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Temperature Conditions in the Gulf of St. Lawrence and on the Scotian Shelf during 1997 Relevant to Snow Crab

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Abstract

Near-bottom temperatures during 1997 in areas of Maritime Canada inhabited by snow crab are presented. Data were available from groundfish surveys in Cabot Strait and Sydney Bight in January, on the Scotian Shelf and Sydney Bight in July, and on the Magdalen Shallows in the Gulf of St. Lawrence in September. Bottom temperatures in large portions of these shelf regions were between -1° and 3°C, conditions considered ideal for snow crab. Relative to the long-term (1961-90) means, bottom temperatures in 1997 were generally colder than the long-term mean (1961-90). Time series of the area of the southern Gulf, Sydney Bight and northeastern Scotian Shelf between -1° to 3°C show that the bottom covered by waters of these properties has been proportionately larger since the late-1980s compared to the 1970s and early 1980s. Analysis of temperatures within each of the snow crab fishing zones show that in the depth range of 50-150 m, temperatures throughout most of the region have generally been below normal since the late-1980s but in the last couple of years has been warming slightly.

Résumé

Les températures à proximité du fond notées en 1997 dans les zones du Canada maritime fréquentées par le crabe des neiges sont présentées. Des données ont été obtenues des relevés du poisson de fond réalisés en janvier dans le détroit de Cabot et la grande baie de Sydney, en juillet sur le plateau néo-écossais et dans la grande baie de Sydney et en septembre sur les hauts fonds des îles de la Madeleine, dans le golfe du Saint-Laurent. Les températures du fond de plusieurs parties de ces zones de plateau oscillaient entre -1 °C et 3 °C, une condition jugée idéale pour le crabe des neiges. Les températures du fond notées en 1997 étaient généralement inférieures à la moyenne à long terme (1961-1990). La série chronologique des zones du sud du Golfe, de la grande baie de Sydney et du nord-est du plateau néo-écossais où la température se situe entre -1 °C et 3 °C montre que la superficie de ces fonds a proportionnellement pris de l'importance depuis la fin des années 1980, comparativement aux années 1970 et au début des années 1980. L'analyse des températures dans chacune des zones de pêche du crabe des neiges indique que, dans la gamme des 50 à 150 m de profondeur, la température de presque toute cette région a généralement été inférieure à la normale depuis la fin des années 1980, mais qu'elle a légèrement augmenté au cours des deux dernières années environ.

Introduction

Snow crab (*Chionoecetes opilio*) is a cold-water species typically inhabiting bottom depths of 80-200 m in water temperatures < 3°C. An active and very lucrative fishery presently exists in the Gulf of St. Lawrence, on Sydney Bight and on the northeastern Scotian Shelf. Annual assessments of the stock abundance, fishing effort, biological characteristics and the environment of the snow crab are undertaken by the Maritimes Region of the Department of Fisheries and Oceans (DFO). The purpose of this paper is to provide information on the temperature conditions during 1997 in areas occupied by snow crab and to compare these temperatures to their long-term means. In contrast to previous reviews (Drinkwater and Pettipas, 1996; Drinkwater et al., 1997), in this paper we have attempted to tailor the temperature analysis more to the snow crab preferences and fisheries zones (see Fig. 1 for location of the snow crab fishing zones). We have, therefore, generated areal indices of bottom water temperatures between -1°C and 3°C for the Gulf of St. Lawrence, Sydney Bight and the northeastern Scotian Shelf. Also, we have provided monthly mean temperature profiles and time series of the monthly mean temperatures at specific depths by snow crab fishing zones. We begin with a description of the temperature data, then provide details of the methods used to analyze the temperature fields and finally present the results.

Data

Extensive near-bottom temperatures in our areas of interest during 1997 were available from three DFO groundfish surveys. All data were collected with a conductivity-temperature-depth (CTD) instrument. The first was undertaken in the Laurentian Channel and adjacent shelf regions during January. For this study, only stations from the western side of the Channel and on the Magdalen Shallows and Sydney Bight were used (Fig. 2a). No data were available south of approximately 46.5°N. The second CTD dataset covered Sydney Bight and the northeastern Scotian Shelf and was part of the annual summer groundfish survey of the Scotian Shelf during July (Fig. 2b). The final dataset was the Gulf of St. Lawrence annual groundfish survey in September that covered the Magdalen Shallows (Fig. 2c). Additional temperature data from 1997 were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive. Pre-1997 data used to estimate long-term means were obtained from the historical hydrographic database maintained at the Bedford Institute of Oceanography (BIO) that contains an edited version of the MEDS holdings.

Methods

The near-bottom temperatures from each of the hydrographic surveys were interpolated onto a specified grid using an objective analysis procedure known as optimal estimation, as described in Drinkwater and Pettipas (1996). This method is similar to other objective techniques such as kriging but offers the advantage that interpolation is 4-dimensional; three space dimensions, two horizontal and one vertical, and the time dimension. In this study the surveys were treated as synoptic and no interpolation in time was carried out. The interpolation used the 15 nearest neighbours within a radius of up to 30 km in the horizontal (x,y) direction and within 15 m of the bottom between 0-50 m and 25 m at depths > 50 m. The maximum profile depth for each station was assumed to be the bottom depth and checked against bathymetric charts. We rechecked the bathymetry files using in previous optimal estimations and found a few incorrect depths, especially in the deeper regions of the Laurentian Channel. In addition to correcting these depths, we increased the maximum depth in the grid for the area off the continental shelf from 500 m to 1000 m which affects the slope region of the Scotian Shelf. The temperature grid for the Scotian Shelf in July and for the Laurentian Channel area in January was 0.2° x 0.2° latitude-longitude and the grid boundaries were selected to match the survey areas. For the Gulf of St. Lawrence in September the grid was 0.1° x 0.1° latitude-longitude. The data were then smoothed and the bottom temperatures contoured. There was, however, no smoothing of the January data because the computer contouring package, through its smoothing routine, produced an unrealistic (weak) temperature gradient over the steep slope of the Laurentian Channel. Instead, the raw optimally-estimated temperatures were hand-contoured. The Gulf of St. Lawrence data collected in September were restricted to depths ≥ 30 m for plotting purposes. This was because inclusion of high temperatures at shallower depths led to strong bottom-temperature gradients towards the coasts which were incorrectly contoured. Also, snow crab do not usually occupy these depths.

Long-term monthly climatological means of the near-bottom temperatures were estimated at each grid point based upon optimal estimations using all available data in the historical temperature, salinity database at the Bedford Institute for the years 1961-1990. The thirty-year period was chosen to coincide with that used by the meteorologists and recommended by the Northwest Atlantic Fisheries Organization (NAFO). The climatological means were then subtracted from the 1997 survey data to produce temperature differences from the long-term means, hereafter referred to as anomalies. We also examined the change in temperature since last year by subtracting the 1996 optimally estimated temperatures from the 1997 estimates.

We calculated the area associated with each grid point on the Scotian Shelf and Sydney Bight and combined these with the optimally-estimated bottom temperatures to estimate the area of the bottom covered by temperatures between -1°C and 3°C. We also estimated the mean temperature within this area. This was carried out for the 1997 surveys as well as for the entire time series of July surveys on the Scotian Shelf and Sydney Bight which began in the 1970s. For the Magdalen Shallows, the -1° to 3°C bottom temperature index for snow crabs was generated from data collected during the September groundfish survey. These data were interpolated onto a grid using kriging. For the Gulf analysis, depths were restricted to ≤ 155 m. These depth limitations were imposed for interannual comparisons because no depths greater than 155 m were sampled during the years 1984-1988. The January surveys have only been carried out for three years and were not included in the areal index analysis.

In addition to the bottom temperatures, monthly mean temperature profiles were determined for each of the snow crab zones (Fig. 1) from the AFAP data base. All available data within each of these zones were averaged by month at standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 250, 300 m). Temperature data from zones 18 and 19, as well as 20 through 22 were combined for the presentation. Estimates of the bottom temperature at any particular depth can be made from these profiles under the assumption of weak horizontal temperature gradients. Annual anomalies were calculated from all available monthly anomalies within the specific calendar year.

Results

Near-bottom Temperatures

Near-bottom temperatures during the January survey of the Laurentian Channel and vicinity ranged from < 1°C in shallow waters on the Magdalen Shallows to over 6°C in the deep Laurentian Channel (Fig. 3). The temperature pattern reflects the topography with a very sharp temperature gradient along the steep slope of the Laurentian Channel. The colder shelf waters (<3°C) are relatively low in salinity, whereas the warmer waters in the deeper Channel are higher in salinity and of offshore (Labrador slope water) origin. Subtracting the long-term means shows that the bottom temperature anomalies in January were mostly above normal, with the largest anomalies (>1°C) on the Magdalen Shallows and on Sydney Bight (Fig. 3). Exceptions were the colder-than-normal temperatures along the slope and in the Laurentian Channel east of the Magdalen Islands, and on the slope near southeastern Cape Breton. Relative to 1996, temperatures appeared to have warmed over Sydney Bight but cooled on the Magdalen Shallows (Fig. 4). In the Laurentian Channel temperatures generally increased by 0° to <2°C.

In July, near-bottom temperatures were estimated for the entire Scotian Shelf although for this study we were only interested in the northeastern region and Sydney Bight. The data show that in these areas, bottom waters were primarily <4°C with a significant portion <3°C (Fig. 5). Temperatures were principally below their long term means with anomalies mostly between 0° and 1°C (Fig. 5). This represents an increase in temperature relative to July 1996 over the inner half of the northeastern Scotian Shelf (Fig. 6) and continues the warming trend observed in 1996. In contrast, on the outer banks, such as Banquereau and Sable Island, bottom temperatures decreased in July 1997 relative to July 1996.

On the Magdalen Shallows, bottom temperatures below 30 m show a typical range of < 0°C to over 10°C (Fig. 7). The coldest waters extend over a large region north of Prince Edward Island (PEI) in depths of 50-80 m. From there, bottom temperatures tend to increase towards the shallower, near shore regions and towards the deeper Laurentian Channel. This is because during summer in the Gulf of St. Lawrence the coldest temperatures are found at intermediate depths (50-150 m). These cold intermediate layer (CIL) waters are sandwiched between the warm solar-heated upper layer waters and the relatively warm, salty deep waters of the Laurentian Channel. In winter, the CIL layer merges with the upper layer as the latter cools. The origin of the waters in the CIL is thought to be by advection of cold Labrador Shelf water through the Strait of Belle Isle and atmospheric cooling of the water within the Gulf of St. Lawrence in winter. The warmest, near-bottom waters are in the shallowest regions, in particular around the Magdalen Islands and along sections of the coast off PEI, Nova Scotia and New Brunswick. The majority of the bottom was covered by waters that were generally below normal by 0 to 1°C. The coldest anomalies were located off northwestern PEI and St. Georges Bay, Nova Scotia. In contrast to 1996, there was a greater portion of the bottom with temperatures above their long-term average during 1997 (Fig. 8).

Areal Index of Cold Water for Snow Crab

Snow crab generally occupy bottom temperatures between -1°C and 3°C. We have therefore, estimated the area of bottom covered by temperatures within this range for the northeastern Scotian Shelf and Sydney Bight based upon data collected during the July surveys and for the Gulf of St. Lawrence based upon the September surveys. This is referred to as the snow crab habitat index. From the July surveys, a time series of the snow crab habitat index based upon optimally-estimated bottom temperatures is available from 1970 to present. For the northeastern Scotian Shelf the grid we used occupied a total area of 70426 km^2 (201 grid points) while on the Sydney Bight the total area was 7801 km^2 (23 grid points). Due to insufficient data coverage no index was estimated for 1975 and 1976 on the Scotian Shelf and 1971, 1973-1976 and 1984 for Sydney Bight. We also estimated the average temperature within the area covered by -1°C to 3°C and correlated these with the areal index.

