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Overview of Oceanographic Conditions within NAFO Subareas 2, 3, and 4 for the 1970-79 Decade

by

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ENVIRONMENTAL SYMPOSIUM, 1970-79

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I. INTRODUCTION

Responding to the request to prepare an oceanographic overview for NAFO Subareas 2, 3, and 4 for the 1970-79 decade infers that one should consider all time scales of from something like one month to 10 years (and longer) and space scales from 10 to 2000 kilometers (and longer). Within this space and time frame the reader might reasonably expect to learn how the 1970's were, compared to the 1960's and to the longer term. Were they average, colder, or warmer than "normal"? Did the winters get warmer and the summers cooler, or the reverse? Was it saltier or fresher? Did the whole area respond similarly, or did each sub-area (and smaller) behave differently? etc. etc. In other words, the task is to provide a summary of climate based on the oceanographic "weather" observed during the decade. Additionally there is no doubt an expectation that one should extend a little beyond this statistical type presentation and attempt to provide plausible explanations of what physical processes may have been mainly responsible for producing the observed conditions.

In attempting to develop a picture of oceanographic conditions over the Continental Shelf and Slope regions between Hudson Strait and Georges Bank, one should keep in mind the various physical processes and driving forces important in determining conditions in any given area. Freshwater input from the rivers, from precipitation, and from melting ice markedly lowers the salinity of the surface layer and affects stratification, transport and mixing processes throughout most of the area under consideration. Local heating and cooling, and other meteorological driving forces result in an easily recognizable seasonal cycle in the upper layers throughout most of the region, but often produce wide variations within an area and on time scales of days rather than months. The invasion of warmer and higher salinity water onto the Continental Shelf and extraction of coastal waters through offshore forcing from the Gulf Stream System produce dramatic effects on a time scale of days to weeks. Vertical and lateral mixing brought about by tidal currents, waves and swell will be a dominant oceanographic feature in some areas. It is not intended to focus specifically on all of these factors, but rather to ensure that they are not overlooked when considering the physical oceanography of the subareas within the region.

To develop a systematic overview of such a large and complex area, with a specific objective of describing the 1970's in relation to "normal" or some previous or longer-term period requires extensive data bases. The accuracy of such descriptions is dependent on the time and space data density. Invariably, one discovers that oceanographic data bases are spotty and inadequate to describe conditions in detail. One must recognize therefore that climatic descriptions will be limited in extent and accuracy.

This paper attempts to develop an overview through two approaches. Firstly, a summary will be given on a subarea basis of oceanographic conditions as reported in the literature. Sufficient time was not available to digest all available documentation, and hence important and relevant papers have undoubtedly been overlooked. Secondly, an attempt will be made to do further analyses of some of the available data bases judged to have sufficient data to provide useful descriptions and hopefully some insights into a few of the possible teleconnections that may be operative within the NAFO area.

II General Features of Area Being Reviewed

In describing general features, the mean circulation is commonly considered to be of major importance in many applications. In spite of this, there is a paucity of direct measurements, and for most areas, patterns have been inferred from temperature and salinity measurements and computed geostrophic currents. From the literature one can find a number of maps showing the mean surface currents in the Northwest Atlantic. (e.g. Sverdrup et al. 1942, Hachey 1961, Leim and Scott 1966, Kudlo et al, 1980, Akenhead et al. 1981).

Most of these composite maps show similarities in the major features although often differing in some of the details. Shown in Fig. 2 is the general surface circulation pattern as given by Sutcliffe et al. (1976). However an important point to remember is that currents at any given time are seldom "average", and a much more noteworthy feature is their variability. For example, surface currents over parts of the Scotian Shelf may be southwestward at 2-5 miles per day when averaged over a year, but may be northeastward at 5-10 miles per day for a given month or offshore at 10-15 miles per day for a given week. Current maps expressed in probabilistic terms will provide a more realistic picture of conditions.

NAFO subareas 2, 3, and 4 all display marked surface layer dilution from freshwater inflow. The input enters the area primarily from the Gulf of St. Lawrence, Hudson Strait, and Davis Strait. Proportionally, more of the input is in the form of ice in the more northern areas. Recent calculations of a world water balance (Baumgartner and Reichel, 1975) provide some useful comparative estimates for the Atlantic coast of North America. They estimated that of the total river inflow between 30-90°N, 53% occurs between 45-55°N. The percentages drop dramatically both to the north and to the south of this zone. Sutcliffe et al. (1976) pointed out that the annual freshwater discharge of the St. Lawrence system alone is greater than the sum of the entire freshwater discharge of the Atlantic Coast of the United States between Canada and Southern Florida. The scale and pattern of influence of freshwater input is illustrated in Figure 2, which shows the mean location of the 32.5 and 34.0°/oo salinity isopleths at 30 M depth (from Worthington, 1976).

The annual cycle of heating and cooling and fresh water input produces a broadly similar structure and pattern of temperature and salinity at any given point throughout much of the area. The general characteristics can be illustrated with data from Station 27, off St. John's, Newfoundland (Fig. 1), which has been occupied generally between 20-30 times per year over the past 30 years. Keeley (1981a) has summarized this data and the average yearly temperature and salinity over depth and time is shown in Figure 3. The annual cycle of heating and cooling is a dominant feature with a distinct surface layer some 30-40 M in thickness developing in May. As heating continues the mixed surface layer decreases in thickness extending only to a depth of about 10 M in August when the maximum temperature for the year is attained on average. Thereafter, the surface layer deepens as cooling progresses becoming nearly isothermal over most of the water columns by late January, with temperatures dropping below 0°C throughout most of the column. Maximum temperature occurs progressively later with depth varying from August at the surface to late January at 190 M. Salinity also shows an annual cycle, but is not congruent with the temperature pattern. A prinicapl difference is the time of occurrence of the minimum salinity. Salinity at the surface varies from a minimum in September-October to a maximum in March-April. The time of occurrence of both the minimum and maximum salinity becomes progressively later with depth, being about 5 - 6 months out of phase at 180 M depth.

Examination of oceanographic data over the Continental Shelf in the 40-

50°N latitude and 50-70°W longitude reveals a generally similar pattern to that at Station 27 although the absolute values and times of occurrence of maxima and minima may vary appreciably. This is particularly true for the salinity minima which arises from the spring melting of Ice and river freshets. The timing of this minimum thus varies widely and may occur at anytime over the year depending on location with respect to the freshwater source.

Of interest as well is the year-to-year variability at any given site. An indication of the magnitude and character of this variability can be seen by comparing a particular year to the mean. In Figure 4, the temperature and salinity pattern for 1966 at Station 27 is shown. In the surface layer one notes that the maximum temperature was about 1°C lower than the mean (Fig. 3) and occurred about 1 month earlier. Note as well, that while water of less than -1°C is normally present at depth from February to November, it was not present at all in 1966. Salinity in 1966 was above the mean at all depths and months except for December. The timing of the surface layer minimum salinity also occurred about 1 month later than the mean.

Another way of viewing the year to year variability in temperature and salinity is shown in Figure 5 which is a plot of the temperature and salinity anomalies at the surface and 150 M for Station 27 for the period 1960-78 relative to the period 1946-77. A number of points should be noted: the records are generally "noisy"; there are periods (from 1-3 years duration) where the temperature is consistently above or below the mean; at periods less than a year there is little correlation between temperature anomalies at the surface and 150 M; for periods less than a year there is little correlation between anomalies of salinity at the surface and 150 M or between anomalies of salinity and temperature at corresponding depths. Smoothing the records by averaging over 3 or more years to reveal longer term trends would probably show some general similarities.

III Review by Regions

1. Labrador Shelf and Sea

Lazier (1981) has analyzed existing data in the Marine Environmental Data Service (MEDS) files for both on and off the Labrador Shelf. From T-S analyses he found that the entire shelf area between 52 and 60°N bore a very close T-S relationship. By lumping together the entire shelf area and using all available data between 1928-78 he developed a picture of the annual cycle of temperature and salinity in the upper 200 M of the water column (Fig. 6). The general pattern is similar to that at Station 27 although the timing and ranges are significantly different. The maximum surface temperature is less than 7° (compared to greater than 12 at Stn 27). Salinity on the other hand shows wider variability ranging both lower and higher than at Station 27. The time of the surface minimum salinity occurs in July-August, - about two months earlier than at Station 27.

In order to look at between-year variations for the period 1950-79, Lazier (1981) analyzed the July temperature and salinity data for the shelf and offshore area, and computed a mean for the top 100 M of water column (Fig. 7). There is no obvious relationship in the year-to-year variation between the shelf and offshore areas. There is, however, some correspondence between temperature and salinity in the offshore region. The downward trend in temperature in the 1966-72 period corresponds to a period of declining salinities as well. These trends also show very strikingly at Station Bravo for salinity (Lazier, 1980), for the period 1967-71 in the top 100 m (Fig. 8). Temperatures at 200 M depth (and presumably above this as well) show a downward trend in the 1967-72 period. Lazier notes that the presence of lower salinity water in the 1967-71 period coincided with relatively mild winters which tended to limit winter convective overturn to about 200 M. Lazier concludes that one of the more probable causes of the changes observed in the Labrador Sea was related to the meteorological conditions over the North Atlantic and Arctic Oceans during the 1960's. It was suggested that an anomalously high pressure cell which existed over Greenland between the early 1950's and the late 1960's (Dickson et al. 1975, Dickson and Lamb, 1972) increased the cold-fresh component of the East Greenland Current which in turn increased the salinity stratification and hence the stability in the Labrador Sea.

Borovkov (1981) and Stein (1981) have discussed autumn oceanographic conditions along or near the Seal Island section. Borovkov found that maximum negative anomalies in temperature (-2.48°C) and salinity (-0.87°/oo) occurred in 1972 in the surface layer over and seaward of the shelf-slope break. Maximum positive anomalies in temperature (3.08°C) and salinity (1.08°/oo) occurred in 1977 inshore near bottom. Temperature anomalies over the top 200 M for USSR Standard Section 8A (Near Seal Island Section) for the 1970-79 period were tabulated by Burmakin (1980). These have been plotted for comparison with the anomaly plots of temperature averaged over the top 50 M for each station along the Seal Island Section (Stein, 1981) and are shown in Fig. 9. As can be seen there is generally good agreement between these two data sets, which show temperatures dropping to a low for the decade in 1972-73 and a high in 1977-78. These results are consistent with those reported by Lazier (1981) for mean July temperatures averaged over the top 100 M, for the offshore area (Fig. 7). Interestingly, Lazier's data do not show the same results for the Shelf area. It appears that the phenomenon may have been more widespread in autumn than in summer, as Stein's data show both the Shelf and Offshore area behaving in a broadly similar way. Temperature and salinity anomaly plots for the 1970-79 period for available data in MEDS Nansen file were computed and plotted by MEDS for selected stations in the Seal Island line. Figures 10 and 11 show respectively for Stations 3 and 8 the potential temperature anomaly (upper diagram) and salinity anomaly (lower diagram) of the 1970's compared to the long term. These figures show the anomalously low temperatures and salinities in the offshore area (Station 8) in the 1971-73 period as discussed previously. The inshore area, as represented by Station 3, shows below normal temperatures for 1972 only, with salinities near normal. In general the inshore and offshore anomaly patterns do not bear a lot of similarity to each other. In part this may be real, but the rather scanty data (only about one sample per year) places severe limitations on the degree of pattern reliability.

Over the past 4 years, the Bedford Institute of Oceanography, as part of its studies in the Labrador Sea and Shelf, has moored current meters at a number of locations, (e.g. Lazier 1979, 1981). One of the longest records available is from Stn 285 (Fig. 1), at 200 M depth in the trough separating Hamilton Bank from the inshore area. Apart from one short gap in August 1978, a continuous 2-year record commencing in October 1978 was obtained. The along-trough current, salinity, and temperature is shown in Figure 12. In general the patterns were similar for both years. Maximum temperature occurred towards the end of December and early January, followed by near-minimum values in mid-February. This period of declining temperatures was also accompanied by a major drop in salinity and an increase in current speeds as well. Lazier (1981) notes that the rise in temperature in December cannot be produced by local convective cooling but must be brought about by advection of water, probably from offshore. Although the general patterns are repeated each year, the full annual variation in properties typically occur in about 1 month rather than 6. Examination of shorter records along the slope (Lazier, 1979) shows, as might be expected, even higher frequency fluctuations, with more than 5°C and greater than 1°/oo changes occurring in periods of less than 1 day, at 100 M depth. Caution must therefore be exercised when attempting to infer warm or cold years based on infrequent sampling. Borovkov (1981) also has pointed out the aliasing problem particularly in the slope area where there is more horizontal structure. During one 24 hr period in October, 1980, the variability roughly equalled the year-to-year variability.

2. Grand Banks - Flemish Cap

Although there is a paucity of data covering the Grand Banks as a whole, the frequent occupation of Station 27 and the Flemish Cap Section provides a relatively good coverage of temperature and salinity applicable to at least the northern part of the Banks. Much less data is available for the southern and southwestern areas which may at times show markedly different features since offshore forcing from warm-core eddies may produce onshore and offshore excursion.

Keeley (1981 b, c) has analyzed available data in the MEDS data files for the Flemish Cap section. There were a total of 43 years in which stations have been sampled along this section. The earliest is 1910 and the record is continuous from 1948 to 1980, although data are sparce in winter months and from stations east of Flemish Cap. Keeley plotted mean monthly cross-sections of potential temperatures, salinity and potential density anomalies, and has presented a volumetric analysis of Θ-S characteristics. Plots of potential temperature and salinity anomalies for 1970-79 period compared to the long term mean at stations 1, 10, and 16 along the section are shown in figs. 13, 14 and 15 respectively. Station 1 is taken to be indicative of conditions in the Avalon Channel, 10 for the western side of Flemish Pass and 16 for the Flemish Cap.

Looking first at Station 1 data, the most striking thing appears to be the negative temperature anomaly in the upper 50 metres between 1974 and 1977. Care must be taken however not to conclude that this was true for all months of the year, since observations were only made in summer during this period. Similarly, there is a suggestion that summer temperatures in the 1970-73 period were generally above normal in the upper 20 M. In 1979 the station was occupied 6 times during the year and a much more complex pattern is displayed. One must question therefore whether the pattern displayed for the 1970-77 period is reliable. It seems probable that one is not warranted to conclude that the picture for this period gives more than the year-to-year summer anomalies.

Figure 14 shows temperature and salinity anomalies at Station 10 which is located near the core of the Labrador Current. It is noted that this station was occupied more frequently than was station 1. Undoubtedly, this plays a significant role in producing a more complex pattern. This time-section indicates that for the surface layer, temperatures were below normal for about 5 periods in the decade and above normal for 5 periods. The character of the signal begins to take on more of that displayed at Stn 27 (Fig. 5). Examining the various stations in the section sheds some light on the extent to which one is looking at spatial vs temporal variability. For example, the positive anomalies shown in 1975 at station 10 in the top 50 M corresponded to negative anomalies at stations 1, 7, and 16. Since station 10 is in an area of relatively strong currents and gradients, it may be that a small lateral shift in the position of the Labrador Current may have occurred and thus produced the anomaly.

The pattern displayed at station 16 (Fig 15) on Flemish Cap is also oversimplified owing to the fact that data for the 1970-76 period was mainly confined to the warmer months. It does, however, suggest that for this period the summers were generally cooler than normal and accompanied by near or slightly below-normal salinities.

3. Gulf of St. Lawrence

The general features of the Gulf of St. Lawrence have been presented by a number of authors (Hachey, 1961, Trites and Walton 1975, Dickie and Trites 1981). It is convenient to think of the Gulf as a large complex estuary with physical oceanographic features determined by a spectrum of parameters such as fresh water discharge, wind, tides, topography and heat exchange across the surface. Primary communication with the open ocean is through Cabot Strait which on an annual average has a seaward transport on the Cape Breton side of about 0.5 Sverdrups, ranging from a low in June of about 0.2 Sverdrups to a maximum in August of more than 0.7 Sverdrups. (El Sabh, 1977). Seaward transports in Cabot are about 30 times the freshwater discharge into the Gulf.

The role that freshwater plays in determining the oceanographic features both in the Gulf and beyond is yet to be fully clarified. As freshwater enters an estuary it drives an estuarine circulation with an outflow of freshwater in the surface layer and an inflow of salt water in a deeper layer. In a large complex estuary like the Gulf of St. Lawrence the circulation and distribution of properties will depend not only on the fresh water discharge, and the supply of salt water through Cabot and Belle Isle Straits, but upon tidal mixing, bathymetry, and air-sea interactions and exchanges. Neu (1975, 1976) has drawn attention to the changes in seasonal discharge of freshwater into the Gulf brought about by major hydroelectric and river regulation projects, and points to the need for understanding how and to what degree the marine environment is being altered through man-made changes.

The year-to-year monthly variations in freshwater discharge from the St. Lawrence rivers (St. Lawrence, Ottawa and Saguenay rivers combined) are shown in

Fig. 16. While one can see long term changes in discharge for all months trending downward from the early 1950's to the early 1960's and followed by an upward trend in the subsequent 10 year period, the most dramatic changes are seen for the spring months (May - June) in the 1964-74 period. The May discharge was nearly 70% higher in May 1974 compared to that in May 1964.

Sutcliffe et al. (1976) extended earlier correlation work and found a high correlation between freshwater disharge of the St. Lawrence, and subsequent sea surface temperatures at several coastal sites through the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine. They point out, however, that the role played by the St. Lawrence River discharge must be viewed cautiously. It cannot be considered as uniquely determining these fluctuations or indeed of being a major contributor. Correlation analysis does suggest, however, that freshwater inflow is in part influential in determining these sea surface temperature changes.

Trends in sea surface temperature for the Gulf of St. Lawrence, as measured at Entry Island will be reviewed in a later section along with other coastal monitoring stations (See Fig. 22).

4. Scotian Shelf and Slope

During the 1950's and early 60's oceanographic effort on the Scotian Shelf and Slope was focussed in large measure on undertaking monitoring and synoptic kinds of measurements. The development and availability of self recording current, temperature, and conductivity sensors, together with improved mooring technology resulted in a major shift in program emphasis in terms of Canadian effort, with increased attention being given to process-oriented studies.

Sigaev (1978), using temperature and salinity data taken by the USSR in the 1963-73 period, computed geostrophic current patterns over the Scotian Shelf on a seasonal basis. Although he found appreciable within-year variation in pattern, particularly in the location of the cyclonic and anticyclonic gyres (which covered most of the Shelf), a southwestward flow near the coast was indicated for all seasons. Likewise, a southwest flow was generally indicated for the shelf edge.

Examination of data from the most frequently occupied Halifax Section (Mann and Needler, 1967, Drinkwater et al. 1979) identify some of the limitations of the data set, in terms of determining year-to-year variability. Drinkwater et al. (1979) computed mean monthly transports through the section and found transports varying from 0.15 Sverdrups in summer to a maximum of 0.6 Sverdrups in winter. Flow over the inshore third of the Shelf accounted for 75% of the calculated net annual transport. Petrie (personal communication) has pointed out that within about one week one can see up to 80% of the variation in transport which occurs from year to year. Similarly up to 90% variation in mean temperature can occur within about a week. Thus at a sampling rate of 4-6 times per year the data are badly aliased because of the high frequency variability. Thus, taken by itself, quarterly sampling on the Halifax Section appears to show little promise of reliably identifying warm/cold or fresh/salty years.

Major mooring programs on the Shelf Slope and in Northeast Channel are helping to identify some of the more important processes (Petrie, 1975, Petrie and Smith, 1977, Smith et al. 1978, Smith 1978, Ramp and Vermersch 1978, Ramp and Wright, 1979, Smith 1979), and shedding additional light on the role internal tides, shelf waves, Gulf Stream warm core eddies, Slope Water, meteorological forcing, etc., play in determining the oceanographic features of the Continental Shelf and Slope.

The importance of cross-shelf mixing in determining the water-mass characteristics and biological productivity of the Scotian Shelf was demonstrated by Houghton et al. (1978). They found through water-mass analysis that the water at the northeastern end of the Shelf was diluted with Slope Water by 40% as a result of cross-shelf mixing by the time the waters reached the Halifax Section. The observed longshore gradients of temperature, salinity, and nitrate concentrations were consistent with productivity requirements and measured low-frequency eddy fluxes at the edge of the Scotian Shelf.

At any given time, the Slope Water area commonly contains a number of anticyclonic warm core eddies embedded in it. These have been shed by the Gulf Stream between 50 and 70°W longitude. While the infant mortality rate is fairly high, with many being reabsorbed by the Stream within a week or two, others may exist for upwards of a year, moving westward almost to Cape Hatteras before disappearing or being reabsorbed. An indication of the eddy field and general complexity of the Gulf Stream - Slope Water area is shown in Fig. 17. This map, prepared by the National Environmental Satellite Service, employed satellite IR data and sea surface temperature observations from ships of opportunity. At least four warm-core eddies are evident on this map. It should be noted that the westernmost eddy (G-80) was formed in early August 1980 at about 62°W, and was finally reabsorbed by the Gulf Stream east of Cape Hatteras during the last week of July 1981 (Atlantic Environmental Group, N.M.F.S. report, August, 1981) having a life-span of almost exactly one year.

The role played by warm-core eddies in extracting surface waters from the Shelf is clearly indicated in Fig. 18. Eddy G-79 developed in mid September, 1979 and Eddy H-79 a week or so later. These eddies entrained large quantities of water from the Southwestern Scotian Shelf (Fig. 18B). The movement of satellite tracked buoys vouch for the accuracy of interpretation of the surface thermal maps. Similarly, Eddy I-79 was producing a large scale excursion from Georges Bank in late October 1979. (Fig. 18D).

Other examples of offshore forcing and removal of Shelf Waters have been reported by Smith (1979). Current meters moored near the Shelf-break off Southwestern Nova Scotia, in 1977, showed clearly the impact of Eddy Q which formed and moved through the slope area in the July-Sept period. Associated with this was an influx of Slope Water through Northeast Channel and onto Browns Bank.

Such large and rapid off-shelf excursions of surface layer water, undoubtedly will transport the bulk of any plankton and ichthyoplankton contained in it. Synoptic measurements have yet to be taken to determine the proportion of fish eggs or larvae that may be lost from the system through this process. Clearly, however, it is potentially of major importance in the Southwestern Scotian Shelf - Georges Bank area, in any studies of factors responsible for good and bad year classes in the commercial fisheries.

5. Bay of Fundy - Gulf of Maine

The strong tidal currents in the eastern Gulf of Maine, Georges Bank and Bay of Fundy distinguish this region from others within the NAFO area. Not only are tidal currents creating intense mixing which virtually removes vertical stratification in some areas (Garrett et al., 1978) but they may be responsible for major upwelling in the area west and southwest of Nova Scotia (Garrett and Loucks, 1976). Interaction of strong tidal currents with the bathymetry may also result in generation of an appreciable mean circulation around areas such as Georges Bank or Browns Bank (Loder, 1980). In terms of impact on ocean climate, one might also expect to see tidally-induced variations in properties over long time periods. For example, Loder and Garrett (1978) point out that the semi diurnal and diurnal tidal forces are modulated by a few percent over the 18.6 year tidal cycle, and should accordingly produce in some areas a significant cycle in sea surface temperature.

The intense vertical and lateral mixing in the area should produce relatively large areas of nearly homogeneous waters and thus one might expect that monitoring of climatic conditions could be achieved with widely spaced sampling sites. The longest oceanographic records for the Canadian Atlantic Coast are of sea surface temperatures at St. Andrews, N.B., where twice daily readings have been taken since 1921. A summary of monthly temperatures is shown in Fig. 19. In addition to the mean monthly values, the extremes and the year in which they occurred are shown. It is of interest to note that of the 24 extremes, 18 of them occurred in one of three years. For the period from Nov. 1922 to Sept. 1923 nine of the eleven months were record cold ones. Conversely the period from Dec. 1950 to April 1951 was a record warm spell. The period May - Sept., 1976 produced record high temperatures although the months of July, August, September, 1951 were nearly as warm.

To see the long term trends annual mean temperatures for the 1921-80 period, derived from the 12 monthly means, are shown in Figure 20. Compared to the averge for the total period (7.0°C) one sees that from the early 1920's to the mid 1940's temperatures were below normal while from the mid 1940's to about 1960 values were above normal. Subsequently the trends are less clear, although the 1960-69 decade was clearly below normal, whereas the 1970-79 decade was above normal. The records reveal that a rather large year-to-year variation in temperature occurs (up to 1.8°C) which is a sizable fraction of the maximum change (3.1°C) between the coldest year (1923) and the warmest (1951).

Rodewald (1972) in his study of temperature conditions in the north and northwest Atlantic for the decade 1961-70 examined temperature records from Boothbay Harbor, Maine, just beyond the western extremity of NAFO Subarea 4. It is useful to place the decade of the 1970's against the 1950's and 1960's, at least for this site. Compared to the normal (1906-45) the three decades, 1950's, 1960's, and 1970's were all above the long term mean (Fig. 21). On a mean annual basis, the period 1951-60 was 1.83°C above normal, 1961-70, 0.4°C above and 1970-79, 0.96°C above. During all 3 decades the deviation from normal had a pronounced seasonal variation ranging from a maximum positive anomaly in winter to a maximum negative anomaly in summer. Overall, one would describe the 1970's as intermediate between the 1950's and 1960's. Its variation over the year however was much more closely matched to the 1960's than to the 50's. In summary, compared to the 1906-45 period, Boothbay Harbor had warmer winters and cooler summers, suggesting that the climate was more under maritime influences in the past 30 years than in the 1906-45 period.

