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Overview of Environmental Conditions in the Northwest Atlantic in 1988

by

R. W. Trites and K. F. Drinkwater

Dept. of Fisheries and Oceans, Physical and Chemical Sciences Br.
Bedford Institute of Oceanography, P. O. Box 1006
Dartmouth, Nova Scotia, Canada B2Y 4A2

INTRODUCTION

This paper provides a brief review of environmental conditions in the Northwest Atlantic during 1988. As in previous reviews (Trites and Drinkwater 1984, 1985, 1986; Drinkwater and Trites 1987, 1988, MS 1988), it is based on selected sets of oceanographic and meteorological data as well as information from national research reports and other research documents prepared for the NAFO Scientific Council. Conditions are compared with those of the preceeding year and the long-term means. The latter have been standardized to a 30-yr base period (1951-1980), in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council. Where 30 years of data were unavailable, 20-yr (1961-1980) or 10-yr (1971-1980) base periods were used, where possible.

OCEANOGRAPHIC OBSERVATIONS

Coastal sea-surface temperatures

Monthly averages of sea-surface temperature (SST) were obtained for Halifax in Nova Scotia, St. Andrews in New Brunswick, and Boothbay Harbor in Maine (see Fig. 1 for locations). The monthly mean temperature anomalies relative to the 1951-80 long-term averages (Trites and Drinkwater, 1984) at each of the sites for 1987 and 1988 are shown in Figure 2.

During 1988 negative anomalies were observed in all months at Halifax and St. Andrews, continuing a trend of below normal temperaturesthat began towards the end of 1987. At Halifax, the largest negative anomalies occurred in June (-1.9°C) and September (-2.2°C), in contrast to St. Andrews where negative anomalies peaked in January and February (-2.0°C) and were smallest in summer. At Boothbay Harbor, the monthly temperature anomalies were generally smaller than at the other two sites but still with a predominance of negative values (8 out of the 12 months). Maximum negative anomalies at Boothbay Harbor were recorded for the months of June and October (1.1°C).

The annual SST anomalies at all sites were below their long-term means (Fig.3). The annual mean was 6.8°C at Halifax (1.0°C below normal), 6.1°C at St. Andrews (1.2°C below normal) and 8.5°C at Boothbay Harbor (0.3°C below normal). At Halifax, it continues the decreasing trend in the annual mean SST observed over the past several years. At Boothbay Harbor the mean temperature increased slightly relative to last year. The annual mean at St. Andrews is the lowest recorded since 1940. The missing data in Fig. 3 were due to instrument malfunctions and extensivewharf reconstruction at St. Andrews.

Offshore sea-surface temperatures

The pattern of monthly SST anomalies along the continental shelf from Chesapeake Bay to southern Labrador (Fig.4) for 1971-87 described by Drinkwater and Trites (MS 1988) was examined for 1988 and compared to earlier years (Fig. 5). The general pattern of above normal temperatures from the Scotian Shelf northward (areas 9-19) and below normal temperatures from the Gulf of Maine southward (areas 1-8), which was dominant in 1987, continued in 1988. Area 13 (off St. John's, Newfoundland) displayed above normal values for all months except February and reached a maximum in November (+2.4°C). For areas 14-17 (Northwest Newfoundland), maximum above-normal temperatures were observed in the September-October period with anomalies reaching as high as 2.7°C. For areas 1-3 (mid-Atlantic Bight) temperatures were below normal for all months of the year. Extreme negative anomalies occurred in January (-2.8°C) and December (-2.5°C) in area 2. The Scotian Shelf displayed less variability from the mean, compared to the other areas, but temperatures were generally above normal in the January-May period and below normal for the remainder of the year.

Sea-surface temperature anomalies for a large region of the Northwest Atlantic (35°-60°N, 40°-76°W), which extends from the southern boundary of the NAFO area northward to southern Greenland (Fig. 6) and is divided into 24 smaller areas to coincide with major water masses (Labrador Current, Gulf Stream, etc.) or fishing banks (Lahave, Georges, etc.) were reported by Trites and Drinkwater (1985) for 1972 to 1983 (compared with the 1972-80 base period) and were extended by Drinkwater and Trites (1987, 1988, MS 1988) for 1984-1987. The monthly mean temperature for each of the 24 areas was computed for 1988. The annual anomalies for 1984 to 1988 relative to the 1972-80 base period and the mean annual temperature for the base period are shown in Table 1. A space-time plot of the annual anomalies for the 24 areas during the 1972-88 period is shown in Fig.7.

The anomaly pattern of 1987 continued in 1988 with positive anomalies in the Cape Farewell area (+1.17°C), fromthe Offshore Labrador Current area to the Eastern Scotian Shelf (+1.03°C for the Central Grand Banks area), and in the Sargasso Sea (+0.24°C). Below normal temperatures were present over part of the Scotian Shelf (-0.62°C for LaHave Bank) and in the shelf region southward from the Gulf of Maine, reaching a maximum (-1.15°C) in the mid-Atlantic Bight area. The high positive temperature anomalies in the the Cape Farewell area have persisted for a 4-year period (1985-1988). For the Central Grand Banks area only 2 years (1981, 1983) have recorded higher mean annual surface temperatures over the duration of the record (17 y). By contrast the extremely low mean annual temperature in 1988 in the mid-Atlantic Bight area was the lowest on record.

Temperature and salinity stations

Station 27. Measurements of temperature and salinity have been routinely taken since 1946 at a site located approximately 10 km off St. John's, Newfoundland, the 27th in a series of transects established by W. Templeman. This station is considered to be representative of the inshore Labrador Current. The station was visited 40 times in 1987, with a monthly maximum of 8 in May and a minimum of zero in February. The data were collected at, or linearily interpolated, to standard depths (0, 10, 20, 30, 50, 75, 100, 125, and 150 m) and monthly means were calculated for each depth. Temperature and salinity anomalies for 1986 relative to the mid-month means for 1947-77 (Keeley, 1981) are shown in Fig. 8.

Temperature anomalies in the upper 30 m fluctuated throughout the year between above and below normal. Negative anomalies dominated the first two months of the year, as well as in July and November with peak values (over 4°C below normal) in mid-summer at 20 m. This appears to be, in part, the result of a shallower-than-normal thermocline. Below 50 m, temperatures in the first half of the year were below normal but rose above normal at several depths in the latter half of the year. Lower-than-normal temperatures have been observed below 75 m for the past 6 years. The apparent warming in 1988 indicates a possible end to the extreme cold conditions in the bottom waters at Station 27 but confirmation of a significant change will require at least another year of data.

Salinity anomalies at Station 27 showed mainly saltier-than-normal water during most of the year. Peak positive salinity anomalies were observed near surface in summer. Negative salinity anomalies were generally weaker than the positive ones and were observed in the near surface waters in September-October, in the deep waters in November and throughout the water column in December. The latter was based on only one observation during the month and so may not reflect mean conditions for the month..

Prince 5. Temperature and salinity measurements are taken once per month at Prince 5, a station off St. Andrews, New Brunswick, near the entrance to the Bay of Fundy (Fig. 1). Anomalies were calculated relative to the 1951-80 means as determined by Drinkwater (1987). The single measurements per month may not necessarily be representative of the "average" conditions for the month and therefore the interpretation of the anomalies must be viewed with caution. No significance should be placed on any individual anomaly but persistant anomaly features are likely to be real. The strong similarity in the anomaly patterns throughout the water column, evident in both temperature and salinity, is due, in part, to the relative homogeneity of the water column caused by the strong tidal mixing in the Bay of Fundy region.

In 1988, as was observed last year, negative temperature anomalies were slightly more frequent, and typically of larger magnitude, than the positive anomalies (Fig. 9). During the winter and autumn months anomalies were below normal with the largest values (in excess of -1°C) in the surface waters during September to November. Spring and summer months were dominated by positive temperature anomalies, although some negative values were observed in May and in the bottom waters in August. Salinity anomalies were typically weak (0.5) throughout most of the year. The high (>1) near-surface salinities observed in May may have been a temporary condition rather than representing mean conditions for the month and were likely associated with local freshwater runoff or the influence of the discharge from the Saint John River. From May to December anomalies were positive except in August, indicating that salinities were above normal throughout most of 1988.

Position of shelf-slope front

The position of the shelf-slope front from Georges Bank to Cape Hatteras has been monitored by the Physical Oceanography Branch of the U.S. National Marine Fisheries Service over the past 15 years. The frontal position, which is derived from satellite infrared imagery, is normally extracted at weekly intervals along 9 section lines and plotted with respect to the 200 m isobath. Strout (MS 1989) reports that the annual mean frontal position in 1988 generally followed the 10-yr (1974-83) mean. The annual mean position for 1988 was seaward of the 200 m isobath on all section lines except for the southernmost one near Cape Hatteras, where the front was shoreward of the shelf break. The standard deviations were about the same, or less than, the 10-yr mean except for the section across Georges Bank (Casco Bay 140°W line) where the 1988 value was greater than the long-term mean. For the section lines across the mid-Atlantic Bight, the 1988 frontal positions generally followed a seasonal pattern of being farther seaward during winter and spring and shoreward during summer into early autumn. No clear seasonal variation was evident for the section lines across Georges Bank. Generally the largest variability in frontal position was associated with the passage of warm-core rings.

Warm-core rings

The life history of anticyclonic warm-core Gulf Stream rings in the region from 45°W to 75°W during 1988 was derived from the NOAA/NWS Oceanographic Analysis maps and from the "*State-of-the-Ocean: Gulf of Maine to the Grand Banks*" reports issued monthly at the Bedford Institute of Oceanography. Owing to the relatively common occurrence of cloudy or foggy conditions, particularly in the eastern half of the region, several weeks may elapse between clear thermal images of the sea surface. Consequently there is frequently uncertainty about the creation or continued existence of a particular ring and, therefore, the statistics derived solely from this data source should be viewed cautiously.

