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Overview of Physical Oceanographic Conditions in the Scotia-Fundy Region in 1994

by

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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 1994 is presented. Waters in the Gulf of Maine were consistently warmer-than-normal as revealed by monthly XBT transects, hydrographic data at Prince 5, and sea surface temperatures at Boothbay Harbor and St. Andrews. This warming, including that in the near shore regions, is believed to be mainly due to the intrusion of warm slope water. This is supported by the presence of high salinity waters at Prince 5. Atmospheric heating may also have played a role in the warming of the upper layer waters in the latter half of the year when air temperatures were well above normal. Temperatures in the deep waters in Emerald Basin on the Scotian Shelf and at Cabot Strait were warmer-than-normal. These waters are derived from the offshore slope waters whose temperatures were also above normal. On the Scotian Shelf temperatures in the 50-100 m layer were typically colder-than-normal except over Emerald Basin. At depths greater than 100 m on the northeastern end of the Shelf temperatures remained below normal. The shelf/slope front and the Gulf Stream were typically shoreward of their long-term mean positions and more Gulf Stream warm-core eddies formed in 1994 than in any single year in the last 13.

RÉSUMÉ

Une analyse des conditions d'océanographie physique qui ont prévalu sur les plates-formes continentales et les régions extracôtières adjacentes au large du plateau Néo-Écossais et le golfe du Maine en 1994 est présentée. Dans le golfe du Maine, les eaux ont été uniformément plus chaudes que la normale comme l'indiquent les transects mensuels de bathythermographie à sonde perdue, les données hydrographiques enregistrées à Prince 5 et les températures de la surface de la mer relevées à Boothbay Harbor et St. Andrews. Ce réchauffement, notamment dans les régions littorales, serait principalement attribuable à l'intrusion d'eau chaude en provenance du talus. Cette hypothèse est corroborée par la présence d'eaux très salines à Prince 5. Le réchauffement atmosphérique a pu également joué un rôle dans le réchauffement des eaux de la couche supérieure durant la dernière moitié de l'année alors que les températures de l'air ont été beaucoup plus élevées que les normales. Les températures dans les eaux profondes du bassin d'Émeraude sur le plateau Néo-Écossais et dans le détroit de Cabot ont été plus chaudes que les normales. Ces eaux proviennent du talus continental où la température des eaux étaient également au-dessus des normales. Sur le plateau Néo-Écossais, les températures dans la couche de 50 à 100 m ont été typiquement plus froides que les normales sauf dans le bassin d'Émeraude. Aux profondeurs dépassant 1200 m sur l'extrémité nord-est de la plate-forme continentale, les températures sont demeurées au-dessous des normales. Le front plate-forme/talus et le Gulf Stream ont été typiquement orientées vers le rivage par rapport à leur position moyenne à long terme et le nombre de tourbillons à centre chaud formés dans le Gulf Stream en 1994 a été le plus élevé des 13 dernières années.

INTRODUCTION

This paper describes some of the physical oceanographic conditions during 1994 on the Scotian Shelf and in the Gulf of Maine as well as their adjacent offshore areas (see Fig. 1 for study region). It includes information on the temperature and salinity characteristics, the position of the shelf/slope and Gulf Stream fronts and Gulf Stream ring activity. The hydrographic data are derived from coastal sea surface stations, long-term monitoring sites, annual groundfish surveys, ships-of-opportunity and research vessels. Most of the data are available in the BIO historical (AFAP) temperature and salinity database which is updated approximately quarterly by the Marine Environmental Data Service (MEDS) in Ottawa from their data archive. The frontal positions and Gulf Stream ring data were digitized from the satellite-derived NOAA Oceanographic Analysis Charts. Oceanographic conditions are compared with their long-term means and, where possible, the latter have been standardized to a 30-yr base period in accordance with the convention of the World Meteorological Organization. Unless otherwise stated, anomalies in this paper are referenced to 1961-90 means. Further details on the oceanographic conditions during the 1994 groundfish survey, including the near bottom temperature field, are provided in Page et al. (1995). Meteorological and sea ice information for the region during 1994 are described by Drinkwater et al. (1995).

COASTAL SEA SURFACE TEMPERATURES

Monthly averages of sea surface temperature (SST) derived from continuous thermograph records or twice daily readings are available from Halifax Harbour in Nova Scotia, St. Andrews in New Brunswick, and Boothbay Harbor in Maine. The monthly mean temperature anomalies at each site for 1993 and 1994 are shown in Fig. 2.

The dominant feature at Boothbay Harbor and St. Andrews was the above normal temperatures during the last 7 months of 1994. In five of the months the anomaly equalled or exceeded one standard deviation. The maximum warming (of approximately 2°C) occurred in July. Anomalies were also relatively high in November and December. These anomalies contrast with conditions in the first five months of the year when temperatures were cooler-than-normal at St. Andrews and of low amplitude but highly variability at Boothbay. The tendency of cold in the first half of the year and warm in the second half roughly corresponds to the air temperature pattern in the region (Drinkwater et al. 1995).

At Halifax, temperatures were colder-than-normal except during April, June and July. As at the other two sites, July had the highest anomalies (> 2°C) but in contrast, Halifax had strong negative SST anomalies during the latter months of 1994.

Annual SST mean temperatures for 1994 were 9.3°C (0.8°C above normal) at Boothbay Harbor, 7.7°C (0.6°C above normal) at St. Andrews, and 7.2°C (0.6°C below normal) at Halifax. They represent a significant rise in temperature over last year at Boothbay (0.8°C) and St. Andrews (1°C) but a minimal increase at Halifax (0.1°C). At Boothbay and St. Andrews, temperatures have generally increased since the late 1980s while at Halifax temperatures have declined over this same period.

HYDROGRAPHIC DATA

Prince 5

Temperature and salinity measurements have been taken nominally once per month since 1924 at Prince 5, a station off St. Andrews, New Brunswick, near the entrance to the Bay of Fundy. This is the longest continuously operating hydrographic monitoring site in eastern Canada. Monthly anomalies for 1994 were calculated except for April when no measurements were available. Single observations per month, especially in the surface layers in the spring or summer, under stratified conditions are not necessarily 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 features are likely to be real.

In 1994, temperatures ranged from a minimum of less than 2°C in February and March to a maximum of over 12°C in August and September (Fig. 4). With the exception of February and March, the monthly temperature anomalies were positive. Maximum values of 2-3°C were observed in June and July. Temperature anomalies from August to December were generally between 1-2°C indicative of significant warming and match similar conditions in the SSTs at St. Andrews. The long-term temperature records at the surface and bottom (90 m) for Prince 5 are highly coherent due to the strong tidal mixing in the Bay of Fundy (Fig. 5). The annual anomalies in 1994 were 1.0°C and 0.9°C at the surface and bottom, respectively. These are warmer than last year's means by 1.5°C. At both depths the maxima occurred in the early 1950s and the minima in the mid 1960s, with recent values below the long-term mean. The warming of the waters in 1994 reverses the general trend of declining temperatures at Prince 5 observed during recent years (Fig. 5).

Salinities at Prince 5 during 1994 were typically saltier-than-normal (Fig. 4). The lowest salinities (<30.5 psu) occurred during June resulting in an anomaly of -0.8 psu in the surface waters. This was short-lived, however, and is unlikely to have been representative of the true monthly mean. The highest salinities (>33 psu) appeared in the near bottom waters in the late summer and early autumn and produced an anomaly of 0.5-1 psu in August. The high salinities throughout the water column reverses the recent trend of below normal values (Fig. 6).

Gulf of Maine Temperature Transect

The Northeast Fisheries Science Center in Narragansett, Rhode Island, has collected expendable bathythermograph (XBT) data from ships-of-opportunity since the late 1970s 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 and averaged any data within these by month. The site locations (center of the boxes) are shown in Fig. 7. In 1994, data were available at 4 to 10 sites per month. They revealed strong (1-3°C) positive anomalies in all months throughout most of the water column. Only at the two most eastern sites located on the Scotian Shelf were anomalies persistently negative. The July data captures the essence of the anomaly pattern during the year although the details do differ from month to month (Fig. 7). The warm waters are consistent with the anomalies at Prince 5 and the warm SSTs observed at Boothbay Harbor and St. Andrews during the latter half of 1994.

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 these 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 1994, temperature measurements were obtained in four separate months with values at 250 m ranging from 10.5 to 9.98°C. This produced monthly anomalies of 0.5°-2.5°C above normal (Fig. 8). The long-term annual average is 8.5°C and the monthly means range from 7.9°C to 9.4°C. These anomalies were typically representative of conditions below approximately 100 m. The warm temperatures of the past couple of years are believed to have begun with an intrusion of warm slope water late in 1991 or early in 1992.

Other Scotian Shelf and Georges Bank Temperatures

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinity for irregularly shaped areas on the Scotian Shelf that generally corresponded to topographic features (Fig. 9). Monthly temperature anomalies were calculated for 1994 in several of these areas at standard depths (averaging any data within the month anywhere within these areas). Unfortunately, data are not available for each month at each area and in some areas the monthly means are based upon only one profile. Thus care again must be taken in over interpreting such data and little weight given to any individual mean.

This analysis was first undertaken during the 1993 review (Drinkwater and Pettipas 1994). It identified several important features. First, the temperature of the upper 30 m during 1993 varied greatly from month to month and was presumed to be linked to direct atmospheric cooling. Second, at intermediate depths of 50 to over 100 m, temperatures in 1993 were colder-than-normal over most of the shelf. Temperatures in this layer 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. The 1993 data suggested that conditions may had begun to moderate. The third main feature was the presence of anomalously warm slope water off the shelf and in the deep basins such as Emerald and Georges. This warm deep water appeared to influence the intermediate depth waters as their anomalies above the basins were generally warmer than elsewhere on the shelves.