To gain an appreciation of the geographic scale of these longer-term temperature changes it is useful first to look at air temperatures since the records are longer and available for more sites than are water temperatures. Sutcliffe et al. (1976) showed that there was a close correlation between the 3-year running means of averge annual temperature for Ottawa, Fredericton, Eastport and Sable Island. Similarly Lauzier (1972) showed that there was a good correlation between St. Andrews sea surface temperature and Sable Island air temperatures when running means over several years are used.

To examine further the geographic scale of these year-to-year changes, average annual temperatures are shown in Fig. 22 for St. Andrews, Halifax, Entry Island, and Station 27 (surface and 150 M) Additionally salinity for Station 27 at surface and 150 M is also shown. Although further filtering of the records would make the comparisons easier, it is apparent from examining the annual means that there is a very close similarity in the long term trends at St. Andrews and Halifax. Entry Island also shows considerable similarity. Temperature and salinity variations at Station 27 however appear to bear little relationship to those at the other sites. On the other hand Rodewald (1972) in his study of decadal changes found coherent changes over the entire region, although he was using mainly offshore data.

Akenhead et al. (1979), in their examination of ocean climate variability pointed out that while sea surface temperatures recorded at Halifax and Sambro Light Vessel (located just off the mouth of Halifax Harbor) have similar long-term features as the St. Andrews data, there are differences in detail. For example, 1953 which was a very warm year at St. Andrews and Sambro was only just above the mean at Halifax. Furthermore, 1939, a cool year at Halifax and St. Andrews, was a warm one at Sambro. Thus for periods of a year or less, shore stations may be representative of a very small geographic area, since Halifax and Sambro are less than 35 km. miles apart.

Akenhead et al. (1979) also further explored spatial scales of temperature variability by computing the correlation function between 1^{o}x 1^{o} squares of monthly mean values on the Scotian Shelf as given in Gulfstream. They found that the correlation was low between neighbouring 1^{o} squares, suggesting that each fishing bank has its own local climate. They concluded that there appears to be a large-scale, slowly varying climate signal with local, higher-frequency variations superimposed. The variance in both signals seemed comparable.

IV Analyses of some available data bases

1) The data bases and methods of analyses.

Since there appears to be serious limitations in the extent to which the shore and inshore monitoring stations can be used to infer within-year conditions on spatial scales of more than a few tens of kilometers, it was felt that a better view of year-to-year ocean climate within the NAFO area might be developed by analyses of sea surface temperature (SST) data held at the World Climate Center in Asheville, North Carolina. Additionally it should provide a nearly continuous data set on long time and space scales. By incorporating other data sets such as river discharge from the St. Lawrence River system, sea level observations, air temperatures and anemometer records, and other atmospheric or oceanographic parameters at specific sites, and using correlation techniques, some new insights into possible mechanisms producing environmental variability might be revealed. Accordingly, data tapes were acquired for Marsden Squares 150 and 151 (area contained within 40° -50°N and 50° - 70°W). To further augment the SST file, data from the bathythermograph files held by MEDS were also incorporated.

Other data in the form of monthly averages were assembled as follows:

Parameter	Location	Source of Data Files
Sea Surface Temperature (shore stations)	Halifax St. Andrews Entry Island	BIO BIO MEDS
Sea Temperatures (regularly occupied stations)	Station 27 Prince 5	BIO BIO
Salinity	Station 27 Prince 5	BIO BIO
Sea Level	Halifax Yarmouth St. John's	BIO BIO Environment Canada Water levels Publications
River Discharge	St. Lawrence	BIO
Atmospheric pressure	Halifax North Atlantic	BIO Dalhousie University
Air Temperature	Ottawa Eastport	BIO BIO
Wind Speed and direction	Sable Island	Atmospheric Environment Service

The SST data base was arranged in 12 files by month of observation ranging in number from a low of 73,000 records for February to a maximum of 116,000 records for May and a total for all months of 1.18 million. Records go back to the 1850's, although the bulk of the data has been acquired in the last 30 years.

Data in each monthly file were sorted by year and by 1° squares. Averages were computed for each year and each 1° square as were the sums of the squared deviations from these averages. Grand means over all years were computed, together with within-year and between-year variances for each degree square. Monthly anomalies for the 1970-79 period compared to 1960-69 decade and to the long term were computed and tabulated.

Since oceanographic data records are typically noisy, data were lumped into larger segments; (e.g., Bay of Fundy, Gulf of Maine, Grand Banks, etc.) and monthly averages for each year in the 1970-79 period determined, as well as mean annual temperatures for each year between 1950 and 1979.

Correlations between variables were computed and correlation matrices tabulated similar to that described by Sutcliffe et al. (1976).

The preliminary results from these analyses are given in the following sections. Sufficient time was not available to undertake as complete an analysis as desirable. Moreover, although attempts were made to screen out bad data in the SST data tapes, errors still are present. While these probably do not produce significant errors in the averages and anomalies when a large number of data points are available (e.g. mean annual temperature for a year), the number of data points available for a particular area and month often become uncomfortably small. Further careful scrutinizing of the data must yet be done, which may produce some measurable changes in the results reported herein.

2) Sea surface temperature anomalies by 1° grid.

Monthly SST anomalies were computed for each 1° square, comparing the 1970-79 decade both to the long term mean as well as to the 1960-69 decade. Out of interest the 1960-69 monthly anomalies compared to the long term mean were also computed. In Figures 23 and 24 the anomalies of the 1970's compared to the 1960's are shown respectively for January and February. For January, a maximum negative anomaly greater than 4°C was located in the St. Lawrence Estuary, off the Gaspe coast, while maximum positive anomalies exceeding 3°C occurred south of Nova Scotia. The area of positive anomaly extended in a large band stretching in a westsouthwest-eastnortheast direction from Georges Bank to the Grand Banks and included some of the Slope Water area. Negative anomalies were found throughout much of the Gulf of St. Lawrence and in the southeastern part of the area analyzed. The February anomaly map has changed appreciably from January's, with in general lower values present. The large area of positive anomalies has diminished in intensity and size. By March (map not shown) it has disappeared entirely and no large area anomalies appear.

Anomaly maps presented in this fashion are very interesting to look at but do not seem to readily lead one toward an improved understanding of what in fact may have been happening. There may be a number of reasons for this. Firstly, the period of 10 years has been arbitrarily chosen, and so, for example, years with extraordinary heating may be pooled with years of extra ordinary cooling and the processes may thereby be masked. Perhaps one should choose a period based either on some theoretical grounds or from observations of cycles or trends in the data set itself; secondly, if there were real seasonal changes occurring, a better view of this probably would emerge by combining two or three months; and thirdly, for some of the squares the total number of observations are small and have a large variance, making some of the values not very accurate.

3) Grouping of data by geographic area.

In order to increase the data available for particular analyses it was decided to do some geographic lumping of data in units larger than 1^{o} squares. Within Marsden squares 150 and 151, 9 subsets were selected as depicted in Figure 25. Boundaries were chosen along lines of latitude and longitude rather than on a bathymetric or other oceanographic basis. Nevertheless, they are sufficient to broadly characterize areas like the Bay of Fundy, Browns Bank, Georges Bank, etc.

Mean annual sea surface temperatures for the period 1942-79 for seven of the subareas identified in Figure 25 are shown in Figure 26. In terms of long term trends all areas show similarities, - a high in the early 1950's, trending down to a low in the mid 1960's, thereafter rising to some intermediate level in the 1970's. On a decadal basis the patterns are generally comparable to that of Boothbay Harbor, -namely highest temperatures in 1950-59, lowest in 1960-69, and intermediate levels in 1970-79 period. There does appear, however, to be some significant differences in some of the details between the different regions. For example, the pre-1950 character of the Slope Water temperature departs from that of the other areas. Also, during the first half of the 1970's, temperatures for the Grand Banks, Eastern Scotian Shelf, and to a lesser extent the Western Scotian Shelf and Gulf of Maine show a downward trend, whereas Slope Water, Georges Bank, and to a lesser extent, Browns Bank hold relatively steady.

Lockwood (1979) reports that sea surface temperatures in the 1971-75 period were significantly colder in both the north central Pacific and North Atlantic, with snow cover area significantly larger and average temperatures of the atmosphere in the low and middle latitidues significantly lower than in the previous five-year period. He also reports that data from the southern hemisphere shows cooling until the mid 1960's and then a slight warming. However, while the

1971-75 cooling trend may have taken place for the North Atlantic as a whole, it appears that the trend did not occur in all our coastal areas.

Table 1 shows the decadal means for each of the 7 areas for the 1950's, 1960's, and 1970's, together with the decadal changes from the 1950's to 1960's and from the 1960's to the 1970's. These figures indicate that the decadal swings in temperature appear to be much larger for the Gulf of Maine, Georges Bank, Browns Bank and Slope Water areas compared to the Eastern Scotian Shelf and Grand Banks. In part this could arise because of the time-blocks chosen for averaging, since the two regions apear to have differences in some aspects of their long-term trends.

4. Interannual variability

The year-to-year variations in SST were broken down on a monthly basis and are shown in Figure 27 for the Browns Bank area. On the left hand side each month for each year is graphed, while on the right hand side a three-year normally-weighted average is plotted for each month. The lowest curve in each diagram is for January. Each month is offset 5°C vertically for visual convenience. The most notable aspects of these plots are: the high of the early 1950's which was most pronounced in winter months, the downward trend for the period 1955-65 which was present in all months, and; the trending up to a high in first half of 1970's, which appeared to be mainly, but not entirely a winter phenomenon.

Figure 28 shows the monthly, between-year plots of temperature for Slope Water area. This area displays essentially the same features as Browns Bank, except that the monthly upward trends in the late 1960's and early 1970's are spread over all months from January to August.

Figure 29 shows the monthly, between-year plots of temperature for the Grand Bank region. This appears to display different attributes than the other two regions. While the early 1950's produced above normal annual mean temperatures, the peak was produced mainly by abnormally high summer temperatures rather than high winter temperatures. Monthly summer trends, which were downward in the 1955-65 period for Browns Bank and Slope Water areas was upward in the Grand Banks area. Also dominant in the Grand Banks records are the below normal temperatures which occurred in 1973-75 period and was noticable for most months of the year except autumn.

These patterns suggest that while the same long term trends in annual mean temperature may have many qualitative similarities over much of the area being considered, they are created through a different combination of seasonal conditions in each area. That is, above normal annual temperatures may be produced by above normal winter temperatures in one area, above normal summer temperatures in another, and by above normal temperatures in all seasons in yet another.

5. Within-year variability

Looking more specifically at the 1970-79 period and comparing it on a year-by-year basis to the average monthly temperatures for the 1960-69 period gives one yet another view of what the 70's were like. As was noted earlier, the Browns Bank area showed higher temperatures in the late winter period during the early 1970's. A plot of monthly anomalies compared to the mean for the previous decade show the higher late winter temperatures (Fig. 30) in a more marked way than does the between year plots for the 1970-74 period and its disappearance in 1975.

To gain an impression of the spatial scale of the the monthly anomalies, plots for 1973 for seven of the areas are shown in Figure 31. One sees that the Gulf of Maine, Georges Bank and Browns Bank all displayed roughly similar features. The other areas generally show smaller anomalies than did the western areas. The Grand Banks anomalies though not large are consistently negative for all but one month of the year.

Since 1976 brought record high temperatures between May and September at St. Andrews, N.B., it is interesting to see the spatial extent of this anomaly. From Figure 32 one sees that all of the areas were above normal for most months of the year, with a moderately close similarity among Gulf of Maine, Georges Bank, and Western Scotian Shelf.

Many pelagic fish species are known to be associated with particular temperatures and thermal fronts. For example, there is evidence suggesting that the northeastward spring migration of mackerel along the Scotian Shelf and into the Gulf of St. Lawrence will roughly match the progression of the 7°C surface isotherm. The SST data were analyzed on a semi-monthly basis, for the April to June period between 1960-79 to see how the 7°C isotherm progressed from year to year. Marked year-to-year variations were found, with up to a month's difference in terms of "arrival" time at a given point. In a so-called "early" year such as 1970, the 7° isotherm tended to move more or less uniformly from offshore towards the coast (Fig. 33) whereas in a "late" year such as 1974, there was a tendency for the isotherm to stall seaward of the Shelf edge, and then making a rapid advance to the coast in June. Loucks (personal communication) has classed each year in the 20-year period into one of three categories, - early, intermediate, or late. For early years the following were noted: 1960, 69, 70, 76 and 79; in the intermediate class were: 1963, 66, 68, 71, 73, 77 and 78, and for the late year classification: 1961, 62, 64, 65, 67, 74 and 75.

6. Correlation Analysis

a) General Comments and Methods of Analysis.

From the foregoing presentation one begins to gain an impression that changes may be induced by large-scale changes in weather patterns, but how does one make the right connections? Basically these large-scale systems must control wind patterns, air temperatures, heat budget and precipitation. Thus for any given location one would expect the variation to be determined both by direct action and by indirect routes. Sutcliffe et al. (1976) have examined this question in some detail and found some interesting interrelationships. Although Cayan (1980) showed that there is a very close relationship between seasurface temperature (SST) and air temperature (SAT) for Marsden square 151 as a whole, Sutcliffe et al. found that for selected stations within the square correlation coefficients between SST and SAT were generally less than 0.7, suggesting that air temperatures alone cannot account for sea temperature variability. It should be noted that the whole Atlantic region can be connected by the surface circulation pattern (Fig. 2) and that the character of this pattern must reflect to an important extent fresh water discharged from the rivers. Sutcliffe et al. (1976) demonstrated that the effects of the St. Lawrence River discharge can be traced by correlation analysis with sea temperatures and found to propogate from the Gulf of St. Lawrence onto the Scotian Shelf and through the Gulf of Maine at known ocean drift speeds.

Although high correlation coefficients by themselves do not permit one to discern direct or indirect relationships they do usefully focus one's attention on particular features. The program used here to develop correlation coefficient matrices was similar to that reported by Sutcliffe et al. (1976). For example, to investigate the relation between surface salinity at Station 27, off St. John's, and Eastern Scotian Shelf sea surface temperature, correlation coefficients were calculated between monthly values of sea temperature and salinity. The data were separated by month and each of the monthly sets were averaged using 3-year equally-weighted running means. The monthly salinities were progressively lagged behind the monthly temperature signals one month at a time (e.g. a December salinity vs. January temperature), beginning with no lag and proceeding to a 12-

month lag.

Correlation coefficients were calculated for each lag and each temperature month (Table 2). This resulted in a 12 x 13 matrix of coefficients where each of the horizontal rows represents correlations at one particular lag time of salinity for each month of temperature. The vertical columns represent correlations between one temperature month and lags of salinity from 0 to 12 months, and a diagonal running downwards from left to right represents correlations between one set of monthly salinity data and each of the 12 months of temperature.

Since one can easily think of some 20 or more variables that might have significant correlations between or among them, it was necessary to exercise some priorities in carrying out the computations. Sutcliffe (personal communication) suggested that Station 27 salinities appeared to be an important data set for indexing purposes. Accordingly, the work to date has placed particular emphasis on correlating this data set with others such as temperature in the various grouped areas. Although we have used other sets such as St. Lawrence River discharge versus temperature, and have examined surface temperature persistence through autocorrelations many other matrices remain to be computed and scanned.

b)Station 27 salinities and Eastern Scotian Shelf sea surface temperatures.

Correlation coefficients were computed for a matrix of temperature and salinity months. In the first instance salinity at Station 27 was progressively lagged from 1-12 months for each month of Eastern Scotian Shelf sea surface temperature (Table 2). Examining this table, one sees an area in the temperature months of Aug, Sept, and Oct, where the correlations are -0.7 and -0.8 (enclosed by the diagonal lines). The table indicates that Aug - Oct temperatures on the Eastern Scotian Shelf are highly correlated with the previous March - May salinities at Station 27. Nov - Dec temperatures also show high correlations at 0-1 month lag. Additionally the Mar - May temperatures show high correlations with the previous October salinities.

To examine the complementary situation where events on the Scotian Shelf precede those at Station 27, a correlation matrix between Station 27 salinities and Eastern Scotian Shelf sea surface temperatures was computed the opposite way round, i.e. salinity for each month was correlated with temperatures progressively lagged. The results are shown in Table 3. Areas of high coefficients have been enclosed within the diagonals. The table indicates that salinities in July - September are highly correlated with the previous April - June temperatures and also that November - December salinities are highly correlated with temperatures on the Eastern Scotian Shelf at zero and 1 month lag.

To satisfy oneself that these high correlation coefficients are not spurious or artificial, plots of the actual salinity and temperature data for the 1955-78 period for the circled correlation coefficients in Tables 2 and 3, are shown in Figs 34A, B. These plots convey reasonably convincingly the inverse relationship between the variables, September - November temperatures and previous April - June salinities (Fig. 34A) and September - November salinities and previous June - August temperatures (Fig. 34B).

As pointed out earlier one has no way of readily discerning whether one is looking at a direct cause-effect relationship, or merely an associative one, or even some combination. The high correlation between late winter-spring salinities at Stn 27 and the following summer-autumn temperatures on the Scotian Shelf is consistent with a cause-effect relationship, invoking an advection-stability hypothesis. From Figure 2, one notes that the mean surface circulation shows Station 27 "upstream" from the Eastern Scotian Shelf area. Using a mean daily speed of 5 miles and a route of 600-800 miles (traversing part of the Gulf of St. Lawrence) would produce a 4-6 month time lag. The negative correlation is consistent with the fact that low salinities would increase the vertical stability of the water column, thereby inhibiting vertical mixing, and hence result in a higher than normal surface layer temperature during the heating season.

Referring again to Table 2, the high correlation in November - December with little or no lag is more likely indicative of an associative meteorological connection, although it is not obvious why it is confined to only 2 months of the year. The correlation between March - May temperatures and the previous October salinities is probably merely a reflection of the relationship of the March - May salinity correlation with the subsequent August - October temperatures. In other words they are both part of the same phenomenon.

Although mean surface circulation maps show Station 27 to be "upstream" from the Eastern Scotian Shelf area, there is evidence that the surface circulation may be significantly altered and partly reversed during some seasons of the year so that Station 27 is "downstream" from the Eastern Scotian Shelf area. Drift bottle data analyzed by Bumpus and Lauzier (1965) and Trites (1979), and satellite tracked drifting buoys (Trites et al. 1981) indicate a movement towards the northeast from the Eastern Scotian Shelf area in spring months, reaching the south coast of Newfoundland as far east as Cape Race in a 2-3 month period.

Although suitable data sets do not exist for the Eastern Scotian Shelf to enable running a correlation between surface temperatures and salinities, there is a good physical basis for believing that, during the heating season, the two variables would be negatively correlated and with near-zero lag. Correlation with phase lags between temperature in one area and salinity in another may well be the result a third factor, - advection. Thus, the key physical linkage factor responsible for producing the high correlations between spring sea surface temperatures on the Eastern Scotian Shelf and summer surface salinities at Station 27 (as shown in Table 3) may be wind-driven surface currents. Certainly available Lagrangian surface current measurements and wind records lend support to the suggestion.

c) Eastern Scotian Shelf sea surface temperatures and Sable Island Winds

To investigate the possible relationship between local winds and sea surface temperatures a correlation matrix between Eastern Scotian Shelf sea surface temperature and the southeast wind component at Sable Island was computed. (Table 3). Again, oblique lines delineate the area of highest coefficients. Interestingly February winds are highly correlated with sea surface temperatures from February to July. A plot of the wind component for the month of February - April and sea surface temperature for the following months of June -August for the period 1953-78 and shown in Figure 35 gives rather convincing visual evidence of the similarity between the two curves.

It is surprising that the wind is not highly correlated with temperatures in any other wind month than February, and likewise that the February "event" should persist in the sea surface temperature "memory" for the following 5 months. It should be noted that if one had used northwest winds the coefficients would have been negative. Typically, in February one would expect to find higher air temperatures associated with southeast winds and the inverse for northwest winds.

d) Other Correlations

The analysis by Sutcliffe et al. (1976) correlating St. Lawrence River discharge with sea surface temperatures from shore stations and lightships suggested a pathway of influence from the St. Lawrence southwestward along the eastern seaboard. The correlation analysis was extended using the grouped area SST's identified in Section IV, 3. The results were consistent with Sutcliffe et al. with peak correlations of 0.7 to 0.8 between spring river discharge and successively later months along the hypothesized drift path, e.g. the peak correlation occurred in August for the Eastern Scotian Shelf, September for the Western Scotian Shelf and September to December for the Gulf of Maine.

Autocorrelations of sea surface temperature for both Eastern and Western Scotian Shelf areas were computed. In general the two areas displayed rather different features. For the East Scotian Shelf, persistence was evident on scales of one to two months except in autumn. For the Western Scotian Shelf area, there was strong month-to-month persistence in the January to May period and very little persistence from May to June - or from June to July. Autocorrelations were at intermediate values for other months. Further analyses is required before any interpretations can be offered.

Cross correlations between other selected data sets are currently being computed but have not yet reached the examination stage.

V. Atmosphere - Ocean Coupling and Response Scales

In the foregoing section on correlations one saw evidence of ocean-atmosphere interactions on the scale of at least a few hundred kilometers. In an earlier section dealing with the Labrador area, it was noted that the declining salinities observed in the 1967-71 period at Station Bravo were probably related to the meteorological conditions over the North Atlantic and Arctic Oceans during the 1960's. One explanation offered by Lazier (1980) was that an increased supply of cold-fresh polar water, brought about by an anomalously high pressure cell over Greenland, lowered both the temperature and salinity of the East Greenland Current. This current flows southward along the east coast of Greenland, turns west and north into the Labrador Sea around Cape Farewell. An ocean-pathway delay time of 12-18 months between Denmark Strait and Bravo, was estimated. The oceanographic response scale in this example appears to be at least 2000 km and probably more.

Namias (1966) noted the contemporaneous occurrence of drought in the northeastern United States with the presence of colder than normal seasurface temperatures along the Atlantic Seaboard in the 1962-65 period. He speculated that an interlocking feedback machanism was operative; increased atmospheric circulation (more northerly winds) increased transport in the Labrador Current which lowered sea surface temperatures and in turn sea air temperatures along the Atlantic coast resulting in increased atmospheric baroclinicity, and thereby completing a positive feedback loop.

Cayan (1980) has shown that the large scale features of sea surface temperature (SST) and surface air temperature (SAT) are closely related on monthly, seasonal and annual time scales over both the North Pacific and North

Atlantic. He found however that the correlation had a seasonal variation, being higher in the summer at mid latitudes, and also that spatial scales varied seasonally and with a different pattern in the Atlantic than in the Pacific. Although Namias (1973) shows a good correlation between sea surface temperatures and thickness of the 1000-700 mb surfaces in the North Pacific, Cayan points out that a strong SST-SAT relationship does not necessarily imply a strong coupling between the lower troposphere and the sea surface.

Namias and Born (1970) show that large SST anomalies may develop over a large area of the North Pacific and persist for many months. Namias (1972, 1976, 1980) discussed teleconnections between these anomalies and subsequent extreme weather conditions over the North American Continent (e.g. anomalous winter 1971-72 and 1978-79). However, the 1978-79 pattern appeared to have also been influenced by a vast area of Arctic blocking, since the statistically derived teleconnection would have predicted a warm winter along the Atlantic Seaborad. Although there is convincing evidence that events in one area produces responses in subsequent months over distances of many thousands of kilometers the 1978-79 pattern emphasizes the unsatisfactory state of understanding that exists in much of the short-term climate variability.

VI. Summary Impressions

1. There is evidence that long term changes (several years) in sea surface temperatures are coherent over space scales of a few thousand kilometers, which is comparable in size to the entire NAFO subareas 2, 3, and 4. However, from the data available, there is an indication that the area does not fit into a single "regime". The Bay of Fundy, Gulf of Maine, Georges Bank and part of the Scotian Shelf appear generally to behave similarly and may be part of a larger "southern" regime. Although there is insufficient data available for the northern region, on a year round basis, it appears that the Labrador area, Grand Banks, and Eastern Scotian Shelf may also display similar tendencies in terms of long-term trends, and may be only part of a larger "northern" regime.

2. Using Boothbay Harbor sea surface temperature data as an index of conditions in the southern part of Subarea 4, it appears that the 1970-79 decade was intermediate between that of the 1950's when temperatures were high and the lows of the 1960's. Compared to the 1906-45 period it appears that for the past 30 years the area has been under an increased Maritime influence, i.e. warmer winters and cooler summers.

3. Using the Grand Banks grouped area as an index for subareas 2, 3 and part of 4, suggests that on a decadal basis the 1970-79 period was slightly cooler than both the 1960-69, and 1950-59 periods. The decadal fluctuations in temperature appears to be much smaller than for the southwestern part of subarea 4. In part this could be the result of the time blocks chosen for averaging, since the two regions appear to have differences in some aspects of their long-term trends.

4. For much of Subareas 2 and 3 the 1970-72 period was one of generally declining surface temperatures and salinities. The more northern areas appeared to have reached a low in temperatures for the decade, in 1972, whereas further south the cooling trend seems to have persisted at least until 1975. By 1978 surface temperatures appear to have returned to "near-normal" levels.

