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Overview of Environmental Conditions in the Northwest Atlantic in 1990

by

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INTRODUCTION

This paper provides a review of environmental conditions in the Northwest Atlantic during 1990 and is based upon selected sets of oceanographic and meteorological data as well as information from research documents prepared for the NAFO Scientific Council. Environmental conditions are compared with those of the preceding year as well as the long-term means. The latter have been standardized to a 30-yr base period (1951-1980), where possible, in accordance with the convention of the World Meteorological Organization and recommendation of the NAFO Scientific Council. This report is the ninth in a series of annual overviews that began in 1982.

OCEANOGRAPHIC OBSERVATIONS

Coastal sea-surface temperatures

Monthly averages of sea-surface temperature (SST) are available from 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 1989 and 1990 are shown in Figure 2.

During 1990 negative anomalies were predominant at St. Andrews. The colder-than-normal temperatures in the first half of the year continued a trend that began in the autumn of 1989 and reached a peak anomaly in December of 1989. In August, a strong positive anomaly (1.2°C) was recorded but in the surrounding months temperatures were near normal. November was again cold but temperatures in December matched the long-term mean. At Halifax, the temperature anomaly pattern showed some similarities to those at St. Andrews with cold temperatures in the winter of 1989/90, warming up in summer but ending 1990 with below normal temperatures. In contrast to St. Andrews, however, the Halifax springtime negative anomalies were weak and there were 4 months in the summer and autumn with above normal temperatures. The largest positive and negative temperature anomalies at Halifax in 1990 were in August (1.6°C) and January (-2.0°C). At Boothbay Harbor during the first half of the year the monthly temperature anomalies were predominantly negative but within one standard deviation of the mean. A sharp change was observed beginning in August as above normal temperatures persisted for the remainder of the year with the maximum anomaly occurring in December (1.5°C).

The annual SST anomalies are shown in Fig.3. The annual means were 7.5°C at Halifax (0.3°C below normal), 7.0°C at St. Andrews (0.3°C below normal) and 9.1°C at Boothbay Harbor (0.3°C above normal). At Halifax, the annual mean was similar to last year's value. At Boothbay Harbor the mean temperature rose by almost 1°C and exceeded the long-term (1951-80) mean for the first time since 1985. At St. Andrews the annual mean increased for the second consecutive year from the extreme low temperature recorded in 1988. The missing data in Fig. 3 were due to instrument malfunctions at Halifax and extensive wharf 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 1971-89 described by Drinkwater and Trites (MS 1990) was examined for 1990 and compared to earlier years (Fig. 5). Negative anomalies were observed in several of the more southern areas at the beginning of the year as part of a trend that began in late 1989. However, warmer-than-normal temperatures were more predominant throughout the rest of the year. They first appeared during the spring in the Mid-Atlantic Bight and off northern Newfoundland. During the latter half of the year they covered the northern Mid-Atlantic Bight, western Gulf of Maine and the areas surrounding Newfoundland.

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 for 1984-1989 by Drinkwater and Trites (1987, 1988, 1989, MS 1990) and by Trites and Drinkwater (1990). The monthly mean temperature for each of the 24 areas was computed for 1990. The annual anomalies for 1986 to 1990 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 1972-90 period is shown in Fig.7.

The 1990 pattern shows a predominance of positive annual SST anomalies throughout the region with the highest magnitude (1.4°C) off southern New England (area SNE). This continues a trend of warmer-than-normal temperatures that began in the northern areas in 1987 and spread southward last year. A weaking of the positive anomaly field in the north is evident, however, with negative anomalies in the Labrador Sea (area LS), in the offshore branch of the Labrador Current (OLC), and on Flemish Cap. Also, near normal sea surface temperatures were observed south of Newfoundland (areas WGB and SP) and in the Gulf of St. Lawrence (GSL). Negative temperature anomalies were also observed on the outer edge of the Scotian Shelf (area SI) and in the western Slope Water (WSW). For the latter area, the anomaly was -0.9°C and represents the fifth consecutive year of below normal temperatures.

Sigaev (MS, 1991) has undertaken a 5-yr analysis (1986-1990) of sea surface temperatures, using data provided by the Hydrometeorcenter of the USSR. Monthly anomalies were conputed for 6 locations extending from the northern Labrador Sea to the slope south of Nova Scotia. He also undertook a longer analysis of autumn water temperatures on the Scotian Shelf (1977-90) based on bathythermograph data collected during the USSR-Canada surveys on silver hake.

Temperature and salinity stations

Station 27. Measurements of temperature and salinity have been routinely taken since 1946 at a site (station 27) located approximately 10 km off St. John's, Newfoundland. This station is considered to be representative of the inshore Labrador Current. The station was visited 45 times in 1990, with a monthly maximum of 10 in May and a minimum of 0 in November. The data were collected at, or linearly interpolated to, standard depths (0, 10, 20, 30, 50, 75, 100, 125, and 150 m) and monthly means were calculated for each depth. The monthly temperature and salinity data for 1990 together with their anomalies relative to the mid-month means for 1947-77 (Keeley, 1981) are shown in Fig. 8.

Cold temperatures extended throughout most of the water column during Jauary through March. In January temperatures were near -0.9°C (an anomaly of -1.5°C), in February they were -1.7°C (an anomaly of -0.9°C) and in March -1.6°C (an anomaly of -0.5°C). Spring heating of the near surface waters appears to have been delayed causing strong negative temperature anomalies in May and June. During the second half of the year the near surface temperatures were consistently above normal with maximaum values of 1.0-1.5°C in August and September in the upper 10 m of the water column. The strong negative anomalies in the thermocline region during the late summer and early autumn indicate the seasonal deepening of the thermocline was delayed in 1990. The near bottom temperatures (between 125 and 150 m) were below normal throughout the year continuing the trend of the last eight years. Similar to last two years, these anomalies were generally weak (between 0 and -0.5°C).

As occurred last year, salinity anomalies were mostly positive but weak (<0.5). The seasonal salinity minimum in the near surface waters appeared in October and resulted in slightly lower than normal (-0.1) salinities. Below 100 m the anomalies were very weak with salinities being within 0.1 of their long-term means.

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 measurement 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 persistent 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 1990, the temperature throughout most of the water column increased gradually from a minimum in Febraury-March of less then 2°C to near 12°C in September (Fig. 9). These resulted in negative temperature anomalies during the first four months of the year and above normal temperatures during the remainder of the year. The highest temperature anomalies occurred in October (1.1-1.4°C) with anomalies exceeding 1°C also in May. The minimum anomalies were in January with temperatures, on average, being -1.5°C colder than normal. The near surface temperature anomalies at Prince 5 differ from those measured at St. Andrews especially the summer. Whereas Prince 5 data suggests positive temperature anomalies, the daily records from St. Andrews indicated slightly lower-than-normal temperatures.

The positive salinity anomalies observed at Prince 5 in 1988 and 1989 (Trites and Drinkwater 1990; Drinkwater and Trites MS 1990) continued through most of 1990 (Fig. 9). Also as in previous years, these were generally weak, i.e. an anomaly of less than 0.5. The spring freshening of the upper portion of the water column resulted in a minimum surface salinity during June of less than 30.5 which represents an anomaly for that month exceeding -0.5. Normally the minimum surface salinity values occur in May. The 1990 observations suggest the possibilty that the peak discharge from the Saint John River, which is the principal cause of the freshening at Prince 5, may have occurred later-than-normal. Again, however, the reader is cautioned that the data at Prince 5 are single point measurements for the month and may not necessarily represent average conditions for that month.

Warm-core rings

The life history of anticyclonic warm-core Gulf Stream rings in the region from 45°W to 75°W during 1990 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 37 warm-core rings were present in the area during some portion of 1990, seven of which survived from 1989 into the new year. Two other rings which appeared in the last satellite images of the 1989 and were previously reported as surviving into 1990 (Drinkwater and Trites, MS 1990) did not appear on the first available satellite imagery of 1990. Six of the 30 new rings which formed in 1990 persisted into 1991. At least 13 of the rings formed in 1990 had a lifespan exceeding 2 months. Their paths and those of the 7 rings that survived from 1989 and which also had a lifespan of over 2 months are shown in Fig. 10A. Rings, whose destruction occurred in 1990, ranged in age from 10 d to more than sixteen months and had a mean life of 87 d with a standard deviation of 100 d. This compares with an age range of less than two weeks to more than seven months and a similar mean of just under three months for 1989. The statistics of ring formation and ring presence, compiled by zones, each covering 2.5° of longitude, are shown in Fig. 10B and C, respectively. One or more rings were formed in each of the zones east of 70°W. A maximum of 6 were generated in both the 55-57.5°W zone and the 62.5-65° zone. The number of rings present in each of the longitude zones varied from two to nine with the highest number present in the two zones spanning 60-65°W. At least one or more rings formed in all months and the maximum number of four formed in March, July, and October.

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 last presence of ice at 24 grid sites (Fig. 11). Results for 1982/83 to 1988/89 were previously summarized by Trites and Drinkwater (1985, 1986, 1990) and Drinkwater and Trites (1987, 1988, 1989, MS 1990). The present analysis has been updated to include data for the 1989/90 season. For each site, the extracted data included ice duration in weeks for the 1989/1990 season, mean duration for all years of record, as well as minimum, maximum and mean duration for years when ice was present (Table 2).

For most of the Gulf of St. Lawrence and in the offshore waters off Newfoundland ice remained longer than normal (Fig. 12, 13; Table 2). Off northern Cape Breton Island (Site G33) the duration of sea ice matched the maximum recorded over a 19-yr period while for the site on the Gulf side of Belle Isle Strait (G86) a new record was set for the maximum duration (Fig.13). Ice was observed for 23 weeks at G86 which is almost 2 months longer than the mean and 1 week longer than the previous maximum. The longer-than-normal duration in the western Gulf and the St. Lawrence Estuary was due principally to the early presence of ice whereas in the northeastern Gulf ice first appeared near the usual time but stayed much longer than normal. Three sites (G12, G31, and G33) in the western Gulf recorded the earliest presence of ice since the measurement program started and off eastern Cape Breton Island (G87) ice first appeared on January 15 matching the previous earliest appearance at that site (Fig. 14A). In the western Gulf the ice left early or near to the average time of departure but in the northeast the ice stayed longer than ever before with new records established at sites G7, G10 and G86 (Fig. 14B).

On the northern Newfoundland Shelf the duration of ice at the stations furthest inshore was near normal (Fig. 13). Off White Bay (N62) this was in spite of an early advance of sea ice and late retreat (Fig. 14A,B). Note that ice duration is based on the presence of ice which is not necessarily the time between the first and last siting of sea ice. Further offshore ice was present longer-than-average. On the two northern most lines this was due to the presence of ice late into the year whereas at the southern sites, N108 and N110, the long duration was primarily the consequence of an early advance of sea ice. The furtherest offshore stations at which ice was present (N23, N68, and N112) also had longer than normal durations in spite of the ice not appearing until later in the year than normal. No ice was observed at the most easterly stations (N25, N27, N70, and N114). Ice has never been observed at stations N27 and N70 and only in 2 and 3 years at N25 and N114, respectively, over a 31-yr period.

