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Shelfwater Response to the Cold Winters of 1977 and 1978 in the South Atlantic Bight (SAB)*

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ABSTRACT

Hydrographic data from winter and summer cruises during the 1976 to 1979 period were used to illustrate atypical oceanographic conditions in the SAB, especially during the cold winters of 1977 and 1978. During this period meteorological conditions resulted in unusually low water temperatures in nearshore regimes (< 6°C in South Carolina coastal waters in January 1977). During other winter cruises surface waters were cooler off Georgia than off South Carolina. Zones of upwelling were observed regularly near Cape Canaveral and off Charleston, while Gulf Stream intrusions were detected at many outer shelf locations.

Salinities indicative of runoff occurred near the coast, from South Carolina to Florida during the winter cruises. High salinities (> 36 ‰) were also measured during the winter cruises in some coastal areas, indicating Gulf Stream intrusions. Surface salinities > 35 ‰ near river mouths were observed during the summers of 1977 and 1978, correlating well with drought conditions in the coastal states.

Surface circulation, as derived from density distributions, was atypical throughout much of the period of this study. The cyclonic eddy normally in Long Bay (south of Cape Fear) was not well-defined or present during the summer cruises, but was quite distinct during winter 1977 in conjunction with three other cyclonic eddies at midshelf locations. In addition, a rather continuous coastal countercurrent was present during winter 1977 from Long Bay to Cape Canaveral. The summer 1976 circulation, however, did not have a Long Bay eddy as usual or it was displaced offshore.

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Key Words: Eddy, Gulfstream, South Atlantic Bight, Surface Circulation, Surface Water Temperature, Upwelling, Water Salinity Profile.

The winters of 1976-77 and 1977-78 were two of the coldest on record in the South Atlantic states, both in terms of air and water temperatures. The effects of two successive winters of abnormal severity were immediate and obvious in several instances, ranging from unusually low water temperatures and the concommitant high mortalities of southeastern shrimp to diminished tourism at southeastern beaches. In particular, white shrimp landings in North and South Carolina in 1977 were the lowest since 1963 (McKenzie 1981). Two of the coldest winters in the 1957 to 1980 period were 1963 and 1977, during which South Carolina coastal waters were below 8.5°C (an empirical temperature associated with white shrimp mortality) for 56 and 48 days respectively (Farmer et al. 1978). In both instances white shrimp landings in the South Atlantic Bight (SAB) were greatly reduced. The third year in each case (1965 and 1979) was relatively mild with greatly-improved catch rates.

Utilizing historical data, Landers (1973) has theorized that weather from 1958 to 1972 was somewhat colder than usual for North and South Carolina and Georgia, while noting that the cold years were interspersed with relatively mild years. Although Landers' data support his premise, they also fit the basic pattern of alternating cold and warm years common to the Southeast. In fact, most winters in South Carolina tend to be almost discrete periods of cold snaps mixed with warm spells. Consequently, nearshore waters may fall below 8.5°C only a few days per winter or not at all, depending upon the length and occurrence of warm spells. Typical of this is the 1960 to 1977 period, during which five years South Carolina had no days with water temperatures < 8.5°C and one year with only three days below 8.5°C (Farmer et al. 1978). Water temperatures in Charleston Harbor never fell below 13.0°C in January of 1974 (Mathews unpublished data), illustrating a mild southeastern winter.

With the above in mind, the 1977 and 1978 winters can be seen to be atypical for several reasons: the actual temperatures, the duration of the cold weather, and the back-to-back effect of the two cold winters. Despite the atypical nature of these two winters, their physical causes are well known, i.e., the disruption of zonal atmospheric flow by the southward displacement of the Arctic atmospheric circulation. Dickson and Namias (1979), in particular, attribute the influx of cold dry air to amplified atmospheric flow, persistence of the abnormal flow, and extreme abnormality in circulation patterns. The resultant weather conditions included unusually cold dry winds in the Midwest and along the South Atlantic coast with atmospheric temperature anomalies, ranging from −5.9°C (January 1977) and −4.9°C (February 1978) at Jacksonville, Florida to −5.3°C (January 1977) and −5.5°C (February 1978) at Cape Hatteras, North Carolina (Ingham 1979). The extent and severity of the winters were shown clearly by Roberts et al. (1982), who recorded a minimum water temperature of 12.6°C during January 1977 in Florida Bay in the Florida Keys.

The following discussion will examine and delineate some of the physical responses of shelf waters in the SAB to the winters of 1977 and 1978. Evaluations of data from cruises from 1976 to 1979 will be made, and these data will in turn be compared to earlier data to illustrate the deviation from typical SAB oceanographic conditions.

METHODS

All water temperatures were determined using reversing thermometers placed on Niskin bottles and using XBT's and MBT's. Unprotected thermometers were used at deep stations (> 100 m) to obtain depths of reversal. Salinity samples were collected with Niskin bottles, stored in 250 ml polyethylene bottles, returned to the Marine Resources Research Institute (MRRI) for analysis, and run on a Beckman RS-7B induction salinometer.

TABLE 1
Temperature and Salinity Ranges by Depth and Cruise.

Cruise	Date	Surface Temperature (°C)	Bottom Temperature (°C)	Surface Salinity (‰)	Bottom Salinity (‰)
DP76-01	Jan.-Feb.1976	10.34°-24.20°	6.81°-22.84°	33.28-36.41	33.67-36.43
DP76-03	Aug.-Sept.1976	25.96°-29.52°	7.80°-27.46°	33.75-36.21	34.36-36.44
DP77-01	Jan.-March 1977	5.39°-23.28°	5.40°-18.94°	31.59-36.45	31.60-36.54
DP77-03	Aug.-Sept.1976	25.44°-28.69°	7.53°-28.25°	35.36-36.74	34.83-36.56
DP78-01	Jan. 1978	9.72°-24.01°	8.26°-21.00°	32.74-36.74	32.83-36.79
DP78-07	Sept. 1978	27.09°-28.98°	8.19°-28.51°	34.87-36.44	34.89-35.60
DP79-04	Aug. 1979	26.88°-30.16°	7.50°-28.24°	33.98-36.41	34.97-36.40

RESULTS

Our data are summarized in Table 1, which shows ranges of temperature and salinity by cruise and depth for 1976 to 79. (Hydrographic samples during the winter of 1979 were not collected, hence only summer data were available). The data are also illustrated in Figs. 1 through 9, which include temperature, salinity, and surface currents as derived from density distributions. Broken lines in some figures represent implied isopleths in areas where data are lacking or incomplete.

DISCUSSION AND CONCLUSIONS

In general, the presence or absence of runoff can be detected in SAB nearshore waters, depending to some extent on the season of the year and, hence, to climatic influences, the water depth, and the Gulf Stream position. Since nearshore waters are rather shallow (< 10 m commonly), both cooling and warming can occur rapidly when appropriate atmospheric conditions exist, when the Gulf Stream moves in or out, or when the amount of relatively cold, fresh runoff varies greatly.

Normally nearshore surface and bottom water in the SAB varies greatly from winter to summer in temperature and, to a lesser extent, in salinity, while Gulf Stream and midshelf bottom waters are quite constant. Surface water off Charleston covered a 15°C range from winter to summer in 1976 with a salinity range of about 1 or 2 ‰ (Figs. 1 and 2). Surface Gulf Stream and midshelf bottom waters on the other hand fluctuated < 8°C and about 0.5 ‰ during the same period.

Usually a band of midshelf bottom water is present at 18° to 20°C during the winter with salinities > 36 ‰, while Gulf Stream surface water normally is ≥ 22° to 24°C and > 36 ‰ (at the shelf edge or beyond). These lower limits are not absolute due to Gulf Stream meanders, upwelling, and intrusions, but they are fairly representative overall. Consequently, the intensity of the cold winters can be better evaluated by comparison with the above general criteria and water temperature records of the last 25 years, which indicate only one winter of comparable severity in the SAB, i.e., the winter of 1963.

