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Mysterious Holes in Antarctic Sea Ice Explained by Years of Robotic Data

Strategic placement of Argo floats yields trove of information

The winter ice on the surface of Antarctica's Weddell Sea occasionally develops an enormous hole. In 2016 and 2017, one such hole drew intense curiosity from scientists and the media.

Scripps oceanographer Lynne Talley's selection of locations to deploy floats off Antarctica helped give scientists an unprecedented vantage on the formation of a polynya in the Weddell Sea in 2016 and 2017.

Though bigger gaps had formed decades before, this was the first time oceanographers had a chance to truly monitor the unexpected gap in Antarctic winter sea ice. It was an opportunity that came about as a result of uncanny timing and a seasoned oceanographer's knowledge of the sea.

A new study co-authored by researchers from Scripps Institution of Oceanography at the University of California San Diego combines satellite images of the sea ice cover and data collected by robotic drifters and even seals outfitted with sensors to better understand the phenomenon. The research led by the University of Washington (UW) explores why this hole appears only some years, and what role it could play in the larger ocean circulation.

The study, published June 10 in the journal Nature, touches on a region considered crucial to climate by oceanographers. The Southern Ocean is thought to play a key role in global ocean currents and carbon cycles, but its behavior is poorly understood. It hosts some of the fiercest storms on the planet, with winds whipping uninterrupted around Antarctica in the 24-hour darkness of polar winter. The study suggests that the phenomena those winds set in motion can have implications for climate worldwide.

"We thought this large hole in the sea ice – known as a polynya – was something that was rare, maybe a process that had gone extinct. But the events in 2016 and 2017 forced us to reevaluate that," said lead author Ethan Campbell, a UW doctoral student in oceanography. "Observations show that the recent polynyas opened from a combination of factors: One being the unusual ocean conditions, and the other being a series of very intense storms that swirled over the Weddell Sea with almost hurricane-force winds."

A "polynya," a Russian word that roughly means "hole in the ice," can form near shore as wind pushes the ice around. But it can also appear far from the coast and stick around for weeks to months, where it acts as an oasis for penguins, whales, and seals to pop up and breathe.

This particular spot far from the Antarctic coast often has small openings and has seen large polynyas before. The biggest known polynyas at that location were in 1974, 1975, and 1976, just after the first satellites were launched, when an area the size of New Zealand remained ice-free through three consecutive Antarctic winters despite air temperatures far below freezing.

The new study used observations from the Southern Ocean Carbon and Climate Observations and Modeling project, or SOCCOM, which has been deploying instruments since 2014 that drift with the currents to monitor Antarctic conditions. Key to the success of the project was the selection of sites in the Weddell Sea where instruments were deployed. In late 2014, Scripps oceanographer Lynne Talley, one of the chief scientists in SOCCOM, chose the location in part because of a distinct feature – an underwater mountain known as Maud Rise. The research team launched modified versions of floats originally built for Argo – a network of nearly 4,000 robots that collect fundamental data to depths of 2,000 meters (6,500 feet) around the world. These specialized units – known as biogeochemical Argo floats – have additional instrumentation that enables measurements related to biological activity.

A study co-author, Talley said she targeted the Maud Rise area because she knew it to be associated with interesting climate phenomena. She knew there was a good chance the ocean physics around the mountain could entrain the floats around the mountain, which could lead to a bonanza of data.

“But we had no clue that the largest event since the mid-1970s would be occurring just when we put those floats in,” she added.

By chance, the formation of the giant polynya occurred in 2016 when the floats were still present in the region to capture the event. A NASA satellite image in August of that year revealed a 33,000-square-kilometer (13,000-square-mile) gap that appeared for three weeks.

An even bigger gap that grew to 50,000 square kilometers (19,000 square miles) appeared in September and October of 2017.

“Recognizing the importance of the Maud Rise region to climate, Lynne ensured Argo floats were present in the area as part of the SOCCOM project,” said Scripps researcher Matt Mazloff, a co-author of the paper. “The float data enabled a thorough study of the causes and impacts of this ice-cover opening, as well as a new understanding of the historical events.”

The study used other Argo data as well as data collected by elephant seals outfitted with tags that beam it back to shore, weather stations, atmospheric reanalysis, and decades of satellite images.

"This study shows that this polynya is actually caused by a number of factors that all have to line up for it to happen," said co-author Stephen Riser, a UW professor of oceanography. "In any given year you could have several of these things happen, but unless you get them all, then you don't get a polynya."

The study shows that when winds surrounding Antarctica draw closer to shore, they promote stronger upward mixing of waters in the eastern Weddell Sea. In that region, Maud Rise forces dense seawater around it and leaves a spinning vortex above. Two SOCCOM instruments were trapped in the vortex above Maud Rise and recorded years of observations there.

Analysis shows that when the surface ocean is especially salty, as was seen throughout 2016, strong winter storms can set off an overturning circulation in which warmer, saltier water from the depths gets churned up to the surface. There air chills it and makes it denser than the water below. As that water sinks, relatively warmer deep water of about 1℃ (34℉) replaces it at the surface, creating a feedback loop where ice can't re-form.

“The mixing that Ethan found over Maud Rise also mixes nutrients and contributed to a large and early chlorophyll bloom that was measured by SOCCOM’s biogeochemical floats,” said Talley, “so we have lots more to discover and understand about this event.”

Driven by climate change, fresh water from melting glaciers and other sources is expected to make the Southern Ocean's surface layer less dense, which might mean fewer polynyas in the future. But the new study questions that assumption. Many models show that the winds circling Antarctica will become stronger and draw closer to the coast. The new paper suggests this would encourage more polynyas to form, not fewer.

These are the first observations to prove that even a smaller polynya like 2016's moves water from the surface all the way to the deep ocean.

"Essentially it's a flipping over of the entire ocean, rather than an injection of surface water on a one-way trip from the surface to the deep," said co-author Earle Wilson (PDF), who recently completed his doctorate in oceanography at the UW.

One way that a surface polynya influences climate is through deep water known as Antarctic Bottom Water. Where and how the deep water is created affects its characteristics, and that would have ripple effects on other major ocean currents.

"Right now people think most of the bottom water is forming on the Antarctic shelf, but these big offshore polynyas might have been more common in the past," Riser said. "We need to improve our models so we can study this process, which could have larger-scale climate implications."

Large and long-lasting polynyas can also affect the atmosphere, because deep water contains carbon from lifeforms that have sunk over centuries and dissolved on their way down. Once this water reaches the surface that carbon could be released.

"This deep reservoir of carbon has been locked away for hundreds of years, and in a polynya it might get ventilated at the surface through this really violent mixing," Campbell said. "A large carbon outgassing event could really whack the climate system if it happened multiple years in a row."

“This polynya was a significant event with important implications regarding our changing climate. It was thanks to Lynne’s wisdom to deploy floats over the Maud Rise that it was so well documented,” Mazloff said. “In addition to this study, other analyses are beginning to emerge, which is a testament to both the significance of the event and the amount of information we have gathered on it thanks to SOCCOM.”

Other co-authors on the paper are Kent Moore at the University of Toronto, who was the 2016-17 Canada Fulbright Visiting Chair in Arctic Studies at the UW; and Casey Brayton at the University of South Carolina, who initiated her work in the project as part of the Summer Undergraduate Research Fellowship (SURF) program at Scripps.

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