5. The makeup of the annual temperature signal shows significant regional differences. For example, even though all parts of subareas 3 and 4 may have experienced a downward trend in average annual SST from the mid-1950's to the mid-1960's, the April-July period was getting warmer over the decade in the Grand Banks area, while for the western part of Subarea 4, the temperature was trending downward over all months.

6. Owing to the paucity of subsurface oceanographic data, there is little that can be said about space and time variations at subsurface depths throughout the NAFO area. From Station 27 data there is no basis for believing that the long-term trends in either temperature or salinity below the depth of convective winter overturn bear close similarity to the properties in the overlying surface layer.

7. Recurrence over a period of several years is an important SST feature. For example, recurrence in the late 1960's at Station Bravo occurred over a 5 year period and appeared to be a response to a large scale atmospheric driver linked through the surface layer circulation regime and operated on a scale of at least 2000 km.

8. The significantly different character of the Gulf of Maine, Browns and Geroges Bank may in part be due to offshore forcing since Gulf Stream eddies are capable of producing major changes in Shelf properties over a period of weeks or months. However, the data base (satellite imagery) is still too short to determine year-to-year variation in eddy numbers and location on decadal time scales.

9. The high positive correlation of freshwater discharge from the St. Lawrence River system with sea surface temperatures through the Gulf of St.

Lawrence, onto the Scotian Shelf, and into the Gulf of Maine phase lagged by realistic surface current drift times, suggests a pathway of river-discharge influence on a scale of up to 2000 km. It may be that increased discharges increases buoyancy and in turn inhibits vertical mixing and confining the incoming radiation to a shallower surface layer. The similarity in long term trends in river discharge in winter and spring months to the trends in annual temperatures for most of NAFO subarea 4 should also be noted.

10. Changing seasonal wind patterns probably produce pronounced changes in the surface circulation patterns on a time scale of several months.

11. The climate signal, as indexed by sea surface temperature at inshore stations, does not necessarily correlate well on spatial scales of even a few tens of kilometers, for time scales of a year or less. There is some indication that further offshore the spatial coherence at these time scales is generally much larger.

12. There is evidence that environmental conditions are the result of both the large-scale slowly-varying processes as well as local, higher-frequency variations, and both may have comparable variance.

13. Using arbitrary 10-year periods for looking at long term variations has limited usefulness and may act to mask out significant changes. The data records themselves should be the guide to time-block analyses.

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TABLE 1. Mean decadal sea surface temperatures for 1950's, 1960's and 1970's and between decade changes for 7 grouped areas within NAFO subareas 3 and 4

Area	Mean 1950's	Mean 1960's	Mean 1970's	Differences 60's-50's	70's-60's
Gulf of Maine	9.80	8.42	9.23	-1.38	+0.81
Georges Bank	10.90	9.59	10.39	-1.31	+0.80
Browns Bank	10.01	8.90	9.58	-1.11	+0.68
Slope Water	16.97	15.69	16.21	-1.28	+0.52
Western Scotian Shelf	7.94	7.44	8.21	-0.50	+0.77
Eastern Scotian Shelf	7.92	7.41	7.82	-0.51	+0.41
Grand Banks	7.86	7.70	7.64	-0.16	-0.06

TABLE 2. Correlation matrix between Eastern Scotian Shelf sea surface temperature and surface salinity at Station 27. Data have been averaged over 3 months and one year. Oblique lines enclose area of highest correlation.

MONTH FOR TEMPERATURE

No. Sal. Months Lagged	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0	-.6	-.4	0	.1	0	-.4	-.5	-.3	-.4	-.5	-.8	-.9
1	-.6	-.6	-.4	0	0	-.2	-.2	-.5	-.3	-.3	-.7	-.8
2	-.4	-.5	-.5	-.3	-.1	-.2	-.3	-.3	-.3	-.2	-.5	-.7
3	-.6	-.4	-.5	-.4	-.3	-.3	-.5	-.5	-.3	-.2	-.3	-.5
4	-.3	-.6	-.5	-.5	-.4	-.4	-.6	-.7	-.7	-.2	-.3	-.4
5	-.3	-.5	-.7	-.5	-.6	-.4	-.5	-.7	$\boxed{-.8}$	-.6	-.3	-.4
6	-.4	-.5	-.6	-.7	-.5	-.6	-.4	-.5	-.7	-.7	-.6	-.3
7	-.6	-.4	-.5	-.5	-.7	-.5	-.5	-.2	-.3	-.5	-.4	-.4
8	-.5	-.6	-.4	-.4	-.5	-.6	-.4	-.3	0	-.2	-.3	-.2
9	0	-.5	-.6	-.4	-.3	-.4	-.4	-.2	0	.1	0	0
10	.3	0	-.5	-.5	-.4	-.3	-.4	-.2	0	.1	.2	.2
11	.6	.4	.1	-.5	-.6	-.4	-.4	-.4	.1	.1	.1	.3
12	.5	.6	.4	0	-.5	-.6	-.6	-.4	-.1	.3	.1	.2

TABLE 3. Correlation matrix between surface salinity at Station 27 and Eastern Scotian Shelf sea surface temperature. Data have been averaged over 3 months and one year. Oblique lines enclose areas of highest correlation.

	MONTH FOR SALINITY											
No. Temp. Months Lagged	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0	-.6	-.4	0	.1	0	-.4	-.5	-.5	-.4	-.5	-.8	-.9
1	-.6	-.5	0	.2	0	-.3	-.7	-.5	-.5	-.4	-.6	-.8
2	-.3	-.5	-.2	.2	.2	-.4	-.7	-.7	-.6	-.5	-.5	-.7
3	-.2	-.2	-.2	.1	.3	-.2	-.7	-.7	$\boxed{-.8}$	-.5	-.5	-.5
4	-.1	-.1	-.2	-.1	.1	0	-.5	-.7	-.7	-.5	-.5	-.4
5	-.1	-.1	-.1	-.1	-.1	-.1	-.2	-.4	-.6	-.4	-.5	-.2
6	.1	-.3	-.2	-.2	-.2	-.2	-.2	-.2	-.4	-.3	-.3	-.1
7	.2	-.1	-.5	-.2	-.3	-.4	-.3	-.1	-.2	0	-.2	.1
8	.4	-.1	-.4	-.5	-.4	-.4	-.5	-.3	-.2	.1	.1	.2
9	.4	.1	-.4	-.5	-.5	-.4	-.5	-.5	-.5	0	.2	.5
10	.4	.1	-.2	-.4	-.4	-.3	-.5	-.5	-.6	-.4	.1	.6
11	.5	.1	-.2	-.3	-.2	-.2	-.3	-.4	-.6	-.5	-.3	.6
12	.4	.3	-.1	-.2	-.2	0	-.3	-.2	-.5	-.6	-.4	.3

TABLE 4. Correlation matrix between Eastern Scotian Shelf sea surface temperature and southeast wind component at Sable Island. Data have been averaged over 3 months and one year. Oblique lines enclose area of highest correlation.

	MONTH FOR TEMPERATURE											
No. Wind Months Lagged	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0	.6	.7	.5	.5	.4	-.3	-.3	-.1	.5	.4	.4	.7
1	.8	.6	.8	.5	.5	.4	-.5	-.4	.2	.6	.5	.5
2	.7	.7	.6	.8	.4	.5	.2	-.5	-.2	.4	.5	.5
3	.7	.6	.5	.6	.8	.6	.5	0	-.2	.1	.3	.4
4	.3	.6	.5	.5	.7	$\boxed{.8}$	.6	.4	.1	.1	.2	.3
5	.2	.3	.6	.5	.5	.6	.7	.4	.3	.3	.4	.3
6	.1	.2	.3	.6	.5	.4	.4	.5	.2	.3	.4	.5
7	.5	0	.1	.4	.5	.4	.2	.1	.2	.2	.3	.4
8	.2	.5	-.1	.1	.3	.4	.1	-.1	.1	.1	.1	.2
9	0	.1	.5	-.2	0	.2	.1	-.2	0	.2	.2	.1
10	-.2	0	.1	.3	-.2	-.1	-.1	-.2	-.1	.1	.3	.2
11	.1	-.1	.1	-.1	.3	-.3	-.4	-.2	-.2	.1	.1	.2
12	.2	.1	0	.2	-.2	.2	-.5	-.6	-.3	-.2	.1	0

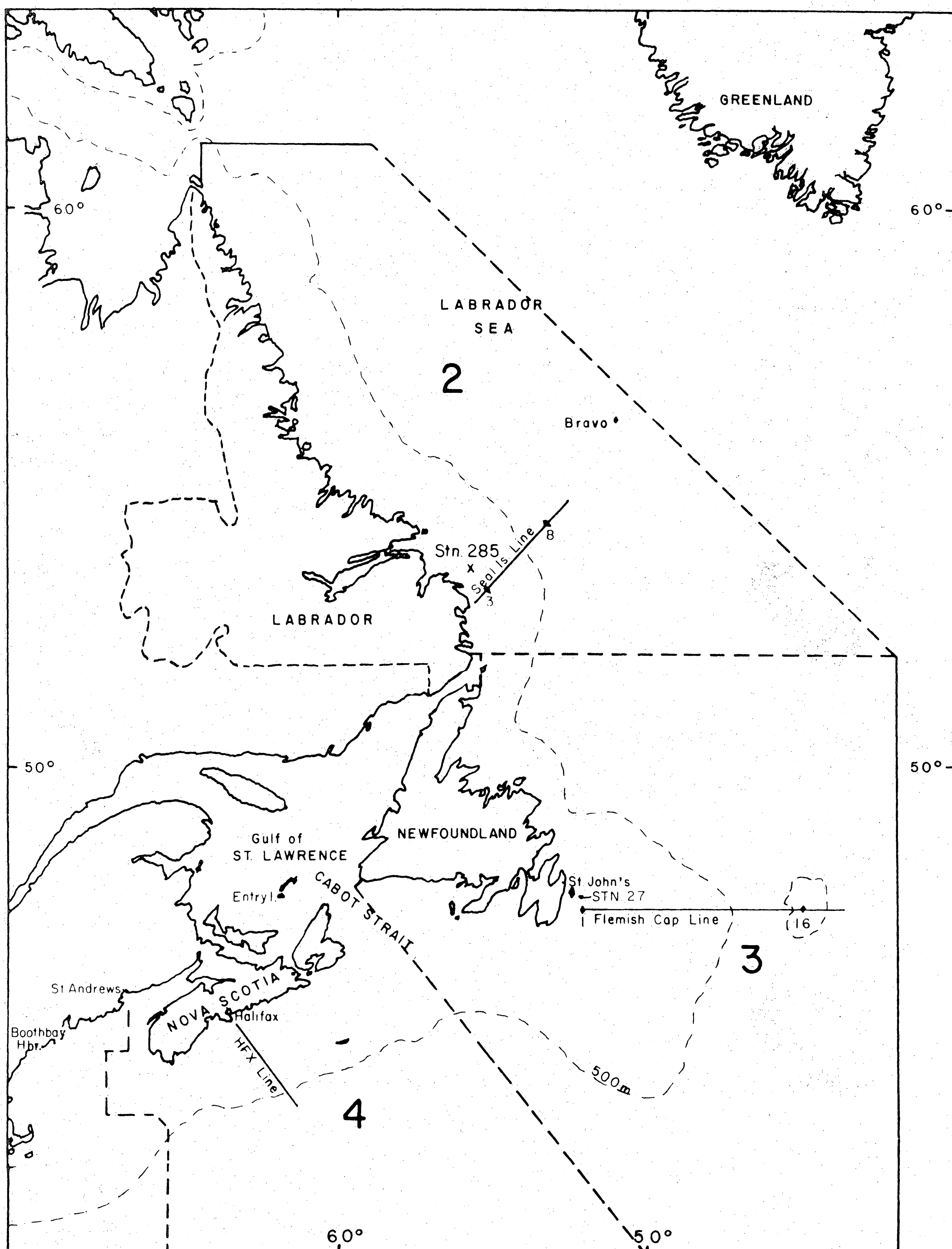


Figure 1 Map of NAFO. Subareas 2, 3 and 4 together with location of stations and sections discussed in the text.

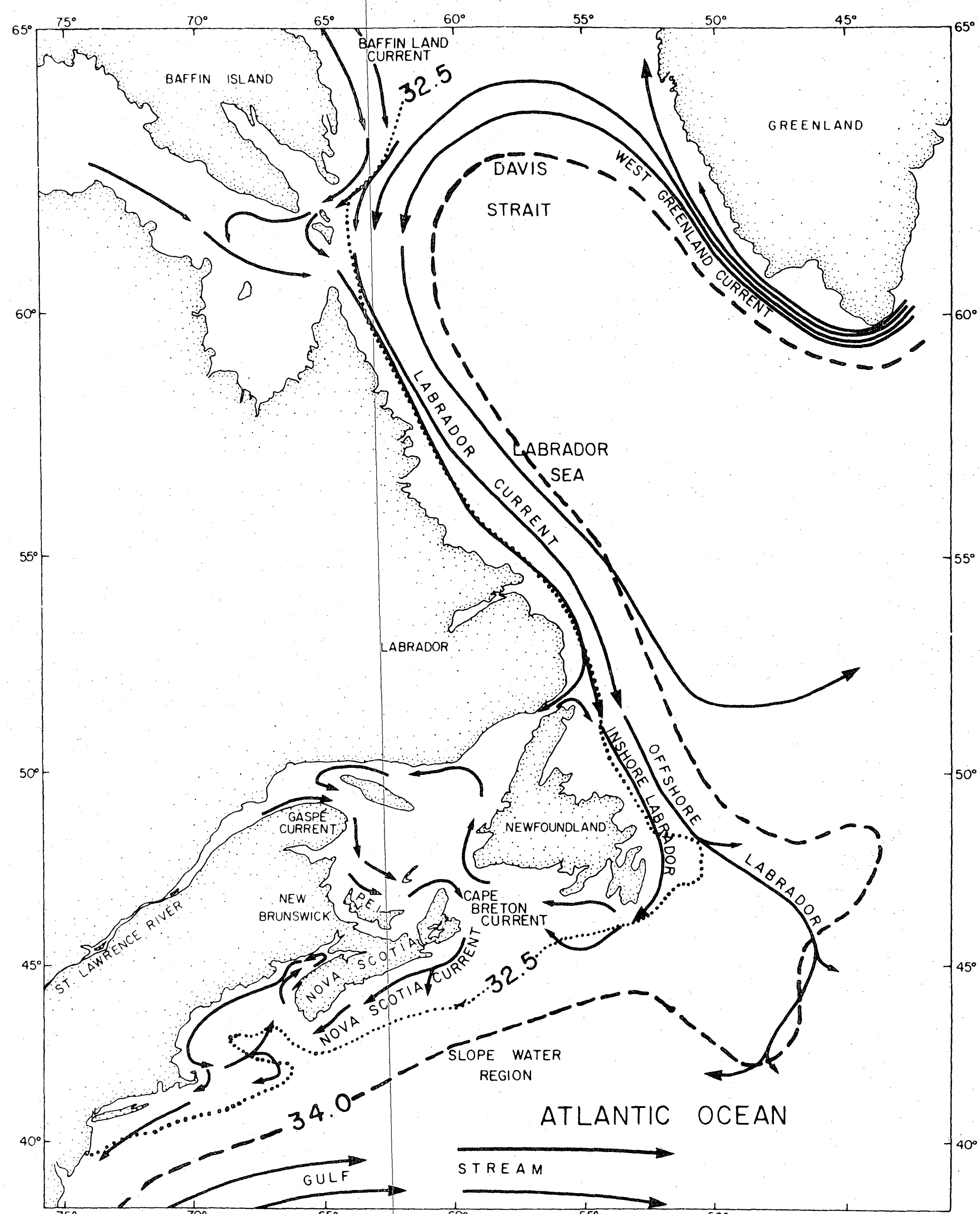


Figure 2 Northwestern Atlantic Coast showing general surface circulation pattern (from Sutcliffe et al. 1976). Approximate locations of the 32.5 $^{o}/oo$ and 34.0 $^{o}/oo$ salinity isopleths at 30 M depth are also shown (from Worthington 1976).

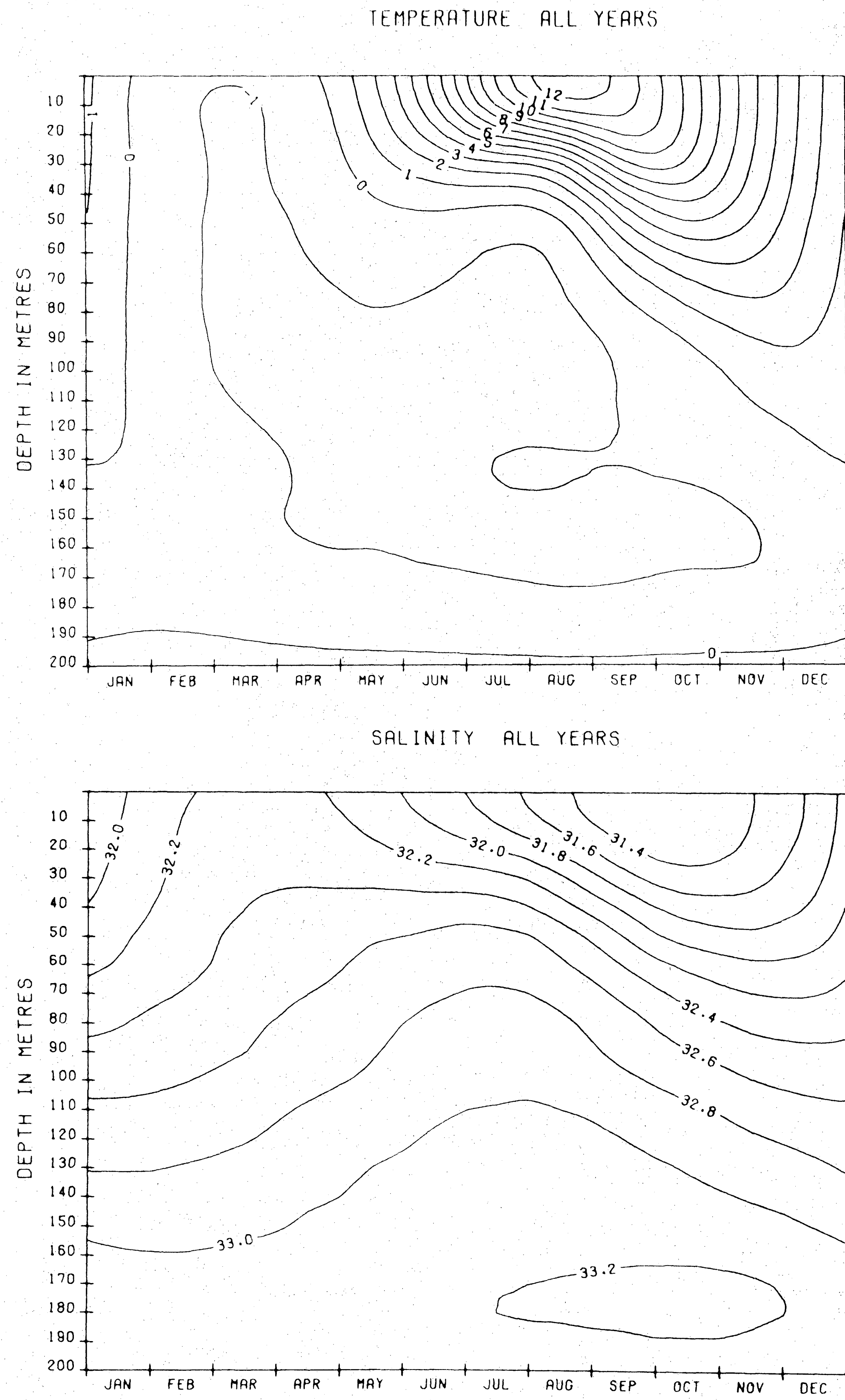
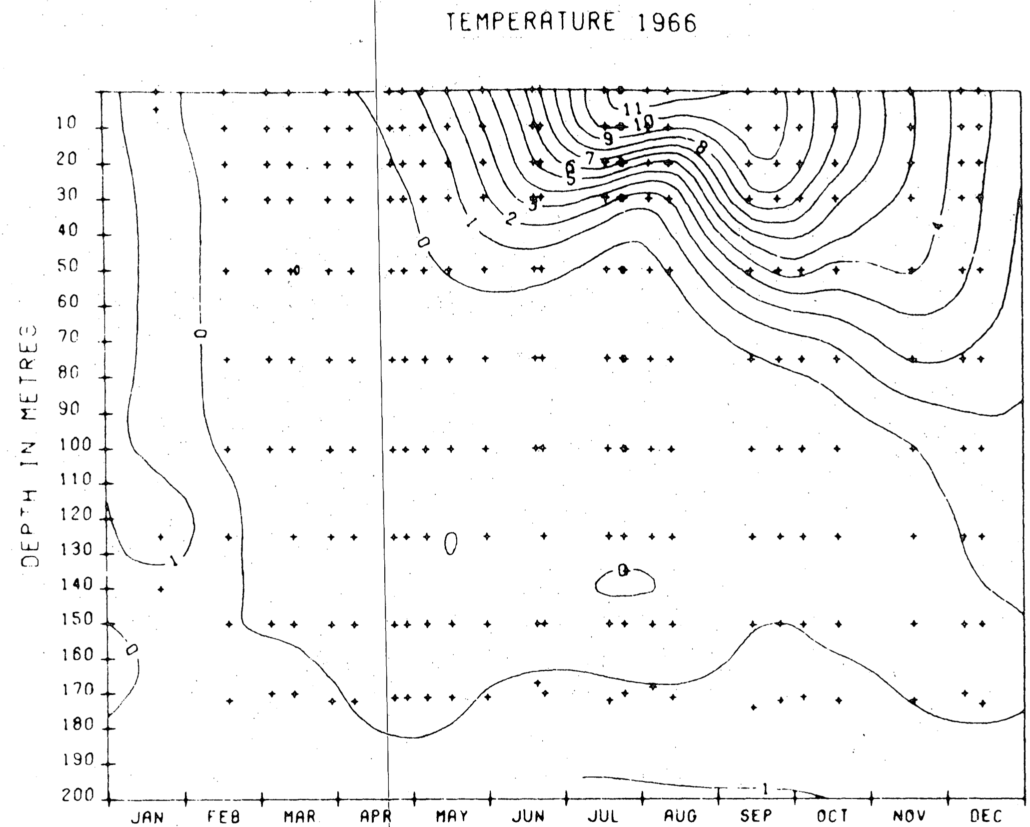


Figure 3 Average yearly temperature (upper diagrams) and salinity (lower diagrams) over depth and time at Station 27 for the year 1946-1977 (from Keeley 1981).



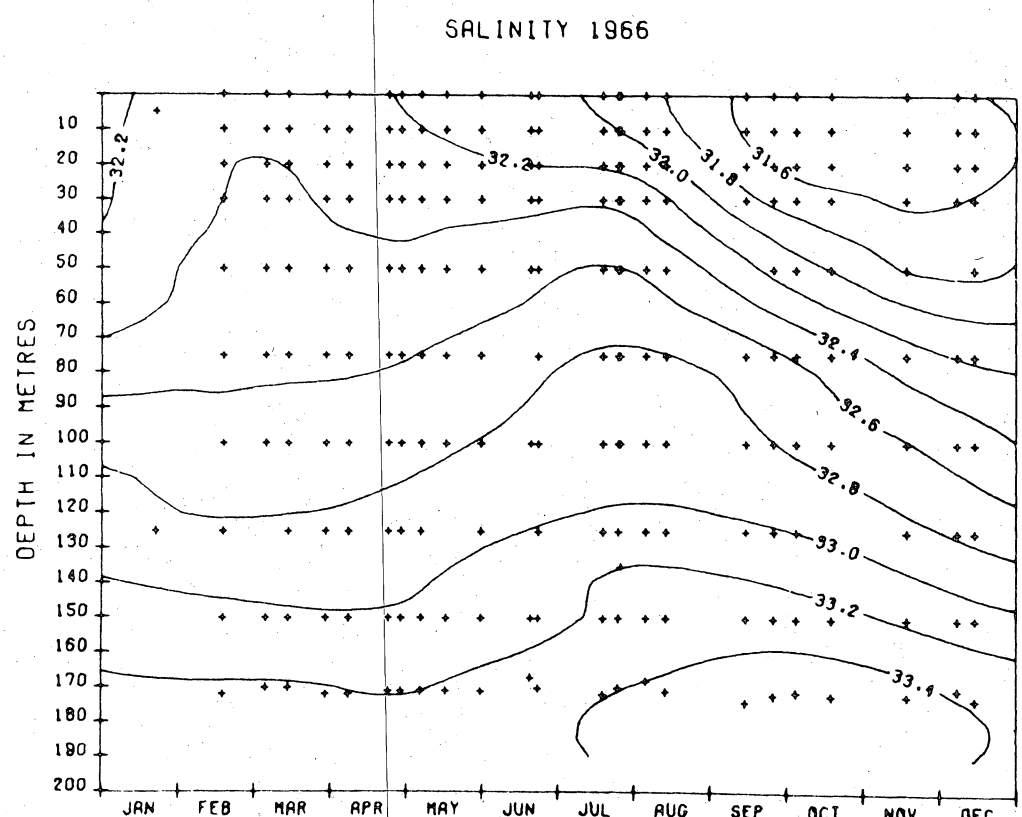


Figure 4 Temperature (upper diagram) and salinity (lower diagram) distribution over depth and time for 1966. (From Keeley, 1981).

