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In the Atlantic Ocean, Subtle Shifts Hint at Dramatic Dangers

The warming atmosphere is causing an arm of the powerful Gulf Stream to weaken, some scientists fear.

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IT'S ONE OF THE MIGHTIEST RIVERS you will never see, carrying some 30 times more water than all the world's freshwater rivers combined. In the North Atlantic, one arm of the Gulf Stream breaks toward Iceland, transporting vast amounts of warmth far northward, by one estimate supplying Scandinavia with heat equivalent to 78,000 times its current energy use. Without this current — a heat pump on a planetary scale — scientists believe that great swaths of the world might look quite different.

Now, a spate of studies, including one published last week, suggests this northern portion of the Gulf Stream and the deep ocean currents it's connected to may be slowing. Pushing the bounds of oceanography, scientists have slung necklace-like sensor arrays across the Atlantic to better understand the complex network of currents that the Gulf Stream belongs to, not only at the surface, but hundreds of feet deep.

"We're all wishing it's not true," Peter de Menocal, a paleoceanographer and president and director of the Woods Hole Oceanographic Institution, said of the changing ocean currents. "Because if that happens, it's just a monstrous change."

The consequences could include faster sea level rise along parts of the Eastern United States and parts of Europe, stronger hurricanes barreling into the Southeastern United States, and perhaps most ominously, reduced rainfall across the Sahel, a semi-arid swath of land running the width of Africa that is already a geopolitical tinderbox.

The scientists' concern stems from their understanding of thousands of years of the prehistoric climate record. In the past, a great weakening or even shutdown of this arm of the Gulf Stream seems to have triggered rapid changes in temperatures and precipitation patterns around the North Atlantic and beyond.

The northern arm of the Gulf Stream is but one tentacle of a larger, ocean-spanning tangle of currents called the Atlantic Meridional Overturning Circulation, or AMOC. Scientists have strong evidence from ice and sediment cores that the AMOC has weakened and shut down before in the past 13,000 years. As a result, mean temperatures in parts of Europe may have rapidly dropped to about 15 degrees Celsius below today's averages, ushering in arctic like conditions. Parts of northern Africa and northern South America became much drier. Rainfall may even have declined as far away as what is now China. And some of these changes may have occurred in a matter of decades, maybe less.

The AMOC is thus a poster child for the idea of climatic "tipping points" — of hard-to-predict thresholds in Earth's climate system that, once crossed, have rapid, cascading effects far beyond the corner of the globe where they occur. "It's a switch," said Dr. de Menocal, and one that can be thrown quickly.

Which brings us to the cold blob. Almost everywhere around the world, average temperatures are rising — except southeast of Greenland where a large patch of the North Atlantic has become colder in recent years.

In short, the cold blob may signal that the northern arm of the Gulf Stream no longer arrives with the same strength to the North Atlantic. That a warming atmosphere has, paradoxically, cooled one part of the world.

The science remains relatively new, and not everyone agrees the AMOC is actually slowing. But in both scientific modeling of climate change and in the prehistoric record, a North Atlantic cooling presages a shutdown of the current. “One of the hallmarks of a shutdown is this cold blob,” says Dr. de Menocal. “The cold blob is a big deal.”

IN 1513, THE SPANISH EXPLORER Juan Ponce de León noticed something bizarre off the coast of today’s Florida: Relentless currents pushing his ships backward, overpowering the winds blowing them forward. He became the first European to describe the Gulf Stream. Benjamin Franklin finally mapped it in the late 1700s — he named it the “Gulf Stream” — by measuring changes in water temperature on a return trip from England.

Over the 20th century, oceanographers came to realize that the northern branch of the Gulf Stream was part of a gigantic loop of water, with warm surface water flowing north and colder water returning south, deep below the surface. This was the network of currents that scientists now call the AMOC.

The system was driven by North Atlantic water that, as it lost heat to the atmosphere and grew dense, sank to the ocean’s depths, pulling warmer surface water northward. In the middle part of the century, oceanographer Henry Stommel elucidated the physics of how the AMOC could change. His insight was that, depending on the balance of heat and salinity, the sinking effect—called “overturning”—could strengthen, or weaken, or maybe stop completely.

In the 1980s, Wallace Broecker, a geochemist at Columbia University’s Lamont-Doherty Earth Observatory, pounced on that idea.

Colleagues studying ice cores from the Greenland ice sheet were seeing evidence of strange climatic “flickers” in the past. As Earth warmed from the deep freeze of the last ice age, which peaked around 22,000 years ago, temperatures would rise, then abruptly fall, then rise again just as swiftly. Dr. Broecker theorized this was caused by stops and starts in what he called the ocean’s “great conveyor belt” — the AMOC.