A total of 28 warm-core rings were present in the area during some portion of 1988, four of which survived from 1987 into the new year. Seven of the 24 new rings which formed in 1988 persisted into 1989. At least 10 of the rings formed in 1988 exceeded an age of 2 months. Their paths, along with those of the four rings from 1987, which also had lifespans of over 2 months, are shown in Fig. 10A. Rings, whose destruction occurred in 1988, ranged in age from less than two weeks to more than a year and had a mean life of just over 3 months. This compares with an age range of two weeks to 9 months and a mean of 3.5 months for 1987. The statistics of ring formation and ring presence, compiled by zones, each covering 2.5° of longitude, are shown in Fig. 10B and 10C, respectively. One or more rings were generated in each of the zones east of 67.5°W. A maximum of 5 formed in the 62.5°-65°W zone. The number of rings present in each of the longitutinal zones varied from 1 to 9 with highest number present between 62.5°-65°W. At least one or more rings formed in all months of the year except January and August. Four rings formed in May, the most productive month.

A separate and more complete analysis of warm-core Gulf Stream rings present in 1988 in the slope water and west of 60°W was undertaken by Sano and Fairfield (MS 1989). The high resolution data from NOAA-9 and NOAA-11 satellites were atmospherically and geometrically corrected and enhanced to clearly identify thermal features. The Oceanographic Analysis maps prepared by NOAA/NWS and NESDIS as well as opportunistic *in situ* data received from scientists and fishermen were used in the compilation. Their analyses indicated that 15 rings were present in the slope water of which 12 were new rings formed in 1988. During the 1974-88 period, the number of rings formed annually ranged from a minimum of 5 in 1974 to a maximum of 12 in 1988, and averaged 9 for the 15 year period. Lifespans of individual rings that disappeared in 1988 ranged from 17 to greater than 170 d with a mean of just under 3 months. At least 3 rings were present in the slope water for 10 months of the year and 4 were present during September and December. Numerous instances of dynamic interactions with shelf waters were noted as the rings move westward and southwestward. Four of the rings which formed in 1988 survived into 1989.

Shelf-slope tempertures in the Mid-Atlantic Bight

Monitoring thermal conditions along a transect extending seaward from New York Harbor across the shelf and slope continued in 1988 for the twelfth consecutive year. From 13 transects of XBT profiles, depictions of the water column temperature structure and of bottom temperatures throughout the year have been derived (Benway, MS 1989). He reports that in 1988 cold-pool water (i.e. <10°C) persisted on the bottom until mid-November, which was similar to that in 1987 and more than a month later than normal. The temporal duration and geographic extent of bottom water (<5°C), a subjective way of estimating winter intensity, was close to normal in 1988. It had dissipated by the end of March, and was contained shoreward of the 50 m isobath. With autumn mixing and convection, temperatures on the bottom reached about 12-13°C in November over most of the mid-shelf to outer shelf depths (50-100 m). For the fourth consecutive year, bottom temperatures along the upper slope (100-200 m) remained above 12°C for most of the year, continuing the trend of warmer temperatures along the upper slope since 1977. Sea surface temperatures averaged 1-2°C cooler on the shelf and 1-3°C cooler in the offshore slope water.

Waves

Wave observations from many locations in the North Atlantic (weather ships, government, naval and merchant vessels, and oil drilling platforms) are transmitted every 6 hr to the Canadian Meteorological and Oceanographic Centre (METOC) at Halifax, Nova Scotia (Neu, 1982). Trites and Drinkwater (1984, 1985, 1986) and Drinkwater and Trites (1987, 1988, MS 1988) provided summary statistics of monthly significant wave heights at three grid points in the northwest Atlantic for each year of the 1970-87 period. The monthly statistics were computed from the 12-hr synoptic wave charts prepared by METOC. The mean monthly significant wave heights in 1987 and 1988, together with the averages for the 1970-80 period, are given in Table 2. The monthly significant wave heights anomalies (relative to the 1970-80 means) for the three areas during 1987 and 1988 are illustrated in Fig. 11. Based on the three sites, the northwest Atlantic experienced more severe wave conditions than average during 1988. In the Labrador Sea the annual mean significant wave hieght for 1988 was 3.01 m and was slightly higher than in 1987 and 0.26 m above the 11-yr mean. Conditions were more variable than in 1987 with wave heights in April and October averaging about 1 m above the 11-y mean. For 9 of the 12 months, waves were higher than normal. For the Grand Banks, the mean annual significant wave height was 0.2 m above the 1970-1980 average. Positive anomalies were present in the January-June period and in August and November. Although the annual mean height was only slightly higher than in 1987, the seasonal pattern was markedly different. In 1987 the monthly wave anomalies displayed an upward trend from April to December, whereas in 1988 they showed a downward trend fro January to October. On the Scotian Shelf wave conditions for the year as a whole were slightly more severe than for 1987. Significant wave height anomalies were positive for all months except December, when the monthly value was 0.1 m below the mean.

Using the number of occurrences of significant wave-heights equal to or exceeding 6, 7, and 8 m (Fig. 12) as an index of frequency of storms, indicates that 1988 was similar to 1986 and 1987 and comparable to the 1970-1980 mean for the Grand Banks and the Scotian Shelf. In the Labrador Sea, however, it was a particularly stormy year and was comparable to that of 1978, 1982, and 1985.

Sea ice

The Ice Climatology and Applications Division of the Canadian Atmospheric Environment Service undertakes an annual analysis of ice conditions in the Gulf of St. Lawrence and off the east coast of Newfoundland and southern Labrador by determining the time of onset, duration and latest presence of ice at 24 grid sites (Fig. 13). Results for 1982/83 to 1986/87 were previously summarized by Trites and Drinkwater (1985, 1986) and Drinkwater and Trites (1987, 1988, MS 1988). The present analysis has been updated to include data for the 1987/88 season. For each site, the extracted data were ice duration in weeks for the 1987/1988 season, mean duration for all years of record, as well as minimum, maximum and mean duration for years when ice was present (Table 3). For the Gulf of St. Lawrence, duration of ice cover was, in most areas, shorter than for the previous year (1986-87). Although the duration at a number of sites was close to the long-term average, the northeast area and Cabot Strait had ice cover for about 2 weeks longer than normal (Table 3). For the area north of Anticosti Island, where ice duration was about 6 weeks shorter than in 1986-87, the date when ice was last present (May 11) was the latest on record (Fig. 14). For the area east of Newfoundland and southern Labrador, the duration of ice cover was generally shorter than in 1986-1987 and comparable to the overall average (Table 3). At two sites (N-21 and N-62) ice cover duration was nearly a month shorter than average, with the last reported ice at N-62 on 12 April, the earliest on record.

Icebergs

The number of icebergs drifting south of 48°N latitude in each year is monitored by the International Ice Patrol Division of the United States Coast Guard. Data is presently being collected using SLAR (Side-Looking Airborne Radar). During the 1987/88 iceberg season (October to September), a total of 187 icebergs were spotted south of 48°N. No icebergs were observed from October, 1987, to February, 1988. The monthly totals for March to September were, respectively, 8, 95, 33, 20, 19, 10, and 2. In the primary iceberg season, March to August, 185 icebergs were observed which represents 99% of the annual total. The numbers of bergs detected in 1987/88 is a decrease of over 100 from the 1986/87 season and is the lowest number recorded since 1982/83 when the SLAR was first used for iceburg tracking.

METEOROLOGICAL OBSERVATIONS

Air temperatures

The Atmospheric Environment Service of Canada publishes the monthly mean air temperature anomalies for Canada in the *Monthly Supplement to Climatic Perspectives*. The 1988 monthly anomalies are plotted in Fig. 15. Seven months showed positive air temperature anomalies over Baffin Island, the Labrador coast and northern Newfoundland although the magnitude of these anomalies were generally weaker than the negative anomalies. The maximum negative values (near 4°C below normal) occurred in the winter months of January, Febraury and December. South of Newfoundland, over the Gulf of St. Lawrence, and off Nova Scotia air temperatures fluctuated almost monthly between positive and negative anomalies. Spring and summer tended to be warmer-than-normal in these regions while the autumn months tended to be colder-than-normal.

The annual air temperature anomalies were positive over northern Baffin Island, over Newfoundland, and off Nova Scotia. Off southern Baffin Island, along the Labrador coast and in the Gulf of St. Lawrence temperatures were above normal. The magnitude of the annual anomalies in the region were weak however, not exceeding 0.5°C. The anomaly pattern for 1988 contrast with that of 1987 which showed negative anomalies over Baffin Island and off Nova Scotia and positive elsewhere.

Sea-surface air pressure

Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas* by Deutscher Wetterdierst, Offenbach, Federal Republic of Germany. The long-term mean pressure patterns are dominated by the Icelandic Low, a low pressure system centered between Greenland and Iceland, and the Bermuda-Azores High, a high pressure system centered between Florida and northern Africa (Thompson and Hazen, 1983). The strengths of the Low and High vary seasonally from winter maximum to summer minimum. Seasonal anomalies of the sea-surface pressure for 1988 relative to the 1951-80 means are shown in Fig. 17. Winter covers December 1987 to February 1988, spring is March to May, summer is June to August and autumn is September to November.

In winter, there was an intensification of both the Icelandic Low and the Bermuda-Azores High. The Low was 4.5 mb below normal and the High was 3.8 mb above normal. This pattern would have resulted in strenghtened westerly winds over the Northwest Atlantic. Over the Labrador Sea and Labrador coast stronger northwesterlies would have been expected. During spring the pressure anomalies were generally weak with a preponderance of positive values over most of the North Atlantic. The intensification of the Icelandic Low and Azores High was also evident in the summer pressure anomalies. The positive anomalies formed a broad band extending from Florida to Western Europe with a peak of 3.4 mb above normal situated on the eastern side of the Atlantic (Fig. 17). The autumn pressure pattern was dominated by high anomalies in the region between Iceland and the United Kingdom whereas elsewhere in the North Atlantic the anomalies were typically weak.

