Gulf Stream Eddies: Recent Observations in the Western Sargasso Sea

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ABSTRACT

A cyclonic Gulf Stream eddy was observed in the western Sargasso Sea by satellite infrared measurements and later confirmed by ship measurements. Fourteen months of observations indicate that the eddy moved southwestward at an average rate of 1 mi day^{-1}. The evidence suggests that the eddy was absorbed by the Gulf Stream off Florida.

1. Introduction

Oceanographers have been interested in Gulf Stream eddies ever since they were first discovered about 35 years ago (Iselin, 1940). Although their formation has been well documented (Fuglister and Worthington, 1951), there is still much to be learned about their movement and life history.

Each cyclonic Gulf Stream eddy or Gulf Stream ring consists of a cold, less-saline mass of slope water surrounded by a ring of counter-clockwise flowing Gulf Stream water. They are formed from large Gulf Stream meanders which finally break off and become separated from the main Gulf Stream current. These eddies are believed to form between 60 and 70W just south of the Gulf Stream (Parker, 1971). They have been tracked in this region for as long as 8 months and found to move in a complicated manner with speeds up to 6 mi day^{-1} (Fuglister, 1971). The motion of the center of each eddy appears to consist of a clockwise translatory movement superimposed on a slower drift to the west. These observations indicate that eddies probably move southwestward into the western Sargasso Sea where they are thought to decay gradually.

Although the lifetime of cyclonic eddies is unknown, measurements made over a 4-month period indicate that they may have a projected life of 3–5 years (Barrett, 1971). Coupling this estimate with the further estimate that the number of eddies formed per year is approximately 5 (Newton, 1961; Barrett, 1971; Fuglister, 1971) indicates that perhaps 15–25 eddies exist at any one time. Since some eddies may be absorbed by the Gulf Stream (Parker, 1971), the above estimates of lifetime and number should probably be considered the upper limits.

2. Satellite and BT observations

This paper describes the longest series of measurements of a cyclonic eddy and the only series of an eddy in the western Sargasso Sea. These observations indicate 1) that the eddy moved from off Cape Hatteras, N. C., toward Florida with an average southwestward speed of one mile per day, 2) that it probably coalesced with the Gulf Stream off Florida, and 3) that it may have had a lifetime of about two years. Observations of three other eddies suggest that they, too, were moving southwest past Cape Hatteras, just offshore of the Gulf Stream. Based on these limited observations, at least two eddies per year move southwest in this area.

The Gulf Stream eddy was first observed by satellite infrared measurements in April 1971. On 12 April the NOAA-1 satellite viewed the eastern seaboard of the United States which was unusually cloud-free. The scanning radiometer (Rao *et al.*, 1971) provided thermal infrared imagery that revealed an intricate Gulf Stream structure (Fig. 1), including a large meander to the north of Cape Hatteras. An oval-shaped area containing cooler water was also seen southeast of Cape Hatteras and offshore of the Gulf Stream. This area was considered a possible Gulf Stream eddy. Surface temperatures in the eddy were near 16C, whereas the temperatures in the Gulf Stream to the west were running approximately 24C (Fig. 2). During the following two days additional NOAA-1 direct-readout infrared measurements showed virtually an identical thermal pattern, assuring that the phenomenon was not atmospheric. The cooler water area was observed by satellite several additional times in May and June. During this period the sea surface temperature anomaly inside the eddy slowly diminished.

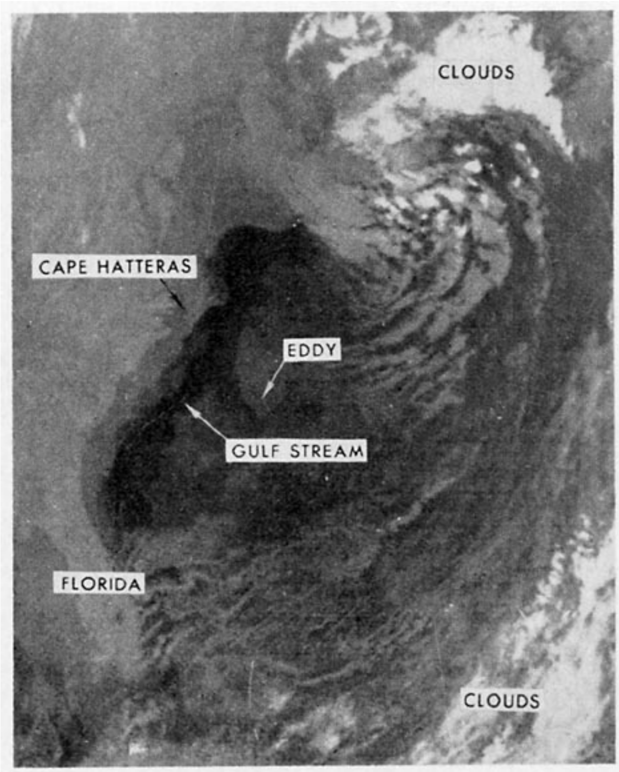

FIG. 1. Infrared image of the southeastern United States and Atlantic Ocean from the NOAA-1 satellite taken at about 0900 GMT 12 April 1971. Darker tones represent warmer areas viewed by NOAA-1 at 790 n mi. The large cold eddy is across the Gulf Stream from Cape Hatteras.

