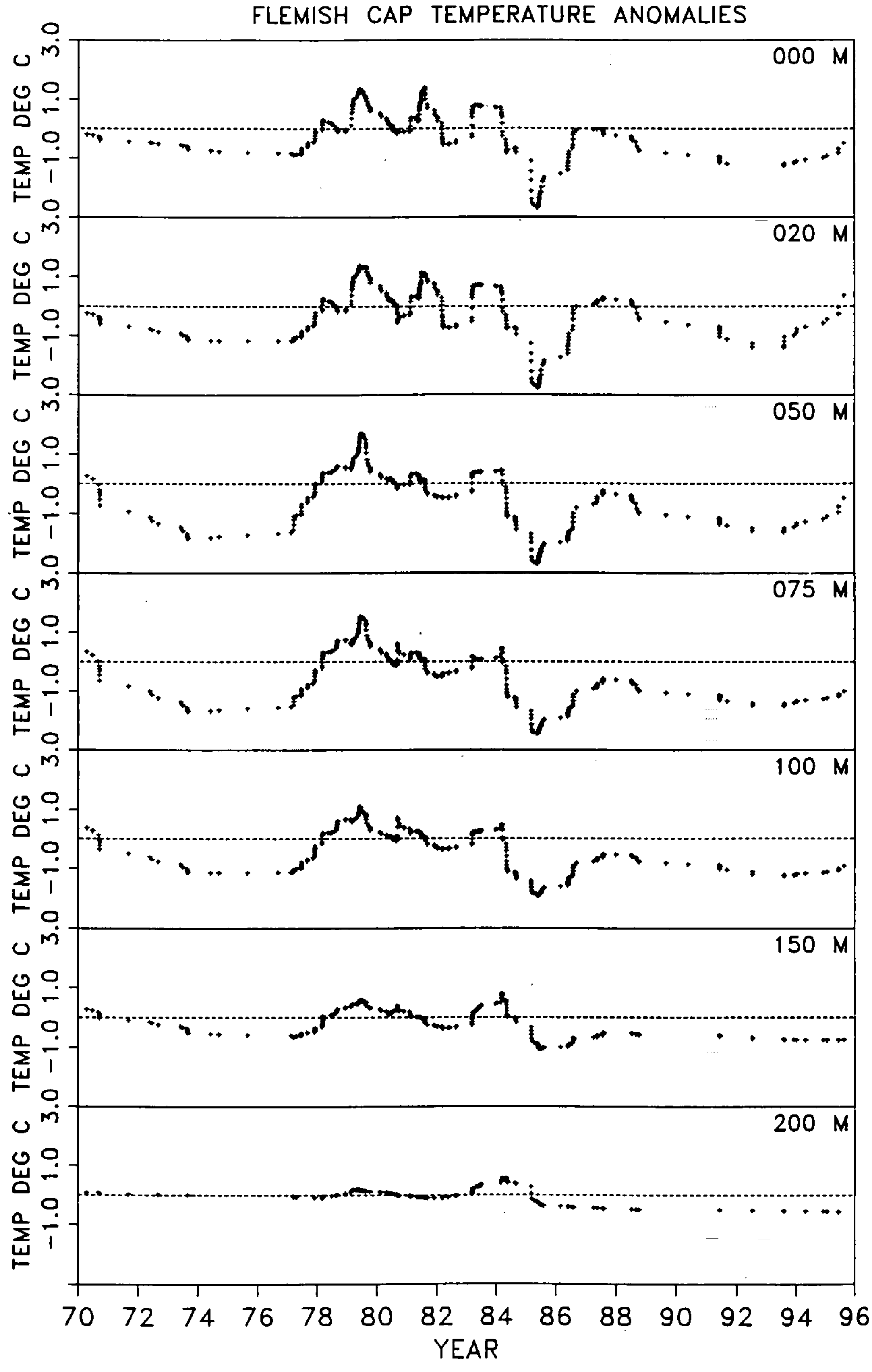


Fig. 9b. Time series of temperature anomalies at standard depths to 200 m on the Flemish Cap.

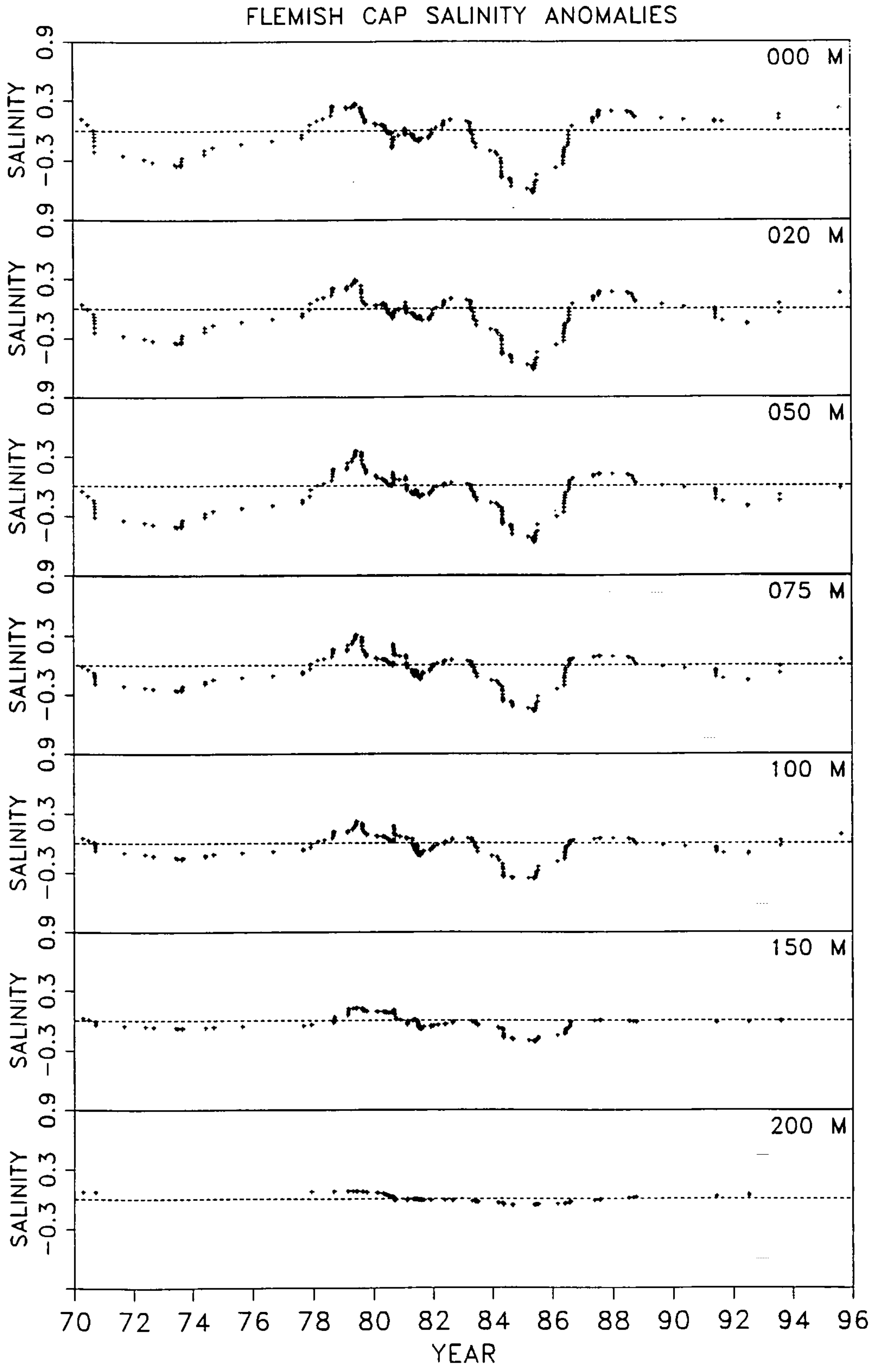


Fig. 9c. Time series of salinity anomalies at standard depths to 200 m on the Flemish Cap.

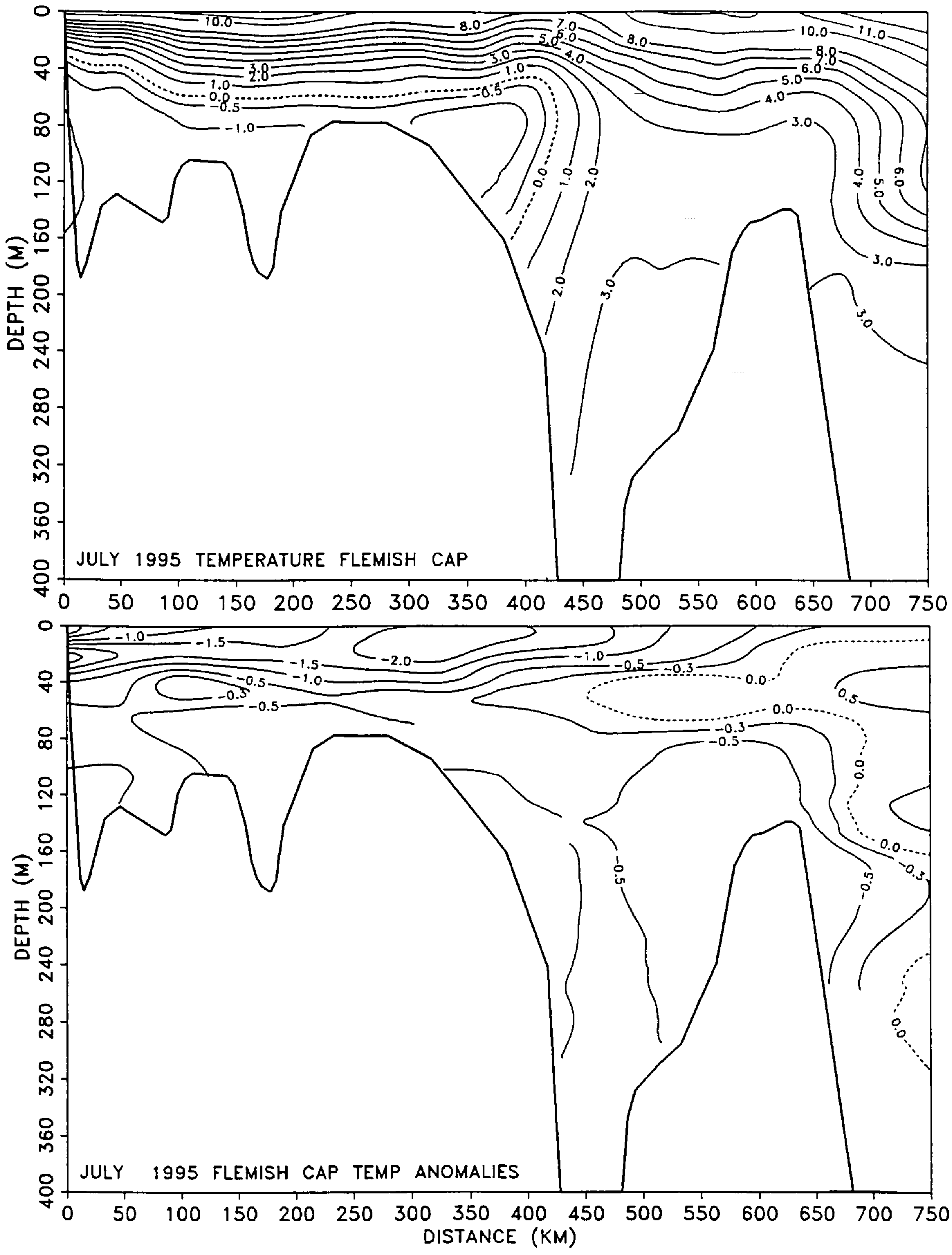


Fig. 10. The vertical distribution of temperature and temperature anomalies along the standard Flemish Cap transect for July 1995.

