Gulf Stream Trajectories Measured with Free-Drifting Buoys

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ABSTRACT

During 1975–78, 35 free-drifting buoys measured surface currents in the Gulf Stream region. The buoy trajectories trace numerous paths of the Stream and show that the Stream is strongly influenced by the New England Seamounts. This influence is manifested as 1) a quasi-permanent, 100 km, southeastward deflection of the Stream and the frequent occurrence of a ring meander over the seamounts; 2) large-amplitude meanders beginning at the seamounts and extending eastward; and 3) small, 20 km diameter eddies which appear to be generated locally by individual seamounts.

A chart of the mean temperature field at a depth of 450 m agrees with several of the patterns seen in the buoy trajectories. West of the seamounts, the mean path of the Gulf Stream is eastward; over the seamounts, the path turns sharply northeastward and the isotherms in the Stream abruptly diverge.

1. Introduction

Recently, the use of satellites to track free-drifting buoys has made it possible to measure surface currents remotely and rather inexpensively. During the last five years numerous satellite-tracked buoys were used to measure velocities and trajectories in the Gulf Stream system. These provide new information on the path of the Stream, especially its complicated structure near the New England Seamounts. Many buoys displayed a characteristic deflection as they passed over the seamounts; other buoys became trapped over the seamounts and made many loops there. The trajectories suggest that the seamounts strongly influence the mean path of the Gulf Stream and that the seamounts are an important source region of mesoscale eddy motion. The implication of these measurements is that the deeper flow, located at the level of the seamounts themselves, is even more strongly perturbed and may be partially blocked from passing through or over the seamounts.

2. The buoys

Most of the buoys were made by Polar Research Laboratory; they had a life of 9–12 months and carried a temperature and drogue sensor. Positions were determined by NASA from the Doppler-shifted radio signal received by the Nimbus F satellite. Typically, two good fixes per day were obtained for each buoy; the rms error of the fixes was estimated to be 1–2 km. Trajectories and velocity along trajectories were computed and plotted by fitting a cubic spline function through the measured positions and by interpolating two positions, velocity, and temperature values per day, evenly spaced in time.

Two types of drogues were commonly used. The first consisted of a 5 m section of 1 cm diameter chain attached to a 200 m section of 3.8 cm diameter polypropylene line (area 8 m^2) with a 25 kg weight attached to the end. The second consisted of the same tether with a window-shade drogue (25 m^2) attached to the bottom. The period of time that the drogues actually remained attached to the buoys is unknown. Tensiometers often failed on account of overloading in a "drogue-on" position after a few weeks at sea. It seems probable, based on the performance of buoys we retrieved and on data obtained from recent, more successful drogue sensors, that the drogues usually remained attached to the buoys for a few months and sometimes as long as seven months. Because of uncertainty in the buoy configuration, it is not clear whether the buoys were following currents in the upper 2 m (the depth of the hull) or in the upper 200 m. It is probably more correct to assume the former. A detailed description of the buoys, drogues and data is given by Richardson *et al.* (1979).

A comparison of buoy trajectories and wind patterns suggests that as long as the buoys were in swift currents (Gulf Stream, rings, intense eddies) the influence of the wind on the buoy's trajectory was small. However, as the buoys moved into regions of sluggish currents, especially after the drogues had fallen off and in windy conditions, the wind could have determined significant portions of the buoys' trajectories. McNally (1981) found no statistical difference between drogued (to 30 m) and undrogued

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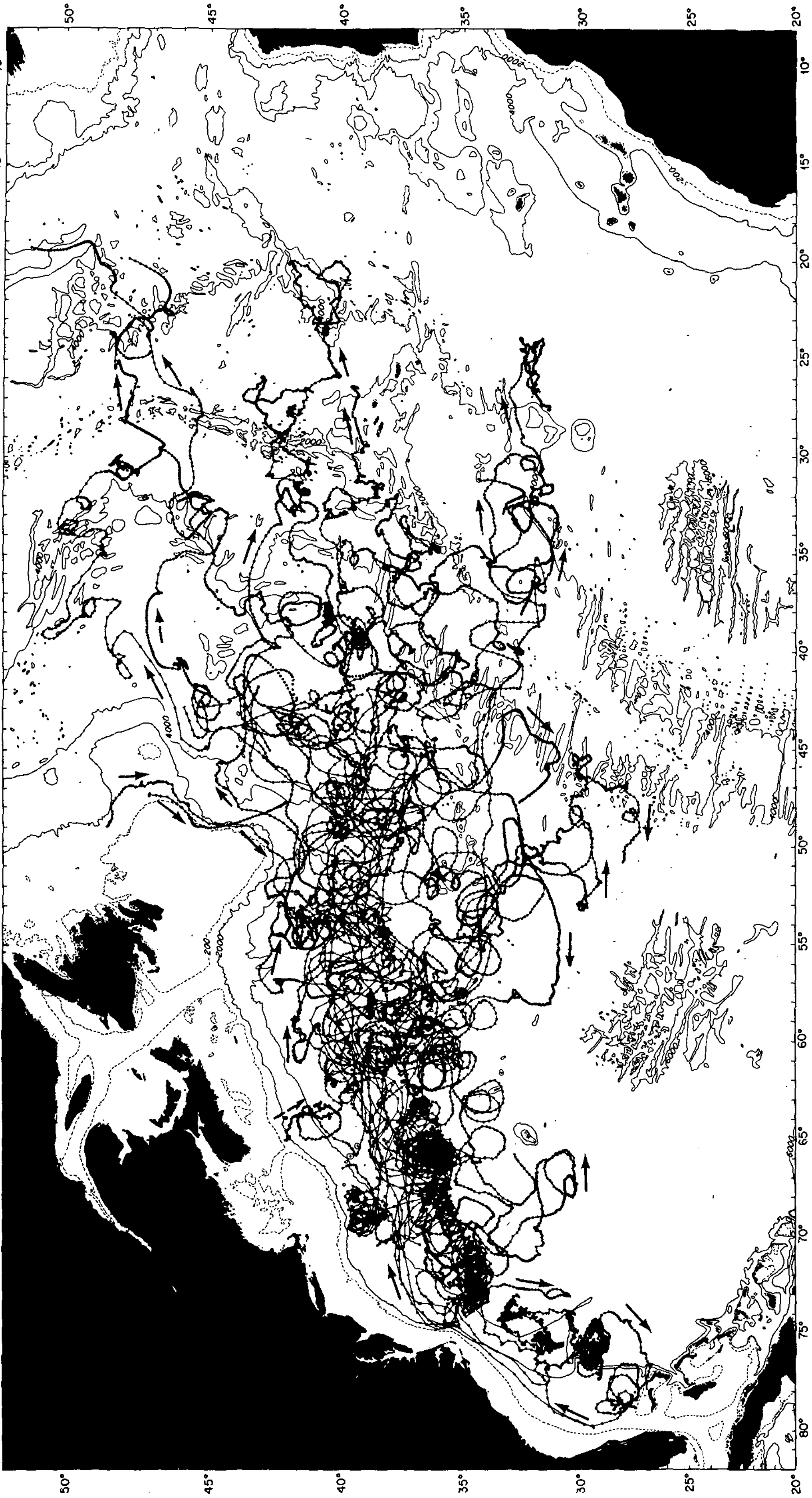

