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The Cold Intermediate Layer on the Labrador and Northeast Newfoundland Shelves, 1978–86

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Abstract

Archived oceanographic data were analyzed in order to describe the variability of environmental conditions on the Labrador and Northeast Newfoundland shelves in 1978–86. The focus of this analysis is primarily on the temperature distribution over the shelves, but moored temperature observations from Hamilton Bank, temperature observations at Station 27, ice coverage, and the cross-sectional area of the cold intermediate layer (CIL), defined as water <0° C, are also discussed. The long-term monthly average temperature distributions across Hamilton Bank and along the Bonavista Section, based on the data archived at the Marine Environmental Data Service, Ottawa, are presented. The summertime temperatures from the Hamilton Bank, White Bay, Bonavista and 47° N sections are discussed with reference to long-term averages. In addition, the variation in ice coverage and cross-sectional area of CIL from the four standard sections are described. Correlation analysis indicates generally coherent behavior of these environmental variables, implying that the spatial scales of variability on the shelves are large. A summary of the 1984–86 environmental conditions is presented along with a ranking of each variable relative to the longest time series available.

Introduction

Templeman (1975) presented the average summer temperature data (Fig. 1) for Hamilton Bank, Cape Bonavista and 47° N (Avalon Peninsula–Flemish Cap) sections, corresponding to NAFO Divisions 2J, 3K and 3L respectively. A major oceanographic feature of these areas is a subsurface layer of cold water, the cold intermediate layer (CIL), whose boundaries may be tentatively defined by the 0° C isotherm. In the region, the CIL has a characteristic thickness of 100–200 m, extends 200–300 km offshore and has minimum summer temperatures of -1.0° to -1.5° C (Fig. 1). The plots of monthly average temperature by depth are shown (Fig. 2) for the inner and outer halves of the Northeast Newfoundland Shelf which is bounded by the 1,000 m isobath. A 200 m thick layer of below-zero water develops in February on the inshore half of the shelf. A minimum core temperature of about -1.5° C at 75 m is reached in April, and, at the same time, a seasonal thermocline is developing at the surface. By November, sub-zero temperatures have disappeared. The offshore half of the shelf follows the same pattern but with some quantitative differences: the CIL is about one-half as thick, minimum core temperature of -0.7° C occurs in June, and sub-zero temperatures generally do not persist past August.

The mean monthly temperature distributions across Hamilton Bank and along the Bonavista Section (Fig. 3 and 4) are based on all available, but not all existing, data archived by the Marine Environmental Data Service. The monthly trends in cross-sectional area of cold water (<0° C) are shown in Fig. 5. The Hamilton Bank averages extend from June to November only, as there were not sufficient data to establish mean conditions for the other months. The intermediate layer appears to have its largest area and lowest temperature in June and July. The temperature of the CIL increases during the summer and autumn, with a corresponding decrease in the area of cold water (<0° C) until it finally disappears in November.

The Bonavista data (Fig. 4, 5) cover the April–November period. In April, the temperature of the water column (0–150 m) was less than 0° C. The coldest water (less than -1.0° C) was confined to the coast. Near the bottom, temperatures ranged from about 2° to 4° C. The development of a warm surface layer began in May and the temperature continued to increase until September. The CIL (Fig. 5) showed a gradual decrease in the area from May–June to November, similar to the decline on Hamilton Bank. Bottom temperatures remained between 2° and 3° C during this period. The average temperature of CIL continued to increase until November when minima are just below 0° C.

Keeley (1981) compiled the mean monthly temperature data for stations along the 47° N section. The best overall coverage was in July and August when the CIL areas were 39.7 and 34.6 km^2 respectively. There was significantly more water with temperatures below -1° C in August.

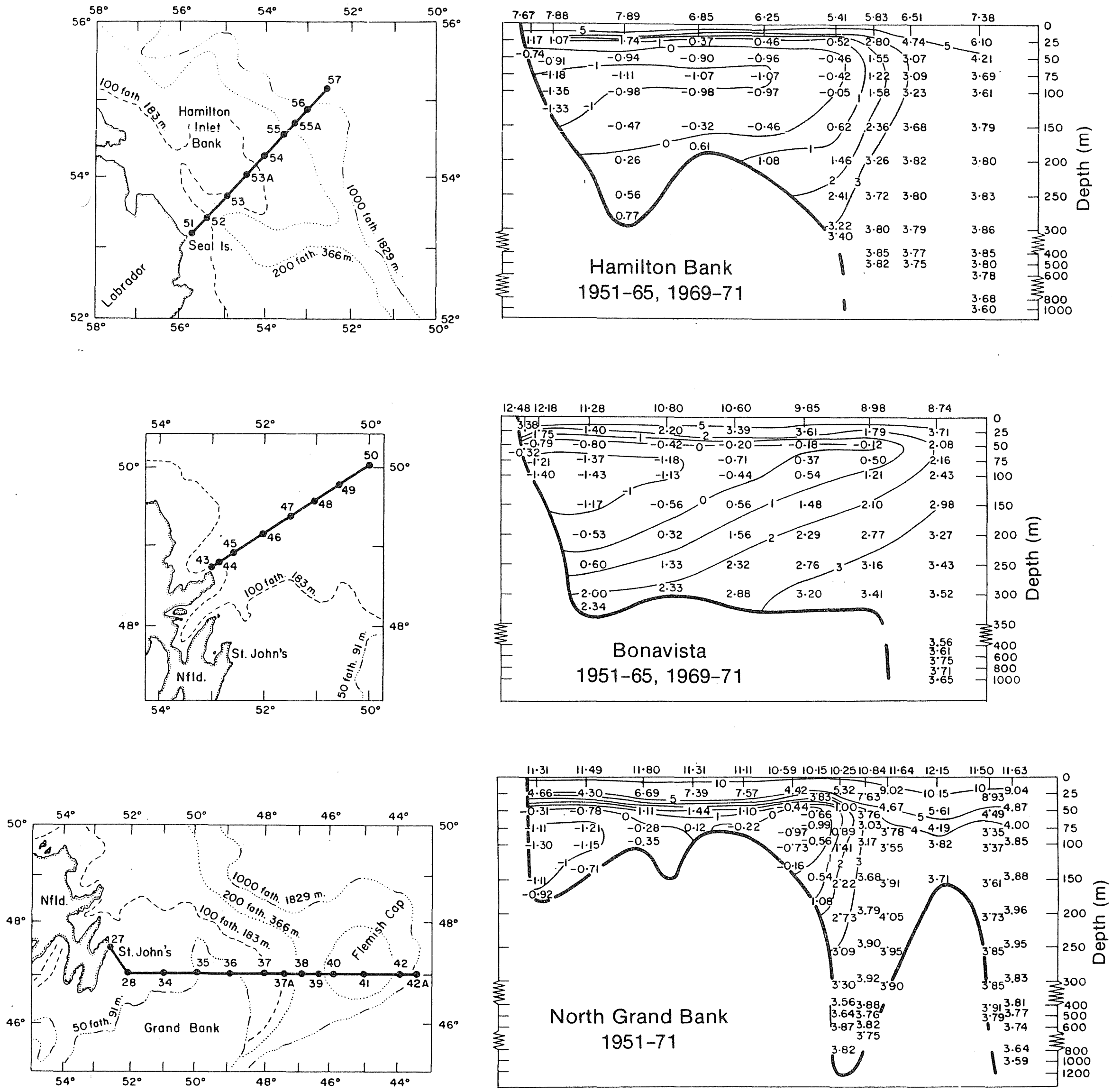


Fig. 1. Average temperatures (°C) on the Hamilton Bank, Bonavista and North Grand Bank (47°N) sections in summer, 1951–71 (from Templeman, 1975).

