Department of Fisheries and Oceans
Canadian Stock Assessment Secretariat
Research Document 97/62

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Ministère des pêches et océans
Secrétariat canadien pour l'évaluation des stocks
Document de recherche 97/62

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Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 1996

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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 1996 is presented. For the second consecutive year, sea surface temperatures at Boothbay Harbor and St. Andrews were above normal throughout most of the year whereas at Halifax they were below normal. In the deep basins and channels on the Scotian Shelf and in the Gulf of Maine, the lower layer waters remained approximately 1-2°C warmer than normal continuing the temperature of recent years. This condition reflects the influence of warm slope water. Deep (200-300 m average) temperatures in Cabot Strait, however, remained near normal. 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 1°C. These cold conditions have persisted since at least the mid-1980s.

Résumé

On présente un examen des conditions océanographiques physiques en 1996 des plateaux continentals et des zones hauturières adjacentes du plateau néo-écossais et du golfe du Maine. Pour la deuxième année consécutive, la température en surface à Boothbay Harbor et à St. Andrews se situait au-dessus de la normale pendant presque toute l'année, tandis qu'à Halifax, elle se situait au-dessous de la normale. Dans les bassins et les chenaux profonds du plateau néo-écossais et du golfe du Maine, les eaux de la couche inférieure sont demeurées plus chaudes que la normale par environ 1 à 2 °C, la tendance des dernières années se poursuivant. Cette condition réfléchit l'influence des eaux chaudes du talus. La température des eaux profondes (200-300 m en moyenne) du détroit de Cabot sont toutefois demeurées près de la normale. La température de la couche 50-100 m de la plus grande partie du plateau néo-écossais et des eaux près du fond du nord-est du plateau est demeurée sous la normale par 1 °C. Ces conditions froides perdurent depuis au moins le milieu des années 80.

Introduction

This paper describes temperature and salinity characteristics during 1996 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 or transects, 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 1996 from the data archive at the Marine Environmental Data Service (MEDS) in Ottawa and most recently in early January 1997. 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). More detailed information on the oceanographic conditions in 1996 during the annual groundfish surveys are provided in Page et al. (1997a,b). Meteorological and sea ice information for the region during 1996 are described in Drinkwater et al. (1997).

Coastal Sea Surface Temperatures

Monthly averages of sea surface temperature (SST) are available from Halifax Harbour in Nova Scotia, St. Andrews in New Brunswick, and Boothbay Harbor in Maine. The monthly mean temperature anomalies relative to the 1961-90 long-term averages at each of the sites for 1995 and 1996 are shown in Fig. 2.

The dominant feature in 1996 at Boothbay Harbor and St. Andrews was the above normal temperatures throughout most of the year. This continued a trend of warm temperatures that began in June of 1994. The 1996 anomalies equalled or exceeded one standard deviation (based upon the years, 1961-90) in 7 months at Boothbay Harbor but only in 1 month at St. Andrews. The maximum monthly anomaly was near 1.5°C in March at Boothbay while at St. Andrews it was 0.75°C in October. The lower anomalies at St. Andrews are typical and are due to the increased vertical mixing by the tides in the Bay of Fundy. In contrast to these warm sea surface anomalies, those at Halifax were predominantly negative. Only in September were significant above-normal anomalies observed. The largest negative anomalies occurred during the spring, reaching -1.2°C in May. The cold temperatures in Halifax also continues a pattern established in 1994.

Time series of annual anomalies show that temperature trends have differed between sites during the last decade (Fig. 2). Surface temperatures at Boothbay Harbor and St. Andrews have generally been warm and on the increase since the late 1980s whereas in Halifax Harbour they have been cold and decreasing. Mean annual SSTs in 1996 were 9.2°C (0.7°C above normal) at Boothbay Harbor, 7.5°C (0.3°C above normal) at St. Andrews, and 7.5°C (0.3°C below normal) at Halifax. These represent a decrease over 1995 temperatures at Boothbay (by 0.6°C) and St.

Andrews (0.3°C) but an increase at Halifax (0.3°C), opposite to the recent temperature trends. At Boothbay the temperatures are close to the highest since the early 1950s whereas at Halifax they are nearly as cold as the mid-1960s.

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. 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 1996, no data were collected in April. Monthly mean temperatures ranged from a minimum of just over 2°C in the upper half of the water column in March to a maximum of over 12°C at the surface in September (Fig. 3). Monthly temperature anomalies tended to be slightly positive, exceptions being the surface waters from March to July and throughout the water column in January and August (Fig. 3). In August, bottom waters reached an anomaly of 1° to 1.5°C below normal. The annual mean temperatures in 1996 at the surface was normal and near bottom (90 m) was 0.2°C above normal (Fig. 4). These have decreased for the second consecutive year but are still well above 1992 and 1993 values. At both depths, the maximum annual temperature occurred in the early 1950s and the minimum in the mid-1960s.

Salinities at Prince 5 during 1996 were consistently fresher-than-normal (Fig. 3). The lowest salinities (<30 psu) occurred during May resulting in an anomaly of -0.7 psu in the surface waters. The largest negative anomaly (-1 psu), however, was observed in the near surface waters during December. The highest salinities (>32 psu) appeared near bottom in the autumn, but were also fresher-than-normal. Time series show that the annual salinity anomalies in 1996 fell by approximately 0.2 relative to 1995 values at the surface and 0.5 at 90 m (Fig. 5). The 1996 anomalies represent the lowest salinities recorded at Prince 5. This freshening parallels that occurring in the deep waters of Jordan and Georges Basin and may be related to offshore forcing from outside the Gulf of Maine (D. Mountain, Woods Hole, personal communication).

Gulf of Maine Temperature Transect

The Northeast Fisheries Science Center in Narragansett, Rhode Island, has collected expendable bathythermograph (XBT) data approximately monthly from ships-of-opportunity since the late 1970s. The XBTs are dropped along a transect in the Gulf of Maine from Massachusetts Bay to the western Scotian Shelf as part of their continuous plankton recorder program. We grouped the available data into 10 equally spaced boxes along the transect, then averaged any data within these by month at standard depths. At the time of writing, 1996 data were only available for the first 4 months of the year, with 5 to 9 sites occupied per month and an average of 7.

Data from February 1996 are shown together with the site locations (center of the boxes) in Fig. 6. No reliable data were available for site 7. The near surface waters varied between 2° and 5°C with warmer water (>6°C) below approximately 75-100 m. These deeper waters typically were warmer-than-normal by 1-2°C. Similar anomalies were observed in the deep waters during all four months. The deep water conditions contrast with those in the near surface waters (0-50 m) in the central and western regions where temperatures were colder-than-average, reaching -2°C at site 5 in the central Gulf. On the eastern side of the Gulf towards Nova Scotia, temperatures were above normal. Anomalies from the other three months (not shown) indicate high variability in the surface waters with the sign and amplitude of the anomalies changing from month to month.

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 1996, temperature measurements in Emerald Basin were obtained to depths of 250 m in four separate months with values ranging from 9.8° to 10.0°C. This produced monthly anomalies of 0.5-1.6°C above normal (Fig. 7). The long-term annual average is 8.5°C and the monthly means range from 7.9°C to 9.4°C. The high positive anomalies were generally representative of conditions below approximately 50 to 100 m. The recent warm period in the deep waters of Emerald Basin began with an intrusion of warm slope water late in 1991 or early 1992. These high temperatures are similar to those occurring in deep waters of the Gulf of Maine (Fig. 6).

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. 8). Their analysis has been updated by Petrie et al. (1996). We produced monthly mean conditions for 1996 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 are similar from area to area, however.

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 1996. 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 along the Atlantic coast of Nova Scotia to Lurcher Shoals. Warmer-than-normal conditions were observed in Emerald and Georges Basins below about 50 to 100 m (see Figs. 6 and 7).

On Sydney Bight (area 1 in Fig. 8) monthly mean profiles from 7 different months show highly variable temperature anomalies in the upper 100 m of the water column and especially in the near surface (< 50 m) waters (Fig. 9). Between 100 and 200 m there is a tendency towards negative temperature anomalies, however, in January the anomalies were positive. At depths > 250 m, which lay within the Laurentian Channel or along its slope, temperatures were above their long-term means but by less than 1°C. The time series of the 100 m temperature anomalies show that in recent years temperatures have been upwards of 1.5°C below the long term mean although the amount of data available in this time period is scanty. During 1995 and 1996 temperatures have been primarily below normal but are suggestive of warming with some monthly anomalies above the long-term mean. Monthly mean temperature profiles for Misaine Bank on the northeastern Scotian Shelf (area 5 in Fig. 8) are available for 6 months during 1996. They too show variable upper layer temperatures with the most prominent anomalies during June when near surface anomalies were approximately 4°C above normal (Fig. 10). During several of the other months temperatures in the top 50 m of the water column were at or below normal. The most consistent feature was the below normal temperatures in the waters >50 m. Temperature anomalies were typically between 0 and -2°C. The time series of the 100 m temperature anomalies show that these negative values have persisted since approximately the mid-1980s (Fig. 10). Recent years have been the coldest or near coldest since the 1950s and match the cold period of the 1960s. This pattern is indicative of the water column below 50 m. Absolute temperatures at 100 m are typically 1-2.5°C depending upon the time of the year. At Lurcher, data were available in 4 months during 1996. The temperature anomaly profiles were negative for 3 of the 4 months with only February (data collected only between 0 and 30 m) being warmer-than-normal (Fig. 11). The warm water in February is based upon data collected during the XBT transect (Fig. 7). The monthly 50 m temperatures at Lurcher show the cooler-than-normal waters and a decline in 1996 relative to 1995. These temperatures are generally representative of the average thermal conditions throughout the water column at Lurcher because of the strong tidal mixing.

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 1996, just under 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 300 m as we were only interested in the temperatures over the shelf. In addition, the 1961-90 means for July were estimated onto the same grid in order to calculate temperature anomalies.

Temperatures in 1996 at the surface varied from <8° to >16°C with the dominant pattern being relatively cool waters off southwest Nova Scotia in the Gulf of Maine due to strong tidal mixing, and warmer temperatures on the Scotian Shelf. The coldest waters are on Lurcher Shoals off Yarmouth and the warmest on Sydney Bight and the central Shelf area (Fig. 12a). At 50 m the coldest temperatures (<2°C) are in the northeast and off Yarmouth and along the continental shelf through the presence of slope waters (Fig. 12b). Note the cold waters covering most of the northeastern Scotian Shelf and off the "south shore" of the Atlantic coast of Nova Scotia. Warm waters penetrated into the central shelf regions into Emerald Basin. The 100 m temperatures show a pattern similar to that for 50 m but with slightly higher temperatures, especially over the Emerald Basin region (Fig. 12c). Bottom temperatures show several typical features (Fig. 12d). 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. Cool waters were also found off southern Nova Scotia. Temperatures in Emerald Basin exceeded 9°C and those in the central Gulf of Maine >8°C. Relatively high temperatures also were found along the continental slope on the western half of the Shelf and in the upper reaches of the Bay of Fundy.