The existence of the eddy was confirmed by the University of Rhode Island's research vessel *Trident* in May 1971. The observations included a survey of the eddy by expendable bathythermographs, ship-drift measurements between fixes calculated by satellite navigator, geomagnetic electrokinetograph measurements, and a hydrographic section (Fig. 3) which consisted of 11 surface-to-bottom hydro stations through the Gulf Stream and to the center of the eddy. The eddy was characterized by 1) surface temperatures of 19C, 3C lower than normally found in this location and time (U. S. Naval Oceanographic Office, 1969); 2) a cold core that was nearly 8C lower at 500 m than temperatures outside the eddy and that extended to at least 3000 m; 3) low salinity in the upper part of the core; and 4) a cyclonic surface circulation of $\sim$100 cm sec^{-1} (2 kt). The diameter of the eddy based on the limits of the 15C isotherm at 500 m was approximately 150 km. Using rising isotherms as a criteron of eddy size will approximately double this value (see Fig. 3).

The eddy was tracked by bathythermographs (BT's) taken from several ships and by BT's obtained from the Navy Fleet Weather Central. The eddy was clearly located in May and October, 1971, and January, February and April, 1972, by BT searches. The four most detailed surveys of the eddy (May, October, January, April) indicated a gradual decrease in size (area enclosed by 15C at 500 m) and deepening of the thermocline in the eddy. These observations are con-

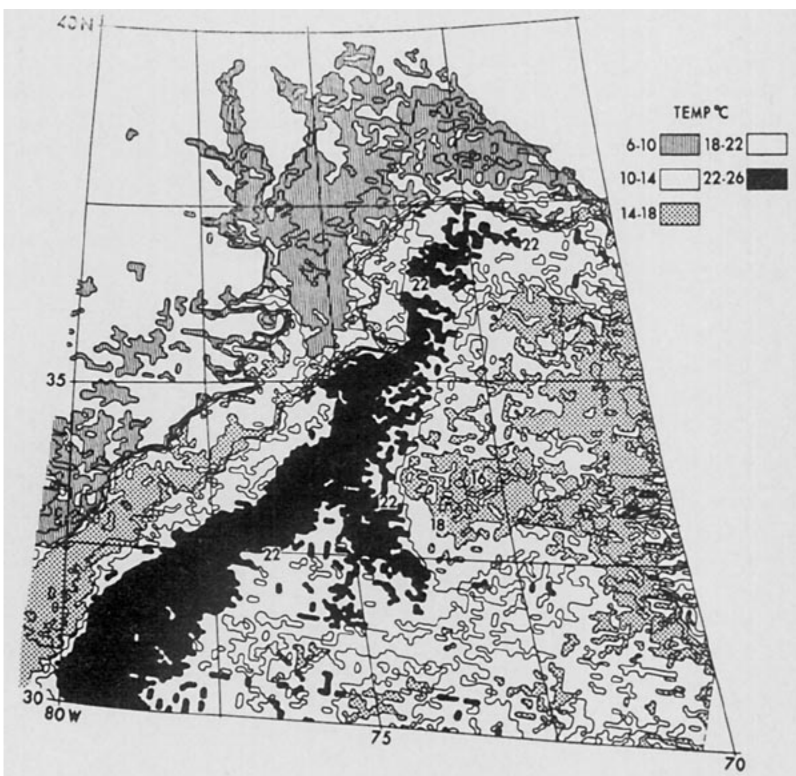

FIG. 2. Surface temperature analysis (°C) of a portion of Fig. 1. The center of the eddy is at the "16" located at approximately 33.5N, 73.0W.

