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Temperature Conditions in Lobster Fishing Area 34 on the Scotian Shelf and Eastern Gulf of Maine: 1999-2004

Conditions de température de la mer dans la zone de pêche du homard 34 – plateau néo-écossais et secteur est du golfe du Maine : 1999-2004

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ABSTRACT

A review of physical oceanographic conditions for Lobster Fishing Area 34 in the Southwest Nova Scotia-Gulf of Maine region from 1999 to 2004 is presented. The analysis is based almost entirely on near-shore temperature time series collected by local fishermen through the Fishermen and Scientists Research Society, supplemented by data collected by the Department of Fisheries and Oceans, satellite-derived sea surface temperatures and the Gulf of Maine Ocean Observing System. From the records we computed the average temperature, the temperature trend and variability for a period roughly corresponding to the lobster fishing season. Average temperatures during the fishing season were generally high in 1999 and became progressively cooler each year during the Dec 1-Jan 15 period, the first part of the fishing season. Temperatures for Jan 15-Feb 28 were highest in 2002. The coldest years for this time were 2003 and 2004 with the temperatures going below zero in 2004. Temperatures were warmest in 1999 for Mar 1-May 31 and became cooler each year after. Data from other sources allow examination of the interannual variability of temperature from 1950 to 2004 during and outside the fishing season. The analysis indicates that the early 1950s had temperatures significantly above normal and that 2003 and 2004 were cold during and outside the fishing season compared to most years. The combination of satellite and ship-based observations, and the highly resolved (in space and time) FSRS data enable us to study the effects of long-term variations of temperature on lobster yields, moulting patterns and shell development.

RÉSUMÉ

Nous faisons un bilan des conditions océanographiques physiques dans la zone de pêche du homard 34, située au sud-ouest de la Nouvelle-Écosse, dans le golfe du Maine, de 1999 à 2004. Notre analyse repose presque entièrement sur les séries chronologiques des températures de la mer près des côtes fournies par des pêcheurs locaux appartenant à la Fishermen and Scientists Research Society (FSRS), complétées par des données recueillies par le ministère des Pêches et des Océans, des données-satellites sur les températures de surface de la mer et des données tirées du Système d'observation de l'océan dans le golfe du Maine. D'après ces données, nous avons calculé les températures moyennes, ainsi que la tendance et la variabilité de la température, pendant une période correspondant plus ou moins à la saison de pêche du homard. Les températures moyennes durant la saison de pêche étaient généralement élevées en 1999, puis ont graduellement diminué chaque année entre le 1er décembre et le 15 janvier, soit le début de la saison de pêche. Entre le 15 janvier et le 28 février, les températures les plus élevées ont été enregistrées en 2002 et les plus basses, en 2003 et en 2004; cette année-là, elles se situaient au-dessous de 0 ^{o}C. Pour la période allant du 1er mars au 31 mai, les températures les plus élevées ont été enregistrées en 1999; elles ont baissées graduellement les années suivantes. Les données provenant d'autres sources nous ont permis d'établir la variabilité interannuelle de la température de 1950 à 2004 durant la saison de pêche et hors saison. Notre analyse indique que les températures de la mer au début des années 1950 étaient significativement au-dessus de la normale; les eaux étaient froides en 2003 et 2004 durant la saison de pêche et hors saison par rapport à la plupart des autres années. En combinant les données recueillies par satellites et par navires et les données FSRS à haute résolution (dans l'espace et le temps), nous avons pu établir les effets des variations à long-terme de la température sur les rendements en homard, le cycle de mue et le développement de la carapace.

INTRODUCTION

We present an analysis of temperatures recorded by instruments deployed through the auspices of the Fishermen and Scientists Research Society (FSRS) in the near-shore zone of the Southwest Nova Scotia-Gulf of Maine region from Goose Point, Shelburne County to Burns Point, Digby County. This region encompasses Lobster Fishing Area 34 (see Fig. 1a for the boundary of LFA 34, Fig. 1b for sites used in text, Fig. 2 for the FSRS deployments from 1999-2004). Instruments are generally deployed twice per year, in the spring and fall. Spring moorings cover LFAs 27-34; fall deployments occur in LFAs 33 and 34. The goal is to have the instruments in place over the entire fishing season, but not all records span the complete time period. Vemco Minilog temperature recorders with 0.1^{o}C resolution and $\pm 0.2^{o}$C accuracy are moored in lobster traps and programmed to record the temperature every hour. Consequently, they are subject to recovery from day to day and are sometimes moved during the fishing season. Depth changes are generally ~10 m, though some exceed 160 m.

Our goal is to present some of the data for LFA 34, primarily from 1999-2004, derive some parameters describing the time series, and finally produce a general summary of conditions. This is an overview report, an initial look at the observations. The FSRS dataset for all LFAs is very large, approaching 800 time series; changes of instrument position during the mooring period introduce complications in data interpretation. We expect more specific, localized, cross-discipline studies will follow.

Before dealing with the FSRS temperature data, we present time series of monthly sea temperature anomalies derived from ship-based observations (1985-present), coastal temperature gauges (1978-2004), the Lurcher Lightship time series (1951-69) and satellite observations (1985-2004) (Fig. 3a-d). These datasets provide a long-term context for the FSRS series. Figure 3a contains in situ data from 0, 20 and 50 m. The period of 1999-2000 featured above normal temperatures, while the 2001-2003 period was generally below normal. The time series show weak long-term trends and standard deviations that are very similar at all depths (~2.3-2.4ºC). Figure 3b shows coastal temperatures from four different depth ranges. These data were obtained from the Department of Fisheries and Oceans Coastal Temperature Database at http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html. Temperatures from these instruments are also generally above normal in 1999 and 2000. In contrast to the above records, a long-term trend is apparent in the Lurcher Lightship data with temperatures about 2^{o}C above normal in the early 1950s and $2\text{-}3^{o}$C below normal in the mid 1960s (Fig. 3c). The coherence between surface and bottom temperatures is high (r=0.92). We have obtained the daily values for the Lurcher Lightship time series and will be constructing daily anomalies for presentation in the future. This long series will enable us to compare the recent FSRS datasets to past conditions. Figure 3d shows the sea surface temperature (SST) anomalies based on satellite observations for LFA 34. This database consists of satellite measurements of (nominally) weekly averaged surface temperatures for the Northwest Atlantic (35-67°N, 35-77°W). The data are obtained from the Physical Oceanography Archive Centre of the Jet Propulsion Laboratory (JPL, http://podaac.jpl.nasa.gov/sst/sst_data.html). Updates to the Ocean

Sciences database are approximately quarterly, as data become available from JPL. The anomalies are constructed using the average temperatures for the period 1985-2003. These data are currently being reprocessed and a major update should be available in 2005. The SST anomalies are remarkably coherent with the other data sets from LFA 34. It shows above normal temperatures in 1999 and 2000 and slightly below average values in early 2001. There is a period of about one year of above normal temperatures in 2001 to 2002, and finally temperatures slightly below average in the first half of 2003. Overall, these different data sets are in agreement for the 1999-2004 period.

DATA AND ANALYSIS

Depth changes of the instruments during the fishing season complicate the interpretation of the temperature records. This problem can be exacerbated by the time of year the moorings are in place; in spring the thermocline is developing, and in fall it is breaking down. During these two periods the temperature variations with depth (the vertical gradients) are usually large; vertical movements of a few meters can give temperature changes that could be interpreted as temporal variations if a record of the instrument depth was not available. During the winter season the problem is not as acute because vertical stratification breaks down due to enhanced mixing caused by wind and cold air temperatures. In LFA 34, strong tidal mixing also contributes to the reduction of vertical temperature gradients. At each site a log sheet of the instrument position was maintained. From these log sheets we constructed time series of the latitude, longitude and depth changes. We note that changes in the depth were recorded frequently without an accompanying change of position. An example of a time series of instrument depth is shown in Fig. 4. The depth changed 40 times over a range of ~162 m during the mooring period. A large number of the records (over 50%) had significant depth changes during their mooring period. In this initial analysis of the total dataset, we did not use these records. We confined ourselves to records that remained at a constant or nearly constant depth (~2 m changes at shallower depths, ~10 m at deeper depths).

Temperature changes that occurred when traps and instruments were recovered from day to day during the season were edited from the records.

An additional constraint was the length of the mooring period. Ideally, we would have preferred to have the records span the entire fishing season. However, some records began later than the opening day of the season and some ended before the last day. To obtain a sufficient number of records to cover a broad range of depths, we set a start date for our analysis several days after the season began. We divided the season into three analysis periods: Dec 1-Jan 15, Jan 15-Feb 28, Mar 1-May 31. Table 1 provides the length of the fishing season and the analysis periods for LFA 34. The last column of the table also shows the number of days in each analysis period.

Figure 5 presents the long-term, daily average water temperatures for 0-10, 10-20, 20-30 and 30-50 m in the coastal zone for LFA 34. These averages have been taken from the current version of the coastal temperature database and do not include the FSRS time series. The figure also indicates the times of the analysis periods. These data sets were used as reference time series in order to calculate record parameters, such as the standard deviation, in the FSRS series over the analysis periods.

The time series in Figure 5 suggest an analysis approach that could provide a concise summary of the 1999-2004 datasets from LFA 34 for periods Dec 1-Jan 15 and Mar 1-May 31. We have illustrated the approach in Figure 6. The observed time series is decomposed into a mean, linear trend and residual record (observations with the mean and trend removed). The series is characterized by three numbers: the mean temperature, the linear trend and the variability. We express the trend as the temperature change (ΔT) over the analysis period as given in Table 2, i.e., the slope of the line times the number of days in the analysis period. The variability is given as twice the standard deviation of the residual record. Another potential parameter to present is the temperature at the beginning of the record from the linear fit. This is related to the mean temperature and the temperature change over the analysis period as T(at start of record, i.e., the intercept)=T(mean)-0.5*ΔT. For the record shown in Figure 6, the mean is 4.62^{o}C, the slope times the analysis period (for brevity we shall refer to this as the slope) is 9.41^{o}C, and twice the standard deviation is 3.61^{o}C. The period Jan 15-Feb 28 generally does not feature a strong linear trend (Fig. 5). We characterize the records from this period by their mean and variability (2*standard deviation). For the Jan 15-Feb 28 period, we subtract the long-term average time series (Fig. 5) from individual FSRS datasets and calculate the standard deviation from the residual time series.

We shall now present the time series and summary statistics from records that remained at constant or nearly constant depths throughout their mooring period from LFA 34 in the following format: time series of temperatures for 1999-2004, and the profiles of the average temperatures, two standard deviations and the slopes. We shall briefly highlight some of the notable features. The last three variables will be summarized to quantify the interannual variability in the region.

