Marine Environmental Conditions off the Atlantic and Gulf Coasts of the United States, January 1977-March 1978

MERTON C. INGHAM

Introduction

The predominant atmospheric events influencing the coastal marine environment in 1977 and early 1978 were two severe winters which yielded record or near-record low temperatures along most of the Atlantic and Gulf coasts. The impact of two successive severe winters on fish stocks on nearshore estuarine waters may have been very significant for some species. Reports have been received of high mortalities in both years of juvenile croaker in Chesapeake Bay and white shrimp in South Carolina's coastal waters.

An unusually large number of warm-core Gulf Stream eddies passed through the Slope Water adjacent to the continental shelf in the Georges Bank and Middle Atlantic Bight areas in 1977. These eddies had direct impact on the lobster and crab fisheries on the outer continental shelf and slope in the form of gear losses due to the strong currents associated with them. Also there were reports of poor catches in the vicinity of the eddies. In addition it is likely that the eddies increased the exchange of Shelf Water and Slope Water and their indigenous biota, which may have led to losses of planktonic larvae of various important species which spawn in the Shelf Water mass.

Merton C. Ingham is with the Atlantic Environmental Group, Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Narragansett, RI 02882.

Major offshore excursions of the Shelf Water front, up to 80-100 nautical miles (n.mi.) (150-185 km) from its normal position near the shelf edge, occurred in February and March 1978, during a period when there was an unusual absence of warm-core Gulf Stream eddies. This excursion apparently influenced the distribution of Atlantic mackerel off Virginia leading to their passage about 20-30 n.mi. (35-55 km) farther offshore than normal, and consequently their escaping the domestic fishing fleet in that area. There have been no other reports of changes in the distribution of migrating pelagic species in the Middle Atlantic Bight this spring, but the likelihood exists.

The winter of 1976-77 produced unusually strong, persistent northwesterly winds in the Georges Bank and Middle Atlantic Bight areas in January and February. Such winds would produce strong southwestward Ekman transports in the upper layer of the sea. In the area off the North Carolina coast, relatively strong westward components of Ekman transport occurred in January 1977 and February 1978, during the offshore spawning period of Atlantic menhaden. Thus, during those 2 months at least, the larval transports toward the nursery grounds in the estuaries should have been adequate for good survival rates.

Conditions in the New York Bight in the spring of 1977 were not appropriate for a repeat of the development of anoxia in the bottom water off New Jersey which occurred in 1976. Only a narrow band of low-oxygen bottom water developed along about 30 n. mi. (55 km) of the central New Jersey coast, and significant fish mortalities do not appear to have resulted.

The bottom water over the continental shelf in the Middle Atlantic Bight was about 3 to 4°C colder than normal in January and February 1977. By May off southern New England and late June off New Jersey, the temperatures had increased to normal values. It is not known how this 5- or 6-month period of anomalously low temperatures influenced the distribution of demersal species. In January-March of 1978 the bottom water in these areas seemed to be about 2 to 3°C cooler than normal and about 1°C warmer than the previous year.

The cold winter of 1976-77 did not significantly lower the temperature of the water over Georges Bank, but the salinity of this water mass was considerably (up to 1‰) higher. This condition apparently was the result of wind-driven transport of higher salinity water from the Gulf of Maine, where it had developed as the result of invasion of the basins in the Gulf by oceanic water in 1976.

The variation of the Eastern Gulf of Mexico Loop Current apparently did not follow the "normal" pattern at all in 1977 and early 1978. Maximum northward intrusion of the current occurred in February 1977 and January 1978, not during the spring and summer months as assumed by the "normal" pattern. The minimum intrusion occurred in the summer and fall of 1977 and continued into the winter period.

Atmospheric Variations Circulation and Air Temperature

A portrayal of weather conditions during 1977 and the first quarter of 1978 compiled by Haynes[1] from meteorological journals reveals that

[1]Haynes, E. D. 1978. Atmospheric circulation in 1977. Unpubl. rep., 7 p. Resource Assessment Division, Office of Science and Environment, National Marine Fisheries Service, NOAA, Wash., DC 20235.

the first 2 months of the period saw a continuation of the severe winter conditions extant along the Atlantic and Gulf coasts in late 1976. Strong, persistent westerly flow over the North Pacific and anomalously cold surface water temperatures in that ocean established the atmospheric circulation pattern which produced the bitter winter of 1976-77 in the eastern United States. The circulation led to the advection of unusually cold and dry continental polar air southeastward across the midwest and Atlantic seaboard.

The effects of this invasion of cold air on coastal weather are evident in the average monthly air temperature anomaly records from coastal weather stations from Portland, Maine, to Brownsville, Tex. (Fig. 1, 2 and Table 1). Significant negative anomalies from long-term averages ranging from -5.3° to -13.0° F, were reported at all stations in January 1977. The strongest anomalies were in the Middle Atlantic Bight, from New York to Norfolk, but those in the South Atlantic Bight and Gulf of Mexico were only a few degrees warmer. In February the severe cold weather moderated considerably, especially in the Middle Atlantic Bight where the strongest anomaly was only -1.1° F at Atlantic City. In the South Atlantic Bight and Florida coastal stations the anomalies were still relatively strong, with Jacksonville showing a value of -6.3° F.

About the end of February a strong atmospheric ridge replaced the wintertime trough over the eastern states, bringing unusually warm temperatures for the early spring. This condition was very apparent in the coastal air temperature anomalies for March (Table 1), with positive anomalies up to 6.6° F showing for all stations except for Corpus Christi, which still showed a weak negative anomaly.

By summer the ridge had moved offshore and nearly normal conditions prevailed, but air temperatures remained above the long-term means by as much as 4.5° F (September in Norfolk and Corpus Christi), with the most extensive and persistent positive anomalies occurring in the Middle and South Atlantic Bights.

Winter circulation patterns returned in October, with upper air patterns very similar to October 1976, except that the ridging in the western United

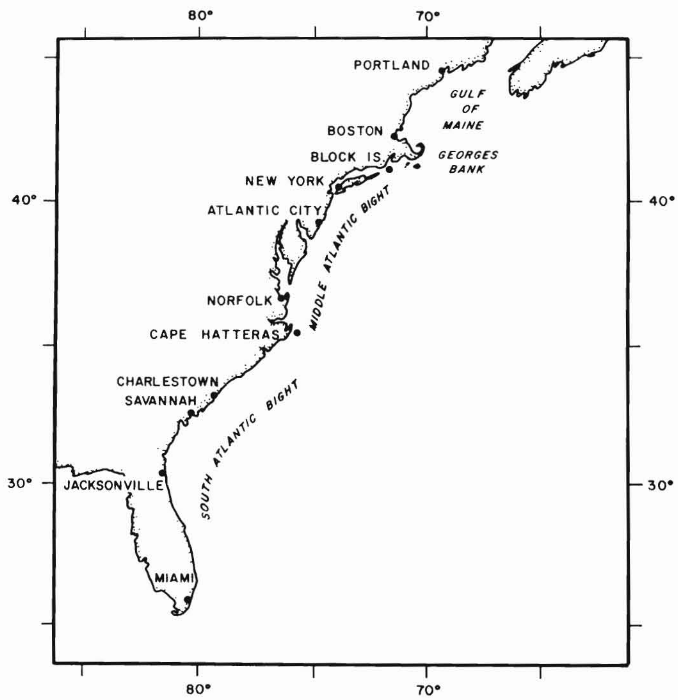


Figure 1.—Atlantic coastal area and weather stations from which data were obtained.

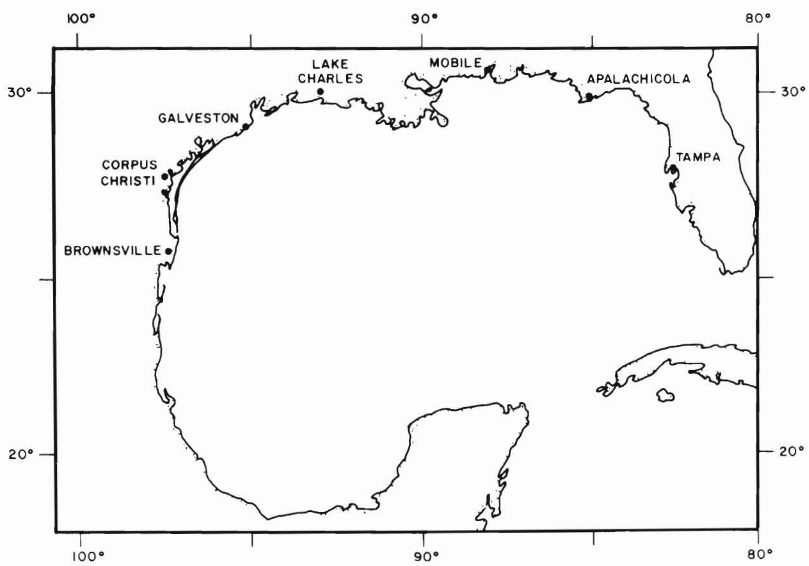


Figure 2.—Gulf coastal area and weather stations from which data were obtained.

