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AROUND AND AROUND, UP AND DOWN: MOTION IN THE SOUTHERN OCEAN

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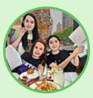
YOUNG REVIEWERS:



HELENA, MOMO, TATI
AGE: 11

JAMES
AGE: 10

The Southern Ocean, which surrounds Antarctica, is unlike any other ocean on Earth. It is home to the world's most powerful currents, biggest waves, craziest ice, and wildest animals. Despite its remoteness, the Southern Ocean plays a major role in Earth's climate. The Southern Ocean connects and stirs together the other major oceans. The fast-flowing currents of the Southern Ocean block heat from being carried toward Antarctica, keeping the continent covered in ice—which is important to prevent dangerous sea-level rise. The Southern Ocean also connects the surface waters with the deep parts of the global ocean, by bringing deep water up to the surface and sending surface water down into the deep. This circulation is crucial for regulating how much heat and carbon the ocean can hold. The more carbon and heat held by the ocean, the slower Earth's climate will change for those of us on land.

WHERE IS THE SOUTHERN OCEAN?

CIRCUMPOLAR

Existing across all longitudes; going all the way around the pole.

The Southern Ocean surrounds the Antarctic continent, around the South Pole. It is a **circumpolar** ocean, which means it covers all 360° longitude around the globe. Since this is not true for other oceans, it may partially explain why people have debated for centuries about what the Southern Ocean should be called—and whether it is an ocean at all!

Some credit James Cook with starting this debate, when he called it the "Southern Ocean" in his 1772–1775 voyage journals. Since then, the name "Southern Ocean" has gone into and out of existence. In 2000, nations voted on the name of this ocean and "Southern Ocean" narrowly won over "Antarctic Ocean" (18 votes to 10). Nations also struggled to agree on the location of the Southern Ocean's northern boundary. In 2021, the National Geographic Society officially recognized the Southern Ocean on its maps by no longer extending the boundaries of the Pacific, Atlantic, and Indian Oceans to Antarctica. Oceanographers prefer to define the Southern Ocean by the position of its currents rather than by a specific latitude or land feature (Figure 1). Despite debates about its name and location, we know the Southern Ocean is vital to life on Earth.