SUMMARY

As last year, the sea surface temperature pattern derived from the ships-of-opportunity data indicated warmer-than-normal in the north and colder-than-normal in the south with the mid-Scotian Shelf being the approximate dividing line. Temperatures in the surface waters of the mid-Atlantic Bight were the coldest in the past 18 years. Coastal SST data at Boothbay Harbor, St. Andrews, and Halifax and temperature profiles at Station 27 off Newfoundland generally provide additional evidence for this anomaly pattern. At St. Andrews the mean annual temperature is the coldest since 1940. In contrast, the extreme cold conditions in the near bottom waters at Station 27 that have persisted over the past 6 years appear to be easing.

The position of the shelf/slope front between Cape Hatteras and Georges Bank and its variability as measured by the standard deviation were near their long-term mean values. Other variables that were near their average included sea-ice duration and air temperatures.

Average wave conditions on the Scotian Shelf, Grand Banks and in the Labrador Sea were more severe than normal although storminess, as measured by the occurance of waves exceeding 6 m in height, was near normal except in the Labrador Sea where conditions were considered stormy.

The most prominant feature of the atmospheric circulation, as derived from sea surface pressure patterns, was the intensification of the Icelandic Low during the winter of 1987-88.

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TABLE 1. Mean sea-surface temperatures for selected areas of the Northwest Atlantic in 1972-80 and anomalies for 1984 to 1988 relative to the base period. (Geographic locations of water masses are shown in Fig. 6. Blank space indicates that annual average not computed when data missing for one or more months.)

Water mass	Mean temp. 1972-80[a]	Annual anomalies (°C) 1984	1985	1986	1987	1988
CF	3.62	-0.01	1.03	0.99	1.12	1.17
LS	5.54	-0.59			0.34	0.20
LCS	2.19				-0.21	-0.42
OLC	5.17	0.06	-0.90	-0.19	-0.30	0.08
ILC	4.83	0.52	-0.38	0.24	0.31	0.85
FC	7.88	-0.14	-0.80	-0.24	0.08	0.52
CGB	6.48	0.84	-0.54	-0.16	0.19	1.03
WGB	6.13	0.62	-0.69	-0.23	0.39	0.61
SP	5.91	0.79	-0.36	-0.28	0.91	0.42
GSL	5.82	-0.02	-0.01	0.08	0.42	0.33
ESS	7.10	0.56	-0.29	-0.24	0.42	0.04
SI	8.27	0.97	-0.49	-0.57	0.02	-0.18
SH	7.85	0.66	-0.18	-0.34	0.70	-0.12
LHB	8.87	0.42	-0.33	-0.53	0.02	-0.62
BR	8.84	0.51	0.17	-0.05	-0.43	0.14
Y	7.64	0.10	-0.45	0.29	-0.37	0.05
GOM	9.59	0.45	0.10	0.25	-0.74	-0.40
GB	10.17	0.37	0.21	0.14	-0.66	-0.31
SNE	12.23	1.08	0.14	0.09	-0.51	-0.18
MAB	14.87	0.08	0.80	0.15	-0.43	-1.15
ESW	15.54	1.25	0.02	-0.34	0.10	0.06
WSW	18.50	-0.17	0.52	-0.16	-0.65	-0.82
GS	22.94	0.08	0.11	0.46	0.30	-0.11
SS	22.26	-0.05	-0.14	0.04	-0.08	0.24

[a] See Trites and Drinkwater (1985) for annual anomalies pertinent to the 1972-80 base period.

TABLE 2. Monthly mean significant wave heights (m) at three locations in the Northwest Atlantic (derived from 12-hr wave charts) for 1987 and 1988 relative to the 1970-80 mean.

	LABRADOR SEA 57.5 N 52.5 W			GRAND BANKS 47.5 N 47.5 W			SCOTIAN SHELF 42.5 N 62.5 W		
MON	1970-80	1987	1988	1970-80	1987	1988	1970-80	1987	1988
JAN	3.50	3.03	3.84	3.76	4.06	4.66	2.91	3.48	2.98
FEB	3.36	3.73	4.03	3.48	3.70	3.84	2.77	3.07	3.21
MAR	3.20	2.79	3.82	2.88	2.63	3.35	2.80	2.68	3.18
APR	2.56	2.67	1.97	2.78	2.28	2.98	2.35	2.40	2.87
MAY	2.02	2.47	2.21	2.22	2.39	2.37	1.82	1.79	1.97
JUN	1.84	2.52	2.33	2.07	2.48	2.50	1.70	1.80	2.00
JUL	1.75	2.03	1.71	1.94	2.18	1.74	1.57	1.23	1.69
AUG	2.01	2.02	2.44	2.22	2.31	2.44	1.62	1.52	1.69
SEP	2.61	2.58	2.93	2.75	2.77	2.62	1.76	1.97	1.82
OCT	3.14	3.13	2.55	3.19	3.31	2.68	2.16	2.29	2.48
NOV	3.33	3.58	4.30	3.41	3.68	3.95	2.69	2.83	3.27
DEC	3.64	3.98	4.02	3.96	4.68	3.81	3.00	3.37	2.92

TABLE 3. Historical data on presence and duration of sea ice at 24 sites off eastern Canada and ice duration at these sites in the 1987/88 (October-September) ice year with 1986/87 data in parentheses.

				Ice Duration (weeks)				
			Yrs	When ice present			Over-all	1987-88
Site	Seasons studied	# of Yrs	with ice	Min	Max	Mean	Mean	(1986-87)
G-7	67/68-87/88	21	21	6	16	10.4	10.4	10 (16)
G-10	76/77-87/88	12	12	3	17	10.7	10.7	13 (12)
G-12	67/68-87/88	21	21	2	15	11.3	11.3	12 (14)
G-22	76/77-87/88	12	12	7	14	11.6	11.6	11 (14)
G-31	68/69-87/88	20	19	8	17	12.3	11.7	13 (15)
G-33	71/72-87/88	17	17	2	14	9.8	9.8	12 (8)
G-35	59/60-87/88	29	13	1	11	3.7	1.7	0 (0)
G-86	76/77-87/88	12	12	6	22	14.8	14.8	16 (15)
G-87	70/71-87/88	18	17	1	12	6.9	6.6	6 (7)
N-19	66/67-87/88	22	22	17	30	23.5	23.5	23 (24)
N-21	67/68-87/88	21	21	5	28	17.6	17.6	13 (14)
N-23	59/60-87/88	29	23	1	17	5.1	4.0	4 (3)
N-25	59/60-87/88	29	2	1	1	1.0	0.1	0 (0)
N-27	59/60-87/88	29	0	0	0	0.0	0.0	0 (0)
N-62	67/68-87/88	21	21	8	27	17.9	17.9	14 (20)
N-64	59/60-87/88	29	28	3	25	12.0	11.6	11 (13)
N-66	59/60-87/88	29	23	1	16	7.2	5.7	7 (1)
N-68	59/60-87/88	29	11	1	10	3.4	1.3	0 (0)
N-70	60/61-87/88	28	0	0	0	0.0	0.0	0 (0)
N-108	59/60-87/88	29	23	1	17	5.5	4.3	4 (4)
N-110	59/60-87/88	29	22	1	12	4.4	3.3	1 (2)
N-112	59/60-87/88	29	9	1	10	4.3	1.3	0 (1)
N-114	59/60-87/88	29	3	1	2	1.3	0.1	0 (0)
N-228	59/60-87/88	29	18	1	14	5.3	3.3	0 (10)