During the past year we examined the spatial extent of the cooling of the intermediate layer waters during the late 1980s and into the 1990s. Visually we were able to trace it throughout most of the Gulf of Maine although it was more apparent in the eastern regions and western inshore regions. Similar cooling at these depths was found to the north on Pierre Bank and at Station 27 off St. John's, Newfoundland. Gilbert (1995) has shown that the cold intermediate layer in the Gulf of St. Lawrence was colder than normal during this same time period. The 1994 data indicate warming of the intermediate layers especially in the Gulf of Maine, e.g. on Lurcher Shoals (Fig. 10). This warming was also observed in the Gulf of Maine temperature transect (Fig. 7) and at Prince 5 (Fig. 4). Over Emerald Basin, conditions in the intermediate waters were again relatively warm, most likely due to mixing with the warm deep waters. While some warmer waters were observed in the northeast Scotian Shelf around Misaine and Banquereau Banks, they were not persistent and temperatures generally remained below normal (Fig. 11). Deep water temperatures (>100 m) in this area also were colder-than-normal (Fig. 11). From the available offshore data no consistent trend in the surface waters (<50 m) over the Scotian Shelf was evident, but rather there were large variations from month to month.

The best data coverage for temperature over the Scotian Shelf within one month was during July as part of the annual groundfish survey. These data were averaged within the areas shown in Fig. 9 and expressed as anomalies. The results for 0, 50 and 100 m are plotted in Fig. 12. They show that at the surface, warm conditions persisted over the entire Scotian Shelf except in the vicinity of Cape Sable in the western region. The highest anomalies were observed off the shelf and on Sydney Bight. At 50 m, the colder-than-normal temperatures extended over the Scotian Shelf with the exception of the Emerald Basin area as discussed above. The coldest anomalies (-1 to -2°C) were found over the offshore banks from Sable Island Bank to Browns Bank. Warm conditions were observed in the Gulf of Maine and offshore in the slope waters. At 100 m, warm conditions were observed in the Gulf of Maine, Emerald Basin, and in the slope waters offshore south of Sable Island. Colder-than-normal temperatures cover the rest of the Scotian Shelf (Fig. 12).

Cabot Strait Deep Temperatures

Bugden (1991) investigated the long-term temperature variability in the deep waters (200-300 m average) of the Laurentian Channel in the Gulf of St. Lawrence from data collected between the late 1940s to 1988. The variability 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 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 of exceeding -0.5°C; Fig.

13). In 1992, however, temperatures rose dramatically to 5.3°C (an anomaly of 0.2°C) and to over 6.0°C (anomaly of 1°C) in 1993. In 1994 temperature anomalies remained positive although temperatures decreased from last year to 5.6°C. This temperature pattern is similar to that for the deep waters in Emerald Basin and is believed to reflect changes in the slope water characteristics near the mouth of the Laurentian Channel (Bugden 1991; Petrie and Drinkwater 1993).

Frontal Positions

Shelf/Slope Front

The waters on the continental shelves off eastern Canada have distinct temperature and salinity characteristics from those found in the adjacent deeper slope waters offshore. The relatively narrow boundary between the shelf and slope waters is regularly detected in satellite thermal imagery. Recently, monthly time series of the position of this front and of the northern boundary of the Gulf Stream between 50°W and 75°W were assembled through digitization of satellite derived SST charts (Drinkwater et al. 1994). From January 1973 until May 1978, the charts only covered the region northward to Georges Bank, but in June 1978 the areal coverage was extended to include the Scotian Shelf and the Grand Banks. The time series consist of the monthly mean position of the shelf/slope front in degrees latitude at each degree of longitude. The years 1973 to 1992 (or all of the data whichever were less) were used to determine long-term monthly means which were then subtracted from the yearly values to obtain monthly and annual anomalies.

The overall average position of the shelf/slope front together with the 1994 annual mean position are shown in Fig. 14. The average position lies close to the 200 m isobath along the Middle Atlantic Bight, separates slightly from the shelf edge off Georges Bank and then runs between 100-300 km from the shelf edge off the Scotian Shelf and the southern Grand Banks. It is typically furthest offshore in winter and onshore in late summer and early autumn. During 1994, the shelf/slope front was seaward of its long-term mean position between 50°W to 58°W, shoreward from 59°W to 70°W and near the mean west of 69°W. Monthly anomalies in the positions of the front were estimated, averaged between 50°W and 75°W, and then low-pass filtered (Cartwright filter with 25 weights and a 50% power reduction at a period of 15 months). The low-frequency variability, based upon these filtered values, indicate that the front was near its long-term mean from 1985 to 1992 but since then has been approximately 30 km northward on average (Fig. 14). The maximum northward position was observed in the mid-1980s whereas the minimum occurred around 1980. Earlier data limited to the area west of 65°W suggest that the front was closer to its long-term mean position in the 1970s.

Gulf Stream Front

Time series of the position of the northern boundary or "wall" of the Gulf Stream were also determined from satellite imagery (Drinkwater et al., 1994). Similar to the shelf/slope front, the series consists of the monthly position at each degree of longitude from 75°W to 50°W. The average position of the north wall of the Stream and the 1994 annual mean is shown in Fig. 15.

The Stream leaves the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W the average position lies approximately east-west. During 1994, the Gulf Stream was generally positioned north of its mean location with the maximum (60-80 km) in the area from 53°W to 63°W. Off the Middle Atlantic Bight (< 71°W), the Gulf Stream was also positioned north of its long-term mean location. The monthly anomalies of the Gulf Stream position averaged over all longitudes were significantly shoreward of the long-term mean position in all months except for December and November when they were near the mean. The low-pass filtered positions (Cartwright filter, as described above for the Shelf/Slope front) show that Gulf Stream has been at or near its maximum northward extent during the last few years (Fig. 15). The Stream was located south of its mean position during the late 1970s and 1980, near it through most of the 1980s and north or it during the late 1980s and into the 1990s.

Warm-core Rings

Meanders in the Gulf Stream occasionally break off from the main current forming anticyclonic eddies that trap warm Sargasso Sea water in their center. These warm-core rings continue to rotate as they move slowly through the slope waters. If they become close to the continental shelf break they may entrain shelf water out into the slope water region. Evidence of reduced recruitment of groundfish species with enhanced ring activity during the spawning and larval periods was provided by Myers and Drinkwater (1987). The life history of these warm-core Gulf Stream rings in the region from 45°W to 75°W during 1994 was derived from the NOAA Oceanographic Analysis charts. Owing to the relatively common occurrence of cloudy or foggy conditions, particularly in the eastern half of the region, several weeks may elapse between clear thermal images of the sea surface. Consequently, there is occasional uncertainty about the exact date of formation or disappearance of some rings.

A total of 38 warm-core rings were present in the area during some portion of 1994, three of which survived from 1993 into the new year. The 35 new rings which formed in 1994 represents the highest number on record (13 years) and 8 above the long-term average (1982-94). Two of the new rings persisted into 1995. Nine of the rings formed in 1994 had a lifespan exceeding 2 months. Rings, whose destruction occurred in 1993, ranged in age from 5 d to 7.7 months and had a mean life of approximately 1.6 months. The average lifespan since 1982 when reliable data have been available is 2.7 months. The statistics of ring formation and ring presence, compiled by zones, each covering 2.5° of longitude, are displayed in Fig. 16. The maximum number of rings generated in any 2.5 degree zone was 8 which matches the largest number ever recorded. This occurred in the zone 62.5-65°W which traditionally spawns the most rings. The number of rings present in each of the longitude zones varied from 2 to 10 with the highest number again in the zone between 62.5 to 65.0°W. The larger number of rings present in the far western zones, compared to the number formed there, reflects westward propagation. The maximum number of rings (6) formed in April, 5 formed in May, 4 in March, June and July, 3 in August, September and October and 1 in January, February and November. No new rings formed in December. The monthly pattern does not differ substantially from the long-term pattern of lower numbers formed during the first and last two months of the year and relatively equal numbers during the remaining 8 months.

DISCUSSION AND SUMMARY

During 1994, the waters in the Gulf of Maine were generally warmer-than-normal. Such conditions were observed throughout most of the year in the monthly XBT transects across the Gulf and at Prince 5, and during the second half of the year in the SST data at Boothbay Harbor and St. Andrews. The high temperatures in the deeper regions of the Gulf are due to the presence of warm slope water. The effect of these waters are believed to have penetrated inshore, contributing to the warming in those regions. This is supported by the large increase in salinity observed at Prince 5. Warm temperatures were also observed in the deep waters of Emerald Basin and Cabot Strait. The source of these deep waters and those in the Gulf of Maine are the slope waters which were found to be warmer-than-normal throughout most of 1994. The warming in the Gulf of Maine included the intermediate depths (50-100 m) which reversed the trend of colder-than-normal temperatures that characterized this layer in the late 1980s and early 1990s. On the Scotian Shelf, except in the vicinity of Emerald Basin, the temperatures at these intermediate depths remained colder-than-normal. In the northeastern section of the Shelf waters below 100 m were also colder-than-normal. Upper layer waters over the Scotian Shelf were significantly warmer-than-normal during the groundfish survey in July. The cause of the cold SSTs at Halifax from August to December remains unclear. Air temperatures were much warmer-than-normal which suggests the cause was advective, perhaps through increased upwelling, or due to vertical mixing. The shelf/slope and the Gulf Stream fronts both lay north of their mean position, on average. Strong ring activity occurred with the largest number of rings being formed in 1994 over the entire 13 year record.