Temperature anomalies show similar patterns amongst the 4 depth levels (Fig. 13). The dominant feature is the below-normal temperatures over most of the shelf although its areal extent decreased with depth. In particular, Emerald Basin in the central Scotian Shelf and eastern Jordan Basin in the Gulf of Maine tend to be warmer-than-normal. Maximum negative anomalies in the surface waters were -3° to -4°C. Elsewhere through the water column, anomalies were typically -0.5 to over -1°C. The southwestern end of the Shelf was also cold with surface anomalies of -2°C and deeper anomalies similar to that in the northeast. In contrast, anomalies in the central Scotian Shelf region were above normal except at the surface. The largest positive anomalies were near bottom and had magnitudes of 1-2°C. The warm water in Emerald Basin during the July survey is consistent with the 250 m temperature time series (Fig. 7) and the cold temperatures in the northeast and southwest during the survey with the temperature time series observed on Misaine Bank (Fig. 10) and off Lurcher (Fig. 11), respectively.

Differences between the temperatures in 1995 and 1996 at the 4 depth levels are displayed in Fig. 14. Subsurface waters warmed slightly in the northeastern Scotian Shelf but cooled along most of the outer banks of the Shelf. Over Emerald Basin temperatures at 50 m warmed substantially (Fig. 14b), perhaps due to mixing with the warm deep waters. However, these warm deep waters cooled between July 1995 and 1996 as evident from the near-bottom temperature differences (Fig. 14d).

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. 15). 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 towards near normal by November. In 1996, temperatures fluctuated about normal which contrasts with the deep waters in Emerald Basin where temperatures remained higher-than-average.

Summary

In 1996, cold conditions existed in the bottom waters and throughout much of the water column on the northeastern Scotian Shelf and off southwestern Nova Scotia and in the inshore surface waters along the Atlantic coast of Nova Scotia. This continued a pattern established in the middle of the 1980s. They are believed to be due to advection of cold water 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. These conditions have persisted since 1992 and reflect the presence of warm slope water offshore. In the Gulf of Maine, salinities were predominantly fresher-than-normal. At Prince 5 the annual salinity anomaly was the lowest on record.

Outlook for 1997

We expect that the cold waters on the northeastern Scotian Shelf will remain colder-than-normal in 1997 but may begin to warm. This predicted warming is based upon the milder winter in the Gulf of St. Lawrence in 1996/97 than in recent years and the assumed importance of winter mixing in the Gulf and subsequent advection onto the Scotian Shelf. Also there has been general warming in the Newfoundland waters during 1995 and 1996. Temperatures in the deep waters of the Gulf of Maine and in Emerald Basin are expected to remain relatively warm during 1997.

Acknowledgements

We wish to thank the many individuals who provided data or helped in the preparation of this paper, including: Graham Glen at the Marine Environmental Data Service in Ottawa; the Bigelow Laboratory for providing Boothbay Harbor temperature data; F. Page and R. Losier of the Biological Station in St. Andrews, for providing St. Andrews, Prince 5 and the Scotian Shelf July groundfish survey data; G. Bugden of the Bedford Institute for his Cabot Strait temperature data; P. Galbraith of the Institute Maurice Lamontagne for his Cabot Strait data; and B. Petrie for providing the Halifax sea-surface temperature data. Thanks also to J. Elliott and E. Colbourne for their comments on an earlier draft of this paper.

References

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

Colbourne, E. 1995. Oceanographic conditions and climate change in the Newfoundland region during 1994. DFO Atlan. Fish. Res. Doc. 95/3, 36 p.

Drinkwater, K.F. and R.G. Pettipas. 1994. On the physical oceanographic conditions in the Scotia-Fundy region in 1993. DFO Atlantic Fish. Res. Doc. 94/37, 31 p.

Drinkwater, K.F. and R.W. Trites. 1987. Monthly means of temperature and salinity in the Scotian Shelf region. Can. Tech. Rep. Fish. Aquat. Sci. 1539: 101 p.

Drinkwater, K.F., R.G. Pettipas and W.M. Petrie. 1996. Overview of physical oceanographic conditions in the Scotia-Fundy region in 1995. DFO Atlantic Fish. Res. Doc. 96/18, 24 p.

Drinkwater, K.F., R.G. Pettipas and W.M. Petrie. 1997. Overview of meteorological and sea ice conditions off eastern Canada in 1996. DFO Atlantic Fish. Res. Doc. 97/51, 29 p.

Gilbert, D. and B. Pettigrew. 1997. A study of the interannual variability of the CIL core temperature in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. Vol. 54 (Suppl. 1): 57-67.

Page, F.H., R. Losier, and J. McRuer. 1997a. Overview of 1996 hydrographic sampling effort and near-bottom water temperature and salinity conditions during the Canadian spring research vessel groundfish surveys conducted within NAFO areas 4VsW and 5Z. DFO Can. Stock Assessment Res. Doc 97/12, 29 p.

Page, F.H., R. Losier, and J. McRuer. 1997b. Overview of 1996 hydrographic sampling effort and near-bottom water temperature and salinity conditions during the Canadian summer research vessel groundfish surveys conducted within NAFO areas 4VWX. DFO Can. Stock Assessment Res. Doc 97/13, 34 p.

Petrie, B. and K. Drinkwater. 1993. Temperature and salinity variability on the Scotian Shelf and in the Gulf of Maine, 1945-1990. J. Geophys. Res. 98: 20079-20089.

Petrie, B., K. Drinkwater, A. Sandström, R. Pettipas, D. Gregory, D. Gilbert and P. Sekhon. 1996. Temperature, salinity and sigma-t atlas for the Gulf of St. Lawrence. Can. Tech. Rep. Hydrogr. Ocean Sci. 178: 256 p.

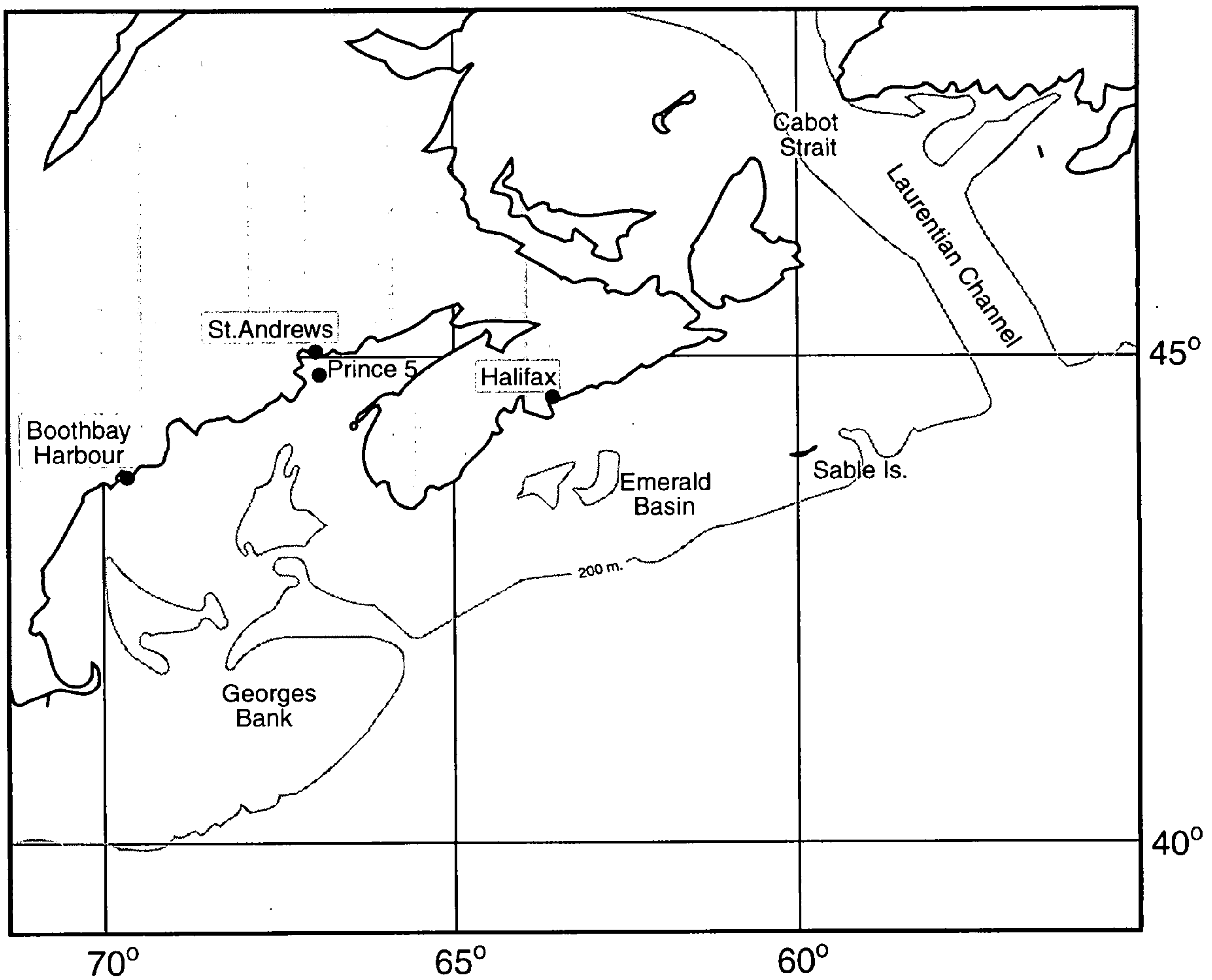


Fig. 1. The Scotian Shelf and the Gulf of Maine showing sea surface temperature stations, Prince 5 and topographic features.

