Ocean currents respond to climate change in unexpected ways

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Ocean currents respond to climate change in unexpected ways

As the planet warms and winds strengthen, the poleward flow of tropical waters is predicted to also intensify. But observations tell a different story.

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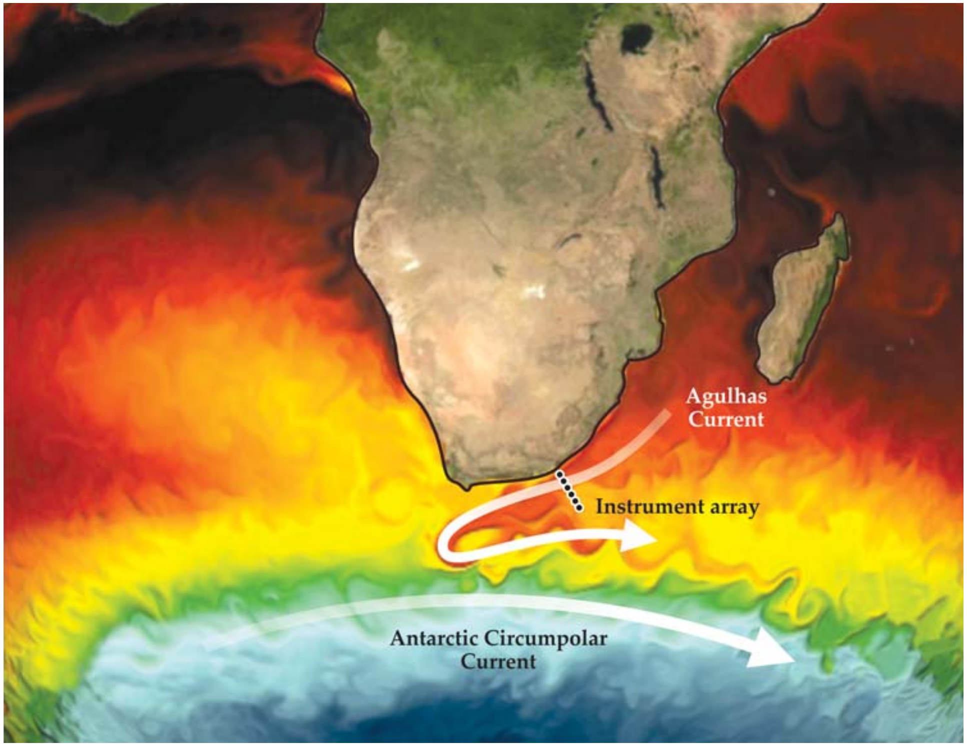

FIGURE 1. THE AGULHAS CURRENT flows southward along the western boundary of the Indian Ocean. A portion of its warm, tropical water—the color scale represents sea-surface temperature—spills into the Atlantic Ocean before the current is deflected eastward by the Antarctic Circumpolar Current. Researchers from the University of Miami led a mission to study long-term changes in the Agulhas Current[2] by deploying an array of instruments, positioned as shown here.

Calgary in Canada lies at about the same latitude as London in the UK, but you wouldn't know it from their respective weather patterns. Local climate depends not only on how far north or south you are but also on the circulation in Earth's atmosphere and oceans that carries air, water, and heat among distant parts of the planet.

Because of the Coriolis effect, which causes fluid flow to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, most of Earth's ocean currents follow a predictable pattern. The warmest currents, which originate in the tropics and flow toward the middle latitudes, occupy the western edges of the five main ocean gyres. The Gulf Stream, which flows north from the Caribbean Sea to the North Atlantic Ocean, is such a western boundary current; others include the Brazil Current in the South Atlantic, the Kuroshio Current in the North Pacific, the East Australian Current in the South Pacific, and the Agulhas Current, shown in figure 1, in the Indian Ocean.

Just as ocean currents affect climate, climate—and changes in climate—affect ocean currents. The wind systems that drive the currents appear to be intensifying. And reconstructed sea-surface temperatures over the past 100 years show that the western boundary currents are warming at twice the rate of the rest of the planet.[1] Together, those factors suggest that the western boundary currents are getting stronger, and climate models predict that they'll continue to strengthen in the foreseeable future.

But a new look at the Agulhas Current, by Lisa Beal and Shane Elipot of the University of Miami, shows that those predictions may need to be revisited. Using satellite altimetry and *in situ* data, the researchers tracked changes in the current over a 22-year period.[2] They found that the current grew no stronger—that is, the total rate of water transport did not increase—but it did get wider, probably because the increased wind energy went into producing turbulent eddies.

Current of needles

For centuries, humanity's spotty knowledge of ocean currents was gleaned from isolated observations from seafaring ships. Indeed, the first records of the Agulhas Current come from 15th-century Portuguese explorers who had rounded the cape of Africa en route to Asia. The current takes its name from the Cabo das Agulhas, or "Cape of the Needles," which may be a reference either to needle-like rock formations or to compass needles; the cape marks the only point on the journey at which true north and magnetic north align.