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 1988/89 iceberg season (October to September), a total of 856 icebergs were spotted south of 48°N. The monthly totals for February to August 1990 were, respectively, 9, 115, 398, 207, 94, 28, and 5. No icebergs were spotted south of 48° during October 1989 to January 1990 and September of 1990. In the primary iceberg season, March to August, 847 icebergs were observed which represents 99% of the annual total. The numbers of bergs detected in 1989/90 is a factor of three times the numbers observed during the last four iceberg seasons (Fig. 15) indicating it was a heavy iceberg year. The late presence of sea ice off northern Newfoundland would have contributed to the preservation of the icebergs through reducing wave action and in maintaining low sea surface temperatures.

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 1990 monthly anomalies are plotted in Fig. 16. Over Labrador and Newfoundland, air temperature anomalies during the winter and early spring were predominantly negative with maximum values of -4 to -8°C centered over the northeastern Gulf of St. Lawrence in February and March. These exceed their standard deviations by 2 to 5°C (see Fig. 15 in Trites and Drinkwater (1986) for plots of the standard deviations for the monthly air temperatures). As noted by Borokov and Tevs (MS 1991), the strong prevailing northerly winter winds in the Northwest Atlantic associated with an anomalously intense Icelandic Low, resulted in large negative air temperature anomalies throughout NAFO Subareas 1-3. For the remainder of the year positive air temperature anomalies were evident over either Newfoundland or Labrador. Positive air temperature anomalies were also observed over Nova Scotia and the southwestern Gulf of St. Lawrence. The highest positive temperature anomalies (2°C) occured in August and December. These exceeded the standard deviation by 1°C in August but were within one standard deviation in December.

The annual air temperature anomaly pattern shows negative anomalies in the northeast including off Baffin Island, along the coast of Labrador, over Newfoundland and in the northeastern portion of the Gulf of St. Lawrence (Fig. 17). Positive anomalies exist to the southwest including over the Magdalen Shallows in the Gulf of St. Lawrence and off Nova Scotia, including the Gulf of Maine. The close similarity in patterns between the annual air temperature anomalies and the monthly values for January, February and December indicates that the annual mean is defined in large measure by wintertime conditions. The annual anomalies tend to be within one standard deviation of the mean except over Hudson Strait were the anomaly exceeds slightly one standard deviation. The pattern contrasts with that from 1989 which showed more uniform negative anomalies over the entire region (Drinkwater and Trites, MS 1990).

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 1990 relative to the 1951-80 means are shown in Fig. 18. Winter includes December 1989 to February 1990, spring is March to May, summer is June to August and autumn is September to November.

During 1990 the major sea level pressure signal was the deepening of the Icelandic Low in winter and its shift slightly to the north east. The amplitude of the peak pressure anomaly exceeded 20 mb near Iceland. The intensified Icelandic low brought strong northerly winds over the Labrador Sea, along the Labrador coast and across Newfoundland. This would have contributed to the cold SSTs observed in the region as well as the relatively heavy ice year. Over the Gulf of St. Lawrence and the Gulf of Maine the sea level pressures gradients from the spring to the autumn, inclusive, were weak.Icelandic Low weakened considerably producing positive pressure anomalies in the northeastern region of the North Atlantic. The sign of the pressure anomaly in the vicinity of the Icelandic Low shifted to negative in the summer and back to positive in autumn. The amplitude of the anomalies was found to be higher than normal in all seasons.

SUMMARY

Coastal and offshore SST data indicate that the winter of 1989-90 was colder-than-normal. Subsurface data from stations such as Prince 5 and Station 27 also show this trend. The region with the coldest temperature anomalies were located in the Labrador Sea and in the Labrador Current. These conditions most likely resulted from the strong northerly winds that prevailed during the winter due to intensification of the Icelandic Low. Air temperatures along the Labrador coast and in Newfoundland also were found to be colder-than-normal especially during the winter. These cold conditions contributed to relatively heavy ice year. Ice appeared early in the Gulf of St. Lawrence setting records for the earliest date for the first presence of ice in the southwestern region of the Gulf. In the northeastern Gulf ice first appeared at or near its usual time but lasted much longer than normal setting new records for the date of last presence of sea ice. In addition, the highest number of icebergs in the past five years were observed crossing 48°N. While cold winter conditions prevailed, summer and autumn temperatures through much of the region were warmer-than-normal.

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TABLE 1. Mean sea-surface temperatures for selected areas of the Northwest Atlantic in 1972-80 and anomalies for 1986 to 1990 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	Annual anomalies (°C) 1986	1987	1988	1989	1990
CF	3.62	0.99	1.12	1.17	0.50	0.75
LS	5.54		0.34	0.20	0.00	-0.31
LCS	2.19		-0.21	-0.42		
OLC	5.17	-0.19	-0.30	0.08	0.02	-0.37
ILC	4.83	0.24	0.31	0.85	0.74	0.21
FC	7.88	-0.24	0.08	0.52	0.04	-0.47
CGB	6.48	-0.16	0.19	1.03	0.76	0.17
WGB	6.13	-0.23	0.39	0.61	0.34	0.06
SP	5.91	-0.28	0.91	0.42	0.01	0.01
GSL	5.82	0.08	0.42	0.33	0.29	0.07
ESS	7.10	-0.24	0.42	0.04	0.45	0.20
SI	8.27	-0.57	0.02	-0.18	0.53	-0.17
SH	7.85	-0.34	0.70	-0.12	0.68	0.39
LHB	8.87	-0.53	0.02	-0.62	0.19	0.12
BR	8.84	-0.05	-0.43	0.14	0.66	0.79
Y	7.64	0.29	-0.37	0.05	0.38	0.27
GOM	9.59	0.25	-0.74	-0.40	0.19	0.20
GB	10.17	0.14	-0.66	-0.31	0.09	0.45
SNE	12.23	0.09	-0.51	-0.18	0.69	1.44
MAB	14.87	0.15	-0.43	-1.15	0.13	0.47
ESW	15.54	-0.34	0.10	0.06	0.61	0.29
WSW	18.50	-0.16	-0.65	-0.82	-1.36	-0.91
GS	22.94	0.46	0.30	-0.11	0.19	0.43
SS	22.26	0.04	-0.08	0.24	0.18	0.15

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

TABLE 2. Historical data on presence and duration of sea ice at 24 sites off eastern Canada and ice duration at these sites in the 1989/90 (October-September) ice year with 1988/89 data in parentheses.

Site	Seasons studied	# of Yr	Yrs with ice	Ice Duration (weeks) When ice present Min	Max	Mean	Over-all Mean	1989-90 (1988-89)
G-7	67/68-89/90	23	23	6	16	10.5	10.5	11 (12)
G-10	76/77-89/90	14	14	3	17	11.2	11.2	16 (13)
G-12	67/68-89/90	23	23	2	15	11.4	11.4	13 (12)
G-22	76/77-89/90	14	14	7	14	11.7	11.7	13 (12)
G-31	68/69-89/90	22	21	8	17	12.3	11.8	14 (12)
G-33	71/72-89/90	19	19	2	14	10.2	10.2	14 (13)
G-35	59/60-89/90	31	15	1	11	3.9	1.9	7 (3)
G-86	76/77-89/90	14	14	6	23	15.6	15.6	23 (18)
G-87	70/71-89/90	20	19	1	12	7.2	6.8	8 (10)
N-19	66/67-89/90	24	24	17	30	23.4	23.4	23 (22)
N-21	67/68-89/90	23	23	5	28	18.0	18.0	26 (17)
N-23	59/60-89/90	31	25	1	17	5.0	4.1	7 (2)
N-25	59/60-89/90	31	2	1	1	1.0	0.1	0 (0)
N-27	59/60-89/90	31	0	0	0	0.0	0.0	0 (0)
N-62	67/68-89/90	23	23	8	27	18.0	18.0	19 (18)
N-64	59/60-89/90	31	30	3	25	12.1	11.7	14 (15)
N-66	59/60-89/90	31	25	1	16	7.7	6.2	14 (12)
N-68	59/60-89/90	31	12	1	10	3.6	1.4	6 (0)
N-70	60/61-89/90	30	0	0	0	0.0	0.0	0 (0)
N-108	59/60-89/90	31	25	1	17	5.6	4.5	9 (6)
N-110	59/60-89/90	31	24	1	12	4.7	3.6	8 (8)
N-112	59/60-89/90	31	11	1	10	3.9	1.4	3 (1)
N-114	59/60-89/90	31	3	1	2	1.3	0.1	0 (0)
N-228	59/60-89/90	31	20	1	14	5.1	3.3	3 (4)

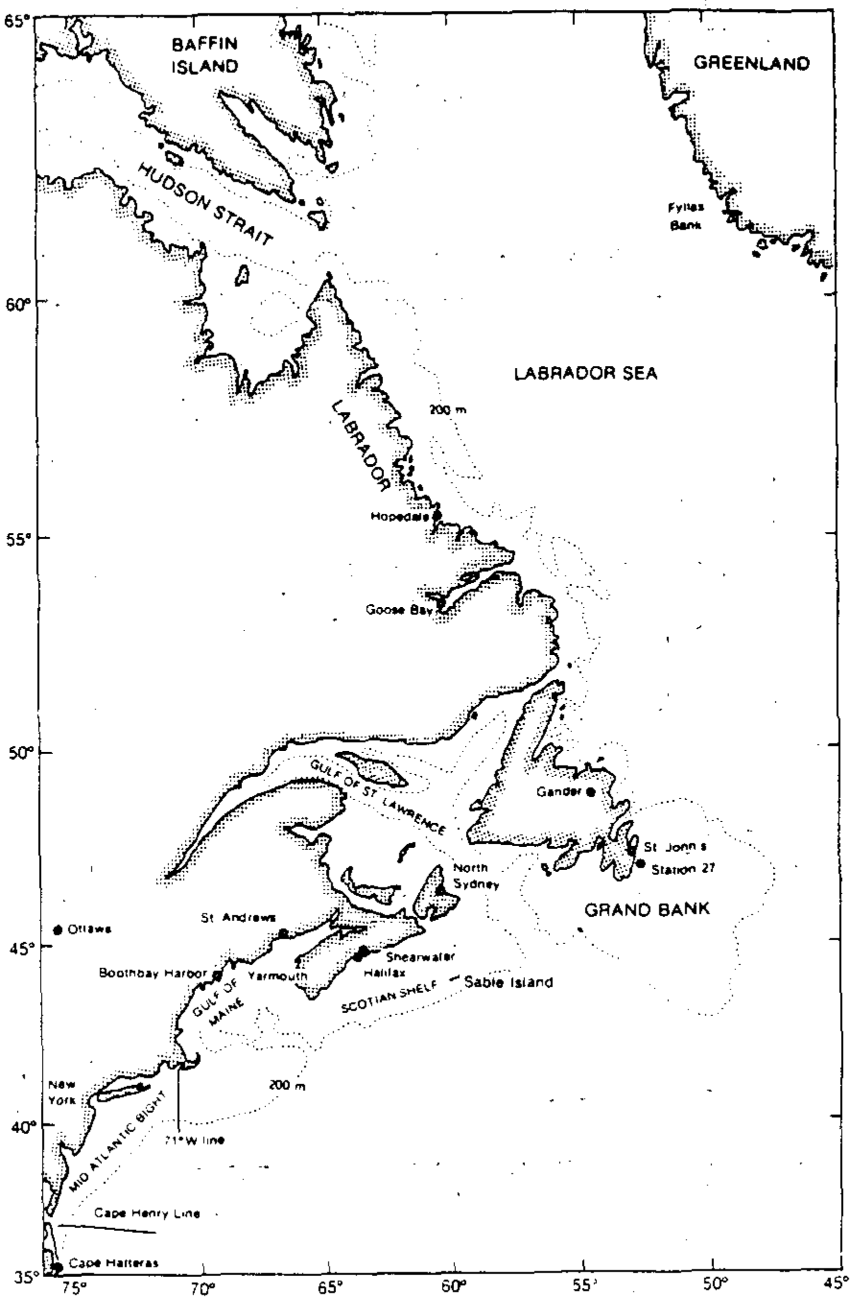


Fig. 1. Map of Northwest Atlantic showing oceanographic stations and sites.