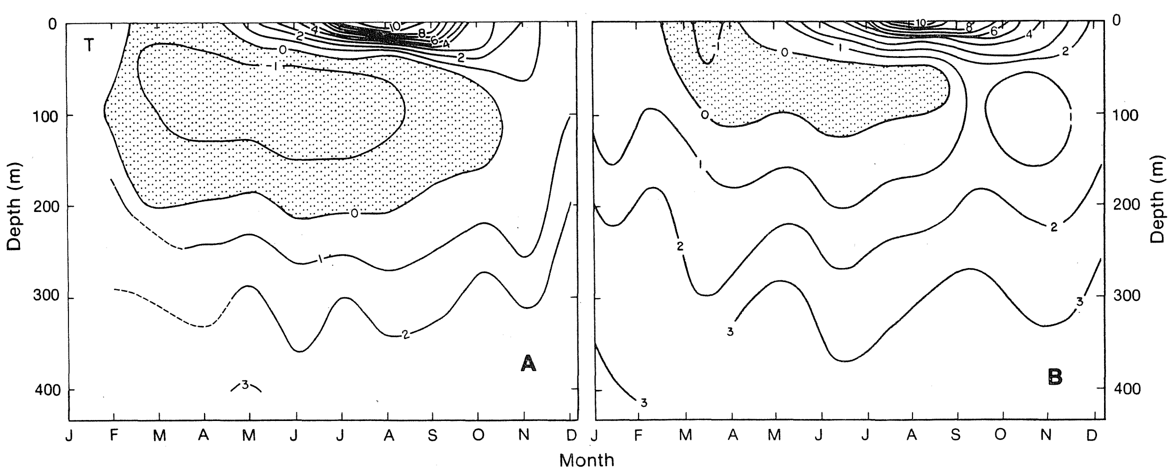


Fig. 2. Average temperature (°C) by month and depth on the (**A**) inner and (**B**) outer halves of the Northeast Newfoundland Shelf, based on the analysis of archived 1910–82 data by Drinkwater and Trites (1986, 1987).

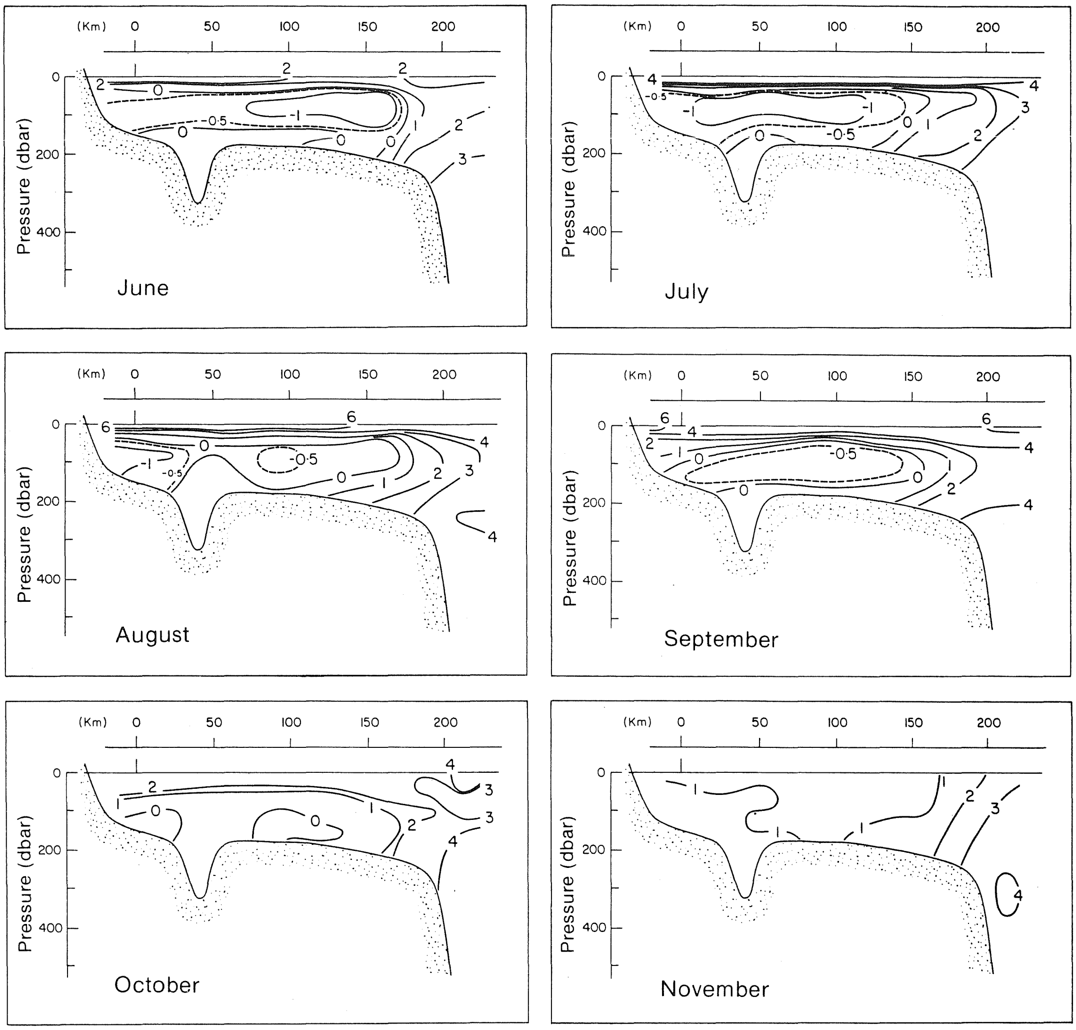


Fig. 3. Average temperatures (° C) on the Hamilton Bank section for June to November, based on all available archived data.

This paper examines the oceanographic conditions off southern Labrador and eastern Newfoundland (Div. 2J, 3K and 3L) for the 1978-86 period, with particular emphasis on the 1984-86 period. The data include hydrographic sections from Hamilton Bank and the Northeast Newfoundland Shelf, the Station 27 observations off St. John's, temperature data from moored instruments on Hamilton Bank, and the areal coverage of ice south of 55° N.

Hydrographic Sections

Hamilton Bank

Temperature sections from summertime hydrographic surveys, conducted by the Bedford Institute of Oceanography, are shown in Fig. 6 for Hamilton Bank in 1980 and 1983-86. The areas of the CIL from these surveys are plotted in Fig. 7A, along with transects taken by the Northwest Atlantic Fisheries Centre (NAFC) during 1984-86 in the same general area but not over the same track. Both surveys show extensive areas (36–46 km^2) of cold water (<0° C) in 1984 and 1985. In fact, a large portion of the water was less than −1.5° C in those years. The temperature of the CIL was below normal and its area was above normal, compared to the long-term mean conditions (Fig. 3 and 5). Conditions improved in 1986 with a decrease in the area of the CIL to 23-30 km^2 and near total disappearance of water less than −1.5° C.

