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Oceanographic conditions in NAFO Divisions 2J 3KLMNO during 1998 with comparisons to the long-term (1961-1990) average

by

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ABSTRACT

Oceanographic observations from Hamilton Bank on the Southern Labrador Shelf to the Southern Grand Bank during 1998 are presented and referenced to their long-term (1961-1990) means. Temperatures at Station 27 ranged from 0.3 to 0.5 °C above normal during winter and spring over most of the water column and into early summer near the surface. By mid-summer, however, a negative temperature anomaly developed in the upper water column with temperatures reaching 1 to 2°C below normal by late summer. These colder than normal temperatures propagated deeper into the water column reaching below 100 m depth by November. Bottom temperatures throughout the year at Station 27 were slightly above normal and upper layer salinities were below normal during the first half of the year, particularly during the summer months. The 1998 summer CIL area off Bonavista and Hamilton Bank increased over 1997 values but was still below normal, continuing a trend established in 1995. Along the Flemish Cap transect across the Grand Bank the CIL area was normal during 1998, a decrease from 1997 and identical to the 1996 value. The total volume of sub-zero °C water on the Newfoundland Shelf during both summer and fall is below normal continuing the trend established in 1995. Bottom temperatures on the Grand Bank during the spring were up to 1°C above the long-term average. During the fall of 1998 bottom temperatures were still above normal over many areas, particularly on the offshore portion of the Northeast Newfoundland. An analysis of the areal extent of bottom water in different temperature bins revealed a significant decrease in the areal extent of sub-zero °C water and a corresponding increase of about 70% in the extent of water above 1°C during the spring of 1998 compared to 1997. In general, the below normal oceanographic trends in temperature and salinity, established in the late 1980s reached a peak in 1991, started to moderate during 1994 and were above normal by 1996. During 1997 and 1998 temperatures continued above normal over many areas, particularly on the Grand Bank during spring and over the deeper portions of the Northeast Newfoundland Shelf. The main exception being the near shore coastal regions in the upper to mid water column where temperatures were colder than normal during summer and early fall.

RÉSUMÉ

Des données océanographiques obtenues d'observations faites en 1998 du banc Hamilton, dans le sud de la plate-forme du Labrador, au sud du Grand Banc sont présentées dans le contexte de leurs moyennes à long terme (1961-1990). À la station 27, les températures ont été de 0,3 à 0,5 °C au-dessus de la normale pendant l'hiver et le printemps dans la plus grande partie de la colonne d'eau et jusqu'au début de l'été à proximité de la surface. Mais à la mi-été, une anomalie négative est apparue dans la partie supérieure de la colonne d'eau où la température était de 1 à 2 °C inférieure à la normale à la fin de l'été. Ces températures inférieures à la normale ont atteint les couches plus profondes pour dépasser les 100 m en novembre. À la station 27, la température au fond a été légèrement supérieure à la normale tout au long de l'année et la salinité de la couche supérieure a été inférieure à la normale pendant la première demie de l'année, surtout en été. La superficie de la CFI pendant l'été de 1998 au large de Bonavista et du banc Hamilton était supérieure à celle de 1997, mais encore en deçà de la normale, et conforme à la tendance apparue en 1995. Le long du transect du Bonnet Flamand traversant le Grand Banc, la superficie de la CFI était normale en 1998, mais inférieure à celle de 1997 et identique à celle de 1996. Le volume total d'eau de température inférieure à 0 °C sur la plate-forme de Terre-Neuve pendant l'été et l'automne était inférieure à la normale et conforme à la tendance apparue en 1995. La température au fond sur le Grand Banc pendant le printemps était supérieure d'une valeur pouvant atteindre 1 °C à la moyenne à long terme. Elle était, pendant l'automne de 1998, encore supérieure à la normale dans bon nombre d'endroits, notamment au large dans la partie nord-est de la plate-forme de Terre-Neuve. L'analyse de la superficie des eaux du fond se trouvant dans d'autres classes de données a montré l'existence d'une diminution significative de la superficie d'eau inférieure à zéro °C et une augmentation correspondante, de 70 % environ, de celle de l'eau à plus de 1 °C pendant le printemps de 1998, comparativement à 1997. De façon générale, les tendances océanographiques des températures et salinités en deçà de la normale, apparues à la fin des années 1980, ont atteint un maximum en 1991, ont commencé à redevenir modérée en 1994 et étaient supérieures à la normale en 1996. En 1997 et 1998, les températures ont continué d'être supérieures à la normale dans un grand nombre de zones, notamment sur le Grand Banc au printemps et dans les parties les plus profondes du nord-est de la plate-forme de Terre-Neuve. La principale exception a été notée dans les zones littorales des régions côtières, du milieu à la partie supérieure de la colonne d'eau, où les températures étaient inférieures à la normale pendant l'été et le début de l'automne.

INTRODUCTION

This report presents an overview of oceanographic conditions in the Newfoundland region during 1998, with a comparison to the long-term average conditions based on historical data. Where possible the long-term means were standardized to a base period from 1961-1990 in accordance with the convention of the World Meteorological Organization and recommendation of the North Atlantic Fisheries Organization's (NAFO) Scientific Council. Most of the long-term averages computed for this report had good temporal coverage over the years 1961-1990 except during the fall period for which most data are 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. Data from the inshore regions around Newfoundland including temperature time series from three Long-Term-Temperature-Monitoring-Program (LTTMP) sites are also used. In addition, all oceanographic observations made during the spring and fall pelagic and groundfish research vessel surveys from the late 1970s to 1998 in NAFO Divisions 2J to 3LMNO are included. Data from all other available sources are also used to help define the long-term means and conditions during 1998.

DATA SOURCES AND ANALYSIS

Oceanographic data for NAFO Divisions 2J 3KLMNO 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 random stratified groundfish surveys using XBTs. Since 1989 net-mounted conductivity-temperature-depth (CTD) recorders have replaced XBTs. 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 when necessary. The SBE-25 and 911s are field calibrated on each survey maintaining accuracies of 0.005 ^{o}C in temperature and 0.005 psu in salinity.

Time series of temperature and salinity anomalies were constructed at standard depths from Hamilton Bank, Station 27, and the Flemish Cap. The 1961-1990 data set 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 determined by fitting a least squares regression of the form $\mathbf{\cos(\omega t-\phi)}$ to the data. Where ω is the annual frequency, $\mathbf{t}$ is the time in days and ϕ is the phase. The fitted values were the mean, the annual frequency ω and two of its harmonics. The seasonal cycle was then removed to determine anomalies. These anomalies (except Station 27) are based on data collected over relatively large geographical areas and therefore may exhibit variability due to spatial differences in the monthly estimates.

Temperature anomalies were also constructed for the inshore region of Notre Dame Bay, Bonavista Bay and Placentia Bay, for the years 1990 to 1998 from the Long-Term-Temperature-Monitoring thermograph sites by computing monthly means from the continuous hourly time series.

Average bottom temperature maps for the Newfoundland Shelf were produced from all available data from 1961 to 1990 and for the spring and fall of 1998. All bottom-of-the-cast temperature values for each time period (except those for which the cast depths were not within 10% of the total water depth) were projected onto a regular grid and contoured. Some temporal and spatial biasing may be present in the analysis given the large area and wide time interval over which the maps were produced. For example, the annual fall groundfish survey is conducted from mid-October to mid-December, a time period when rapid cooling of the water column is taking place. A further analysis of the bottom temperature data from the surveys was made by calculating the total area of the grids used in the bottom temperature maps within selected temperature ranges. The mean bottom temperature of all grid values was also calculated. A time-series of the percent of the total area covered by bottom water in selected temperature ranges as well as the average bottom temperatures were constructed from 1990 to 1998.

TEMPERATURE AND SALINITY TRENDS

Station 27 (Division 3L)

A total of 53 temperature and salinity profiles were collected at Station 27 off Cape Spear (Fig. 1) during 1998. The data from this time series are presented in several ways to highlight seasonal and interannual variations over the entire water column. Depth versus time contour maps of temperature and salinity values and their associated anomalies are displayed in Figs. 2 and 3. The annual time series of monthly temperature and salinity anomalies at standard depths are shown in Figs. 4 and 5.

The cold near isothermal water column during the winter months has temperatures ranging from 0°C to colder than –1.7°C over the entire water column and from -1°C to near -1.5°C throughout the year, near the bottom. The time series shows the surface layer temperatures near constant at about 0°C from January to early April, after which the surface warming commenced. By early May the upper layer temperature had warmed to 2°C and to above 12°C by August at the surface, after which the fall cooling commenced. These temperatures ranged from 0.3° to 0.5°C above normal for the winter months over most of the water column and up to 1°C at the surface during May to July. By mid summer a negative temperature anomaly developed over the upper water column with anomalies reaching 1°C to 2°C below normal centered at about 25-35 m depth range. These colder–than-normal temperatures penetrated deeper into the water column reaching 100-m depth by November. A similar situation existed during 1997 (Colbourne 1998). These cold anomalies may have been caused by the advection of cold water from the Northern Labrador Coast that formed during mid-winter and was advected southward by the Labrador Current arriving at Station 27 by mid to late summer. They could also have been the result of increase stratification in early summer, which would have slowed the rate of vertical mixing, resulting in the colder saltier water observed in Figs. 2 and 3 during the late summer and fall periods. Fall temperatures in the upper layer were about normal. Bottom temperatures throughout the year ranged from 0° to 0.3°C above normal.

Upper layer salinities reached a maximum of 32.2 psu in mid-March and decreased to a minimum of 31.1 psu by late August. These values ranged from 0.2 to 0.5 psu below the long-term mean and were associated with the positive temperature anomaly. In the depth range from 50 to 100 m salinities generally ranged from 32.4 to 32.8 psu. Bottom layer values ranged from 32.2 to 33 psu throughout the year. Except for a positive anomaly (up to 0.3 psu) centered at about 50-m depth during fall, these values were near normal throughout the year.

The interannual time series of temperature and salinity anomalies at standard depths show three major colder and fresher than normal periods at near decadal time scales since the early 1970s (Fig. 6a). At the surface the negative temperature anomalies that began in late 1990, reaching a peak in mid 1991, had moderated to above normal conditions by the summer of 1994. Since then surface temperatures have oscillated above and below normal. At the greater depths of 100 and 175 m negative temperature anomalies have persisted since 1983 with only 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 and by 1996 were above the long-term normal. Temperatures during 1998 decreased to below normal values at 100-m depth but remained above normal near bottom at 175-m depth.

Upper layer salinity anomalies show the large fresher than normal anomaly that began in early 1991 had moderated to near normal conditions by early 1993 but returned to fresher conditions by the summer of 1995 which continued into 1996. Salinities approached near normal values during 1997 but decreased at the surface through most of 1998 and remained near normal below 100-m depth. Other periods with colder and fresher than normal salinities particularly in the early 1970s and mid 1980s are associated with strong positive NAO index anomalies, colder than normal winter 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. 1994, Drinkwater et al. 1996).

The vertically averaged annual temperature anomaly (which is proportional to the water column heat content anomaly) time series (Fig. 7) shows large amplitude fluctuations, at near decadal time scales, with cold periods during the early 1970s, mid 1980s and early 1990s. During the time period from 1950 to the late 1960s the heat content of the water column was generally above the long-term mean. It reached a record low during 1991, a near record high during 1996 and near the long-term mean in both 1997 and 1998. The 0 to 50 m vertically averaged summer (July-September) salinity anomalies (Fig. 7) show similar behaviour as the heat content time series with fresher than normal periods corresponding to the colder than normal conditions. The low salinity anomaly on the inner Newfoundland Shelf during the early 1990s is comparable to that 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 decreased again by the summer of 1995 to near record lows, these increased again in 1996 and returned to near normal values in 1997 which persisted into 1998.

Hamilton Bank (Division 2J)

The time series of temperature and salinity anomalies from 1950 to 1998 on Hamilton Bank are shown in Fig. 8a and 8b at standard depths of 0, 50, 75 and 150 m. The monthly values show high frequency variations, which may indicate spatial variability over the bank at the same depth level. A low frequency trend was calculated by smoothing the time series using a five-point running mean. This suppresses the high frequency variations at seasonal scales and gives an indication of any long-term trends. It should be noted that the monthly averages consist of a variable number of observations.

The time series is characterized by large variations with amplitudes ranging from ±1°C and with periods ranging from 2 to 10 years. The cold periods of the early 1970s, the mid-1980s and to a lesser extent the early 1990s are present, however, the amplitude of these anomalies vary considerably with depth. The long-term trend indicates that temperatures on Hamilton Bank appear to be moderating, particularly in the deeper layers, where the trend had been below normal since the early 1980s, similar to conditions further south at Station 27. During 1998 temperatures appear to be above normal over most of the water column. The smoothed salinity time series show very similar conditions as elsewhere on the shelf with fresher than normal conditions in the early 1970s, mid 1980s and early 1990s. The below average trend established in the early 1990s continued into 1996; however, measurements made during 1997 and 1998 indicate moderating conditions.

Flemish Cap (Division 3M)

Similar to the Newfoundland Shelf the monthly temperature and salinity anomalies on the Flemish Cap (Fig. 9a) 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, while 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 tendency towards positive anomalies. By 1985 in the top 100-m of the water column, negative temperature anomalies had returned. This cold period moderated briefly in 1987 but returned again by 1988 and continued into the early 1990s. From 1995 to 1998 temperatures have moderated, particularly above 100-m depth.

The time series of salinity anomalies (Fig. 9b) 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 0.6 psu below normal. The trend in salinity values during the early 1990s range from slightly above normal at the surface to below normal at 50 and 100 m depth and about normal at 200 m depth. In general, the temperature and salinity anomalies are very similar to those at Station 27 and elsewhere on the continental shelf over similar depth ranges (Colbourne 1998).

Coastal Near-Surface Temperatures

Hourly temperature measurements at 10-m depth were made at inshore monitoring sites at Comfort Cove in Notre Dame Bay since 1981, Stock Cove in Bonavista Bay since 1967 and at Arnold's Cove in Placentia Bay since 1981. These were used to calculate monthly mean temperatures from which a temperature anomaly time series was constructed. The 1998 measurements all show above normal values for the first 7 months except in July at Comfort Cove, which was about 1°C below average. During September and October temperatures were below normal but recovered again by November (Fig. 10).

The interannual time series indicate that temperatures were up to 4° to 6°C below average during 1991 and 1993 in the summer months in Notre Dame and Bonavista Bays and up to 2 °C below average in Placentia Bay. Temperatures were from 1° to 3°C above normal during the summer months of 1994 and throughout most of 1996 at all 3 sites. By mid-1997, temperatures were below normal at all three sites but recovered to above normal values late in the year, which continued into 1998 (Fig. 11).

STANDARD TRANSECTS

Seal Island

Temperatures along the Seal Island transect (Fig. 12a) ranged from 0°C at 40-m depth to between 6°C to 7°C at the surface. Temperatures below 50-m were generally subzero °C over most of the shelf except near bottom. Near the shelf break temperatures increase to between 3.5°C to 4°C. Temperature anomalies along the Seal Island transect ranged from 0.25° to 0.5°C below normal near shore, to 0.25° to 1°C above normal over mid-shelf and in the offshore region beyond the shelf edge. An area of below normal temperatures occurred near the shelf break at mid-depths, near the offshore edge of the shelf water. Surface salinities along the Seal Island transect (Fig. 12b) ranged from 31 psu near shore too greater than 33 psu offshore. Below the surface layer salinities ranged from 32 psu to 34.psu near bottom. Surface salinity anomalies were above normal near shore and below normal at the surface on the outer shelf. Below the surface layer, salinities were near normal over the shelf and above normal offshore of the shelf edge.

Bonavista

Temperatures along the Bonavista transect in the upper 20 m of the water column ranged from 10°C to 12°C over most of the continental shelf, about 0.8° to 2°C above normal. Close to shore, in the depth range of 10 to 100-m and near the offshore edge of the shelf water in the depth range of 30 to 200-m, temperatures were up to 1°C below normal. In general, however, except for these anomalies temperatures over most of the shelf were above normal in July of 1998.

Bonavista transect salinities (Fig. 13b) ranged from 31 psu near the surface in the inshore region to 33.5 psu in the offshore region. Bottom salinities ranged from 32.5 over the inshore portion of the transect, to 34.75 psu at about 325-m depth near the shelf edge. Salinities were fresher than normal in the surface layer and near the offshore edge of the shelf water and above normal offshore of the shelf edge. Bottom salinities across the shelf were near normal.

Flemish Cap

Summer temperatures along the Flemish Cap transect (Fig. 14a) ranged from greater than 12°C near the surface to subzero below 50-m in the Avalon Channel and at the edge of the Grand Bank. Over the Flemish Cap temperatures were 13°C at the surface and about 4°C at 80-m depth to the bottom. These values were about 1°C above normal in the upper layer over the Grand Bank, 0° to 0.5°C above normal near bottom over the Grand Bank and about 0.5° to 1°C above normal over Flemish Cap. In the Flemish Pass temperatures were up to 2°C below normal, in the depth range of 20 to 80-m. Surface temperatures over the Cap were up to 2°C above normal. Upper layer salinities (Fig. 14b) were slightly saltier than normal over the Grand Bank and across the Cap and slightly fresher than normal at the edge of the Grand Bank.

CIL Time Series

The vertical temperature structure on the Newfoundland continental shelf during the summer is dominated by a layer of cold sub-zero °C water trapped between the seasonally heated upper layer and warmer slope water near the bottom, commonly referred to as the CIL (Petrie et al. 1988). This cold, relatively fresh, shelf water is separated from the warmer saltier water of the continental slope by a strong temperature and salinity front near the edge of the continental shelf. Figure 15 shows a time series of the CIL cross-sectional area of the sub-zero °C water for the Seal Island, Bonavista and Flemish Cap transects. The positions of the transects are shown in Fig 1.

Along the Bonavista transect during the summer of 1998 the CIL extended offshore to about 220 km, with a maximum thickness of about 220 m corresponding to a cross-sectional area of about 24.8 km^2 (Fig. 13a), compared to the 1961-90 average of 26.8 km^2. This value is about 5% below normal compared to 28% below normal in 1997 and 10% below normal in 1996. From 1990 to 1994 the CIL was above normal reaching a peak of more than 60% in 1991. The CIL area along the Seal Island transect was also below normal by about 15% during 1998, compared to 38% in 1997 and 12% during 1996. 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 was near normal compared to 20% above normal in 1997 and near normal conditions during the summer of 1996. In 1995 it was about 18% above normal compared to 12% in 1994 and to 48% during 1991. In general, the total cross-sectional area of sub-zero ^oC water on the Newfoundland Shelf is continuing a below normal trend established in 1995 in many areas, except on the Grand Bank where it is about normal.

The minimum core temperatures measured in the summer CIL for all three transects from 1950 to 1998 are shown in Fig. 16. The minimum temperature observed along the Seal Island transect during 1998 was -1.58°C compared to a normal of-1.57°C. Core temperatures along the Bonavista transect were near normal at -1.66°C and along the Flemish transect they were -1.62°C compared to a normal of -1.52°C. Except for the Grand Bank, minimum temperatures were similar to 1997 values.

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 2.0×10^5 km^3. The calculation of the volume of sub-zero ^oC water overlying the continental shelf has been described by Colbourne and Mertz (1995). The spatial variation in the amount of subzero ^oC water on the shelf in different years is determined by calculating the thickness of the layer of water less than 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 warm 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 zero near the edge of the shelf, on the southern Grand Bank and on Hamilton Bank during warm years in the fall.

The time series of total volume of sub-zero ^oC water over the 2J, 3KL area shows maximum values during the cold periods of the mid 1980s and early 1990s (Fig. 17). The total volume of sub-zero ^oC water on the shelf increased from approximately 3.3×10^4 km^3 during the summer of 1989 to 5.6×10^4 km^3 in 1990, a 70% increase. Since 1991 the volume of subzero ^oC water on the Newfoundland Shelf has been slowly decreasing, and by 1995 it had decreased to values of the early 1980s and from 1986 to 1989. The 1998 volumes were similar to 1997 values in both summer and fall. Both years were significantly below average. The 1980 to 1998 average volume of sub-zero ^oC water on the shelf during the summer is $4.0 \pm 0.9 \times 10^4$ 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 is reduced to 2.4 ± 0.8 x 10^{14}, km^3 about one-half the summer value. Due to data limitations, the volume estimates were not calculated prior to 1980. Time series of the volume of sub-zero °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).