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FIG. 1a. Trajectories of 35 free-drifting buoys including seven buoys whose data were provided by E. Kerut, D. Kirwan, A. Leetmaa and R. Weir. Two positions per day evenly spaced in time are shown by dots. The bathymetry was taken from Uchupi (1971). Nineteen of the buoys were launched in Gulf Stream rings, seven buoys were launched in the Gulf Stream itself, and nine in other nearby areas.

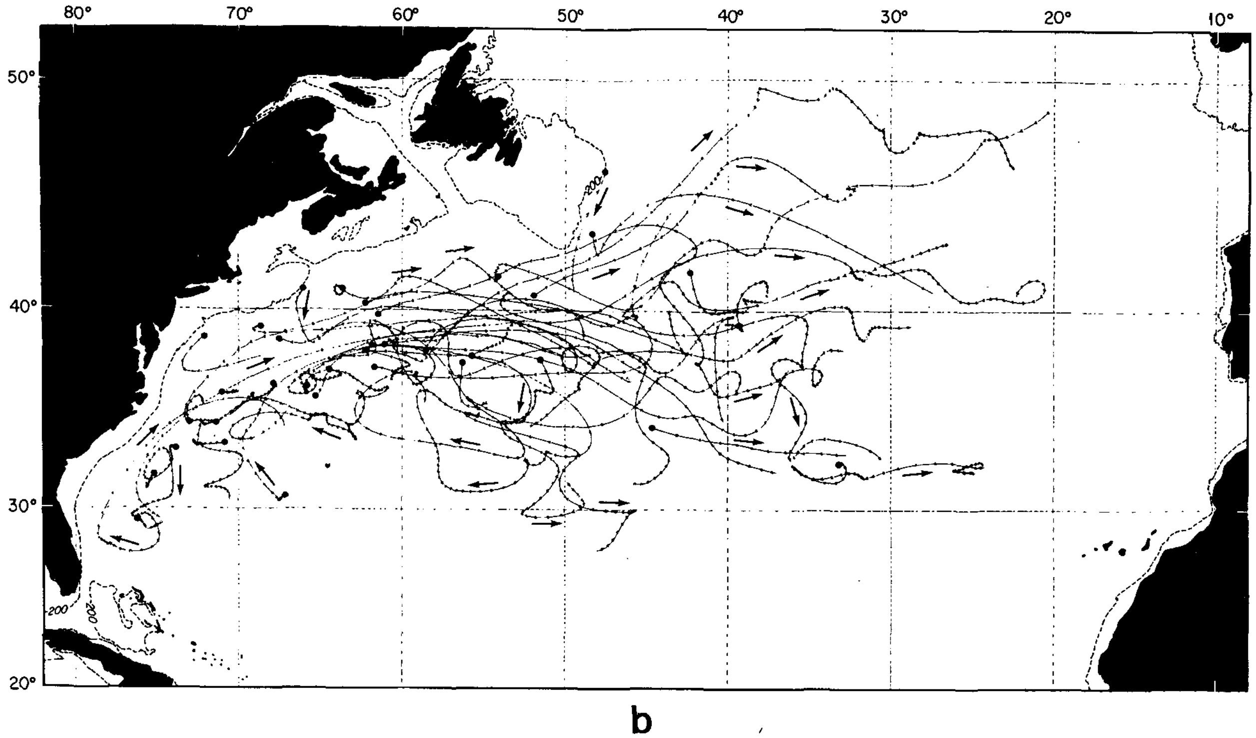

FIG. 1b. Buoy trajectories smoothed with a 40-day Gaussian filter to show large-scale motion. Large dots mark the beginning of trajectories, smaller dots are evenly spaced at 5-day intervals.

buoys in the northeastern Pacific, which suggests the slippage of his undrogued buoys was small compared to the wind-driven currents.

3. The trajectories

During the period July 1975–April 1978, 35 buoys were launched in the Gulf Stream region.[1] Nineteen of the buoys were launched in Gulf Stream rings; most of these were in cyclonic rings south of the Stream and were part of the Gulf Stream Ring Experiment. Frequently, rings coalesced with the Stream, either partially or completely, and the buoys were entrained into the Stream and drifted eastward. Seven buoys were launched in the Gulf Stream current itself and nine others in nearby areas; three in the slope water region, three in the Sargasso Sea, two in the Labrador Current, and one near the Mid-Atlantic Ridge.

Summary plots of all the trajectories (Figs. 1a and 1b) show the area covered by the buoy measurements and also some important characteristics of the currents. (A map of the mean temperature field of this region, which will be discussed later, is shown in Fig. 2.) The trajectories graphically show different flow regimes in features such as the Gulf Stream, rings, topographic and other mesoscale eddies and in different geographical areas such as the western and eastern basins of the North Atlantic. Many trajectories in rings can be seen between Bermuda and the Gulf Stream. Buoys in rings looped cyclonically with periods ranging from 1.5 to 10 days and translated with rings, generally but not always westward (Richardson, 1980a).

Two areas of the chart show conspicuous loops associated with seamounts. The first of these is along the New England Seamounts which extend from Georges Bank southeastward towards 34°N, 56°W. The second is over and southwestward of the Corner Rise Seamounts which are centered near 36°N, 52°W. A more complete description of the Corner Rise trajectories has been given by Richardson (1980b).