White Bay

From the hydrographic surveys conducted by NAFC along the White Bay section in August 1984-86, the area of the CIL (Fig. 7B) shows the same behavior as on Hamilton Bank, with large areas in 1984 and 1985

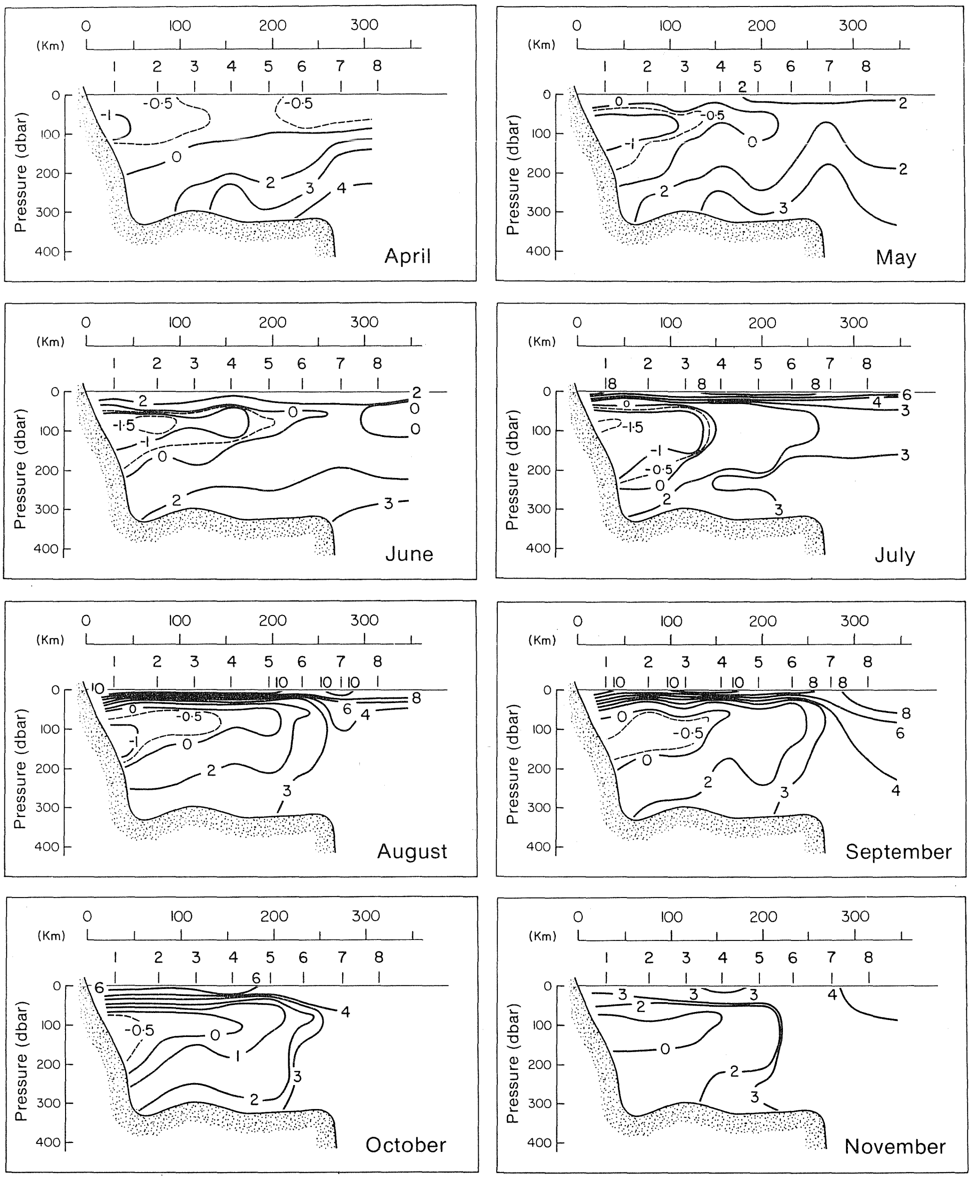


Fig. 4. Average temperatures (°C) on the Bonavista section for April to November, based on all available archived data for the standard section.

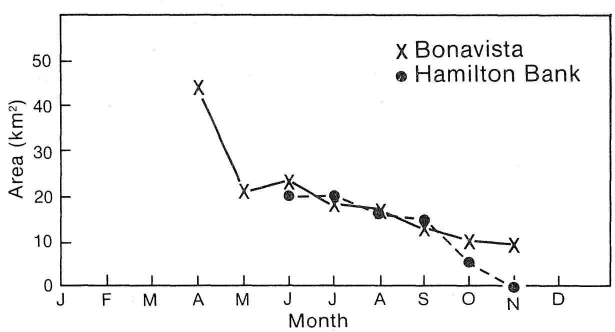
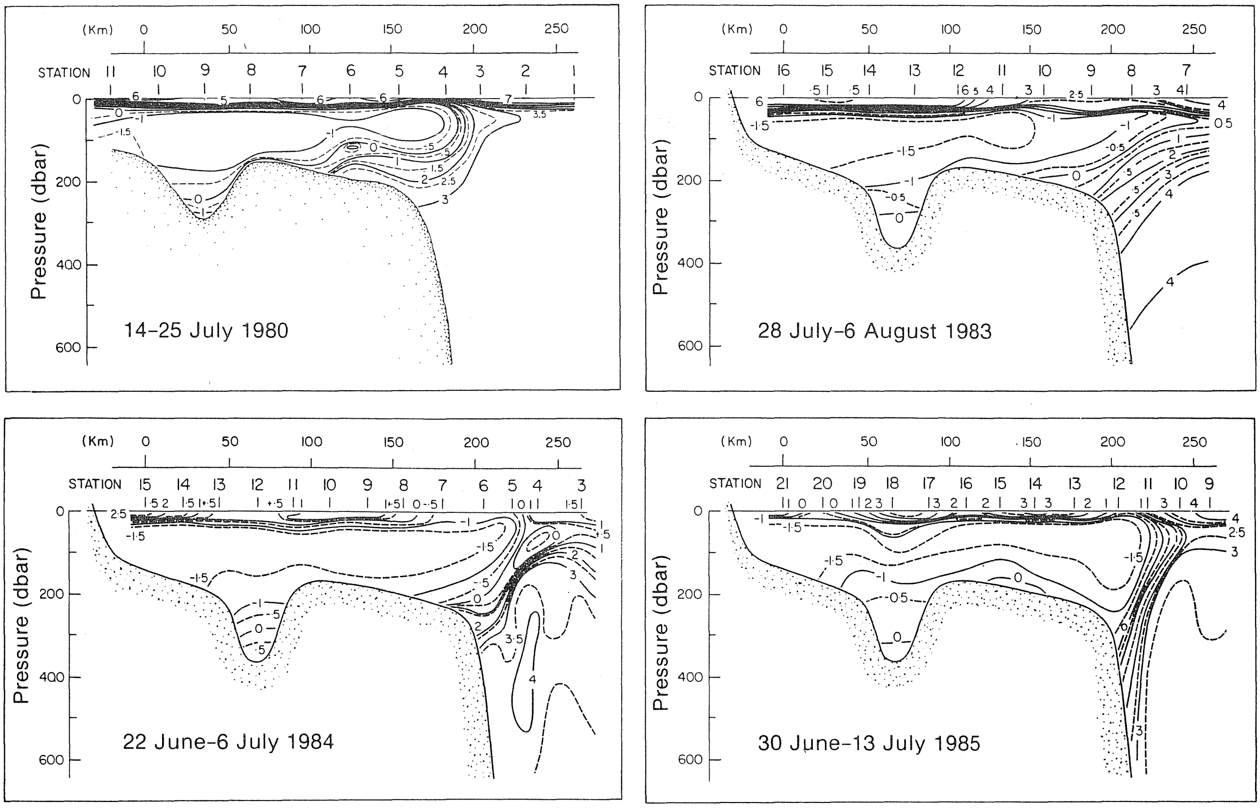


Fig. 5. Monthly trends in cross-sectional area of cold water (≤0° C) on the Hamilton Bank and Bonavista sections shown in Fig. 4 and 5.