BOTTOM TEMPERATURE ANALYSIS

Horizontal Maps

The average (1961-90) and the 1998 spring and fall bottom temperature for the 3LNO and the 2J3KLNO areas respectively are shown in Fig. 18. The average spring (April-May) bottom temperature ranges from sub-zero °C on the northern Grand Bank and in the Avalon Channel to 3°C at the shelf edge. Over the central and southern areas average bottom temperatures ranges from 0°C to above 2°C on the southeast shoal and to above 3°C along the edge of the bank. During the spring of 1998 sub-zero °C water was restricted to a small area in the Avalon Channel and above normal conditions persisted over the entire Grand Bank in water depths less than 200-m. Over the central and southern Grand Bank bottom temperatures were up to 1°C above the long-term average (Fig. 18a).

The average fall bottom temperature (Fig. 18b) over most of the Northeast Newfoundland Shelf (2J3K) ranges from less than 0°C inshore, to above 3°C offshore at the shelf break. The average temperature over most of the Grand Bank varies from -0.5°C to 0°C over the central and northern areas, 0° to 3°C over southeastern regions and to above 3°C at the shelf break. In general, bottom isotherms follow the bathymetry exhibiting onshore-offshore gradients over most of the Northeast Newfoundland Shelf. The percentage area of water less than -0.5°C over the Grand Bank and Northeast Newfoundland Shelf from 1990 to 1994 was much 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°C over the Grand Bank (Colbourne 1994). During the fall of 1996 bottom temperatures warmed over most areas on the Newfoundland Shelf with anomalies up to 0.5°C above normal in many places. During 1996 the percentage area of water less than -0.5°C on the Grand Bank was below average with a complete absence of sub-zero °C water on the Northeast Newfoundland Shelf from the northern Grand Bank to Nain Bank. Bottom temperatures during the fall of 1997 and 1998 were still above normal over many areas, particularly on the offshore portion of the shelf.

AREAL INDEX

Oceanographic data from groundfish assessment surveys have been collected in the 3LNO region during spring since the early 1970s and in 3L during fall since 1981. Systematic fall surveys in divisions 3NO started in 1990. These together with other available oceanographic data were gridded at a spatial resolution of approximately 390 km^2. A total of 640 grid points or 250,000 km^2 were used within the boundaries of the 3LNO regions. The mean bottom temperature for each grid was then calculated and combined with the grid area to produce a time series of bottom area covered by water in selected temperature ranges. The areas are expressed as a percentage of the total surveyed area. The mean bottom temperature time series was also constructed for the region.

Shown in Fig 19 are time series of the areal extent of the bottom covered with water less than 0°C, between 0° to 1 °C and greater than 1 °C for NAFO divisions 3LNO during spring and for the Grand Bank region with water depths within 100-m. Note the general decrease in the percentage area of the bottom covered by subzero °C water since 1994 and the corresponding increase in the area covered by water greater than 1°C. The area covered by water in the 0° to 1 °C temperature range varied from less than 20% in 1993 to near 30% in 1996. During the spring of 1998 water with temperatures above 1°C covered more than 50% of the bottom area, compared to about 10% in 1990 on the Grand Bank. The level of increase during 1998 compared to previous years on the Grand Bank within 100-m depth shows a dramatic increase over previous years.

The average bottom temperature of the surveyed area in divisions 3LNO during the spring ranged between 0.3°C to 1.3°C from 1990 to 1997 and increased to near 1.8°C during 1998 (Fig. 20, upper panel). On the banks in water depths generally less than 100-m the average temperature from 1990 to 1997 ranged between approximately -0.3°C to 0.7°C, which increased to 1.2°C during 1998.

Shown in Fig 21 are time series of the areal extent of bottom covered with water less than 0°C, between 0°C to 1°C, and greater than 1 °C for NAFO divisions 3LNO during the fall period and for the Grand Bank region with water depths within 100-m. In general the percentage area of the bottom covered by subzero °C water decreased significantly during 1995 to roughly one-half the values during the first half of the 1990s. The area covered by water in the 0° to 1 °C temperature range varied from a low of 12% to near 40% in with no significant trend evident. A corresponding increase in the areal extent of water greater than 1°C occurred during 1995. From 1995 to 1998 this remained relatively constant at about 50% of the total area. Again the trends were more pronounced on the Grand Bank in water depths less than or equal to 100-m.

The average bottom temperature of the surveyed area in divisions 3LNO during the fall decreased from approximately 1.5°C during 1990 to 1°C during 1993, then increased to approximately 2°C during 1995 and remained relatively constant up to 1998 (Fig. 22, upper panel). On the Grand Bank in water depths generally less than 100-m the average temperature decreased from 1.2°C in 1990 to 0.3°C in 1994, then increased to about 1.5°C in 1995 and has remained relatively constant through 1998.

SUMMARY

Time series of temperatures at Station 27 show values ranging from 0.3° to 0.5°C above normal for winter and spring over most of the water column and into the summer months near the surface. By mid-summer a strong negative upper layer temperature anomaly developed with anomalies reaching 1° to 2°C below normal by late summer. These colder than normal temperatures appear to have propagated deeper into the water column reaching below 100-m depth by November. Fall temperatures in the upper layer were about normal, while bottom temperatures throughout the year were slightly above normal. Upper layer salinities from January to August were below normal by 0.5 psu in July. Except for a slightly positive anomaly centered at about 50-m depth during the fall salinities were near normal over the rest of the water column throughout the year.

During the summer of 1998 the CIL cross-sectional area off Bonavista and Hamilton Bank increased over 1997 values but was still below normal continuing a trend established in 1995. Along the Flemish Cap transect across the Grand Bank the CIL area was normal during the summer of 1998, a decrease from 1997 but identical to the 1996 value. The total volume of sub-zero °C water on the Newfoundland Shelf during both summer and fall has continuing the below normal trend established in 1995. Minimum CIL core temperatures were near normal except over the Grand Bank where they were below normal.

Bottom temperatures on the Grand Bank during the spring were up to 1°C above the long-term average with a very small area of sub-zero °C values restricted to the deeper portions of the Avalon Channel. Bottom temperatures on Hamilton Bank and the Grand Bank during the fall period of 1996 increased significantly over previous years and were up to 0.5°C above normal over many areas. During the fall of 1997 and 1998 bottom temperatures were still above normal over many areas, particularly on the offshore portion of the Northeast Newfoundland Shelf. An analysis of the areal extent of bottom water in different temperature bins reveals a significant decrease in the areal extent of subzero °C water and a corresponding increase of about 70% in the extent of water above 1°C during the spring of 1998 compared to 1997.

In general, the below normal oceanographic trends in temperature and salinity, established in the late 1980s reached a peak in 1991. This cold trend continued into 1993 but started to moderate during 1994 and 1995. During 1996 temperature conditions were above normal over most regions, however, summer salinity values continue to be slightly below the long-term normal. During 1997 and 1998 oceanographic temperatures were still above normal over many areas, particularly on the Grand Bank during spring and over the deeper portions of the Northeast Newfoundland Shelf. The main exception

being the near shore coastal regions in the upper to mid water column where temperatures were colder than normal during summer and early fall.

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I thank C. Fitzpatrick, D. Senciall, P. Stead, D. Foote and S. Kennedy of the oceanography section at NAFC for the professional job in data collection and processing. I also 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. I also thank the captain and crew of the CCGS Teleost for a successful annual oceanographic survey.

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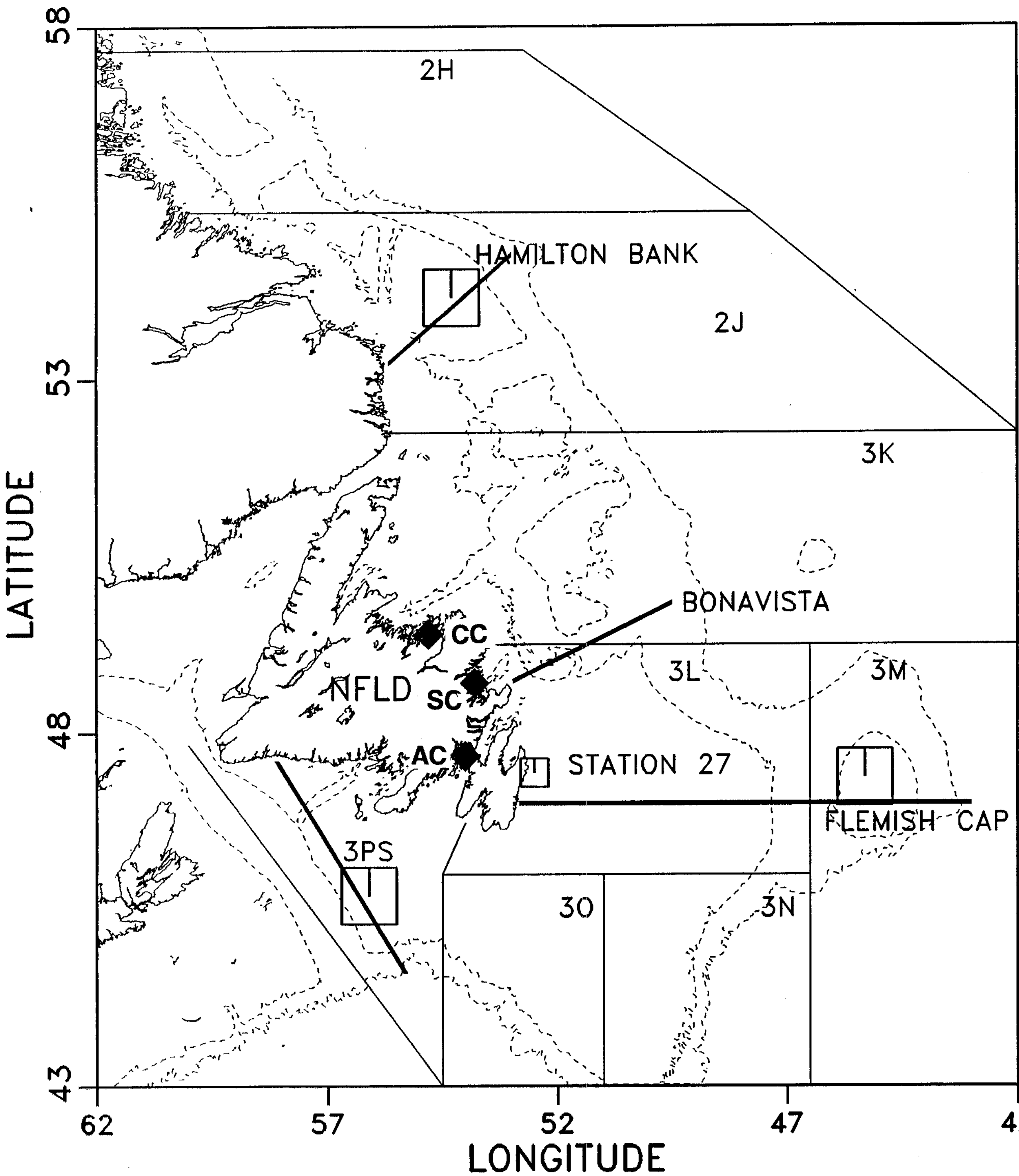


Fig. 1. Location map showing the position of the Seal Island, Bonavista and the Flemish Cap (47 °N) transects. The locations of the Long-Term-Temperature-Monitoring (LTTM) sites Arnold's Cove (AC), Stock Cove (SC), Comfort Cove (CC) and Station 27 are also shown. Bathymetry lines are 300 and 1000 m.

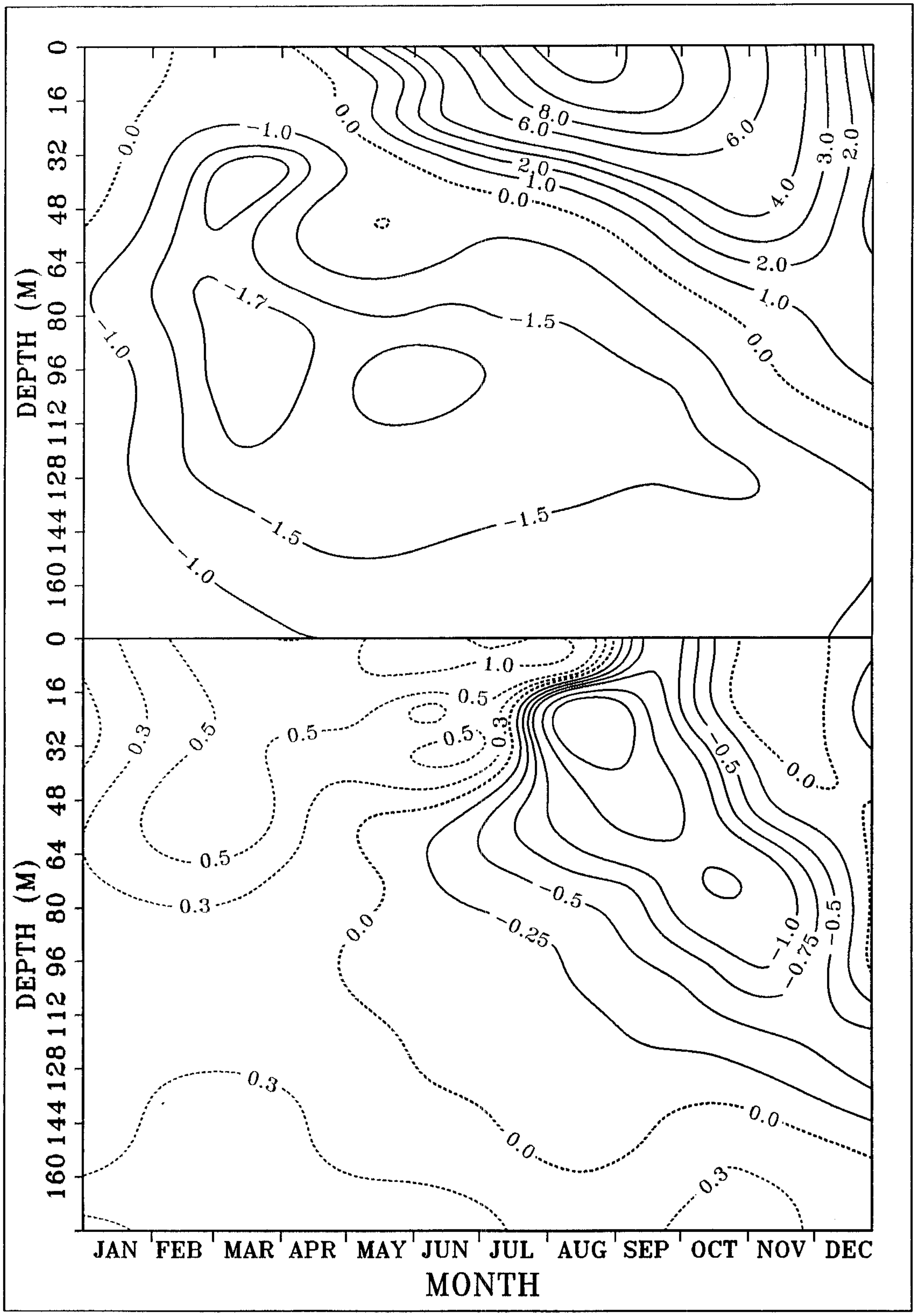


Fig. 2. Monthly temperatures (top panel) and anomalies (bottom panel) in °C at Station 27 as a function of depth for 1998.

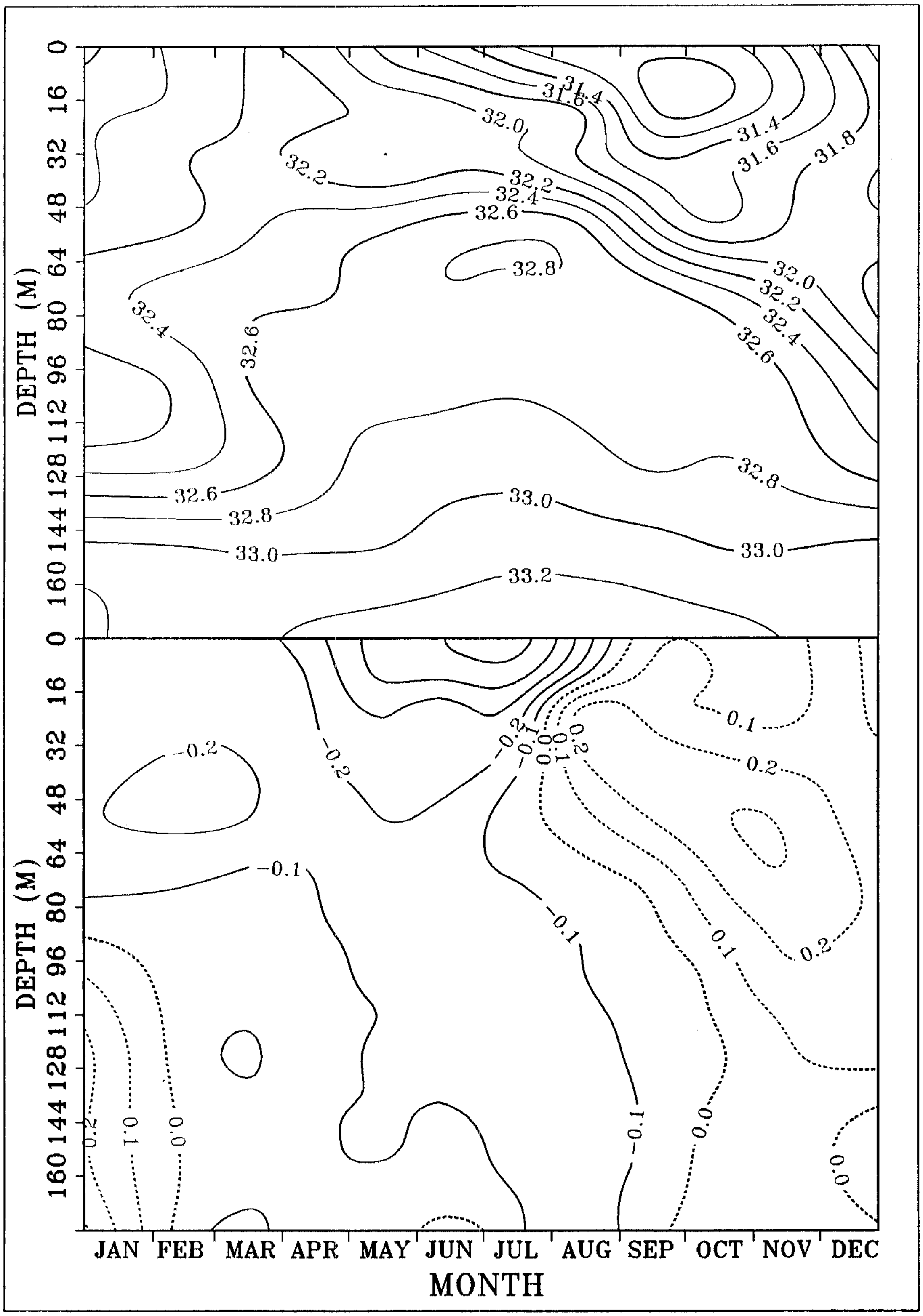


Fig. 3. Monthly salinity (top panel) and anomalies (bottom panel) at Station 27 as a function of depth for 1998.

