Small Eddies Proliferating in the Atlantic

The smallest eddies yet found appear to be carrying batches of water hundreds and perhaps thousands of kilometers across the ocean

Ocean eddies, those slow swirls of water found in recent years to be common features in the sea, have always come in a variety of sizes. In the North Atlantic the typical eddy is about 200 kilometers in diameter, although some have been as small as 150 kilometers. Now, physical oceanographers are finding eddies less than 100 kilometers and as little as 20 kilometers wide. The experience is somewhat analogous to the discovery by meteorologists of the existence of local storms only after years of plotting the broad highs and lows of the national weather map. Small eddies, like some of their larger brothers, are particularly interesting because their whirling motion protects the seawater within them, together with its heat, salt, and other dissolved material, from being lost as the eddies travel perhaps thousands of kilometers.

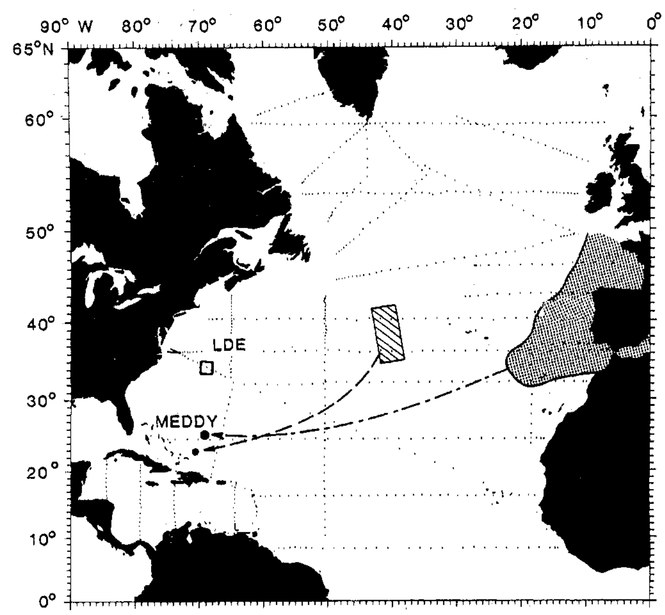
Oceanographers found the first of the smallest eddies in 1978 at the beginning of the Local Dynamics Experiment (LDE), a purely American phase of the joint U.S.-U.S.S.R. POLYMODE program in physical oceanography (*Science*, 10 August 1979, p. 571). American and Soviet scientists heard new details about the LDE eddies at a recent POLYMODE meeting.* American oceanographers had carefully designed a grid of observation sites, spaced only 25 kilometers apart, to monitor the ocean southwest of Bermuda in the Sargasso Sea. Preliminary processing of the data by a shipboard computer revealed that, much to everyone's surprise, the observation network had snared a tiny eddy, one so small that it might have been missed between sites.

New, more closely spaced instrument lowerings provided a good picture of the eddy. Brady Elliot of the University of Washington reported at the meeting that it was circular, 20 kilometers wide, and rotated clockwise with currents of up to 1 kilometer per hour. The 2000-meter-thick, pancake-shaped eddy, dubbed eddy D1 for "deep number 1," was buried 1000 meters beneath the surface. In addition to its motion, this eddy stood out because of its physical properties. Its water had a salinity 0.05 part per thousand lower than that of its surroundings, and its temperature differed by 0.27°C. These differences might appear negligible, but physical oceanography is a science of subtle differences. The salinity of almost half of the Pacific Ocean, for example, ranges between 34.6 and 34.7 parts per thousand, yet such differences help drive many of the ocean's currents.

Other small eddies having distinctive water characteristics soon turned up in the LDE area. Unlike the thick eddy D1, which lay entirely below the boundary between warm surface and cold deep waters (the permanent thermocline), eddy S3 (shallow number 3) was only 175 meters thick and moved within the thermocline itself. Its water contained 0.18 part per thousand less salt as well as much less dissolved oxygen than adjacent water. A third eddy, S2, which was discussed by Eric Lindstrom of the University of Washington, differed from the others in a number of ways: it extended from a depth of 1000 meters all the way to the surface, was dome-shaped, and rotated counterclockwise.