OUTLOOK FOR 1995

In the Gulf of Maine, the extremely warm slope waters that appear to influence conditions throughout the water column and into the inshore regions would be expected to persist through much of 1995. This is supported by the January to March SST anomalies at Boothbay Harbor being upwards of 2°C above normal. Cold waters will likely remain on the northeastern Scotian Shelf but appear to be moderating. We expect further warming of the intermediate waters especially on the southwest Scotian Shelf. Temperatures in the deep basins and channels are expected to remain warmer-than-normal given the continuing presence of large amounts of warm slope waters offshore.

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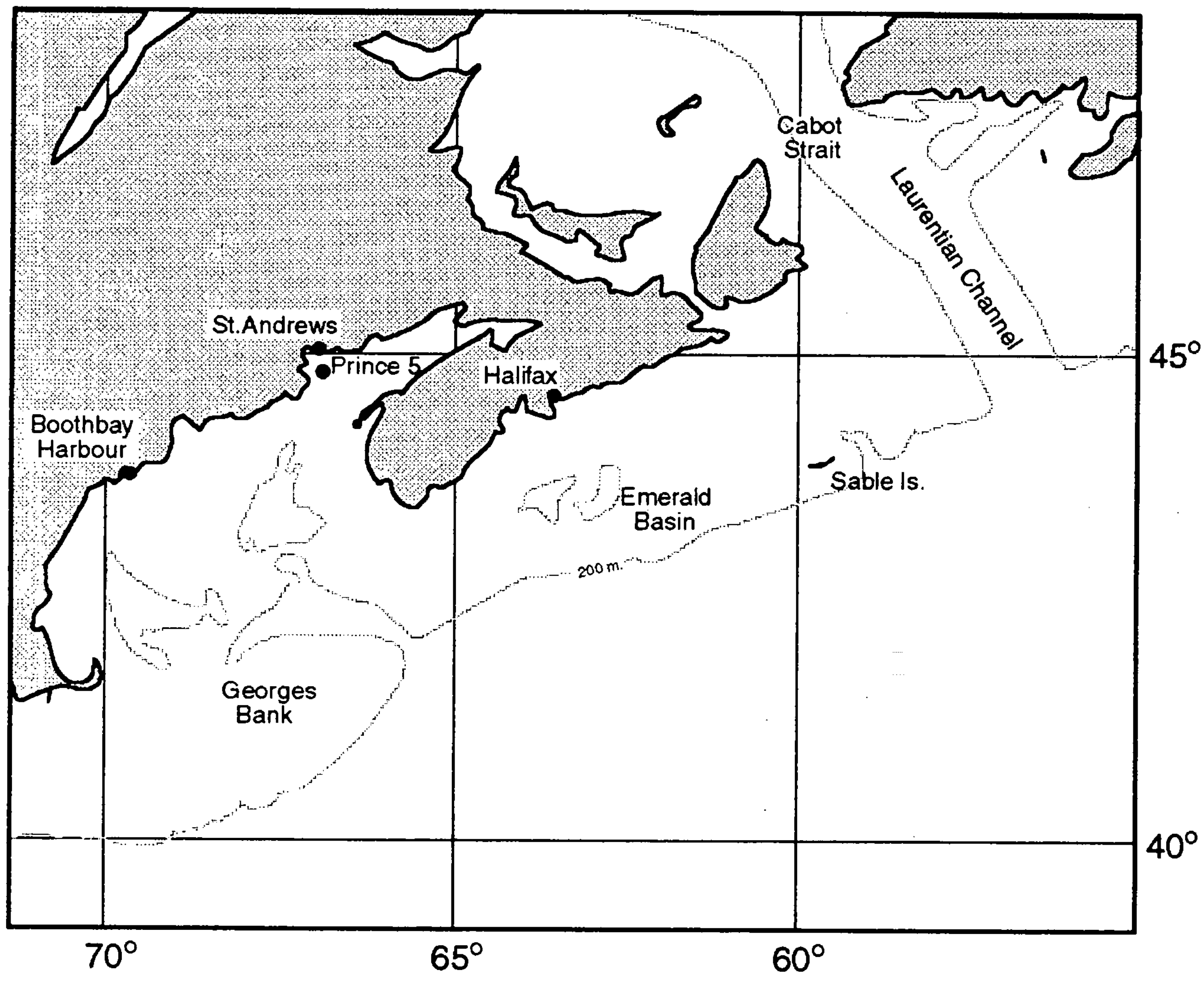


Fig. 1. The Scotian Shelf and Gulf of Maine showing hydrographic stations and some topographic features.

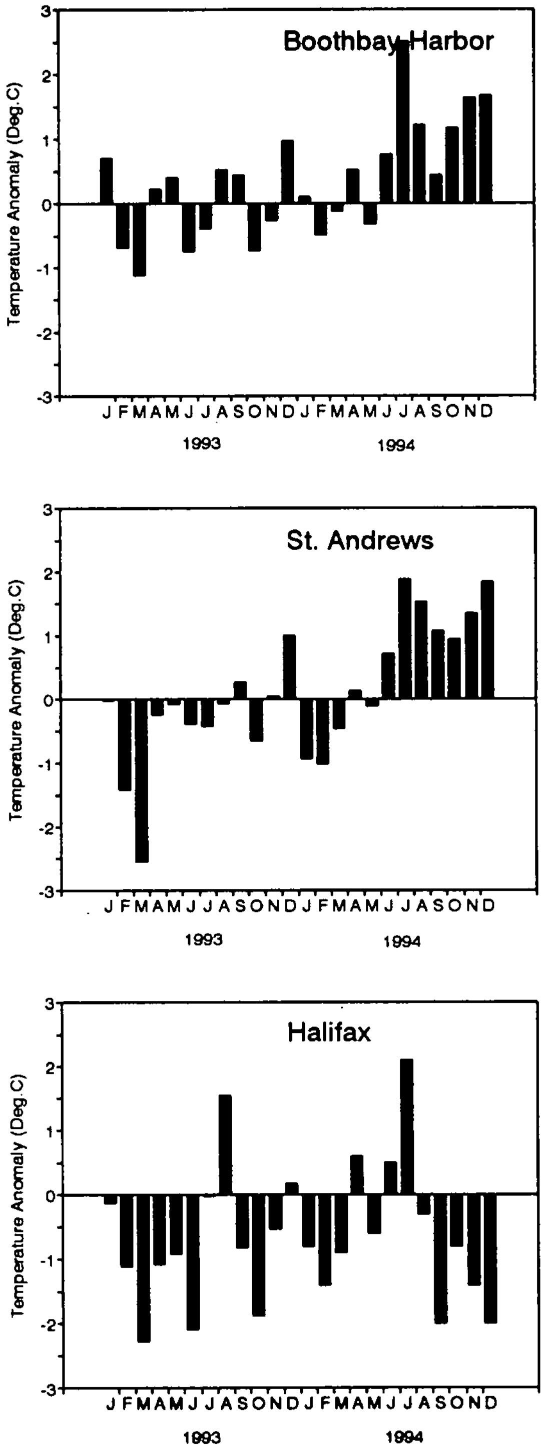


Fig. 2. The monthly sea surface temperature anomalies (relative to 1961-90) during 1993 and 1994 for Boothbay Harbor, St. Andrews and Halifax.

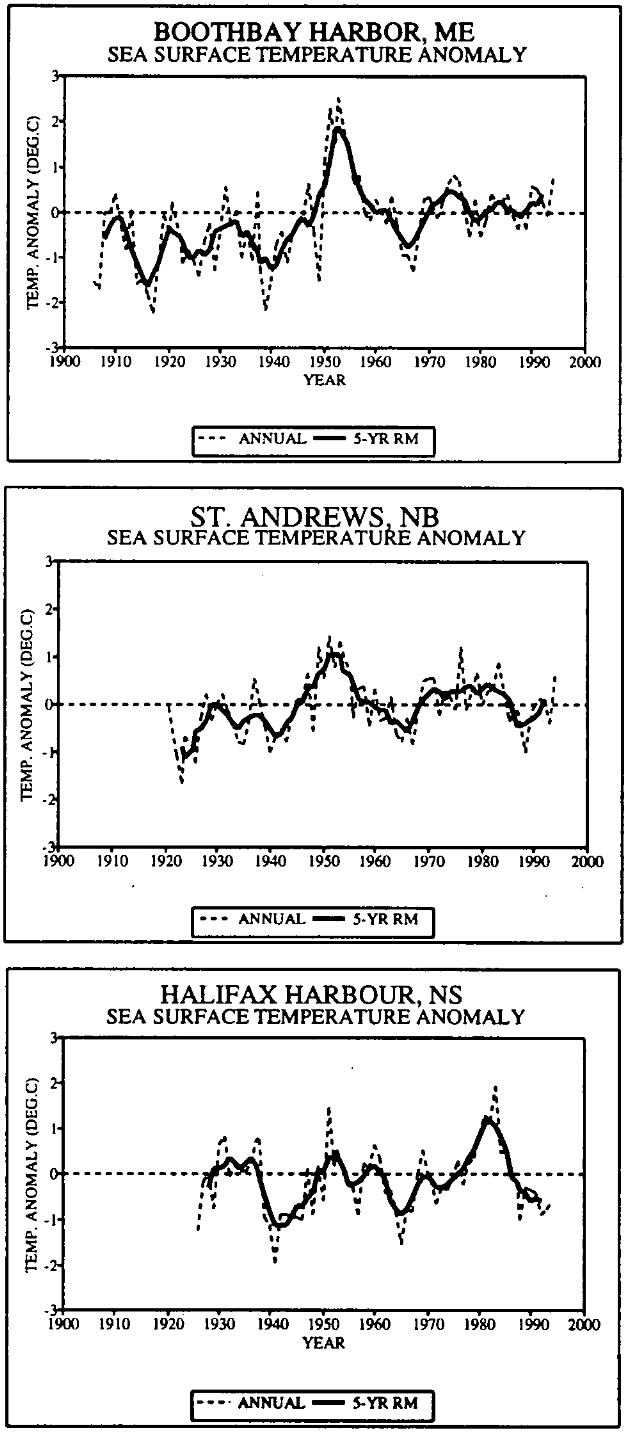


Fig. 3. The annual anomalies of sea surface temperature and their 5-yr running means at Boothbay Harbor, St. Andrews and Halifax.

