726

NOAA Technical Report NMFS SSRF-726

The Gulf of Maine Temperature Structure Between Bar Harbor, Maine, and Yarmouth, Nova Scotia, June 1975-November 1976

Robert J. Pawlowski

December 1978

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

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U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator
Terry L. Leitzell, Assistant Administrator for Fisheries
National Marine Fisheries Service

CONTENTS

Figures

Table

The Gulf of Maine Temperature Structure Between Bar Harbor, Maine, and Yarmouth, Nova Scotia, June 1975-November 1976

ROBERT J. PAWLOWSKI[1]

ABSTRACT

Monitoring of the temperature structure on a vertical section between Bar Harbor, Maine, and Yarmouth, Nova Scotia, has permitted observation of the seasonal warming and cooling trends in the northern Gulf of Maine. Data have revealed a rise in both temperature and salinity from 1975 to 1976.

INTRODUCTION

In June 1975 the Northeast Fisheries Center and the Atlantic Environmental Group of the National Marine Fisheries Service (NMFS) began a cooperative temperature study of the northern Gulf of Maine as a part of the continuing NMFS Ship of Opportunity Program. Observations were obtained monthly through November 1976, except for February 1976, aboard the Canadian National Railways Ferry (C/N), MV *Bluenose*, during its service from Bar Harbor, Maine, to Yarmouth, Nova Scotia. The purpose of this paper is to review and summarize the data, compare them with historical data, and compare the data for the summer and autumn of 1975 and 1976.

Long-term and seasonal temperature trends in the Gulf of Maine have been noted by Bumpus and Chase (1967) and Colton and Stoddard (1972). Colton (1968) reported on a warming trend that reached its maximum from 1952 to 1953, followed by uninterrupted cooling into 1967 Davis[2] found an end to this cooling trend in 1968 and resumption of a warming trend that continued into 1975. Present monthly temperature observations show that the warming trend has continued into 1976. The monitoring of these trends is being continued. The area between Bar Harbor, Maine, and Yarmouth, Nova Scotia, was chosen because of the year-round ferry service and our assumption that it gave a representative section across the Gulf of Maine. Analysis of the circulation in the Gulf of Maine (Bumpus and Lauzier 1965; Lauzier 1967) showed that this section crossed both water of Scotian Shelf origin off Nova Scotia and waters mixed with the Bay of Fundy to the west. The temperature structure of water deeper than 150 m represents localized movement in the deep Gulf of Maine and the influence of waters entering through the Northeast Channel.

METHODS

Expendable bathythermograph (XBT) stations were taken at 30-min intervals along the ferry track (Fig. 1) on dates specified in Table 1. Temperature data were collected on a Sippican Model R-603C XBT system, which provided continuous vertical temperature profiling with ±0.2°C temperature and ±0.2% depth accuracy. The recorder was calibrated to specifications prior to each cruise and checked for reference temperature (16.7°C) before each cast. At the station, a sea surface bucket temperature was taken and compared with the recorder surface temperature. Comparison was also made between the ship's bathymetric sounding and the trace bottom mark. As data compared within the system's accuracy, temperatures were read for 0.1°C.

At each station, a sea surface salinity sample was collected for processing ashore on a Beckman Model RS-7B inductive salinometer. The salinometer was calibrated at the beginning and end of each set of samples by water of known conductivity. This method met the manufacturer's specified accuracy (±0.003‰), with data reported to 0.01‰.

Data are presented as vertical temperature sections, sea surface and bottom temperature plots, and sea surface salinity plots. Position data were used in organizing these figures. Each position was determined at sea through Decca radio navigation or radar ranges and bearings on navigational aids or coastal land masses. A standard bathymetric profile was also developed using ship's soundings and the Canadian Hydrographic Office Chart #4011. Temperature was contoured to vertical section for

Table 1.—Dates of expandable bathythermograph observations from MV *Bluenose* between Bar Harbor, Maine, and Yarmouth, Nova Scotia.

18 June 1975	16 Dec. 1976	15 July 1976
16 July 1975	25 Mar. 1976	17 Aug. 1976
13 Aug. 1975	20 Apr. 1976	14 Sept. 1976
17 Sept. 1975	25 May 1976	19 Oct. 1976
14 Oct. 1975	16 June 1976	09 Nov. 1976
18 Nov. 1975		

[1]Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Woods Hole, Mass.; present address: NOAA Ship George B. Kelez (R-441), POB 176, Ryder Station, Brooklyn, NY 11234.

[2]C. W. Davis. 1976. Spring and autumn water temperatures in the Gulf of Maine and Georges Bank, 1968-1975. ICNAF Res. Doc. No. 85, Ser. No. 3897, 13 p. Unpubl. manuscr.