4. The Gulf Stream

a. General pattern

The Gulf Stream can be seen in the buoy trajectories as a band of swift, meandering current which sweeps north and east in a large arc from the Florida Straits to 38°N, 45°W (Figs. 1a and 1b). The trajectories indicate the Stream reaches its maximum

[1] Data from seven of these buoys were provided by E. Kerut (343, 373), D. Kirwan (357), A. Leetmaa (167, 1167) and R. Weir (177, 271). One of the Gulf Stream trajectories has been discussed by Kirwan *et al.* (1976).

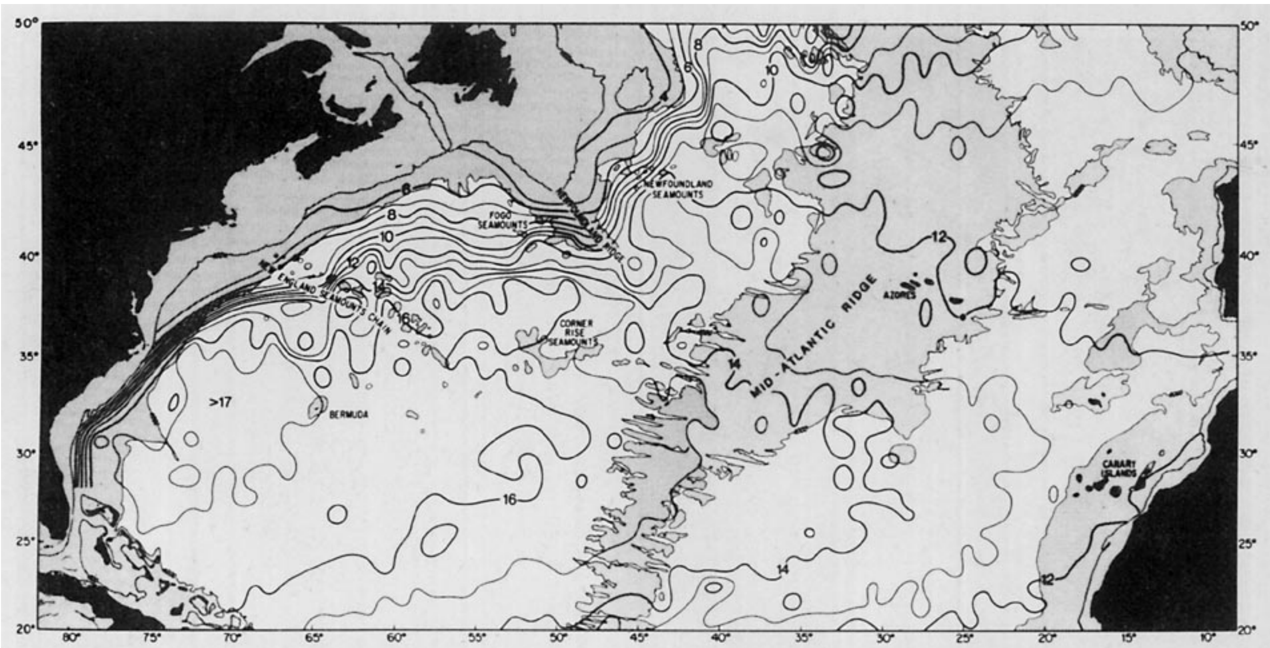

FIG. 2. Mean temperature distribution at a depth of 450 m based on 1° square averages of the NODC data. The strong-temperature-gradient region of the Gulf Stream (9–14°C) is deflected southeastward near the New England Seamounts. The isotherms approach the seamounts in an eastward direction between 37 and 38°N, curve cyclonically toward the northeast and pass over the seamounts. The northern isotherms (9–11°C) reach their northernmost point near 41°N, 58°W and then dip south again near 54°W. Eastward of the seamounts there is a marked spreading of isotherms, an indication of the large-amplitude meanders in this region.

latitude between 55 and 60°W; from there the Stream flows southeastward along the western side of the Newfoundland Ridge which extends southeastward from the Grand Banks. Reaching the area near 38°N, 45°W, the buoys fanned out in several different directions. Some buoys swung around the Newfoundland Ridge, turned northeastward, and moved across the Mid-Atlantic Ridge north of the Azores. A second group of buoys continued southeastward from the main current on the western side of the Newfoundland Ridge and crossed the Mid-Atlantic Ridge south of the Azores near latitude 33°N. The two areas in which the buoys moved eastward across the Mid-Atlantic Ridge coincide with two areas of high eddy potential energy density, part of a high-energy region extending eastward from the Gulf Stream (Dantzler, 1977). One of the buoys in the second, southern, branch meandered across the ridge with a relatively high speed, 50 cm s^{-1} against the wind; the trajectory looks similar to many of the trajectories in the Gulf Stream farther to the west. A third group of buoys moved southwestward on the south side of the Gulf Stream, an area of intense mesoscale activity.

West of 60°W, buoys located outside the Gulf Stream showed a strong tendency to be entrained into the Stream. This occurred for the buoys in rings as well as those in the slope-water region and Sargasso Sea. Once in the Stream the buoys usually moved rapidly eastward to the region south of the Grand Banks. One-third of the 12 buoys in the Stream that passed over the New England Seamounts looped there for various lengths of time. East of 60°W approximately half of the buoys in the Stream moved southward into the region of the Gulf Stream recirculation, and half continued eastward. A few of the buoys stopped their eastward drift as they approached the Mid-Atlantic Ridge, suggesting a possible blocking of the surface currents by the Ridge. It is interesting that none of the buoys moved into the slope-water region north of the Stream, or at least any buoys that did move into the slope water were rapidly entrained into the Gulf Stream again. Peak speeds in the Stream decreased from ~250 cm s^{-1} in the west to 50 cm s^{-1} in the east (Fig. 3). A quantitative analysis of surface currents is in progress.

b. The New England Seamounts

As the Gulf Stream flows eastward, it crosses over an impressive subsurface mountain chain, the New England Seamounts (Uchupi *et al.*, 1970). These seamounts extend from the continental shelf off Georges Bank near 40°N, 67°W southeastward to the Sohm Abyssal Plain near 34°N, 56°W; they rise 2–3 km above the depth of the nearby seafloor and occupy a large portion of the deep water region (Fig. 4). The deep water of the Stream must either be blocked by the seamounts or flow over or through