Temperature 1976

The winter of 1975-76 was relatively mild and representative of a typical southeastern winter, especially with respect to the succeeding winters. December 1975 air temperatures averaged < 1.0°C below the thirty year mean, January and February 1976 were about 3.0°C below and 2.3°C above the mean respectively (NOAA 1977). The air temperatures were reflected in nearshore waters, which did not approach the empirical mortality temperature for white shrimp of 8.5°C. Despite the mildness of the winter, the nearshore isotherms were moderately unusual in distribution. Surface and bottom waters below Savannah were somewhat cooler (< 11°C) than water near Charleston (< 12°C) and about the same as waters in Long Bay below Cape Fear, due perhaps to runoff from the Savannah River (Fig. 1). Mathews and Pashuk (1977) found surface water temperatures of 14° to 18°C near Savannah during winter 1973, while Schroeder (1966) reported surface water temperatures of about 14° to 16°C for January in the Savannah area, using long-term averages. Anderson et al. (1961) found nearshore surface temperatures of 12.76° to 16.50°C along the Georgia coast during the 1953-54 *Theodore N. Gill* cruises. Offshore surface water temperatures were basically normal, especially near the Gulf Stream where temperatures were 22° to 24°C or higher (Fig. 1).

While surface and bottom nearshore waters in winter 1976 were about the same temperature, considerable differences existed at outer shelf stations. Bottom water at the shelf edge was < 8°C, in sharp contrast to the surface water (22° to 24°C) and to the midshelf bottom water (18° to 20°C), located nearby at the same latitude (Fig. 1). This cold water probably resulted from the intrusion of deep water at several locations along the shelf edge. Similar conditions were observed in the SAB during the winters of 1973 and 1974 (Mathews and Pashuk 1977 and 1982).

Summer water temperatures were moderately cool, reflecting air temperatures which were lower than normal. Negative air temperature

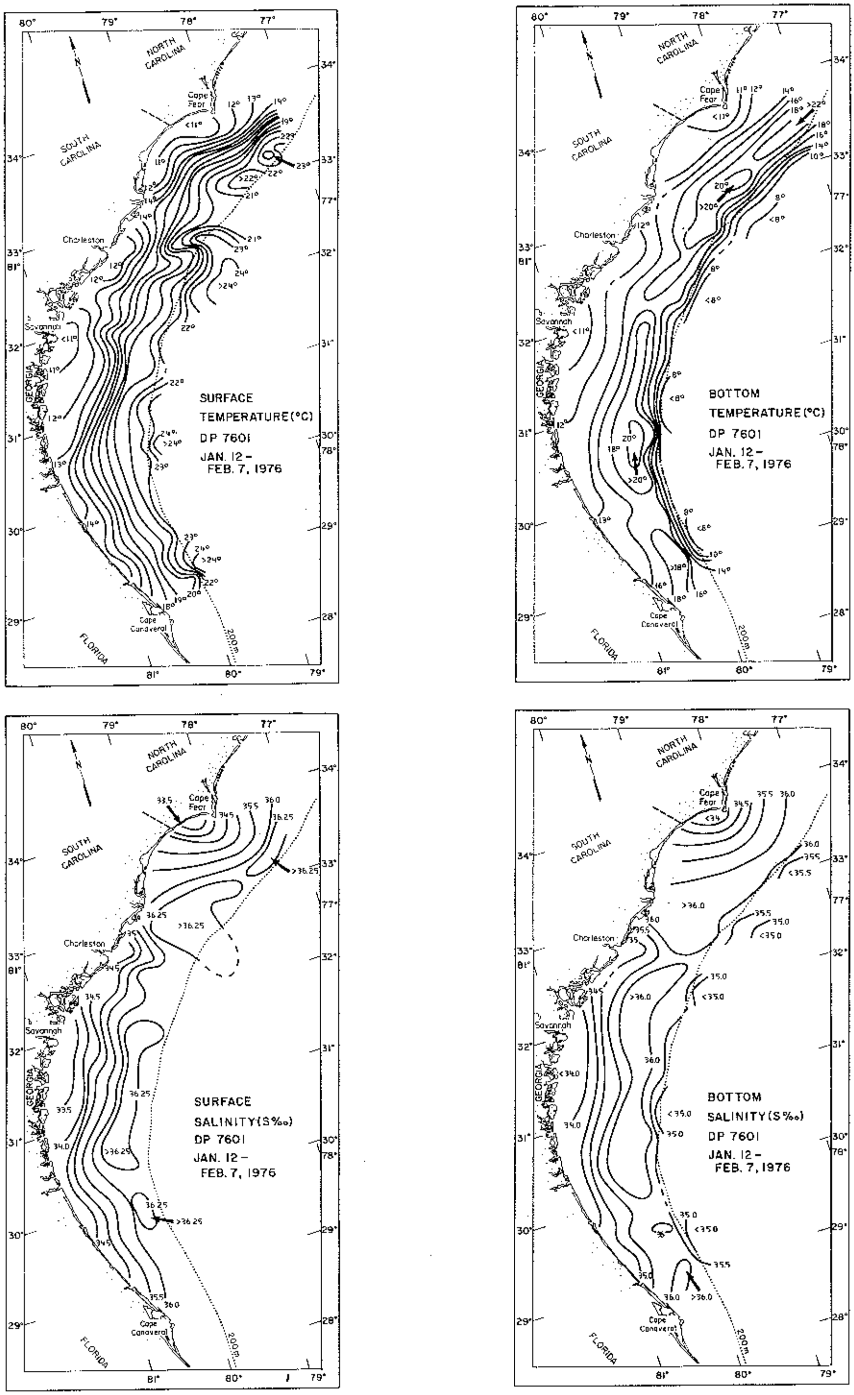

FIG. 1

Surface and Bottom Temperature and Salinity for Winter 1976.