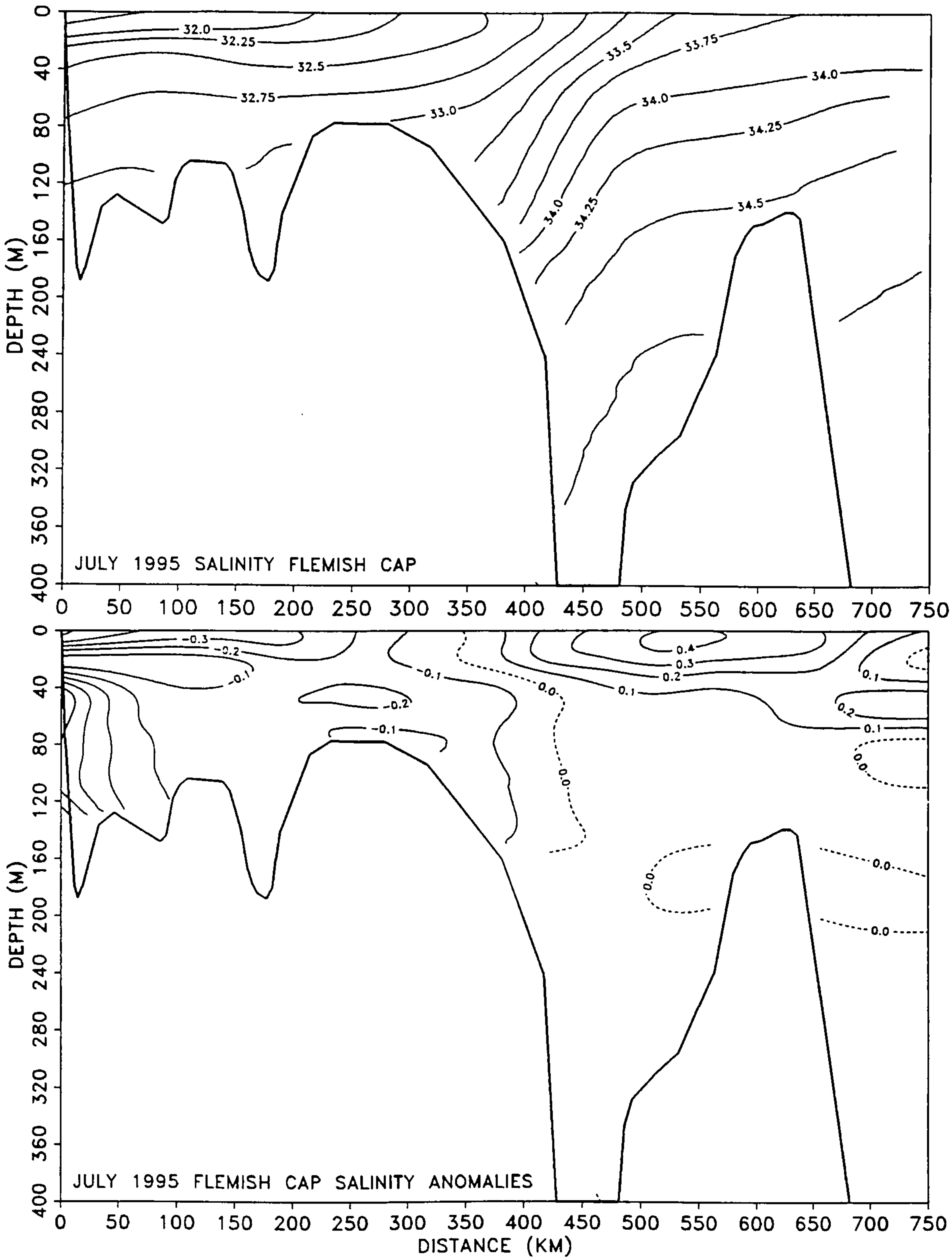


Fig. 11. The vertical distribution of salinity and salinity anomalies along the standard Flemish Cap transect for July 1995.

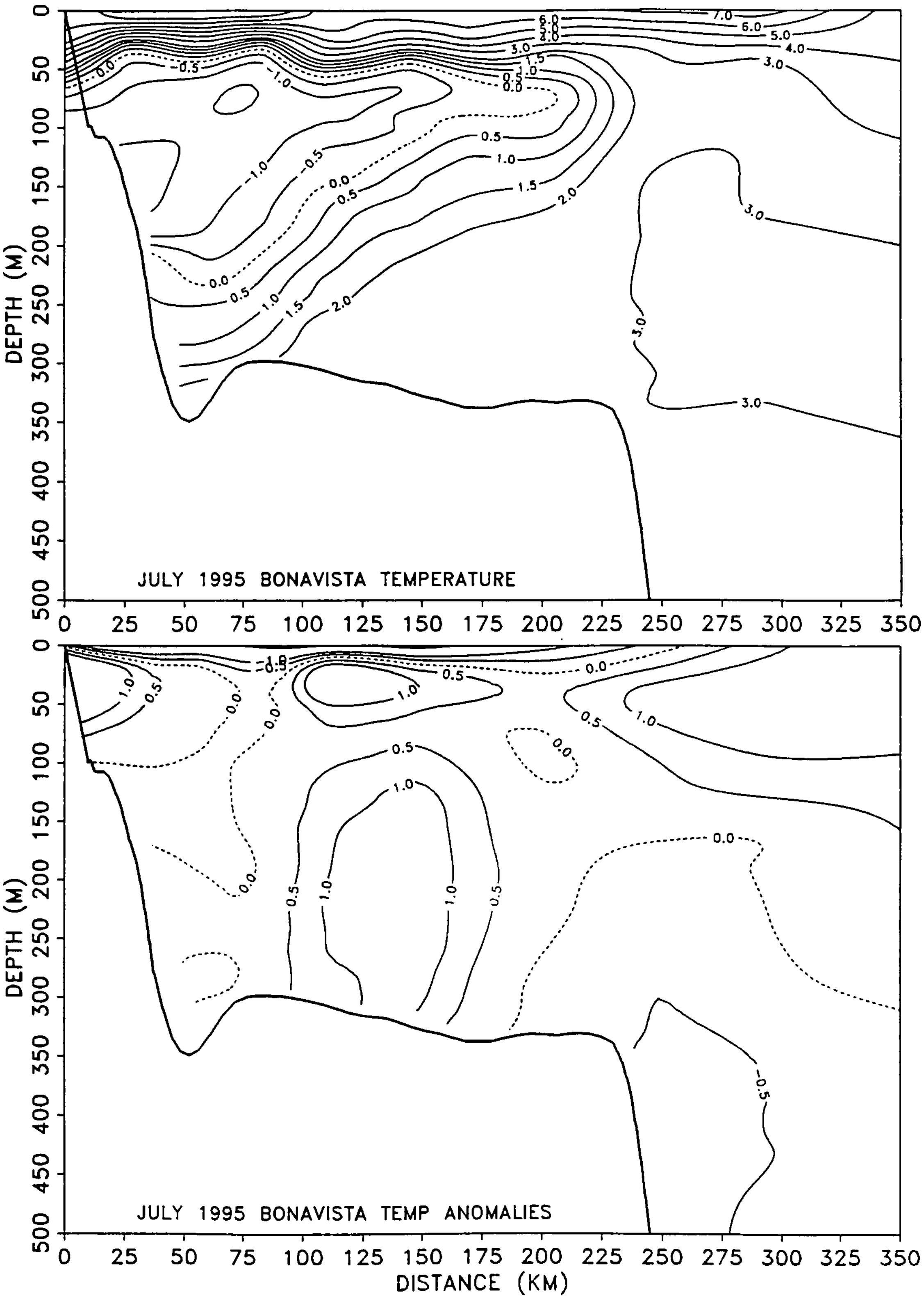


Fig. 12. The vertical distribution of temperature and temperature anomalies along the standard Bonavista transect for July 1995.

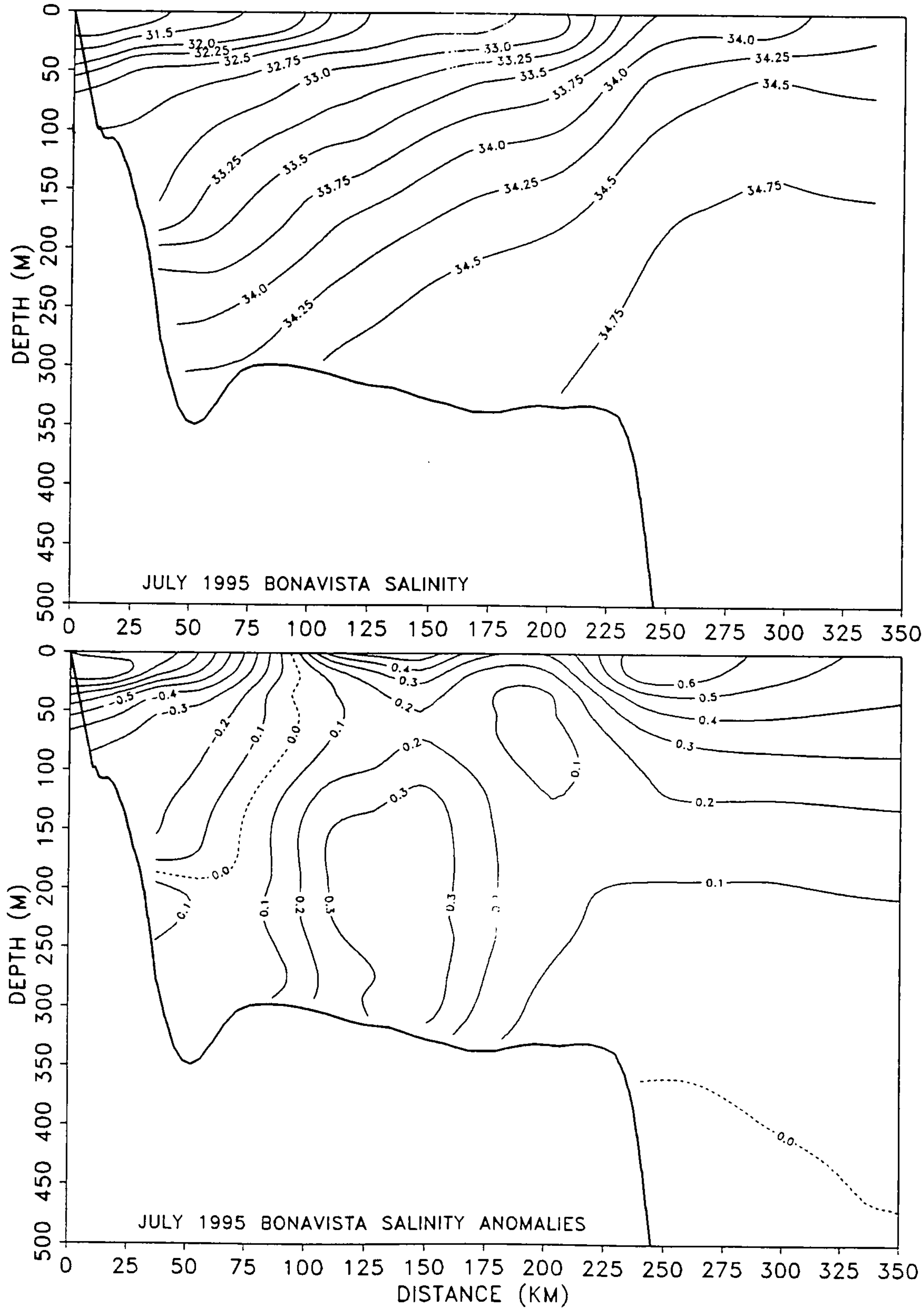


Fig. 13. The vertical distribution of salinity and salinity anomalies along the standard Bonavista transect for the summer (July) of 1995.