Table 1. Monthly air temperature anomalies (°F) from selected weather stations along the Atlantic and Gulf coasts. Dark shading indicates negative anomalies of -2°F or larger, light shading +2°F or larger

Station	J 1977	F	M	A	M	J	J	A	S	O	N	D	J 1978	F	M
Portland, ME	-6.9	-1.0	+4.4	-0.3	+1.7	-3.2	+0.2	+0.2	-1.1	-1.0	+0.8	-0.3	-0.4	-3.7	-1.6
Boston, MA	-5.9	+0.3	+6.6	+2.7	+4.0	-0.6	+1.6	+2.1	-0.1	-0.1	+2.9	+1.2	-0.7	-3.3	-1.9
Block Island, RI	-8.8	-2.7	+3.2	+1.1	+2.2	+0.4	+1.6	+1.7	+0.3	-0.2	+1.9	+0.6	-2.2	-4.9	-2.7
New York, NY	-9.4	-0.1	+4.4	+1.1	+1.9	-2.1	0.0	-0.3	-0.2	-3.6	+0.7	-0.6	-2.2	-5.4	-0.6
Atlantic City, NJ	-13.0	-1.1	+4.7	+0.8	+0.1	-2.8	+0.2	+1.9	+2.4	-1.8	+3.6	+0.3	-2.3	-10.1	-1.6
Norfolk, VA	[illegible]	+0.1	+6.6	+4.1	+1.5	-0.2	+3.1	+4.1	+4.5	-1.2	+3.2	+1.2	-3.5	-8.8	-2.0
Cape Hatteras, NC	-9.5	-1.5	+4.6	+4.0	+2.6	+0.3	+2.8	+2.0	+3.6	-1.8	+3.4	+1.1	-3.3	-10.1	-0.5
Charleston, SC	-10.0	-4.8	+4.1	+1.8	+0.7	+3.3	+3.6	+1.8	+3.5	-2.6	+5.0	+0.7	-5.1	-7.8	-1.3
Savannah, GA	-10.0	-2.9	+4.1	+1.5	+0.7	+2.9	+2.2	+0.5	+2.7	-3.0	+4.1	-0.4	-6.0	-8.5	-1.7
Jacksonville, FL	-10.6	-6.3	+3.8	-1.0	-1.3	+2.1	+1.7	+0.9	+1.9	-4.4	+1.3	-2.1	-6.0	-8.8	-2.5
Miami, FL	-6.1	-1.7	+3.6	-0.2	-1.0	+0.7	+1.4	+0.3	+1.3	-1.3	+1.8	+0.8	-3.2	-4.6	-2.4
Tampa FL	-9.2	-4.3	+4.9	-0.5	-0.7	+2.7	+1.0	+0.8	+1.5	-2.2	+0.9	-2.9	-5.4	-8.6	-1.8
Apalachicola, FL	-8.9	-5.7	+2.2	-1.3	-1.8	+1.1	-0.1	-0.8	+1.7	-4.3	+1.2	-2.0	-8.1	-8.9	-4.4
Mobile, AL	-10.3	-1.8	+3.2	+0.3	+0.8	+2.6	+1.9	+1.9	+3.4	-3.7	+2.4	-2.1	-10.0	-8.9	-2.7
Lake Charles, LA	-8.2	-0.9	+1.8	-0.6	+0.8	+0.6	-0.3	-0.9	+1.6	-1.0	+1.6	-1.0	-9.4	-9.5	-2.5
Galveston, TX	-7.3	-1.1	+1.2	+0.8	+0.2	-0.3	-0.5	-0.7	+1.4	-0.3	+1.6	+0.7	-8.6	-9.2	-2.7
Corpus Christi, TX	-6.0	-1.0	-1.1	-1.3	+0.9	+0.5	-0.2	+1.6	+4.5	+1.8	+2.6	+2.8	-7.1	-7.9	-1.0
Brownsville, TX	-5.3	-1.5	+1.3	-1.2	+0.9	-0.2	+0.2	+1.5	+2.7	+1.4	+1.7	+1.6	-5.7	-7.5	-0.9

States was not as intense. Consequently, moist maritime air masses were common, producing conditions that were not as cold, but stormier and wetter than the previous fall. Negative anomalies as large as -4.4°F were recorded for October at all stations except Corpus Christi and Brownsville. However, positive anomalies returned in November for all stations as the weather moderated, and the anomalies remained weakly positive in December for most of the stations.

In January and February of 1978, severe cold stormy conditions settled over the eastern two-thirds of the United States, and total snow cover exceeded that of 1977. Unlike the preceding winter, sudden warming did not occur in late February and March. All the coastal weather stations showed negative air temperature anomalies through March.

As pointed out in Anonymous (1978), the two successive cold winters (1976-77 and 1977-78) combined may have set a new record for paired cold winters. The impact of these very cold winters has been greatest in estaurine areas, where water temperatures have fallen to record lows. For example, there was extensive mortality both winters among the juvenile croakers, which overwinter in the tributaries to Chesapeake Bay, yielding two successive short year-classes in this commercial fish stock[2]. Similarly, in South Carolina coastal waters the white shrimp stocks were decimated by record cold temperatures both winters, yielding two successive disastrous trawling seasons (Hamrick, 1978).

River Runoff

Records of streamflow in the Middle Atlantic Bight region reflect the precipitation patterns for 1977 and early 1978. A summary of flow of the streams tributary to Chesapeake Bay prepared from U.S. Geological Survey records by Haynes[3] revealed that the exceptional warming of late February and March of 1977 yielded a record mean flow of 195,000 cubic feet per second in March. Flow records for the Hudson River and cumulative discharge into Long Island Sound show a record value of 43,000 cubic feet per second for the former and a high value of 82,000 cubic feet per second for the latter in March.

In all three river systems, flows remained relatively high in April, then fell to below-average values during May-August. Flows increased dramatically in September and October, leading to record or near-record values during the latter month. The flow levels then remained substantially above average through January 1978, then fell to average or below in February and March in the Long Island Sound tributaries, but the Chesapeake Bay tributaries rebounded in March to record levels.

Wind-Driven Transport

The unusual winter of 1976-77, which was much in evidence in January and February, carried with it substantially anomalous wind conditions which in turn produced unusual wind-driven (Ekman) transports in the upper layer of the water column. Time line portrayals of the monthly average Ekman transport vectors for 1977 and the first quarter of 1978 and for 1964-73 computed from mean monthly atmospheric pressure fields[4] provide a graphical description of these anomalous conditions (Fig. 3, 4) off the Atlantic and Gulf coasts.

Along the Atlantic coast in 1977, the unusually large magnitudes (about twice the 1964-73 average) of the southwestward transports in January and February in the northern area and in January in the central area were a manifestation of the patttern of strong, prevailing northwesterly winds, continuing from the last 2 months of 1976. The southern area experienced transport to the west-southwest instead of

[2]Wojcik, F. J. Effects of cold winter on Virginia's finfish. Press release, 17 April 1978. Virginia Institute of Marine Science, Gloucester Point, VA 20362.

[3]Haynes, E. D. 1978. Freshwater runoff into Chesapeake Bay during 1977. Unpubl. rep., 2 p. Resource Assessment Division, Office of Science and Environment, National Marine Fisheries Service, NOAA, Wash., DC 20235.

[4]Pacific Environmental Group, National Marine Fisheries Service, NOAA, c/o Fleet Numerical Weather Central, Naval Post Graduate School, Monterey, CA 93940.