Dec 1-Jan 15

There are several notable features in the time series for this period (Fig. 7). During the Dec 1-Jan 15, 2003 period, there is an abrupt drop in temperature beginning around January 6, proceeding to below zero values at the end of the period. In the preceding years, 1999-2001 and the deeper depths in 2002, the temperatures at the beginning of the period are quite warm, about 1-3ºC warmer than 2003. The temperatures in the upper 20 m in 2002 are also relatively cold in comparison to these years, particularly 1999. Stronger vertical temperature gradients are also noticeable in 1999, 2000 and at the deeper depths in 2002.

Jan 15-Feb 28

The data sets available for 2004 span over 180 m and show a significant vertical temperature gradient (Fig. 8). The shallower depths (7.3-18.3 m) remain fairly constant around -2-1ºC with the exception of a few depths that are much higher, between 2 and 5ºC. The deeper depths (22-64.4 m) range from about -2-5ºC and the deepest depths are fairly warm at about 2-10ºC. None of the other years show consistent sub-zero temperatures. Temperatures were relatively constant from 2001-2002. In 2001 there was one depth, 20.1 m, which was 2-4ºC warmer than the others. The shallower depths from 2003 feature very little variation throughout the analysis period; temperatures were between 0 and 2ºC.

Mar 1-May 31
The temperature begins to steadily increase at the end of the season for all years. Temperatures are warmer at the beginning of the season in 2000 and 2002, at about 2º-4ºC. The largest change over the analysis period was for the shallower records in 2003.

SUMMARY AND CONCLUSIONS

The depth profiles of average temperatures and two times the standard deviation for each analysis period are shown in Figure 10, as well as the slope for the Dec 1-Jan 15 and Mar 1-May 31 periods. The summary of average temperatures for Dec 1-Jan 15 shows that 2002 and 2003 were cold. The variability, given by two standard deviations, is strong in 2003. At the shallower depths (0-50 m) for 2004 the temperatures are much cooler than in other years for the Jan 15-Feb 28 period. It is difficult to determine the variability from the figures, but overall it seems to be similar for all years with a range of about 0.5-1.5ºC. At the deeper depths for 2004, temperatures are warmer and variability is higher than at the shallower depths. During the final analysis period, Mar 1-May 31, 2003 and 2004 are the coolest years while 2002 is warmer by approximately 2-3ºC. The only record from 2000 has the warmest average temperature at about 6.5 ºC. The variability for 2003 and 2004 is higher than other years with a magnitude of ~0.5-1.5ºC.

To clarify the difference among years, we have averaged the data over 0-20, 20-40 and 40-60 m depth ranges (Fig. 11). The Dec 1-Jan 15 period shows a cooling trend from 1999-2003. This is similar to the trend for LFAs 27-33 reported by Petrie and Pettipas (2004). The variability for this time is uniform from 1999-2002 with it becoming high in 2003. The temperatures peak in 2002 during the Jan 15-Feb 28 analysis period. The years 2003 and 2004 are the coldest years with temperatures below zero in the 0-20 and 20-40 m depth ranges in 2004. Temperature variability was high in 2000, 2002 and 2003 and low in 2001 and 2004. The Mar 1-May 31 period has a similar cooling trend as the Dec 1-Jan 15 period and approximately uniform variability.

The FSRS data are limited to 1999 to the present. In situ (ship-based) data from Lurcher Shoals and satellite-derived temperatures (Pathfinder) are compared with the FSRS data from the 0-20 m depth range. Note, the Lurcher Shoals data correspond to Area 24 in the Scotian Shelf-Gulf of Maine temperature and salinity atlas (Petrie et al., 1996) and are different from the Lurcher Lightship observations. A strong correlation means that the in situ and Pathfinder data could serve as proxies for the FSRS time series and allow for a longer-term comparison of biological and physical observations. The data are quantitatively similar with correlations of 0.99 and 0.98 (FSRS vs. Pathfinder, FSRS vs. Lurcher, Dec 1-Jan 15), 0.87 and 0.68 (FSRS vs. Pathfinder, FSRS vs. Lurcher, Jan 15-Feb 28), and 0.69 and 0.85 (FSRS vs. Pathfinder, FSRS vs.

Lurcher, Mar 1-May 31), which is encouraging. We note however that there are few degrees of freedom for these correlation calculations. The scatter plots in Figure 12 show that the regression between the FSRS and the Pathfinder and Lurcher data are similar for the Dec 1-Jan 15 and the Jan 15-Feb 28 periods but change for the last analysis period. The limited comparison also shows excellent agreement between the Lurcher Shoals and Pathfinder data (slope 1.2, offset 1.6^{o}C). These analyses indicate that there is some promise in using the in situ and satellite data to extend the FSRS data to earlier time periods.

We have assembled a number of in situ time series in addition to the FSRS data. They include observations from the Lurcher Lightship from 1950-1969, the Long-term Temperature Monitoring Program (LTTMP) which began in 1978 and is ongoing, and other mooring programs which were carried out in the area. (We note that the earlier LTTMP moorings used Ryan recorders which proved to be inadequate for the broad range of temperatures encountered. These records are not included in the analysis.) The data series, although sporadic, allow us to compare recent temperatures derived from the FSRS records with past variability (Fig. 13). They indicate that for the Dec 1-Jan 15 period, 1985, 1994, 1997, 2002 and 2003 were significantly colder than the other years, particularly the early 1950s. The Jan 15-Feb 28 period featured 1985, 1994 and 2004 as the coldest years. For the Mar 1-May 31 period, 1961, 1965-1967 and 2004 were the coldest.

There is also interest in the temperature conditions from June to November, i.e., the period when the fishing season is closed. During this time, temperature conditions can affect moulting and hardening of the lobsters' shell. However, continuous records throughout this period are not available except for a few years. Consequently, we used ship-based data from Lurcher Shoals (Area 24, Scotian Shelf-Gulf of Maine temperature and salinity atlas (Petrie et al., 1996)) to determine temperature anomalies from 1950-present for the June 1-Nov 30 period (Fig. 14). Bear in mind that the anomalies are based on monthly mean temperatures from very limited sampling in each June-November period; on average 4.6, 4.4 and 4.3 months were sampled each year at 0, 20 and 50 m from 1950 to 2003. Only one measurement per month was required to calculate the anomaly for that month. The anomalies were relative to the 1971-2000 mean at each depth. Figure 14 shows that the coldest June-November period occurred in the mid-1960s. Some recent years have been cold but 2003 was slightly above normal at all three depths from the ship-based data. Also shown in Figure 14 are the 30 m data from Sandford; its anomalies are also based on the 1971-2000, 30 m mean from ship observations. These data indicate above average temperatures for the 2001-2004 period.

There was a soft shell problem in LFA 34 in the fall of 2003. There are also some indications of a similar problem in 2004. Therefore, we have combined all of the data currently available for those years to examine the temperature in detail (Fig. 15). From these data, we conclude that overall 2004 was a colder year than 2003, the winters were particularly cold relative to the long-term mean, and through the June-November period, temperatures were coldest at 50 m. Sea surface temperature, GoMOOS buoy and the Sandford observations are summarized as degree days relative to 0°C for the January-November period, except for the GoMOOS buoy which is June-November (Fig. 16). The satellite data indicate that 2004 was the coldest January-November period, closely followed by 1998, 2001 and 2003. The limited data from the GoMOOS buoy indicate that 2004 was colder than 2003 at 2, 20 and 50 m. The Sandford observations rank 2004 as the coldest followed by 2003, 2001 and 2002. We conclude from these data that if temperature were an important factor affecting the hardening of the lobsters' shells, they would have been impacted most significantly in 2004, the coldest year. The temperatures in 2003 and 2001 were only slightly warmer than 2004 and could have had a similar effect. Of the last few years, 2002 was by far the warmest.

ACKNOWLEDGEMENTS

We thank the many individuals who, through the Fishermen and Scientists Research Society, moored, maintained and recovered the temperature recorders in all of the Lobster Fishing Areas. We also acknowledge Carl MacDonald who assembled the time series and provided them to us for use in this study. Funding from the Nova Scotia Department of Agriculture and Fisheries supported A. F.

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Table 1. Lobster fishing season and analysis periods for LFA 34.

LFA	Fishing Season	Analysis Periods
34	Last Monday of November-May 31	Dec 1-Jan 15, 45 days Jan 15-Feb 28, 44 days Mar 1-May 31, 91 days

Table 2. Average temperatures and two times the standard deviation (SD) for the three analysis periods at three depth intervals, 1999-2004.

Year	Analysis Period	Average Temp	2*SD
0-20 m			
1999	Dec 1-Jan 15	6.1	0.82
2000	Jan 15-Feb 28	2.1	1.16
2000	Mar 1-May 31	6.4	1.12
2000	Dec 1-Jan 15	4.4	1.17
2001	Jan 15-Feb 28	1.3	0.62
2001	Mar 1-May 31	4.8	0.98
2001	Dec 1-Jan 15	5.4	0.74
2002	Jan 15-Feb 28	2.1	1.24
2002	Mar 1-May 31	5.2	0.86
2002	Dec 1-Jan 15	3.5	0.91
2003	Jan 15-Feb 28	1.0	1.13
2003	Mar 1-May 31	3.9	1.27
2003	Dec 1-Jan 15	4.0	1.49
2004	Jan 15-Feb 28	0.9	0.83
2004	Mar 1-May 31	2.7	1.03
20-40 m			
1999	Dec 1-Jan 15	6.9	0.74
2000	Jan 15-Feb 28	2.7	1.18
2000	Mar 1-May 31	-	-
2000	Dec 1-Jan 15	5.6	0.77
2001	Jan 15-Feb 28	1.9	0.50
2001	Mar 1-May 31	3.8	0.61
2001	Dec 1-Jan 15	6.0	0.53
2002	Jan 15-Feb 28	2.5	1.05
2002	Mar 1-May 31	4.8	0.64
2002	Dec 1-Jan 15	4.7	0.70
2003	Jan 15-Feb 28	1.0	1.08
2003	Mar 1-May 31	3.2	0.79
2003	Dec 1-Jan 15	4.5	1.20
2004	Jan 15-Feb 28	-0.1	0.99
2004	Mar 1-May 31	2.3	0.84
40-60 m			
1999	Dec 1-Jan 15	7.7	0.69
2000	Jan 15-Feb 28	-	-
2000	Mar 1-May 31	-	-
2000	Dec 1-Jan 15	6.7	0.58
2001	Jan 15-Feb 28	2.5	0.53
2001	Mar 1-May 31	-	-
2001	Dec 1-Jan 15	6.7	0.53
2002	Jan 15-Feb 28	3.3	0.72
2002	Mar 1-May 31	4.6	0.44
2002	Dec 1-Jan 15	-	-
2003	Jan 15-Feb 28	-	-
2003	Mar 1-May 31	-	-
2003	Dec 1-Jan 15	5.0	1.13
2004	Jan 15-Feb 28	0.9	1.06
2004	Mar 1-May 31	2.5	0.96