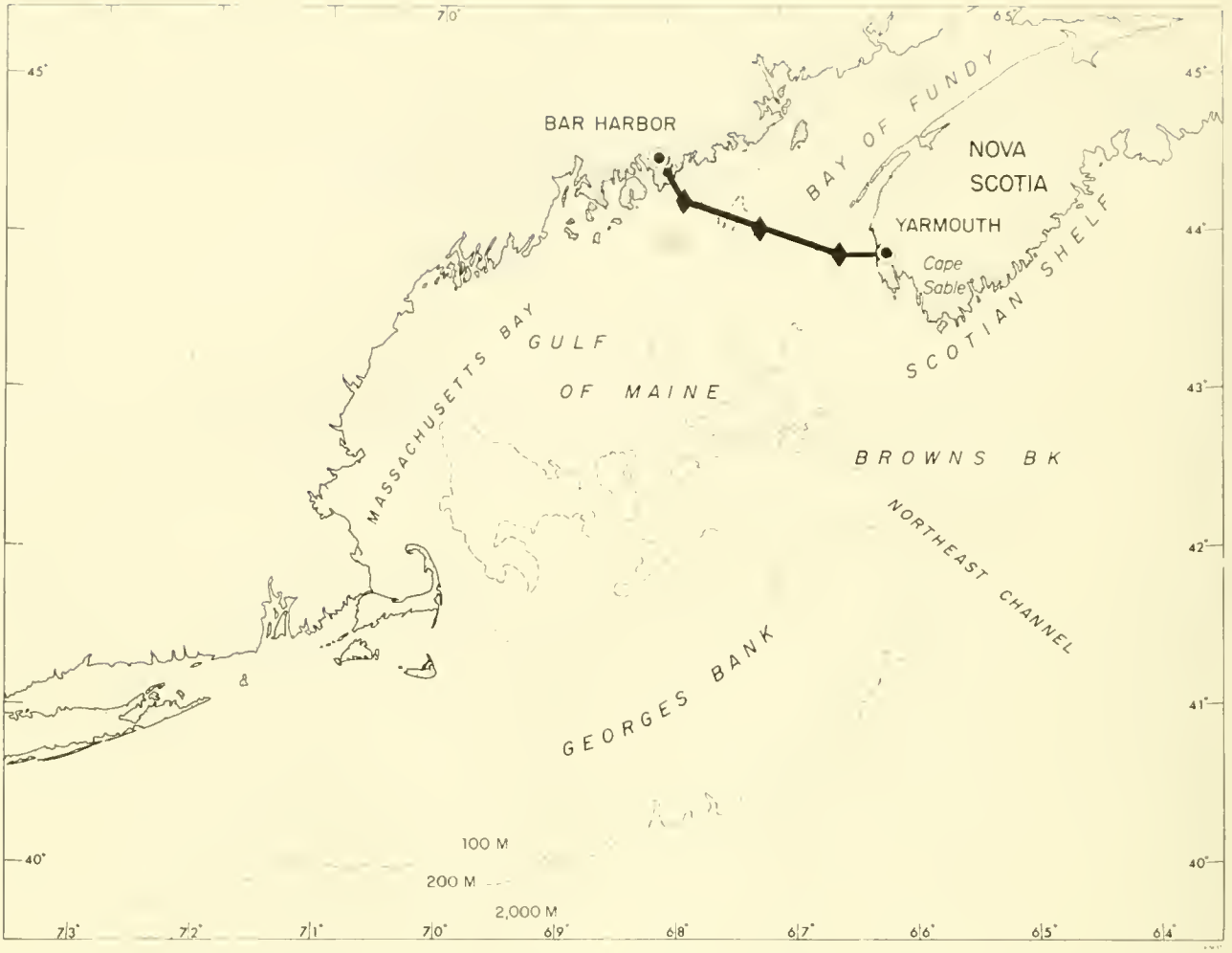

Figure 1.—Location of temperature section monitored by the MV *Bluenose* from June 1975 through November 1976. Positions chosen for sea surface temperature and salinity and bottom temperature plots are shown along the track. Depth in meters.

1°C intervals, with additional 0.5°C isotherms drawn where appropriate for clarity.

Mean historical sections (Figs. 8-11), taken from Chamberlin et al. (1976), were drawn for each month from horizontal charts based on data collected between 1940 and 1959 for 0 to 100 m (Colton and Stoddard 1972) and on bottom temperature observations between 1940 and 1966 for waters deeper than 100 m (Colton and Stoddard 1973). Data were read from isotherm intersection points along the transect at 0-, 10-, 20-, 30-, 40-, 50-, 75-, and 100-m depths. Linear interpolation was used between the 100-m and the bottom temperature values. Sections were drawn to coincide with sampling dates from 18 June 1975 through 25 May 1976 (Table 1). Many inconsistencies arose due to the scarcity of data for mean sections, as the majority of bottom temperature data were based on a single year's observations (Colton and Stoddard 1973). For such reasons, the mean sections should be used for general comparison only.

Sea surface temperature and salinity and bottom temperatures were plotted against time for three standard locations across the Gulf of Maine (Figs. 12-14); off coastal Maine (lat. 44°15′N, long. 67°58′W), off coastal Nova Scotia (lat. 43°47′N, long. 66°30′W), and in the center of the Gulf of Maine (lat. 44°00′N, long. 67°16′W) as shown in Figure 1. As station positions d'd not always coincide with the standard positions, the plotted values were determined by linear interpolation for these locations.

RESULTS

Temperature sections were organized by seasons: Summer (June-August), Autumn (September-November), Winter (December-February), and Spring (March-May) with mean historical sections similarly arranged to allow for comparison. The descriptive results were listed under the appropriate season and year. Analysis dealt primarily with the seasonal trends and differences between summer and autumn 1975 and 1976. Additional analysis was made of the sea surface salinity trend over the 18-mo sampling period. The historical sections were discussed fully by Chamberlin et al. 1976.

Summer 1975

The temperature structure of summer 1975 (Fig. 2) was characterized by four prominent features: the development of a strong seasonal thermocline above 50 m offshore of the 100-m isobath, vertical mixing and warming of coastal waters, breakdown of two temperature minimum cells below the thermocline (50-150 m), and the minor fluctuation of temperatures in waters deeper than 150 m.

Summer solar warming developed a thermocline above 50 m in the central Gulf of Maine, with gradual downward conduction of heat. Above the thermocline waters warmed at a rate of about 2°C per month. The maximum surface temperature, 13.6°C, was reached in August, with surface temperatures generally being 1° to 2° C higher than in coastal waters (Fig. 2).

Coastal waters (inshore of the 100-m isobath) warmed throughout the water column, with weak thermocline development off Maine and homogeneous conditions off Nova Scotia. Bottom temperatures reflected the mixing conditions off Nova Scotia, having a greater monthly rise and higher maximum temperature than coastal Maine.