On the northeastern Scotian Shelf, the snow crab habitat index in 1997 was 35,300 km^2 representing approximately 50% coverage of the total grid area. This index has been relatively high since the mid-1980s and near constant since the early 1990s (Fig. 9). The maximum coverage was reached in 1991 (over 60% of the total grid area). These results are consistent with the hypothesis of Tremblay (1997) that the expansion of the areal distribution of snow crab on the Scotian Shelf during the 1990s was related to an increase in their preferred habitat. The minimum bottom area covered by temperatures between -1°C and 3°C occurred in 1984 (only 4.5% of the bottom) and was relatively small in the late 1970s and early 1980s (< 30%). On the Scotian Shelf, the average temperatures within this area is highly correlated with the size of the area ($r=-0.88$, $p<.001$). Thus, when the area of the preferred snow crab habitat increases there is usually a decrease in the temperature within this area (Fig. 9). However, since 1995, the snow crab habitat index has been decreasing but there has not been a corresponding increase in the bottom temperature.

On Sydney Bight, the snow crab habitat index in 1997 was relatively high (representing slightly over 30% coverage of the total grid area) and has been (varying between 26-43%) since the mid-1980s (Fig. 10). Prior to 1982, the index was low (generally <20%). The lower percent coverage of the bottom with temperatures between -1°C and 3°C on Sydney Bight compared to the Scotian Shelf is due to the greater percentage of the grid area for the former being in deep regions (>200 m deep and hence in the relatively warm waters of the Laurentian Channel). Correlations between the average temperature within the index area and the habitat index itself were low and not significant (Fig. 10). The reason for the difference between the Scotian Shelf and Sydney Bight in this regard is not known, however, on Sydney Bight there was much lower spatial resolution because of the reduced number of grid points to average over. This reduced resolution may have contributed to the lack of correlation.

The area of the bottom covered by waters between -1°C and 3°C in the Magdalen Shallows during the September groundfish survey also shows a relatively high value (over 55000 km^2) in 1997 (Fig. 11). This represents about 80% of the Magdalen Shallows grid. This habitat index has been relatively steady for the last 5 years and only slightly less than the peak in 1990. It is also consistent with the very cold CIL waters throughout the Gulf of St. Lawrence since the mid-1980s as first revealed by Gilbert and Pettigrew (1997) and updated in Drinkwater et al. (1996).

Monthly Mean Temperature Anomaly Profiles and Time Series

Monthly mean temperature profiles were determined within the snow crab fishing zones (see Fig. 1 for boundaries used in the temperature analysis). At the time of writing, data over the central Magdalen Shallows (zone 12) for 1997 were only available during September, i.e. from the annual groundfish survey. Expressed as deviations from the long term (1961-90) mean, the mean anomaly profile for September shows below normal temperatures from 20 to 175 m (Fig. 12). This depth range covers most of the bottom depths over the Magdalen Shallows. Below 175 m and in the top 10 m the anomalies are positive. The deeper data would have been collected in the Laurentian Channel. The time series of monthly mean temperatures at 75 m shows high variability but a definite tendency for below normal temperatures since the mid-1980s (Fig. 12). Note that not all months of each year contain data. Recent years have suggested a slight warming trend although the temperatures have generally remained below normal. This is consistent with the snow crab areal index results discussed above and the cold intermediate layer results published by Gilbert and Pettigrew (1997). Part of the high month to month variability shown in Fig. 12 is believed to be due spatial differences in sampling.

These results contrast with zone 26 (formerly 25 and 26), north of Prince Edward Island. Again only data from September were available and they show positive anomalies (up to 2°C) over the top 50 m. Most of the zone contains depths less than 60 m. The time series at 30 m shows no consistent trend in recent years (Fig. 13). At 50 m (not plotted) there is a tendency towards negative anomalies since the mid-1980s but not as consistently as in zone 12. There are also much less data at 50 m then at 30 m in zone 26. At the shallower depths, temperature will be determined by local atmospheric processes and can change within relatively short (< a month) time scales. This contrasts with the deeper waters on the Magdalen Shallows (>50 m) which are more isolated from the effects of short-term storms and reflect instead the overall winter conditions. Because of the short term temperature variability in these shallower waters and the general lack of data in any one month, zone 26 is considered to be undersampled. Therefore, the time series of monthly mean temperatures for this zone may not reflect true trend and any results must be interpreted with extreme caution.

Temperatures within fishing zones 18 and 19 along the Gulf side of Cape Breton Island were combined for this analysis. They contain deep data from the Cape Breton Trough. Measurements were made during both January and September of 1997 and the mean profiles indicate colder-than-normal conditions at depths ranging from 50 m to 125 m and below (Fig. 14). Representative of this depth range, the time series at 100 m shows these cooler conditions have persisted since at least the late 1980s (Fig. 14). At 150 m there are few data and no overall trend was observed. Data during January and September of 1997 were also available from zone F. In January the upper 50 m of the water column was above normal while deeper than 50 m the anomalies were negative (Fig. 15). In September, temperatures were warmer-than-normal except at 20 and 30 m and at 100 and 125 m. The time series at 100 m in zone F is similar to both zone 12 and the combined 18&19, i.e. a strong tendency towards below normal anomalies since about the mid-1980s (Fig. 15). This 100 m record is reasonably representative of conditions from 75 to 150 m in zone F. To the north in zone E, data were only available during September. The mean temperature anomaly profile for this month shows colder-than-normal temperatures at mid-depths (20-100 m), with warmer-than-normal values above (top 10 m) and normal conditions deeper than 100 m. The temperature time series at 100 m for zone E shows the typical pattern of negative anomalies since the mid-1980s (Fig. 16). Deeper than 100 m there is also the tendency for below normal temperatures since the mid-1980s but with several measurements warmer-than-normal.

The temperature data for snow crab fishing zones 20 through 22 were combined in our analysis. From the 7 months of 1997 when observations were taken, no dominant trend emerged (Fig. 17). The time series at 100 m shows colder-than-normal waters since the mid-1980s but warming during recent years (Fig. 17). This same pattern is observed from 50 to 150 m and is consistent with that reported for the Sydney Bight region in last year's report (Drinkwater et al., 1997).

On the northeastern Scotian Shelf in zone 23, temperatures below approximately 50 m were predominantly below normal in 1997 and the time series shows familiar pattern of cold temperatures since about the mid-1980s with temperatures in recent years trending upwards (Fig. 18). This is consistent with the results presented in past reports based upon data from Misaine Bank (Drinkwater et al. 1997). In zone 24, data were available in 6 months of 1997. Although there is the tendency towards below normal temperatures deeper than 50 m in 1997, the observations reveal more variability than for zone 23 (Fig. 19). The time series analysis also shows a less consistent pattern than in zone 23 although there has been the tendency towards a greater percentage of the measurements being below normal since the late 1980s (Fig. 19). Within zone 24, to the northeast of Middle Bank lies relatively cold bottom temperatures (<4°C), the origin of which is primarily the Gulf of St. Lawrence. To the southwest of the Bank towards Emerald Basin, the zone includes bottom waters with warmer temperatures whose origins are offshore slope waters. These waters penetrate onto the shelf between Emerald and LaHave banks, flooding into Emerald Basin and surrounding regions. These waters have been warmer-than-normal during recent years in contrast to those waters to the northeast. The distribution of data within zone 24 can greatly affect the monthly mean temperature and hence any apparent trends must be viewed with caution for this zone.

Summary

Near-bottom temperatures collected during groundfish surveys in January in Cabot Strait and Sydney Bight, in July on the northeastern Scotian Shelf and in September on the Magdalen Shallows during 1997 have been compared to their long term means. Additional temperature data were also examined. There was a tendency for colder-than-normal conditions throughout the region at bottom depths from approximately 50 m to 250 m. Such cold conditions have persisted since the mid- to late-1980s. A snow crab habitat index based upon the area of temperatures preferred by snow crab (-1°C to 3°C) was constructed. This index was near its maximum in 1997 with relatively large portions of the shelf region containing suitable habitat for snow crab. The index has been high since the late-1980s. Temperature analysis in each of the snow crab fishing zones reveal a consistent pattern of colder-than-normal bottom temperatures in most zones since the mid- to late-1980s although there has been slight warming in recent years. Exceptions include the zone north of PEI (26) and zone 24 on the northeastern Scotian Shelf where no consistent temperature pattern was observed.

Acknowledgements

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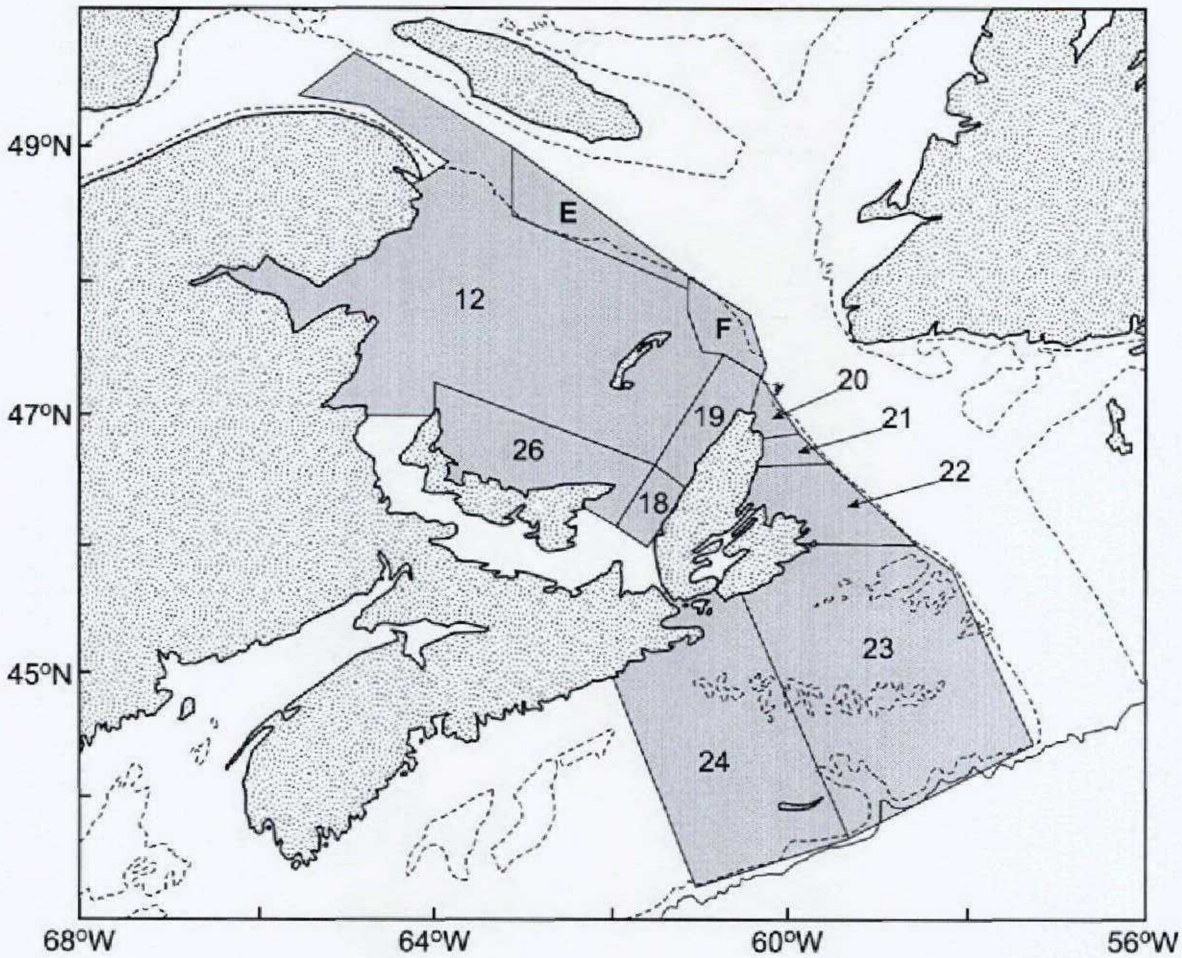


Fig. 1. The Gulf of St. Lawrence and Scotian Shelf showing boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated.