In all, four positively identified small eddies passed through the LDE area (200 by 200 kilometers) during the 2 months of the study, reported Bruce Taft of the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory in Seattle. He found two more patches of anomalous water that were probably traceable eddies, but the data require still further analysis before he can be sure. In all likelihood, he says, more closely spaced observation sites would have detected even more small eddies.

Where these eddies came from is not yet clear. Their exotic contents must be from outside the Sargasso Sea, Taft said, or their physical properties would not contrast so sharply with their surroundings. Lindstrom suggested that eddy S2, the oddball of the four closely studied eddies, may be the remnant of a Gulf Stream ring (*Science*, 28 October 1977, p. 387). Gulf Stream rings found in the Sargasso Sea are pools of colder, less saline water from the north side of the Gulf Stream enclosed by a bit of the Gulf Stream itself that has pinched off from the main current. Such cold-core rings are several hundreds of kilometers wide, have peak currents of 3 to 4 kilometers per hour, and generally remain to the north of the LDE area. Even so, Lindstrom argues that eddy S2 resembles an old ring more than it resembles the other small eddies. Like a ring, its motion extends all the way to the surface, it



Possible origins and trajectories of two small eddies discovered near the Bahamas. The "Meddy" seems to have originated within the gray area near the outfall of Mediterranean water at the Strait of Gibraltar. The other eddy, containing relatively high concentrations of oxygen, may have formed within the rectangle. [Modified from a map by Scott McDowell]

*The Final Joint POLYMODE Symposium, held 29 June to 2 July 1981, in Boston, Massachusetts, by the U.S. POLYMODE Organizing Committee headquartered at the Massachusetts Institute of Technology.

0036-8075/81/0807-0632$01.00/0

rotates counterclockwise, it is dome-shaped, and its water is less saline.

Some at the meeting speculated about the origin of the water in eddy D1. Elliot suggested that it might possibly have originated 1400 kilometers to the north when water from the Labrador Current somehow slipped south across the Gulf Stream. He cited a report made earlier during the POLYMODE symposium by Ross Hendry of the Bedford Institute of Oceanography. Hendry found a swift current of cold, less saline water 1000 meters beneath the surface, south of the Gulf Stream off the Grand Banks. Because this water resembled the water of the shallow Labrador Current, he suggested that it had dropped from near the surface to 1000 meters as it crossed the Gulf Stream. Eddy D1, Elliot noted, also matches the water of the Labrador Current, as well as that of an eddy-like feature reported in 1978 in the same area as Hendry's current.

Hendry then pointed out that a simpler hypothesis might be that the eddy formed only a few hundred kilometers to the west of the LDE area, where deep Labrador water hugs the continental shelf. Elliot responded that he would not argue with that—he was simply pointing out the consistency of the evidence supporting a far northern formation. No one, including Elliot or Hendry, cared to argue strenuously for either possibility. Some additional support for the distant formation of small eddies came from Scott McDowell of EG&G Environmental Consultants, Waltham, Massachusetts, Stephen Riser of the University of Washington, and Thomas Rossby of the University of Rhode Island, who tentatively placed the origin of eddy S1's water 3000 kilometers away in the North Equatorial Current.

Researchers have a bit firmer idea for the origin of a slightly larger but still smallish type of eddy found in the Atlantic. While surveying water properties near the Bahamas in 1976, McDowell and Rossby stumbled upon a remarkably saline, 100-kilometer-wide eddy. The 500-meter-thick, warm thermocline eddy had a salinity 0.46 part per thousand higher than the surrounding water. The nearest location where that sort of water can be found, they say, is 4000 kilometers to the northeast, no more than 1300 kilometers west of the Strait of Gibraltar. There, the warm, saline water of the Mediterranean slips out and sinks into the middle depths of the Atlantic. The Meddy, as they named it, would have had to travel for 3 years or more without being broken up by the turbulence of the open ocean. This is an unusually long

The Russians Are Coming?