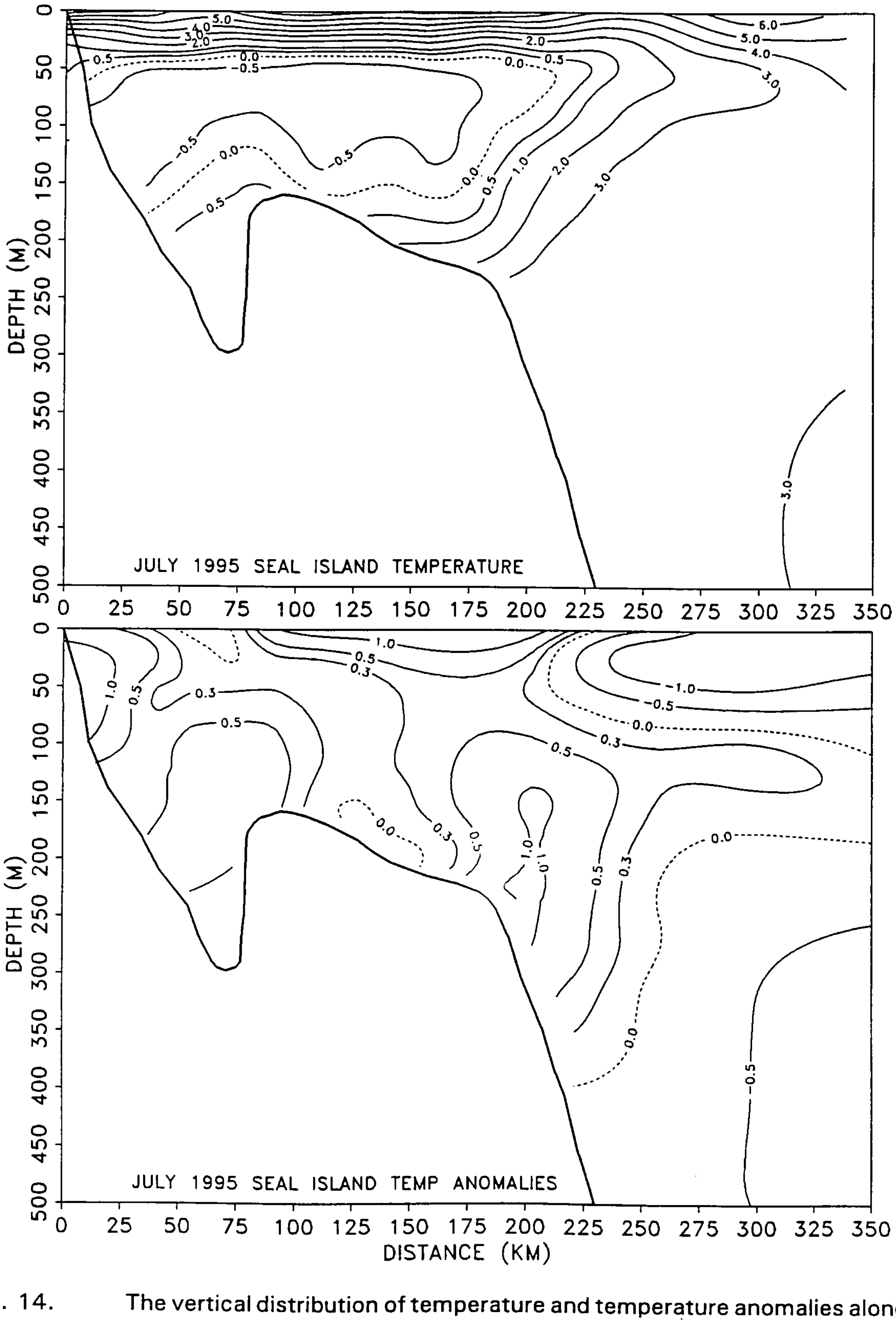


Fig. 14. The vertical distribution of temperature and temperature anomalies along the standard Seal Island transect for the summer (July) of 1995.

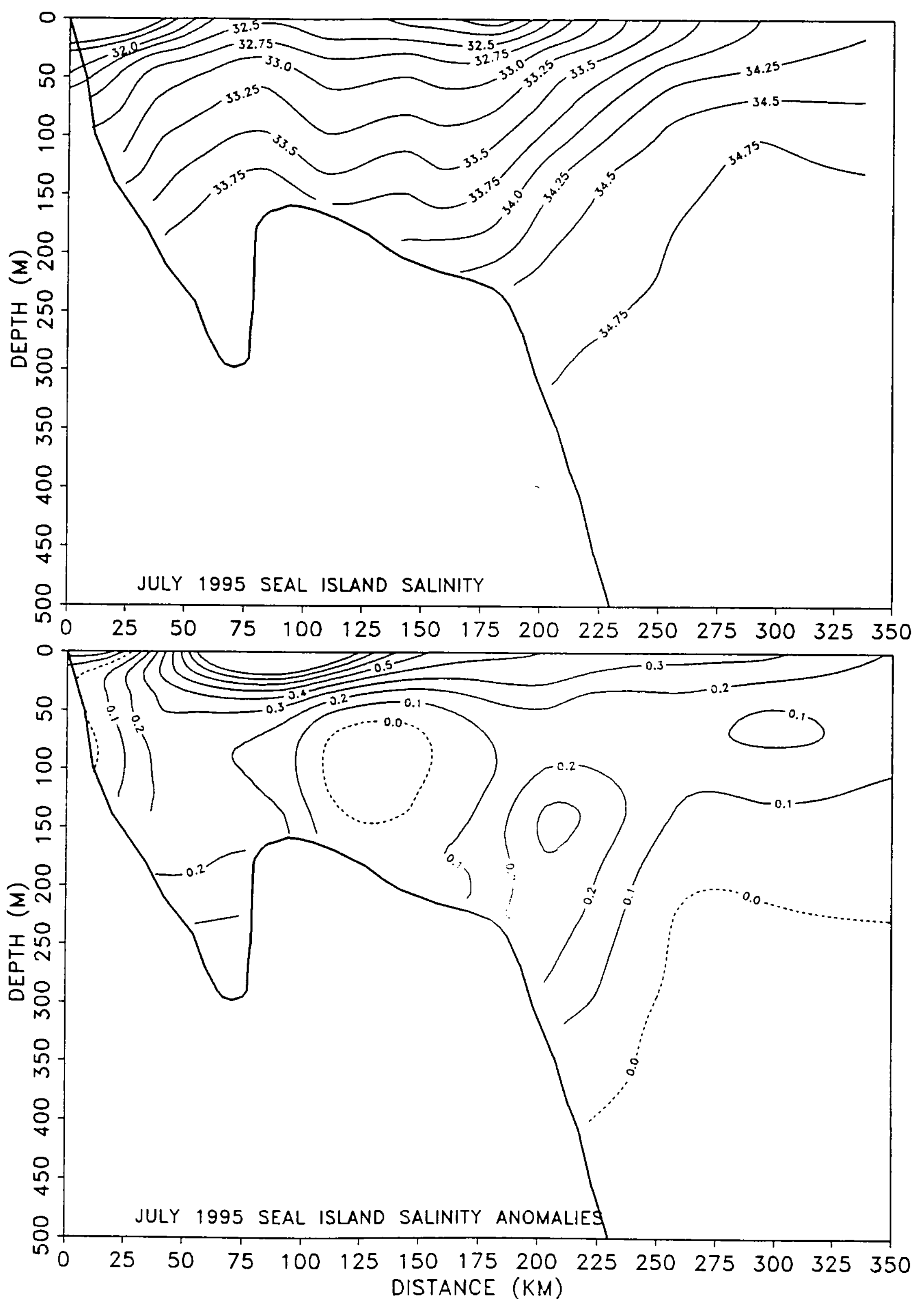


Fig. 15. The vertical distribution of salinity and salinity anomalies along the standard Seal Island transect for the summer (July) of 1995.

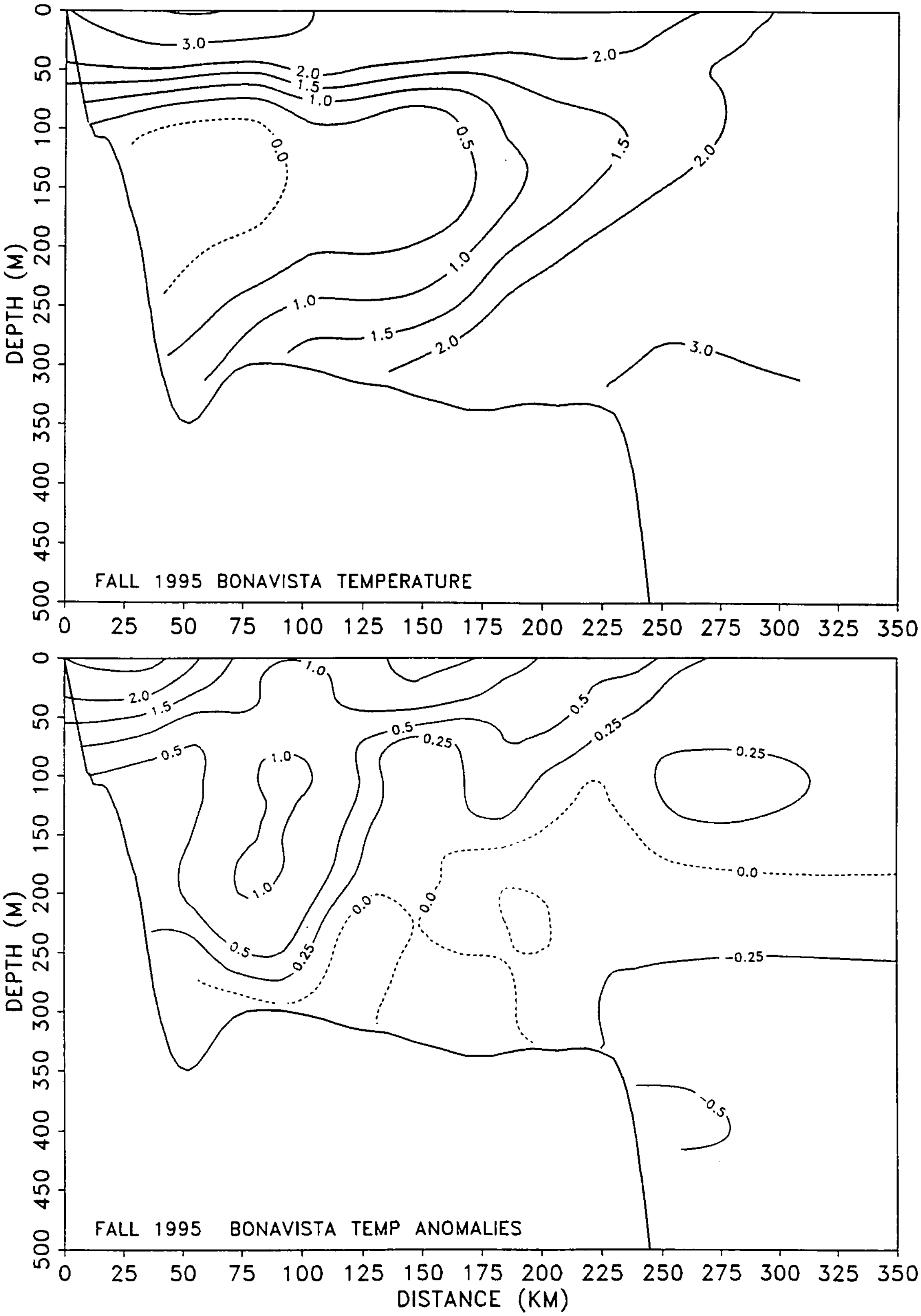


Fig. 16. The vertical distribution of temperature and temperature anomalies along the standard Bonavista transect for the fall of 1995.