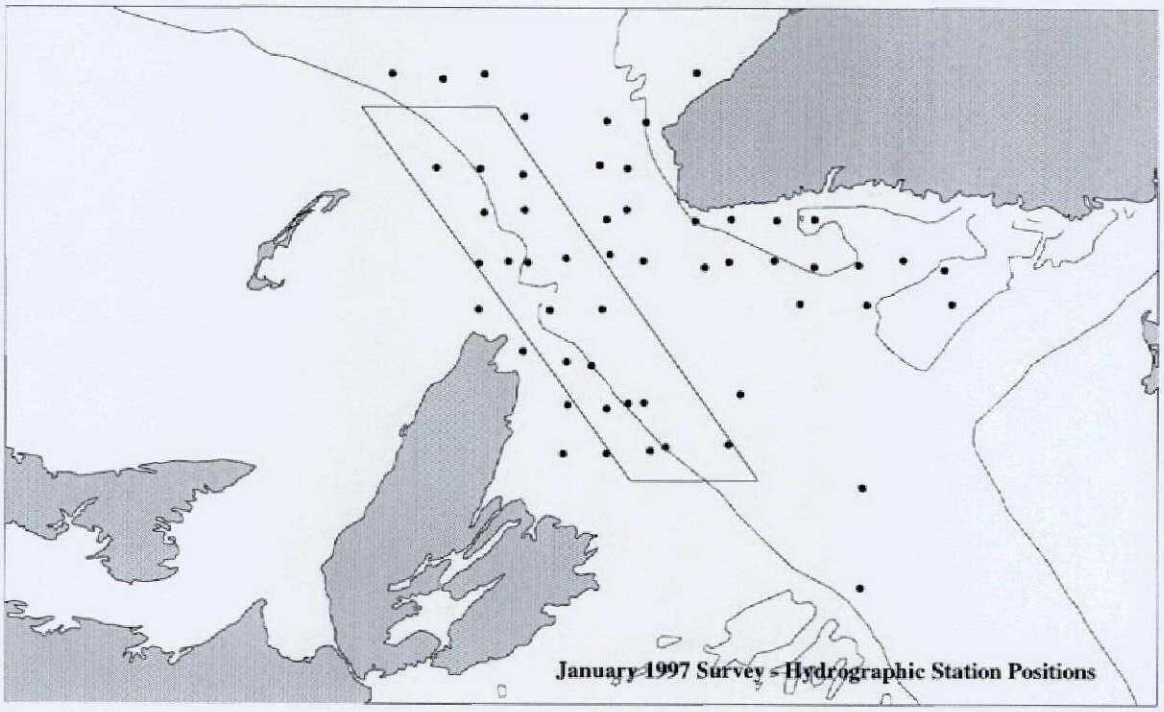


Fig. 2a. The location of the CTD stations taken during the January 1997 survey. The box indicates the area within which the bottom temperatures were optimally estimated.

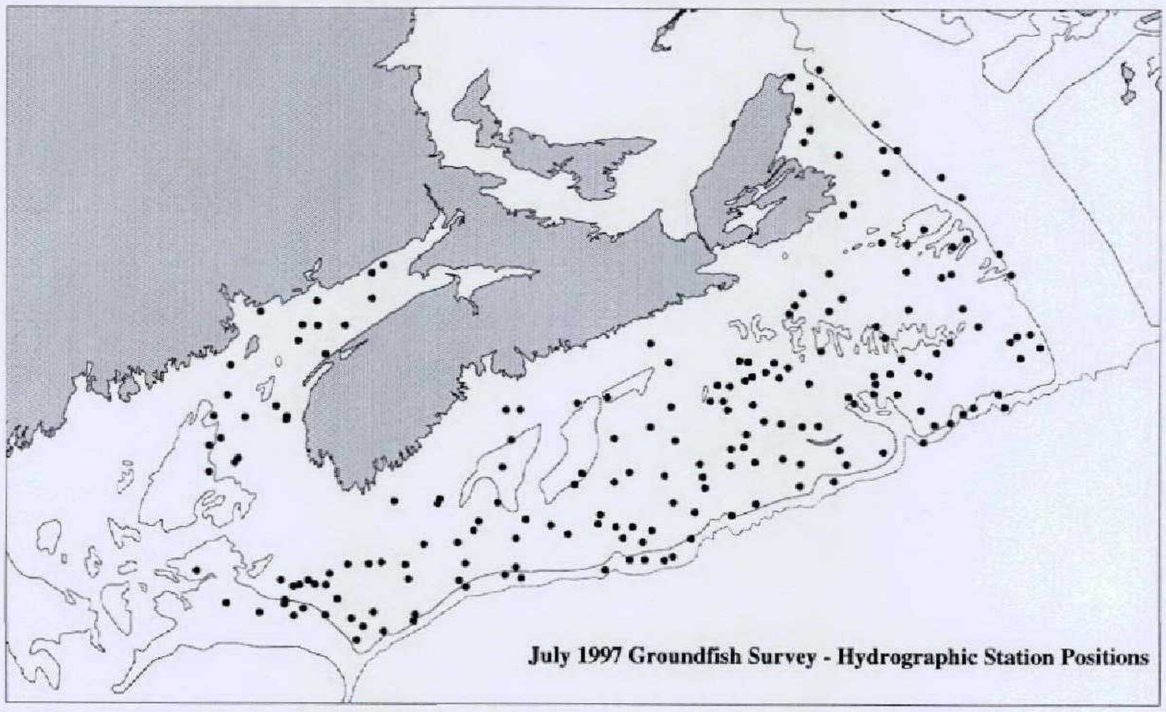


Fig. 2b. The location of the CTD stations taken during the July 1997 survey.

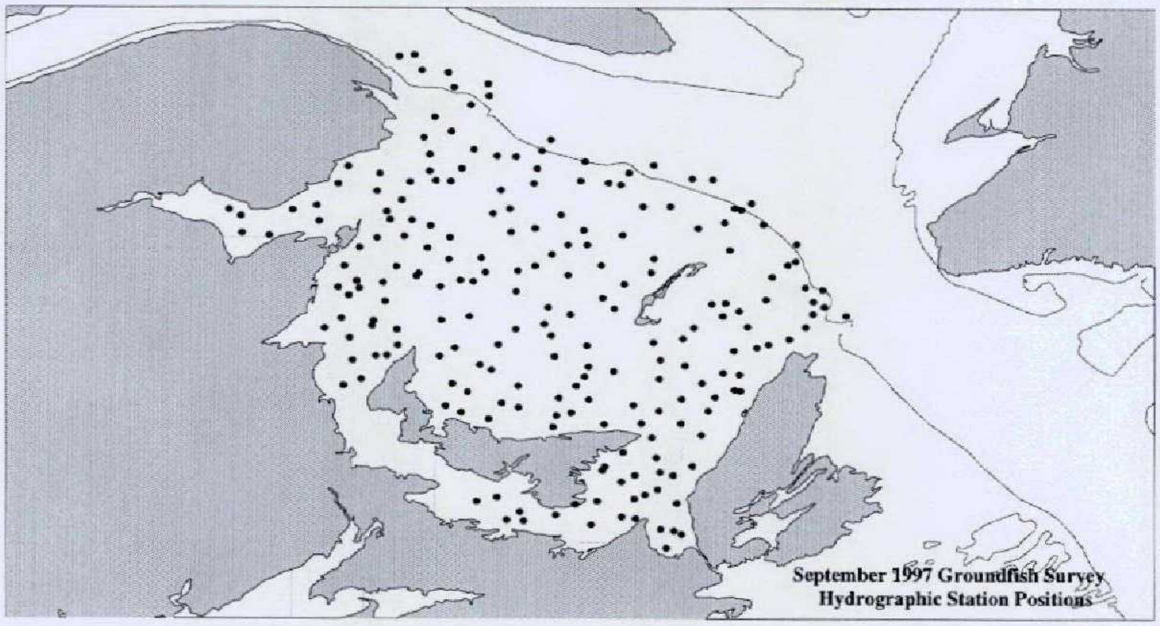


Fig. 2c. The location of the CTD stations taken during the September 1997 survey.

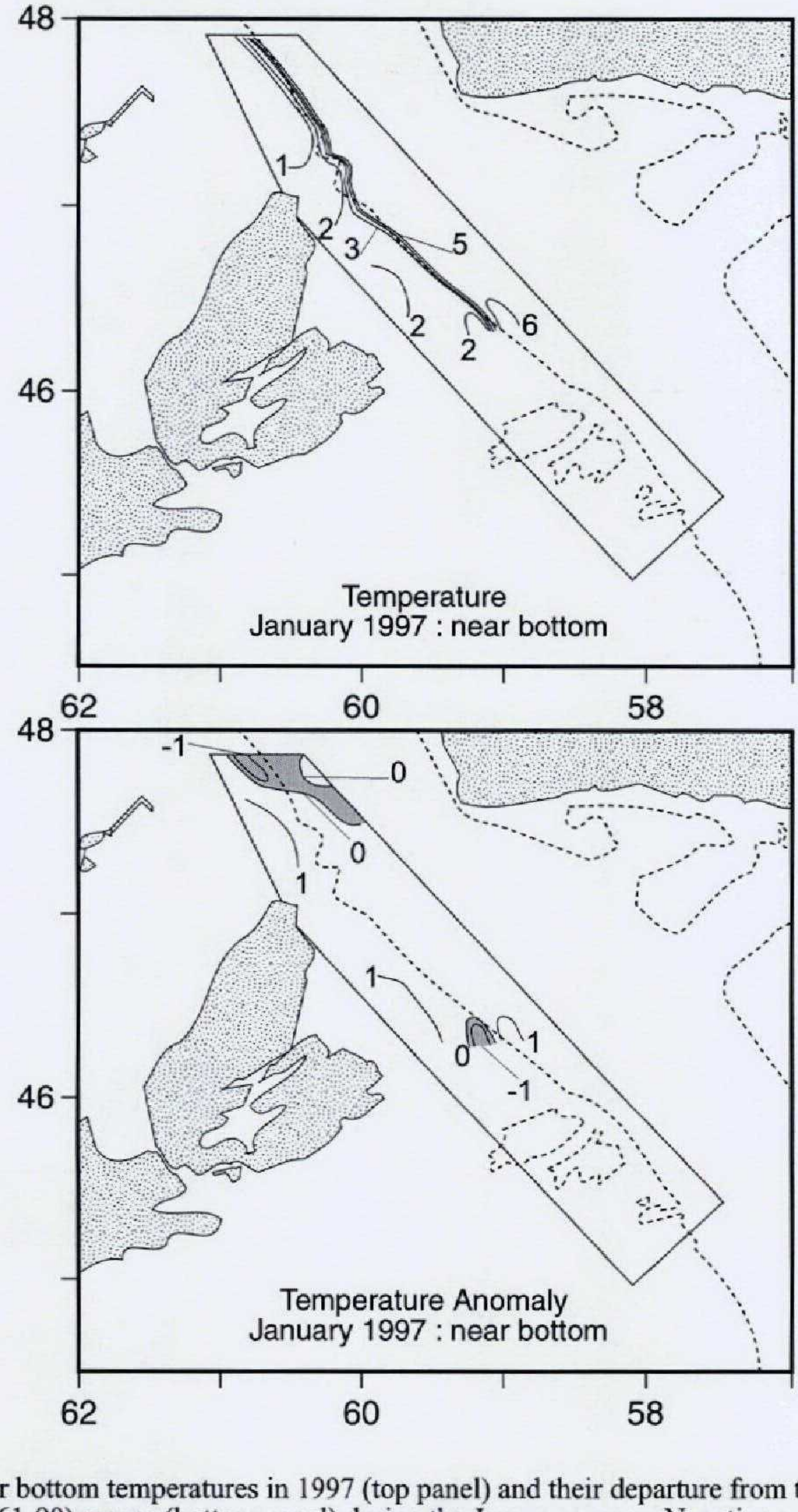


Fig. 3. Near bottom temperatures in 1997 (top panel) and their departure from the long-term (1961-90) means (bottom panel) during the January survey. Negative anomalies are shaded.

