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Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 1997

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

Department of Fisheries and Oceans, Maritimes Region
Ocean Sciences Division, Bedford Institute of Oceanography
Box, 1006, Dartmouth, N.S. B2Y 4A2

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Abstract

A review of physical oceanographic conditions on the continental shelves and adjacent offshore areas off the Scotian Shelf and Gulf of Maine during 1997 is presented. For the third consecutive year, sea surface temperatures at Boothbay Harbor and St. Andrews were predominantly above their long-term means while Halifax was below normal. In the deep basins on the Scotian Shelf and the Gulf of Maine, the temperature in the deep layers remained approximately 1°C warmer than normal continuing the trend of recent years. This condition reflects the presence of warm slope water along the continental slope of the Scotian Shelf and Gulf of Maine. Deep (200-300 m average) temperatures in Cabot Strait, however, were near normal and also continue a trend established during the last few years. In the 50-100 m layer over most of the Scotian Shelf and in the near-bottom waters in the northeastern Shelf, temperatures remained below normal by upwards of 1°C. These cold conditions have persisted since at least the mid-1980s although most regions show that temperatures have been warming slightly during the past few years.

Résumé

Un résume des conditions océanographiques physiques des plateaux continentaux et des zones hauturières avoisinantes du plateau néo-écossais et du golfe du Maine pour l'année 1997 est présenté. Pour la troisième année consécutive, les températures des eaux de surface à Boothbay Harbor et à St. Andrews ont été généralement supérieures à la moyenne à long terme tandis qu'elles ont été inférieures à la normale à Halifax. Dans les bassins profonds du plateau néo-écossais et du golfe du Maine, la température des couches profondes est demeurée de 1 °C environ supérieure à la normale, ce qui correspond à la tendance des dernières années. Cet état traduit la présence d'eau de pente plus chaude le long de la pente continentale du plateau néo-écossais et du golfe du Maine. Les températures des zones profondes (moyenne de 200 à 300 m) du détroit de Cabot étaient cependant près de la normale, ce qui est aussi conforme à une tendance notée au cours des dernières années. Dans la couche des 50-100 m de la plus grande partie du plateau néo-écossais et près du fond du plateau nord-est, les températures sont demeurées en deçà de la normale d'une valeur pouvant atteindre 1 °C. Ces conditions froides se sont maintenues au moins jusqu'au milieu des années 1980, mais elles se sont légèrement élevées dans la plupart des régions au cours des dernières années.

Introduction

This paper describes temperature and salinity characteristics during 1997 in the waters on the Scotian Shelf and in the Gulf of Maine (Fig. 1). The data are derived from coastal sea surface stations, long-term monitoring stations, annual groundfish surveys, ships-of-opportunity and research vessels. Most of the data are available in the BIO historical temperature and salinity (AFAP) database which was updated several times in 1997 from the data archive at the Marine Environmental Data Service (MEDS) in Ottawa and most recently in early January 1998. Additional data were obtained directly from the DFO fisheries personnel. In order to detect temperature trends we have removed the large seasonal cycle by expressing oceanographic conditions as monthly deviations from their long-term means, called anomalies. Where possible, these long-term means have been standardized to a 30-yr average using the base period 1961-1990 in accordance with the convention of the World Meteorological Organization and recommendations of the Northwest Atlantic Fisheries Organization (NAFO). Meteorological and sea ice information for the region during 1997 are described in Drinkwater et al. (1998).

Coastal Sea Surface Temperatures

Monthly averages of sea surface temperature (SST) for 1997 were available at Boothbay Harbor in Maine, St. Andrews in New Brunswick and Halifax in Nova Scotia. The monthly mean temperature anomalies relative to the 1961-90 long-term averages at each site for 1996 and 1997 are shown in Fig. 2.

The dominant feature in 1997 at Boothbay Harbor and St. Andrews was the above normal temperatures throughout most of the year (8 out of the 12 months at both sites) which continues a trend of warm temperatures that began in June of 1994. The 1997 anomalies equalled or exceeded one standard deviation (based upon the years 1961-90) in 6 months at Boothbay Harbor (January-May and August) but in only one month at St. Andrews (July). The maximum monthly anomaly was near 1.9°C in January at Boothbay while at St. Andrews it was 0.8°C in October. The lower amplitude anomalies at St. Andrews compared to Boothbay are typical and due to the increased vertical mixing by the tides in the Bay of Fundy. In contrast, at Halifax negative sea surface temperature anomalies dominated with 7 of the 12 months being colder-than-normal including March to July inclusive (Fig. 2). These cold anomalies also continue a trend observed at Halifax over the last several years. Temperatures are increasing at Halifax, however, based upon the increasing number of months that positive temperature anomalies were observed in 1997. Only in 2 months did the temperature anomaly exceed the long-term standard deviations, those occurring in May and July.

Time series of annual anomalies show that the surface temperature at both Boothbay Harbor and St. Andrews have been above their long-term means in recent years and generally on the increase since a minimum in the late 1980s (Fig. 2). This minimum was as low as that of the mid-1960s at St. Andrews but at Boothbay Harbor the minimum was only slightly below normal.

Consistent with the recent trends, the 1997 annual mean temperature was above normal (mean of 7.3°C and 0.2°C above normal at St. Andrews and 9.0°C and 0.5°C above normal at Boothbay). However, at both sites the temperature had fallen relative to 1996 and the recent peak in 1995 (Fig. 2). This decrease is consistent with the observed year-to-year variability and can not yet be construed as indicative of a downward trend in surface temperatures at longer time scales. In contrast, at Halifax temperatures have been below normal since the mid-1980s although there has been a slow but steady warming since the early 1990s. The 1997 annual sea-surface temperature at Halifax was 7.8°C producing an anomaly relative to the 1961-90 mean of -0.2°C.

Prince 5

Temperature and salinity measurements have been taken once per month since 1924 at Prince 5, a station off St. Andrews, New Brunswick, near the entrance to the Bay of Fundy (Fig. 1). It is the longest continuously operating hydrographic monitoring site in eastern Canada. Single observations per month, especially in the surface layers in the spring or summer may not necessarily be representative of the "average" conditions for the month and therefore the interpretation of the anomalies must be viewed with some caution. No significance should be placed on any individual anomaly but persistent anomaly features are likely to be real. The general vertical similarity in temperatures over the 90 m water column is due to the strong tidal mixing within the Bay of Fundy.

In 1997, no data were collected in March. Monthly mean temperatures ranged from a minimum of over 2.5°C throughout the water column in February to a maximum of over 12°C near the surface in September (Fig. 3,4). The monthly temperature anomalies were dominated by positive values, the exception being the latter half of the spring when anomalies were negative throughout the water column and continuing in the surface and near bottom during the summer (Fig. 3). In June, surface waters reached an anomaly of 1°C below normal. The annual mean temperatures exhibit high year to year variability (Fig. 4). In 1997 these mean temperatures were just above normal at both the surface (anomaly of 0.16°C) and near bottom at 90 m (0.10°C above normal). This represents a slight increase relative to 1996 at the surface while near bottom the 1997 temperature was similar to that of the previous year. These represent a decline from the peak in the mid-1990s but above the low levels of the early 1990s. At both depths, the maximum annual temperature occurred in the early 1950s and the minimum in the mid-1960s.

Salinities at Prince 5 during 1997 were mostly fresher-than-normal (Fig. 5). The lowest salinities (<31 psu) occurred during May and June but these were typically for this time of the year. The highest salinities (>32.5 psu) appeared near bottom in the autumn, and these also were near normal. The largest negative anomalies (below 0.5 psu) were observed throughout the water column in January and February. Time series show that the annual salinity anomalies in 1997 rose by approximately 0.4-0.5 relative to 1996 values at both the surface and 90 m (Fig. 5). The 1996 anomalies represented the lowest salinities recorded at Prince 5. It was a continuation of the generally freshening that has been occurring since the late 1970s. The recent low values parallel salinity events occurring in the deep waters of Jordan and Georges Basin and appear to be related to advection from areas further to the north (P. Smith, BIO, personal communication).

Deep Emerald Basin Temperatures

Petrie and Drinkwater (1993) assembled a time series of monthly temperature data from 1946 to 1988 at multiple depths in Emerald Basin in the center of the Scotian Shelf. They showed that there was high temperature variance at low frequencies (decadal periods). This signal was more visible at depth (below 75 m) where the low-frequency variance was higher and there was less high-frequency (year-to-year) variability. High coherence at low frequencies was found throughout the water column as well as horizontally from the mid-Atlantic Bight to the Laurentian Channel, although year-to-year differences between locations were observed. Temperature anomalies at 250 m have been used as a representative index.

In 1997, temperature measurements in Emerald Basin were obtained to depths of 250 m in nine separate months with values ranging from 9.2° to 9.7°C. This produced monthly anomalies of 0.9°-1.6°C above normal (Fig. 6). The long-term (1961-90) annual average is 8.5°C and the long-term monthly means range from 7.9°C to 9.4°C. The high positive anomalies in 1997 were generally representative of conditions in the Basin below approximately 50 to 100 m. The recent period of relatively warm waters in the deeper regions of Emerald Basin began with an intrusion of warm slope water late in 1991 or early 1992. The high temperature anomalies have also been observed in the deep waters of the Gulf of Maine (Drinkwater et al., 1997). The long term trends are shown by the bold solid line in Fig. 6. This represents the 5-year running mean of the annual anomalies. The annual anomalies were the average of all available monthly values within that year. In some years data were available for 10-12 months of the year but in some years only 1 or 2 months were there data. The long term trend shows a maximum in the early 1950s declining to a minimum in the early 1960s that has been described in detail by Petrie and Drinkwater (1993). The temperatures rose rapidly in the late 1960s, remained relatively high in the 1970s but dropped in the late 1970s and again in the early 1980s. With the exception of a short period in the early 1990s, the temperatures in the deep basin have been well above the long term mean and at the highest sustained levels on record.

Other Scotian Shelf and Gulf of Maine Temperatures

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinities for irregularly shaped areas on the Scotian Shelf and in the eastern Gulf of Maine that generally corresponded to topographic features such as banks and basins (Fig. 7). Their analysis has been updated by Petrie et al. (1996). We produced monthly mean conditions for 1997 at standard depths for selected areas (averaging any data within the month anywhere within these areas) and compared them to the long-term averages (1961-90). Unfortunately, data are not available for each month at each area and in some areas the monthly means are based upon only one profile. As a result the series are characterized by short period fluctuations or spikes superimposed upon long-period trends with amplitudes of 1-2°C. The spikes represent noise and most often show little similarity between

regions. Thus care again must be taken in interpreting these data and little weight given to any individual mean. The long period trends often show similarity over several areas, however. To better show such trends we have estimated the annual mean anomaly based on all available means within the year and then calculated the 5-year running mean of the annual values. This is similar to our treatment of the Emerald Basin data.

In previous analysis, Drinkwater and Pettipas (1994) examined long-term temperature time series for most of the areas on the Scotian Shelf and in the Gulf of Maine and identified several important features. First, the temperatures in the upper 30 m tended to vary greatly from month to month, due to the greater influence of atmospheric heating and cooling. Second, at intermediate depths of 50 m to approximately 150 m, temperatures had declined steadily from approximately the mid-1980s into the 1990s. On Lurcher Shoals off Yarmouth, on the offshore banks and in the northeastern Scotian Shelf the temperature minimum in this period approached or matched the minimum observed during the very cold period of the 1960s. This cold water was traced through the Gulf of Maine from southern Nova Scotia, along the coast of Maine and into the western Gulf. Cooling occurred at approximately the same time at Station 27 off St. John's, Newfoundland, off southern Newfoundland on St. Pierre Bank (Colbourne 1995) and in the cold intermediate layer (CIL) waters in the Gulf of St. Lawrence (Gilbert and Pettigrew 1997). Data in 1994 and 1995 indicated warming of the intermediate layers in the Gulf of Maine but a continuation of colder-than-normal water on most of the Scotian Shelf (Drinkwater et al. 1996). The third main feature was the presence of anomalously warm slope water off the shelf and in the deep basins such as Emerald on the Scotian Shelf and Georges in the Gulf of Maine. This warm deep water appeared to influence the intermediate depth waters above the basins as their anomalies were generally warmer than elsewhere on the shelves.

