# Small Eddies Are Mixing the Oceans

***Long-lived small eddies are crisscrossing the oceans carrying the effects of local mixing hundreds and even thousands of kilometers***

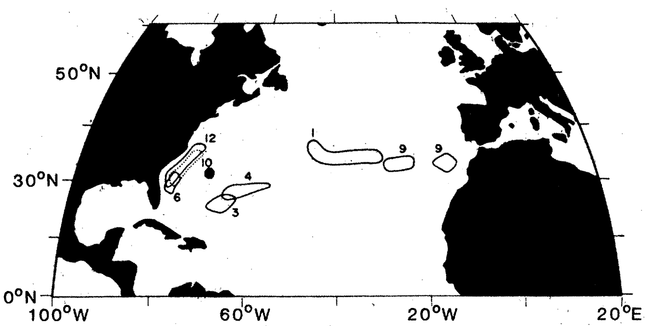
Oceanographers have caught enough small eddies in their observations to begin to speculate about how and where small eddies form, how they survive, and how much long-range mixing of the ocean they might cause. First discovered in any number off Cape Hatteras (*1*), these swirling pools of chemically distinctive water, spanning several tens of kilometers, have now been identified in mid-ocean from near the surface to depths of more than 5000 meters from the Arctic to Antarctica's Weddell Sea.

James McWilliams of the National Center for Atmospheric Research in Boulder, Colorado, assembled recent data and found 13 types of small eddies as classified by their density (which determines their depth) and by their salinity and oxygen content relative to the surrounding water (*2*). McWilliams found six types at the Local Dynamics Experiment site off Cape Hatteras, two types in the South Atlantic, one in the Weddell Sea, and two in the North Pacific. Another type, commonly called a Meddy, forms from the salty water of the Mediterranean as it spills from the Strait of Gibraltar. Fifteen to thirty Meddies drift within about 1000 kilometers of the strait at any one time.

Most small eddies are well under 100 kilometers across, but the type found in the Arctic off Alaska are just 20 kilometers or less across. More than 100 of this type have been sighted, mostly in observations made from floating ice islands. Undoubtedly, more types in addition to the 13 remain to be found. For example, Raymond Schmitt of Woods Hole Oceanographic Institution recently found another type in tropical waters 12° north of the equator off the coast of South America.

Although these small eddies inhabit different depths in different parts of the ocean and display different combinations of anomalous compositions, they have one thing in common, observes McWilliams. Every one that has been observed with sufficient completeness has had anticyclonic rotation, that is, their rotation is always clockwise in the Northern Hemisphere, like that of a high-pressure weather system.

Oceanographers can see now that not only are small eddies widespread but those at any one spot can originate in far-flung corners of an ocean. Scott McDowell of EG&G, Waltham, Massachusetts, has used the oxygen content, salinity, and density of an eddy as tracers to locate its place of origin (*3*). He compared these characteristics of eddies at the Local Dynamics Experiment site, 800 kilometers southeast of Cape Hatteras, with typical water properties around the North Atlantic. The method cannot always be rigorous, but there appears to be good evidence that shallow eddies at the site can originate 4500 kilometers to the east toward Gibraltar, 800 kilometers to the southeast within the central ocean gyre, and 500 kilometers to the west at the Gulf Stream. Eddies at greater depths seem to come from equally diverse locations in the eastern and western Atlantic as well as from near the Caribbean islands and Iceland.




S. McDowell

***Sources of small eddies***

*The unusual stability of small eddies let them travel great distances with loads of salt and other chemicals. Here, the possible origins of seven shallow eddies are indicated.*

McDowell estimates that some small eddies must be several years old to account for the apparent biological consumption of their oxygen, the time to drift such distances with the relatively slow currents found away from the Gulf Stream, or both. At first inspection, such unusually long lifetimes had seemed a bit unreasonable, but more leisurely analysis has shown that small eddies are remarkably sturdy. Only after years of losses to friction and diffusion would a small eddy disperse.

How to get small eddies started in the first place has also been an awkward question. McWilliams notes that there are numerous mechanisms that can create eddies. For example, a current can bend back on itself and pinch off a loop, as might be the case with the Alaskan Coastal Current in the Arctic. But the only mechanism that McWilliams considers a reasonable cause of most small eddies begins with mixing. Local mixing can occur in many ways, through a current brushing the bottom, a strong wind blowing across the surface, extreme surface cooling, or a current of dense water passing through a strait into deep water, as happens at Gibraltar.

Once a blob of water is thoroughly mixed, the differences in density between it and its surroundings tend to flatten it into a lens and thus spread it outward. But the spreading water, like the moving air of a weather system, cannot follow a straight line on the rotating Earth. All flows must tend to curve under the influence of the Coriolis effect, so the outward flowing water turns to form an anticyclonic eddy. Thus mixing and the subsequent adjustment of the lens to its surroundings always produces anticyclonic rotation, an apparent requirement for the generation of nearly all small eddies, McWilliams notes.

How much small eddies might be mixing the ocean by carrying and then releasing heat, salt, or other components remains unclear. Only in the case of Arctic eddies and Meddies are enough examples known. In the case of Meddies, McWilliams finds that "it remains quite likely that this one particular [small eddy] type does play an important role, if not the dominant one," in the transport of salt, which has become concentrated in the Mediterranean by evaporation.

—RICHARD A. KERR


**References**

1. R. A. Kerr, *Science* **213**, 632 (1981).
2. J. C. McWilliams, *Rev. Geophys.* **23**, 165 (1985).
3. S. E. McDowell, *J. Phys. Ocean.*, in press; part of a special issue on small eddies and other phenomena at the Local Dynamics Experiment site.