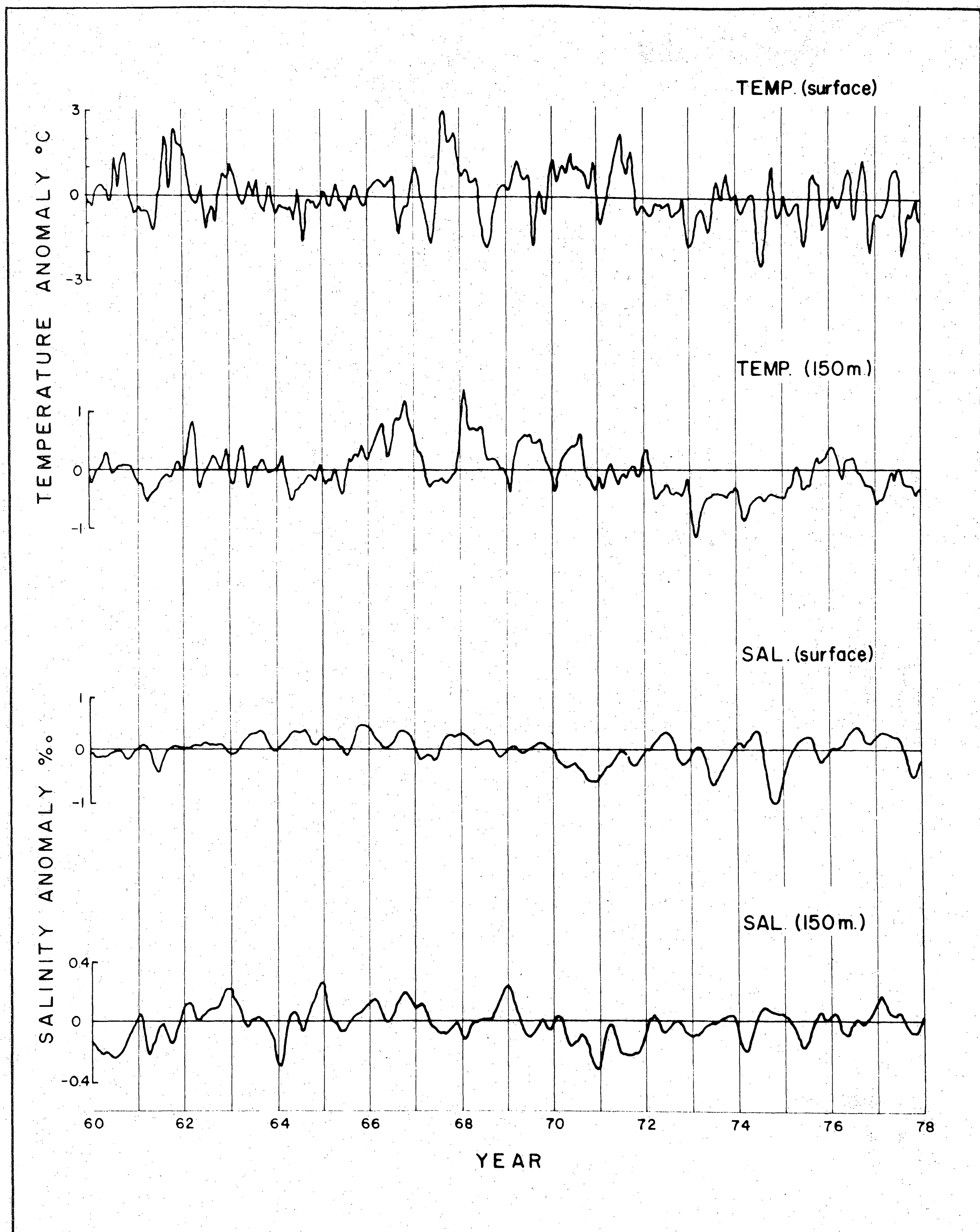


Figure 5 Temperature and salinity anomalies at surface and 150 m for Station 27 for period 1960-77, relative to period 1946-1977. (Redrawn from Keeley, 1981).

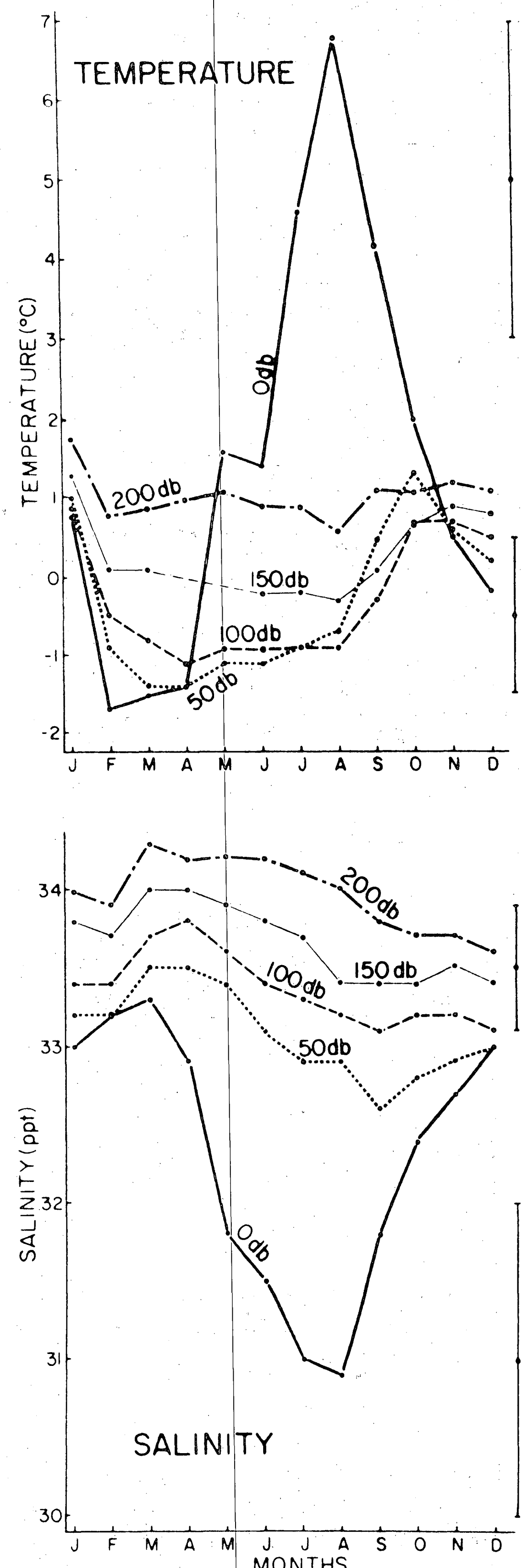


Figure 6 The average yearly cycle of temperature and salinity at selected depths for the Labrador Shelf, using available data for period 1928-1978 at the Marine Environmental Data Service (From Lazier 1981).

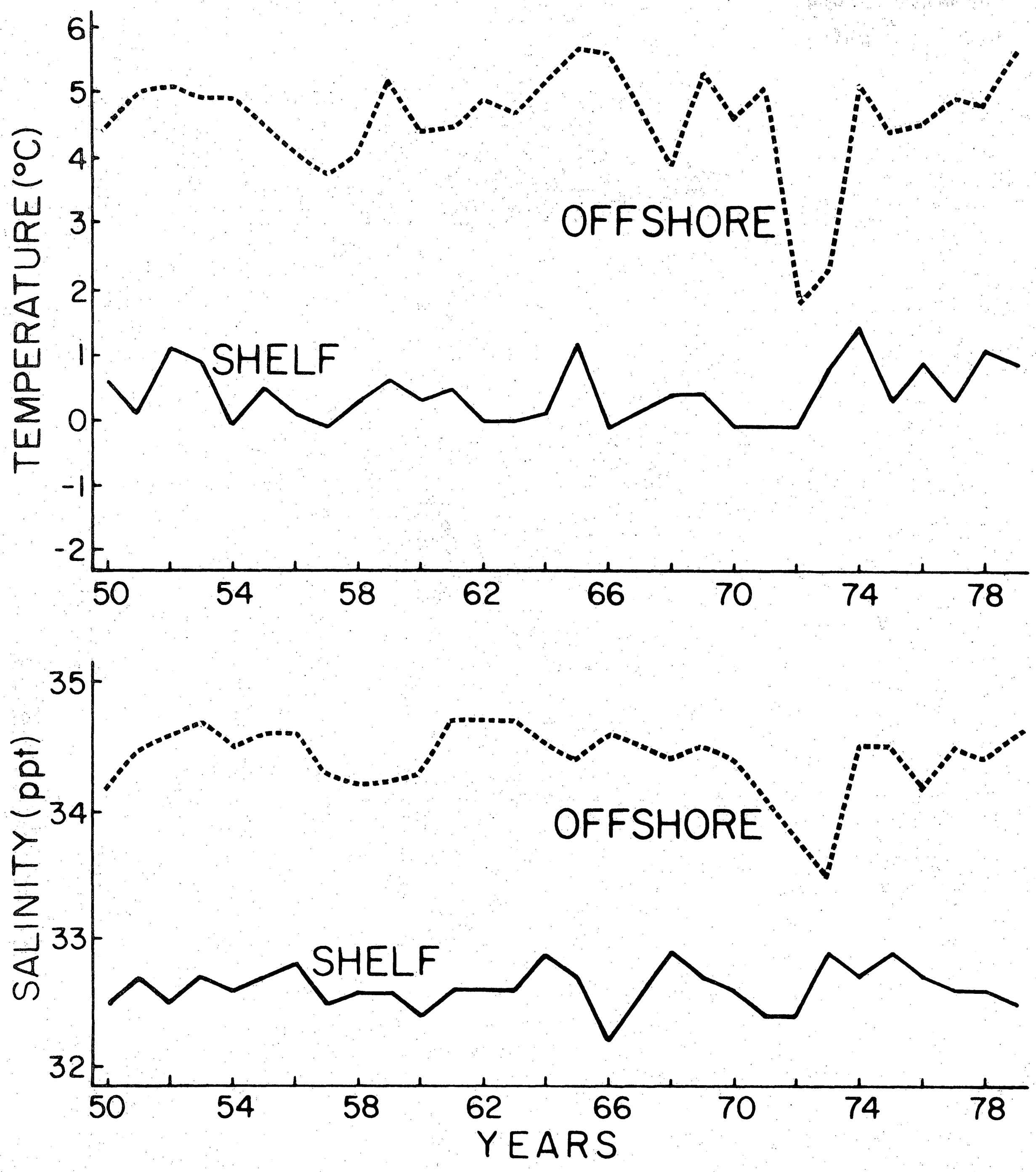


Figure 7 July temperature (upper diagram) and salinity (lower diagram for the Labrador Shelf and the offshore area for the period 1950-1979. Values have been averaged for the top 100 metres of the water column. (From Lazier 1981).

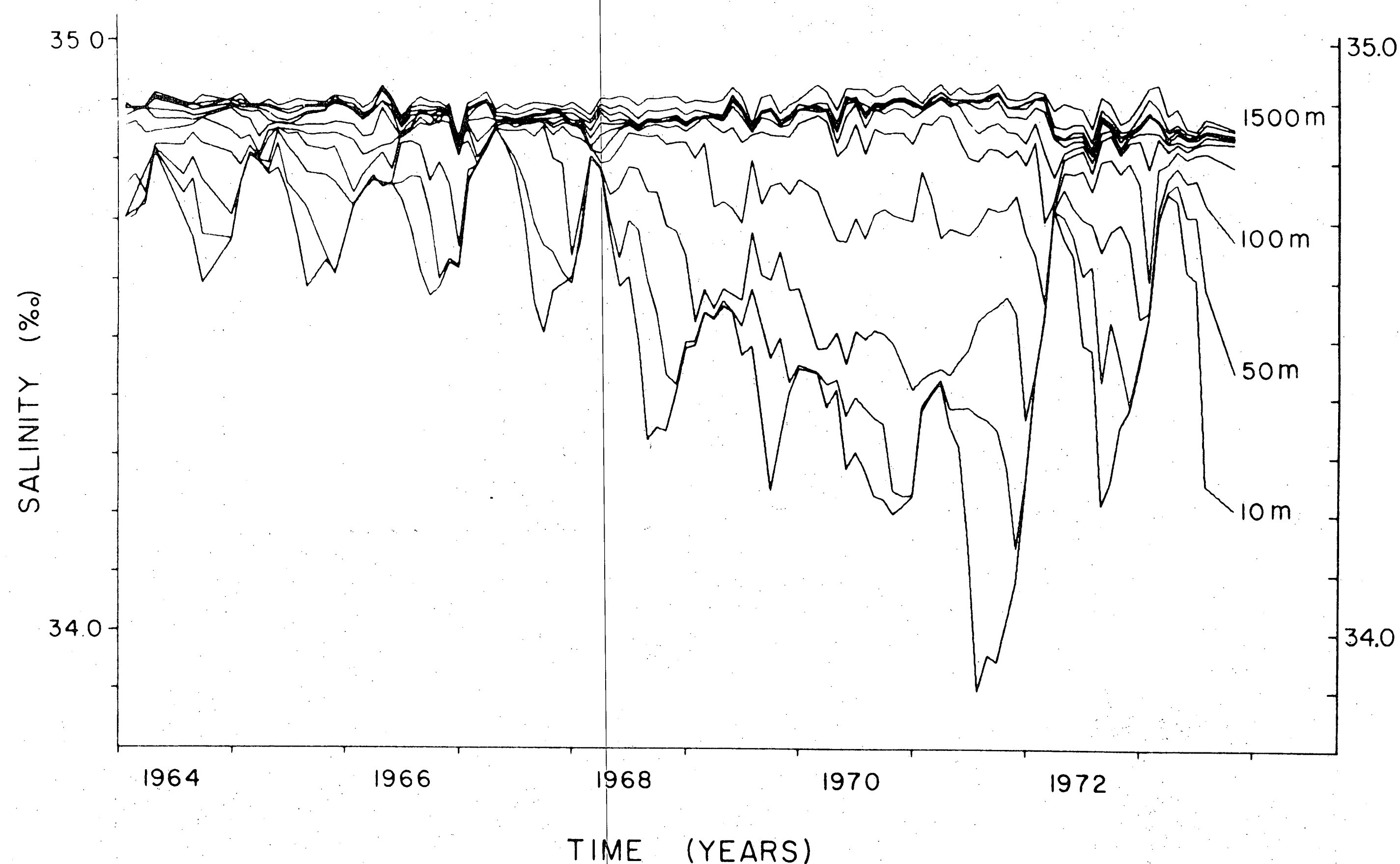


Figure 8 Monthly averages of salinity at eleven different stations Bravo from 1964 to 1973 (From Lazier 1980).

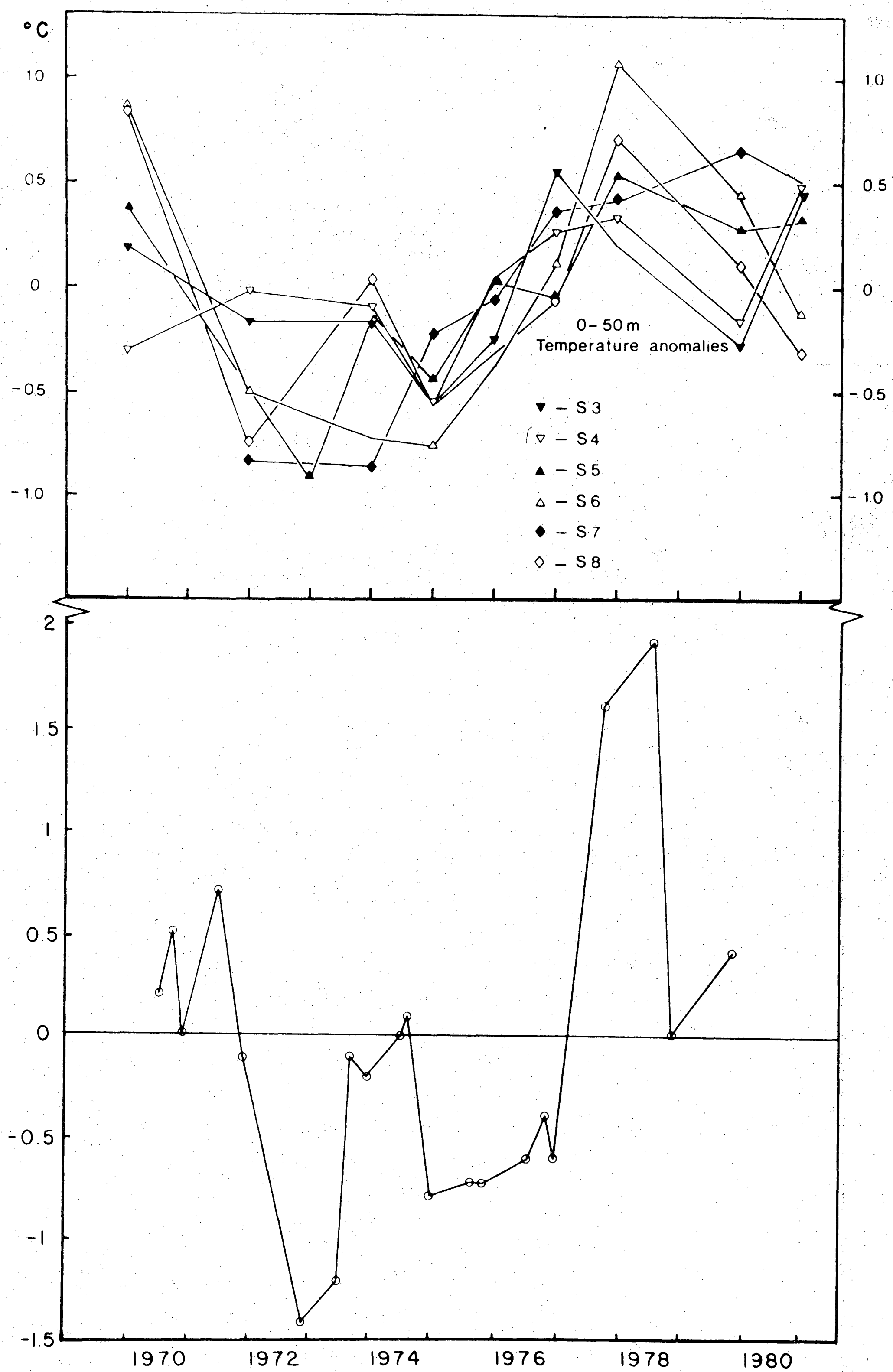
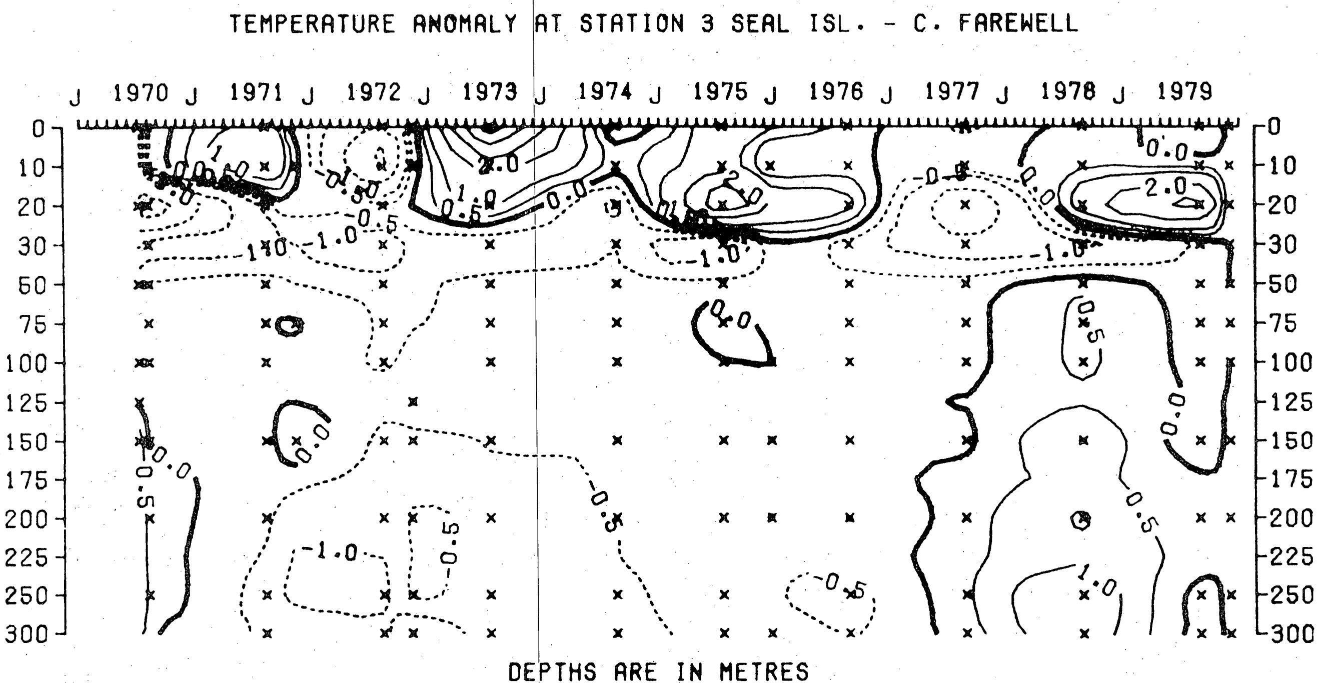


Figure 9 Upper diagram: Autumn temperature during 1969-80 period for upper 50 M of water column at 6 stations on the Seal Island section. (From Stein 1981). Lower diagram: Water temperature anomalies for 0-200 M layer in USSR standard section 8A (near Seal Island section) for 1970-79 period. (data from Burmakin, 1980).



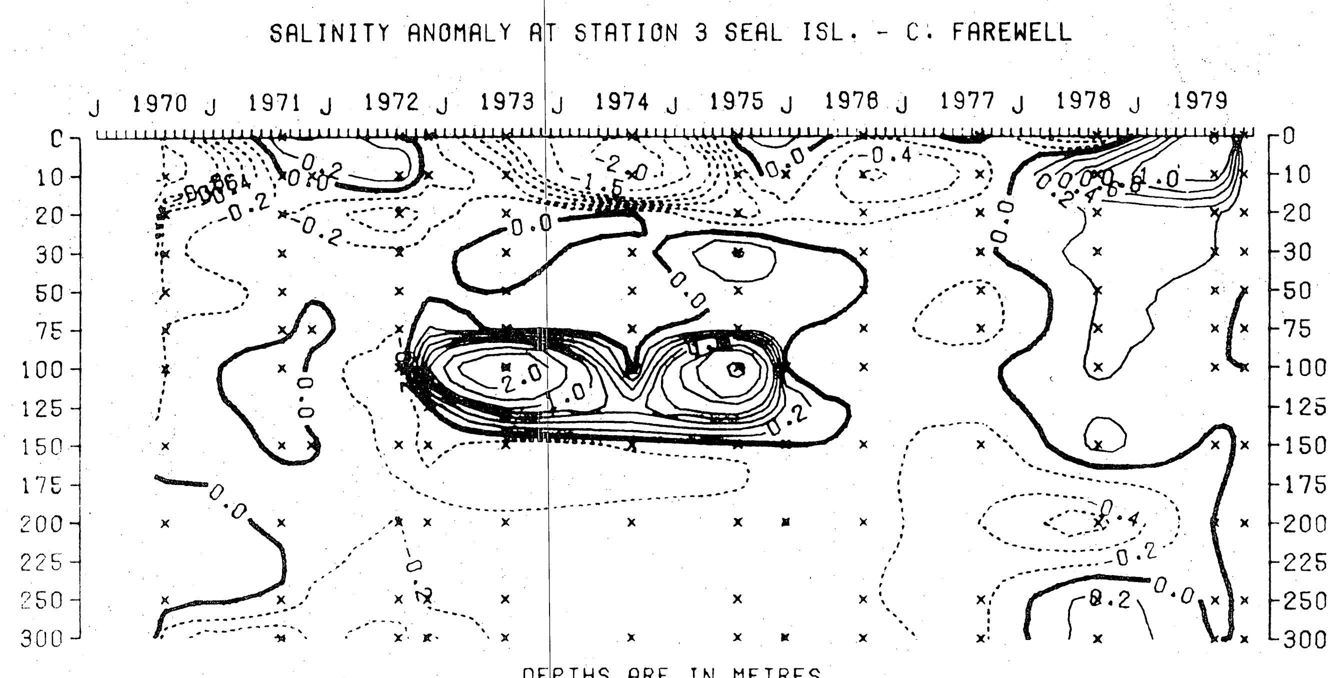
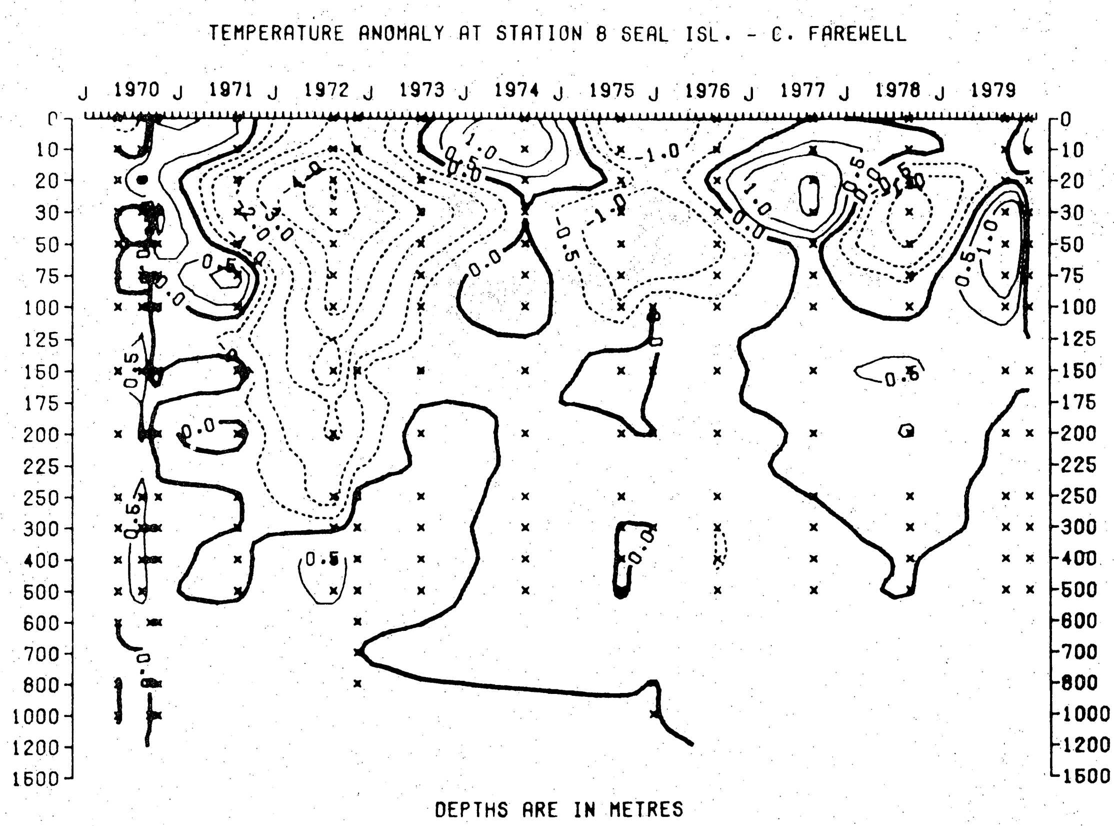


Figure 10 Potential temperature anomaly (upper diagram) and salinity anomaly (lower diagram) at Station 3 of the Seal Island section for period 1970-79.