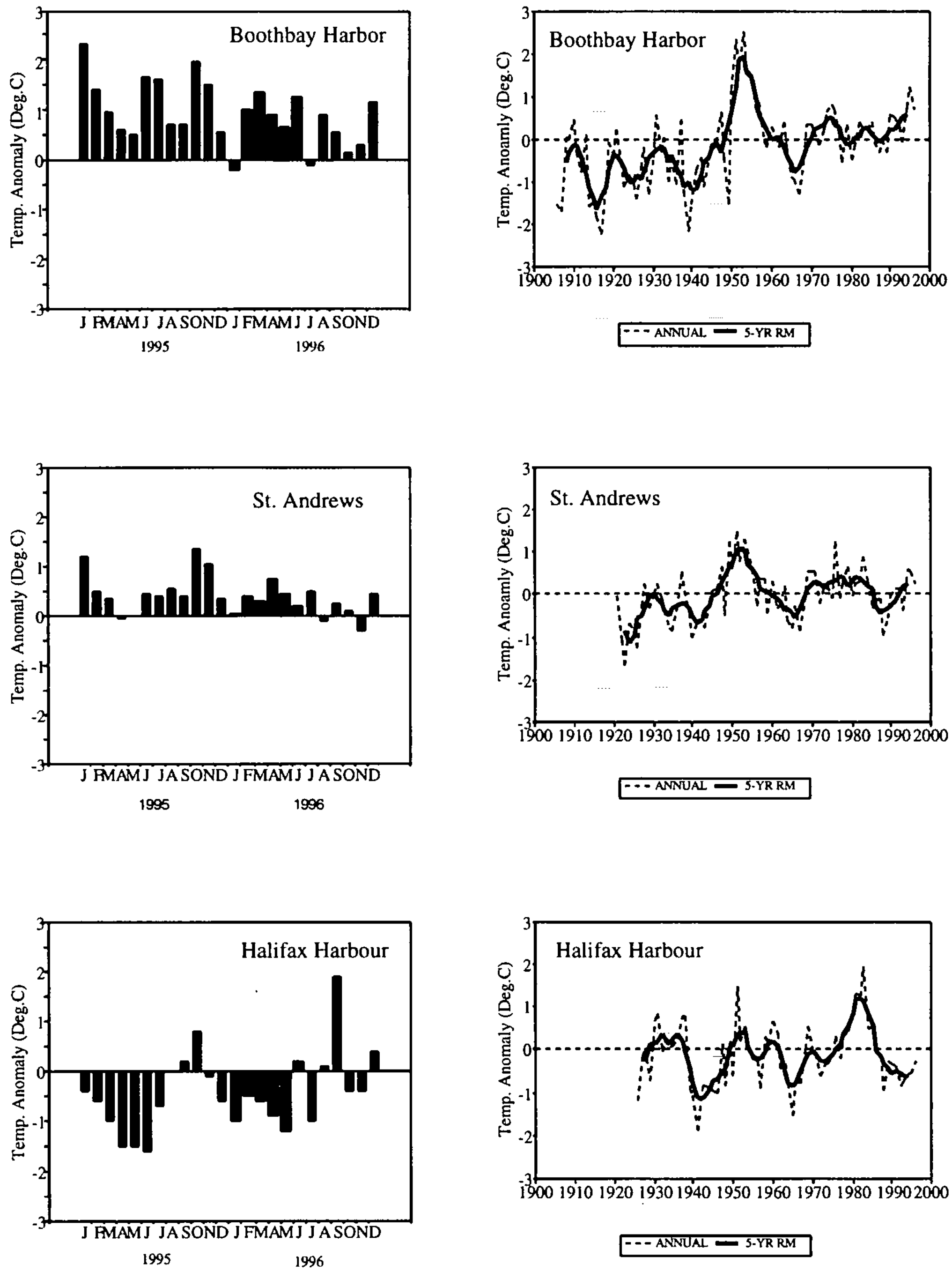


Fig. 2. The monthly sea surface temperature anomalies during 1995 and 1996 (left) and the annual temperature anomalies and their 5-year running means (right) for Boothbay Harbor, St. Andrews and Halifax. Anomalies are relative to 1961-90 means.

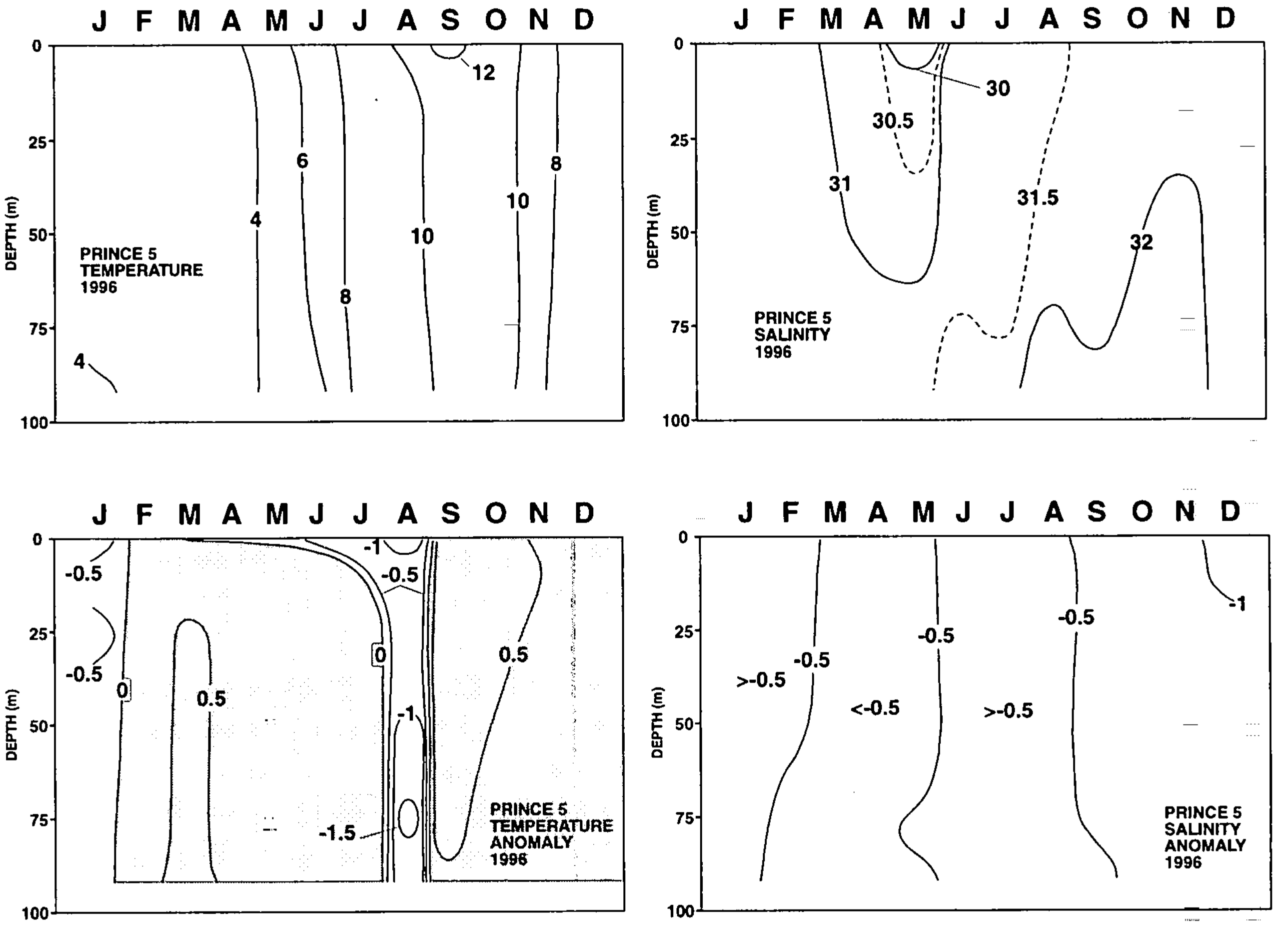
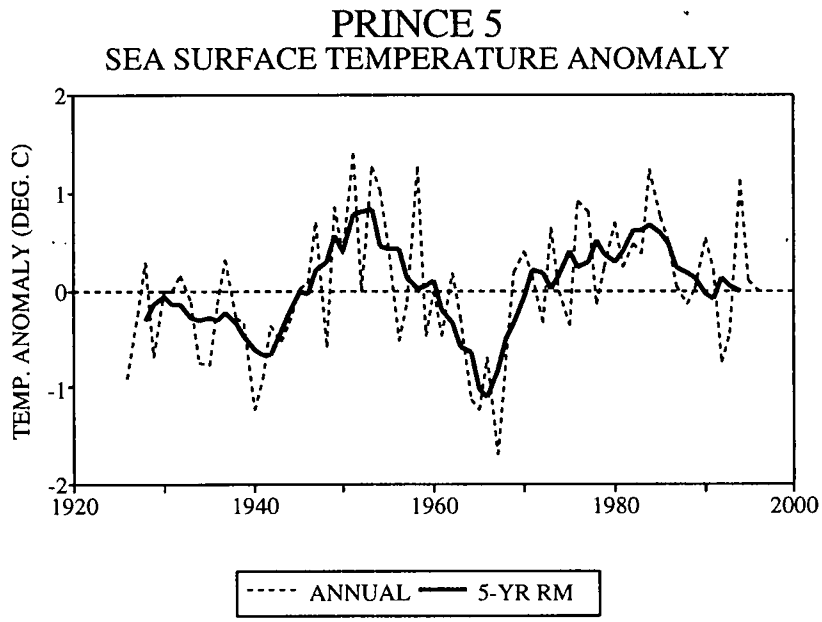


Fig. 3. Monthly temperatures and salinities and their anomalies at Prince 5 as a function of depth during 1996 relative to the 1961-90 means. Shaded areas are positive anomalies.