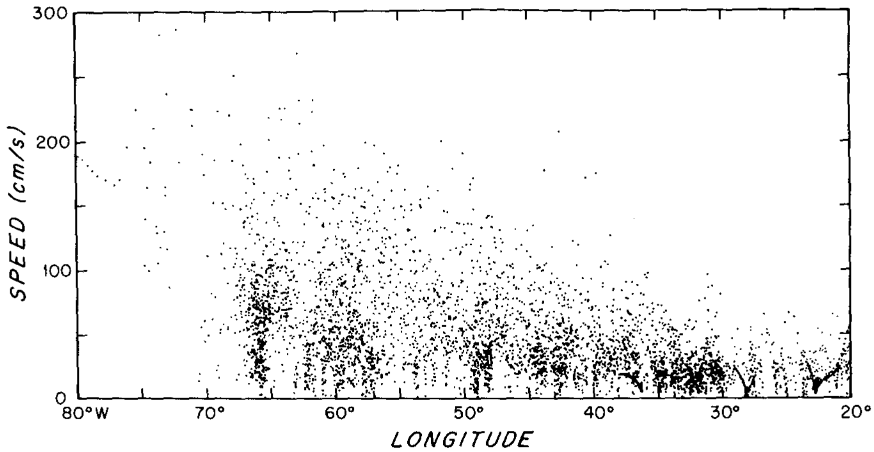

FIG. 3. Speed of 15 buoys in the Gulf Stream region showing a marked decrease in speed with distance eastward. The cluster of speed values near 66°W is from a buoy in a ring, and the cluster near 60°W occurs where many buoys looped near the New England Seamounts (see Fig. 8). The few anomalously high speeds (>250 cm s^{-1}) could have been caused by erroneous fixes.

them. Evidence from the drifting buoys suggests that the influence of the New England Seamounts extends quite strongly to the sea surface where the seamounts cause a deflection of the Gulf Stream and intense mesoscale eddies.

A particularly interesting buoy trajectory and one that clearly shows the eddies near the seamounts is given in Fig. 5. Buoy 1076 approached the seamounts from the west with a speed of ~125 cm s^{-1}, slowed to 5 cm s^{-1} as it made an anticyclonic meander over the top of Atlantis II Seamount, and then accelerated as it began to loop near the other seamounts with speeds of 50–80 cm s^{-1}. For four months, buoy 1076 looped near the seamounts; some of the loops were small, 20 km diameter; some were larger, 150 km diameter. The first large loop was cyclonic, the next three large loops were anticyclonic and had a mean period of 15 days. The next three were cyclonic, similar to cold-core ring trajectories, and had a period of six days. After

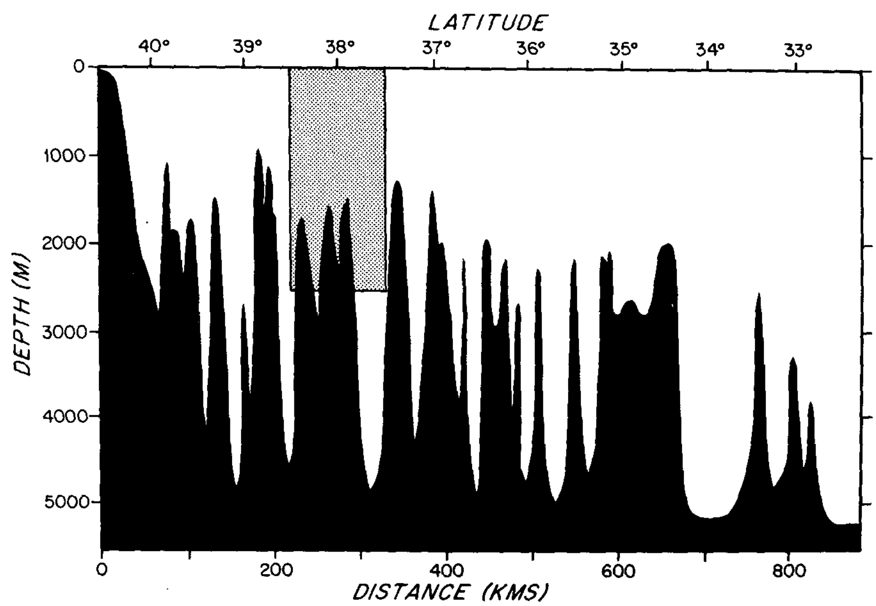

FIG. 4. A north–south section showing the projected depth profile along the New England Seamounts. The Gulf Stream is shown schematically by the stippled region, which is 110 km wide and 2.5 km deep. The seamounts extend from Georges Bank southeastward to the Sohm Abyssal Plain near 34°N, 56°W; thus this projection emphasizes the close spacing of seamounts.

