

A Summary of Spring and Autumn Bottom-water Temperatures  
on the Atlantic Continental Shelf from  
Cape Hatteras to Cape Sable, 1963-77

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## ABSTRACT

Bottom-water temperature data collected during spring and autumn were analyzed for four areas of the continental shelf between Cape Hatteras and Cape Sable: (1) Gulf of Maine, (2) Georges Bank, (3) southern New England, (4) Middle Atlantic Bight. During the spring series (1968-77) adjusted temperatures were generally low in all areas prior to 1972, reached their maximum in either 1974 or 1976, and except for Georges Bank, declined sharply in 1977. The autumn series (1963-77) is marked by large annual oscillations except for the Gulf of Maine where adjusted temperatures declined steadily from 1963-66 and thereafter generally increased to a maximum in 1976. Only the Middle Atlantic Bight was negatively anomalous in the autumn of 1977.

## INTRODUCTION

Since 1963 observations of water temperatures have been made regularly in western North Atlantic waters by research vessels of the National Marine Fisheries Service, Woods Hole, Massachusetts. Initially, cruises were conducted routinely only during the autumn and covered southern New England, Georges Bank, and the Gulf of Maine. In the autumn of 1967 the cruises were expanded to cover the Middle Atlantic Bight and, starting in 1968, the entire region, mostly within the 40-200 m isobaths between Cape Hatteras and Cape Sable, was routinely sampled each year during both spring and autumn.

Two earlier papers by Davis (1978) and Davis<sup>1</sup> describe bottom-water temperature conditions in the Gulf of Maine - Georges Bank areas during

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<sup>1</sup>Davis, C. W. Bottom-water temperature trends from Cape Cod to Cape Hatteras during spring and autumn, 1964-76. Northeast Fisheries Center, Woods Hole, Massachusetts. Unpubl. Ms. (Submitted for publication as NOAA Tech. Rep. NMFS, SSRF in April 1978).

1963-75 and in the southern New England - Middle Atlantic Bight areas during 1964-76, respectively. The purpose of this paper is to briefly summarize in one report for the entire region the general results of the earlier reports and to include the effects of the severe climatic winter of 1976-77.

#### DATA AND METHODS

Data were collected by mechanical (1963-69) and expendable (1970-77) bathythermograph casts at randomly selected stations in the region between Cape Hatteras, North Carolina, and Cape Sable, Nova Scotia during research cruises designed for assessment of groundfish stocks. The region was divided into four areas for temperature analysis - the Gulf of Maine, Georges Bank, southern New England, and the Middle Atlantic Bight (Figure 1). The Gulf of Maine and Georges Bank were further divided into subareas for additional analyses. Approximately 250-300 temperature observations were collected during each cruise.

In order to evaluate the year-to-year variations of the seasonal collections, the observed indices of mean bottom-water temperatures were adjusted to common sampling dates (Table 1) by a method described by Davis (1978). The 1977 adjusted indices and seasonal anomalies are summarized in Table 2. The observed indices are based on the actual measurements taken in situ during each cruise; both indices are weighted means based on the percentage of bottom area covered by 2°C contours or temperature class intervals (TCI's). Calculation of tables of TCI percentages allows a more reasonable estimate of the thermal environment than the use of mean temperatures. A summary of the 1977 TCI percentages is shown in Table 3.

## RESULTS

### Gulf of Maine

Spring. Adjusted mean bottom-water temperatures gradually increased from  $5.4^{\circ}\text{C}$  in 1968 to a maximum of  $7.2^{\circ}\text{C}$  in 1976 and then dropped abruptly in 1977 to a minimum of  $5.1^{\circ}\text{C}$  (Figure 2). The  $6^{\circ}\text{-}8^{\circ}\text{C}$  TCI that usually dominated the thermal bottom layer was replaced by the  $4^{\circ}\text{-}6^{\circ}\text{C}$  TCI in 1977 and virtually no water greater than  $8^{\circ}\text{C}$  was present in the Gulf during this coldest spring (Table 4). The 10-year average for the entire Gulf was  $6.2^{\circ}\text{C}$  with the coldest water found in the westernmost sector (Subarea I) and the warmest water in the east central sector (Subarea IV) (Table 5).