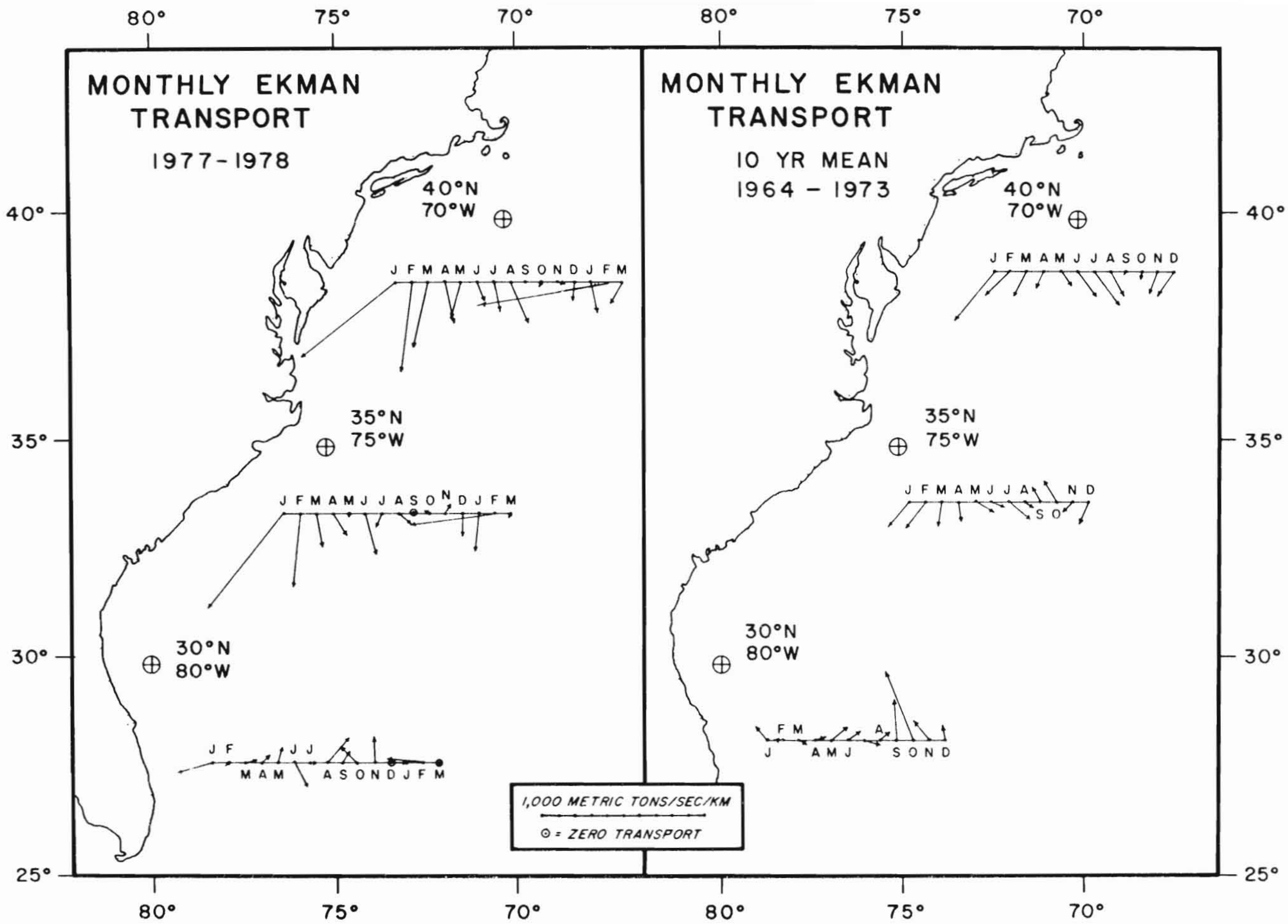


Figure 3.—Average monthly Ekman transports for January 1977-March 1978 and 1964-73 at selected grid points along the Atlantic coast. Data were computed from mean monthly atmospheric pressure fields by the NMFS Pacific Environmental Group, Monterey, Calif.

the usual northwest at about twice the usual magnitude in January, as a consequence of the northwesterly winds produced by the winter pattern of atmospheric circulation.

In 1978 in the northern area, the transports in January and March were close to the average magnitude, but the direction in January was south-southeast instead of southwest. It was in February, however, that very unusual Ekman transport conditions prevailed, to the west-southwest at over triple the average magnitude. This condition apparently was in response to strong, prevailing winds from the north-northwest during that month. The central area experienced similarly anomalous February conditions, with a transport over twice the long-term average for that month, directed toward the west. If menhaden spawning south of Cape Hatteras was in progress during that month, the Ekman transport should have been quite favorable for conveying the larvae toward the Carolina estuaries (Nelson et al., 1977). During March, however, the mean transport fell to nearly zero, a condition which would have provided none of the transport required for good larval survival. In the southern area, the transports were relatively small, as is to be expected from the long-term monthly values, but even here an unusually strong westward transport occurred in February.

In the Gulf of Mexico in 1977, the anomalous winter wind conditions were apparently only in the western portion, where the January Ekman transport vector was about 1½ times the average and toward the northwest instead of the usual north-northeast. This shift in transport would arise from prevailing northeast winds as a by-product of the winter circulation pattern. In 1978 a similar, but less intense, pattern showed and prevailed for 2 months, January and February, instead of just one. In the central and eastern Gulf, the only substantial difference in transport in the first

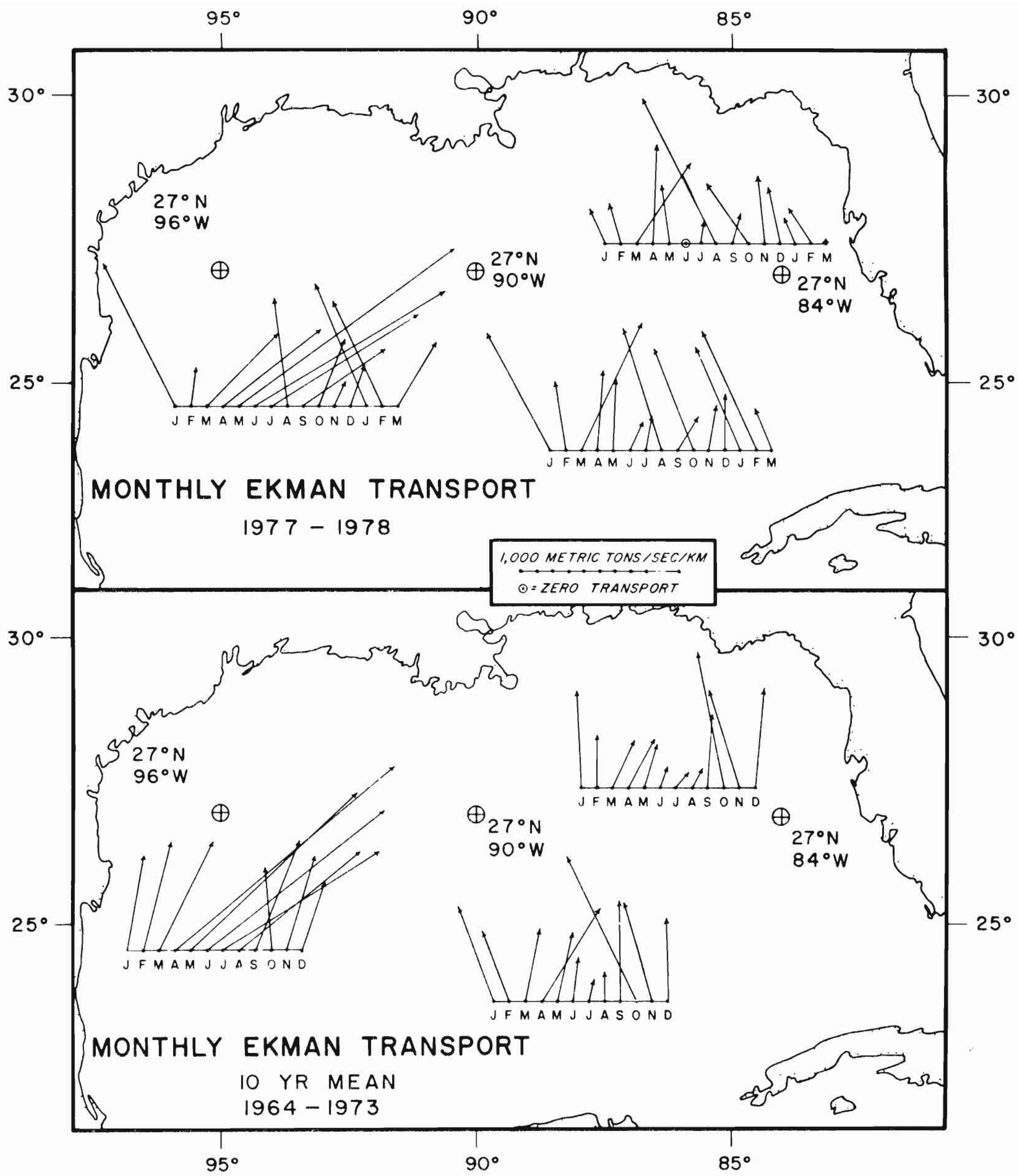


Figure 4.—Average monthly Ekman transports for January 1977-March 1978 and 1964-73 at selected grid points in the Gulf of Mexico. Data were computed from mean monthly atmospheric pressure fields by the NMFS Pacific Environmental Group, Monterey, Calif.

quarter of 1978 was the very small value found in March. This was particularly apparent in the eastern portion.