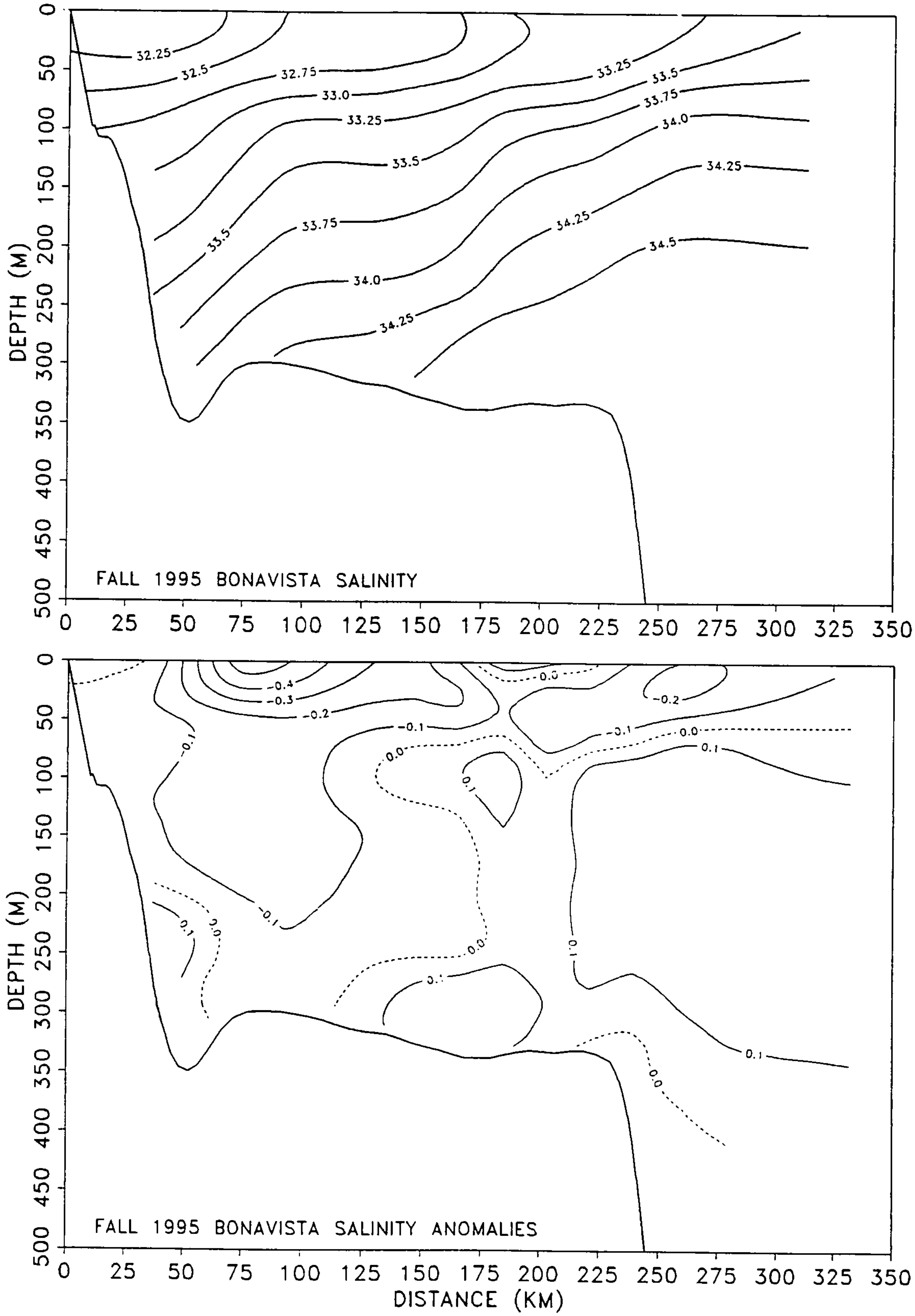


Fig. 17. The vertical distribution of salinity and salinity anomalies along the standard Bonavista transect for the fall of 1995.

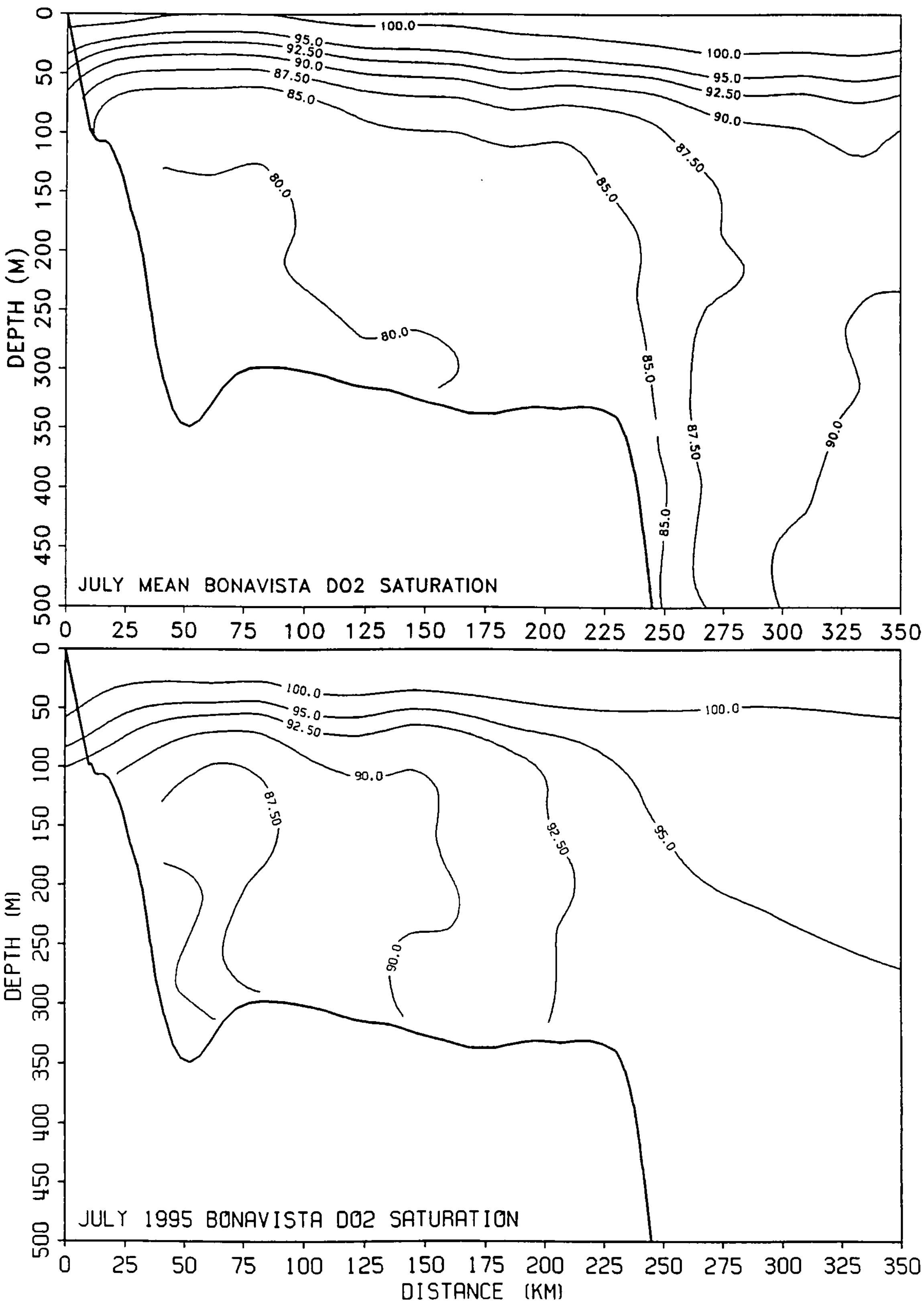


Fig. 18. The vertical distribution of dissolved oxygen saturation along the standard Bonavista transect for the average of historical data (top panel) and for July, 1995 (bottom panel).

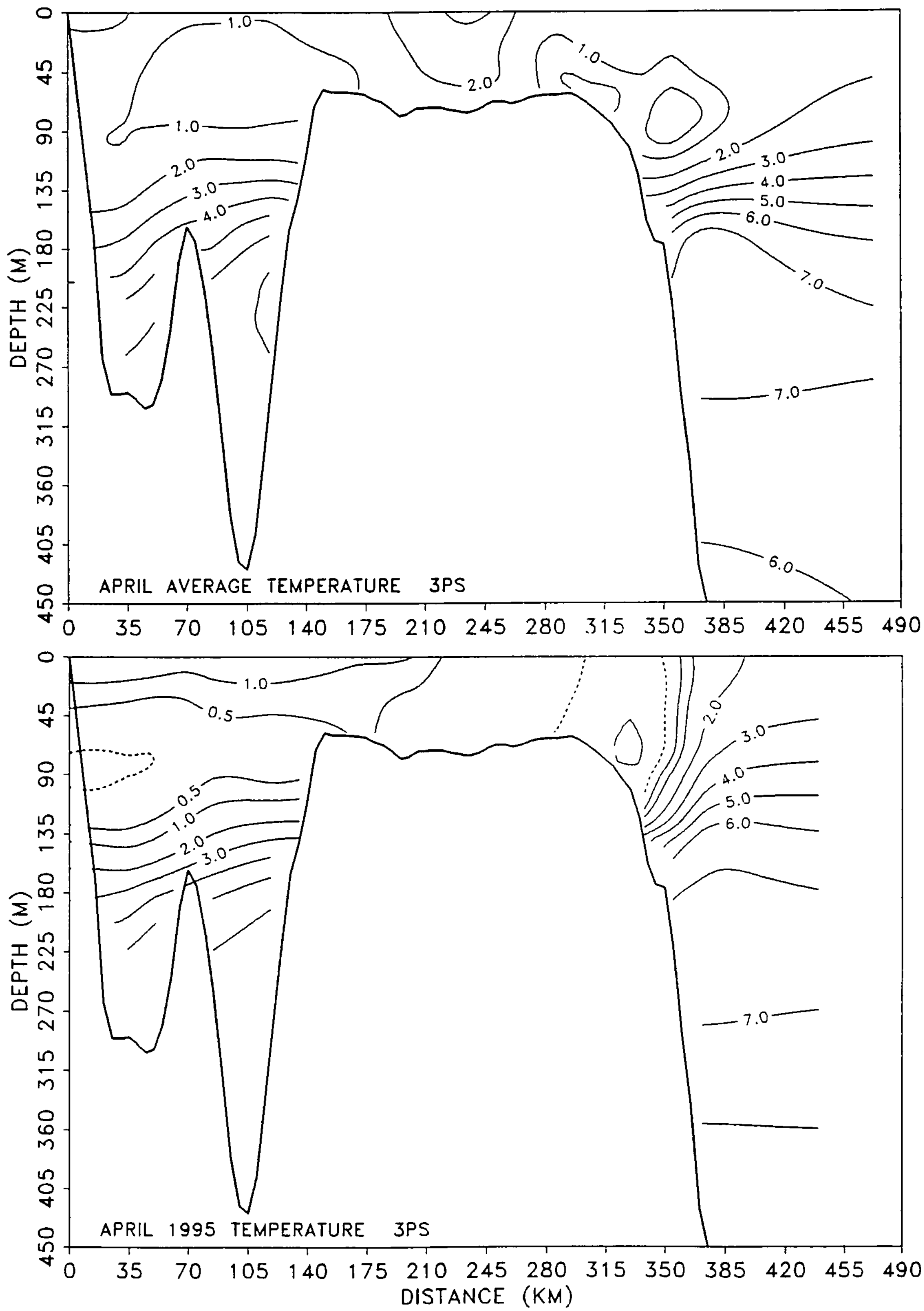


Fig. 19. The average and the 1995 April temperature along the transect shown in Fig. 1 for NAFO Subdivisions 3Pn and 3Ps.