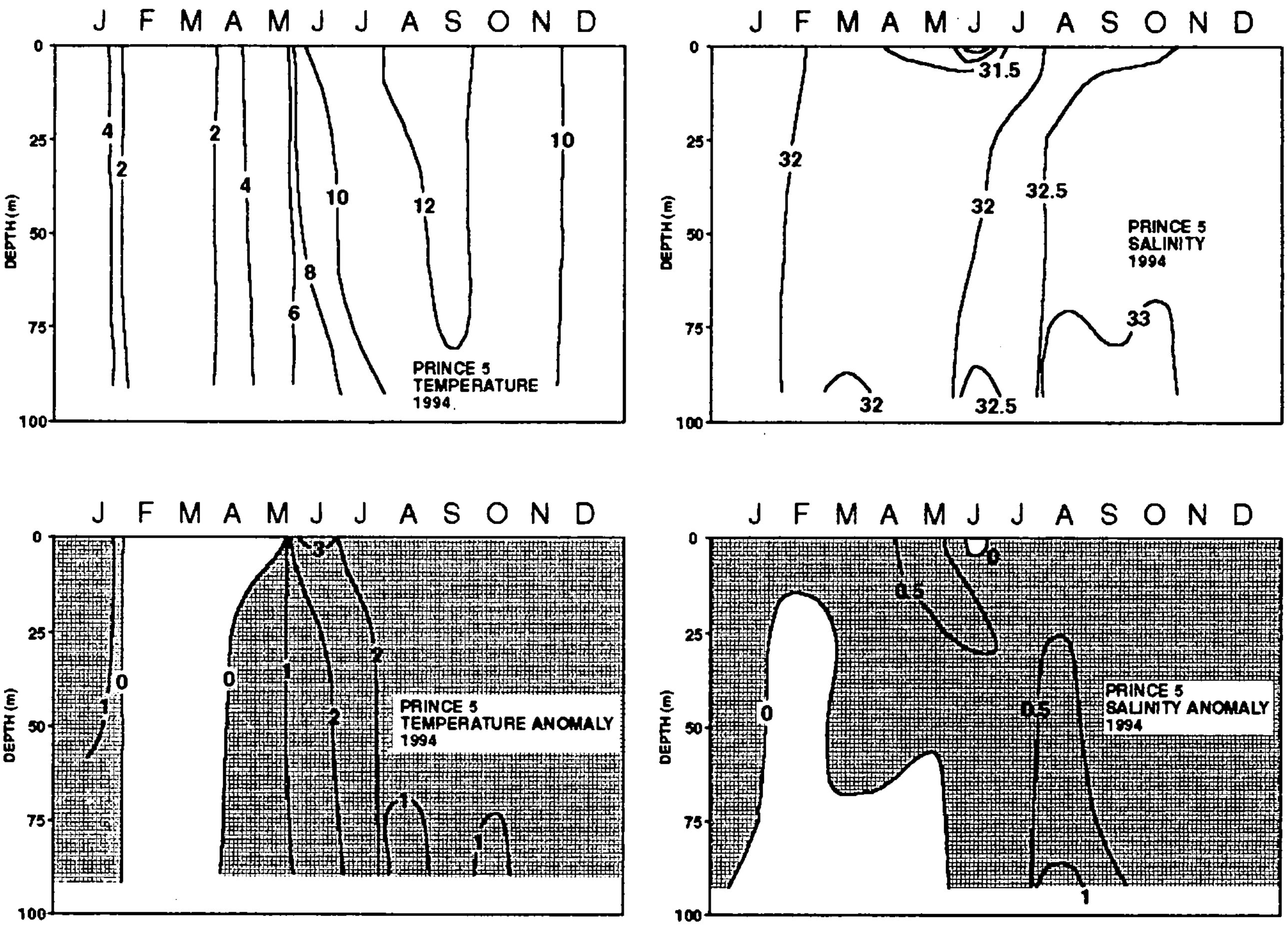


Fig. 4. Prince 5 monthly temperatures and salinities (top) and their anomalies as a function of depth during 1994. Shaded areas are positive anomalies.

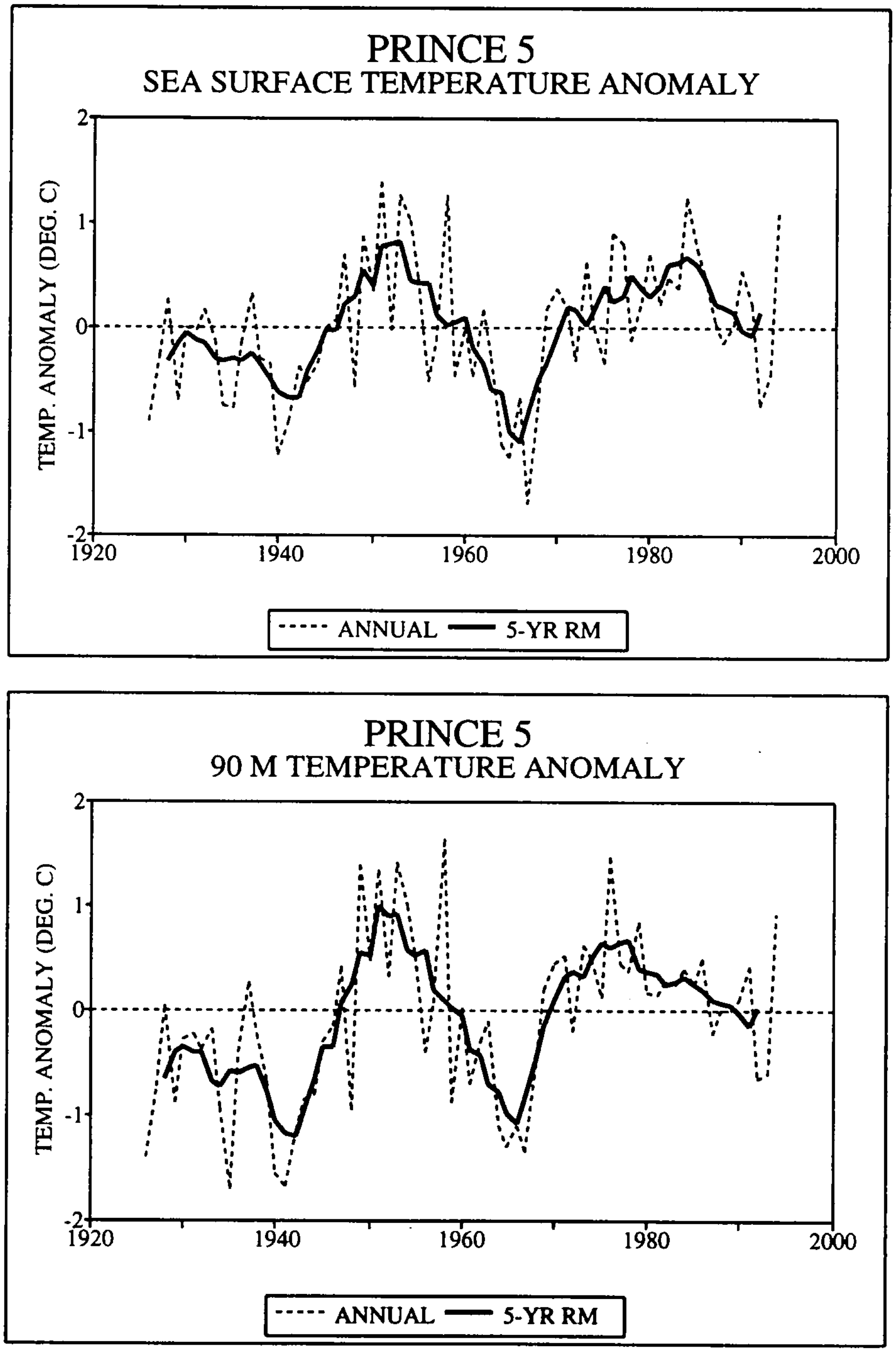
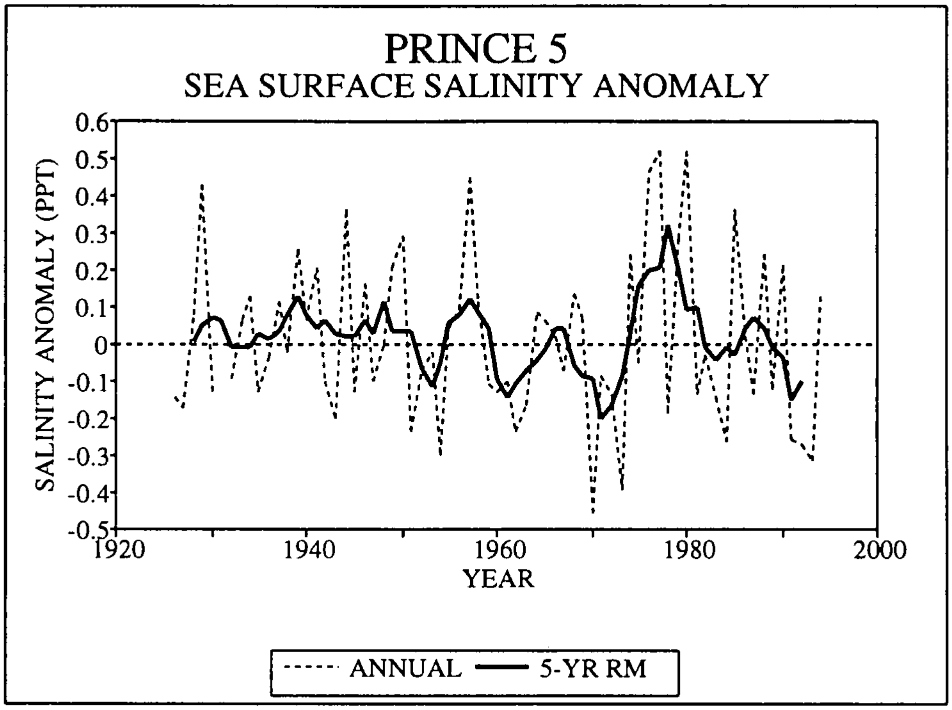