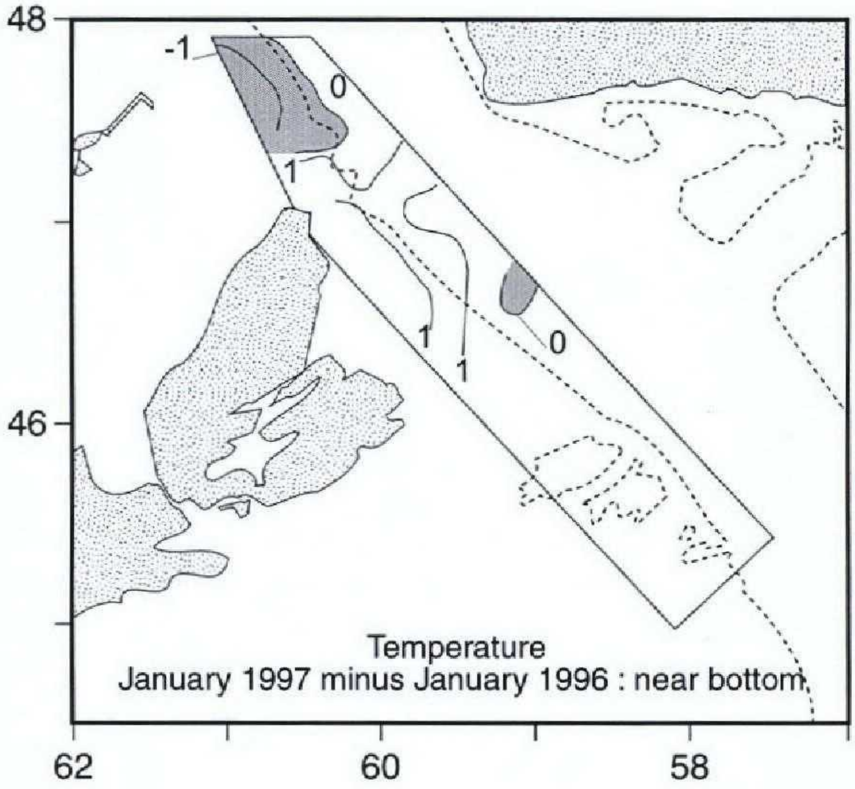


Fig. 4. The difference between the 1997 and 1996 temperature fields for the January survey. Positive values indicate warming in 1997 and negative a cooling. Negative differences are shaded.

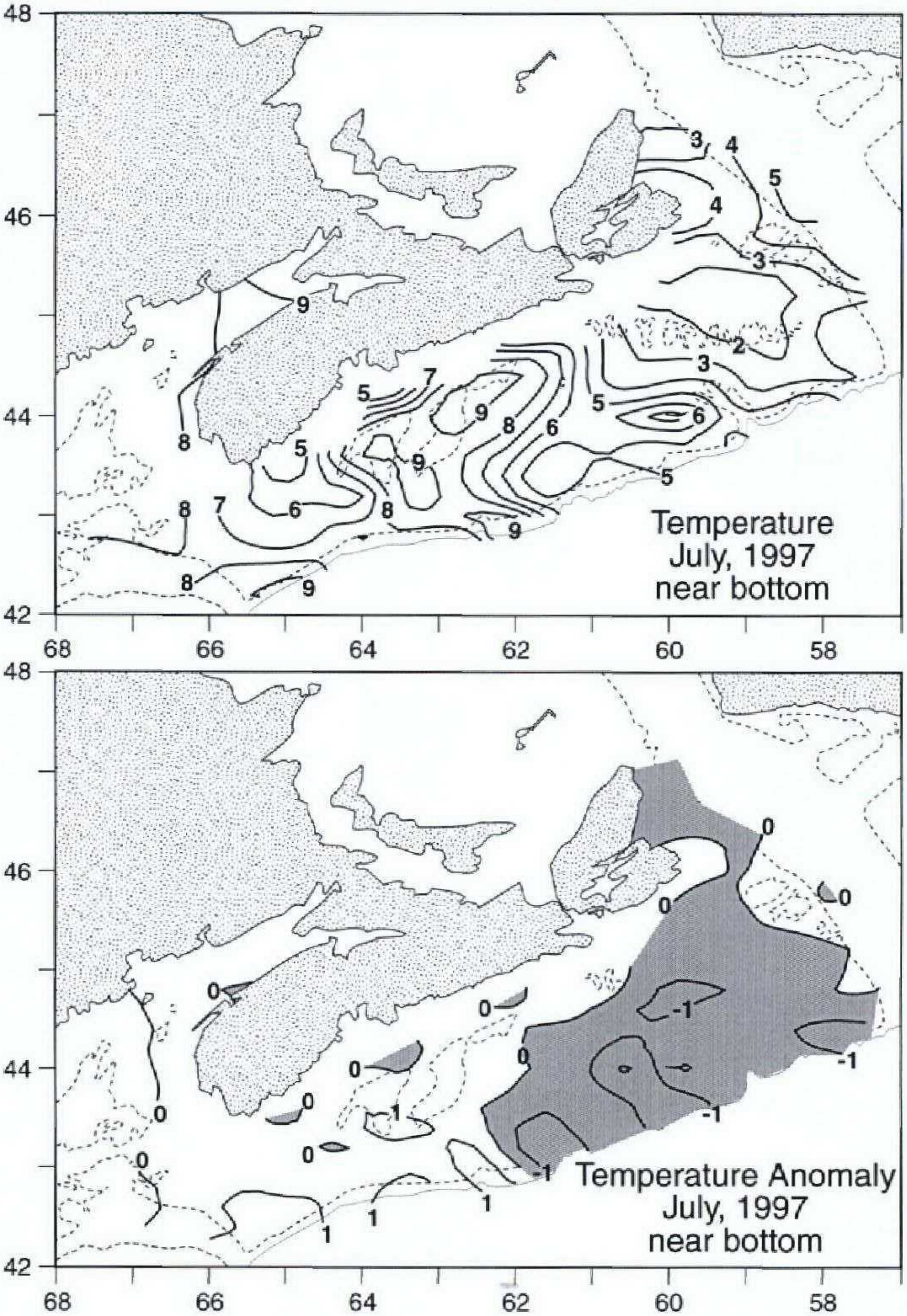


Fig. 5. Near bottom temperatures in 1997 (top panel) and their departure from the long-term (1961-90) means (bottom panel) during the July survey. Negative anomalies are shaded.

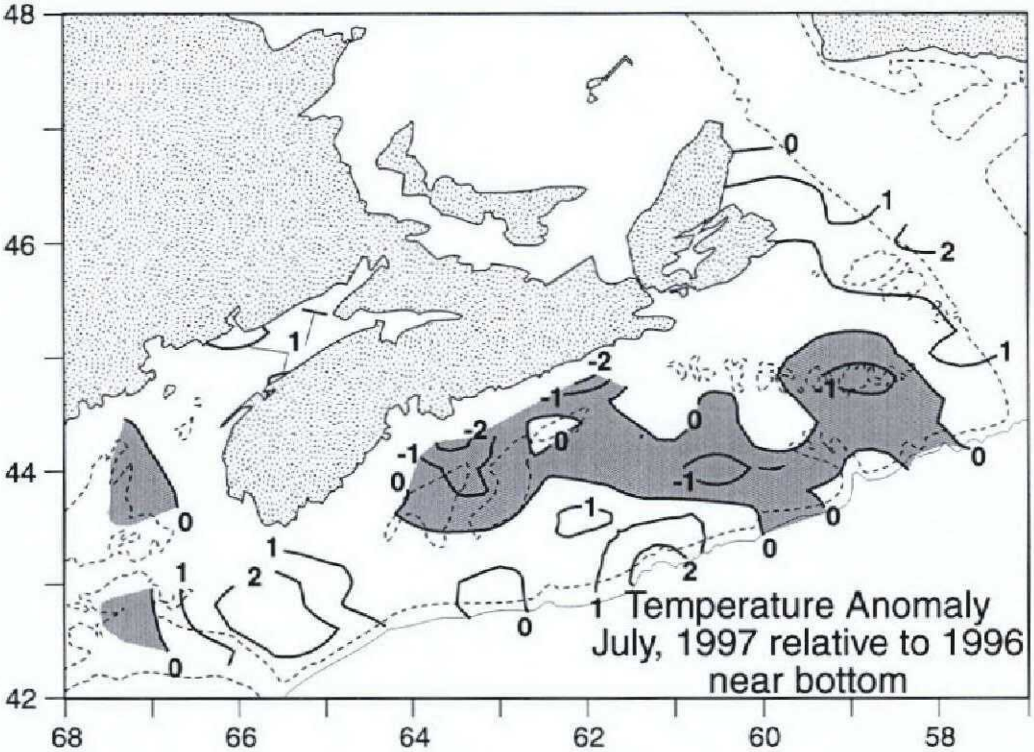


Fig. 6. The difference between the 1997 and 1996 temperature fields for the July survey. Positive values indicate warming in 1997 and negative a cooling. Negative differences are shaded.

