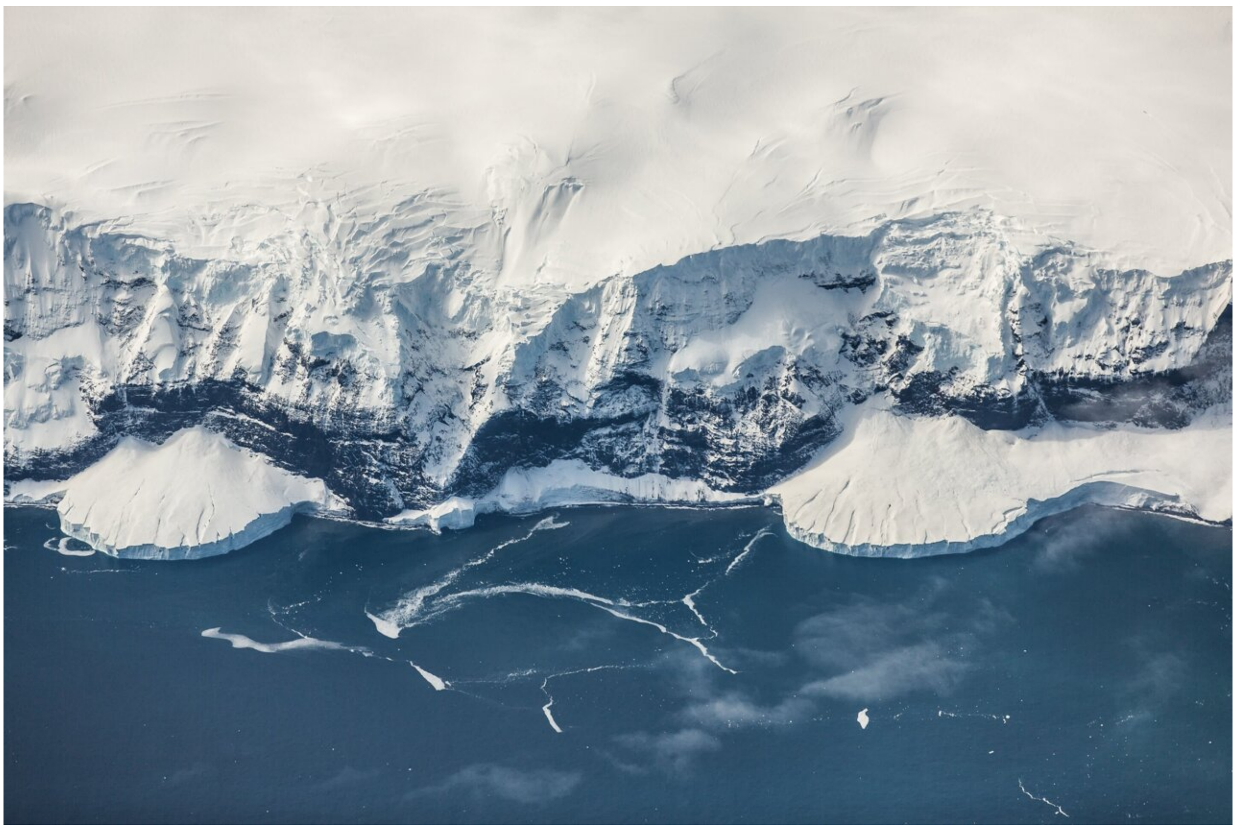
Research aircraft reveal a surprisingly strong Southern Ocean carbon sink

December 2 2021



Credit: Unsplash/CC0 Public Domain

The Southern Ocean is a significant carbon sink, absorbing a large amount of the excess carbon dioxide emitted into the atmosphere by human activities, according to a new study led by the National Center for

Atmospheric Research (NCAR).

The findings provide clarity about the role the icy waters surrounding Antarctica play in buffering the impact of increasing greenhouse gas emissions, after research published in recent years suggested the Southern Ocean might be less of a sink than previously thought.

The new study, published this week in the journal *Science*, makes use of observations from research aircraft flown during three field projects over nearly a decade, as well as a collection of atmospheric models, to determine that the Southern Ocean takes up significantly more carbon than it releases. The research also highlights the power that airborne observations have to reveal critical patterns in the global carbon cycle.

"You can't fool the atmosphere," said NCAR scientist Matthew Long, the paper's lead author. "While measurements taken from the ocean surface and from land are important, they are too sparse to provide a reliable picture of air-sea carbon flux. The atmosphere, however, can integrate fluxes over large expanses. Airborne measurements show a drawdown of CO_2 in the lower atmosphere over the Southern Ocean surface in summer, indicating carbon uptake by the ocean."