(70–77 km²) relative to 1986 (56 km²). Water below -1.5° C was a major constituent of the CIL in 1984-85 but was present in only minor amounts in 1986.

Bonavista

Summertime temperature data, collected by NAFC in 1978–86 (1980 missing), highlight the CIL for this region (Fig. 8). The area of the CIL (Fig. 7C) shows a general increase for the 1978–84 period, when it reached a maximum of 48 km². It dropped to about 40 km² in 1985, followed by a further decrease to about 22 km² in 1986. Extensive areas of water with temperatures less than -1.5° C were present in 1984, whereas the



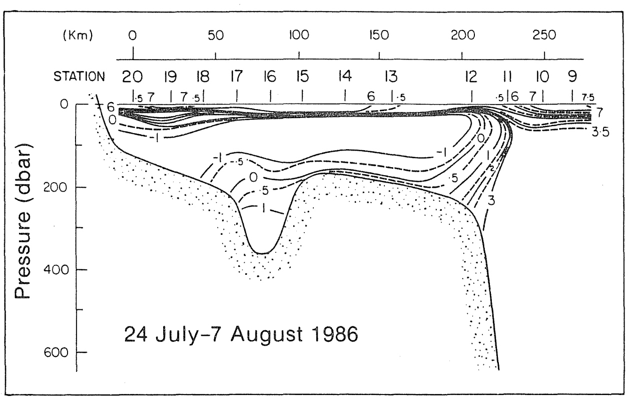


Fig. 6. Summer temperatures (°C) on the Hamilton Bank section, 1980 and 1983-86, from surveys by the Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

proportion of this very cold water was reduced in 1985. In 1986, only small areas of such water were present. Comparison of the 1984 and 1985 sections to the long-term mean (Fig. 4) indicates that the CIL temperatures were below normal.

Avalon Peninsula-Flemish Cap (47° N)

Summertime temperature data, collected by NAFC in 1978-86, highlight the CIL for this region (Fig. 9). The area of the CIL during 1982-86 (Fig. 7D) decreased very slightly from 39 km² to 36 km². This is in contrast to the other three sections (described above) which showed marked decreases in area in 1986. Temperatures over the Grand Bank were below normal and similar from year to year during the 1982-85 period (Akenhead, MS 1986). Temperatures in 1986 were not significantly different from the previous 4 years.

Oceanographic Time Series

Station 27 off St. John's

The monthly temperature anomalies from Station 27 at 0, 50, 100 and 150 m are shown in Fig. 10. The 1983-86 period was characterized by below-normal temperatures, particularly at the deeper levels. Temperatures in 1984 and 1985 were well below normal with conditions generally improving in 1986, but the

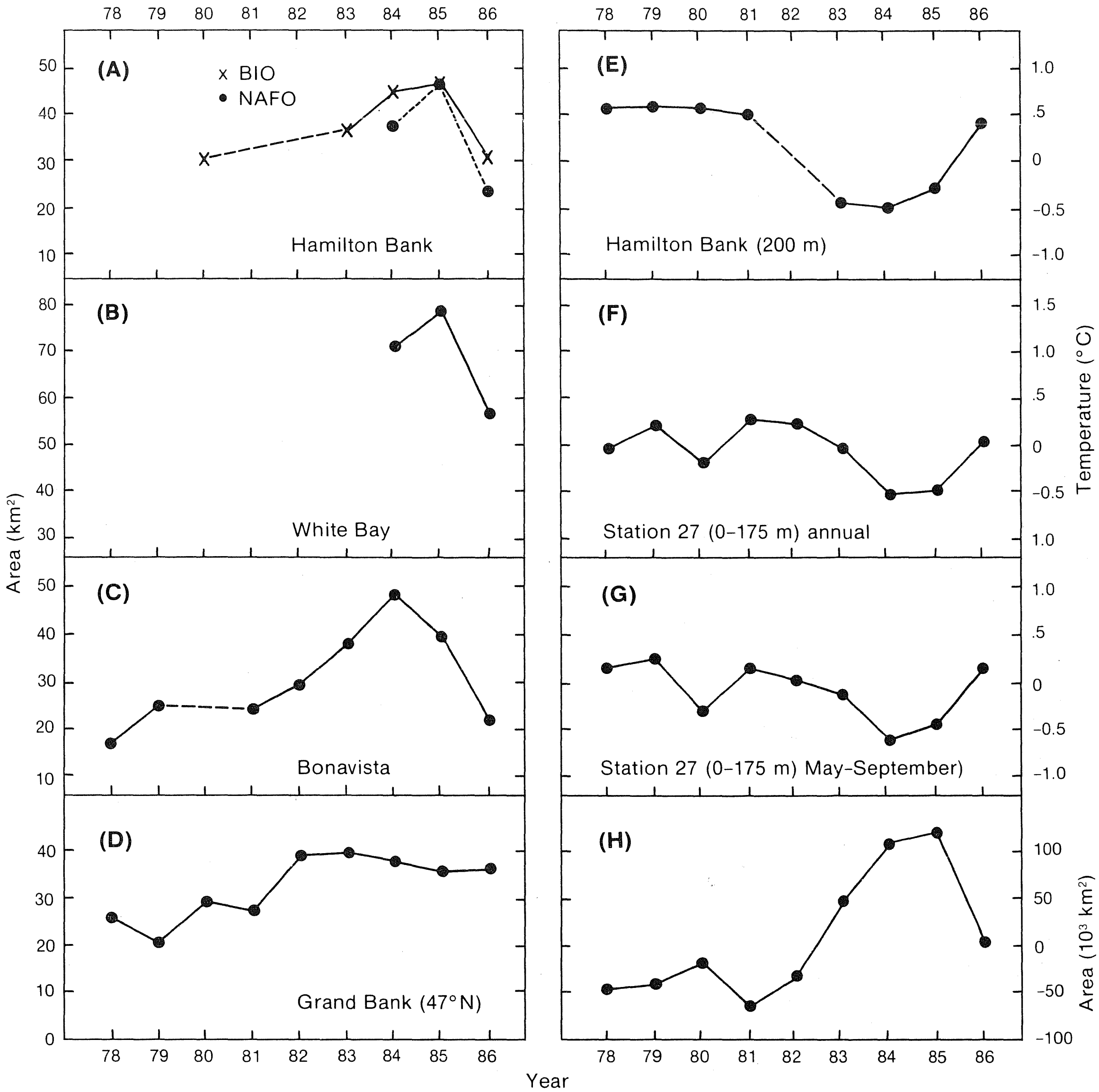


Fig. 7. Variation in cross-sectional area of cold intermediate water (<0° C) in summer on (**A**) Hamilton Bank section, (**B**) White Bay section, (**C**) Bonavista section, and (**D**) Grand Bank 47° N section; variation in annual temperature anomaly (**E**) at 200 m on Hamilton Bank, (**F**) 0–175 m at station 27, and (**G**) May-September temperature anomaly in 0–175 m at Station 27; and (**H**) variation in extent of ice south of 55° N off Newfoundland based on average of January-June observations.

temperatures, overall, still remained slightly below normal (Table 1). The positive monthly temperature anomalies that did occur in 1986 at Station 27 generally were evident between the late spring and early autumn. Towards the end of the year, negative anomalies returned at all depth levels.

