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Surface and Bottom Temperature and Temperature Anomaly Time Series From the Northeast Fisheries Center Spring and Fall Bottom Trawl Survey Program, 1963-1989

by

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INTRODUCTION

The Northeast Fisheries Center has conducted bottom trawl surveys each spring since 1968 and each fall since 1963 to determine the distribution and relative abundance of the groundfish stocks off the northeast coast of the United States. The trawls have been made on a stratified random grid with approximately 300 stations from Cape Hatteras to the Gulf of Maine and from near the coast to the edge of the continental shelf (Grosslein, 1969). On selected stations temperature observations were made to record surface and bottom temperature.

Earlier presentations and summaries of the bottom temperature data from the bottom trawl surveys are included in Davis (1978 and 1979). Contoured distributions of the surface and bottom temperatures for all of the surveys from 1963 to 1987 are presented in Holzwarth and Mountain (1990).

Temperature anomalies relative to an established mean temperature field have been determined for all of the surface and bottom observations on each survey. The areal average temperatures and temperature anomalies for four regions of the shelf have been calculated and are presented in time series form. Correlations have been calculated between the anomaly series in the different regions to indicate the temporal and spatial scale of the interannual variability in surface and bottom temperature.

DATA AND METHODS

Surface temperature measurements were made using a surface sampling bucket with thermometer. In the early years of the survey program bottom temperature measurements were made using a mechanical bathythermograph (MBT). Since 1971 the bottom measurements have been made using expendable bathythermograph probes (XBT). The accuracies of these different measurement techniques are listed in Table 2.

The temperature data used in this report were retrieved from the survey data base maintained on computer at the Northeast Fisheries Center in Woods Hole, MA. The date, position, bottom depth and station number for the observations were also retrieved from the data base. Observations from stations without assigned station numbers also were included. When duplicate observations existed at the same location on a survey, only the first observation at the location was used.

The shelf wide surveys require five or six weeks to complete. Distributions of mean surface temperature presented by Mountain and Holzwarth (1989) suggest that changes of 2-4 °c could be expected in water temperature, particularly at the surface, over the period of a survey. This means that the survey temperature distributions are not synoptic. Also, the timing of surveys varied by a few weeks between years depending upon ship schedules so that direct comparison between years may not be a reliable indication of actual interannual variation in water temperature. In order to account for the different timing of observations within a survey and between years, a temperature anomaly is calculated for each temperature observation. The anomaly represents the difference between the observed temperature and the expected temperature at the location and on the day of the year that the observation was made.

The expected temperatures are derived through a method described by Mountain (1989). This method uses a series of mean annual temperature curves for about 160 standard station locations on the continental shelf. These curves were derived for both surface and bottom temperature from analysis of an eleven-year time series of hydrographic observations at the standard station locations. The expected temperature for a given location and day is determined by first identifying the closest standard stations. Then the expected temperature at each selected standard station is determined for the given day from its annual curve. The expected temperature at the given location is then determined by a weighted average of the temperatures at the nearby standard stations, with the weighting being inversely proportional to the square of the distance from the standard station to the given location.

Bottom temperature on the shelf can vary considerably with bottom depth. When estimating the expected value for a bottom temperature observation, the difference in depth between the observation site and a potential nearby standard station was determined. If the depth difference was greater than 25m and greater than one quarter of the water depth at the observation site, the standard station was judged to not represent the bottom conditions at the observation site and was not included in determining the expected bottom temperature. This depth selection process is somewhat arbitrary and the criteria used were selected after trials with a range of values. The depth filtering is especially important in the region of large gradient in bottom depth between the northern edge of Georges Bank and the southern Gulf of Maine.

To summarize the temperature and temperature anomaly data, the survey area is divided into four regions - Gulf of Maine, Georges Bank, Northern Middle Atlantic Bight and Southern Middle Atlantic Bight (figure 1). These are the same regions used by Davis (1978 and 1979). If the temperature observations within a region were not uniformly distributed, a simple average of them may not provide the best characterization of the temperature conditions in the region. Instead, an areal weighted average is desired. An areal average was calculated by first gridding the region into 0.25 degree longitude by 0.20 degree latitude boxes. For each box the nearest survey stations were identified and the area of the box was divided among these stations in proportion to the inverse square of the distance from the station to the center of the box. This was done for all of the boxes in a region so that all of the area in the region was divided among the stations. For each station the areas assigned from the different boxes were summed to determine the total assigned area to the station. Then a weighting factor was calculated for each station by dividing the total area assigned to the station by the total area of the region. These weighting factors indicate the proportion of the region each station represents. The areal average temperature or anomaly for the region was calculated by summing the products of the station weights and station temperature or anomaly values:

$$M = \sum a_i \; V_i$$

where

M = the areal average value
a_i = the weighting factor for the i^{th} station
V_i = the temperature or temperature anomaly value for the i^{th} station

If for any grid box in a region no survey stations were found within approximately 60 km, an areal average for the region was not calculated. Instead, a simple average of the observations that were within the boundaries of the region was determined.

To establish confidence limits on the calculated average temperatures, the measurement error must be considered. The original temperature measurements have inherent uncertainties, as listed in Table 2. The measurement errors for the temperature observations are assumed to be normally distributed with a standard deviation equal to these uncertainties. The regional average temperatures are determined by averaging a number of observations and therefore the expected standard deviation associated with the average will decrease in proportion to the inverse square root of the number of stations. Since 40 or more stations are usually included in an average, this means that the standard deviations for the averages are generally less than 0.1 °c. For the MBT data they are less than 0.2 °c. By calculating average temperature over broad areas of the shelf so that many observations are included, the confidence limits on the average temperature values are relatively narrow.

In calculating the average temperature anomalies, an additional source of error must be considered. The anomaly for an individual observation is the difference between the observed temperature and the expected temperature at the same location for the same day of the year. The uncertainty in the expected temperature is determined from the standard deviations associated with annual curves for the standard stations used to calculate the expected temperature (Mountain, 1989). The resulting standard deviations for the expected temperatures are generally on the order of 1.0 °c. The areal average temperature anomaly is, in essence, the difference of two means - the mean of the observed temperatures minus the mean of the expected temperatures. Therefore the uncertainty in the areal average anomaly is determined by:

$$\mathrm{SDV1} = \sqrt{a_i^2 \sigma_i^2 + a_i^2 \alpha_i^2}$$

where

a_i = the weighting factor for the survey station in the areal averaging

σ_i = the standard deviation of the temperature observation for the i^{th} survey station

α_i = the standard deviation of the expected temperature for the i^{th} survey station

This value indicates how well the calculated anomaly represents the true average temperature anomaly for the region as a whole. The values for SDV1 are generally on the order of 0.1-0.3 °c.

Another question of interest is how well does the areal average value represent the anomaly one might find at any particular location within the region. This uncertainty is represented by the standard deviation of the individual anomalies within the region and is referred to in this report as SDV2.

RESULTS

The areal average temperatures and temperature anomalies have been calculated for the four regions in both the spring and the fall and for the surface and the bottom. The results are listed in Table 1. Cases where a simple average was determined are indicated in the table by an "*". The standard deviations SDV1 and SDV2 are also included in the table.

The time series of average temperature and of temperature anomaly for each region for spring and fall and for surface and bottom are presented in figures 2-7. Since the standard deviations associated with the temperature and the anomaly values are relatively small (0.1-0.3 °c) no error bars are included in these figures. The difference between surface and bottom temperature anomalies in the fall for each region are plotted in figure 8. This difference in anomalies represents the anomaly in thermal stratification over the whole water column.

The autocorrelation functions for the temperature anomaly series are plotted in figure 9. The correlations between the surface and bottom anomalies in each region are listed in Table 3. The correlations between the anomaly series in the different regions are listed in Table 4. The correlations between the anomalies in the spring and the subsequent fall are listed for each region in Table 5. The correlations between the fall and the following spring are in Table 6. In each of the correlation tables the values are significant at the 95% level unless they are enclosed in parentheses.

DISCUSSION

The time series plots of the areal average temperature data (figures 2-3) illustrate many of the characteristic features of the temperature patterns on the northeast continental shelf. In the spring the surface and the bottom temperatures in the different regions are all very similar, although the southern Middle Atlantic Bight temperatures are about 1 °c warmer than the other regions. The similarity in surface and bottom temperatures indicates that seasonal warming and thermocline formation have not begun when the spring survey is conducted (mid-March to the end of April).