Oceanographic Variation

Gulf of Maine

Temperature Structure

The strong cooling conditions of the winter of 1976-77 produced slightly (about 1°C) cooler than usual temperatures in the upper waters of the Gulf of Maine. The minimum temperatures measured were found[5] on both the United States and Canadian sides in February when they were less than 1°C. However, the most significant difference between 1977 and the previous year was a decrease in the amount of warm, saline, Slope Water (8°C) intruded into the Gulf at depths of about 150 m and greater. In 1976, 8°C water existed below 150 m in

[5]Pawlowski R J 1978. Vertical temperature structure and sea surface salinity in the Gulf of Maine during 1977 Unpubl rep., 20 p Northeast Fisheries Center, NMFS, NOAA, Woods Hole, MA 02543.

every transect, but in 1977 these temperatures disappeared from March to October. This reduced inflow of Slope Water may have caused the observed decrease of surface salinity values, from 0.2 to 1.0‰ less than those of 1976.

In January-March 1978 the temperature structure in the surface layers was quite similar to that during the same period in 1977, with the minimum values occurring in February, including values of less than 1°C on both the United States and Canadian sides. At depths greater than 100 m, however, there was very little water as warm as that (<8°C) found early in 1977 and throughout 1976.

Sea surface temperature (SST) data collected from merchant ships in the Gulf of Maine are scarce, especially in the winter months. However, there are some data for each month in the 1° square in the vicinity of Boston (lat. 42°-43°N, long. 79°-71°W) in the monthly SST anomaly charts provided by the Pacific Environmental Group. Not surprisingly, these SST anomalies reflect most of the variation shown by the Boston air temperature anomalies (Table 2), the most outstanding of which are the cold conditions of January 1977 and January-March 1978 and the strong warming of March 1977. During the spring and summer months, the correspondence between sea and air temperature was not as good, because of the big difference in heating processes at sea and ashore.

Georges Bank

Temperature Structure

The severe winter of 1976-77 did not appreciably cool the waters over Georges Bank, at least not eastward and northward from Nantucket Shoals[6,7]. However, there were significant differences found in the salinity of these waters during 1977. The salinities measured early in the year (February) were more than 1‰ greater than average, ranging from 33.5‰ to over 34‰, the highest ever measured there. The source of this high salinity is thought to have been a major influx of oceanic water into the Gulf of Maine in the late spring of 1976, filling the basins with water of about 8°C and 34‰. The water was mixed up into the water column by the strong, cold winds in the late fall of 1976 and driven out over Georges Bank by the strong winter winds. By May 1977 the extreme salinities, in excess of 34‰ had disappeared, and by fall they had returned to normal.

The SST anomaly data for Georges Bank for the first 3 months of 1978 indicate that winter conditions in 1977-78 may have led to significant cooling of the waters over the Bank. The overall SST anomaly for the Bank was -0.8°C in January, -1.4°C in February, and -1.5°C in March.

Shelf Water Front

A surface frontal zone separating the Shelf Water and Slope Water masses is usually located a short distance seaward from the edge of the Bank (200 m isobath). The position of this feature, the Shelf Water front, was monitored by measuring its position as shown in weekly Satellite Observed Gulf Stream Analysis charts produced by the National Environmental Satellite Service[8]. The measurements were made relative to the Shelf edge (200 m) along arbitrary transect lines (Fig. 5). The results along two selected lines, Casco Bay 120 and Nantucket Island 180, for 1977 (Fig. 6) are pertinent to Georges Bank. These results show that along Casco Bay 120 the frontal positions agreed fairly well with the 1973-77 mean positions, except for a period in February and March when the front was observed four times (out of six) to be much nearer the shelf edge than usual, and a period in July-September when it was shoreward of its mean position. During the latter period, the front actually encroached on the Bank, getting as much as 30 km inside the 200-m isobath. Cloudy weather early in 1978 blocked satellite observations along this transect until March when the front appeared to be offshore from its average position for that month, but within one standard deviation of it.

Along the Nantucket Island 180 transect in 1977 the frontal positions

6Wright, W. R. 1978. High salinity in the Georges Bank region in February 1977. Unpubl. rep., 9 p. Northeast Fisheries Center, NMFS, NOAA, Woods Hole, MA 02543.

7Davis, C. W. 1978. A summary of spring and autumn bottom-water temperatures on the Atlantic continental shelf from Cape Hatteras to Cape Sable, 1963-77. Unpubl. manuscr., 16 p. Northeast Fisheries Center, NMFS, NOAA, Narragansett, RI 02882.

8Gunn, J. T. 1978. Variation in the Shelf Water front position in 1977 from Georges Bank to Cape Romain. Unpubl. rep., 8 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

Table 2.—Surface temperature anomalies in the Gulf of Maine area for January 1977-March 1978.

Date	SST anomaly (lat. 42°-43°N, long. 70°-71°W) (°C)	Surface air temperature anomaly (Boston) °F	°C
1977 J	-1.8	-5.9	-3.3
F	-1.2	0.3	0.2
M	2.8	6.6	3.7
A	-08	2.7	1.5
M	-0.6	4.0	2.2
J	-2.3	-0.6	-0.3
J	-1.1	1.6	0.9
A	-0.9	2.1	1.2
S	-0.6	-0.1	-0.1
O	-0.4	-0.1	-0.1
N	0.0	2.9	1.6
D	1.3	1.2	0.7
1978 J	-1.0	-0.7	-0.4
F	-1.5	-3.3	-1.8
M	-1.0	-1.9	-1.1

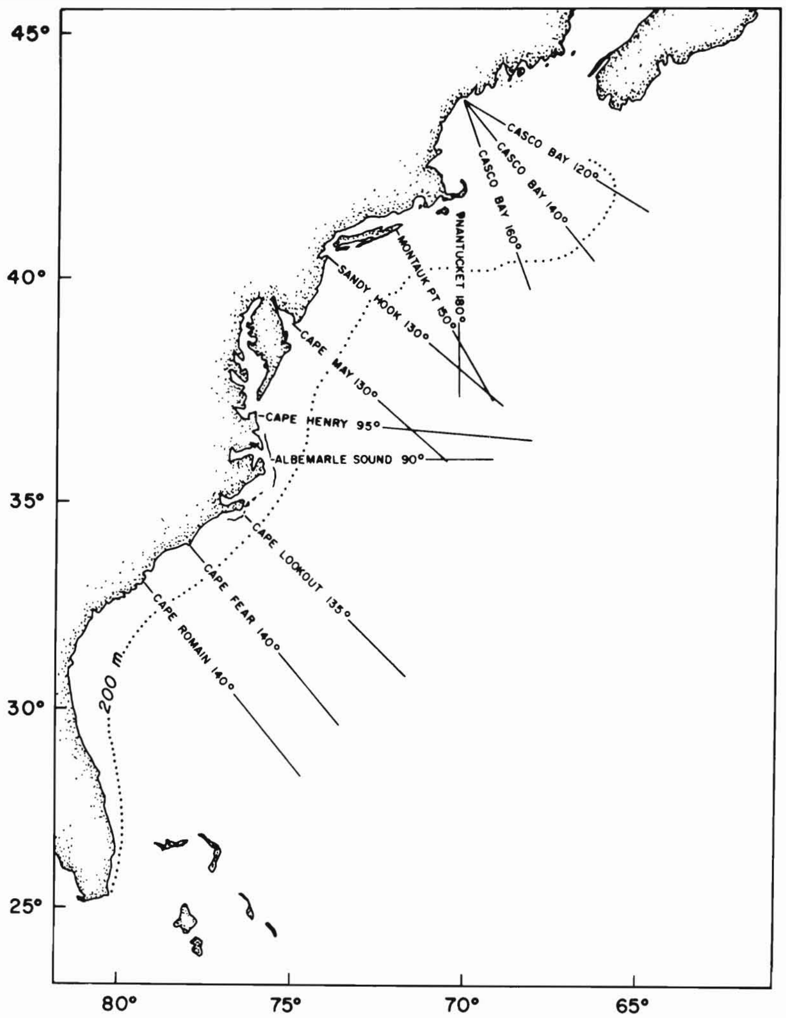


Figure 5.—Location of reference points and bearing lines used to portray the variation of the position of the Shelf Water front relative to the 200-m isobath (dotted line).