The general patterns first identified by Drinkwater and Pettipas (1994) have continued into 1997. Monthly mean temperature profiles reveal that cold conditions prevailed in the deeper waters on Sydney Bight, on Misaine Bank in the northeast Scotian Shelf, and on Lurcher Shoals. Warmer-than-normal conditions were observed in Emerald Basin (Fig. 6) below 50 to 100 m.

On Sydney Bight (area 1 in Fig. 7) monthly mean profiles from 7 different months show highly variable temperature anomalies throughout the water column (Fig. 8). In the near surface (<10 m) waters, however, temperatures were primarily above the long-term mean with the exception of August (Fig. 8). In the top 100 m August showed the coldest anomalies in 1997. The time series of the 100 m temperature anomalies show high temperature anomalies in the 1950s that fell to a minimum around 1960 and then rose steadily through the 1960s. Temperatures remained relatively high during the 1970s. By the 1980s temperatures began to decline and by the mid-1980s dropped quickly to below normal values reaching a minimum anomaly around -1°C in the early 1990s. Temperatures in recent years have generally remained below normal but have been slowly increasing with several monthly anomalies each year of above normal being observed since 1995.

Monthly mean temperature profiles for Misaine Bank on the northeastern Scotian Shelf (area 5 in Fig. 7) are available for 6 months during 1997. They show variable upper layer (0-30 m)

temperatures (Fig. 9). However, below approximately 30 m temperatures are predominantly below the long-term mean throughout the year. Below 50 m, anomalies lay between -1° and 0°C but decreased to as low as -2°C or colder at depths shallower than 50 m. The time series of the 100 m temperature anomalies show that these negative values have persisted since approximately the mid-1980s (Fig. 9). This pattern is indicative of the water column below 50 m. Recent years, although exhibiting generally below normal temperatures, have seen increasing temperatures slowly from the minimum in the early 1990s. As at Emerald Basin, temperatures were relatively high in the 1950s. Temperatures then declined and at Misaine Bank reached a minimum around 1960, several years earlier than areas further to the southwest. Temperatures were near normal from the mid-1960s to the mid-1970s before rising to a maximum in the late 1970s. By the mid-1980s, temperatures fell to below normal and reached a record sustained minimum of around -1°C in the first half of the 1990s. Since then, as on Sydney Bight, temperatures have remained below normal but with evidence of a slow but steady increase that continued into 1997.

At Lurcher, data were available in 8 months during 1997 (Fig. 10). There was high temperature variability about the long-term mean in the top 40 m. At depths between 40 and 80 m which covers most of the bottom of Lurcher Shoals, 1997 shows a greater number of months with below normal temperatures than above normal. At 100 m which lays at the edge of the Shoals, temperatures again varied between above and below normal. The monthly 50 m temperature anomalies at Lurcher show mostly cooler-than-normal waters in 1997. This depth represents conditions over much of the bottom of the Shoals. Temperatures over Lurcher Shoals was high in the late 1940s and early 1950s, declined to a mid-1960s minimum, rose rapidly into the 1970s and remained above normal into the mid-1980s. As elsewhere, temperatures declined by the mid-1980s to below normal reaching a long-term minimum in the early 1990s. Since then temperatures have been warming and from 1994 on some positive monthly temperature anomalies have been observed although the annual means have remained below normal.

The time series of temperature in the deep regions of Georges Basin (Fig. 11; area 26 in Fig. 7) shows a striking similarity to that observed in Emerald Basin (Fig. 6). This includes the low values in the mid-1960s, rising sharply to a peak in the early 1970s and varying slightly but generally remaining above the long-term (1961-90) mean ever since. This is not surprising given that the source of the waters are primarily the offshore slope waters (Petrie and Drinkwater, 1993). On the Canadian portion of Georges Bank (area 28 in Fig. 7), the short-period variability is of much higher amplitude than in Georges Basin, for example (Fig. 11). This reflects not only the higher temporal fluctuations but also spatial differences within area. The longer-term trend shows positive anomalies in the 1950s, the low 1960s and a tendency towards positive anomalies since the 1970s. However, from the late 1980s on, the long-term temperature trend has not been significantly different than normal.

Temperatures during the Summer Ground Fish Survey

The most extensive temperature coverage over the entire Scotian Shelf occurs during the annual groundfish survey, usually in July. In 1997, around 200 conductivity-temperature-depth

(CTD) stations were occupied. Temperatures were interpolated onto a 0.2 by 0.2 degree latitude-longitude grid using an objective analysis procedure known as optimal estimation. The interpolation method uses the 15 "nearest neighbours" and a horizontal scale length of 30 km and vertical scale lengths of 15 m in the upper 30 m and 25 m below that. Data near the interpolation grid point are weighted proportionately more than those further away. Temperatures were optimally estimated onto the grid for depths of 0, 50, 100 m and near bottom. Maximum depths for the interpolated temperature field were limited to 500 m as we were primarily interested in the temperatures over the shelf. The 1997 temperatures were also compared to the 1961-90 means for July.

Temperatures in 1997 at the surface varied from <9° to >16°C with the coldest temperatures at the mouth of the Bay of Fundy and the warmest on Sydney Bight and the central Scotian Shelf (Fig. 12a). Warmer temperatures and weaker temperature gradients prevailed on the Scotian Shelf relative to the Bay of Fundy. Note that no data were collected on the Lurcher Shoals during this survey. At 50 m the coldest temperatures (<1°C) are in the extreme northeast and off Mahone Bay on the Atlantic coast of Nova (Fig. 12a). Note the warm waters (4°-5°C) appear to be penetrating onto the central shelf regions from the offshore. The 100 m temperatures show a pattern of cold waters (<3°C) in the northeast and warm waters (>5°C) to the southwest (Fig. 12b). Bottom temperatures show similar features to 100 m and are typical (Fig. 12b). First is the large contrast between the northeast and central Scotian Shelf. In the northeast, bottom temperatures were generally cold with minima less than 2°C in the Misaine Bank region. Temperatures in Emerald Basin exceeded 9°C. Relatively high temperatures also were found over southern Browns Bank and in the upper reaches of the Bay of Fundy.

Temperature anomalies at the surface show generally weak, spatially-varying anomalies except in the Bay of Fundy which was below normal by greater than 1°C (Fig. 13a). The dominant feature at 50 m is the below-normal temperatures over most of the shelf with maximum anomalies of below -2°C in the vicinity of Emerald Basin but not over the central Basin (Fig. 13a). At 100 m and near bottom the anomalies are below normal in the northeastern Scotian Shelf and extend onto Sable and Western Bank on the outer Shelf (Fig. 13b). At 100 m we also see colder-than-normal temperatures over Emerald Basin and in the Bay of Fundy. The colder-than-normal temperatures over Emerald Basin are different than 1996 when these were warmer-than-normal (Drinkwater et al., 1997). The warm water near bottom in Emerald Basin during the July survey is consistent with the 250 m temperature time series (Fig. 6) and the cold temperatures in the northeast with the temperature time series observed on Misaine Bank (Fig. 9).

A new analysis was carried out during the past year in which we optimally estimated the near bottom temperatures for all of the July surveys from 1970 to present. We included not only data during the surveys but any data collected during the month. We then estimated the bottom area covered by each one degree temperature range (i.e. 1-2°C, 2-3°C, 3-4°C, etc.) within NAFO subareas 4Vn, 4Vs, 4W and 4X. The area associated with each grid point in the optimal estimation was first determined, and then those areas that had a temperature within the designated range were summed. The time series of these areas for each NAFO subarea are shown in Fig. 14a,b. Several

points are note worthy. First is the increase in temperature from 4Vs/4Vn to 4W and 4X. In 4Vn almost all of the bottom is covered by waters less than 6°C and almost 50% <5°C (Fig. 14a). For 4Vs, 80-90% is <6°C and 75% <5°C (Fig. 14a). In 4W <50% and in 4X<20% is covered by temperatures <6°C (Fig. 14b). The time series for 4Vn and 4Vs show an increase in the 0°-1°C and especially <3°C waters during the late 1980s and early 1990s (Fig. 14a). Also in 4Vs there are waters <1°C during this colder period. In 4W there is also an increase in the area of the waters <3°C but it is of smaller amplitude than in 4V (Fig. 14b). In 4X there is an increase in waters <4°C but it is not as large an amplitude as in the other regions (Fig. 14b). These time series allow us to examine the changes in area of preferred temperature habitat for different stocks. We have examined the area of 2°-6°C bottom waters in 4Vs and 4W (Fig. 15). These correspond to temperatures at which most of the cod were caught during the July surveys (Page et al., 1994). In 4Vs there is high year-to-year variability with a general decrease in area of the 2°-6°C waters especially during the 1990s. During 1996 and 1997 the area has risen to levels comparable to 1993 and 1994 and above the extremely low areas of the early 1990s and 1995. In 4W there is no dominant trend but the area of the 2°-6°C water in 1997 and 1996 were near maximum.

Cabot Strait Deep Temperatures

Bugden (1991) investigated the long-term temperature variability in the deep waters of the Laurentian Channel in the Gulf of St. Lawrence from data collected between the late 1940s to 1988. The variability in the average temperatures within the 200-300 m layer in Cabot Strait was dominated by low-frequency (decadal) fluctuations with no discernible seasonal cycle. A phase lag was observed along the major axis of the channel such that events propagated from the mouth towards the St. Lawrence Estuary on time scales of several years. The updated time series based primarily upon ice forecast cruises conducted by the Bedford Institute in November-December show that temperatures declined steadily between 1988 and 1991 to their lowest value since the late 1960s (near 4.5°C and an anomaly exceeding -0.9°C; Fig. 16). Then temperatures rose dramatically reaching 6.0°C (anomaly of 0.6°C) in 1993. By 1994 temperatures had begun to decline although anomalies remained positive. Temperatures continued to fall in 1995 and 1996 towards near normal. In 1997, data available in January and December were both 5.5°C which is slightly above the long-term mean (Fig. 16).

Summary

In 1997, colder-than-normal conditions continued in the bottom waters and throughout much of the water column on the northeastern Scotian Shelf, along the Atlantic coast of Nova Scotia and off southwestern Nova Scotia. This pattern was established in the mid-1980s with maximum cooling in the early 1990s. In recent years there has been a slow but steady increase in temperatures in these regions. The presence of these cold waters is believed to be due to advection from the Gulf of St. Lawrence and off the Newfoundland Shelf and to a lesser extent *in situ* cooling during the winter although the relative importance has not yet been established. In contrast to these

cool conditions, the waters in the central Scotian Shelf over Emerald Basin and in the deep basins of the Gulf of Maine were warmer-than-normal in 1997 and near the highest on record. These very warm conditions have persisted since 1992 and reflect the presence of warm slope water offshore.