The integrated (0–175) monthly temperature anomalies for Station 27 (Fig. 11; see also Fig. 7F, 7G) show a period of below-normal temperatures in 1984, 1985 and early 1986. The anomalies became positive by mid-1986, and this persisted until the end of the year.

TABLE 1. Annual temperature anomalies for four depths at Station 27 off St. John's.

	Temperature anomaly (° C)			
Year	0 m	50 m	100 m	150 m
1984	-0.42	-0.61	-0.34	-0.26
1985	-0.79	-0.56	-0.51	-0.48
1986	-0.18	0.10	-0.13	-0.11

Overall, 1984 had the coldest annual temperature (0–175 m) in 40 years, 1985 was third coldest, and 1986 ranked sixteenth.

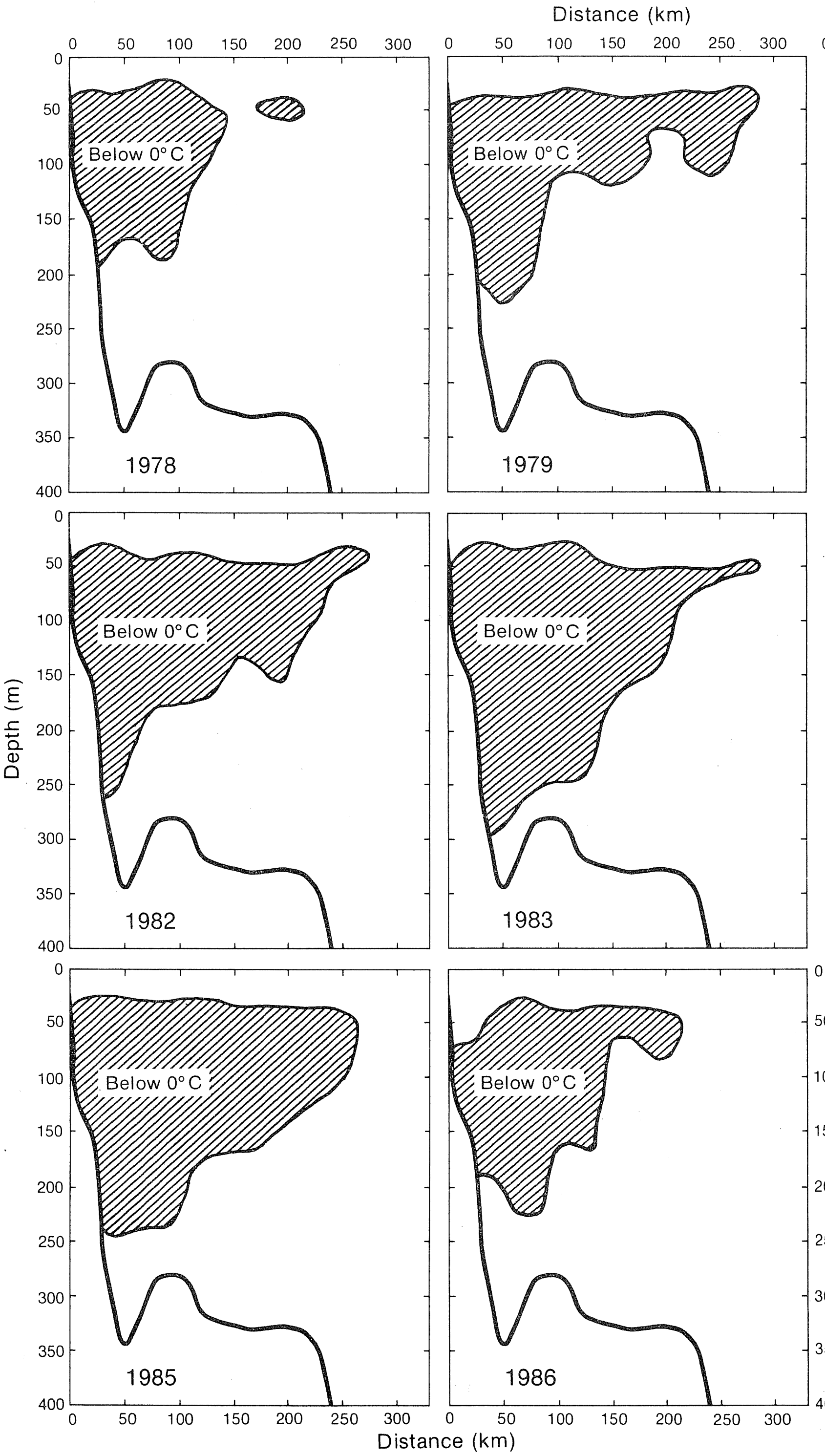


Fig. 8. Extent of cold intermediate water (<0°C) in summer on the Bonavista section, 1978–86.

Hamilton Bank

The time series of monthly temperature anomalies (mean = –0.63° C) from a current meter at a depth of 200 m on the western side of Hamilton Bank is shown in Fig. 12 for the 1978–86 period. From October 1978 to October 1980, temperatures were higher than average by 0.54° C, whereas, in the period from December 1982 to November 1985, temperatures were lower than average by 0.5° C. There was a change to positive anomalies