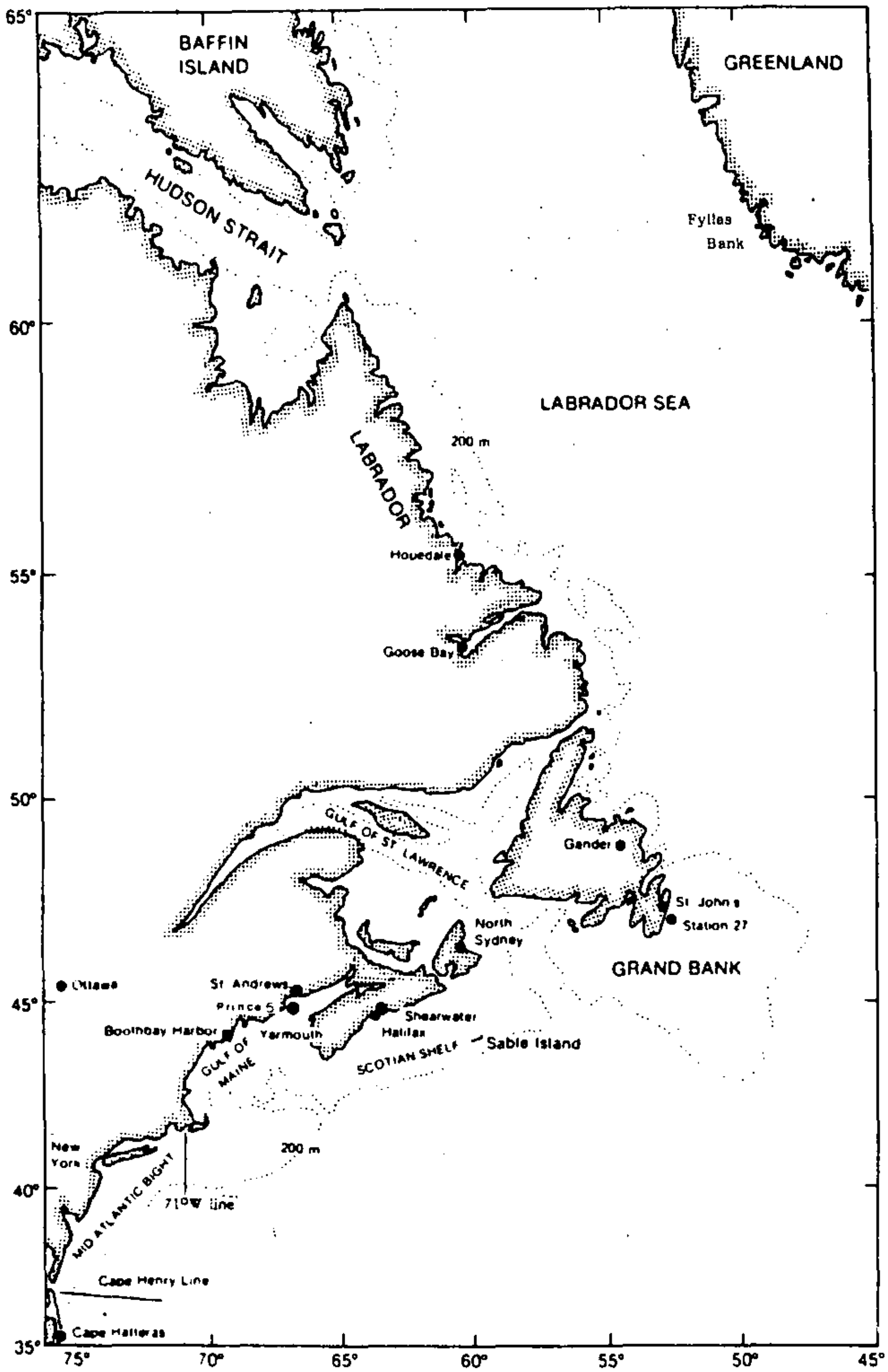

Fig. 1. Map of Northwest Atlantic showing oceanographic stations and other sites mentioned in the text.

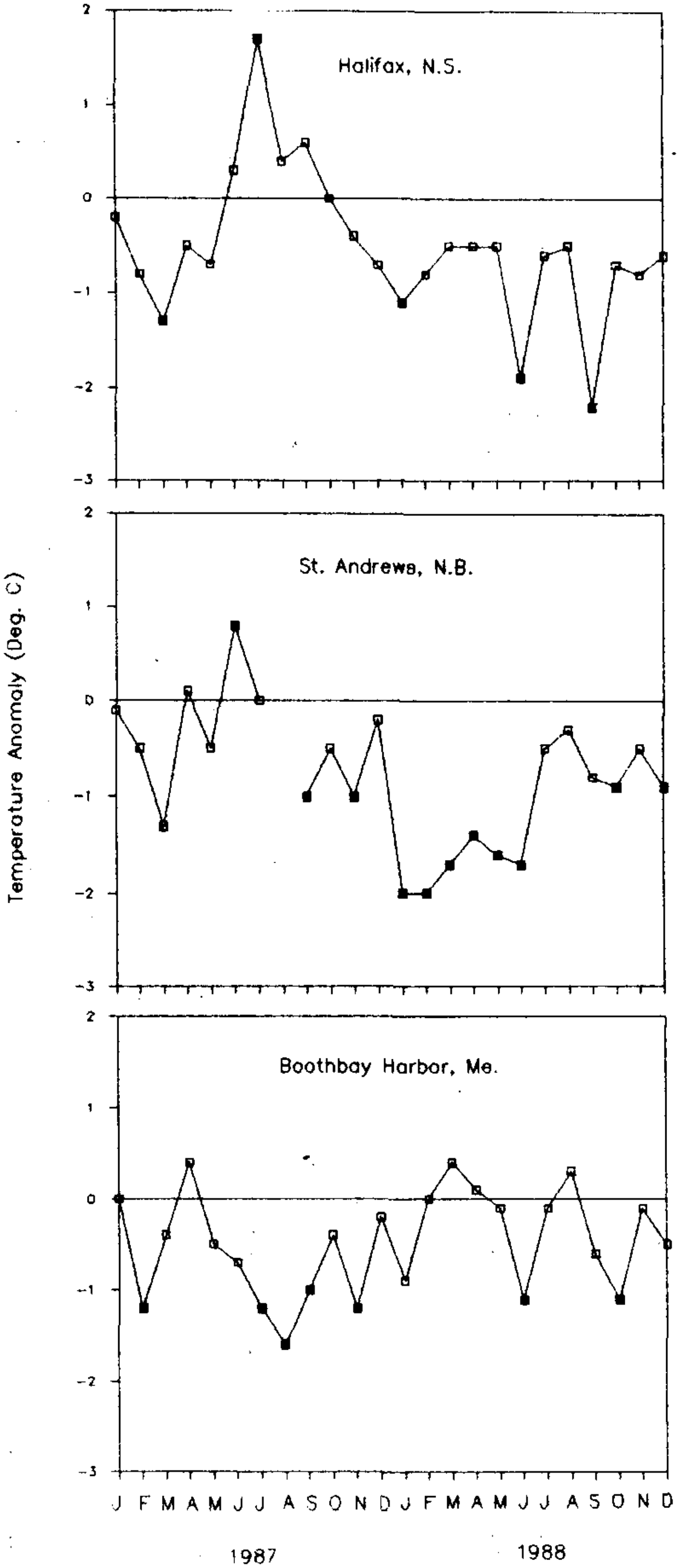

Fig. 2. Monthly sea-surface temperature anomalies at Halifax, St. Andrews and Boothbay Harbor in 1987 and 1988 relative to the 1951-80 means. (Solid squares indicate months when the anomalies equalled or exceeded one standard deviation. The missing data for St. Andrews during the August, 1987, was due to an instrument malfunction.

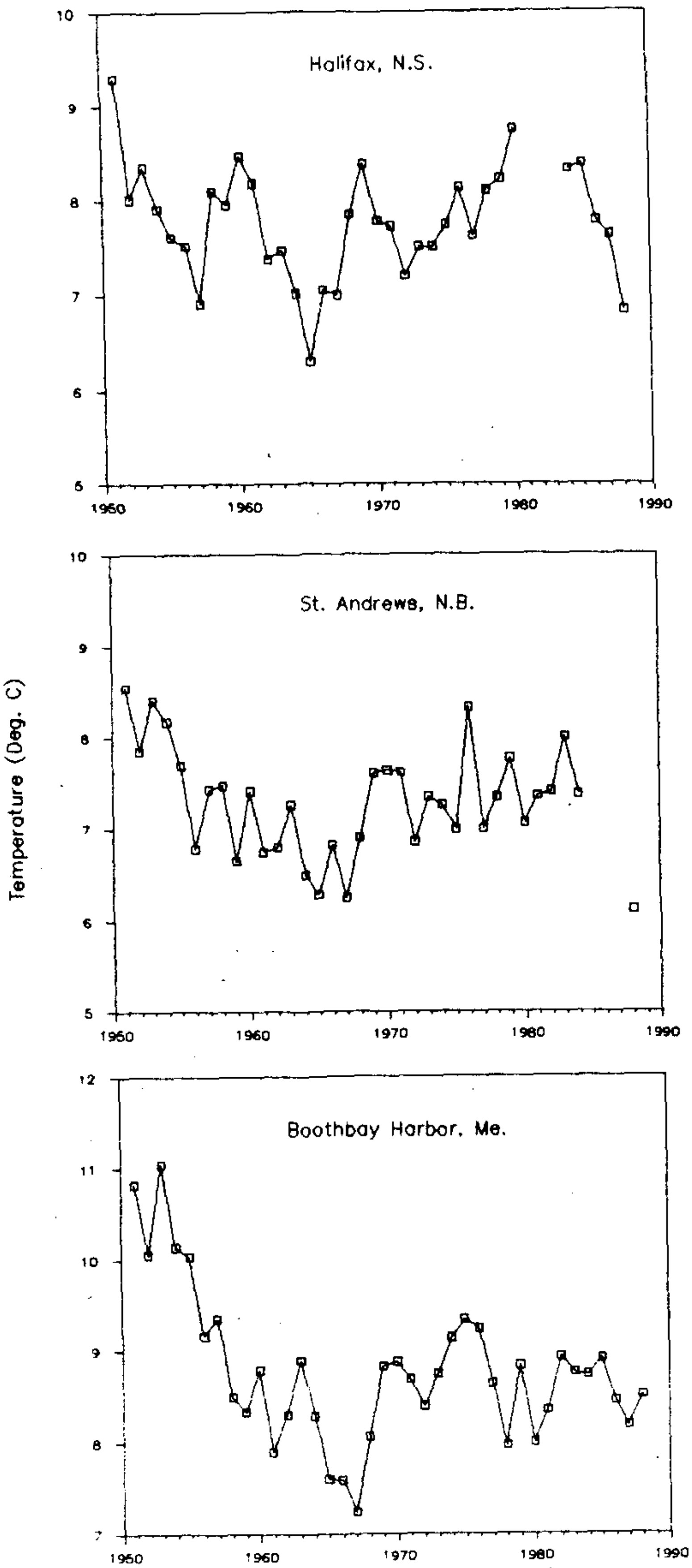

Fig. 3. Annual sea-surface temperatures at Halifax, St. Andrews and Boothbay Harbor during 1951-88.

