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Oceanographic Conditions in NAFO Subareas 5 and 6 During 1970–79

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Abstract

The oceanographic conditions in NAFO Subareas 5 and 6 during the 1970-79 decade are summarized, utilizing primarily surface and bottom temperature data for the continental shelf areas from Cape Hatteras to the Gulf of Maine. The dominant trend in sea-surface temperature was the continuation of a warming which began in the late 1960's to maximum temperatures in the mid-1970's, followed by decreasing values to the end of the decade. Relative to the long-term monthly mean temperatures, the beginning and the end of the decade were characterized by anomalously cold winters and warm summers, whereas the middle of the decade exhibited the reverse. Seasonal-averaged bottom water temperatures showed the same general trend as the surface temperatures. The change in average bottom temperature from the minimum values in the 1960's to the maximum values in the mid-1970's was quite large, with an increase of over 4° C on Georges Bank and 3° C in the Gulf of Maine. Analysis of temperatures and salinity data for the Gulf of Maine indicated that the temperature changes resulted not only from local processes but also from variations in the character and flow rate of slope water entering the Gulf through the Northeast Channel.

Introduction

This paper presents an overview of hydrographic conditions in NAFO Subareas 5 and 6 during the 1970–79 decade. The data analyzed are primarily sea-surface and near-bottom temperature measurements from the continental shelf areas between Cape Hatteras and Nova Scotia, including the Gulf of Maine. The purpose of this overview is to provide both a description of the hydrographic changes within the decade and continuity with previous studies of earlier decades. The emphasis is on multi-year changes or trends and not on individual or short-lived events. A noteworthy example of the latter is the extreme anoxia conditions that developed in the Middle Atlantic Bight in the summer of 1976 (Swanson and Sindermann, 1979).

The oceanographic and atmospheric conditions and trends over the western North Atlantic Ocean during earlier decades have been discussed by several authors (e.g. Rodewald, 1972; Dickson and Lamb, 1972; Cushing and Dickson, 1976). In general, mid-latitude sea-surface temperatures increased to a maximum in the early 1950's and decreased through the middle to late 1960's. A return to increasing temperatures at the end of the 1960–69 decade was indicated in many cases. Associated with these temperature changes (and their probable indirect cause) was a surface atmospheric pressure anomaly pattern during the cooling period (1956–65) that had a high value over Greenland and a low over the mid-latitude area of the North Atlantic Ocean (Dickson and Lamb, 1972). The resultant anomalous wind circulation would bring cold Arctic air to lower latitudes along the east coasts of Canada and the United States.

Surface Water Temperatures

Trends at coastal stations

The longest available time series of oceanographic observations are sea-surface temperatures recorded at coastal stations. These allow the conditions during the 1970–79 decade to be put into perspective with conditions during earlier decades to the beginning of the century. The yearly average sea-surface temperatures at Boothbay Harbor, Maine, during 1905–79 (Welch, MS 1981) and at Woods Hole, Massachusetts, during 1945–79 are shown in Fig. 1. Both series clearly show the warming during the 1940's and early 1950's and the subsequent cooling through the 1960's. Both series also show a return to warmer conditions in the 1970's. The magnitude of the change was larger at Boothbay Harbor, but both series show similarity in the nature of the year-to-year variations. At Boothbay Harbor, the average sea-surface temperature which ranged from 7.7° to 8.0° C for the earlier decades were all lower than in the three most recent

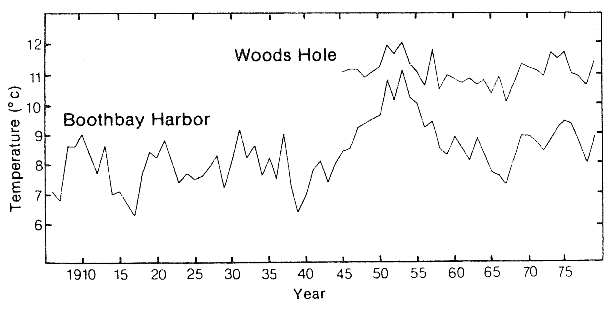

Fig. 1. Annual average sea-surface temperatures (° C) at Boothbay Harbor, Maine, for 1906–79 and at Woods Hole, Massachusetts, for 1945–79.