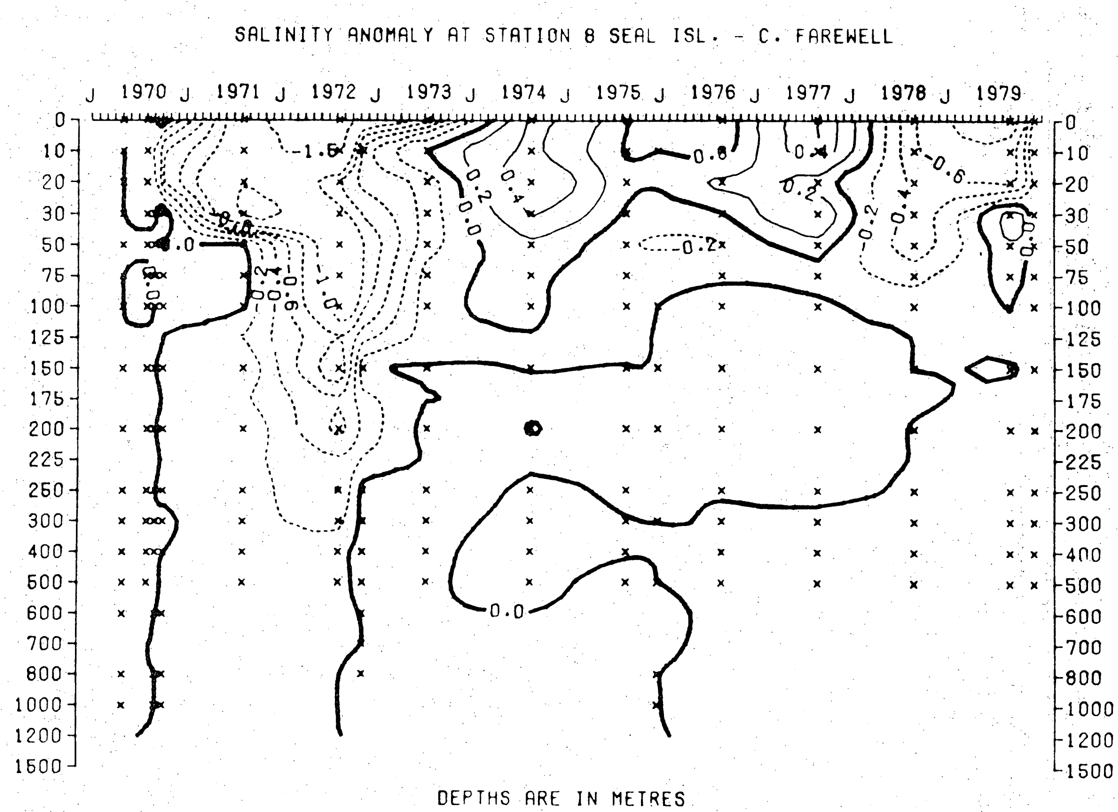


Figure 11 Potential temperature anomaly (upper diagram) and salinity anomaly (lower diagram) at station 8 of the Seal Island section for period 1970-79.

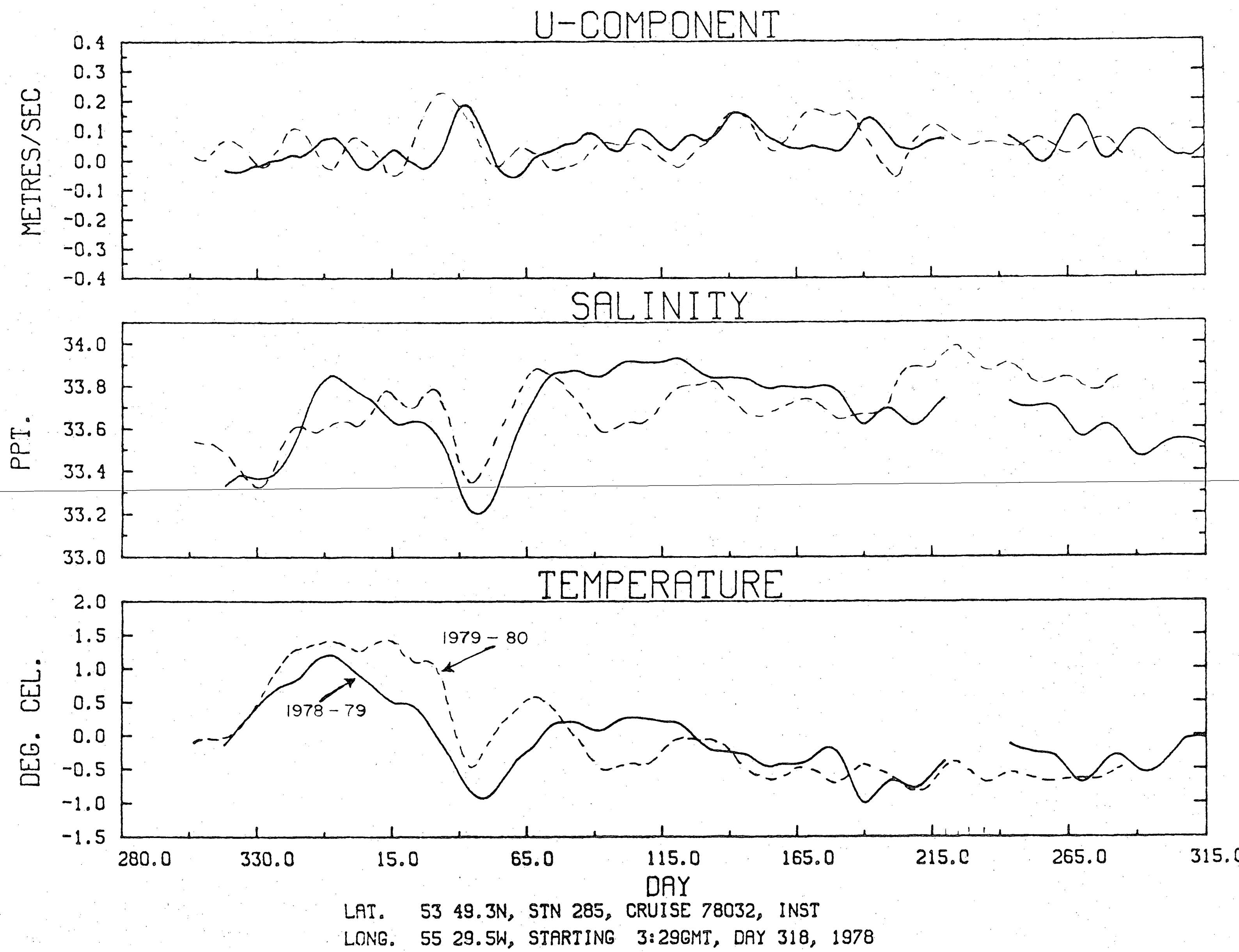
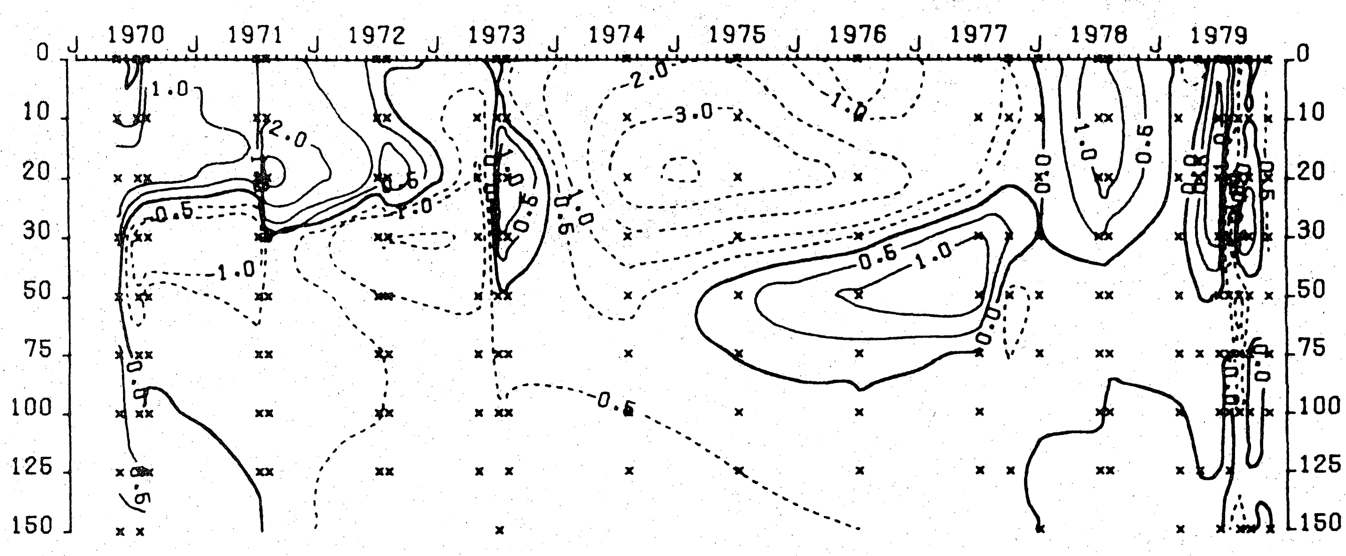


Figure 12. Current, salinity, and temperature variation at 200 M at Stn 285 on Labrador Shelf between October 1978 and October 1980. Current is component parallel to bank. Solid line is for 1978-79 and dashed line is for 1979-80 (From Lazier 1981).

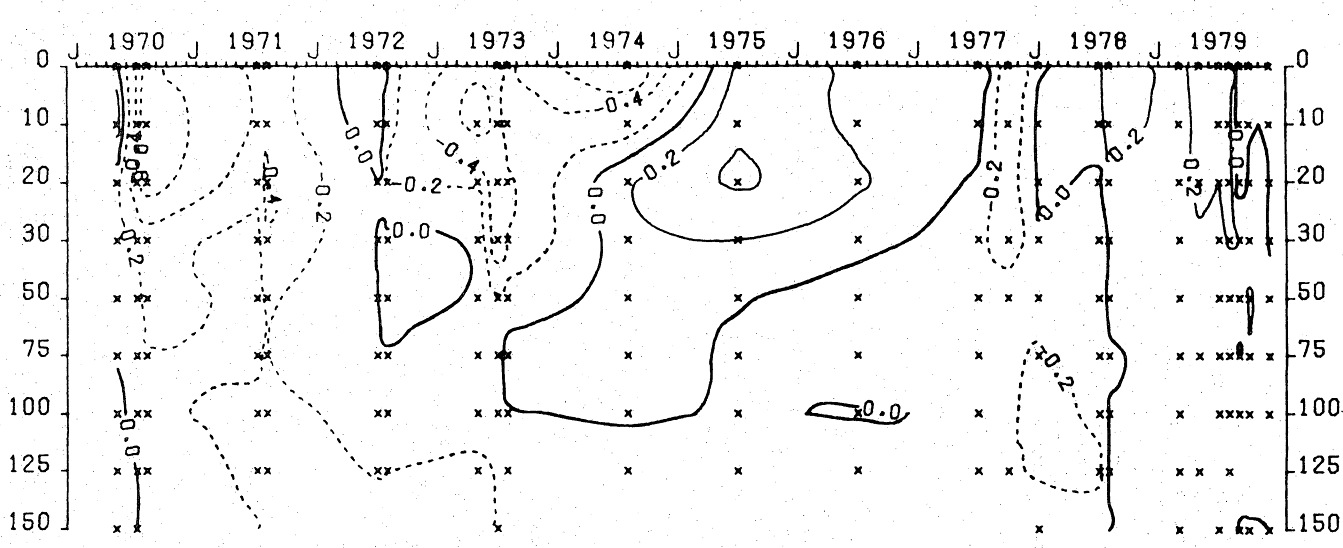
POTENTIAL TEMPERATURE ANOMALY AT STATION 1 OF THE FLEMISH CAP SECTION



DEPTHS ARE IN METRES CONTOURS ARE DEGREES C

DASHED LINES ARE NEGATIVE ANOMALIES

SALINITY ANOMALY AT STATION 1 OF THE FLEMISH CAP SECTION



DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

DASHED LINES ARE NEGATIVE ANOMALIES

Figure 13 Potential temperature anomaly (upper diagram) and salinity anomaly (lower diagram) at Station 1 of the Flemish Cap section for 1970-79 period.

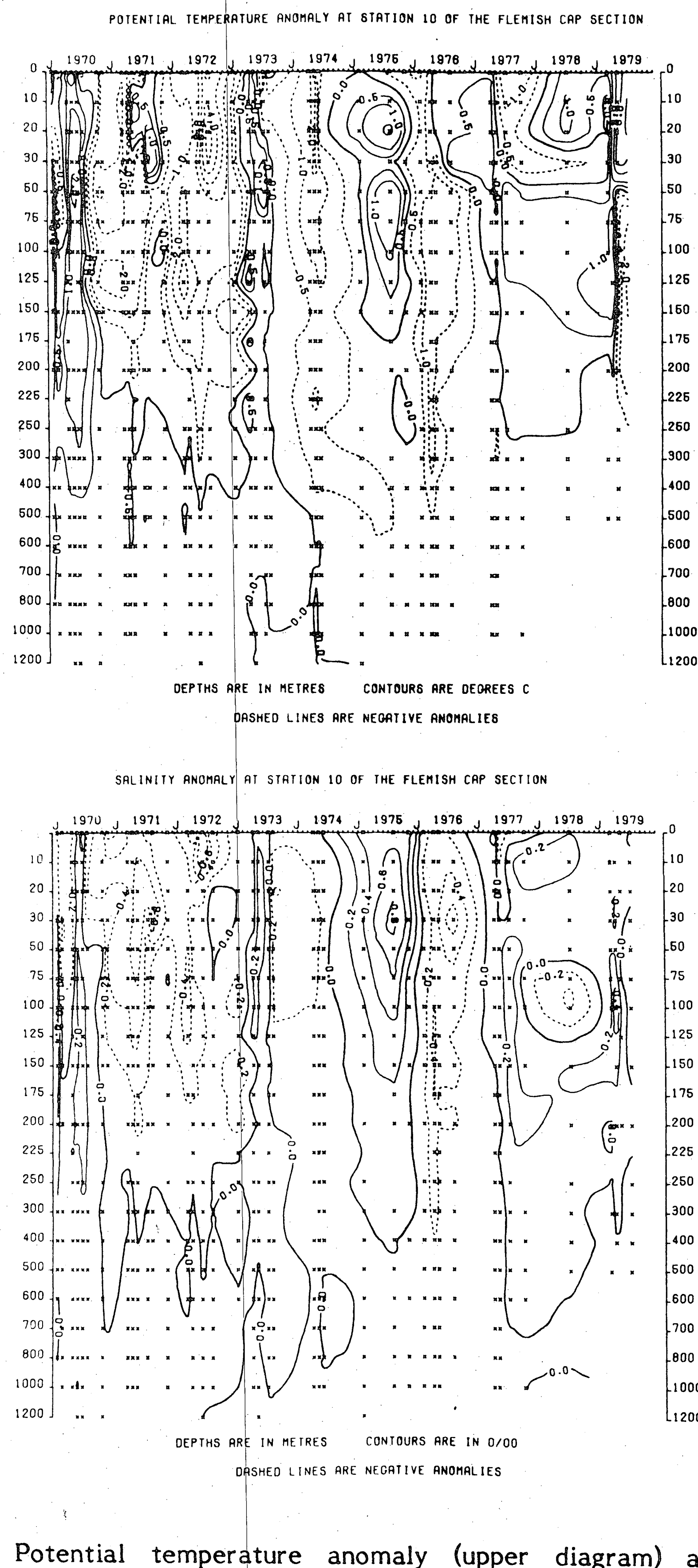
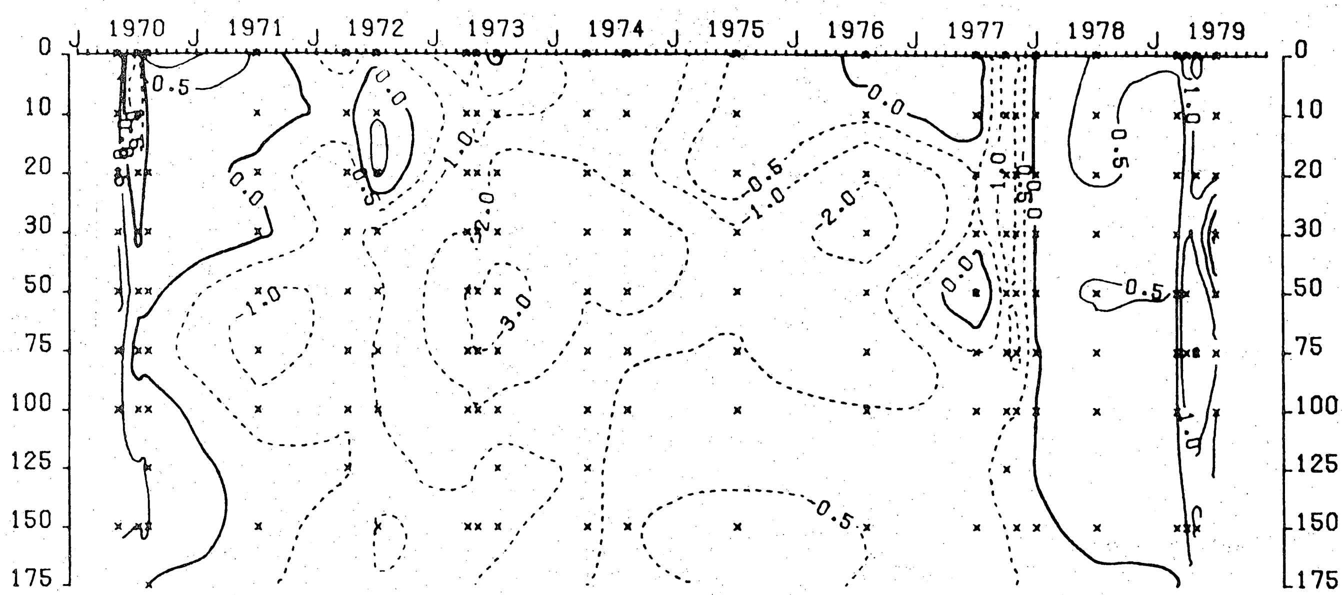


Figure 14 Potential temperature anomaly (upper diagram) and salinity anomaly (lower diagram) at Station 10 of the Flemish Cap section for 1970-79 period.

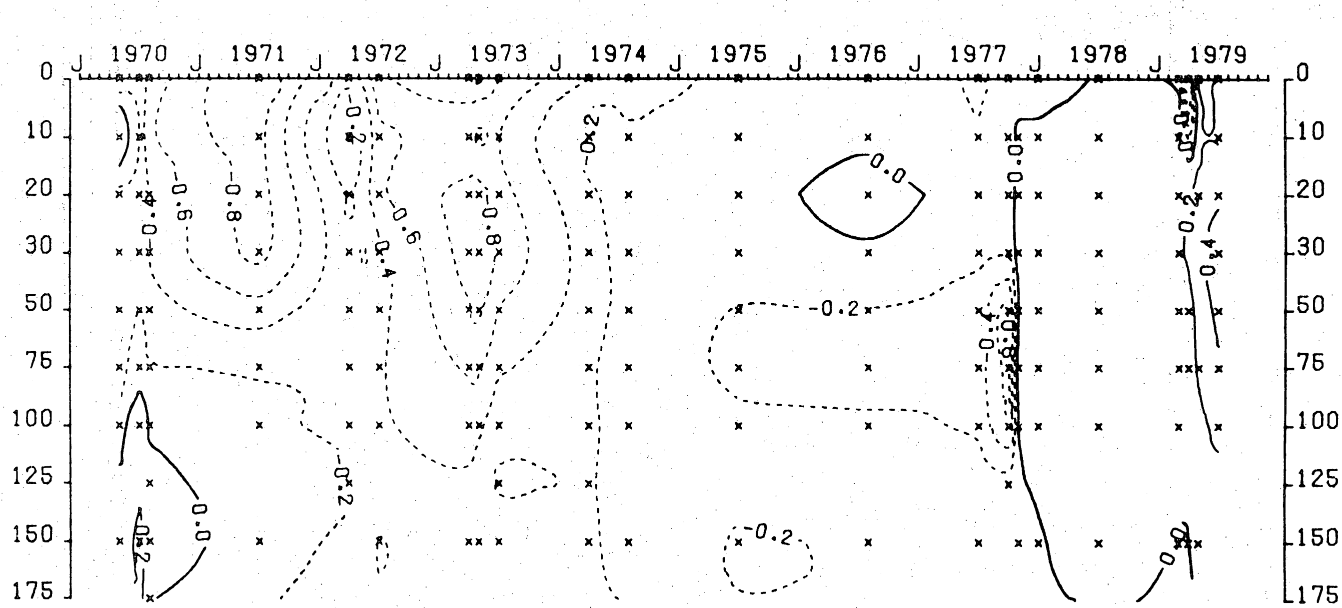
POTENTIAL TEMPERATURE ANOMALY AT STATION 16 OF THE FLEMISH CAP SECTION



DEPTHS ARE IN METRES CONTOURS ARE DEGREES C

DASHED LINES ARE NEGATIVE ANOMALIES

SALINITY ANOMALY AT STATION 16 OF THE FLEMISH CAP SECTION



DEPTHS ARE IN METRES CONTOURS ARE IN 0/00

DASHED LINES ARE NEGATIVE ANOMALIES

Figure 15 Potential temperature anomaly (upper diagram) and salinity anomaly (lower diagram) at Station 16 of the Flemish Cap section for the 1970-79 period.