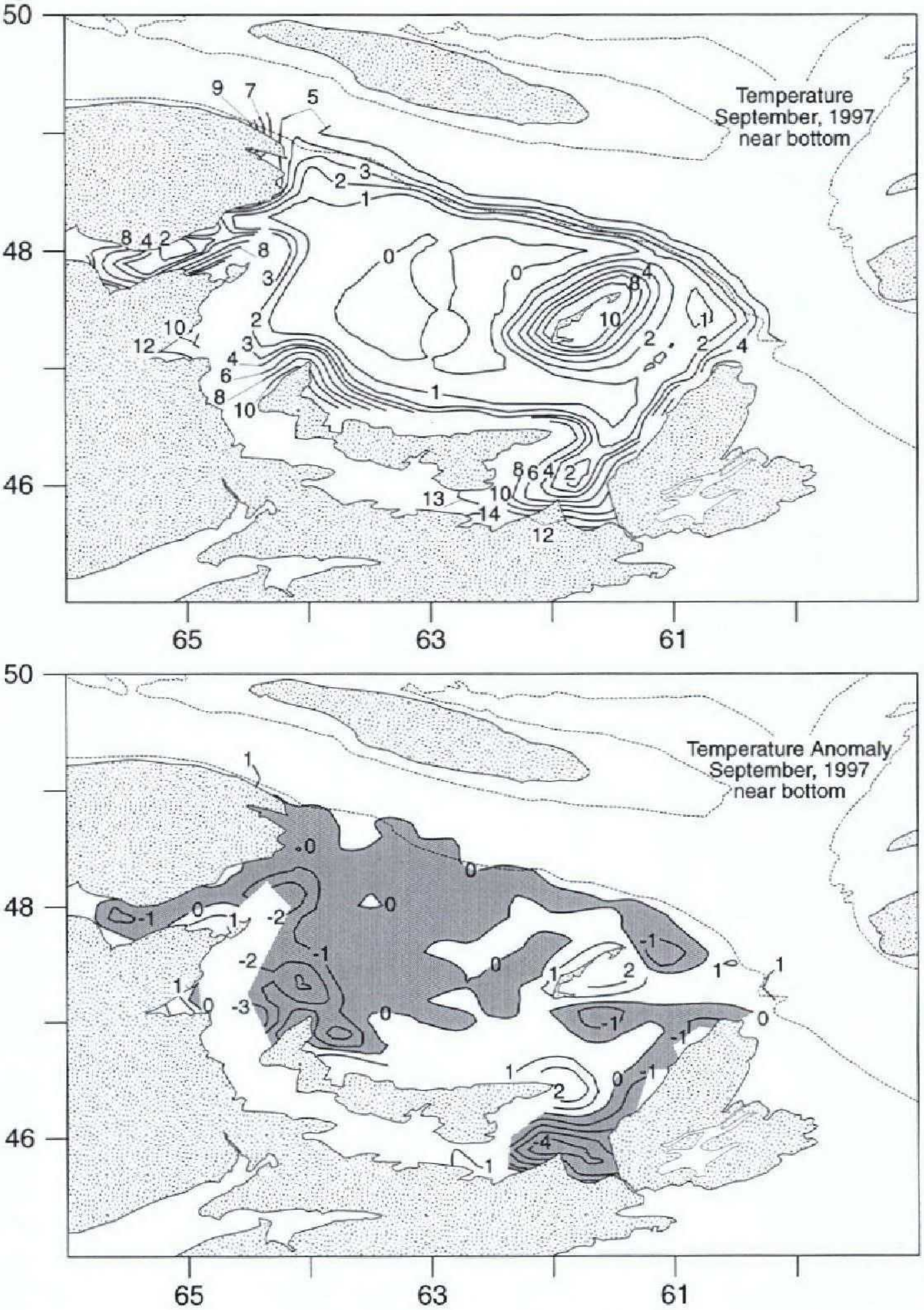


Fig. 7. Near bottom temperatures in 1997 (top panel) and their departure from the long-term (1961-90) means (bottom panel) during the September survey. Negative anomalies are shaded.

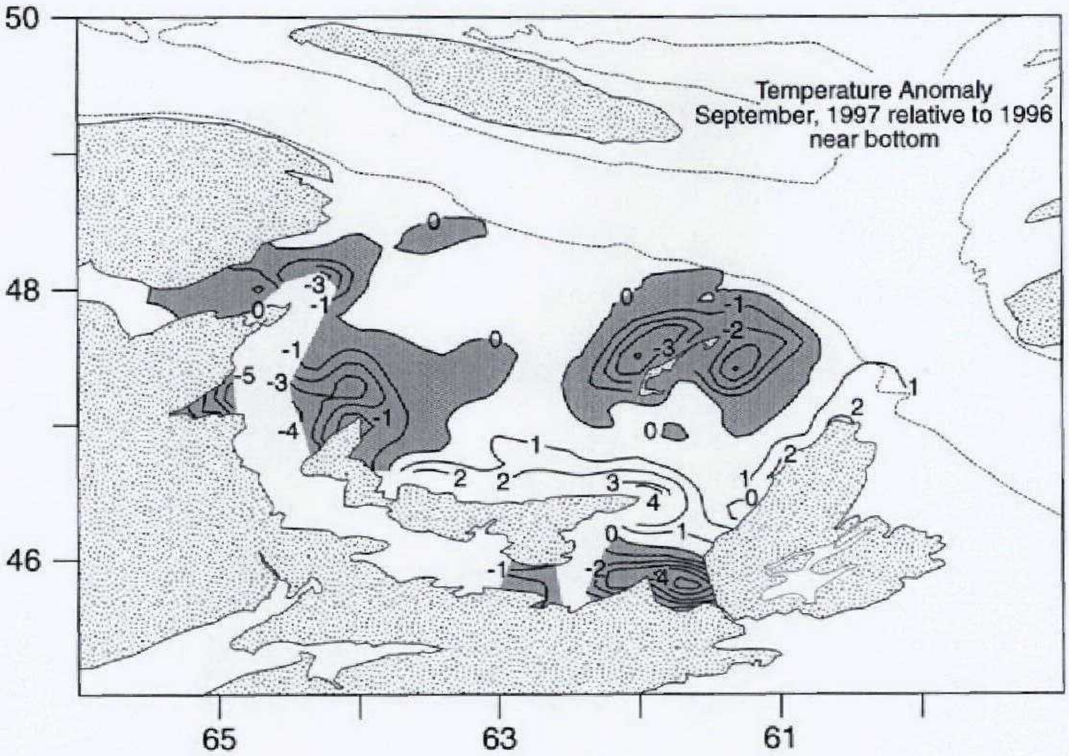


Fig. 8. The difference between the 1997 and 1996 temperature fields for the September survey. Positive values indicate warming in 1997 and negative a cooling. Negative differences are shaded.

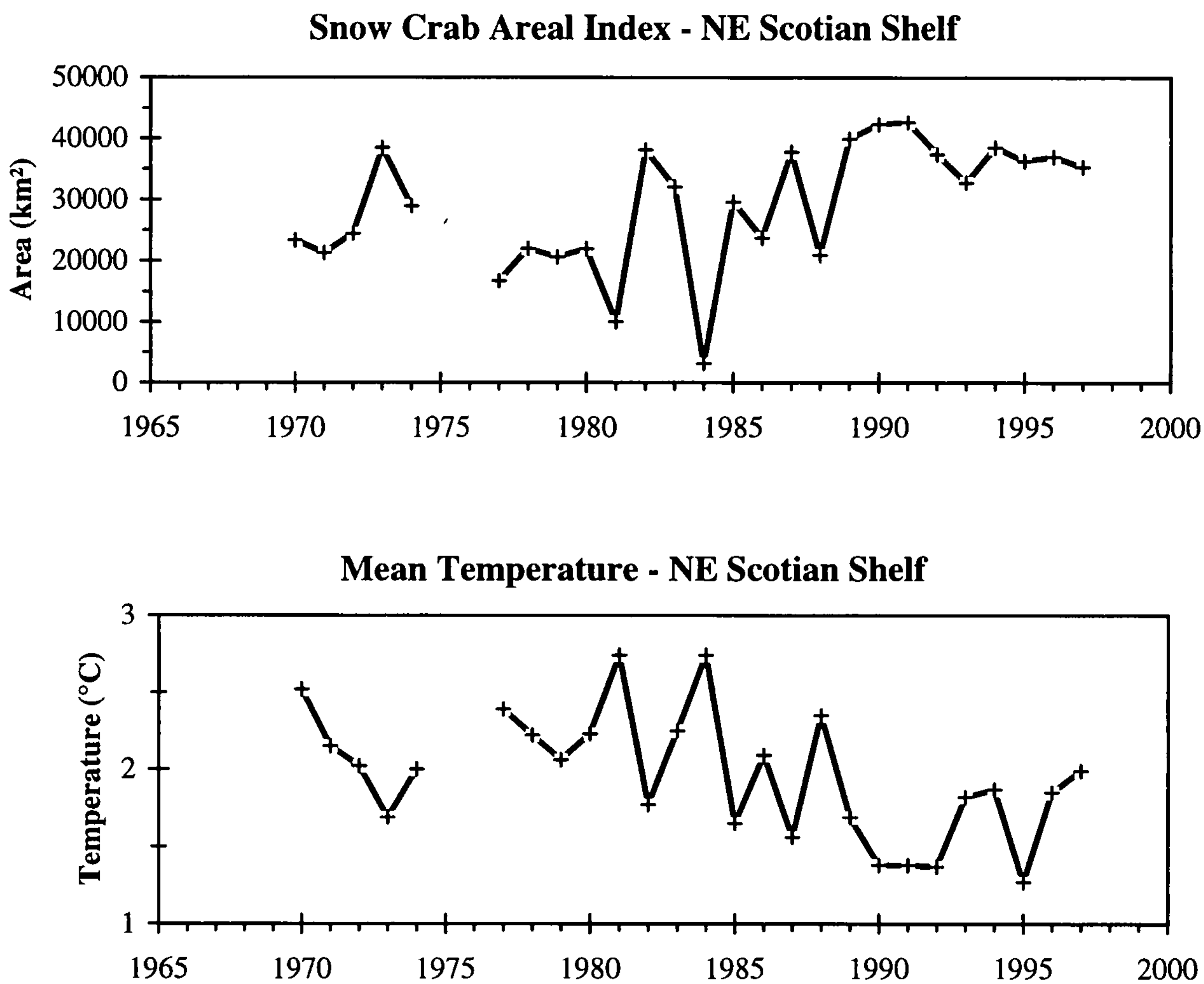


Fig. 9. Time series of the area of the northeast Scotian Shelf covered by bottom temperatures between -1° and 3°C (top panel) and the mean temperature within that area (bottom panel).