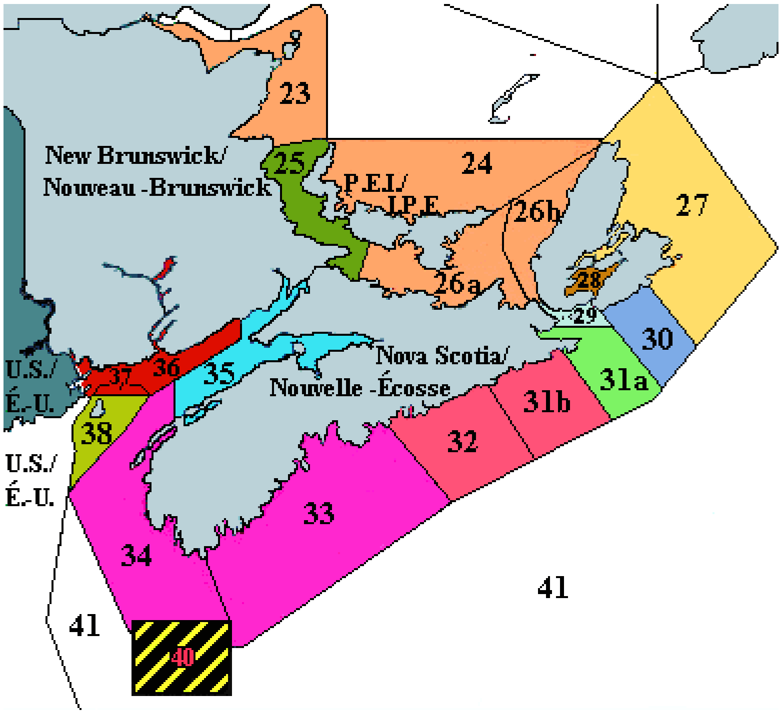

Figure 1a. The Scotian Shelf and the Gulf of Maine showing the boundary of Lobster Fishing Area 34.

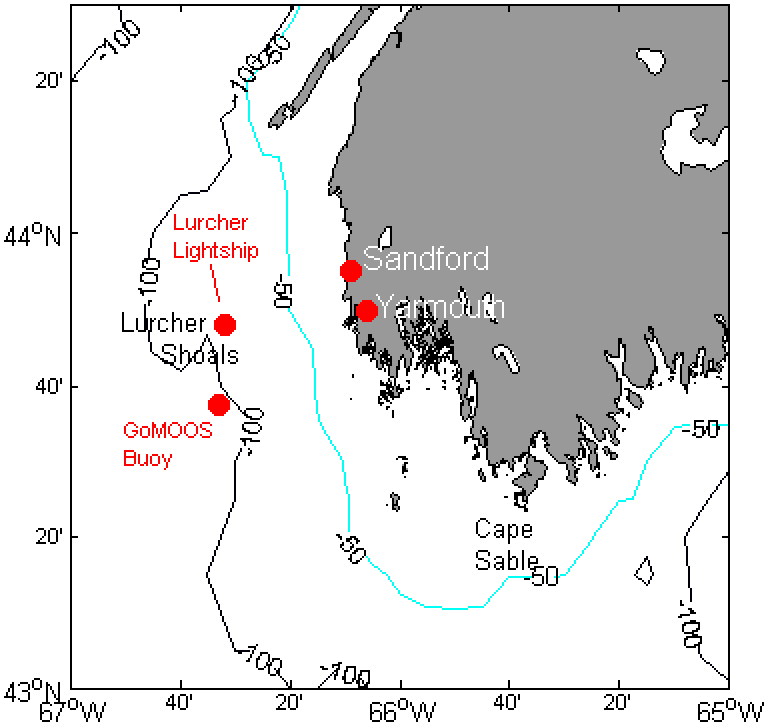

Figure 1b. Map with place names used in text.

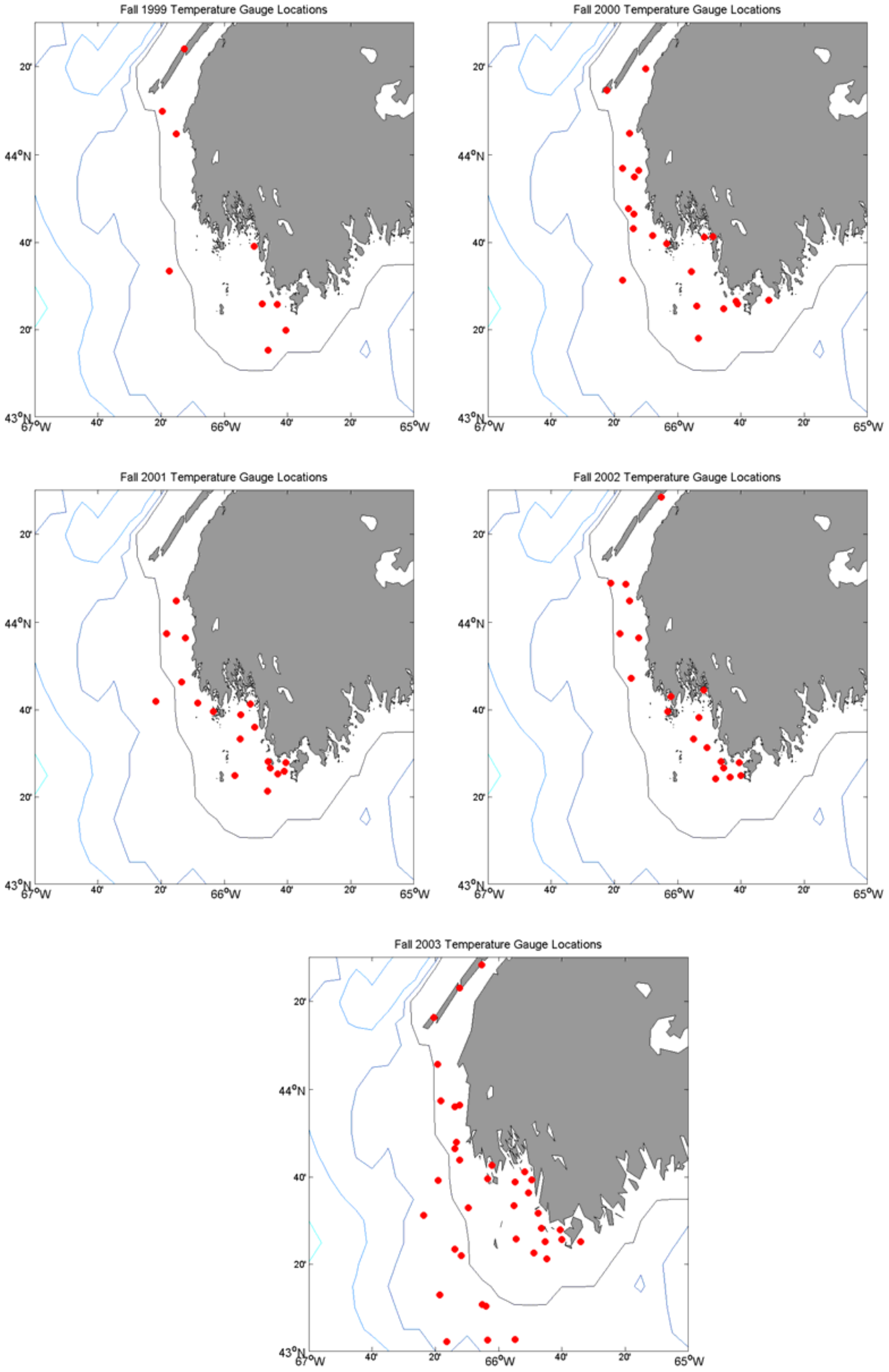

Figure 2. The locations (red dots) of temperature gauges deployed under the auspices of the Fishermen and Scientists Research Society from 1999-2004.

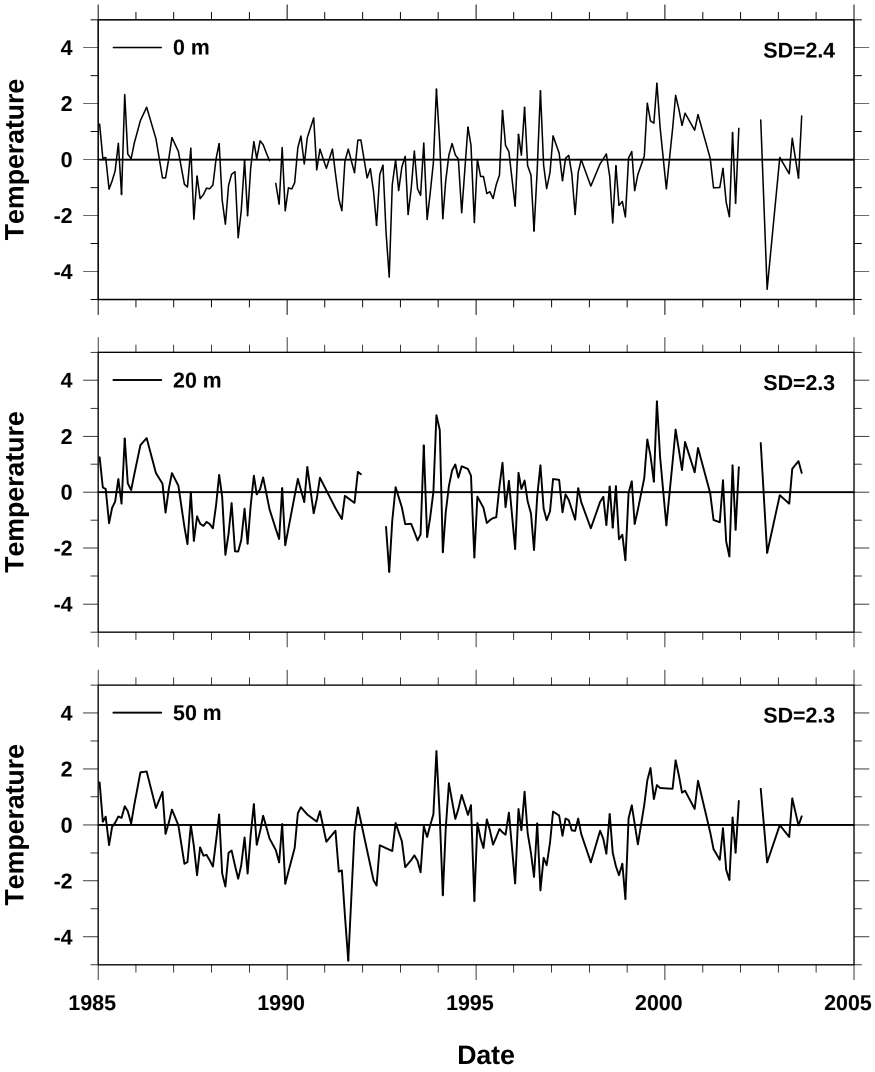

Figure 3a. Time series of temperature anomalies from 1985-2003 derived from in situ observations. The anomalies are obtained by subtracting the long-term (1971-2000) mean from the actual measurements. The standard deviation is given.

