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Interannual Variability in Temperature and Salinity

on the Southeast Shoal of the Grand Bank

by

John W. Loder and Charles K. Ross
Physical and Chemical Sciences, Department of Fisheries and Oceans
Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada B2Y 4A2

SPECIAL SESSION ON ENVIRONMENTAL CONDITIONS

ABSTRACT

Preliminary results are presented from an analysis of historical temperature and salinity data from the southern Grand Bank. The data are interpolated to standard depths and sorted into four areas. Annual cycles are then determined and anomalies are computed for each season of each year. The resulting anomaly time series are used to examine the time scales, and horizontal and vertical space scales over which the anomalies are correlated. Correlations with the Station 27 hydrographic time series and a wind energy input index are also presented.

The preliminary results show significant interseasonal, vertical and horizontal coherence, suggesting that the dataset is sufficient to extract a real interannual variability signal. The seasonal anomalies for the Southeast Shoal in the 1980's are presented and discussed.

INTRODUCTION

For many years now, hydrographic observations have been routinely collected on the Newfoundland Shelf as part of fisheries (e.g. Templeman 1975) and iceberg surveys (e.g. Smith et al. 1937). The most extensive time series of such data, from Station 27 near St. John's, Newfoundland, has recently been analyzed to show significant interannual variability related to large-scale atmospheric and oceanographic variations in the northwestern Atlantic (Myers et al. 1988; Petrie et al. 1988a,b).

Another area from which a large quantity of observations has been taken, and where fisheries and oceanographic research studies are currently in progress (e.g. Frank and Carscadden 1988; Carscadden et al. 1988; Loder and Ross 1988), is the Southeast Shoal of the Grand Bank (see location map in Fig. 1). Scientifically, the examination of interannual hydrographic variability there is appealing on several counts. The warmest summertime bottom temperature on the entire Grand Bank occurs over the Shoal (Loder and Ross 1988; see Fig. 2), and there are suggestions that this temperature feature may influence the location and timing of capelin spawning (Frank and Carscadden 1988; Carscadden et al. 1988). Furthermore, the Shoal's southern location places it near the boundary between water masses of subpolar (relatively-cool shelf water) and subtropical (slope water) origin so that the magnitude of any hydrographic variability may be amplified. From a fisheries management perspective, the location over the Shoal of the boundary of Canada's exclusive economic zone increases the importance of spatial shifts and other hydrographic variability which may affect fish distributions (e.g. Carscadden et al. 1988).

In this paper, we present preliminary results from an examination of the historical hydrographic data from the southern Grand Banks region. The examination is one component of a co-operative research program between Canada's Department of Fisheries and Oceans (DFO) and McGill University into oceanographic variability on the Southeast Shoal and its influence on fish distributions and recruitment (see Loder and Ross (1988) for a summary of the program's mooring component). The emphases here will be on the correlation space and time scales of interannual variations in the season-averaged anomalies of temperature and salinity over the Shoal, the relation of these variations to wind forcing as hypothesized by Frank and Carscadden (1988), and the anomalies in the 1980's.

DATA ANALYSIS

Data Grouping and Temporal Distribution

The analysis is based on all temperature and salinity data available from the Marine Environmental Data Service of DFO as of April 1986 for the years up to 1980, and as of June 1988 for 1981 to 1987. For each station, interpolated values of temperature and salinity were determined for vertical levels of 0, 10, 20, 30, 40, 50, 60 and 75 m (below the sea surface), provided that there was observed data within half the distance to adjacent levels. The interpolated data were then time-stamped according to the observation date, and arbitrarily grouped into 4 areas (Fig. 1): area 1 - the southwestern slope, where Templeman and Hodder (1965) observed slope water intrusions; area 2 - the central Bank, chosen to be representative of any southward drift over the Bank (e.g. Petrie and Anderson 1983); area 3 - the eastern shelf-break, influenced by a southward-flowing branch of the Labrador Current (e.g. Petrie and Anderson 1983); and area 4 - the Southeast Shoal, corresponding to the climatological bottom-temperature feature in Figure 2. Quality control was performed on each data group, consisting of deletion of stations with depths greater than the maximum chart depth in each area and critical examination (and deletion, as appropriate) of all stations with any interpolated value greater than 4 standard deviations from the monthly mean for that level and area.

The temporal distribution of the data in the area of primary interest here (area 4) is illustrated in Tables 1 and 2, where the number of temperature and salinity values at the 0- and 50-m levels is shown by month over all years, and by year over all months. These levels are chosen to be nominally representative of the surface and bottom water, respectively. Over all years (Table 1), the temperature data are reasonably well-distributed across months, except for December through February when the data quantity is marginal for the determination of a climatological annual cycle, let alone the examination of interannual variability. The salinity data have a similar distribution across months, but are reduced in quantity such that any analysis for November through February is even more marginal. The distribution by year (Table 2) shows promise for examining interannual temperature variability in the 1960's, 70's and 80's, and possibly salinity variability in the 1980's.

Annual Cycle Determination

To facilitate the examination of interannual variability, the climatological annual variation in each data group was determined and extracted, using least squares regression to a mean, a sinusoid of period one year, and its higher harmonics (following the general approach of Akenhead 1987). In general, there was little reduction in the mean square difference between the observed data and the regression model prediction upon the inclusion of the third harmonic, so only the first (annual) and second (semi-annual) harmonics were retained.

Seasonal Anomaly Determination

The anomaly of each interpolated value was then determined as its difference from the value of the fitted annual cycle for that day. Because of the data sparcity, arithmetic averages of these anomalies were computed for each season of each year (referred to as season-averaged or seasonal anomalies), in contrast to the monthly anomalies (or residuals) computed for the larger Station 27 dataset (Akenhead 1987). The seasons were arbitrarily chosen as : Winter - January to March; Spring - April to June; Summer - July to September; and Autumn - October to December. The seasonal anomalies can then form a time series over all seasons and years, or can be subsampled by season to form time series over years for particular seasons.

Station 27 Data

Time series of the monthly anomalies of temperature and salinity at standard depths, and for the vertical intervals 0-20 m and 75 - 150 m at Station 27 (47° 38'N, 52° 38'W) were obtained for the years 1959 - 1987 from B.D. Petrie (personal communication 1988). Anomalies for each season were then computed by arithmetic averaging.

Wind Stress Data

Time series of the monthly standard deviation of the north and east components of surface wind stress, derived from 6-hourly geostrophic winds (Atmospheric Environment Service, Downsview, Ontario, Canada) at 44°06'N, 50°30'W were provided for the years 1946-1986 by K.F. Drinkwater (personal communication 1988). A total standard deviation of wind stress was computed for each month, and then cubed to obtain a rough estimate of wind energy input to the ocean (see Appendix A of Loder and Greenberg 1986). The average of this parameter was then computed for each season. This estimate is based on the observation (e.g. Saunders 1977; Petrie and Smith 1977) that most of the wind energy over the northwestern Atlantic shelf is in the storm band (period of days to weeks) and hence approximately reflected by the monthly standard deviation.

Exploratory Correlation Analyses

The lagged autocorrelation of each time series of seasonal temperature and salinity anomalies for areas was computed to examine the interseasonal persistence of the anomalies. In addition, the lagged correlation between each of the 0- and 50-m anomaly time series and the anomaly time series for the other levels in each area was computed to examine the vertical coherence of the temperature and salinity anomalies. Statistical significance was computed using the student's t test (without accounting for any serial correlation at this point). The results of these analyses for area 4 alone are presented in this preliminary report.

As an initial examination of the horizontal correlation scales of the anomalies, correlations at zero lag were computed between each of the 0- and 50-m temperature and salinity anomaly time series in area 4 and the 0- and 50-m anomaly time series in the other three areas. Correlations at zero lag were also computed between the 0- and 50-m time series for each area and the 0-20 m, 50 m and 75-150 m time series for Station 27. The statistical significance of these correlations was computed as noted above.

Finally, to examine whether the seasonal-anomaly time series show support for Frank and Carscadden's (1988) hypotheses regarding strong wind-mixing influences on the hydrographic structure over the Southeast Shoal, correlations at zero lag were also computed between the 0- and 50-m temperature and salinity anomalies in area 4, and the season-averaged wind stress standard deviations. These correlations were computed by season to allow for any seasonal variation in the wind-stress influence.

RESULTS

Annual Cycles

The interpolated temperature and salinity values for the 0- and 50-m levels in area 4 are shown in Figures 3 and 4, with the data for all years plotted against Julian day. The regression curves for each dataset are also shown.

The largest annual cycle is found for the temperature at 0 m, with 87% of the total variance explained by the regression. The data show some persistent deviations from the computed cycle (e.g. in August and September), however, so that the absolute magnitude of each season-averaged anomaly should only be interpreted in relation to the long-term (over all years) mean of the anomalies for that particular season. The annual temperature cycle at 50 m is substantially weaker than at 0 m, and only accounts for 27% of the variance. This vertical variation is consistent with the dominating influence of the annual cycle in solar radiation on the heat content of the near-surface water.