During June and July two low temperature cells existed between 50 and 150 m in central gulf waters, bounded by the shallow thermocline and seaward progression of warmer coastal waters. As the season progressed, these cold areas dissipated through warming influence from surrounding layers. A temperature inversion of 1°-2°C occurred below 150 m during June and July with upward mixing that appeared to isolate the shallower cold cells. By August this inversion disappeared and temperatures monotonically decreased to the bottom.

Autumn 1975

Autumn 1975 temperatures (Fig. 3) involved a change from the warming to a cooling trend, with increased vertical mixing. Coastal Maine and central gulf waters began a steady cooling trend in September, while waters off Nova Scotia reached a maximum temperature during September and cooled through October and November. The central gulf's thermocline mixed downward, with continued warming of middepth waters into November. Bottom waters (deeper than 150 m) warmed through September and October, then cooled in November.

Winter 1975-76

The temperature for the winter of 1975-76 (Fig. 4) showed an acceleration in the cooling trend as the largest temperature decrease occurred between December and January (>2°C above 50 m). Minimum temperatures

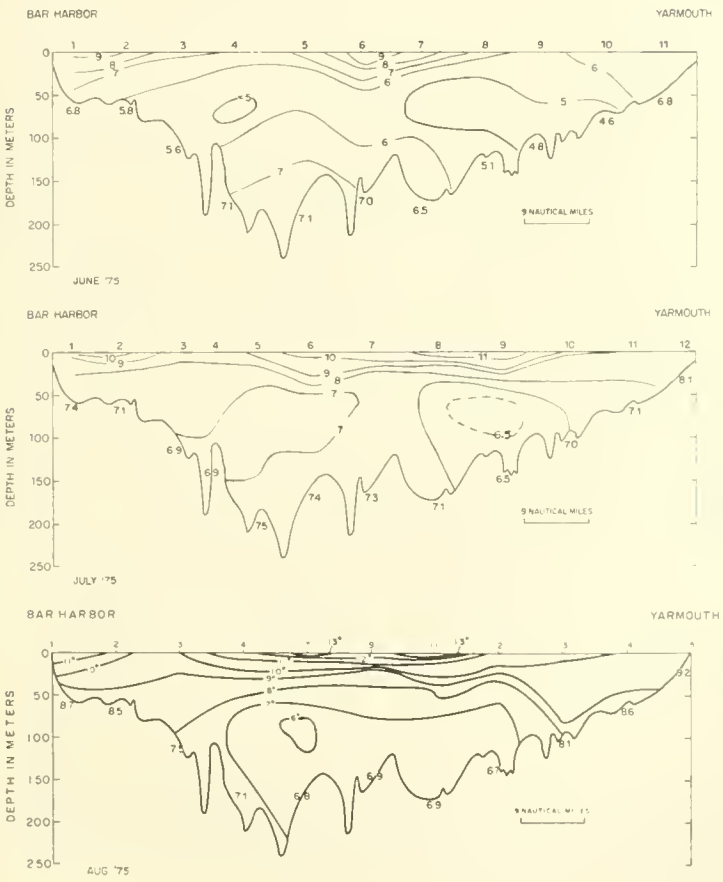

Figure 2.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, summer 1975.

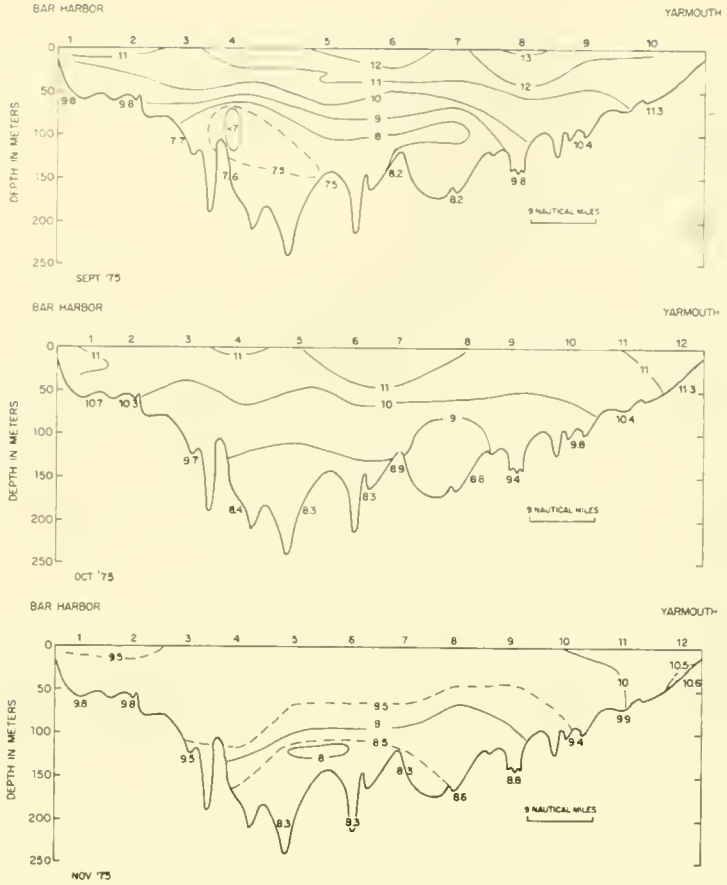

Figure 3.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, autumn 1975.