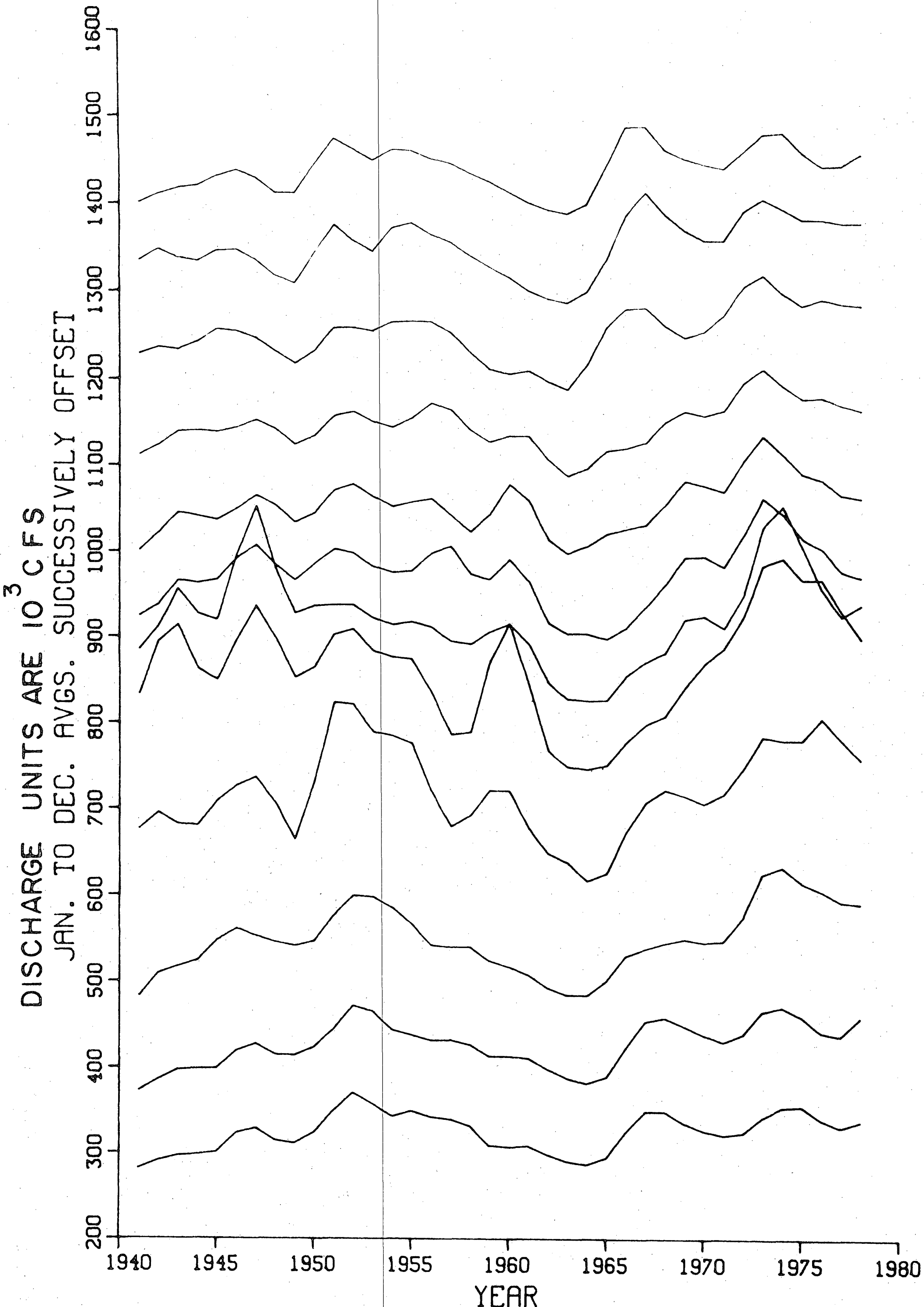


Figure 16 Plot of between year monthly discharge of St. Lawrence River system for period 1941-78. Lowest curve is for January. Each month is successively offset 10^5cfs for visual convenience. Three-year normally weighted smoothing has been applied.

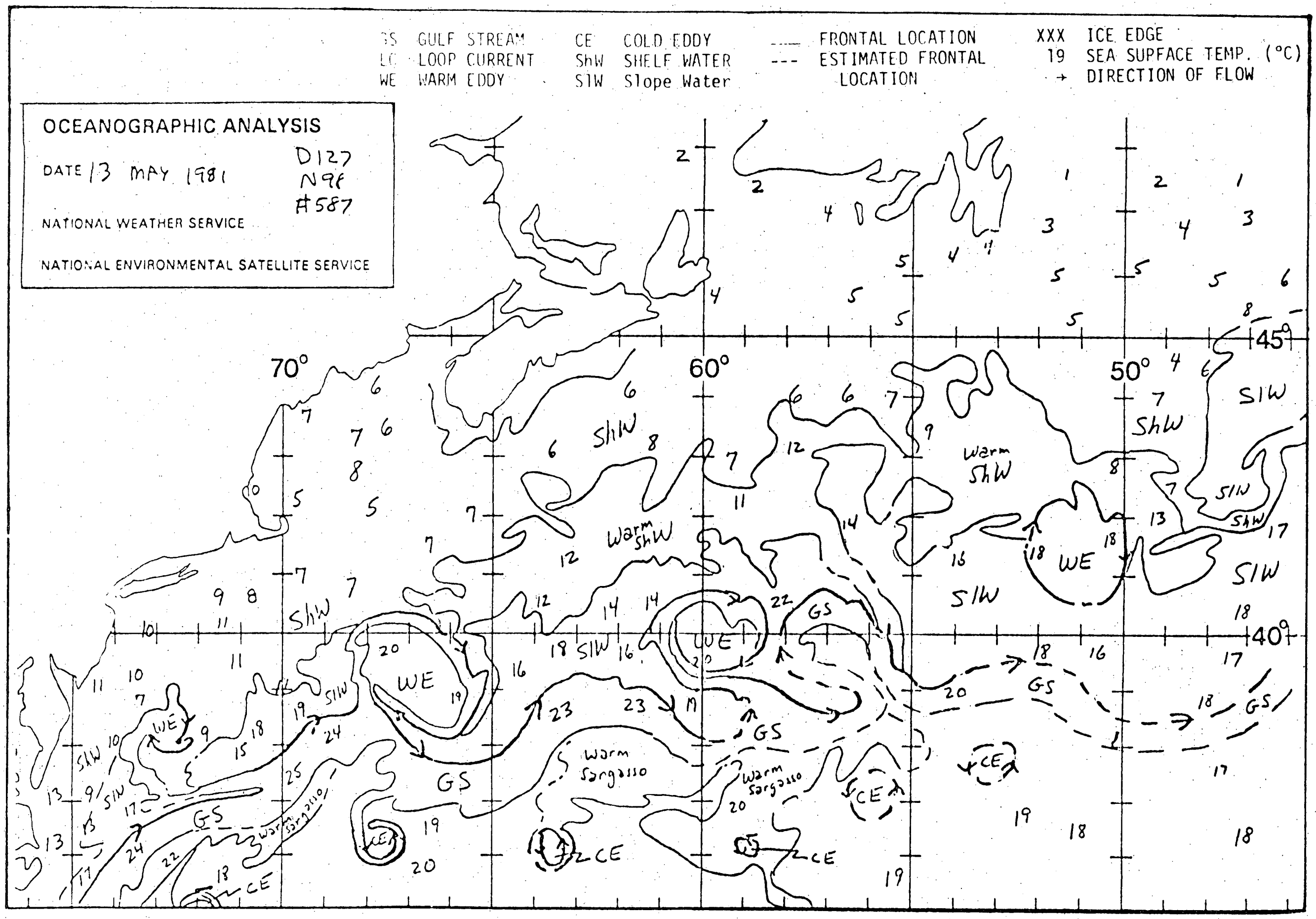


Figure 17 Map showing sea surface temperatures and frontal features for May 13, 1981, based on satellite infrared imagery and sea surface temperatures provided by ships of opportunity. (Prepared by the National Environmental Satellite Service of the U.S. National Weather Service).

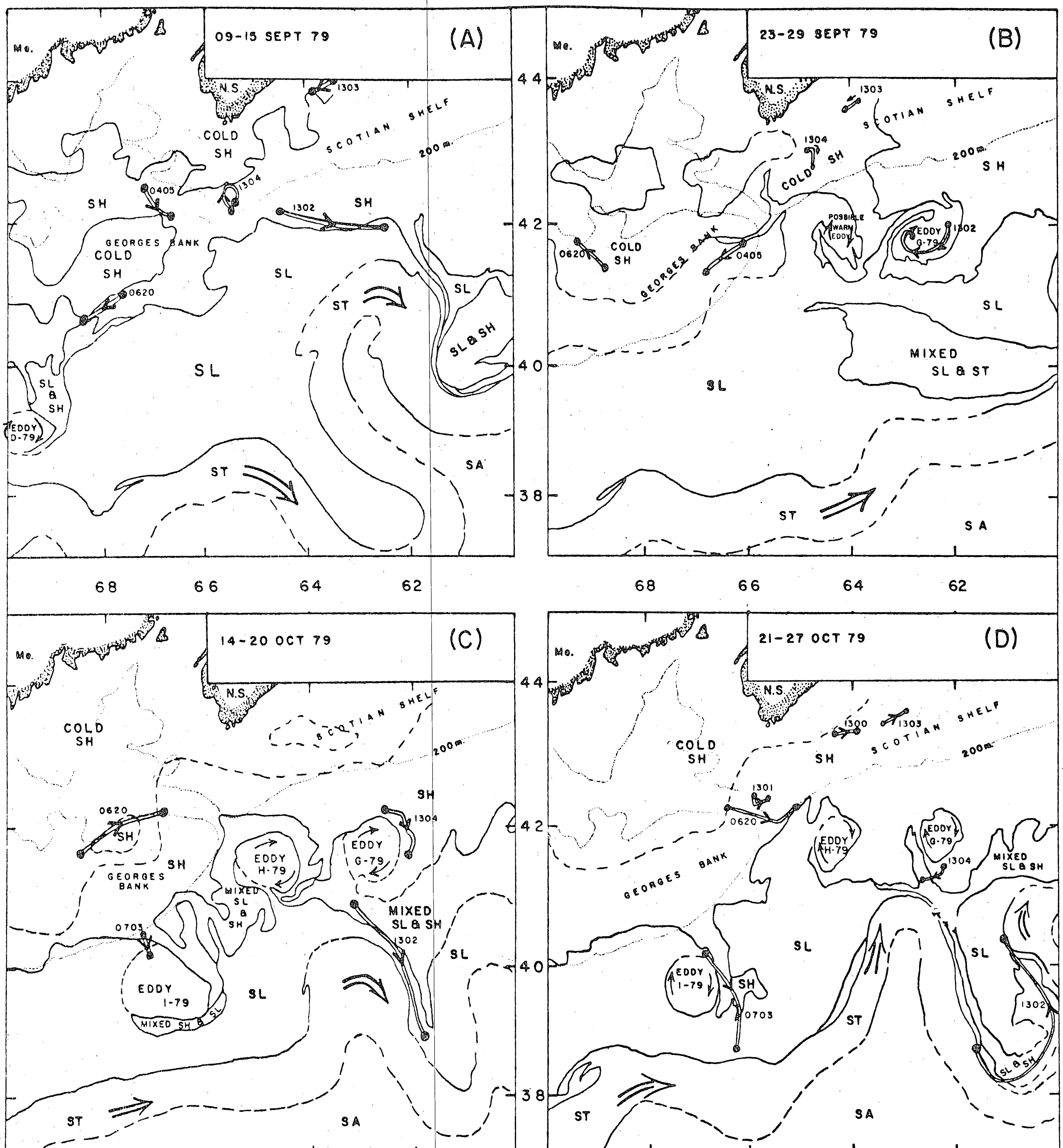


Figure 18 Maps showing surface thermal features for weekly periods and extracted from the U.S. Naval Oceanographic Experimental Ocean Frontal Analysis Charts: (A) 09-15 Sept 1979, (B) 23-29 Sept 1979, (C) 14-10 Oct 1979, and (D) 21-17 Oct 1979. Key for water types: SA = Sargasso, ST = Gulf Stream, SL = Slope Water, SH = Shelf water, and COLDSH = Cold Shelf water. Approximate trajectories of buoys for each 7 day period are also shown.

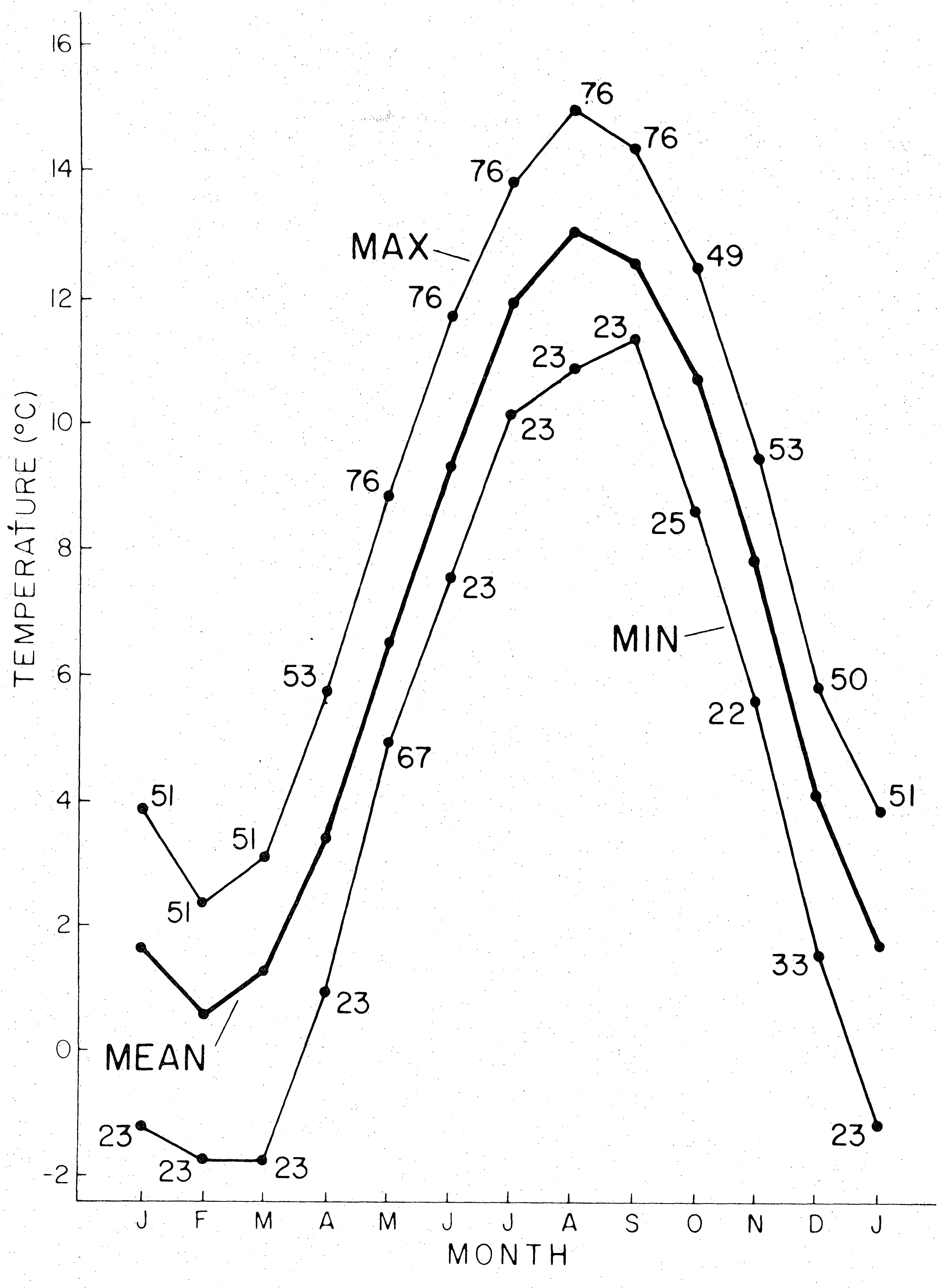


Figure 19 Mean monthly sea surface temperature, St. Andrews, N.B., 1921-1980 including monthly maxima and minima and the year of occurrence (23 = 1923, etc.).

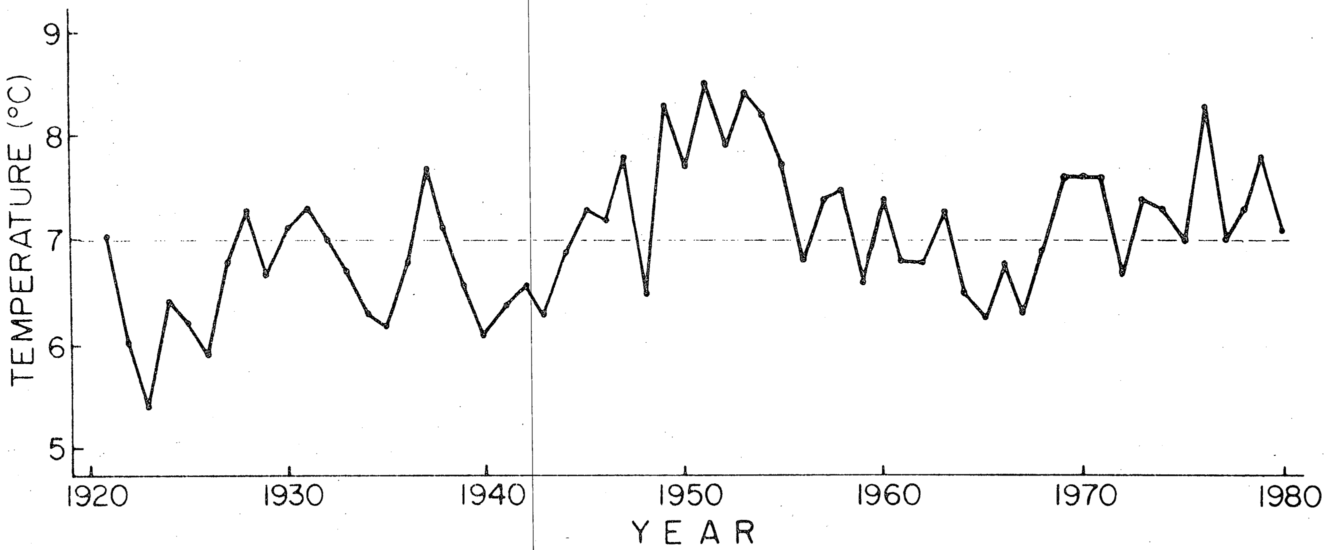


Figure 20 Mean annual sea surface temperature, St. Andrews, N.B. for period 1921-1980.

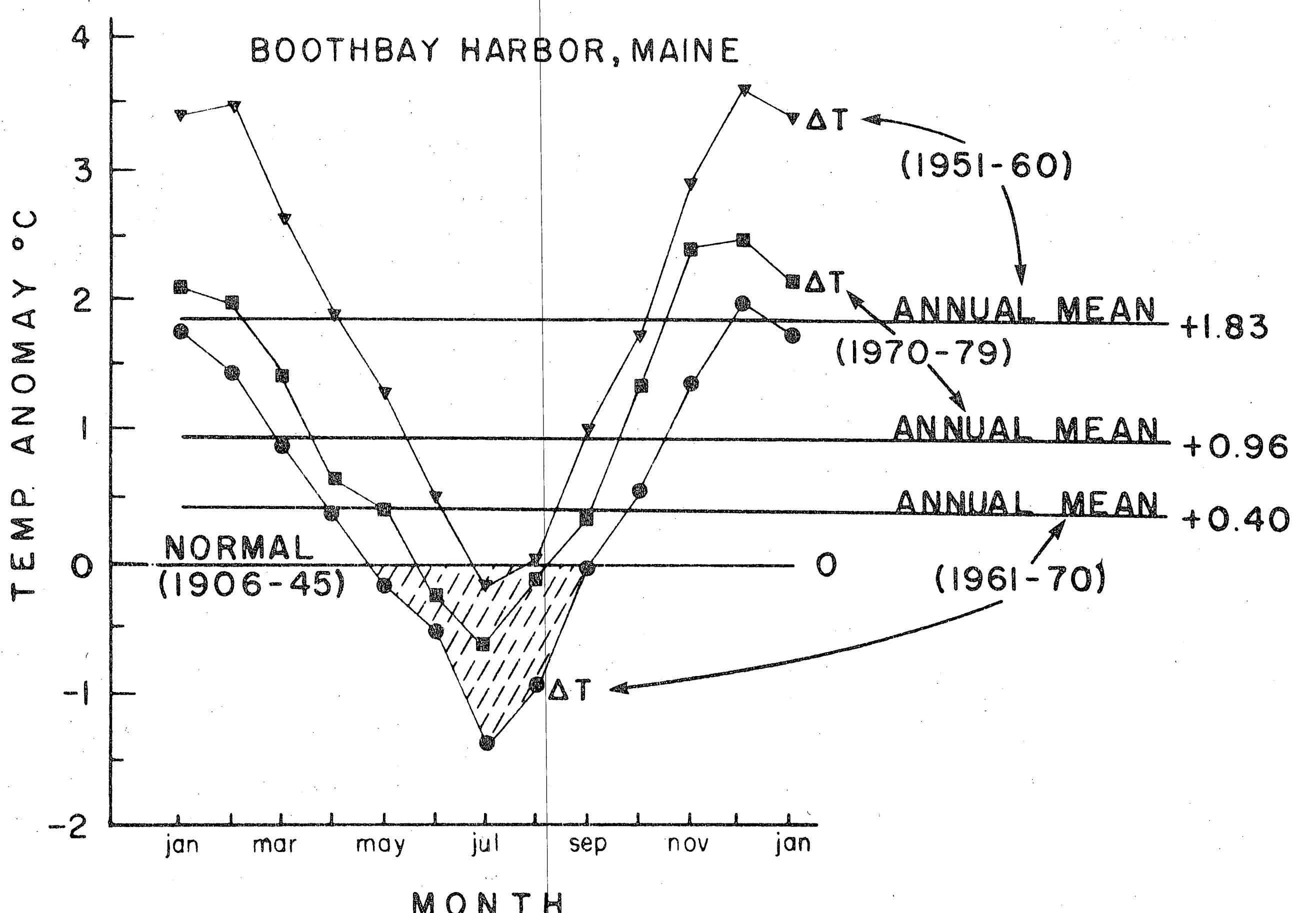


Figure 21 Deviation of 1951-60, 1961-70, and 1970-79 decadal monthly and annual means of sea surface temperature from normal for Boothbay Harbor, Maine, U.S.A. (Pre 1970 data from Rodewald 1972).

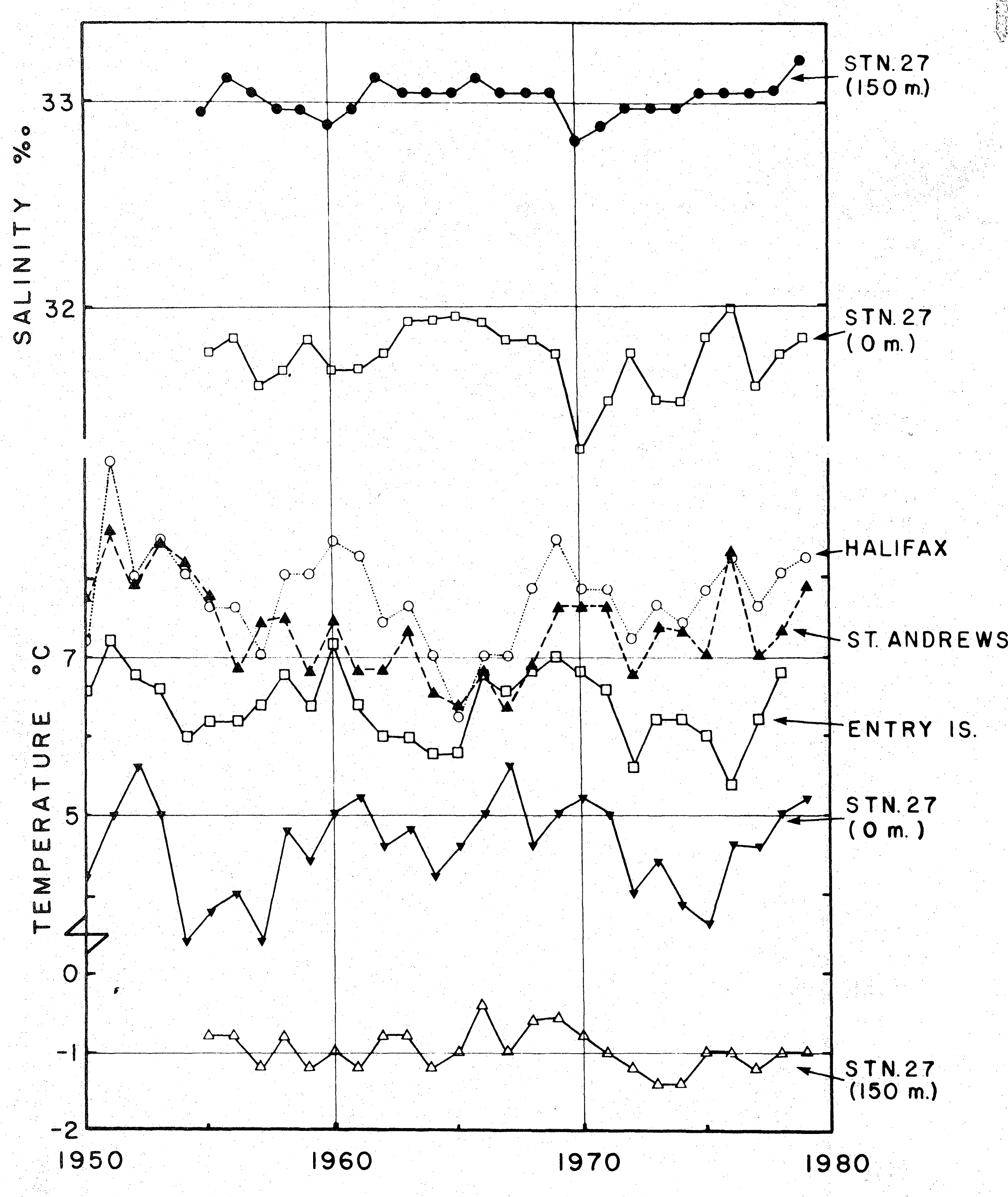


Figure 22 Mean annual sea surface temperature for St. Andrews, Halifax, and Entry Island for period 1950-1979. Mean annual temperature and salinity at surface and 150 M at Station 27 for period 1955-79 are also shown.