Autumn. Starting in the autumn of 1963, bottom temperatures decreased from  $7.2^{\circ}\text{C}$  to a minimum of  $5.6^{\circ}\text{C}$  in 1966 and then increased rather steadily to a maximum of  $9.3^{\circ}\text{C}$  in 1976 (Figure 3). A moderately large decrease of  $0.5^{\circ}\text{C}$  was noted in 1977 but the mean values in all subareas of the Gulf that year were well above the 15-year average of  $7.3^{\circ}\text{C}$  for the entire Gulf (Table 5). There was practically no water  $>10^{\circ}\text{C}$  in 1977 which was unusual considering the relatively high observed mean (Table 3).

### Georges Bank

Spring. Bottom temperatures on Georges Bank during spring are marked by rather large oscillations, but except for 1975, adjusted temperatures during 1972-77 were well above the 10-year average of  $5.0^{\circ}\text{C}$  (Figure 2). The minimum ( $3.8^{\circ}\text{C}$ ) occurred in 1968, the maximum ( $6.3^{\circ}\text{C}$ ) in 1974, and the mean temperature in 1977 ( $5.4^{\circ}\text{C}$ ) was only  $0.1^{\circ}\text{C}$  less than in 1976. During 1977, however, eastern Georges had a negative anomaly of  $0.6^{\circ}\text{C}$  while western and central sectors of the Bank were positively anomalous (Table 6). The entire Bank was covered essentially by water of  $4^{\circ}\text{-}8^{\circ}\text{C}$  and the 1977 TCI distribution was unique for this time-series of observations (Table 7).

Autumn. The autumn series of adjusted temperature observations on Georges Bank is characterized by three series of warm and cold periods, i.e., usually above the time-series average ( $11.8^{\circ}\text{C}$ ) during 1964-68 and 1973-77 and below this average during 1969-72 (Figure 3). Maximum adjusted temperatures occurred in 1965 ( $13.1^{\circ}\text{C}$ ) and 1976 ( $13.6^{\circ}\text{C}$ ) and minimum values were observed in 1969-70 ( $10.4^{\circ}$ - $10.5^{\circ}\text{C}$ ). Eastern Georges was characteristically cooler than either the central or western sectors of the Bank during 1977 (Table 6).

#### Southern New England

Spring. An obvious warming trend was noted in southern New England waters starting in the spring of 1970 ( $5.1^{\circ}\text{C}$ ), peaking in 1976 ( $8.3^{\circ}\text{C}$ ) and then dropping abruptly to  $5.3^{\circ}\text{C}$  in 1977 (Figure 2). The significant drop in 1977 was caused not so much by a large volume of coldest water but by a relatively small volume of water  $>10^{\circ}\text{C}$  (Table 3). The 1968-77 average bottom-water temperature for this season was  $6.7^{\circ}\text{C}$ .

Autumn. Adjusted bottom temperatures oscillated strongly during the autumn but all years between 1972-77 except 1975 were well above the 1963-77 average of  $11.7^{\circ}\text{C}$  (Figure 3). A minimum of  $9.7^{\circ}\text{C}$  occurred in 1967. Noticeably different was the small percentage of water  $<10^{\circ}\text{C}$  and large percentage of water  $>14^{\circ}\text{C}$  found in 1977 (Table 3).