For salinity, only 27% and 8% of the total variance are explained by the regression curves for the 0- and 50-m levels, respectively. The annual cycle at 0 m is consistent with the late-summer arrival on the Newfoundland Shelf of the seasonal low-salinity pulse (e.g. Petrie et al. 1988b), although the variation for winter is poorly determined. The computed cycle at 50 m is not statistically significant.

The annual cycle curves for temperature and salinity at all the vertical levels between 0 and 50 m are shown in Figure 5. For temperature, the amplitude of the annual cycle decreases, and the phase lag increases with depth below the surface, as expected for vertical mixing of the surface heat input (e.g. Petrie et al. 1988b). For salinity, the 0-m cycle is also seen at 10 m, and at 20 m with reduced amplitude and increased lag, while the cycles at deeper levels are not statistically significant.

<u>Seasonal Anomalies</u>

The time series of the seasonal anomalies of temperature and salinity at 0 and 50 m in area 4 are shown in Figures 6 and 7 for all seasons and years since 1930 (a few observations from earlier years were included in the annual cycle variation determination but their associated anomalies are not shown here). The standard deviation about each seasonal anomaly is also shown. Anomalies based on even a single observation are included, although specification of some minimum number of observations per season is being considered for the final analysis. Some possibility for the extraction of a real interannual variability signal is indicated by the variation among the anomalies being comparable in magnitude to the typical standard deviation of the individual anomalies. The anomalies for the 1980's are discussed in more detail in a later section.

a. Autocorrelations

The autocorrelation results for temperature and salinity at 0 and 50 m in area 4 are shown in Figure 8. For 0-m temperature and salinity, the correlations are statistically significant at the 95% confidence level for lags of one season only. In contrast, the correlation for 50-m temperature is significant for lags up to and including 4 seasons, while for 50-m salinity, it is also significant for a lag of 3 seasons. The 0-m temperature autocorrelation is consistent with the previous results of Thompson et al. (1988) and Petrie et al. (1988b) that sea surface temperature anomalies in the northwestern Atlantic and at Station 27, respectively, have decorrelation time scales of only several months. Similarly, the 50-m temperature autocorrelation is consistent with Petrie et al.'s finding that the decorrelation time scale of subsurface temperature at Station 27 is substantially longer than that for surface temperature. The interseasonal persistence of the computed anomalies also provides support for the dataset being large enough to extract real interannual variability.

b. Vertical Correlations

The lagged correlations between each of the 0- and 50-m anomaly time series, and the anomalies of the same variable at other levels in area 4 are generally maximum for zero lag. These zero-lag correlations, all significant at the 95% level, are shown in Figure 9. Although these results confirm significant vertical coherence for the seasonal anomalies of both temperature and salinity on the Southeast Shoal, the correlations are substantially higher for salinity. The low correlations between the 0-m temperature anomalies and those for depths below 20 m suggests that surface temperature may not be a very representative index of interseasonal oceanographic variability at depth over the Shoal.

c. Horizontal Correlations

Preliminary results on the horizontal coherence of the seasonal anomalies over the southern Grand Bank are presented in Table 3, in the form of correlations at zero lag between each of the 0- and 50-m temperature and salinity anomalies in area 4, and the anomalies at 0 and 50 m in areas 1, 2, and 3. It can be seen that, in general, the anomalies are most highly correlated with the anomalies of the same parameter at the same level in the other areas, with the highest correlations for the 0-m time series. There are also significant correlations across the vertical levels for the salinity data, and for the temperature data in some cases. These results suggest that there may be a coherent variation in each of surface and bottom temperature across the southern Grand Bank, and of salinity throughout the water column. This is again supportive of the existence of a real variability signal in the data.

The zero-lag correlations between the 0- and 50-m temperature and salinity anomalies for area 4, and the near-surface (0-20 m), 50-m and lower water column (75-150 m) anomalies at Station 27 are shown in Table 4. These correlations are substantially lower than those within the southern Grand Bank, although still significant for temperature for 0 m in area 4 versus 0-20 m at Station 27, and 50 m in area 4 versus 75-150 m at Station 27. However, there are no significant correlations (at zero lag at least) between the salinity anomalies in area 4 and at Station 27. The temperature results are again consistent with the previous results of Thompson et al. (1988) and Petrie et al.(1988b), while those for salinity are somewhat surprising in view of the coincidence of anomalously high salinities on Southeast Shoal and at Station 27 in 1987 (Loder and Ross 1988; Myers et al. 1988) On the other hand, the salinity results may be a reflection of a strong slope-water influence on Southeast Shoal salinity anomalies, or of insufficient salinity data.

d. Correlations with Wind Energy Input

The correlations between the 0- and 50-m temperature and salinity anomalies in area 4 and the seasonal wind energy index are shown in Table 5 for the spring and summer seasons which have the largest datasets. No significant correlations are found. Thus, the season-averaged data show no statistically significant support for an influence of wind mixing on interannual surface and bottom temperature variability on Southeast Shoal, although the sign of the surface temperature correlations is consistent with Frank and Carscadden's (1988) hypothesis. (There is, however, some support for a significant wind-mixing influence on the time scale of days in moored measurements taken on the Shoal in 1986; Loder and Ross 1988.)

e. Anomalies in the 1980's

The temperature and salinity anomalies at 0 and 50 m in area 4 in the 1980's are shown in Figures 10 and 11. A temperature anomaly is shown for most seasons, and a salinity anomaly for over half of the seasons, but spring is the only season for which there is an anomaly based on at least 3 observations for both temperature and salinity at both levels in all years (1980-87). Hence, we focus attention here on the spring anomalies.

The 0-m temperature anomaly undergoes a slow variation between positive and negative anomalies in 1981 - 1983, with the spring anomalies in 1983 and 1981 being the first and second largest positive anomalies in the entire spring dataset (43 years). Spring 0-m temperature was near or below normal in 1984 - 1987, with 1985 having the largest negative anomaly of the 80's (ninth overall).

The 50-m temperature anomaly is less variable than the 0-m temperature anomaly, and less variable in the mid 1980's than in the early 1980's. The largest positive spring anomalies in the 80's were in 1983 and 1984 (fourth and sixth largest positive in 37 years), and the largest negative anomaly was in 1985 (third largest negative overall). These anomalies are qualitatively consistent with the June bottom temperatures presented by Carscadden et al. (1988) in their examination of spawning capelin distributions.

The 0-m salinity anomalies were most negative in 1985 and 1984, with the spring anomalies in those years being the second and fourth largest negative anomalies respectively in 26 years. The largest positive anomalies were in 1987 and 1980, sixth and seventh largest overall. The 50-m salinity anomalies show greater interannual variability than those at 0 m, with the 1983 and 1987 spring anomalies being the first and third most positive in 22 years, and the 1985 and 1984 being the second and third most negative.

DISCUSSION

This preliminary examination of the 0- and 50-m seasonal temperature and salinity anomalies on the southern Grand Bank suggests that the existing hydrographic dataset is sufficient to examine interannual variability, particularly for temperature, for the 1960's, 1970's and 1980's, and for coarse space (order 100 km) and time (seasons) scales. Further analysis of this dataset is planned, in relation to other available indices of atmospheric and oceanographic variability in the northwestern Atlantic and in conjunction with the ongoing DFO-McGill field studies of oceanographic and larval capelin variability on the Southeast Shoal.

ACKNOWLEDGEMENTS

The data analyses reported here were carried out by Maria José Graça whose dedication and organization have been invaluable in obtaining results for presentation at this Symposium. We are grateful to Maria José, as well as to Ken Drinkwater and Brian Petrie for providing datasets, and to our colleagues (particularly Miriam Morrison) at the Marine Environmental Data Service for co-operation and patience in providing the hydrographic dataset.

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TABLE 1. Number of interpolated temperature and salinity values at the 0- and 50-m levels in area 4 by month, summed over all years.

	TEMPERATURE		**SALINITY**	
MONTH	**0 m**	**50 m**	**0 m**	**50 m**
January	10	3	5	2
February	13	5	2	0
March	54	17	14	11
April	192	74	20	14
May	226	125	65	58
June	411	222	60	37
July	153	72	35	22
August	115	55	44	16
September	142	82	18	7
October	119	70	33	35
November	62	38	7	2
December	17	11	2	1

TABLE 2. Number of interpolated temperature and salinity values at the 0- and 50-m levels in area 4, by year summed over all months.