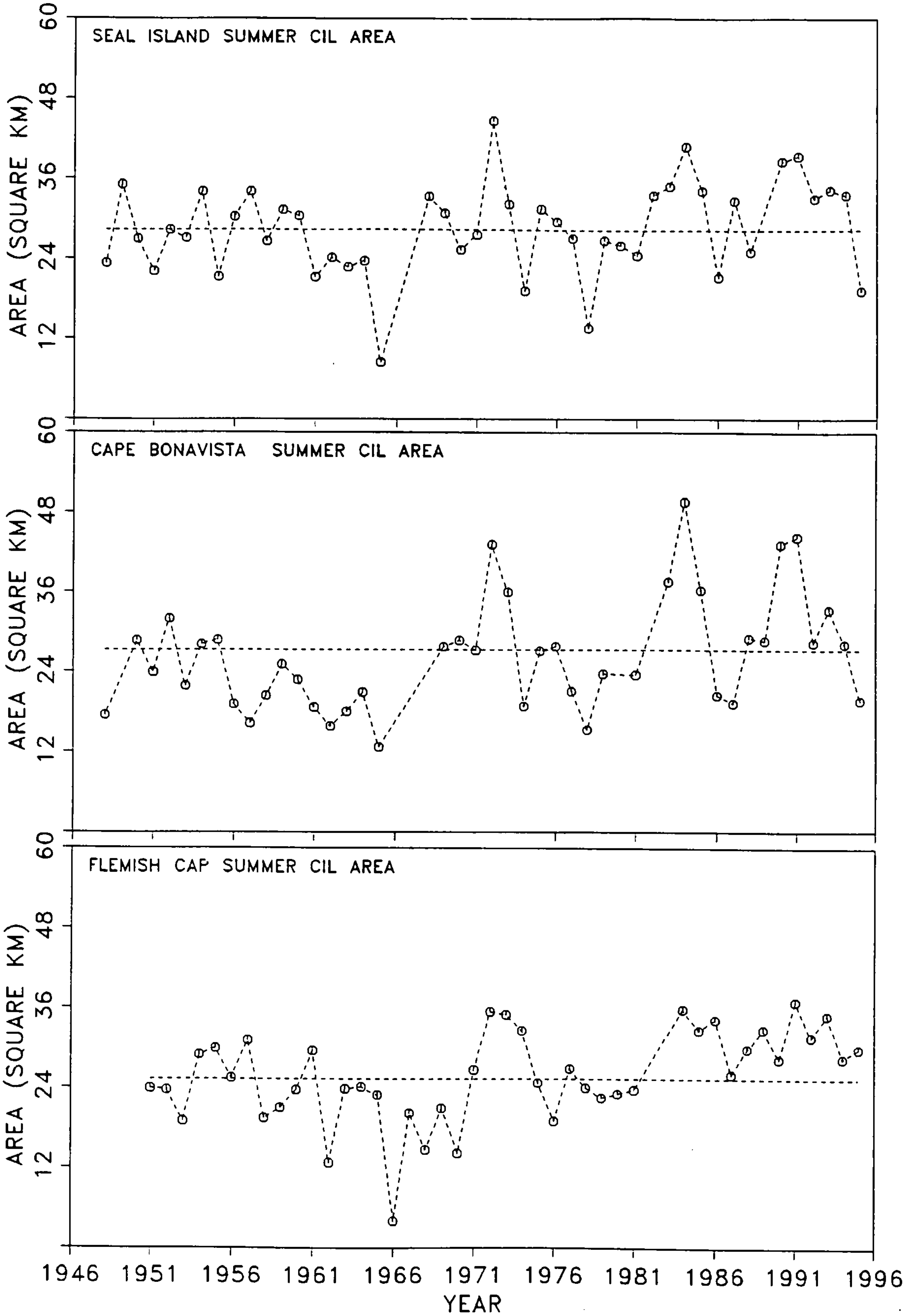


Fig. 20. Time series of CIL area along the Seal Island, Bonavista and Flemish Cap transects. The dashed line represents the 1961-90 average.

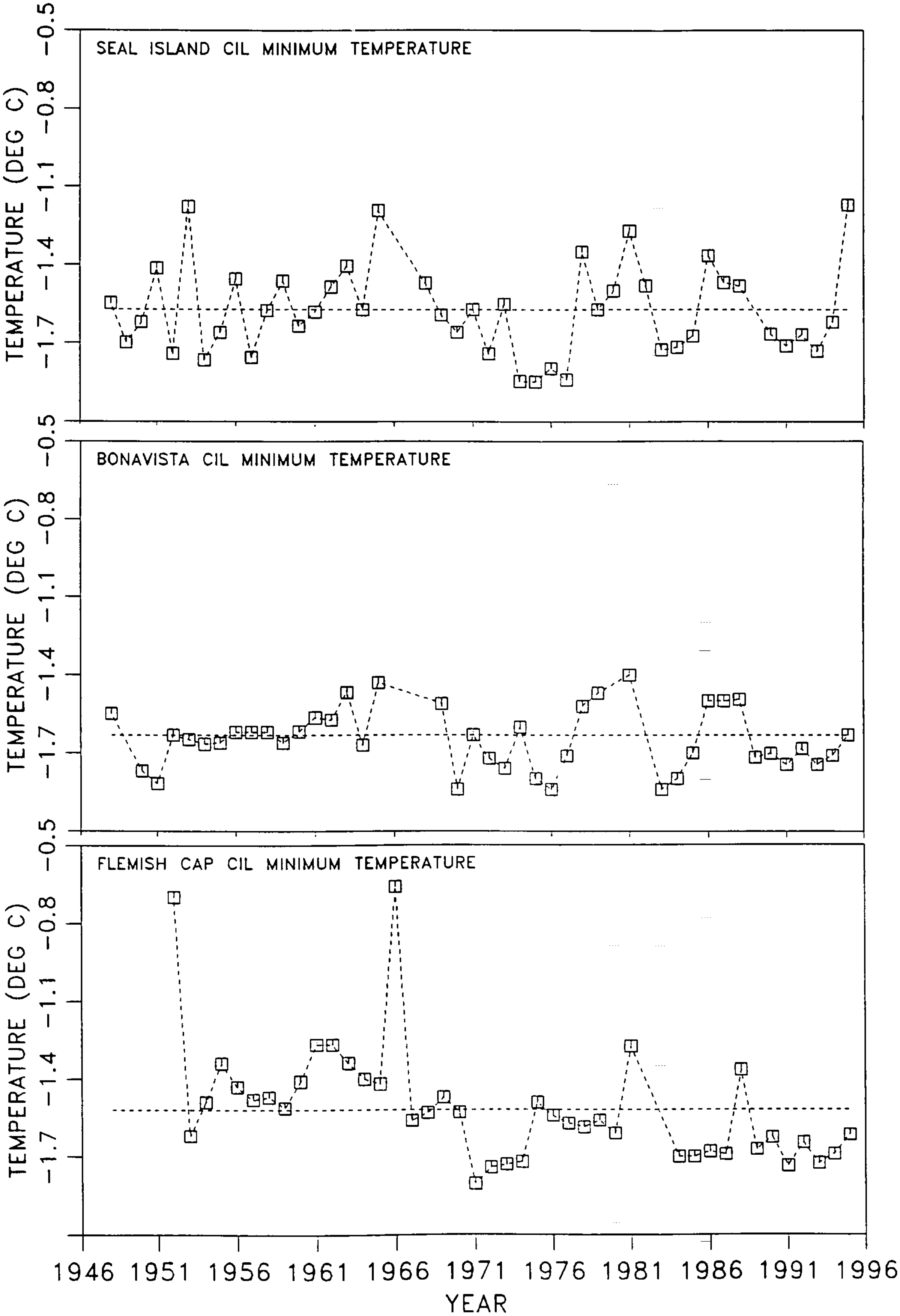


Fig. 21. Time series of CIL minimum temperature along the Seal Island, Bonavista and Flemish Cap transects. The dashed line represents the average.