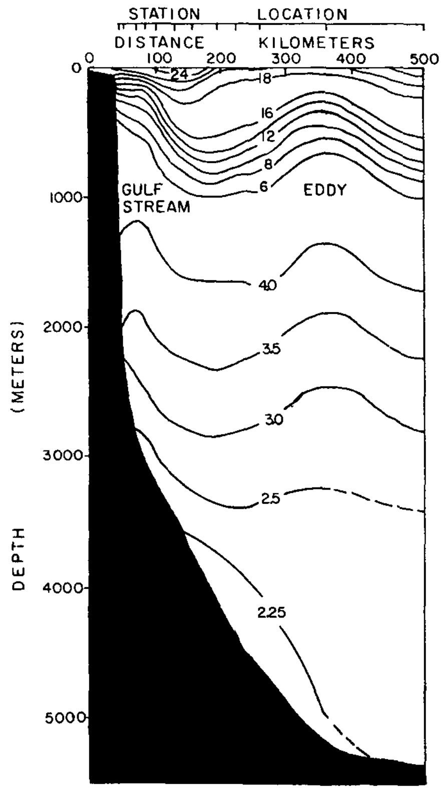

FIG. 3. Temperature section (°C) through the Gulf Stream and eddy southeast of Cape Hatteras, N. C., in May 1971. The isotherms slope down to the right through the Gulf Stream and rise in the cold core of the eddy. The cold core is apparent down to at least 3000 m. The data are from *Trident* cruise 98, hydrographic stations 2–12. The farthest offshore station was an STD station taken by the Coast Guard to a depth of 3000 m (13 May 1971).

sistent with the conclusion that the measurements were made on the same eddy and that it was slowly decaying. In addition there are BT's in March, July, August and December, 1971, that confirm its motion. An exhaustive search of all BT's taken in the area during the series of observations did not identify any other cold-water feature. A summary of the observations is listed on Table 1 and shown on Fig. 4. The measurements from March 1971 through April 1972 indicate that the eddy moved southwestward with an average speed of about 1 mi day^{-1}.

A thorough search was made of the area east of Florida and north of the Bahamas by BT at the end of April 1972, but no water colder than 15C at 500 m was found. There was, however, an area 30 km to the northwest of the 8 April position where temperatures down to 15.5C were recorded. On the basis of this information we suggest that the most reasonable possibilities of what occurred are the following: 1) the eddy continued on its course until it coalesced with the Gulf Stream; 2) the temperature anomaly of its cold core and/or its size decreased rapidly and the eddy moved toward the northwest; 3) the eddy's course and speed changed dramatically and it moved out of the searched areas. The first two possibilities seem the most likely on the basis of the previous movement of the eddy. We suggest that the eddy was eventually absorbed by the Gulf Stream.

3. Possible previous history of the eddy

To reveal the history of the eddy before May 1971 we have searched the data held by the National Oceanographic Data Center and the Navy Fleet Weather Central. When the motion from May 1971 to April 1972 is projected back in time, the date and position match remarkably well (within 40 mi) with an eddy observed forming in June 1970 by the Navy (U. S. Naval Oceanographic Office, 1970a). Measurements in July 1970 indicated that this eddy was also moving southwestward, although the speed from June to July of about 3 mi day^{-1} is considerably higher than the later average value of 1 mi day^{-1}. There is no way

TABLE 1. Observations of the eddy.

Date	Ship	Operating agency*	Observations**
1971			
Mar. 23	(Classified)	NFWC	6 XBT's
Apr. 12–14	(NOAA-1)	NOAA	satellite infrared data
May 12	(NOAA-1)	NOAA	satellite infrared data
May 9–11, 17–18	*Trident*	URI	65 XBT's, 3 hydrostations, GEK, ship drift
May 12	Dallas	Coast Guard	1 STD station
Jun. 1	(NOAA-1)	NOAA	satellite infrared data
Jul. 16, 23	(Classified)	NFWC	2 XBT's
Aug. 3, 22	(Classified)	NFWC	2 XBT's
Oct. 21–24	*Trident*	URI	28 XBT's, ship drift, 4 STD stations
Dec. 10	*Kane*	NAVOCEANO	3 XBT's
1972			
Jan. 8	*Wilkes*	NAVOCEANO	10 XBT's
Jan. 19	*Evergreen*	Coast Guard	2 XBT's
Feb. 29	*Mizar*	NRL	7 XBT's
Apr. 8–9	*Researcher*	NOAA	22 XBT's
Apr. 23–27	*Kane, Wilkes*	NAVOCEANO	searched for eddy, took approximately 100 XBT's, but could not find it
1970†			
Jun. 8	*Franconia*	NAVOCEANO	11 XBT's
Jul. 7	*Knorr*	WHOI	3 BT's
Jul. 18	*Rockaway*	Coast Guard	2 STD stations

* NAVOCEANO—Naval Oceanographic Office. WHOI—Woods Hole Oceanographic Institution. NFWC—Navy Fleet Weather Central. NOAA—National Oceanic & Atmospheric Administration. URI—University of Rhode Island. NRL—Naval Research Laboratory.

** XBT—Expendable bathythermograph. STD—Salinity-temperature-depth. GEK—Geomagnetic Electrokinetograph.

† Possible earlier observations of the same eddy.