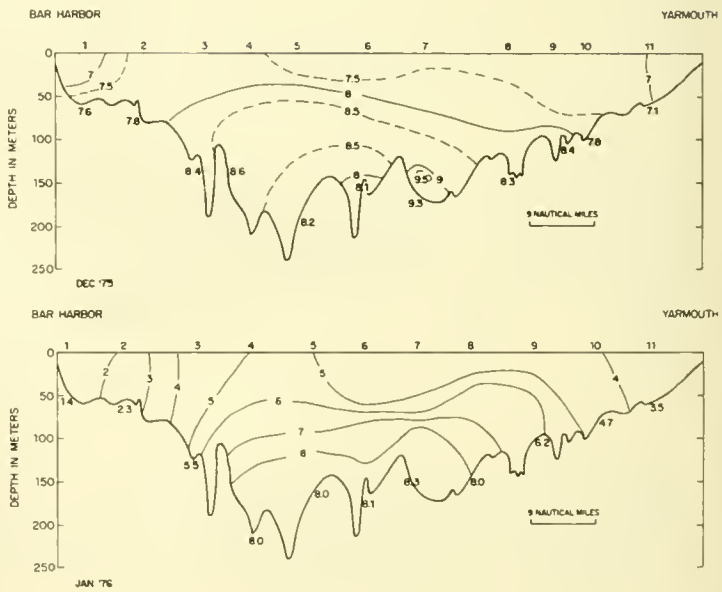

Figure 4.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, winter 1975-76.

were reached in January for coastal Maine and central gulf waters, and in March for Nova Scotian waters (see Figs. 12 and 13). However, due to lack of observations in February, the time for minimum temperatures and reversal to a warming trend could not be accurately established. Below 150 m, a warm cell (>9°C) formed in the eastern basin (Station 7) during December, which cooled and dissipated by January.

Spring 1976

The spring 1976 warming trend (Fig. 5) began in surface waters during March. Minimum temperatures at 50 to 150 m were reached in March, while waters deeper than 150 m continued a cooling trend until April and May. As the spring progressed, coastal waters warmed from the shores outward, while a thermocline developed in the central gulf area above 50 m. These two processes, along with the relatively constant temperature in deep water, constricted the winter-cooled water into a minimum temperature layer between 50 and 100 m. This layer was similar to that found in summer 1975 (Fig. 2), but lacked the cellular structure noted previously.

Summer 1976

The data from summer 1976 (Fig. 6) showed temperature characteristics similar to those of the previous year, but generally 2°C warmer. The thermocline developed through the summer, with rapid surface warming (>2°C) in June and July, followed by a decrease in the warming rate during August as waters neared maximum temperature. The minimum temperature layer dissipated by July, with continued warming at middepths through August. Temperatures below 150 m warmed into June, followed by a rapid increase in the eastern basin during July and continued increases in both basins through August.

Autumn 1976

Autumn 1976 (Fig. 7) was characterized by a continuation of stable water column conditions and warming into September, with yearly maximum temperatures being 1° to 3°C higher than in 1975. A change to cooling and loss of stability occurred in October with a breakdown of the thermocline. This cooling continued into November bringing temperatures and structure similar to the previous year. Waters deeper than 100 m showed a westerly shift of the 9°C isotherm, but otherwise maintained constant temperatures in September. October followed with cooling and development of an 8°C cell in the western basin. This cell dissipated with an unexplained return to warming in November.

The historical mean data (Figs. 8-13) show the same major features found in the 1975 and 1976 data: the development of a surface water thermocline, the spring-summer minimum temperature layer, and a bottom temperature inversion. Seasonal trends were consistent between historical and present sections. Variations existed in the extent of thermocline development into coastal waters and the change in deep bottom temperature structure. Temperatures were 1° to 5°C warmer in 1975 and 1976 than the mean historical temperatures.

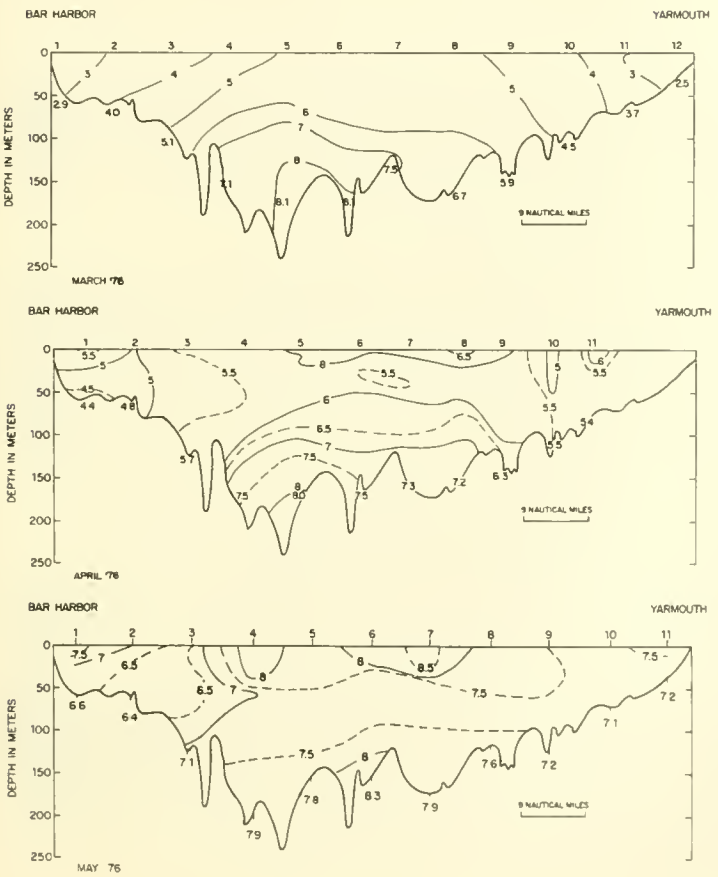

Figure 5.—Vertical temperture sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, spring 1976.