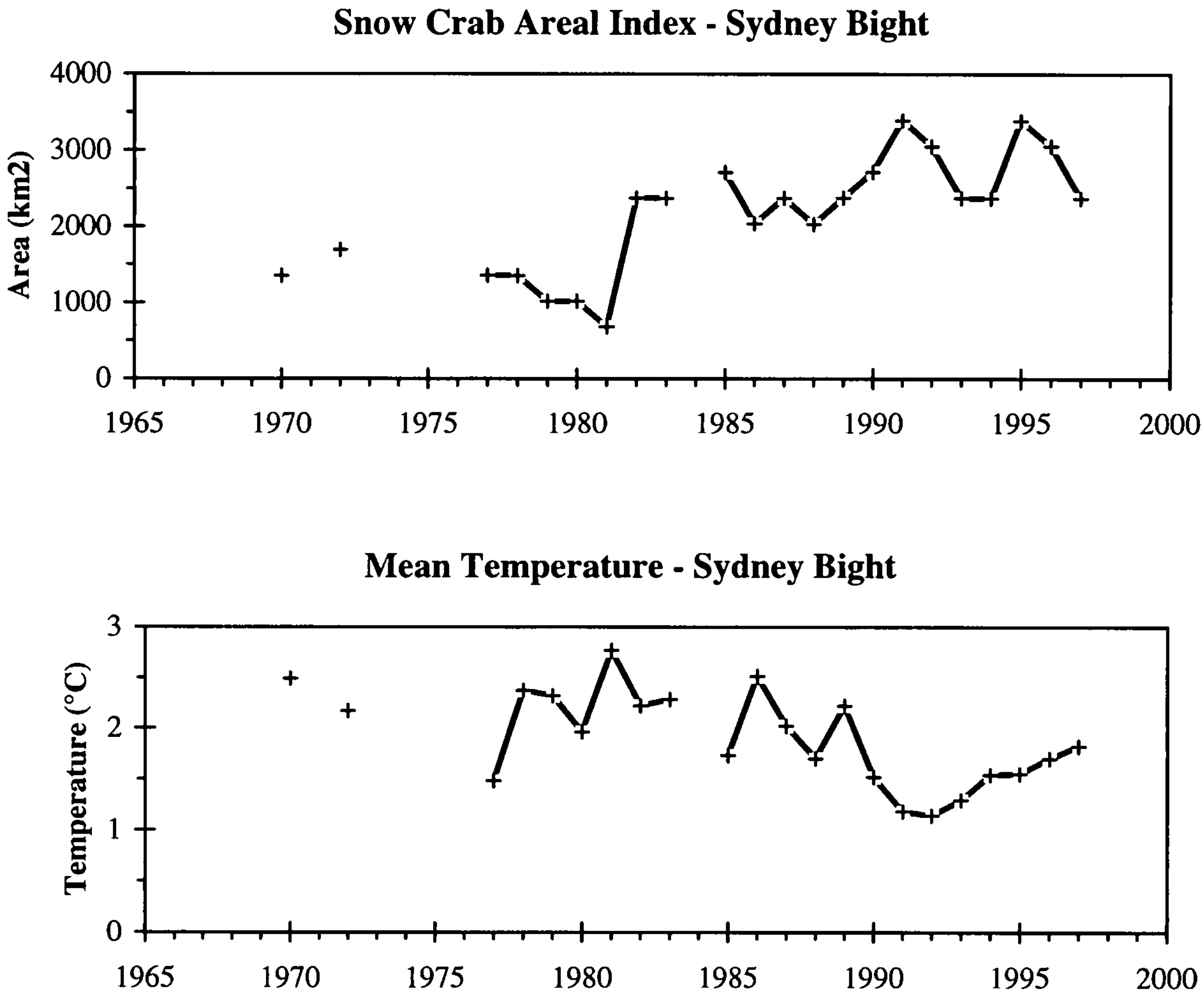


Fig.10. Time series of the area of Sydney Bight covered by bottom temperatures between -1° and 3°C (top panel) and the mean temperature within that area (bottom panel).

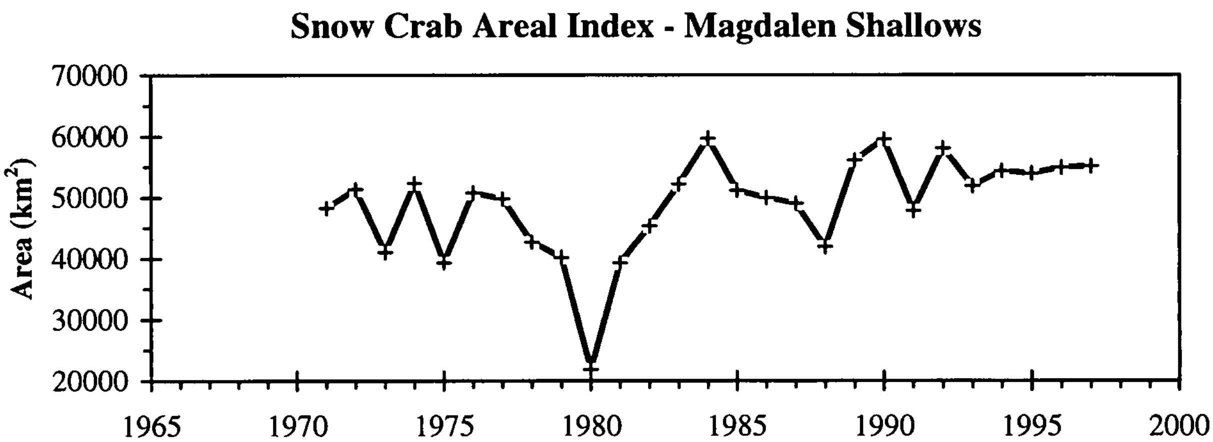


Fig.11. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C (top panel).

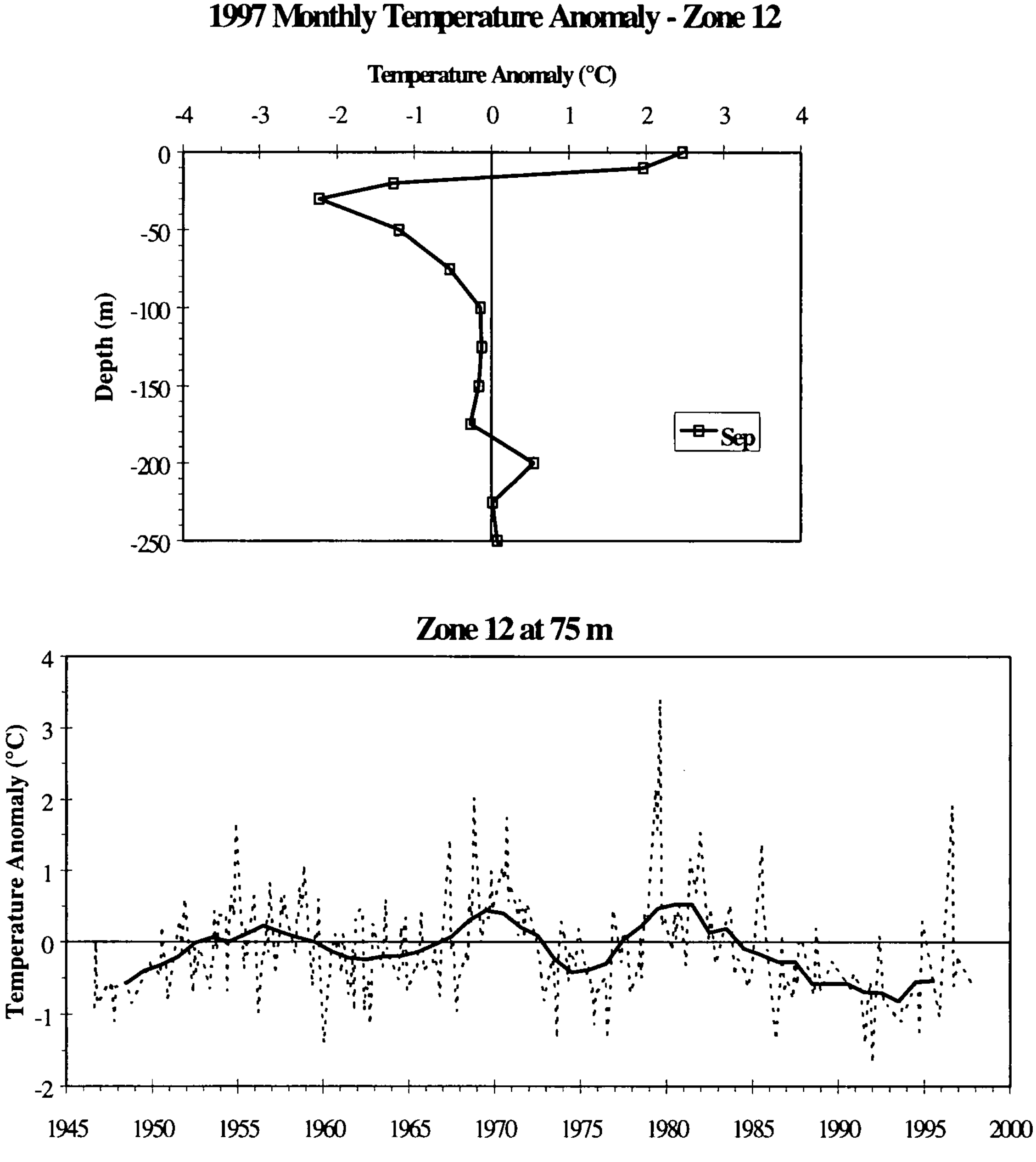
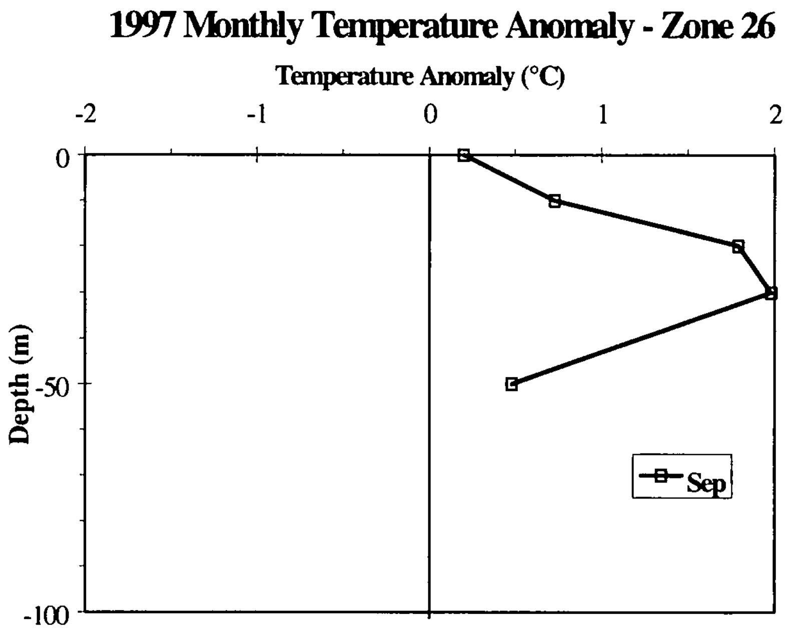


Fig. 12. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 75 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zone 12.



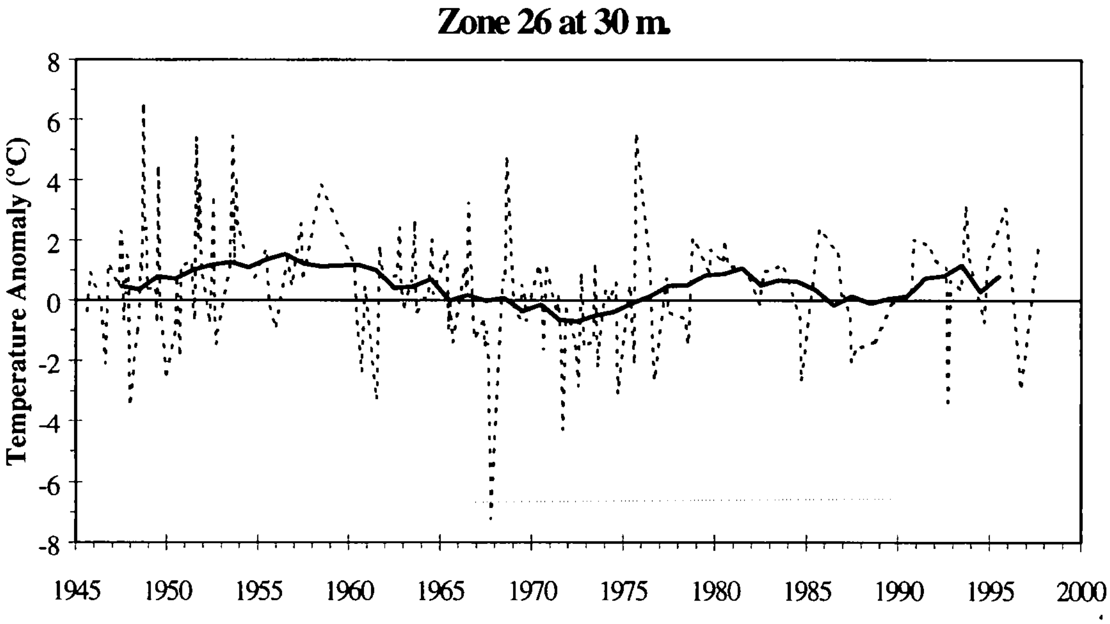
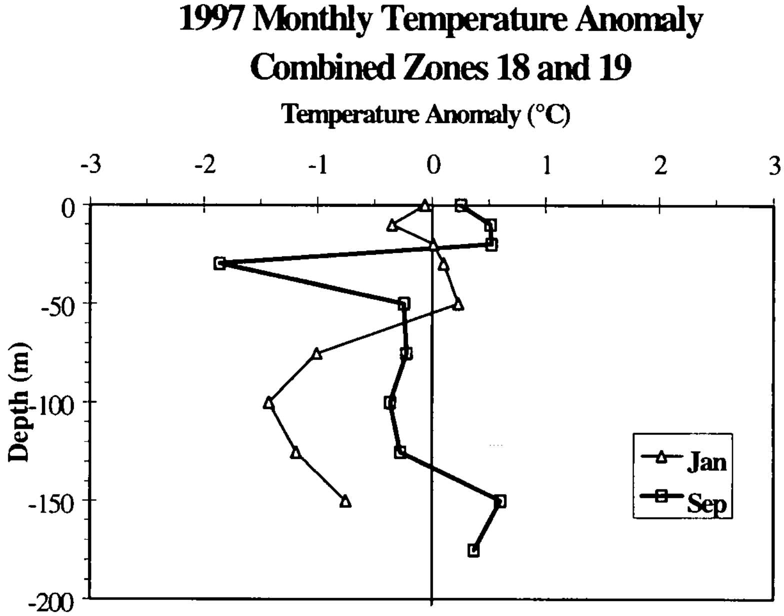


Fig. 13. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 30 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zone 26.



