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Tracking a Gulf Stream Eddy

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Eddies that reach a diameter of nearly 200 miles are spawned within the Gulf Stream, and may be a significant factor in ocean circulation. In the last few years, studies at the Woods Hole Oceanographic Institution have revealed that these Gulf Stream eddies may have a very long lifetime (estimated to be three to five years) and may be found over a wide area of the western Sargasso Sea. Yet no one has followed a cyclonic Gulf Stream eddy for the duration of its existence, so no one really knows where they go or how long they last. In my work, I am attempting to follow an eddy in order to learn more about its movement and decay rate.

The Gulf Stream flows north from the Straits of Florida to Cape Hatteras and then toward the east. It is a relatively narrow band of high-velocity water with a width of about 75 miles and peak speeds of four to six miles per hour. One of the most interesting features of the Gulf Stream is the way it exhibits horizontal wave motion or meanders. South of Hatteras these meanders are fairly small, but north of Hatteras they become very large with wavelengths of about 200 miles and widths of about 200 miles.

A particularly interesting aspect of this meander phenomenon is the way some meanders increase in amplitude, form a loop, and then finally pinch off from the Gulf Stream to form eddies. The process is similar to the phenomena occurring when river meanders pinch off to form oxbow lakes. Eddies formed south of the Gulf Stream are called cyclonic or cold-core eddies or, sometimes, Gulf Stream rings. They consist of a ring of Gulf Stream water flowing counterclockwise around a cold, less saline, mass of water which was originally between the continental slope and the Gulf Stream. Each eddy has an overall diameter of about 200 miles and an area 25 times the size of Rhode Island. Once detached from the stream, eddies can move about as separate entities.

One of the difficulties in studying eddies is their transient behavior. First, one is never sure where or when an eddy is going to form. Once formed, they may move as fast as five miles a day in a complicated manner. Tracking an eddy requires a great deal of ship time and some luck. Another difficulty is the gradual loss of the initial surface temperature characteristics of an eddy. As the eddy decays the temperature difference between the core and the ring decreases and this occurs first near the surface. Deep measurements become imperative to "see" an eddy.

We are presently tracking an eddy in the western Sargasso Sea. The eddy was first "seen" by the infrared measurements of a NOAA environmental satellite in April 1971. In May 1971 we confirmed its existence and surveyed it aboard the R/V *Trident*. It was characterized by temperatures up to 8° C colder than outside the eddy and counterclockwise surface speeds slightly over two miles per hour. Since May it has been clearly located in October, January, February, and April. There are additional measurements in March, July, August and December that confirm the movement shown in the figure. These observations are unique in that they are the longest continuous observations of any cyclonic eddy and the only continuous observations of an eddy in the western Sargasso Sea.

The measurements from March 1971 through April 1972 indicate that the eddy has moved southwest with a very uniform average velocity of about one mile per day. A projection of the course and speed suggest that it may be absorbed by the Gulf Stream by June or July of 1972. When the motion is projected back in time, the date

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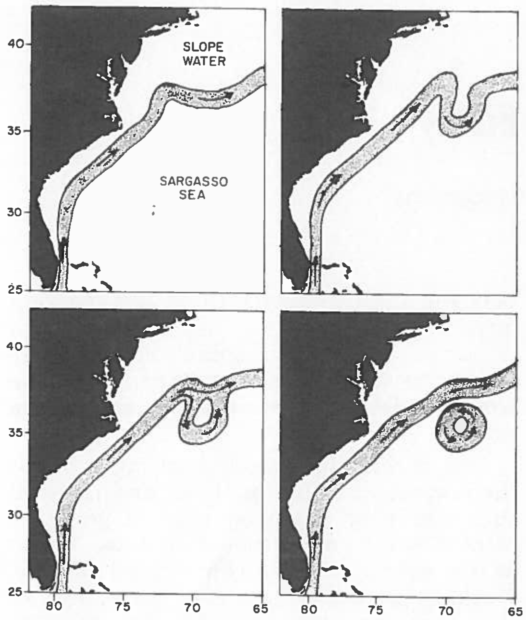
At left: The movement of the eddy, indicating the dates when its position was recorded. The dotted lines show the limits of the area where water at a depth of 500 meters is colder than 15° centigrade.



The formation of an eddy based on measurements made in May and June 1970 by the U.S. Naval Oceanographic Office.

and position match remarkably well with an eddy observed forming in June 1970 by the Naval Oceanographic Office. There is no way to prove as yet that this is the same eddy, although the size and temperature structure of the observed eddy are consistent with the June 1970 one and the extrapolated position is correct.