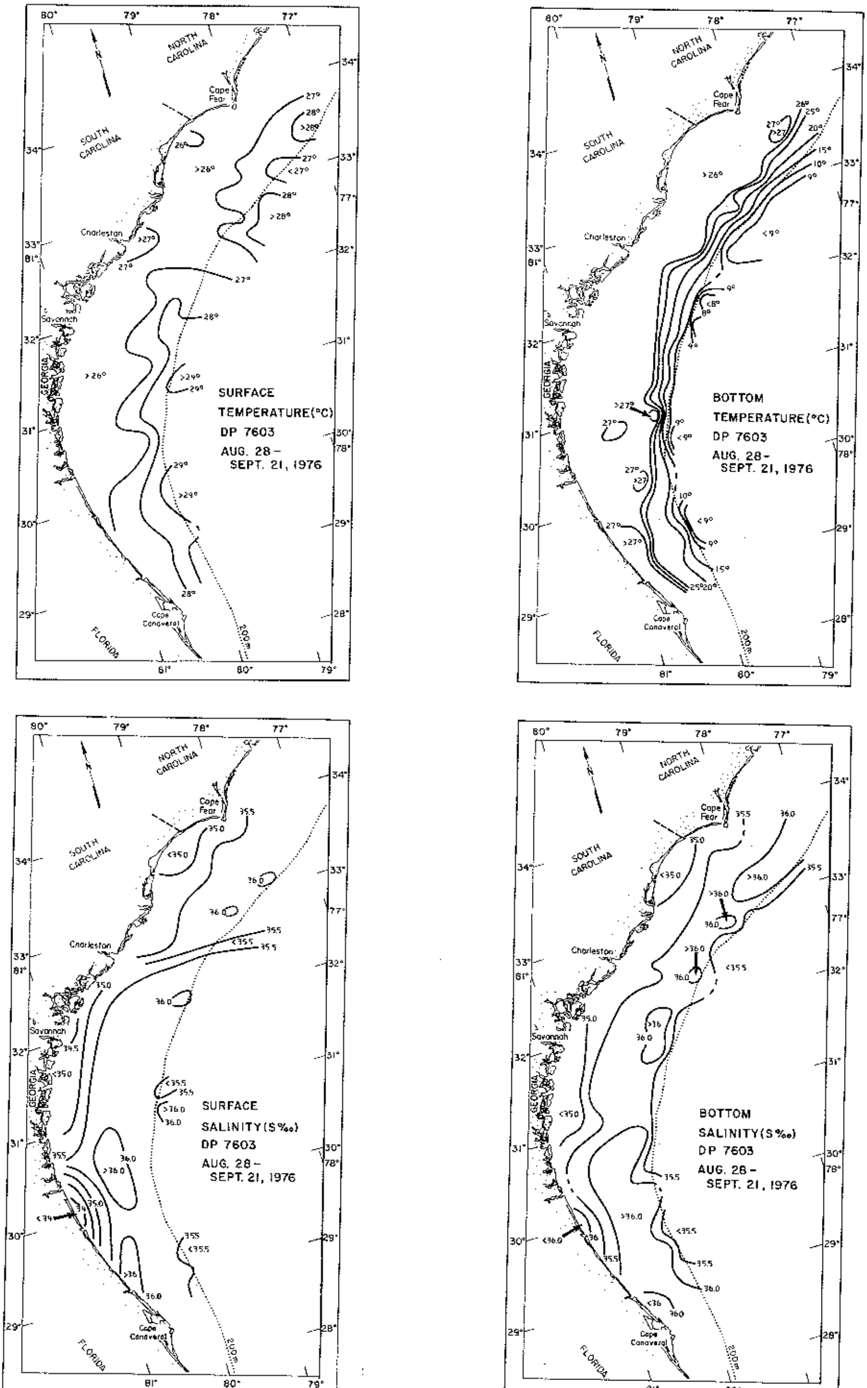

FIG. 2

Surface and Bottom Temperature and Salinity for Summer 1976.

anomalies up to 1.8°C were recorded during the summer of 1976 (NOAA 1977). Surface waters were similarly cool, ranging from < 26°C in Long Bay to about 29°C at the shelf edge at lat. 31°N (Fig. 2). Off Charleston the temperature was about 26° to 28°C, as compared with 27° to 29.5°C in 1973 (Mathews and Pashuk 1977) and about 28.5°C in 1974 (Mathews and Pashuk 1982). Charleston Harbor was also cooler during this period compared to other years, e.g., only a few days in late July and early August 1976 had water temperatures up to 29°C, but the same summer period in 1972 and 1975 went up to 30°C and often over 29°C (Mathews unpublished data).

Surface and bottom water temperatures were quite similar out to midshelf locations (Fig. 2). Near the shelf edge, however, bottom temperatures declined sharply to < 8°C near latitude 32°N, probably due to the deflection of the Gulf Stream by the "Charleston bump" and the resulting intrusion of cold deep water. Other areas along the shelf edge were < 9°C with rather compressed isotherms, especially near latitude 31°N where bottom temperatures ranged from about 10° to 27°C (Fig. 2). Mathews and Pashuk (1977) found bottom temperatures < 8°C at latitude 29°N and 32°N during August 1973, while Atkinson et al. (1979) recorded bottom temperatures down to 10°C off Georgia during July 1977.

Temperature 1977

The winter of 1976-77 was unusually cold as discussed above. Both air and surface water temperatures were among the lowest recorded in the Southeast since 1940 (NOAA 1977a). A surface water minimum of 5.39°C was recorded in January in Long Bay near the North Carolina border (Table 1 and Fig. 3), which was the lowest surface temperature we recorded anywhere in the SAB for the 1972 to 81 period. Historic surface temperatures for January in the SAB have been as low as 9° and 10°C, but are generally higher (Schroeder 1966, Anderson et al. 1961). During January 1977 surface temperatures off Charleston and northern Florida were < 8°C and < 10°C respectively (Fig. 3). In most areas temperatures were 3 and 4°C lower than in 1976 at the same location. Surface Gulf Stream temperatures were about 2°C lower than in 1976 in the zone from Cape Canaveral to Savannah, but more than 4°C lower to the east of Long Bay (Fig. 3). Even in March, waters off Savannah were still < 12°C (Singer et al. 1980) as compared with February and March 1973, when temperatures were 14° or 15°C in the same area (Mathews and Pashuk 1977). While 1973 was not as cold as 1977, a record snowfall occurred in parts of Georgia and South Carolina (down to the beaches near Charleston). Cold runoff from this snow lowered nearshore water temperatures south of Charleston to southern Georgia, but not to the extent of 1977.

Bottom water temperatures were approximately the same as those at the surface out to midshelf locations (Fig. 3). Temperatures < 6°C were found in Long Bay, < 8°C off Charleston, < 9°C near Savannah, and < 10°C off northern Florida. Several cells of warm water were detected along the outer shelf as in 1976, but temperatures were somewhat lower, i.e., 15° to 18°C vs. 18° to 20°C. Bottom water near the shelf edge was actually warmer than surface or bottom water in Long Bay and near Charleston (Fig. 3).

The summer of 1977 was one of the hottest and driest on record for coastal South Carolina since 1954, with air temperatures up to about 40°C (NOAA 1978). As a consequence, surface waters were warm as usual, e.g., > 28.5°C off Charleston and at the shelf edge (Fig. 4). A relatively cool (25° to 27°C) tongue of water extended from Cape Canaveral to about 32° north latitude, due perhaps to upwelling of deep Gulf Stream water near Cape Canaveral. Surface water off northern Florida and Georgia would usually be > 27°C during the late summer (Schroeder 1966; Mathews and Pashuk 1982).

Bottom waters were similar to surface waters in temperature primarily in nearshore locations. Cold water (about 8°C) was present at the shelf edge, indicating intrusions of deep cold water (Fig. 4). The cool surface water north of Cape Canaveral extended to the bottom, supporting the premise of upwelling. Temper-

