New study finds early warning signs prior to 2002 Antarctic ice shelf collapse

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Large tabular icebergs located between Antarctica's Larsen C ice shelf and the A-68 ice island, which calved off of the Larsen C, as seen on a NASA Operation IceBridge mission on Oct. 16, 2018. Credit: NASA

In 2002, an area of ice about the size of Rhode Island dramatically broke away from Antarctica as the Larsen B ice shelf collapsed. A new study of the conditions that led to the collapse may reveal warning signs to watch for future Antarctic ice shelf retreat, according to a Penn State-led team of scientists.

"The collapse of the Larsen B ice shelf is generally thought of as an independent event," said Shujie Wang, assistant professor of geography at Penn State. "Our work shows that it was the last phase in a calving sequence that began in 1998 and was controlled by both atmospheric and oceanic warming anomalies that weakened the ice shelf structure over time."

Ice shelves are floating tongues of ice connected to land but extend out and float on ocean water. Scientists have long known that warming air and ocean temperatures melt and weaken ice shelves from the surface and the subsurface, but the exact processes leading to collapse are not well understood.

And because ice shelves act as a buttress, holding back glaciers on land flowing toward the ocean, understanding how they will react to continued warming is important for getting sea-level rise predictions right, the scientists said.

"Ice-shelf loss from environmental warming is the fastest way for Antarctica to drive sea-level rise, but remains very hard to predict in part because we have so few observations," said Richard Alley, Evan Pugh University Professor of Geosciences at Penn State and a co-author on the study. "The Larsen B ice shelf was not holding back much land ice, and so its loss was not very important for sea level, but it offers an outstanding laboratory to learn the early warning signs and the processes of ice-shelf loss. The new insights gained here should help in the larger effort to project how warming will interact with the ice shelves to control future contributions to sea-level rise."

The scientists gathered data on the ice shelf from as far back as the 1960s and analyzed changes over time using satellite observations, modeling experiments and climate reanalysis data.

Prior to the 2002 collapse, the ice shelf experienced a transition from typical large calving events—when chunks of ice break off into the ocean—to more frequent, smaller calving and to a faster, widespread flow of ice toward the sea.

"Typically, large chunks of ice break off, regrow for decades and break off again," said Wang, lead author on the study and an associate of the Earth and Environmental Systems Institute and Institute for Computational and Data Sciences at Penn State. "Here, many smaller calving events occurred, and the ice did not regrow. And when it retreated from rocky islands that served as a buttress for the ice shelf, that could no longer hold the flow back."

The findings suggest that widespread flow acceleration and frequent small-iceberg calving may serve as quantifiable precursors for ice-shelf destabilization, the scientists reported in the journal *Earth and Planetary Science Letters*.

Five calving pulses observed between 1998 to 2002 corresponded with climate anomalies caused by La Niña and the Southern Annular Mode, characterized by strong westerly winds in the Southern hemisphere moving closer to Antarctica.

Warmer ocean waters may have cut sub-ice-shelf channels, further weakening vulnerable parts of the ice shelf called shear margins. These margins separate flowing ice from stagnant ice or rock, and the areas often have more fractures and softer ice, the scientists said.

"The results suggest that warm climate anomalies control the occurrence of calving, while the extent and speed of calving are governed by ice shelf geometry and mechanical conditions, in particular, the sturdiness of the weakest shear margin," Wang said.

Failure of a shear margin in the northern portion of the ice sheet may have triggered the calving pulses, and as the ice retreated, it moved away from rocky islands that had served as buttresses holding the sheet in place, the scientists said.

"When you pin a piece of paper to a wall, the pins prevent the paper from falling to the floor," Wang said. "It's the same with ice flow—these rocky islands serve as 'pinning points' that anchor ice and slow down its march to the sea."

The distribution of these pinning points may help determine the vulnerability of an ice sheet, as a weak shear margin with limited buttressing sources played a predominant role in destabilizing the Larsen B ice shelf and starting the small-iceberg calving sequence, the scientists reported.

"Those smaller areas matter for the whole region," Wang said. "If you think about an ice shelf as a complex system, local areas may have a dominant impact on the whole ice shelf. These fundamentals are important because if we don't understand the fundamentals, we can't make the most accurate predictions for the future."

More information: Shujie Wang et al, Multidecadal pre- and post-collapse dynamics of the northern Larsen Ice Shelf, *Earth and Planetary Science Letters* (2023). DOI: 10.1016/j.epsl.2023.118077

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