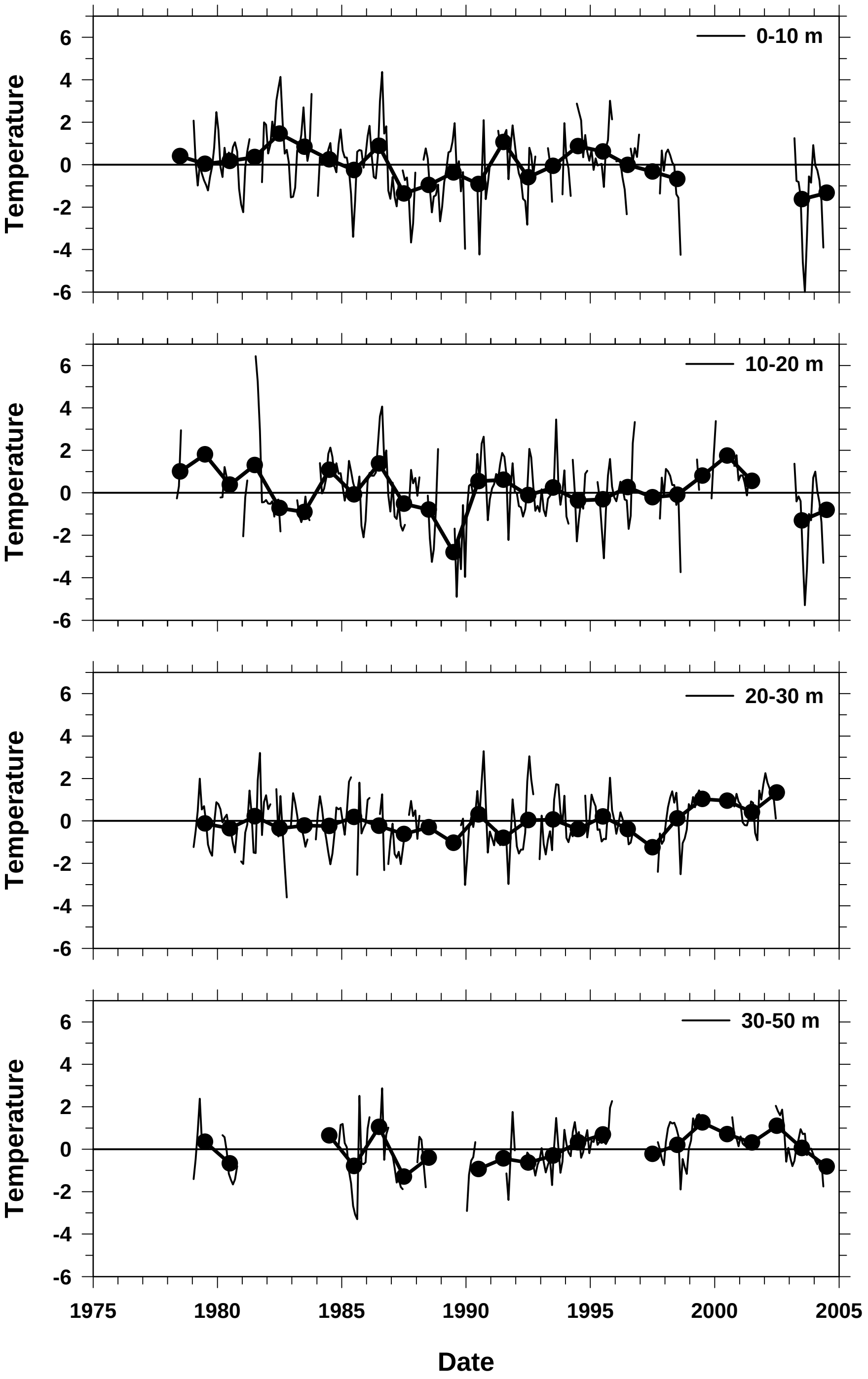

Figure 3b. Time series of monthly temperature anomalies from long-term DFO coastal sites. The heavy lines with dots show the annual temperature anomalies.

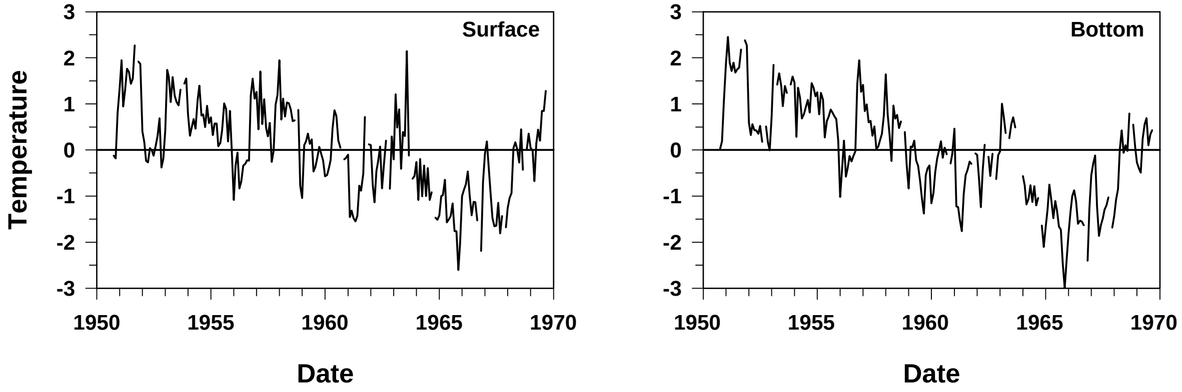

Figure 3c. Time series of Lurcher Lightship monthly anomalies. Bottom depth is 90 m.

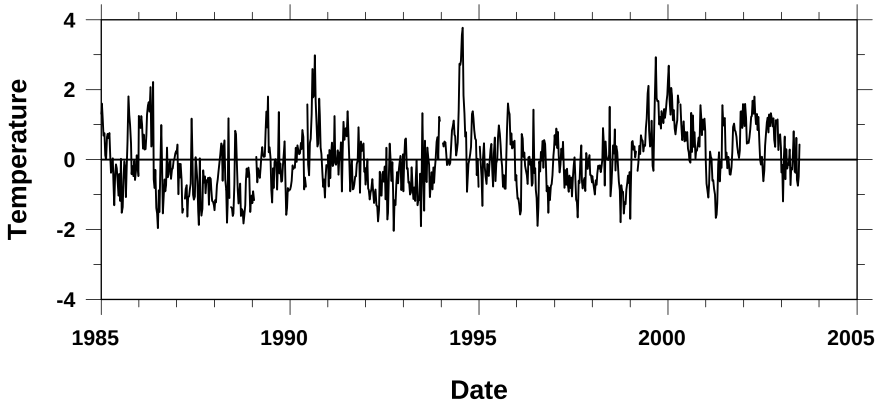

Figure 3d. The eight day SST anomaly based on satellite data for LFA 34.

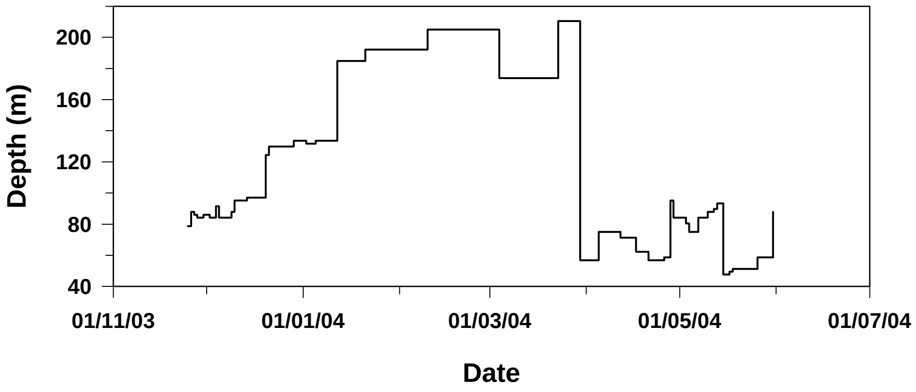

Figure 4. Example of a time series of instrument depth created from a station log sheet for the 2003 season in LFA 34.