#### Middle Atlantic Bight

Spring. Adjusted bottom-water temperatures in the Middle Atlantic Bight during spring are characterized by large oscillations, but nevertheless, a warming trend is evident with all years between 1972 and 1976 above the 1968-77 average of  $7.5^{\circ}\text{C}$  (Figure 2). The minimum occurred in 1970 ( $4.6^{\circ}\text{C}$ )

and the maximum in 1974 ( $10.1^{\circ}\text{C}$ ). The negatively anomalous 1977 bottom temperature of  $6.7^{\circ}\text{C}$  was caused by a relatively large amount of  $2^{\circ}\text{-}4^{\circ}\text{C}$  water and a corresponding low amount of water  $>10^{\circ}\text{C}$  (Table 3).

Autumn. The autumn series of adjusted bottom temperatures in the Middle Atlantic Bight exhibited even more wildly the oscillations between years observed in southern New England and on Georges Bank during this season (Figure 3). Only three years (1969, 1972, and 1975) had temperatures exceeding the 1967-77 average of  $13.8^{\circ}\text{C}$ , with a maximum of  $15.7^{\circ}\text{C}$  occurring in 1972. The minimum bottom temperature occurred in 1970 ( $12.1^{\circ}\text{C}$ ) and the 1977 value was only  $12.7^{\circ}\text{C}$ .

#### DISCUSSION

Previous studies of alternations of water temperatures along the northwest Atlantic coast, based mostly on sea-surface observations, revealed a warming trend from the early 1940's that reached a maximum during 1952-53 followed by a cooling period continuing through 1967 (Colton 1972). The present data indicate a general continuation of the cooling trend in the autumn in the Middle Atlantic Bight, southern New England, and on Georges Bank until 1970 followed by another period of warming to 1977 (Figure 3). In the Gulf of Maine the autumn cooling period ended in 1966 and temperatures generally increased thereafter in a definite warming sequence. During spring a general warming trend, interrupted but intermittently, is indicated since 1968 in all waters between Cape Sable and Cape Hatteras (Figure 2).

Colton (1972) attributed earlier warming and cooling periods to changes in the composition of the subsurface water, i.e., slope water was either displaced or modified during cold years, and warm years occurred when slope water bordered upon the 200 m isobath accompanied by a low ratio of coastal to central Atlantic water. Examination of the  $8^{\circ}\text{C}$  isotherm in the spring

that intrudes into the Gulf of Maine in the spring (Davis 1978) and the 10°C isotherm south of Cape Cod support the slope water border principle for controlling temperatures. Also of great importance is the amount of winter chilling of coastal waters accompanied by prevailing northwesterly winds (Bigelow 1927). A case in point is the exceptionally severe winter climate in 1977 and the subsequently low spring water temperatures characterized by: (1) the 10°C isotherm in southern New England well seaward of its average position as determined by Wright (1976); (2) absence of the 8°C isotherm of slope water usually penetrating into the eastern Gulf of Maine (Davis 1978); and (3) a relatively large amount of 2°-4°C inshore coastal water prevailing over much of the Middle Atlantic Bight. As a result of these three factors, respective temperatures in these areas were well below average in the spring of 1977, but Georges Bank remained above average. Based on temperature data alone, one can only speculate why Georges remained rather warm, but it seems logical that deeper, warmer Gulf of Maine water adjacent to Georges, by advective processes and upwelling, tempered the effects of winter chilling. It will be interesting to see if the bottom-water temperature conditions in the spring of 1978 parallel the 1977 observations in these areas as the winter of 1978 was also extremely cold.

LITERATURE CITED

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Table 1. Mid-dates of cruises and years of sampling bottom-water temperatures in four areas of the Atlantic continental shelf, 1963-1977.

Area	Spring	Years	Autumn	Years
Gulf of Maine	April	1968-77	November	1963-77
Georges Bank	April	1968-77	November	1963-77
Southern New England	March	1968-77	October	1964-77
Middle Atlantic Bight	March	1968-77	October	1967-77

Table 2. Adjusted mean bottom-water temperature indices and anomalies in four areas of the western North Atlantic continental shelf during spring and autumn of 1977.