In the fall the surface temperatures are considerably warmer than the bottom temperatures within the different regions. At the surface there is an increase in temperature from north (Gulf of Maine) to south (southern Middle Atlantic Bight). The bottom temperature in the Gulf of Maine stands out as being a few degrees colder than the other areas, which exhibit fairly similar average bottom temperatures. The colder bottom temperatures in the Gulf of Maine are due in large part to the Gulf being considerably deeper than the other three regions such that heat from the seasonal surface warming does not penetrate to the bottom.

The temperature anomaly time series plots (figures 4-7) illustrate characteristics of the interannual variability of temperatures on the continental shelf. The variability in the fall is generally larger than that in the spring. Within a region and for either season the surface and bottom temperatures exhibit a comparable degree of variability. The range of interannual temperature variation is somewhat larger in the Middle Atlantic Bight (3-4 °c) than on Georges Bank or in the Gulf of Maine (2-3 °c).

The autocorrelation functions for the different anomaly series (figure 9) indicate that the seasonal temperature variability on the northeast continental shelf generally has a time scale of a number of years. With the exception of the spring surface temperatures in the Gulf of Maine and Georges Bank, the first zero crossing of the autocorrelation functions occurs at a lag of three years or more. The high correlation between the anomalies in different areas (Table 4) indicates that the variability also has a length scale longer than the region covered. The lack of correlation between the spring and fall anomalies (Table 5 and 6), however, suggests that anomalies do not persist throughout the year. Individual anomalies, therefore, must have a time scale of less than 6 months, although similar anomalous conditions tend to reoccur seasonally from one year to the next.

The spring temperature anomalies at the surface and bottom of the water column are highly correlated (Table 3), indicating the ability of winter conditions to influence the entire water column. In the fall only on the relatively shallow Georges Bank are the surface and bottom anomalies correlated. In the deeper

Gulf of Maine the characteristic three layer water column (Hopkins and Garfield, 1979) and the influence of the deep Northeast Channel inflow (Ramp et al., 1985) decouple the surface and bottom variability. The lack of correlation in the Middle Atlantic Bight during the fall most likely results from the bottom conditions there being influenced by the "cold pool" and related more to temperature conditions on Georges Bank and Nantucket Shoals during the previous spring than to the local surface conditions (Houghton et al., 1982).

The difference between the surface and bottom anomalies during the fall (figure 8) is an indication of the anomaly in thermal stratification over the water column. This stratification index is very similar in the Gulf of Maine and on Georges Bank (R = 0.54) and similar in the northern and southern Middle Atlantic Bight (R = 0.76). Whether changes in the index represents actual changes in the degree of stratification which occurred during the summer and fall or changes in the timing of the fall breakdown of stratification cannot be determined from these data.

The temperature anomalies in figures 4-7 display the long term temperature trends on the northeast continental shelf. As shown by Davis (1978 and 1979) the mid 1960's were quite cold, while the early to middle 1970's were warm. The temperature anomalies presented here suggest that during the period of the late 1970s' and early 1980's (1978-1982) the temperatures were generally intermediate between the two earlier extremes. In the mid 1980's (1983-1986) the temperatures were again warm, being comparable to the mid 1970's. The late 1980's (1987-1989) remained warm in the Middle Atlantic Bight, except for the fall bottom temperatures where were relatively cool. The Gulf of Maine and Georges Bank regions were characterized by cold conditions in the late 1980's. This grouping of years into warm and cool periods is not precise and there is considerable variability within and between the different time series on a year to year basis. The relatively small uncertainties associated with the temperature anomaly values (SDV1 in Table 1), however, suggest that the differences in temperature between individual years from the cool and the warm periods are significant.

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Table 1. Areal average surface and bottom temperature and temperature anomaly for the spring and fall bottom trawl surveys in the four regions of the northeast continental shelf shown in figure 1: "#Obs", the number of observations included in each average; "Temp", the areal average temperature; "Anomaly", the areal average temperature anomaly; "SDV1", the standard deviation associated with the average temperature anomaly; "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived. An "*" indicates that a true areal average could not be calculated due to poor station coverage and that the average values listed were derived from a simple average of the observations that were within the region. All of the temperature values are in °c.

Spring - Gulf of Maine

	Surface					Bottom				
Year	#Obs	Temp	Anomaly	SDV1	SDV2	#Obs	Temp	Anomaly	SDV1	SDV2
1968	74	3.9	-0.7	0.1	0.7	67	5.1	-0.5	0.2	1.0
1969	68	3.7	-0.5	0.2	1.0	59	5.4	-0.2	0.2	1.1
1970	93	3.7	-0.4	0.1	0.7	87	6.4	0.6	0.2	1.1
1971	89	3.9	-1.0	0.1	0.6	81	6.1	0.6	0.2	1.2
1972	97	4.6	-0.0	0.1	0.8	93	6.2	0.8	0.1	1.0
1973	73	6.0	-0.2	0.2	0.9	71	6.4	0.6	0.1	1.2
1974	71	5.7	0.2	0.2	1.0	47	* 6.6	1.1	0.1	0.7
1975	68	5.2	-1.0	0.2	1.1	62	6.6	0.6	0.1	1.3
1976	102	6.2	1.0	0.1	0.7	98	7.0	1.3	0.1	1.0
1977	97	6.3	-0.1	0.1	1.2	93	5.5	-0.2	0.1	1.2
1978	99	5.8	-1.1	0.1	0.8	93	5.5	-0.2	0.1	0.9
1979	120	5.4	0.0	0.1	0.9	114	5.4	-0.2	0.1	0.9
1980	81	5.8	0.1	0.1	0.7	78	5.6	0.0	0.1	1.0
1981	89	7.2	0.1	0.1	0.6	82	5.5	-0.3	0.1	1.0
1982	81	5.7	-0.2	0.1	1.0	75	5.8	0.1	0.1	0.9
1983	82	5.3	0.1	0.1	1.0	78	5.6	-0.0	0.1	1.2
1984	76	4.4	-0.4	0.1	1.0	75	5.9	0.2	0.1	1.2
1985	28	4.4	-0.1	0.2	1.1	25	* 5.4	0.3	0.2	1.1
1986	39	6.0	1.0	0.2	0.7	37	7.2	1.7	0.2	0.9
1987	39	4.3	-1.0	0.2	1.1	38	5.6	0.0	0.2	1.2
1988	33	4.2	-0.3	0.2	0.9	31	6.0	0.9	0.2	0.9
1989	24	* 4.3	-0.1	0.2	0.7	24	* 5.5	-0.2	0.2	0.7

Table 1. Continued.

Fall - Gulf of Maine

	Surface					Bottom				
Year	#Obs	Temp	Anomaly	SDV1	SDV2	#Obs	Temp	Anomaly	SDV1	SDV2
1963	89	8.6	-1.0	0.1	0.7	86	7.0	-0.7	0.2	1.2
1964	74	8.3	-1.6	0.2	0.9	73	5.8	-1.8	0.2	1.0
1965	75	10.5	-2.2	0.2	1.4	73	6.1	-1.8	0.2	1.6
1966	72	10.8	-1.5	0.1	1.2	65	5.9	-2.0	0.2	1.6
1967	79	8.6	-1.3	0.1	0.7	58	6.2	-1.6	0.2	1.1
1968	68	9.6	-0.5	0.2	1.2	60	7.6	-0.4	0.2	1.3
1969	79	9.8	-0.2	0.2	0.7	67	7.4	-0.5	0.2	1.1
1970	80	10.2	-0.1	0.2	0.7	77	7.6	-0.2	0.2	1.4
1971	88	11.6	1.0	0.1	1.0	83	8.4	0.5	0.2	1.7
1972	87	9.9	-0.7	0.2	0.8	78	8.2	0.3	0.1	1.3
1973	83	10.1	-0.4	0.1	0.9	73	8.5	0.7	0.1	1.4
1974	91	11.6	0.1	0.1	0.8	84	9.2	1.3	0.1	1.6
1975	99	11.7	0.5	0.1	0.8	96	8.2	0.4	0.1	1.5
1976	79	10.0	-0.4	0.1	0.7	70	9.1	1.2	0.1	1.2
1977	114	9.5	-0.0	0.1	0.8	103	7.9	0.1	0.1	1.3
1978	184	11.1	-0.3	0.1	0.7	171	7.4	-0.4	0.1	1.1
1979	177	10.9	0.4	0.1	0.6	165	8.1	0.4	0.1	1.4
1980	93	10.1	-0.8	0.1	0.8	84	7.8	-0.2	0.1	1.4
1981	104	10.6	-0.4	0.1	0.7	99	7.4	-0.6	0.1	1.2
1982	100	11.2	0.1	0.1	0.8	95	7.8	-0.2	0.1	1.6
1983	106	11.2	0.1	0.1	0.8	103	8.1	0.1	0.1	1.7
1984	57	12.4	0.9	0.2	0.8	45	8.9	0.8	0.2	1.6
1985	34	11.7	0.8	0.2	1.1	33	8.6	0.6	0.2	2.3
1986	40	11.3	-0.0	0.2	0.7	52	8.5	0.6	0.2	1.4
1987	38	11.4	-0.5	0.2	1.0	35	7.8	-0.1	0.2	2.2
1988	41	11.2	-0.8	0.2	0.7	41	7.7	-0.4	0.2	1.4
1989	43	11.7	-0.0	0.2	0.8	41	7.4	-0.5	0.2	1.5