Fig. 5. The annual temperature anomalies and their 5-yr running means at Prince 5, 0 and 90 m.



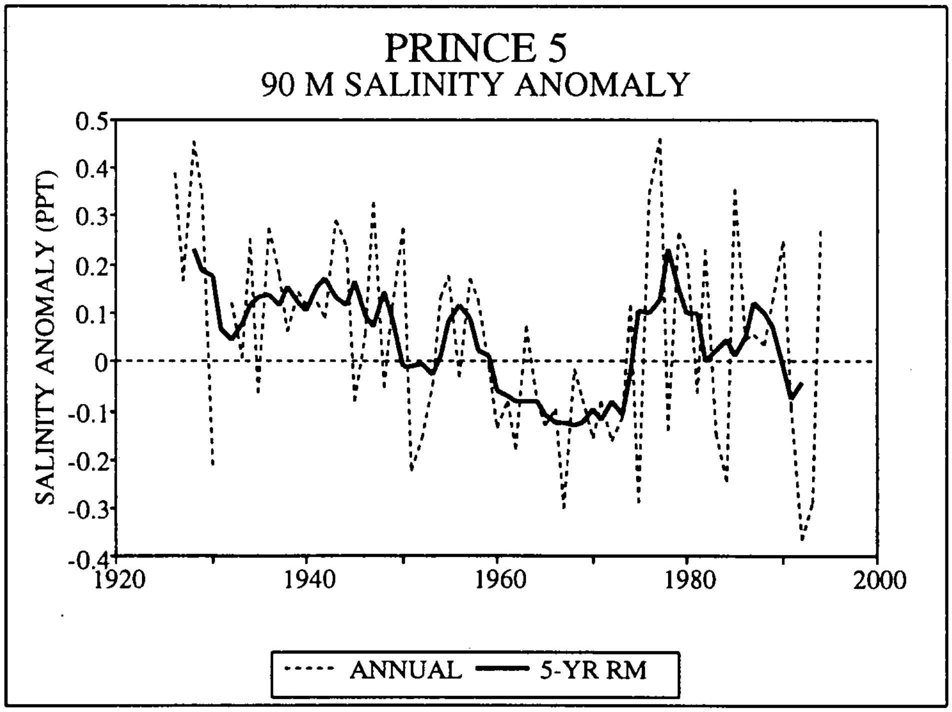


Fig. 6. The annual salinity anomalies and their 5-yr running means at Prince 5, 0 and 90 m.

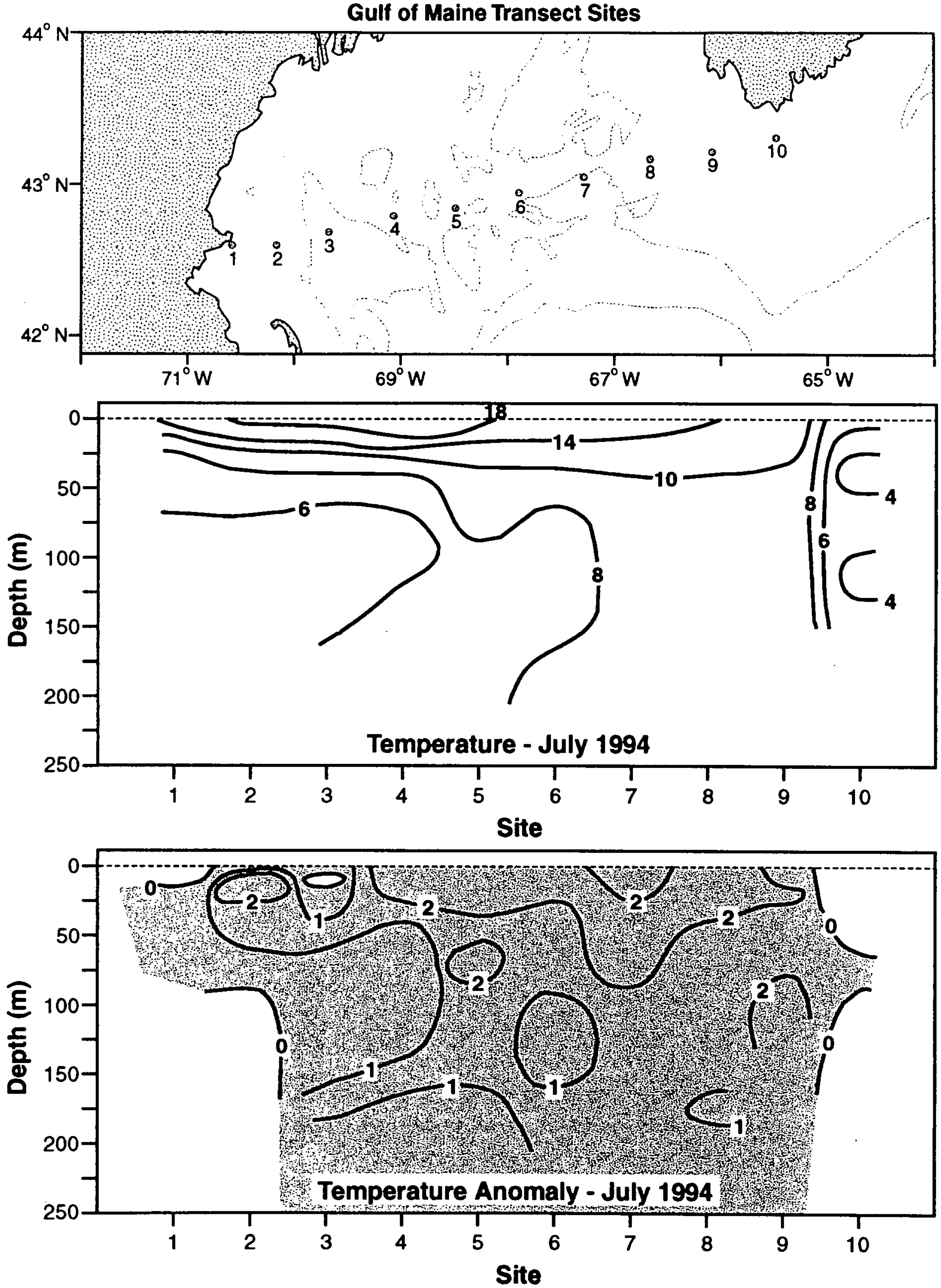


Fig. 7. The temperature (middle) and temperature anomalies (bottom) along a XBT transect (top) across the Gulf of Maine from Cape Ann, Mass., to Cape Sable, N.S.