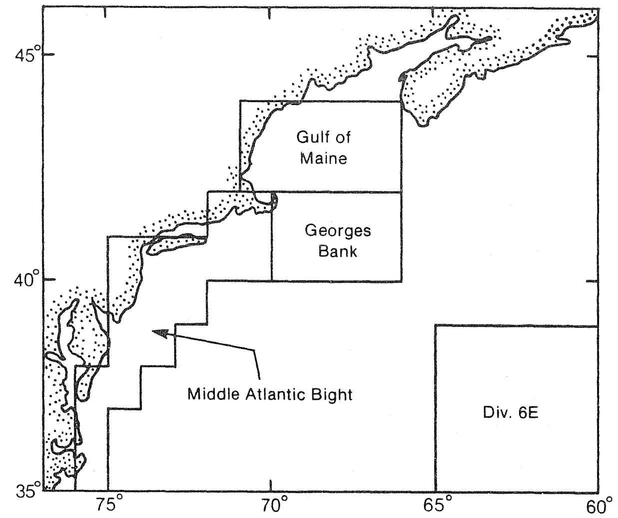

Fig. 2. The four regions for which sea-surface temperatures were averaged by month for use in calculating the anomalies plotted in Fig. 3.

decades: 9.7°C in 1950-59, 8.2°C in 1960-69, and 8.8°C in 1970-79.

Offshore temperature anomalies

Monthly average sea-surface temperature anomalies for large areas of the western North Atlantic Ocean are reported in 1° × 1° (latitude × longitude) rectangles by the Pacific Environmental Group of the U. S. National Marine Fisheries Service (e.g. McLain, 1976). The data originated from ship reports received by the U. S. Navy, and anomalies were calculated for each rectangle and month relative to the mean for 1948-67. This reference period includes both the peak warming in the 1950's and the cooling in the 1960's. For analysis in this paper, four regions were chosen: Gulf of Maine, Georges Bank, Middle Atlantic Bight, and NAFO Division 6E (Fig. 2). The last area is included to provide an offshore deep-ocean series for comparison with the near-shore or continental shelf changes. The monthly average surface temperature anomalies for the four regions throughout the 1970-79 decade are shown in Fig. 3. A high level of variability might be expected in these time series due to both the nature and the irregular reporting of the original data. However, large anomalies, representing seasonal variations, tend to persist for several months and are simultaneously evident in more than one area. The magnitude of variation is greatest in the Middle Atlantic Bight and smallest in Division 6E. The reduction in offshore variation is reasonable, because any anomaly in air temperature, originating over the continent and influencing the ocean surface, would be moderated by the ocean before reaching the offshore area.

The major trend of the 1970-79 decade in the Middle Atlantic Bight was from large periodic negative anomalies in the early years to a warming in 1974-76

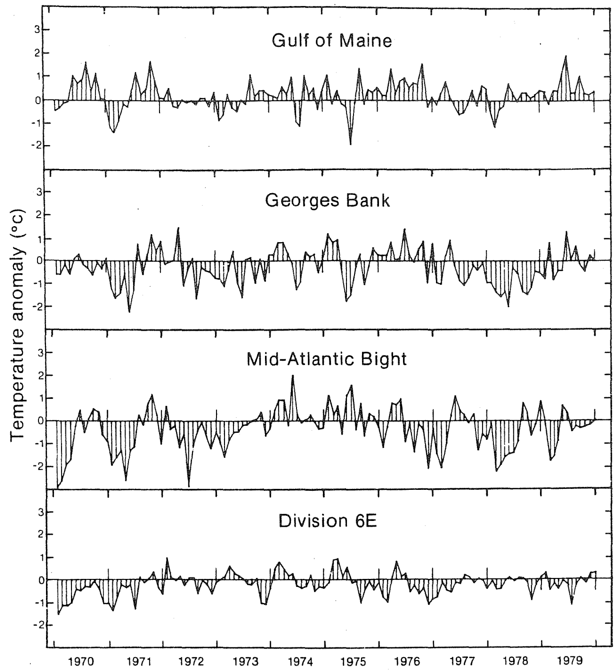

Fig. 3. Monthly average sea-surface temperature anomalies (° C) for 1970-79 in the four regions shown in Fig. 2. (The reference period is 1948-67).