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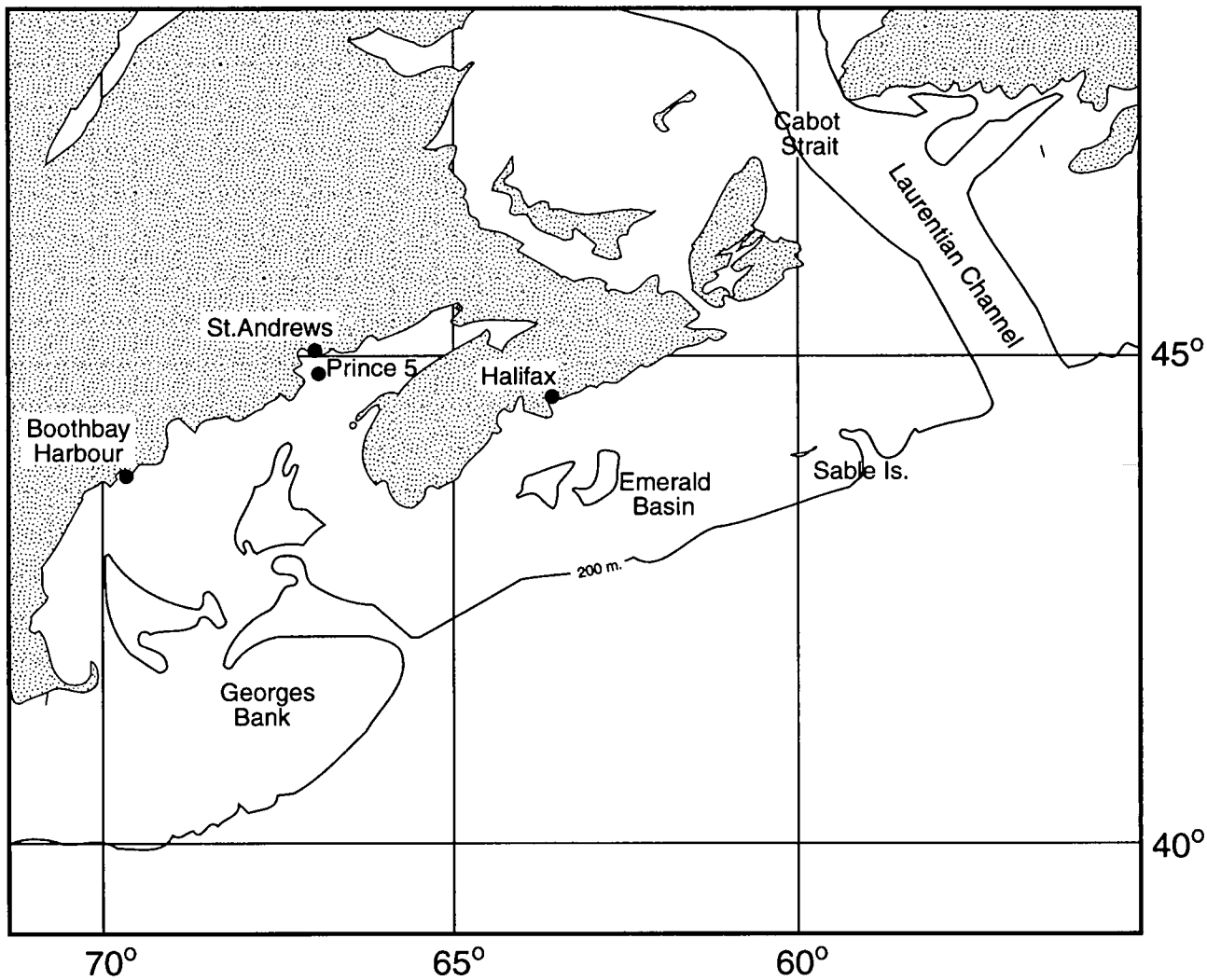


Fig. 1. The Scotian Shelf and the Gulf of Maine showing sea surface temperature stations, Prince 5 and topographic features.

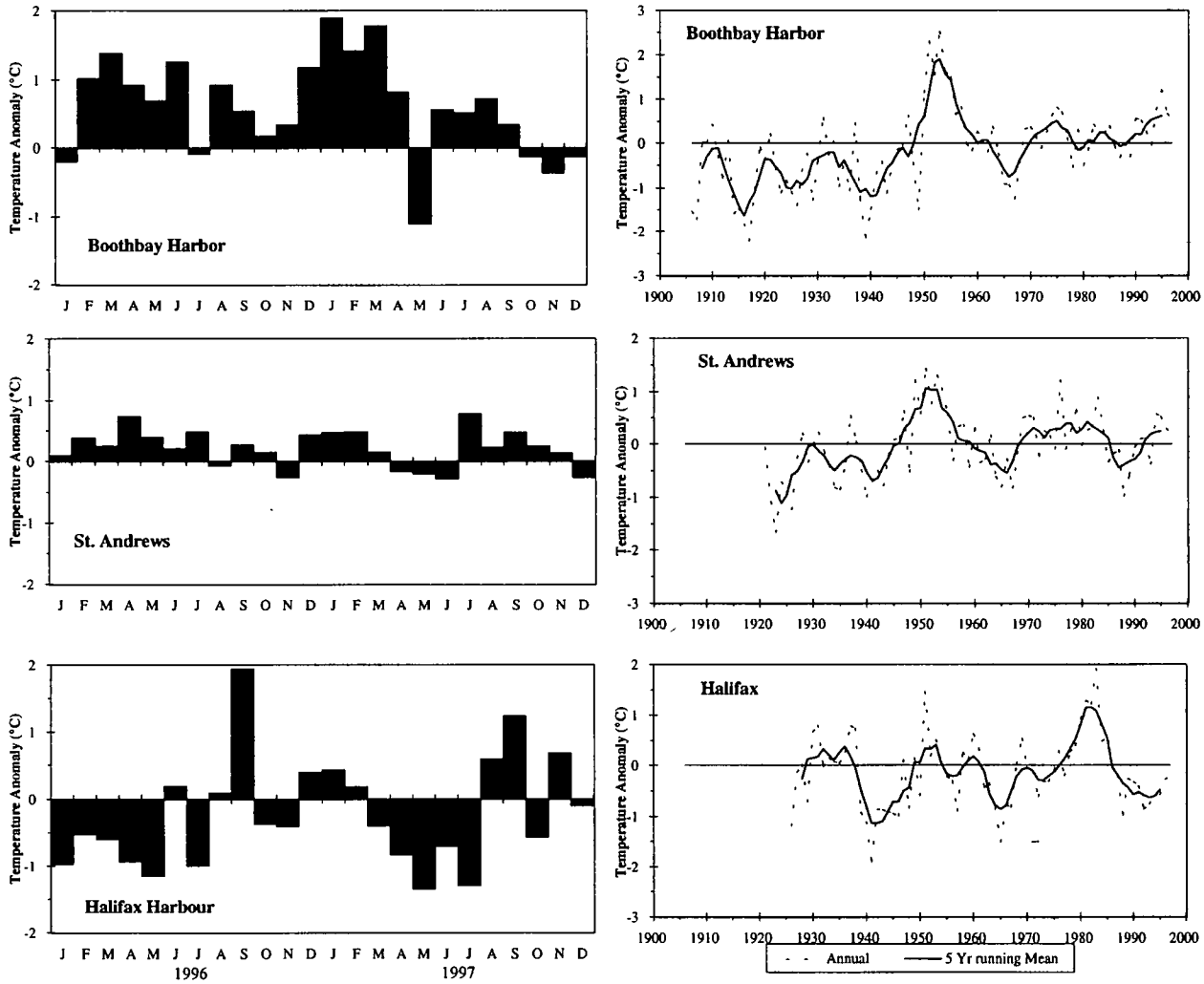


Fig. 2. The monthly sea surface temperature anomalies during 1995 and 1996 (left) and the annual temperature anomalies and their 5-year running means (right) for Boothbay Harbor, St. Andrews and Halifax. Anomalies are relative to 1961-90 means.

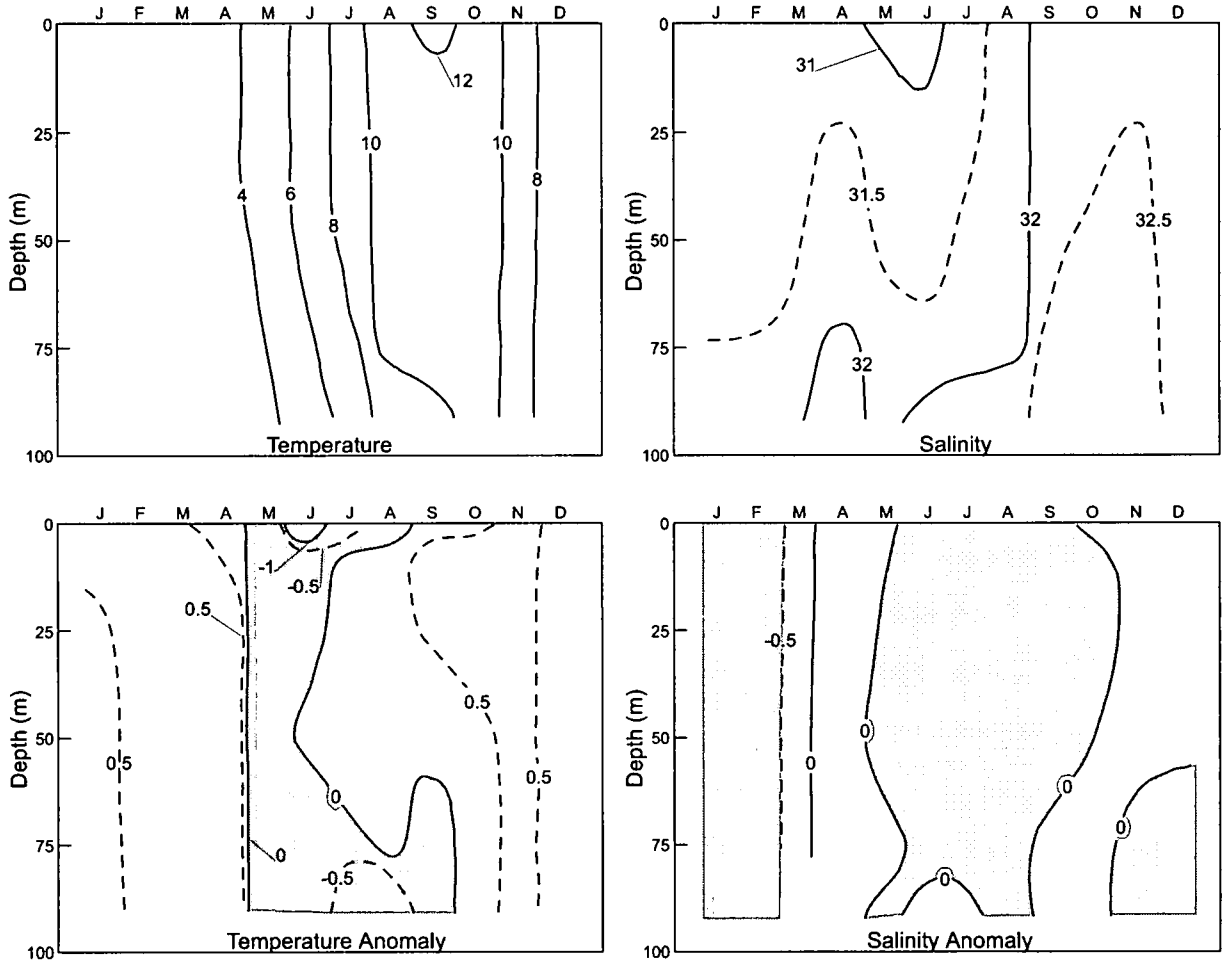


Fig. 3. Monthly temperatures and salinities (top panels) and their anomalies (bottom panels) at Prince 5 as a function of depth during 1997 relative to the 1961-90 means. Shaded areas are negative anomalies.