In addition to this eddy, another one has been tracked for four months. It was discovered in January 1972 and is apparently following the same path as the first eddy. In February it was only 20 miles from the position where the first eddy was in May 1971. Perhaps this movement southwest past Cape Hatteras is a fairly routine event.

The purpose of this study is to try to establish the relative importance of Gulf Stream eddies to the large-scale ocean circulation. While eddies are known to be an important transport mechanism in the atmosphere, their role in the ocean is not understood. Calculations suggest that Gulf Stream eddies may represent an important transport mechanism in the sea. For example, if one eddy per year, 200 miles in diameter, extending to a depth of 3,000 meters, moves southwest past Cape Hatteras, the volume transport of water associated with this eddy is eight million cubic meters per second. If five eddies move south each year the transport associated with them is greater than the transport of the Gulf Stream through the Straits of Florida. The transport of eddies may be a significant contribution to the circulation of the North Atlantic and to the inflow to the Gulf Stream.

There are several interesting problems concerning Gulf Stream eddies. One is that the depth to which eddies extend is not known, nor whether the entire water column under an eddy moves with it as a unit. It is generally accepted, however, that the Gulf Stream does extend to the sea floor in the region where eddies form. Thus it seems probable that they extend to the bottom when they first form. Hydrographic measurements in the eddy in May 1971 suggest that it extended to at least a depth of 3,000 meters. Another problem is whether eddies propel themselves or are carried by the regional flow. We plan to investigate these questions in the near future.

Algae Form a Nursery for Winter Flounder

Successful hatching of winter flounder in Rhode Island estuaries appears to be closely related to the growth of certain simple plant forms called diatoms. This complex relationship was reported by fishery biologists Connie R. Arnold and Carolyn Rogers at the National Marine Fisheries Service Laboratory on Narragansett Bay.

Winter flounder spawn from January through April in Rhode Island estuaries with a peak spawning period in late February. The male and female swim in a large circle, release their spawn into the water column, and the sticky eggs then sink to the bottom.

Scuba divers from the laboratory conducted weekly inspections of the spawning grounds in Pettaquamscutt River and Bissel Cove, two Narragansett Bay estuaries. The divers, in addition to project leader Arnold, were Alphonse S. Smigielski, Thomas A. Halavik, and H. Wes Pratt.

They found winter flounder eggs only among the filaments of certain diatoms, types of algae that form extensive mats on the bottom of the estuary. Most abundant of these algae is *Melosira nummeloides* with lesser amounts of *Melosira juergensi* and *Amphipleura rutilous.*

Under the microscope these diatoms revealed large numbers of eggs, but there were no eggs in the adjacent sandy or muddy areas where diatoms did not occur. Three other plant species occurred in the same area — eelgrass *(Zostera marina)* and the algae *Ulva lactuca* or sea lettuce and *Enteromorpha intestinalis,* but none contained winter flounder eggs.

The three diatoms found associated with the flounder eggs occur from mid-November to May, which more than encompasses the spawning period of the winter flounder. Furthermore, the geographical range of the *Amphipleura rutilous* and *Melosira nummeloides* coincides closely with that of the winter flounder, from Chesapeake Bay to the north shore of the Gulf of St. Lawrence. Scientific literature gives no evidence of *Melo-*

Divers examine the diatom complex for winter flounder eggs. Below: algae as it grows on the bottom of the Pettaquamscutt River. Quarter indicates relative size of plant.

sira juergensi north of Cape Cod Bay in the western Atlantic. But since all these diatoms are commonly found in complex association, it is probable that other species form a similar type of mat farther north, and may serve the same nursery function for flounder eggs.

Before Smigielski and Arnold developed a successful technique for separating and incubating winter flounder eggs, scientists at the Narragansett laboratory found that eggs clumped together about two minutes after fertilization. Those in the inner part of the clump died, probably from a lack of oxygen, and then decomposed resulting in the loss of most of the remaining eggs.

Arnold and Rogers find it reasonable to conclude that in the natural environment, clumping and subsequent death of the flounder eggs is prevented by the diatom environment. After the spawning fish release their eggs and sperm, the individual eggs are spread by the prevailing currents across the widespread mats of algae. The sticky eggs then adhere to the diatom filaments where they are held in place off the bottom, prevented from clumping, and exposed to well-oxygenated flowing water. In short the algae provide a suitable and hospitable hatching environment.