and a return to negative anomalies in the later years. The same pattern, although with lesser amplitude, is evident in the Georges Bank and Division 6E regions, but little trend is seen in the Gulf of Maine series throughout the decade. The large anomalies in the first years (1970-72) extended across the three coastal regions and were characterized by negative values in winter and positive values in summer. The warming was greatest in the Gulf of Maine and the cooling was greatest in the Middle Atlantic Bight. The warming in mid-decade (1974-76) was largely the result of the winters having positive temperature anomalies. The largest cooling events during these years were in spring and summer in the Gulf of Maine and Georges Bank areas. The cooling in later years (1977-78) resulted from a return to dominant wintertime negative anomalies.

To consider the 1970-79 decade as a whole relative to the reference period, the anomaly values were averaged by season (Table 1). Only the Gulf of Maine showed a positive anomaly for the decade relative to the 20-year reference period. Seasonally, large negative values occurred in winter and spring on Georges Bank and in the Middle Atlantic Bight, in summer on Georges Bank, and in autumn in the Middle Atlantic Bight and Division 6E, whereas the largest positive values occurred in summer and autumn in the Gulf of Maine. Thus, the summer warming tendency was dominant in the Gulf of Maine and the winter cooling tendency dominated in the other regions.

TABLE 1. Average sea-surface temperature anomalies (C°) by season and region in Subareas 5 and 6 for 1970–79 decade.

Region	Decade	Winter (Jan-Mar)	Spring (Apr-Jun)	Summer (Jul-Sep)	Autumn (Oct-Dec)
Gulf of Maine	0.22	-0.05	0.17	0.38	0.38
Georges Bank	-0.27	-0.28	-0.42	-0.24	-0.15
Middle Atlantic Bight	-0.27	-0.65	-0.33	-0.10	-0.33
Division 6E	-0.18	-0.10	-0.04	-0.18	-0.40

Bottom Water Temperatures

Trends on the continental shelf

Bottom water temperatures for the three continental shelf areas identified in Fig. 2 have been collected by the U. S. National Marine Fisheries Service during groundfish surveys carried out each autumn (October-November) since 1963 and each spring (March-April) since 1968. Davis (1978, 1979) calculated average bottom temperatures in both seasons for the Gulf of Maine, Georges Bank, and the northern and southern parts of the Middle Atlantic Bight, the latter two areas being separated by the Hudson Canyon. The same procedure was used to extend this series to 1979 (Fig. 4).

In the Gulf of Maine, minimum bottom temperatures in autumn occurred during the mid-1960's. This was followed by a sharp rise near the end of the decade and a gradual increase until 1974. A subsequent decrease then began, although interrupted by a peak temperature in 1976. The spring data mirrored this pattern closely. Spring values for 1965 and 1966 derived from two other data sources (Colton *et al.*, 1968) indicate that the marked cooling evident in the autumn data also occurred in the spring (Fig. 4). For the Georges Bank area, there was a similar warming trend from the 1960's to 1974, followed by decreasing temperatures. For both the northern and southern Middle Atlantic Bight areas, the spring curves showed similar trends, although the peak in temperature in the mid-1970's was more exaggerated. The autumn temperatures in the Middle Atlantic Bight leveled off or peaked in 1971–72, two years earlier than in the Gulf of Maine and Georges Bank areas. The sharp decline in bottom temperature in the southern Middle Atlantic Bight area in the autumn of 1970 was due, at least in part, to the timing of the autumn survey about a month