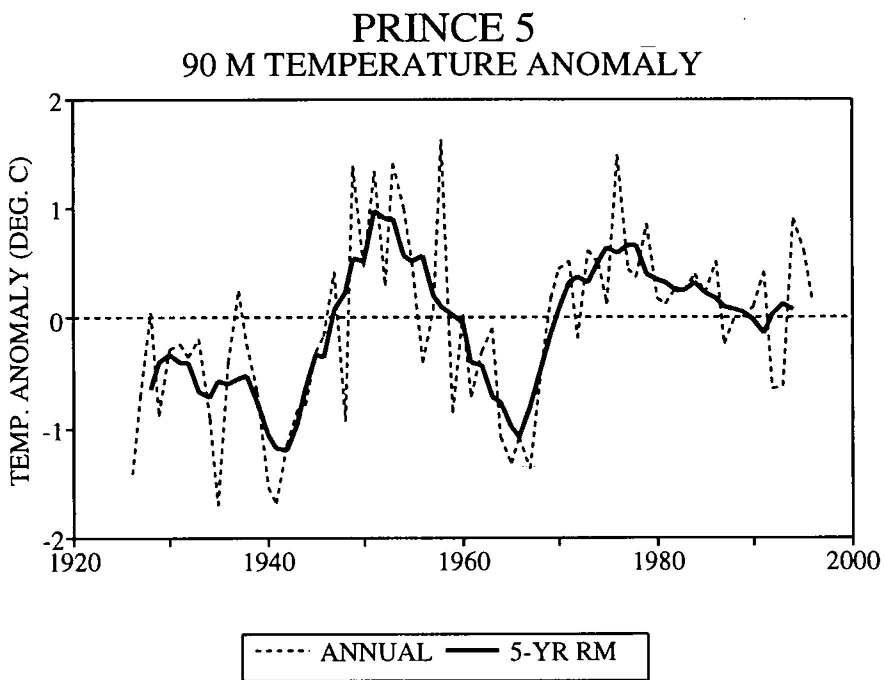
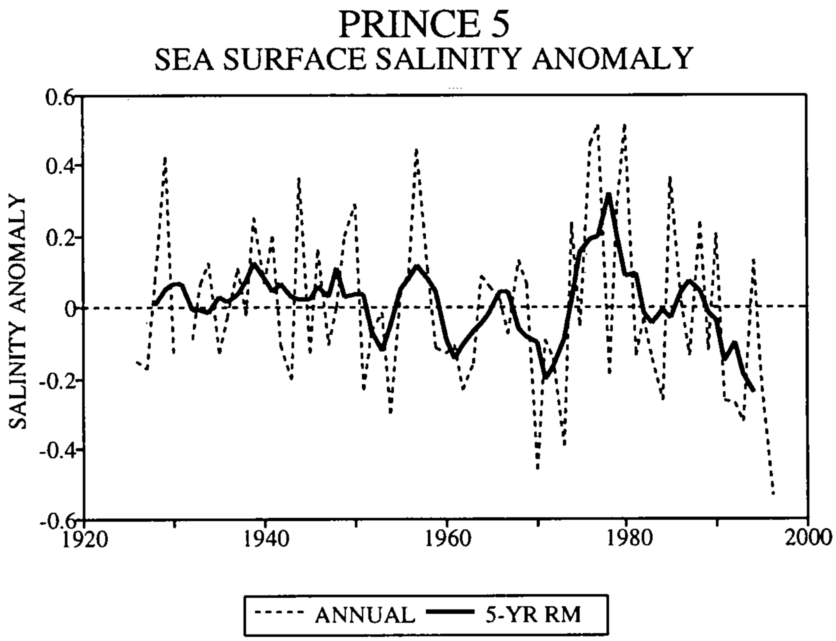


Fig. 4. The annual means and the 5-year running means of the temperature anomalies for Prince 5, 0 (top) and 90 m (bottom).



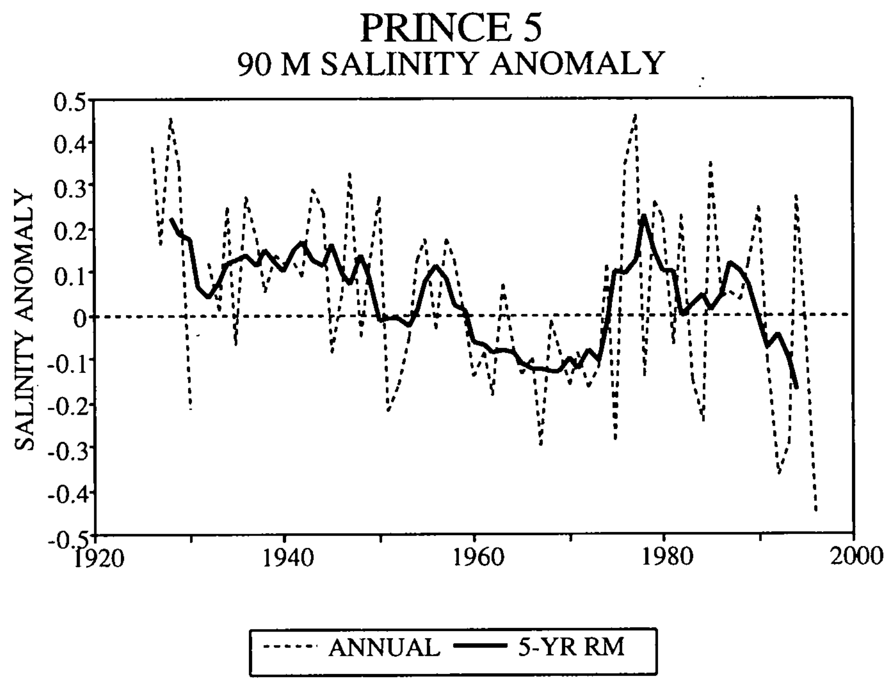


Fig. 5. The annual means and 5-year running means of the salinity anomalies for Prince 5, 0 (top) and 90 m (bottom).

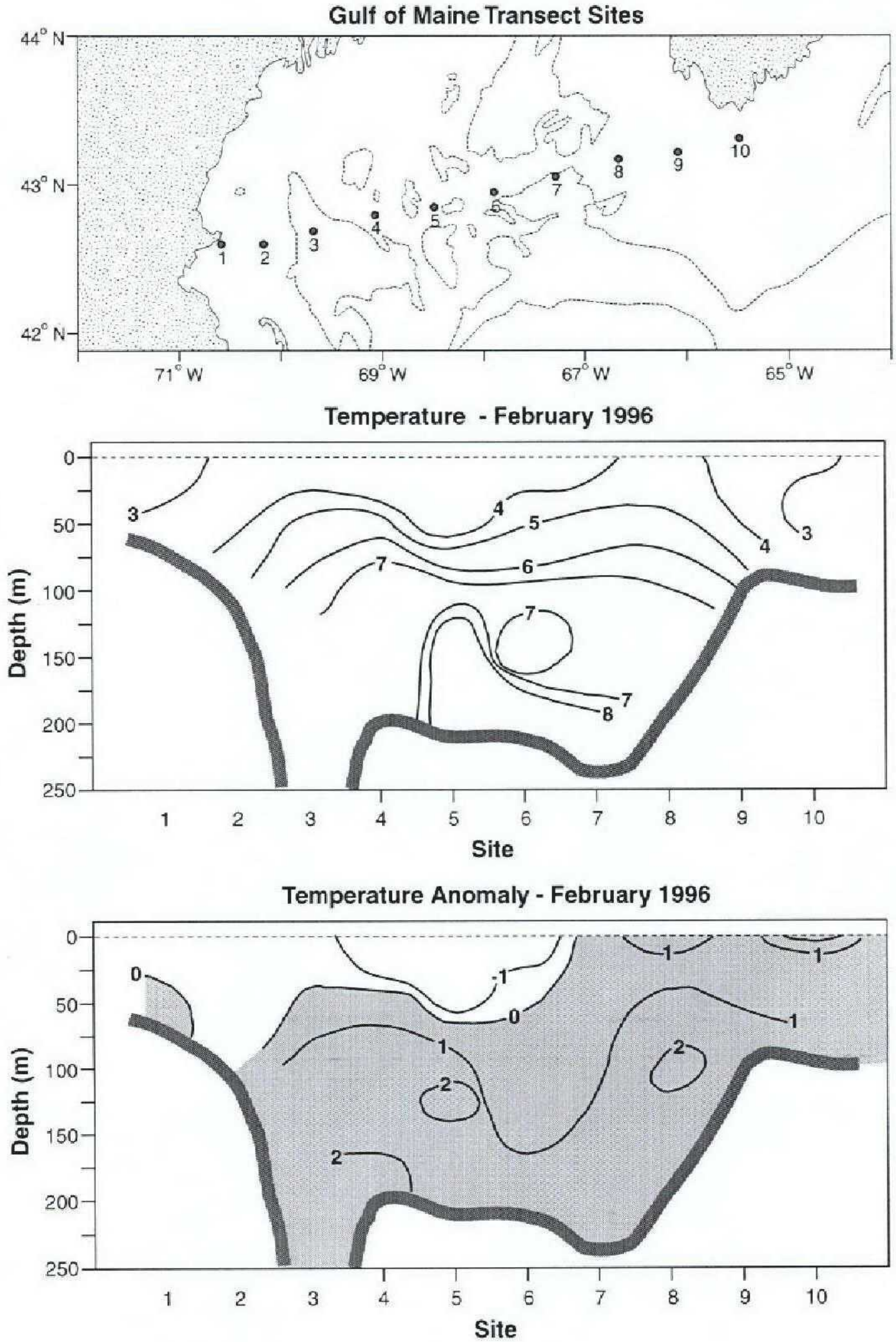


Fig. 6. The temperature (middle) and temperature anomalies (bottom) in degrees Celsius along an XBT transect (top) across the Gulf of Maine during February 1996.