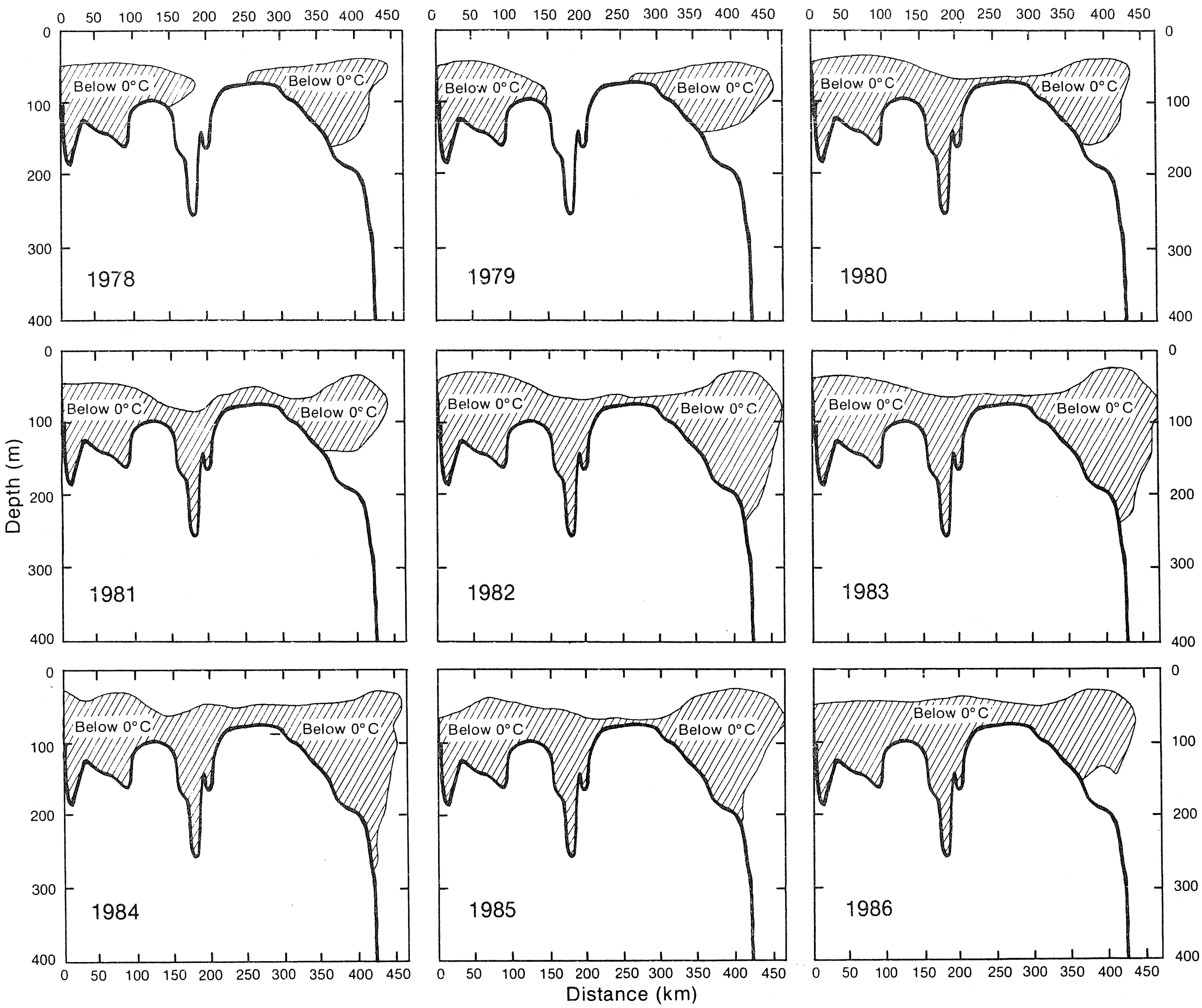


Fig. 9. Extent of cold intermediate water (<0°C) in summer on the North Grand Bank 47°N section, 1978–86.

in December 1985 which continued to August 1986, with an average anomaly over this period of 0.32°C.

The annual temperature anomalies (Fig. 7E) show an apparent (and expected) inverse relationship with the time series of CIL area on the Hamilton Bank, White Bay and Bonavista sections. A positive correlation is also evident in data from the two Station 27 times series (Fig. 7F, 7G).

Ice extent

The time series (1963–86) of monthly anomalies in the area of ice south of 55°N (Fig. 13) was compiled from maps which were prepared by the Canadian Atmospheric Environment Service. It is apparent that 1983–85 were years of above-normal ice coverage. On the other hand, 1986 appears to be a transition year, beginning with an above-normal ice extent and changing in May to below-normal coverage. The average monthly anomalies of ice extent based on the January-June monthly anomalies are shown in Fig. 7H for 1979–86. The ice season, beginning in December 1986, started with above-normal coverage.

Intercomparison of oceanographic time series

Scatter plots of the monthly temperature anomalies at Hamilton Bank (200 m) with those at 0, 50, 100 and 150 m on Station 27 are shown in Fig. 14. The zero-lag correlation coefficient for Hamilton Bank *versus* Station 27 (150 m) is 0.67, decreasing monotonically for Hamilton Bank lagging Station 27 and oscillating between 0.6 and 0.75 for Hamilton Bank leading Station 27 by up to 23 months. This is indicative of a generally north to south advection. Correlation coefficients were lower for Hamilton Bank (200 m) and the other depths at Station 27.

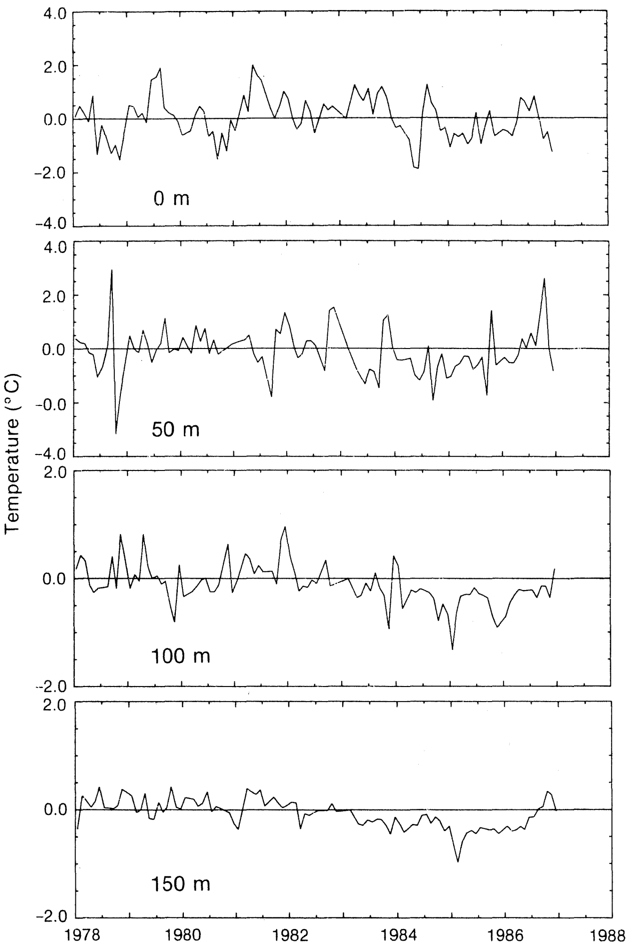


Fig. 10. Monthly temperature (° C) anomalies at Station 27 in depths of 0, 50, 100 and 150 m, 1978-86.

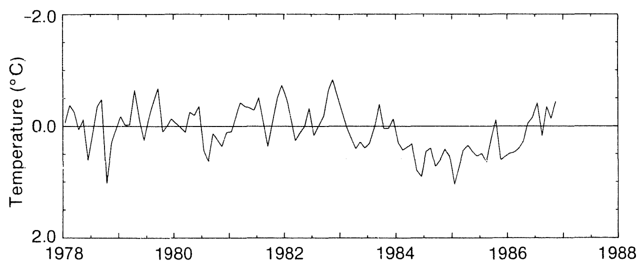


Fig. 11. Monthly temperature (° C) anomalies at Station 27, averaged over 0-175 m, 1978-86.

Figure 15 shows scatter plots of the monthly temperature anomalies for four depths at Station 27. At zero lag, the correlation coefficients are 0.41 (100-150 m), 0.31 (100-50 m) and 0.14 (100-0 m) for 40 years of data. This implies small vertical scales of variability and/or significant phase differences with depth. A cross-spectral analysis of these observations is planned to attempt to sort out these difficulties.

The scatter plots of ice coverage with the 200 m Hamilton Bank and Station 27 temperature anomalies are shown in Fig. 16. There appears to be negative

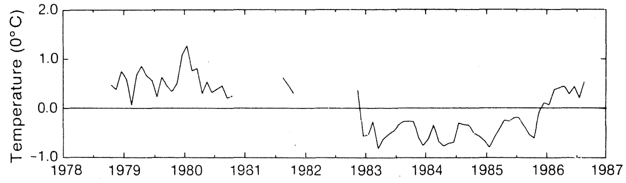


Fig. 12. Monthly temperature (° C) anomalies from a current meter at 200 m on Hamilton Bank, 1978-86.

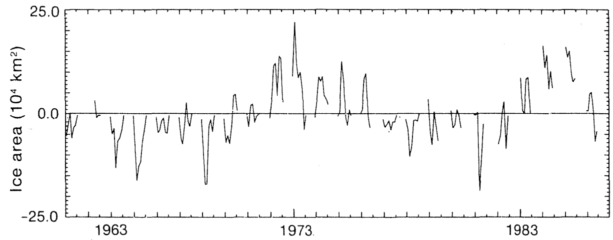


Fig. 13. Trend in monthly anomalies of ice area (units of 10^4km^2) off eastern Newfoundland south of 55° N, 1963-86.

correlation coefficients between the ice coverage and all of the temperature series.