One of the most difficult problems encountered during the 7 years of POLYMODE, the cooperative U.S.-U.S.S.R. experiment in physical oceanography, was arranging its final meeting. A breakdown in communication between Soviet and American participants forced the American organizers of the final scientific symposium of POLYMODE to shorten and reschedule it just days before it was to begin. Then, the Soviets arrived at the rescheduled meeting halfway through the formal presentations. Still, the inconveniences of the meeting bothered American physical oceanographers less than the problems that the Soviets have had with some of their POLYMODE data.

Arrangements for the symposium seemed to go smoothly at first, according to Robert Heinmiller of the POLYMODE executive office. In late February 1981, the U.S. organizing committee sent a message to the Soviets by telex saying that it would be selecting 5 days for the meeting from the 15-day period previously specified by the Soviets as being convenient. On 11 May, having received no objections, the U.S. committee telexed them that the final dates would be 25 to 30 June.

By mid-June, the Americans were becoming a bit uneasy about the arrangements. Nothing had been heard from the Soviets about the dates since January. Then, the U.S. State Department provided a list of the 17 scientists who had applied for visas. The Americans had hoped for a delegation of 25. More disturbing, the visa requests listed an arrival date of 28 June, 3 days after the scheduled start of the meeting. Although the entry date could be changed at the last minute, the U.S. organizing committee, just to be sure, sent off an urgent cable that contained a formal invitation to the 25 June meeting. The science attaché at the U.S. embassy in Moscow was to hand deliver it, but no one would accept the cable. In the meantime, a Soviet telex message shrank the delegation to nine scientists.

Four days before the expected arrival of the Soviets, they telexed the Americans that the 25 June date mentioned in the cable came as a great surprise to them. The Soviet delegation, the message said, could not possibly arrive before 28 June. The U.S. organizing committee notified the 30 American participants that the meeting would be delayed until 29 June, and, because of the small Soviet delegation, cut from 5 to 3 days.

On 28 June, no one showed up on the Soviet flight that was expected to carry the delegation. The symposium began on time, though, following an agenda that was repeatedly rearranged to accommodate the always imminent arrival of the Soviets. They did not arrive until a day and a half after the start, blaming the delay on airline connections and immigration officials. Why the problems? Some observers suggest that the Soviet bureaucracy simply does not work. Others believe that perhaps the Soviets did not want the meeting held at all because of the limited amount of worthwhile data that they had to present at that time.

The Soviet POLYMODE program has certainly had its problems. At the Boston symposium, Thomas Rossby of the University of Rhode Island showed that Soviet current meters indicate speeds that are 1.75 times higher than the actual speeds. He compared the Soviet data with the speeds of American floats that happened to be carried near the current meters. The high variability in the correlation between meter and float speeds limits the usefulness of the Soviet data, he said, to cases in which they can be integrated over a long period of time. The Soviets' insistence that this discrepancy not be mentioned in any joint POLYMODE publications has deadlocked plans for one cooperative scientific paper. In another experiment, the Soviet seawater density data are not available yet, reportedly because of computer processing problems.

Although useful data have already been exchanged and more may be forthcoming, these and other technical and procedural problems have dulled American POLYMODE oceanographers' interest in formal cooperative programs with the Soviets, Heinmiller believes. When the bilateral agreement that includes cooperative physical oceanography comes up for renewal this fall, few American scientists may object to its expiration.—R.A.K.

time. The energetic swirling of Gulf Stream rings may protect their cold, fresh cores from dissipation for 2 to 3 years, but they are often resorbed by the Gulf Stream sooner than that.

If the Meddy actually did originate in the far eastern Atlantic from Mediterranean water, it had company. Laurence Armi of Scripps Institution of Oceanography returned in June from an oceanographic cruise to the eastern Atlantic during which he found not one but three eddies containing "relatively undiluted Mediterranean water." Their salinity was elevated by 0.80 part per thousand, "a huge anomaly oceanographically," Armi notes. About 80 kilometers wide, 900 meters thick, and centered about 1100 meters beneath the surface, these eddies were near the Meddy's proposed source area (the vicinity of 32°N, 23°W). But, because their salinity anomalies are so strong, Armi says, they must have formed even closer to the Mediterranean outfall itself.