The clearest example began about 12,800 years ago. Glaciers that had once covered much of North America and Europe had retreated considerably, and the world was almost out of the deep freeze. But then, in just a few decades, Greenland and Western Europe plunged back into cold. Temperatures fell by around 10 degrees Celsius, or 18 degrees Fahrenheit, in parts of Greenland. Arctic-like conditions returned to parts of Europe.

The cold snap lasted perhaps 1,300 years — before reversing even more abruptly than it began. Scientists have observed the sudden changes in the pollen deposited at the bottom of European lakes and in changes in ocean sediments near Bermuda.

This forced a paradigm shift in how scientists thought about climate change. Earlier, they had tended to imagine creeping shifts occurring over many millennia. But by the late 1990s, they accepted that abrupt transitions, tipping points, could occur.

This didn’t bode well for humanity’s warming of the atmosphere. Dr. Broecker, who died in 2019, famously warned: “The climate system is an angry beast and we are poking it with sticks.”

WHY DID THE AMOC shut down? A leading theory is that meltwater from retreating glaciers emptied into the North Atlantic or Arctic oceans. Freshwater is lighter than saltwater, and the sudden influx of more buoyant water could have impeded the sinking of denser, saltier water — that critical “overturning” phase of the AMOC.

Today we don’t have massive glacial lakes threatening to disgorge into the North Atlantic. But we do have the Greenland ice sheet, which is melting at the upper end of projections, or about six times faster than in the 1990s. And according to one study, the subpolar North Atlantic recently became less salty than at any time in the past 120 years.

There’s little agreement on cause. Changes in wind patterns or currents may be contributing, as could greater rainfall. But Stefan Rahmstorf, a physical oceanographer with the University of Potsdam in Germany, suspects that, similar to what happened some 12,800 years ago, meltwater from Greenland is beginning to slow the AMOC.

In 2014, a remarkable project launched in the North Atlantic. An array of sophisticated sensors were moored to the ocean floor between Newfoundland, Greenland and Scotland. They're starting to provide an unprecedented view of the currents that shape the Atlantic.

In 2015, Dr. Rahmstorf and his colleagues published a seminal paper arguing that the AMOC had weakened by 15 percent in recent decades, a slowdown they said was unprecedented in the past 1,000 years. He and his colleagues recently published another paper that used additional reconstructions of sea temperature around the North Atlantic, some going back 1,600 years, to determine that the recent slowdown began with the Industrial Revolution in the 19th century, then accelerated after 1950.

Other scientists have also presented different evidence of a slowdown. The South Atlantic has become saltier in recent decades, according to a study by Chenyu Zhu at Ocean University of China and Zhengyu Liu at Nanjing Normal University, suggesting that more of the salt that once traveled north with the AMOC now remains in the tropics, producing what they call a "salinity pile-up."

And Christopher Piecuch of the Woods Hole Oceanographic Institution recently argued that the Gulf Stream along Florida's coast, also called the Florida current, has weakened. He found this by measuring the differences in sea level across the Gulf Stream. Earth's rotation deflects flowing water to the right; this causes the two sides of the current to have slightly different sea levels — and the faster the current, the greater the difference. Tide gauge measurements going back 110 years indicate that this contrast has declined, Dr. Piecuch found, particularly in the past two decades. This suggests the current has slowed.

For Dr. Rahmstorf, these lines of evidence bolster the argument that the AMOC is slowing. In his view, the change is occurring right on schedule. "The long-term trend is exactly what was predicted by the models," he said.

A 2019 report by the United Nations' Intergovernmental Panel on Climate Change, a synthesis of the most significant climate research worldwide, says that while the AMOC will "very likely" weaken later this century, collapse is "very unlikely." Yet Dr. Rahmstorf worries about the unknowns in a system that scientists understand can rapidly shift between different states.

He points out that, in IPCC jargon, "very unlikely" translates to a probability of less than 10 percent. But if a nuclear reactor in your neighborhood had a less-than-10-percent likelihood of blowing up, he asked, "would you be reassured?"

"We still don't know how far away this threshold is where it could break down altogether," he said. If we limit warming to 1.5 degrees Celsius above preindustrial times — a goal of the Paris agreement among nations to fight climate change — a shutdown is unlikely, he thinks. "But for unmitigated warming," which is the world's current trajectory, "I think there's increasing risk where we make AMOC so weak it goes over the edge and collapses."

"There will be a lot of surprises if we disturb climate that much," he said. "It's not at all predictable how bad things will be."

Scientists also emphasize that the ultimate consequences of that weakening remain unclear. That's in part because the world is in such uncharted territory. In the past, Europe became drastically cooler when the current shut down, but today any cooling might ultimately be muted or possibly canceled out by continued global heating.

But if past is prologue, a drastically altered AMOC could certainly shift rainfall patterns, scientists said, making parts of Europe and Northern Africa drier, and areas in the Southern hemisphere wetter. Changing ocean currents might affect marine ecosystems that people rely on for food and livelihood.