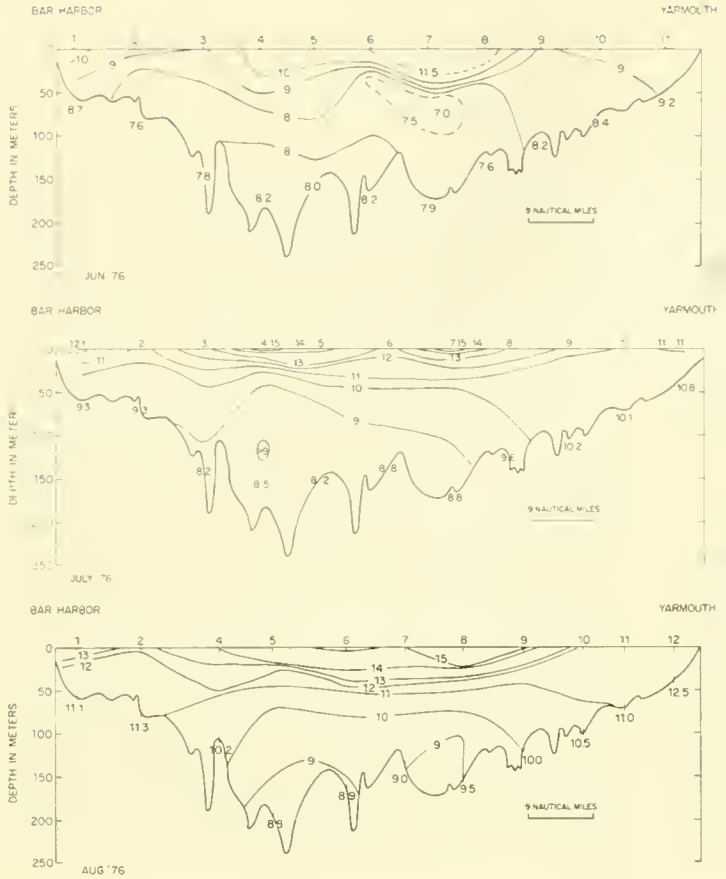

Figure 6.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, summer 1976.

The surface salinity (Fig. 14) varied throughout the sampling period with no distinct seasonal characteristics. An overall increasing trend occurred through the sampling period. In most cases, the salinities were higher in the central gulf waters than in coastal waters. The salinity along the study track increased through summer 1975, reaching a peak in October. After October, central gulf and Nova Scotian waters rapidly decreased (0.5‰/month) into November and December, while Maine coastal waters maintained a slower rate. In December the salinity in Maine waters dropped significantly (0.6‰); the lowest values occurred in January, followed by an increase into spring. Both Nova Scotian and central gulf waters maintained a steady increase of salinity through the winter, with peaks in March for central gulf waters and in April for coastal Nova Scotian waters. The gulf waters fluctuated through the spring, with a rise into summer 1976. Salinities continued to increase through the summer and fall, with values about 1‰ higher than in 1975.

DISCUSSION

The Gulf of Maine transect can be divided into five areas: coastal Maine (offshore to 100 m), coastal Nova Scotia (offshore to 100 m), central surface waters (above 50 m), central middepth waters (50-150 m), and central bottom waters (deeper than 150 m). Each area showed distinct characteristics and interactions with the surrounding environment.

Coastal Maine Waters

Coastal Maine waters underwent a warming trend from March through September with development of a weak thermocline through the summer months. The thermocline broke down in the fall, with cooling from the shores outward through January. Maximum temperatures were reached in September and minimum temperatures in January.

Coastal Nova Scotian Waters

Coastal Nova Scotian waters had homogeneous conditions throughout the sampling period. The warming trend existed from April through September, with bottom temperatures 0.5° to 1.5°C warmer than coastal Maine. The cooling trend proceeded slowly through the fall, accelerated through the winter, bringing minimum temperatures by March. The historical means exhibit similar seasonal development; however, they show a summer thermocline near the Nova Scotian coast which was not present in 1975 and 1976.

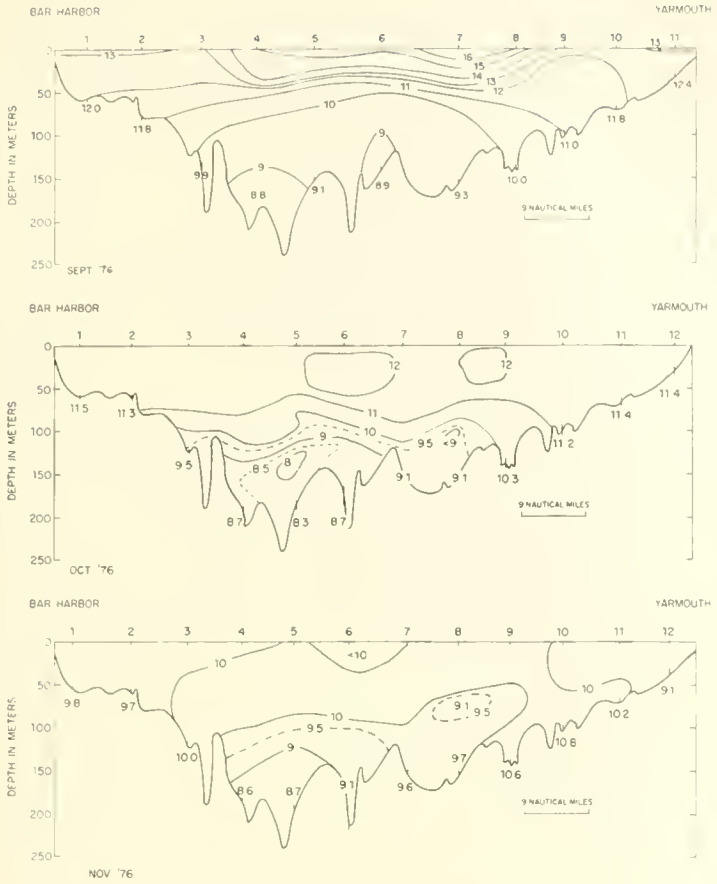

Figure 7.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, autumn 1976.