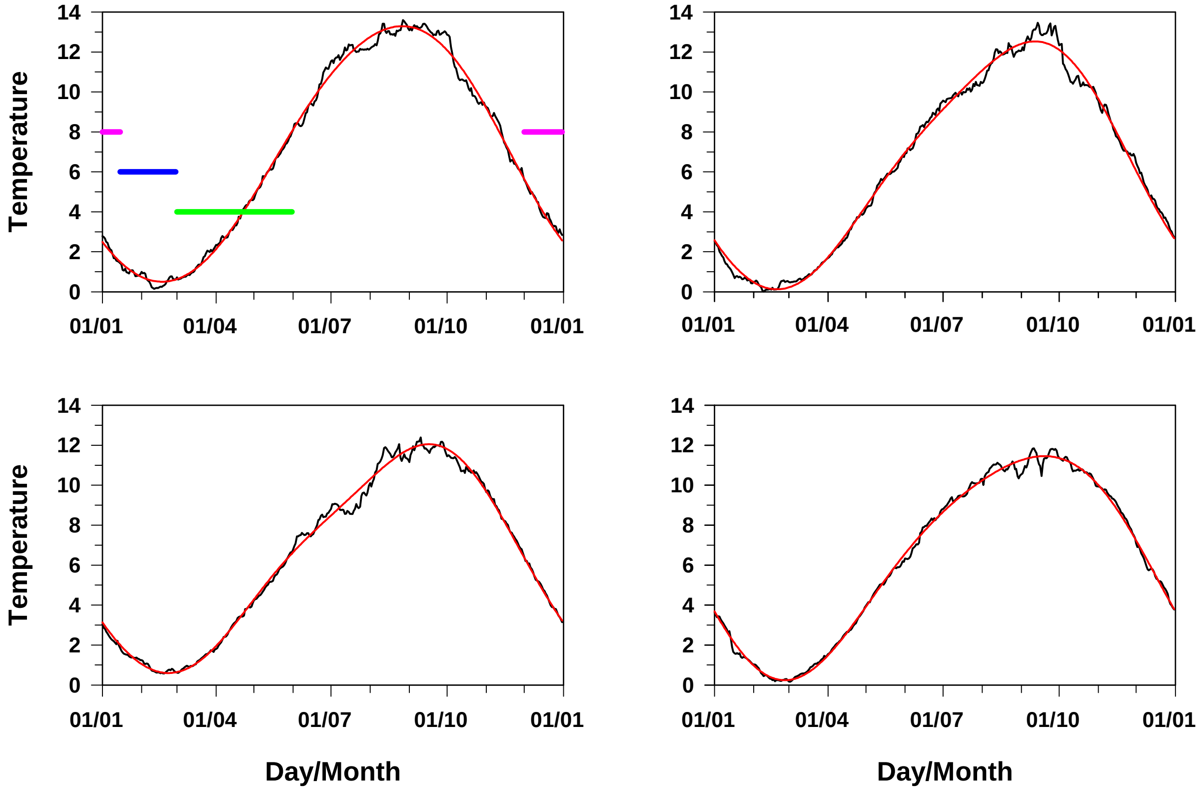

Figure 5. The long-term, average daily water temperatures (black line) for various depth intervals in LFA 34. The red line represents a harmonic fit to the data. The horizontal lines (0-10 m panel) represent the three analysis periods of Table 1.

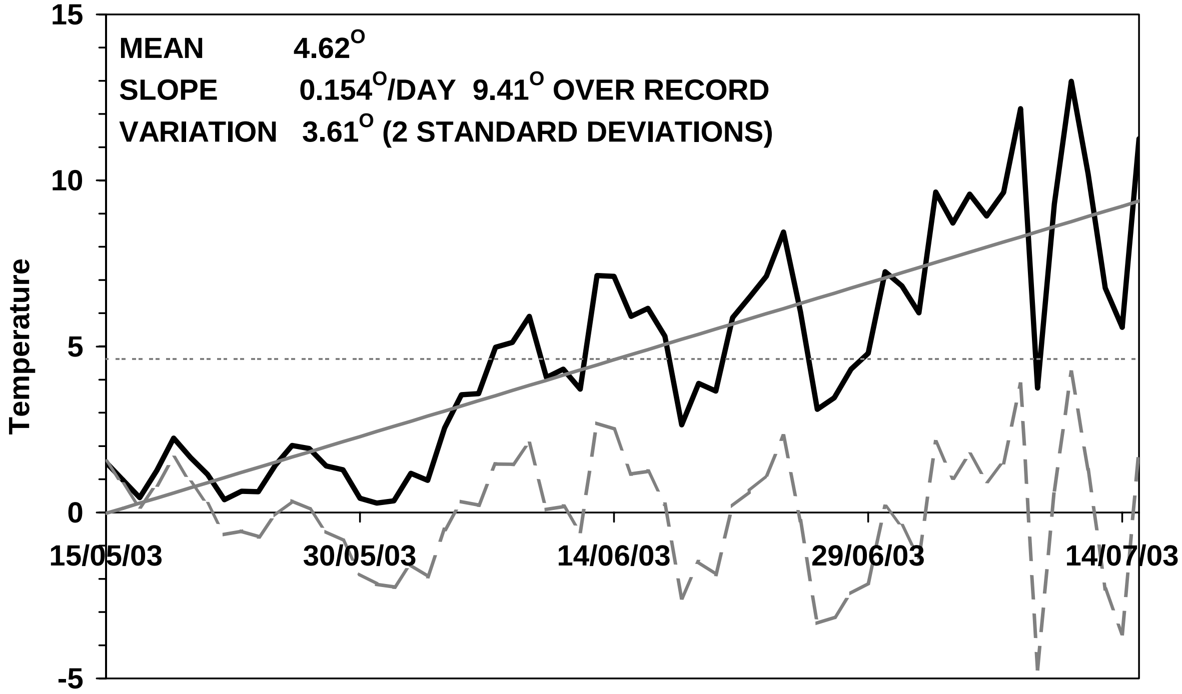

Figure 6. The temperature record from LFA 27 for 22.3 m in 2003 (solid black line) showing the mean (grey, dotted line), the linear trend (solid grey line) and residual (temperature with mean and trend removed; grey, long dashed line) over the record.

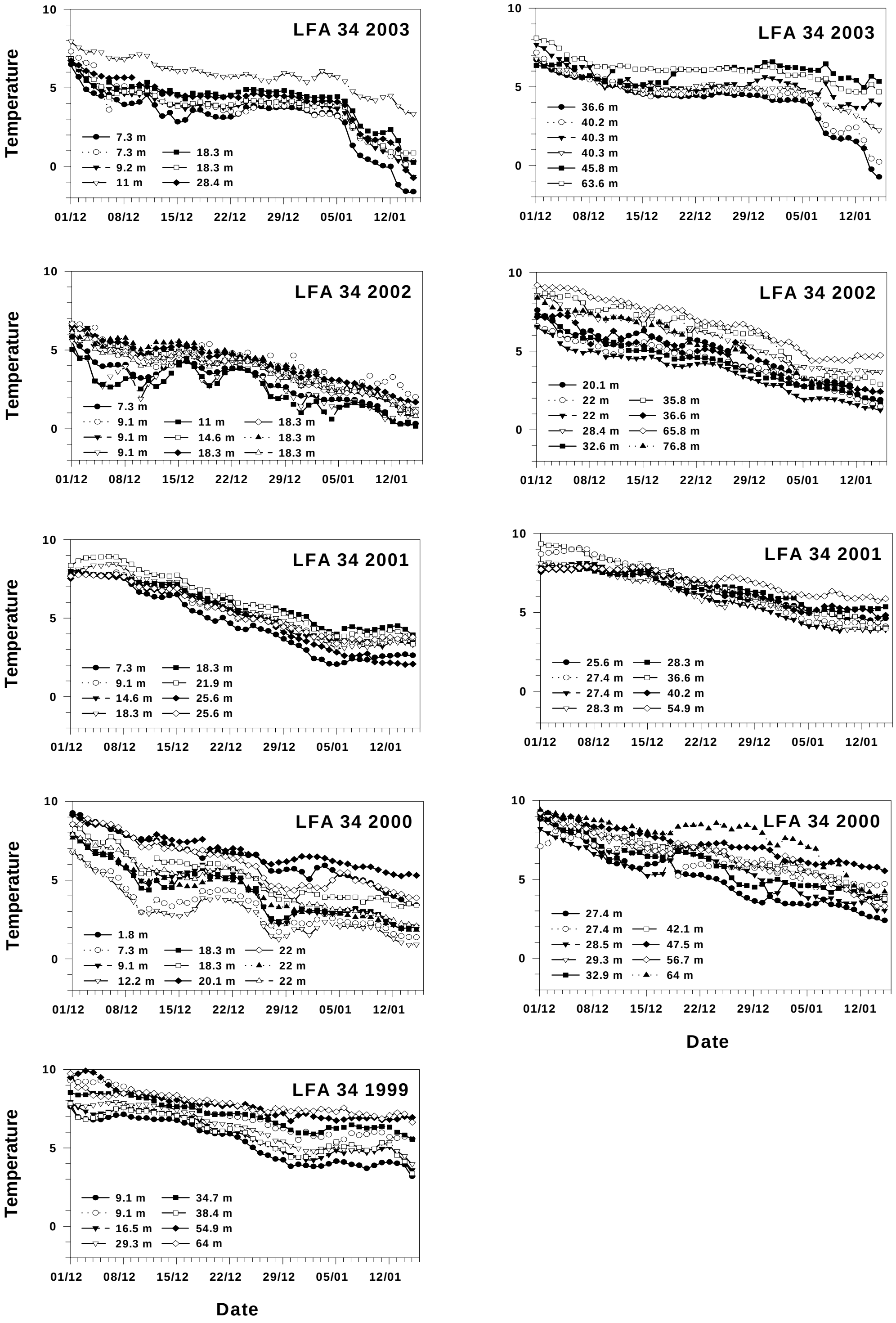

Figure 7. Time series of daily temperatures for the period of Dec 1-Jan 15, 1999-2003 at depths indicated in the legends.