Area	Spring		Autumn	
	Index ( $^{\circ}$ C)	Anomaly ( $^{\circ}$ C)	Index ( $^{\circ}$ C)	Anomaly ( $^{\circ}$ C)
Gulf of Maine	5.1	-1.1	8.8	+1.5
Georges Bank	5.4	+0.4	12.2	+0.4
Southern New England	5.3	-1.4	12.8	+1.1
Middle Atlantic Bight	6.7	-0.8	12.7	-1.1

s (TCI's) and observed mean bottom-water temperature  
 h Atlantic continental shelf during spring and autumn 1977.

Index °C	Index										Index °C
	4°-6°C	6°-8°C	8°-10°C	10°-12°C	12°-14°C	14°-16°C	16°-18°C	18°-20°C	>20°C	<1	
6.9	0	0	1	48	20	22	8	<1			12.6
6.0	0	0	2	40	24	33	<1	0			12.7
6.2	0	2	11	26	32	29	0	0			12.5
5.7	6	43	50	1	0	0	0	0			7.9

Table 4. Percentages of temperature class intervals (TCI's) and observed mean bottom-water temperature indices in the Gulf of Maine during spring and autumn 1977.

Subarea	Spring					Index			Autumn			Index °C
	2°-4°C %	4°-6°C %	6°-8°C %	8°-10°C %	10°-12°C %	4°-6°C %	6°-8°C %	8°-10°C %	10°-12°C %	Index °C		
I	29	71	0	0	0	0	15	76	8	8.8		
II	8	92	0	0	0	20	62	19	0	7.0		
III	0	83	17	<1	0	7	72	21	0	7.3		
IV	0	18	79	3	0	0	30	70	0	8.4		
V	0	59	41	0	0	0	10	89	1	8.8		
Entire Gulf	4	64	32	1	0	6	43	50	1	7.9		

Table 5. Adjusted mean bottom-water temperature indices and anomalies for the Gulf of Maine in 1977. Anomalies are based on the 1968-1976 mean in the spring and the 1963-1976 mean in the autumn.

Subarea of the Gulf of Maine	Spring		Autumn	
	Index ( $^{\circ}$ C)	Anomaly ( $^{\circ}$ C)	Index ( $^{\circ}$ C)	Anomaly ( $^{\circ}$ C)
I	3.8	-0.4	9.7	+1.9
II	4.3	-1.6	7.9	+1.0
III	4.9	-1.3	8.3	+1.2
IV	6.3	-0.7	9.5	+1.8
V	5.4	-0.6	9.9	+1.6
Entire Gulf	5.1	-1.1	8.8	+1.5

Table 6. Adjusted mean bottom-water temperature indices and anomalies for Georges Bank in 1977. Anomalies are based on the 1968-1970 mean in the spring and the 1963-1976 mean in the autumn.

Subarea of Georges Bank	Spring		Autumn	
	Index (°C)	Anomaly (°C)	Index (°C)	Anomaly (°C)
Western	5.5	+0.2	12.9	+0.5
Central	5.7	+0.6	13.0	+0.7
Eastern	4.5	-0.6	10.7	+0.5
Entire Bank	5.4	+0.4	12.2	+0.4

Table 7. Percentages of temperature class intervals (TCI's) and observed mean bottom-water temperature indices on Georges Bank during spring and autumn 1977.

Subarea	Spring			Autumn			Index		
	4°-6°C %	6°-8°C %	8°-10°C %	6°-8°C %	8°-10°C %	10°-12°C %	12°-14°C %	14°-16°C %	Index °C
Western	23	74	2	2	10	14	22	52	13.2
Central	26	73	0	<1	5	12	52	31	13.2
Eastern	83	17	0	3	22	62	14	0	10.8
Entire Bank	41	58	1	2	11	26	32	29	12.5