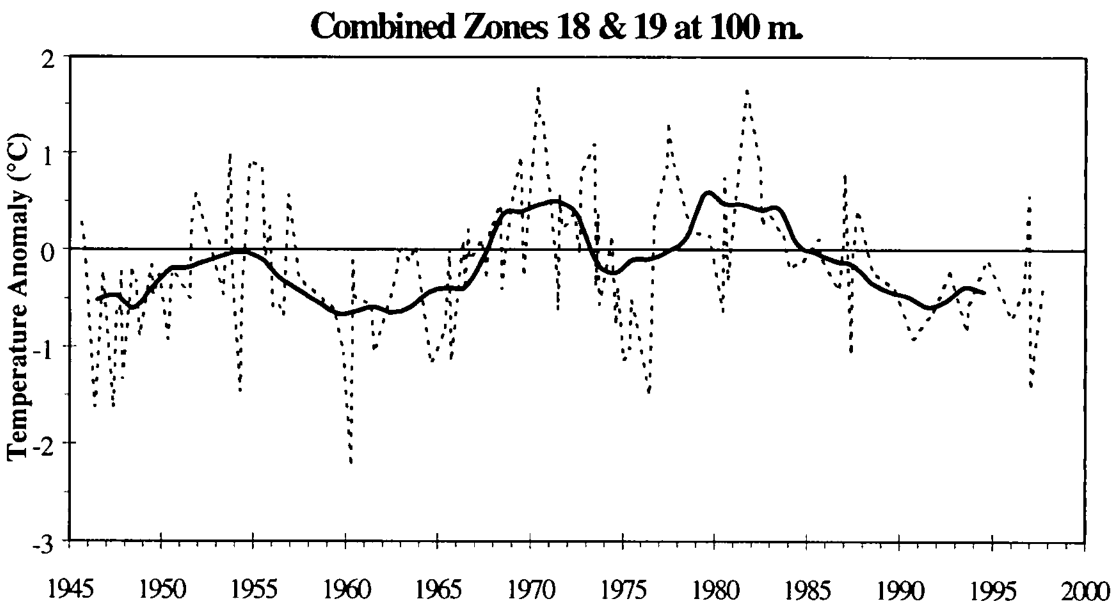
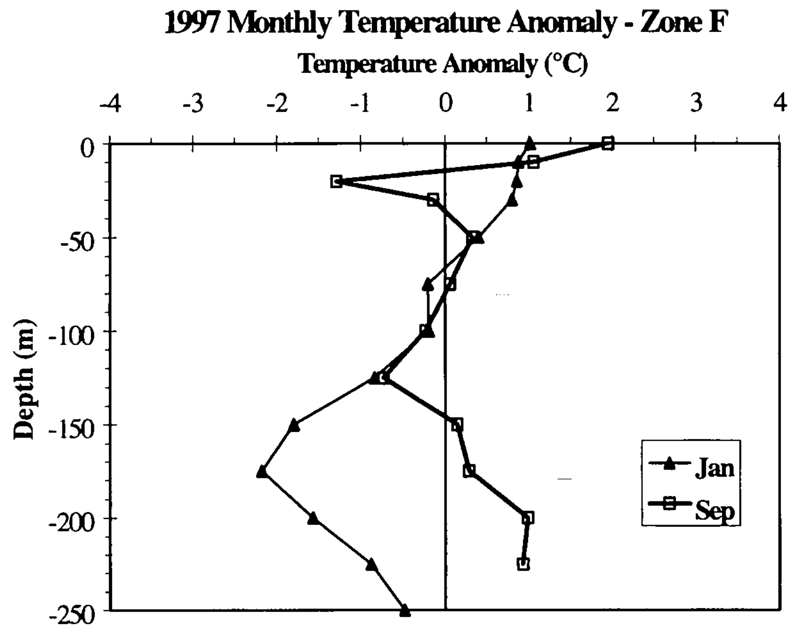


Fig. 14. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 100 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zones 18 and 19, combined.



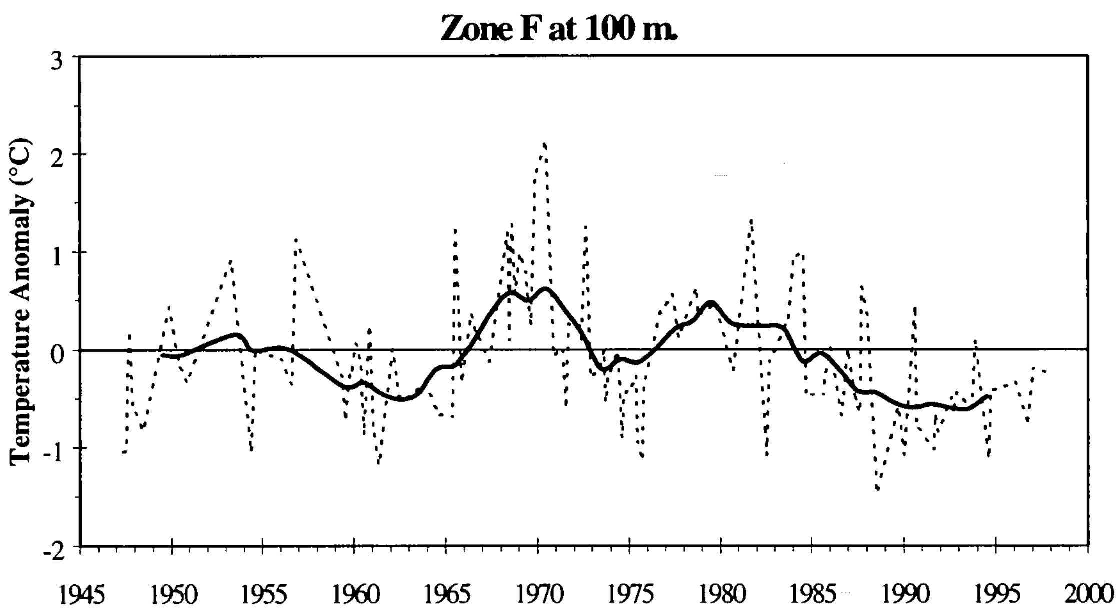
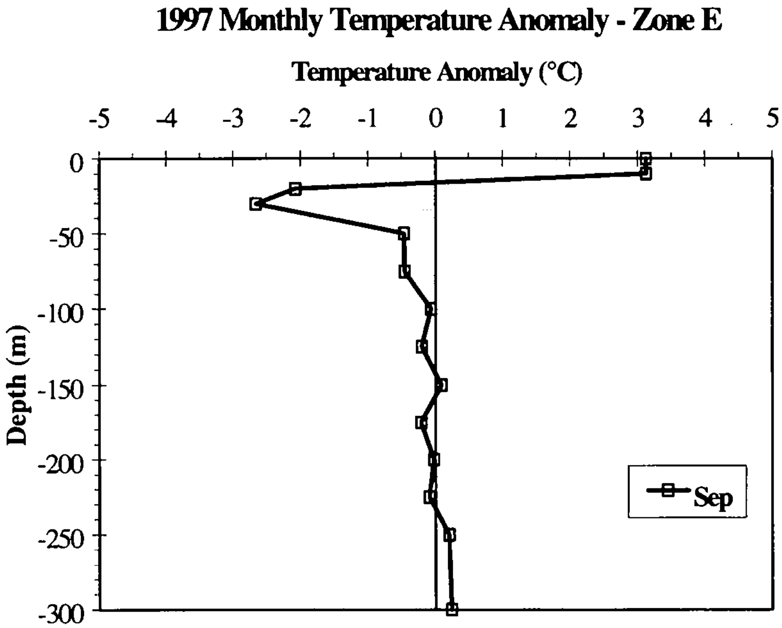


Fig. 15. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 100 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zone F.



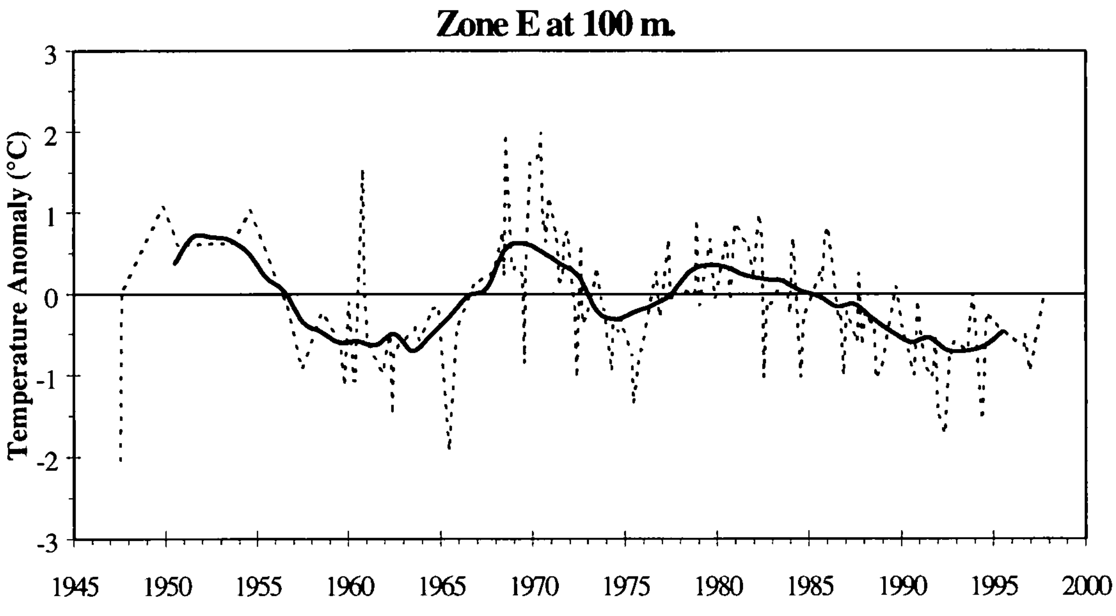


Fig. 16. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 100 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zone E.