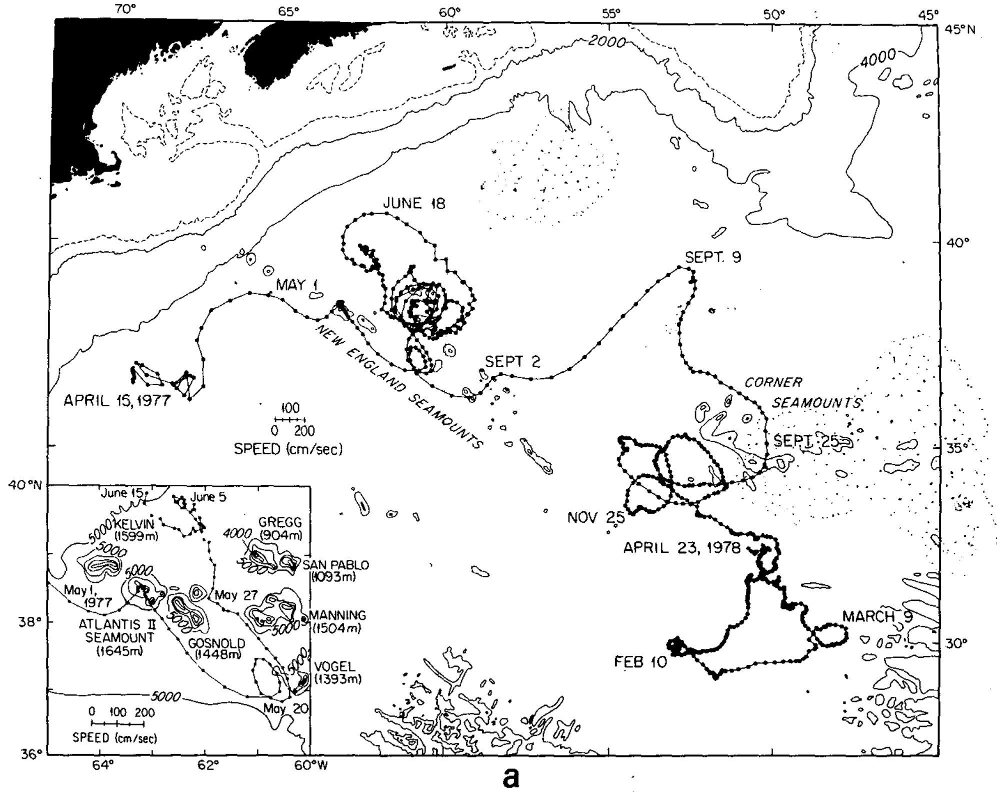

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FIG. 5a. Trajectory of buoy 1076, launched near the center of cyclonic Gulf stream ring Bob from 15 April 1977 to 23 April 1978. Two positions per day are shown by dots. This trajectory shows several different types of motion and clearly illustrates the important influence of seamounts on near-surface currents. During April 1977 buoy 1076 looped in ring Bob. At the end of April the buoy was entrained into the Gulf Stream as Bob partially coalesced with the Stream. From May to September, the buoy was trapped in strong eddy motion near the New England Seamounts. In September the buoy continued eastward in the Gulf Stream and from 25 September to 5 December looped in a warm core anticyclonic eddy formed near the Corner Rise Seamounts. During 1978 buoy 1076 drifted rather slowly and aimlessly near 30°N, 50°W. The inset shows the trajectory of buoy 1076 from 1 May to 15 June 1977, as it approached the seamounts in the Gulf Stream with a speed of 125 cm s^{-1}, slowed to 5 cm s^{-1} as it made a partial anticyclonic loop over the top of Atlantis II Seamount, and then accelerated again as it began its complicated looping motion near some of the other seamounts.

leaving the New England Seamounts, buoy 1076 drifted northeastward, then southward, and looped southwestward of the Corner Rise Seamounts. These loops consisted of small, 20 km diameter, anticyclonic loops superimposed on larger, 200 km diameter anticyclonic loops.

As buoy 1076 looped near the New England Seamounts, an unusually good satellite infrared image gave the path of the warm water in the surface Gulf Stream (Fig. 6). An interpretation of the image suggests that the Gulf Stream had formed a large, 350 km diameter, ring meander located partially over the seamounts, and another meander north of the seamounts. This image and many others (not included) show what appears to be a common feature, a ring meander which extends southward or southeastward near the seamounts. The structure is called a ring meander because it looks like a meander that is in the process of pinching off from the Stream to form a ring (Fuglister, 1972) yet the ring meander seems to remain as a quasi-permanent feature in this region. Whether the ring stays attached to the Stream for long periods of time or whether it repeatedly separates and reattaches is not clear. Several rings have been observed near the seamounts (Fuglister, 1972; Richardson, 1980a) but most of these rings seem to have coalesced with the ring meander; they also may have been formed from the same structure. Earlier observations of the ring meander over the seamounts have been given by Fuglister and Worthington (1951), Fuglister (1963), and Fuglister and Voorhis (1965).

Further evidence for the presence of the ring meander and of strong eddies near the seamounts is given by six buoys, including 1076 (Fig. 7). During the period January–August 1977 there was always at least one buoy looping cyclonically near the seamounts; frequently as one buoy left the ring meander

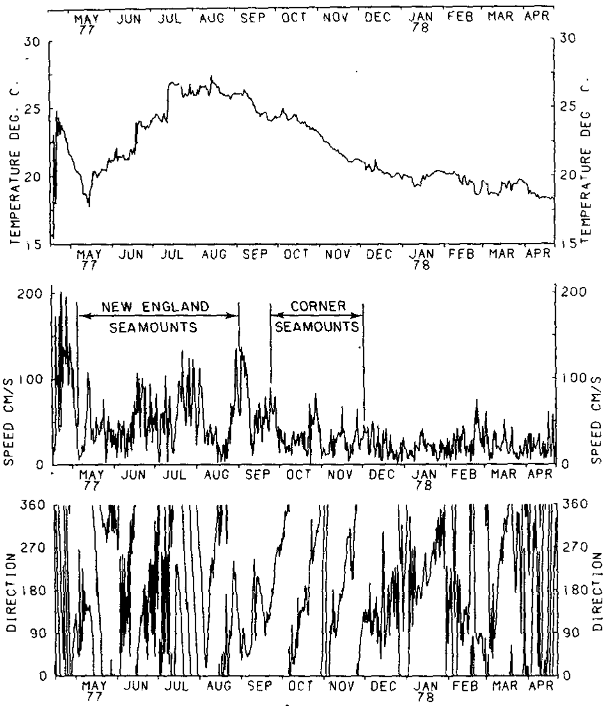

FIG. 5b. Time series for buoy 1076 of temperature, speed and direction.

and stopped looping, another buoy was entrained into the same feature and began to loop (373, 264, 1076). When the six trajectories are viewed together (Fig. 8) the seamounts stand out as a region (37°N, 60°W) in which the loops are concentrated. Most, though not all, of the loops are cyclonic and ringlike and they have the following typical characteristics: 3–8 day period, 40–150 km diameter, and 50–100 cm s^{-1} speeds.

The majority of the buoys in the Gulf Stream passed over the seamounts without looping in mesoscale eddies.[2] A possible explanation of why these buoys did not show a perceptible local seamount-scale deflection when others did is that they were located in the Stream where strong vertical shear insulated the high-speed surface flow from the weaker, deeper perturbed flow (Hogg, 1973). Although the exact trajectories differ, there does seem to be a similarity in their pattern (Fig. 9). The buoys approached the seamounts between 37 and 39°N, dipped slightly southward, shot northeastward over the seamounts, crested behind them near 59°W and dipped south again near 55°W. As they went over the seamounts, most buoys passed close and northwest of the shallowest of the seamounts, Gregg, which has a minimum depth of 904 m. Three of the buoys (252, 343, 1370) dropped southward near 59°W just after passing the seamounts; these buoys may have been in the northern part of the ring meander structure. East of the seamounts, the latitudinal spread of the trajectories, which extended from 37 to 42°N, is much greater than the spread

[2] One of these (1040) approached the seamounts at the same time as did two other buoys (215 and 1076), which looped near the seamounts. Buoy 1040 made a large gyre-scale loop, moving southward near 47°W, westward near 32°W, and then northward near 58°W. On reaching the seamounts for the second time, it looped for three months (Fig. 7) and then drifted eastward again.

