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Overview of Environmental Conditions in NAFO Divisions 2J+3KL in 1991

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Abstract

Environmental conditions on the Newfoundland and Labrador continental shelves during 1991 are summarized from meteorological, ice cover and ocean temperature data. Both the air temperatures and ice cover extent indicate that the winter conditions in 1991 were established several weeks ahead of normal and extended 4-6 weeks beyond the norm. Furthermore, in terms of ice cover extent and duration, 1991 was the worst ice year in 30 years. Consequently, not only was the warming of the oceanic surface delayed considerably, but the rate of warming and the thickness of the surface mixed layer were lower than other cold years. The subzero temperature water mass was also found further south in 1991 relative to other years.

Introduction

The environmental conditions on the Newfoundland and Labrador continental Shelves were anomalous in 1991. This paper compares the ice cover and oceanographic conditions that prevailed in 1991 to other years. The comparison is based on oceanographic temperature data collected during physical oceanographic and fisheries assessment surveys, and yearlong moored instrumentation and on ice-cover and atmospheric data provided by Environment Canada.

Meteorological Conditions

In contrast to the general global situation of higher than normal air temperatures during the decade, northeastern Canada, particularly the Labrador and Newfoundland coastal regions experienced below normal air temperatures during the 1980s. An examination of the winter temperatures for individual years, however, shows that the 1980s started with positive anomalies but changed to abnormally cold conditions in 1983 (Table 1). From then on, except for a warm period during mid-80s, the negative anomaly persisted over the Baffin Island, Labrador and Newfoundland coasts.

The persistent cold weather condition is found to be continuing into the 1990s. The 1990 monthly anomalies over Newfoundland and Labrador were also predominantly negative during winter and early spring (Drinkwater and Trites 1991). Even though the air temperatures were near normal during summer months, the negative anomalies once again prevailed over most of Labrador from October 1990 to May 1991, and except in March over the southern Labrador and Newfoundland coasts from January to September (Fig. 1).

There were significant differences, however, in the anomaly patterns between 1990 and 1991. In January 1991 the air temperatures over Labrador and Newfoundland were 6° to 8° below normal (compared to a -2°C anomaly in 1990), which is similar to the anomalies found during February of 1990. Thus winter conditions in 1991 occurred several weeks ahead in time as compared to 1990 conditions. Another major difference between the two years was the persistence of below normal air temperatures in Newfoundland throughout the summer, as compared to just for May in 1990. These differences had a significant impact on the ice cover and oceanographic conditions over the continental shelf off Newfoundland and Labrador.

Ice Conditions

During the winter of 1990/91, the Canadian east coast experienced below normal air temperatures and above normal ice cover extent. When the ice cover advanced in 1991 along the Labrador coast, air temperatures were significantly below normal. This increased the ice growth throughout the area and decreased the ice melt rates along the advancing ice edge (Fig. 2). When the ice cover retreated in April to June of 1991, air temperatures in the southern region remained 1.8°C below normal, reducing ice melt rates. Figure 3 shows the total ice cover on 17 June 1991 in comparison to the mean ice limit over 1962 to 1987.

Cold Arctic air masses coming from the northwest and west not only cause local ice growth along Labrador and Newfoundland coasts, but advect the pack ice down from higher latitudes. Monthly wind histograms can be used to estimate the monthly free-ice drift when one assumes that ice drifts at 2.5% of the wind speed and at 35° to the right of the wind (this empirical relationship between the winds and the free-ice drift was derived from ice beacon drift data). For the 25-year mean winds of 1955 to 1980, the distances the ice drifted per month due to wind forcing in 16 directions (22.5° sections) are shown in Fig. 4. For each month, the figure shows the contour made by joining the 16 vector end points. These 16 displacement vectors can be added vectorially to give a net monthly displacement (Table 2). The results show that for the Newfoundland Shelf, ice is advected at a rate of 145 km/month by the wind towards the southeast in winter and at 90 km/month towards south and southeast in the spring. For the southern Labrador coast the ice is advected at 170 km/month to the southeast. In the spring, the ice on the Labrador Coast is advected predominantly to the south but at a reduced rate of 100 km/month.

For the 1990/91 ice season, winds off Newfoundland and southern Labrador and the referred ice drifts (Fig. 4) were stronger than the mean 1955-80 winds. Drifts were larger by 37% for the winter off Newfoundland, and 55% and 90% for the winter and spring periods off southern Labrador. In general, during 1990/91 ice drifted 20° clockwise from the 25-year mean. Compared to the mean, this means that ice was restricted more to the shelf as offshore ice drift components were reduced. This is especialy noticeable in the March drift comparison, when the ice drift direction rotated from 140° and 150° to 210° and 190° for the Newfoundland and southern Labrador Shelves respectively.

The ice cover extent in 1991 was as severe as past anomalies of the mid 70's and mid 80's (Fig. 5). In the Hamilton Bank and the NE Newfoundland Shelf regions, the ice cover extent was a month ahead in time, and almost double in areal extent for both Hamilton bank region in December and NE Newfoundland Shelf in January (Fig. 6). This is not surprising since the air temperature anomalies also indicated similar shifts. Throughout the winter, the areal extent of the ice cover was above normal in all areas except for a short period in March when persistent onshore winds pushed the pack ice inshore causing severe rafting conditions. The ice cover over the NE Newfoundland Shelf area was reduced in width from 100 miles to 30 miles, suggesting rafting up to three layers on the average, increasing the inshore ice cover thickness from an average of 60 cm to 180 cm. Most of this ice melted over the shelf itself as less offshore ice advection was observed. Hence, although Fig. 6 shows below normal ice extent for a few weeks in March, in reality more ice was actually present than normal at this time.

The ice cover retreated slowly for the entire area, with ice occurrences in all three areas lasting as long as the 25 year observed maximum. Ice lingered around the Grand banks until early May, over the NE Newfoundland Shelf until mid July and in the Hamilton bank area until early August.

Transect data

A dominant characteristic of the temperature field on the Newfoundland and Labrador Shelves is the so called cold intermediate layer (CIL). In late winter, vigorous mixing and convection create a uniform water mass at near-freezing temperatures which may extend to the bottom. Since spring ice melt and summer warming increase the stratification in the upper layers, and thus inhibit heat transfer downwards, the intermediate layers remain cold throughout the spring and summer. In the autumn and early winter the CIL undergoes rapid warming due to a combination of vertical mixing and horizontal advection. Petrie et al. (1988) has shown that the CIL area across the shelf, the annual and summer temperatures at Station 27 and ice extent south of 55° N, are all generally highly correlated with one another.

1991 temperature transects across the Hamilton Bank, off St. Anthony on the northern tip of Newfoundland and off Cape Bonavista (Fig. 7), indicate that the warm upper layer was less than 20 m thick in July. Furthermore, the CIL area was found to be comparable to the extreme large areas of 1983-85, and 1972-73 (Fig. 8) when large ice extent anomalies occurred (Fig. 5).

STATION 27

Since 1946, measurements of temperature and salinity have been routinely taken at STATION 27. Oceanographic conditions at this station are considered to be representative of the inshore Labrador Current. Since STATION 27 temperature anomalies are also found to be strongly correlated with the cross sectional area of the CIL on the shelf, these can be used to estimate the variability in the oceanographic conditions on the continental shelf off Newfoundland and southern Labrador.

Figure 9 shows the STATION 27 temperature time series for the period 1970 to 1991. The annual cycle, of warm summer and cold winter water temperature is clearly noticeable in the shallow surface layers. Interannual variability due to extreme winter-summer can also be noticed. Even near the bottom where the annual temperature range is smaller, temperatures were below normal for the 1972-75 and the 1983-85 periods. Even though the conditions seem to have improved in 1986 and 87, the second cooling trend was found to be forming in 1988 and continued to 1991.

Another feature, though not obvious in this diagram, is the variability in the onset of warming process. In Fig. 10, temperatures at selected depths and years are compared to the monthly means of the averages over 1980's. Clearly, the oceanographic conditions in 1991 were in many ways significantly different from the normal as well as from other cold years. The surface warming in 1991 for example, was 4 to 6 weeks later than normal, and even when the maximum temperature was reached in August more or less on time, the peak values were over a degree lower than average. In comparison, even though similar delay in surface warming occured in 1984, the near-surface peak temperature was about August; in contrast, even in 1984, temperatures reached above zero values by end of May. In addition the bottom temperatures in 1991 were below normal throughout the year.

Figure 11 shows the year-to-year variability in the formation and decay of the different temperature layers at STATION 27. For example, this diagram shows that the entire water column was at subzero temperatures until the end of May in 1991 and 1984, whereas in other years, the near-surface layers were warmed up to above-zero values by end of April. As expected, the thickness of the warm surface layer was the lowest in 1991, about 30 m in August of 1991 compared to over 60 m in other years.

It is to be expected that even though 1972-73, 1983-85 and 1990-91 are all refered to as cold years, many differences exist in the temperature structres among these years due to the differences in one or more of the processes that influence the temperature characteristics. Thus, even if the winter conditions were very similar between any two years differences in spring/summer meteorological conditions between those two years could result in totally different upper layer structures in summer and fall.

Fisheries survey data

During the assessment surveys for cod, capelin and other species, water temperatures are routinely collected. Data available from 1986 to 1991 were analyzed to extract the variability in the southward extent of the sub-zero temperature water mass over on the Grand Bank. All data collected for the period May 15 to July 15 of each year are assumed to be synoptic and representative of the spring temperature structure on the shelf. Similarly, data collected from October 1 to mid-December are assumed to be representative of the fall conditions. Such a wide time interval was chosen to accomodate the variability in the dates of the survey cruises from one year to the next, as well as to ensure sufficient data to produce horizontal temperature maps. The measurements are then mapped onto a 0.5 ° X 0.5°C horizontal grid, and an average profile for each grid is calculated; this gridded data are used to calculate areal extent of different temperature water masses at selected depths for the NAFO region 3L.

The binning of the data can potentially reduce the resolution of these maps as well as introduce aliasing errors, especially along the shelf edge where spatial and temporal scales are shorter than the bin width. However, it is perhaps reasonable to assume that, on the Grand Bank where bathymetry is relatively flat, these maps represent the general characteristics of the spring and fall temperature conditions.

Figure 12a shows the percent areal extent during the spring, of water masses within four different temperature ranges from 1986 to 1991. The warm near-surface temperatures indicated in this diagram is partially due to averaging 2 months of data. However, in spite of this, the delay in surface warming in 1991 is still evident. It is also interesting to note that, though 1986 was found to be a comparatively warm year in terms of Davis Strait sea ice anomaly (Table 1), the areal extent of subzero temperatures at 50 m and at the bottom, was greater than most years and almost as large as that in 1991. Data from STATION 27 confirm this since the entire water column here was at temperatures less than -1.5 °C from mid February to end of March .

During the fall period (Fig. 12b), on the other hand, there was hardly any subzero temperatures at 50 m depth in

1986 whereas over 40% of 3L in 1991 had temperatures below zero. As expected, the areal extent of subzero temperatures at the bottom was the largest in 1991.

Time series data from moored instruments

The circulation and the water mass characteristics are strongly influenced by the regional bathymetry. The NE Newfoundland Shelf bathymetry consists of two major banks, Funk Island and Belle Isle, separated from each other and from the coast by deep channels. Exchanges between the inshore and offshore branches of the Labrador Current are known to occur through these channels; these channels are also identified as the highways along which cod migrates inshore in the spring. Data collected from the NE Newfoundland Shelf show that the bottom temperatures in these channels were well above zero throughout the year (Fig. 13), colder temperatures occurring inshore, confirming onshore flow of warmer slope waters through these channels. Of course, inshore of these deep channels, the CIL reaches the bottom, as evidenced in the data from BB3.