Spring - Georges Bank

	SURFACE					BOTTOM				
Year	#Obs	Temp	Anomly	SDV1	SDV2	#Obs	Temp	Anomaly	SDV1	SDV2
1968	49	4.1	-0.8	0.2	0.5	36	4.0	-1.1	0.3	0.7
1969	59	5.1	0.5	0.2	0.8	45	4.9	0.2	0.3	0.7
1970	76	4.5	-0.6	0.2	0.8	62	4.6	-0.7	0.3	1.1
1971	64	3.8	-0.7	0.2	0.5	51	4.3	-0.6	0.3	1.0
1972	59	5.0	0.2	0.2	1.2	46	5.1	0.2	0.2	0.8
1973	59	5.6	0.0	0.2	0.7	47	6.4	1.0	0.2	1.4
1974	56	5.9	0.8	0.2	1.1	44	6.5	1.1	0.3	0.9
1975	51	5.5	-0.2	0.2	0.8	41	6.1	0.6	0.2	0.8
1976	60	6.0	1.1	0.2	0.6	51	6.0	0.9	0.2	1.1
1977	63	7.2	1.4	0.2	1.1	50	6.0	0.4	0.2	1.0
1978	61	4.7	-0.8	0.2	0.9	52	4.6	-0.9	0.2	1.0
1979	109	5.5	-0.0	0.2	0.7	97	5.5	-0.2	0.2	0.8
1980	59	6.4	0.5	0.2	1.1	51	6.5	0.7	0.2	1.0
1981	57	5.8	-0.3	0.2	0.7	43	5.7	-0.2	0.2	0.7
1982	58	5.2	-0.4	0.2	0.7	42	5.0	-0.3	0.2	1.3
1983	55	6.3	1.1	0.2	0.9	45	6.0	0.7	0.3	0.8
1984	54	5.6	0.8	0.2	0.8	43	6.0	1.0	0.2	0.9
1985	23	5.4	0.7	0.3	1.0	17	5.2	0.4	0.3	0.7
1986	23	6.1	1.1	0.3	0.5	20	6.4	1.4	0.3	1.2
1987	27	6.6	0.9	0.2	2.6	22	6.4	0.6	0.3	1.4
1988	22	4.6	-0.2	0.3	0.7	27	4.5	-0.3	0.3	1.1
1989	29	4.5	0.0	0.2	0.6	23	4.9	0.0	0.3	1.1

Table 1. Continued.

Fall - Georges Bank

	Surface					Bottom				
Year	#Obs	Temp	Anomaly	SDV1	SDV2	#Obs	Temp	Anomaly	SDV1	SDV2
1963	43	8.9	-1.4	0.2	1.1	30	8.7	-1.6	0.3	1.6
1964	52	10.7	-2.0	0.2	1.1	36	9.3	-2.3	0.3	1.0
1965	56	12.3	-1.3	0.2	1.8	40	11.0	-1.2	0.3	1.8
1966	54	11.4	-1.8	0.2	1.2	37	10.1	-2.0	0.3	1.6
1967	50	8.8	-1.7	0.2	1.0	36	8.6	-1.8	0.3	0.9
1968	52	12.7	-0.4	0.2	1.4	41	12.3	0.2	0.3	1.4
1969	55	12.3	-1.0	0.2	1.3	29	11.9	-0.6	0.3	1.3
1970	55	13.3	-0.5	0.2	1.2	40	11.3	-0.9	0.3	1.7
1971	55	15.0	1.0	0.2	1.5	49	12.3	-0.0	0.3	1.9
1972	55	13.0	-1.0	0.2	1.3	43	12.1	-0.4	0.2	1.5
1973	57	14.6	0.3	0.2	1.4	42	13.4	1.0	0.2	1.7
1974	56	15.1	0.5	0.2	1.4	47	13.1	0.5	0.2	1.4
1975	63	14.7	-0.1	0.2	2.0	50	11.9	-0.6	0.2	1.4
1976	50	13.6	0.1	0.2	1.0	43	13.4	1.1	0.2	1.3
1977	73	13.5	-0.2	0.2	1.3	61	13.2	0.8	0.2	2.1
1978	118	14.1	-0.2	0.2	1.3	105	11.6	-0.8	0.2	1.4
1979	105	14.3	0.5	0.1	1.0	91	13.2	0.9	0.2	1.5
1980	78	15.0	0.7	0.2	1.8	62	13.2	0.9	0.2	1.2
1981	74	12.8	-1.3	0.2	1.4	62	11.4	-1.1	0.2	1.5
1982	69	13.8	-0.2	0.2	1.7	61	11.5	-0.9	0.2	1.7
1983	89	15.1	0.7	0.2	1.2	77	11.8	-0.7	0.2	1.8
1984	32	14.9	0.0	0.3	1.0	26	13.1	0.6	0.3	2.0
1985	26	15.5	1.5	0.3	1.5	22	13.2	1.1	0.3	2.5
1986	20	13.8	-0.6	0.3	1.1	28	12.4	-0.0	0.3	1.1
1987	29	13.9	-1.0	0.2	0.8	26	11.3	-1.6	0.3	2.6
1988	22	13.8	-1.0	0.3	1.5	20	11.3	-1.0	0.3	1.5
1989	36	14.4	-0.1	0.2	1.1	34	11.8	-0.7	0.3	1.9

Spring - Middle Atlantic Bight North

	Surface					Bottom				
Year	#Obs	Temp	Anomaly	SDV1	SDV2	#Obs	Temp	Anomaly	SDV1	SDV2
1968	30	3.0	-1.4	0.3	0.9	20	* 3.5	-1.2	0.4	2.5
1969	41	4.1	-0.3	0.3	1.2	28	5.4	-0.3	0.4	1.8
1970	43	5.8	-0.6	0.3	0.8	32	* 4.9	-0.7	0.3	1.7
1971	47	4.0	-0.8	0.3	0.7	32	* 5.9	0.6	0.3	2.3
1972	48	5.4	1.0	0.3	1.0	34	6.3	1.0	0.4	1.4
1973	50	6.5	1.9	0.3	1.8	37	7.4	2.0	0.4	1.8
1974	39	6.7	1.9	0.3	1.3	30	8.2	2.4	0.4	1.8
1975	28	5.8	1.0	0.4	0.9	23	* 5.7	0.8	0.3	1.9
1976	44	6.2	1.7	0.3	1.0	34	* 7.3	2.5	0.3	1.5
1977	39	6.1	0.4	0.3	1.3	27	5.2	-1.0	0.4	2.1
1978	55	4.4	-0.6	0.3	0.6	45	3.9	-1.5	0.4	1.4
1979	55	6.0	0.1	0.3	1.1	44	6.2	0.2	0.3	1.6
1980	93	6.3	0.8	0.2	1.0	81	6.3	0.3	0.3	1.1
1981	50	6.0	0.3	0.3	0.7	38	5.6	-0.6	0.4	1.6
1982	17	* 4.3	-1.0	0.4	0.5	15	* 5.1	0.0	0.4	2.4
1983	34	6.0	1.3	0.3	0.9	24	* 5.4	1.3	0.3	1.1
1984	41	5.0	0.5	0.3	0.9	31	5.7	-0.2	0.4	1.7
1985	14	5.5	1.2	0.4	1.4	13	* 6.1	1.5	0.4	1.8
1986	15	* 6.5	1.9	0.4	0.8	11	* 6.1	1.7	0.5	1.3
1987	22	6.2	0.8	0.4	1.8	16	* 5.6	-0.1	0.4	0.7
1988	19	4.6	0.1	0.4	1.0	23	6.8	1.3	0.4	1.4
1989	6	* 5.8	1.5	0.7	1.6	4	* 5.0	1.1	0.8	1.7

Table 1. Continued.