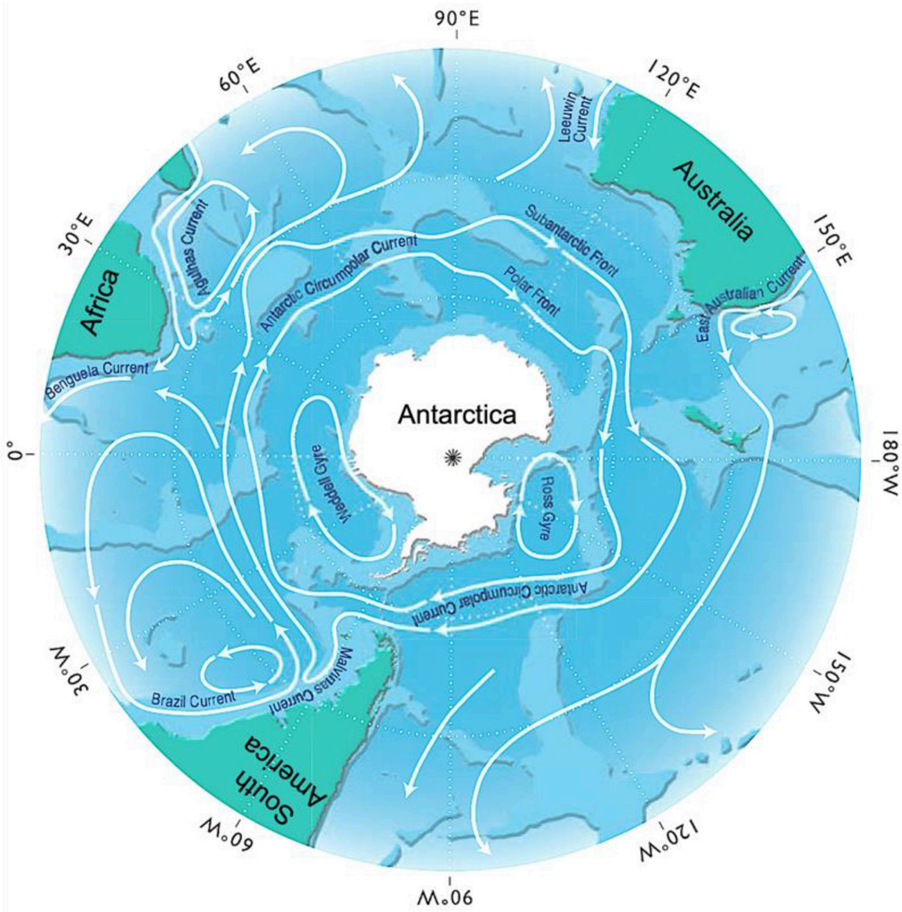


Figure 1

Figure 1

The major ocean currents are shown by the arrows. The largest current in the world, the Antarctic Circumpolar Current, circles from west to east around Antarctica (adapted from: https://discovery.princeton.edu/2013/11/03/secrets-of-the-southern-ocean/).

CURRENTS OF THE SOUTHERN OCEAN

The Southern Ocean is home to the mightiest current in the world, called the **Antarctic Circumpolar Current** (ACC). The ACC flows eastward around the globe, carrying about 170 million cubic meters of water per second past the southern end of South America. The ACC is made up of a bunch of smaller currents, like thin branches of quickly flowing water, that together can be up to 2,000 km wide and reach down more than 4,000 m to the seafloor. On its northern boundary, the ACC connects with the ocean **gyres** to its north. Gyres are large, almost circular systems of currents. The ACC also connects the Indian, Pacific, and Atlantic Oceans together. Toward Antarctica, the Southern Ocean also has big gyre circulations in the Ross and Weddell Seas, and other important currents around the Antarctic continent. All of these currents are important for transporting water around the Southern Ocean. You can watch a beautiful computer simulation of Southern Ocean currents here.

ANTARCTIC CIRCUMPOLAR CURRENT

A series of strong currents that flow continuously across all longitudes of the Southern Ocean.

GYRE

A large system of ocean currents that create a circular pattern of horizontal motion, contained and guided by the coasts of nearby continents.

FLIPPING THE SOUTHERN OCEAN UPSIDE DOWN

In addition to the mighty eastward-flowing current system of the ACC, the Southern Ocean is also home to another, much slower, vertical circulation (Figure 2). In this up-and-down circulation, waters that cooled and sank in the North Atlantic hundreds to thousands of years ago finally make their way back to the sea surface in the Southern Ocean, by climbing upward as they follow the ACC around Antarctica [1]. These old, deep waters that rise back to the surface are replaced by downward flows of Southern Ocean surface waters, in two ways. On the northern edge of the Southern Ocean, the winds make surface waters **subduct**, or sink, into the mid-depths of the ocean. On the southern edge, waters near the Antarctic continent lose their heat to the atmosphere and gain salt when **sea ice** forms, becoming both colder and saltier. These dense waters sink to the bottom of the ocean, forming the deepest **water mass** on Earth, called Antarctic Bottom Water. This water fills up 30–40% of the world's oceans [2].

SUBDUCT

To sink; in our context, the sinking of water down into the lower layers of the ocean as it becomes more dense.

SEA ICE

Ice that floats on the ocean's surface, formed by the freezing of ocean water. Importantly, when sea ice forms, only the freshwater freezes and the salt remains in the ocean water.

WATER MASS

A layer of water in the ocean that has different properties (like temperature, saltiness, and oxygen concentration) than the layers above or below it.

THE SOUTHERN OCEAN PROTECTS US FROM CLIMATE CHANGE

The strong eastward-flowing currents of the ACC are like a wall, blocking the waters from crossing north to south or south to north. This blocks the extra heat that the Earth receives from the Sun at the equator from crossing the ACC and making its way directly to Antarctica. The barrier that the ACC makes, blocking heat traveling southward, is crucial for us because it keeps Antarctica cold and fully covered in ice. If all of the ice covering Antarctica were to melt, the average global sea level would increase by about 60 meters [3]!