were fairly consistent with the mean values except for an offshore excursion in late July and one onshore in November, which was associated with the movement of warm-core Gulf Stream eddies south of Georges Bank. The spring and summer periods, when encroachment usually occurs, did not provide good viewing conditions about half the time, but the good views which were available showed the front to be farther up on the Bank than average, except for the offshore excursion in July mentioned above.

In 1978, the front was observed to be more onshore than normal in January and about average in February, then it moved offshore steadily in March until it was about 150 km offshore in early April. This last position, more than four standard deviations offshore of the mean, is associated with the total disappearance of warm-core eddies in the Slope Water for the first time in about 5 years of satellite monitoring.

Middle Atlantic Bight

Temperature Structure

The variation of sea surface temperature (SST) in the Middle Atlantic Bight in 1977 showed some of the same temporal and spatial patterns shown by the coastal air temperature anomalies. A plot of the SST anomalies for selected 1° squares in Atlantic coastal waters (Fig. 7), produced by the Pacific Environmental Group, shows the most intense negative anomalies occurring in February, about a month after the strongest air temperature anomalies. The lag time is not unexpected because of the greater thermal inertia of the ocean in comparison with the atmosphere. The locations of the strongest negative anomalies of SST are off Virginia, about 150-200 n.mi. south of Atlantic City, N.J., the apparent center of the negative anomaly pattern for the atmosphere. This displacement is also to be expected when one considers the direction of the winter winds and the drift of the Shelf Water mass.

Substantial positive SST anomalies appeared off the New Jersey-Virginia coast during April, once again about a month after the unusual warming in the atmosphere in March. These warm anomalies persisted off the Delmarva Peninsula through July, but occurred sporadically off New Jersey and Virginia.

In 1978, the SST anomaly patterns closely paralleled the anomalously cool air temperatures in January-March. The SST anomalies were about as strong as in 1977 and were centered off Virginia again, but they persisted longer, through March at least.

The unusually cold weather of January and February 1977 left its mark on the Shelf Water mass in the Middle Atlantic Bight. Normally, minimum water temperatures, down to about 3°C nearshore, are reached during February or March, and during this time the water mass is well mixed and vertically isothermal. Stratification and thermocline development normally begins in April or May, sealing off the cold bottom water from above so that it warms only slowly throughout the summer months, until the fall overturn in October or November.

Based on expendable bathythermograph (XBT) data transects across the

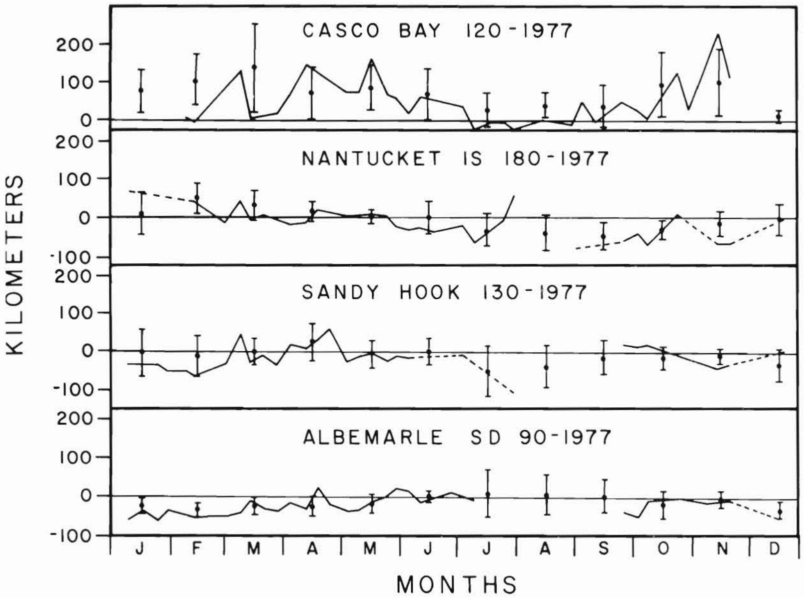


Figure 6.—Positions of the Shelf Water front in 1977 relative to the 200-m isobath (positive distances are seaward) along selected bearing lines. A dashed line segment indicates a 20-30 day gap in the data, and an omitted line segment indicates a gap greater than 30 days. Large dots indicate monthly means for the 1973-77 period and bars indicate a range of ± 1 standard deviation for the same period.

shelf off Sandy Hook, N.J.,[9] the winter minimum temperatures in Shelf Water in February 1977 ranged from less than 0°C nearshore to 9°C at the shelf break 50-90 n.mi. farther offshore. By April, warming and stratification had begun, with the bottom water temperatures ranging from less than 4°C nearshore, still colder than normal, to 9°C at the shelf break. These low temperatures prevailed until early June, but by late in the month warming and mixing had raised the minimum bottom water temperatures to about 7°C, which is normal for that time of year. Gradual warming occurred throughout the summer and early fall until the overturn began in October, when the minimum bottom temperatures had risen to greater than 10°C.

Thus, the only significant temperature anomaly in the bottom water on the shelf in the central portion of the Middle Atlantic Bight in 1977 was the unusually cold temperatures persisting from January to June.

The temperature structure observed off New Jersey in January-March 1978 was less extreme than for the first quarter of 1977. The minimum Shelf Water temperatures, measured in February, ranged from less than 2°C nearshore to greater than 6°C at the shelf break. Surface warming began in late March with the nearshore temperatures climbing to 4°-5°C in response to the warmer air present along the eastern seaboard (Table 1).

A similar cycle of bottom temperatures was reported[10] from XBT data collected on transects across the shelf off southern New England (approx. long. 71°W) at the northern end of the Bight. A portrayal of bottom temperatures on a time VS bottom depth coordinate grid (Fig. 8) shows that the minimum values, measured in February-March, were less than 1°C nearshore, which was about 3°-4°C colder than found in previous years (1974-76). Analysis by Davis (footnote 7) of bottom temperatures from spring (February-March) groundfish surveys showed that the average value off southern New England in 1977 was about 2.5°C colder than the long-term (1968-77) mean. By May the bottom temperature pattern was much like those observed in previous years, so in this area the effects of the unusually severe cooling in the winter of 1976-77 lasted for just the first 4 months of 1977. In the first quarter of 1978 the minimum bottom temperature, measured in March, was less than 2°C nearshore, about 1° warmer than in 1977.

The timing and extent of the winter cold bottom water temperatures on the outer continental shelf are in part dependent upon the passage of warm-core Gulf Stream eddies in the adjacent Slope Water. These eddies, with their anticyclonic (clockwise) circulation, apparently first inject warm, saline Slope Water shoreward then draw off cooler, less saline Shelf Water seaward as they pass. For example, maximum cooling on the outer shelf was recorded in February just after eddy 76D had passed, but was interrupted by the passage of eddy 76G and reestablished in mid-March after the eddy had left the area. By late March, however, seasonal warming became evident.