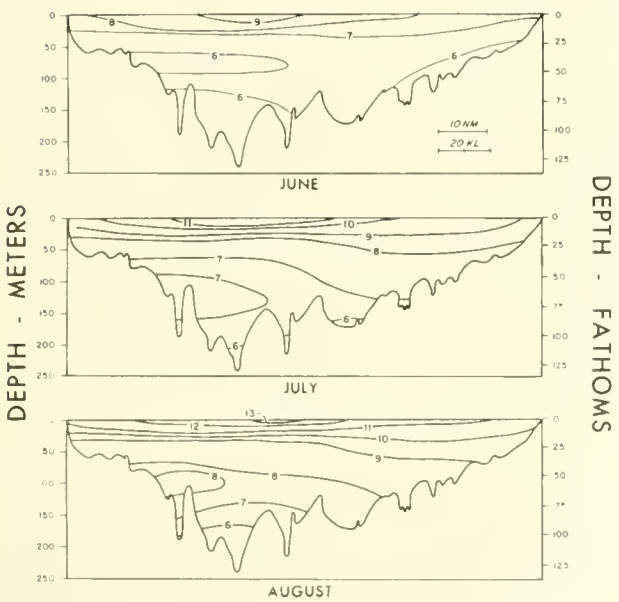

Figure 8.—Summer mean temperature sections (°C) (1940-66) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, from Chamberlin et al. (1976).

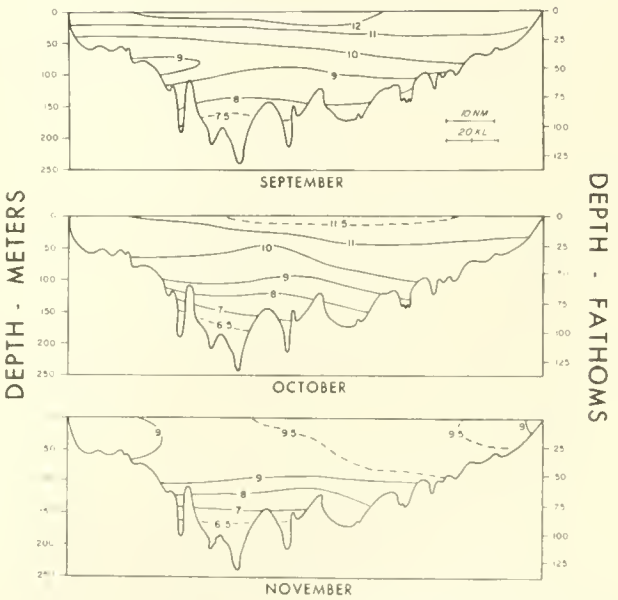

Figure 9.—Autumn mean temperature sections (°C) (1940-66) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, from Chamberlin et al. (1976).

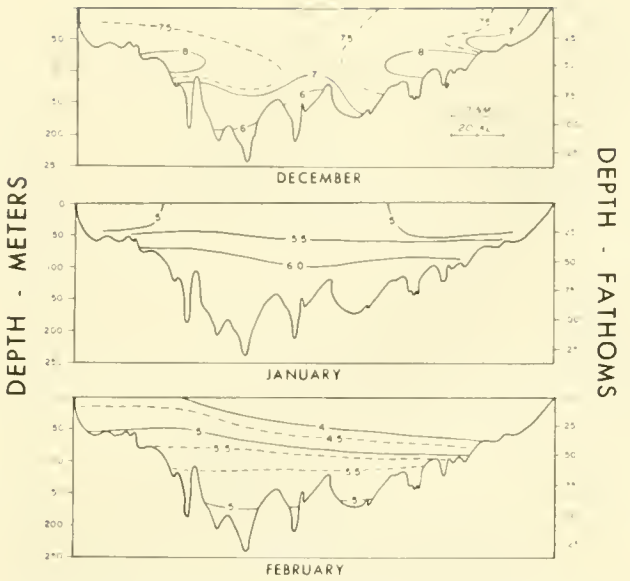

Figure 10.—Winter mean temperature sections (°C) (1940-66) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, from Chamberlin et al. (1976).

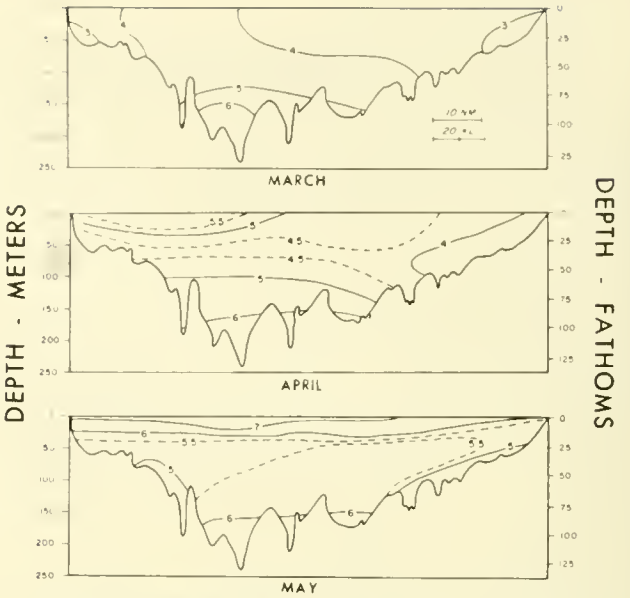

Figure 11.—Spring mean temperature sections (°C) (1940-66) for the Gulf of Maine, and Yarmouth, Nova Scotia, from Chamberlin et al. (1976).