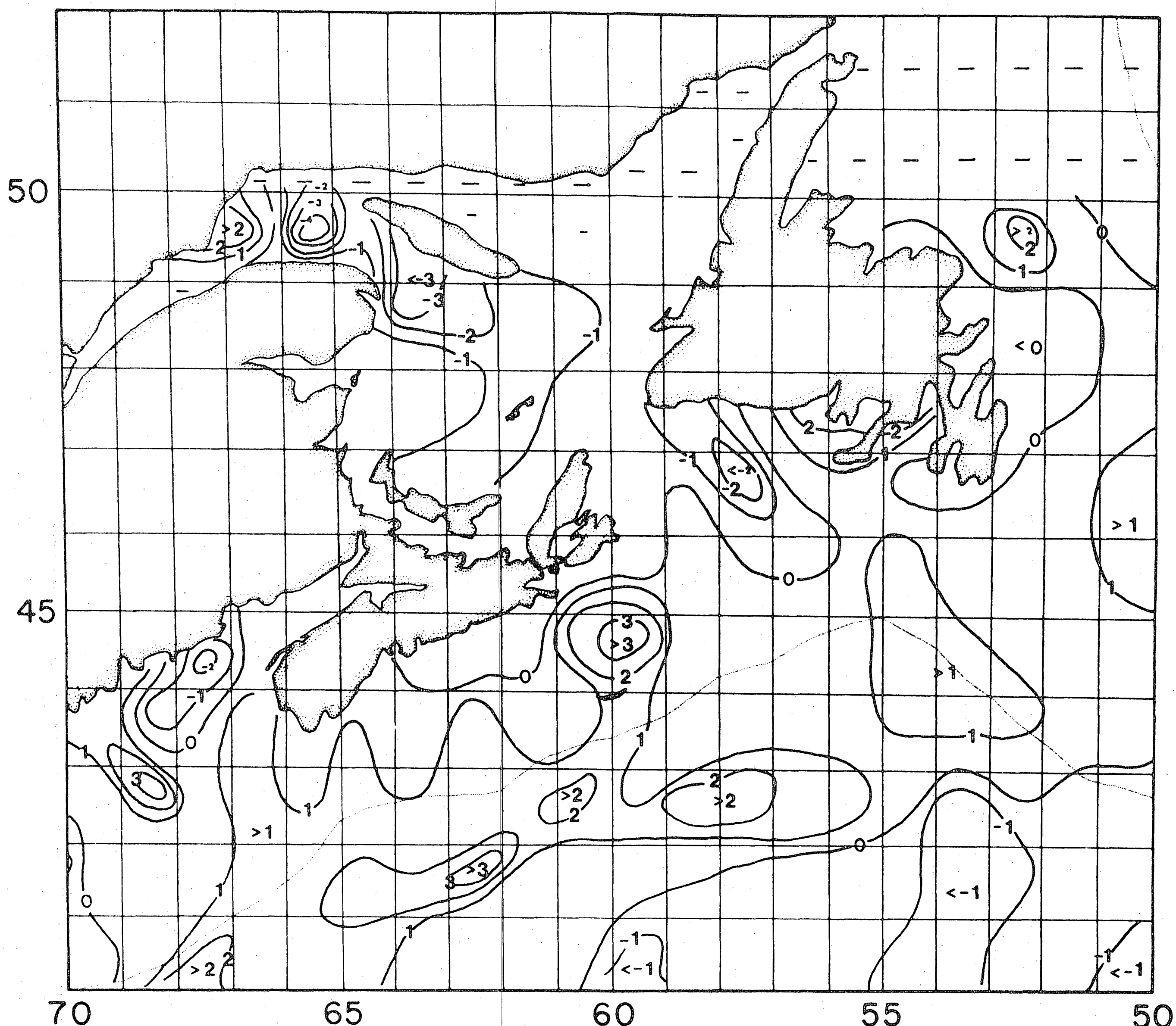


Figure 23 Sea surface temperature anomaly for the month of January in the 1970-79 period compared to that of January in the 1960-69 period. (data from World Climate Center, Asheville, N.C. and MEDS, Ottawa, and analyzed on a 1° square basis).

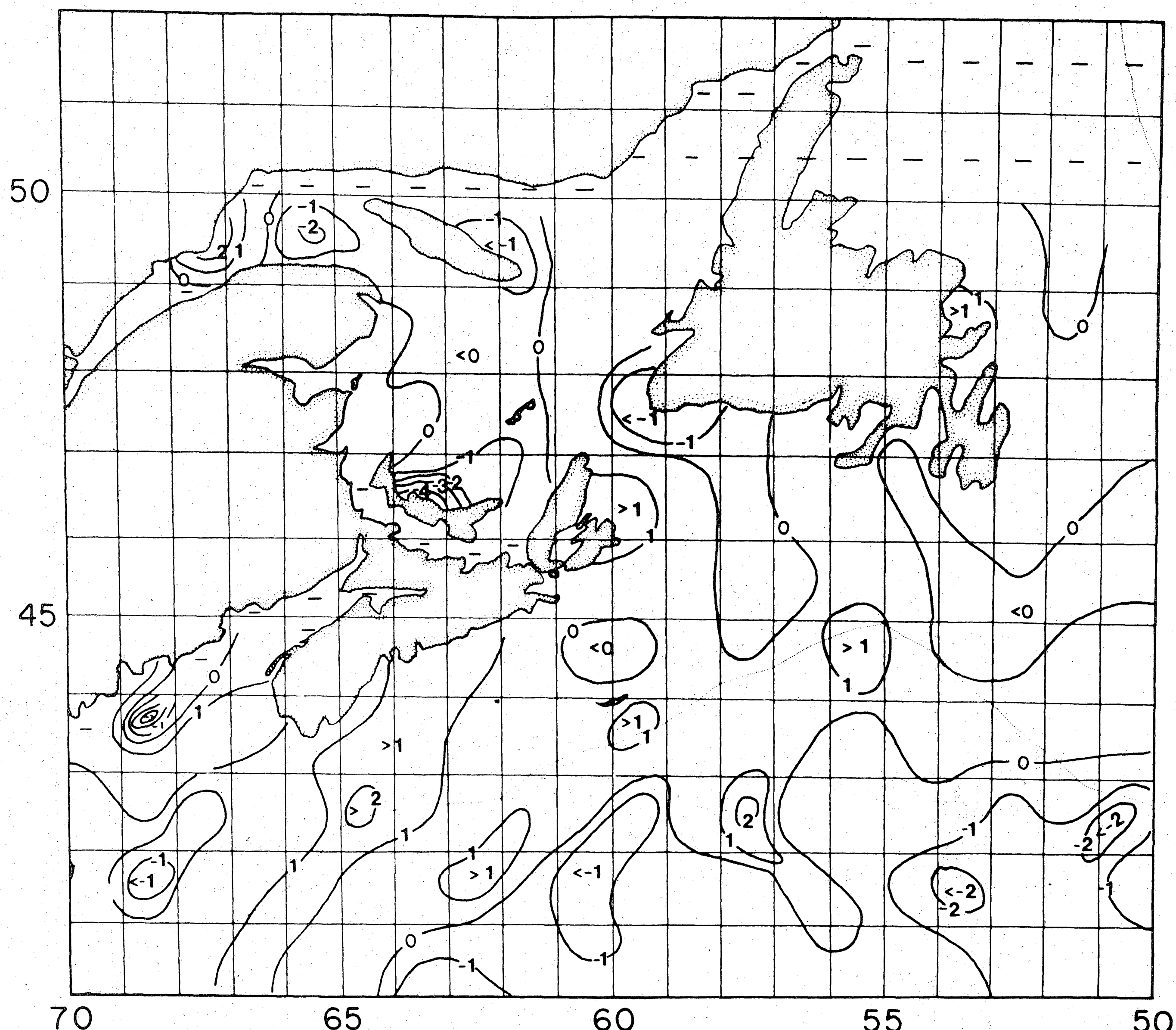


Figure 24 Sea surface temperature anomaly for the month of February in the 1970-79 period compared to that of February in the 1960-69 period. (Data from World Climate Center, Asheville, N.C. and MEDS, Ottawa, and analyzed on a 1° square basis).

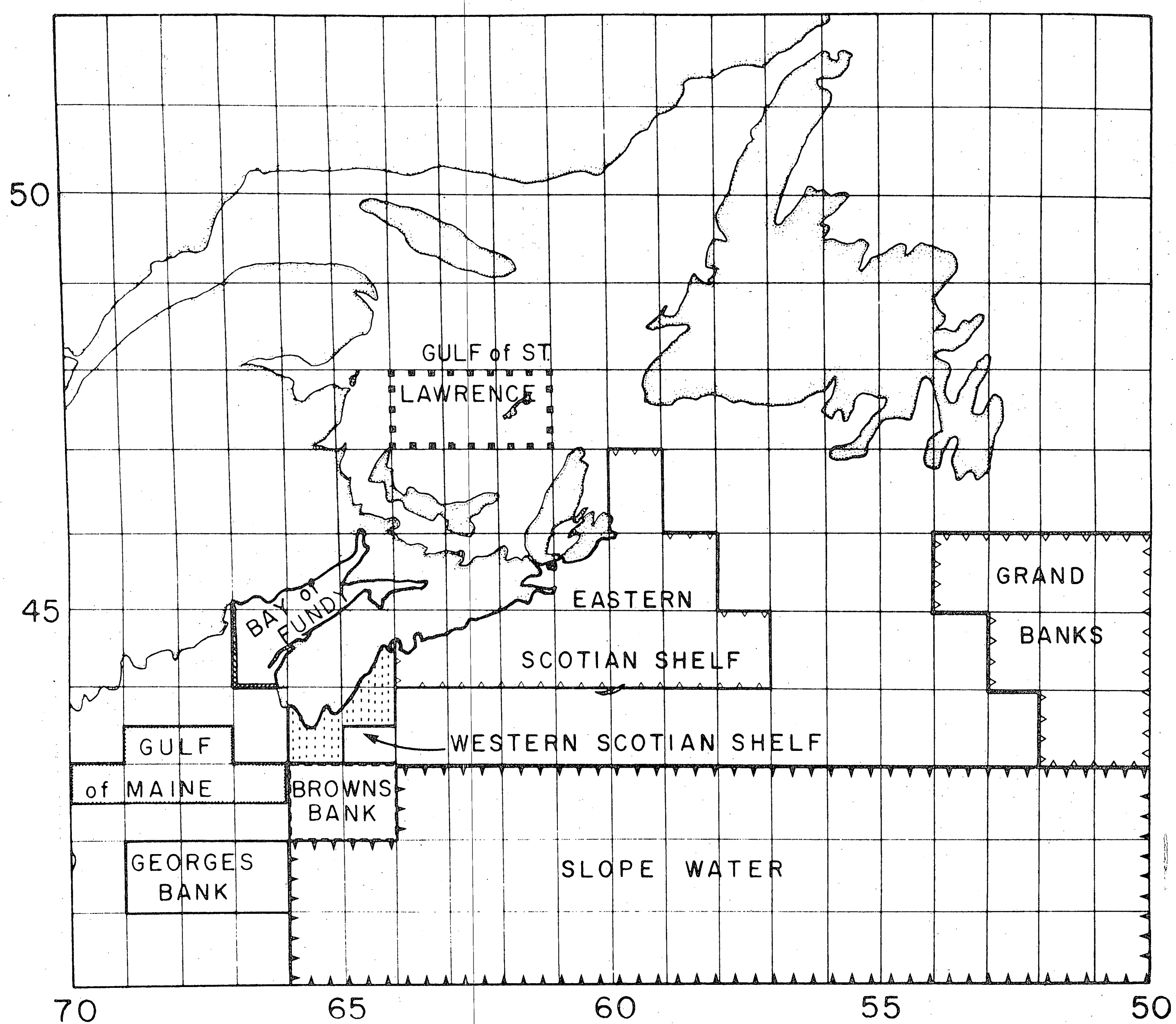


Figure 25 Map showing nine areas where sea surface temperature data were grouped together.

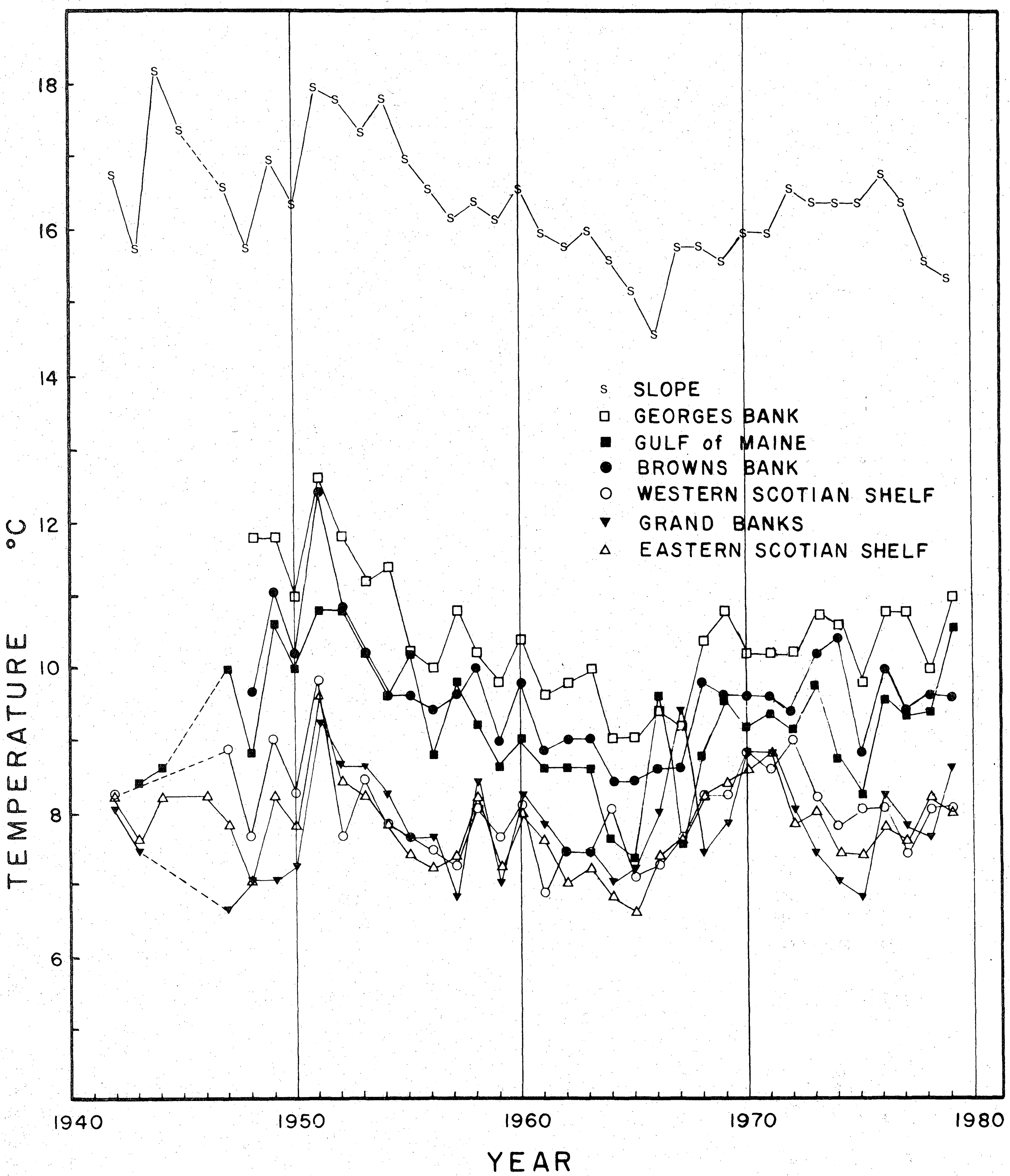


Figure 26 Mean annual sea surface temperature for period 1942-79 for seven of the subareas identified in Fig. 25.

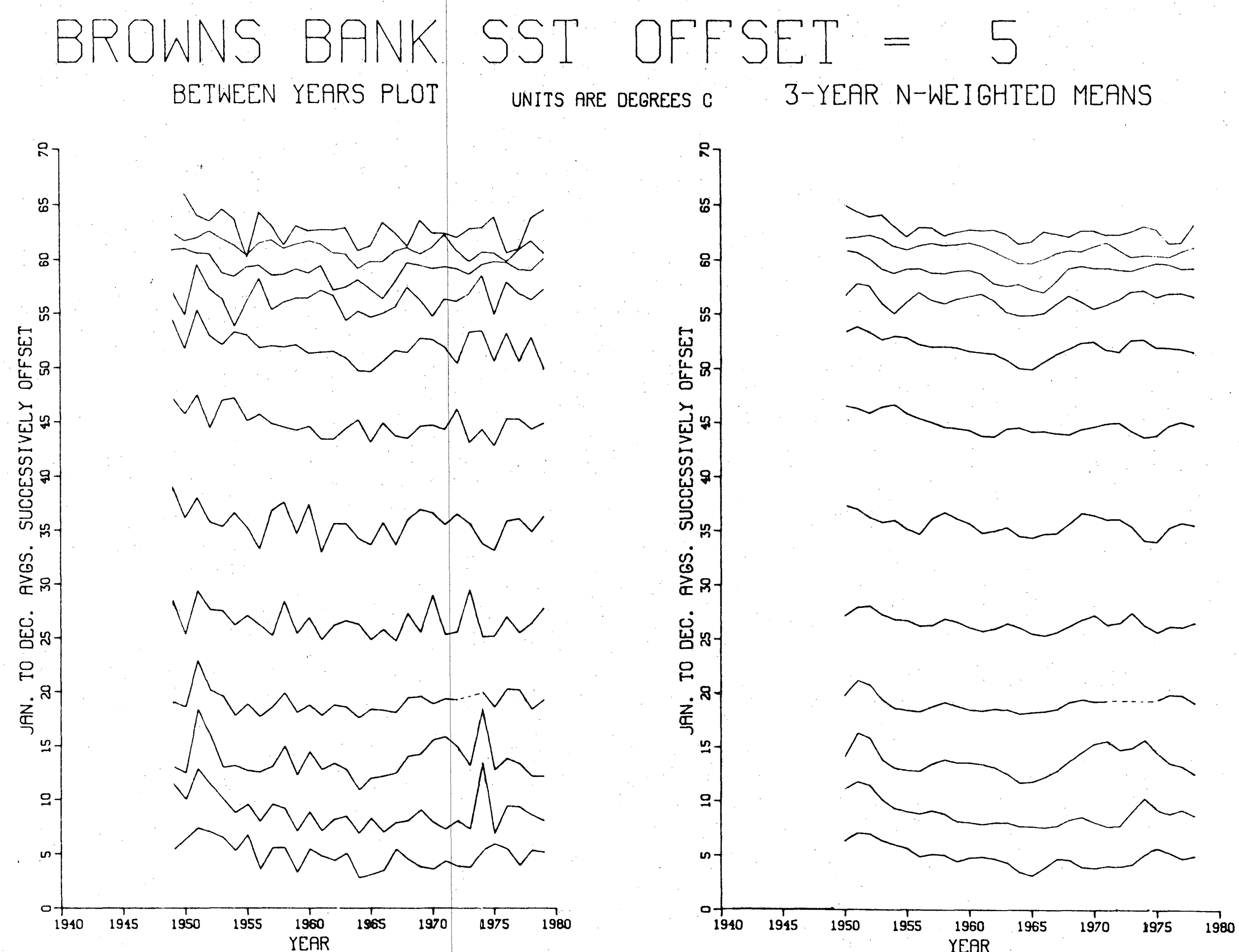


Figure 27 Plot of between year monthly temperature for Browns Bank area for period 1949-79. Lowest curve is for January. Each month is successively offset 5°C for visual convenience. Left hand diagram is unsmoothed. Right hand diagram is smoothed using 3-year normally weighted means.

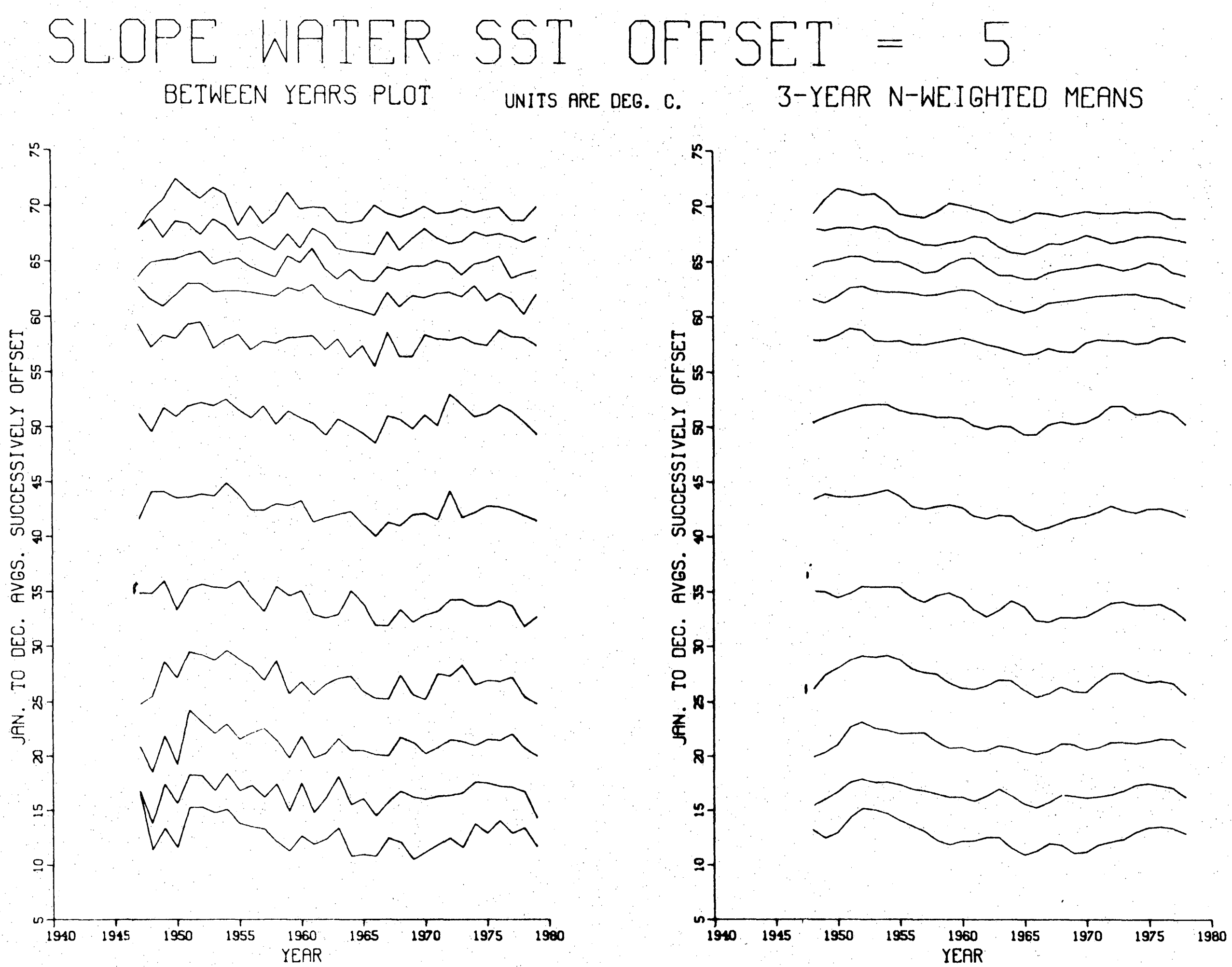


Figure 28 Plot of between year monthly temperature for Slope Water area for period 1947-79. Lowest curve is for January. Each month is successively offset 5°C for visual convenience. Left hand diagram is unsmoothed. Right hand diagram is smoothed using 3-year normally weighted means.

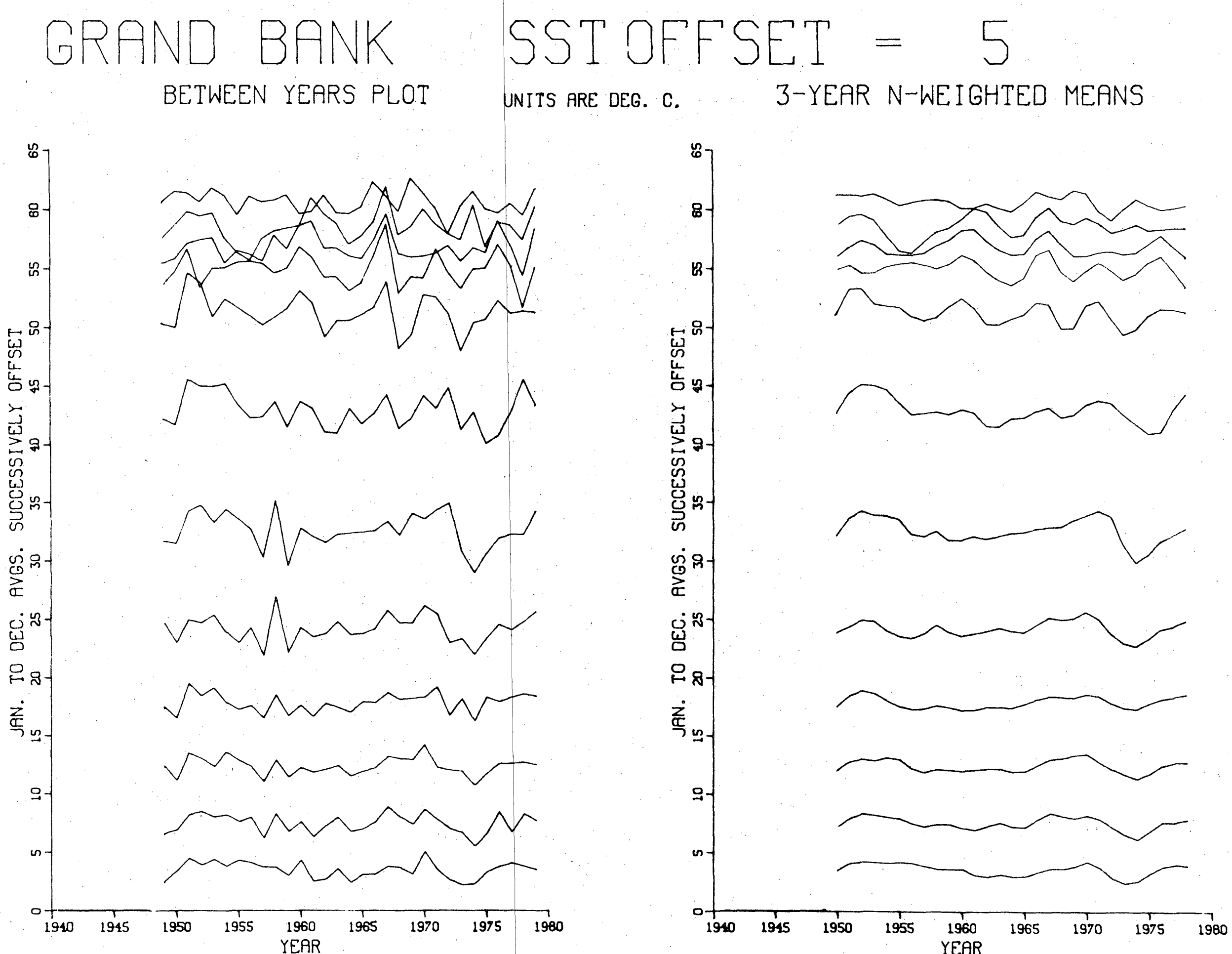


Figure 29 Plot of between year monthly temperature for Grand Bank area for period 1949-79. Lowest curve is for January. Each month is successively offset 5°C for visual convenience. Left hand diagram is unsmoothed. Right hand diagram is smoothed using 3-year normally weighted means.