Uncertainty about the role of the Southern Ocean

Once human-produced emissions of CO_2—from burning fossil fuels and other activities—enter the atmosphere, some of the gas is taken up by plants and some is absorbed into the ocean. While the overall concentration of CO_2 in the atmosphere continues to increase, causing the global temperature to rise, these land and ocean "sinks" slow the effect.

A more precise understanding of where carbon sinks exist, how big they are, and how they may be changing as society continues to emit more

CO_2 is crucial to projecting the future trajectory of climate change. It is also necessary for evaluating the impact of potential emission reduction measures and CO_2 removal technologies.

Scientists have long thought that the Southern Ocean is an important carbon sink. In the region around Antarctica, cold water from the deep ocean is transported to the surface. This upwelling water may not have seen the surface of the ocean for hundreds of years—but once in contact with the atmosphere, it's able to absorb CO_2 before sinking again.

Measurements of CO_2 and related properties in the ocean suggest that 40 percent of all human-produced CO_2 now stored in the ocean was originally taken up by the Southern Ocean. But measuring the actual flux at the surface—the back and forth exchange of CO_2 between the water and the overlying air throughout a year—has been challenging.

In recent years, scientists have used observations of pH taken from autonomous floats deployed in the Southern Ocean to infer information about air-sea carbon flux. The results of those efforts suggested that the carbon sink in the Southern Ocean might be much smaller than previously thought. The possibility that the prevailing understanding of the role the Southern Ocean plays in the carbon cycle might be wrong generated a lot of discussion within the scientific community and left unanswered questions, including where the excess CO_2 is going if not into the Southern Ocean. Could there be a significant sink on land or elsewhere in the global oceans that scientists have missed?

The value of atmospheric measurements

In the new study, the research team sought to address the uncertainty by looking at carbon in the air instead of in the water. The atmosphere and the ocean exist in balance, and they are constantly exchanging CO_2, oxygen, and other gases with each other.

The research team pieced together airborne measurements from three different field projects with deployments stretching over nearly a decade: the HIAPER Pole-to-Pole Observations (HIPPO) project, the O_2/N_2 Ratio and CO_2 Airborne Southern Ocean (ORCAS) study, and the Atmospheric Tomography (ATom) mission.

While there are also surface monitoring stations that measure CO_2 in the atmosphere over the Southern Ocean, these stations are relatively few and far between, making it difficult to characterize what is happening across the entire region.

"The atmospheric CO_2 signals over the Southern Ocean are small and challenging to measure, especially from surface stations using different instruments run by different laboratories," said NCAR scientist Britton Stephens, a co-author of the study who co-led or participated in all of the field campaigns. "But with the suite of high-performance instrumentation we flew, the signals were striking and unequivocal."

Critically, the data from the aircraft campaigns captured the vertical CO_2 gradient. For example, during the NSF-funded ORCAS field campaign, which took place in January and February 2016, Stephens, Long, and other scientists on board the NSF/NCAR HIAPER Gulfstream V research aircraft could see a decrease in CO_2 concentrations on their instruments as the plane descended.

"Every time the GV dipped near the surface, turbulence increased—indicating the air was in contact with the ocean—at precisely the moment when all the CO_2 instruments registered a drop in concentrations," Stephens said. "You could feel it."

The new study finds that this gradient is quite sensitive to the air-sea carbon flux, offering researchers an unprecedented opportunity to characterize the Southern Ocean's carbon uptake.

"We needed observations that included both intensive surveys at a particular time of the year and that spanned the seasonal cycle," Long said. "That was the motivation for combining multiple aircraft campaigns that span roughly a decade. We were able to aggregate them together to assess the mean seasonal cycle of CO_2 variability in the atmosphere."

After piecing together how CO_2 typically varies in the atmosphere at a particular time of the year, the research team turned to a suite of atmospheric models to help them translate their atmospheric profiles into an estimate of how much CO_2 the ocean was soaking up or releasing. Their conclusion was that the Southern Ocean takes in significantly more carbon in the summer than it loses during the winter, absorbing a whopping 2 billion tons of CO_2 over the course of a year. In the summer, blooms of photosynthetic algae, or phytoplankton, play a key role in driving CO_2 uptake into the ocean.

The research team noted that a regular program of future airborne observations over the Southern Ocean could also help scientists understand whether the area's capacity to continue taking up carbon may change in the future. A similar measurement strategy could yield important information in other regions of the globe too.

"We've really seen that these observations are hugely powerful," Long said. "Future aircraft observations could yield extremely high scientific value for the investment. It's critical that we have a finger on the pulse of the carbon cycle as we enter a period when global society is taking action to reduce CO_2 in the atmosphere. These observations can help us do just that."

More information: Matthew Long, Strong Southern Ocean Carbon Uptake Evident in Airborne Observations, *Science* (2021). DOI: 10.1126/science.abi4355. www.science.org/doi/10.1126/science.abi4355

Provided by National Center for Atmospheric Research