YEAR	TEMPERATURE 0 m	TEMPERATURE 50 m	SALINITY 0 m	SALINITY 50 m	YEAR	TEMPERATURE 0 m	TEMPERATURE 50 m	SALINITY 0 m	SALINITY 50 m
1926	3	3	3	3	1964	13	10	1	1
1932	1	0	1	0	1965	8	6	1	1
1933	1	1	1	1	1966	4	0	0	0
1934	3	2	3	2	1967	23	10	0	0
1935	2	1	2	1	1968	28	8	0	2
1937	1	0	1	0	1969	57	16	3	0
1938	2	4	2	4	1970	19	13	10	7
1947	5	5	5	4	1971	26	12	18	7
1948	2	0	0	0	1972	38	16	1	0
1949	1	0	1	0	1973	35	12	29	11
1950	1	1	1	1	1974	10	3	1	1
1951	7	4	7	4	1975	36	20	0	0
1952	6	1	3	1	1976	21	10	0	0
1953	4	2	4	2	1977	31	19	0	0
1954	6	2	3	1	1978	68	33	9	7
1955	16	9	4	3	1979	41	14	10	3
1956	6	3	3	2	1980	117	41	29	9
1957	7	2	1	0	1981	84	44	6	5
1958	11	6	2	1	1982	30	15	8	6
1959	38	25	4	3	1983	45	22	10	8
1960	20	13	7	6	1984	40	22	10	6
1961	15	9	2	2	1985	74	49	24	19
1962	7	4	1	0	1986	293	148	20	9
1963	21	6	1	1	1987	187	128	54	61

TABLE 3. Correlations between each of the seasonal temperature and salinity anomalies at the 0- and 50-m levels in area 4, and each of the temperature and salinity anomalies at the 0- and 50-m levels in areas 1, 2, 3 and 4. Correlations significant at the 95% confidence level are marked by an asterisk.

	T (A4, 0m)	T (A4, 50m)	S (A4, 0m)	S (A4, 50m)
T (A1, 0m)	.81 *	.31 *	-.11	.24
T (A2, 0m)	.72 *	.21	.02	.23
T (A3, 0m)	.59 *	.20	-.19	.00
T (A4, 0m)	1	.25 *	-.14	.05
T (A1, 50m)	.12	.40 *	.08	.20
T (A2, 50m)	.18	.55 *	.33 *	.24
T (A3, 50m)	.25 *	.47 *	.07	.08
T (A4, 50m)	.25 *	1	.05	-.09
S (A1, 0m)	.15	.17	.61 *	.29 *
S (A2, 0m)	-.04	.17	.70 *	.56 *
S (A3, 0m)	-.20	-.13	.65 *	.49 *
S (A4, 0m)	-.14	.05	1	.62 *
S (A1, 50m)	-.02	.07	.52 *	.55 *
S (A2, 50m)	-.11	-.08	.58 *	.71 *
S (A3, 50m)	-.16	-.21	.31 *	.27
S (A4, 50m)	.05	-.09	.62 *	1

TABLE 4. Correlations between each of the seasonal temperature and salinity anomalies at the 0- and 50-m levels in area 4, and each of the temperature and salinity anomalies for the 0-20 and 75-150 m vertical intervals at Station 27 (B. Petrie, personal communication 1988). Correlations significant at the 95% confidence level are marked by an asterisk.

	T (A4,0m)	T (A4,50m)	S (A4,0m)	S (A4,50m)
T (S27,0-20m)	.39 *	-.11	-.11	.23
T (S27,50m)	-.15	.17	.09	.15
T (S27,75-150m)	.20	.37 *	.28 *	.22
S (S27,0-20m)	-.10	-.12	.23	.17
S (S27,50m)	.19	-.01	.10	-.05
S (S27,75-150m)	.06	.00	.18	.12

TABLE 5. Correlations between the temperature and salinity anomalies for the spring and summer seasons at the 0- and 50-m levels in area 4, and the wind energy input index for the corresponding season. None of the correlations are statistically significant at the 95% confidence level.