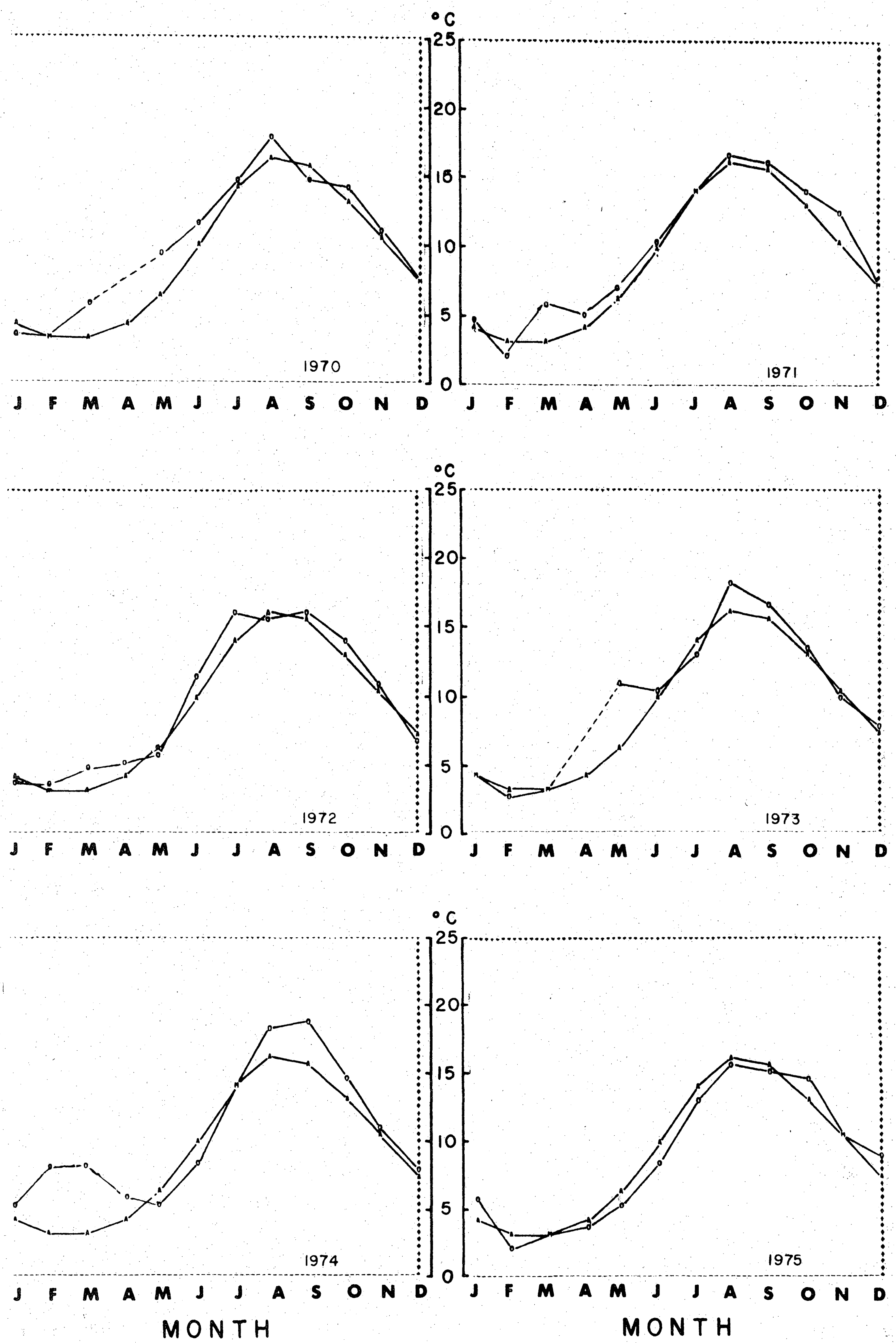


Figure 30 Mean monthly sea surface temperature in Browns Bank area for each year in the period 1970-75 inclusive. Shown also is the mean monthly temperature for the 1960-69 period.

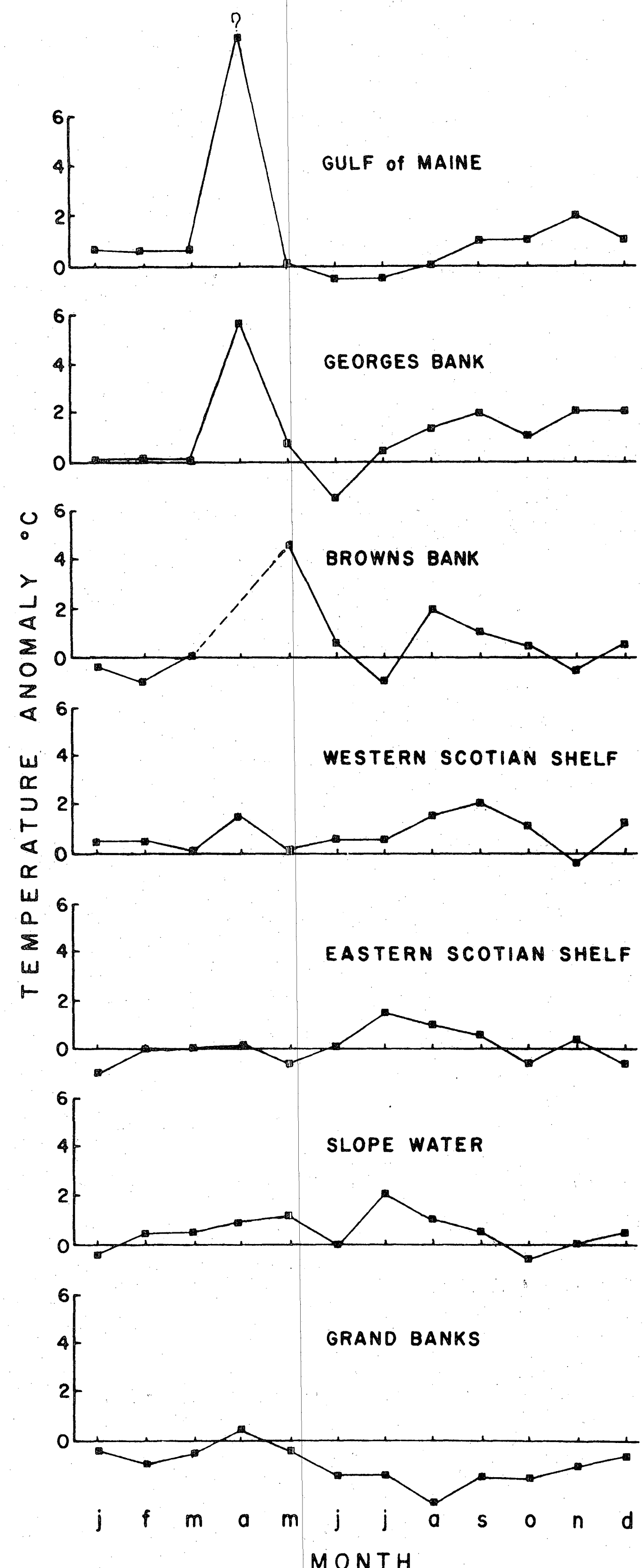


Figure 31 Monthly sea surface temperature anomaly for 1973 for seven of the grouped areas compared to the mean for 1960-69 decade.

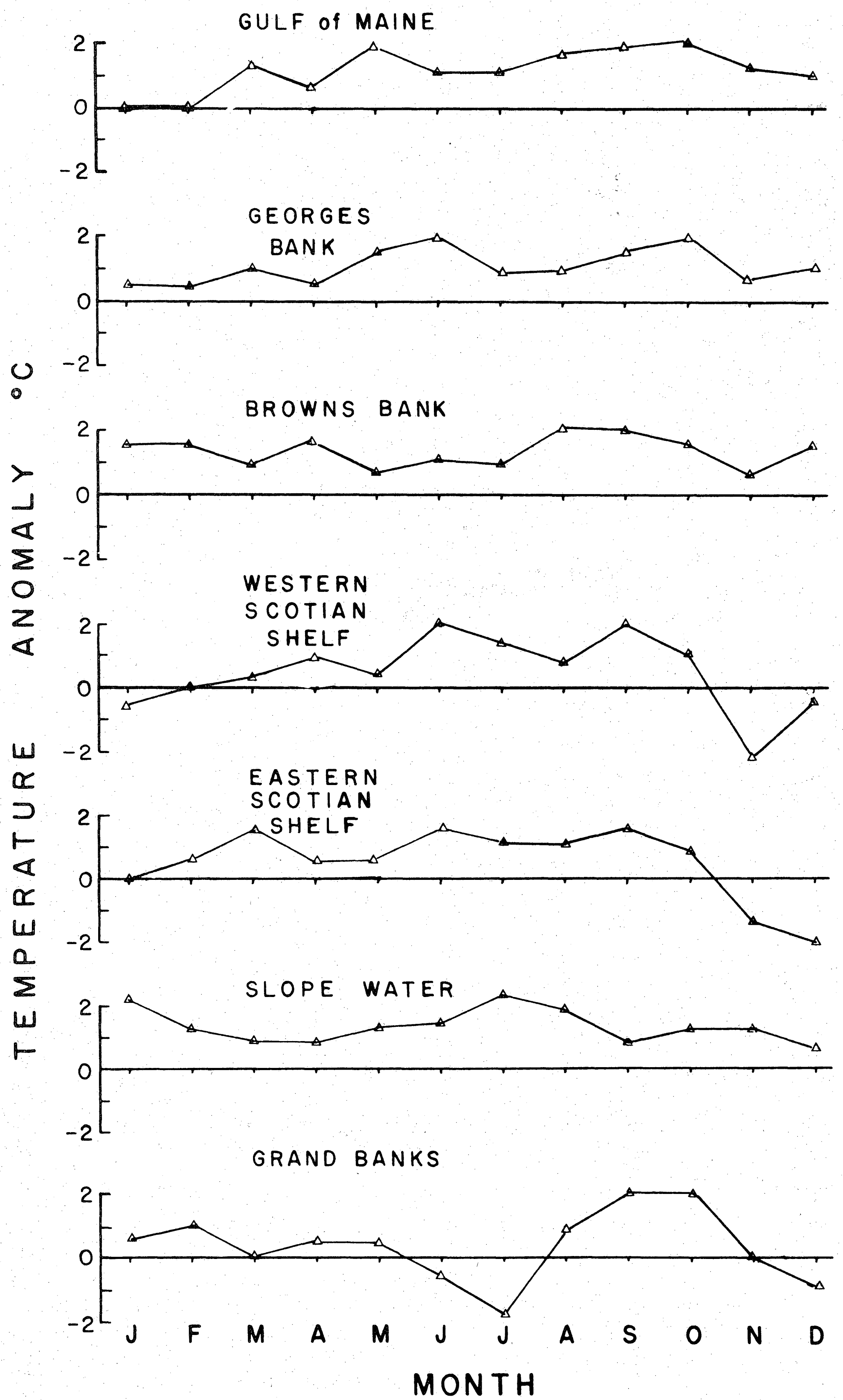


Figure 32 Monthly sea surface temperature anomaly for 1976 for seven of the grouped areas compared to the mean for 1960-69 period.

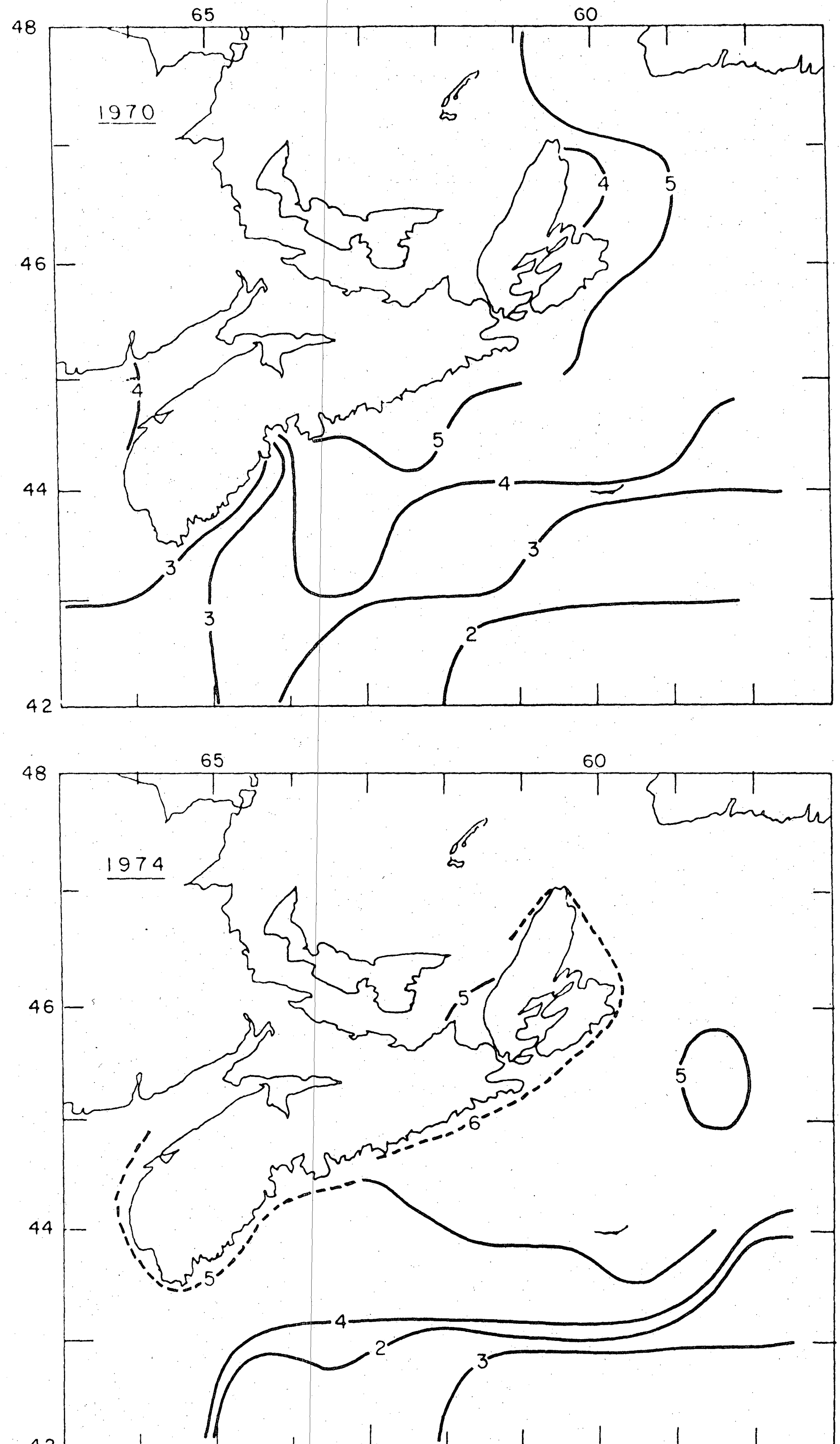


Figure 33 Maps showing the progression of the 7°C surface isotherm across the Scotian Shelf in the April to June period for a relatively warm spring, 1970 (upper diagram) and a relatively cool yer, 1974 (lower diagram). Location of isotherm is coded 1 = 1-15 April, 2 = 16-30 April, 3 = 1-15 May, 4 = 16-31 May, 5 = 1-15 June, 6 = 16-30 June.

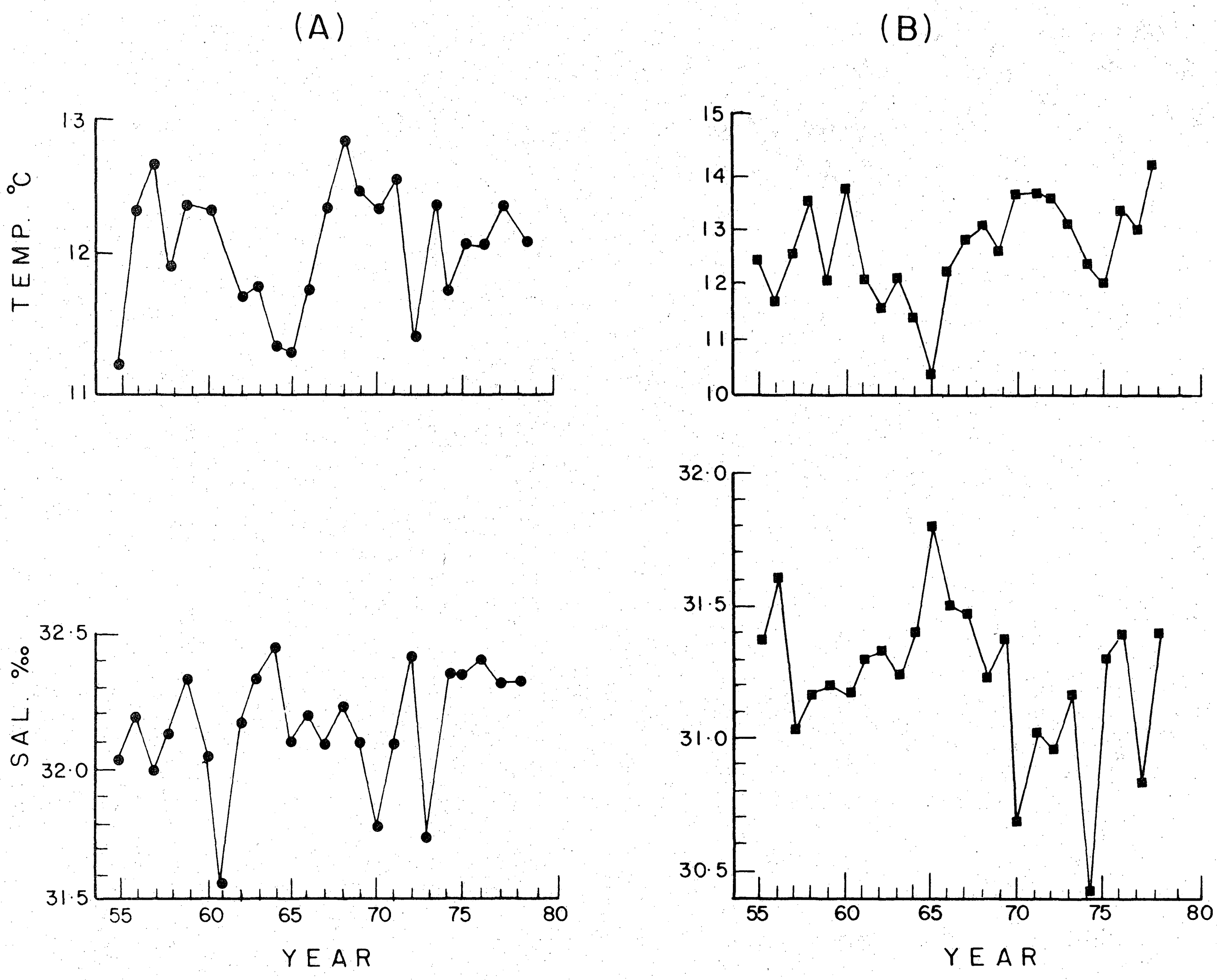


Figure 34A Plot of sea surface temperature (upper diagram) for Eastern Scotian Shelf area for months of September-November and sea surface salinity (lower diagram) for Station 27 for previous months of April-June for period 1955-78. Same data as used to compute correlation coefficient circled in Table 2. (r = -0.8).

Figure 34B Plot of sea surface temperature (upper diagram) for Eastern Scotian Shelf for months of June-August and sea surface salinity (lower diagram) for Station 27 for following months of September-November for period 1955-78. Same data as used to compute correlation coefficient circled in table 3 (r = -0.8).

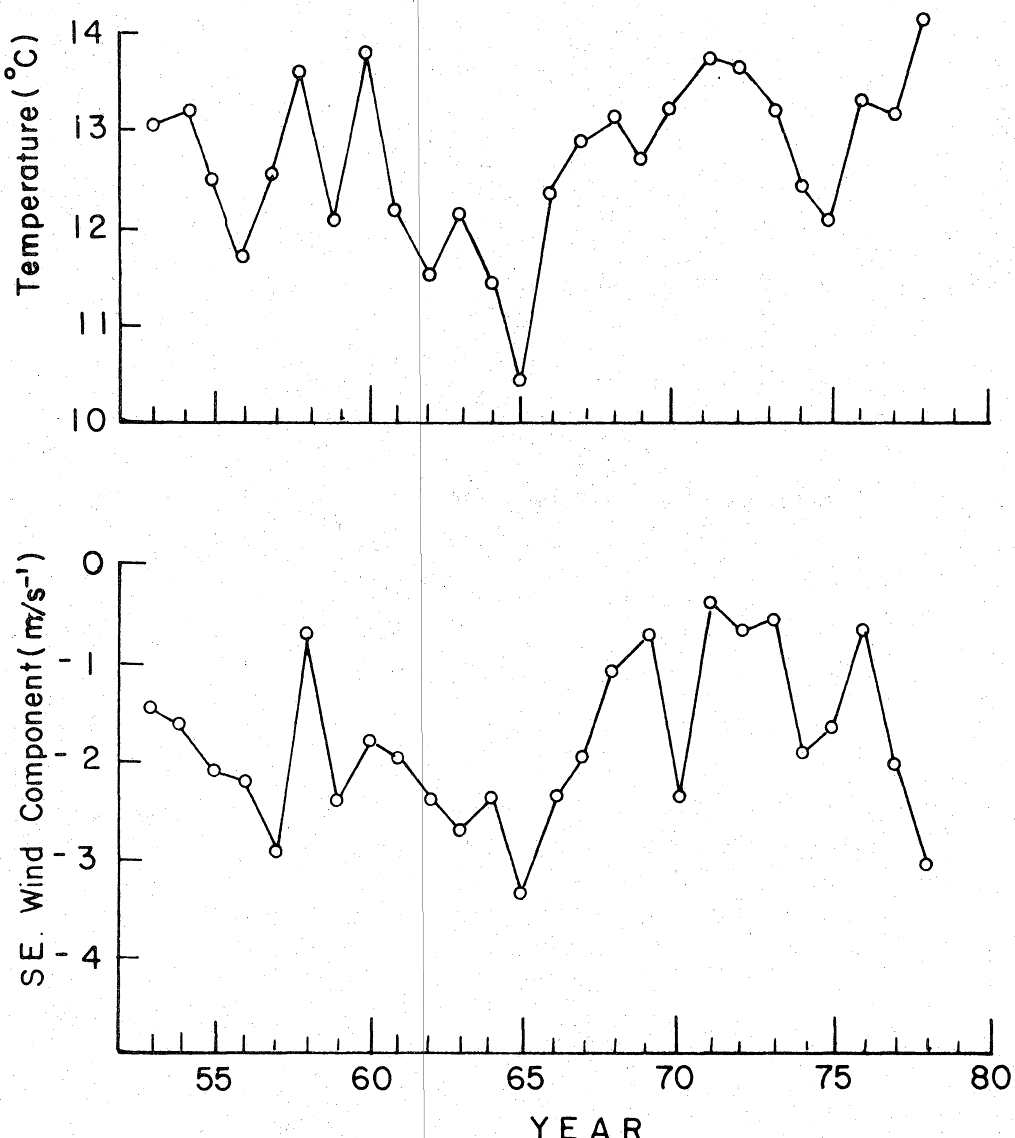


Figure 35 Plot of southeast component of wind speed (lower diagram) for Sable Island for months of February-April and sea surface temperature (upper diagram) for Eastern Scotian Shelf for following months of June-August, for period 1953-78. Same data as used to compute correlation coefficient circled in Table 4 (r = 0.8).