Fall - Middle Atlantic Bight North

	Surface					Bottom				
Year	#Obs	Temp	Anomaly	SDV1	SDV2	#Obs	Temp	Anomaly	SDV1	SDV2
1963	30 *	10.3	-0.8	0.3	1.2	20 *	11.4	0.2	0.4	1.2
1964	32	13.2	-1.9	0.3	0.9	20 *	11.1	-2.2	0.4	1.3
1965	35	13.1	-1.3	0.3	1.5	23	10.3	-3.0	0.4	1.8
1966	34	12.4	-1.7	0.4	1.4	23 *	9.6	-3.5	0.4	1.2
1967	46	14.3	-0.7	0.3	0.9	29	9.3	-3.7	0.4	1.2
1968	39	16.5	0.4	0.3	0.9	29	11.0	-1.9	0.4	1.8
1969	37	16.5	0.4	0.3	1.4	29 *	12.3	-0.4	0.3	1.6
1970	43	16.9	1.0	0.3	2.0	30 *	10.7	-2.5	0.3	1.4
1971	47	19.3	2.2	0.3	1.0	38	11.1	-1.5	0.4	2.2
1972	43	18.2	1.2	0.3	1.3	37	13.0	0.2	0.4	1.6
1973	43	17.9	0.6	0.3	1.0	30 *	12.9	0.6	0.3	1.5
1974	40	17.9	0.1	0.3	1.3	28	12.5	-0.2	0.4	1.5
1975	36	16.0	0.0	0.3	1.1	28 *	12.0	-0.8	0.3	1.3
1976	42	17.8	0.6	0.3	1.2	32	12.4	-0.3	0.4	1.4
1977	41	16.7	-0.1	0.3	1.2	31 *	13.0	0.0	0.3	1.6
1978	73	16.6	-0.5	0.3	0.9	59	11.6	-0.7	0.3	1.7
1979	67	16.5	-0.2	0.3	1.2	56	11.4	-1.3	0.3	1.4
1980	32	18.4	1.7	0.3	1.6	27 *	12.5	-0.4	0.3	1.9
1981	41	14.7	-2.1	0.3	1.5	33 *	10.8	-1.7	0.3	1.2
1982	37	17.6	0.6	0.3	1.5	25	12.7	-0.2	0.4	1.6
1983	36	18.2	1.0	0.3	0.7	27	11.2	-1.3	0.4	1.4
1984	30	17.6	-0.1	0.4	1.4	21	12.0	-0.2	0.4	2.0
1985	13	17.5	1.1	0.5	1.7	9 *	13.4	0.8	0.6	1.0
1986	24	18.1	0.8	0.4	1.3	22	12.4	-0.3	0.5	1.7
1987	18 *	17.6	0.0	0.4	0.8	17 *	10.8	-1.1	0.4	1.9
1988	22	18.6	0.7	0.4	1.1	17	11.2	-1.1	0.5	2.0
1989	16	19.4	1.7	0.5	1.5	15 *	12.6	0.0	0.4	2.2

Spring - Middle Atlantic Bight South

	Surface					Bottom				
Year	#Obs	Temp	Anomaly	SDV1	SDV2	#Obs	Temp	Anomaly	SDV1	SDV2
1968	57	4.8	-1.0	0.3	1.2	44	5.5	-0.5	0.4	1.4
1969	51	4.9	-1.0	0.3	1.3	36	5.0	-1.0	0.4	1.4
1970	54	8.2	-1.4	0.3	1.2	37	6.9	-0.9	0.4	1.3
1971	51	6.4	-0.5	0.3	1.6	39	6.6	-0.1	0.4	2.4
1972	55	7.3	1.6	0.3	1.4	46	8.1	2.2	0.3	1.4
1973	62	6.9	0.7	0.3	1.6	46	7.4	1.2	0.3	1.3
1974	41	9.6	3.2	0.4	1.7	31	9.8	3.5	0.5	1.7
1975	41 *	7.6	1.1	0.3	1.1	30 *	7.4	1.2	0.3	1.0
1976	59	7.8	1.9	0.2	1.4	48	8.3	2.3	0.3	1.2
1977	58	7.0	0.4	0.2	1.7	50	6.2	-0.2	0.3	1.5
1978	56	6.2	-0.4	0.3	1.4	48	6.3	0.0	0.3	1.6
1979	55	7.2	0.3	0.3	1.5	39	6.7	0.1	0.4	1.3
1980	48	7.4	0.9	0.3	2.0	38	7.4	0.9	0.4	1.7
1981	52	7.0	0.2	0.3	1.3	41	6.8	0.5	0.4	1.2
1982	17 *	6.6	-0.4	0.5	1.4	14 *	6.6	-0.1	0.6	1.2
1983	47 *	7.8	1.3	0.3	1.1	37 *	7.7	1.1	0.3	1.4
1984	49	6.7	1.0	0.3	1.3	38	7.3	1.4	0.4	2.1
1985	16 *	8.0	1.5	0.4	1.6	12 *	6.9	0.9	0.5	1.1
1986	26 *	7.4	1.3	0.4	1.3	22 *	7.2	1.1	0.4	1.0
1987	31 *	6.5	-0.3	0.3	1.7	35	6.2	-0.3	0.4	2.0
1988	21	6.2	0.3	0.4	1.2	19	7.0	0.8	0.4	1.3
1989	15 *	8.0	0.9	0.5	1.3	12 *	8.1	1.4	0.6	0.6

Table 1. Continued.

Fall - Middle Atantic Bight South

Year	Surface #Obs		Surface Temp	Surface Anomaly	Surface SDV1	Surface SDV2	Bottom #Obs		Bottom Temp	Bottom Anomaly	Bottom SDV1	Bottom SDV2
1963	10	*	10.5	-1.2	0.5	0.9	8	*	10.3	-1.2	0.6	0.6
1964	9	*	14.1	-2.0	0.6	1.2	5	*	9.7	-2.6	0.7	1.3
1965	8	*	14.1	-1.8	0.7	1.5	2	*	10.6	-2.8	1.0	1.9
1966	12	*	12.9	-2.4	0.6	1.5	3	*	11.3	-1.8	0.8	2.4
1967	61		16.5	-0.5	0.2	0.9	38		12.9	-1.6	0.4	2.0
1968	62		19.3	1.2	0.2	1.0	51		12.8	-1.9	0.3	2.8
1969	49		18.7	0.4	0.3	0.7	41		15.3	1.1	0.3	2.2
1970	61		22.8	1.0	0.2	0.8	47		10.0	-3.3	0.3	2.4
1971	57		21.0	1.9	0.3	1.3	41		12.8	-1.6	0.4	3.9
1972	49		19.6	-0.2	0.3	1.1	37		15.1	1.1	0.3	2.5
1973	47		21.3	1.4	0.3	1.4	39		14.5	0.3	0.3	1.9
1974	50		20.8	0.6	0.3	1.2	40		14.6	0.6	0.3	1.8
1975	56		16.8	0.4	0.3	1.2	44		14.3	-0.2	0.3	1.7
1976	64		19.3	0.4	0.2	0.8	54		14.5	0.2	0.3	2.4
1977	58		19.7	-0.1	0.3	1.1	48		13.2	-1.1	0.3	1.7
1978	46		22.2	0.4	0.3	1.1	40		11.0	-2.0	0.3	1.7
1979	47		20.3	0.1	0.3	1.4	37		12.5	-1.4	0.3	2.4
1980	52	*	21.3	1.5	0.3	0.8	40	*	11.4	-1.8	0.3	1.8
1981	48		19.3	-1.0	0.3	1.1	35		13.8	0.2	0.4	2.5
1982	50		20.8	0.3	0.3	1.6	42		12.5	-1.1	0.4	2.0
1983	53		21.6	0.9	0.3	1.1	42		13.3	-0.4	0.3	1.7
1984	45		20.7	-0.5	0.3	1.8	37		11.8	-1.6	0.3	2.6
1985	26		21.7	1.6	0.4	1.7	22	*	15.2	1.4	0.4	2.4
1986	30		21.0	-0.1	0.3	1.6	35		14.4	0.6	0.4	3.4
1987	25		22.7	1.2	0.4	1.0	21		11.5	-1.6	0.4	2.1
1988	23		21.2	-0.2	0.4	1.3	21		10.6	-3.0	0.4	3.5
1989	20	*	23.0	1.4	0.4	1.0	17	*	12.0	-2.1	0.5	3.2

Table 2. Inherent uncertainties in the three measurement techniques used in obtaining the temperature data.