As shown in the temperature cross section off Cape Bonavista (Fig. 7) the CIL extends to several hundred meters over most of the shelf. Consequently, monthly averaged temperatures at 75 m were mostly below zero, even though on occasion, for short period of time, above zero values existed especially in the fall (Fig. 14).

Along the shelf edge, on the banks as well as in the channels, significant vaiability occurs at 6-8 day period, associated with the oscillations of the shelf water/ slope water front, as evidenced in the time series temperature plot (Fig. 15).

The mooring program on the NE Newfoundland Shelf was intiated in 1989. Hence, the time series data base was not sufficiently long to assess the interannual temperature variability in this region. However, to monitor the variability of the Labrador Current, an oceanographic mooring program on Hamilton Bank (H1 and H2 in Fig. 13) was established in 1978. Temperature data collected at the bottom on the bank (Fig. 16) indicate below normal conditions from 1983 to 86, never reaching above zero values even after the fall warming (similar variability was not evident at the offshore location H1). The time series also indicates a second cooling trend which commenced in 1988/89. Even though the fall warming in 1990 raised the temperature at this site to above zero values, duration of these temperatures were shorter than normal; winter cooling lowered the monthly averaged temperatures in 1991 to values below those in 1990.

Summary

The environmental conditions on the Newfoundland and Labrador continental Shelves were anomalous in 1991. Below normal early winter air temperatures increased ice growth and retarded ice melt of the advancing pack ice. Stronger northwesterly winds increased ice flux from higher latitudes, while less frequent offshore winds kept the ice floes over the shelf, reducing the ice melt. In response to major storms with onshore winds in the spring, severe rafting occured, increasing the ice volume over the shelf. Below normal spring/summer air temperatures reduced ice melt during ice retreat. The net result was that 1991 was the worst ice year in 30 years both in terms of ice cover and duration.

Increased ice cover extent and duration, and above normal ice-melt on the shelf resulted in a 4-6 weeks delay in surface water warming, and a significantly thinner surface water layer. Furthermore, the 1991 July CIL area was one of the largest since 1948, comparable to 1984 in total area. The subzero water mass was also found to extend much further south in 1991 compared to other years.

References

Drinkwater. K. F., and R. W. Trites. 1991. Overview of environmental conditions in the northwest Atlantic in 1990. NAFO SCR Doc. 91/87. 27 p.

Petrie, B., S. Akenhead, J. Lazier and J. Loder. 1988. The cold intermediate layer on the Labrador and Northeast Newfoundland Shelves, 1978-1986. NAFO Sci. Coun. Stu. 12: 57-69.

Table 1. Observed temperature anomaly for Baffin Island, Ungava region of Quebec, Labrador and Newfoundland and sea ice anomaly in Davis Strait or 1980-91 winters compared to 1950-79 mean.

WINTER	BAFFIN ISLAND	UNGAVA	LABRADOR	NFLD	DAVIS STRAIT SEA ICE ANOMALY
80	+	+	+	+	-
81	+	+	+	+	-
82	+	+	+/-	+/-	-
83	-	-	-	+	+
84	-	-	-	-	+
85	+/-	+	-	-	0
86	+	+/-	+/-	+/-	-
87	-	+	+	-	0
88	+/-	-	-	-	+
89	-	-	-	-	+
90	-	-	-	-	+
91	-	-	-	-	+

Table 2. Monthly displacements of ice due to wind forcing. Monthly mean wind speeds for 16 directions, each an average over 22.5°C out of the 360°C, were multiplied by their frequency of occurence and by 2.5% to represent ice speed and turned 35° to the right of the wind tc represent drift direction.

VECTORIAL MEAN ICE DRIFT (TO) BY WIND FORCING

	NEWFOUNDLAND SHELF (GANDER WIND)				S. LABRADOR SHELF (CARTWRIGHT WIND)			
	1955-1980		1990/1991		1955-1980		1990/1991	
Month	DIST (KM)	DIR. (DEG)	DIST (KM)	DIR. (DEG)	DIST (KM)	DIR. (DEG)	DIST (KM)	DIR. (DEG)
NOV	140	100	170	115	170	120	315	195
DEC	180	105	220	95	190	125	280	115
JAN	170	115	280	120	170	125	280	125
FEB	155	125	210	115	165	130	240	125
MAR	115	140	115	210	170	150	140	190
APR	95	150	100	195	140	180	190	175
MAY	65	130	95	135	110	185	170	190
JUN	120	75	50	140	50	150	210	200
JAN-MAR	145	125	200	145	170	135	265	145
APR-JUN	90	115	80	155	100	170	190	190

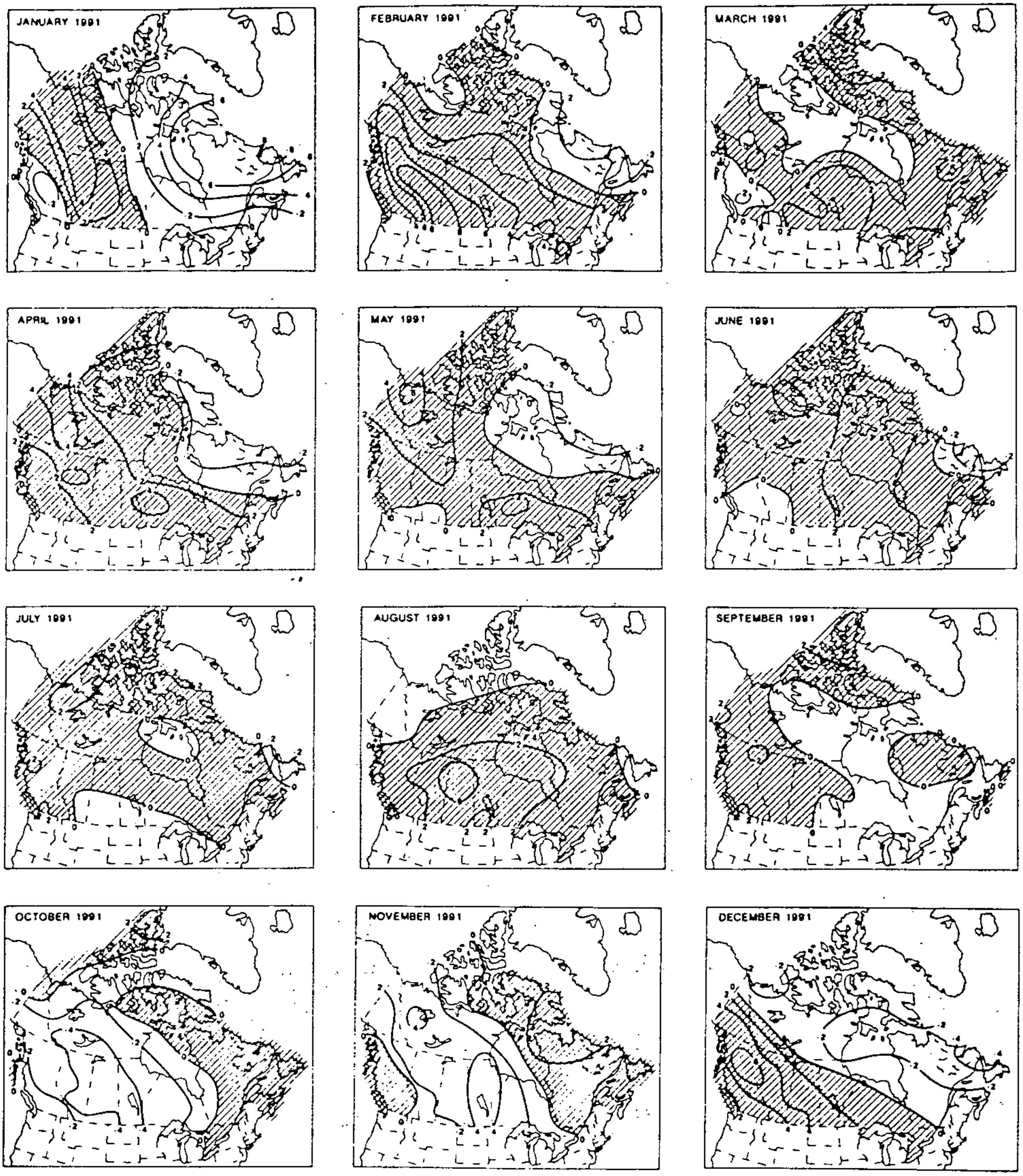


Fig. 1. Anomalies of monthly air temperatures for 1991. (Climative Perspectives, Vol. 13, Environment Canada).

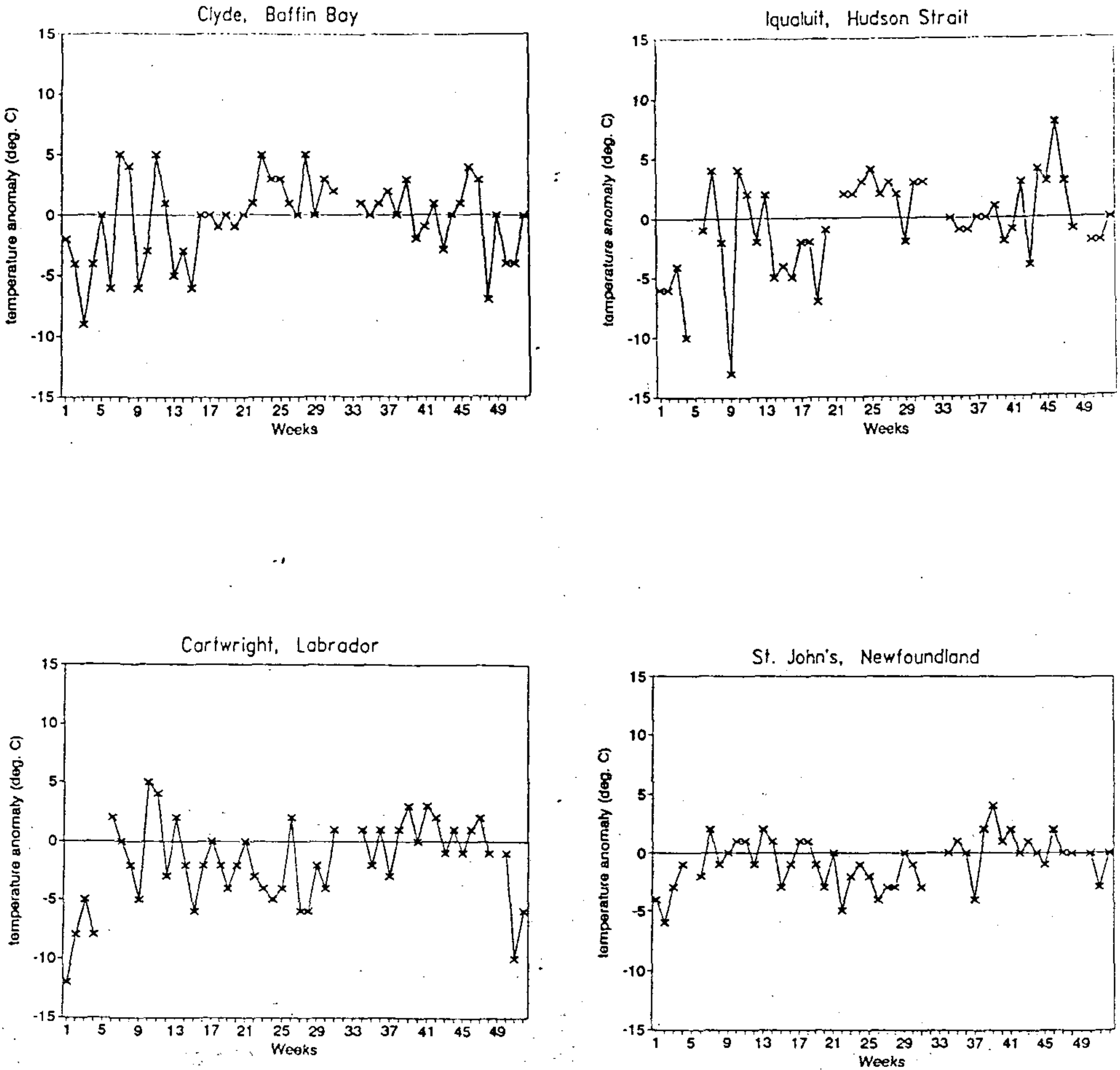


Fig. 2. Anomalies of weekly air temperatures for 1991. (Climatic Perspectives, Vol. 13, Environment Canada).