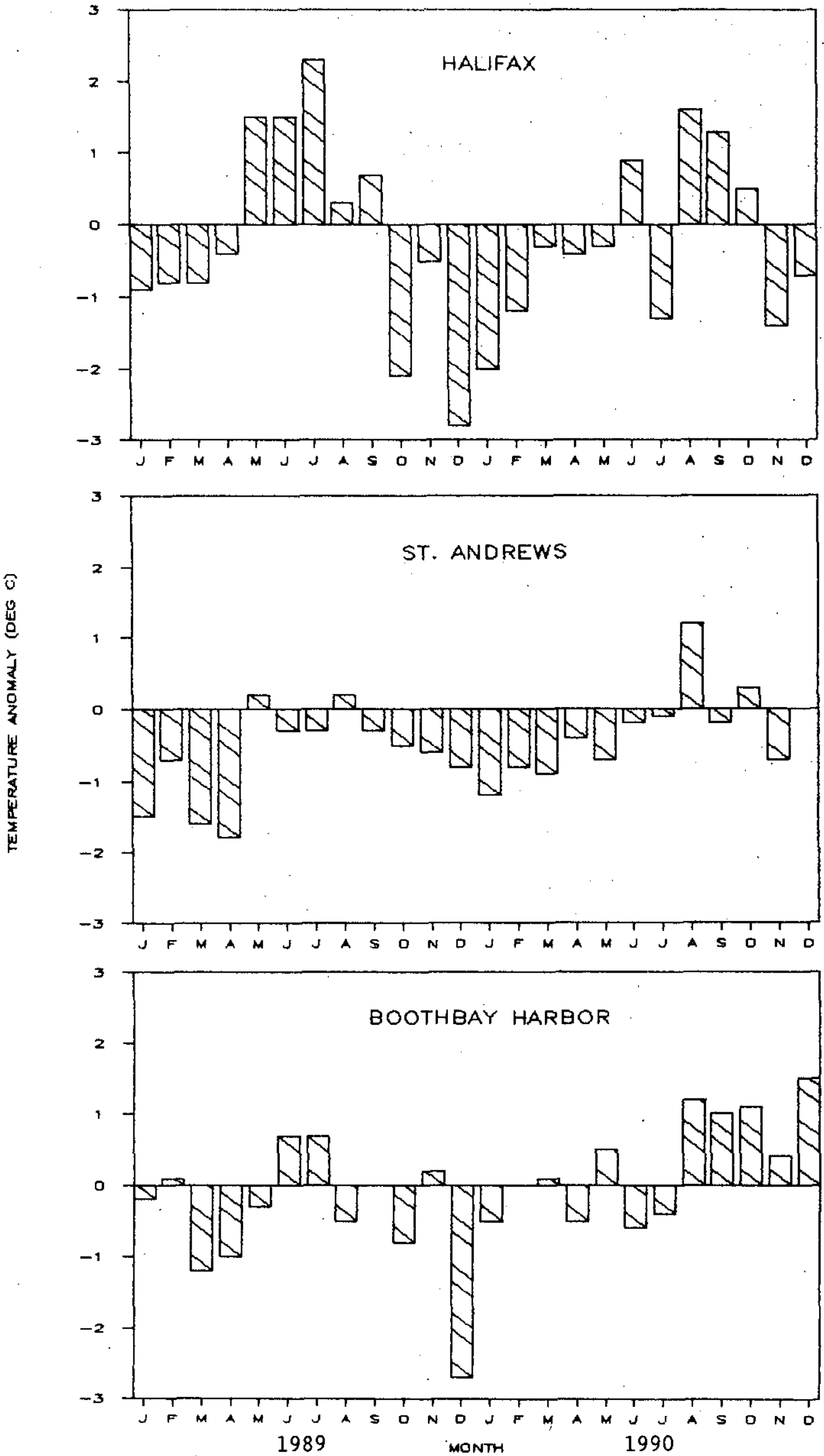


Fig. 2. Monthly sea-surface temperature anomalies at Halifax, St. Andrews and Boothbay Harbor in 1989 and 1990 relative to the 1951-80 means. (Solid squares indicate months when the anomalies equaled or exceeded one standard deviation.)

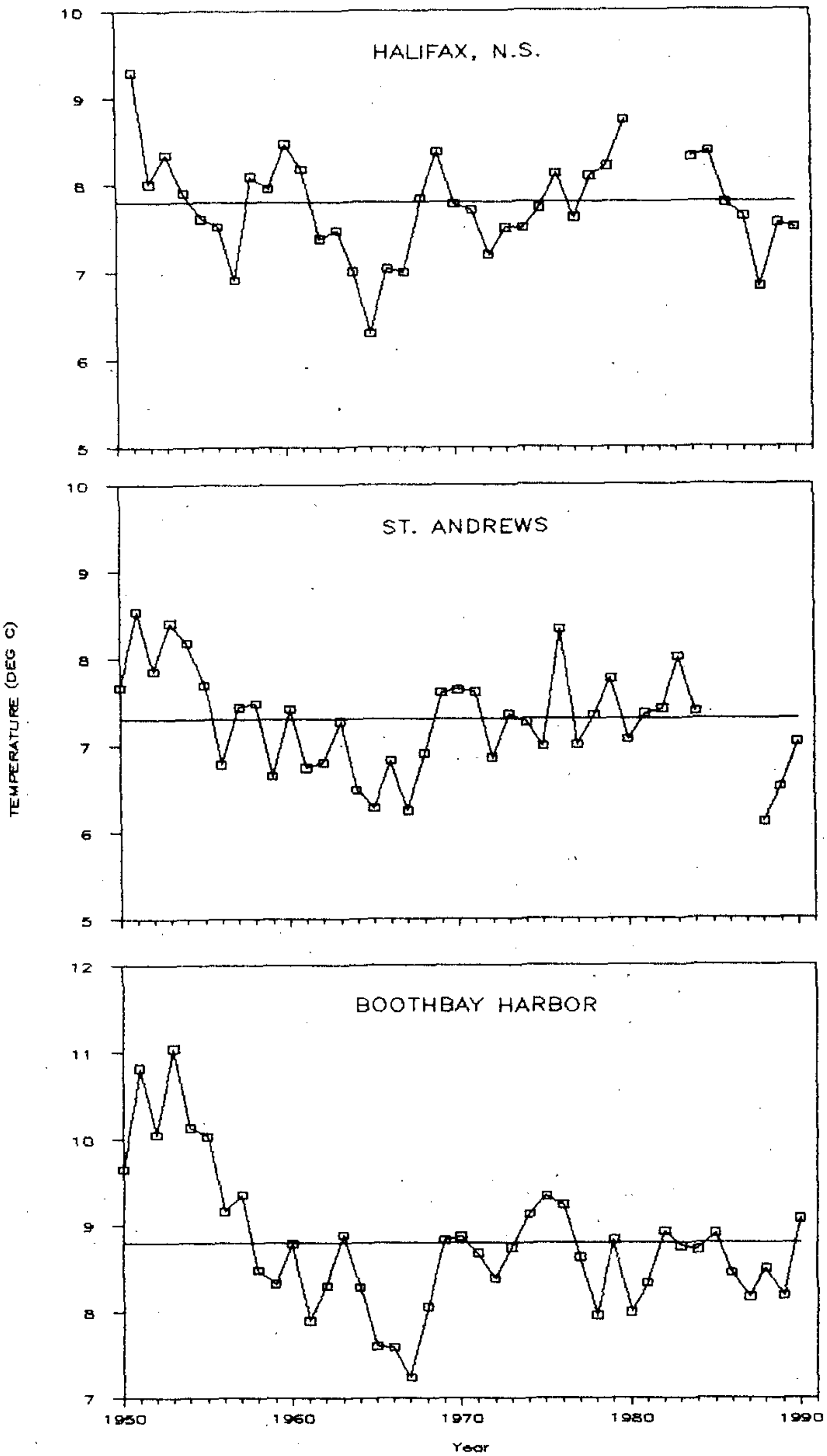


Fig. 3. Annual sea-surface temperatures at Halifax, St. Andrews and Boothbay Harbor during 1951-90.

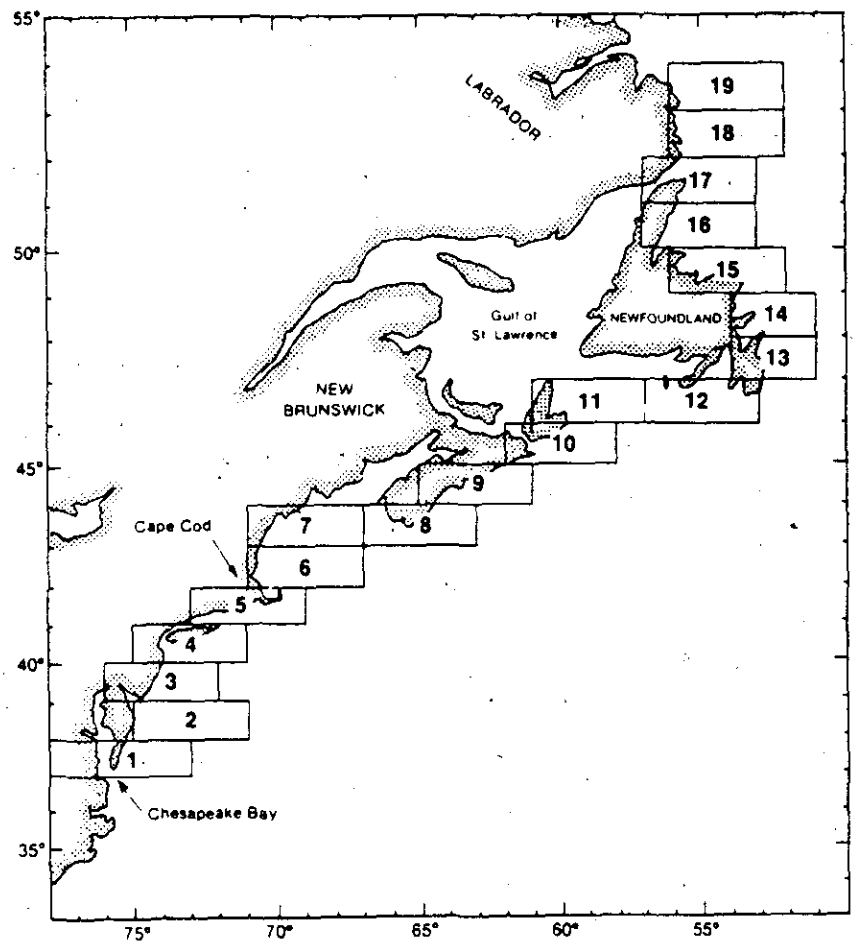


Fig. 4. Locations of 19 areas in the Northwest Atlantic (Chesapeake Bay to southern Labrador) for which sea-surface temperature data were grouped for analysis.