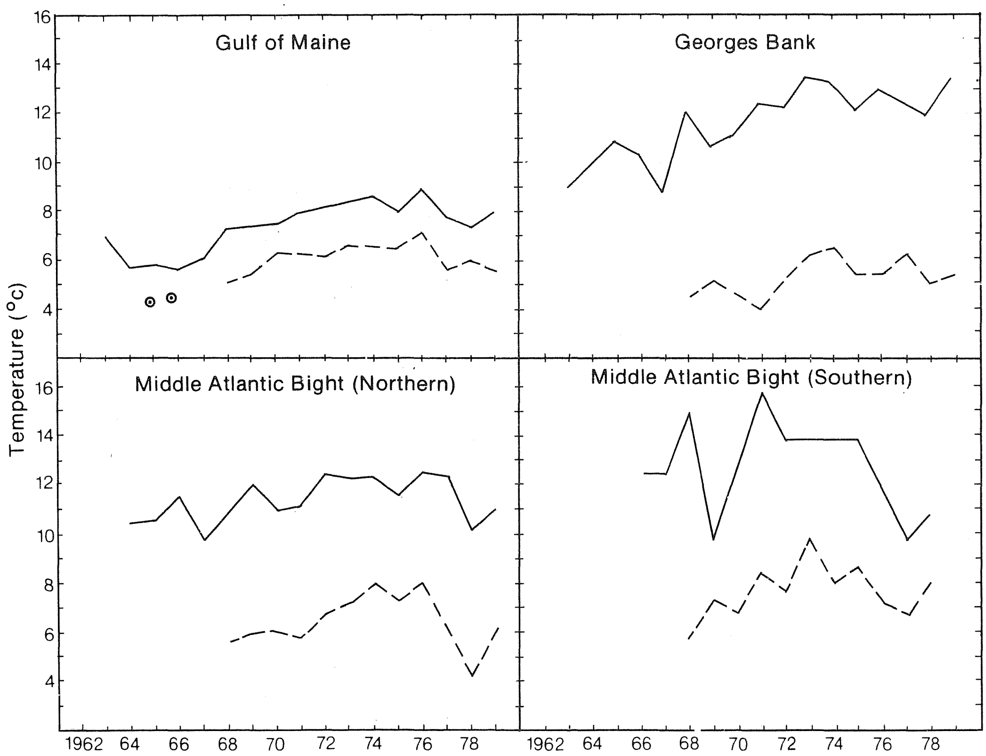

Fig. 4. Average bottom water temperatures from spring and autumn groundfish surveys by the U. S. National Marine Fisheries Service in the four continental shelf regions of Subareas 5 and 6, 1963–79. (Circled points indicate data from other sources.)