The Agulhas is unusual among ocean currents in how tenuously it's confined to its ocean. As it passes the southernmost tip of Africa, it continues to flow southwest, heading out of the Indian Ocean and into the South Atlantic. It's finally deflected eastward, far from any land mass, by the westerly winds that prevail in the Southern Hemisphere temperate latitudes. But a portion of the Agulhas Current fails to make the hairpin turn and spills out into the Atlantic, so the current has a warming effect not just on southern Africa but on the entire Atlantic Ocean. With climate change, the westerly winds are expected to intensify and recede to the south, and Agulhas leakage is predicted to increase.[3]

The complexity of ocean currents came into full view in the early 1990s with the launch of *TOPEX/Poseidon*, the first precision satellite altimeter. Currents are related to the ocean's pressure field, which in turn is related to its surface topography. *TOPEX/Poseidon*, along with its successors *Jason-1* and *Jason-2*, measured that topography with centimeter precision while crisscrossing the globe on fixed paths. The data they collected revealed that the oceans are far from a steady-state system: From year to year, currents can speed up and slow down, spin off eddies, and meander off course.

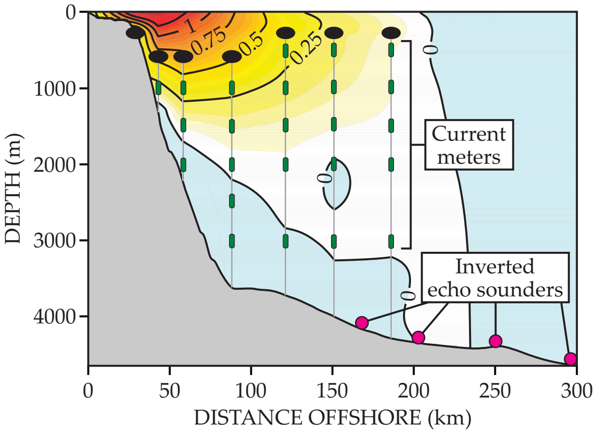

FIGURE 2. THE INSTRUMENT ARRAY deployed to measure the Agulhas Current consisted of strings of moored, floating current meters and four inverted echo sounders that use acoustic signals to estimate the flow profile of the water above them. The contours indicate the mean flow velocity in meters per second. (Adapted from ref. 2.)

But altimetry measurements don't tell the whole story. The ocean is three-dimensional, and the dense waters at the bottom often flow at a different speed—or even in a different direction—than the buoyant waters at the top. A single water column can contain several layers, or strata, behaving in different ways; altimetry, which measures a single number for each point on the ocean's surface, can't capture that vertical complexity.

Furthermore, transforming the surface topography into a current field requires knowledge of the seafloor topography, and it's most easily done when the seafloor is flat. But as shown in figure 2, the Agulhas Current tracks close to the African coast, where the seafloor is steeply sloped at the edge of the continental shelf.

Taking to the seas

Beginning in 2010, Beal led a series of seagoing missions to get a more complete picture of the Agulhas Current by measuring it *in situ*. Her team deployed an array of instruments, as shown in figure 2, including strings of current meters tethered to the seafloor and inverted echo sounders that use acoustic measurements to estimate the current profile above them. The instruments remained in place until 2013 and captured the structure and transport of the current during that time.

Because the instruments were positioned along one of the tracks followed by the altimetry satellites, the *in situ* data could be directly related to measurements of surface topography. By using their data to calibrate the surface-topography measurements, Beal and Elipot were able to derive a more accurate interpretation of altimetry data from 1993 to 2015—the entire period for which precise surface topography measurements were available.

A few similar studies have been carried out before for other currents. But seagoing missions are expensive and uncertain: Procuring a ship to deploy and retrieve the instruments isn't easy, and even with careful design, the instruments don't always remain in place for the duration of the study. The expense and uncertainty are compounded for the Agulhas Current because of its remote location with respect to the global oceanographic community.

But studying the Agulhas can yield insights not available from other western boundary currents. Because of the leakage into the Atlantic Ocean, the current influences climate far beyond itself. And Indian Ocean currents offer a uniquely clear view into long-term oceanic trends. Conditions in the Atlantic and Pacific Oceans change a lot from year to year and from decade to decade—El Niño, for example, originates in the Pacific—so a 22-year record from either of those oceans would be dominated by those short-lived signals. But in the relatively stable Indian Ocean, it's just possible to tease out the effects of long-term climate change.

"We were surprised by the results," says Beal. "Based on the rapid warming observed over western boundary currents and on recent climate model and reanalysis studies, we expected the current to be strengthening." Instead, the data showed no long-term trend in the amount of water transported. But the width of the current increased, as did the frequency of turbulent eddies tens of kilometers in diameter.

Increased eddy activity so near the shore could have important consequences. Shallow coastal waters are often rich with organisms and the nutrients they feed on, and they can harbor high concentrations of anthropogenic pollutants. Eddies speed the mixing of those coastal waters with the deep ocean and thus could sweep those organisms and pollutants out to sea.

It's too soon to say exactly what the wider, more turbulent Agulhas Current will mean for how heat is distributed as the planet warms. For one thing, the measurements captured only a single cross section of the current, and they don't prove that all parts of the current behave the same way. But they do suggest that ocean models, which mostly postulate a linear relationship between currents and the winds that drive them, may need to be refined worldwide. "If western boundary currents are not strengthening as winds intensify, then linear dynamical theory is not dominant in those areas," says Beal. "This is a fundamental result with widespread implications."

The results also suggest that seagoing oceanographic missions could have many more surprises in store; despite their expense and risk, they are necessary to accurately understand the changing ocean. Beal and her colleagues are working toward mitigating some of the expense by building a collaboration with South African scientists, with an eye toward turning leadership of the project over to them in the future.

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