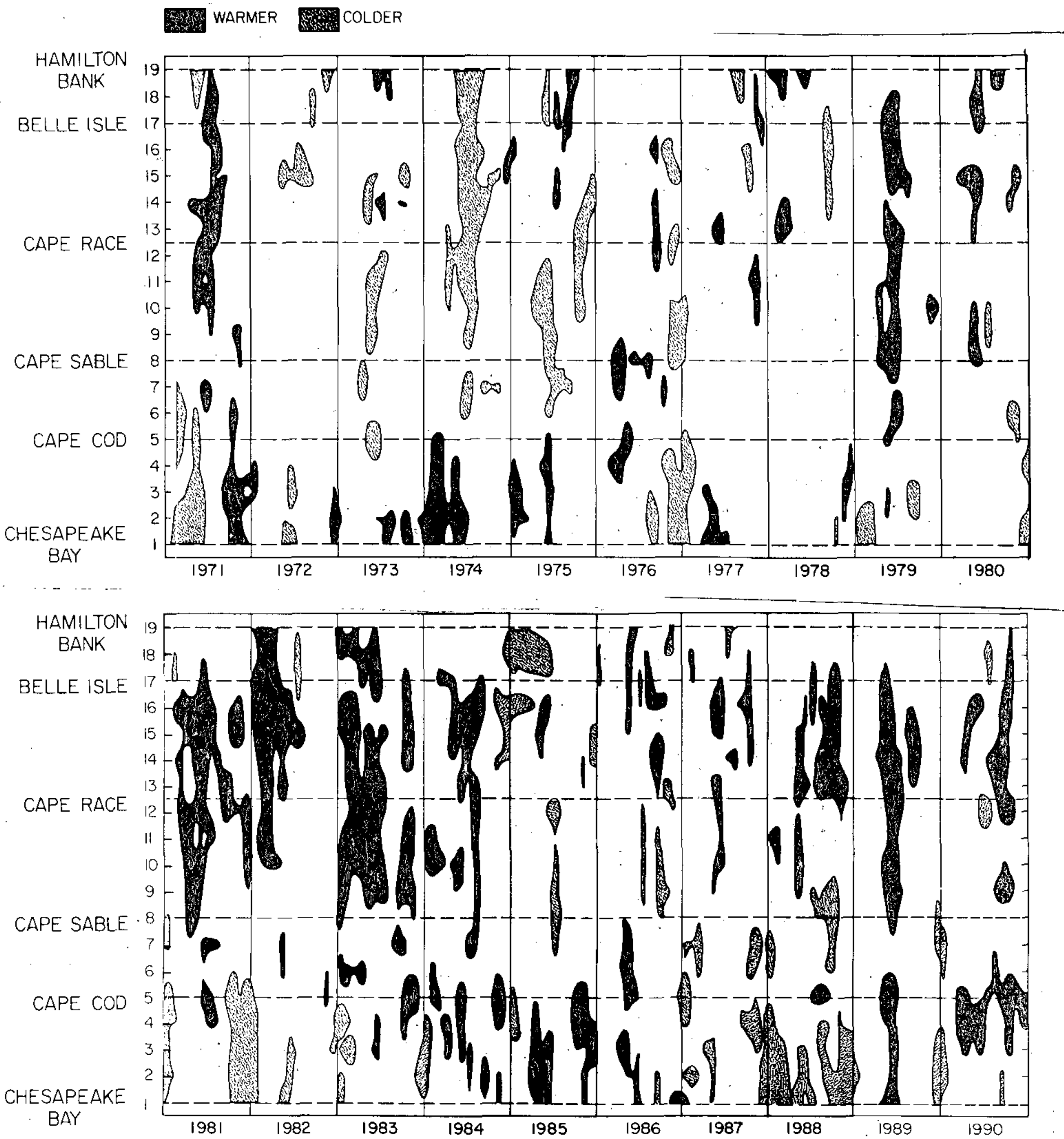


Fig. 5. Contoured monthly sea-surface temperature anomalies (relative to the 1971-80 means) for the 1971-90 period by area (Fig. 4). (Only anomalies exceeding 1°C (black) and less than -1°C (dotted) which extended in space through at least two neighbouring areas and in time for at least two consecutive months have been contoured.)

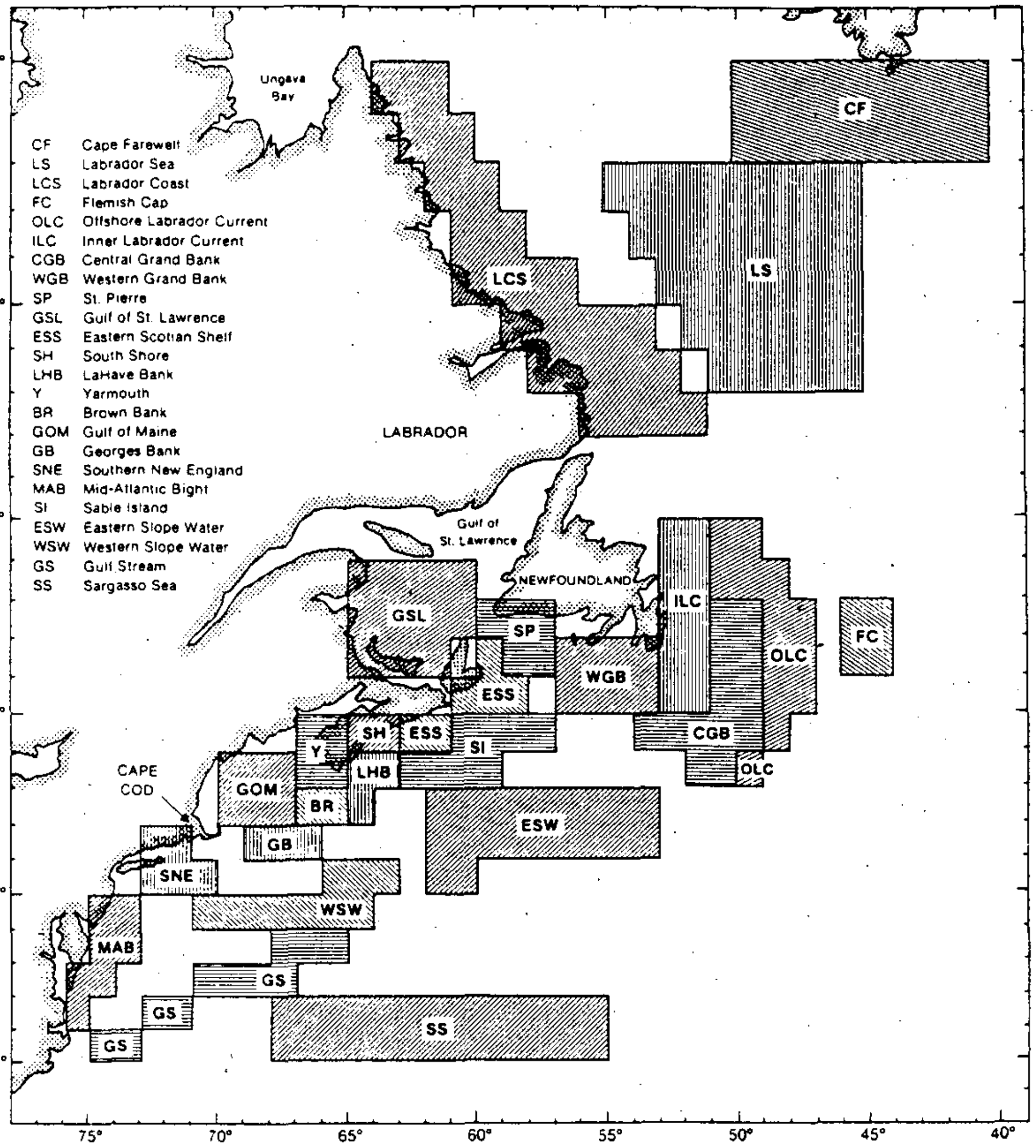


Fig. 6. Geographic boundaries of 24 subregions (Cape Hatteras to Cape Farewell) for which sea-surface temperatures were analyzed on a monthly basis.