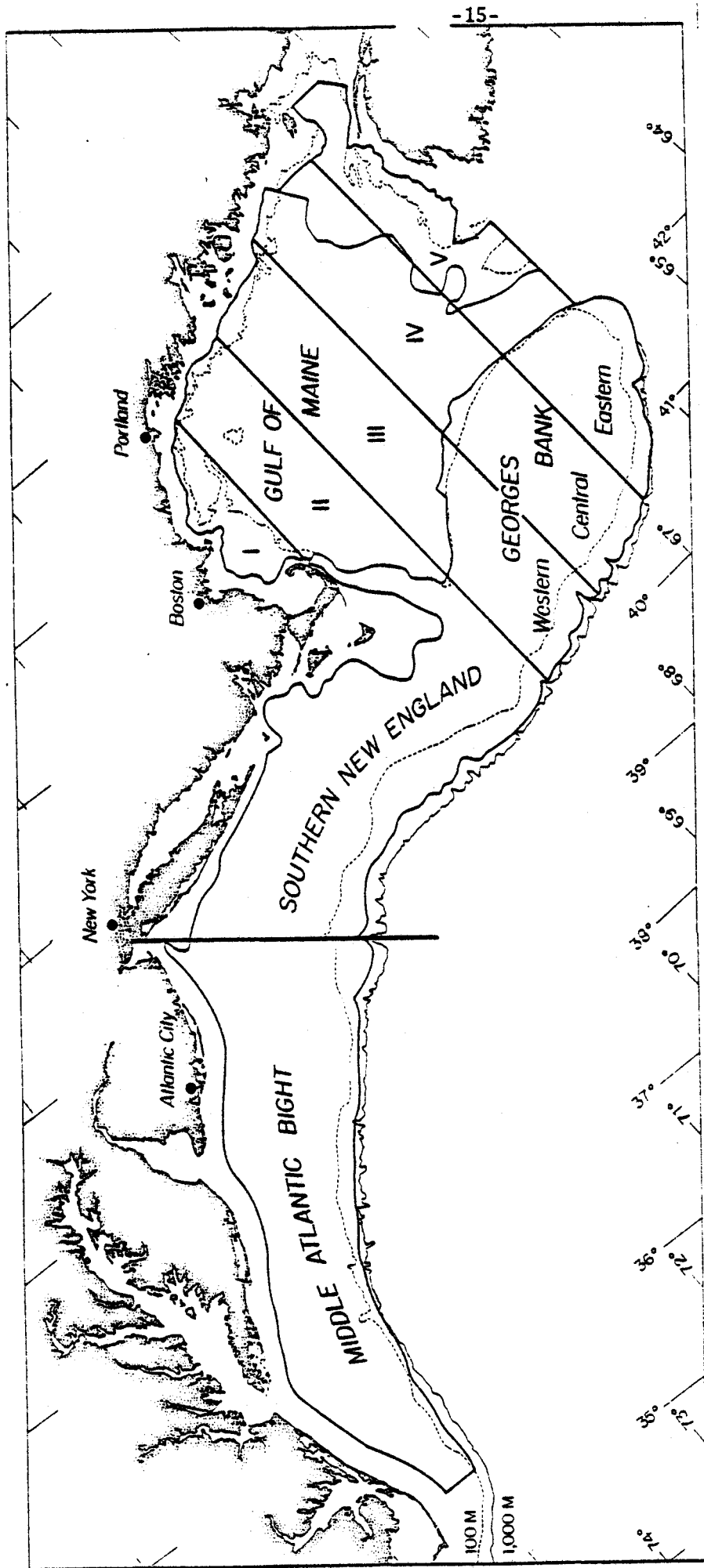


Figure 1. Area of the Atlantic continental shelf showing major areas and subareas used for analysis of bottom-water temperature data.



