Friction means Antarctic glaciers more sensitive to climate change than we thought

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Antarctic glacier. Credit: British Antarctic Survey

One of the biggest unknowns in understanding the effects of climate change today is the melting rate of glacial ice in Antarctica. Scientists agree rising atmospheric and ocean temperatures could destabilize these ice sheets, but there is uncertainty about how fast they will lose ice.

The West Antarctic Ice Sheet is of particular concern to scientists because it contains enough ice to raise global sea level by up to 16 feet, and its physical configuration makes it susceptible to melting by warm ocean water. Recent studies have suggested that the collapse of certain parts of the ice sheet is inevitable. But will that process take several decades or centuries?

Research by Caltech scientists now suggests that estimates of future rates of melt for the West Antarctic Ice Sheet—and, by extension, of future sea-level rise—have been too conservative. In a new study, published online on March 9 in the *Journal of Glaciology*, a team led by Victor Tsai, an assistant professor of geophysics, found that properly accounting for Coulomb friction—a type of friction generated by solid surfaces sliding against one another—in computer models significantly increases estimates of how sensitive the ice sheet is to temperature perturbations driven by climate change.

Unlike other ice sheets that are moored to land above the ocean, most of West Antarctica's ice sheet is grounded on a sloping rock bed that lies below sea level. In the past decade or so, scientists have focused on the coastal part of the ice sheet where the land ice meets the ocean, called the "grounding line," as vital for accurately determining the melting rate of ice in the southern continent.

"Our results show that the stability of the whole ice sheet and our ability to predict its future melting is extremely sensitive to what happens in a very small region right at the grounding line. It is crucial to accurately represent the physics here in numerical models," says study coauthor Andrew Thompson, an assistant professor of environmental science and engineering at Caltech.

Part of the seafloor on which the West Antarctic Ice Sheet rests slopes upward toward the ocean in what scientists call a "reverse slope gradient." The end of the ice sheet also floats on the ocean surface so that ocean currents can deliver warm water to its base and melt the ice from below. Scientists think this "basal melting" could cause the grounding line to retreat inland, where the ice sheet is thicker. Because ice thickness is a key factor in controlling ice discharge near the coast, scientists worry that the retreat of the grounding line could accelerate the rate of interior ice flow into the oceans. Grounding line recession also contributes to the thinning and melting away of the region's ice shelves—thick, floating extensions of the ice sheet that help reduce the flow of ice into the sea.

According to Tsai, many earlier models of ice sheet dynamics tried to simplify calculations by assuming that ice loss is controlled solely by viscous stresses, that is, forces that apply to "sticky fluids" such as honey—or in this case, flowing ice. The conventional models thus accounted for the flow of ice around obstacles but ignored friction. "Accounting for frictional stresses at the ice sheet bottom in addition to the viscous stresses changes the physical picture dramatically," Tsai says.

In their new study, Tsai's team used computer simulations to show that even though Coulomb friction affects only a relatively small zone on an ice sheet, it can have a big impact on ice stream flow and overall ice sheet stability.

In most previous models, the ice sheet sits firmly on the bed and generates a downward stress that helps keep it attached it to the seafloor. Furthermore, the models assumed that this stress remains constant up to the grounding line, where the ice sheet floats, at which point the stress disappears.

Tsai and his team argue that their model provides a more realistic representation—in which the stress on the bottom of the ice sheet gradually weakens as one approaches the coasts and grounding line, because the weight of the ice sheet is increasingly counteracted by water pressure at the glacier base. "Because a strong basal shear stress cannot occur in the Coulomb model, it completely changes how the forces balance at the grounding line," Thompson says.

Tsai says the idea of investigating the effects of Coulomb friction on ice sheet dynamics came to him after rereading a classic study on the topic by American metallurgist and glaciologist Johannes Weertman from Northwestern University. "I wondered how might the behavior of the ice sheet differ if one factored in this water-pressure effect from the ocean, which Weertman didn't know would be important when he published his paper in 1974," Tsai says.

Tsai thought about how this could be achieved and realized the answer might lie in another field in which he is actively involved: earthquake research. "In seismology, Coulomb friction is very important because earthquakes are thought to be the result of the edge of one tectonic plate sliding against the edge of another plate frictionally," Tsai said. "This ice sheet research came about partly because I'm working on both glaciology and earthquakes."

If the team's Coulomb model is correct, it could have important implications for predictions of ice loss in Antarctica as a result of climate change. Indeed, for any given increase in temperature, the model predicts a bigger change in the rate of ice loss than is forecasted in previous models. "We predict that the ice sheets are more sensitive to perturbations such as temperature," Tsai says.

Hilmar Gudmundsson, a glaciologist with the British Antarctic Survey in Cambridge, UK, called the team's results "highly significant." "Their work gives further weight to the idea that a marine ice sheet, such as the West Antarctic Ice Sheet, is indeed, or at least has the potential to become, unstable," says Gudmundsson, who was not involved in the study.

Glaciologist Richard Alley, of Pennsylvania State University, noted that historical studies have shown that ice sheets can remain stable for centuries or millennia and then switch to a different configuration suddenly.

"If another sudden switch happens in West Antarctica, sea level could rise a lot, so understanding what is going on at the grounding lines is essential," says Alley, who also did not participate in the research.

"Tsai and coauthors have taken another important step in solving this difficult problem," he says.

Provided by California Institute of Technology

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