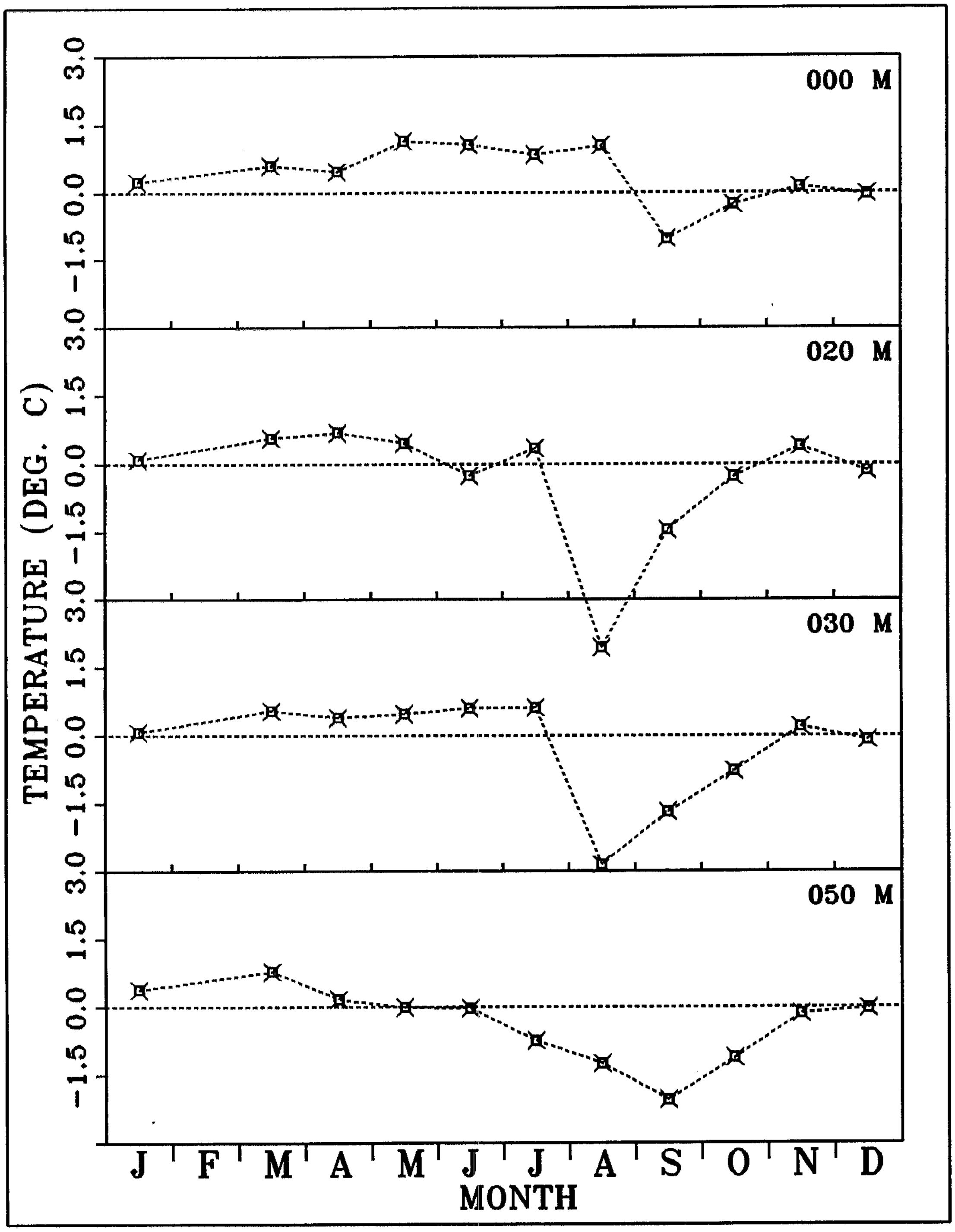


Fig. 4a. Monthly temperature anomalies at Station 27 during 1998 at standard depths.

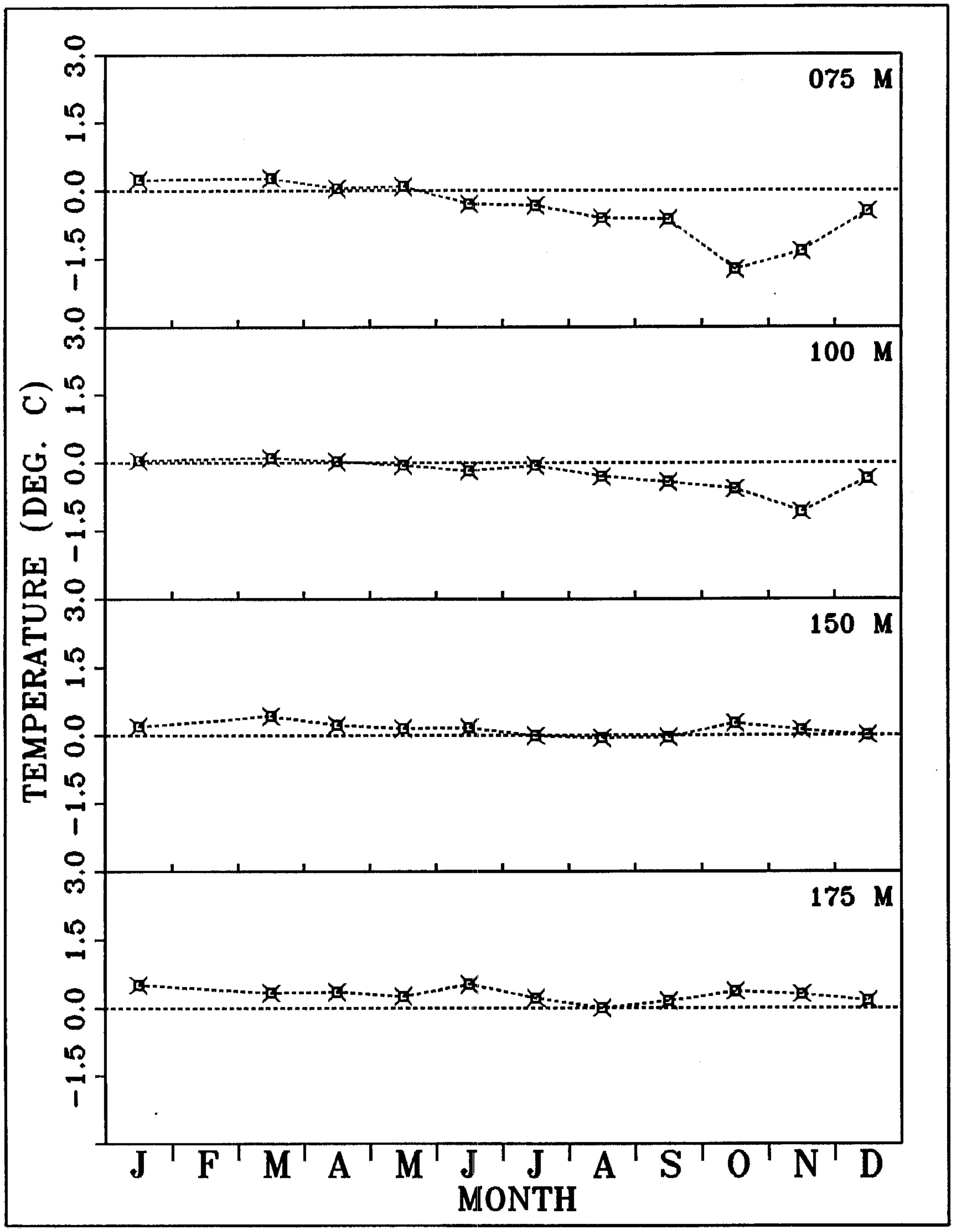


Fig. 4b. Monthly temperature anomalies at Station 27 during 1998 at standard depths.

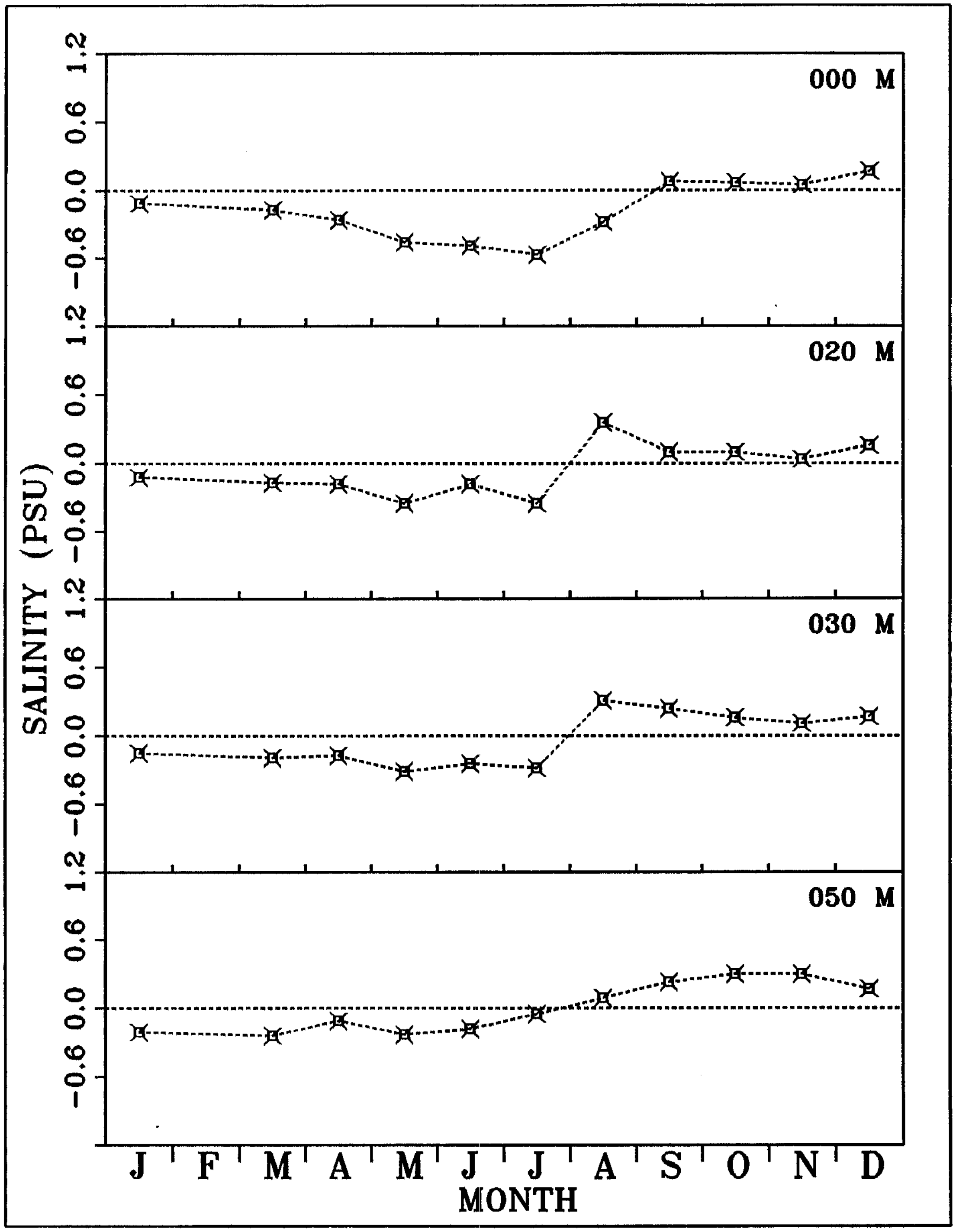


Fig. 5a. Monthly salinity anomalies at Station 27 during 1998 at standard depths.

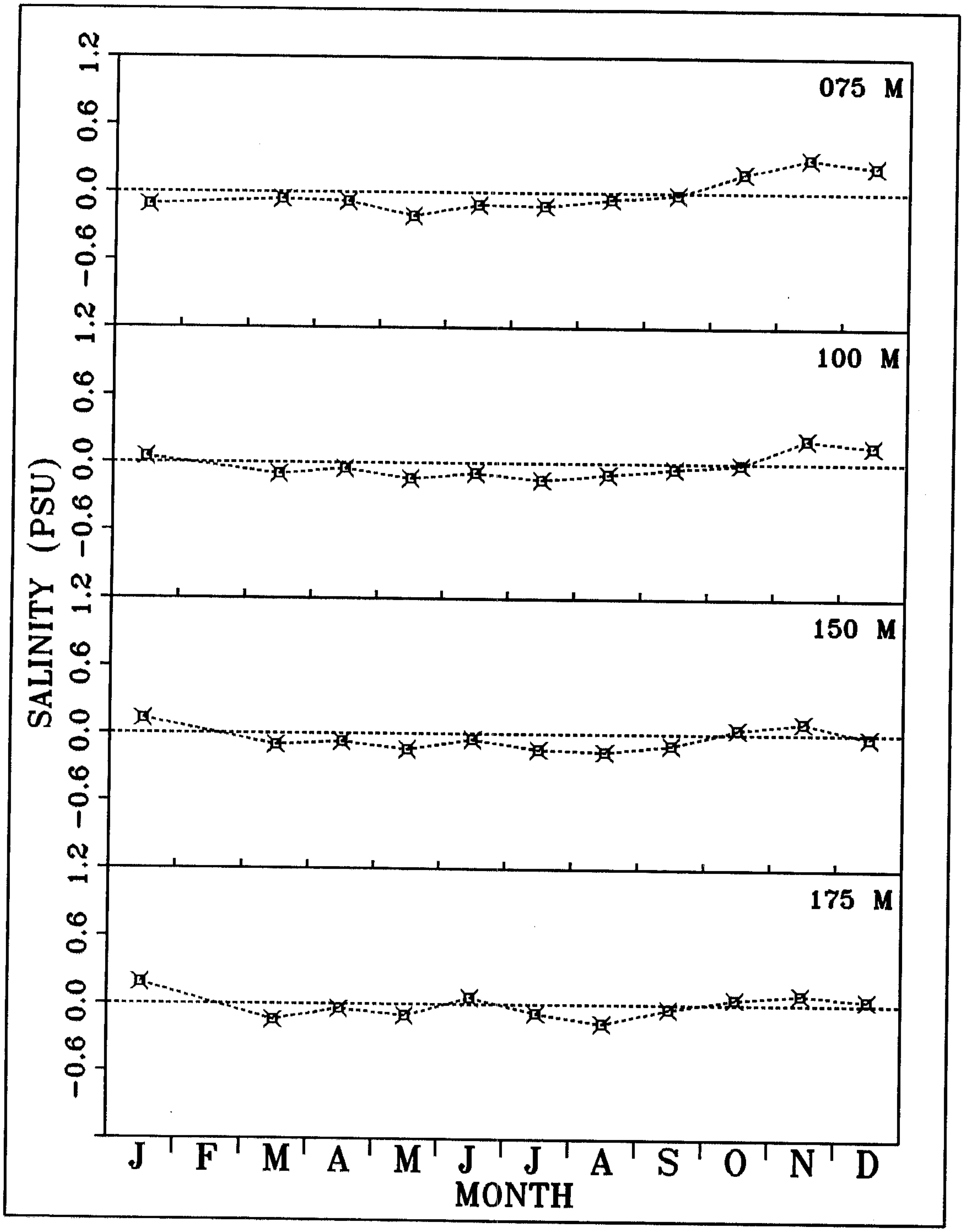


Fig. 5b. Monthly salinity anomalies at Station 27 during 1998 at standard depths.

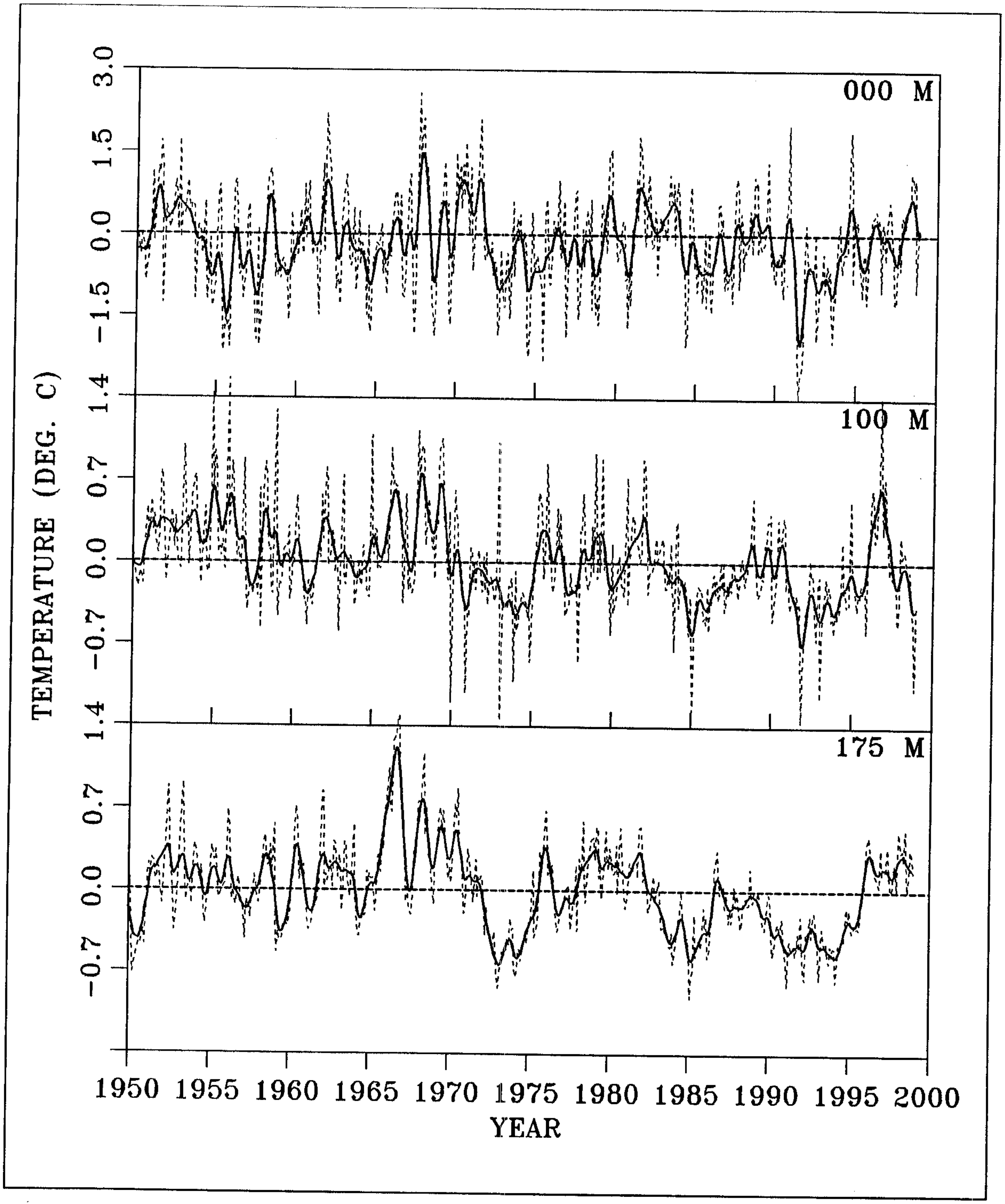


Fig. 6a. Time series of monthly temperature anomalies at Station 27 at standard depths from 1950 to 1998. The heavy lines represent the low-passed filtered values.