Surface bucket with thermometer	± 0.2 °C
Mechanical Bathythermograph (MBT)	± 1.0 °C
Expendable Bathythermograph (XBT)	± 0.2 °C

Table 3. Correlation between the surface and bottom temperature anomalies in the four areas of the shelf: Gulf of Maine (GM), Georges Bank (GB), Middle Atlantic Bight North (MABN) and Middle Atlantic Bight South (MABS). Values in parentheses are not significant at the 95% level.

	Spring	Fall
GM	0.49	(0.40)
GB	0.82	0.78
MABN	0.79	(0.30)
MABS	0.95	(0.16)

Table 4. Correlation between the temperature anomalies in the four areas of the shelf. See Table 3 for explanation of the abbreviations.

	Spring		Fall	
	Surface	Bottom	Surface	Bottom
GM - GB	0.58	0.48	0.46	0.79
GM - MABN	0.60	0.70	(0.35)	0.56
GM - MABS	0.60	0.57	0.51	0.51
GB - MABN	0.67	0.62	0.62	0.63
GB - MABS	0.59	0.59	0.58	0.61
MABS-MABN	0.83	0.78	0.78	0.83

Table 5. Correlation between the temperature anomalies in the spring and in the subsequent fall for the four areas of the shelf. See Table 3 for explanation of the abbreviations.

	Surface	Bottom
GM	(-0.12)	(0.44)
GB	(0.28)	(0.21)
MABN	(-0.06)	(0.41)
MABS	(-0.08)	(0.38)

Table 6. Correlation between the temperature anomalies in the fall and the following spring for the four areas of the shelf. See Table 3 for explanation of the abbreviations.

	Surface	Bottom
GM	(-0.30)	(0.38)
GB	(0.46)	0.57
MABN	(0.23)	(0.18)
MABS	(0.20)	(0.17)

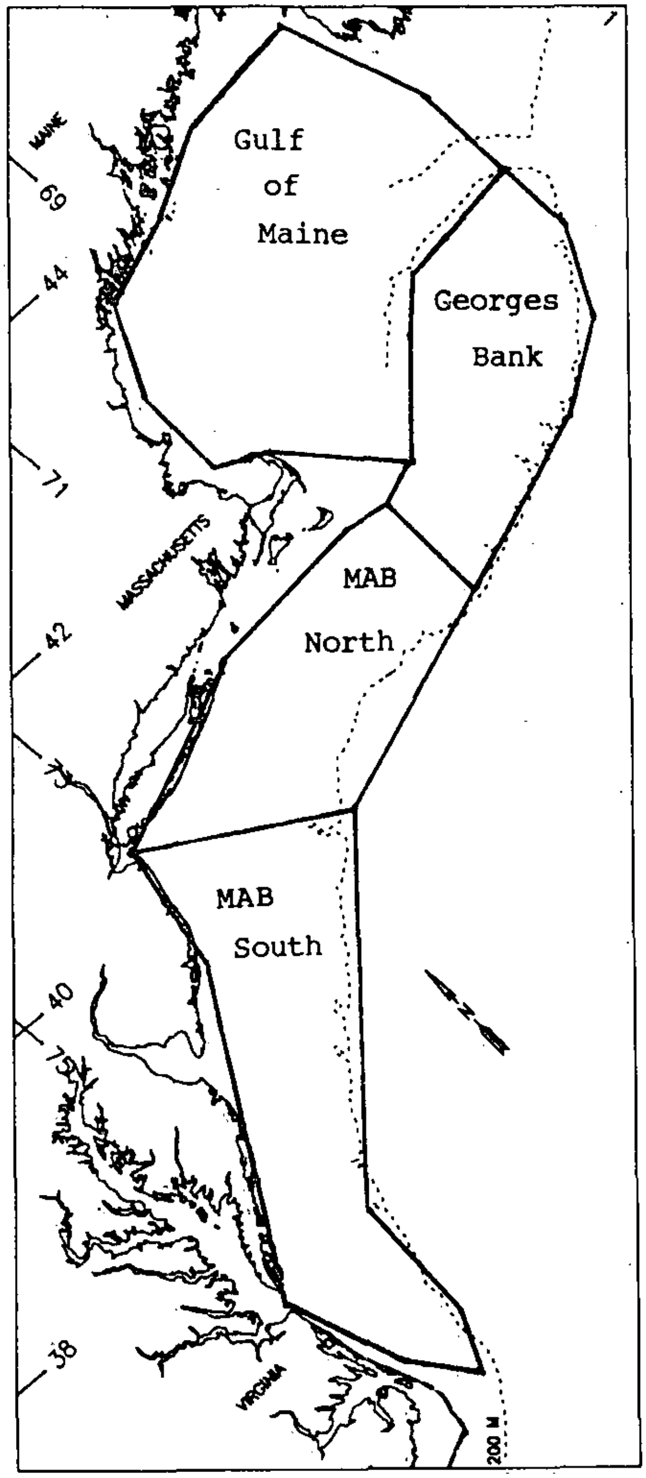


Figure 1. The region of the northeast continental shelf covered by the Northeast Fisheries Center bottom trawl survey. The boundaries of the four areas of the shelf for which average temperature and anomaly values are calculated are shown - Gulf of Maine, Georges Bank, Northern Middle Atlantic Bight and Southern Middle Atlantic Bight.

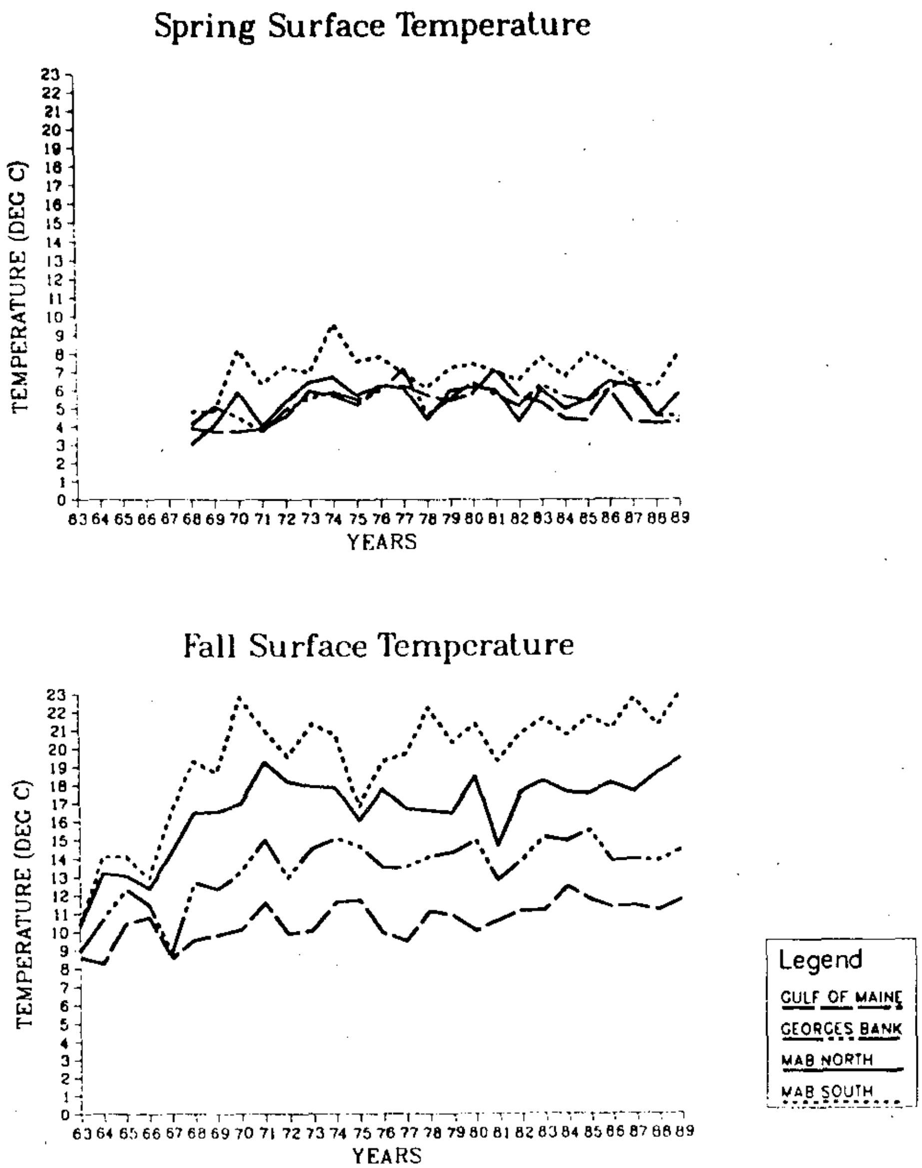
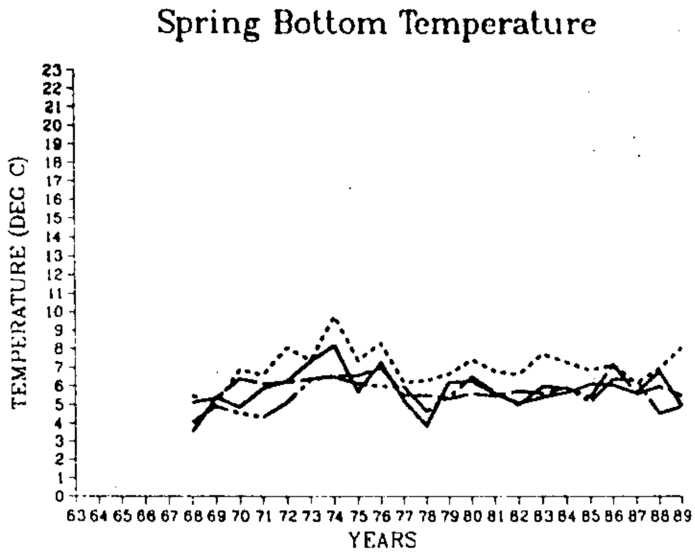