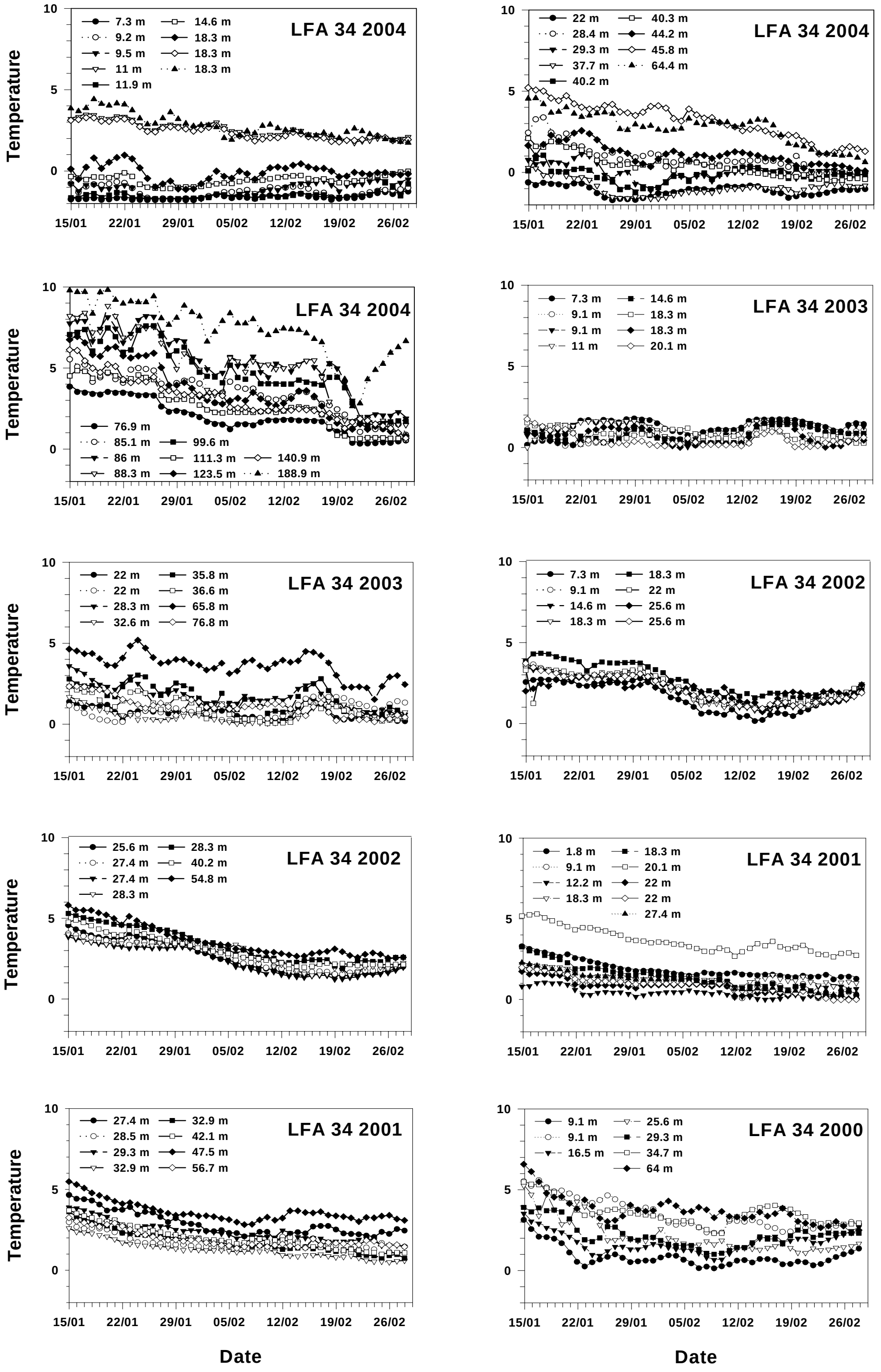

Figure 8. Time series of daily temperatures for the period of Jan 15-Feb 28, 2000-2004 at depths indicated in the legends.

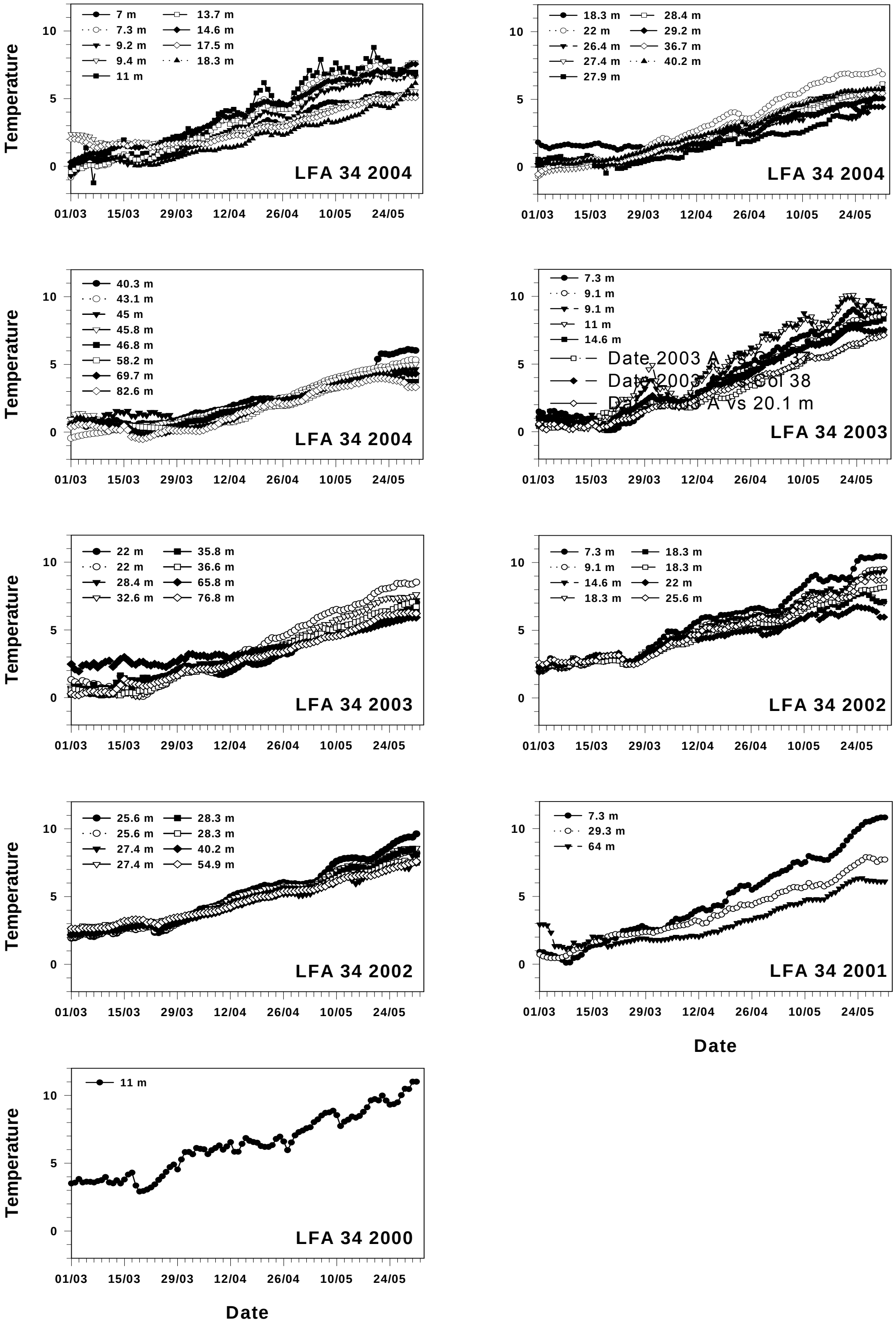

Figure 9. Time series of daily temperatures for the period of Mar 1-May 31, 2000-2004 at depths indicated in the legends.

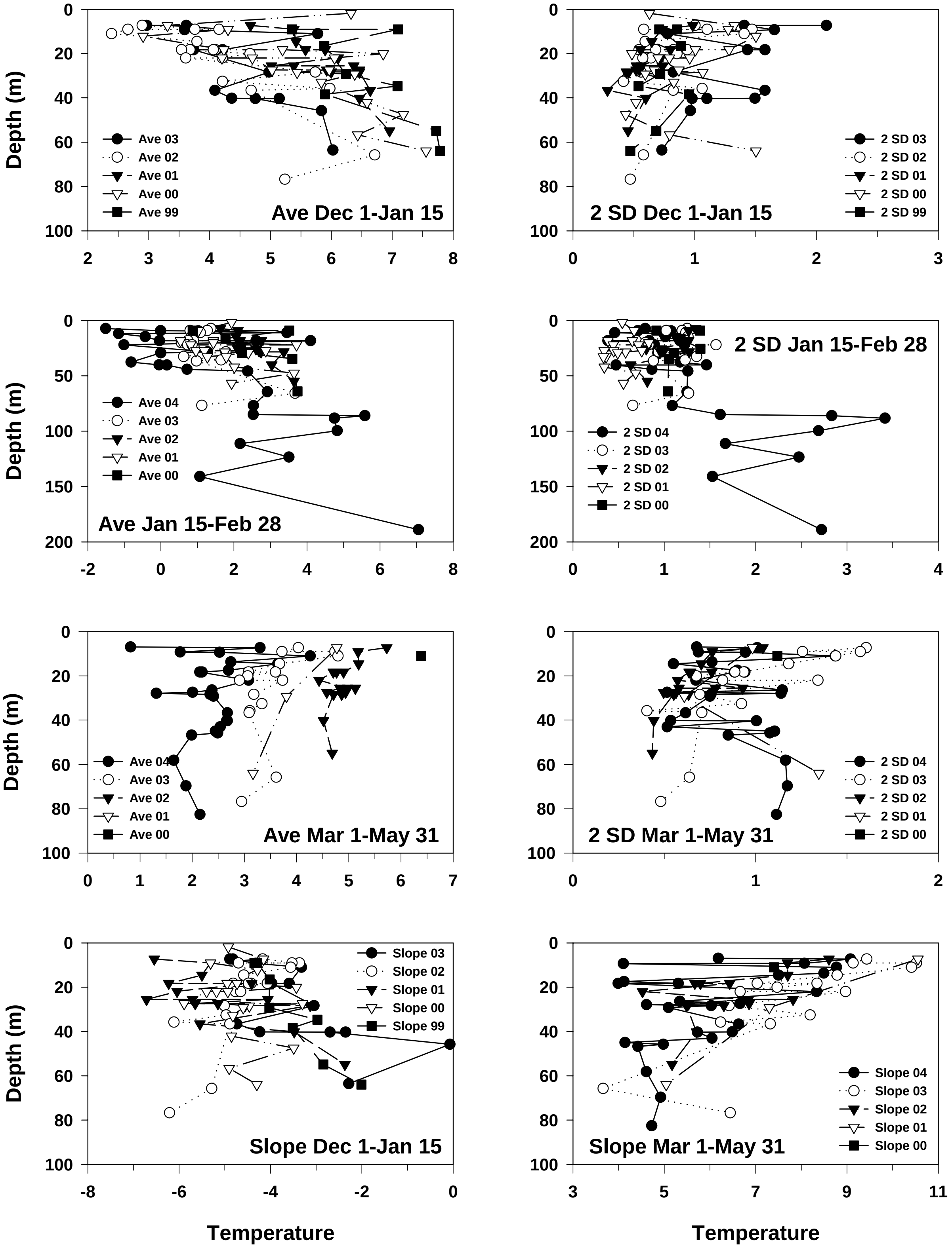

Figure 10. Depth profiles of average temperatures, two times the standard deviation, and slope (not calculated for Jan 15-Feb 28) for each analysis period.