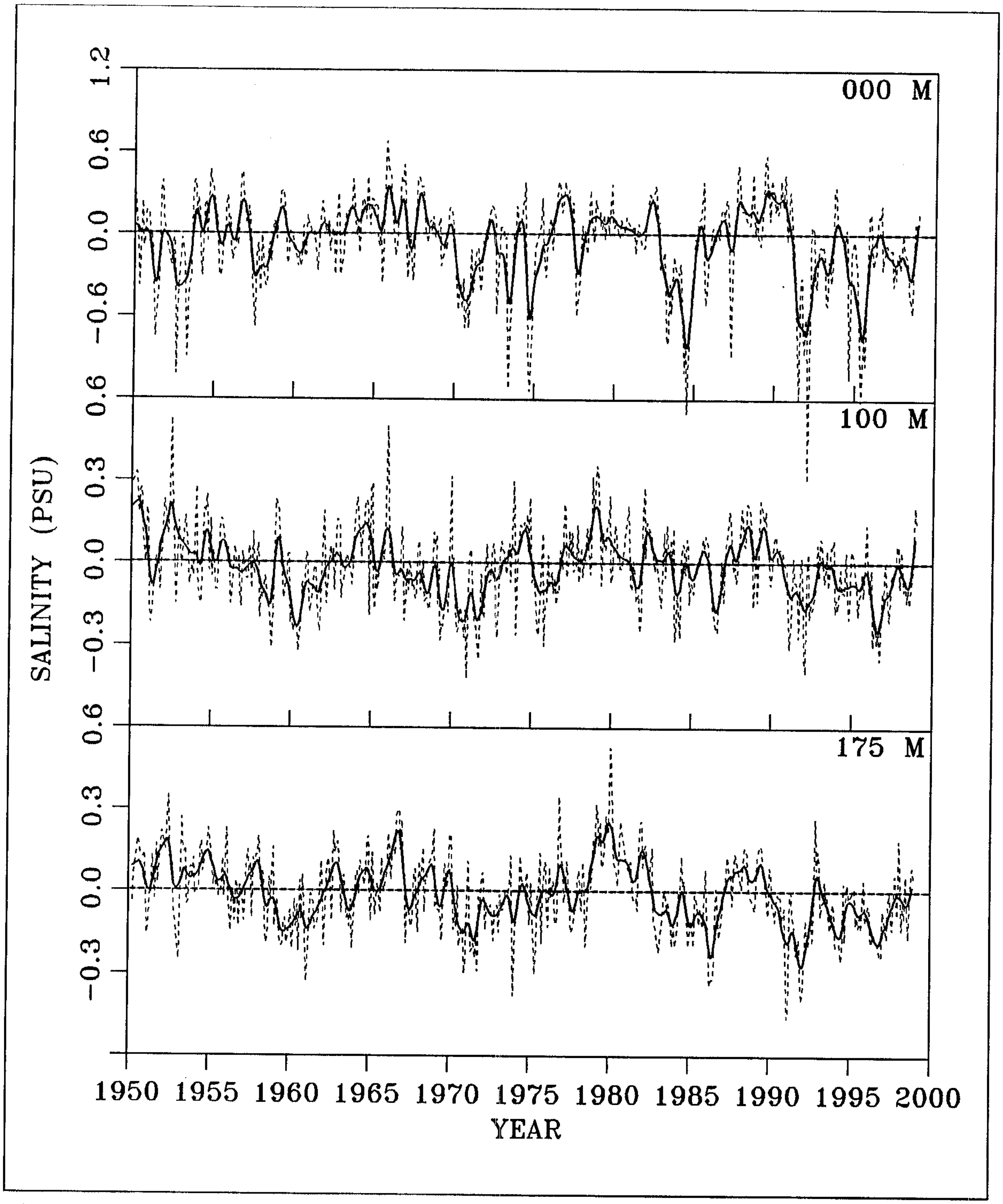


Fig. 6b. Time series of monthly salinity anomalies at Station 27 at standard depths from 1950 to 1998. The heavy lines represent the low-passed filtered values.

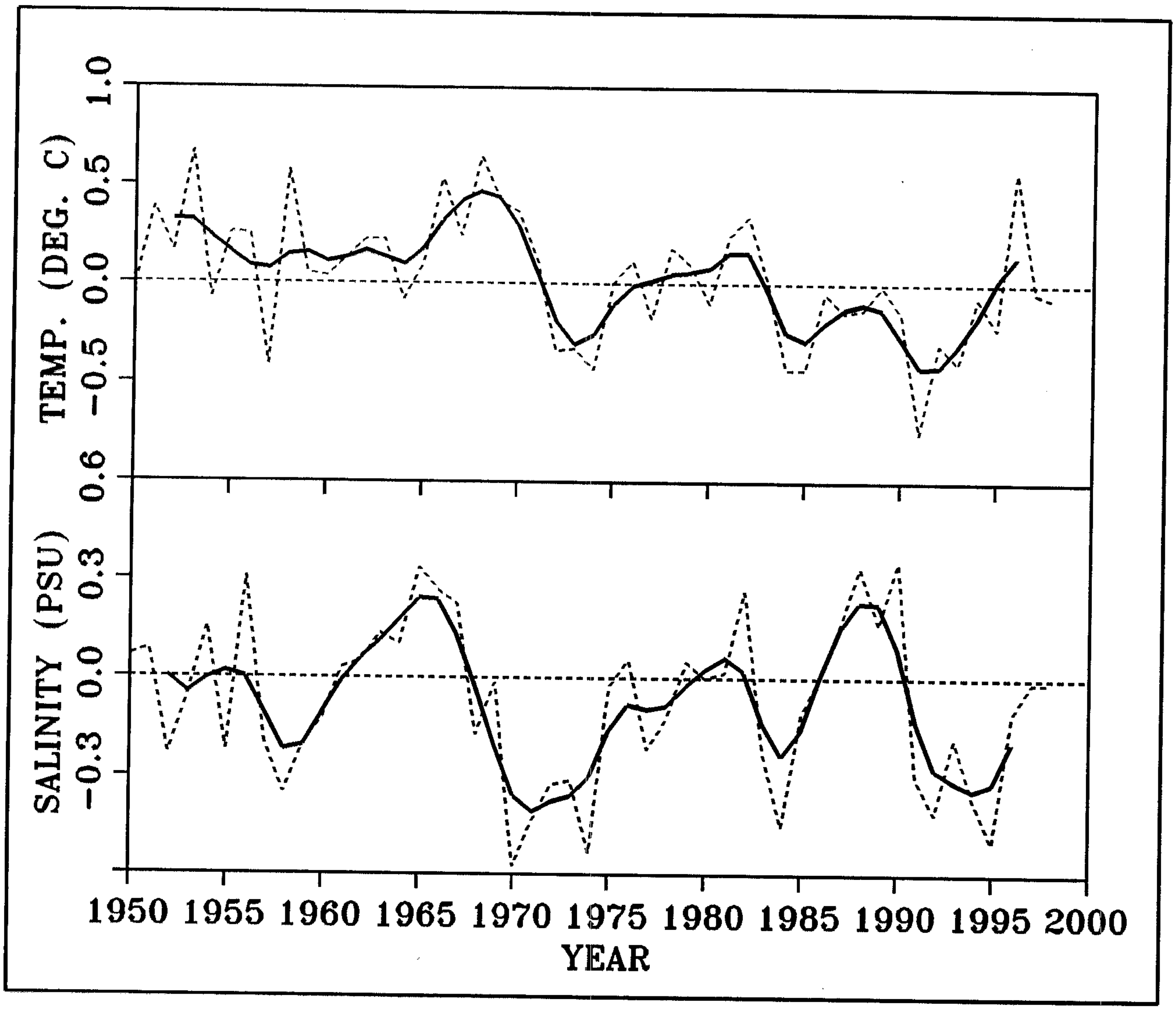


Fig. 7. Time series of the annual vertically averaged (0-176 m) Station 27 temperature anomalies and the vertically averaged (0-50 m) summer (July-Sept.) Station 27 salinity anomalies. The heavy lines are the three-year running means.

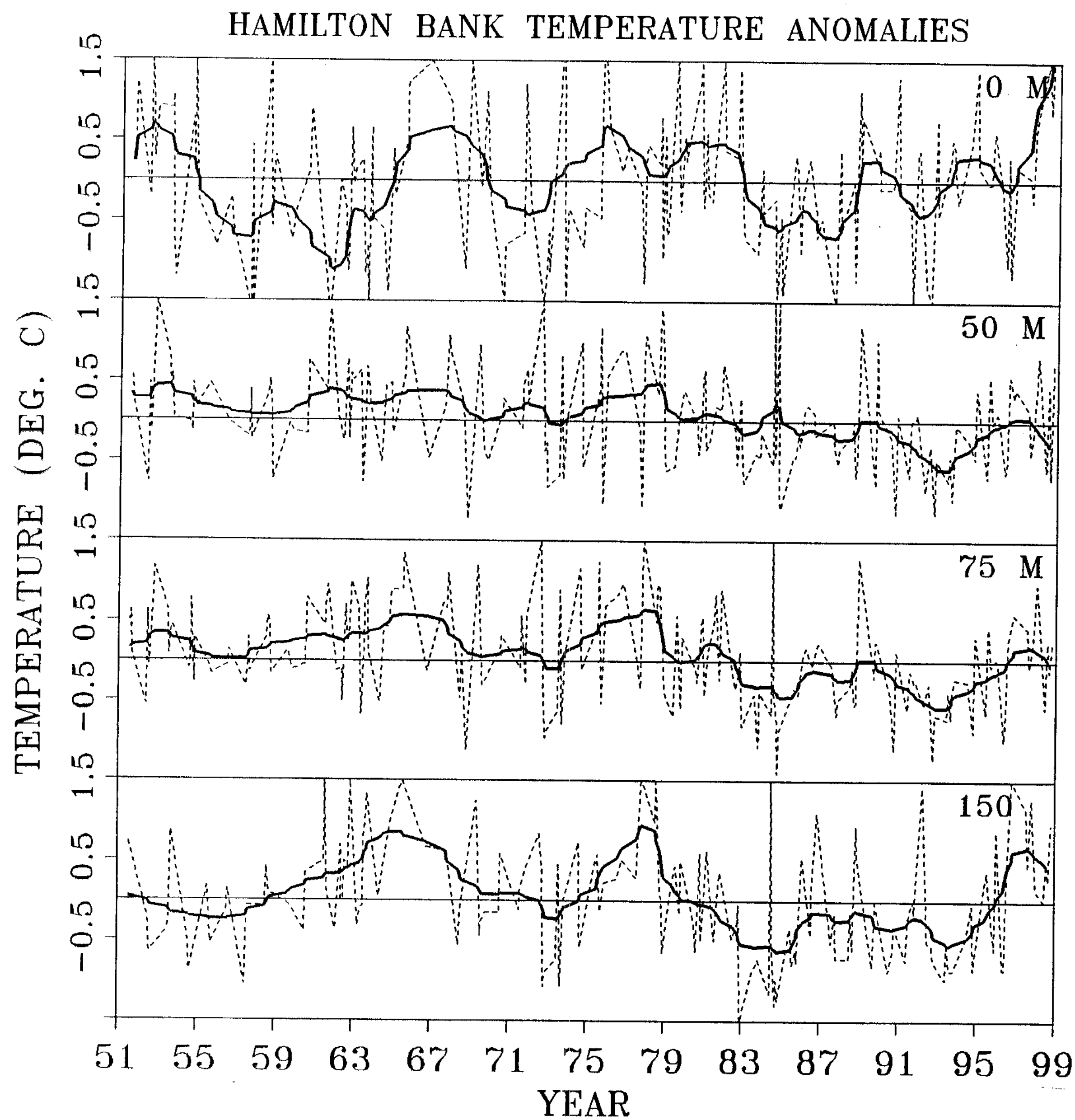


Fig. 8a. Time series of monthly temperature anomalies at standard depths of 0, 50, 75 and 150 m on Hamilton Bank in NAFO Division 2J. The solid line represents the smoothed temperature anomalies.

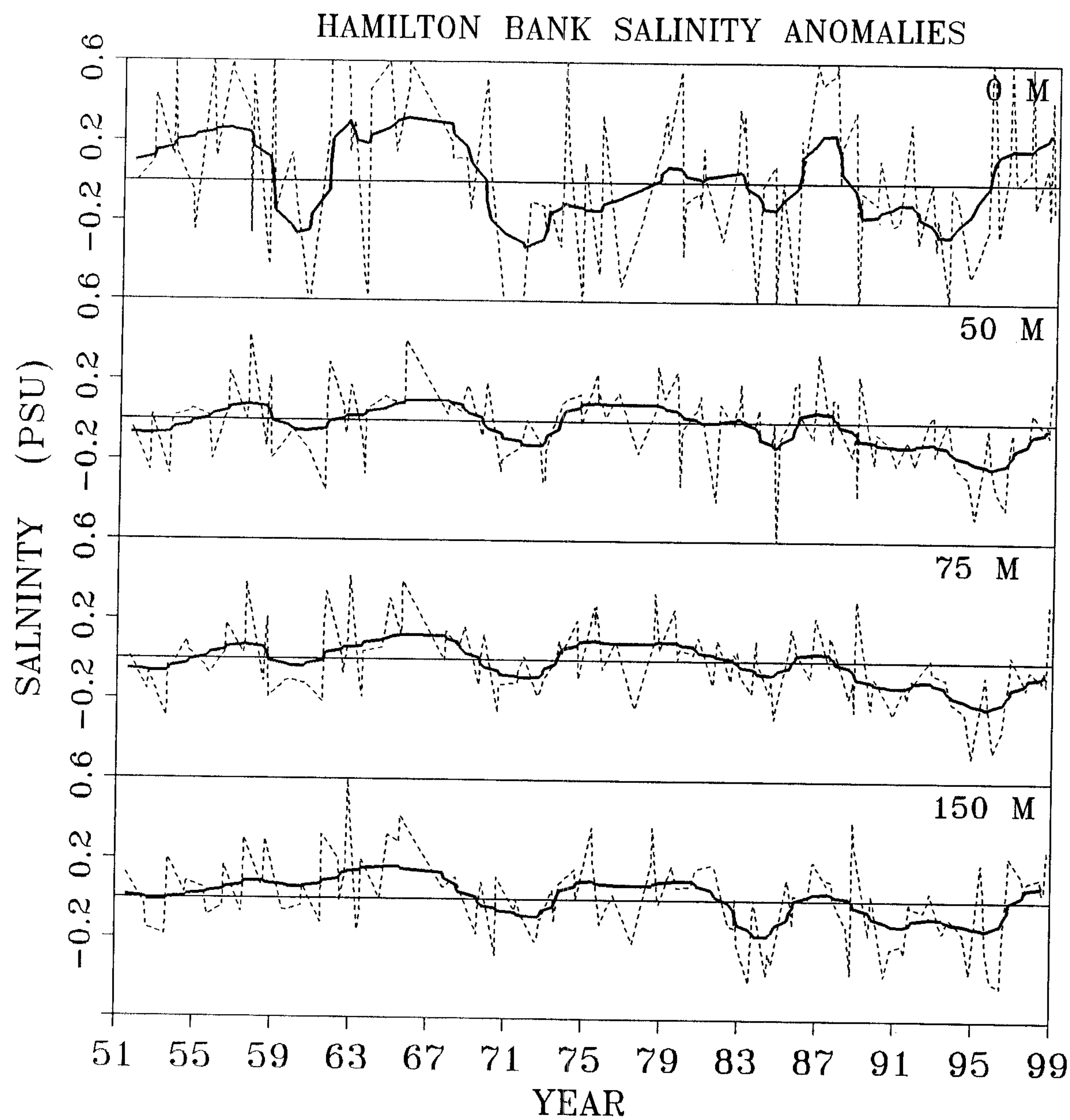


Fig. 8b. Time series of monthly salinity anomalies at standard depths of 0, 50, 75 and 150 m on Hamilton Bank in NAFO Division 2J. The solid line represents the smoothed salinity anomalies.

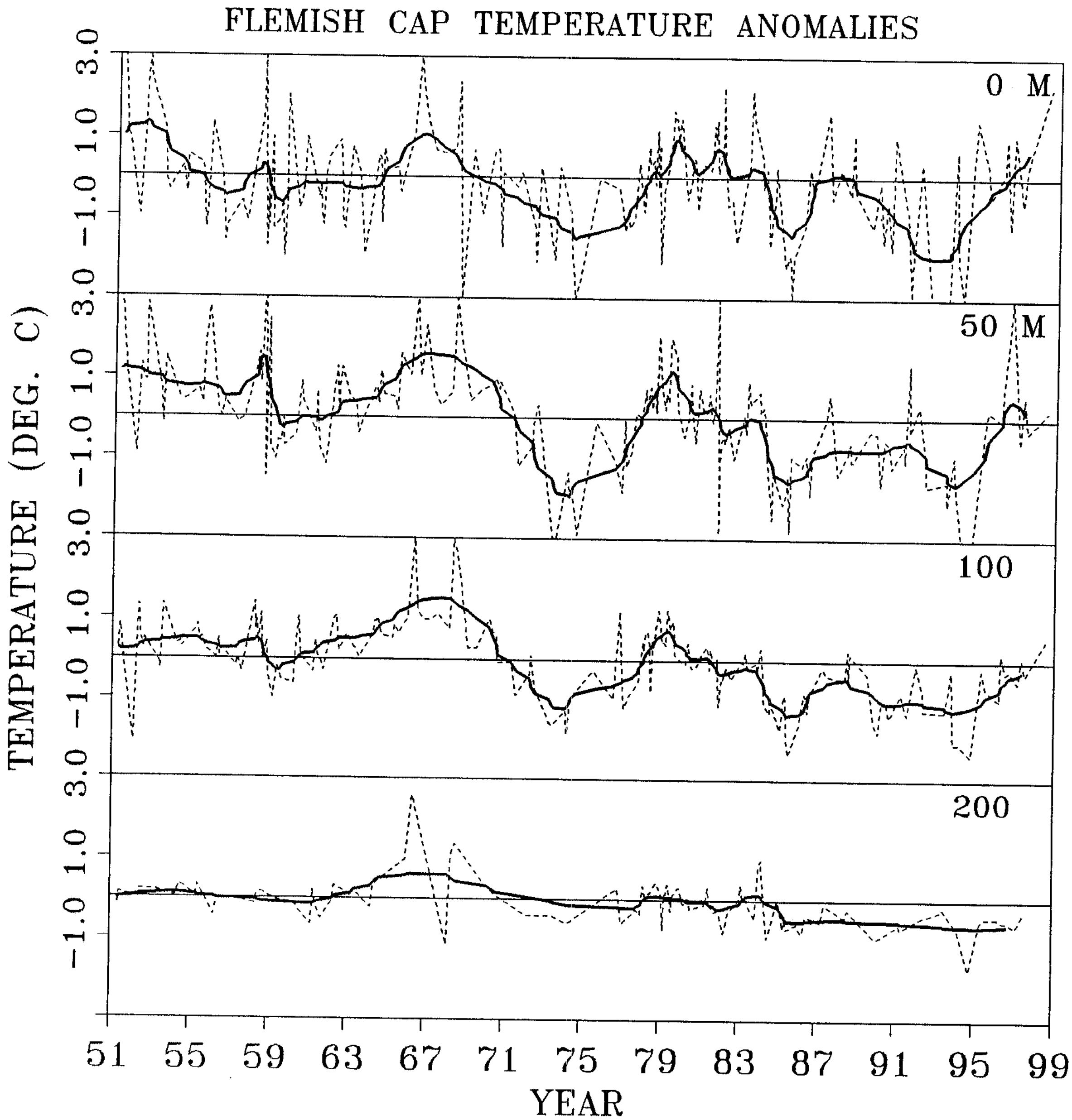


Fig. 9a. Time series of monthly temperature anomalies at standard depths of 0, 50, 100 and 200 m on the Flemish Cap in NAFO Division 3M. The solid line represents the smoothed temperature anomalies.