The cooling and deepening of the surface layer, which marks the end of the annual heating cycle, began off southern New England in September. This was accompanied by warming of the bottom water, as mixing progressed down through the water column. The timing of this bottom temperature rise is variable from year to year, generally occurring during the September-November period. In early November 1977, when the warming of bottom water was approaching its

[9]Cook, S. K. 1978. Water column thermal structure across the shelf and slope southeast of Sandy Hook, N.J. in 1977. Unpubl. rep., 8 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

[10]Crist, R. W., and J. L. Chamberlin. 1978. Bottom temperatures on the continental shelf and slope south of New England during 1977. Unpubl. rep., 17 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

						1977								1978		
	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
1 44 N 66 W		-1.7 1		-.3 1	0.0 2	1.2 5	1.9 17	2.3 8	0.7 6	1.2 1	2.4 2		1.1 6	-.2 10	0.7 5	0.9 4	
2 43 N 68 W			0.6 1		0.9 3	1.4 1	-.9 1		-1.3 2	1.6 3	0.0 4	1.1 8	0.8 3	0.4 2	-.7 1	-.2 4	
3 41 N 69 W		-.2 6	-1.1 16	-.3 22	0.5 23	0.0 15	1.1 6	-.3 10	-.9 13	-.2 19	-1.0 22	-.4 24	0.6 12	-.4 8	-1.9 8	-1.6 20	
4 40 N 71 W		-1.1 38	-.9 63	-.9 41	-2.2 7	0.4 8	0.6 13	-.4 11	-1.4 15	-.4 16	-1.4 8	0.6 19	-1.1 12	0.4 10	-.7 17	-1.9 22	
5 40 N 72 W		-1.5 44	-1.8 10	-.6 25	-1.5 5	0.4 5	-.4 11	0.3 10	0.4 7	-1.3 6	-.9 11	-.9 2	-.4 7	1.1 2	-.4 3	-2.7 10	
6 39 N 73 W		-.3 10	-2.7 7	-.9 13	1.0 16	0.6 4	1.2 15	-.5 11	-.4 16	0.8 26	-2.7 16	0.6 17	-.2 17	-.4 18	-1.1 10	-1.1 14	
7 37 N 74 W		-.6 40	1.0 34	0.6 57	2.6 33	2.0 59	1.1 32	1.1 28	-.3 36	0.6 52	-1.5 37	-2.4 37	0.9 27	0.7 14	-2.4 30	0.8 47	
8 36 N 75 W		-2.6 38	-4.0 10	-1.2 19	2.4 7	-1.1 25	-.3 26	1.3 22	-.5 32	1.4 31	-2.0 17	-1.6 18	-1.3 13	-3.6 12	-3.6 28	-2.8 30	
9 34 N 75 W		-.6 25	-1.4 16	0.6 22	0.4 35	-.7 28	0.2 31	0.8 22	-.8 18	-.2 50	-.3 15	1.1 26	0.0 25	-1.0 23	-.5 26	-1.6 34	
10 33 N 77 W		-2.3 12	-3.0 6	-1.0 9	0.5 14	-1.3 8	1.2 7	1.0 5	-.9 12	0.2 11	-.6 7	1.1 9	-1.7 10	-3.9 12	-4.0 9	-1.4 11	
11 32 N 78 W		-2.9 17	-1.2 5	-1.7 16	0.5 28	-1.6 13	-.6 14	-.5 11	0.4 12	-.2 14	-.9 11	-.4 14	-1.1 14	-3.0 8	-3.6 8	-1.0 16	
12 30 N 80 W		-2.7 12	1.1 17	0.6 15	-2.2 13	-1.2 10	-.7 7	0.4 136	0.2 190	-.1 208	0.4 37	0.8 21	0.4 10	-4.8 11	-.4 19	-1.7 17	
13 28 N 79 W		-1.6 14	-2.1 19	-.3 22	0.4 19	-.4 19	-.8 26	-.6 11	-.9 20	-.8 16	-.3 18	-.2 17	0.2 19	0.8 14	-.6 14	-.6 16	
14 26 N 79 W		-1.6 16	-1.6 14	-.2 30	-.0 27	-1.1 22	-.2 37	-.4 16	-.9 32	-.8 23	-.8 29	-.2 26	0.5 26	-1.2 16	-.8 23	-.5 26	
15 24 N 80 W		-1.2 14	-.6 13	0.1 18	0.4 18	-.1 22	-.3 21	0.1 12	-.6 17	-.1 21	0.7 20	-.2 19	-.6 15	-2.0 9	-.1 18	-.9 13	

SEA SURFACE TEMPERATURE MONTHLY ANOMALIES

Figure 7.—Anomalies of average monthly sea surface temperature (°C) from the 1948-77 mean for selected one-degree squares along the Atlantic coast. Approximate geographic location of squares is as follows: 1-Fundy, 2—Portland, 3—Cape Cod, 4—southern New England, 5—Long Island, 6—New Jersey, 7—Delmarva, 8—Virginia, 9—North Carolina, 10—South Carolina, 11—Georgia, 12—North Florida, 13—Canaveral, 14—Grand Bahama, 15—Florida Straits. Latitudes given are for the southeast corners of the one-degree squares. Open grid shading indicates positive anomalies of 1°C or more. Close line shading indicates negative anomalies of 1°C or larger. Small numbers in lower left corners of squares indicate the number of observations used in computing anomalies. Data display produced by NMFS Pacific Environmental Group, Monterey, Calif.

maximum, warm water from a band of Gulf Stream water encircling a warm-core eddy adjacent to the shelf edge was thrust under the resident bottom water raising the temperature to 17°C in the 50-60 m depth range. This is the highest bottom temperature observed at mid-shelf depths in the 1974-77 monitoring period.

Warm-Core Eddies

The most outstanding variation in the oceanographic conditions in the Middle Atlantic Bight during 1977 was the unusually large number of persistent warm-core Gulf Stream eddies, ranging from 40 to 150 n.mi. (70-270 km) in diameter, and moving westward and southward in the Slope Water along the edge of the continental shelf (Fig. 9). A summary of eddy activity in

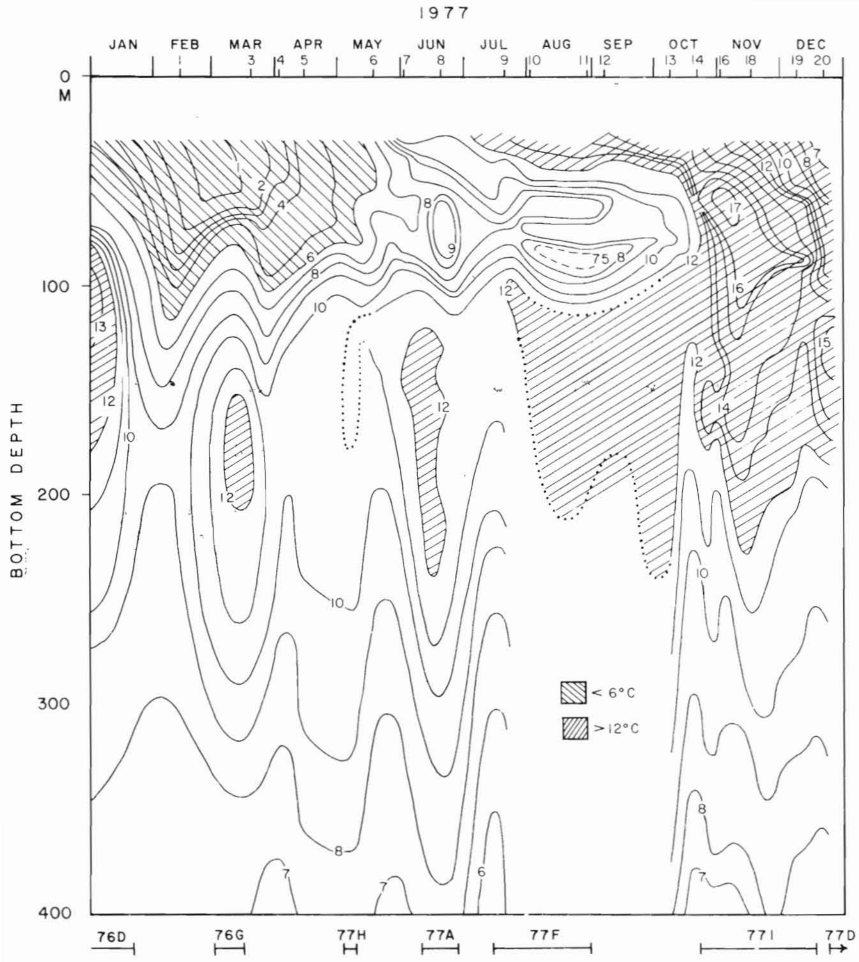


Figure 8.—Bottom temperatures on the continental shelf and slope south of New England during 1977. XBT sections are numbered along top. Dots mark the inshore and offshore bottom depth limits for each section. Horizontal lines at bottom of diagram indicate duration of warm-core Gulf Stream eddy passages south of New England.