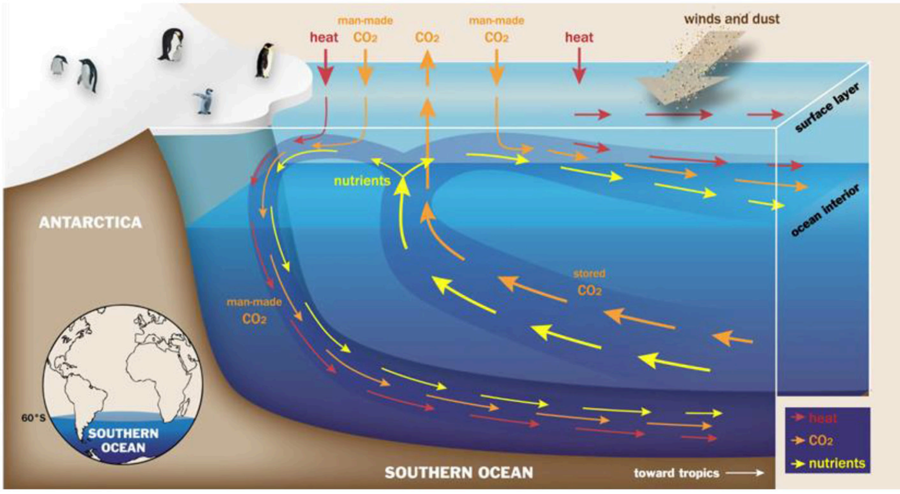


Figure 2

Figure 2

Vertical circulation in the Southern Ocean and its impact on global climate. Man-made carbon dioxide and heat enter the ocean from the atmosphere and are carried into the deep ocean. Natural carbon dioxide and nutrients that have been stored in the deep ocean travel back up to the surface (adapted from: https://www.ipcc.ch/srocc/chapter/chapter-5/5-2changing-oceans-and-biodiversity/5-2-2changes-in-physical-and-biogeochemical-properties/5-2-2-2changing-temperature-salinity-circulation/ipcc-srocc-ch_5_4/).

Therefore, without the ACC, there would be a lot less land available for us to live on, and most of today's cities would be completely under water.

When surface waters plunge into the deep ocean, they take lots of heat and carbon from the atmosphere with them. By flipping the ocean waters upside down, the Southern Ocean controls how hot it feels to us on land. About 90% of the excess heat produced by human activities is being absorbed by the global ocean (Figure 3), with 75% of it going into the Southern Ocean [4]. The Southern Ocean also absorbs more of the greenhouse gas carbon dioxide (CO_2) emitted by human activities than any other ocean (for more information see here). So, the Southern Ocean can slow down climate change on land by storing heat and carbon in the deep ocean, but this ocean storage can have long-lasting climate impacts and have negative effects on those living in the ocean. For example, as the ocean warms and absorbs more carbon, it becomes more acidic. The **acidity** of the global ocean has increased by about 30% since the industrial revolution. This is harmful to some small ocean critters—especially those that have shells—and bigger animals rely on these smaller organisms for food.

The vertical motion in the Southern Ocean brings deep waters back up to the surface—waters that have not been near the ocean surface since they sank in the North Atlantic hundreds to thousands of years ago. During that long journey southward, this water mass builds up nutrients, as sinking organic particles (sometimes called marine snow) dissolve back into the ocean. So, when the deep water finally returns to the surface in the Southern Ocean, it is packed full of nutrients that provide food for **phytoplankton**—the base of the Southern Ocean food web. All life in the Southern Ocean, from tiny, shrimp-like krill to enormous humpback whales, depends on the nutrients that help phytoplankton to grow. Not only do phytoplankton make up the base

ACIDITY

A measure of how basic (like milk) or acidic (like orange juice or vinegar) something is.

PHYTOPLANKTON

Microscopic plants that live in the surface waters of the ocean and make up the base of the Southern Ocean food web.