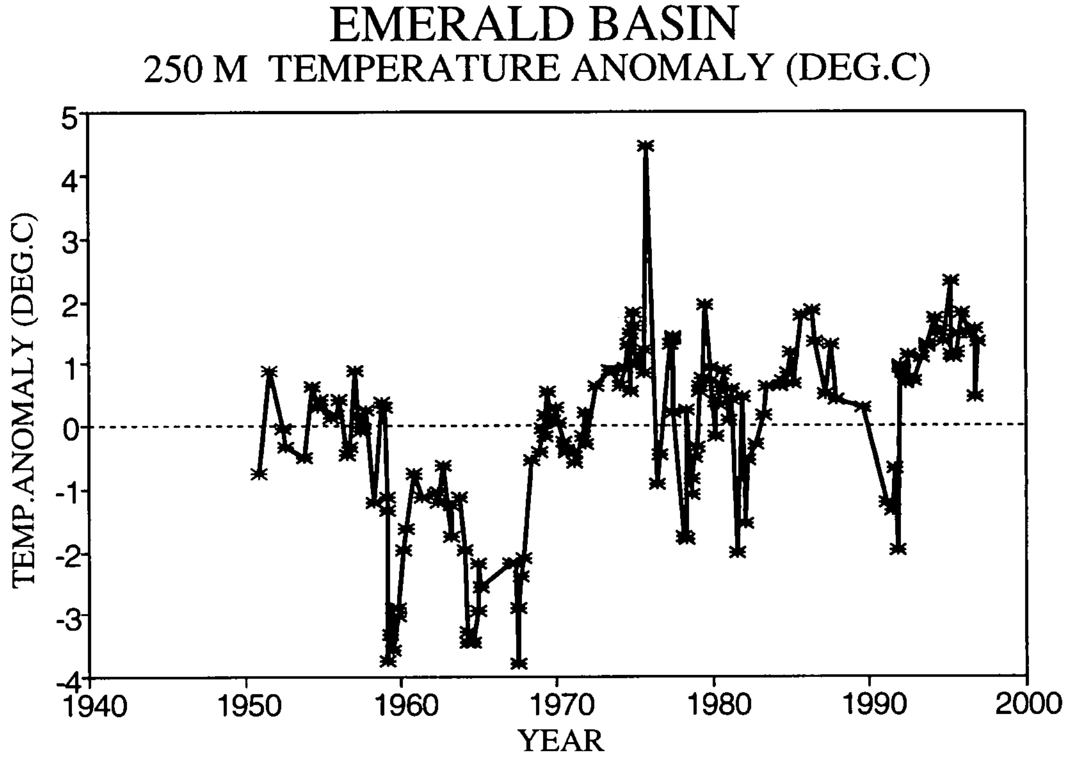
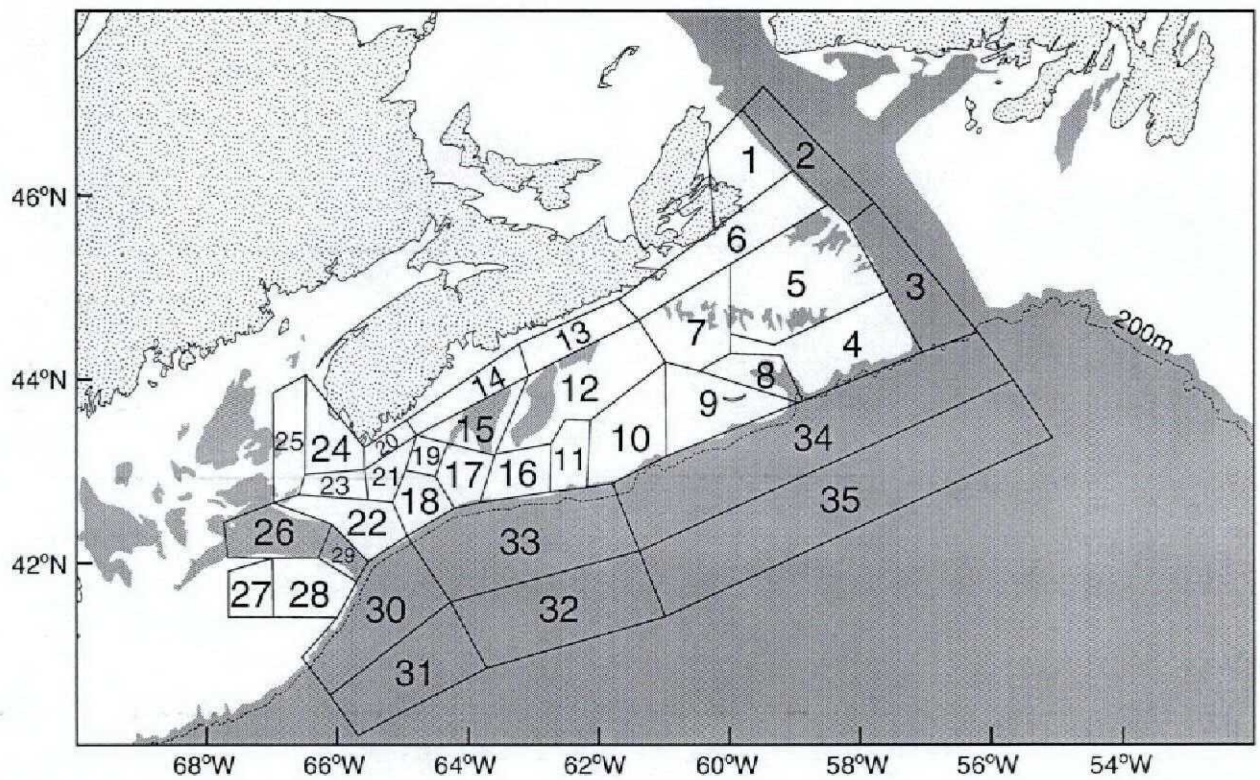


Fig. 7. Temperature anomalies (relative to 1961-90) at 250 m in Emerald Basin.



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

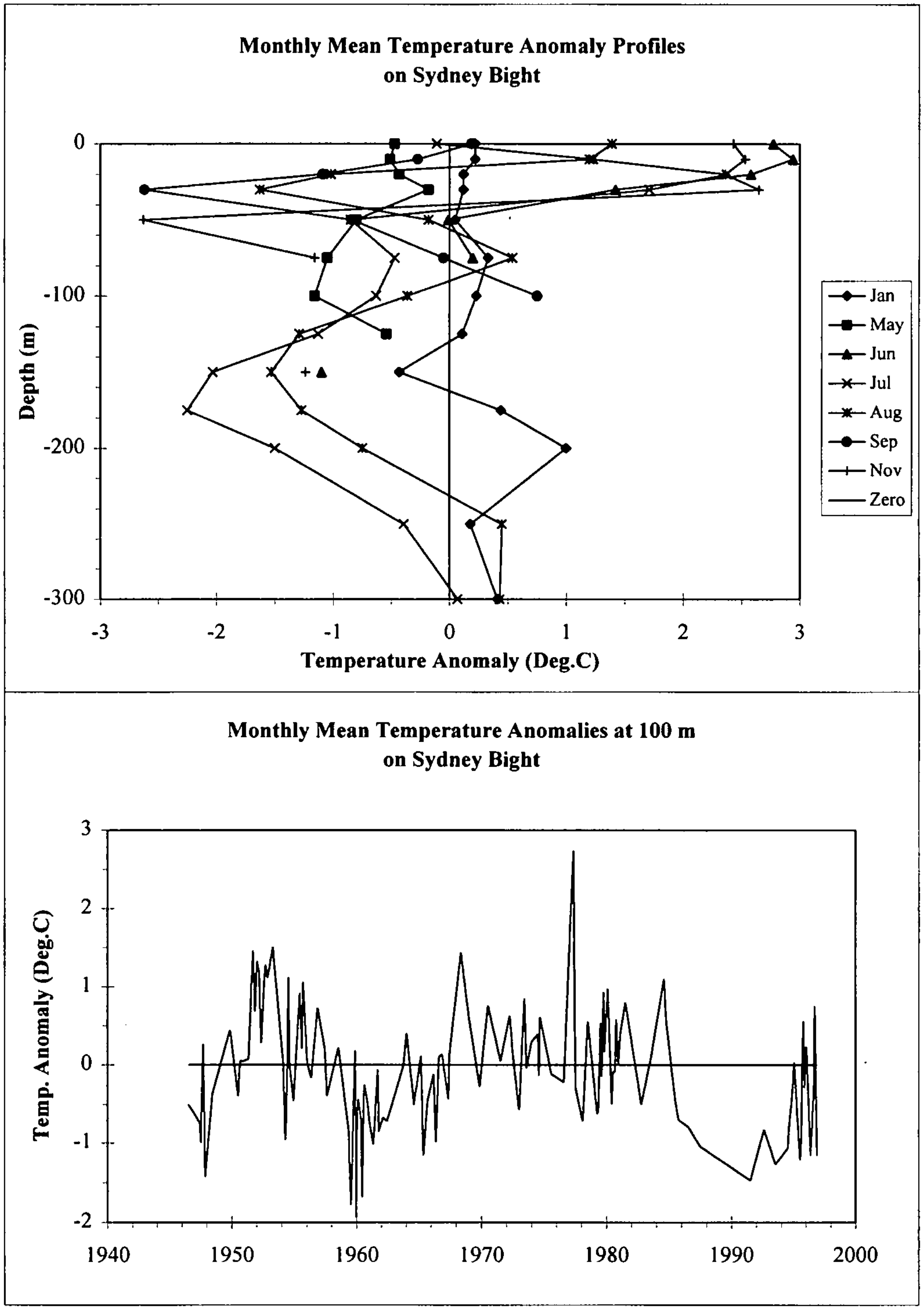


Fig. 9. The 1996 monthly temperature anomaly profiles (top) and temperature anomaly time series at 100 (bottom) for Sydney Bight (area 1 in Fig. 8).

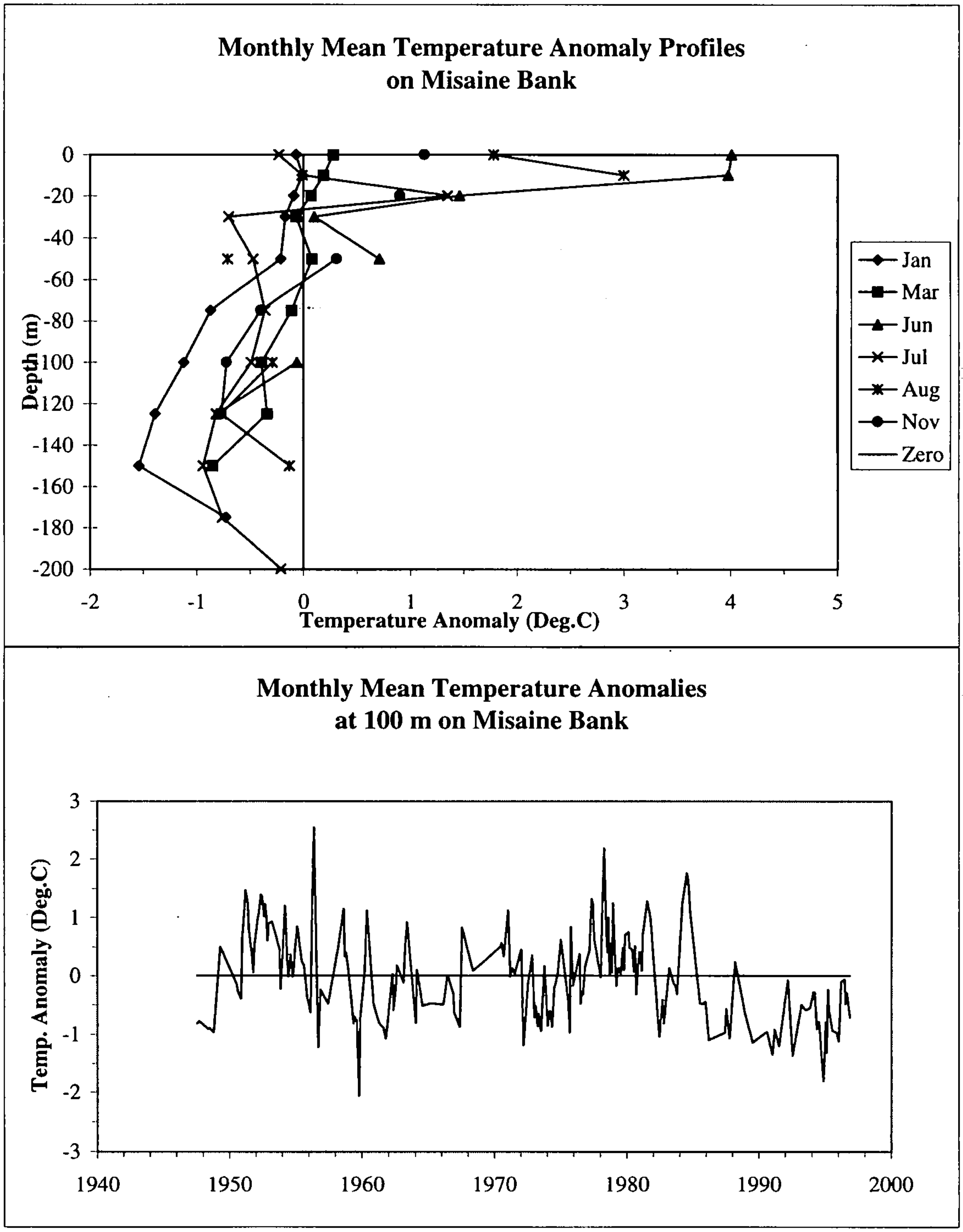


Fig. 10. The 1995 monthly temperature anomaly profiles (top) and temperature anomaly time series at 100 m (bottom) for Misaine Bank (area 5 in Fig. 8).