	T (A4,0m)	T (A4,50m)	S (A4,0m)	S (A4,50m)
SPRING	-.09	-.22	-.07	-.10
SUMMER	-.23	.08	.14	.14

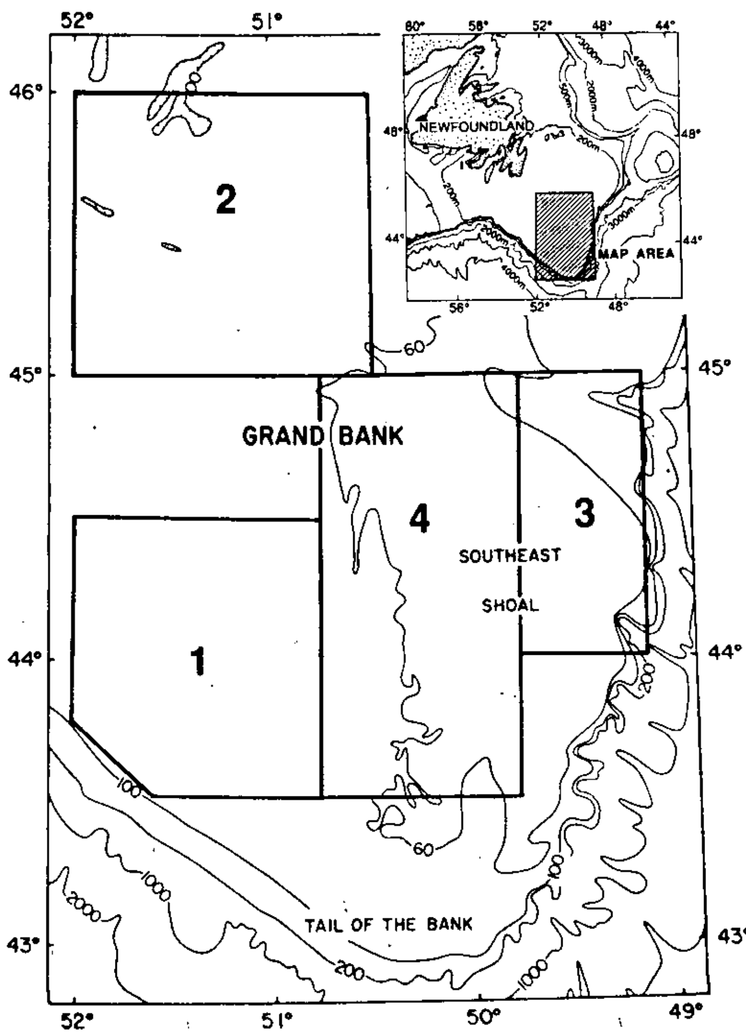


Figure 1. Location map of the southern Grand Bank showing the

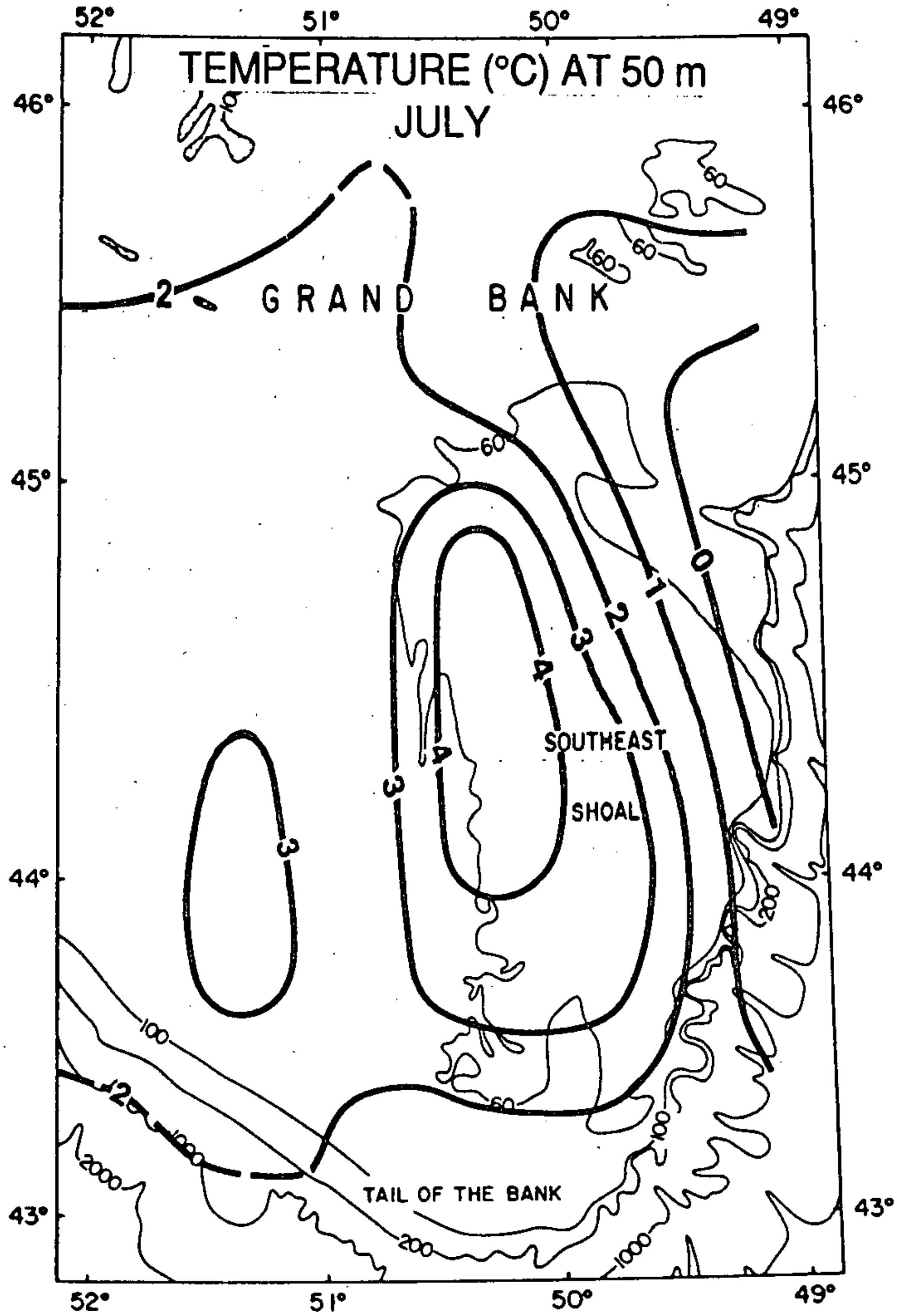
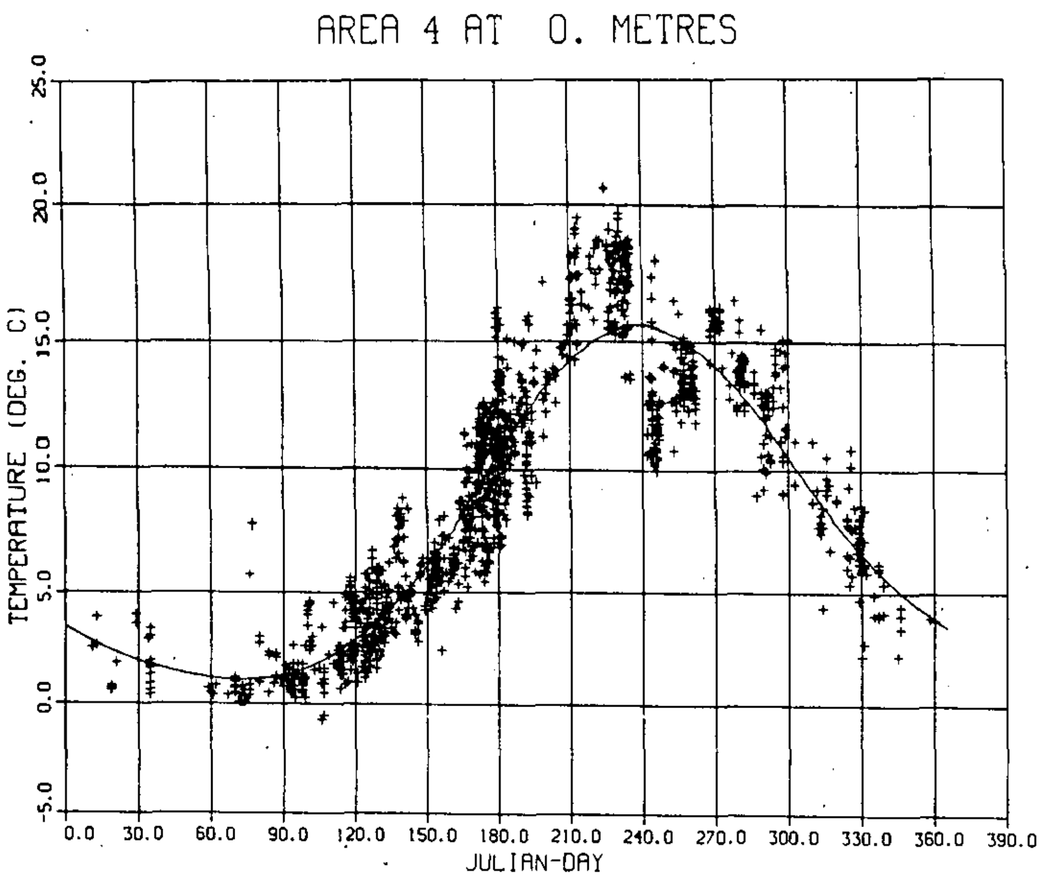


Figure 2. Climatological temperature distribution at the 50-m level on the southern Grand Bank in July. Contours are based on the MEDS long-term monthly-means for 1/2 x 1/2 degree areas.



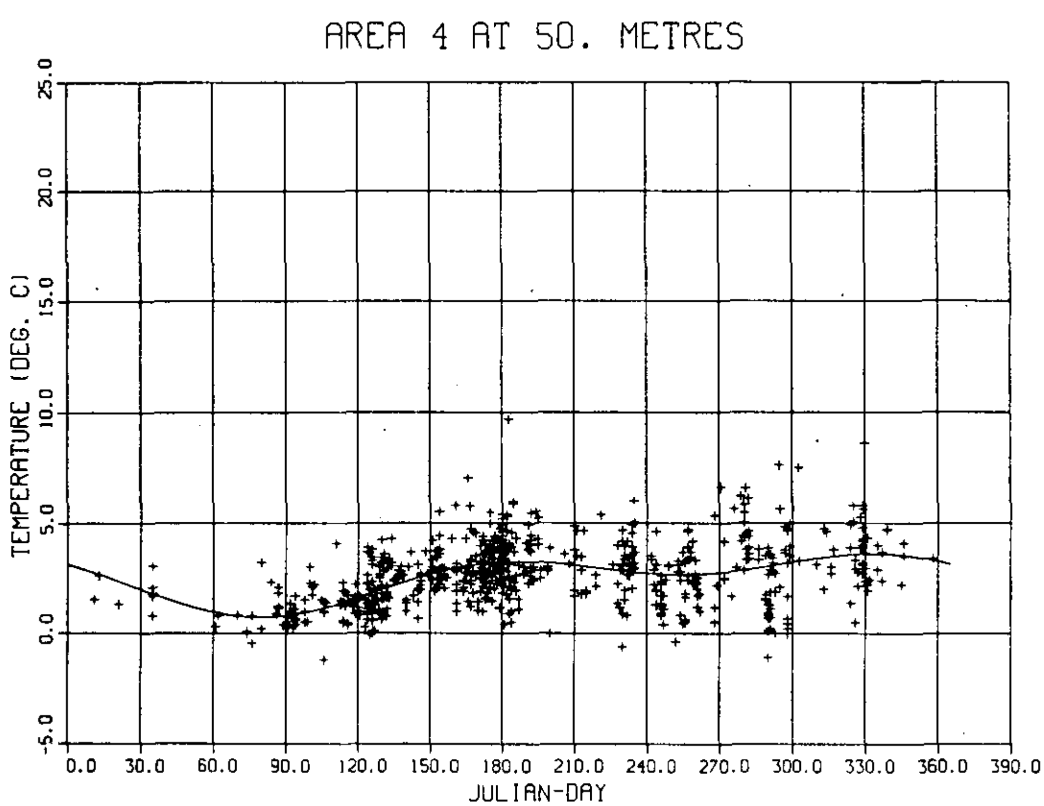
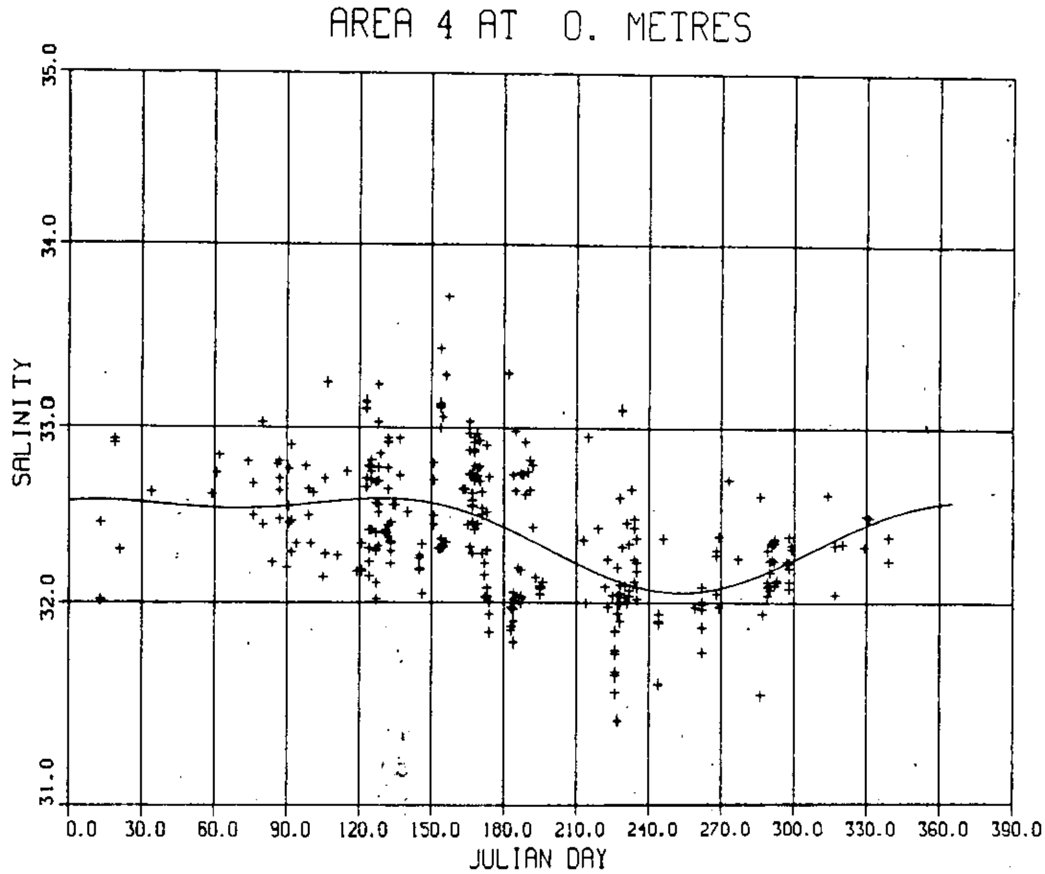