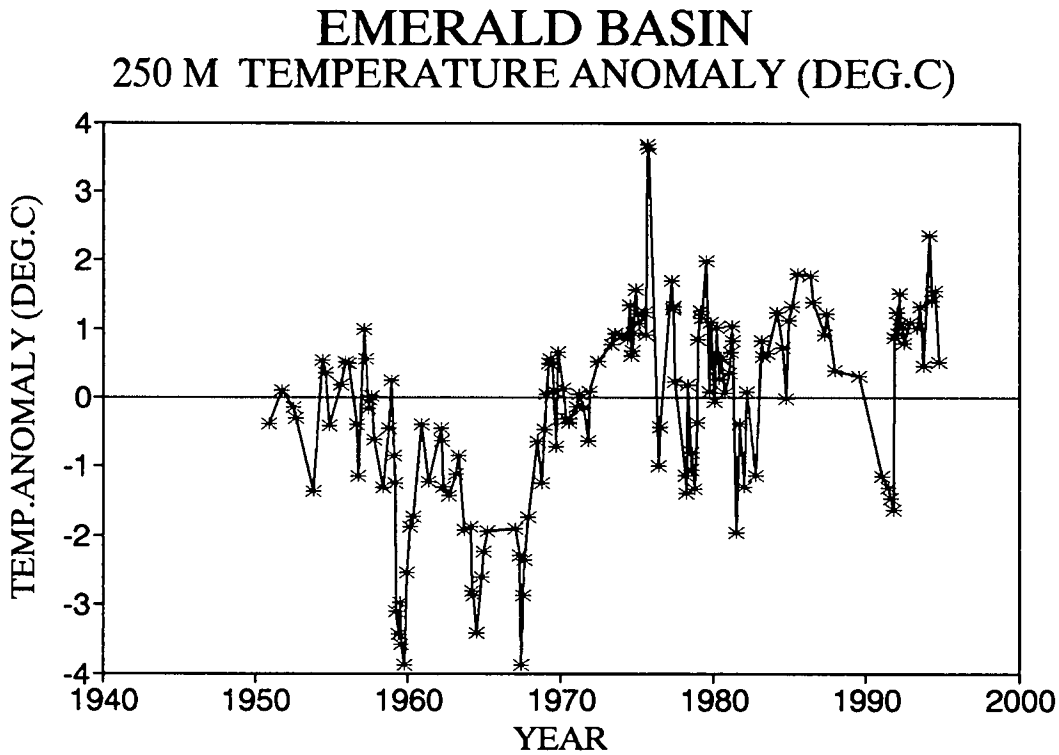
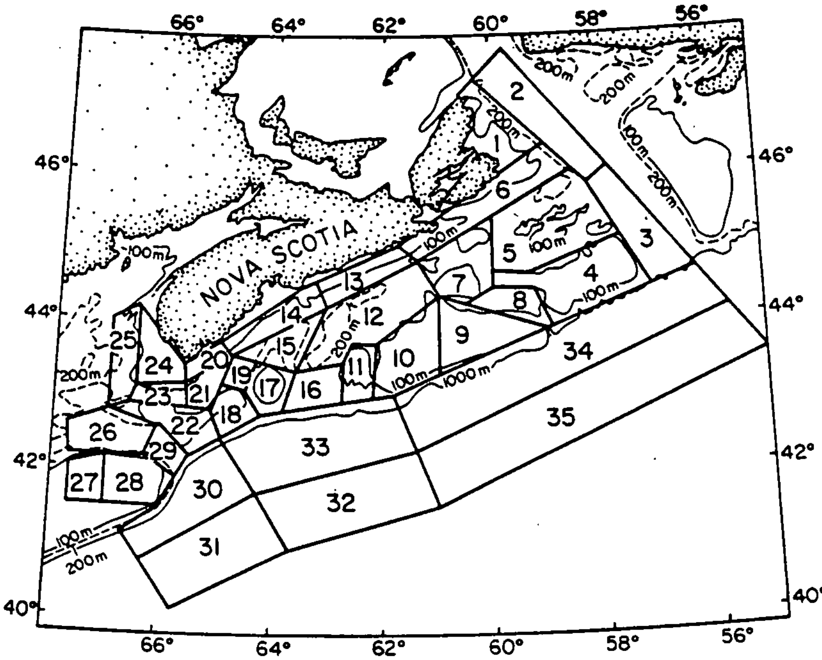


Fig. 8. Temperature anomalies at 250 m in Emerald Basin.



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. 9. The areas in which monthly mean temperature and temperature anomalies were estimated (from Drinkwater and Trites 1987).

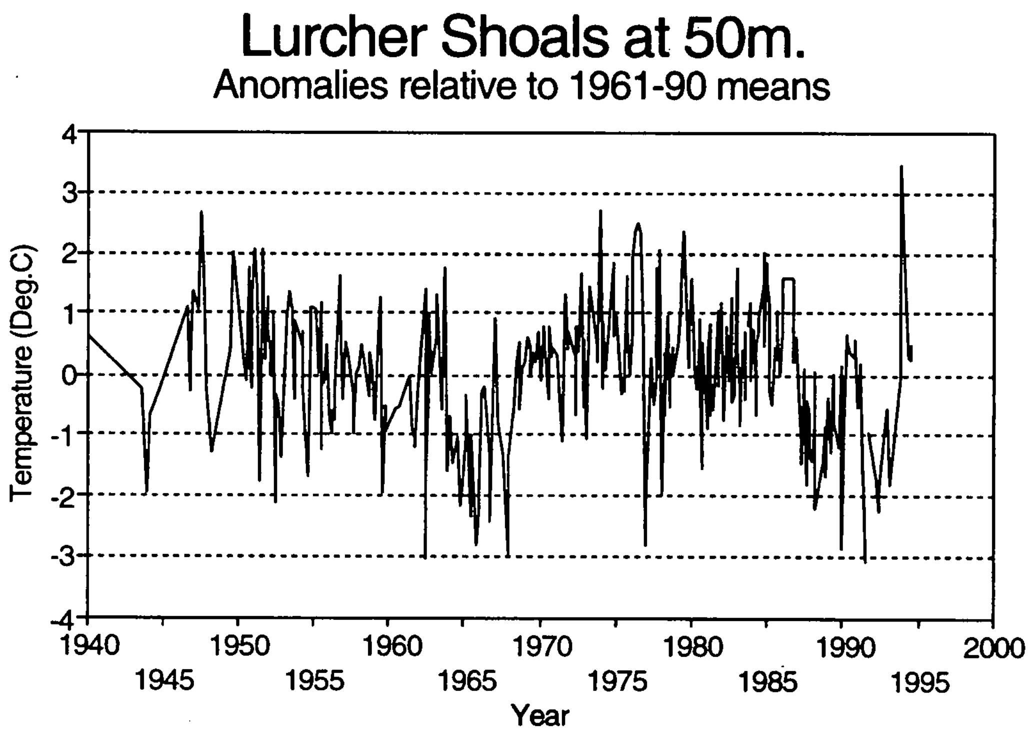


Fig. 10. The time series of temperature anomalies at 50 m for Lurcher Shoals (area 24 in Fig. 9).

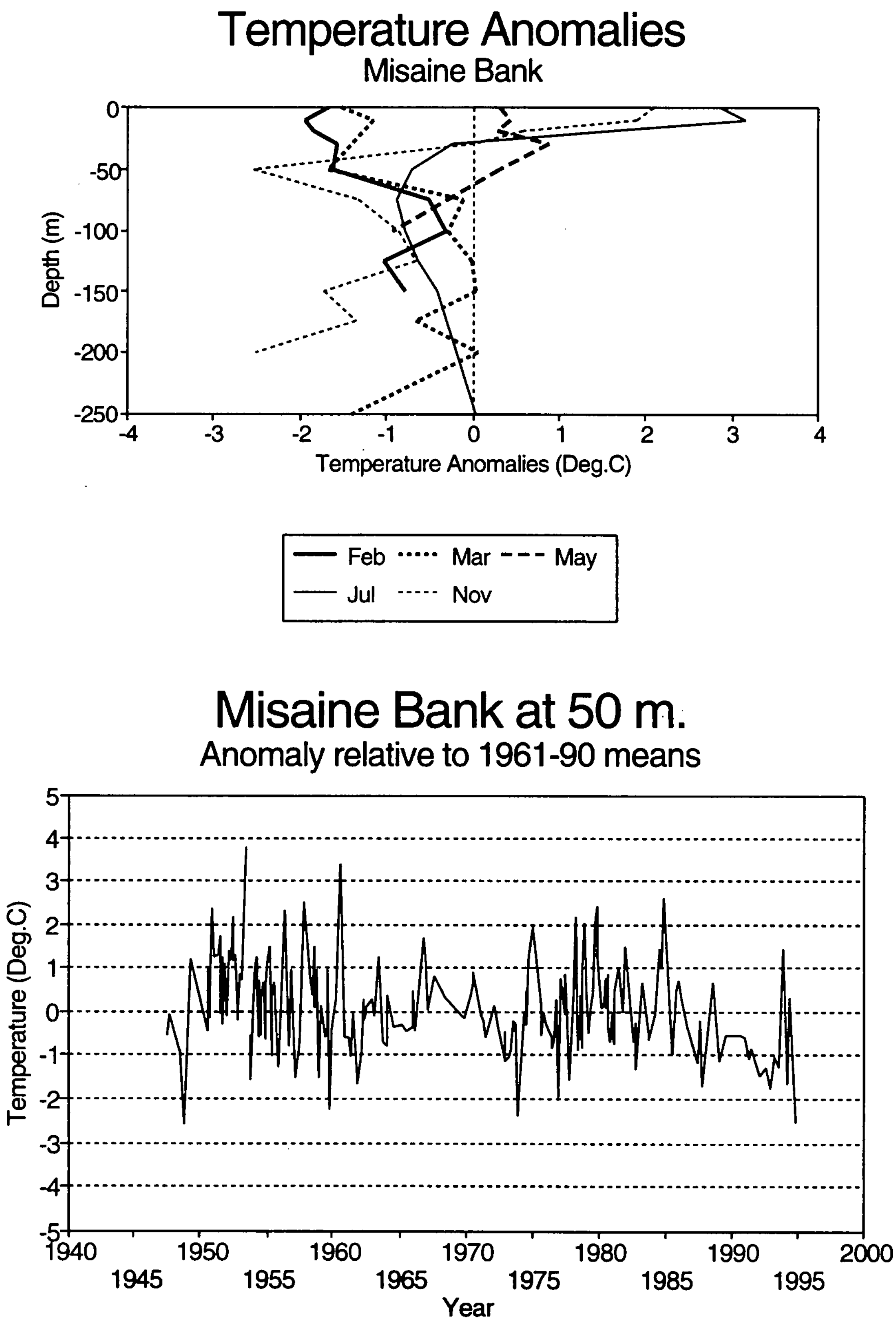


Fig. 11. The 1994 monthly anomaly profiles (top) and time series of temperature anomalies at 50 m (bottom) for Misaine Bank (area 5 in Fig. 9).

