Glaciers are squishy, holding slightly more ice than thought

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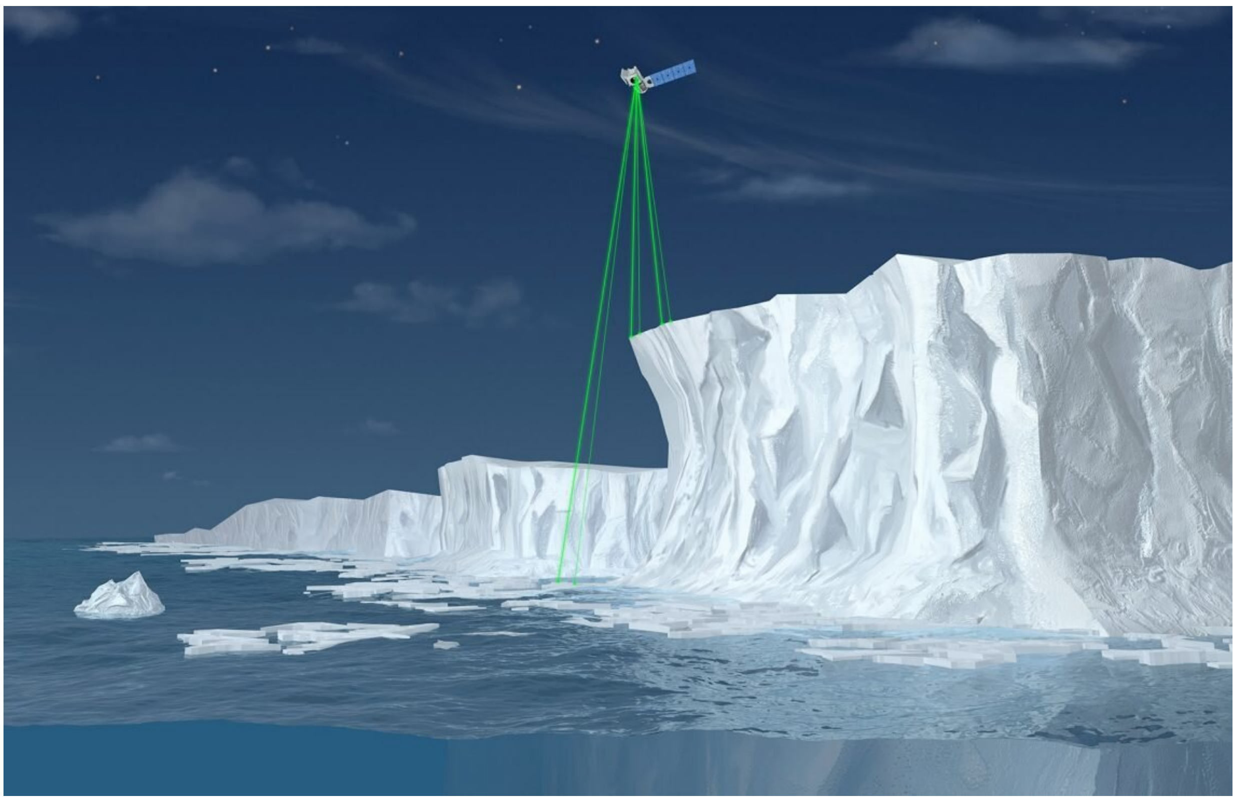

NASA's ICESat-2 uses six laser beams (green) to measure elevations over an ice sheet from space, as illustrated in this artist's rendering. Accounting for the ice sheet's compressibility could make these types of measurements even more precise. Credit: NASA, ICESat-2/SCAD Collaborative Student Project

Glacier ice is usually thought of as brittle. You can drill a hole in an ice sheet, like into a rock, and glaciers crack and calve, leaving behind vertical ice cliffs.

But new University of Washington research shows that glaciers are also slightly compressible, or squishy. This compression over the huge expanse of an ice sheet—like Antarctica or Greenland—makes the overall ice sheet more dense and lowers the surface by tens of feet compared to what would otherwise be expected, according to results published Jan. 19 in the *Journal of Glaciology*.

"It's like finding hidden ice," said author Brad Lipovsky, a UW assistant professor of Earth and space sciences. "In a sense, we discovered a big piece of missing ice that wasn't accounted for correctly."

Compression of the ice lowers the surface by up to 37 feet (11.3 meters) on the Antarctic ice sheet and by up to 19 feet (5.8 meters) on the Greenland ice sheet. Averaged across the entire Antarctic ice sheet, the surface is lower by 2.3 feet (0.7 meters), which represents 30,200 gigatons of additional ice. For Greenland, the surface of the ice sheet is lowered by an average of 2.6 feet (0.8 meters), which represents 3,000 gigatons of ice.

The mass of the ice sheet is only partly to blame: Since a glacier's temperature increases with depth, thermal compression makes the colder ice, near the surface of the ice sheet, denser, squishing the ice almost as much as its weight.

Together, the combined effects of gravitational and thermal compression add about 0.2% to the total mass of the ice sheet. Though that sounds small, including this effect will help improve calculations of glacier changes over time—especially as the newest satellites can make precise measurements of glaciers' elevation to monitor their responses to climate change.

Brad Lipovsky (right) hikes over Easton Glacier on Washington’s Mount Baker in September 2021 with UW graduate students Danny Hogan (left) and Quinn Brencher. Credit: Mark Stone/University of Washington

"The long-term behavior of the ice is that it flows, and it also slides a bit. But at the same time, if you hit the ice with a hammer, it goes bing, bing, bing," Lipovsky said. "On short timescales the glacier is a solid, and on long timescales it's a fluid."

Currently even the long-term climate models don't account for the compression, which becomes a bigger effect for large ice sheets like in Antarctica and Greenland.

"In the long-term flow models, ice is always treated as incompressible. I think if you had really pressed people, and said, "There's seismic pressure waves in glaciers, they must be compressible," they would have agreed. But it's not something people have been thinking about," Lipovsky said.

The additional water content probably doesn't matter to future sea-level rise—the new results might add 8 inches (20 centimeters) to the projected 260 feet (80 meters) of sea level rise in the very unlikely event of all the planet's glaciers melting, Lipovsky said.

But compressibility affects measurements of the difference in glacier elevation between winter, when they are weighted with fresh snow, and summer, when much of that snow has drained off. These seasonal measurements are used to monitor how the glacier is changing over time. The new study estimates that adding ice compressibility could eliminate about one-tenth of the error around these estimates, improving the monitoring of large ice sheets as they respond to climate change.

"Going forward, I hope this will become a correction that's more commonly accounted for," Lipovsky said.

More information: Bradley Paul Lipovsky, Density matters: ice compressibility and glacier mass estimation, *Journal of Glaciology* (2022). DOI: 10.1017/jog.2021.132

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