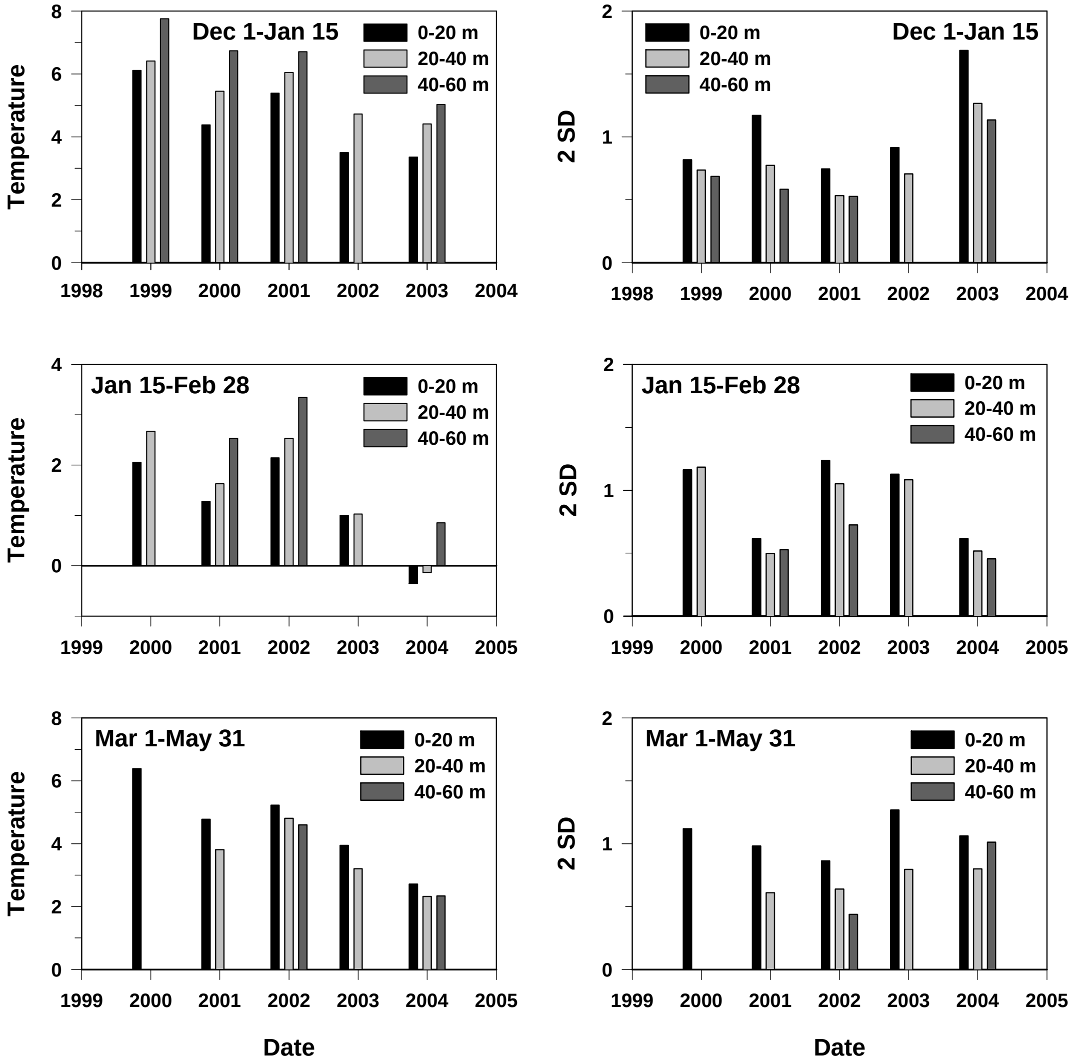

Figure 11. Average temperatures and two times the standard deviation by depth range for the three analysis periods.

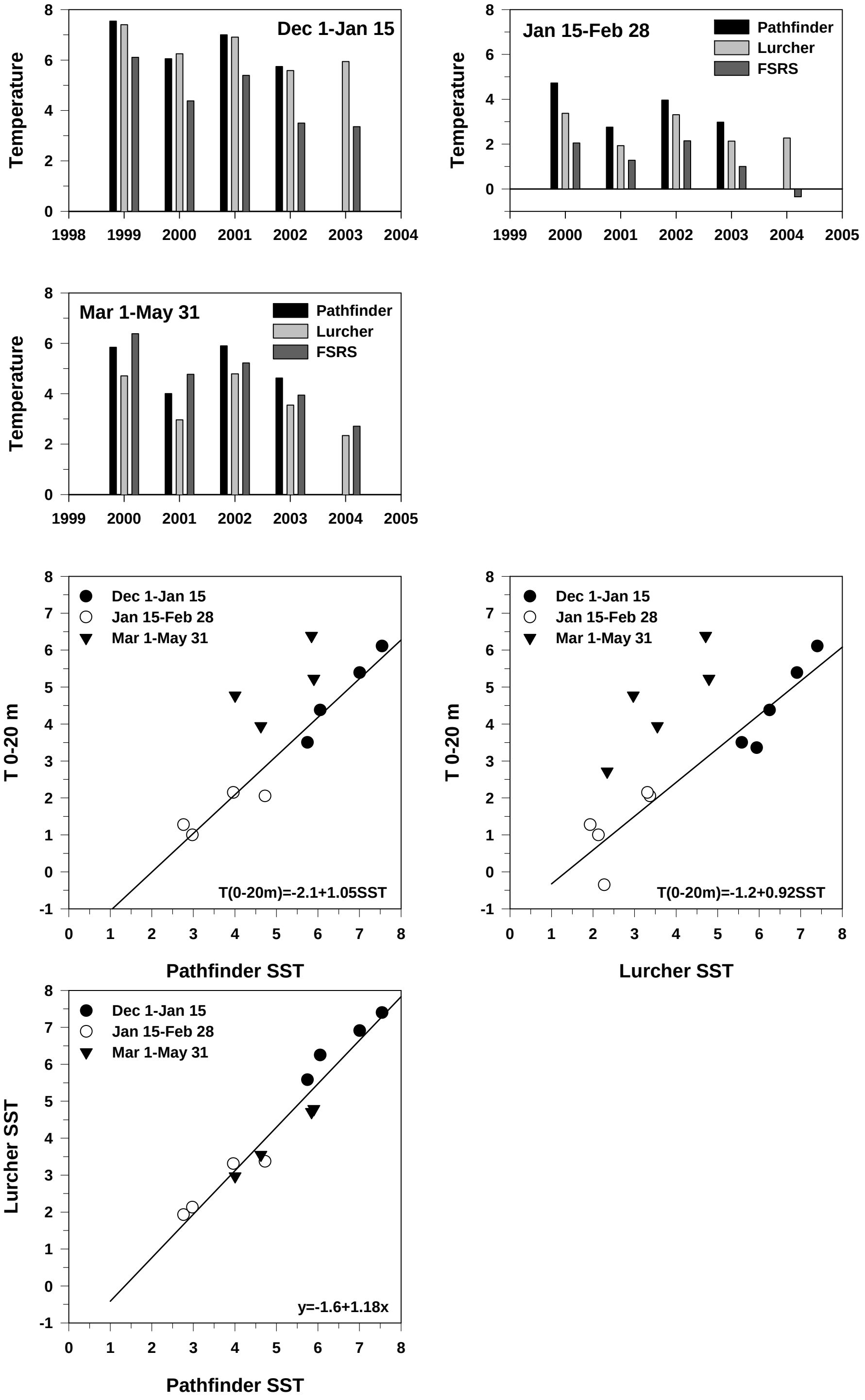

Figure 12. Comparison of the average temperatures for the three analysis periods: Pathfinder (satellite, 0 m), Lurcher (in situ, ship-based observations, 0-5 m), and FSRS data (0-20 m) as time series and scatter plots.

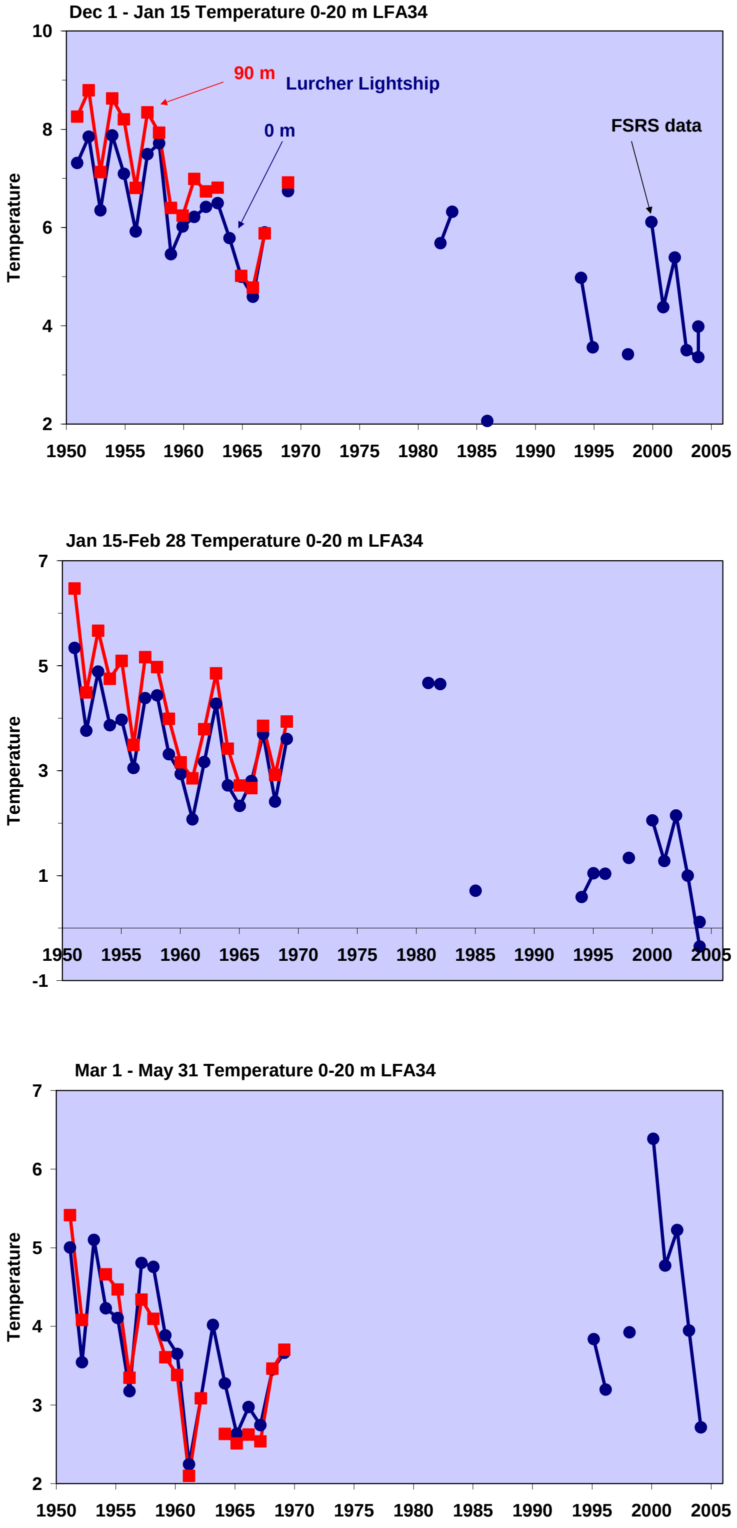

Figure 13. Average temperatures for the periods Dec 1-Jan 15, Jan 15-Feb 28 and Mar 1-May 31 for LFA 34, 0-20 m.

