Modeling deep water three-dimensional upwelling pathways in the Southern Ocean

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A team of researchers, including Wilbert Weijer of the Laboratory's Computational Physics and Methods group, examined the deep water upwelling the global overturning circulation in the Southern Ocean around Antarctica. Their study published in *Nature Communications* combines ocean observations with three state-of-the-art ocean models. The research reveals the full 3-D pathway of deep water to the surface of the Southern Ocean for the first time. Animation: Atlantic Ocean particle pathways over a 50-year time period.

Significance of the work

The Southern Ocean absorbs nearly half of the carbon dioxide and 75 percent of the total heat that is absorbed by the world's oceans from the atmosphere. However, the Southern Ocean represents only 30 percent of the global ocean. The strong winds blowing over the ocean pull cold, deep water from the ocean abyss to the sea surface, forming a connection between the deep ocean and the atmosphere. Despite the importance of the Southern Ocean upwelling, the three-dimensional pathways of deep water masses are largely unknown.

The upwelling forms a branch of the global overturning circulation and balances the descent of water into the abyss at high latitudes. This overturning completes the global circulation loop, which is important for the oceanic uptake of carbon and heat, the resupply of nutrients for use in biological production, as well as the understanding of how ice shelves melt.

The overturning circulation is an important part of the climate system because it has the capacity to sequester heat and carbon from the atmosphere, mitigating anthropogenic carbon emissions and its resulting warming. It also brings relatively warm water close to the Antarctic continent, where it has the potential to interact with the ice shelves, potentially destabilizing them.

The team determined that the under-sea topography and the eddy field, rather than the winds, control the structure of the upwelling. This study identified critical regions for upwelling of deep water, which can now be targeted by future research expeditions and modeling studies. To predict whether the Southern Ocean will continue to absorb heat and carbon dioxide from the atmosphere at its current rate, it is necessary to understand the processes that generate upwelling of the ocean's deepest waters. Animation: Atlantic Ocean particle pathways with particle-transport over a 50-year time period.

Achievements

The team determined the upwelling pathways by releasing virtual water particles in the deep ocean in three high resolution ocean and climate simulation models. The researchers tracked the pathways of the particles toward the surface of the Southern Ocean, and compared the results to hydrographic observations. The investigators found that deep, relatively warm water from the Atlantic, Indian and Pacific ocean basins enters the Southern Ocean and spirals southeastwards and upwards around Antarctica before reaching the ocean's mixed layer, where it interacts with the atmosphere. These pathways spiral while being transported eastward by the enormous Antarctic Circumpolar Current, which flows around the northern edge of the Southern Ocean. The Antarctic Circumpolar Current is both the world's strongest current, and also the only major current that circles the globe unimpeded by continent.

While the pathways make several loops around the Antarctic continent as part of the Antarctic Circumpolar Current, the upward spiral is not smooth. It displays distinct jumps where the current meets topographic obstacles, making the circulation more turbulent. Undersea ridges and plateaus create hotspots of swirling eddies that push water southward and up toward the surface. The study identified five major upwelling hotspots associated with large undersea topographic features, which are responsible for most of the upwelling in the Southern Ocean. The upwelling time was surprisingly short (on average less than a century), which is important for understanding the time in which a change in the North Atlantic can be conveyed to the Southern Ocean.

The researchers also calculated how much water from each ocean basin made it up the spiral staircase. They determined that half of the water that reached the mixed layer originated from the Atlantic Ocean, while the Indian and Pacific oceans each contributed approximately a fourth.

The research team

Reference: "Spiraling Pathways of Global Deep Waters to the Surface of the Southern Ocean," *Nature Communications 8*, 172 (2017); doi: 10.1038/s41467-017-00197-0. Authors: Veronica Tamsitt, Lynne D. Talley and Matthew R. Mazloff of Scripps Institution of Oceanography; Henri F. Drake of Princeton University, currently Massachusetts Institute of Technology and Woods Hole Oceanographic Institution); Adele K. Morrison of Princeton University, currently Australian National University; Carolina O. Dufour, Alison R. Gray, Jorge L. Sarmiento and Stephen M. Griffies of Princeton University; Jinbo Wang of California Institute of Technology); and Wilbert Weijer of the Laboratory's Computational Physics and Methods group.

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See the Science Highlights for more information.