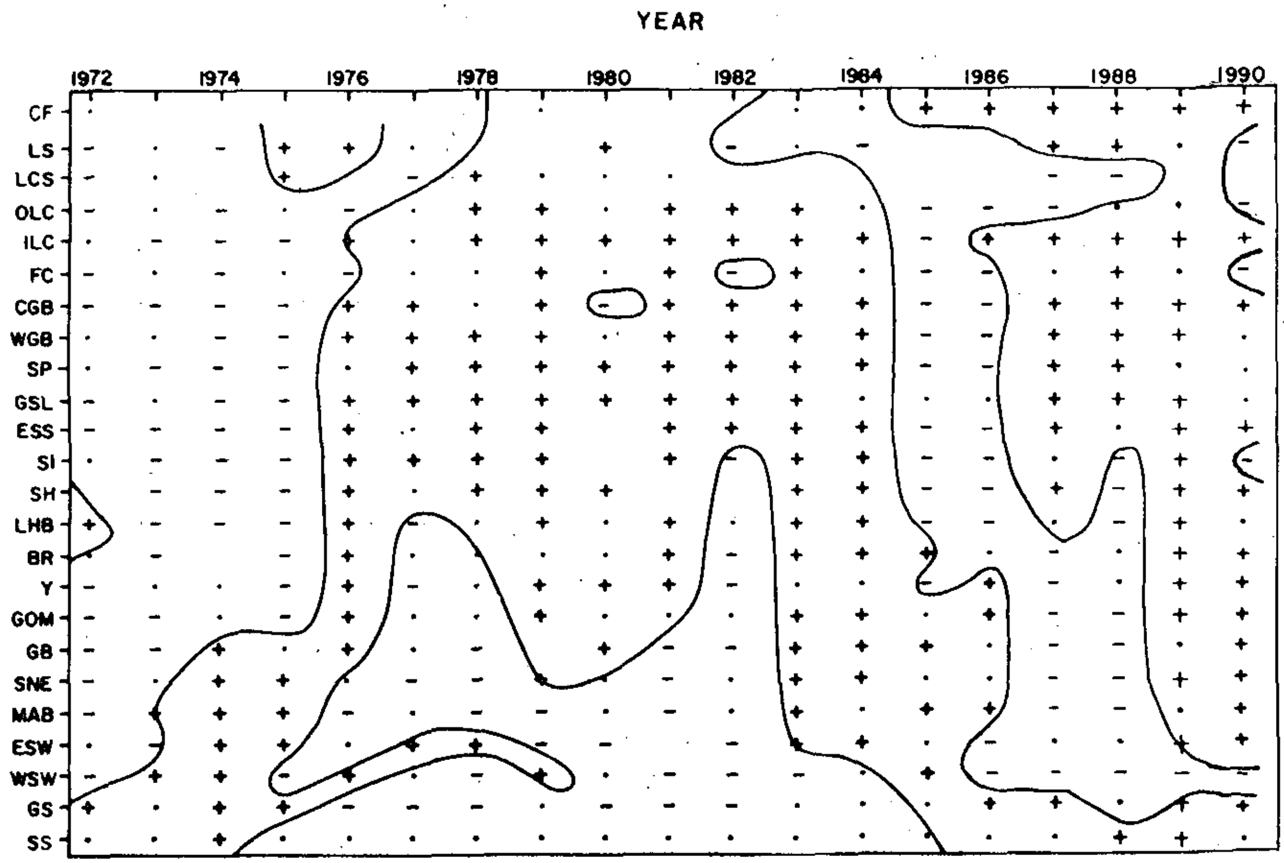


Fig. 7. Distribution of positive (+) and negative (-) annual sea-surface temperature anomalies in 1972-90 by subregion (Fig. 6) relative to the 1972-80 means. (Only anomalies less than -0.15°C and greater than +0.15°C were used in drawing the contours.)

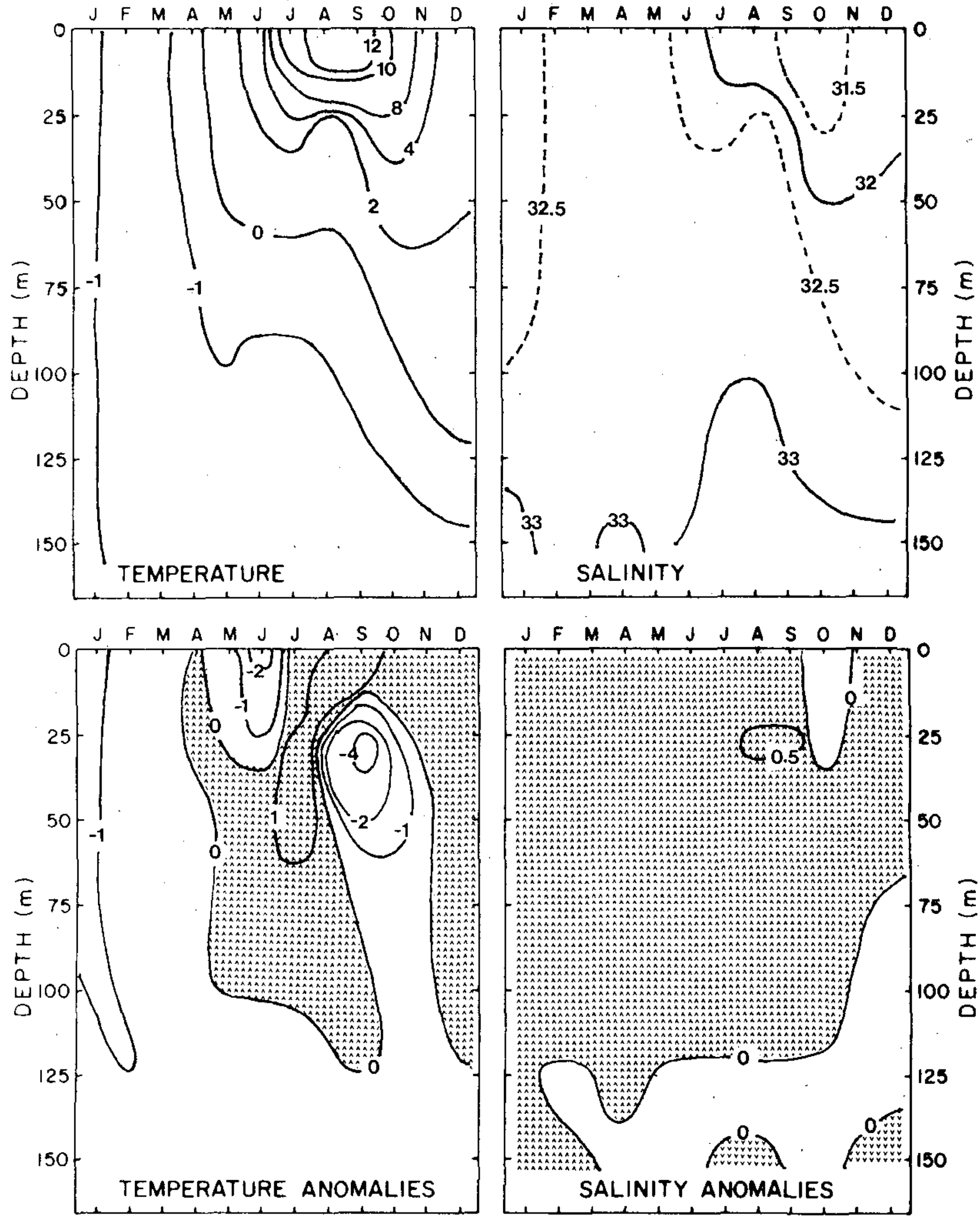


Fig. 8. Monthly temperature and salinity values and anomalies at Station 27 off St. John's during 1990. Anomalies are relative to the 1946-77 means (Keeley, 1981). (Shaded areas represent positive anomalies)

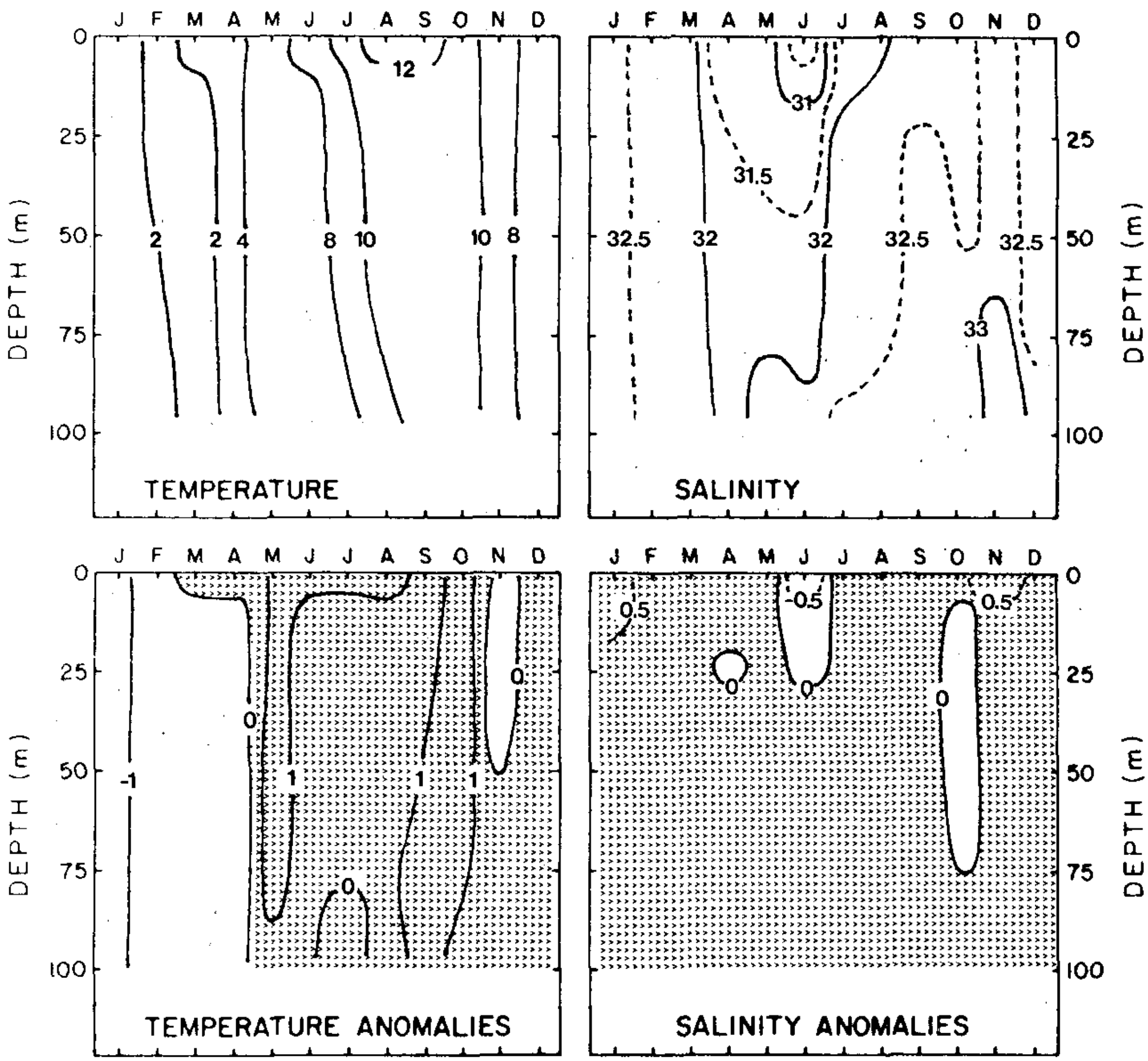


Fig. 9. Monthly temperature and salinity values and anomalies at Prince 5 near the entrance to the Bay of Fundy during 1990 relative to the 1951-80 means (shaded areas represent positive anomalies).