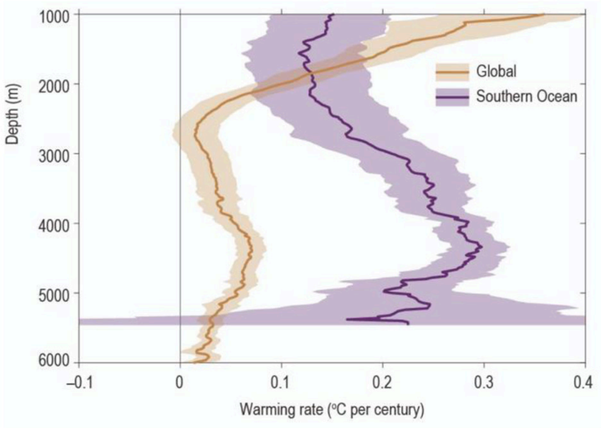


Figure 3

Figure 3

Observed rates of deep-ocean warming from 1981–2019 in the oceans all over the world (orange) and in the Southern Ocean (purple). The shaded areas show the amount of uncertainty in these estimates; we are 95% confident that the true value lies within the shaded areas. From 1981–2019, the deep Southern Ocean warmed at approximately 0.2°C per century, or 0.02°C 10 years, which is much faster than the oceans as a whole (Credit: https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/IPCC-SROCC-CH54.jpg).

of the food web, but they are also effectively massive ocean forests, inhaling CO_2 from the atmosphere and exhaling oxygen back out. In half of all the breaths we take, we are breathing in oxygen from phytoplankton—that is more oxygen than all of the tropical rainforests on land make, combined.

WHAT ABOUT THE FUTURE?

We still have lots to learn about how carbon and heat move through the Southern Ocean. This ocean is a place of mystery and wonder, with many big unanswered questions. For example, how much natural CO_2 will the Southern Ocean eventually release back into the atmosphere, and how will this affect us? We are certain that the Southern Ocean has warmed and gotten less salty in recent decades due to greenhouse gas emissions from human activities [5]. We are also certain that changes in the circulation of the Southern Ocean will play a big role in Earth's changing climate—by influencing how quickly the Antarctic Ice Sheets melt, how much CO_2 remains in the atmosphere, and the health of ocean ecosystems. Our actions play a key role in the wellbeing of the Southern Ocean. By reducing our greenhouse gas emissions, we will help the Southern Ocean adapt to our changing climate.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

HELENA, MOMO, TATI, AGE: 11
This fun-loving trio enjoys science and writing. They love to explore new topics and are especially interested in eco-friendly ways to combat climate crises to create a brighter future for our planet. Helena likes to hike and play soccer. She also adores her two cats. Momo enjoys being in nature, especially in city parks, because urban ecology shows her how strong nature can be. Tati loves dogs. She is an amazing sewer and builder. Momo took the lead in this review but usually they do everything together.

JAMES, AGE: 10
Hi, my name is James and I like basketball and soccer. My favorite subject is Math. In the future, I want to be an electronical and mechanical engineer, for example a car expert. I love doing craft with using natural materials, such as wood sticks or vine, to make backpacks.

AUTHORS

ANNIE FOPPERT

Annie Foppert is a physical oceanographer in the Australian Antarctic Program Partnership. She works at the Institute for Marine and Antarctic Studies, University of Tasmania in Hobart, Tasmania. She uses various kinds of ocean observations to study the circulation and dynamics of the Southern Ocean, including data from floating devices, data collected by instruments attached to the heads of seals, shipboard surveys, satellite data, and more. Her favorite part of being an oceanographer is going to sea, spending weeks out on the ocean in large research vessels, collecting data and admiring the natural wonders of the world. *annie.foppert@utas.edu.au

PAUL SPENCE

Paul Spence is an associate professor of ocean climate modeling at the Institute for Marine and Antarctic Studies, University of Tasmania. He uses physics and computers to understand the ocean's role in global climate. Paul grew up in a small town in Canada playing in the Great Lakes and dreaming of the ocean. He thinks the Southern Ocean is the "one ring to bring them all, and in the darkness bind them" (quote from The Lord of the Rings by J.R.R. Tolkien).