Figure 2. Average surface temperature in the four regions of the continental shelf shown in figure 1 for the spring (top) and the fall (bottom). The data are listed in Table 1.



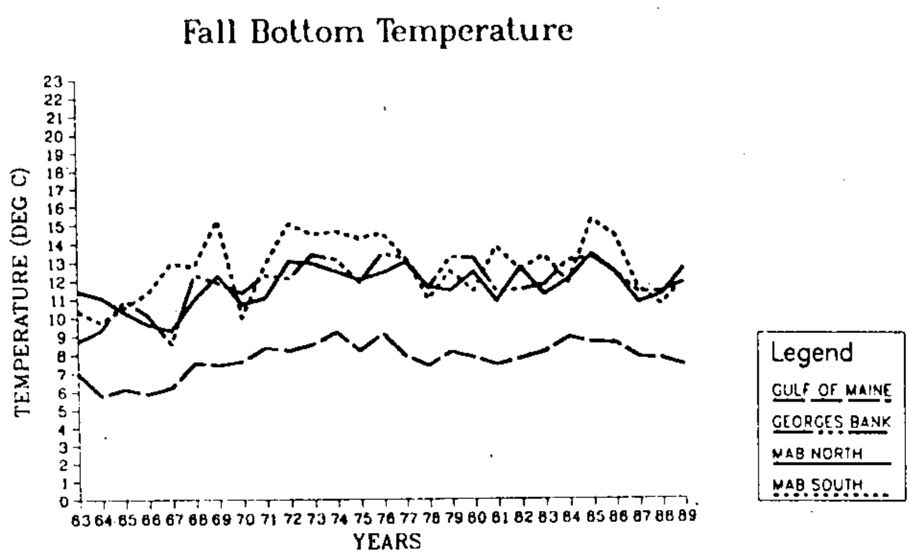


Figure 3. Average bottom temperature in the four regions of the continental shelf shown in figure 1 for the spring (top) and the fall (bottom). The data are listed in Table 1.

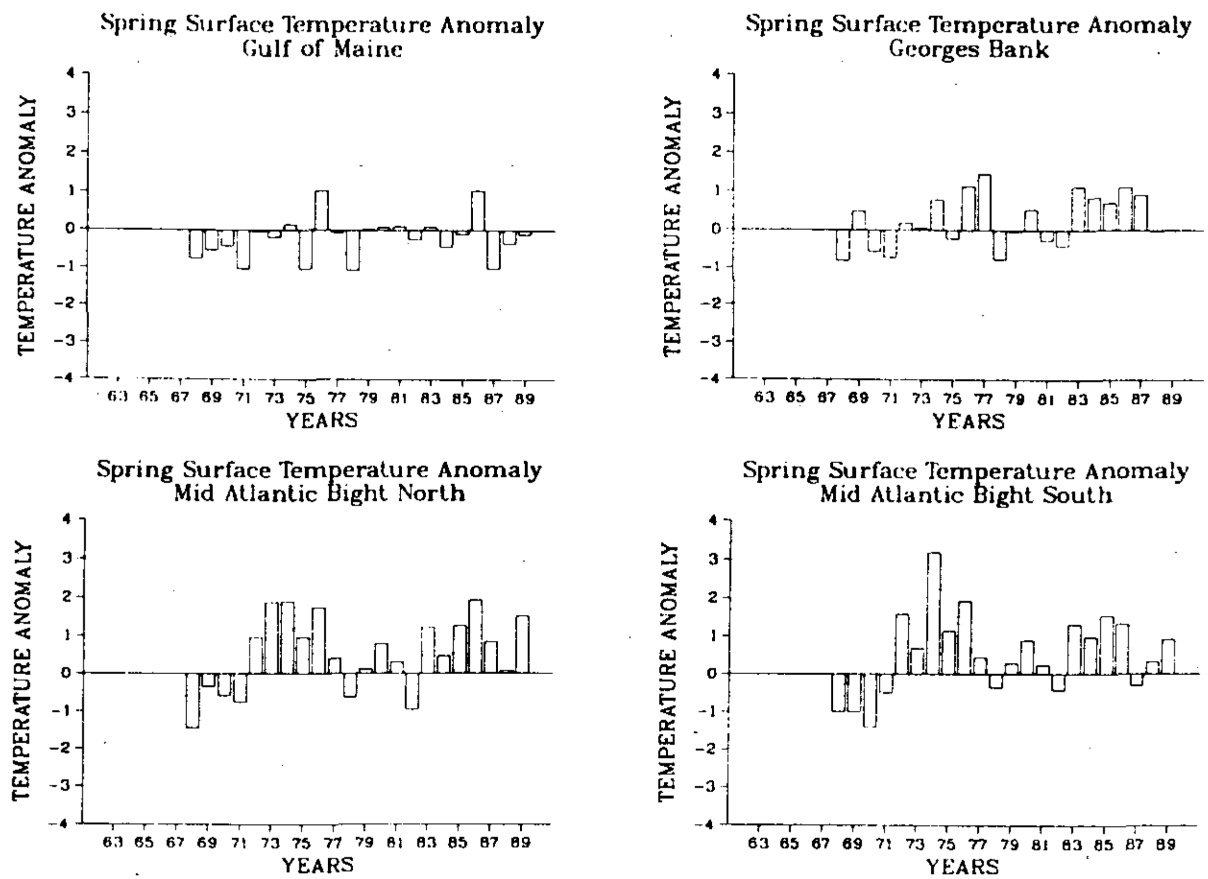


Figure 4. Average surface temperature anomaly in the spring for the four regions of the continental shelf shown in figure 1. The data are listed in Table 1.