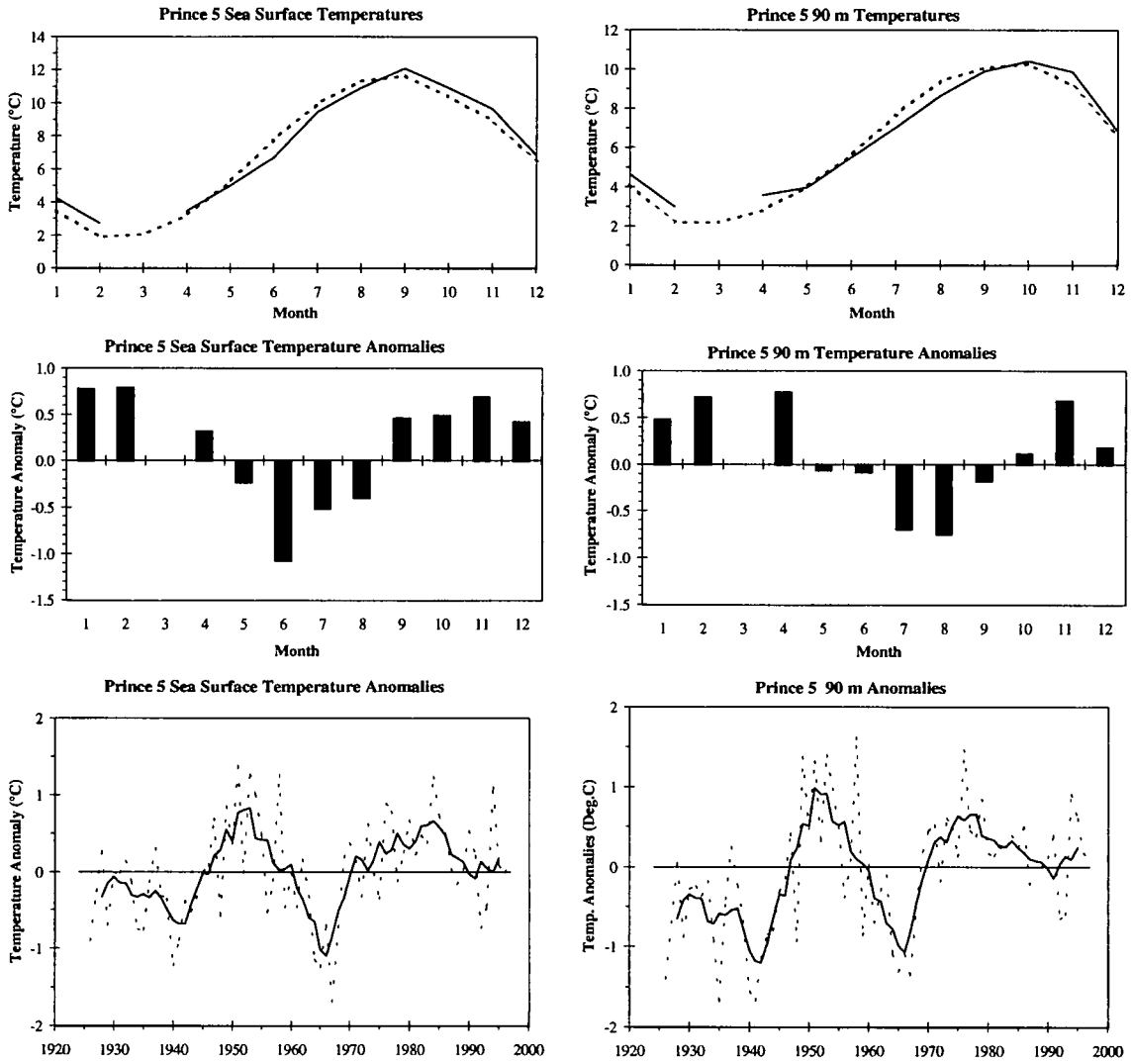


Fig. 4. The monthly mean temperatures for 1997 (solid line) and the long-term means (top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panels the time series of the annual means (dashed line) and 5-year running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

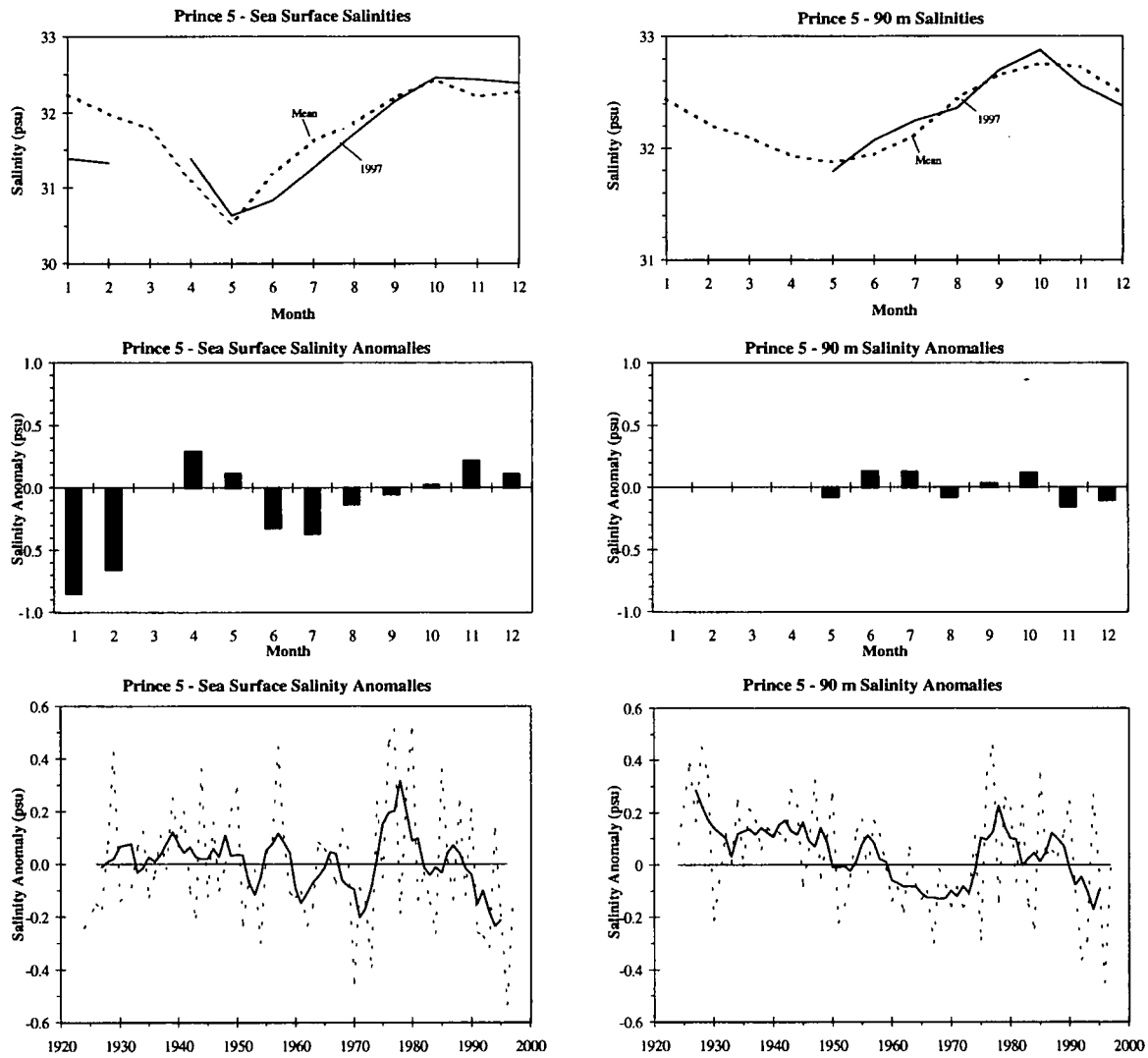


Fig. 5. The monthly mean salinities for 1997 (solid line) and the long-term means (top panels), the monthly anomalies relative to the long-term means for 1961-90 (middle panels) and in the bottom panels the time series of the annual means (dashed line) and 5-year running means (solid line) for Prince 5, 0 m (left) and 90 m (right).

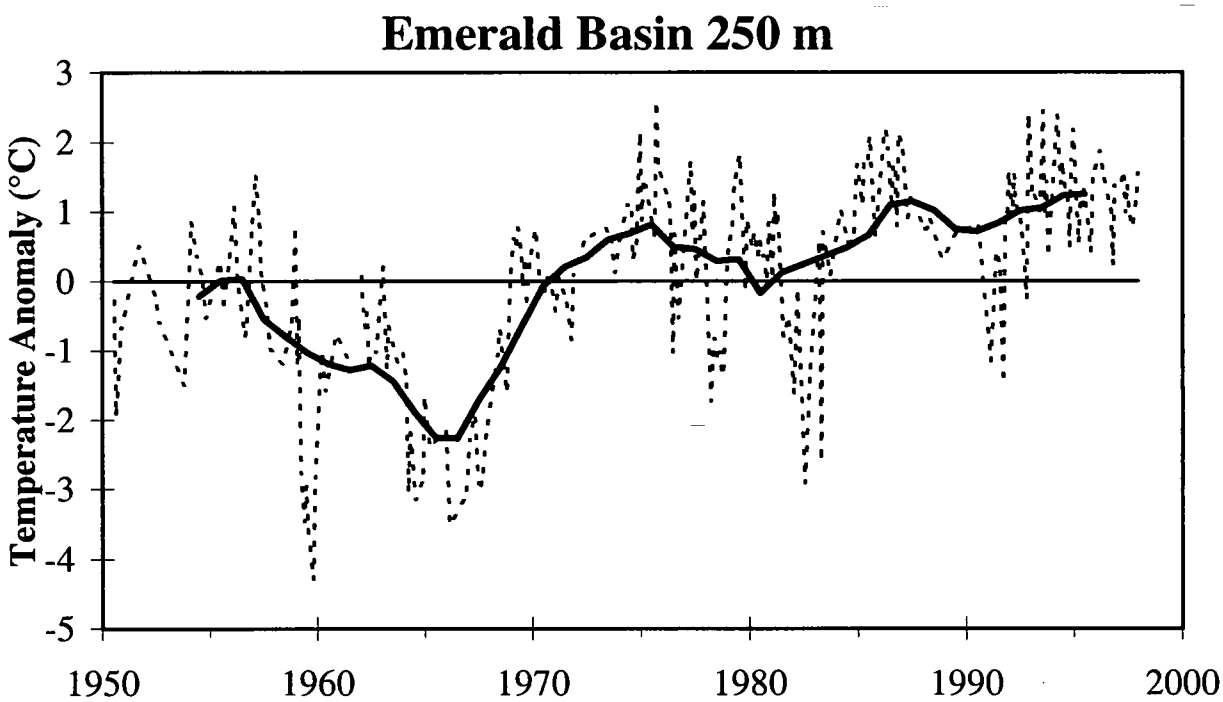
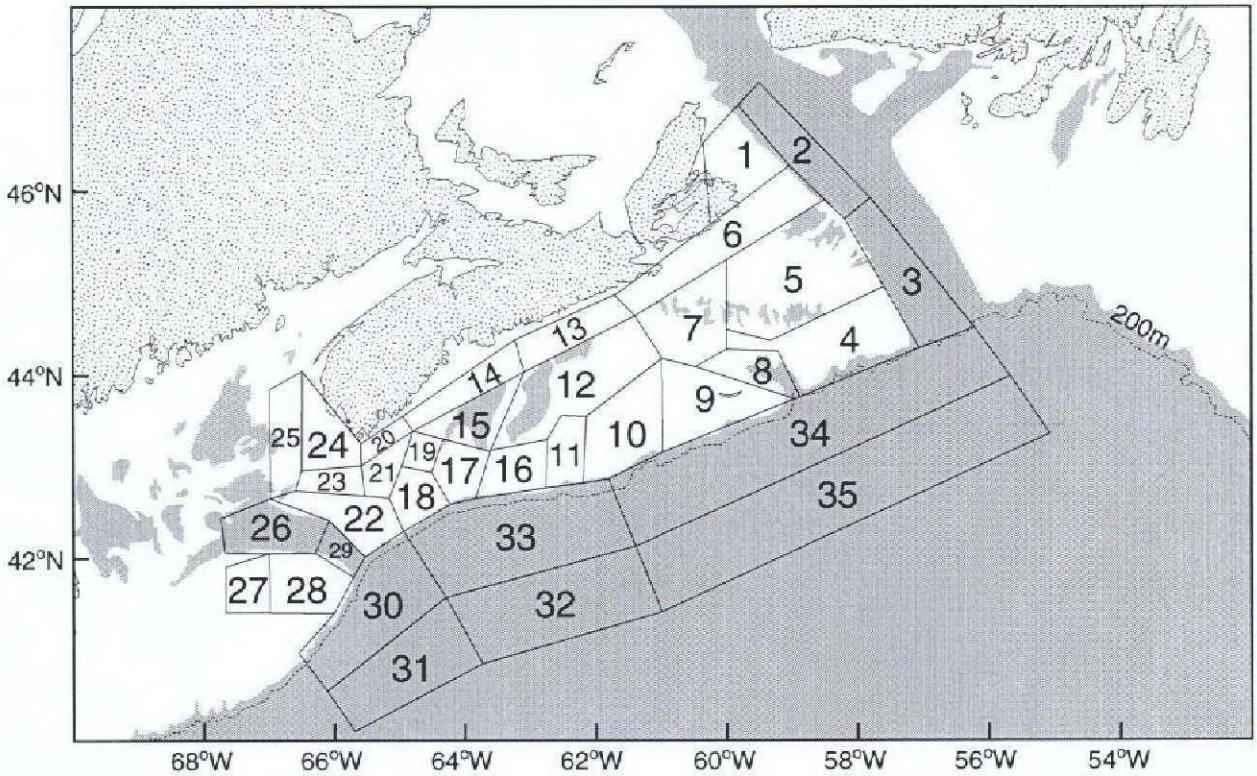


Fig. 6. Temperature anomalies (relative to 1961-90) at 250 m in Emerald Basin.