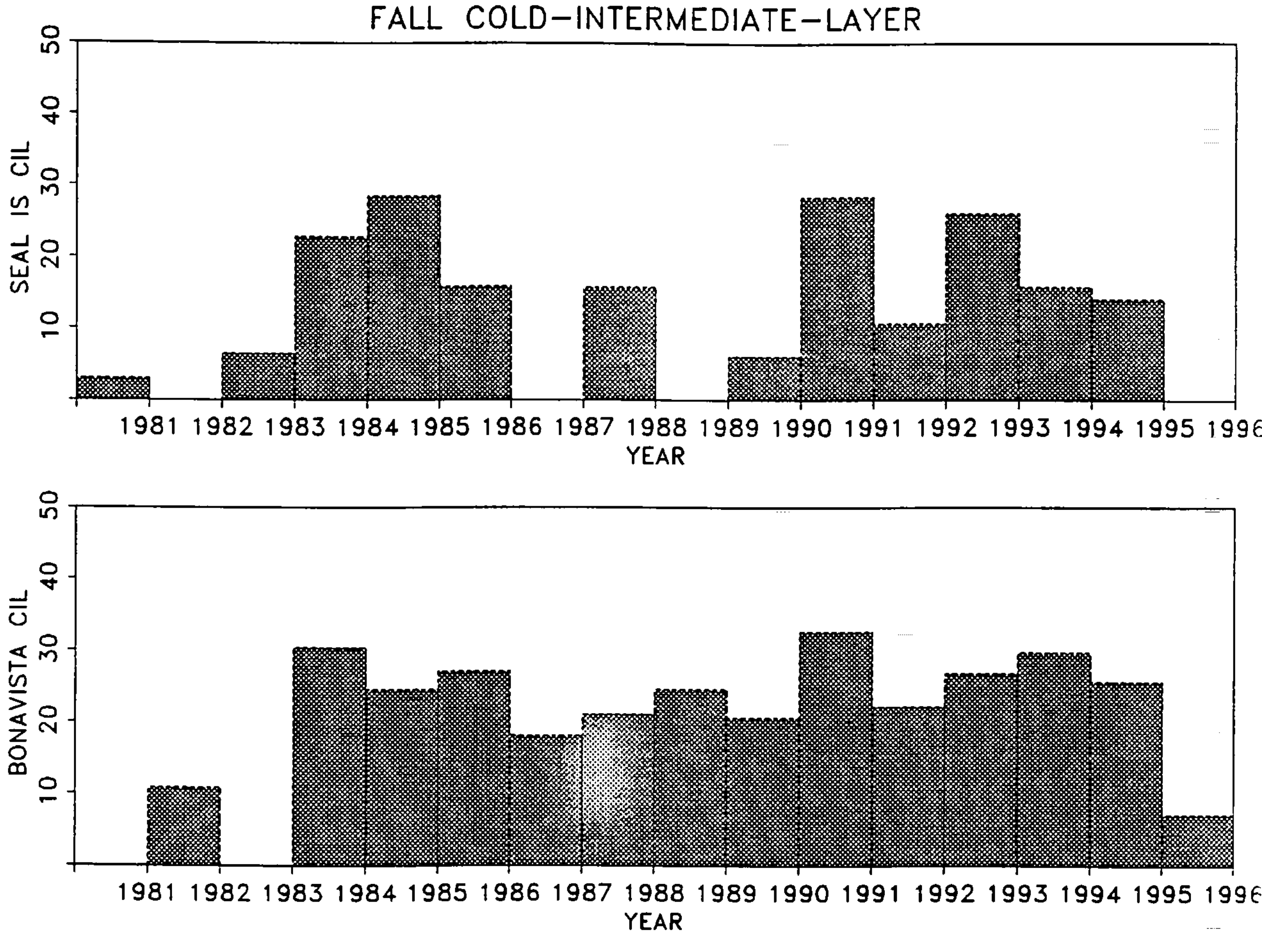


Fig. 22. Time series of CIL cross sectional area less than 0.0 °C during the fall for the Seal Island (top panel) and for the Bonavista transects (bottom panel).

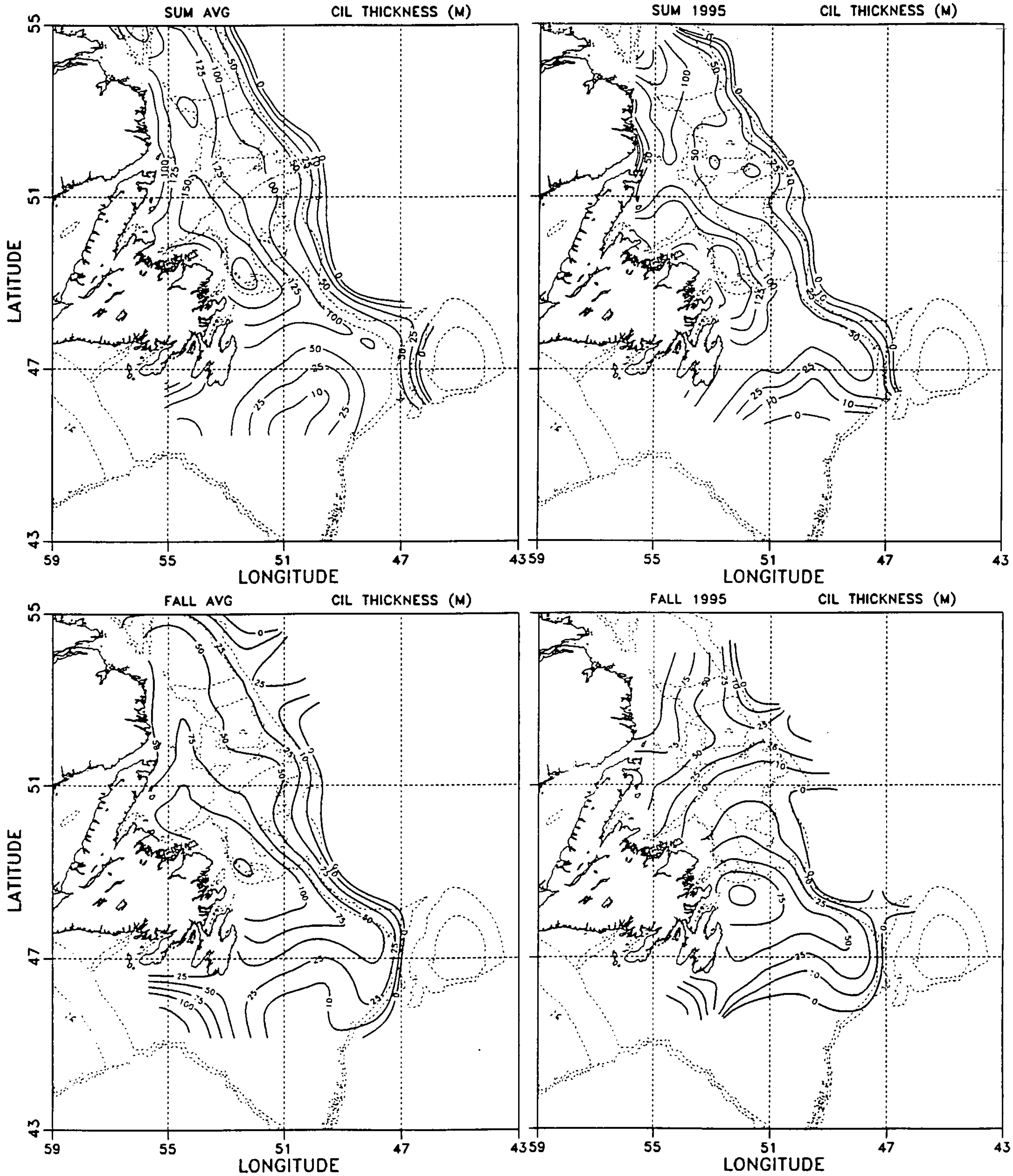


Fig. 23. Horizontal maps of the average summer and fall CIL thickness (m) over the 2J to 3KL areas and for the summer and fall of 1995.

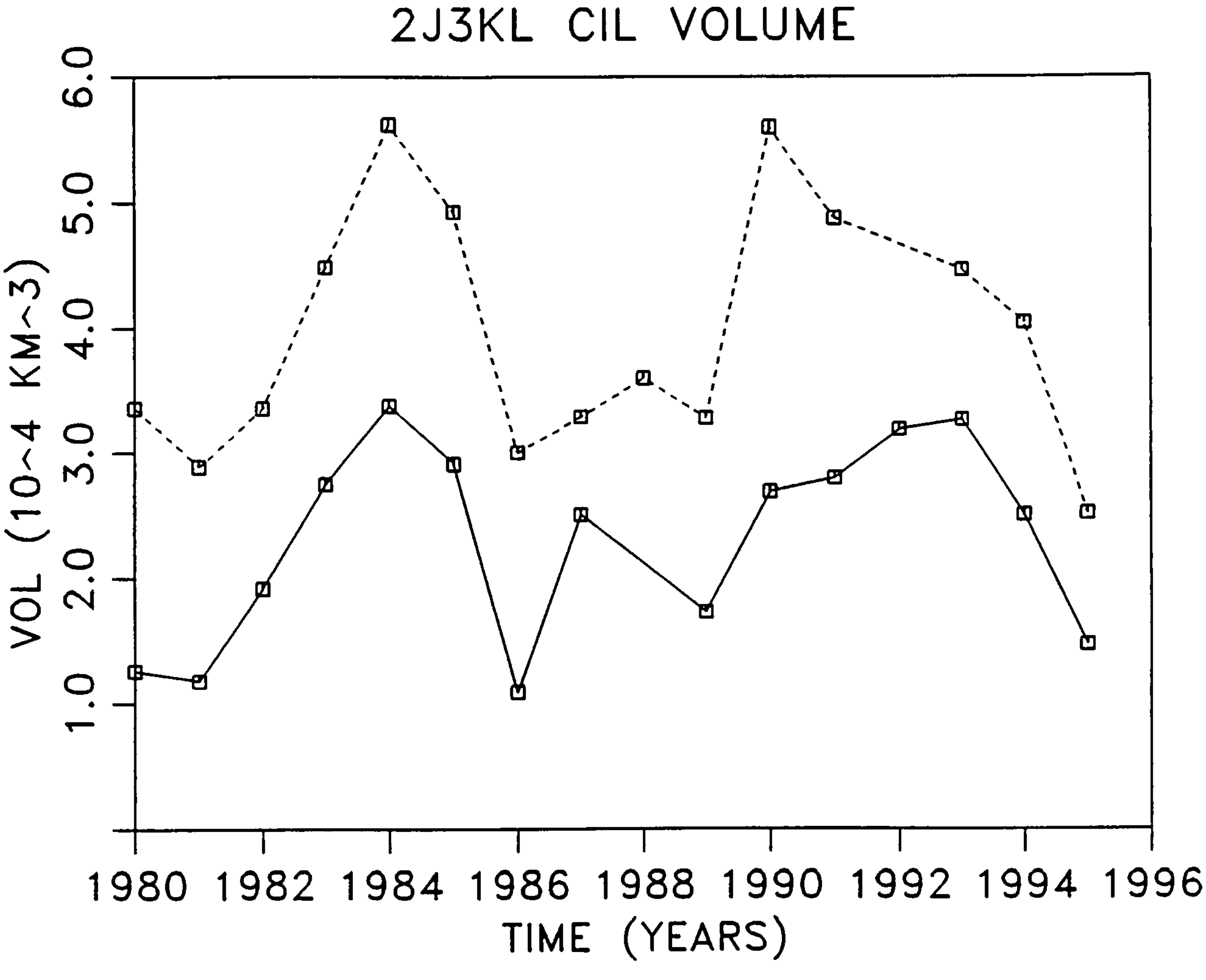


Fig. 24a. Time series of summer (dashed line) and fall (solid line) CIL volumes (km^3) over the 2J to 3KL areas from 1980 to 1995.