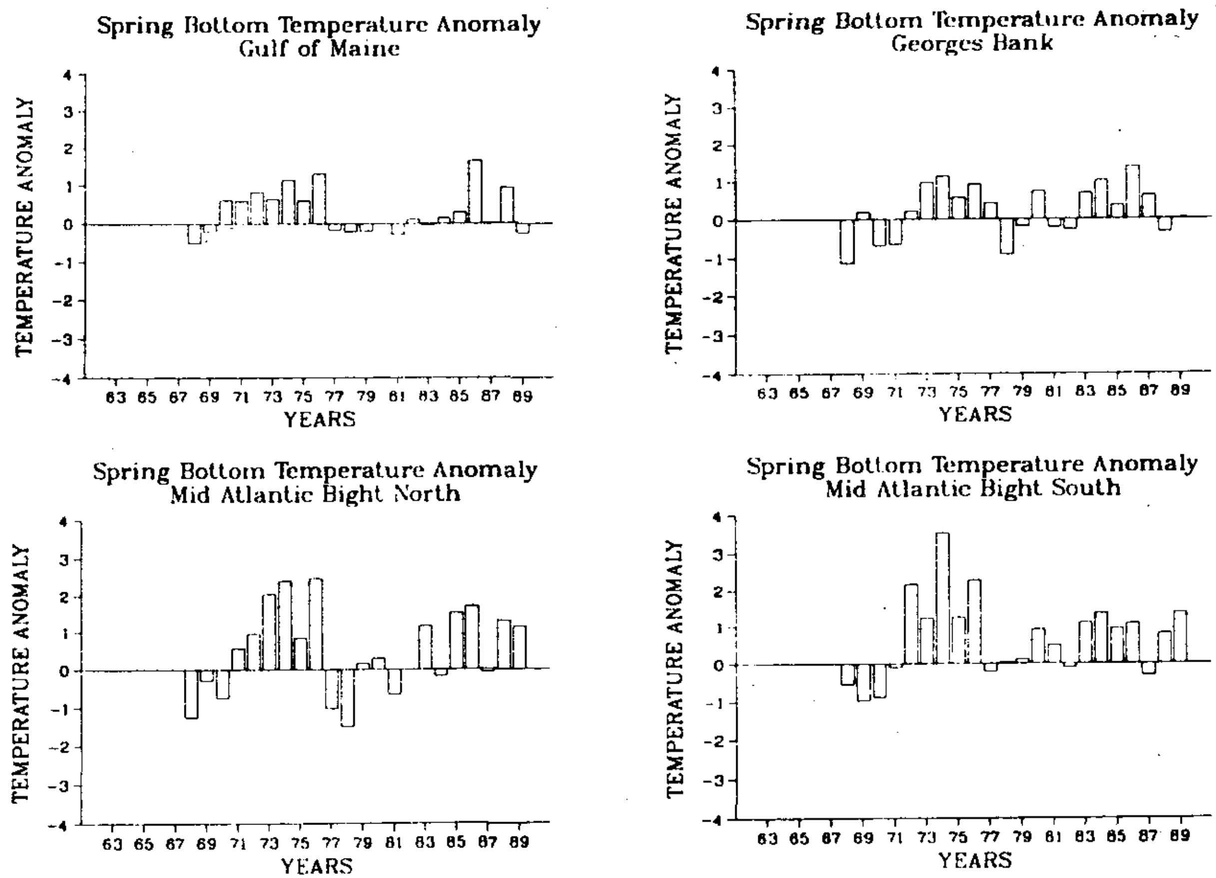


Figure 5. Average bottom temperature anomaly in the spring for the four regions of the continental shelf shown in figure 1. The data are listed in Table 1.

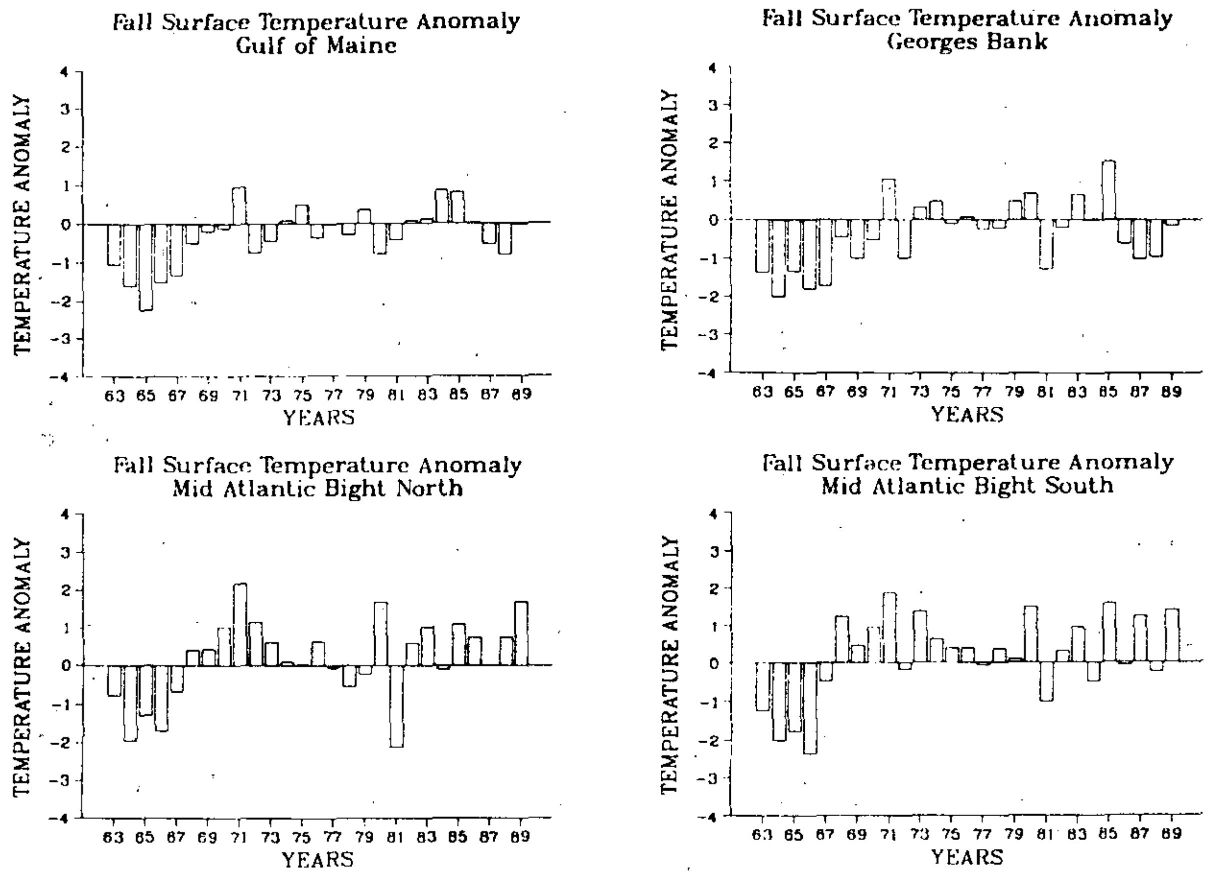


Figure 6. Average surface temperature anomaly in the fall for the four regions of the continental shelf shown in figure 1. The data are listed in Table 1.