1. Sydney Bight
2. N. Laurentian Channel
3. S. Laurentian Channel
4. Banquereau
5. Misaine Bank
6. Canso
7. Middle Bank
8. The Gully
9. Sable Island
10. Western Bank
11. Emerald Bank
12. Emerald Basin
13. Eastern Shore
14. South Shore
15. Lahave Basin
16. Saddle
17. Lahave Bank
18. Baccaro Bank
19. Roseway Bank
20. Shelburne
21. Roseway Basin
22. Browns Bank
23. Roseway Channel
24. Lurcher Shoals
25. E. Gulf of Maine
26. Georges Basin
27. Georges Shoal
28. E. Georges Bank
29. N.E. Channel
30. Southern Slope
31. Southern Offshore
32. Central Offshore
33. Central Slope
34. Northern Slope
35. Northern Offshore

Fig. 7. The areas in which monthly means of temperature were estimated by Drinkwater and Trites (1987).

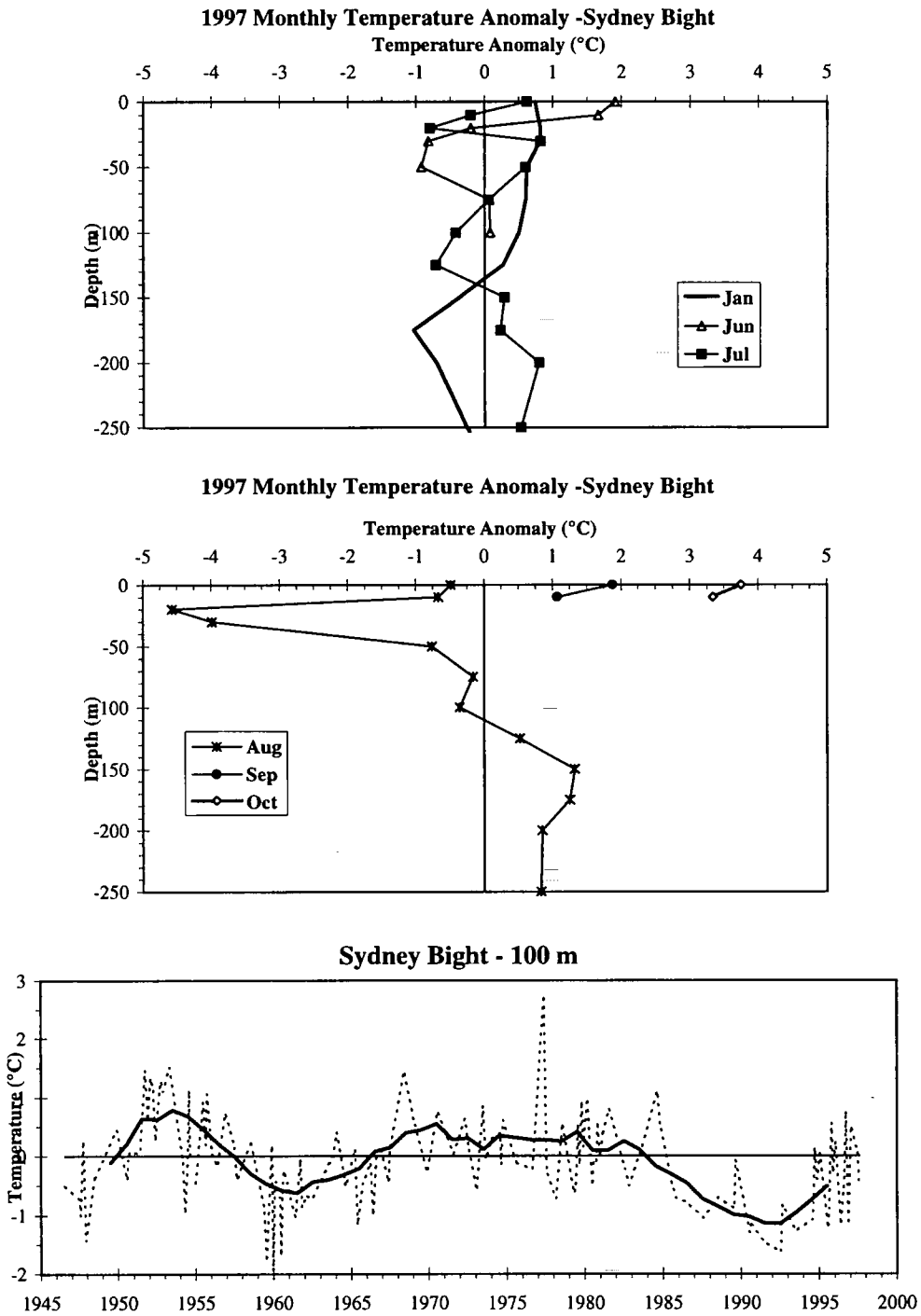


Fig. 8. 1997 monthly temperature anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m for Sydney Bight (area 1-Fig. 7).

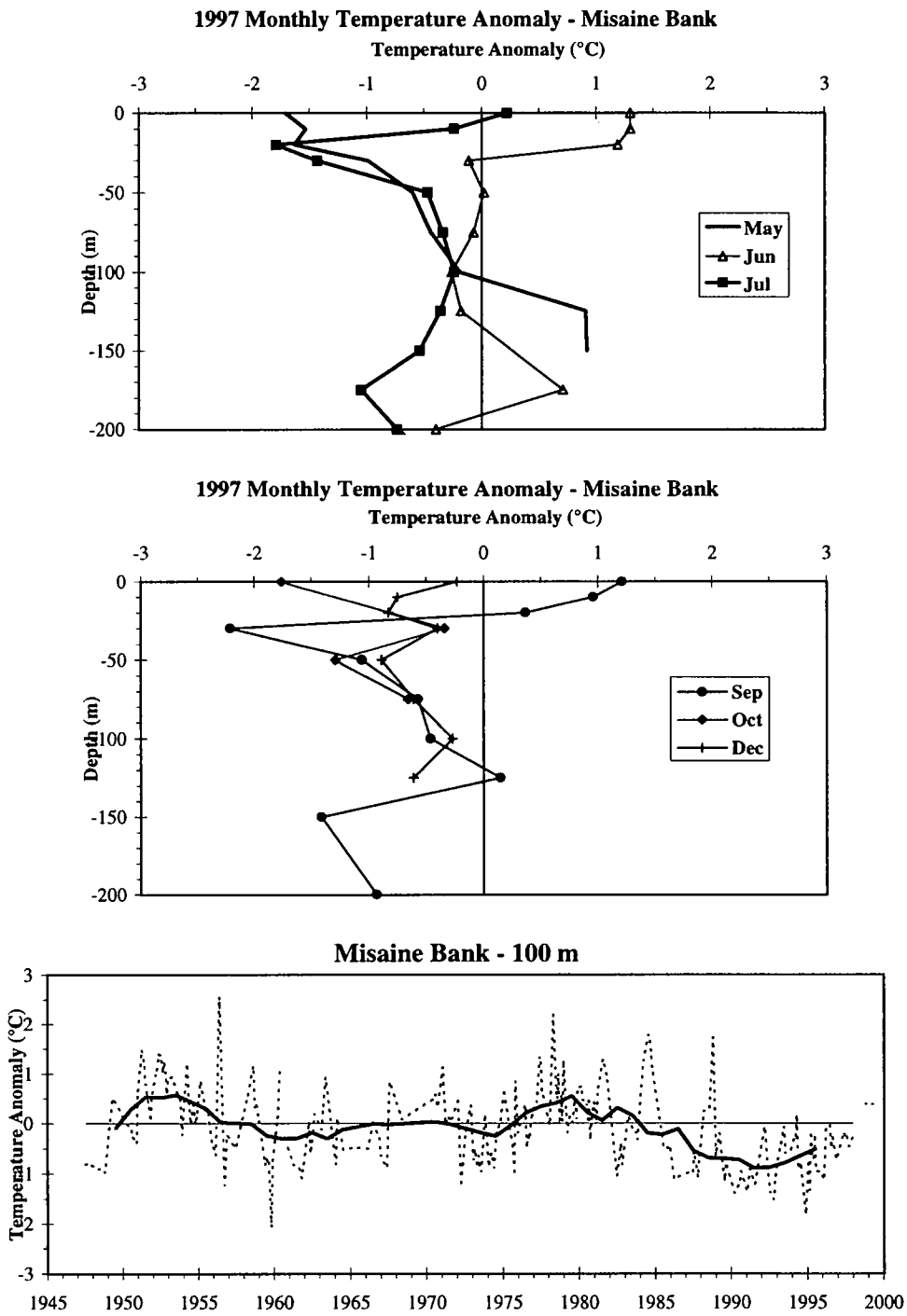
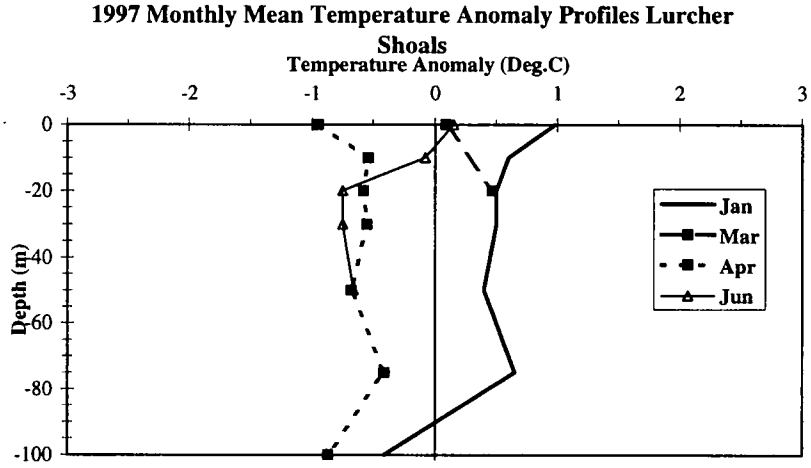
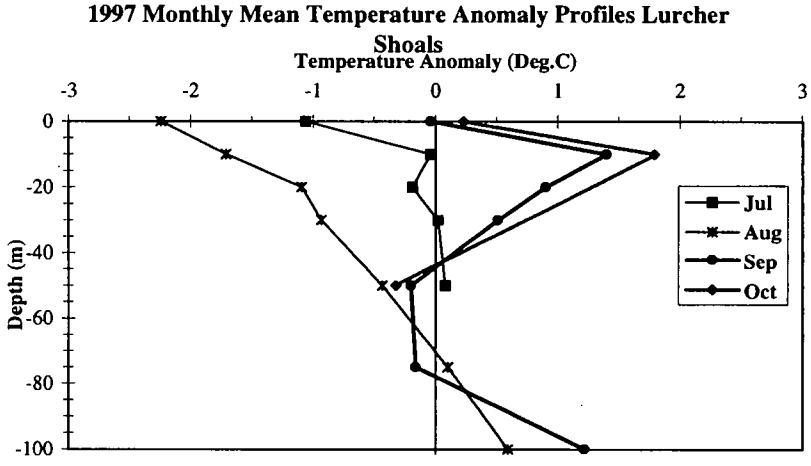


Fig. 9. 1997 monthly temperature anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 100 m for Misaine Bank (area 5-Fig. 7).