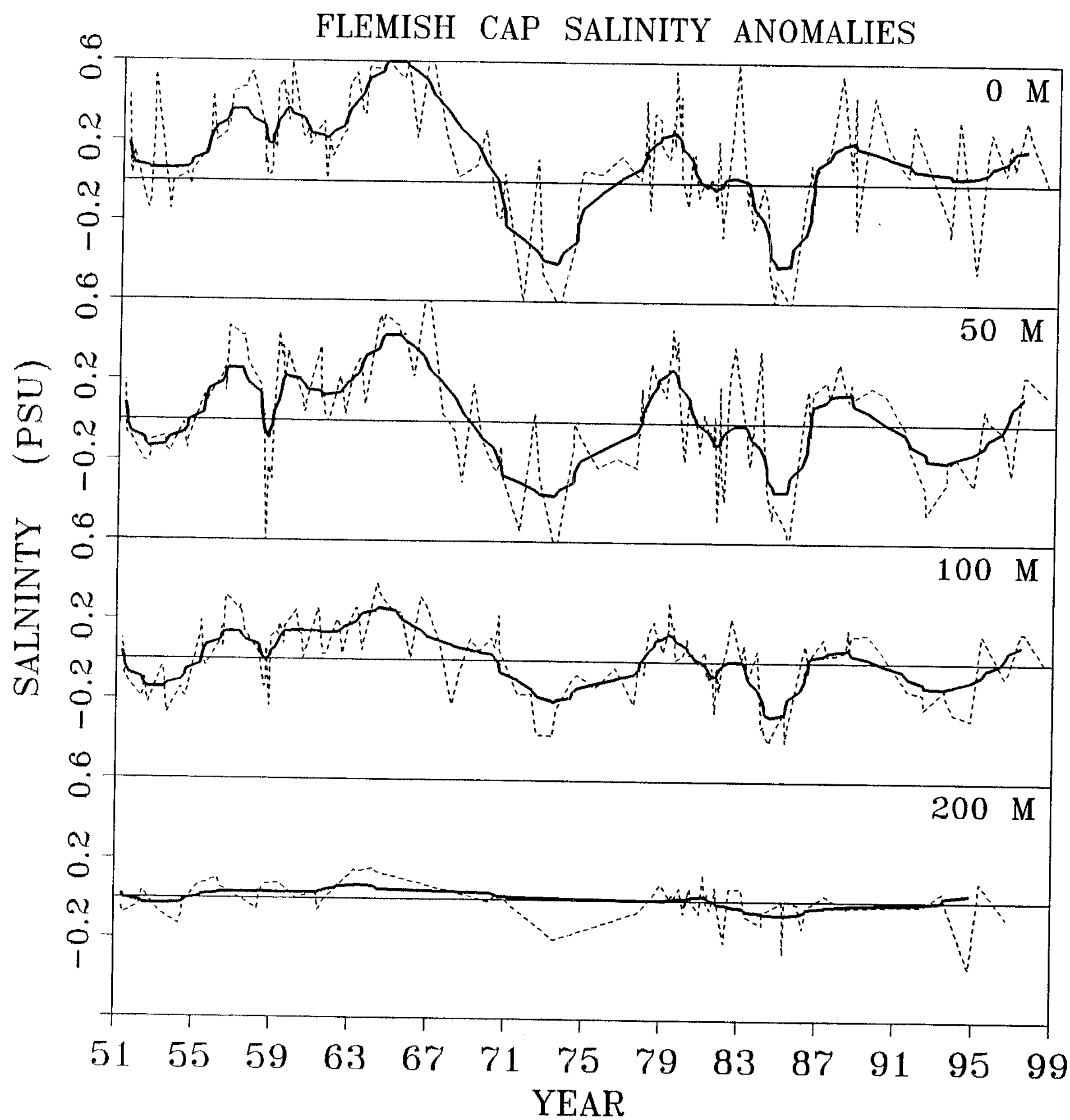


Fig. 9b. Time series of monthly salinity anomalies at standard depths of 0, 50, 100 and 200 m on the Flemish Cap in NAFO Division 3M. The solid line represents the smoothed salinity anomalies.

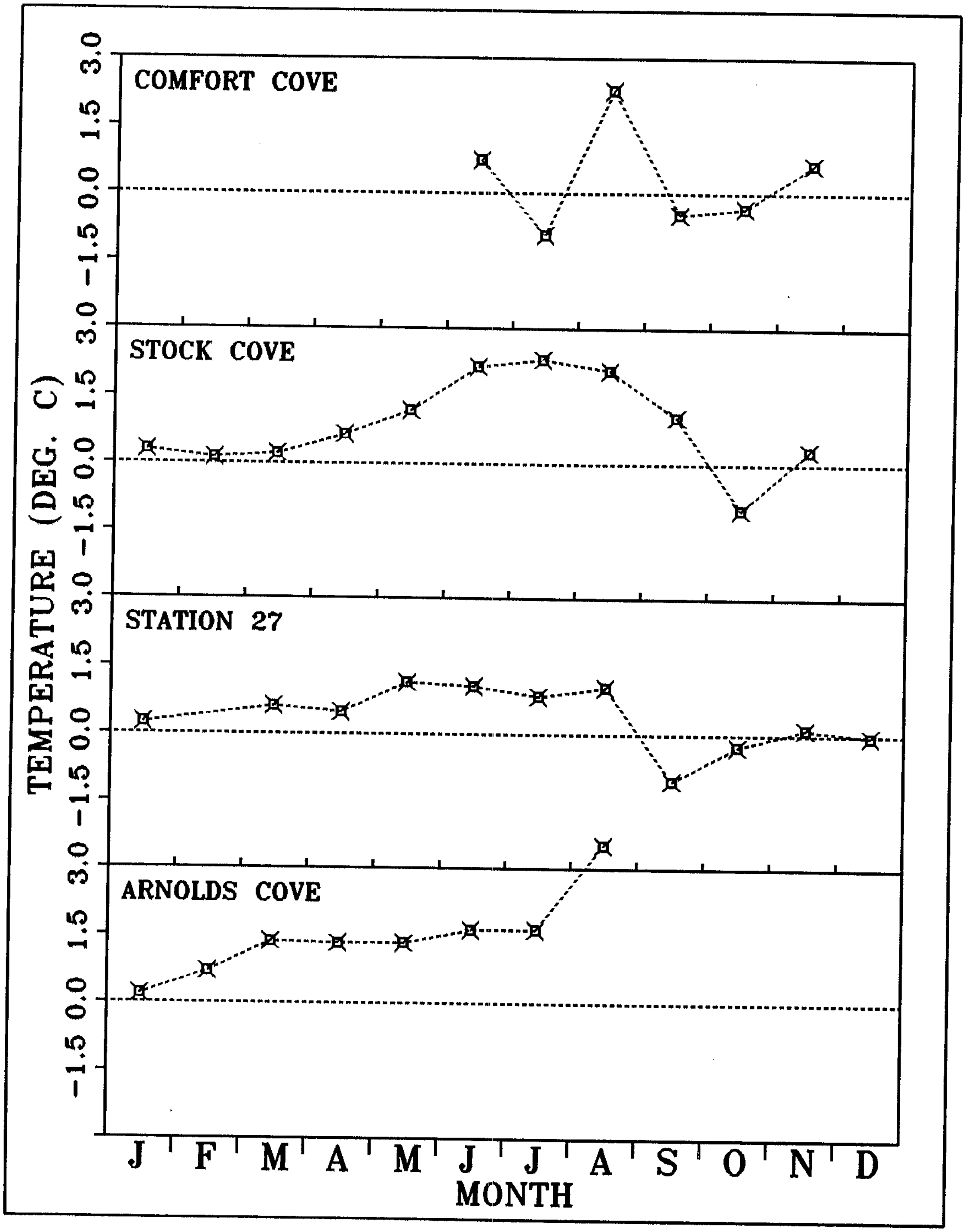


Fig. 10. Monthly temperature anomalies at 10 m depth for Comfort Cove, Notre Dame Bay, Stock Cove, Bonavista Bay, Station 27 and for Arnold's Cove, Placentia Bay (Fig. 1) during 1998.

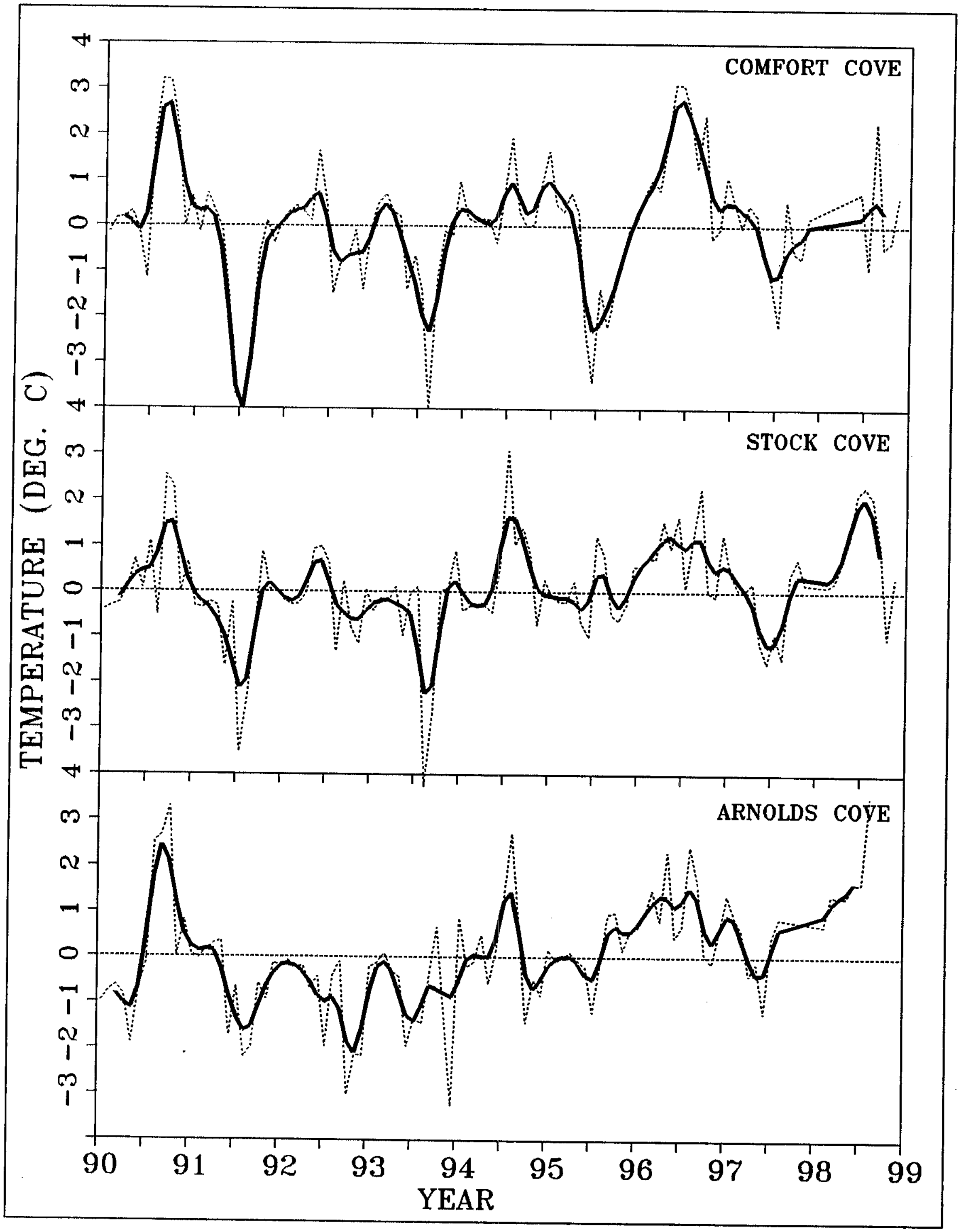


Fig. 11. Time series of monthly temperature anomalies at 10 m depth for Comfort Cove, Notre Dame Bay, Stock Cove, Bonavista Bay and for Arnold's Cove, Placentia Bay (Fig. 1).

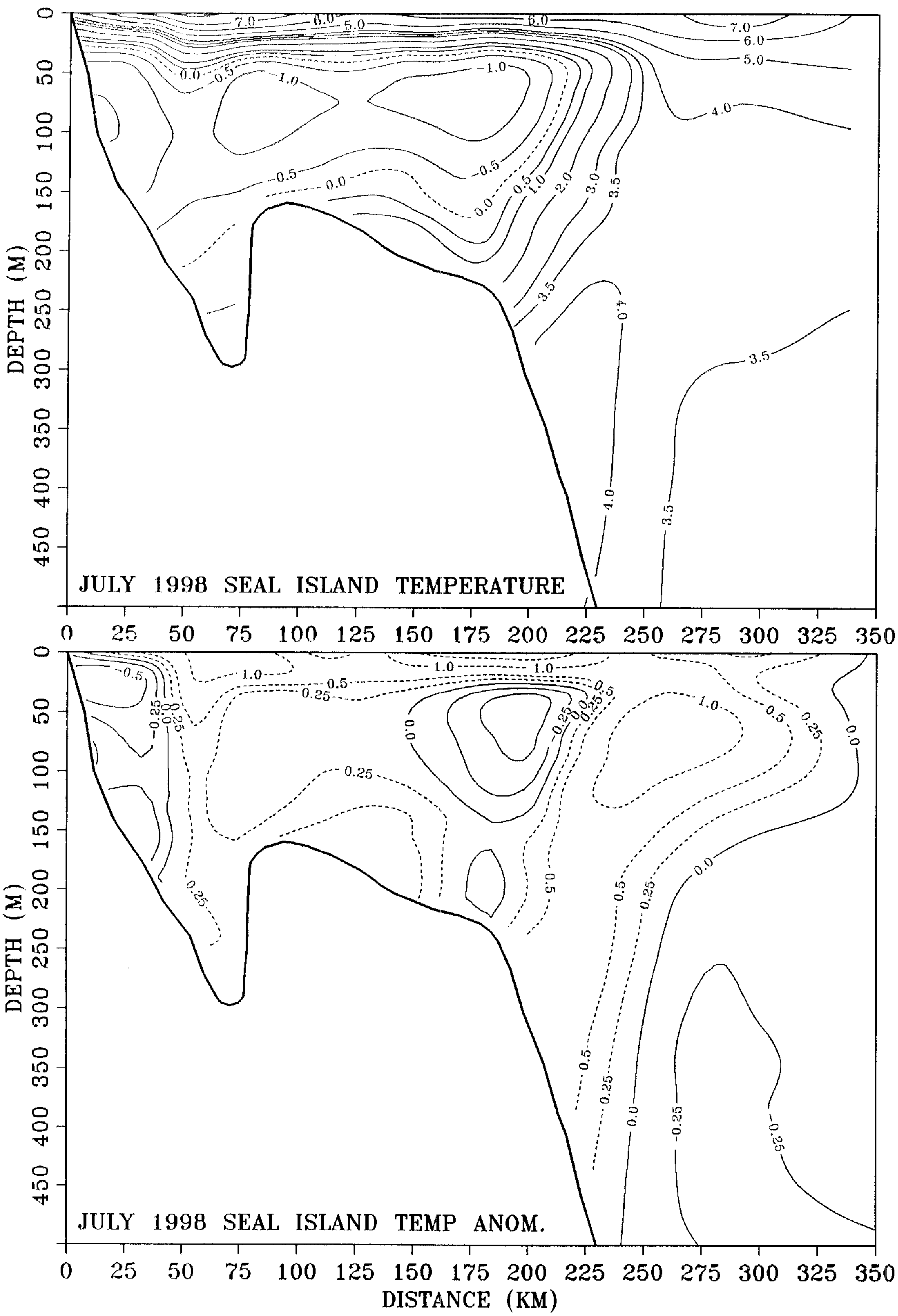
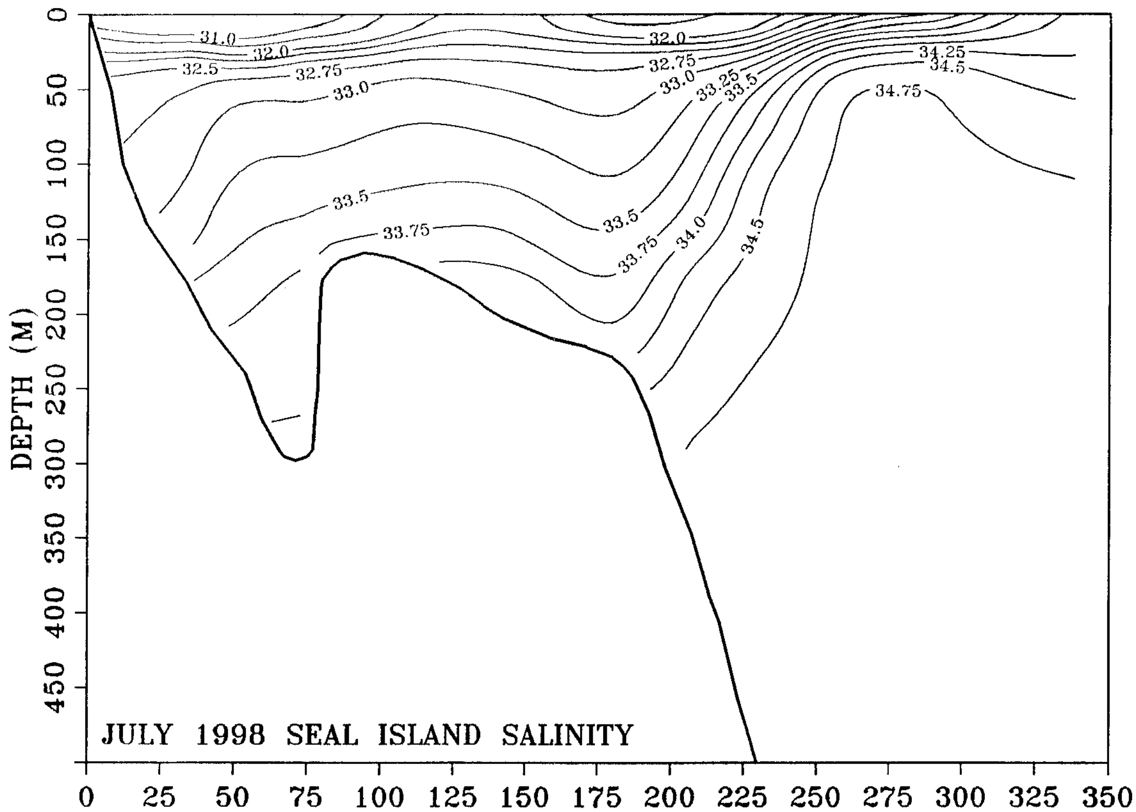


Fig. 12a. A vertical cross-section of temperature and temperature anomalies in °C along the standard Seal Island transect for the summer of 1998. Positive anomaly contours are dashed.



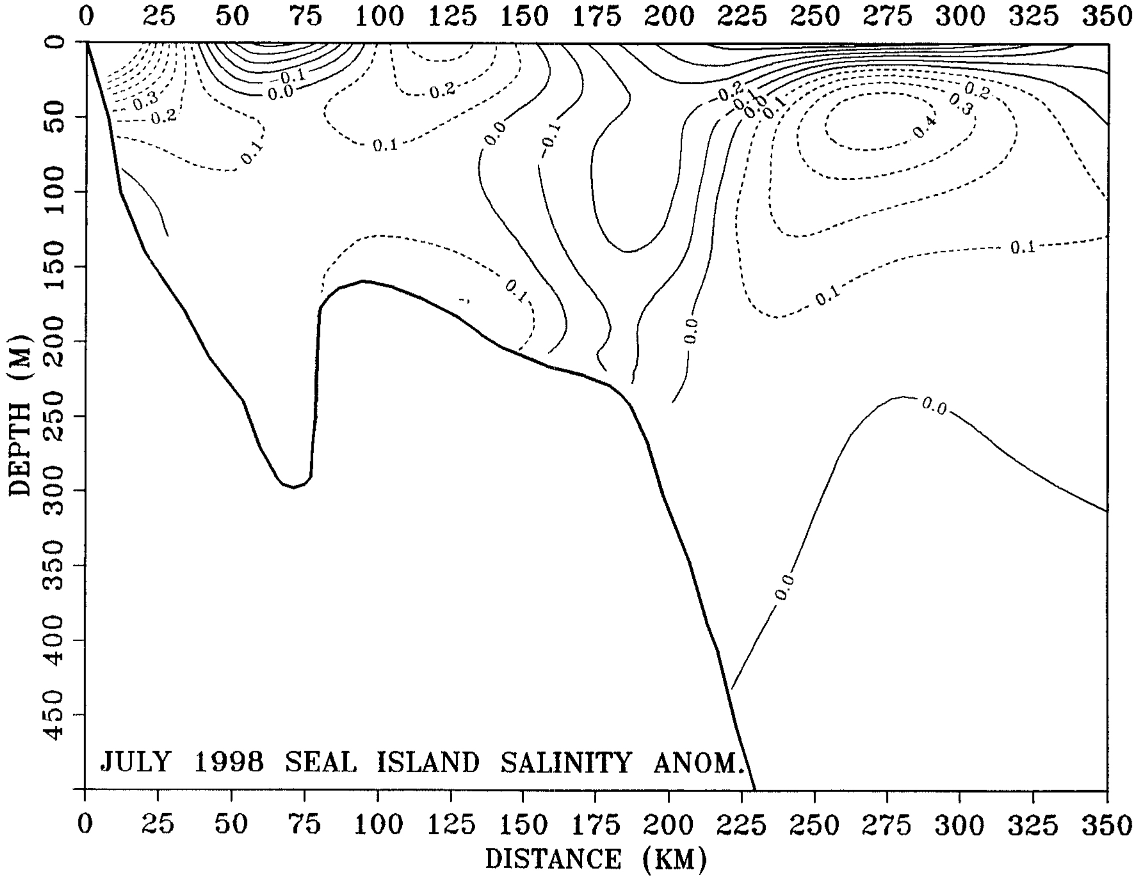


Fig. 12b. A vertical cross-section of salinity and salinity anomalies along the standard Seal Island transect for the summer of 1998. Positive anomaly contours are dashed.