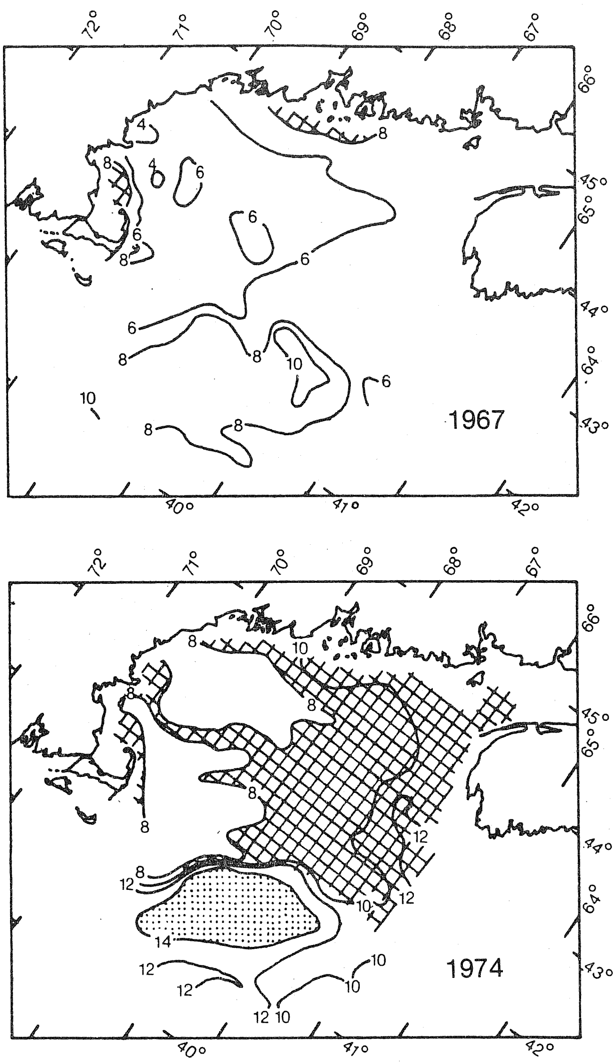

Fig. 5. Distribution of bottom water temperature in autumn (1967 and 1974) from U. S. groundfish surveys of the Gulf of Maine and Georges Bank regions (from Davis, 1978). (Temperatures greater than 14° C on Georges Bank and greater than 8° C in the Gulf of Maine are indicated by different cross-hatching.)

earlier than in other years and before the annual maximum temperature is usually obtained. Davis (1979) estimated an upward adjustment of 2.2° C for this timing difference.

The changes in temperature, illustrated in Fig. 4, were substantial and occurred in all continental shelf areas under consideration. The range in extreme values was over 3° C in the Gulf of Maine, over 4° C on Georges Bank, and over 5° C in the southern Middle Atlantic Bight. Comparison of the autumn temperature distributions for the Gulf of Maine and Georges Bank in 1967 and 1974 emphasizes this point (Fig. 5). In 1967, bottom temperatures above 8° C occurred only in a few small coastal areas of the Gulf of Maine and were generally between 8° and 10° C on Georges Bank, with no values above 12° C. In 1974, the entire eastern Gulf of Maine had temperatures over 8° C (above 10° C in some places) and the 8° C isotherm encompassed about half of the western Gulf. Bottom temperatures were generally above 14° C on Georges Bank.

Variation in Gulf of Maine bottom water

Unlike the shallow continental shelf areas of Georges Bank and the Middle Atlantic Bight, bottom water in the Gulf of Maine is derived by advection of slope water through the Northeast Channel. This inflow into the Gulf occurs generally below 75 m depth (Ramp *et al.*, MS 1980). Thus, changes in the character of bottom water, indicated in Fig. 4, may be due in part to changes in the character and rate of slope water inflow to the Gulf and not solely to heating, cooling and mixing processes at the surface. Colton (1968) concluded that changes in temperature in the Gulf of Maine from 1955–60 to 1961–65 were due to changes in the character of the inflowing water from warm slope water to colder Labrador slope water. Wright (1979) attributed unusually high salinity water on Georges Bank in February 1977 to a large influx of slope water into the eastern Gulf of Maine in the spring of 1976.

To investigate the origin of the observed temperature changes, the amount of heating and cooling of the Gulf of Maine bottom water in successive seasons was considered from the information in Fig. 4. Any warming from spring to autumn must derive from advection of heat (i.e. inflow of slope water), because the near-surface thermocline and mid-depth minimum temperature layer that develop in the spring isolate the bottom water from downward exchange of heat. Cooling between autumn and spring is more complicated, being a balance of heat loss through vertical mixing induced by surface cooling and of heat gain by slope water inflow. The two curves for the Gulf of Maine (Fig. 4) are closely parallel, indicating that the warming from spring to autumn is about the same each year. Differences do occur, as in 1968, 1977 and 1979, when the warming was larger than in other years, and in 1970 and 1975, when it was somewhat less. The major changes in the trend of the curves, however, are first seen in the spring values, due to differences in the amount of cooling from one autumn to the following spring. The cooling over the winters of 1967/68 and 1975/76 was smaller than normal, whereas over the winter of 1976/77 it was considerably larger than in other years.

Variation in the character and rate of slope water inflow should result in changes not only in the temperature of bottom water but also in its salinity. To investigate this, temperature and salinity values at or near 200 m depth, obtained from the autumn surveys, were averaged to yield characteristic water types for the western

