

Subarctic seawater flows south in an unexpectedly wide, messy pattern

Textbooks depict the Gulf Stream, the Kuroshio, and other great ocean currents as smooth, riverlike streams. Reality is messier. Gravitationally bound to the spinning globe, the oceans constitute a complex, turbulent system.

Indeed, the Gulf Stream is so variable that the organizers of the biannual Newport-to-Bermuda yacht race feel it prudent to provide competitors with three pre-race reports of the current's strength, direction, and whereabouts.

Now, a computational and field study has found that turbulence influences not only the variability of ocean currents but also whether water flows in an identifiable current at all.¹ The study was led by Amy Bower of Woods Hole Oceanographic Institution in Massachusetts.

Bower's subject is the southward flow of cold, deep water from the Labrador Sea to lower latitudes in the Atlantic. In winter, winds blow eastward over Canada's tundra. When those winds reach the Labrador Sea, heat is transferred from the warmer sea to the colder air. The chilled, newly dense water sinks to form what oceanographers call the Labrador Sea Water.

The LSW participates in the vast north-south circulation of the Arctic, Atlantic, and Antarctic oceans. Oceanographers presumed that the LSW flows south mainly in the Deep Western Boundary Current, which hugs the eastern seaboard's continental slope all the way to the equator. But in 2000 a team from the Scripps Institution of Oceanography in San Diego, California, reported a puzzling result: Barely any of the floats the team released at the DWBC's head kept to the current's coastal route.²

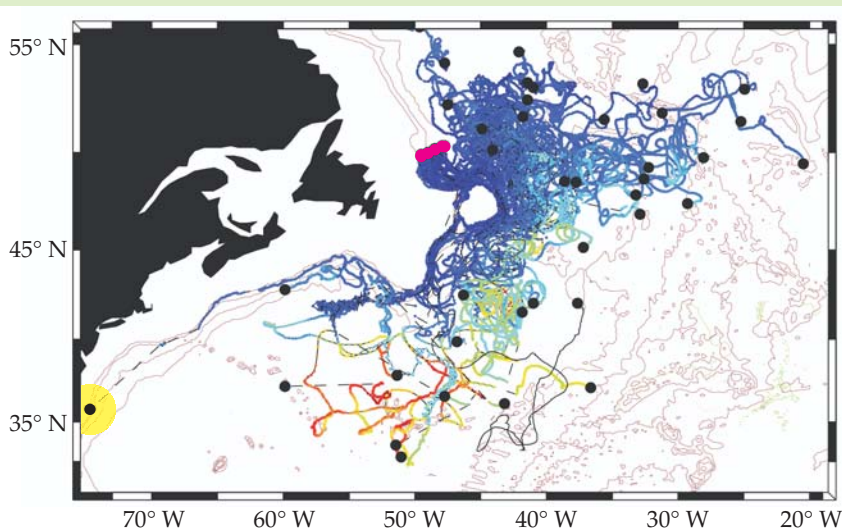
Bower thought she knew why. In general, the ocean is vertically stratified. Horizontal velocity varies with depth, and vertical displacements are modest. The Scripps team had used profiling floats, which follow a flow at fixed depth and periodically surface to radio their positions to a satellite. Bower wondered whether the surfacing and diving might have caused the floats to stray from the DWBC path.

In 2003 she and her colleagues began a five-year field study to track the DWBC. Unlike the Scripps team, she used so-called RAFOS floats. Designed in the late 1980s, the floats record their courses by triangulating signals from a set of moored sound beacons. Like nuclear submarines, the floats surfaced only at the end of their two-year voyages, whereupon they beamed

their recordings to a satellite.

The accompanying figure shows the tracks of 40 of 76 floats released at a rate of six every three months. The pink dots show the starting points; the black dots indicate the positions after two years. Only one float (highlighted with a yellow halo) followed the DWBC's coastal route for its entire two-year voyage. The rest spread out in a wide, messy pattern. Colored lines indicate the floats' paths and the local temperature (some floats were unable to report their positions all the time). The southernmost tracks are red, indicating the floats had passed beneath the Gulf Stream and joined the deep, warm water farther south.

Bower's colleagues Susan Lozier and Stefan Gary simulated the experiment's two-year run and found similar results. Emboldened by the resemblance, Lozier and Gary simulated a further 13 years of the floats' progress. A rich, complex flow pat-



tern emerged. According to the simulations, if Bower repeated her experiment with 1300 floats and tracked them until 2015, she'd find that almost every possible route from the Labrador Sea to the Gulf Stream is followed. Floats join the Gulf Stream off Florida, off Iceland, and anywhere in between.

Understanding such patterns in the present-day ocean, says Bower, is an essential ingredient for predicting the effects of global warming on Earth's future climate.

Charles Day

References

1. A. S. Bower, M. S. Lozier, S. F. Gary, C. W. Böning, *Nature* **459**, 243 (2009).
2. K. L. Lavender, R. E. Davis, W. B. Owens, *Nature* **407**, 66 (2000).

still yield glycine. But over time, the mutations accumulate and the genetic code drifts. In a small population, genetic change, good or bad, can become fixed. (For more on population genetics, see the article by Oskar Hallatschek and David Nelson on page 42 of this issue.)

The risk of genetic drift causing a TF to become dysfunctional is lowest for an infrequently used TF. Contrary to

the use-it-or-lose-it principle, adverse mutation is mitigated by (++) control when a nutrient is scarce and by (--) control when a nutrient is abundant. Gerland and Hwa dubbed the selection principle "wear and tear."

To investigate which principle prevails under what conditions, Gerland and Hwa developed a simple mathematical model. They represented the fluctuating concentration of a nutrient

by a periodic box-car function: short, widely spaced cars for scarcity; long, closely spaced cars for abundance.

Mutations can kill a functioning TF, but they can also revive a dysfunctional one. Because genes, like wristwatches and cell phones, are easier to break than fix, destructive mutations are more likely than restorative mutations—10 times more likely, Gerland and Hwa assumed.