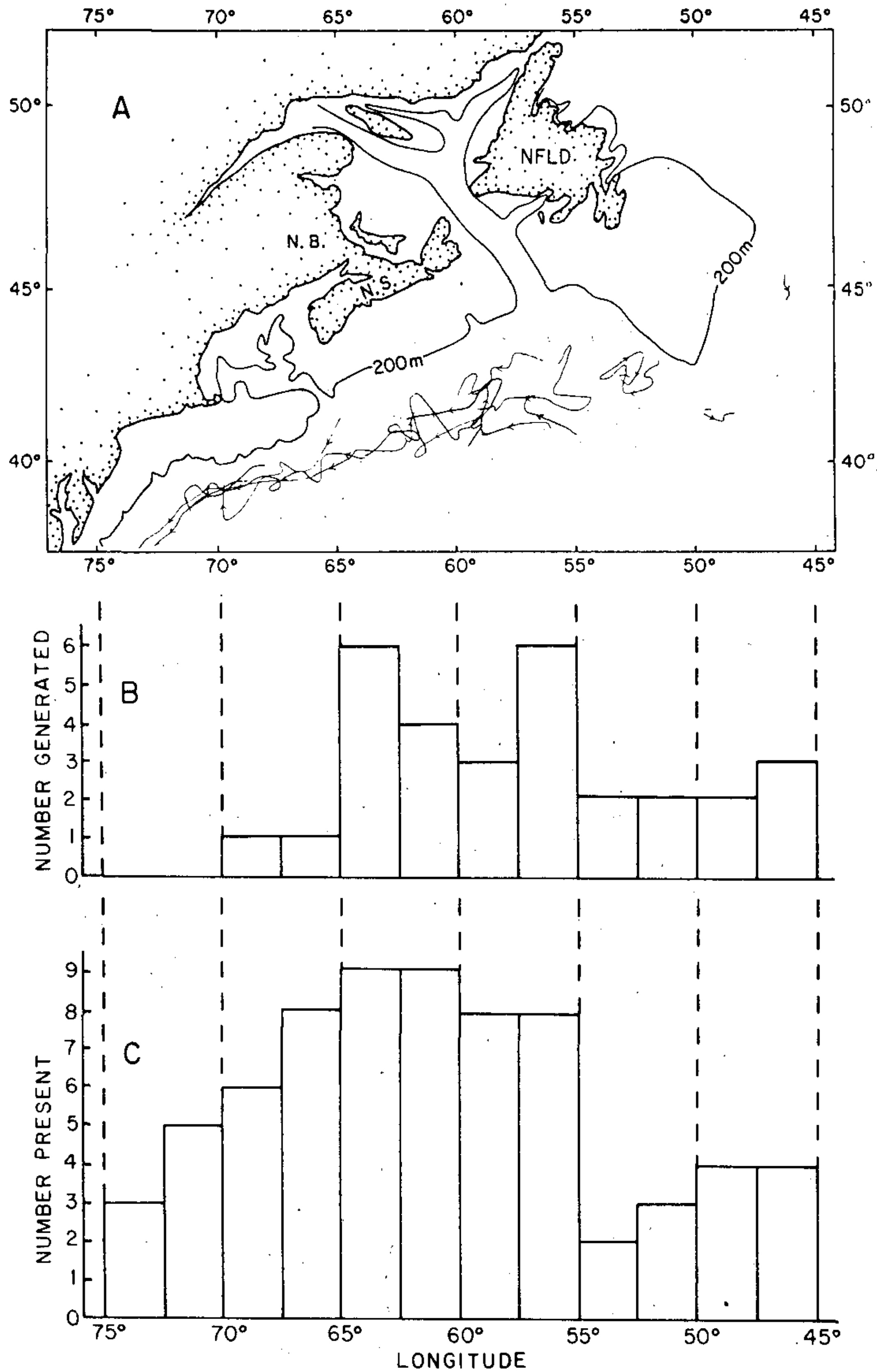


Fig. 10. Warm-core Gulf Stream rings in the region between 45°W and 75°W during 1990: (**A**) tracks of rings with a lifespan longer than 2 months; (B) number of rings generated in each 2.5° zone of longitude; and (C) number of rings present in each 2.5° zone during some part of the year.

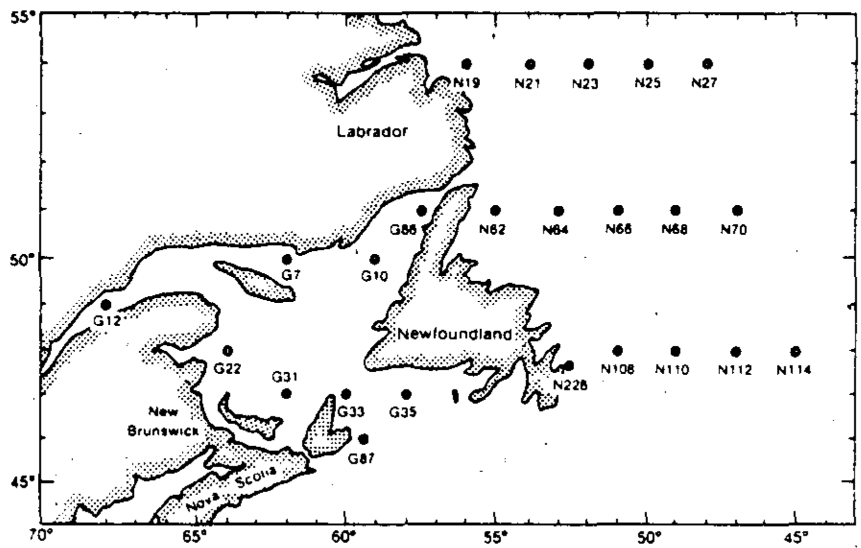


Fig. 11. Locations of 24 grid points in the Northwest Atlantic where ice statistics have been extracted from ice charts.

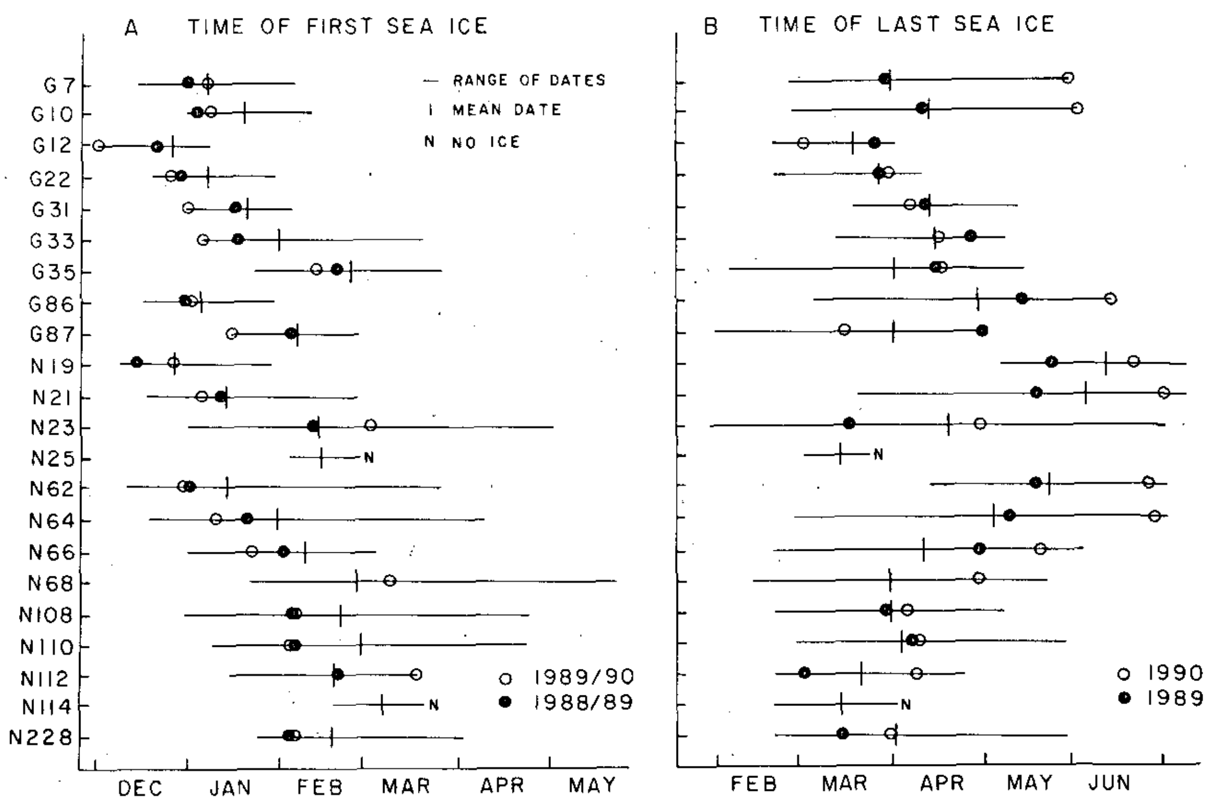


Fig. 12. Ranges of dates for the presence of first sea-ice **(A)** and last sea-ice **(B)** at 22 sites in the Northwest Atlantic (Fig. 11) with mean dates and the 1989 and 1990 dates. (Ice has never been observed at N27 and N70).