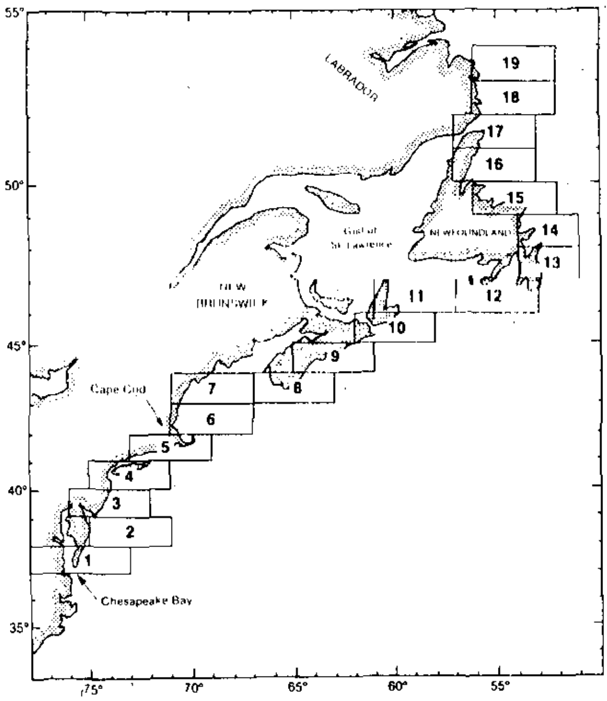

Fig. 4. Locations of 19 areas in the Northwest Atlantic (Chesapeake Bay to southern Labrador) for which sea-surface temperature data were grouped for analysis.

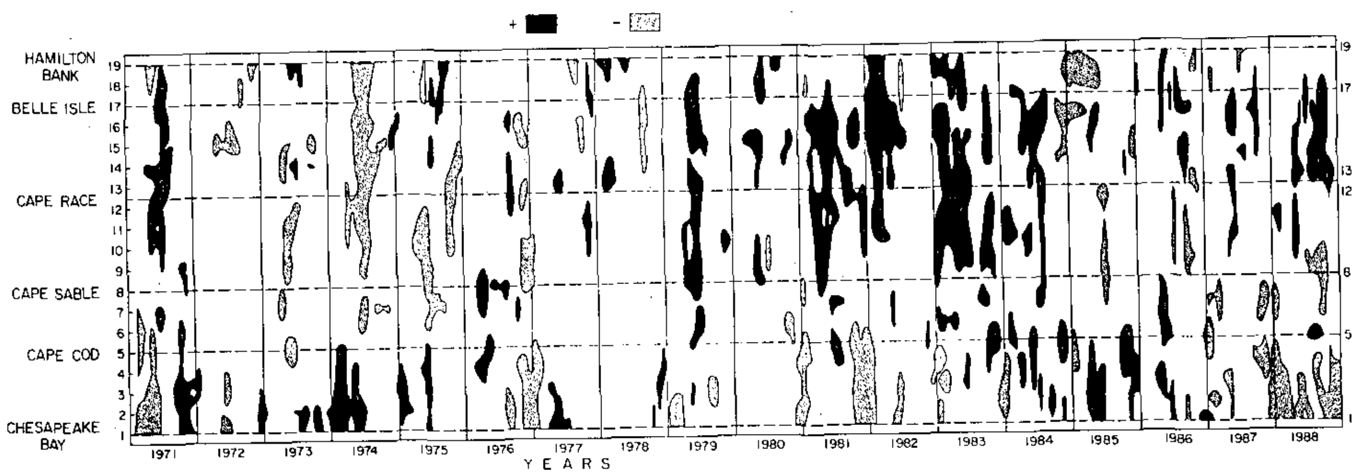

Fig. 5. Contoured monthly sea-surface temperature anomalies (relative to the 1971-80 means) for the 1971-88 period by area (Fig. 4). (Only anaomalies exceeding 1°C (black) and less than -1°C (dotted) which extended in space through at least two neighbouring areas and in time for at least two consecutive months have been contoured.)

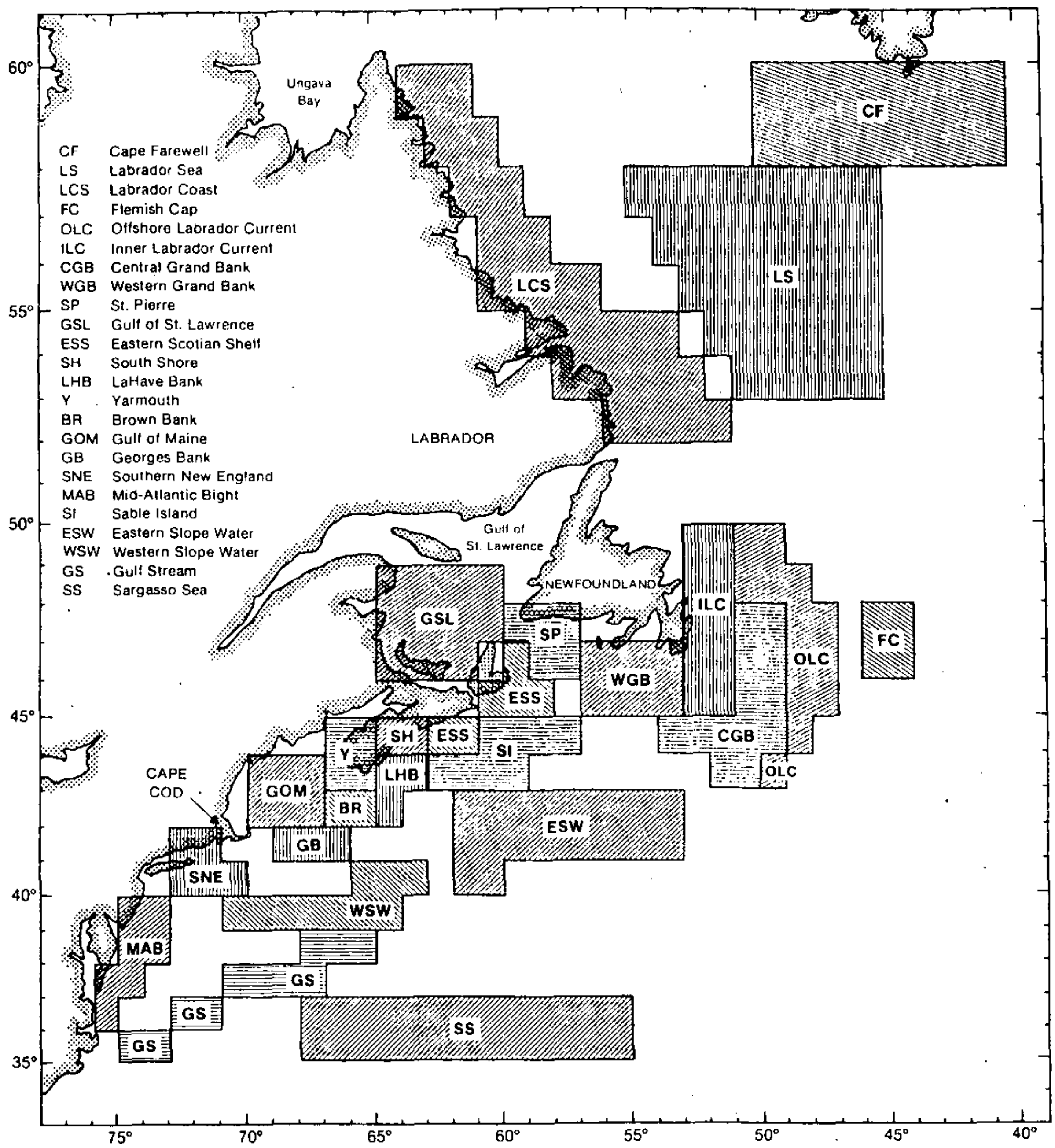

Fig. 6. Geographic boundaries of 24 subregions (Cape Hatteras to Cape Farewell) for which sea-surface tmeperatures were analyzed on a monthly basis.

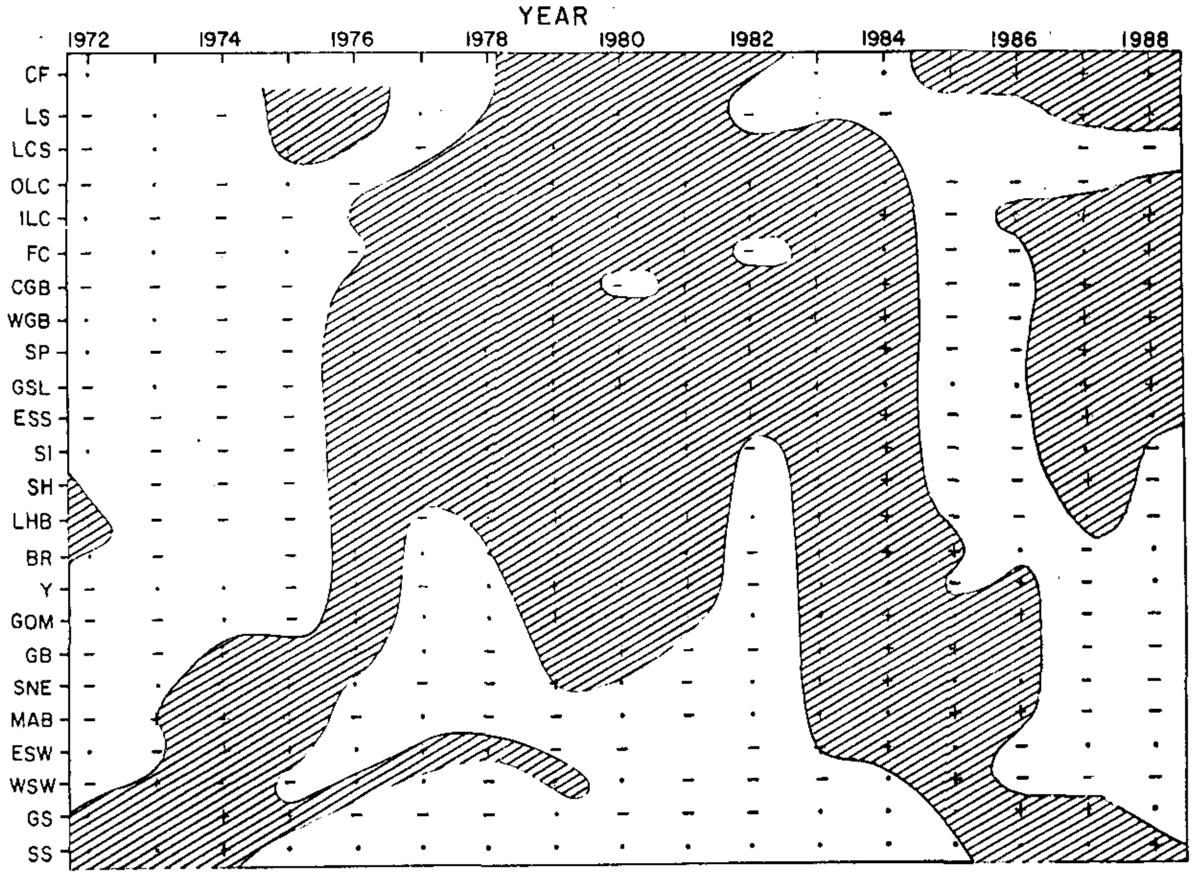

Fig. 7. Distribution of positive (+) and negative (-) annual sea-surface temperature anomalies in 1972-88 by subregion (Fig. 6) relative to the 1972-80 means. (Only anomalies less than -0.15°C and greater than +0.15°C were used in drawing the contours.)