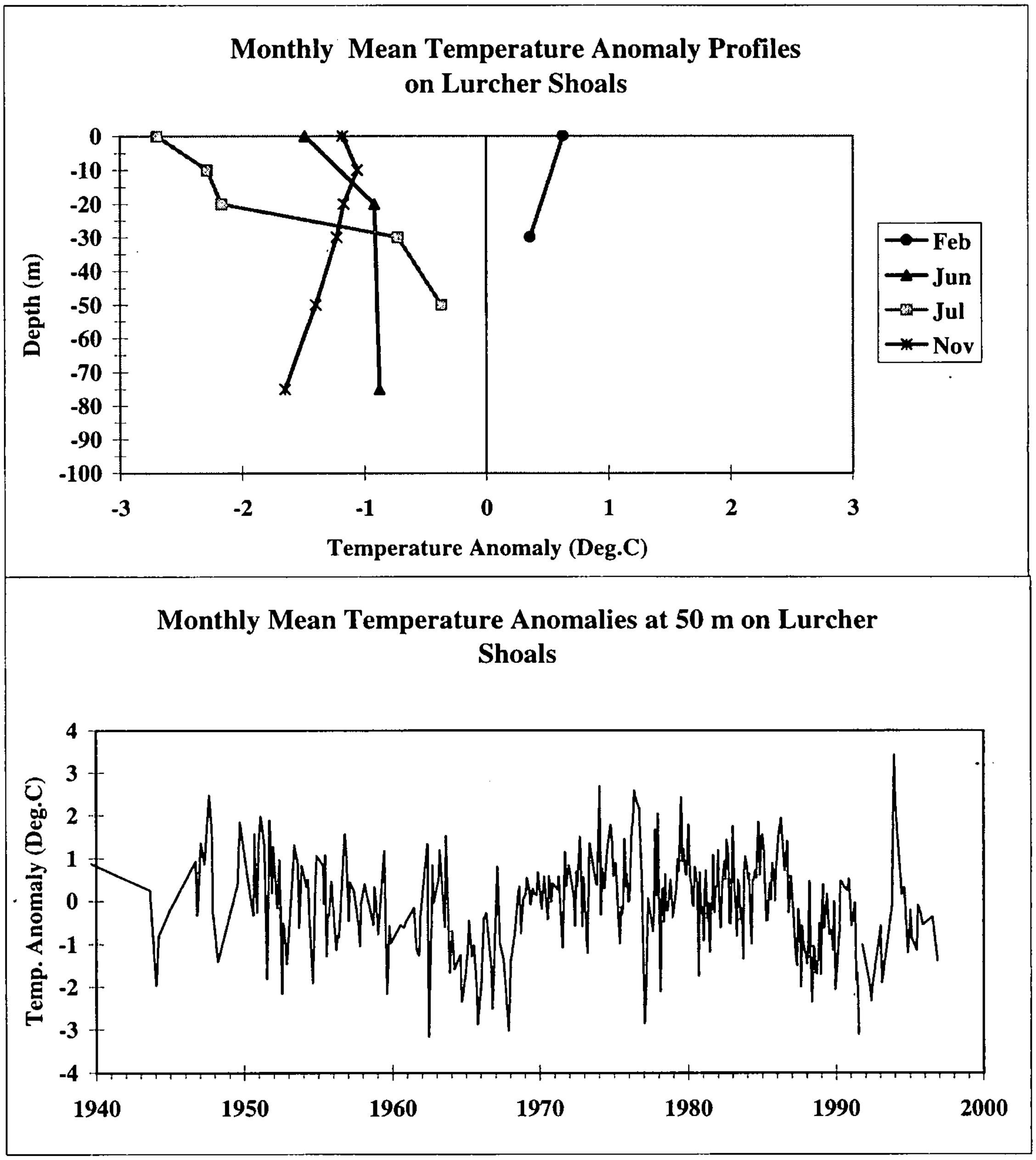


Fig. 11. The 1995 monthly temperature anomaly profiles (top) and temperature anomaly time series at 50 m (bottom) for Lurcher Shoals (area 24 in Fig. 8).

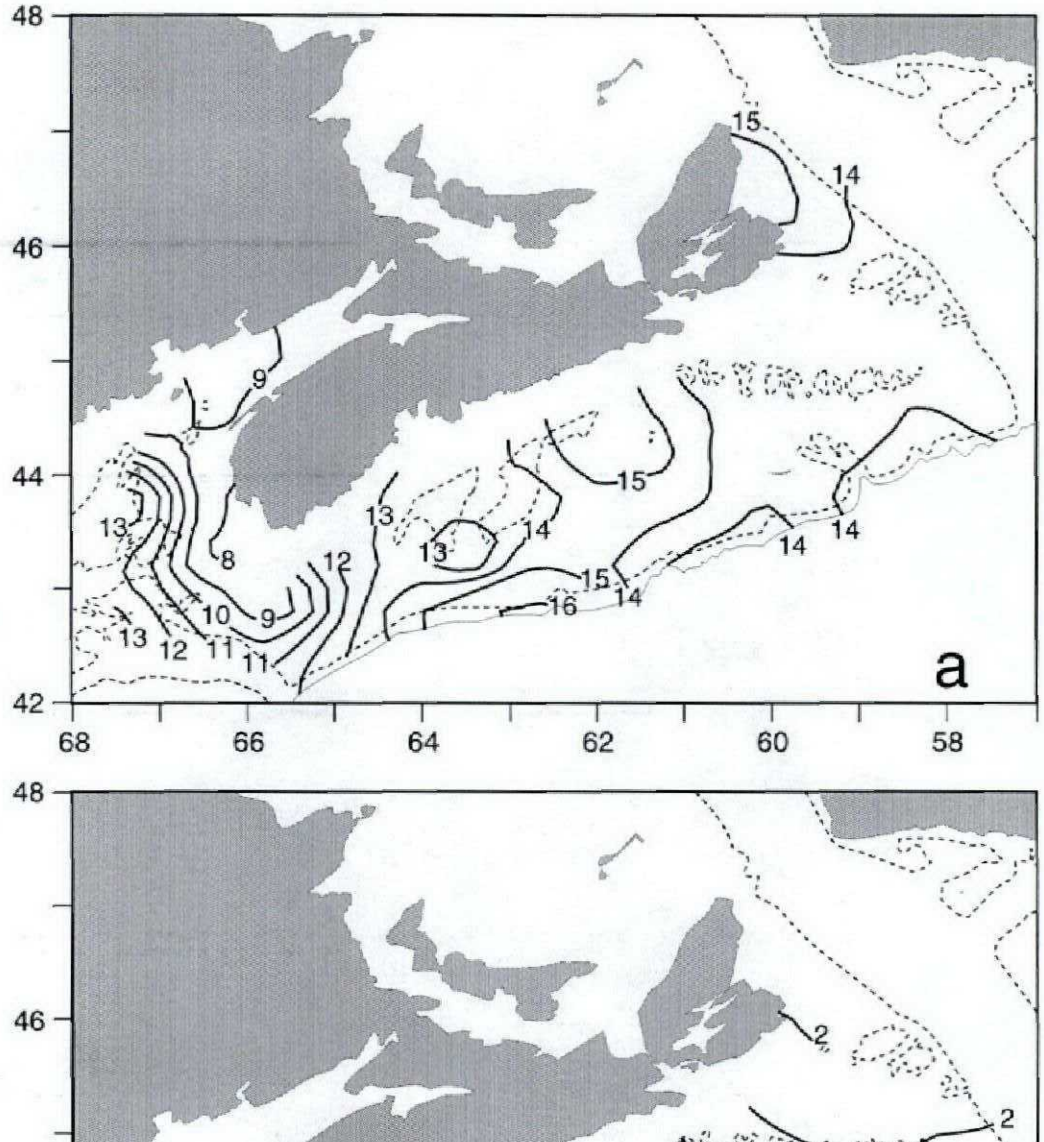


Fig. 12. Contours of optimally estimated temperatures at the surface (a) and 50m (b) during the 1996 July groundfish survey.