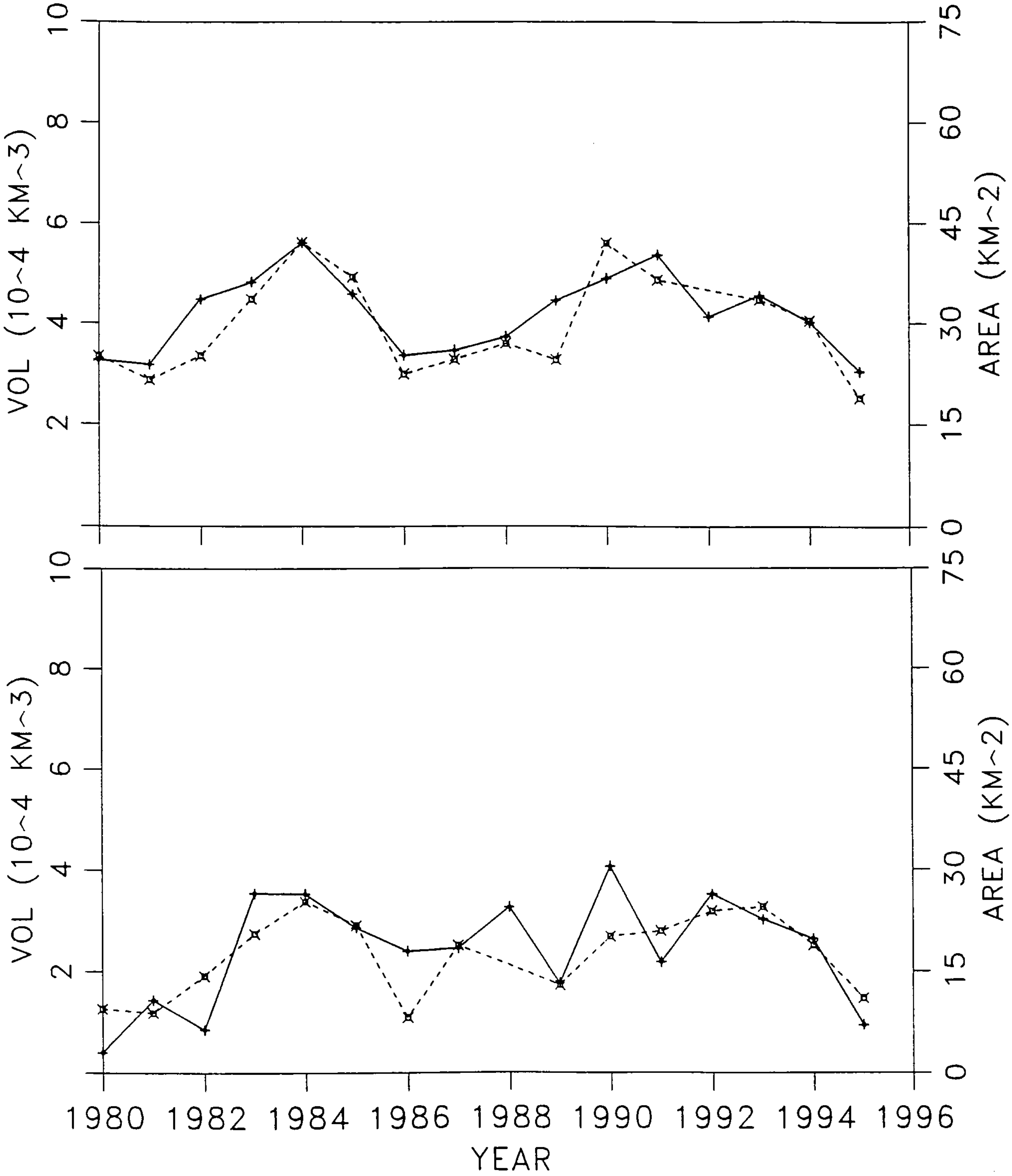


Fig. 24b. Time series of summer (top panel) and fall (bottom panel) CIL volumes in NAFO Divisions 2J and 3KL (dashed lines) and the average area of the Seal Island, Bonavista and Flemish Cap transects (solid lines) from 1980 to 1995.

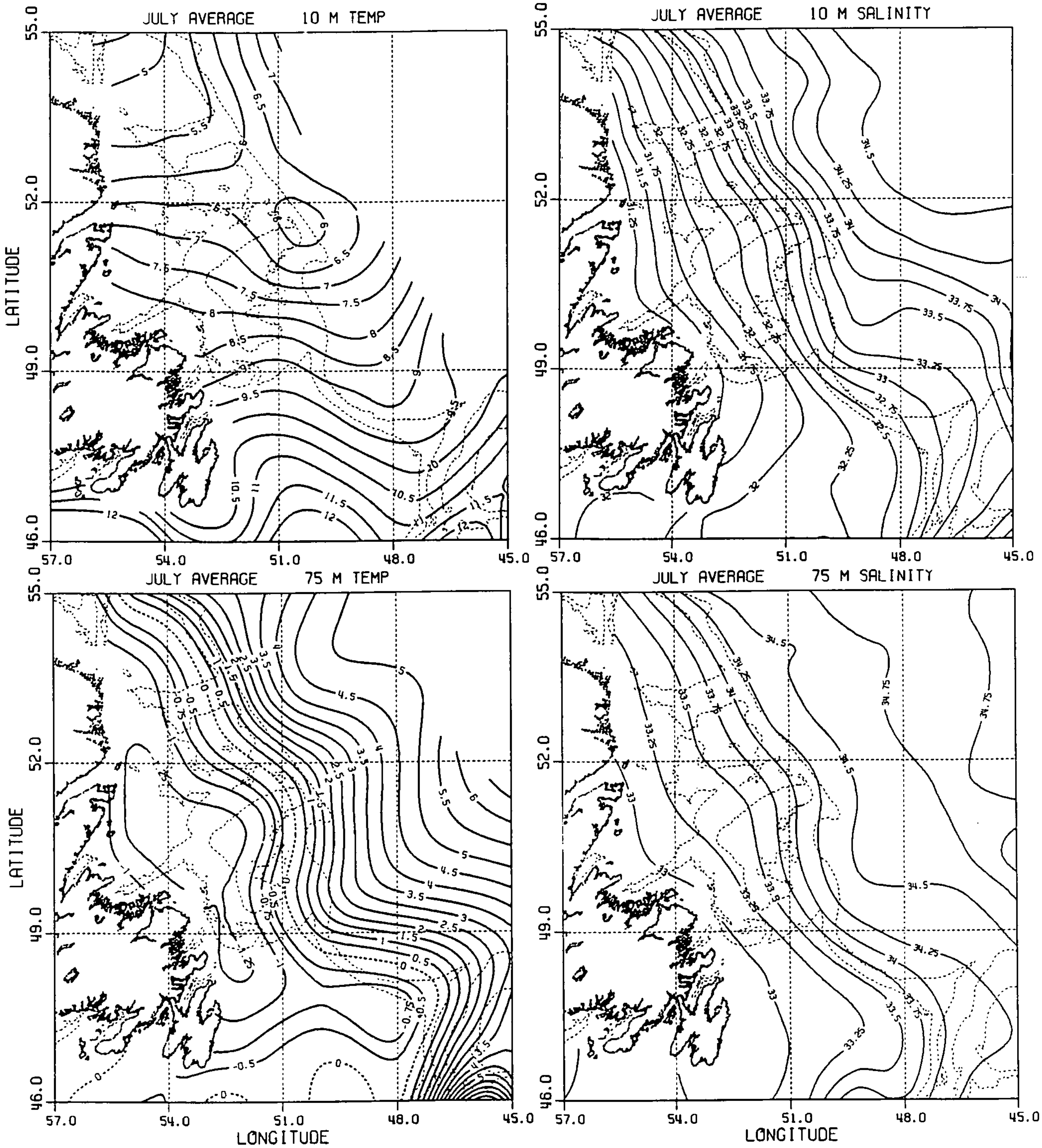


Fig. 25. Horizontal surface (10 m) and 75 m average (1961-1990) summer (July) temperature and salinity maps for the Newfoundland Shelf region.

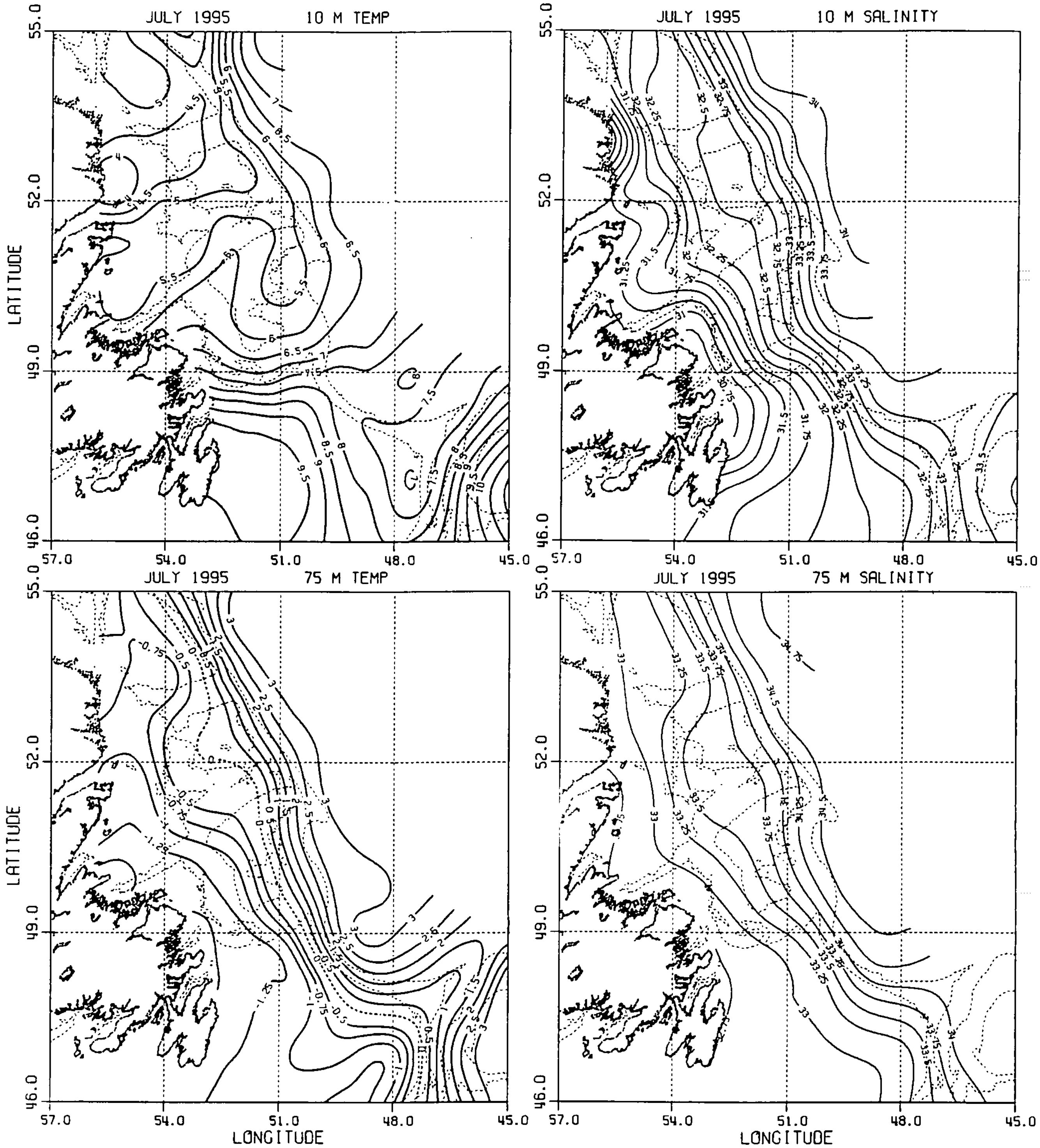


Fig. 26. Horizontal surface (10 m) and 75 m summer (July) 1995 temperature and salinity maps for the Newfoundland Shelf region.