TEMPERATURE ANOMALIES

SALINITY ANOMALIES

Fig. 8. Monthly temperature and salinity anomalies at Station 27 off St. John's during 1988 relative to the 1946-77 means (Keeley, 1981). (Shaded areas represent positive anomalies)

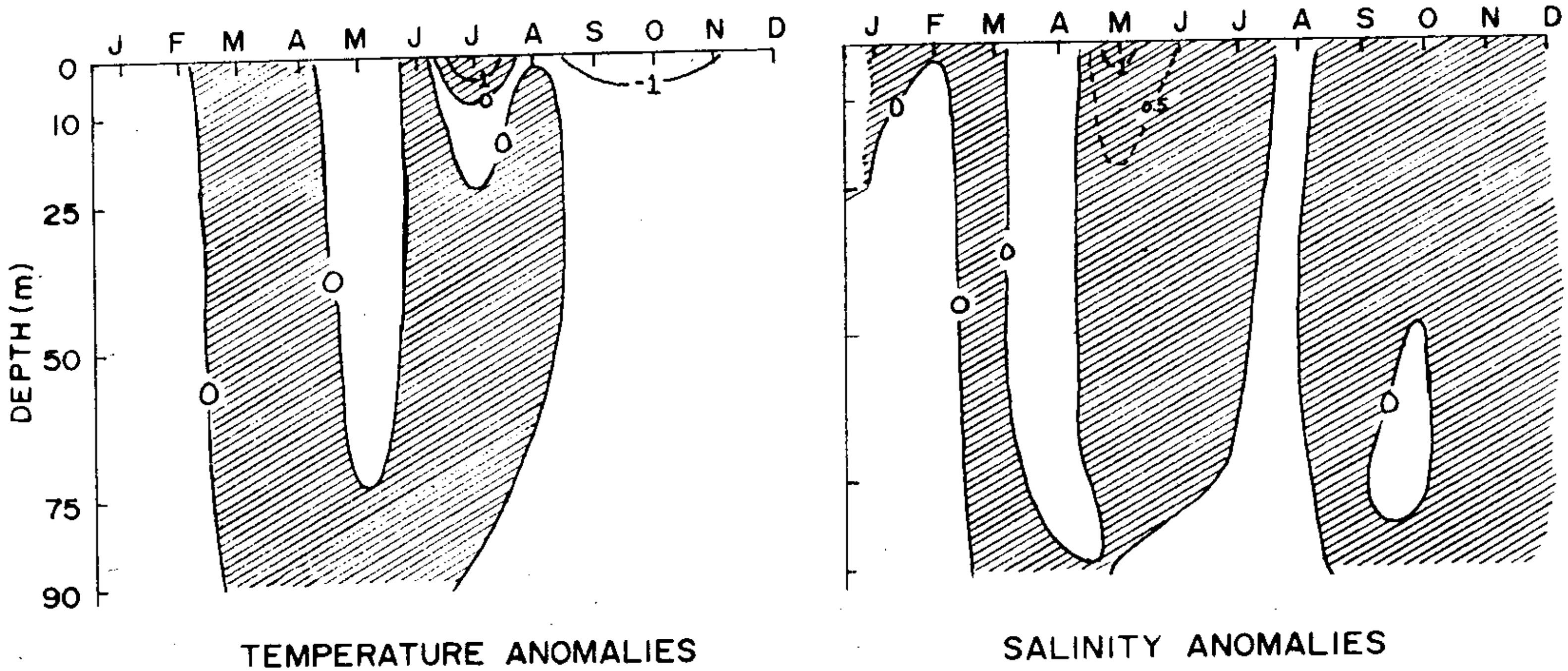

Fig. 9. Monthly temperature and salinity anomalies at Prince 5 near the entrance to the Bay of Fundy during 1988 relative to the 1951-80 means (shaded areas represent positive anomalies).

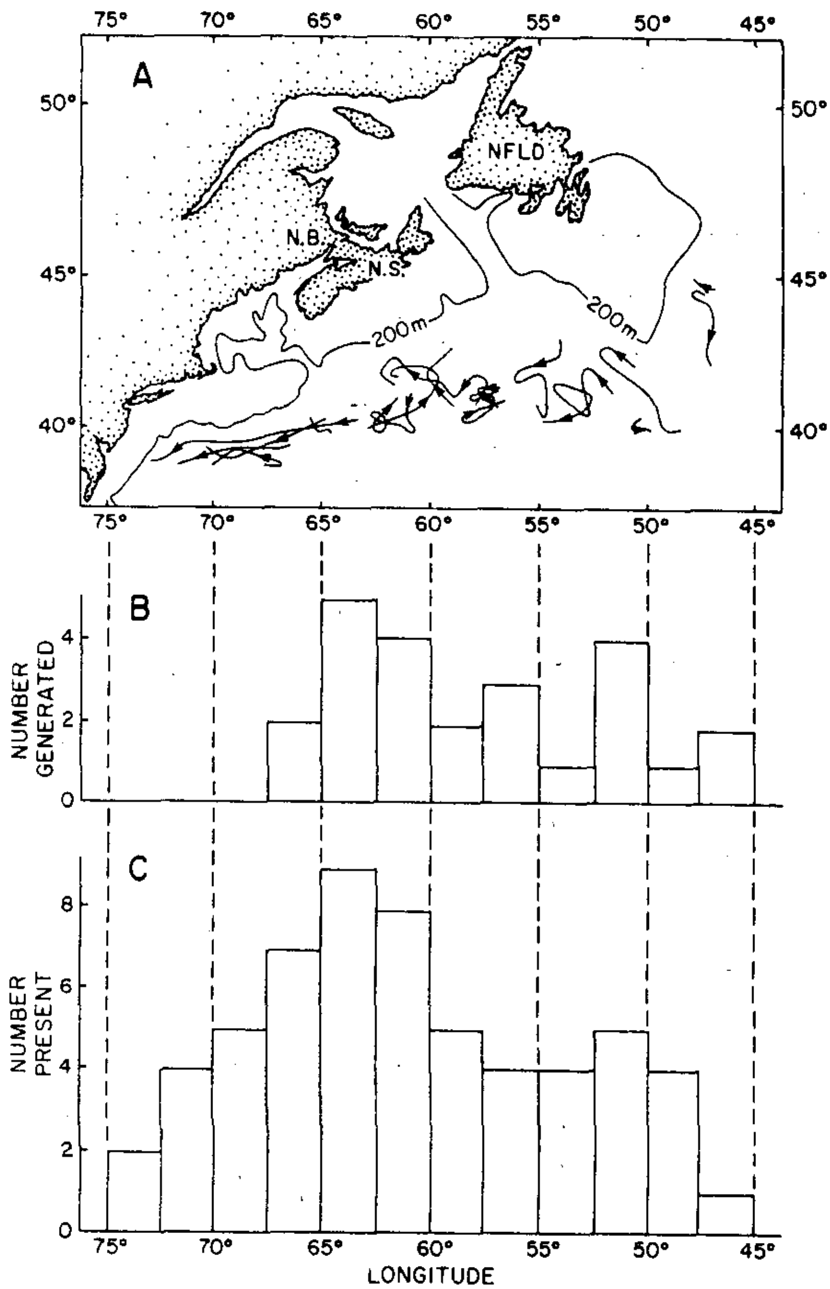

Fig. 10. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1988: (A) tracks of rings with a lifespan longer than 2 months; (B) number of rings generated in each 2.5° zone of longitude; and (C) number of rings present in each 2.5° zone during some part of the year.