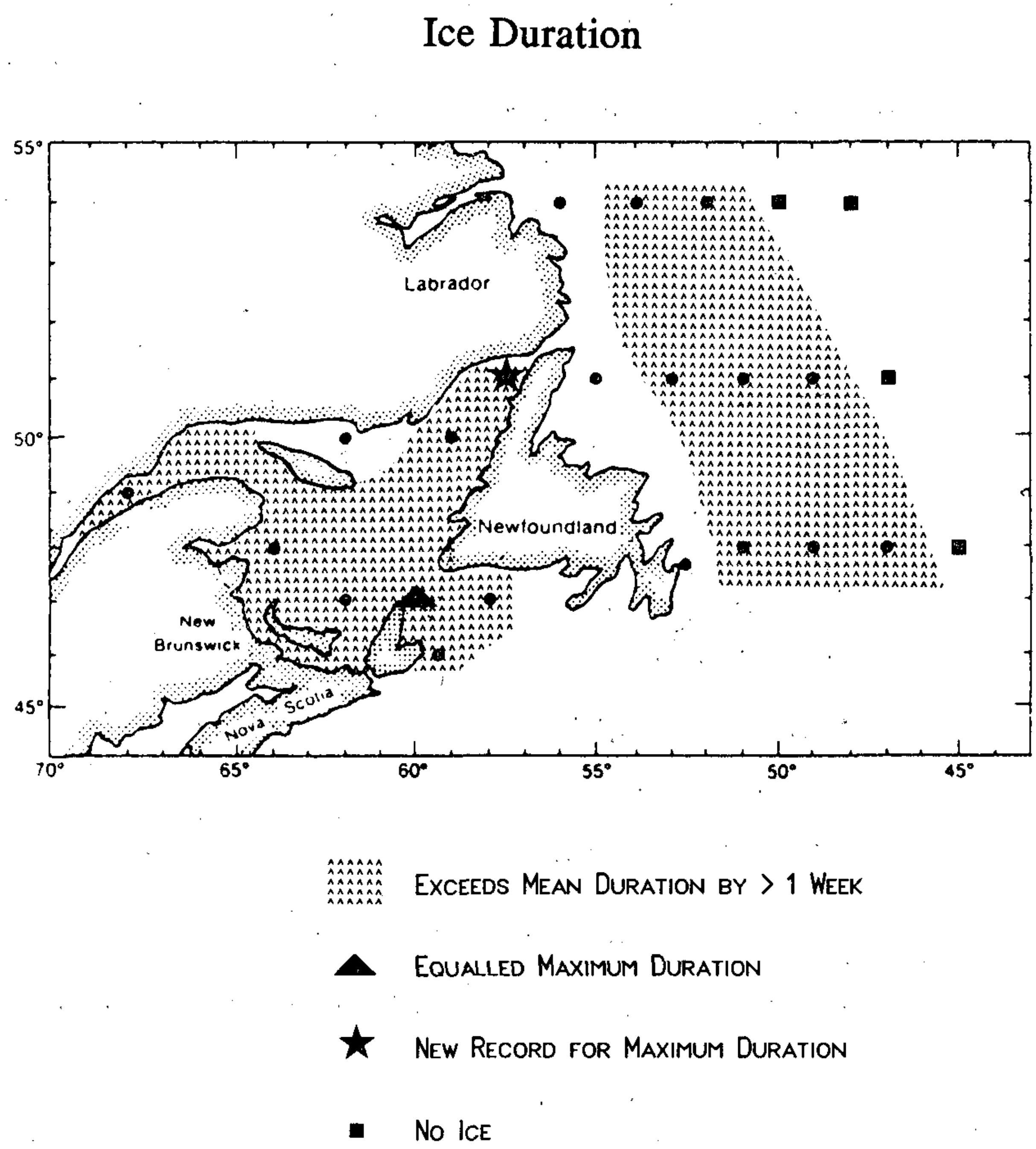
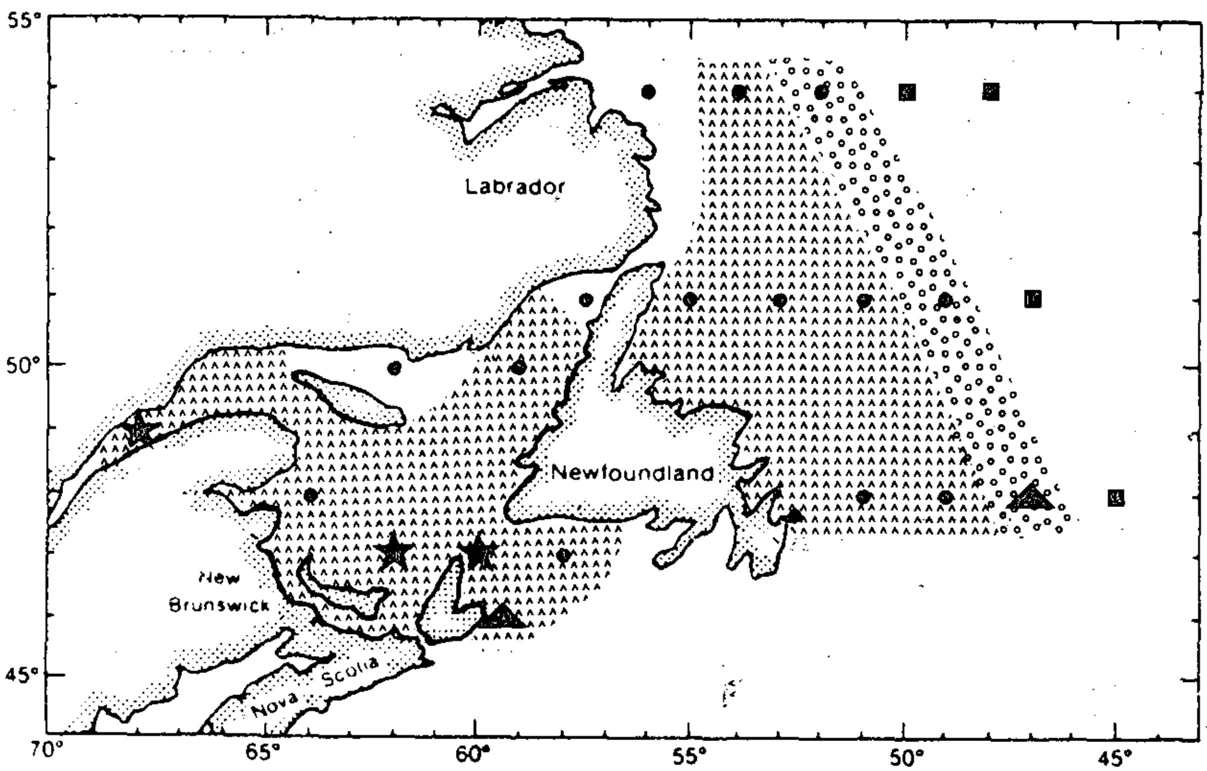


Fig. 13. Duration of ice at grid points shown in figure 11. Circles not surrounded by shading indicate sites were the ice duration was near average (within ± 1 week).

Presence of First Ice



EARLY ADVANCE (PRECEEDS MEAN DATE BY > 1 WEEK)

LATE ADVANCE (LATER THAN MEAN DATE BY > 1 WEEK)

NEW RECORD FOR EARLIEST DATE OF FIRST APPEARANCE

EQUALLED PREVIOUS RECORD

NO ICE

Fig. 14A. The presence of first ice at the grid points shown in figure 11. Circles not surrounded by shading indicate sites where the ice advance was within 1 week of their mean dates.

Presence of Last Ice

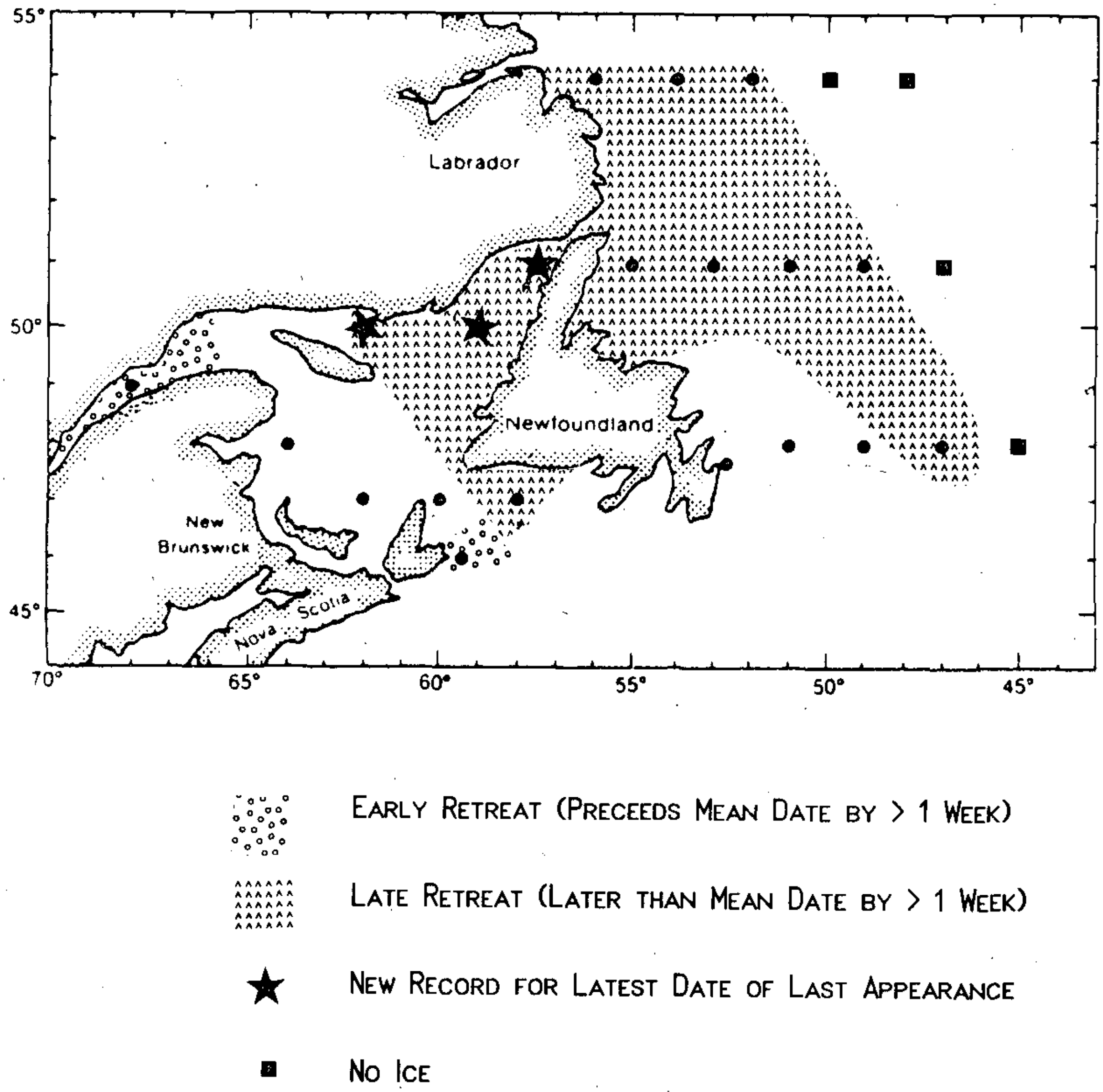


Fig. 14B. The presence of last ice at the grid points shown in figure 11. Circles not surrounded by shading indicate sites where the ice retreat was within 1 week of their mean dates.

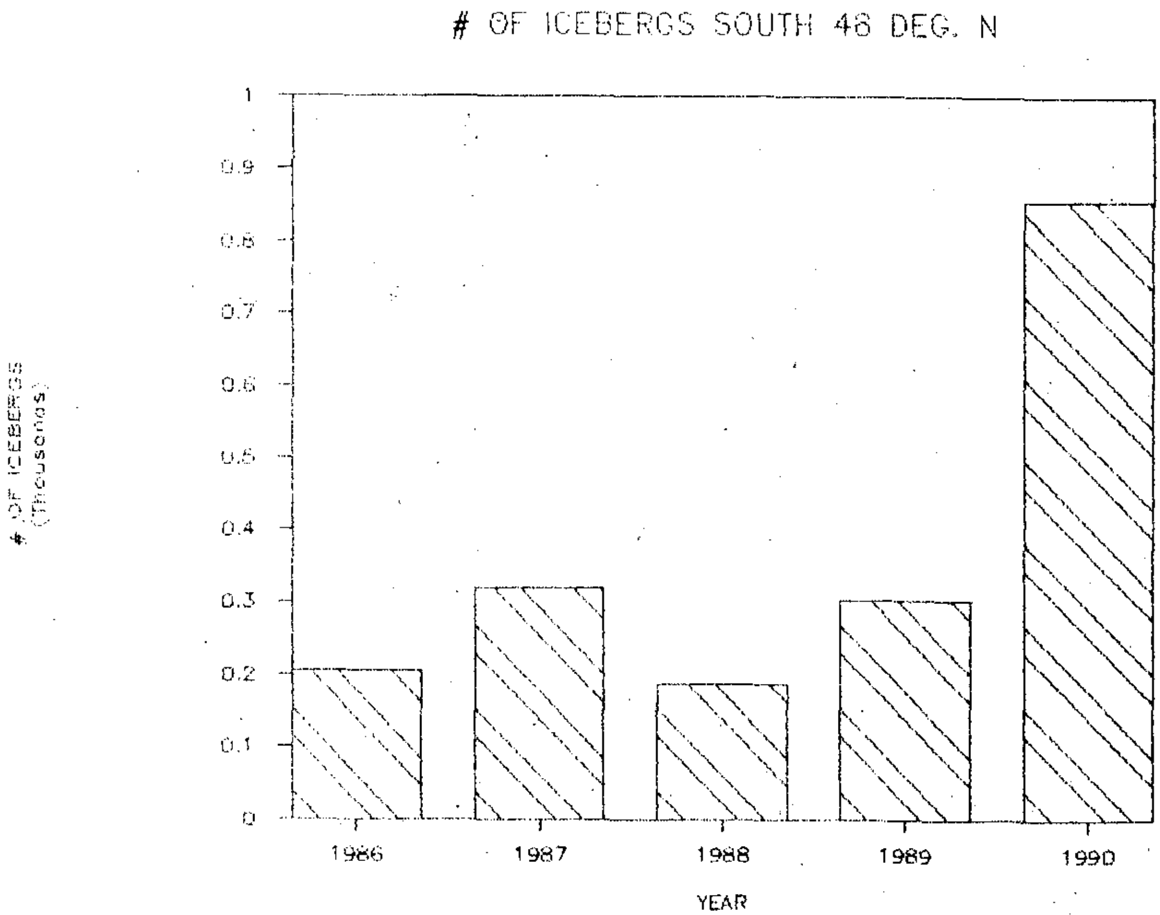


Fig. 15. The number of icebergs crossing 48°N during the last five iceberg seasons, October to September. Year 1986 refers to October 1985 to September of 1986.