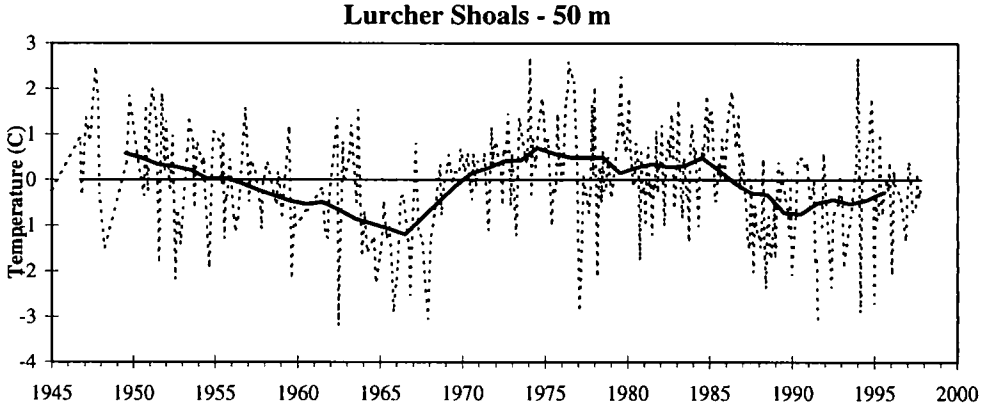


Fig.10. 1997 monthly temperature anomaly profiles (top 2 panels) plus the monthly mean temperature anomaly time series (dashed line) and the 5-yr running mean of the estimated annual anomalies (solid line) at 50 m for Lurcher (area 24-Fig. 7).

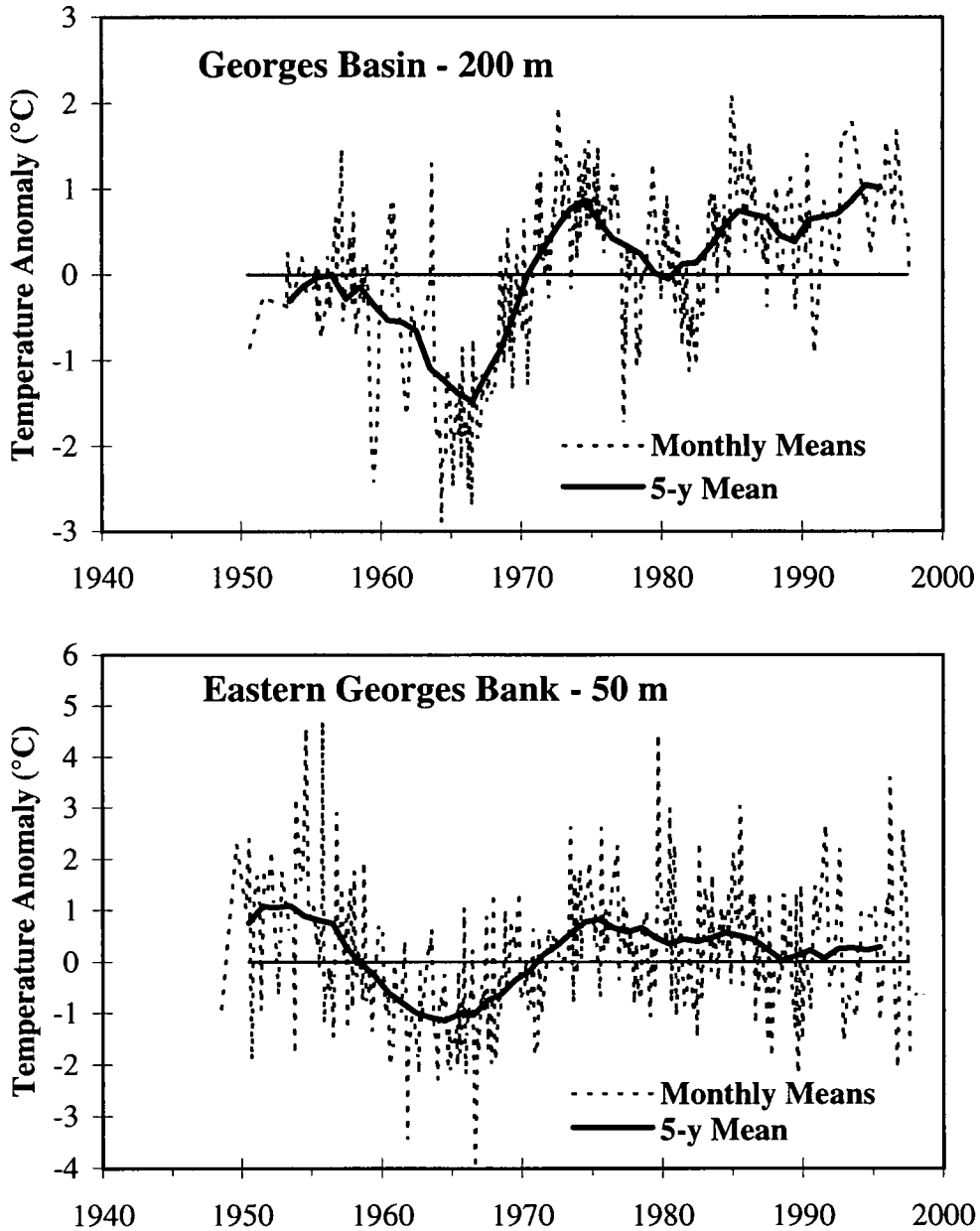


Fig.11. Time series of the monthly means (dashed lines) and the 5-year running means of the annual anomalies at 200 m in Georges Basin (top panel; area 26 in Fig. 7) and eastern Georges Bank (bottom panel; area 28 in Fig. 7).

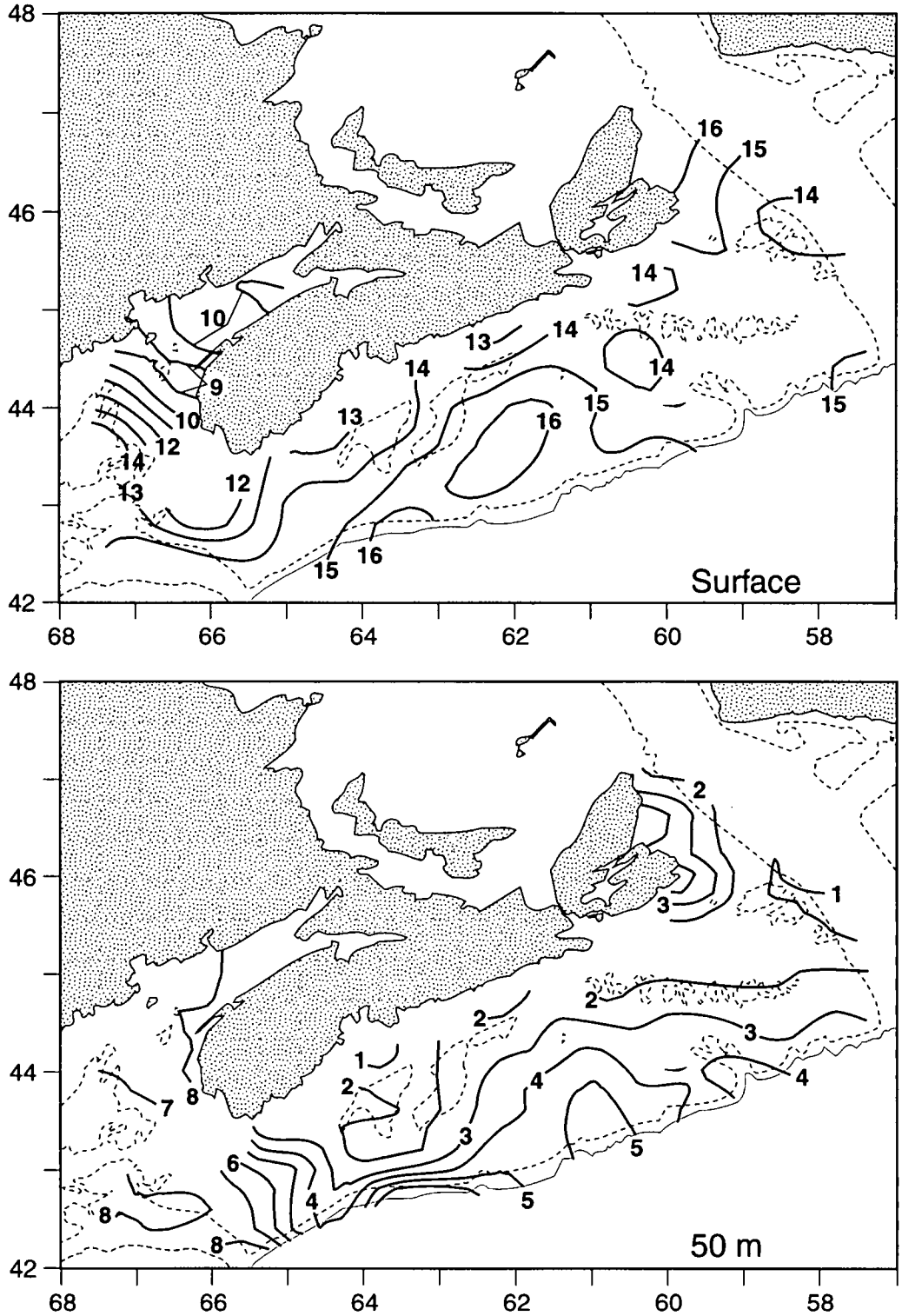


Fig. 12a. Contours of optimally estimated temperatures at the surface (top panel) and 50 m (bottom panel) during the 1997 July groundfish survey.

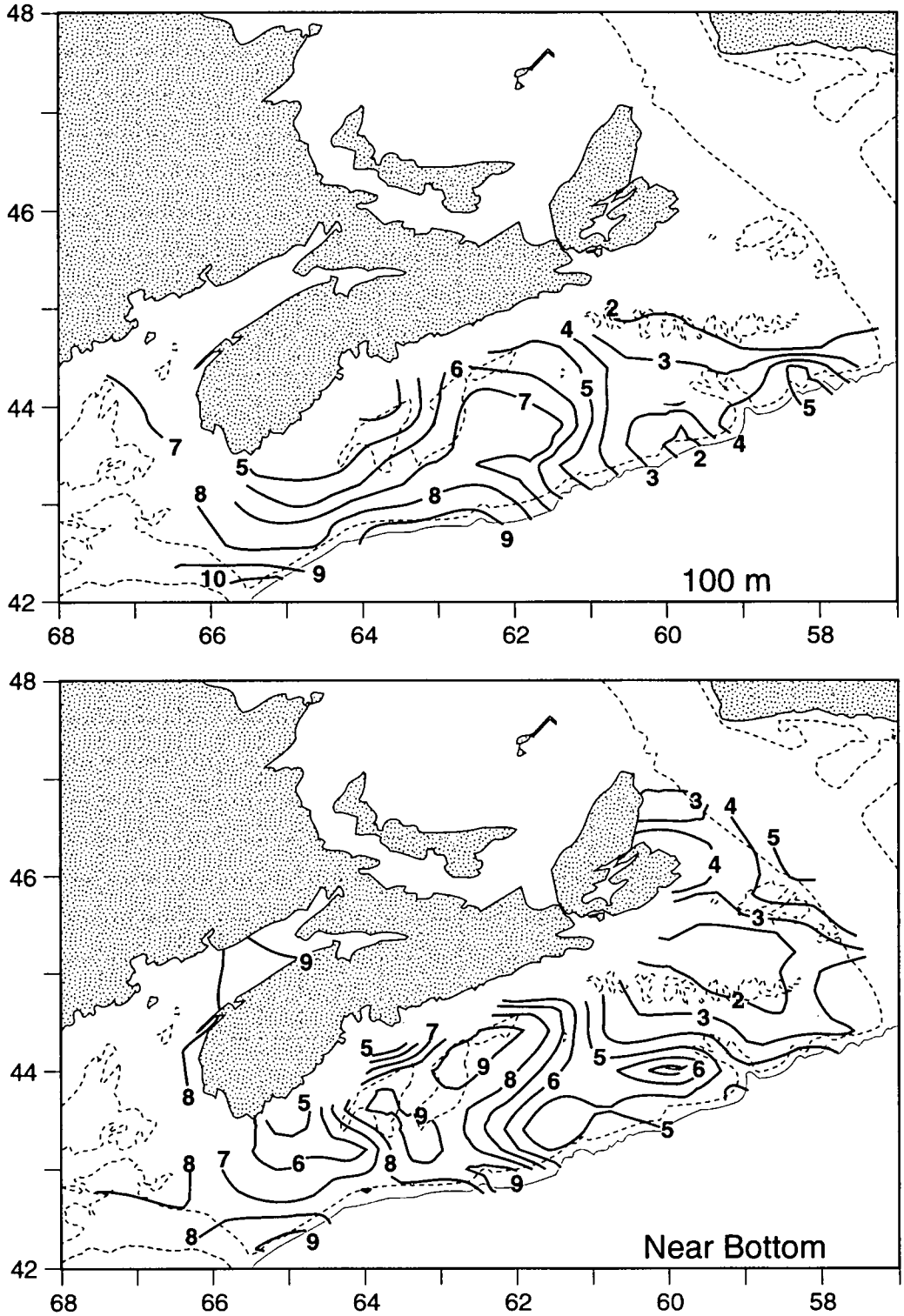


Fig. 12b. Contours of optimally estimated temperatures at 100 m (top panel) and near bottom (bottom panel) during the 1997 July groundfish survey.