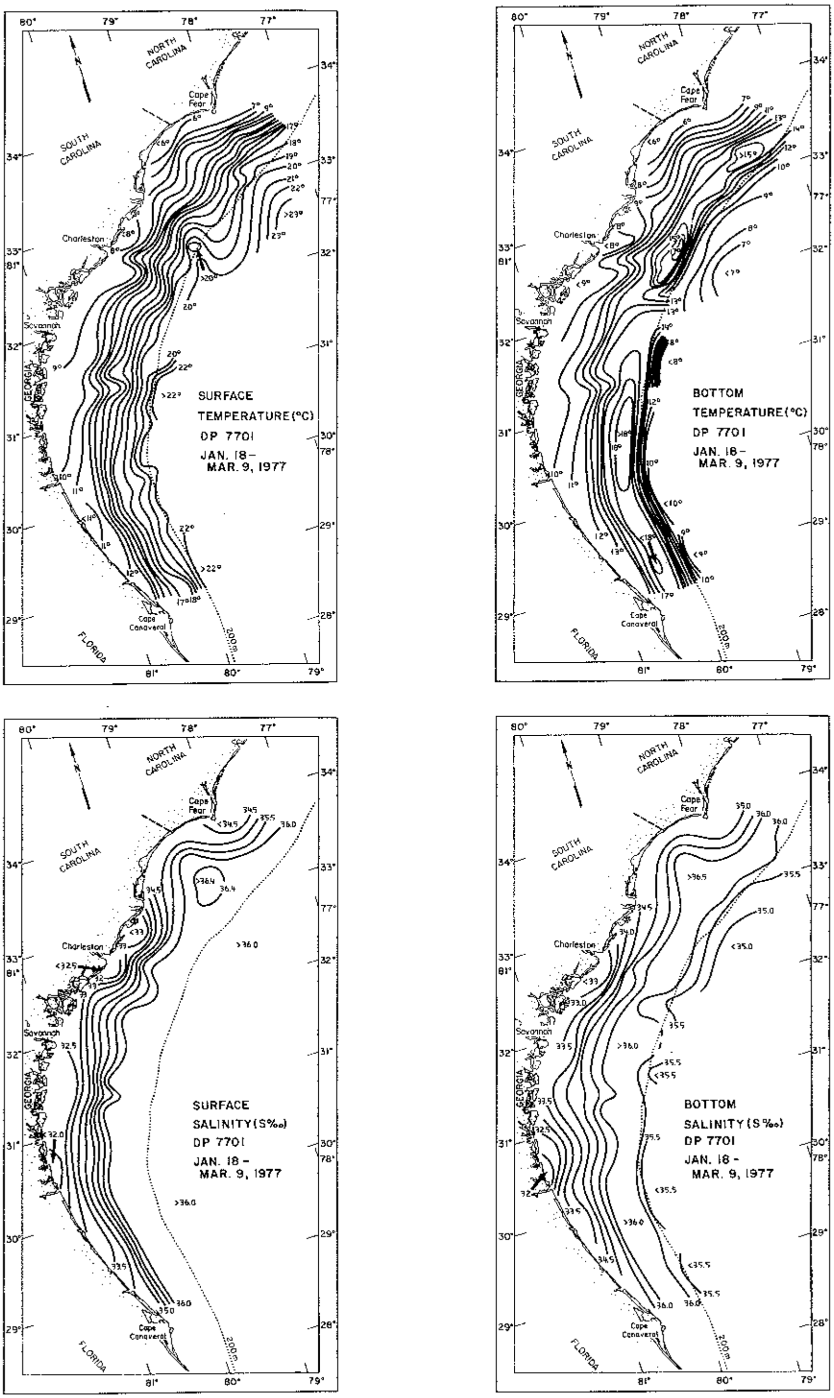

FIG. 3

Surface and Bottom Temperature and Salinity for Winter 1977.

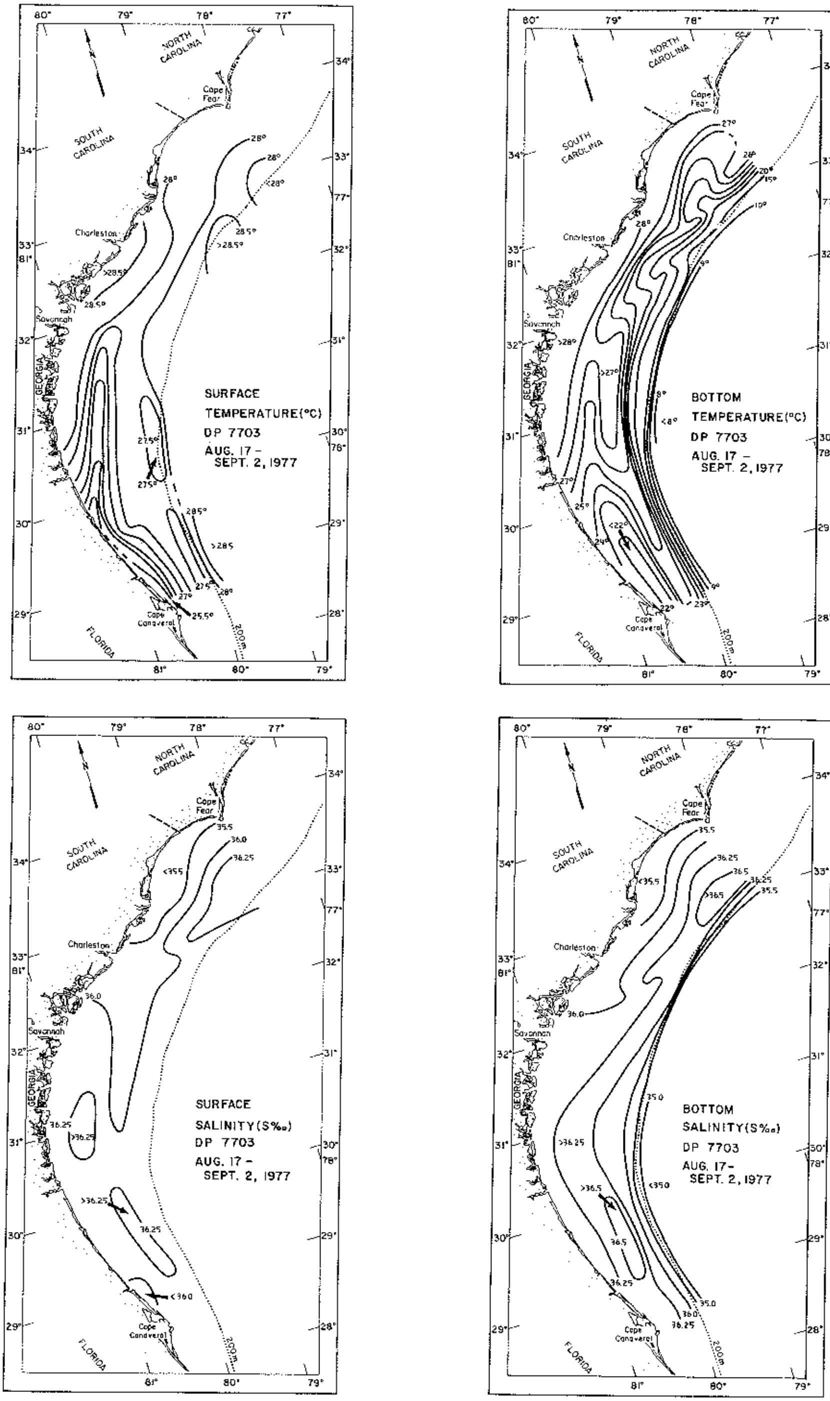

FIG. 4

Surface and Bottom Temperature and Salinity for Summer 1977.