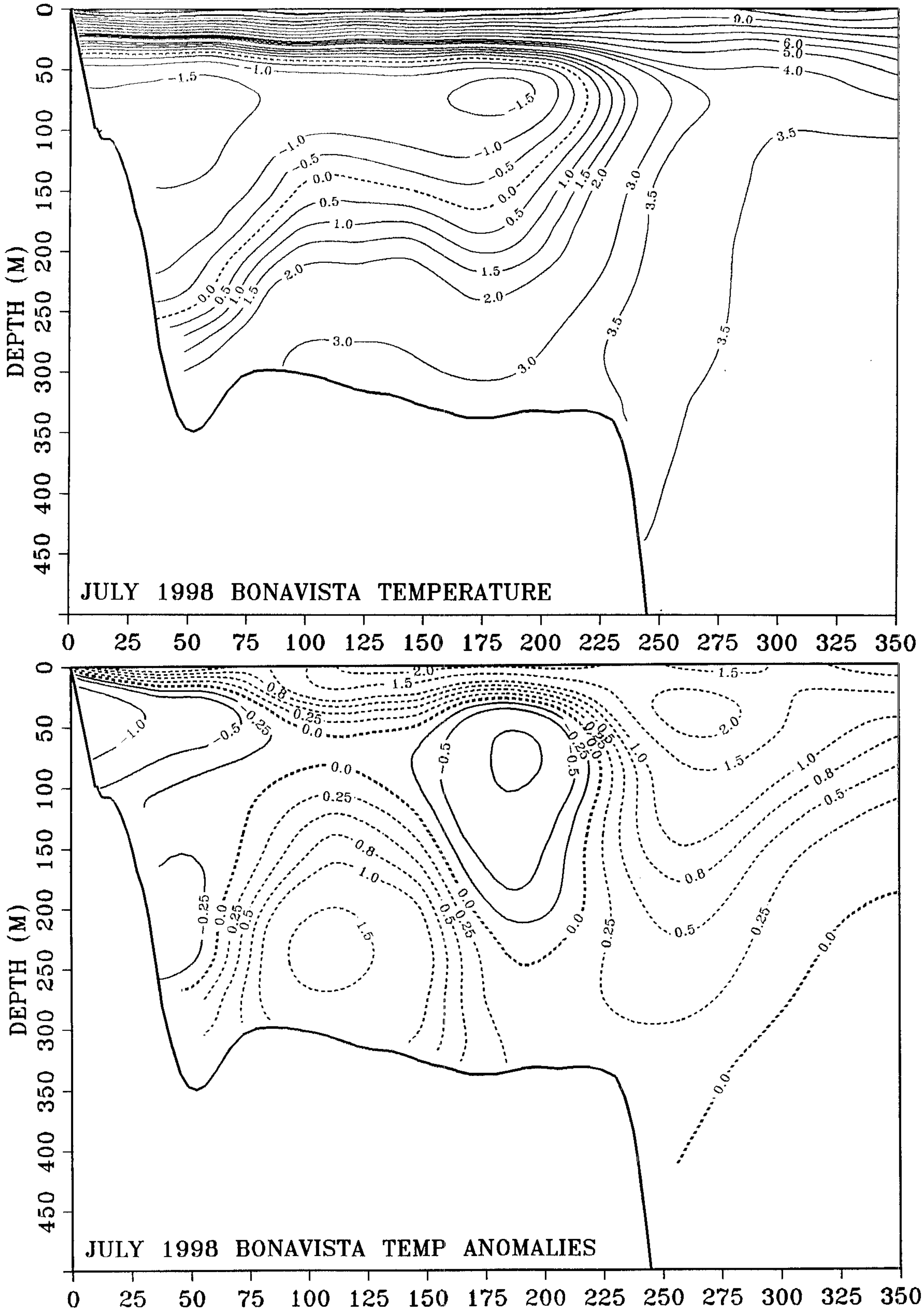


Fig. 13a. A vertical cross-section of temperature and temperature anomalies in °C along the standard Bonavista transect for the summer of 1998. Positive anomaly contours are dashed.

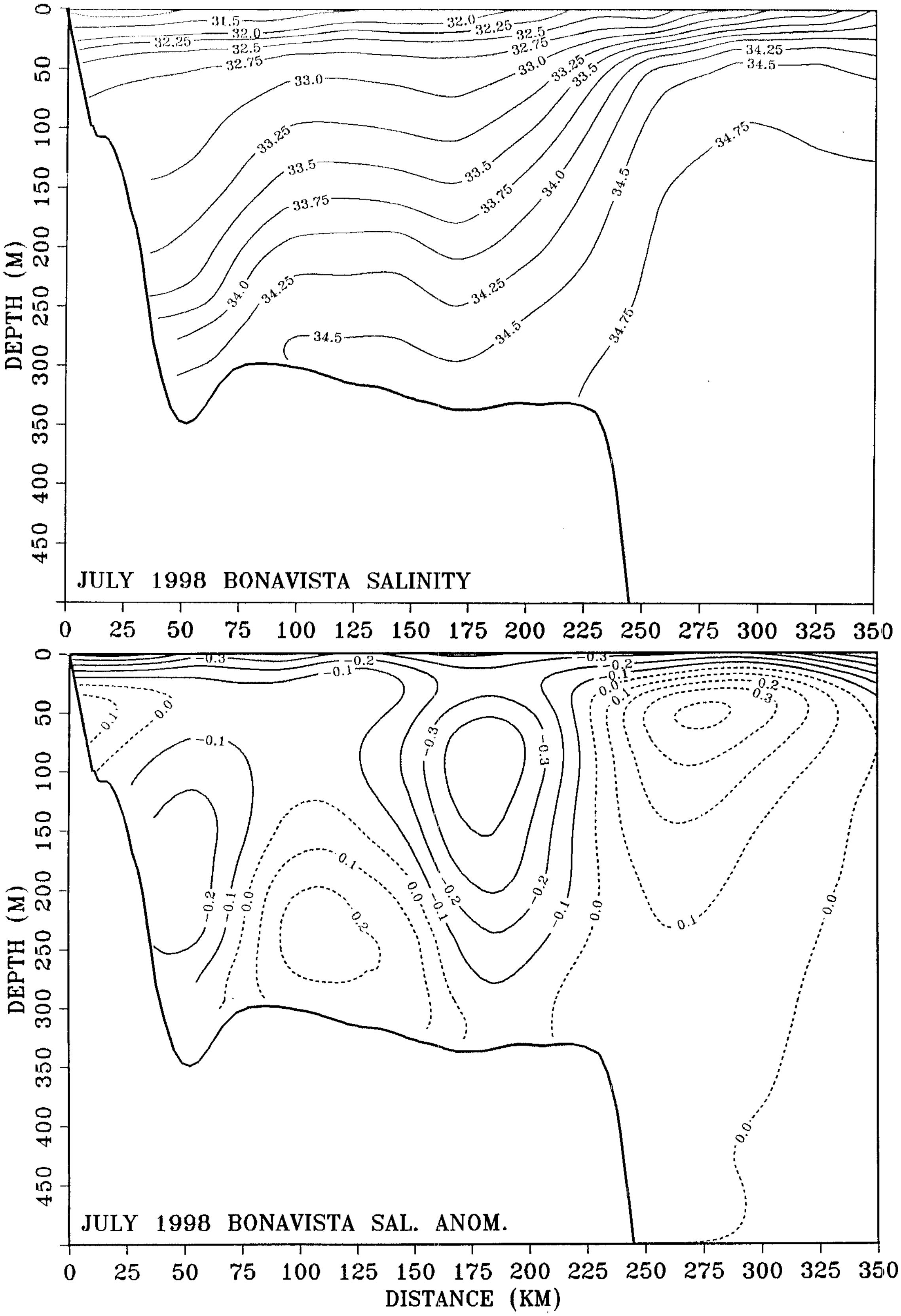


Fig. 13b. A vertical cross-section of salinity and salinity anomalies along the standard Bonavista transect for the summer of 1998. Positive anomaly contours are dashed.

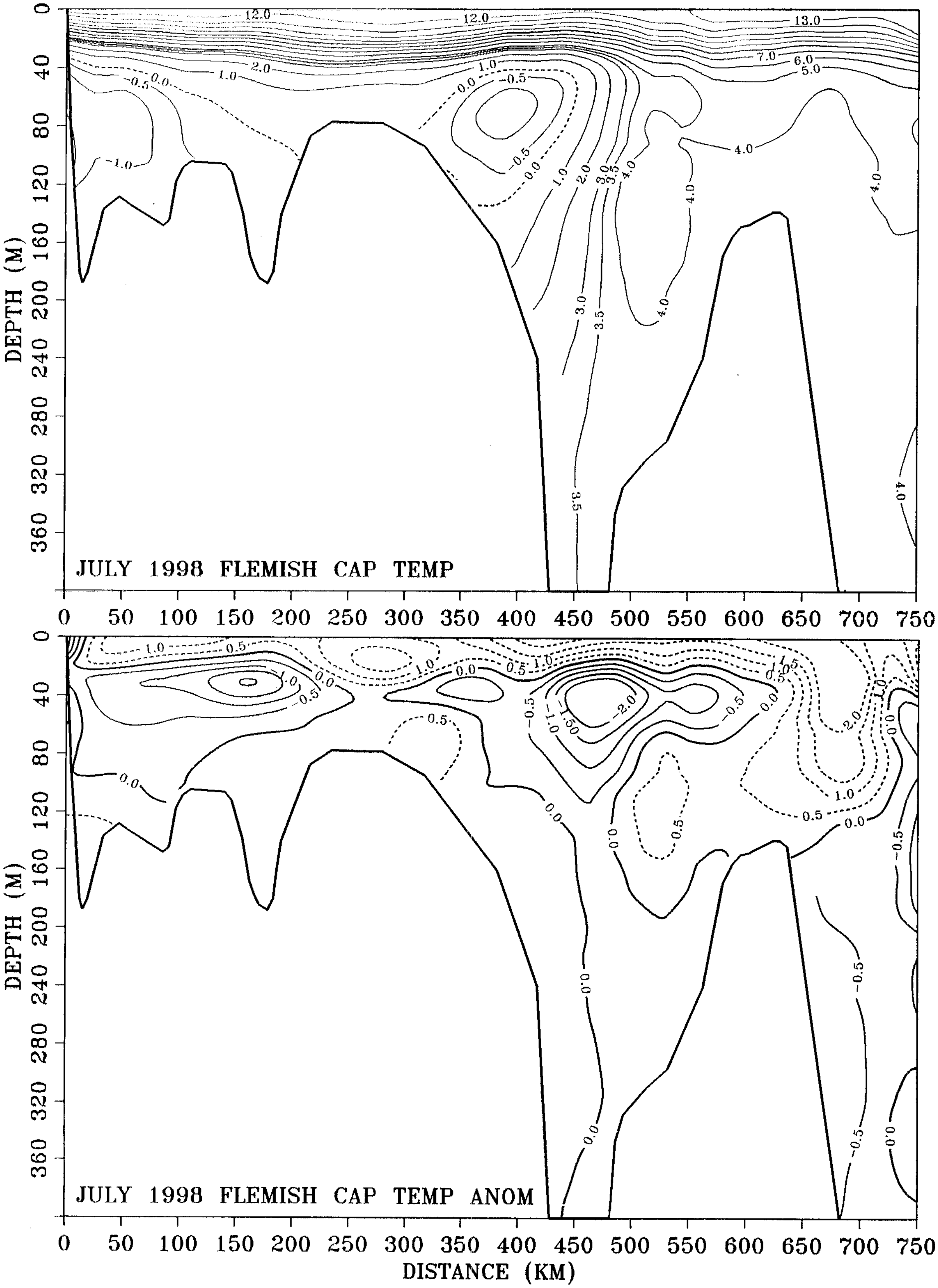


Fig. 14a. A vertical cross-section of temperature and temperature anomalies in °C along the standard Flemish Cap transect for the summer of 1998. Positive anomaly contours are dashed.

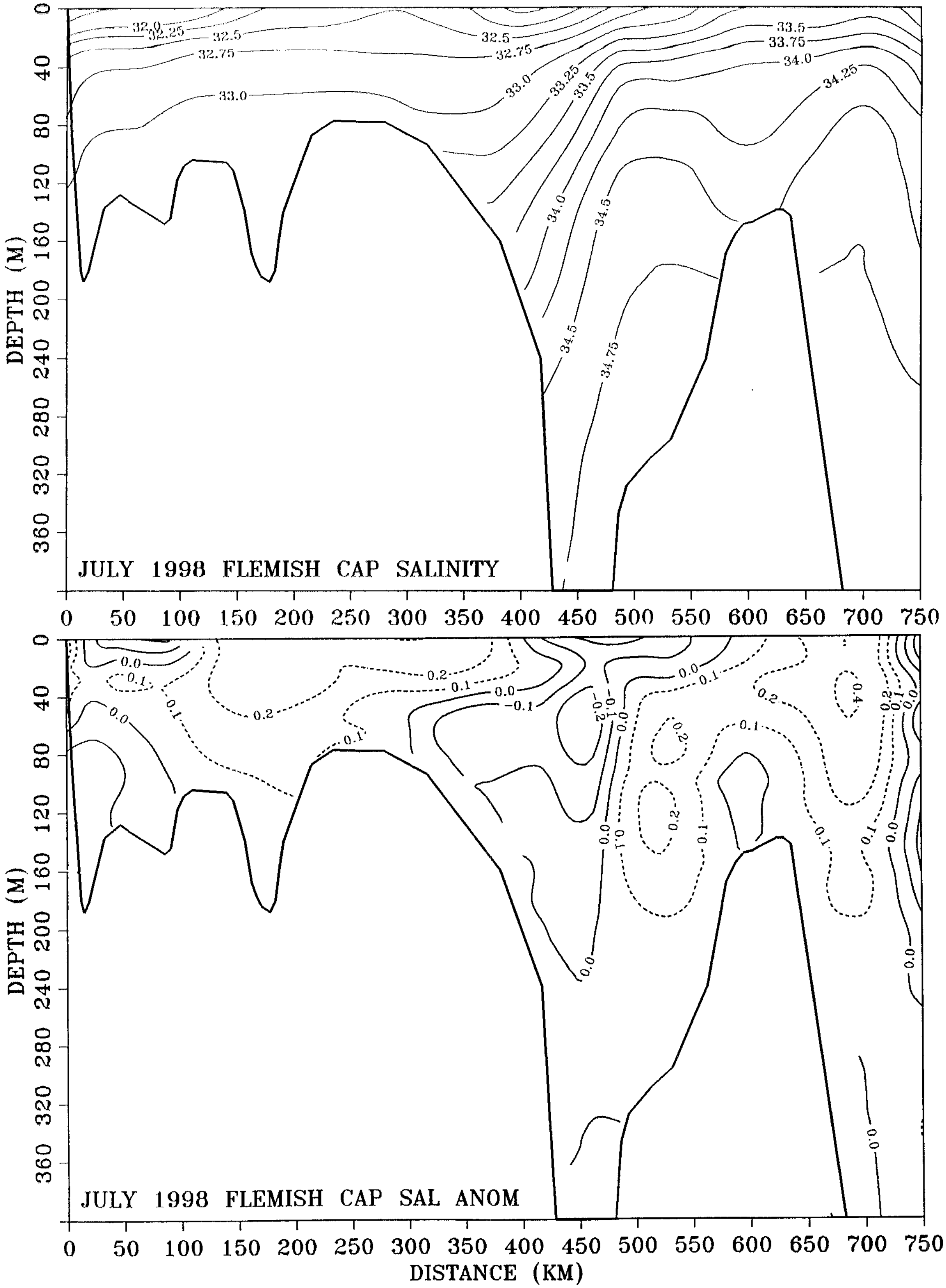


Fig. 14b. A vertical cross-section of salinity and salinity anomalies along the standard Flemish Cap transect for the summer of 1998. Positive anomaly contours are dashed.

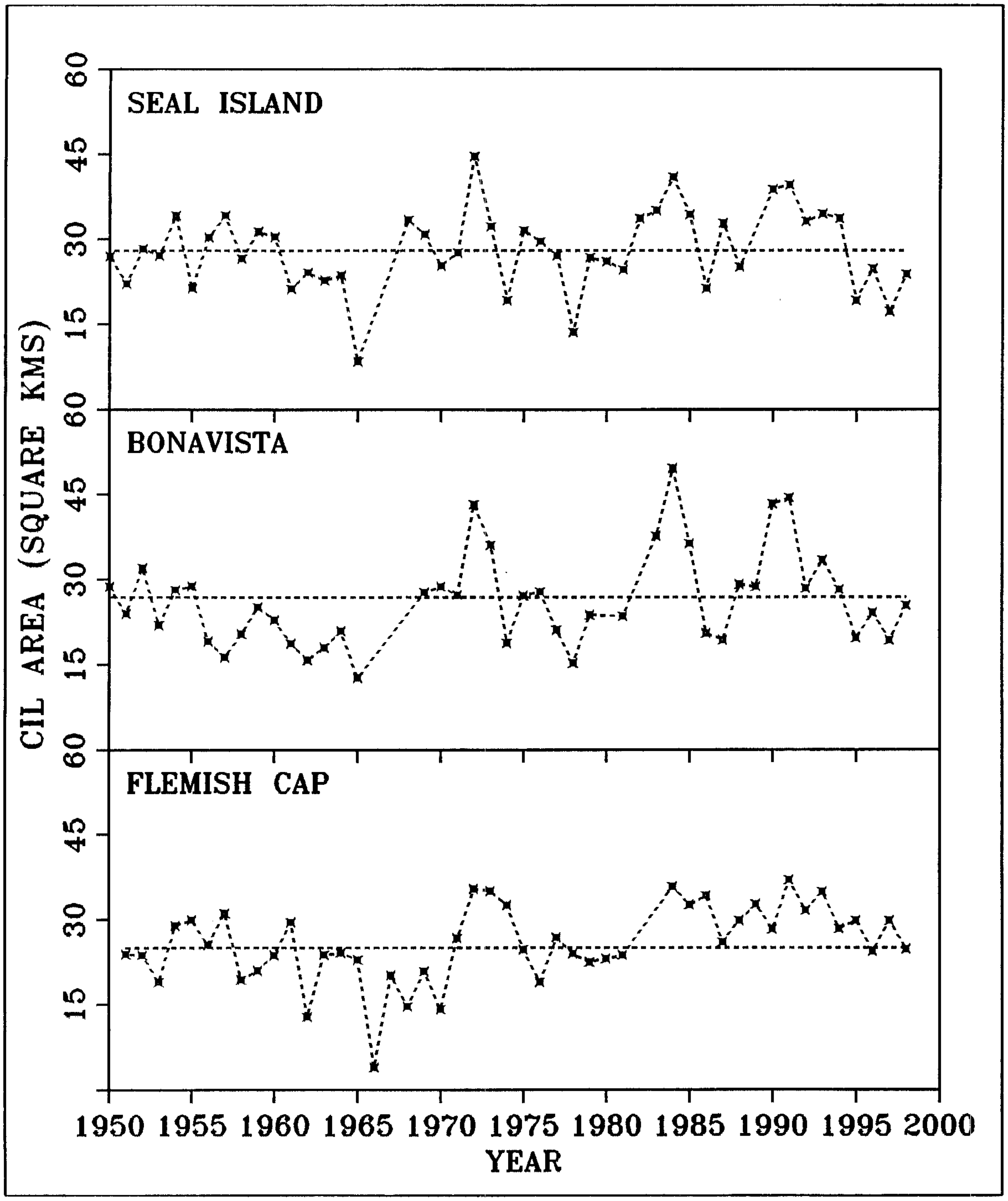


Fig. 15. Time series of CIL cross-sectional area along the Seal Island, Bonavista and Flemish Cap transects. The horizontal dashed lines represent the 1961-90 average.