Intercomparison of section parameters

Table 2 contains the correlation coefficients for all variables plotted in Fig. 7. Of the 21 possible correlations, 18 were significant at the 95% confidence level, that is, the variables are generally highly correlated with one another. The average of the correlation coefficients (Table 2) of each variable with the others has been calculated for qualitative purposes in order to give an indication of which variable is best correlated with all the others. Ice extent was best correlated with the six other variables, with an average correlation coefficient ($\bar{r}$) of 0.86, followed by the Bonavista section CIL (0.83), the 200 m Hamilton Bank temperature (0.82), the Station 27 (0-175 m) May-September temperature anomaly (0.80), the Hamilton Bank CIL area (0.79), the Station 27 (0-175 m) annual temperature anomaly (0.76), and finally the 47° N CIL area (0.58). There is little to chose between these variables except for the 47° N section which appears to be the least related to the other six on the basis of this simplified and qualitative analysis.

TABLE 2. Correlation coefficients and numbers of observations for pairs of variables from the data plotted in Fig. 7. (* indicates not significant at P = 0.05.)

Data	A	C	D	E	F	G	H
A	—	0.85	0.47*	-0.75*	-0.87	-0.78	0.99
C	4		0.63	-0.94	-0.76	-0.93	0.87
D	5	8		-0.84	-0.38*	-0.53	0.61
E	4	7	7		0.72	0.76	-0.91
F	5	8	9	8		0.92	-0.89
G	5	8	9	8	9		-0.86
H	5	8	9	8	9	9	—

A = Hamilton Bank CIL area; C = Bonavista CIL area; D = Section 47° N area; E = Hamilton Bank T (200 m); F = Station 27 annual T (0-175 m); G = Station 27 May-Sep T (0-175 m); H = Ice extent south of 55° N.

Summary and Discussion

A summary, for the 1984–86 period, of most of the variables discussed here with their rank relative to the longest time series assembled to this point is shown in Table 3. The CIL appears to have had nearly its greatest

TABLE 3. Summary of oceanographic conditions of southern Labrador and eastern Newfoundland, 1984–86. (* = from largest to smallest area for A and C, and from lowest to highest temperature for B.)

Region	Years of data	1984	Rank*	1985	Rank*	1986	Rank*
A. CIL cross-sectional area (km²)							
Hamilton Bank	5	44.3	2	45.9	1	30.5	4
Bonavista	8	48.2	1	39.4	2	21.7	7
47° N Section	9	37.2	3	35.2	5	35.5	4
B. Annual temperature anomaly (°C)							
Hamilton Bank (200 m)	8	-0.54	1	-0.35	3	0.35	4
Station 27 (0–175 m)	40	-0.55	1	-0.51	3	0.03	16
Station 27 (0 m)	40	-0.42	12	-0.79	5	-0.18	19
Station 27 (50 m)	40	-0.61	2	-0.56	9	0.10	17
Station 27 (100 m)	40	-0.34	4	-0.51	2	-0.13	6
Station 27 (150 m)	40	-0.26	6	-0.48	1	-0.11	12
C. Monthly (Jan–Jun) ice cover anomaly (km²)							
South of 55°N	23	106,000	2	118,000	1	700	9

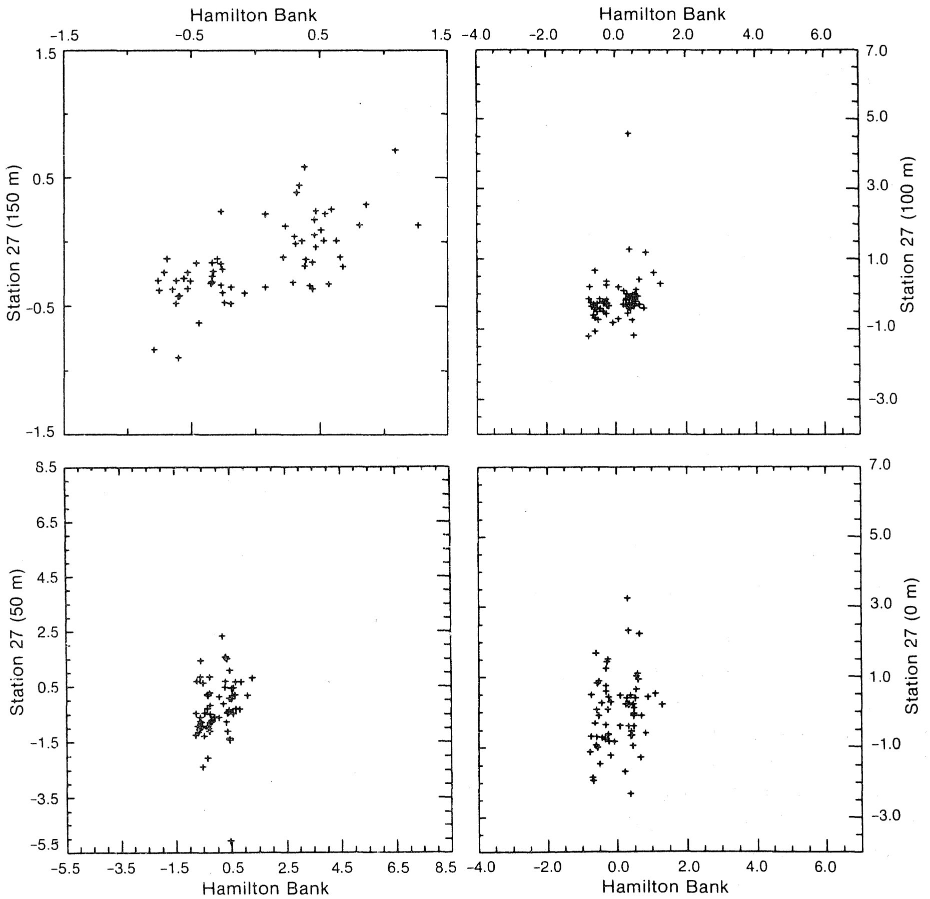


Fig. 14. Correlation plots of monthly temperature (° C) anomalies at 200 m on Hamilton Bank with those for 0, 50, 100 and 150 m depths at Station 27.