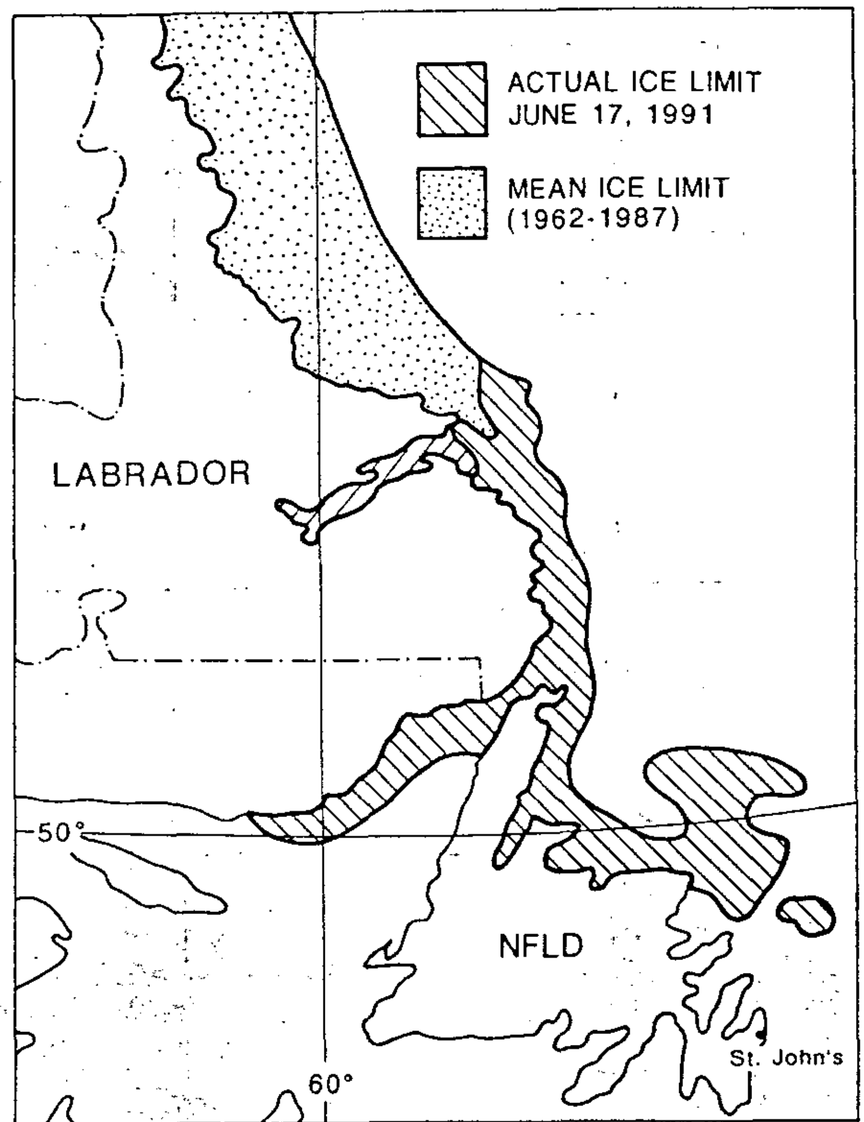


Fig. 3. Total ice cover on 17 June 1991 in comparison to mean ice cover over 1962 to 1987.

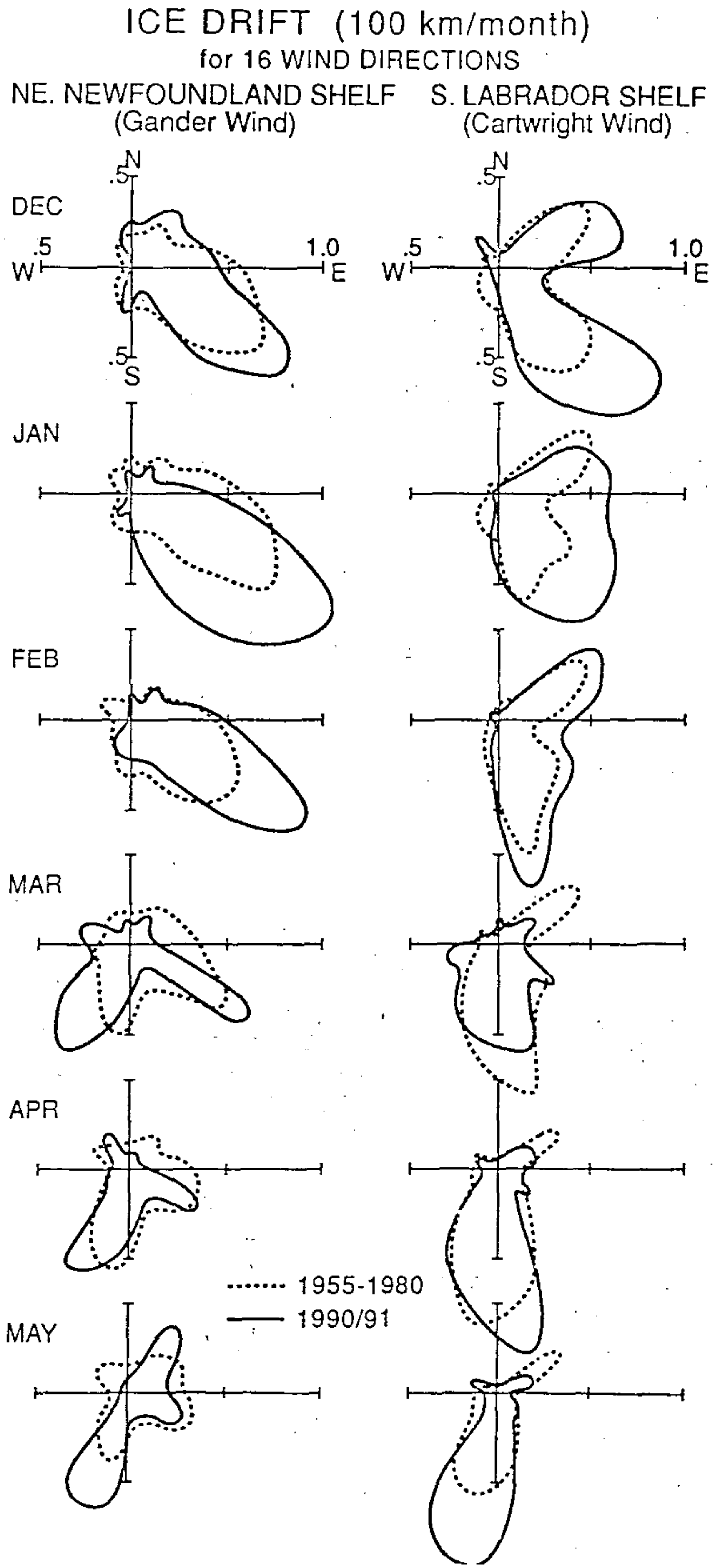


Fig. 4. Comparison of monthly free ice-drift for 1990/91 to mean over 1955-1980.

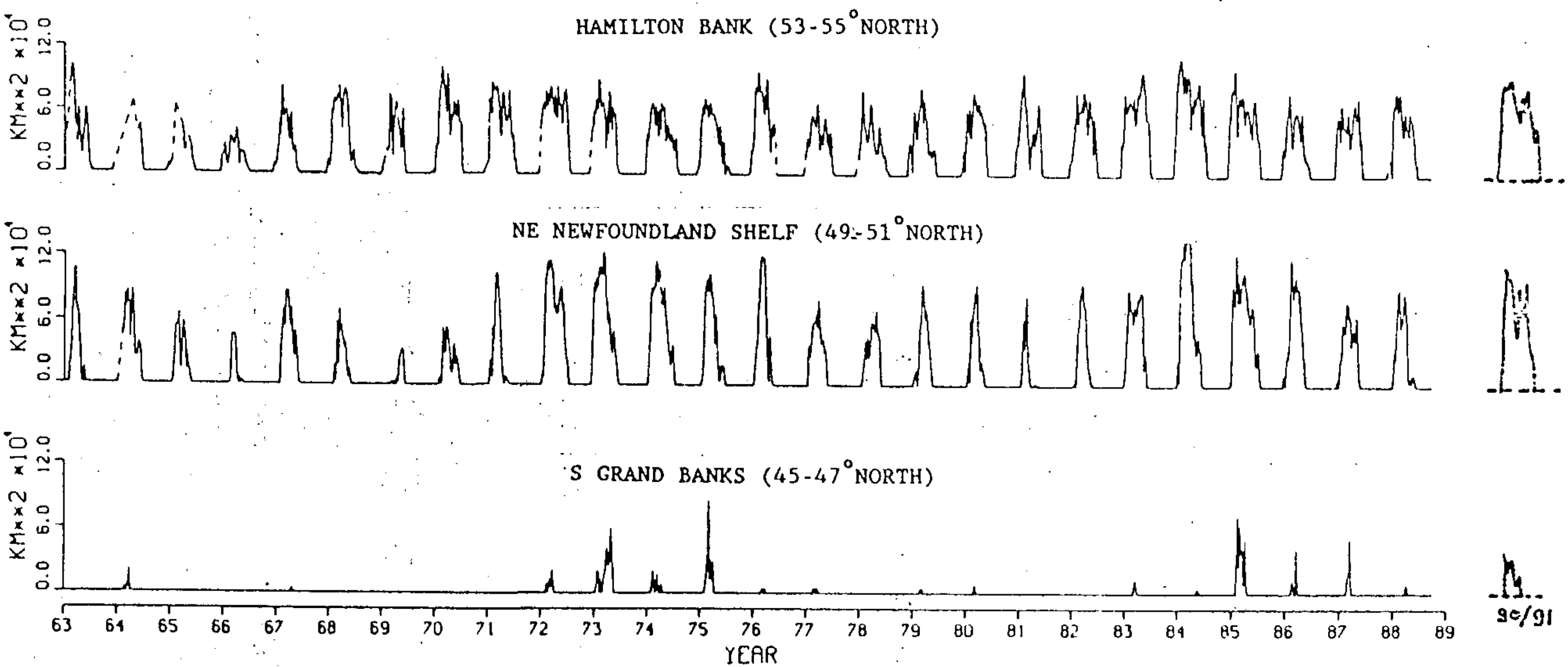


Fig. 5. Seasonal ice cover extent in $10^4 km^2$ (weekly values) for three areas along the Canadian East coast: Hamilton Bank area from 53 to 55°N, NE Newfoundland shelf from 49 to 51°N and S Grand Bank from 45 to 47°N.