The last of the 1977 eddies, 77D, formed in March, passed along the shelf edge off southern New England in January 1978 and was resorbed by the Gulf Stream east of Delaware Bay in the last week of February. From then until early May there were no warm-core eddies in the Slope Water, with curious consequences; the Shelf Water mass extended out much farther seaward, to the Gulf Stream edge in some places, overriding the Slope Water in a layer up to 50 m thick.

The unusual eddy activity in 1977 apparently led to loss of gear and poor catches for the lobster and crab fishermen working on the outer continental shelf and slope. The paths taken by the eddies (Fig. 10) shows that the potential for interaction in those waters was great. A compilation of 1977, compiled by Mizenko and Chamberlin[11] revealed that nine warm-core eddies formed during the year, eight of them in the first 4 months, and the ninth in July. In addition, three others which formed in 1976 continued to exist in the area in 1977. There were at least two eddies adjacent to the shelf edge between eastern Georges Bank and Virginia at all times during the year, and in May there were five present (Table 3). The lifespans of the eddies ranged from 37 to over 300 days with an average of about 150 days (Table 4).

Table 4.—Eddy formation and destruction dates and lifespans.

Eddy: Mizenko and Chamberlin[1]	EOFA[2]	Dates[3]	Lifespan (days)
76D	H	5/20/76-2/6/77	262
76F	K	10/15/76-2/4/77	112
76G	J	10/27/76-5/26/77	201
77A	L	1/7/77-10/7/77	273
77B	M	1/26/77-(3/11/77)	44
77C	Q'	(2/12/77)-(5/18/77)	95
77D	Q	(3/20/77)-2/21/78	338
77E	N	4/10/77-10/12/77	185
77F	—	(4/11/77)-(5/18/77)	37
77G	Q	4/17/77-5/24/77	37
77H	P	4/25/77-9/5/77	133
77I	R	7/16/77-2/12/78	211

[1]See text footnote 11
[2]Experimental Ocean Frontal Analysis charts produced weekly by the U.S. Naval Oceanographic Office.
[3]Dates in parentheses could be off by greater than a week. Dates not in parentheses are accurate to within a week and, generally, are accurate to within several days.

Table 3.—Eddy positions at mid-month with respect to zone during 1977.

Area	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
E. Nova Scotia		77B		77D	77D 77F	77D	77D					
W. Nova Scotia	77A		77C	77C	77C			77D	77D			
E. Georges Bank	76F	77A		77E	77G					77D		
W. Georges Bank	76G		77A		77E	77E		77I			77D	
Southern New England		76G		77A	77A	77A	77E		[1]77I	77I		77D
Long Island - New York Bight	76D		76G		77H		77A	77E	77E		77I	77I
New Jersey - Delaware				76G		77H	77H	77A	77A			
Virginia					76G			77H				

[1]Meander

[11]Mizenko, David, and J. L. Chamberlin. 1978. Gulf Stream anticyclonic eddies (warm-core rings) off the northeastern United States during 1977. Unpubl. rep., 23 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

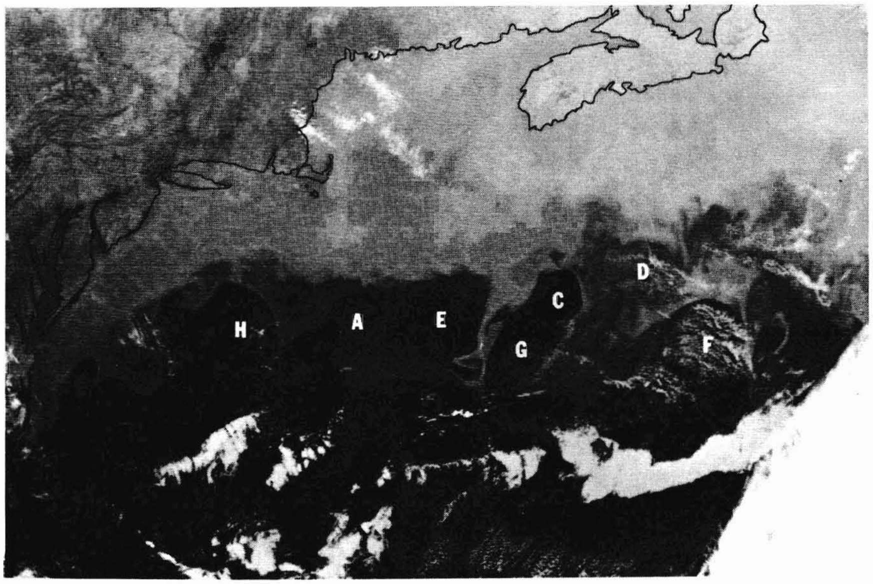
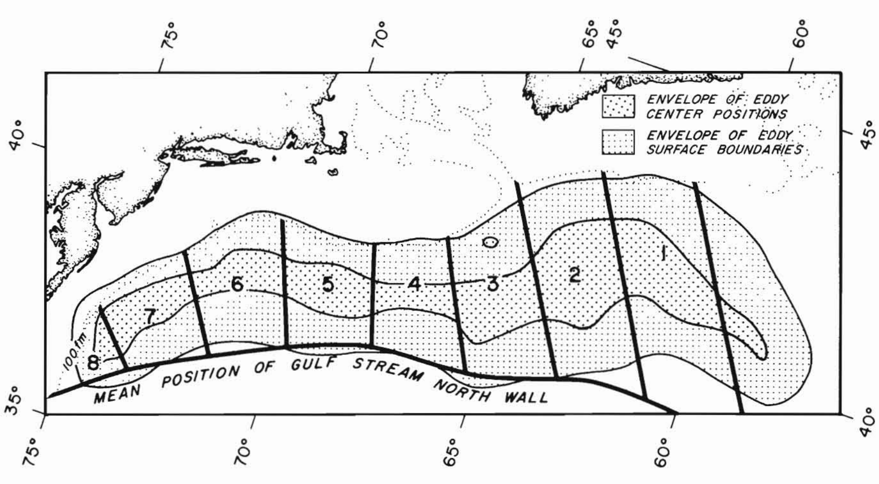


Figure 9.—The numerous warm-core Gulf Stream eddies that formed off northeastern North America during the first 4 months of 1977, as seen in infrared imagery from NOAA 5 environmental satellite on 30 April 1977. Warmer temperatures register darker. These clockwise rotating eddies, which are warmer than the water around them, are labeled alphabetically in the order that they detached from the Gulf Stream. During the balance of 1977, four of these eddies (A, E, G, and H), plus one more (I) which formed in July, moved westward and southwestward off the southern New England and Middle Atlantic Bights, and apparently caused strong currents at various times and places over the continental slope. The principal evidence of this eddy influence is from several deep-sea red crab and lobster fishermen, who reported that strong, persistent currents toward the east or northeast caused losses of gear and interference with fishing. Eddies C, D, and F were resorbed by the Gulf Stream before they reached the fishing grounds. Immediately south of the eddies the warm, meandering Gulf Stream is visible in the picture, although partly obscured by clouds. The coastline has been retouched to make its location clearly visible.

Figure 10.—Envelopes of surface boundaries and center positions of warm-core Gulf Stream eddies off the Atlantic shelf during 1977. Numbered areas are arbitrary zones used in the statistical analysis of eddy position data (see Table 3).



eddy locations and reports from lobster or crab fishermen in waters over the continental slope (<200 m) of gear loss, displacement, or surface float submergence has been made[12] and is summarized in Table 5. In addition, the eddies probably were responsible for the mixing of large volumes of outer Shelf Water and plankton into the Slope Water, as was evidenced by the frequent appearance of cooler Shelf Water entrained and wrapped around the eddies. During the absence of eddies in the Slope Water, the Shelf Water extended out, unmixed, developing an unusual two-layer structure with cooler, fresher water over warmer, saltier water.