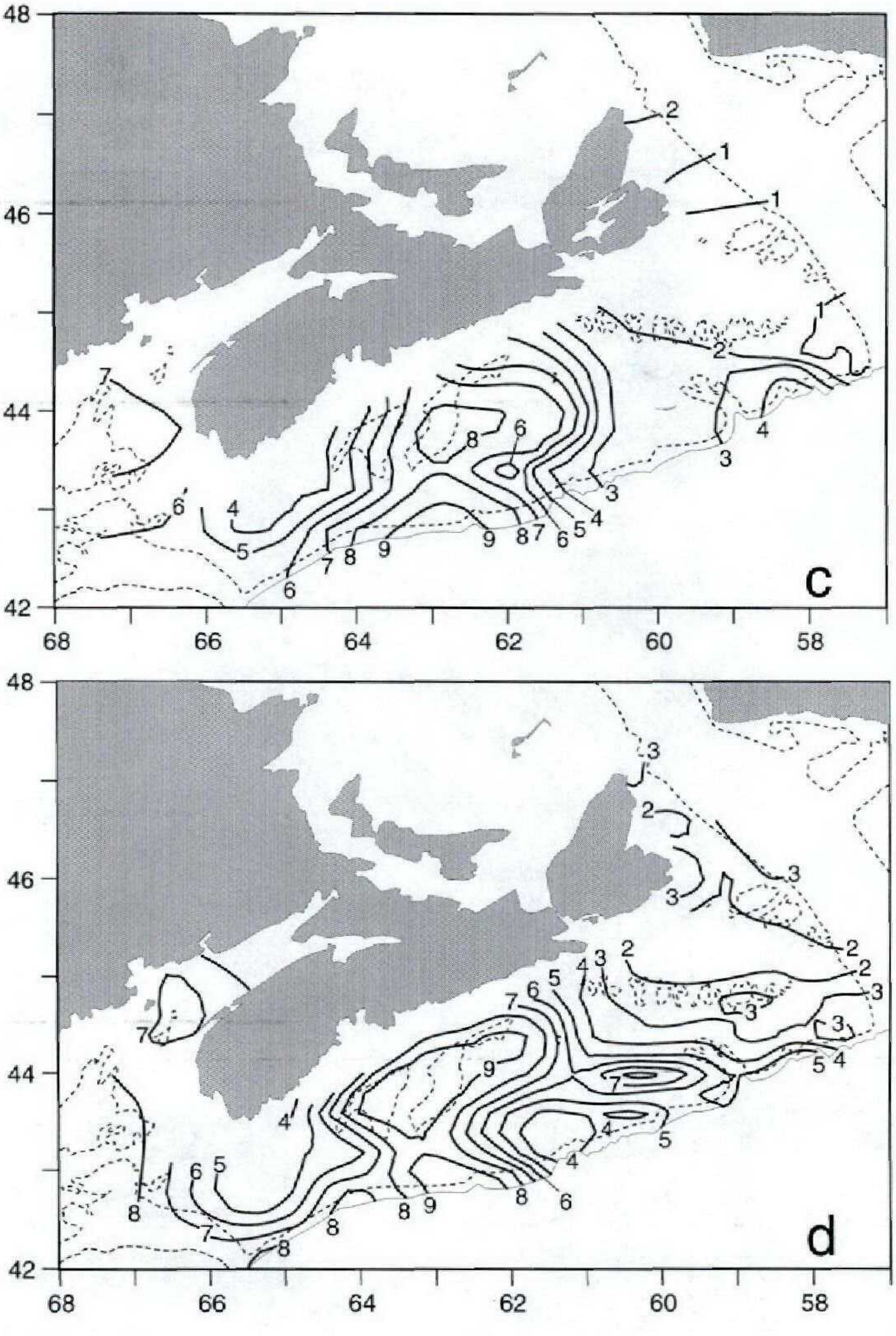


Fig. 12cont'd. Contours of optimally estimated temperatures at 100m (c) and near bottom (d) during the 1996 July groundfish survey.

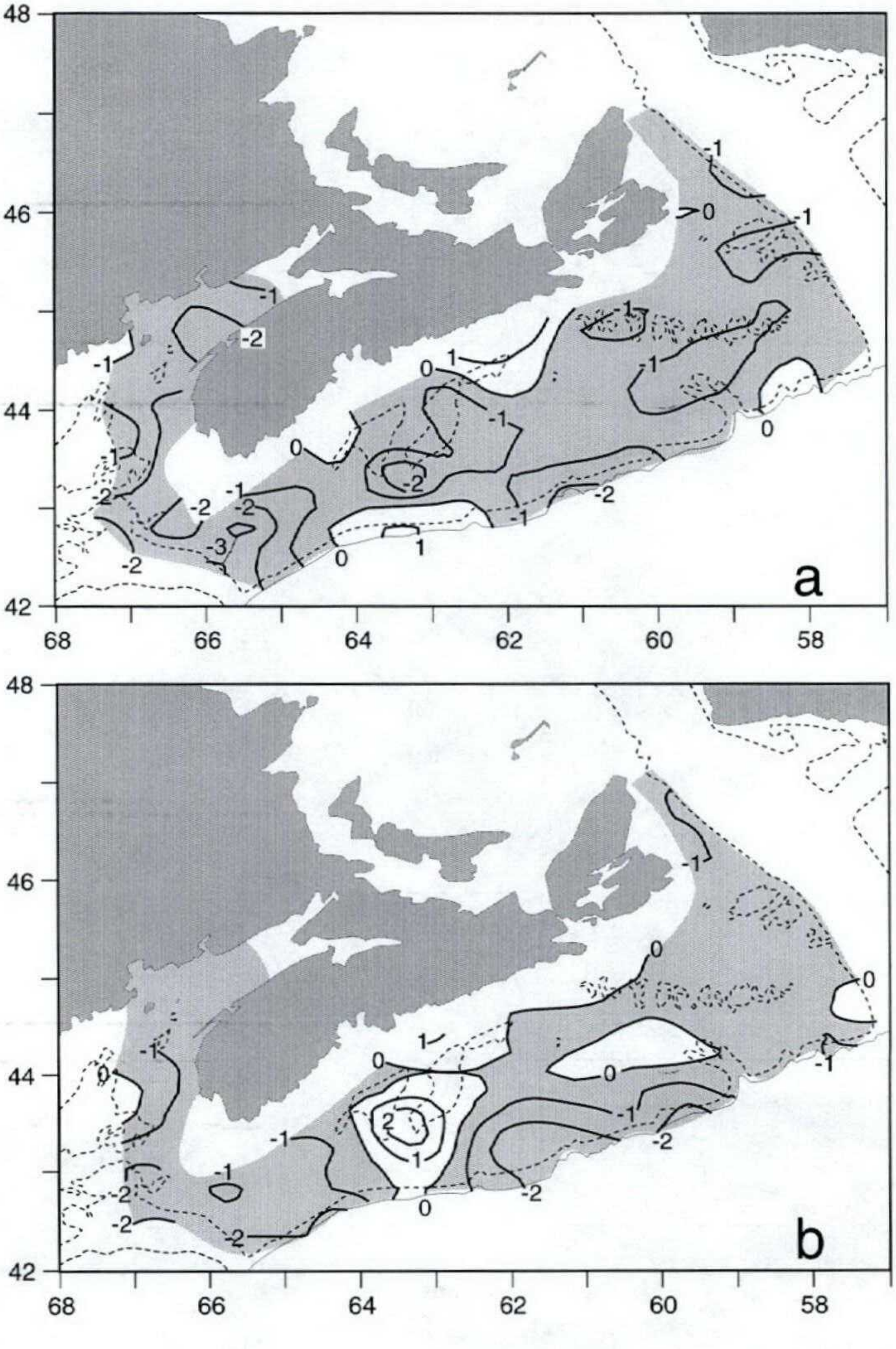


Fig. 13. Contours of optimally estimated temperature anomalies at the surface (a) and 50m (b) during the1996 July groundfish survey.

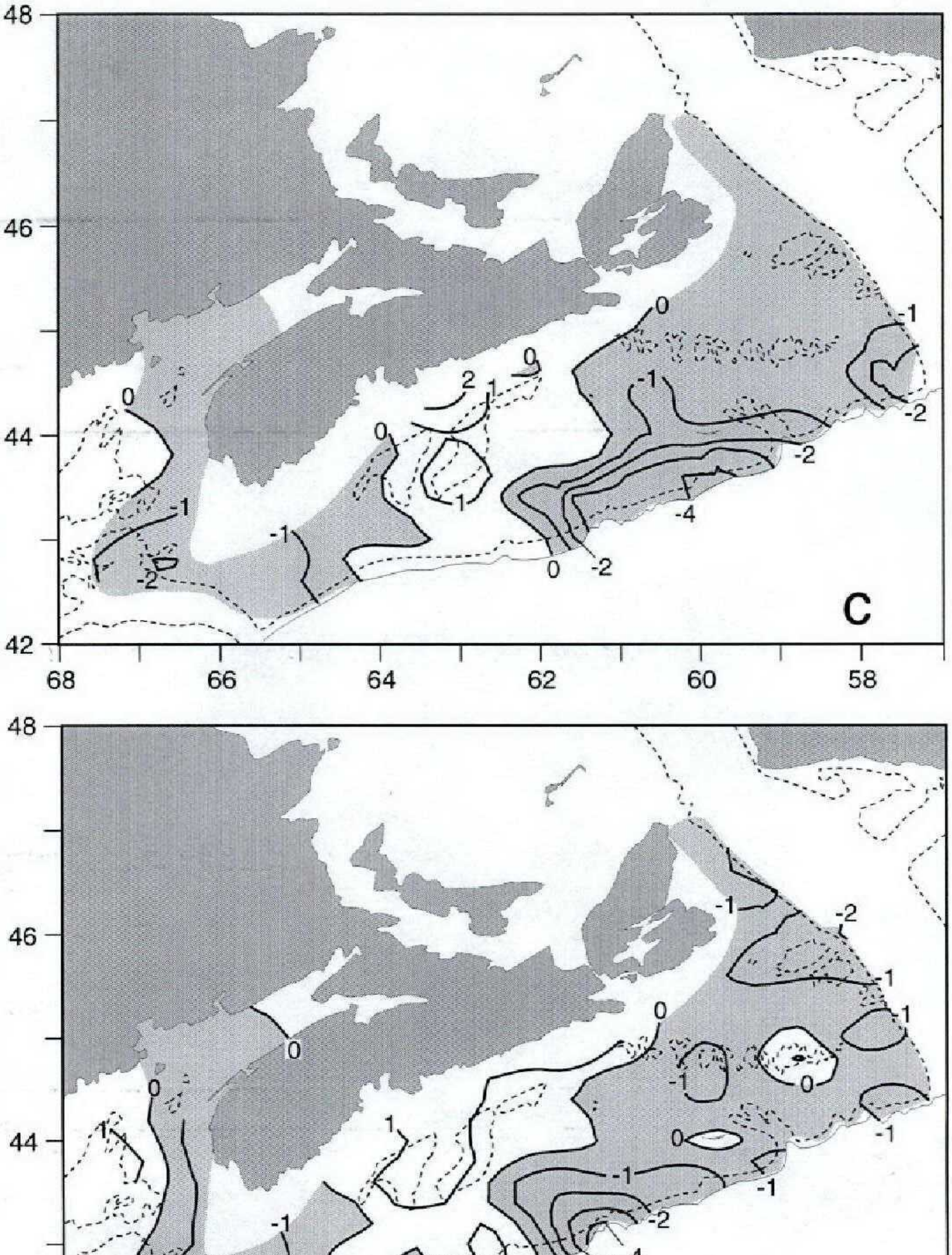


Fig. 13cont'd. Contours of optimally estimated temperature anomalies at 100m (c) and near bottom (d) during the 1996 July groundfish survey.