Figure 3. Interpolated temperature values for all years



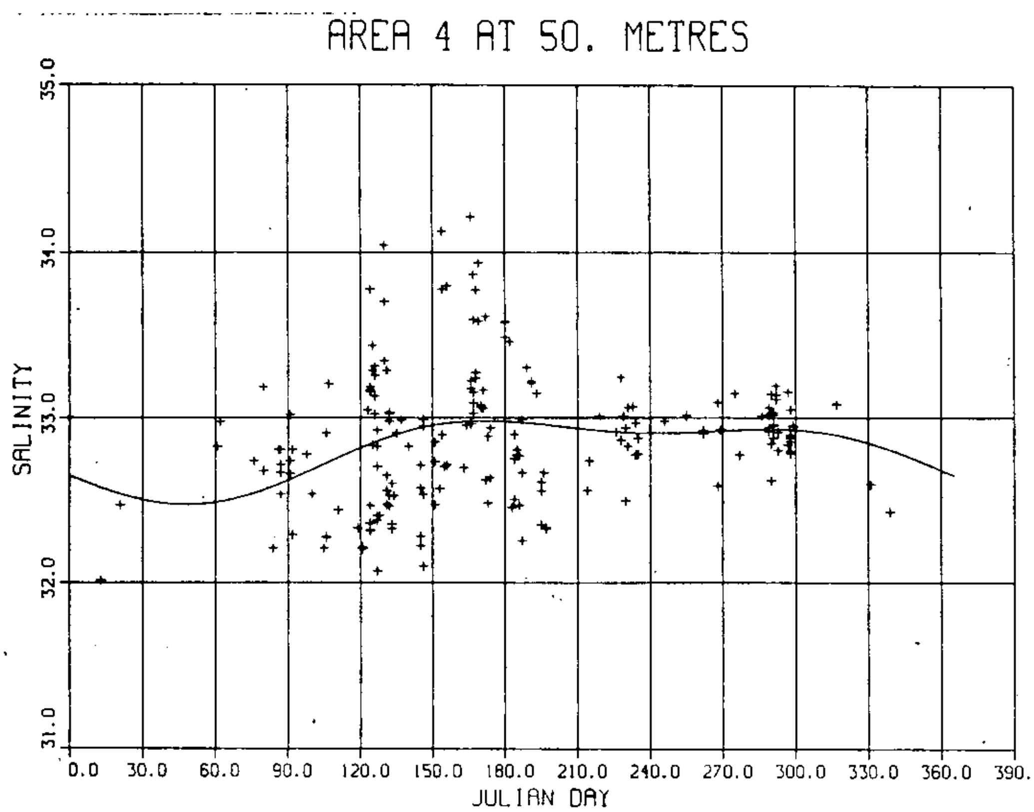


Figure 4. Interpolated salinity values for all years, together with regression curves, for 0 and 50 m in area 4.

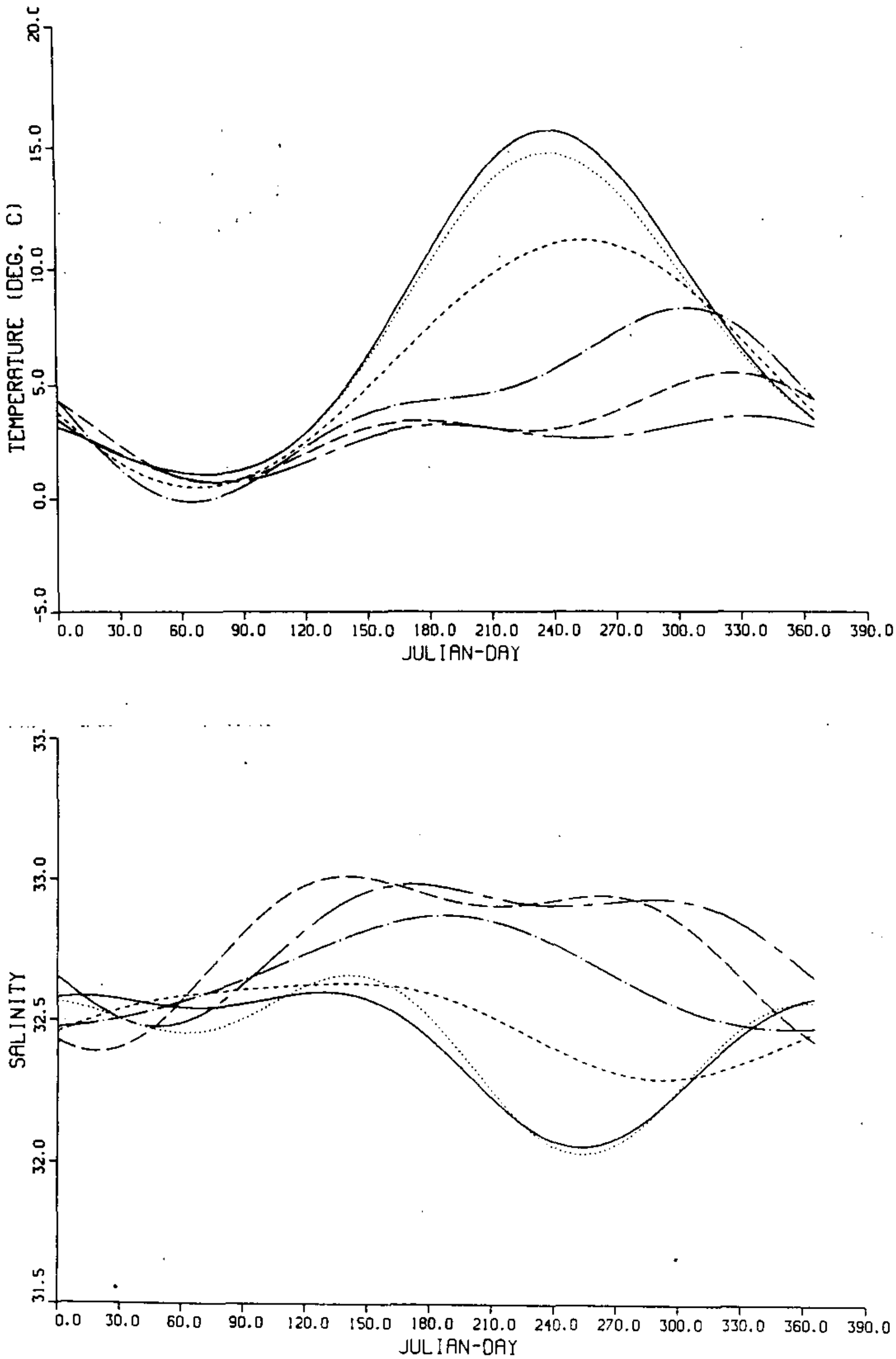
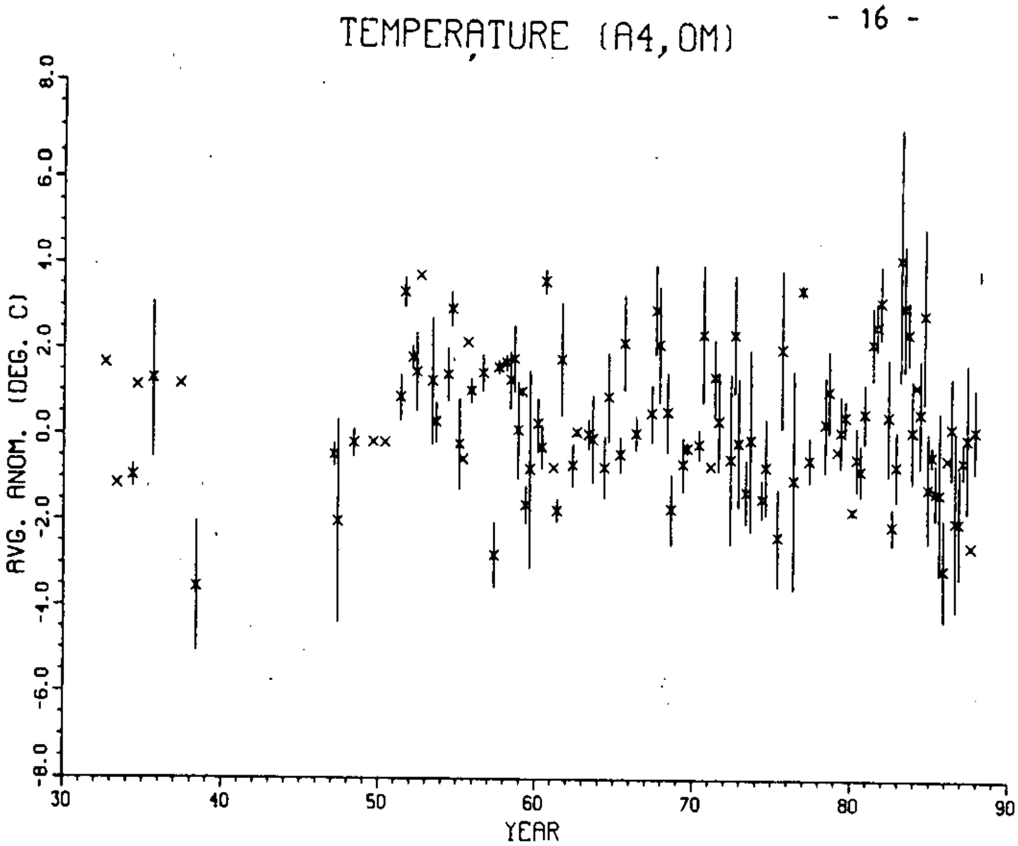