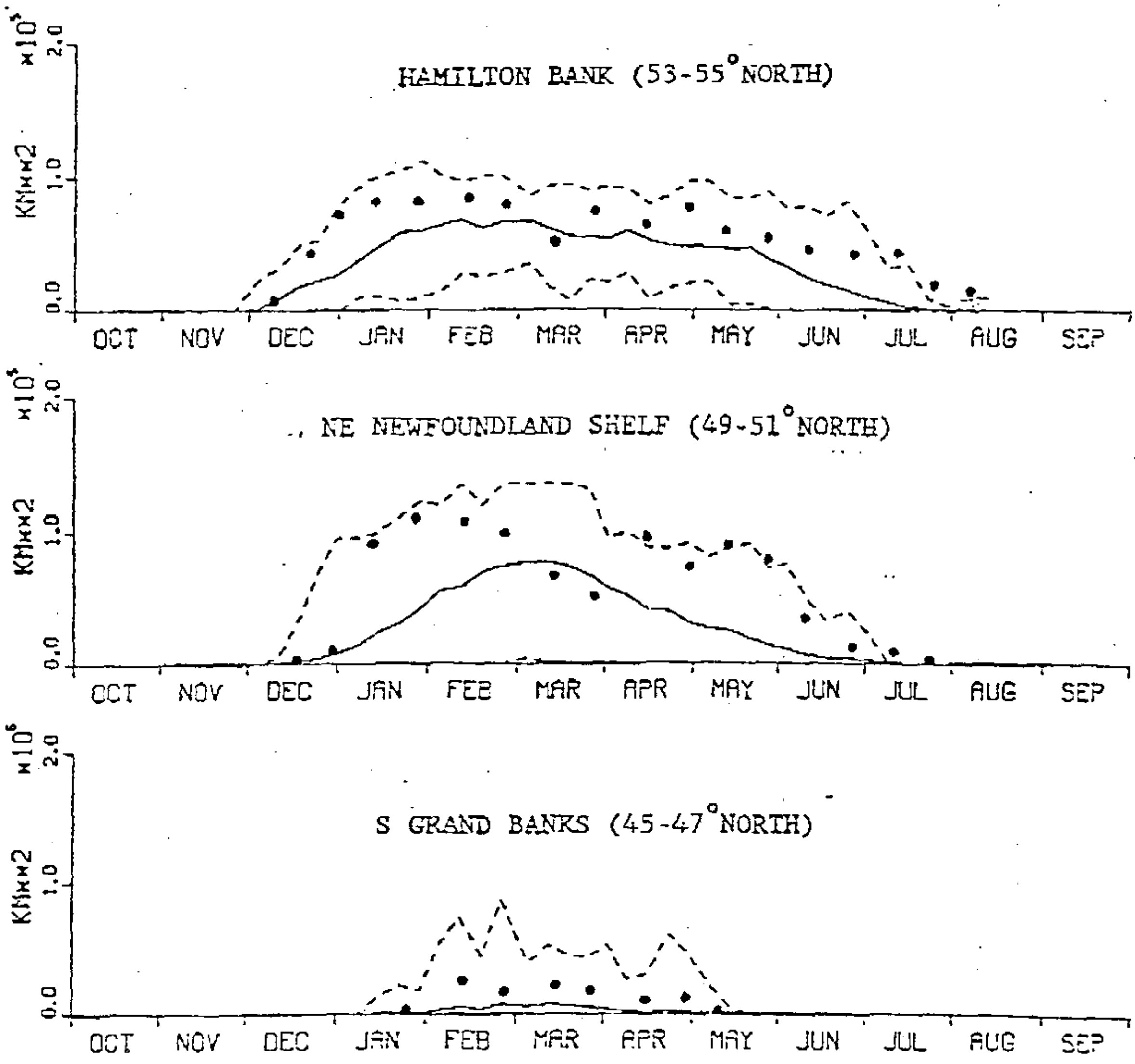


Fig. 6 Weekly mean ice extent with solid lines showing the 20-year mean, dashed lines the minimum and maximum ice extent in total 20-year records and dots the biweekly winter values of 1990/91.

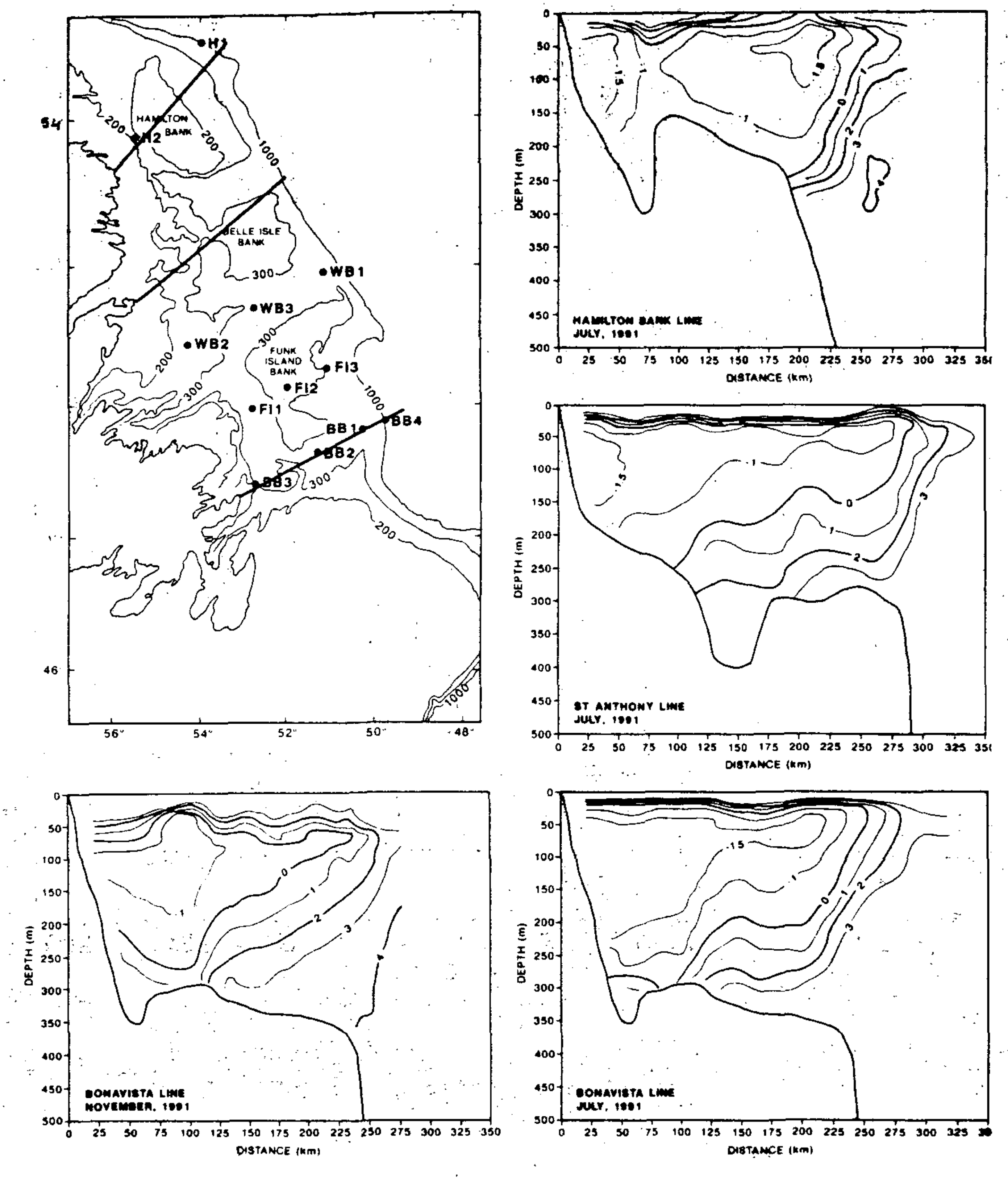


Fig. 7. Selected temperature transects.

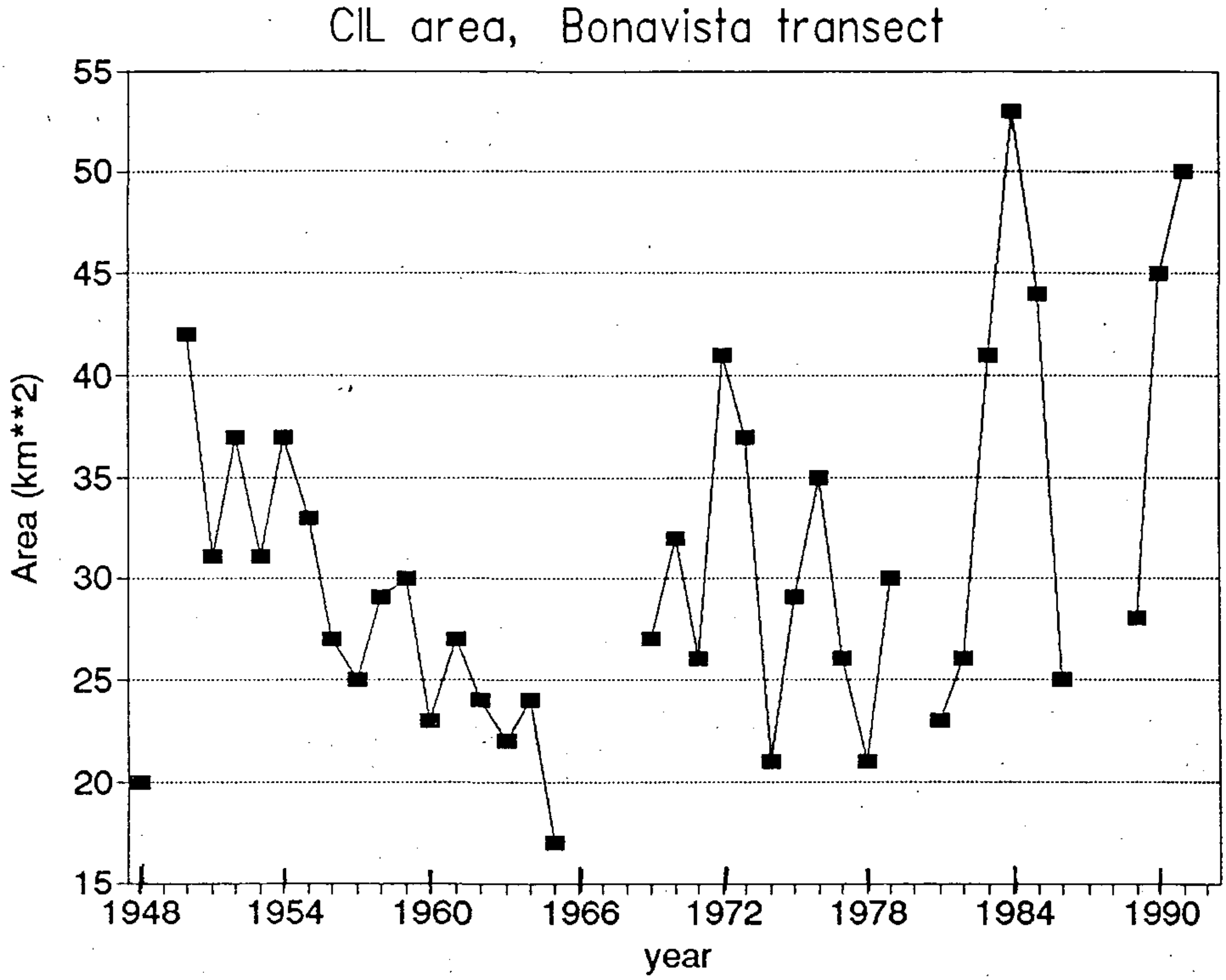


Fig. 8 Interannual variability in the CIL area.