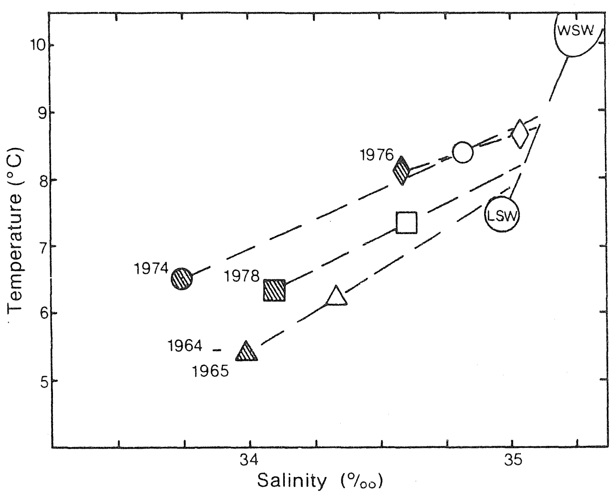

Fig. 6. Temperature-salinity characteristics at or near 200 m in the western and eastern parts of the Gulf of Maine in the autumn of the years indicated. (1965 and 1966 data from *Albatross IV* (USA) surveys in September, 1974 data from *Prognoz* (USSR) survey in September and *Wieczno* (Poland) survey in October; 1976 data from *Researcher* and *Albatross IV* (USA) surveys in December; 1978 data from *Belogorsk* (USSR) surveys in August and October.)

and eastern Gulf of Maine in different years, the dividing line being 68°W. The autumn season was chosen because it was farthest removed in time from the complicating effect of alteration of water properties through convection induced by surface cooling. For each year, the lower salinity and cooler water type occurred in the western Gulf of Maine (Fig. 6). The initial indication is that the salinity values varied considerably in different years. The temperature-salinity characteristics of warm slope water and colder Labrador slope water (Gatien, 1975) and a line indicating their mixing products are included in Fig. 6. If the inflowing slope water is assumed to mix uniformly and progressively with resident water as it spreads across the Gulf of Maine, a line through the western and eastern water types would pass through the characteristics of the original slope water. The lines so defined for the different years do intersect different slope water characteristics. The colder years (1964 and 1965) indicate the presence of nearly pure Labrador slope water, whereas the warmer years (1974 and 1976) indicate higher proportion of warm slope water input, with 1978 being intermediate between the two extremes. The assumption about mixing, indicated above, is overly simplistic, because the resident time of water in the Gulf of Maine is 1–2 years, and, therefore, the western Gulf water is likely to have been exposed to the effects of winter cooling. Still, the consistency of the implications, cold years with cold slope water and warm years with warmer slope water, supports the concept that variation in Gulf of Maine bottom water is due, at least in part, to changes in the character of the inflowing slope water.

Another interesting aspect of Fig. 6 is the distance from the eastern Gulf of Maine water type to the original slope water values. In 1976, the bottom water in the eastern Gulf was nearly pure slope water, whereas it was far removed from slope water characteristics in 1964 and 1965. This greater distance in 1964 and 1965 is indicative of greater isolation from the source slope water, resulting from reduced inflow of slope water and consequently increased resident time of water in the Gulf. The 1976 value, on the other hand, implies a greater volume of inflow, as suggested by Wright (1979), thus accounting for the peak temperature of bottom water in that year (Fig. 4).

Discussion

The variations in sea-surface temperature anomalies, demonstrated in Fig. 4, were likely to have been related to variations in local air temperature over the same period. Comparison with the air temperature anomalies presented by Ingham (1982) indicates that the two variables are similar in their major characteristics. The frequency and magnitude of negative anomalies decreased during the mid-decade and the positive anomalies increased. The later years of the 1970–79 period in both temperature series were dominated by extremely cold winters.

The increase in both air and sea temperatures during the early 1970's was likely to have been related to large-scale atmospheric patterns. Cushing and Dickson (1976) showed that the pressure change between the late 1960's and early 1970's was marked by a low over Greenland and a high over mid-latitudes of the North Atlantic Ocean. The resulting wind pattern would bring lower latitude, warm air to the coastal areas of northeastern United States and southeastern Canada. This pattern is inverse to that observed during the earlier cooling period of 1945–65 (Dickson and Lamb, 1972).

A latitude dependence is evident in both the sea-surface and air temperature patterns, particularly in the cold winters of 1977, 1978 and 1979. The magnitude of cooling was greatest in the Middle Atlantic Bight area and considerably smaller or absent in the Gulf of Maine.

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