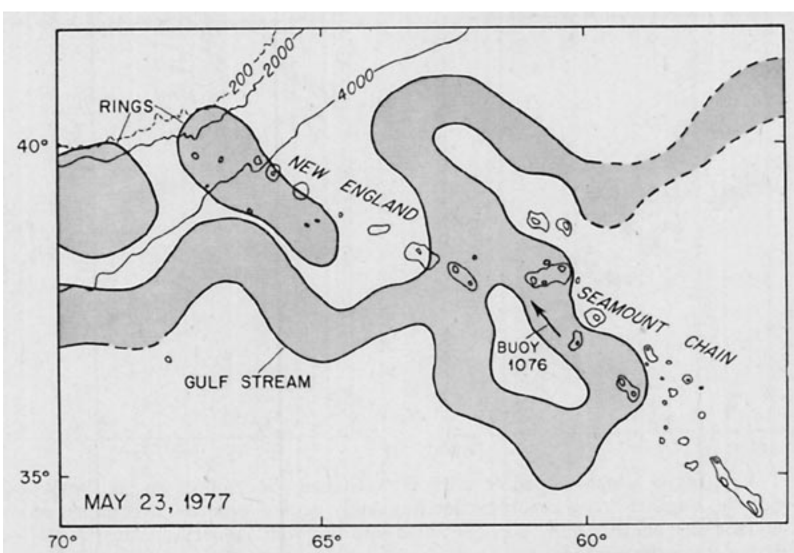

FIG. 6. Interpretation of a NOAA 5 satellite infrared image of the Gulf Stream region, 23 May 1977, as buoy 1076 (speed 45 cm s^{-1}) began looping near the New England Seamounts. The Gulf Stream formed a large, 350-km diameter ring meander partially overlying the seamounts and another meander north of the seamounts. The total north-south extent of the Gulf Stream near the seamounts is 700 km.

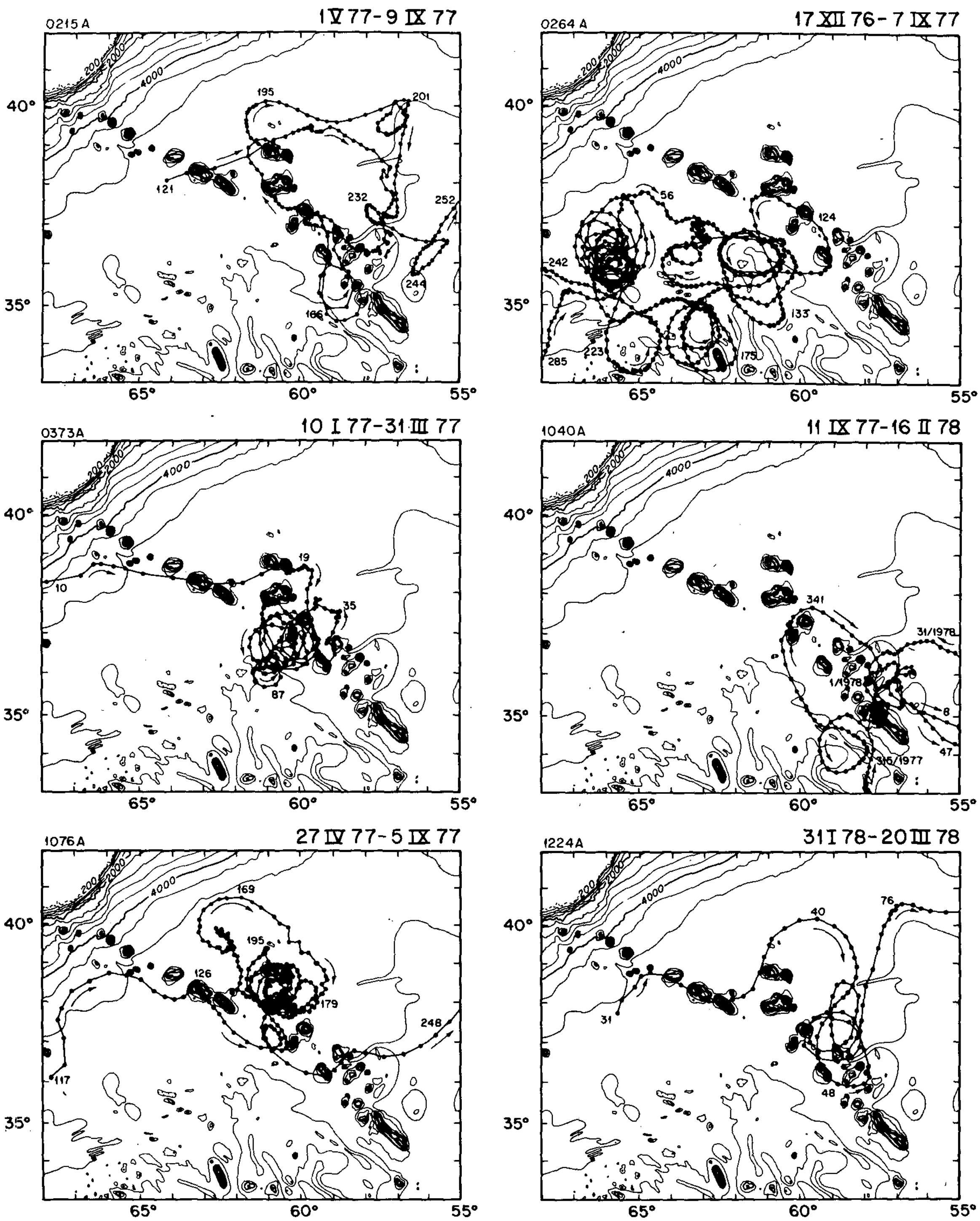

FIG. 7. Trajectories of six buoys which looped near the New England Seamounts during the period December 1976–March 1978. The trajectories suggest that a ring-meander frequently occurs near the seamounts; often as one buoy was detrained from the ring-meander another buoy was entrained into it. From January to August 1977 buoys 373, 364 and 1076 successively and almost continuously looped cyclonically in the same ring-meander structure.

west of the seamounts. The patterns observed in these trajectories add evidence to Fuglister's (1963) and Warren's (1963) suggestion that the Gulf Stream makes an abrupt turn to the north near 62°W and that this longitude marks a point at which the meander amplitude abruptly increases to the east.