Figure 5. Regression curves for temperature and salinity in area 4 for : 0 m (solid), 10 m (dotted), 20 m (short-dashed), 30 m (dotted/long-dashed), 40 m (medium-dashed) and 50 m (short-dashed/long-dashed).



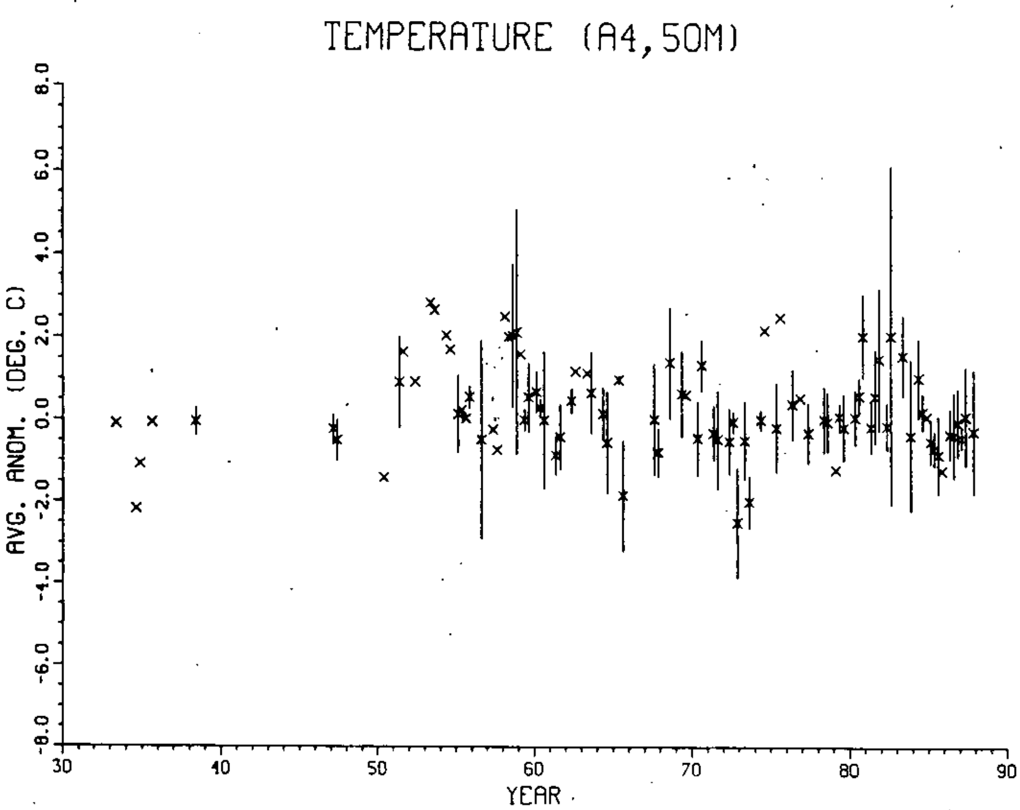
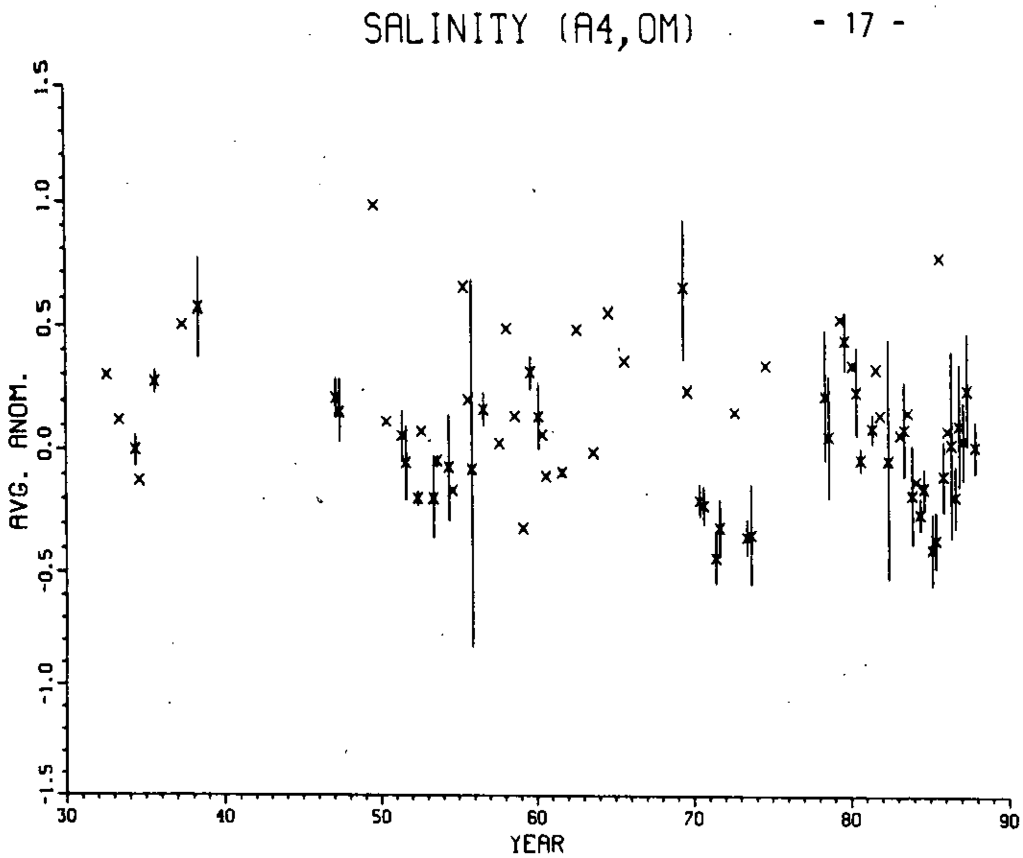


Figure 6. Seasonal temperature anomalies at 0 and 50 m in area 4 for the years 1930 - 1987. The standard deviation of each anomaly is indicated by the vertical line, for anomalies based on two or more data points.