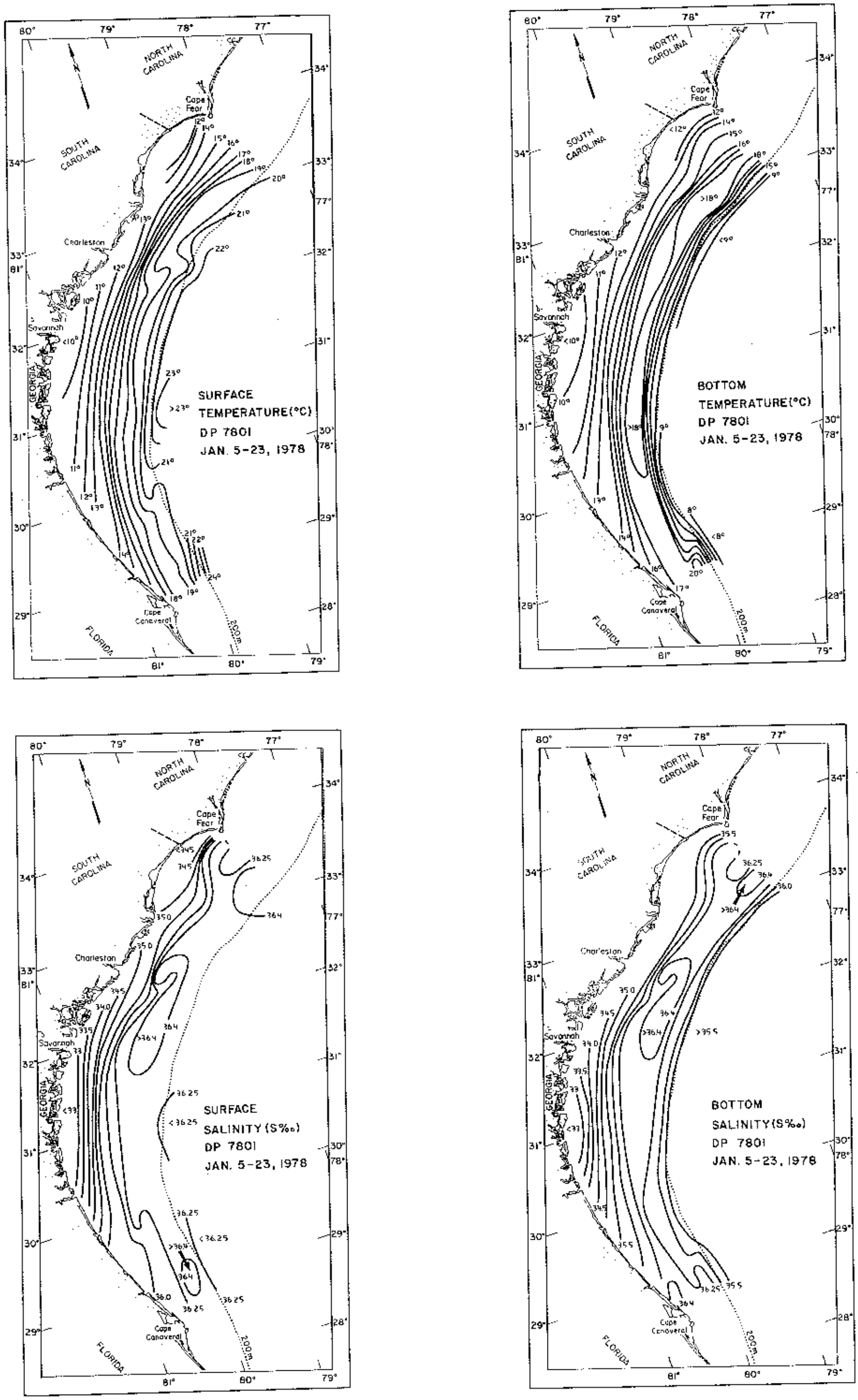

FIG. 5

Surface and Bottom Temperature and Salinity for Winter 1978.

atures < 22°C were recorded as this zone spread northward along the inner shelf.

Temperature 1978

The winter of 1978 was very cold, but not as severe as 1977. As in 1976, surface and bottom waters were colder off the Georgia coast than in the zone from Long Bay down to Charleston, i.e., about 10° near Savannah vs. 12°C in Long Bay (Fig. 5). First appearances suggest that the winter of 1978 was quite similar to 1976 (not 1977) in terms of water temperatures and the distribution of isotherms. While many similarities exist with respect to offshore waters, the estuaries experienced 45 days with < 8.5°C water temperatures (Biernbaum 1981). Hence, the adverse effects of two cold winters were compounded, accounting for the reduced white shrimp landings.

The coolest water (< 10°C) was found along the Georgia coast, with 11° and 12° isotherms extending down to northern Florida (Fig. 5). The highest temperatures (up to 24°C) were at the surface in the vicinity of the Gulf Stream. Singer et al. (1980) reported essentially the same results for a transect off Savannah in January 1978. The warmest bottom water was located at middle and outer shelf stations, where a long band of > 18°C water and a small area of > 20°C water (off Cape Canaveral) were present. The warm water was indicative of Gulf Stream intrusions onto the outer shelf. Located beyond the warm zone were areas of cold upwelled water from < 8° to < 9°C.

During the summer of 1978 surface water temperatures of about 28.5°C were observed over much of the SAB (Fig. 6). A band of cooler water (< 27.5°C) was located along the outer shelf from Charleston to upper Florida. A Gulf Stream deflection was also evident off Charleston, where the isotherms turned sharply eastward.

Surface and bottom temperatures agreed reasonably well in shallow nearshore zones, but the orientation of the isotherms was quite different. Bottom isotherms, unlike surface isotherms, were distinctly zonal, following the shelf orientation closely (Fig. 6). The bottom temperature gradient was rather even out to the shelf edge, where temperatures dropped from 15°C to < 9°C.

Temperature 1979

The winter of 1979, though less severe than the preceding two, was nonetheless colder than usual, continuing the effects of 1977-78. Negative temperature anomalies were recorded for the air and surface waters in the Southeast during the winter and spring of 1979, succeeding strong positive air temperature anomalies in the fall of 1978. Ingham and Haynes (1980) reported surface water temperature anomalies up to 2.4°C for December 1978, −3.5°C for January 1979, −4.2°C for February 1979, and −3.0°C for March 1979 in the SAB. Somewhat cooler conditions continued into June, with May and June having air temperature anomalies of about −1.7° and −2.1°C for the Charleston area (NOAA 1980).

Surface water temperatures in the summer of 1979 were indicative of the preceding cool winter and spring, with return to normal summer conditions being incomplete. The 1979 summer surface temperature range (Table 1) was not abnormal overall (cf. Atkinson 1976; Mathews and Pashuk 1982), but the distribution was somewhat unusual, e.g., off Savannah (Fig. 7). Temperatures in this zone were < 27°C, probably due to runoff. Another cool area with temperatures < 27°C was located in Long Bay, possibly due to the offshore spreading of runoff from Winyah Bay (located on the South Carolina coast at about 33° north latitude).

Bottom water temperatures were zonal with regular contours following the coast. Agreement with surface temperatures was only minimal, even in nearshore areas (Fig. 7). Signs of intrusions and/or upwelling were evident at several points along the shelf edge, where temperatures < 8°C were recorded and isotherms were somewhat compressed, e.g., north of Cape Canaveral.