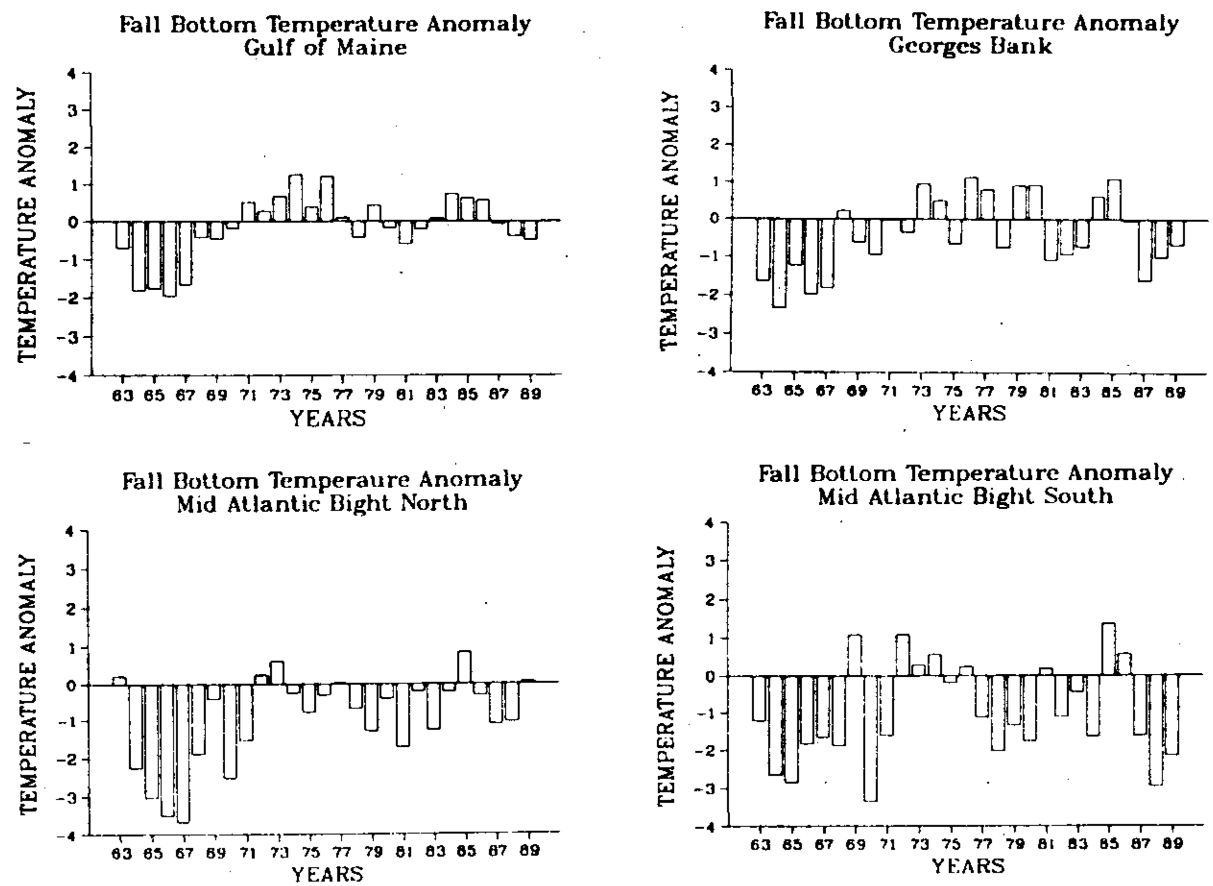
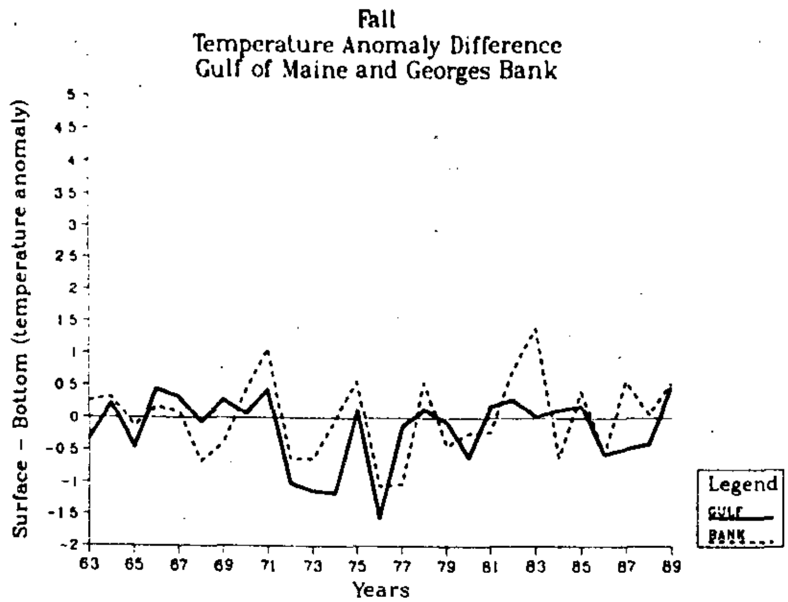


Figure 7. Average bottom temperature anomaly in the fall for the four regions of the continental shelf shown in figure 1. The data are listed in Table 1.



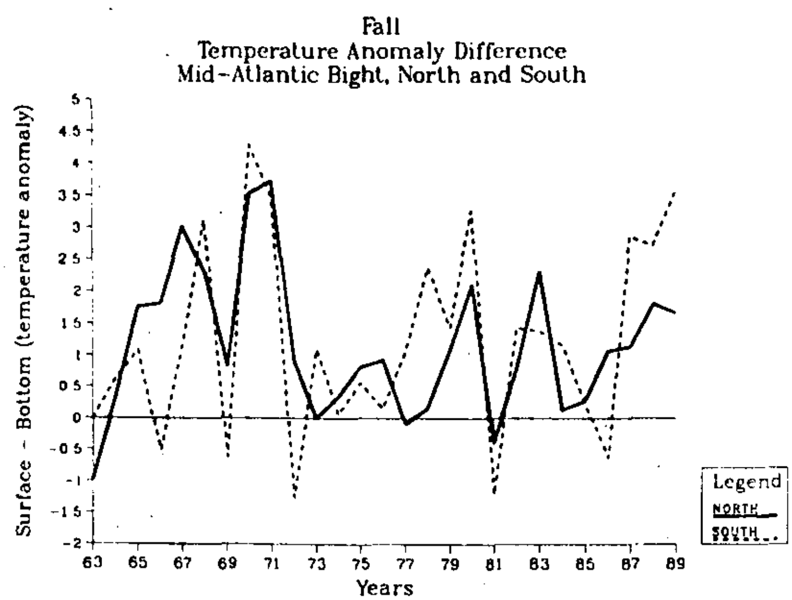


Figure 8. Difference between the fall average surface and bottom temperature anomalies in the four regions of the continental shelf in figure 1.

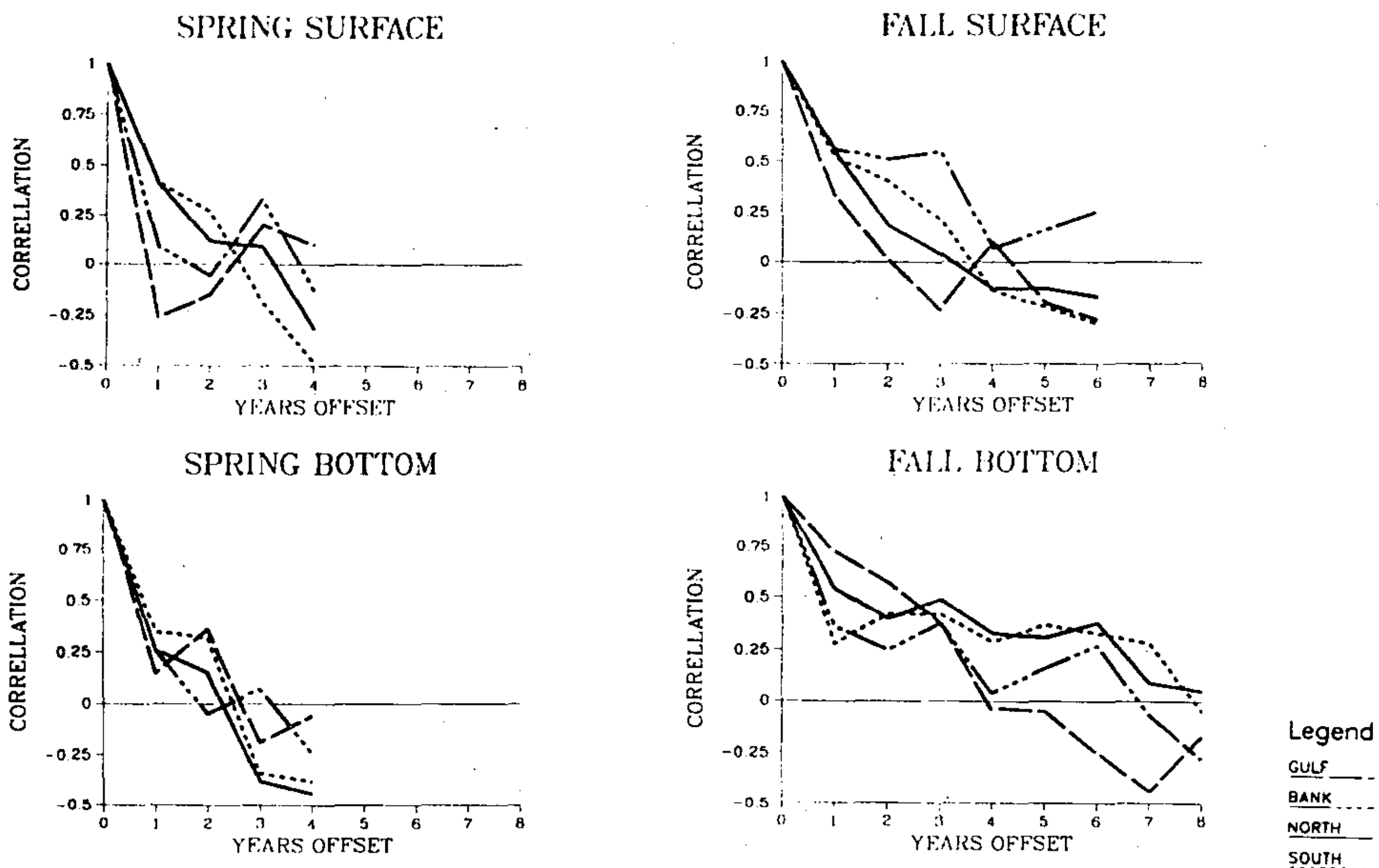


Figure 9. Autocorrelation function for the average temperature anomaly series listed in Table 1.