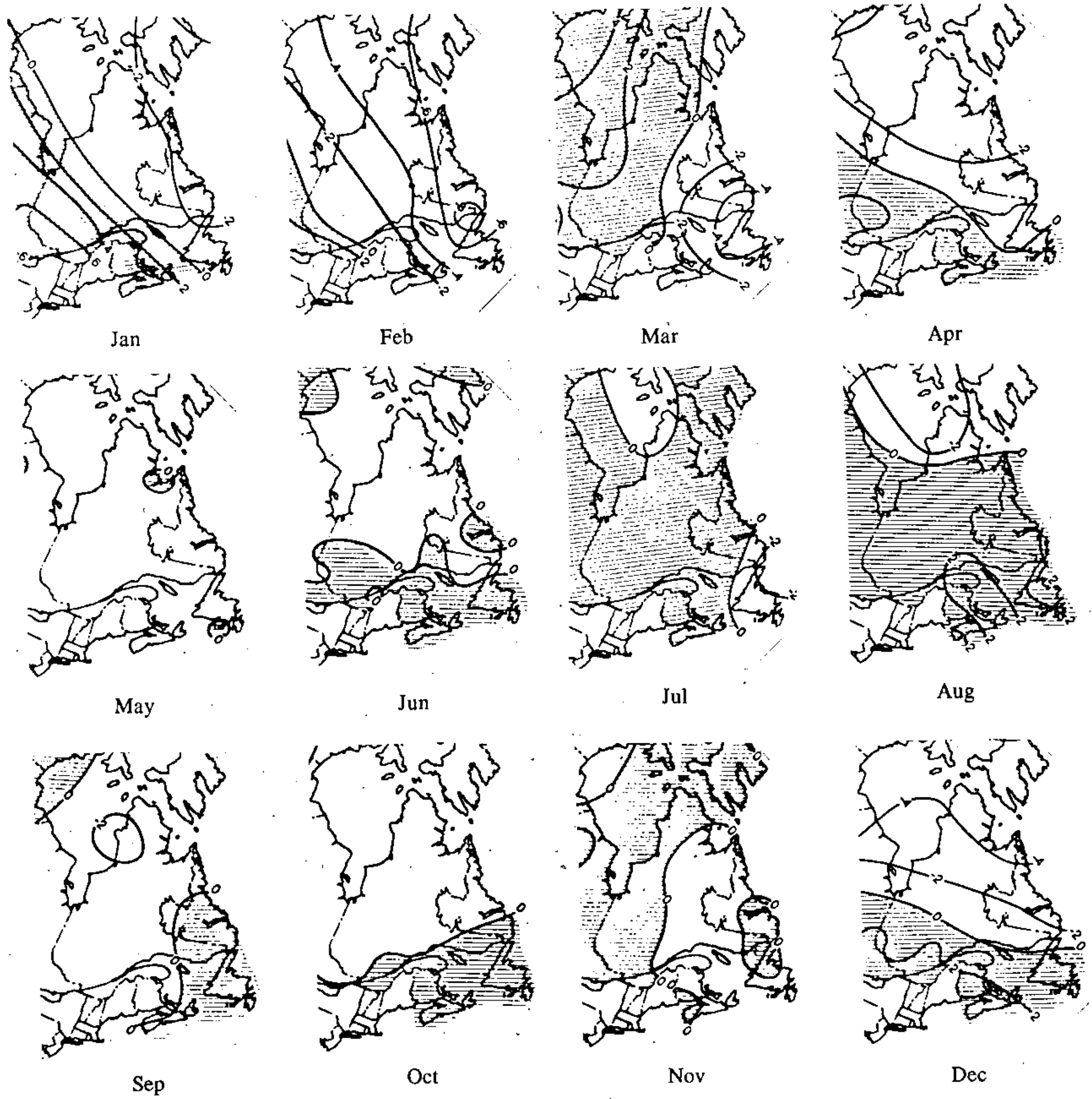


Fig. 16. Monthly air temperature anomalies ($^{\circ}C$) over eastern Canada in 1990 relative to the 1951-80 means. (Positive anomalies are shaded.)

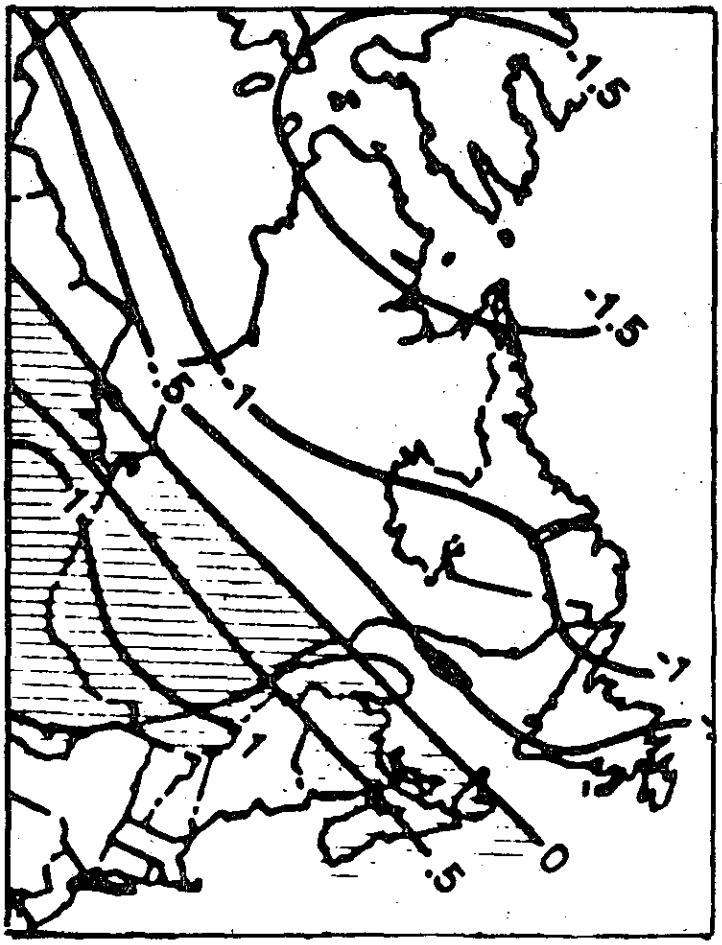


Fig. 17. Annual air temperature anomalies (°C) over eastern Canada in 1990 relative to the 1951-80 means. (Positive anomalies are shaded.)

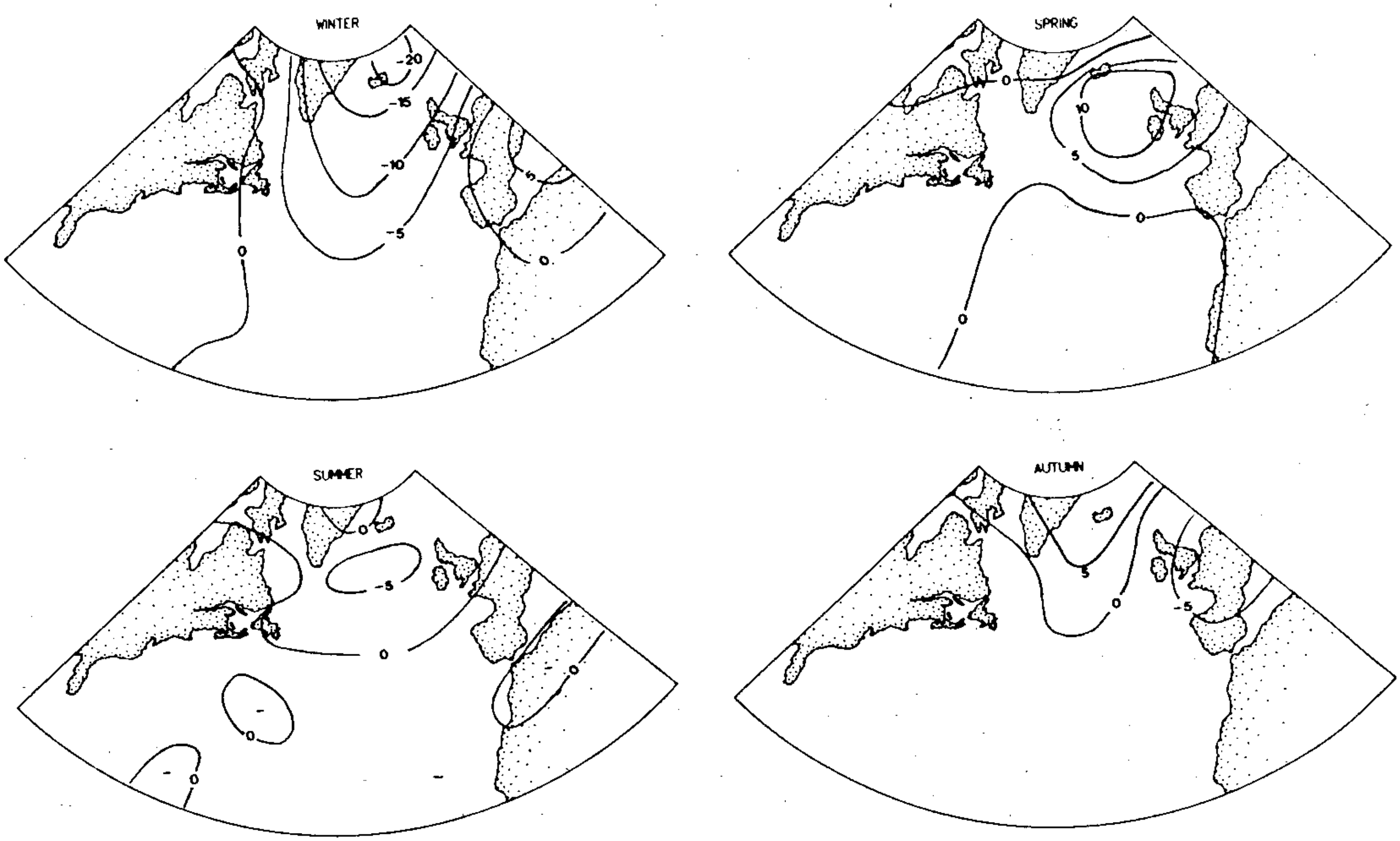


Fig. 18. Seasonal sea-surface air-pressure anomalies (mb) over the North Atlantic in 1990 relative to the 1951-80 means.