Salinity 1976

Surface salinities were relatively low in

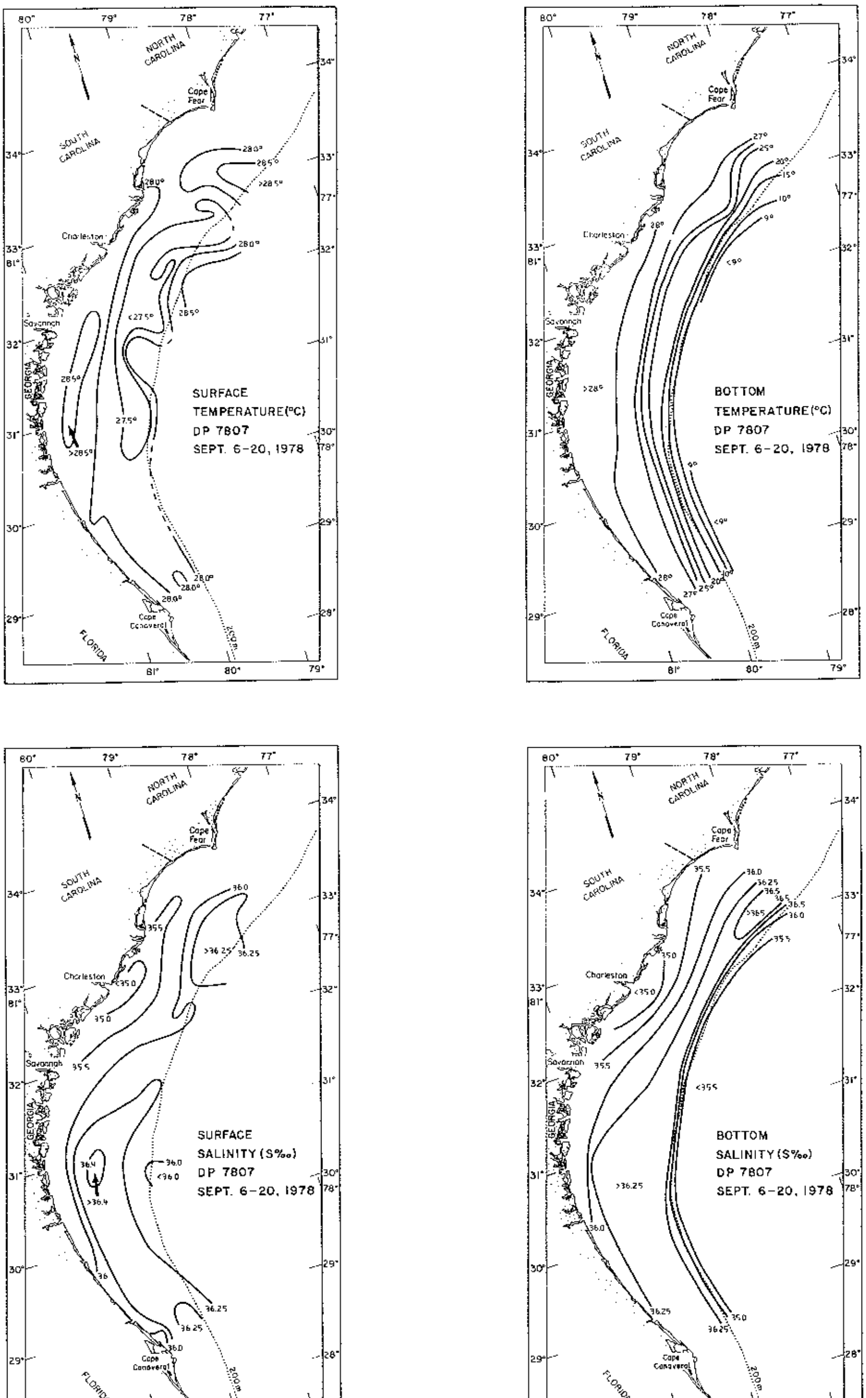

FIG. 6

Surface and Bottom Temperature and Salinity for Summer 1978.

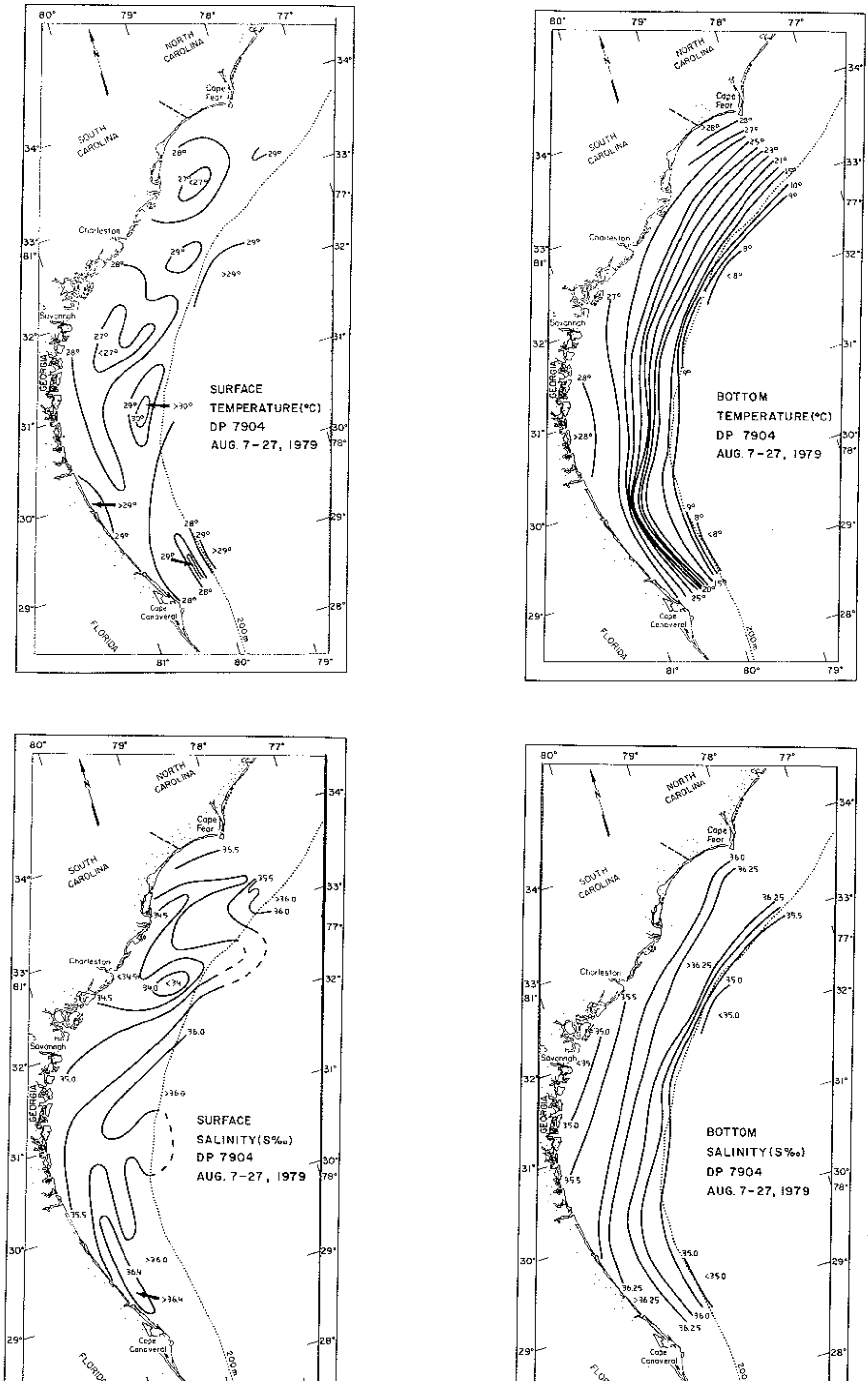

FIG. 7

Surface and Bottom Temperature and Salinity for Summer 1979.

nearshore zones during the winter due to runoff. Salinities < 33.5 ‰ were evident near Cape Fear and along the Georgia coast down to northern Florida (Fig. 1). If water < 35 ‰ is chosen as being indicative of runoff, then runoff extended from Charleston almost to Cape Canaveral. High salinity water (> 35 ‰) was located from the middle shelf out to the shelf edge. One exception to this occurred north of Charleston, where water > 36.25 ‰ came within a few kilometers of the coast, presumably due to a shoreward deflection of the Gulf Stream.

Winter bottom isohalines rather closely followed surface isohalines in terms of orientation and concentration, with low salinities (< 35 ‰) near the coast and high salinities (> 35 ‰) at midshelf and outer shelf zones (Fig. 1). Near the shelf edge were several areas with salinities < 35 ‰, indicating upwelling. Very similar results were obtained during winter 1973 and 1974 (Mathews and Pashuk 1977, 1982).

Summer surface salinities ranged from < 35 ‰ near the coast to > 36 ‰ at midshelf locations (Fig. 2). Salinities in 1974 were found to be distributed comparably from Savannah southward to Cape Canaveral. The high salinity (> 36 ‰) tongue of water north of Cape Canaveral was apparently a Gulf Stream intrusion (Fig. 2), resembling a zone of high salinity in the same area during summer 1974 (Mathews and Pashuk 1982).

Bottom salinities, in general, paralleled surface salinities during summer 1976, especially in nearshore environs. The 35.5 ‰ isohaline extended from Cape Fear to northern Florida, generally following the coastline (Fig. 2). A rather large zone of water > 36 ‰ extended from Cape Canaveral northward to southern Georgia, corresponding closely to the > 36 ‰ surface water noted above. Other isolated pockets of > 36 ‰ bottom water were present along the shelf edge up to Cape Fear.