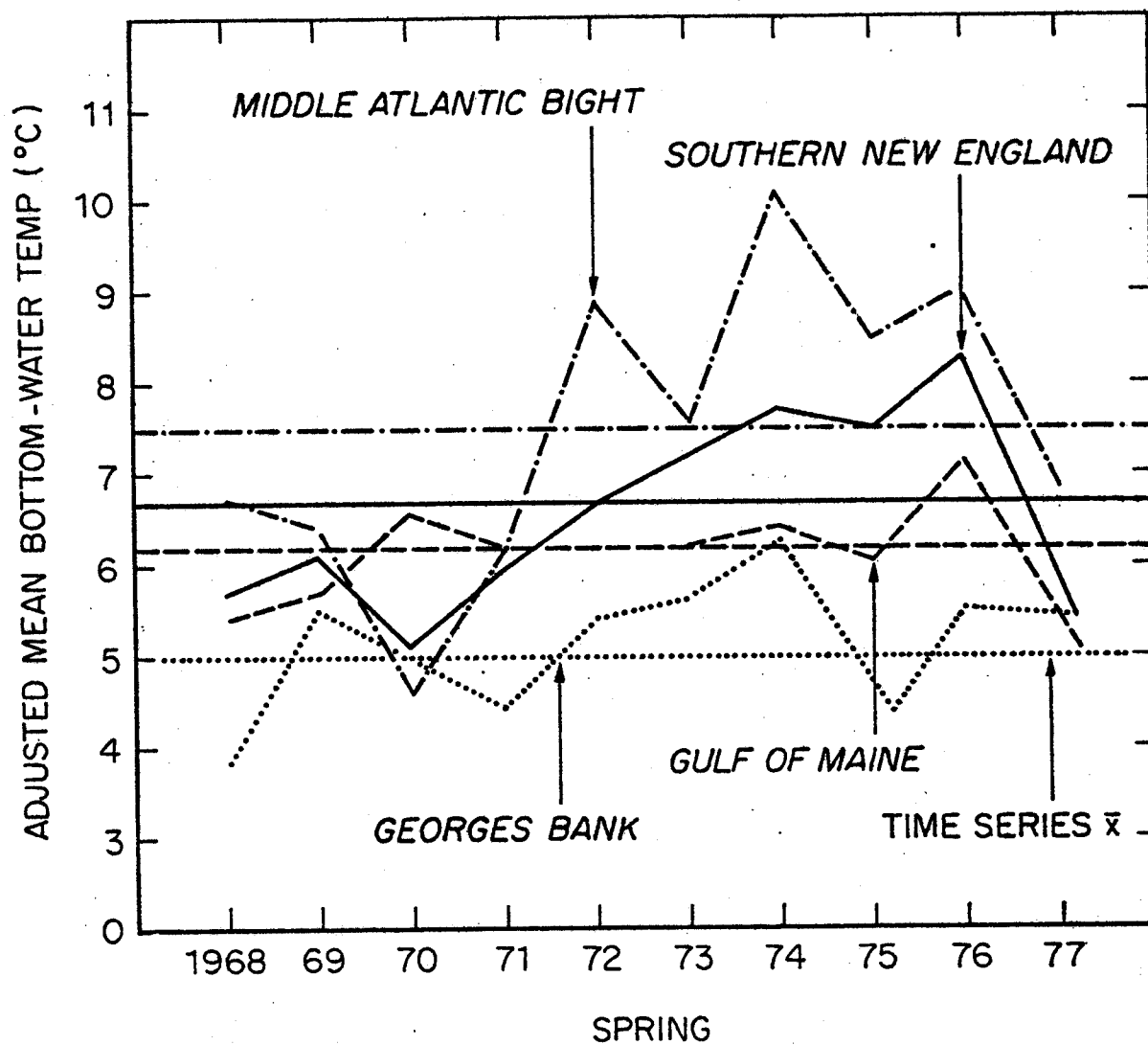


Figure 2. Adjusted annual and time-series mean bottom-water temperatures in four areas of the Atlantic continental shelf during spring, 1968-77.

