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The secrets hidden under the Antarctic ice sheet

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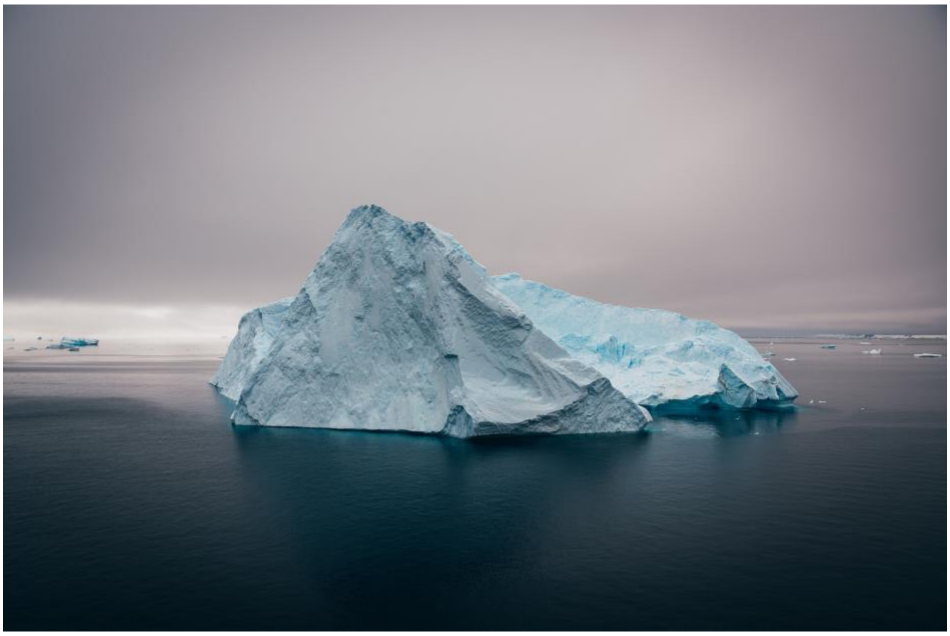
ABSTRACT

Antarctica is losing ice. The shape of the bed under the ice sheet may explain why some sectors are more vulnerable to climate change than others. It is, however, extremely difficult to see through thousands of meters of ice. By combining measurements at the surface with math, we find the deepest canyon on Earth and ridges that have important consequences for its future stability.



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The Antarctic ice sheet has been losing ice at an increasing rate. It remains unclear whether this mass loss will further accelerate over the coming decades. The continent of Antarctica is vast, bigger than the US and Mexico combined, and because it is so cold there, the snow does not melt and becomes ice. The ice layer is so thick that it deforms under its own weight to form rivers, called ice streams, which transport ice from the interior of the ice sheet to the coast. For the ice sheet to be stable, there needs to be a perfect balance between the mass added through the accumulation of snow at the surface, and the mass removed through melting at the ice/ocean interface or through the formation of icebergs along the coast. We observe today that, while the precipitations of snow have been rather stable over the past decades, there has been a large increase in the discharge of ice into the ocean and extensive retreat.

One of the most important factors that control how quickly the ice sheet will be retreating as the climate continues to warm is the shape of the bedrock underneath the ice. The regions where the bedrock deepens as we move inland, for example, are particularly unstable and the glaciers that flow over these landscapes can retreat rapidly inland until the bed rises again or if there is a pronounced ridge in the topography that can act as "anchor point" and stop or slow down the retreat. It is, therefore, essential to map the bed as precisely as possible. The problem is that this landscape is buried under thousands of meters of ice, and remains extremely poorly known, making it difficult to predict how fast sea level will rise over the coming decades to centuries.

The most efficient way of determining the shape of the bedrock consists of mounting a radar under the wings of airplanes and then fly over the ice sheet. The antenna sends an electromagnetic wave that can penetrate the ice and then is reflected at the ice/bed interface. The time it takes for the radar signal to travel from the surface of the ice sheet to the bed is then converted into ice thickness, and by subtracting that from the surface elevation, we get the bed elevation directly underneath the aircraft. While efficient, it is completely impractical and cost-prohibitive to use this method to map the landscape under the entire ice sheet. Therefore, we developed a method that combines these sparse measurements with other datasets: ice speed measured by satellite, and snow accumulation rates from regional climate models, to reconstruct the ice thickness in-between measurements based on the physical principle of conservation of mass. The idea is fairly simple: what comes in has to come out since ice is an incompressible fluid. In zones of convergence of flow, we expect a depression in the bed topography, and in a zone of divergence, we expect the bed to rise. By combining all available data, we mapped the entire coast of Antarctica, where this method is most robust and made a new map of the bed: BedMachine.

This approach reveals the widespread presence of deep submarine ice-covered valleys, with a bed deep enough below sea level to enable strong interactions between ice and oceanic heat. Some of these valleys had never been found before and coincided with the presence of fast ice streams. We also found that Glaciers flowing across the Transantarctic Mountains and Victoria Land are protected by broad, stabilizing ridges near the location where grounded ice becomes afloat. These ridges are located in the middle of deep troughs but rise above sea level, making it virtually impossible for glaciers to retreat further upstream on short time scales. This is one of the good news of this study! Under Denman glacier in East Antarctica, we mapped a valley of more than 3,500 m below sea level for the first time, reaching the deepest continental point on Earth. This canyon could be one of the weak points of East Antarctica, that holds significantly more ice the West Antarctica.

These newly unveiled topographic details have a profound impact on the distribution of potential higher-risk zones for the rapid sea-level rise from Antarctica that calls for a re-evaluation by numerical ice sheet models using the new ice-sheet geometry.