Salinity 1977

The surface and bottom salinities during winter 1977 were very similar and appeared to be a continuation of summer 1976 conditions, i.e., low nearshore salinities (< 35 ‰) extending down to northern Florida and high midshelf salinities (> 36 ‰) (Fig. 3). The winter 1977 isohalines were more continuous than those of the previous summer with even lower salinities near the coast. In fact, the surface salinity of 31.59 ‰ during the winter 1977 cruises was the lowest of the 1976-79 period (Table 1). The 31.59 ‰ value, however, was not as low as the salinities recorded during winter and summer 1973 following record snows and rains, when salinities off Charleston and Savannah were 27 ‰ and 30.5 ‰ respectively (Mathews and Pashuk 1977). A high salinity Gulf Stream intrusion was evident in the region near Long Bay, where salinities ≥ 36.5 ‰ were measured (Fig. 3).

Summer 1977 was characterized by unusually high salinities throughout the SAB. While surface and bottom isohalines did not correspond as well as those of winter 1977, they were nonetheless close enough for general comparison (Fig. 4). Salinities > 35.5 ‰ and > 36 ‰ were observed off Charleston and Savannah, with the 36.25 ‰ bottom isohaline extending southward to Cape Canaveral. Such high salinities near river mouths are uncommon, especially when encountered throughout the area. Singer et al. (1980) also found comparably high salinities (35.5 ‰) near Savannah during September 1977 (about two weeks after our transect). As in winter 1977, another high salinity Gulf Stream intrusion was present in Long Bay, where surface and bottom salinities were > 36.25 ‰ and > 35.5 ‰ respectively. The only salinities < 35.5 ‰ were near the coast in Long Bay and on the bottom, at or beyond, the shelf edge.

Salinity 1978

Surface and bottom salinities during winter 1978 agreed well, except at the shelf edge. Nearshore salinities were low (< 34.5 ‰) from Charleston to upper Florida and even lower (< 33 ‰) along the southern Georgia coast (Fig. 5). Surface salinities were high (> 36.25 ‰) from Cape Fear to Cape Canaveral at midshelf to outer shelf locations (Fig. 5). The bottom counterpart to the surface was a band of > 36.25 ‰ water along the middle shelf more or less following the coastline (Fig. 5). Both surface and bottom salinities indicated a Gulf

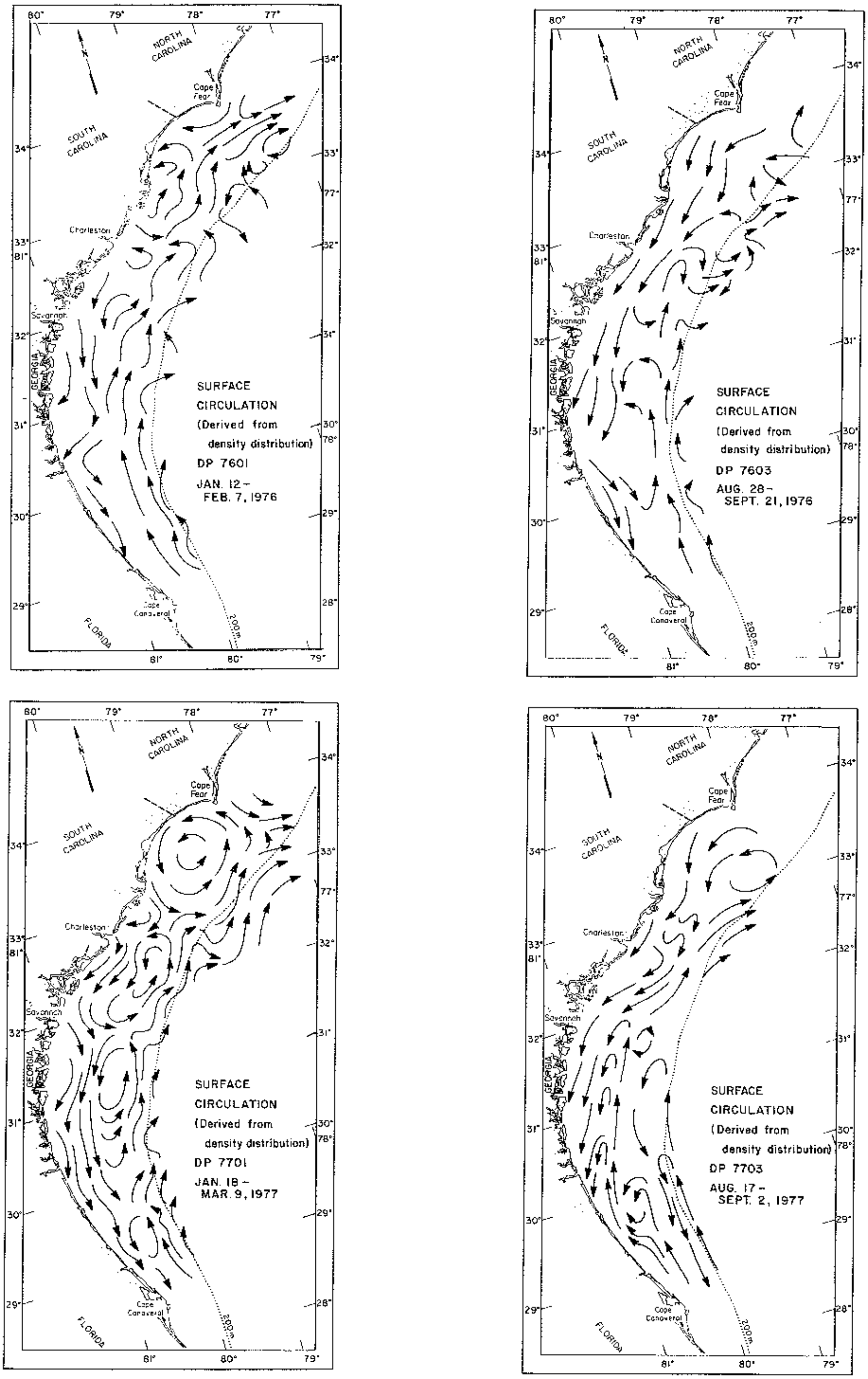

FIG. 8

Surface Circulation during Winter and Summer 1976 and 1977.