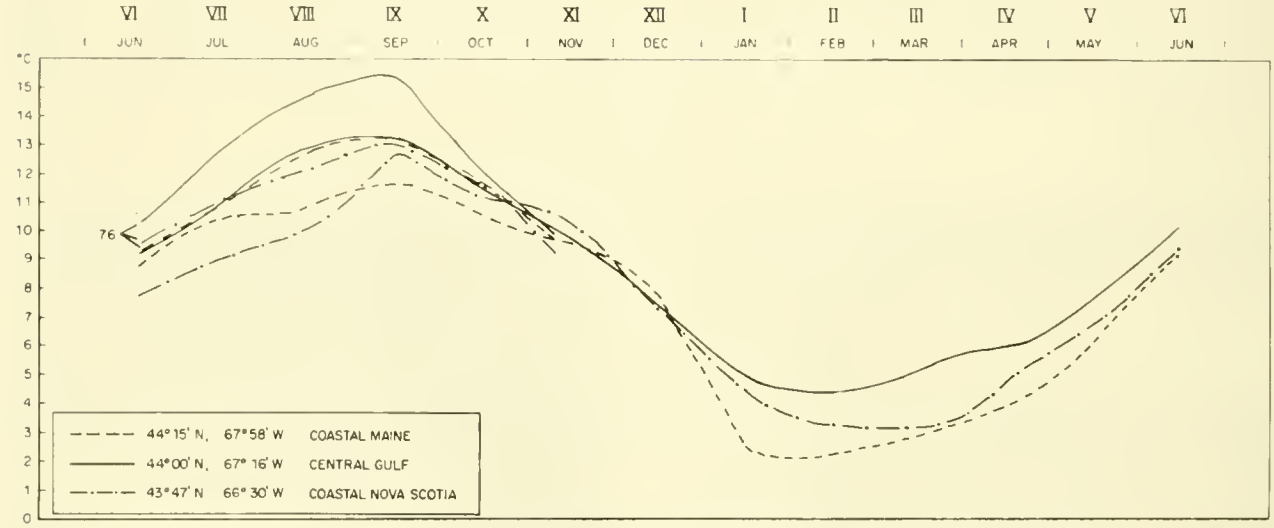

Figure 12.—Sea surface temperature (°C) at three locations (Fig. 1) across the Gulf of Maine, June 1975-November 1976. 1976 Summer and Autumn data indicated by "76".

Central Surface Waters

In the central surface waters the thermocline developed in April and May with warming (>2°C per month) into August. The warming rate slowed in August as temperatures neared the yearly maximum. Maximum temperatures were reached in late August to mid-September, with temperatures 1° to 2°C higher than coastal waters. It is probable that most solar radiation is restricted to heating above the thermocline in this region with little downward mixing by wind or currents. Bumpus and Lauzier (1965) showed the central area to be part of the counterclockwise gyre circulation of the Gulf of Maine during summer. Vertical mixing occurred in the autumn with breakdown of the thermocline by November. Rapid cooling and homogeneous conditions characterized the winter, with minimum temperatures observed in January. Again, seasonal trends and temperature structures for 1975 and 1976 were similar to historical data, with the exception that minimum temperatures historically occurred in March.

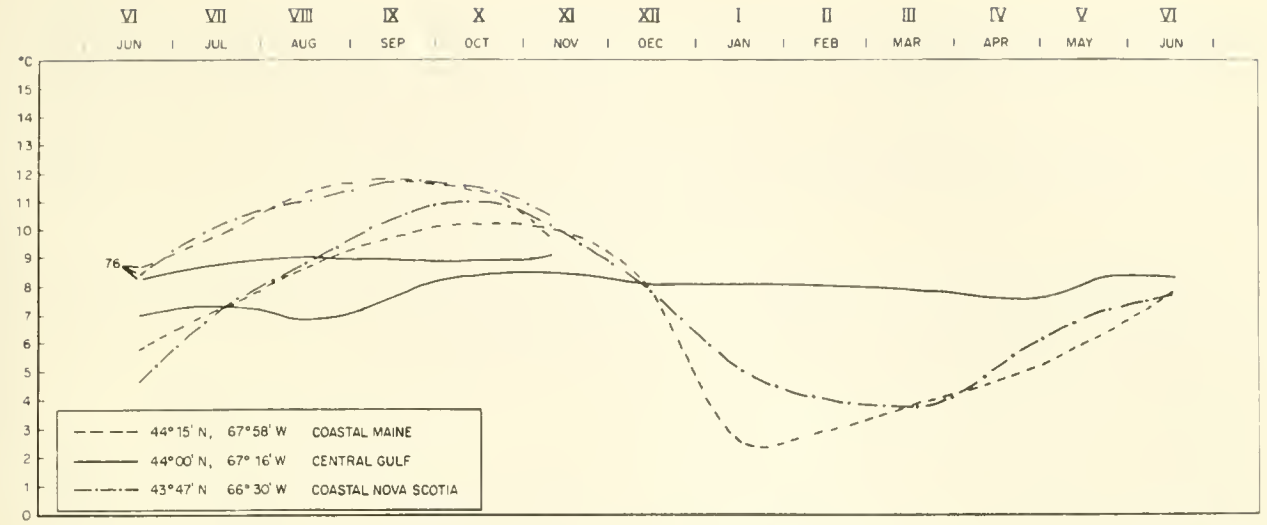

Figure 13.—Sea bottom temperature (°C) at three locations (Fig. 1) across the Gulf of Maine, June 1975-November 1976. 1976 Summer and Autumn data indicated by "76".