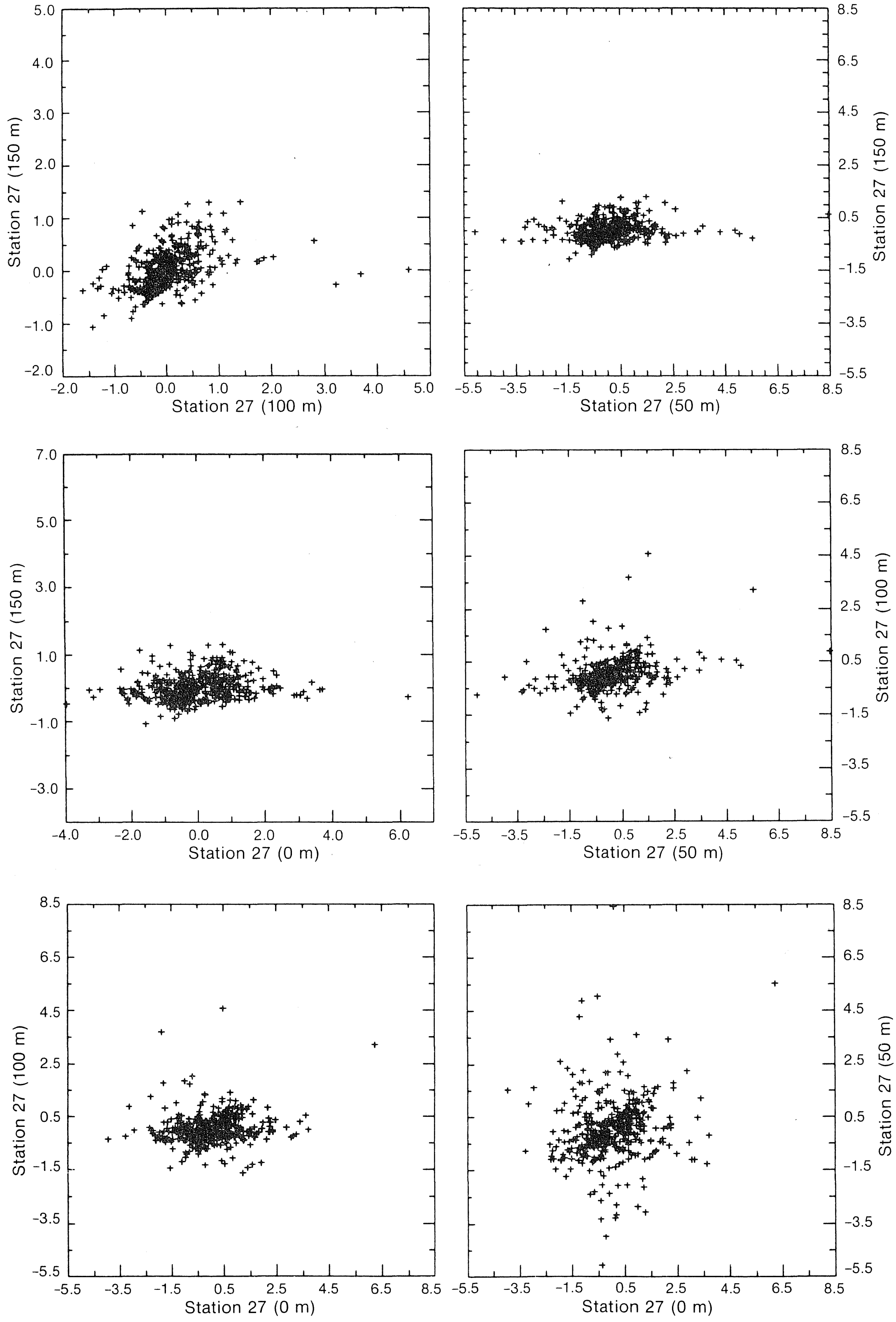


Fig. 15. Correlation plots of monthly temperature (° C) anomalies between all possible pairs of depths at Station 27.

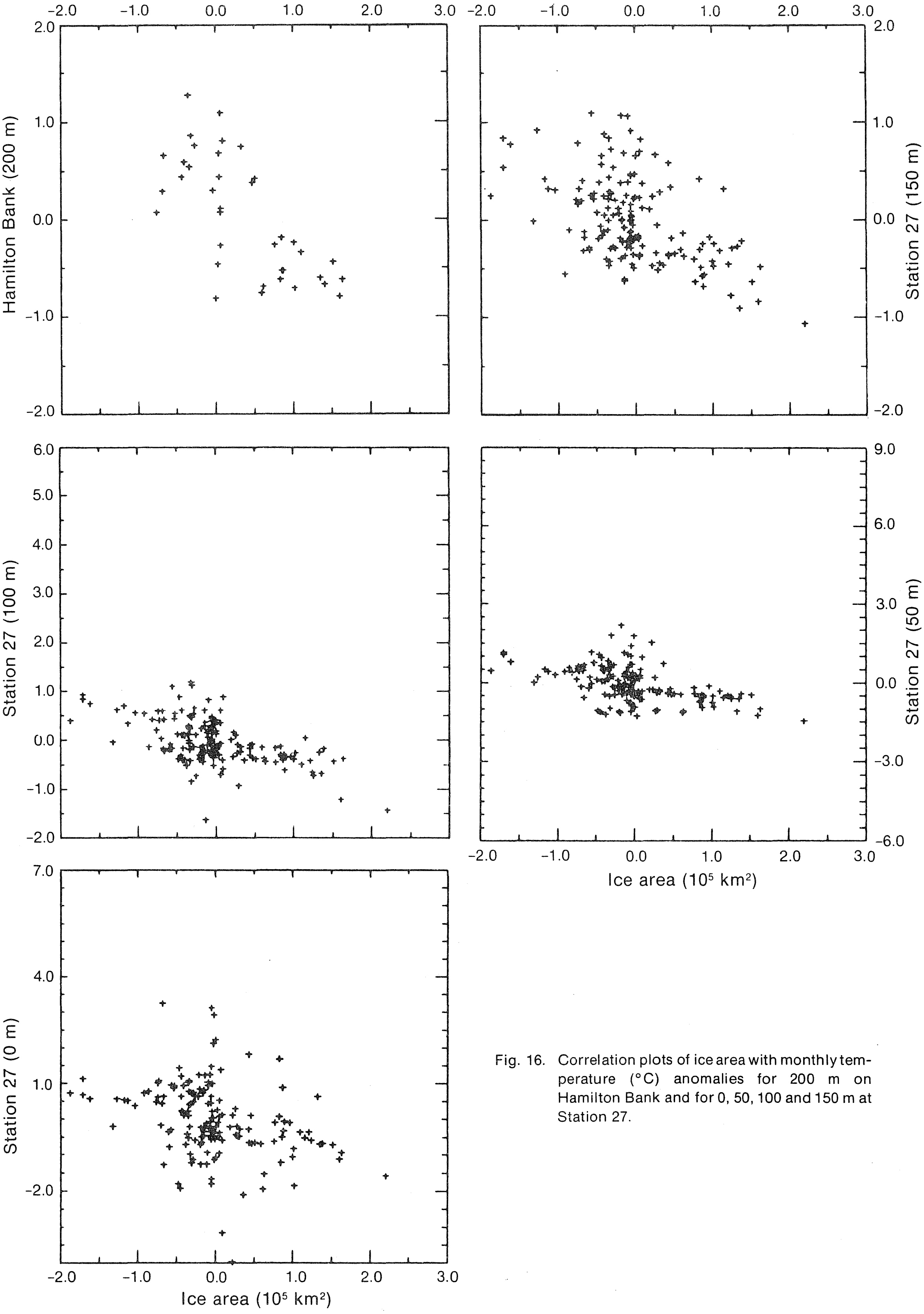


Fig. 16. Correlation plots of ice area with monthly temperature (°C) anomalies for 200 m on Hamilton Bank and for 0, 50, 100 and 150 m at Station 27.

extent in 1984 over all three sections. Conditions in 1985 were not too different from those in 1984, but 1986 appeared to have CIL areas below normal (i.e. CIL area smaller than average) for two sections and above normal for the third. The temperature time series indicate that 1984 and 1985 were exceptionally cold years. In 1986, temperatures were closer to, but perhaps slightly below, normal. Ice cover was greatest in 1984-85 and near normal in 1986.

The other point that deserves reiteration is the indication that the oceanography of the area appears to be varying in a coherent fashion, with perhaps the one exception being data for the 47° N hydrographic transect. This may be because large areas of this transect are quite shallow and are insulated from direct effects of the Labrador Current. The temperature distribution along the 47° N transect may have a stronger locally generated component with a smaller contribution from advection. This merits additional investigation.

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