Shelf Water Front

Gunn's (footnote 8) analysis of Shelf Water front positions from satellite charts for this area (Sandy Hook 130 transect, Fig. 5, 6) showed that in 1977 the front generally remained relatively close to the 1973-77 mean position. However, in the first 2 months of the year the front was about 40-70 km shoreward of its mean position along the shelf edge.

In the first quarter of 1978, the satellite infrared imagery revealed a spectacular displacement of the Shelf Water front offshore, beginning in February just 10 km from the shelf edge and moving out to 130 km by the first week in April. This anomalous displacement coincides with the unusual absence of warm-core eddies in the Slope Water region, suggesting a dynamic relationship between the eddies and the front or a mutual dependence of the two features on a common set of forcing functions.

An interesting result of this unusual offshore excursion of the Shelf Water was the apparent offshore diversion of migrating schools of Atlantic mackerel. The schools passed off Virginia about 20 n.mi. farther offshore than usual, generally escaping the domestic

[12]Chamberlin, J. L. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882, pers. commun.

fishing fleet, which was working nearer to shore.[13]

Anoxic Layer

The spring conditions in 1976 (early stratification, prevailing southwesterly winds, low storm incidence, and unusually heavy phytoplankton bloom) which led to the formation of an anoxic bottom layer in a large area of the subthermocline water on the shelf off New Jersey during the summer of 1976 were not repeated in 1977. Dissolved oxygen data collected from various ships for the MESA (Marine Ecosystem Analysis program) New York Bight Project in the spring and summer of 1977 revealed just a narrow band ($\geq$ 3 n.mi. wide) of low oxygen water nearshore along about 30 n.mi. (55 km) of the central New Jersey coast in late August.[14] Farther offshore, in the area which became anoxic the previous year, the dissolved oxygen levels remained above 2.5 ml/l.

South Atlantic Bight

Temperature Structure

Except for meteorological data, satellite imagery, and sea surface temperature data (collected from ship intakes), no routine monitoring information presently is available to us from the South Atlantic Bight. The temporal-spatial patterns of sea surface temperature anomalies (Fig. 7) show extensive patterns of cold anomalies in January-March of both 1977 and 1978: In both years the anomalies were most intense off South Carolina and Georgia. In 1978 the cold anomalies were not as intense off Florida as they were the previous winter.

During the spring and summer months of 1977 the waters of the South Atlantic Bight did not experience the anomalous warming which occurred in the Middle Atlantic Bight. In fact, a considerable portion of the former continued to show negative SST anomalies throughout the period.

Gulf of Mexico

Temperature Structure

The sea surface temperature data set available for the Gulf of Mexico does not provide good areal coverage and replication. The observations are most numberous along shipping lanes from either the Yucatan Channel or Florida Straits to major ports from Mobile, Ala., to Corpus Christi, Tex., and absent in the northeastern and southwestern Gulf. Nevertheless, in the area covered, seasonal changes are apparent in the data set for 1977 and early 1978.

In January and February 1977 negative SST anomalies, up to -3.7°C in magnitude, were found in virtually all of the coastal 1° squares monitored. In March this pattern moderated considerably in the eastern Gulf, but persisted in the western half. In April, both halves were experiencing nearly normal sea surface temperatures with weak positive or negative anomalies showing in most squares. This period of normalcy lasted until October, when strong negative anomalies appeared in the eastern Gulf. This condition disappeared in November, but reappeared in January, began spreading westward in February, and occurred in both halves in March 1978. The magnitudes of the cold anomalies in 1978 were only slightly less than in 1977, but the anomalous region was more extensive and more persistent in 1978.

The variation of coastal sea surface temperatures in both winters clearly was a reflection of atmospheric events, as indicated by the coastal air temperatures (Table 1). Here also, anomalies in early 1978 were only of slightly lesser magnitude than in 1977, but were more widespread and persistent. Comparing the air and sea temperature records for March and April also reveals a lag time of about 1 month for the warming of the sea surface, as is to be expected.

The prolonged cool temperatures in early 1978 apparently have had an effect on at least one marine resource organism, the brown shrimp, in the western Gulf. Growth in this animal has been noticeably retarded this season.[15]

Eastern Gulf Loop Current

In his efforts to summarize the state of knowledge of the Eastern Gulf Loop Current and to describe its configuration in 1977 and early 1978, Brucks (footnote 15) has found that the classical generalized seasonal cycle of the current has recently come under scrutiny (Behringer et al., 1977). The cycle of maximum northward intrusion into the Gulf in spring and summer and minimum intrusion in fall

Table 5.—Gulf Stream eddies associated with reports by deep sea red crab and lobster fishermen of strong currents interacting with fishing gear over the continental slope off the southern New England and Middle Atlantic coasts during 1977.

Eddy[1]	Date	Area	Fishing gear
77H	Last week of June to third week of July	Between Baltimore and Washington Canyons	Red crab Lobster
77A	First to third weeks of September	Between Baltimore and Washington Canyons	Red crab Lobster
77E	Sept. 2-3	East of Hudson Canyon	Red crab
77I	Nov. 20-Dec. 4	East of Hudson Canyon	Red crab Lobster
77G	Third and fourth weeks of December	Between Atlantis and Block Canyons	Lobster

[1]Eddies listed in their order of entering the region off southern New England and designated by their year of formation and alphabetically in their order of formation.

[13]Austin, H. M., Virginia Institute of Marine Science, Gloucester Point, VA 23062, pers. commun.

[14]Swanson, R. L., MESA New York Bight Project, SUNY, Stony Brook, NY 11794, pers. commun.

[15]Brucks, J. T., National Fisheries Engineering Laboratory, NMFS, NOAA, Bay St. Louis, MS 39520, pers. commun.

and winter has not held up in the light of recent studies. Satellite infrared imagery and winter cruise data have revealed instances of major intrusions in the winter months. A case in point is the cycle observed in plots produced by the NESS Field Service Station[16] in 1977 and early 1978, shown in Figure 11. Maximum intrusion in the 15-month period occurred in February 1977 and another slightly inferior maximum occurred in January 1978. A minimum was detected in the summer and fall periods using cruise data because satellite viewing conditions are degraded then because of poor contrast due to surface heating.

The current's trajectory takes it into the Gulf northward from the Yucatan Channel, occassionally as far as the outer shelf off the Mississippi-Florida coast, then eastward and southward along the shelf off western Florida, then out through the Straits of Florida. Variations in its strength and extension northward into the Gulf must strongly influence the environment of the biota of the continental shelf, as well as the distribution of the pelagic species associated with the current itself.

Mississippi River Discharge

Flow data for the Mississippi River

[16]Satellite Field Service Station, NESS, NOAA, P.O. Box 8243, Coral Gables, FL 33124.

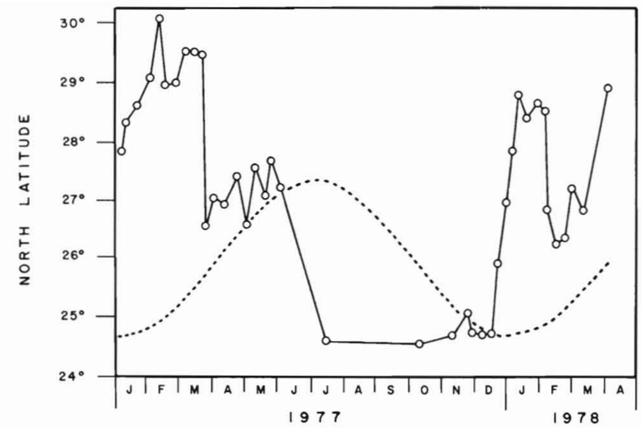


Figure 11.—Northward extension of the Eastern Gulf Loop Current into the Gulf of Mexico during January 1977-March 1978, based on sea surface frontal charts produced by the NESS Satellite Field Service Station in Miami, Fla. Dashed line curve represents the generalized annual cycle of extension of the current (from Behringer et al., 1977).

at Tarbert Landing,[17] reveal a long-term (1963-76) average cycle of high flow in March-May, with the average maximum of about 720,000 cubic feet per second in April and low flow in August-November, with the average minimum of about 200,000 cubic feet per second in September. The flow pattern in 1977 was below average during the normally high flow period, with record lows in February and June, and above average during most of the normally low flow period and extending into December.

[17]Computed by the U.S. Corps of Engineers Regional Office at New Orleans, La.

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