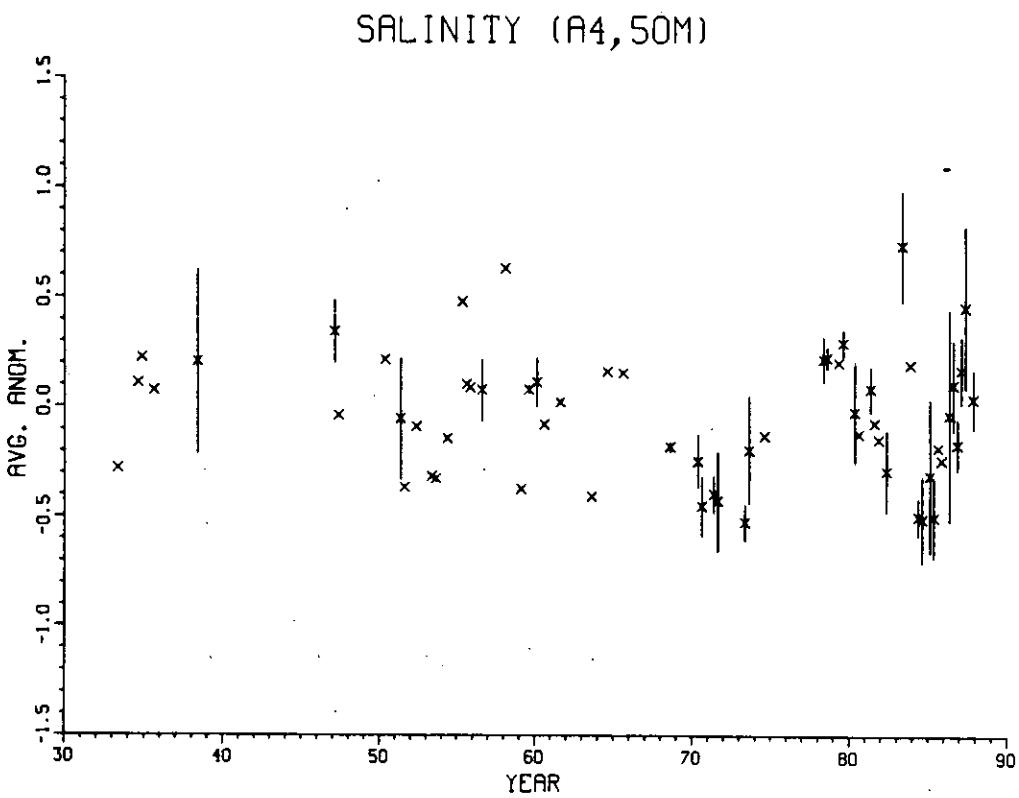


Figure 7. Seasonal salinity anomalies at 0 and 50 m in area 4 for the years 1930 - 1987. The standard deviation of each anomaly is indicated by the vertical line, for anomalies based on two or more data points.

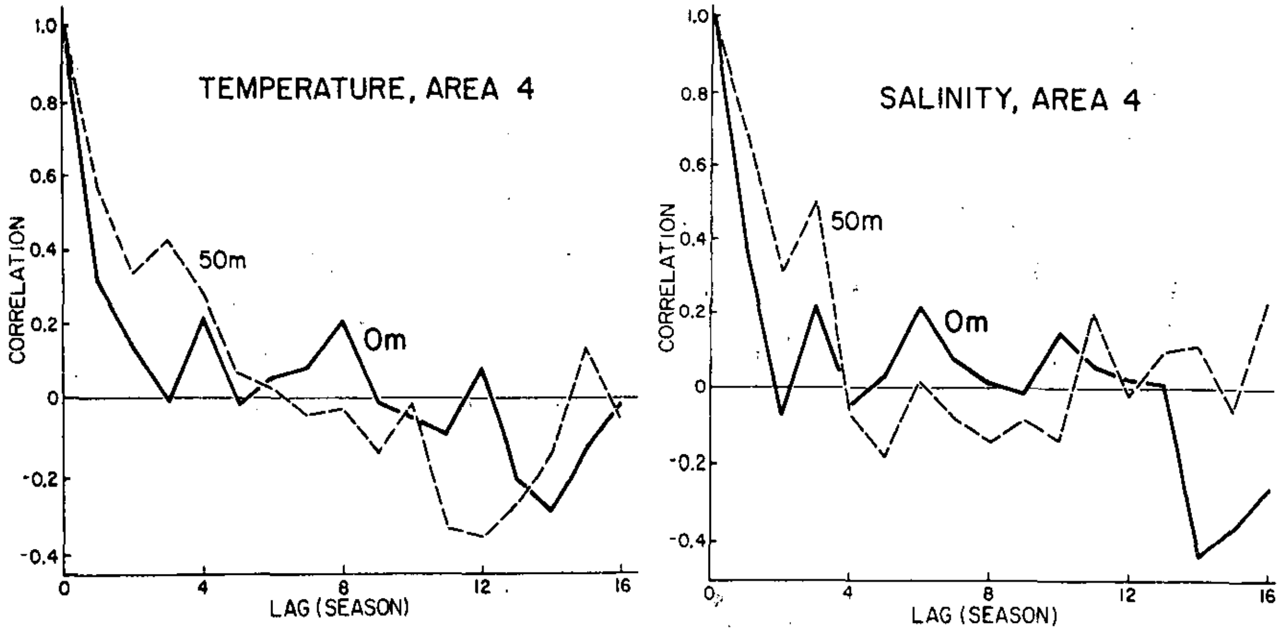


Figure 8. Lagged autocorrelations of the 0- and 50-m temperature and salinity anomalies for area 4.

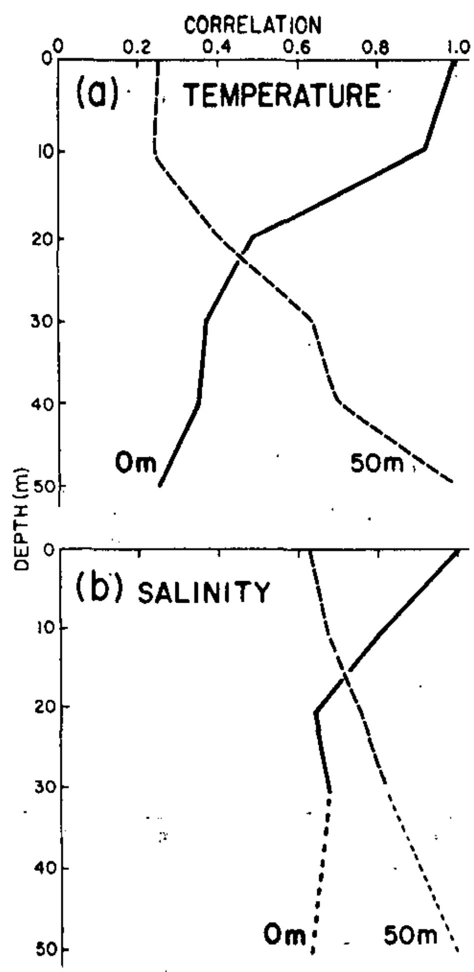
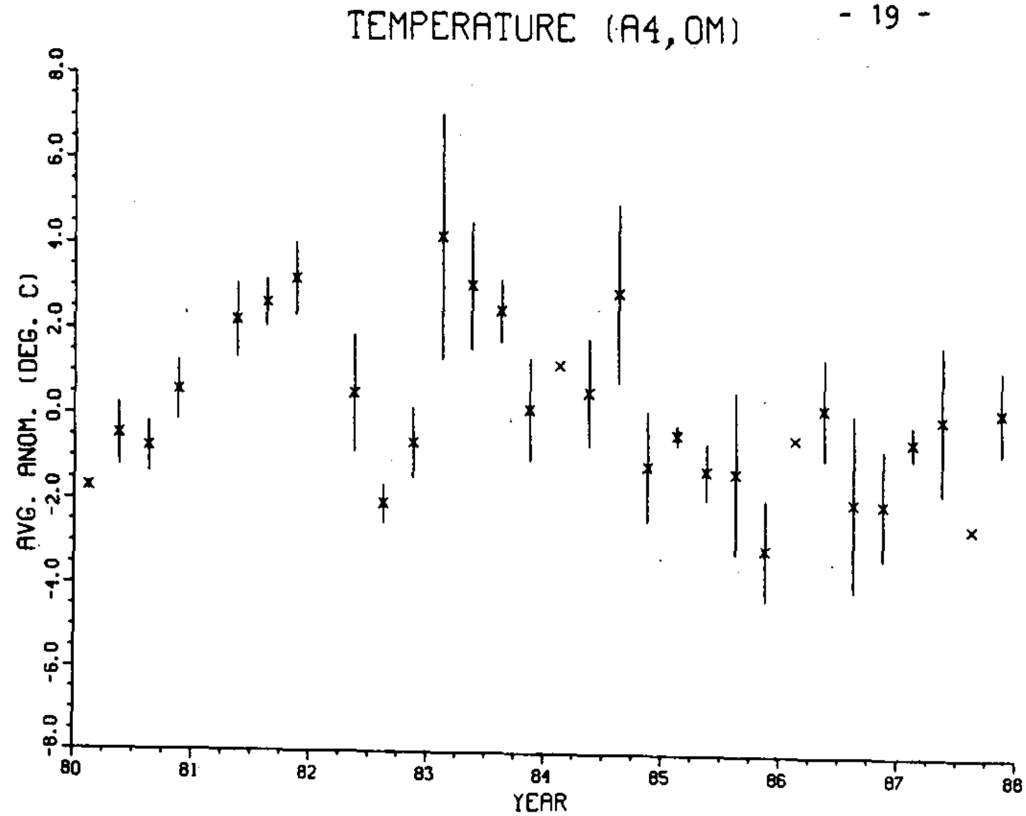


Figure 9. Zero-lag correlations between the 0- and 50-m temperature and salinity anomalies, and the anomalies of that parameter at other vertical levels, for area 4.