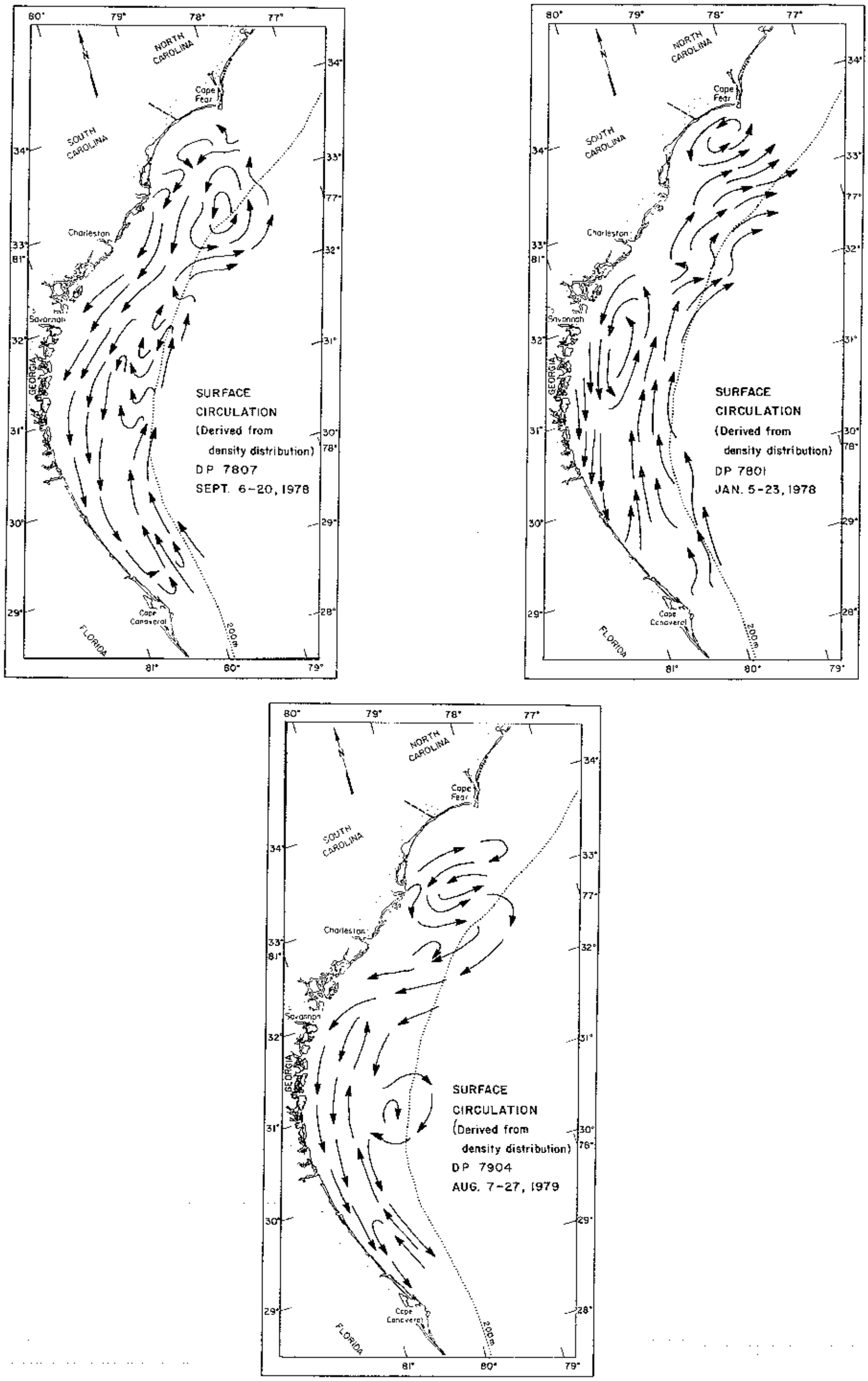

FIG. 9

Surface Circulation for Winter and Summer 1978 and Summer 1979.

Stream intrusion in Long Bay extending close to Cape Fear.

Summer 1978 salinities were generally high throughout the SAB, although not as high as during summer 1977. Surface and bottom salinities (summer 1978) were in good agreement near the coast as usual. The only low salinity water (< 35 ‰) recorded was off Charleston in a small nearshore area (Fig. 6). Bottom salinities were more zonal than corresponding surface salinities, with a band of > 36.25 ‰ water occupying most of the shelf from Cape Canaveral northward to about latitude 31°30'N. A Gulf Stream intrusion was indicated by high salinity surface (> 36.25 ‰) and bottom water (> 36.5 ‰) in the Long Bay area much like summer 1977 (Fig. 6).

Salinity 1979

Summer salinities during 1979 were like those recorded during the two preceding summers in several ways. Surface salinities were high (> 36 ‰) near Long Bay and Cape Canaveral, indicating Gulf Stream intrusions (Fig. 7). Bottom salinities were zonal with highest salinities (> 36.25 ‰) located in a mid-shelf band. Also the only low bottom salinities (< 35 ‰) were found near Savannah and at the shelf edge. Unlike 1977 and 1978 however, the 1979 surface salinities were low (< 34.5 ‰) in a rather large area near Charleston, indicating a spreading of runoff from South Carolina rivers (Fig. 7).

Surface Circulation

The general characteristics of circulation in the SAB have been summarized and discussed by Bumpus (1973), who observed that the southerly flowing coastal current is very transient, restricted to a narrow band along the coast, and secondary to a broad, slow, northerly drift along most of the continental shelf. The amount of river runoff, wind direction and force, and location of the Gulf Stream all have an effect on the circulation, especially the coastal current. Specific circulation features, such as upwelling and intrusions, have been examined by Brooks and Bane (1978), Pietrafesa et al. (1978), Legeckis (1979), Blanton et al. (1981), Janowitz and Pietrafesa (1982), and Smith (1983). Much of the preceding work was performed utilizing satellite imagery to detect large-scale features, while using hydrographic data from oceanographic cruises (as available) for confirmation. As a consequence, upwelling near Cape Canaveral and the Charleston bump have been identified and described in some detail. Shelf-edge intrusions were also detected at many locations by utilizing similar techniques.

Our studies in conjunction with many other similar programs have indicated that circulation below Cape Fear is roughly bimodal with discernible winter and summer patterns. Several features are usually found: a countercurrent of varying intensity (more continuous in the summer), a cyclonic eddy in Long Bay (generally larger in the summer), a large offshore deflection of the Gulf Stream in the area of the Charleston bump and consequent upwelling of deeper water downstream of the deflection, and upwelling to the north of Cape Canaveral. A relatively stable midshelf band of bottom water also exists, most evident during winter in terms of temperature and salinity and, to a lesser degree, during summer with respect to salinity. Due to shoals at Capes Lookout and Fear, circulation is divided into three unequal zones, i.e., Raleigh Bay, Onslow Bay, and south of Cape Fear to Cape Canaveral.

Surface circulation (based on density distribution) is shown in Figs. 8 and 9. The countercurrent can be seen in every season, but each year the summer countercurrent is continuous from Long Bay southward, while the winter countercurrent begins near Savannah or the lower portion of South Carolina. The extent of the countercurrent is related to the amount of runoff and often to the size of the cyclonic eddy in Long Bay. When the eddy is large, it tends to reinforce the general southwesterly drift of nearshore waters, typically during summer. On the other hand, when the eddy is small or displaced to the north or east (usually during winter), the countercurrent is much shorter, beginning as far south as Savannah.

Upwelling, occurring on a quasi-permanent basis at the Charleston bump and near Cape Canaveral, may be the result of bottom topography, downstream or lee eddies, or divergent isobaths (Janowitz and Pietrafesa 1982). Meanders of the Gulf Stream (as shown in Figs. 8 and 9) presumably increase the probability of upwelling or intrusions onto the shelf as discussed by Rooney et al. (1978) and Blanton et al. (1981).

While most of the features described above are to some extent evident in our results, considerable differences were observed in both winter and summer current patterns. Circulation during winter 1976, however, was basically normal without a Long Bay eddy and with a shortened countercurrent (Fig. 8). Winter 1977 had a well-established cyclonic eddy in Long Bay with three other cyclonic eddies at midshelf locations and a countercurrent from Long Bay to Cape Canaveral (Fig. 8). A small, but distinct, cyclonic eddy was also present in Long Bay during winter 1978, but the countercurrent was normal, beginning near Savannah in the vicinity of an elongated cyclonic eddy (Fig. 9).

Summer circulation was also somewhat modified, but not as much as that in winter. Summer 1976 had a continuous countercurrent from Cape Fear to northern Florida, where a cyclonic eddy formed the southern end of the current (Fig. 8). Long Bay had no well-defined cyclonic eddy, however, unlike the summers of 1977 and 1978, which were basically typical (Figs. 8 and 9). The currents during summer 1979 were considerably modified in that the Gulf Stream deflection at Charleston was far greater than usual, resulting in an offshore movement of the countercurrent and the spreading of warm, low salinity water off Charleston (Figs. 7 and 9). The countercurrent was, however, continuous from Long Bay down to Cape Canaveral.

In conclusion, the SAB circulation during the winters and summers of 1977 and 1978 appears to have been modified significantly by meteorological conditions. Much of what we observed in terms of eddies and Gulf Stream deflections has been categorized by Legeckis (1979), i.e., Gulf Stream deflection with cyclonic rotation, stable waves, and unstable waves. Undoubtedly upwelling near Cape Canaveral and other locations along the shelf can have a great effect on shelf-water oceanography and, in particular, the dynamics of the Charleston bump. When all of the various influences are compounded, e.g., during winter 1977, the effect on shelf-water oceanography can be quite profound and even devastating to some organisms.

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