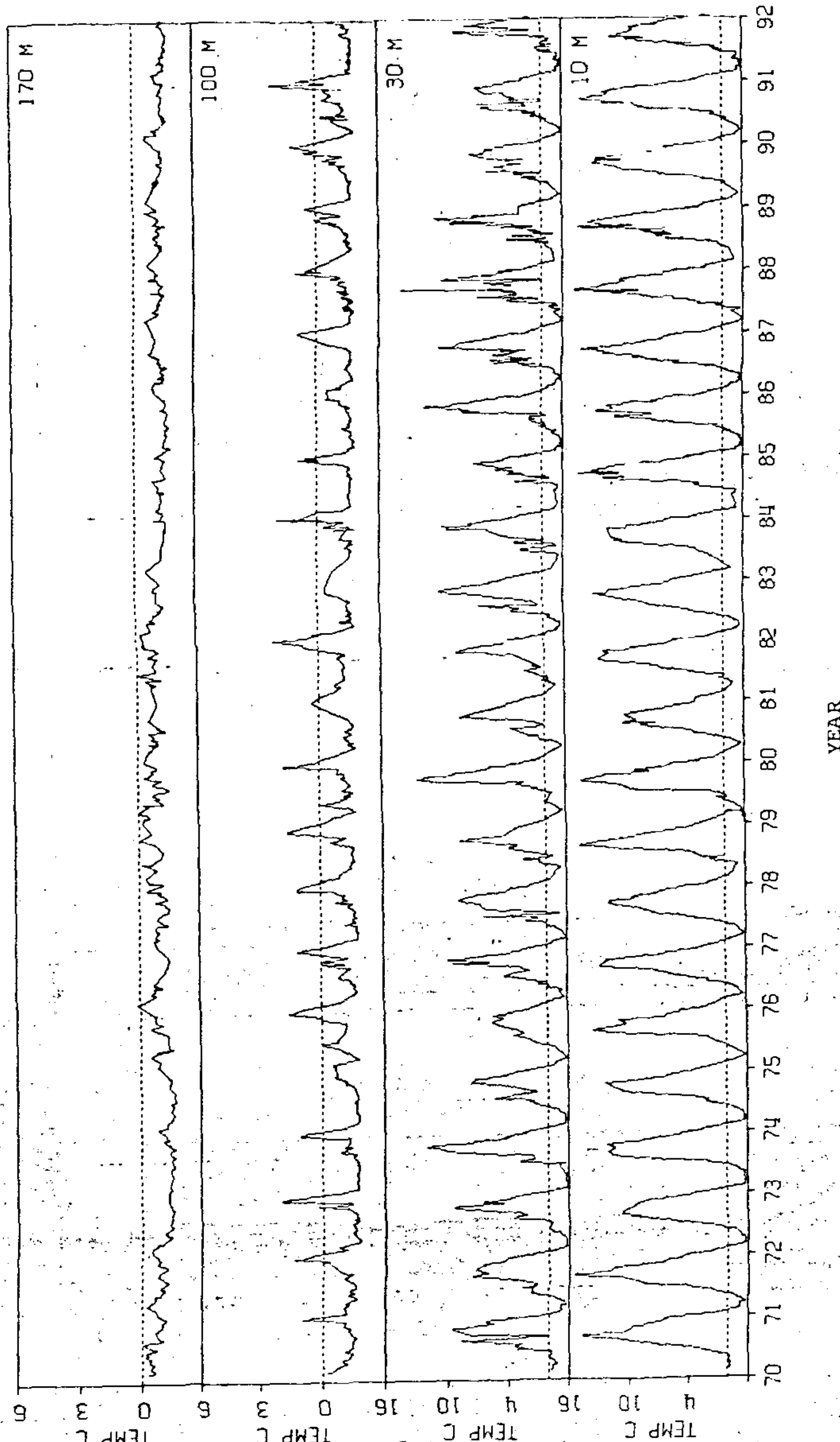


Fig. 9. STATION 27 temperature time series at selected depths.

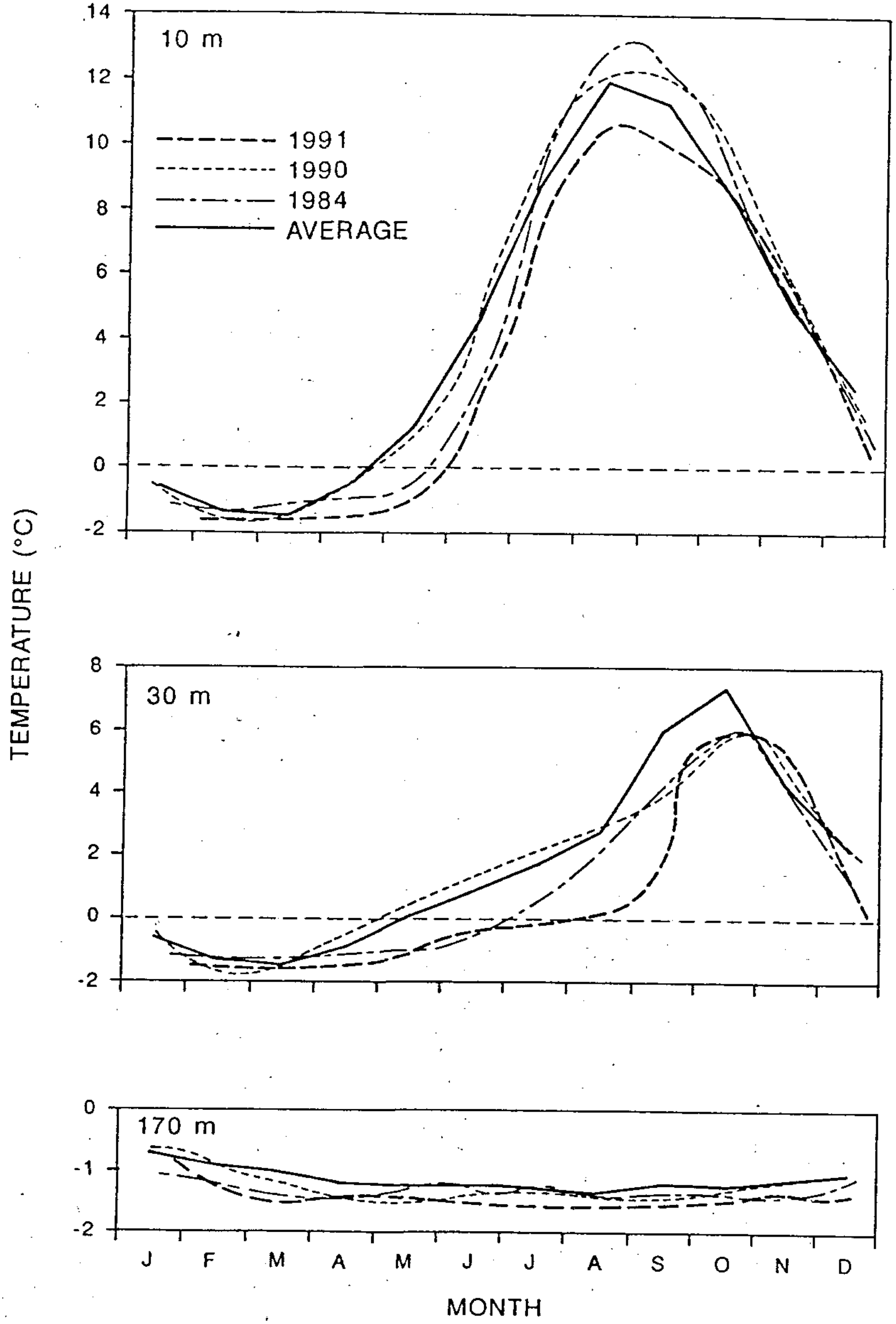


Fig. 10. Comparison of 1991 STATION 27 temperatures at selected depths with those in 1990 and 1984, and with the average monthly temperatures over the 1980s.

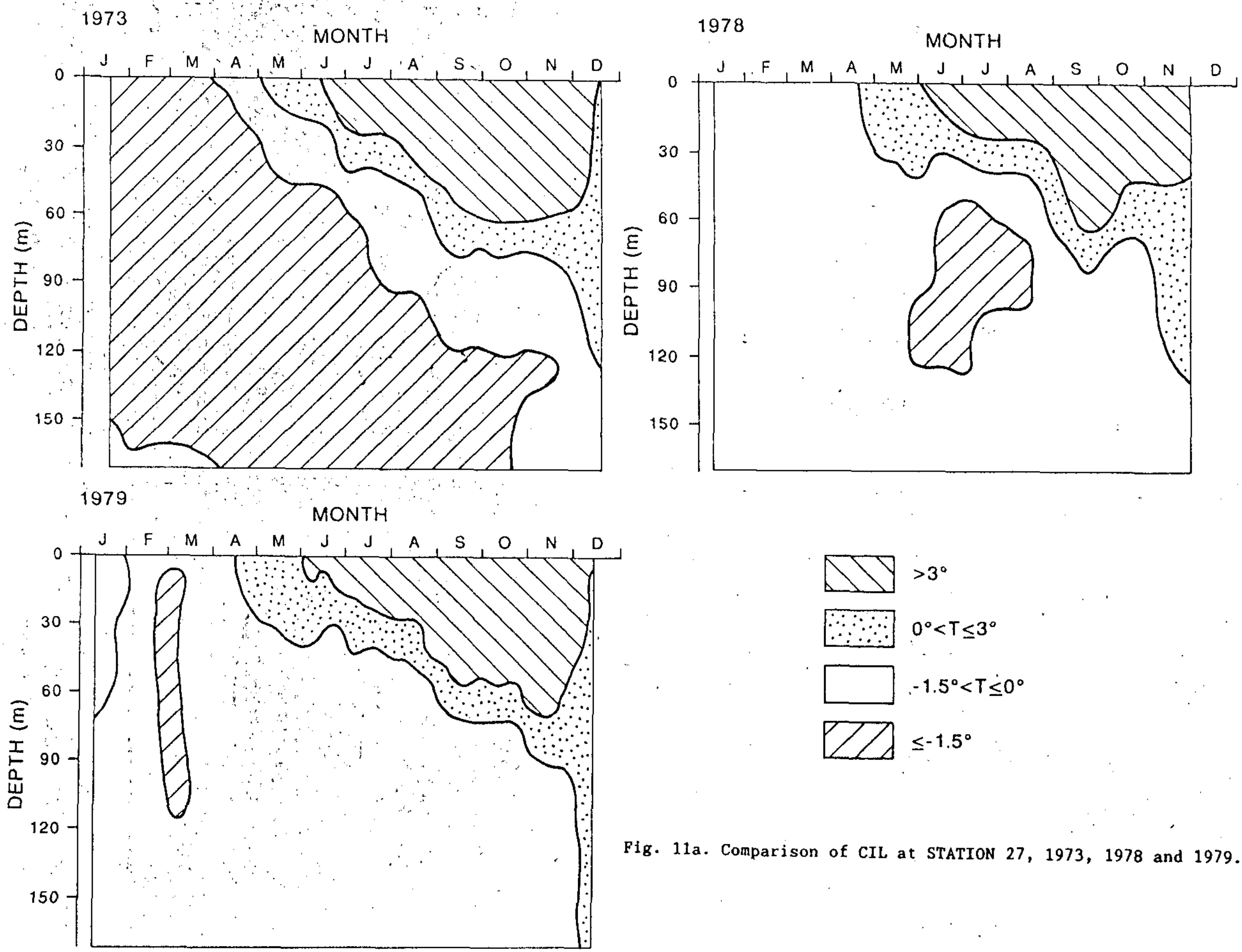


Fig. 11a. Comparison of CIL at STATION 27, 1973, 1978 and 1979.