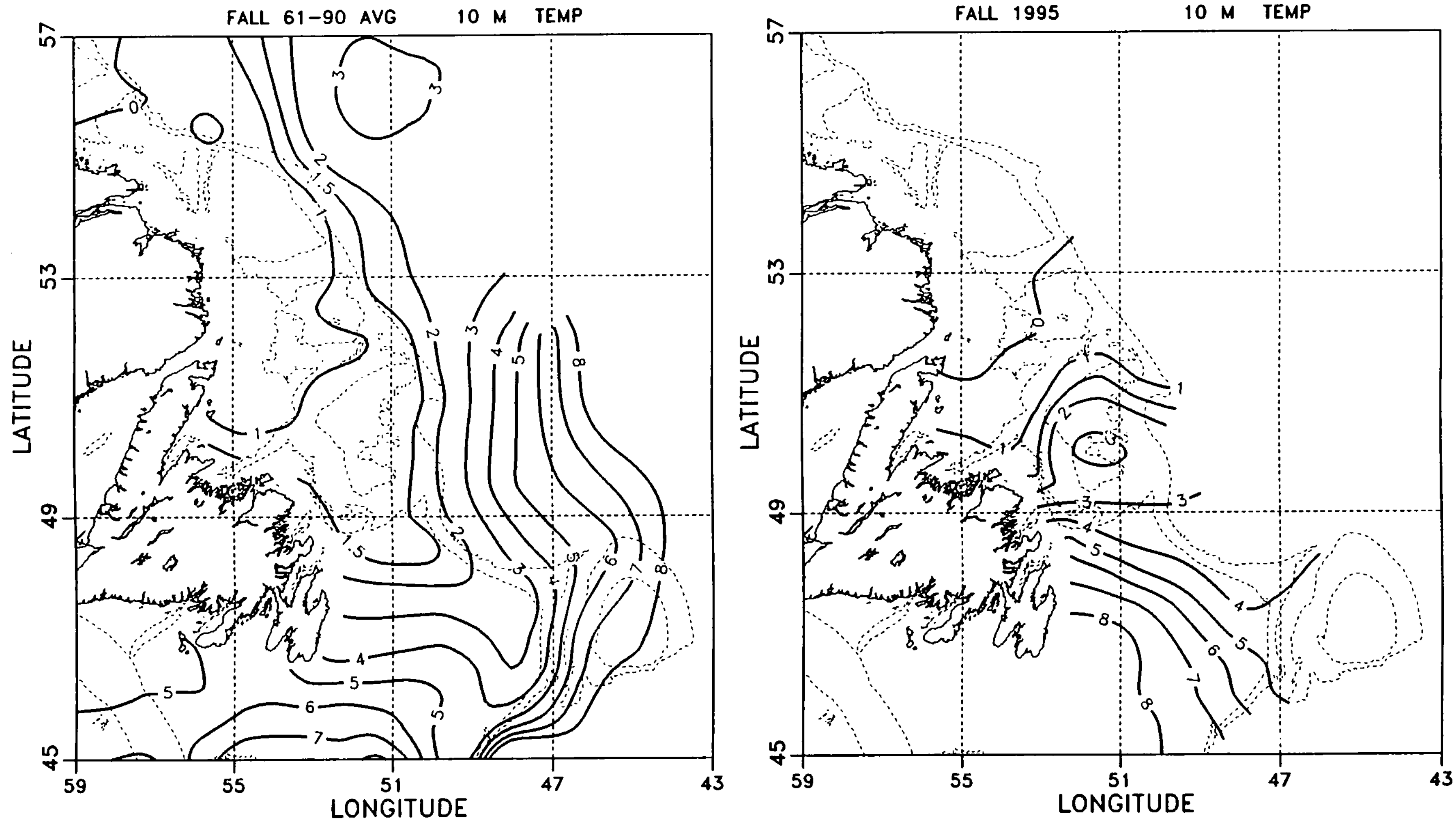


Fig. 27. Horizontal surface (10 m) temperature maps for the fall average (1961-1990) and for the fall of 1995 for the Newfoundland Shelf region.

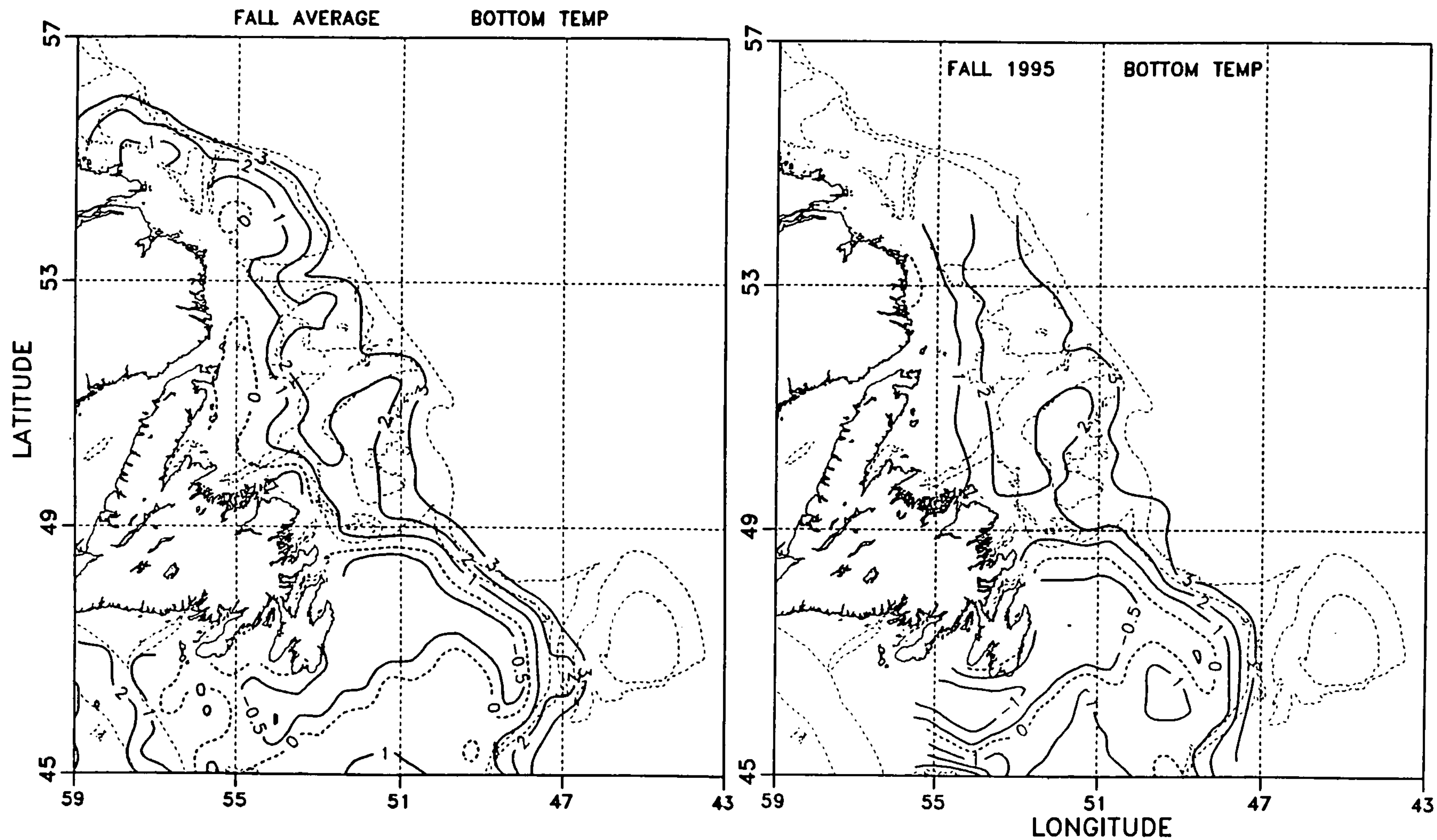


Fig. 28. Horizontal bottom temperature maps for the fall average (1961-1990) and for the fall of 1995 for the Newfoundland Shelf region.

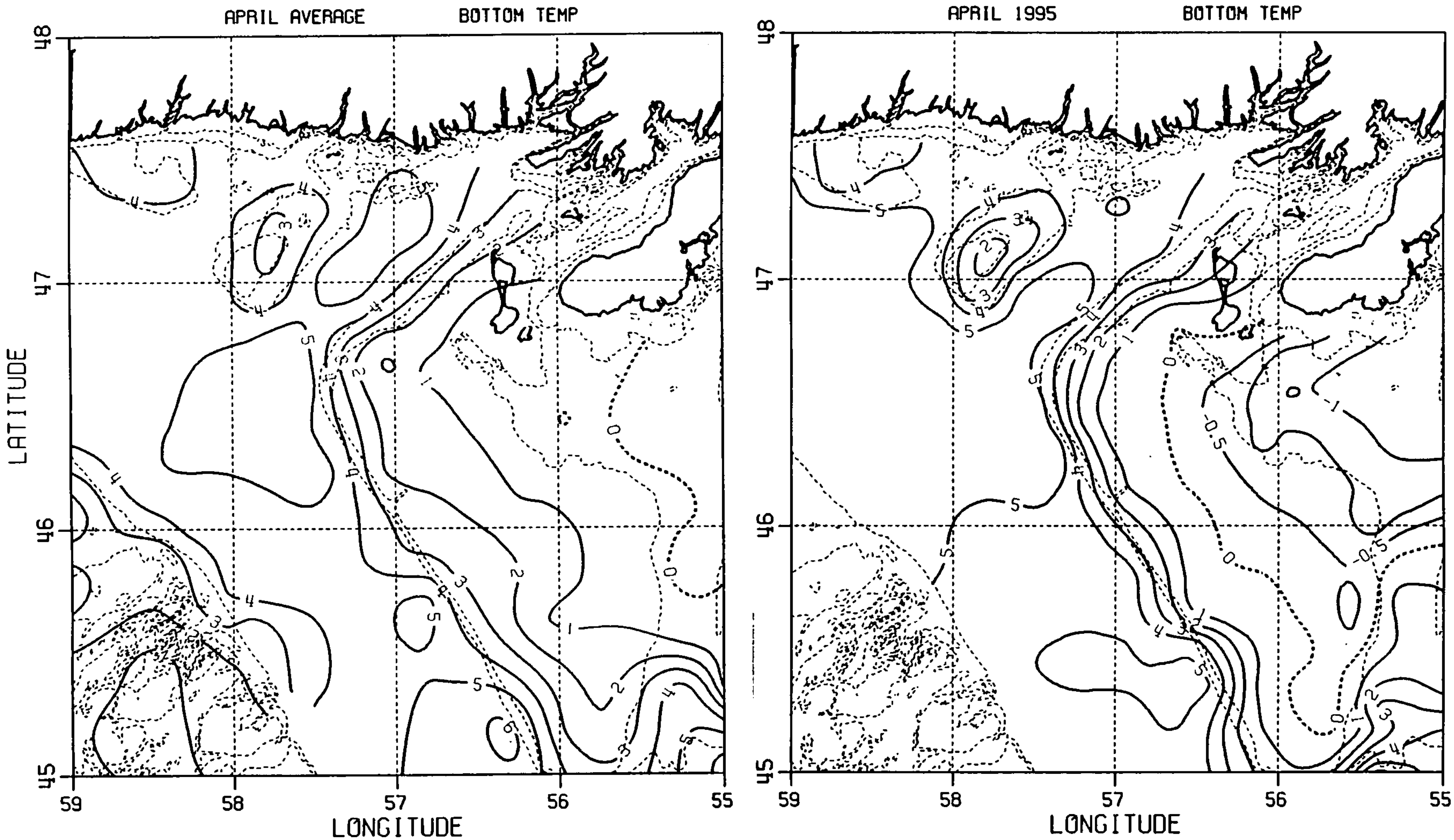


Fig. 29. Horizontal bottom temperature maps for the April average and April of 1995 in NAFO Subdivisions 3Pn and 3Ps.