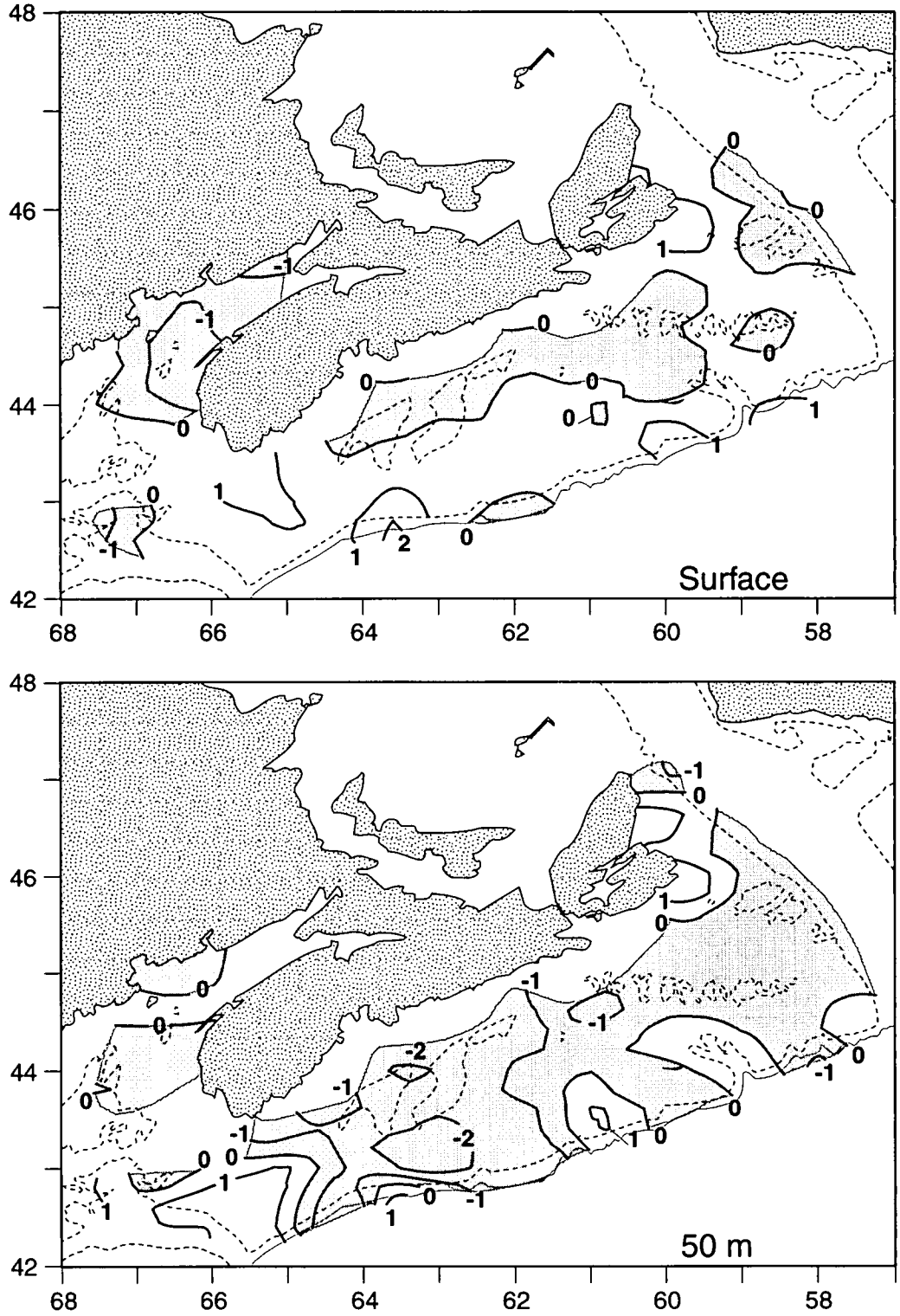


Fig. 13a. Contours of optimally estimated temperature anomalies at the surface (top panel) and 50 m (bottom panel) during the 1997 July groundfish survey.

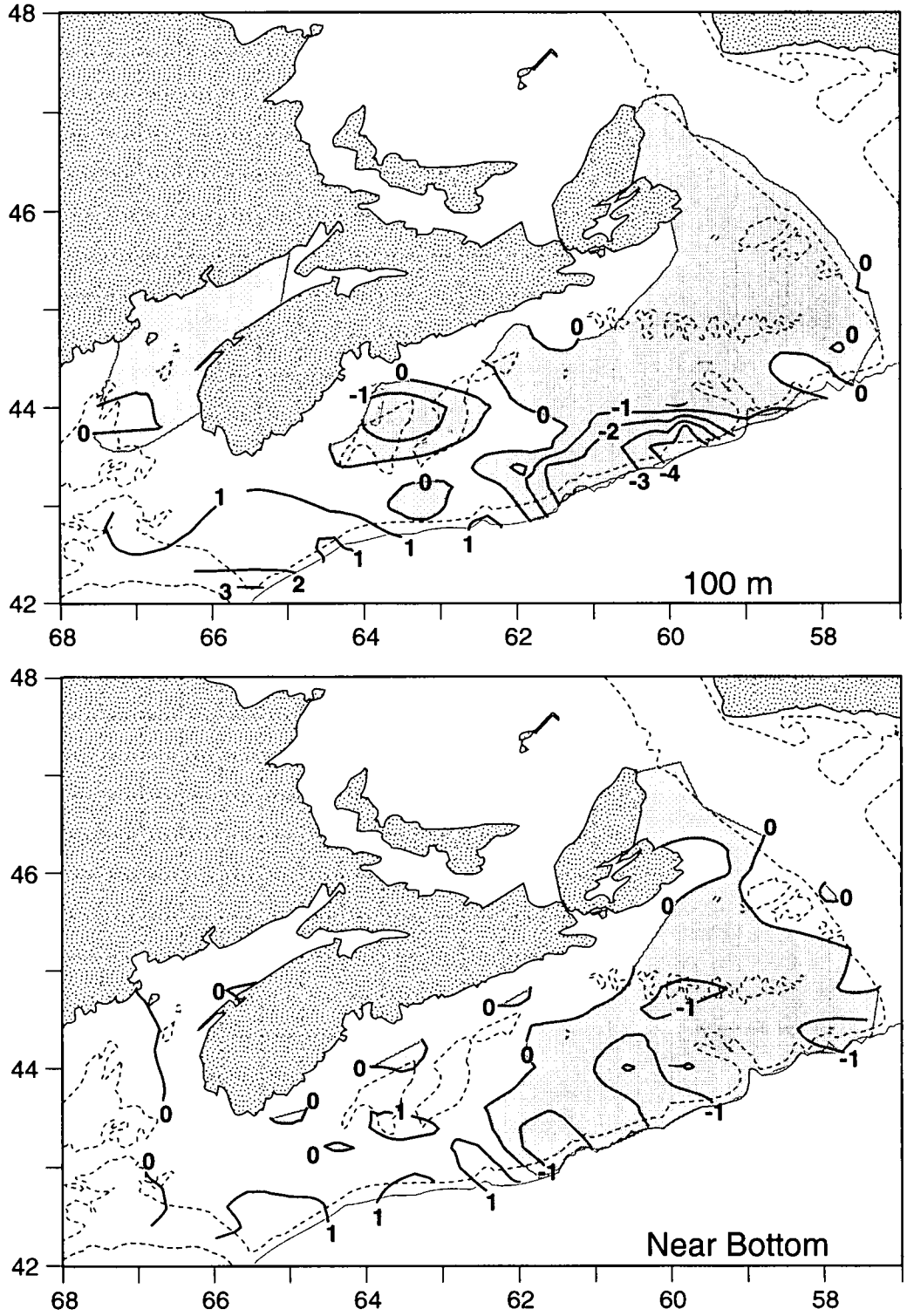


Fig. 13b. Contours of optimally estimated temperature anomalies at 100 m (top panel) and near bottom (bottom panel) during the 1997 July groundfish survey.

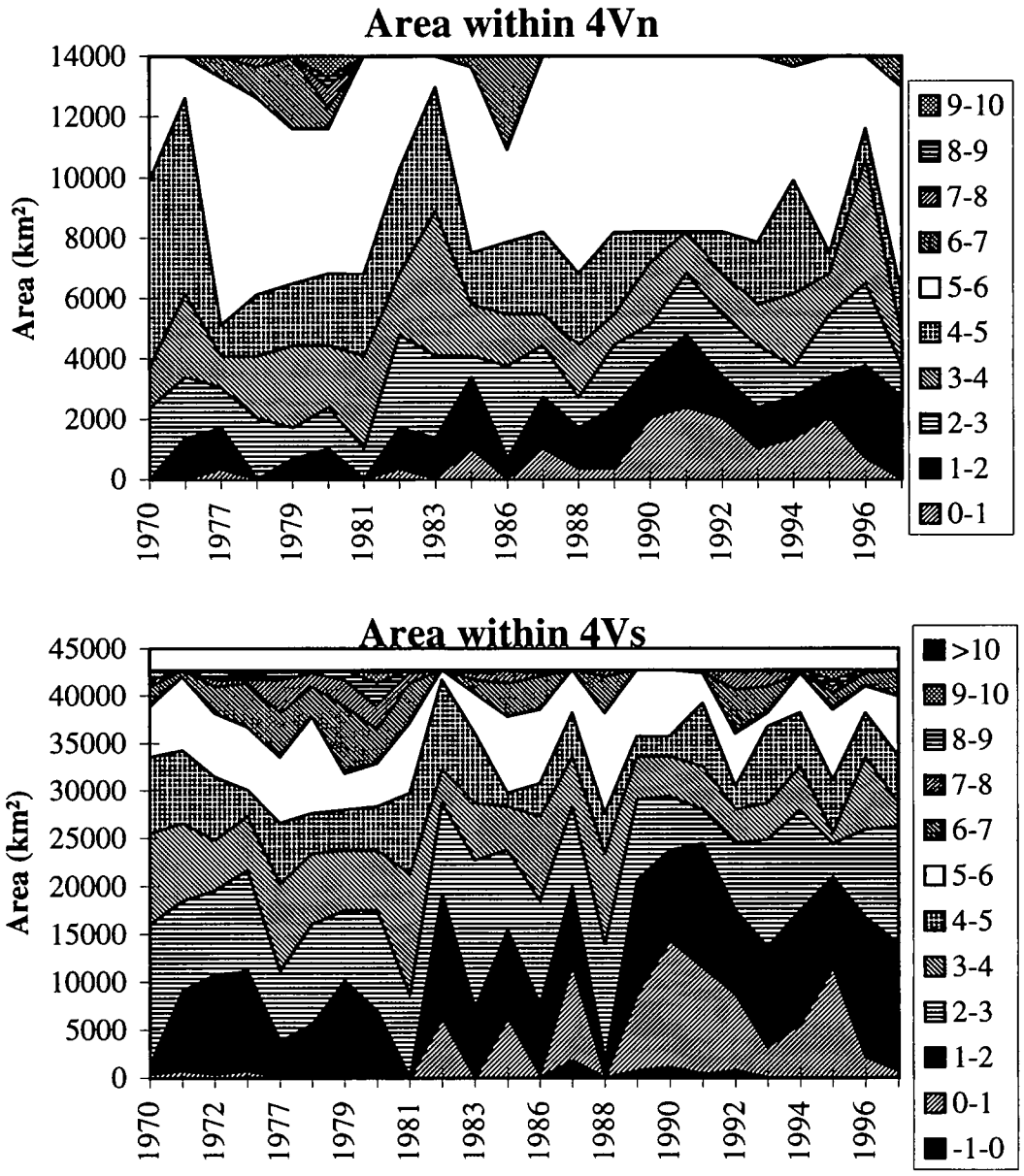


Fig. 14a. The time series of the area of the bottom for each one degree temperature range for NAFO subareas 4Vn (top panel) and 4Vs (bottom panel).