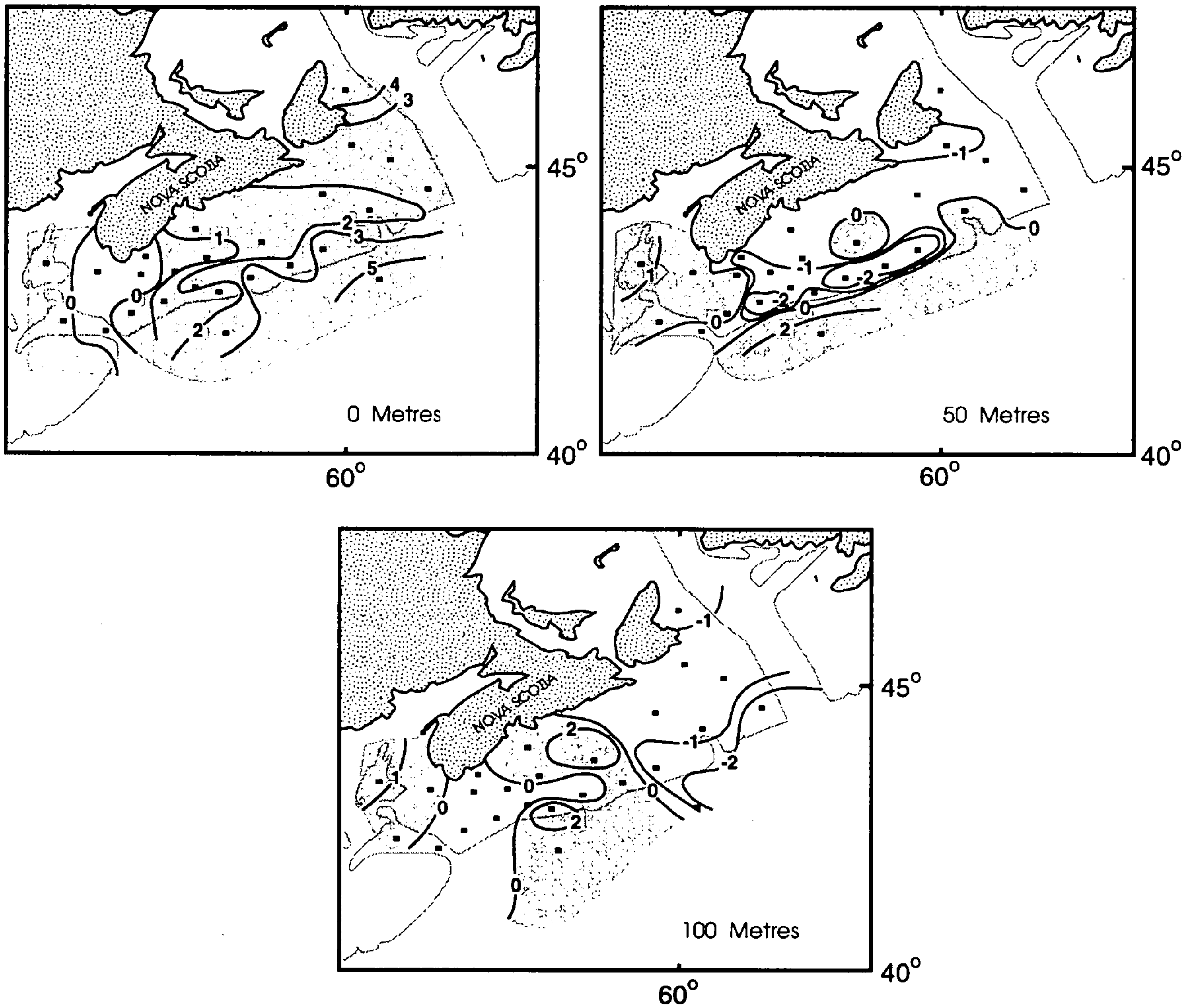


Fig. 12. The temperature anomalies during July at 0, 50 and 100 m based on July data averaged over areas in Fig. 9. Positive anomalies are shaded and the center of the areas in which there were data are denoted by a small square.

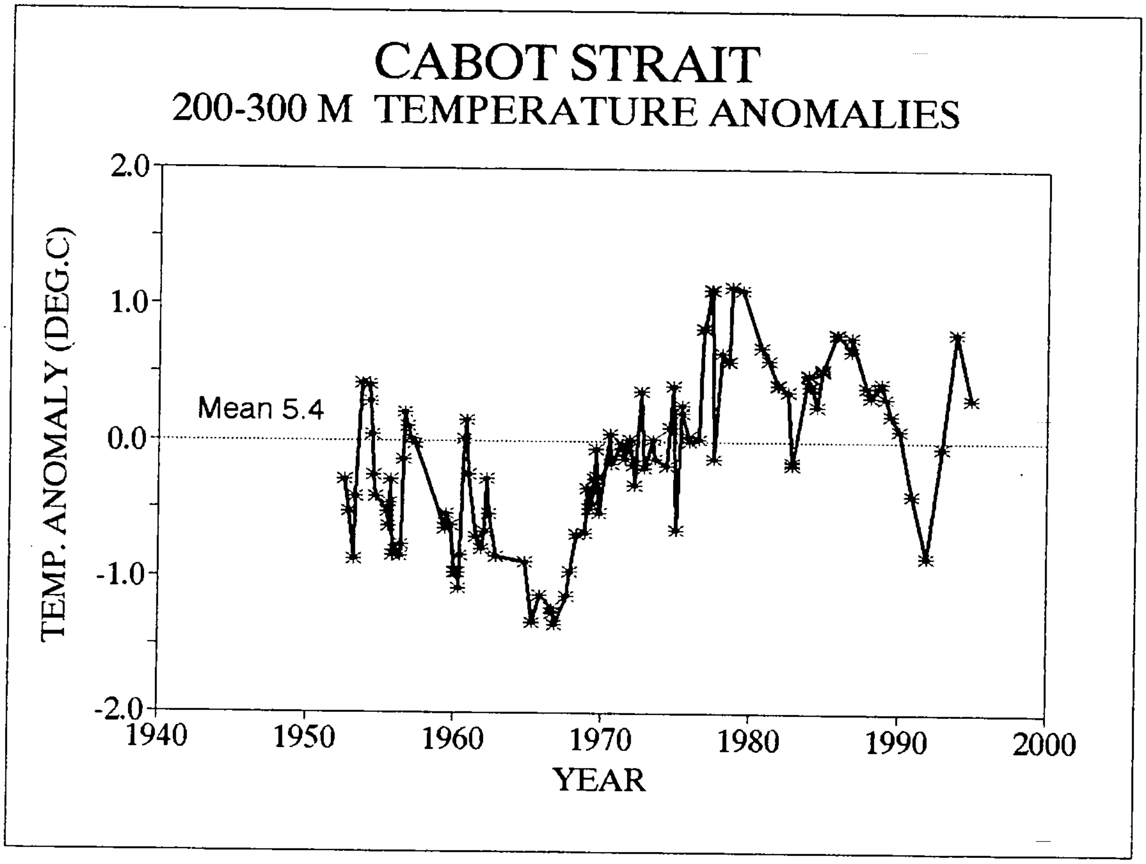
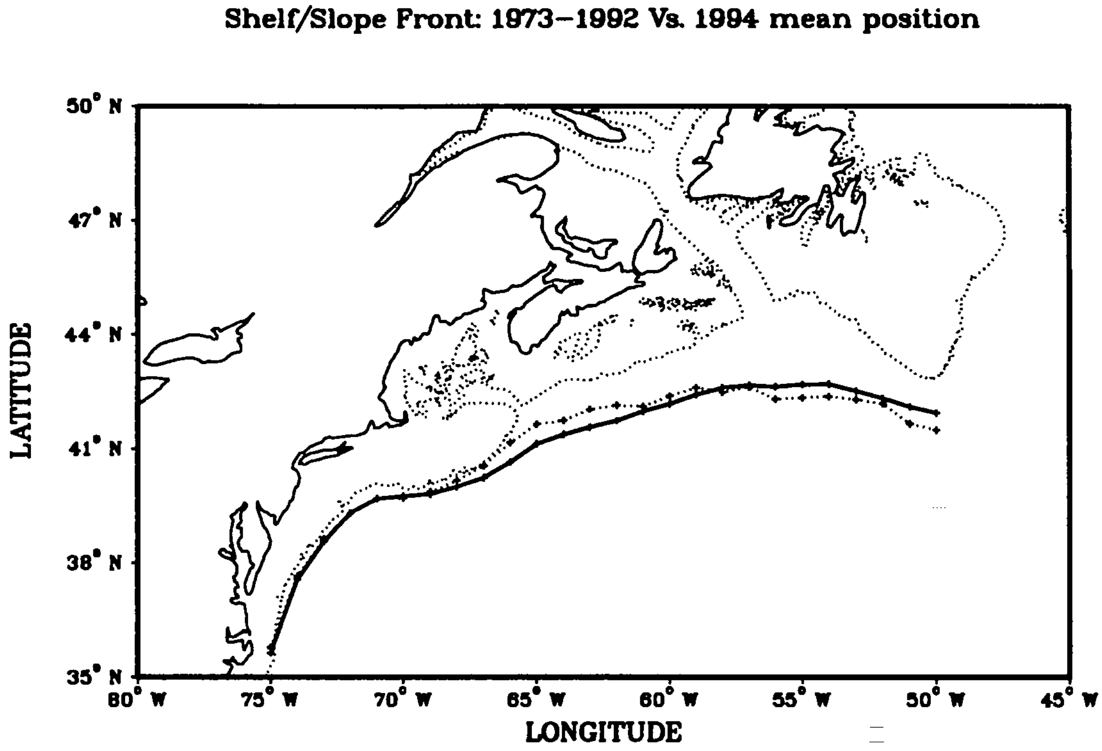


Fig. 13. Anomalies of the average temperature in the 200-300 m depth layer in Cabot Strait.