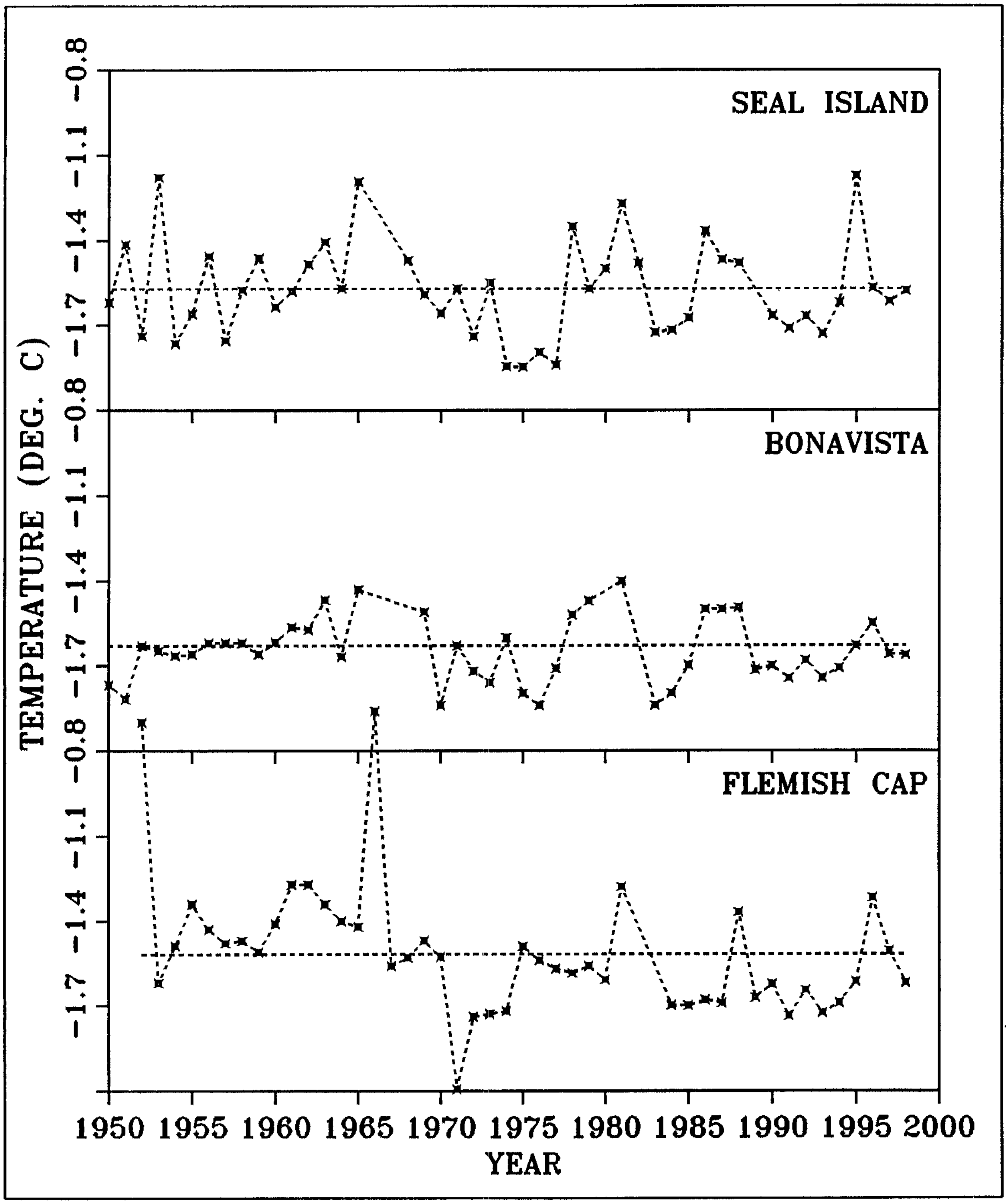


Fig. 16. Time series of CIL minimum temperature along the Seal Island, Bonavista and Flemish Cap transects. The horizontal dashed lines represent the 1961-90 average.

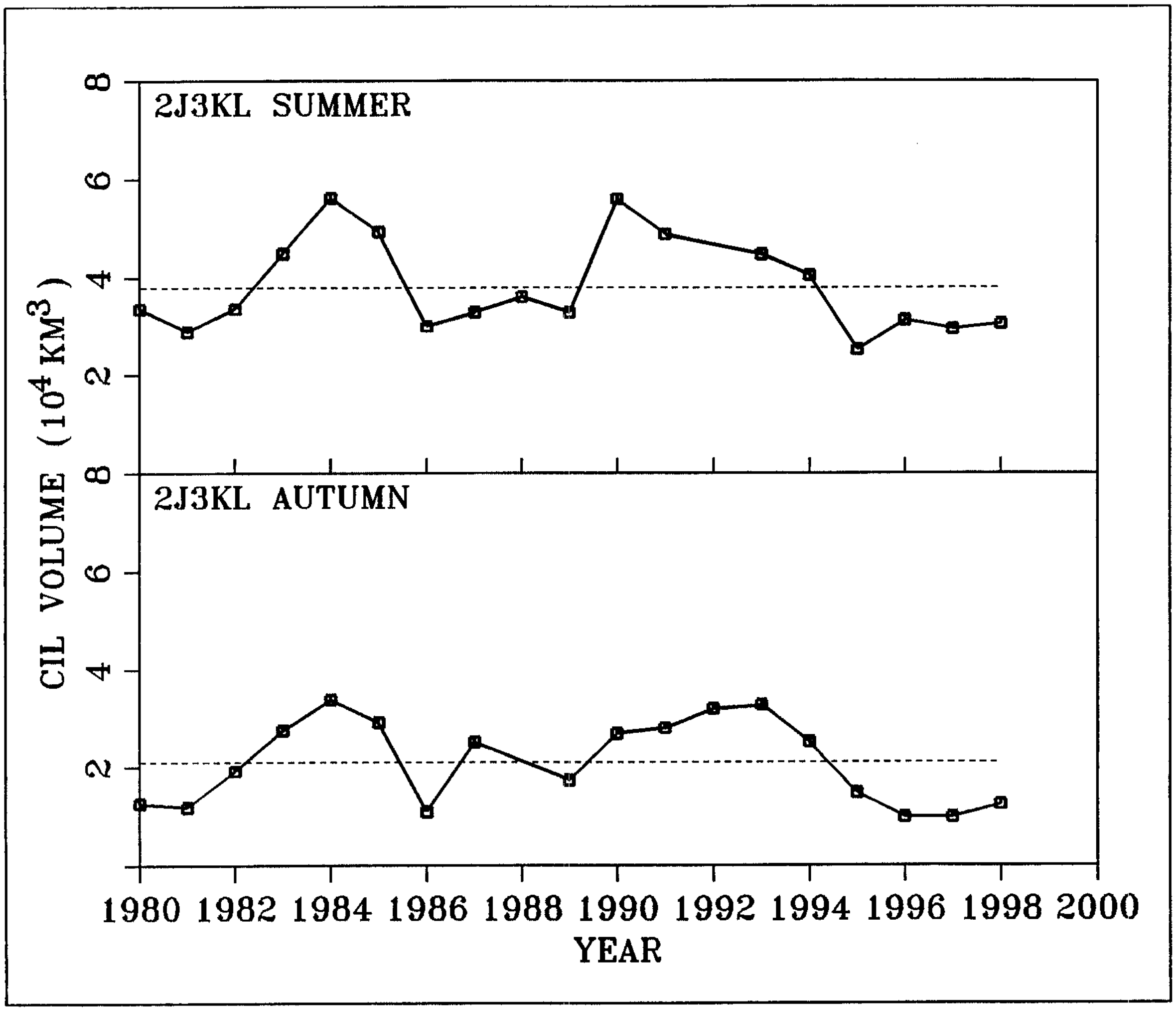


Fig. 17. Time series of summer and fall CIL volumes (km^3) over the 2J to 3KL areas from 1980 to 1998. The horizontal dashed line is the 1980-1998 average.

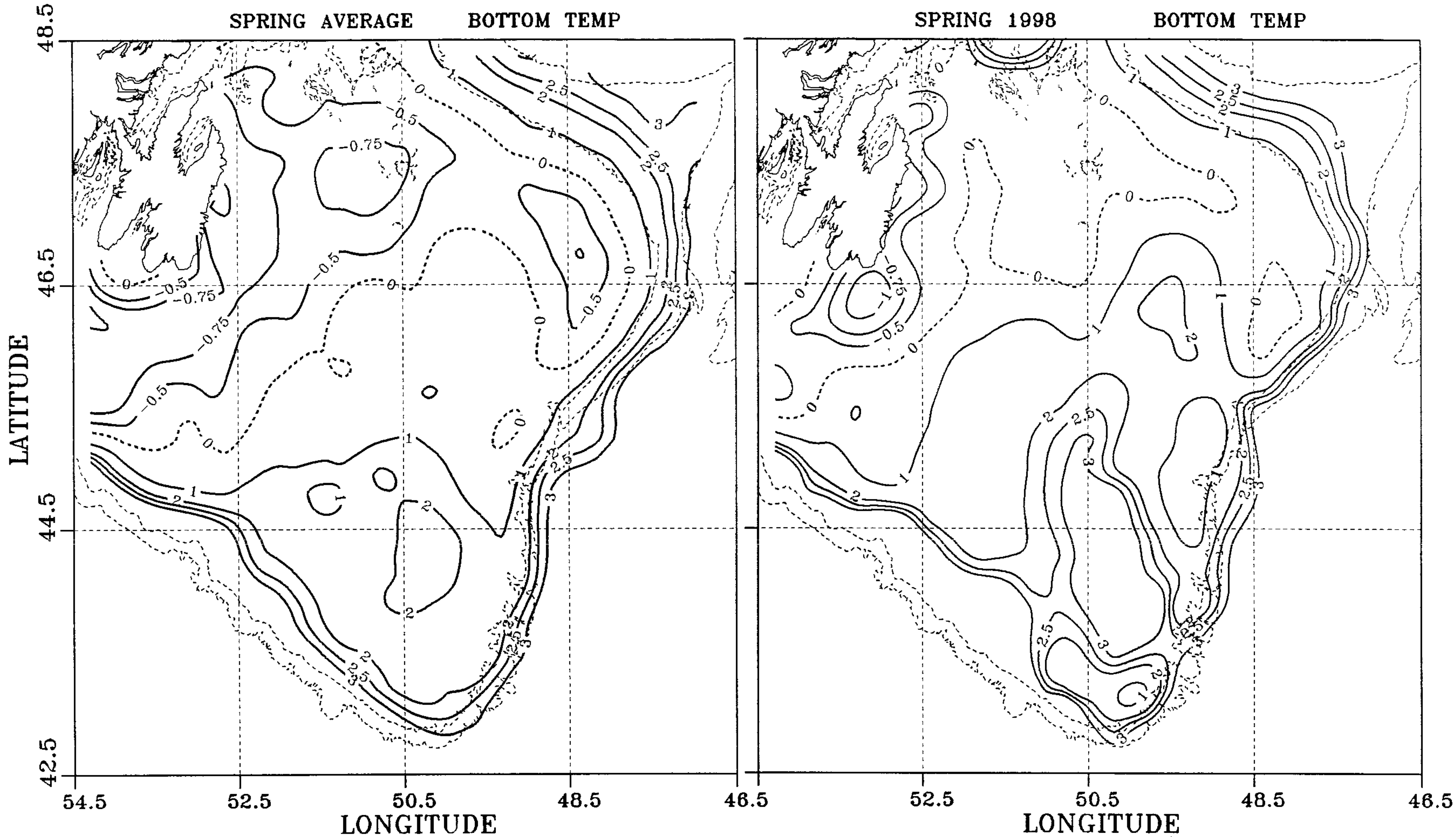


Fig. 18a. Horizontal bottom temperature contours (in °C) for the spring average (1961-1990) and for the spring of 1998 for the Grand Bank region.

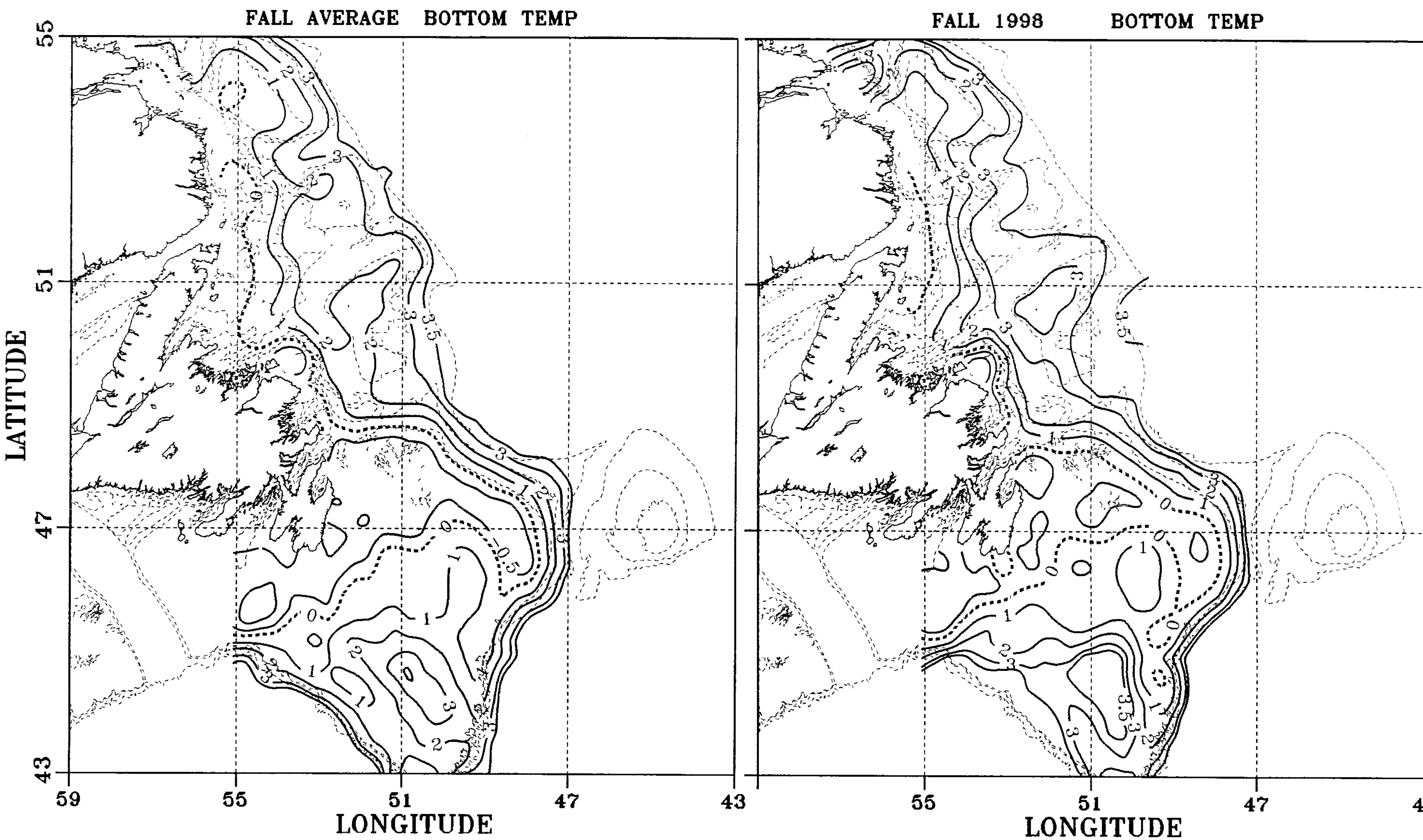


Fig. 18b. Horizontal bottom temperature contours (in °C) for the fall average (1961-1990) and for the fall of 1998 for the Newfoundland Shelf region.

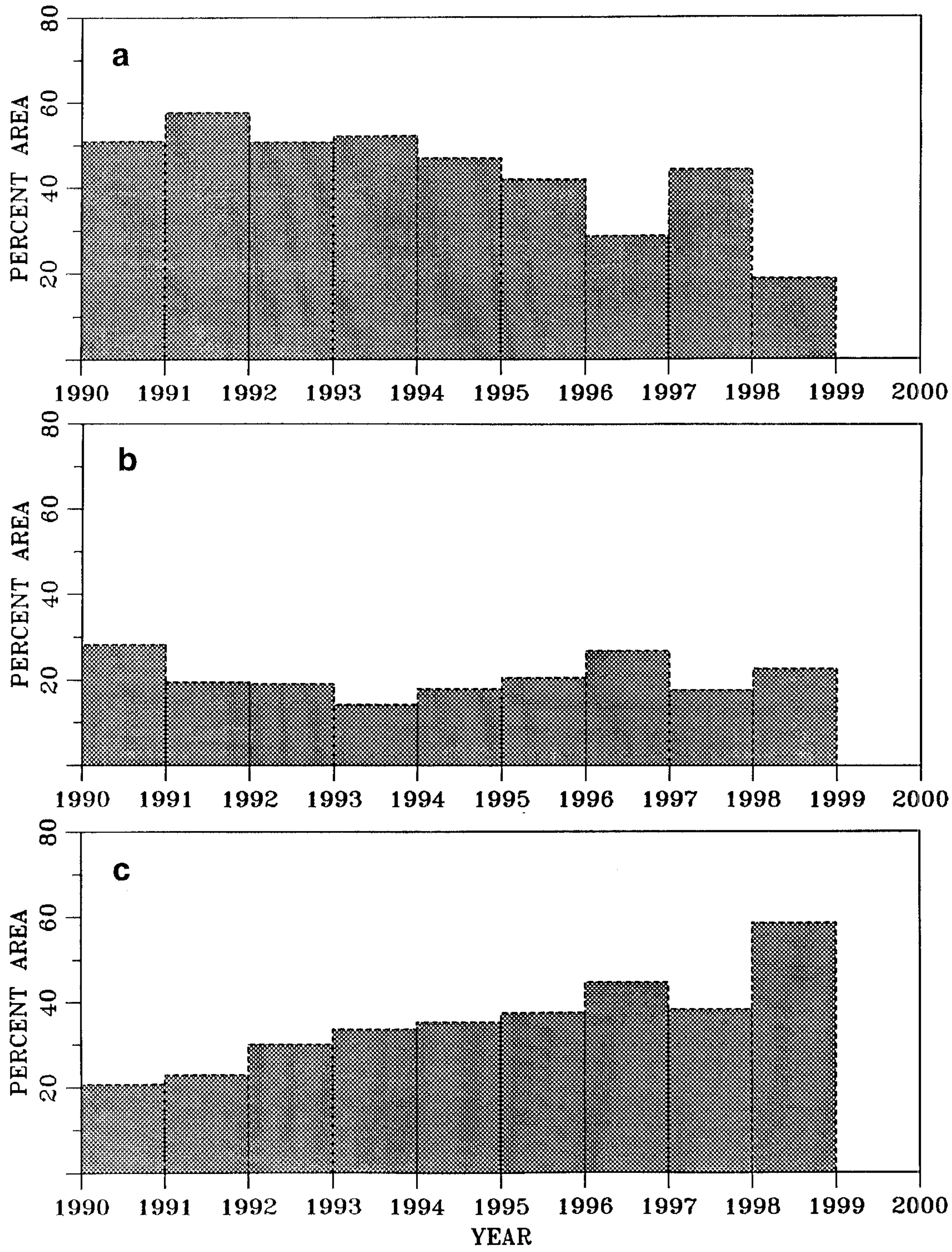


Fig. 19a. Time series of the percentage area of NAFO divisions 3LNO covered by water with bottom temperatures (a) less than 0°C (b) between 0°C to 1°C and (c) greater than 1°C, during spring.

