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Ice sheet melting: it's not just about sea level rise

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ABSTRACT

Climate change is causing the Greenland and Antarctic Ice Sheets to melt, which releases cold, fresh meltwater into the nearby ocean. This meltwater causes sea level rise, but a lesser-known side effect is the disruption of deep ocean currents, and climate patterns worldwide. Our modelling study investigated these processes.

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You've probably heard that climate change is melting the polar ice caps - but what does this actually mean? It refers to the Greenland and Antarctic Ice Sheets, which are large systems of interconnected glaciers, kilometres thick. They are formed by snow falling on land, which compacts into ice and slowly flows downhill towards the ocean. When the ice sheets come into contact with a warming atmosphere or ocean, they begin to melt faster than new ice can form. This releases cold, fresh meltwater into the surrounding ocean. The most well-known consequence of this process is sea level rise, as the volume of the ocean increases. Unfortunately, there are other side effects beyond sea level rise.

The oceans around Greenland and Antarctica are unusual, because they are the only regions of the world's oceans with significant vertical mixing. Everywhere else, the ocean is stratified, forming layers of water organised by density, with the lightest water at the surface and the heaviest water at the seafloor. The layers don't interact with each other very much. But in a few locations around the coast of Antarctica, as well as in the North Atlantic Ocean near Greenland, surface water becomes cold and salty enough to sink into the deep ocean. Then it slowly travels around the world for about a thousand years, like a deep-ocean conveyor belt, before resurfacing. This process of "deep water formation", occurring in just a few regions, affects deep ocean currents which transport heat around the world and influence climate patterns worldwide. But what happens when ice sheet meltwater is released into these deep water formation regions? How are the ocean currents and climate patterns affected?

Our study addressed this question using two different models: an ice sheet model, which simulates the flow of the glaciers making up the Greenland and Antarctic Ice Sheets, and a climate model, which simulates the global atmosphere, ocean, sea ice, and vegetation. Both models run on supercomputers and solve huge numbers of physics equations. Our study was novel because the ice sheet model and the climate model were able to communicate with each other, exchanging information regularly throughout the simulations.

We ran a number of different simulations over the 21st century, using several different scenarios for fossil fuel emissions, which might decline in the future but might continue to grow. In some experiments, the climate model considered the effect of ice sheet meltwater in its calculations; in other experiments, it ignored the meltwater. This allowed us to isolate the impact of ice sheet meltwater on the climate system.

In our simulations, ice sheet melting slowed down the rate of nearby deep water formation. The fresh meltwater reduced the density of the surface ocean, making it more difficult for surface waters to sink. In the North Atlantic, this reduction in deep water formation altered the pathways of nearby ocean currents. The Gulf Stream, which travels up the east coast of North America, and its extension the North Atlantic Drift, which cuts across the Atlantic towards Europe, were redirected such that less heat was transported from North America to Europe. While both locations still warmed (due to climate change), eastern North America experienced a bit of extra warming, while in Europe some of the warming was cancelled out. Furthermore, temperatures became more variable in many regions, indicating a greater prevalence of extreme weather.

Around Antarctica, deep water formation connects the cold atmosphere to the warmer subsurface ocean. This allows the ocean to release heat, warming the atmosphere while cooling the deep ocean. In our simulations, a reduction in deep water formation suppressed this effect, trapping heat beneath the ocean surface. Ice sheet melting therefore caused the atmosphere around Antarctica to warm less than it otherwise would have, while the subsurface ocean warmed more dramatically. This result is particularly troubling because the Antarctic Ice Sheet is in contact with these regions of the ocean. It suggests a vicious cycle whereby ice sheet melting causes subsurface ocean warming, which causes more ice sheet melting, and so on.

It is now clear that the effects of ice sheet melting are not just limited to sea level rise. We can expect ice sheet meltwater to have many more side effects, on ocean currents and weather patterns. But how much will the ice sheets actually melt? That depends on fossil fuel emissions, and how they change in the future. Our study used models, but the same experiment is currently being run in the real world, in real time.