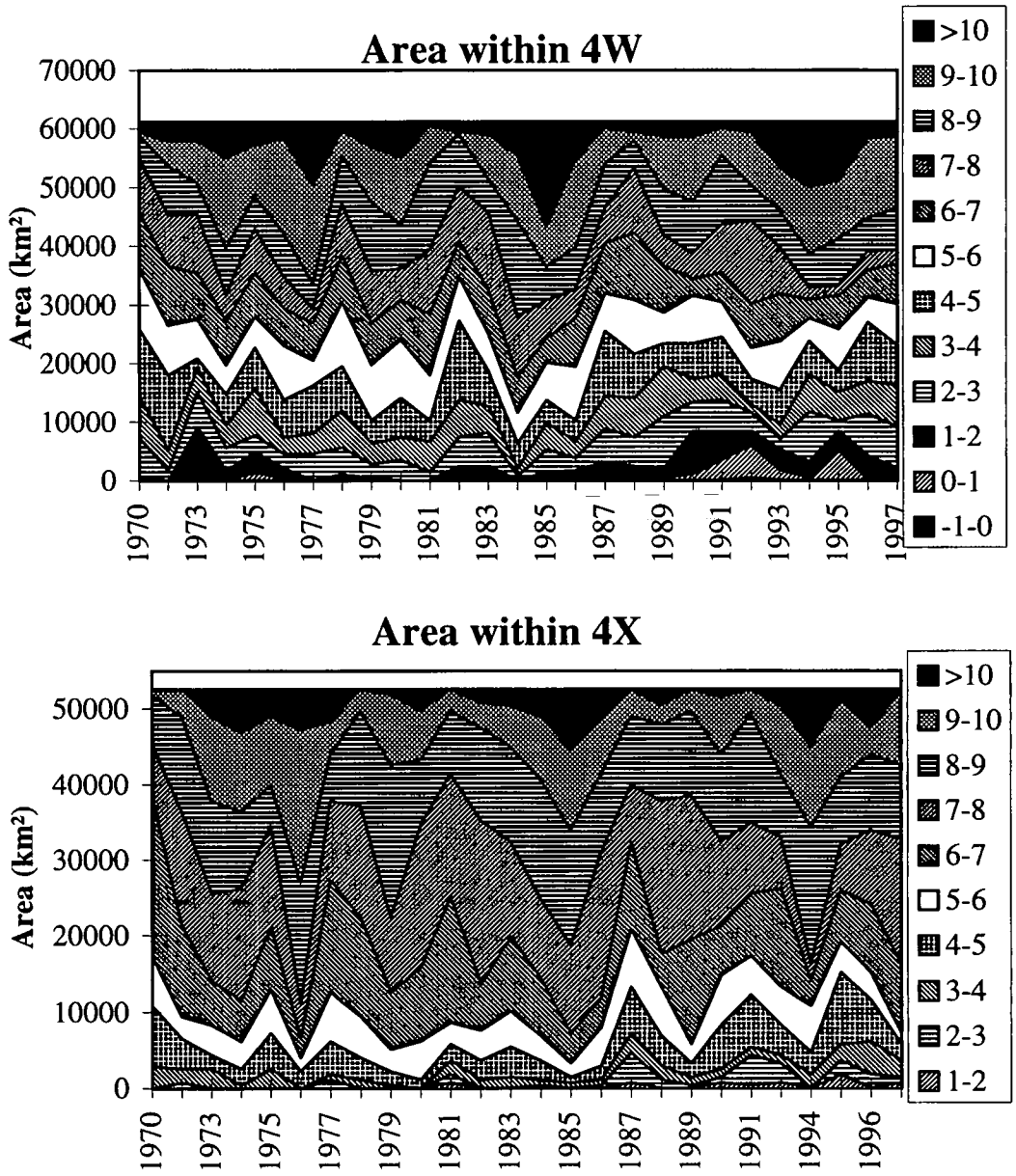


Fig. 14b. The time series of the area of the bottom for each one degree temperature range for NAFO subareas 4W (top panel) and 4X (bottom panel).

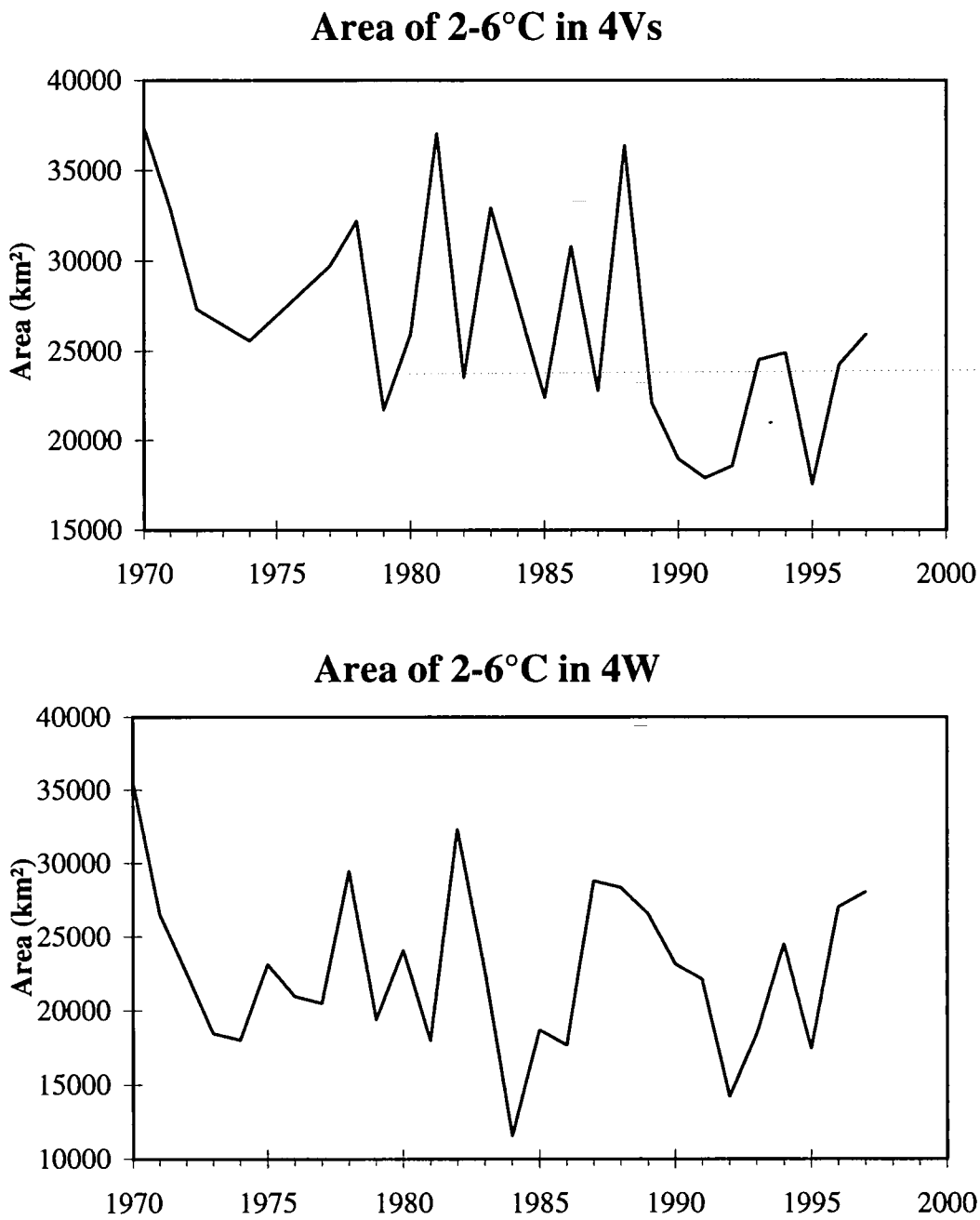


Fig. 15. The area of bottom covered by water of temperatures 2-6°C in NAFO subareas 4Vn (top panel) and 4Vs (bottom panel).

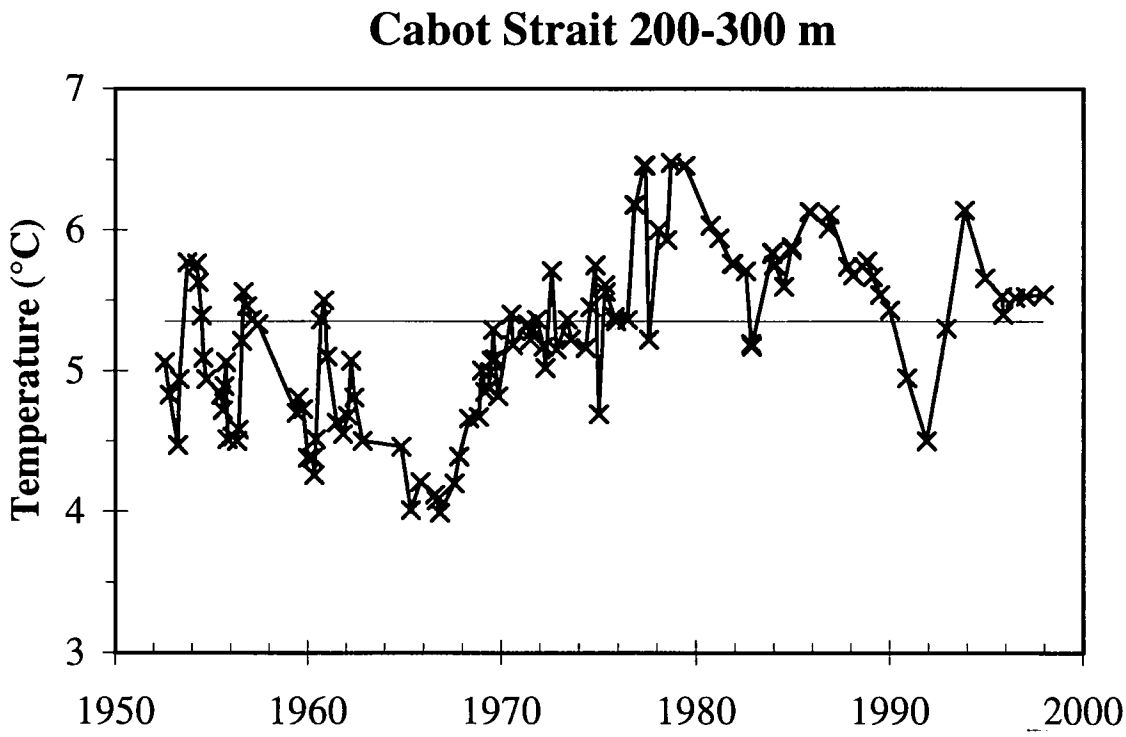


Fig. 16. Average temperature over the 200-300 m layer in Cabot Strait. The horizontal line indicates the long-term mean during 1961-90.