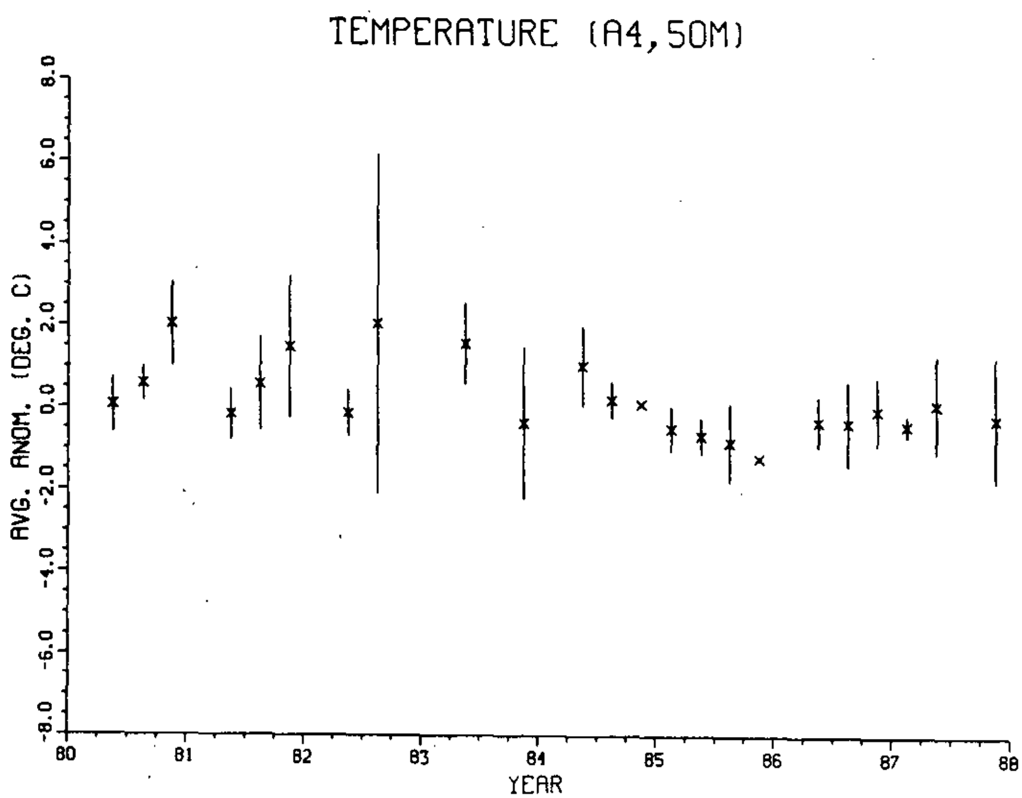
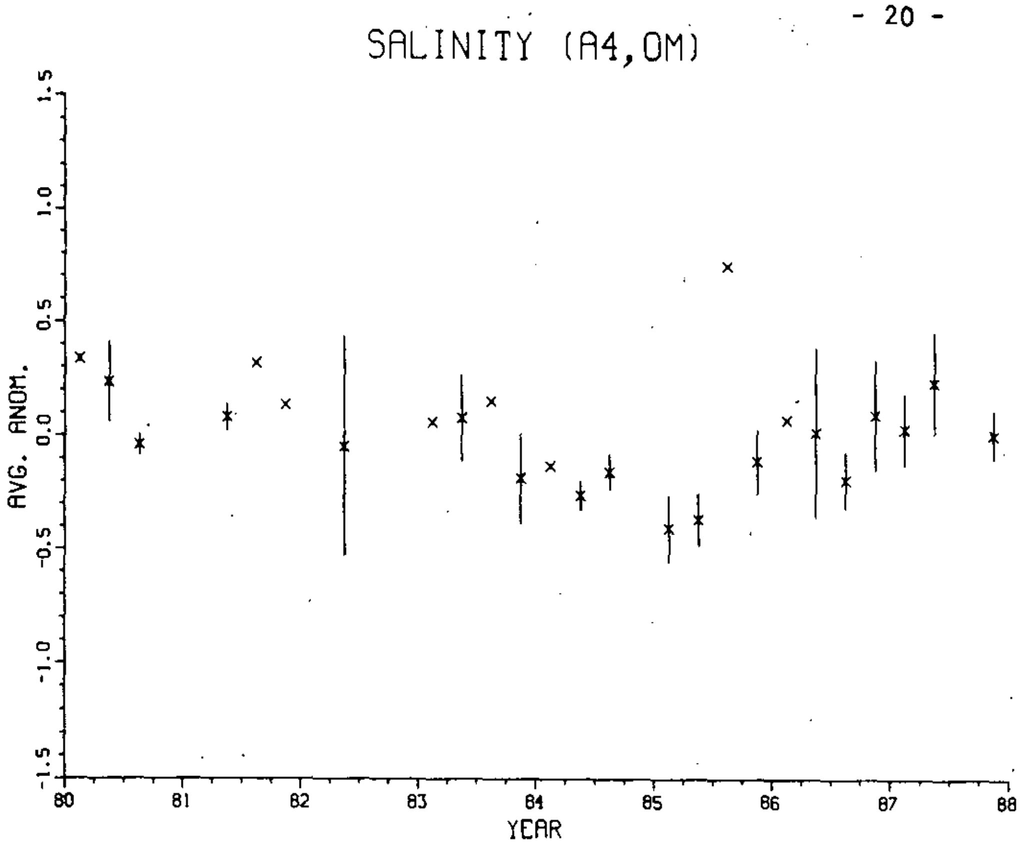


Figure 10. Seasonal temperature anomalies at 0 and 50 m in area 4 for the years 1980 - 1987. The standard deviation of each anomaly is indicated by the vertical line, for anomalies based on two or more data points.



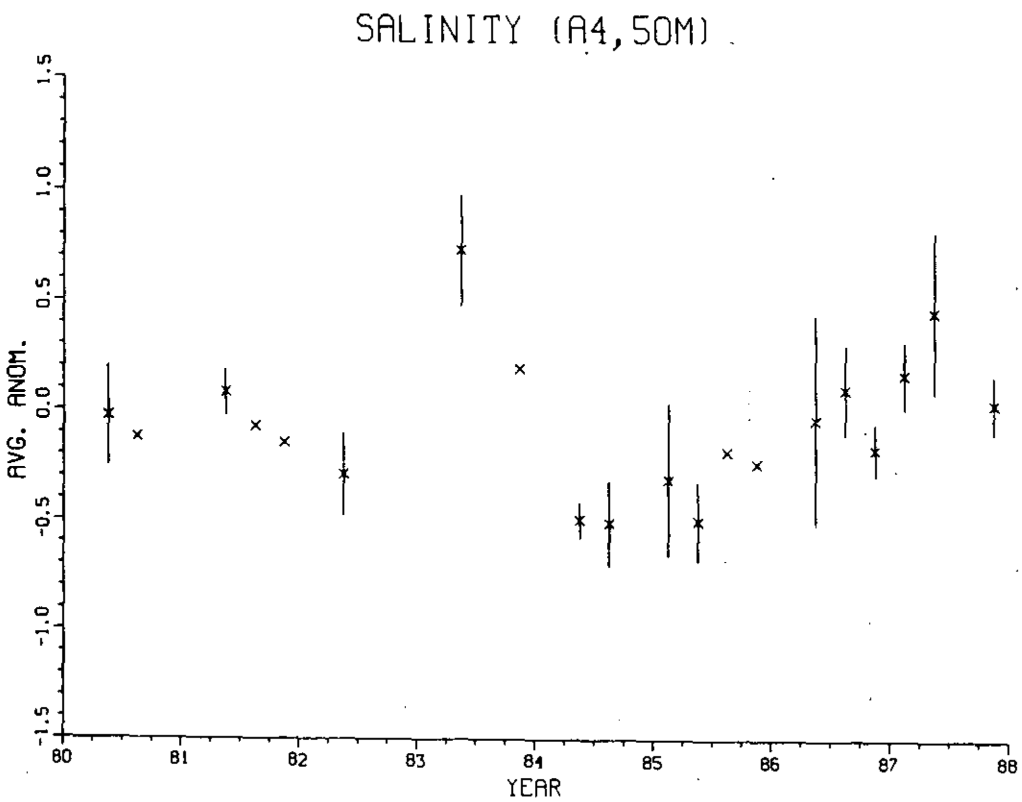


Figure 11. Seasonal salinity anomalies at 0 and 50 m in area 4 for the years 1980 - 1987. The standard deviation of each anomaly is indicated by the vertical line, for anomalies based on two or more data points.