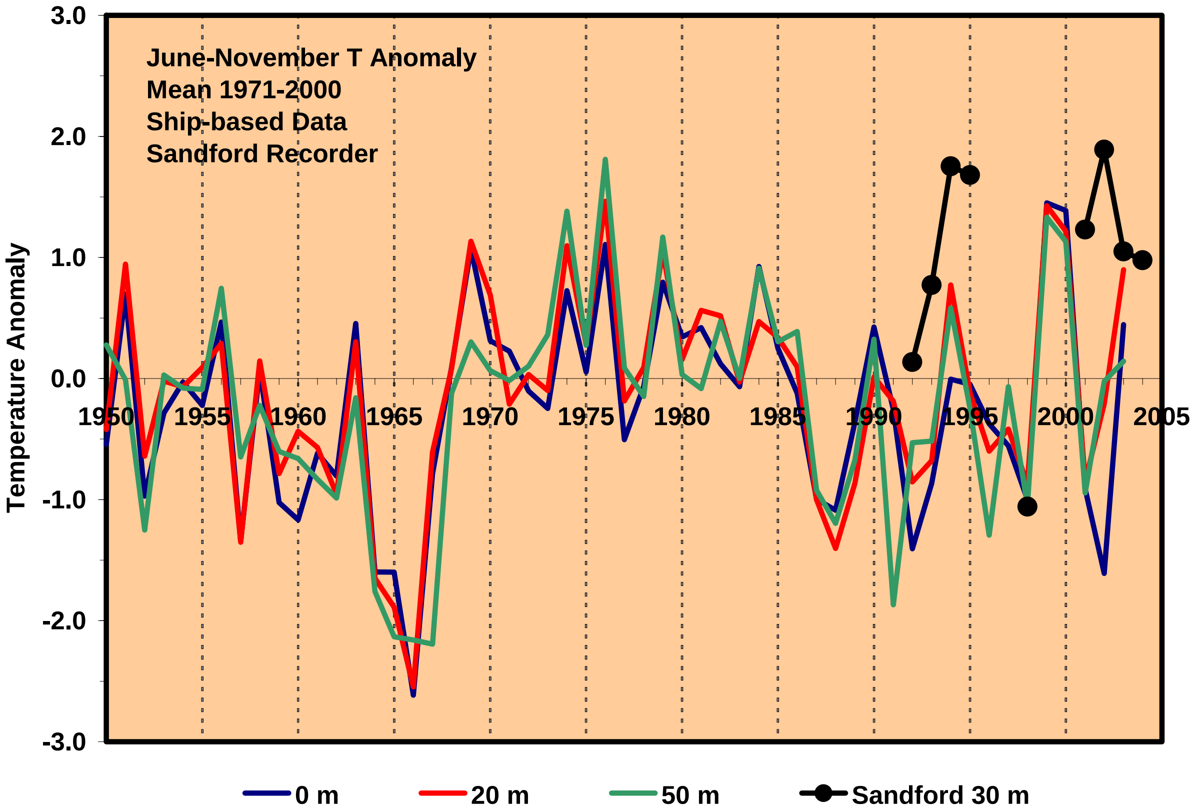

Figure 14. Temperature anomaly time series for the June 1-Nov 31 period from 1950-2003 from ship-based observations at 0, 20 and 50 m. Also shown are temperature anomalies calculated from the LTTMP data collected off Sandford (43.94ºN, 65.18ºW) at 30 m. In both cases the anomalies were based on the monthly means at the appropriate depths determined from the 1971-2000 ship-based observations.

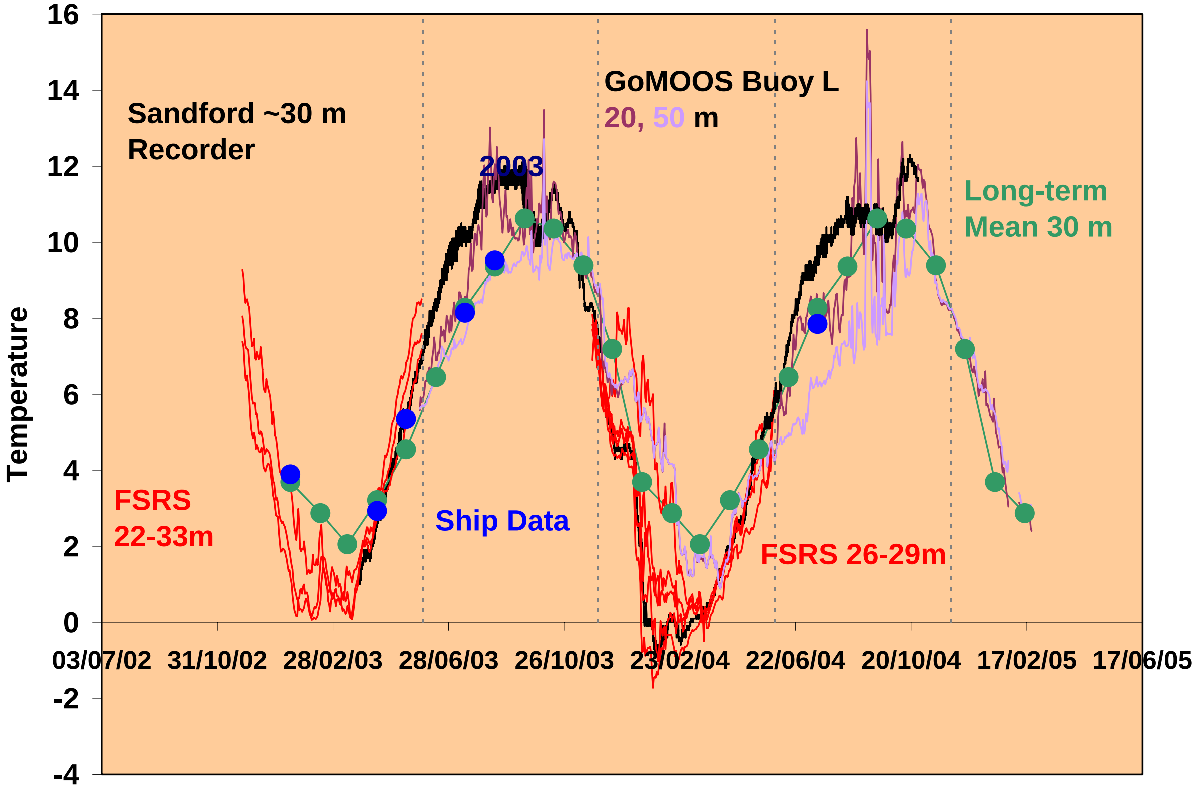

Figure 15. Temperature series for 2003-2004 from the FSRS instruments (red line), Sandford (black line), GoMOOS Buoy L (43.625°N, 66.554°W, 98 m; dark and light purple lines), ships of opportunity (blue dots) and 1971-2000 monthly long-term means from ship-based observations for the Scotian Shelf-Gulf of Maine atlas area 24 (Petrie et al., 1996; green dots, line). Vertical, grey broken lines indicate the June-November periods in 2003 and 2004.

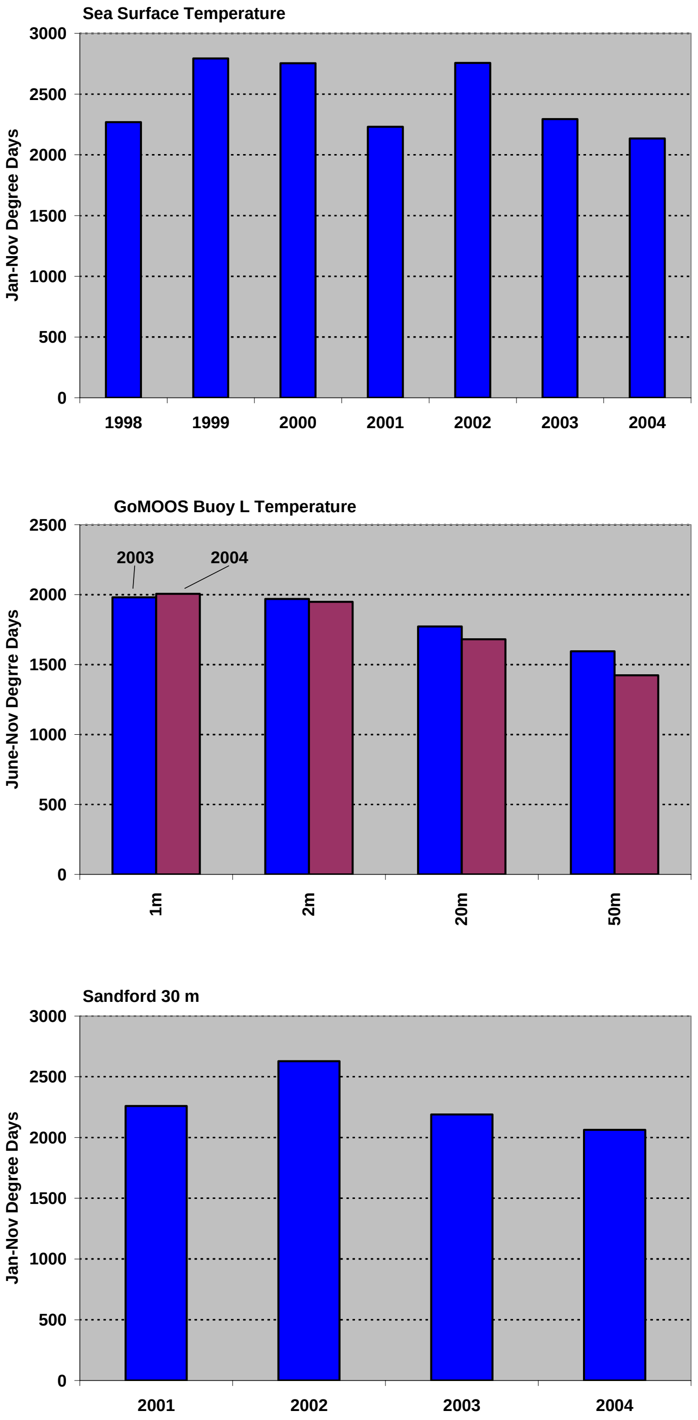

Figure 16. Accumulated degree days for the January-November period relative to 0^oC for SST based on satellite observations, the GoMOOS buoy (June-November only), and temperature recorders moored at 30 m off Sandford.