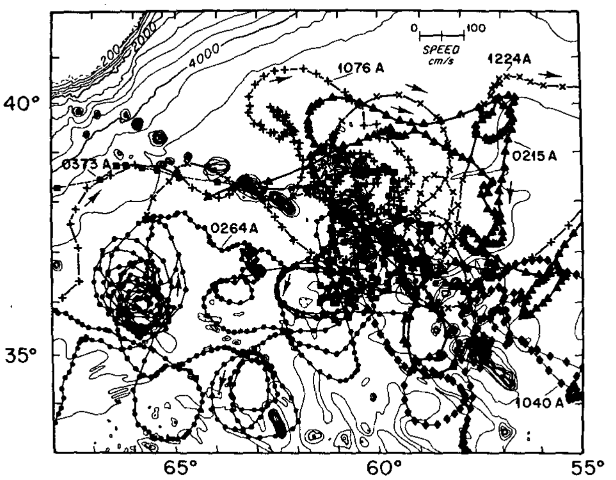

FIG. 8. Superposition of the six trajectories shown in Fig. 7. The New England Seamounts can be seen as an area of intense mesoscale eddies centered near 37°N, 60°W.

c. *Caryn Seamount*

There is evidence that individual, small seamounts can generate eddies in the surface flow. An example of this comes from buoy 1167, which became entrained into the Gulf Stream, moved eastward and passed 50 km north of Caryn Seamount (Fig. 10). This relatively small seamount rises from a background depth of 4800 m up to a peak near 2900 m. Just after passing the seamount, the buoy slowed and made two small anticyclonic loops (period 4 days, diameter 25 km) before speeding up again and continuing its eastward movement in the Gulf Stream. Perturbed flow near Caryn Seamount has also been observed by T. B. Sanford (personal communication) in velocity profiles; he found anticyclonic vorticity and strong inertial waves located over this seamount. Another example of anticyclonic loops in an otherwise relatively smooth trajectory is given by a buoy that moved eastward in the Kuroshio and spent nearly seven weeks looping in the lee of a seamount in the Emperor Seamount Chain (Cheney *et al.*, 1980).

5. Mean temperature at a depth of 450 m

The buoy trajectories show several features in common with the mean 450 m temperature distribution in the Gulf Stream system (Fig. 2). The temperature map was prepared by calculating the average temperature in each 1° square. There were typically 50 observations per square, mainly from 450 m expendable bathythermographs (XBT's).

The Gulf Stream is clearly seen in the west as a region of tightly packed isotherms. The central isotherms in the Stream, 9–14°C, remain closely

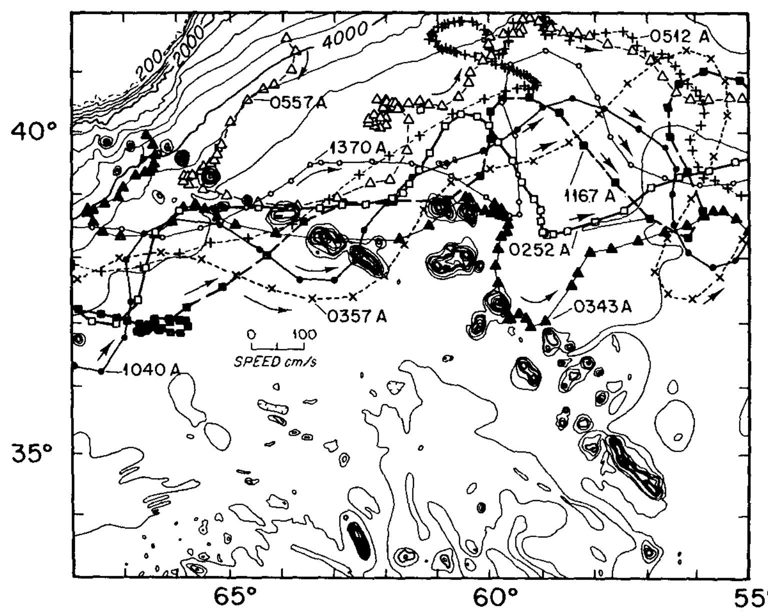

FIG. 9. Trajectories of eight buoys which passed over the New England Seamounts without being caught in strong eddy motion, during the period 30 July 1975 to 20 January 1978. Buoys 343 and 557 were located in the slope water region north of the Gulf Stream but were subsequently entrained into the Stream and moved eastward. These trajectories suggest that the Gulf Stream frequently approaches the seamounts in an eastward direction between 37 and 39°N; as it passes over the seamounts, the Stream meanders northward cresting near 59°W and then south again near 55°W. East of the seamounts the envelope of trajectories is much wider (530 km) than west of the seamounts (220 km).

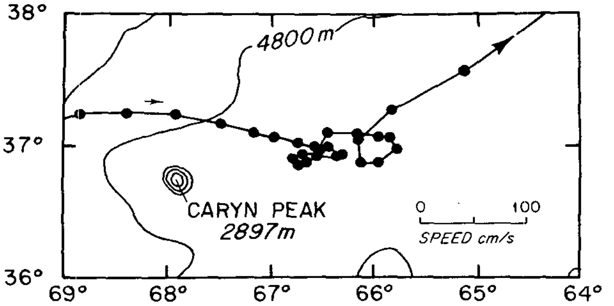

FIG. 10. Trajectory of buoy 1167 from 28 July to 10 August 1976, as it moved eastward in the Gulf Stream, passed north of the Caryn Seamount, slowed and made two clockwise loops. The loops had a characteristic period of rotation of four days, diameter of 25 km and speed of 25 cm s^{-1}. After the two loops, buoy 1167 accelerated and continued moving eastward in the Gulf Stream. The data for buoy 1167 were provided by A. Leetmaa.

spaced as they arc north and east toward the seamounts. In front of the seamounts the isotherms (10–14°C) run due eastward; they then make a small southward dip and then change direction to run northeastward over the seamounts much like the buoys (Fig. 9). The northern isotherms (9–10°C) crest near 58°W and then dip southward near 54°W in front of Fogo Seamount near 52°W.