Although the origin of the water of smaller eddies has been estimated with some certainty, how the eddies form remains a matter for speculation. One possibility for the Mediterranean eddies is that the narrow outfall current becomes unstable and spins them off, perhaps as it encounters the submarine ridges and seamounts and the islands west of Gibraltar. That mechanism seems to work in the eastern Caribbean Sea, according to Thomas Kinder and his group at the Naval Ocean Research and Development Activity, Bay St. Louis, Mississippi, and George Hepburn of Science Applications, Inc., Monterey. They found three 90-kilometer-wide eddies spinning clockwise just west of the island chain of the Lesser Antilles. Because the eddies were too large to have been carried through the island passages by the prevailing east-to-west current, Kinder and his colleagues believe that the current shed them after being narrowed to the width of the island passages. Their computer model of the process supports that idea.

Physical oceanographers also continue to be puzzled by a curious aspect of smaller eddies—their apparently irregular distribution in time and space. The LDE found six eddies, but the preceding Mid-Ocean Dynamics Experiment, which used 40-kilometer spacing of observations in an area centered 400 kilometers to the south, found no immediately obvious evidence of them, according to Taft. Armi notes that his survey turned up three eddies whereas four surveys in a region to the west found anomalous water at only one out of 150 sites.

A big help in sorting out possible sources, according to McDowell, would be greater use of other tracers in addition to salinity, temperature, and oxygen. He cites the case of a second, smaller eddy found near the Bahamas by himself and Rossby that, unlike the Meddy, had only a small salinity anomaly. In addition to salinity, they used the concentrations of dissolved oxygen, phosphate, silicate, and the radioactive tritium from nuclear testing to locate the water's origin within a relatively small area 3000 kilometers to the northeast. With such increased precision, observations of small eddy formation might not be the matter of chance that their discovery was.

—RICHARD A. KERR

Do Jumping Genes Make Evolutionary Leaps?

The genomes of higher organisms are in a state of dynamic change. This must have important consequences for evolutionary change

In the last analysis it is the genome, the package of genetic material, that is inherited through parent to progeny, and so on through succeeding generations. And it is the characteristics of the genome of one species that erect a biological barrier between it and all other species. It is therefore natural to scrutinize the various components of genome structure to determine their functions in an evolutionary context. Molecular and evolutionary biologists met recently in Cambridge, England, to do just this.*

The all-pervading message of the Cambridge meeting was that genomic DNA is in a surprisingly dynamic state. "Whenever you look at a plant genome you see indisputable evidence for sequence amplification and rearrangement," said Richard Flavell of the Plant Breeding Institute, Cambridge. "Everything you say about plants can be applied to sea urchins," responded Eric Davidson of the California Institute of Technology. Such comments were reiterated many times, embracing a wide range of organisms. The notion of a fluid genome, in which there is a constant flux of sequences, is now an accepted fact. The question is, what does it imply?

This question, particularly its evolutionary ramifications, applies to three major levels: chromosomal architecture, the status of repeated sequences, and the function of structural genes. Perhaps most intriguing of all, however, is whether the issue of fluidity is involved in the establishment of a biological barrier between species.

The most obvious comment to make about the genomes of higher organisms is that biologists understand the function of only a tiny proportion of the DNA in them: namely, the genes that code for proteins. In the human genome, for instance, these protein-coding genes constitute marginally more than 1 percent of all the DNA. The rest of the genome is the target of much speculation, but few secure answers.

The DNA in the human genome that does not code for proteins falls into three classes. Some 5 percent is made up of many families (sometimes with many millions of members) of short, simple repeats of nucleotide sequences known as satellite DNA. A quarter of the genome is formed of families of longer more complex repeat sequences, denoted intermediate repetitive DNA. The bulk of the genome is composed of unique sequence, or single copy, DNA that is interspersed with the intermediate repeats. The proportions of these classes, whose distinctions can often become blurred, can vary enormously between organisms.

The longer biologists searched in vain for functions for these three classes of noncoding DNA, the stronger grew the conviction that much of the DNA might well be "junk" that for some reason could be tolerated in the nuclei of higher organisms. The most recent intellectual

*"Genome Evolution and Phenotypic Variation," held at King's College, Cambridge, England, 22 to 24 June 1981. Proceedings will be published in paperback by Academic Press in January.

0036-8075/81/0807-0634$01.00/0