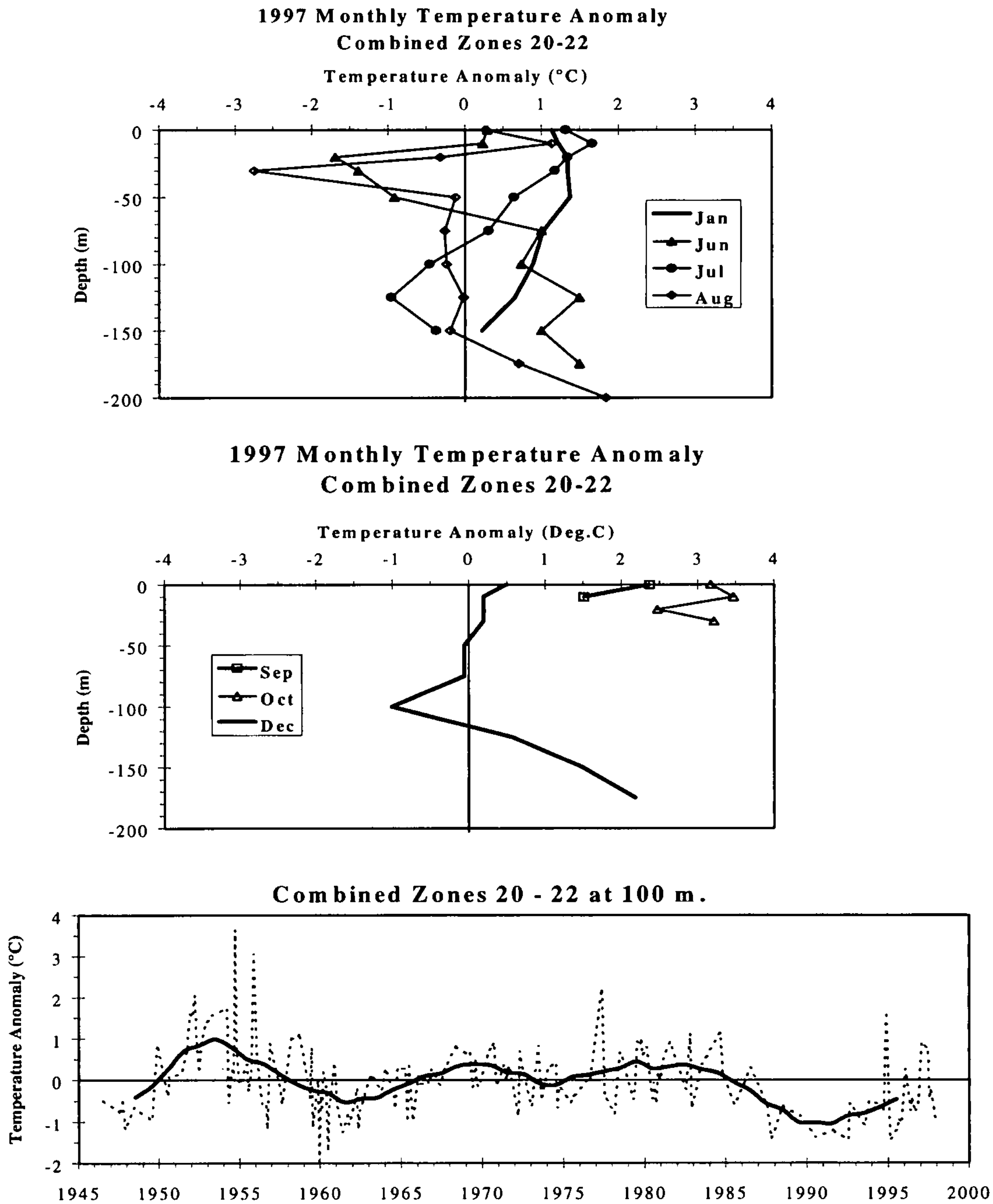


Fig. 17. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 100 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zones 20-22, combined.

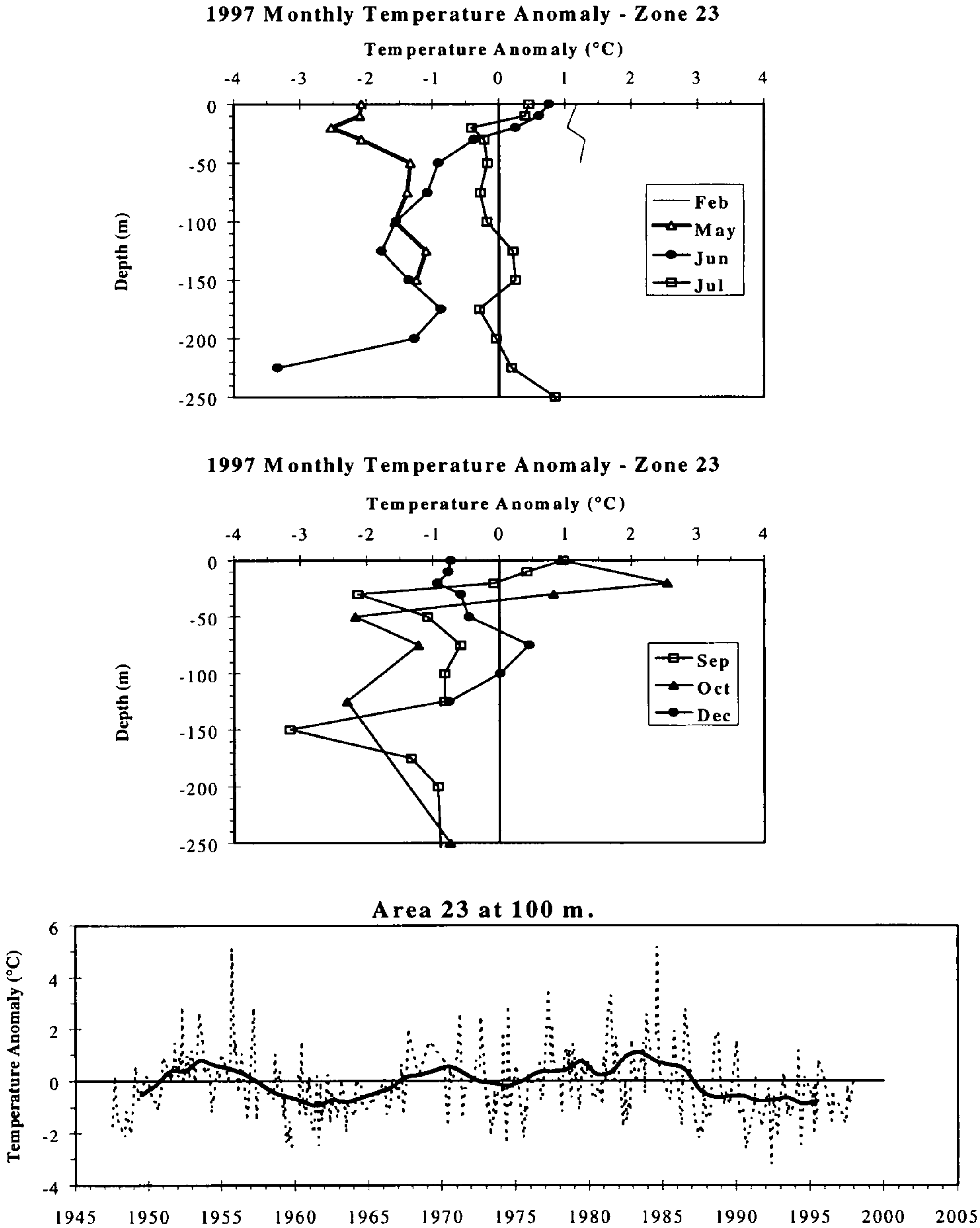


Fig. 18. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 100 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zone 23.

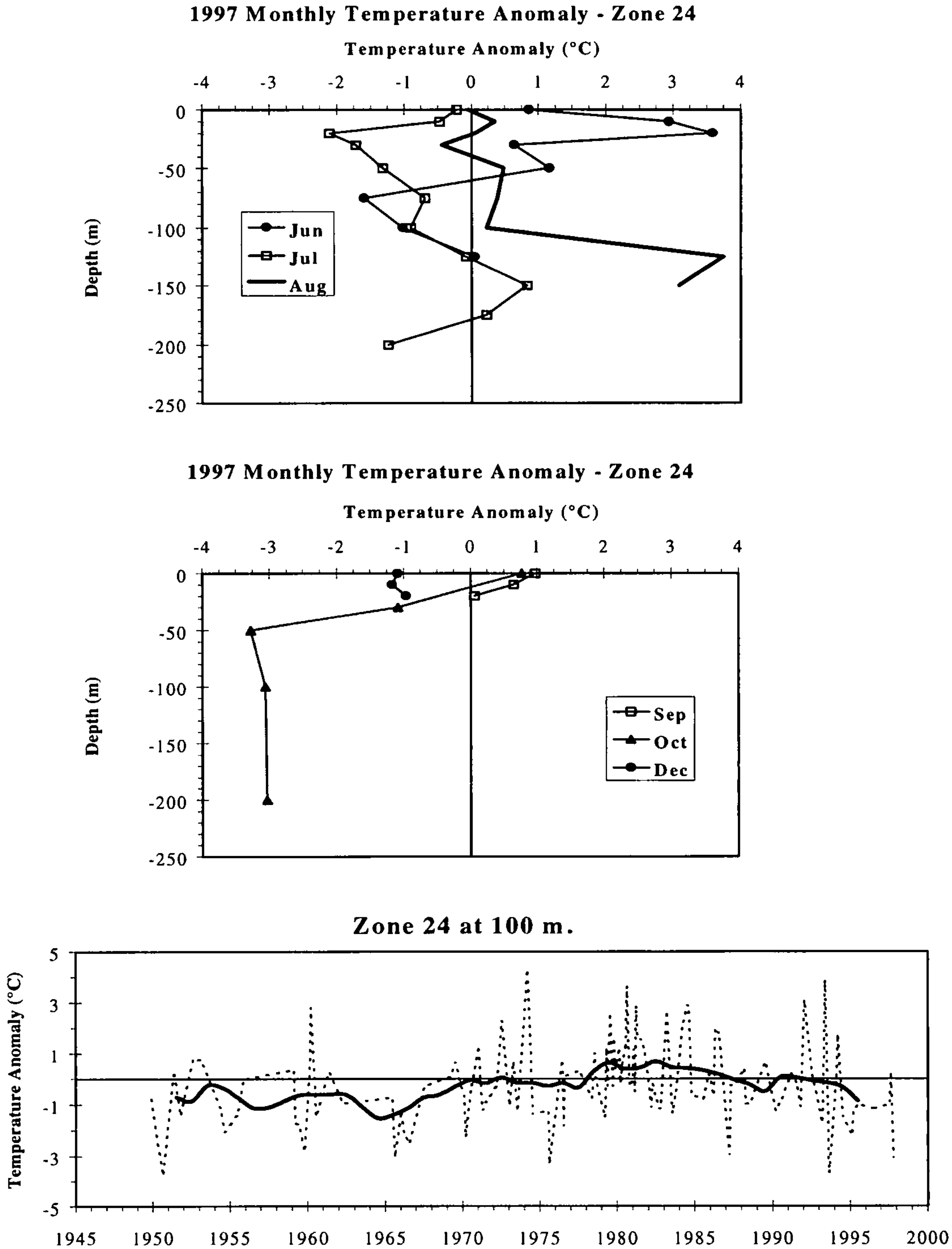


Fig. 19. Monthly mean temperature anomaly profiles during 1997 (top panel) and the time series of monthly temperature anomalies at 100 m (dashed line bottom panel) and their 5 year running means (solid line) for snow crab fishing zone 24.