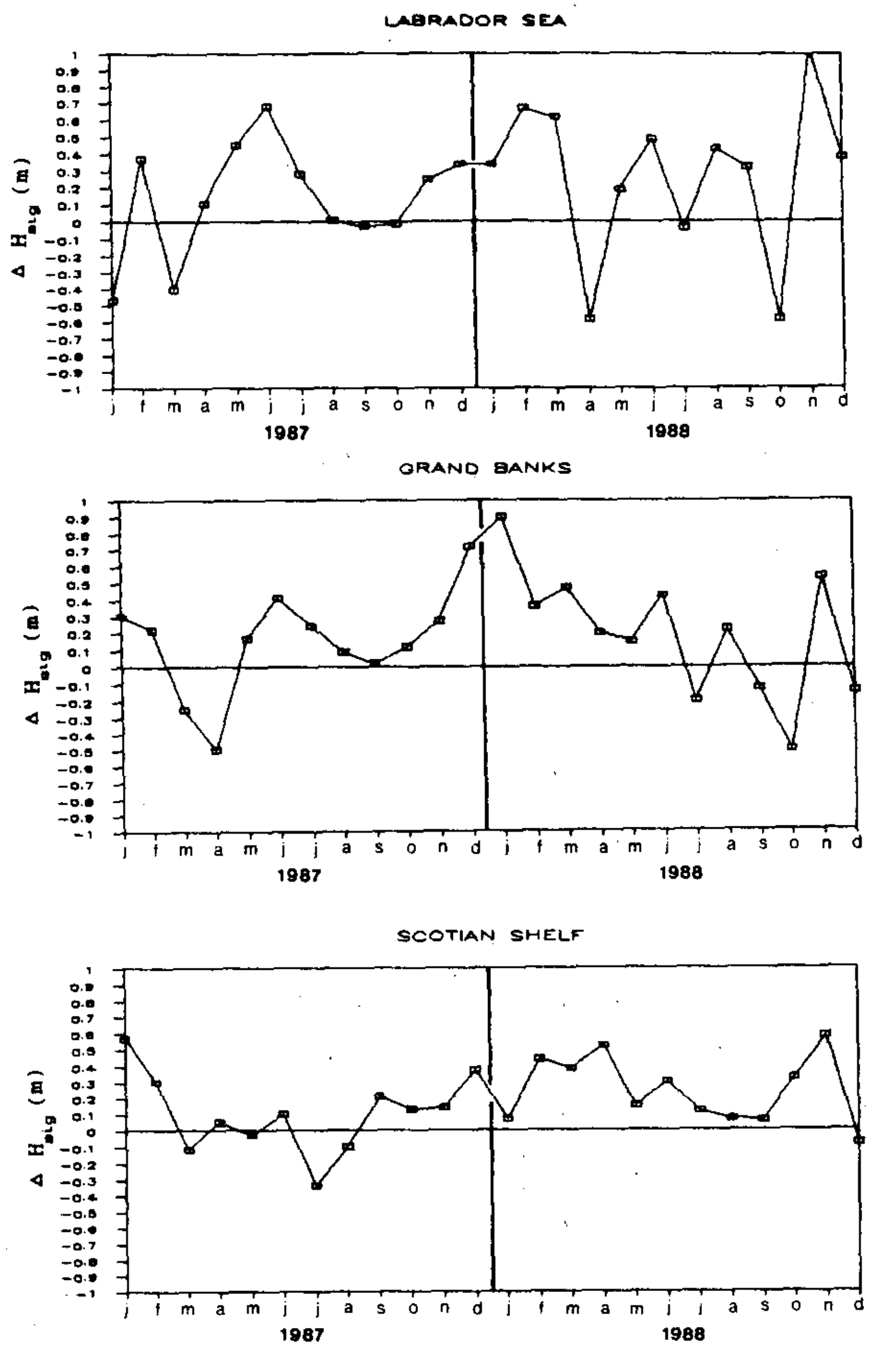

Fig. 11. Monthly significant wave heights (ΔH_{sig}) in three regions of the Northwest Atlantic during 1987 and 1988 relative to the 1970-80 means.

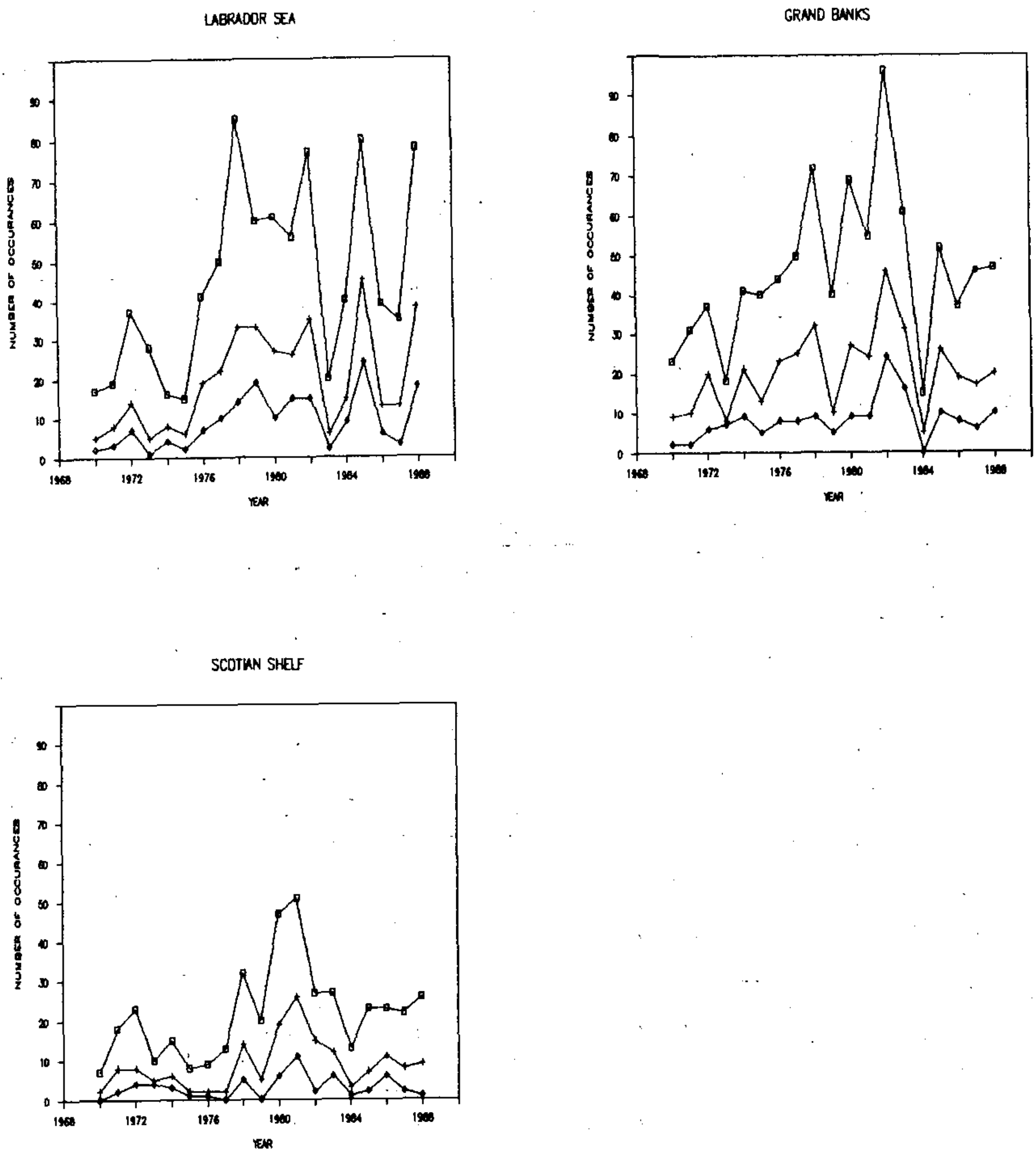

Fig. 12. Annual occurrences of storms during which wave heights exceeded 6, 7, and 8 m in three regions of the Northwest Atlantic during 1970-88.

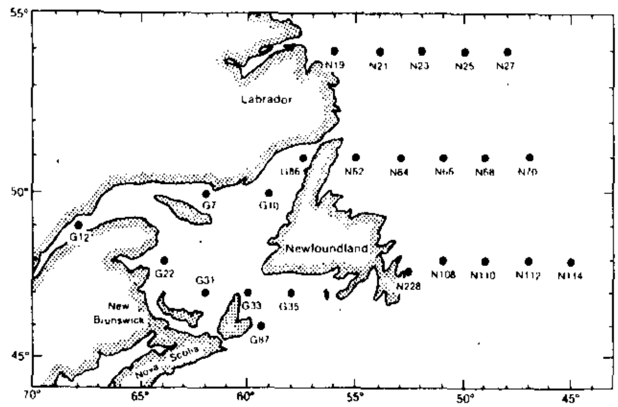

Fig. 13. Locations of 24 grids points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