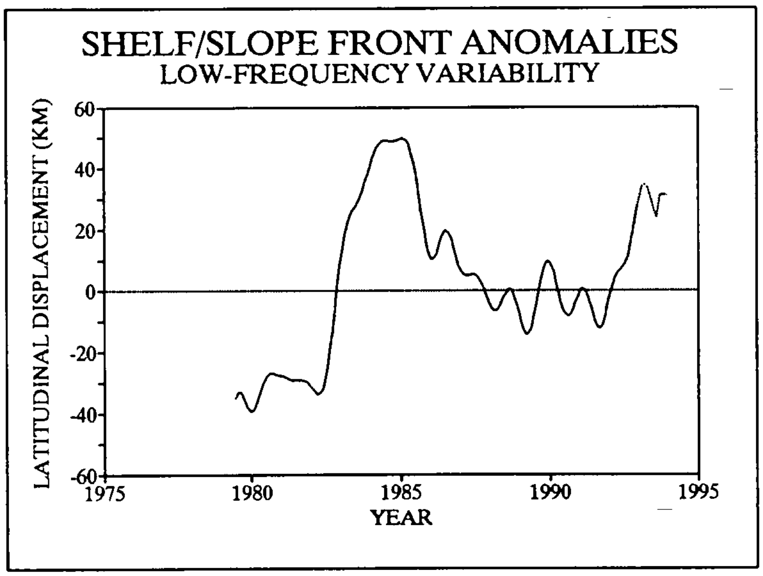
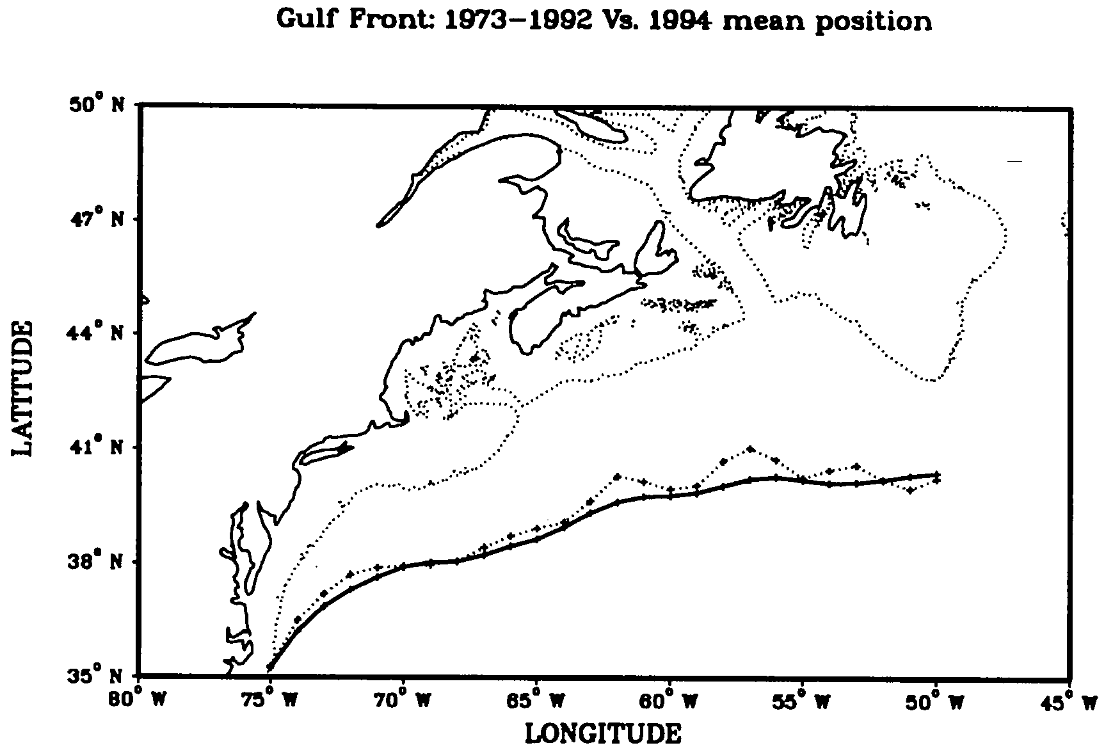


Fig. 14. The 1994 (dashed line) and long-term (1973-90; solid line) mean position of the shelf/slope front (top) and the low-pass filtered time series of the anomaly of the averaged (50°-75°W) position of the Shelf/Slope front (bottom). The dashed line indicates the new data using the 1994 data.



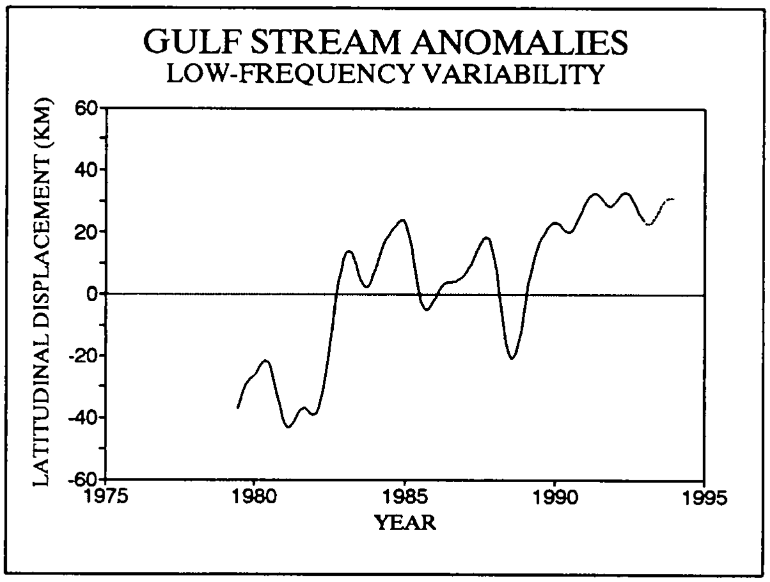


Fig. 15. The 1994 (dashed line) and long-term (1973-92; solid line) mean position of the northern edge of the Gulf Stream (top) and the low-pass filtered time series of the anomaly of the averaged (50°-75°W) position of the Gulf Stream front (bottom). The dashed line indicates the new data using the 1994 data.

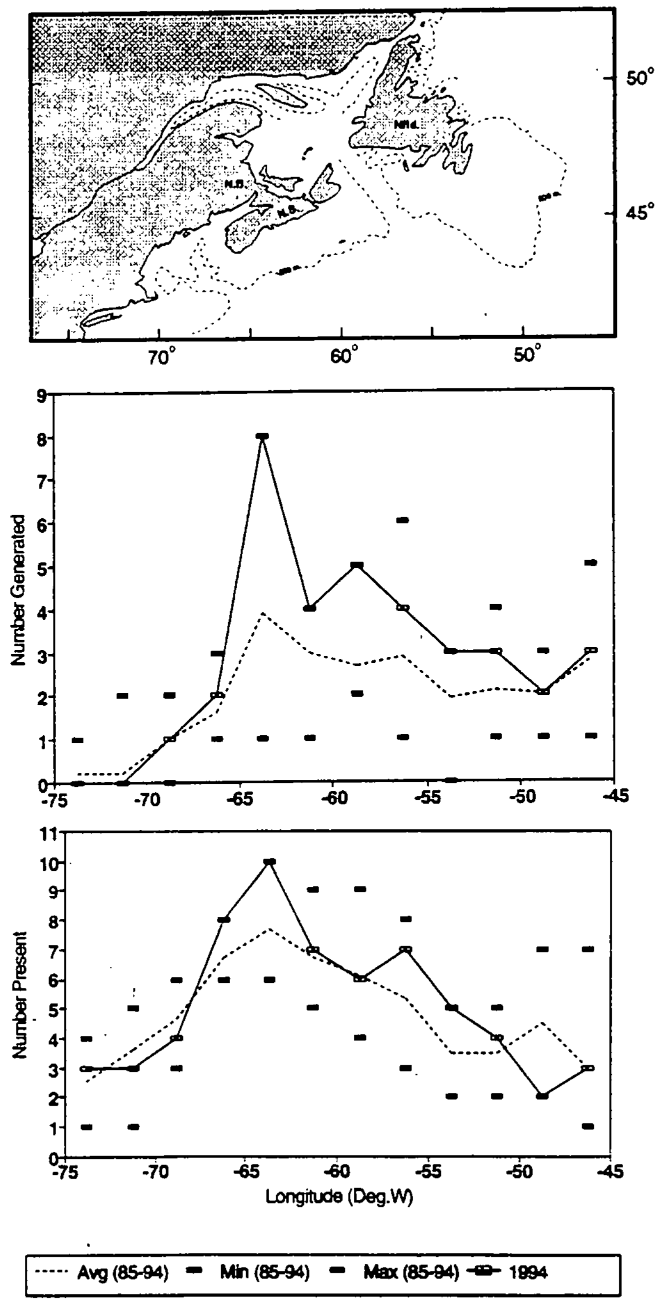


Fig. 16. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1994: (top) the area of interest; (middle) the number of rings generated in each 2.5° zone of longitude; and (bottom) the number of rings present in each 2.5° zone during some part of the year.