A changing Gulf Stream could also accelerate sea-level rise along parts of the Atlantic coast of the United States. In 2009 and 2010, when the stream inexplicably weakened by 30 percent, the Northeast saw seas rise at a rate unprecedented in the entire roughly 100-year record of tide gauges.

And if water in the tropical and subtropical Atlantic becomes warmer because that heat is no longer shunted north, the expanding reservoir of energy could strengthen hurricanes, something that scientists at the National Oceanography Centre in the United Kingdom argue is already happening. Hurricanes derive their energy from heat in the water.

Finally, in a perverse twist, a shutdown of the AMOC could exacerbate global heating. The ocean absorbs nearly one-third of human carbon dioxide emissions. But the sinking of salty, dense water — the overturning portion of the AMOC — is critical to that absorption. So, if the AMOC stops or greatly slows, and that water stops sinking, the accumulation of heat-trapping gases in the atmosphere could accelerate.

THEN THERE ARE THOSE CONSEQUENCES that fall in the category of "global weirding."

Scientists at the U.K.'s National Oceanography Centre have somewhat counterintuitively linked the cold blob in the North Atlantic with summer heat waves in Europe. In 2015 and 2018, the jet stream, a river of wind that moves from west to east over temperate latitudes in the northern hemisphere, made an unusual detour to the south around the cold blob. The wrinkle in atmospheric flow brought hotter-than-usual air into Europe, they contend, breaking temperature records.

"That was not predicted," said Joel Hirschi, principal scientist at the centre and senior author of the research. It highlights how current seasonal forecasting models are unable to predict these warm summers. And it underscores the paradox that, far from ushering in a frigid future for, say, Paris, a cooler North Atlantic might actually make France's summers more like Morocco's.

Even so, Dr. Hirschi takes a wait-and-see stance on whether the AMOC is actually slowing. "I have great respect for what Dr. Rahmstorf is doing. And it may well be spot on in the end," he says. "But I'm afraid the data, the really robust data, is not there."

Susan Lozier, a physical oceanographer and dean at the College of Sciences at Georgia Tech, also has her doubts about whether the AMOC is currently slowing. At issue, she says, is how scientists infer changes in the AMOC. We can directly measure many aspects of the ocean, such as temperature (it's warming), oxygen levels (they're declining), even how stratified it has become (more so). "There are very strong signals in the ocean of climate change," she said.

But most studies on the AMOC don't measure the "conveyor belt" directly. Instead, they use proxies to infer that the overturning has changed.

Such inference can be problematic when considering changes that occur over short time frames, says Dr. Lozier, because the changes observed could have other causes. Consider that cold blob in the North Atlantic, she said. Dr. Rahmstorf and others see it as evidence of a weakening Gulf Stream, but Dr. Lozier notes that shifts in wind patterns or how storms move over the ocean could also underlie the phenomenon. "There are other ways to explain it," she said. "A lot of our conceptual understanding of AMOC is in isolation of other things going on in the ocean."

Direct measurement of the AMOC only began relatively recently. A line of sensors between the Bahamas and the Canary Islands, called Rapid, was installed in 2004. A second sensor array, spanning the North Atlantic from Canada to Greenland to Scotland and called Osnap, went live in 2014. (Dr. Lozier is the international project lead for Osnap.)

Neither project has operated long enough to produce clear trends, in Dr. Lozier's view. What they have shown, though, is lots of natural variability. In 2009 and 2010, for example, the AMOC weakened — "people were like, 'Oh my God, this is happening,'" she said — only to pick right back up again over the following years.

They've also revealed a system of currents that's far more complex than once envisioned.

Dr. Broecker's old schematics of the AMOC posit a neat warm current flowing north along the western edge of the Atlantic and an equally neat cold current flowing back south below it. In fact, says Dr. Lozier, that deeper current is not confined to the western edge of the Atlantic, but rather flows southward via a number of "rivers" that are filled with eddies. The network of deep ocean currents is much more complicated than once envisioned, in other words, and figuring out how buoyant meltwater from Greenland might affect the formation of cold deepwater has become more complicated as well.

This is the place scientists currently find themselves in. They suspect the AMOC can work like a climate switch. They're watching it closely. Some argue that it's already changing, others that it's too soon to tell.

“There’s no consensus on whether it has slowed to date, or if it’s currently slowing,” said Dr. Lozier. “But there is a consensus that if we continue to warm the atmosphere, it will slow.”

Sources: Float and mooring data by the Overturning in the Subpolar North Atlantic Program project. Sea surface current and temperature data provided by Asia-Pacific Data Research Center, part of the International Pacific Research Center at the University of Hawaiʻi at Mānoa, funded in part by NOAA. Large scale ocean circulation arrow from *The Relationship Between U.S. East Coast Sea Level and the Atlantic Meridional Overturning Circulation: A Review* by Christopher M. Little et al.

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