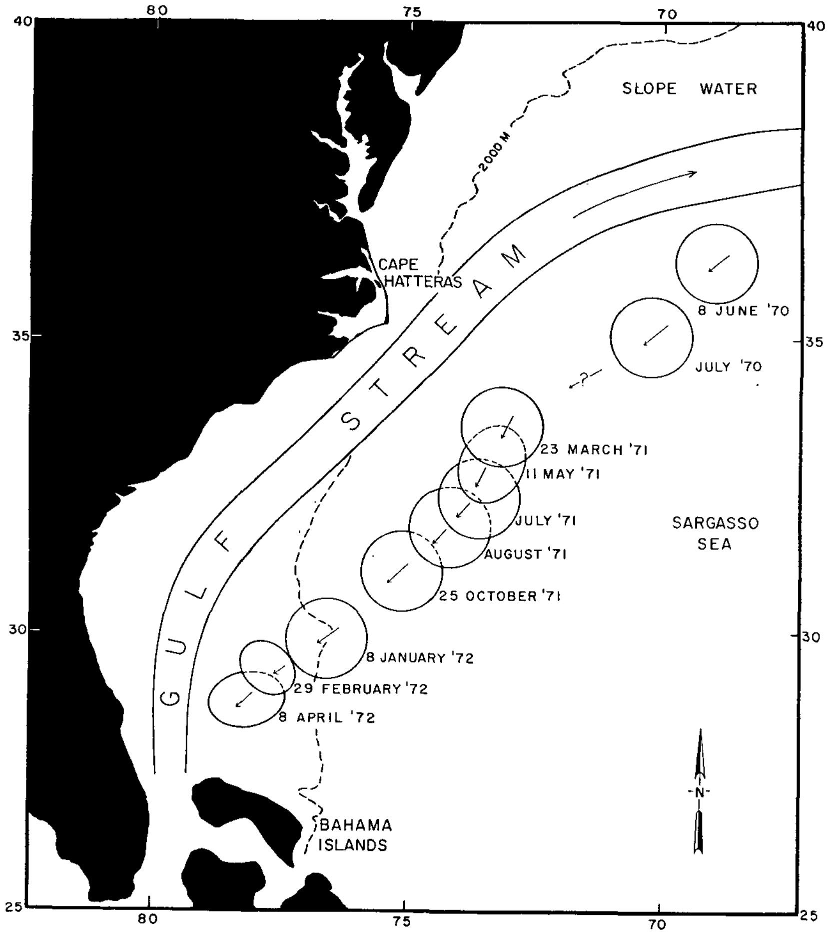

FIG. 4. The movement of the eddy. Within the limits shown the water is colder than 15C at a depth of 500 m. Near the center of the eddy, temperatures dropped to about 9C at this depth; while outside the eddy, temperatures of about 17C are usually found in this region offshore of the Gulf Stream. The position of the eddy in December 1971 was not obvious from the limited data and therefore the location was not plotted. Cold water was observed, however, indicating that the eddy was located somewhere between the October and January positions.

to prove as yet that this is the same eddy except that the size and temperature structure of the two eddies are consistent, that they are moving in the same direction, and that the extrapolated position based on a speed of 1 mi day^{-1} is nearly correct. In October 1970 another eddy was observed (U. S. Naval Oceanographic Office, 1970b) near the location of the eddy in June 1970. If the average speed of eddies is higher in this northern region, then it is possible that the October observation represents an earlier visit to the same eddy tracked in this study.

Observations of several other eddies in the western Sargasso Sea suggest that this eddy is not unique in its movement. In February 1972 a second cyclonic eddy was observed off Cape Hatteras within 20 mi of where the first was located in May 1971. Indications of a third eddy were found off Cape Hatteras in June 1972 and a fourth in August 1972 (U. S. Naval Oceanographic Office, *The Gulf Stream*, in preparation). Additional measurements indicate these are moving southwestward at approximately 1–2 mi day^{-1}. These additional observations, taken in conjunction with other reported observations in the past (Parker, 1971), suggest that perhaps the southwest movement of Gulf Stream eddies just offshore of the Gulf Stream is a common phenomenon with two eddies per year following this path.

Such a movement of eddies may represent a mechanism by which slope water is carried south to combine with the Gulf Stream at lower latitudes and Gulf Stream water is recirculated to the south. The Gulf Stream increases in volume transport downstream from the Straits of Florida to at least 65W (Knauss, 1969). Part of the large transport downstream from Cape Hatteras could be recirculated back toward the southwest by Gulf Stream eddies. For example, the volume transport associated with the movement of two eddies per year, each one 300 km in diameter and 3000 m deep, is 14×10^6 m^3 sec^{-1}. This is equivalent to about 40% of the transport of the Gulf Stream off Miami and about 50% of the increase of transport added to the Gulf Stream between Miami and Cape Hatteras. Of course, not all of the above transport necessarily recombines with the Gulf Stream. For example, the Gulf Stream off Florida is limited by bottom topography to depths less than 1000 m; thus, only the top 1000 m of an eddy could coalesce with the Gulf Stream.

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