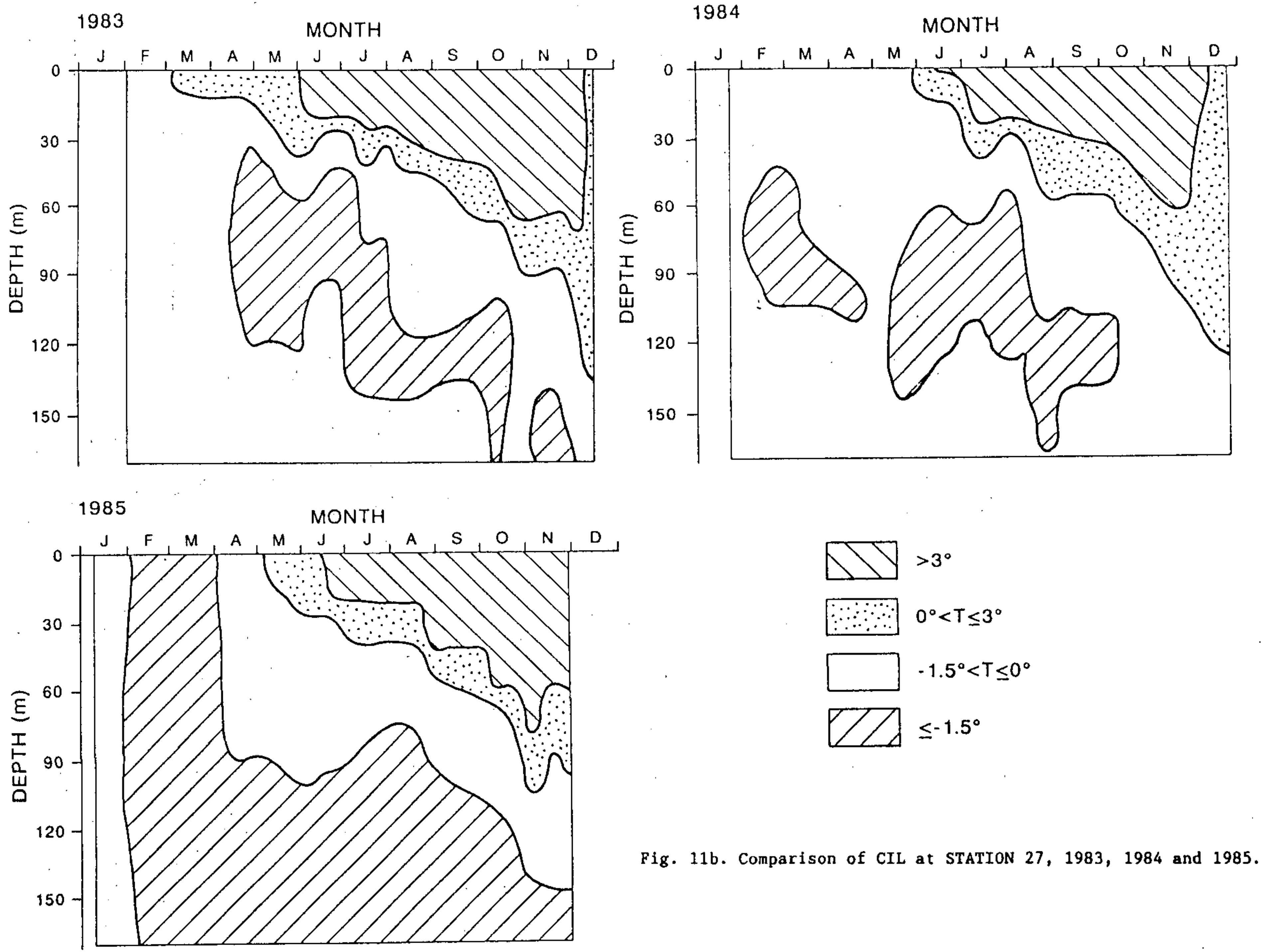


Fig. 11b. Comparison of CIL at STATION 27, 1983, 1984 and 1985.

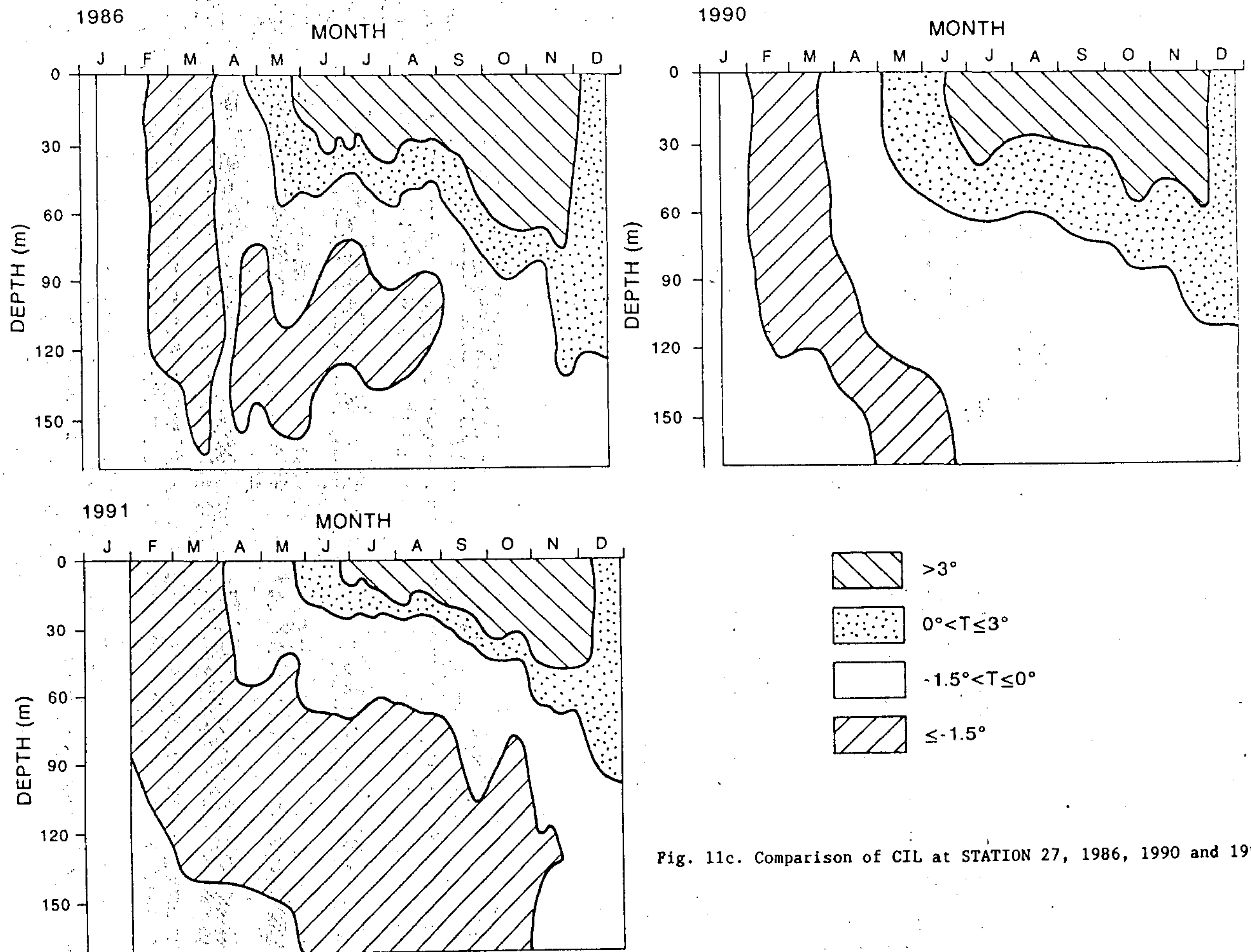


Fig. 11c. Comparison of CIL at STATION 27, 1986, 1990 and 1991.