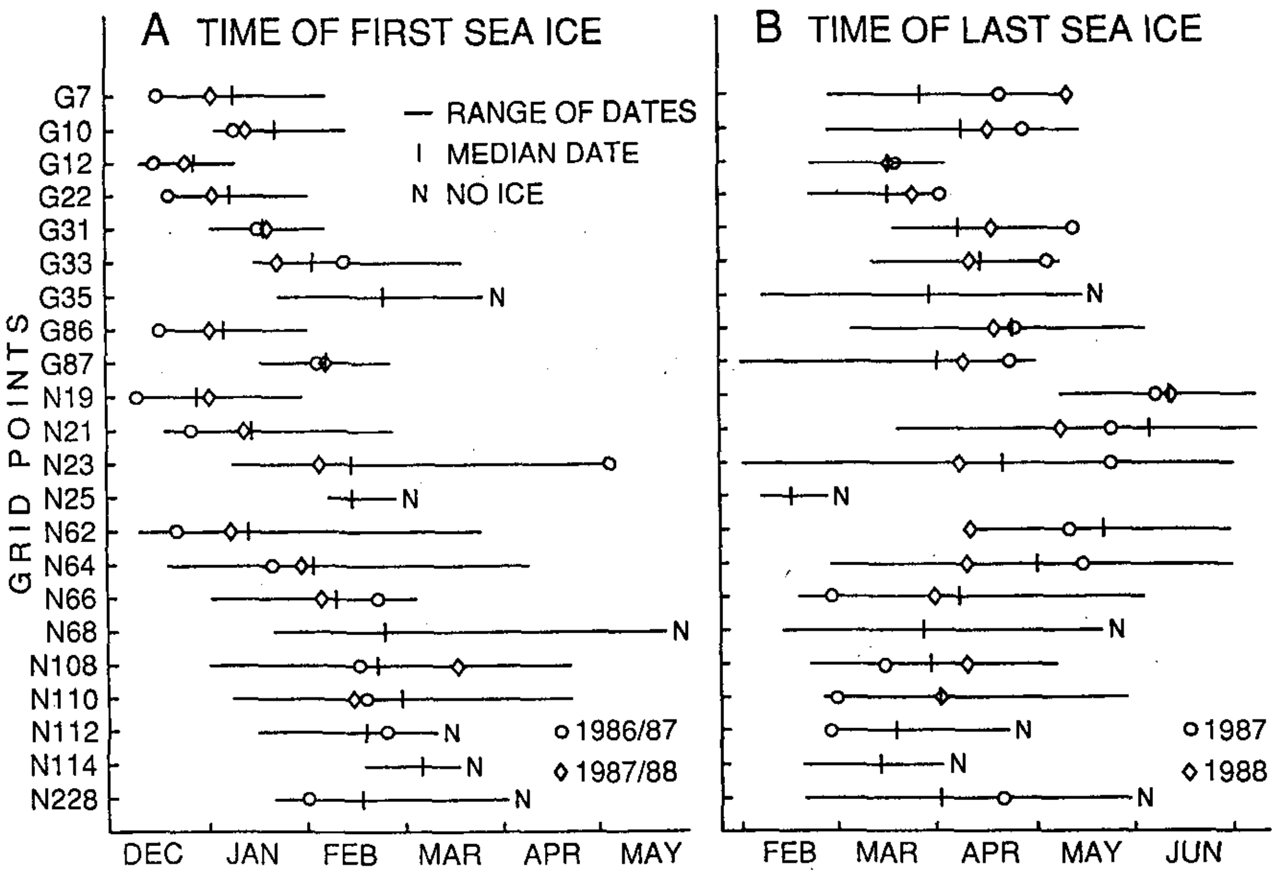

Fig. 14. Ranges of dates for the presence or first sea-ice (A) and last sea-ice (B) at 22 sites in the Northwest Atlantic (Fig. 13) with mean dates and the 1987 and 1988 dates. (Ice has never been observed at N27 and N70.)

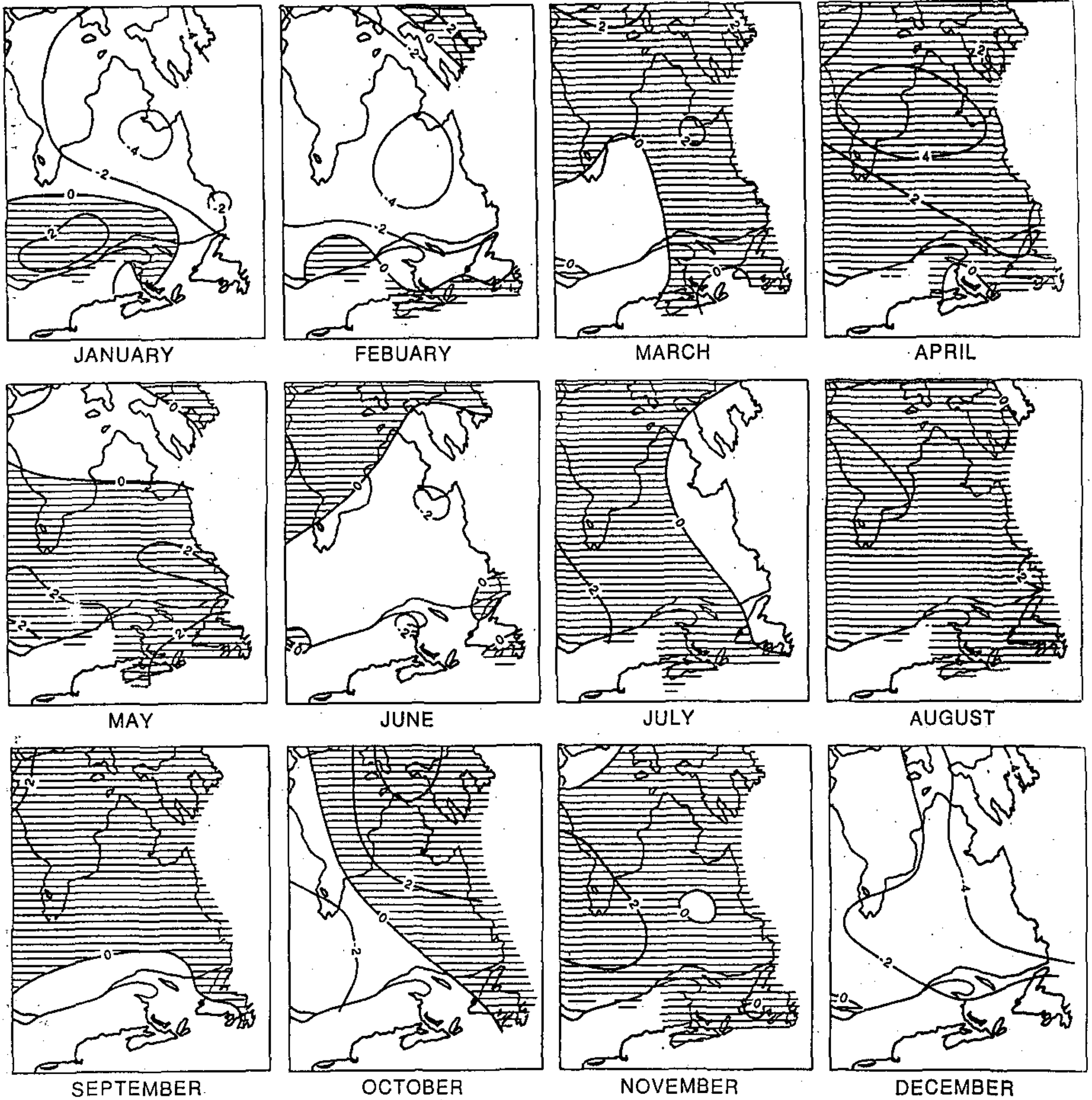

Fig. 15. Monthly air temperature anomalies (°C) over eastern Canada in 1988 relative to the 1951-80 means. (Positive anomalies are shaded.)

Fig. 16. Annual air temperature anomalies (°C) over eastern Canada in 1988 relative to the 1951-80 means. (Positive anomalies are shaded.)

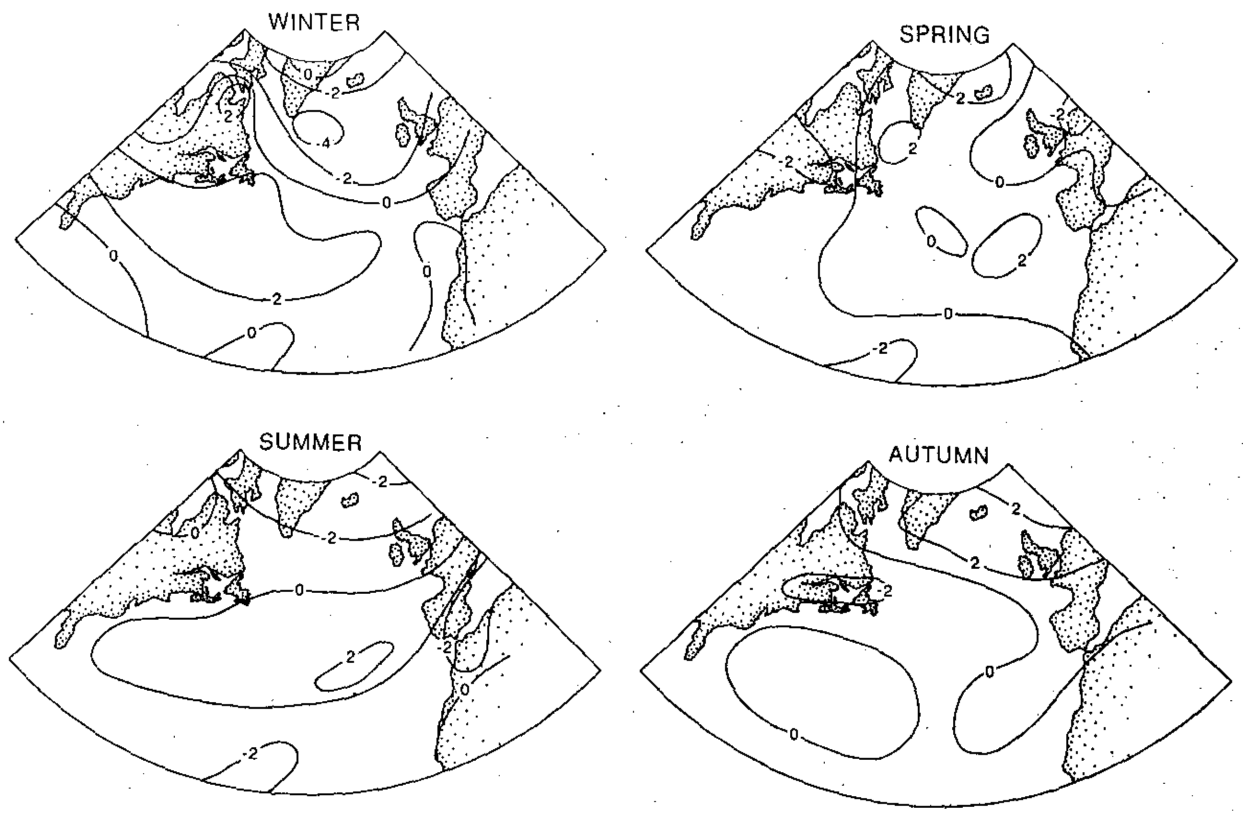

Fig. 17. Seasonal sea-surface air-pressure anomalies (mb) over the North Atlantic in 1988 relative to the 1951-80 means.