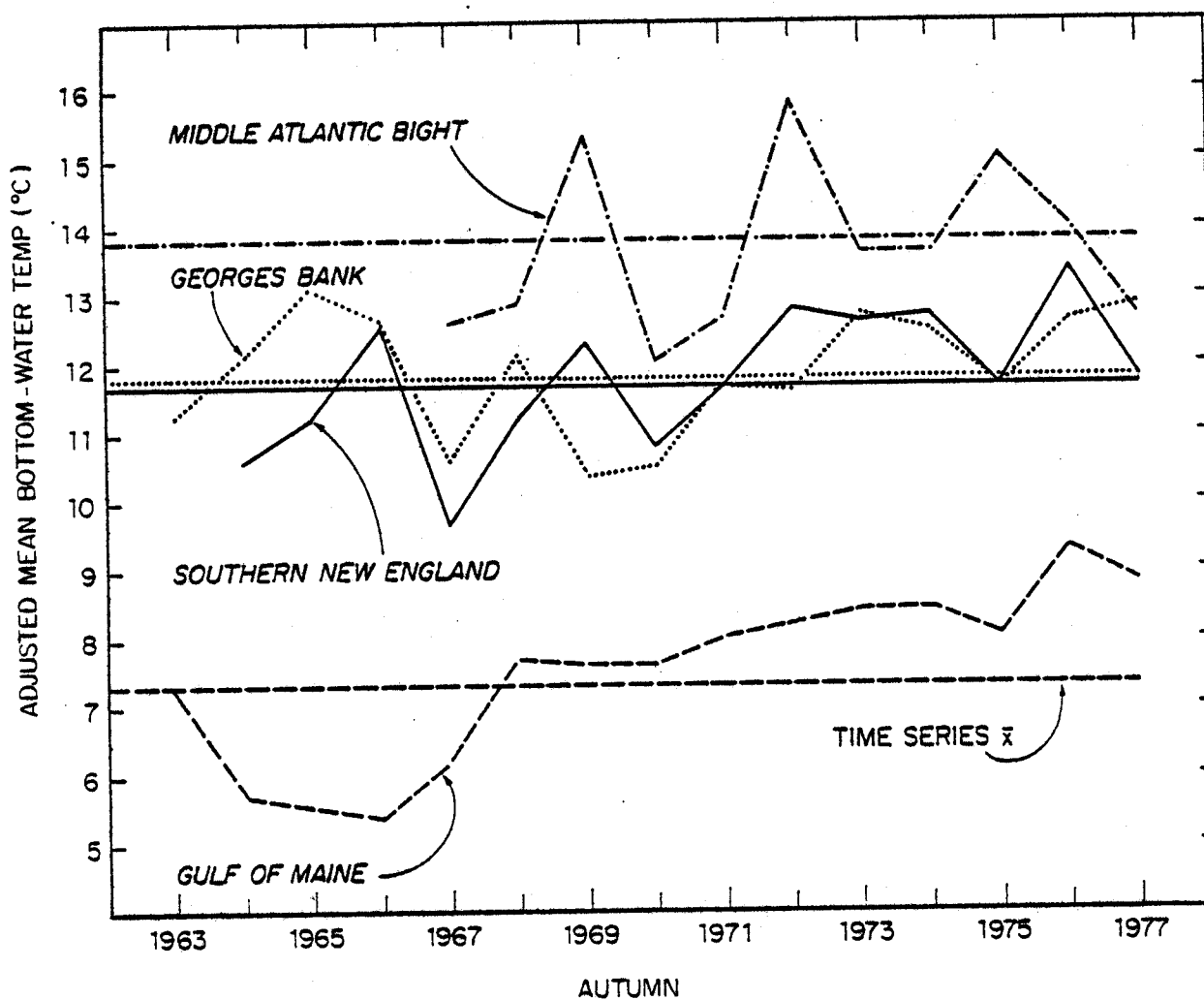


Figure 3. Adjusted annual and time-series mean bottom-water temperatures in four areas of the Atlantic continental shelf during autumn, 1964-77.