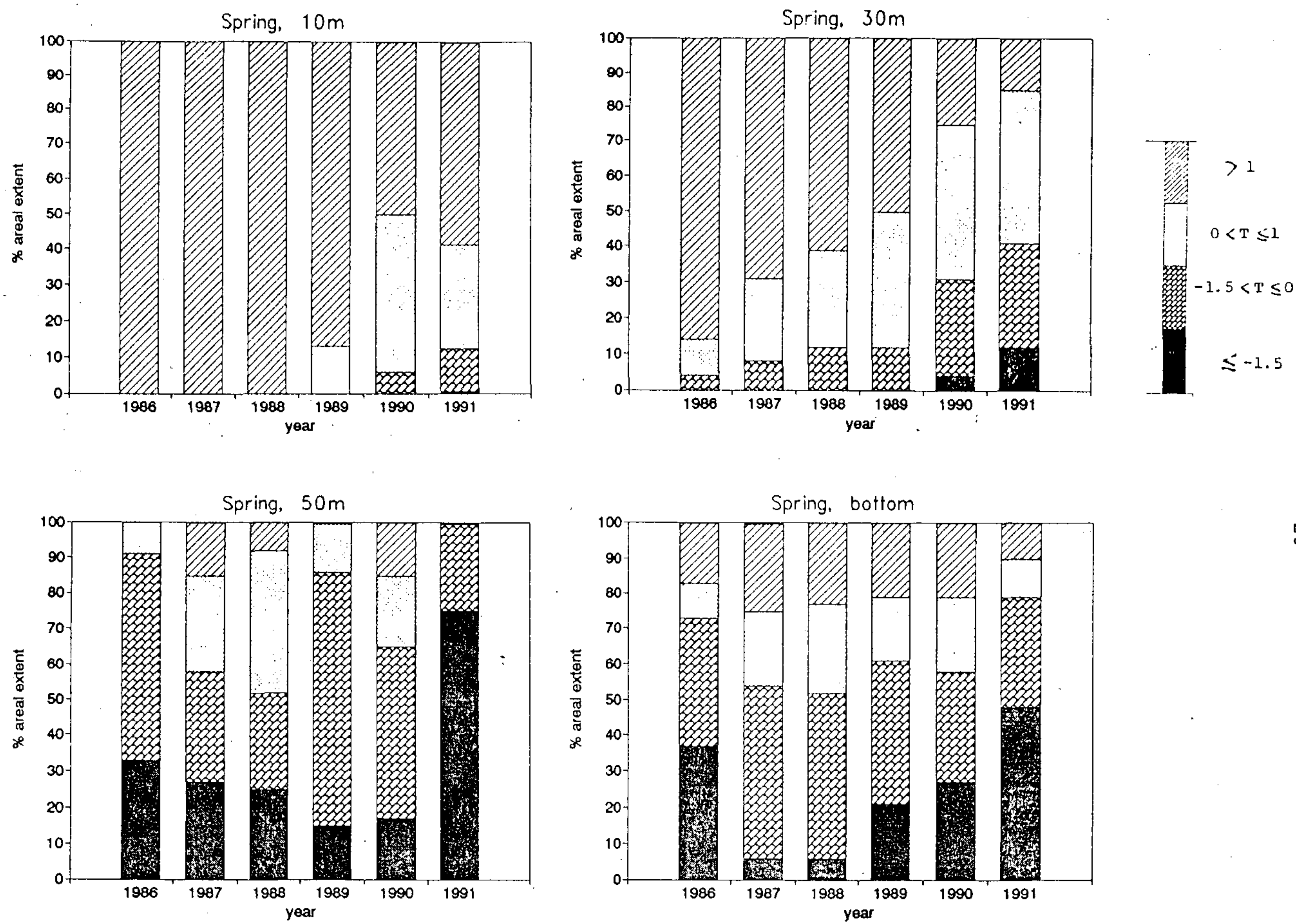
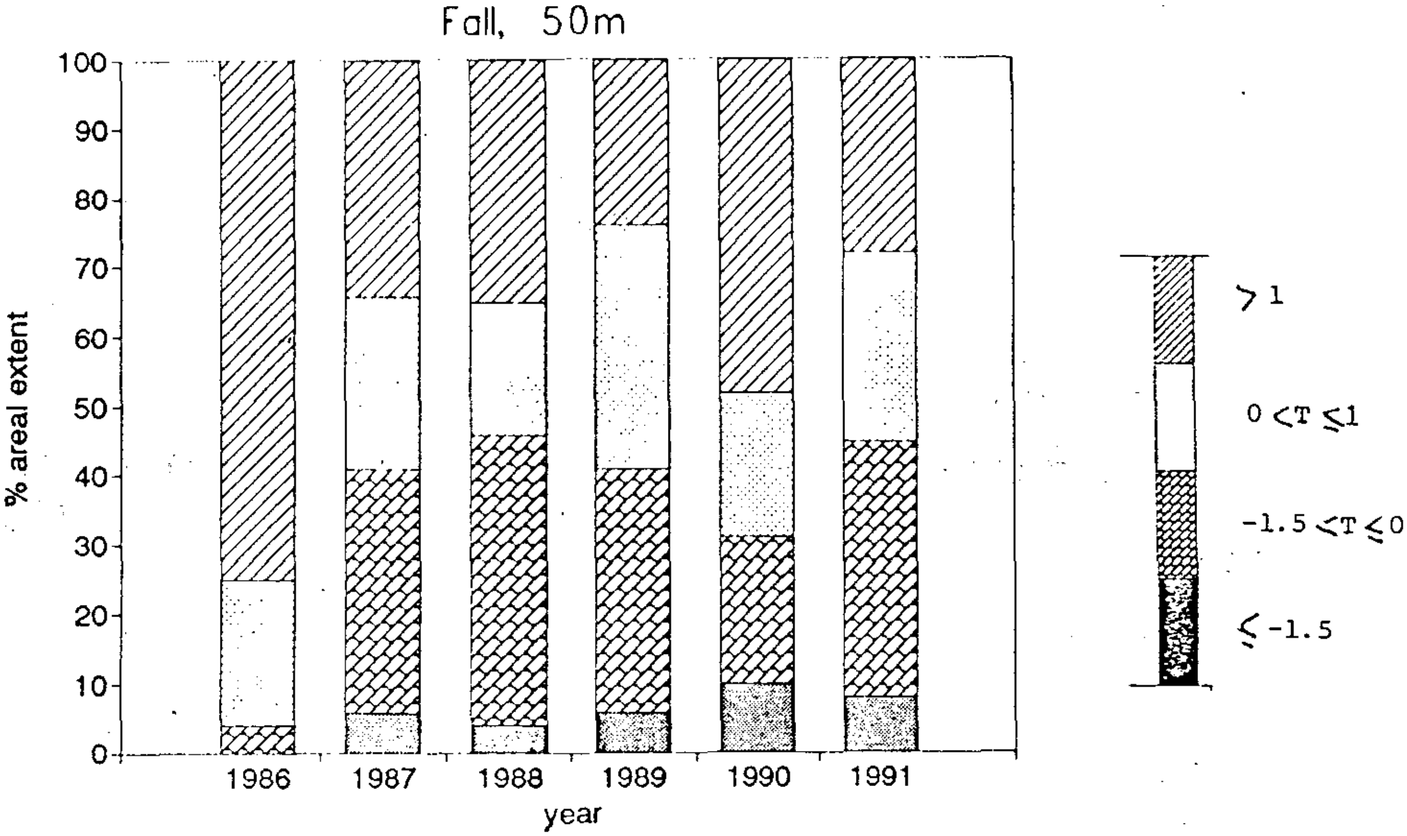


Fig. 12a. Interannual variability in percent areal extent of different temperature water masses in NAFO division 3L, spring.



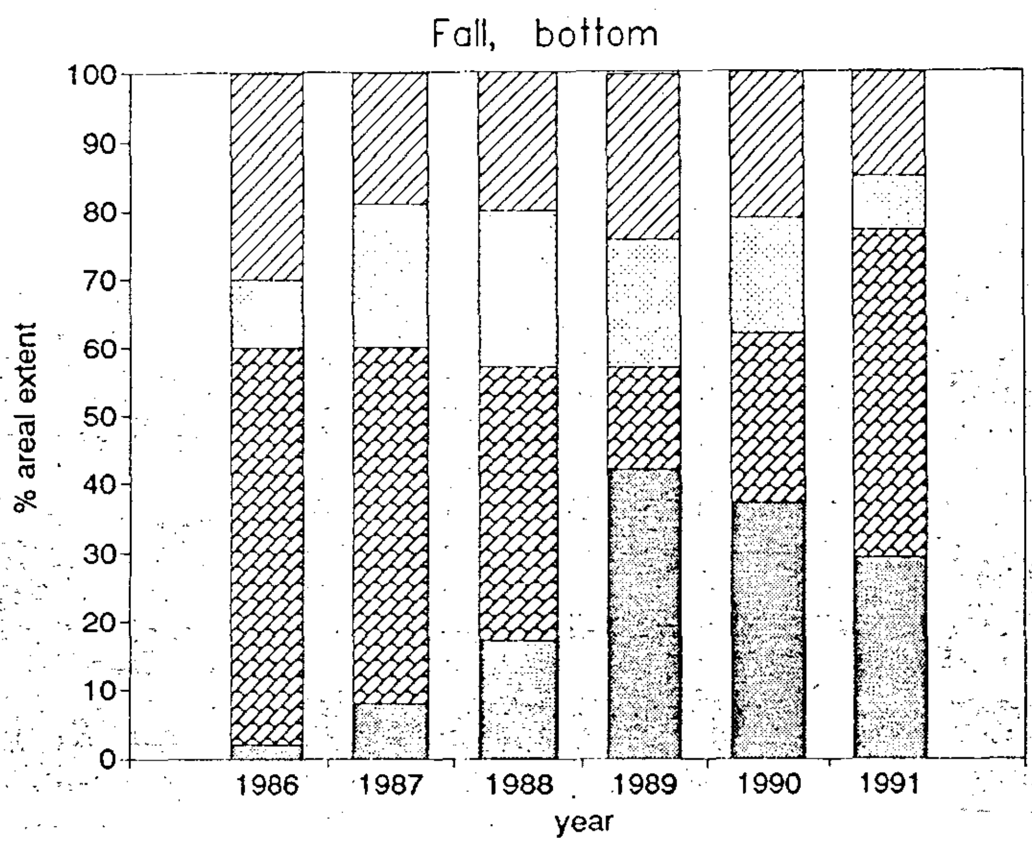


Fig. 12b. Interannual variability in percent areal extent of different temperature water masses in NAFO division 3L, fall.

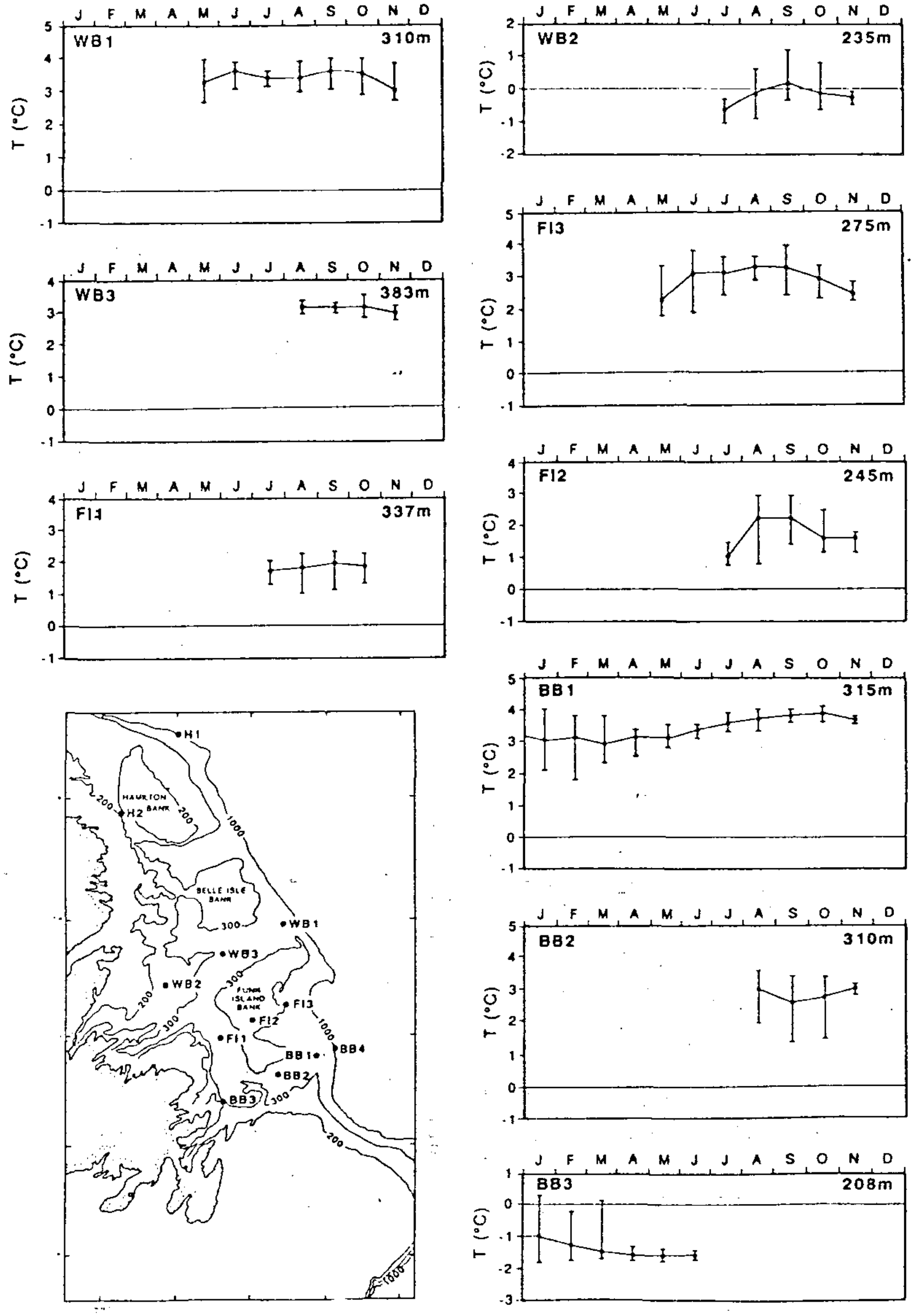


Fig. 13. 1991 monthly mean bottom temperatures on the NE Newfoundland Shelf.