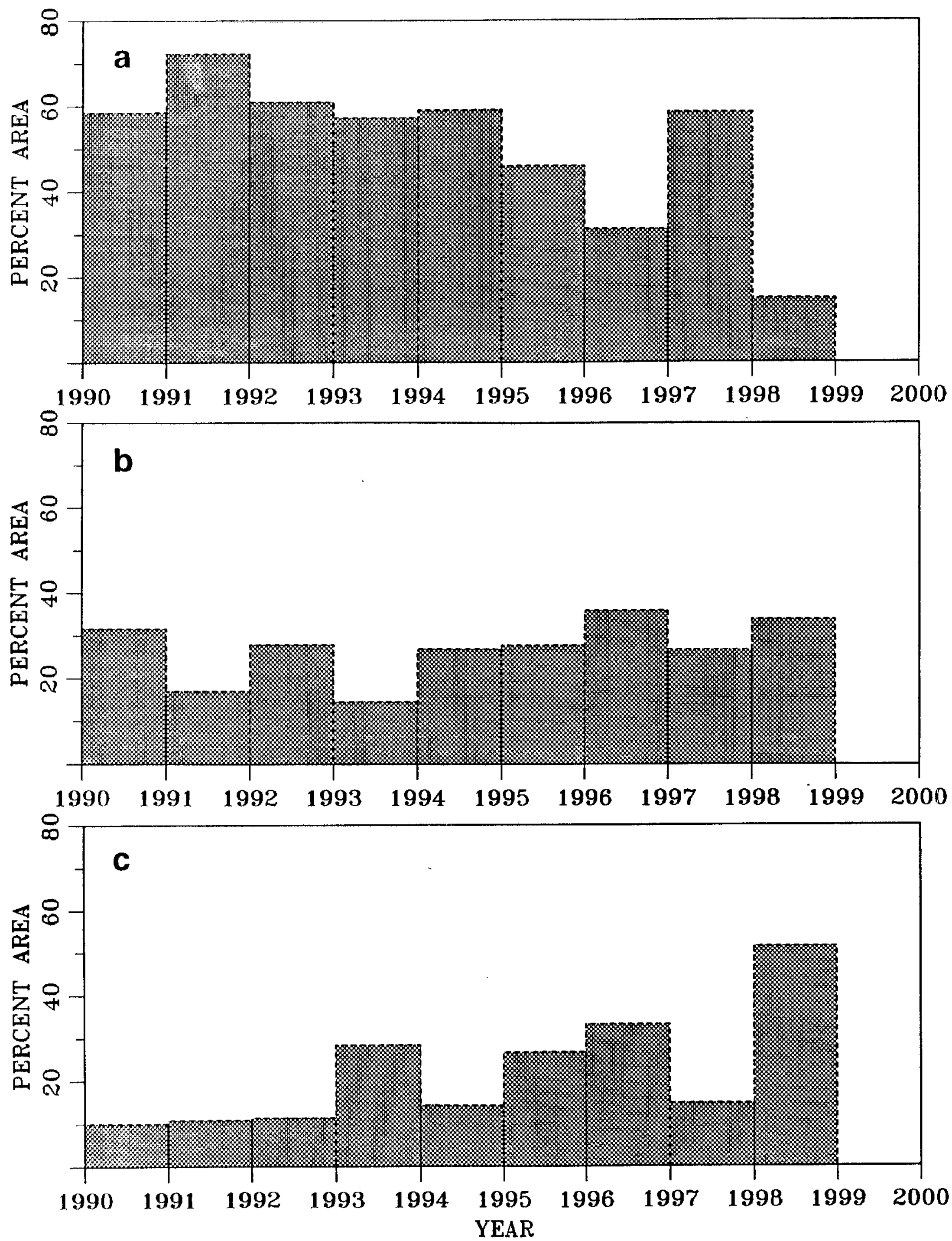


Fig. 19b. Time series of the percentage area of the Grand Bank (with water depths within 100-m) covered by water with bottom temperatures (a) less than 0°C, (b) between 0°C and 1°C and (c) greater than 1°C, during spring.

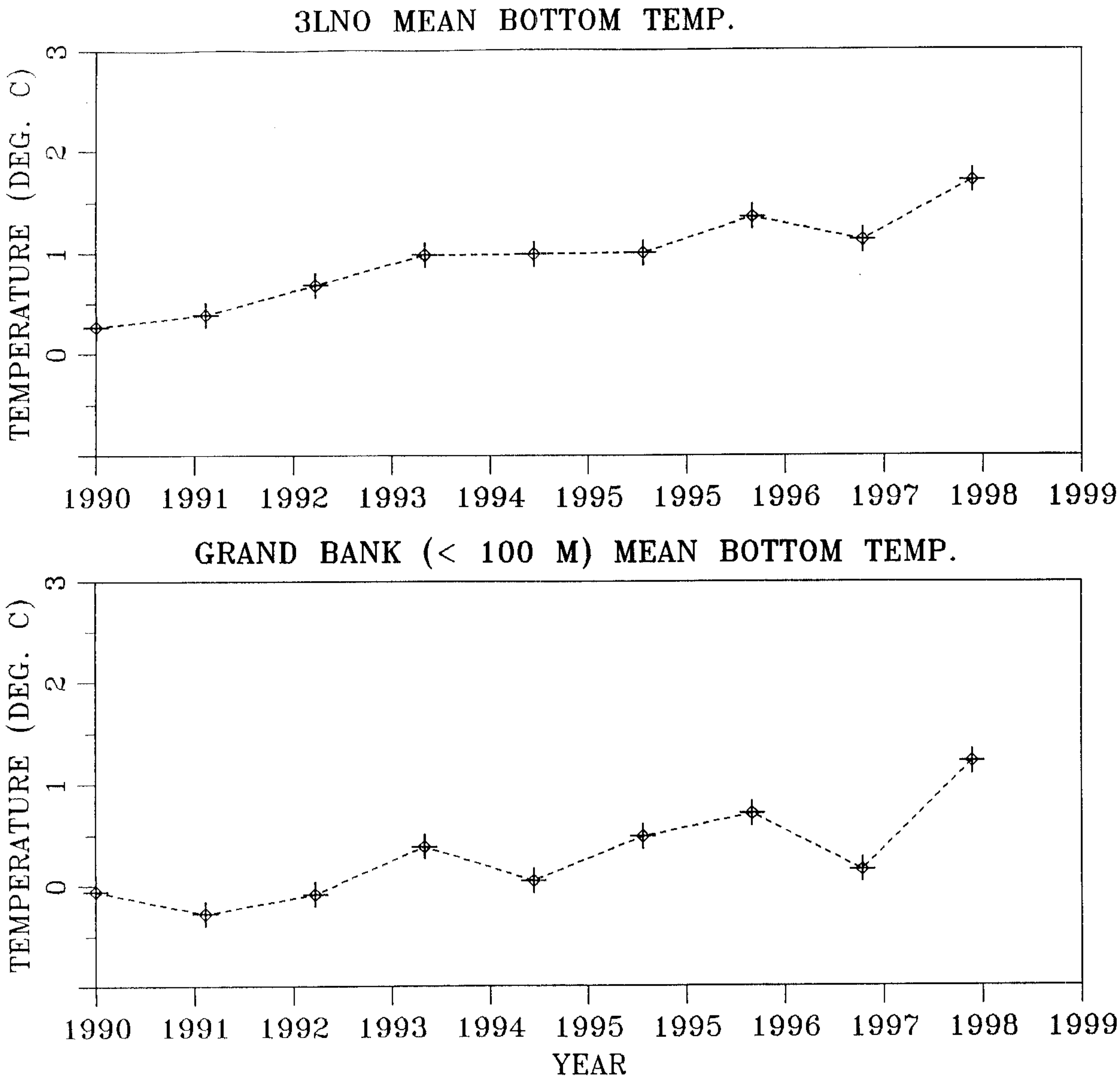


Fig. 20. Time series of the mean bottom temperature in NAFO Divisions 3LNO (top panel) and the mean bottom temperature on the Grand Bank within 100-m depth (bottom panel) during spring.

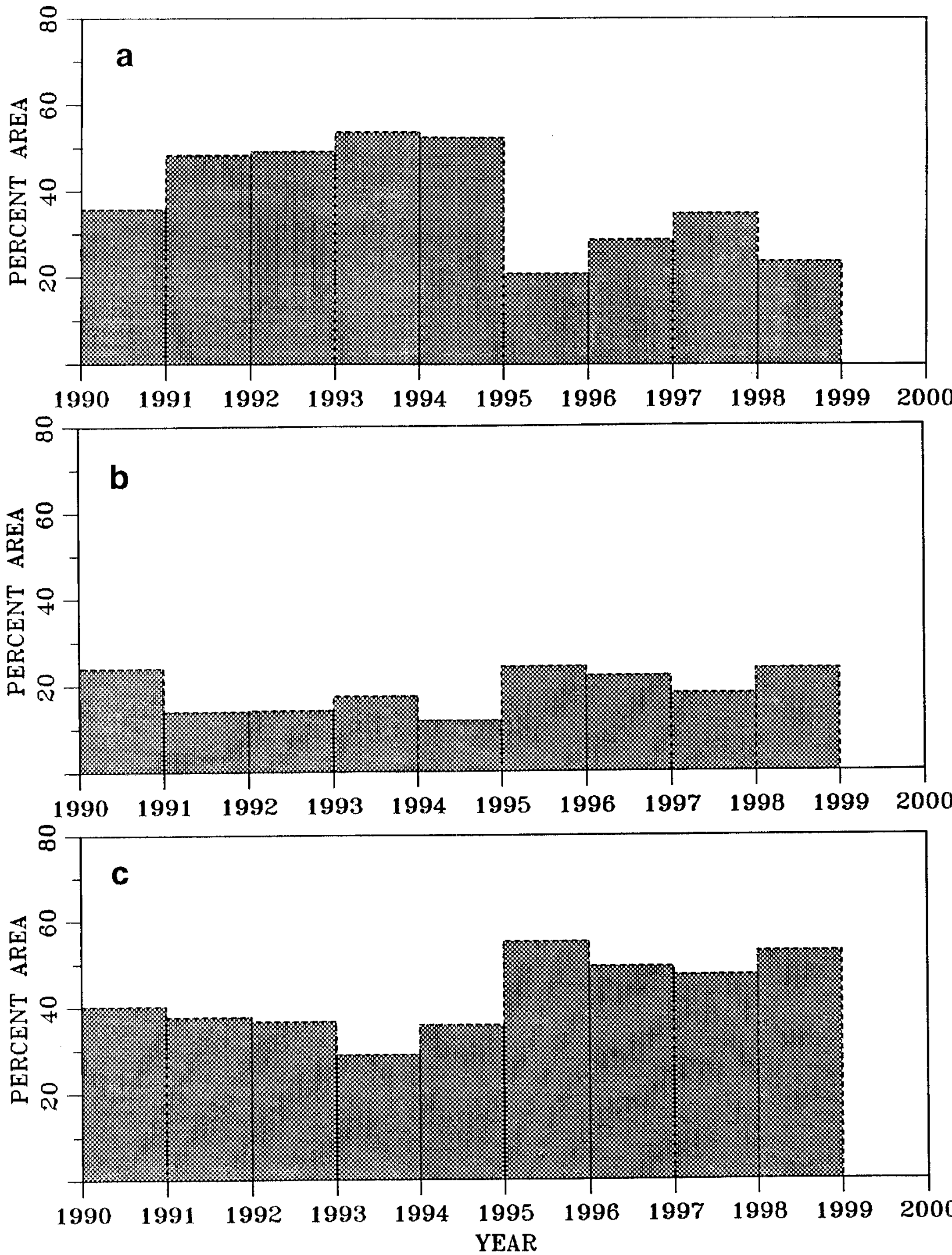


Fig. 21a. Time series of the percentage area of NAFO divisions 3LNO covered by water with bottom temperatures (a) less than 0°C (b) between 0°C to 1°C and (c) greater than 1°C, during autumn.

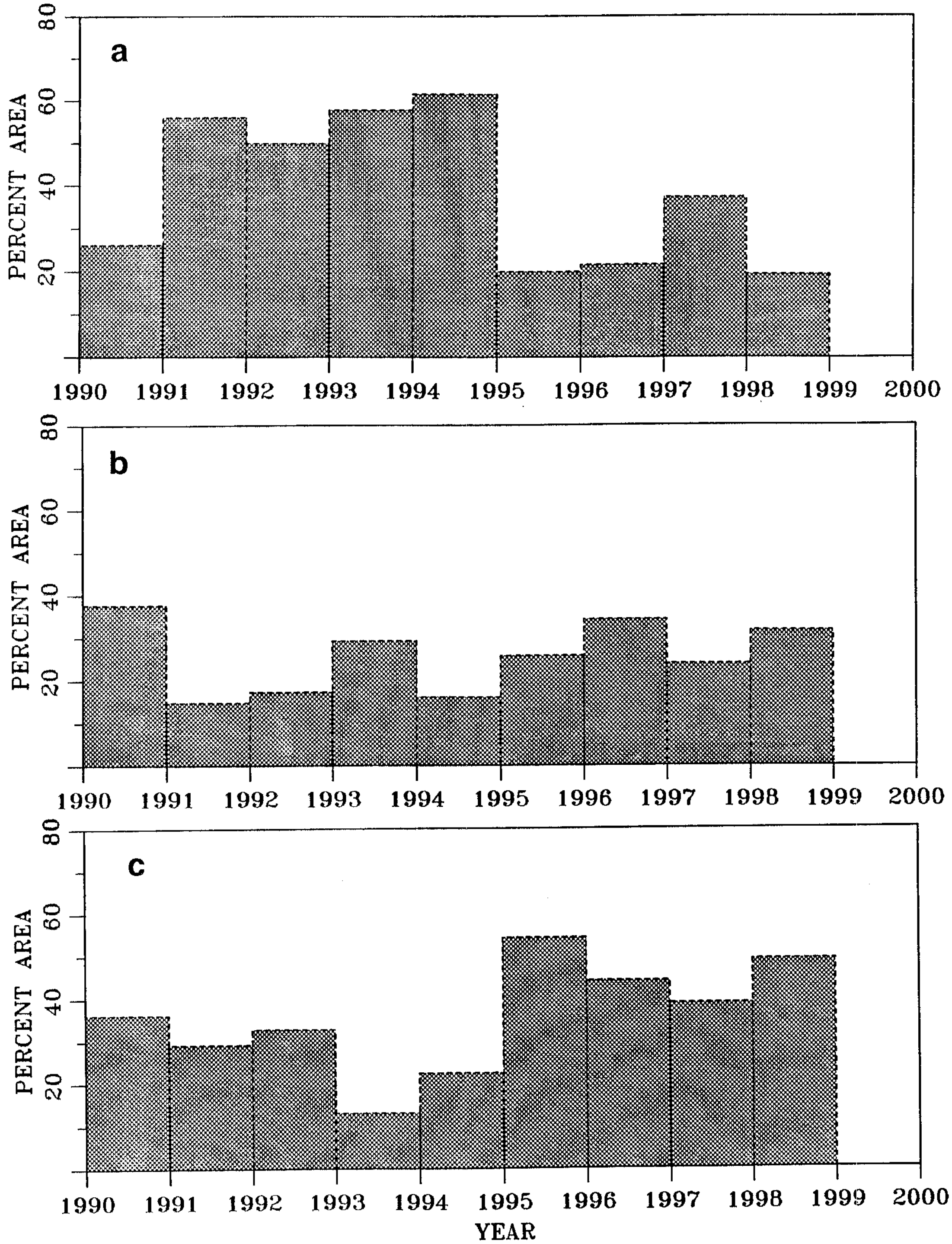


Fig. 21b. Time series of the percentage area of the Grand Bank (with water depths within 100-m) covered by water with bottom temperatures (a) less than 0°C, (b) between 0°C and 1°C and (c) greater than 1°C, during autumn.

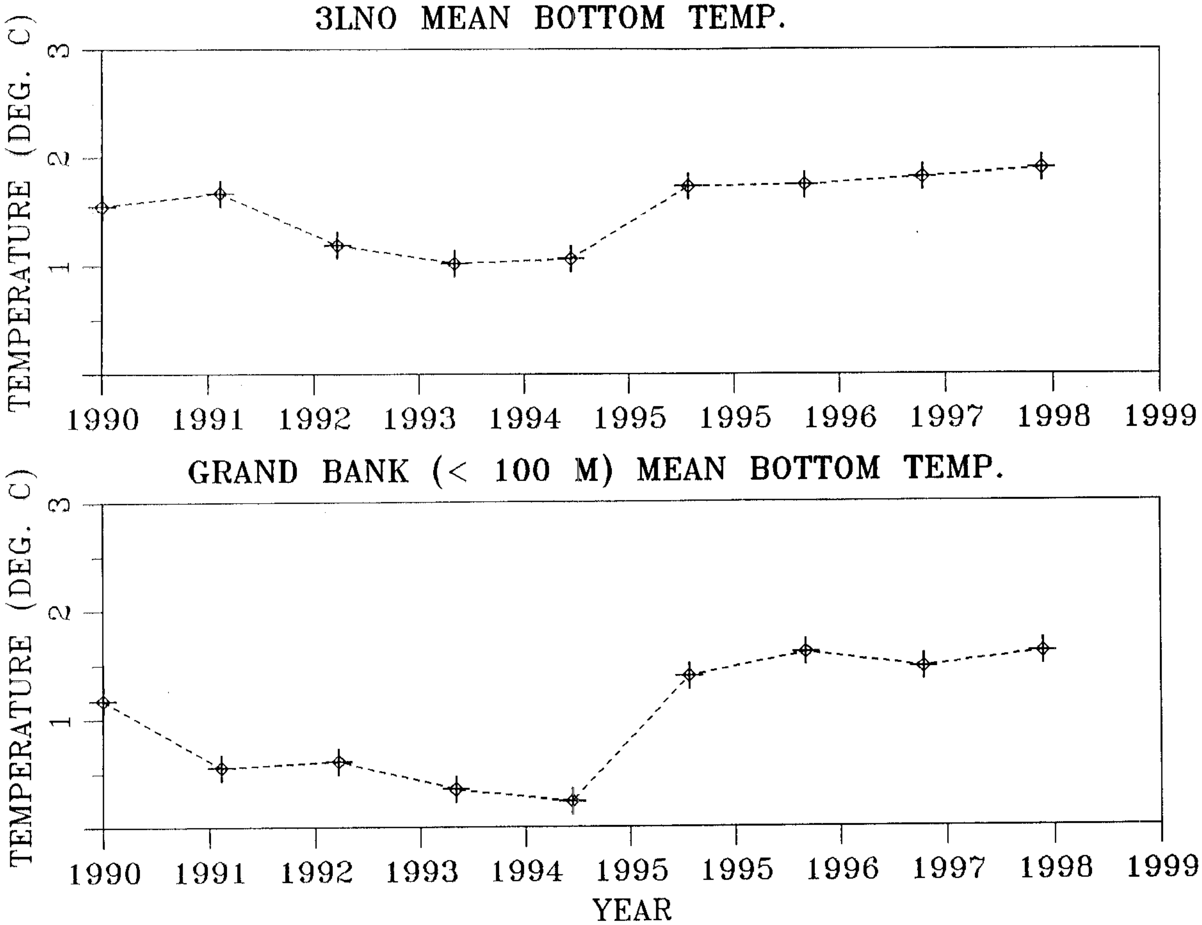


Fig. 22. Time series of the mean bottom temperature in NAFO Divisions 3LNO (top panel) and the mean bottom temperature on the Grand Bank within 100-m depth (bottom panel) during autumn.