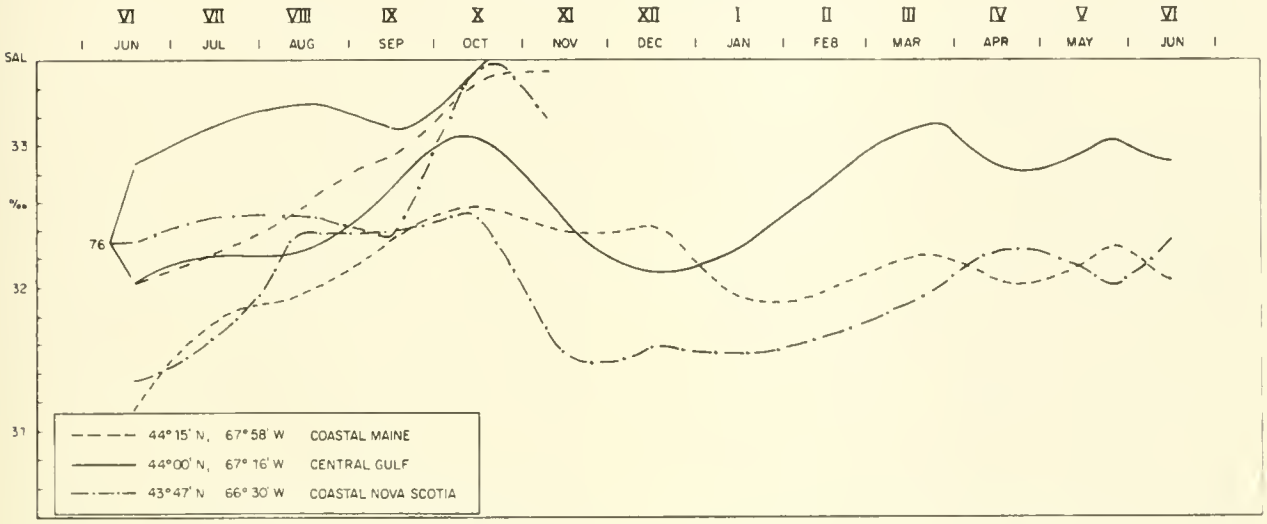

Figure 14.—Sea surface salinity (‰) at three locations (Fig. 1) across the Gulf of Maine, June 1975-November 1976. 1976 Summer and Autumn data indicated by "76".

Central Middepth Waters

The cooler middepth temperatures found in spring and early summer 1976, summer 1975, and historical spring and summer sections, appear to be formed from winter-cooled water constricted by the offshore progression of warmer coastal waters, the development of the surface thermocline, and the persistence of warmer central bottom waters (>150 m). This layer warmed during summer 1975, and dissipated by August of that year. Warming continued at middepth through October as surface-warmed waters mixed downward. A change from warming to cooling occurred in November with homogeneous conditions developing. This cooling trend accelerated through the winter months, with minimum temperatures occurring during March 1976. As the surface and coastal warming trends began, the minimum temperature layer developed its spring characteristics, with slow warming (1°C per month) into early summer and dissipation by July. The occurrence of this layer in both years and in historical data indicates that it is a characteristic part of the spring temperature structure.

Central Bottom Waters

Waters deeper than 150 m maintained a slow rise (<1°C per month) in temperature, with no seasonal pattern of warming or cooling evident from the data. A lack of seasonal trends was also evident in historical sections.

This is consistent with Colton (1968) in which no seasonal trends were noted for bottom temperatures in the Gulf of Maine. Colton pointed out:

> It would appear that trends in subsurface temperatures can be traced to variation in the composition of these offshore waters as well as to the volume of their indraft through the Northeast Channel.

A review of the sections showed abrupt warming in October and December 1975, and in July and August 1976. These changes are presumably due to influence from mixed slope water. The bottom circulation for the Gulf of Maine inferred from seabed drifters indicates (Lauzier 1967) inflow to this area. However, due to lack of subsurface salinity data, the amount of slope water present cannot be determined. Davis (see footnote 2) noted a bottom-water warming trend from 1971 through 1974, with abrupt cooling by autumn 1975 in the Gulf of Maine. The slow rise in deep temperatures for these sections (Fig. 13) and the differences between 1975 and 1976 for summer and fall temperatures (Figs. 2, 3, 7, 8) indicate fall 1975 as a break in the existing warming trend, followed by a return to warming in 1976.

SUMMARY

All sections showed similar water column structure and seasonal changes when compared to historical sections, but temperatures were generally 1° to 5°C warmer in the 1975-76 sections.

Warming trends began in late winter and continued through summer, progressing from the coast outward in waters inshore of the 100-m isobath. Central gulf waters developed a spring and summer thermocline above 50 m that restricted rapid warming (>2°C/month) to surface waters. Maximum temperatures occurred from late August to September. Cooling trends began in September and October, developed homogeneous conditions by late fall, and cooled through January. Reversal to a warming trend occurred during February to March.

A minimum temperature layer developed in the spring months at middepths with constriction of winter-cooled water by the surface thermocline and offshore progression of warmer coastal waters. This layer continued warming with influence from surrounding layers and dissipated by late summer. The minimum temperature layer appeared in 1975 to consist of two cold spells separated by warmer water. Such structure may be related to deep flow into and out of the northern Gulf of Maine. Waters deeper than 150 m fluctuated in temperature regardless of season, probably due to influence from sporadic slope water inflow at the Northeast Channel.

Oceanographic conditions in the Gulf of Maine were warmer in 1976 than in 1975. Fall 1976 followed with cooling that brought similar temperatures for both years by November. Surface waters in summer and fall 1976 were more saline (1‰) than in 1975.

ACKNOWLEDGMENTS

I thank the members of the Atlantic Environmental Group for the preparation of historical sections and for assistance in gathering the data. A special word of thanks is also in order to the officers and crew of the Canadian National Ferry, MV *Bluenose*, for their outstanding assistance throughout this project.

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