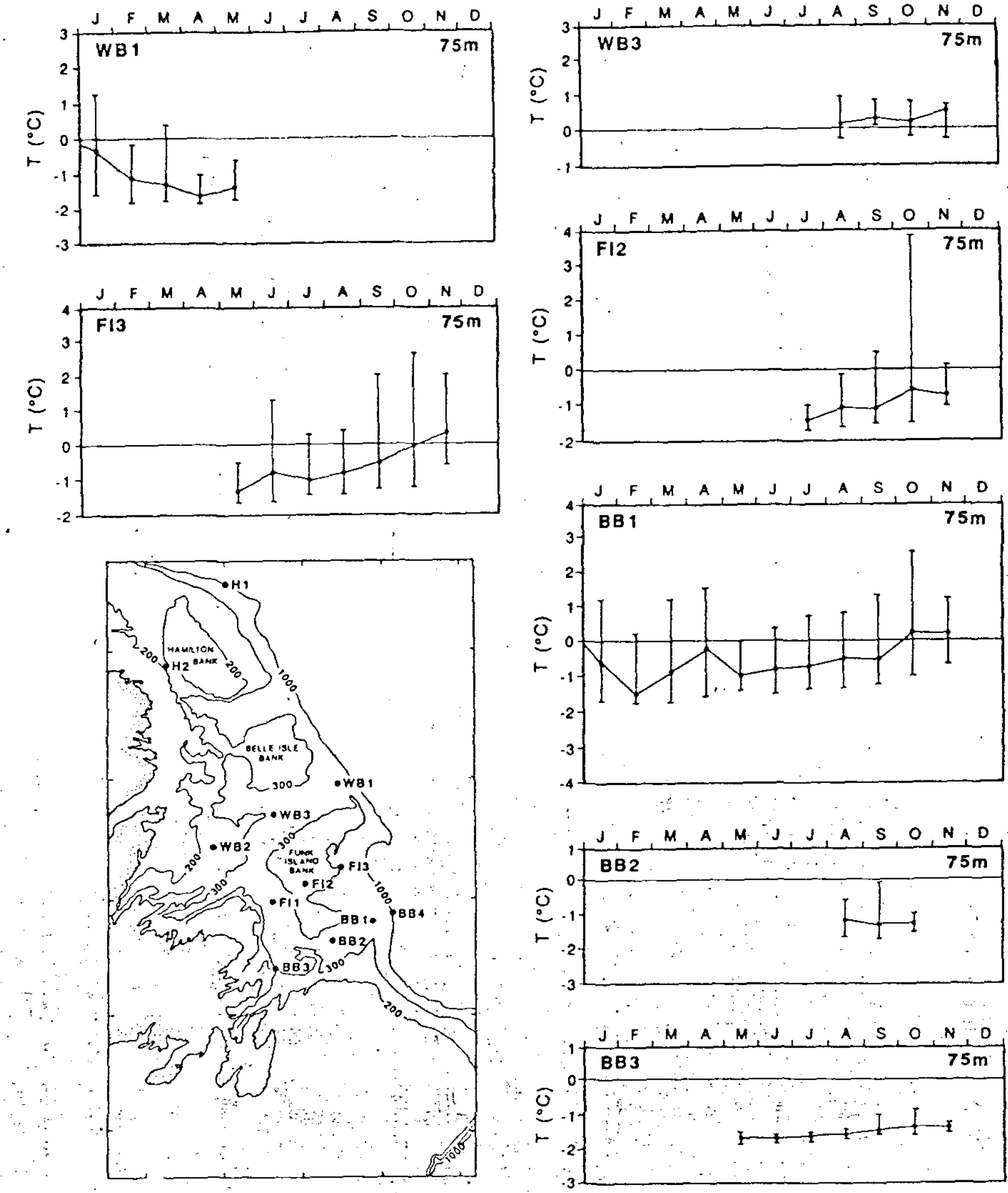
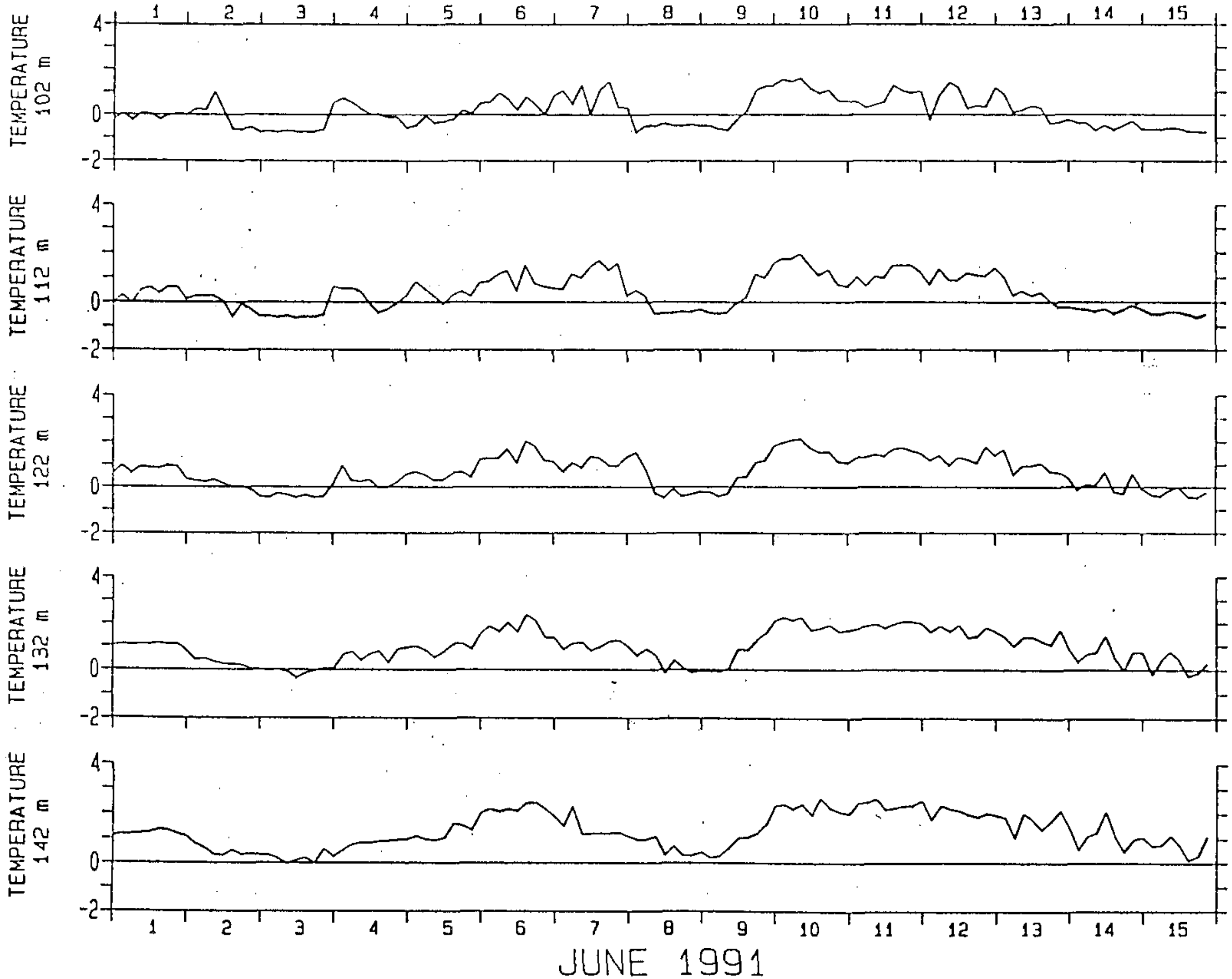


Fig. 14. 1991 monthly mean temperatures at 75 m on the NE Newfoundland Shelf.

Fig. 15. Temperature time series from the shelf edge site, FI3.



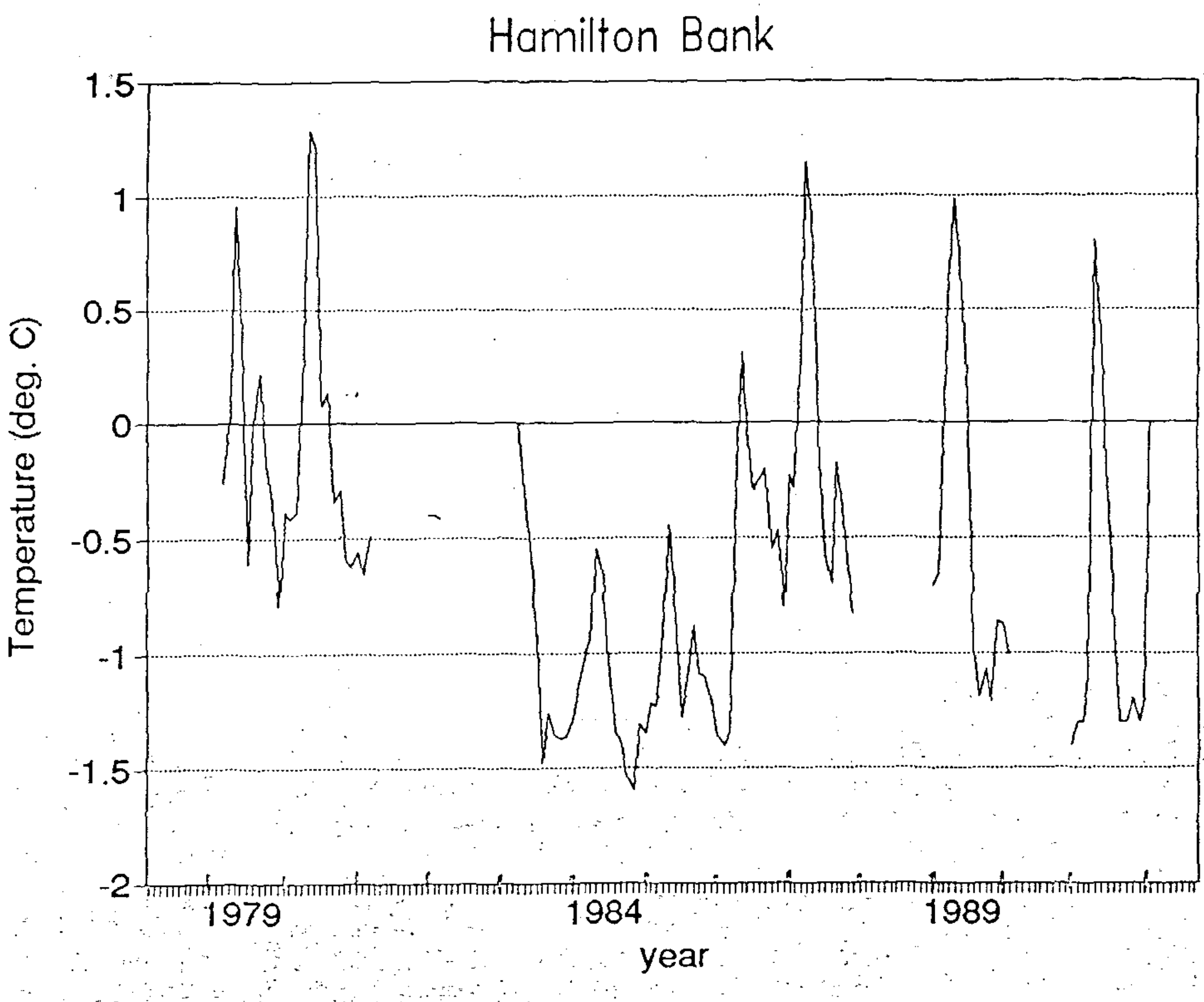


Fig. 16. Monthly mean bottom temperatures at Station H, on Hamilton Bank, for the period 1978 - 1991.