The isotherm pattern indicates that the mean Gulf Stream is deflected ~100 km southeastward near the line of seamounts. In this case deflection means a shift in position and direction of the isotherms from smooth interpolated curves passing through this region connecting the Gulf Stream west of 70°W to the Stream east of 60°W. It seems probable that in the absence of the seamounts the Gulf Stream would run more nearly parallel to the path shown by the 8° isotherm. A similar deflection is seen on earlier maps of the mean temperature field at a depth of 200 m (Fuglister, 1954; Schroeder, 1963).

A significant spreading of the 9–14°C isotherms begins at the New England Seamounts. West of the seamounts, the width of the mean Gulf Stream (9–14°C) is ~100 km; east of the seamounts, the width increases to 350 km. This spreading is an indication of the large-amplitude meanders in this region.

The northern isotherms of the Gulf Stream, 9–11°C, merge with the 5–8°C isotherms to form a second tightly packed region near the Grand Banks. This is partly due to the southward and westward movement of cold Labrador Current water around the Banks. These isotherms pass around the Grand Banks and up to 50°N before peeling off in an eastward direction. Only two buoys followed the path of these northern isotherms. The majority of the buoys followed the path of southern isotherms (12–15°C), which continued eastward until they reached 38°N, 45°W where they rapidly diverged much like the local bottom topography. Near 34°N, 40°W the 13–15°C isotherms converge toward each other; in this area three buoys moved eastward, one quite rapidly. It should be noted that in this eastern area surface currents are significantly driven by the local wind and can differ from the geostrophic currents indicated by the temperature field.

South of the Gulf Stream is a wedge-shaped area of cold water which projects westward along 35°N from near 40°W to the New England Seamounts (57°W). The Gulf Stream recirculation flows southwestward along the north side of this wedge between 35 and 37°N. On the south side of the wedge is an eastward flowing current which extends across the Atlantic in the latitude band 30–35°W. The recirculation has been observed with current meters (Schmitz, 1980), ship drift data (U.S.N.O.O., 1978), hydrographic stations (Reid, 1978; Wunsch, 1978) as well as in numerical models of the general circulation (Holland and Lin, 1975; Semtner and Mintz, 1977). The 16°C isotherm in this cold wedge almost meets the smaller cold ridge overlying the seamounts, suggesting the presence of a partially closed gyre centered near 37°N 52°W that contains relatively high temperatures. Coinciding with this possible gyre, and perhaps another indication of it, is a bare spot on the map of buoy trajectories (Fig. 1). One buoy, 1040, made a large anticyclonic gyre-scale loop around this region.

Extending southward from the Gulf Stream along 65.5 and 73.5°W are two relatively cool areas. These are probably due to the large number of XBT's taken in Gulf Stream rings (Fuglister, 1972; 1977; Cheney and Richardson, 1976). Although rings are frequently found in these regions (Parker, 1971; Lai and Richardson, 1977) the calculated mean temperature is probably biased low by 1–2°C. The cold tongue (11–14°C) extending southeastward on the north side of the New England Seamounts is near the area in which many buoys looped in the ring-meander and in which three buoys (252, 343, 1370) meandered southward.

6. Discussion

The New England Seamounts seem to disrupt the Gulf Stream. This disruption is manifested as a large-scale southeastward deflection of the Stream over the seamounts and large meanders downstream of them. Frequently, the Stream forms a ring meander trapped over the seamounts. A possible explanation of the deflection of the Stream and the large-amplitude meanders is that the Gulf Stream feels the integrated effect of the seamounts as a topographic ridge extending southeastward from the continental shelf off Georges Bank. As the Gulf Stream encounters this ridge, the current is deflected to the right (the Stream tries to follow f/H contours). East of the ridge the Stream rebounds northward beginning a pattern of large meanders.

The pattern observed in the buoy trajectories and mean temperature field has much in common with a model of a broad, steady, inertial, eastward-flowing current impinging on a meridional ridge (McCartney, 1976); model streamlines are deflected southward over the ridge reaching a maximum deflection just east of the ridge crest. The streamlines then rebound to the north overshooting and oscillating about their original latitude and forming a stationary Rossby wake downstream of the seamounts. A difference between the model streamline pattern and the measured isotherm pattern is that the maximum isotherm deflection, the area of strong cyclonic curvature, is located just in front of the seamounts. However, this difference may be due to the complexity of the real ocean in comparison to the model. First, unlike the model, the Gulf Stream is a narrow jet exhibiting time-dependent meanders and interacting with a complicated configuration of individual and high seamounts. Second, the mean Gulf Stream approaches the seamount chain obliquely at an angle of about 50°, not perpendicularly. Third, the temperature map is an average of numerous Gulf Stream configurations including meanders and rings.

Individual seamounts also disrupted the Gulf Stream. Several buoys (215, 373, 1040, 1076, 1167) made small (seamount-scale) loops downstream from individual seamounts and one buoy, 1076, made a small anticyclonic meander directly over the Atlantis II Seamount. These loops and the meander suggest that individual seamounts generated eddies which at times extended to the ocean surface. Evidence of the deflections and distortions of isotherms near the Atlantis II Seamount, and the existence of warm and cold core eddies in its lee, has been given by Vastano and Warren (1976). The observed trajectories agree with predicted flow patterns in a two-layer model of flow impinging on a circular topographic bump (McCartney, 1975). An upper layer streamline pattern (McCartney, 1975, Fig. 7b) contains an anticyclonic meander over the bump almost identical to buoy 1076's trajectory over the Atlantis II Seamount. In the model the lower layer contains a Taylor column, a region of closed streamlines; the upper layer meander is the surface manifestation of the Taylor column. Downstream of the bump, McCartney (1975, 1976) shows a meandering wake region which, under certain conditions, has cyclonic and anticyclonic eddies embedded in it. One possible explanation for the small observed loops in buoy trajectories is that buoys passing near to seamounts occasionally become entrained into the wake eddies and loop there. A second possible explanation of the small observed loops is that the buoys had become entrained into eddies forced over or downstream of seamounts and had been advected away in the time-varying Gulf Stream current (Huppert and Bryan, 1976). Clusters of seamounts also may act together as broad topographic bumps and be responsible for the larger scale loops seen in the trajectories.

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