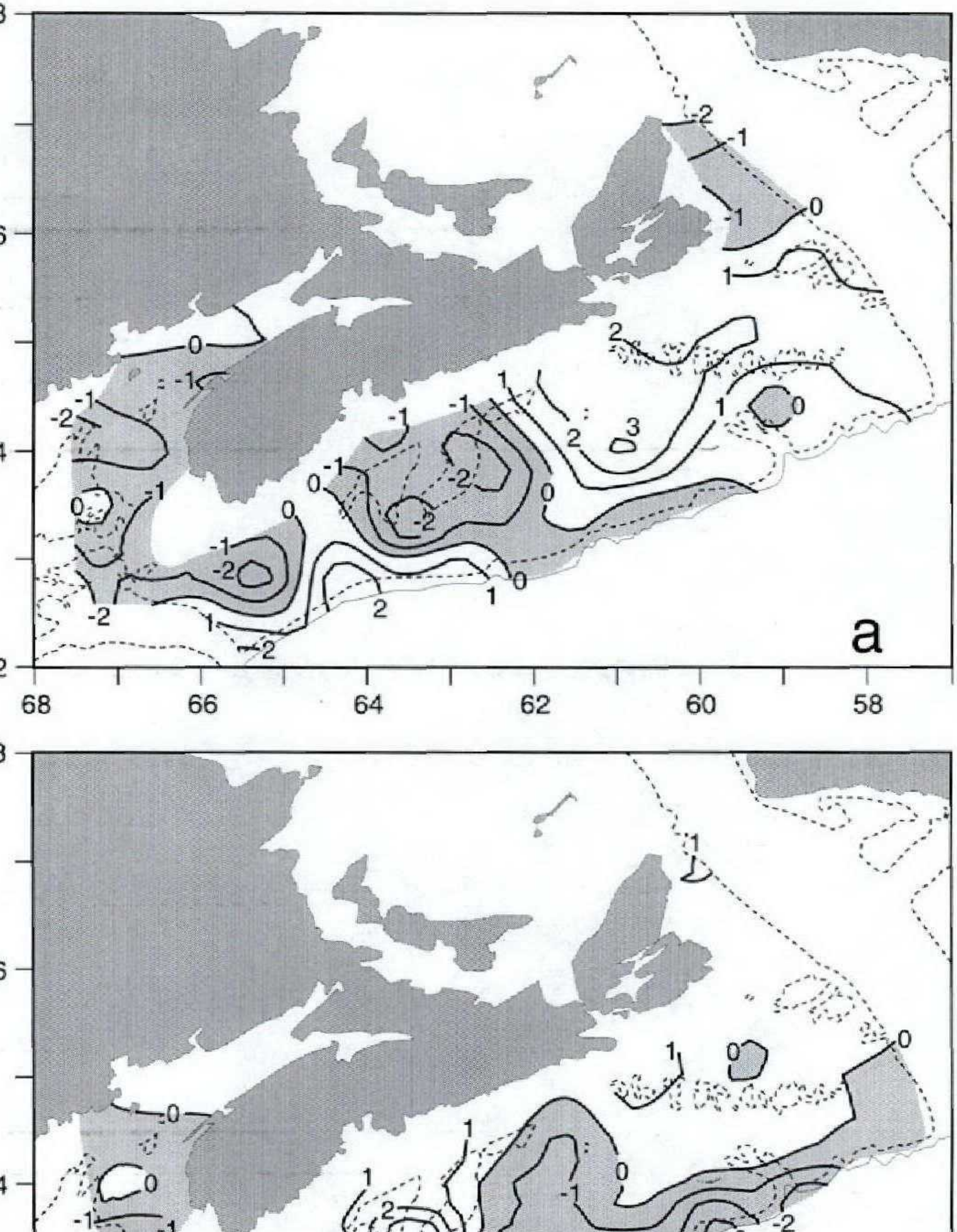


Fig. 14. The difference between the 1996 and 1995 temperature fields at 0m (a) and 50m (b) for the July survey. Positive values indicate warming and negative a cooling. Negative differences are shaded.

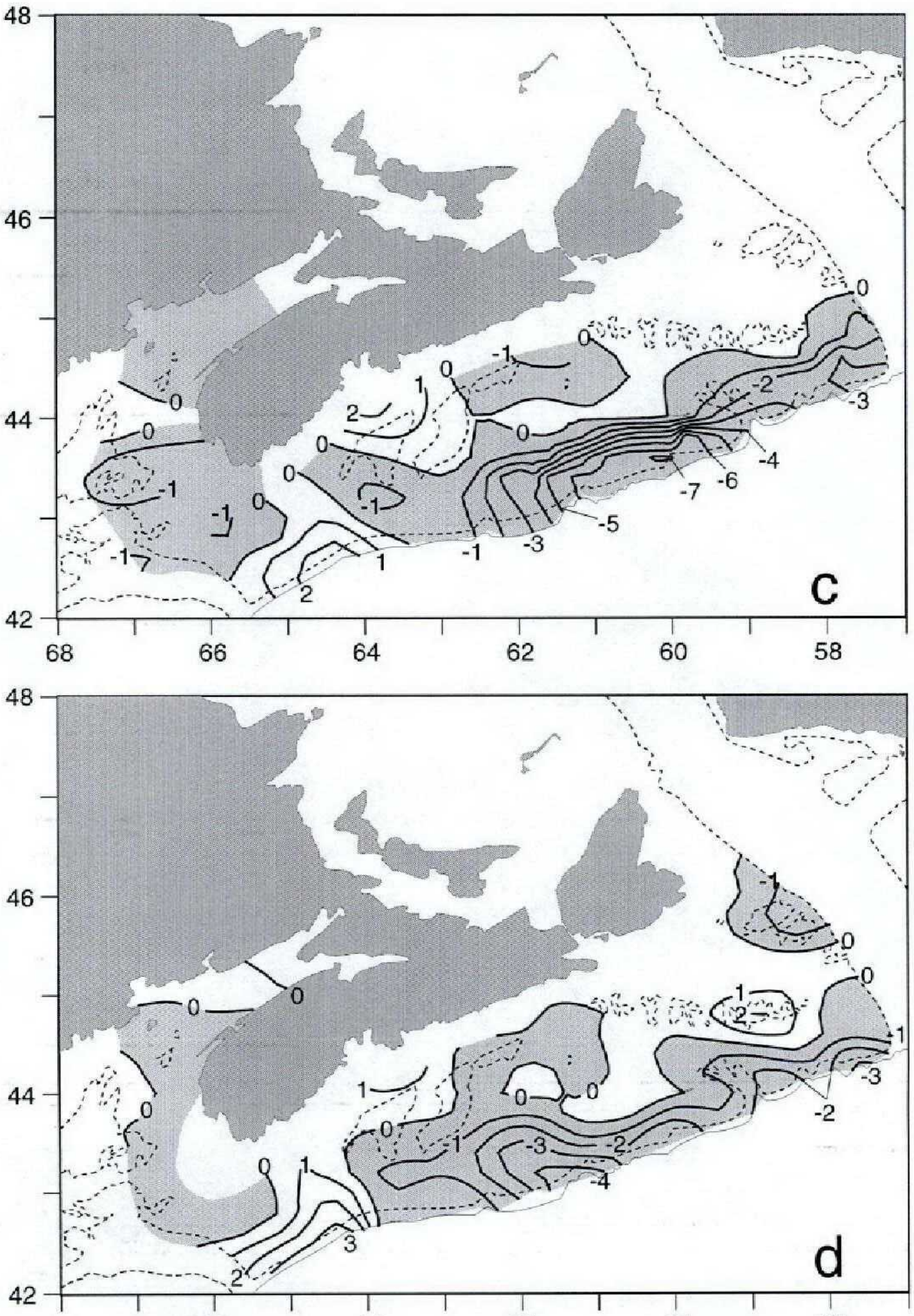


Fig. 14cont'd. The difference between the 1996 and 1995 temperature fields at 100m (c) and near bottom (d) for the July survey. Positive values indicate warming and negative a cooling. Negative differences are shaded.

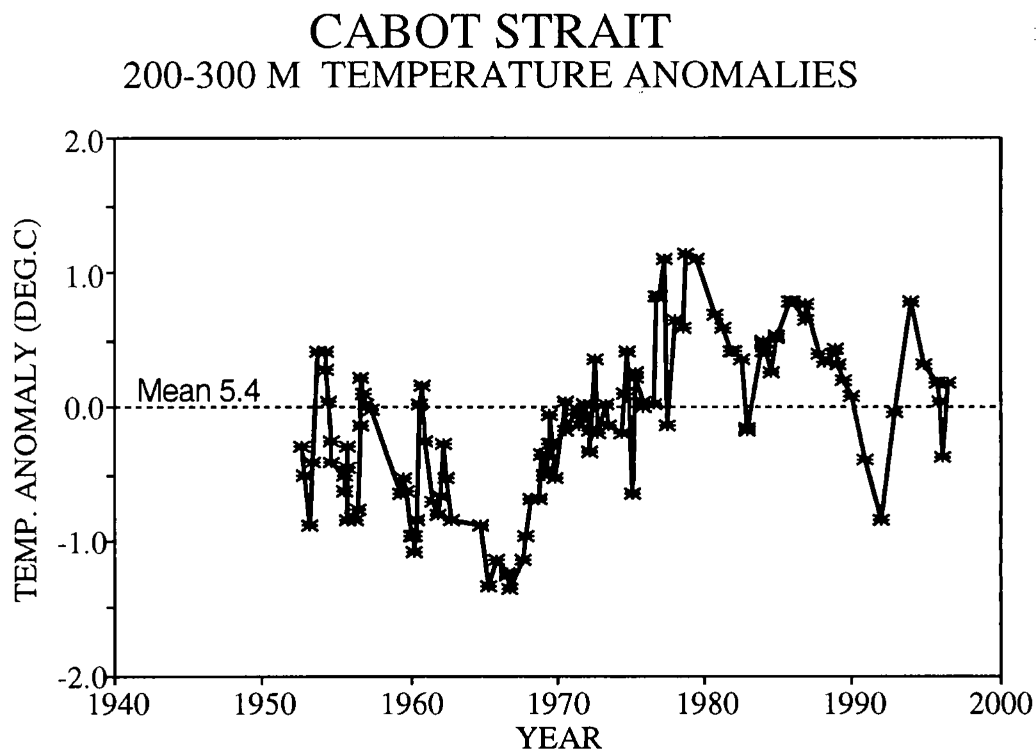


Fig. 15. Temperature anomalies (relative to 1961-90) over the 200-300 m layer in Cabot Strait.