West Antarctica's contribution to sea level rise as Earth's climate warms

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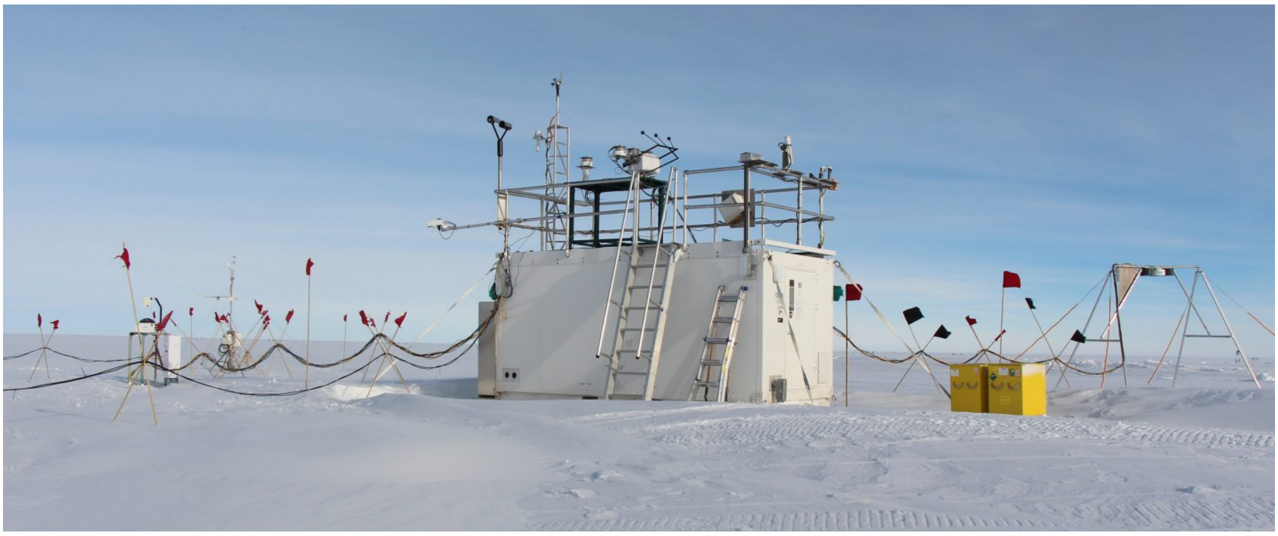

Meteorological and remote sensing instruments on the West Antarctic Ice Sheet during the AWARE field campaign

Dr Dan Lubin, Researcher at the Scripps Institution of Oceanography, explores the contribution of West Antarctica to sea level rise as Earth's climate warms

Sea level rise (SLR) is one of the most pressing concerns with greenhouse gas-induced climate warming. Over one-third of the human population, including nearly two-thirds of the global urban population, lives within 100 km of the sea.

SLR increases flooding from storm surges and high tides, deterioration of infrastructure, shoreline erosion, contamination of agriculture, and numerous other hardships. Climate warming causes SLR in two primary ways: the melting of polar ice sheets and glaciers and the thermal expansion of the ocean as it warms.

The two largest contributors to SLR from the steadily warming polar regions are the Greenland Ice Sheet (GIS) and the West Antarctic Ice Sheet (WAIS), at approximately 280 and 160 gigatons of ice per year, respectively. The GIS and WAIS have contrasts in the details of their ice mass loss.

Most of the GIS is situated on terrain above sea level, and the GIS is exposed to every atmospheric anomaly that brings near-surface air temperatures above freezing. Over the past two decades, GIS mass loss has been relentless and closely tied to large-scale weather patterns in the North Atlantic and the overall global warming trend.

The West Antarctic Ice Sheet

In contrast, the WAIS is a marine ice sheet, meaning that it is situated on terrain mostly below sea level. The location where the ice sheet meets the ocean is called the grounding line. Most of West Antarctica's underlying terrain slopes downward to increasing depths below sea level as one travels inland from the grounding line.

An ice sheet gradually settles under its own weight, with ice flowing outward toward the ocean. The total mass contained in an ice sheet results from the balance between this gravitational outflow (mass loss) and the gradual accumulation of snowfall over many years (mass gain).

But in recent decades, steady warming of the Southern Ocean has melted ice at the WAIS grounding line and, in many places, driven it inland and toward lower depths, meaning the ice sheet's thickness at the grounding line has increased.

As the ice sheet becomes thicker at its exit point into the ocean, its outflow rate increases. Hence, the WAIS is fundamentally unstable in a steadily warming climate. Because ocean warming is very steady compared with atmospheric warming impulses that have interannual variability, WAIS mass loss is steadily accelerating.

The great ice sheets

The great ice sheets aren't spatially uniform in their gradual motion. Due to underlying terrain, some locations are static while others exhibit motion channeled into an ice stream, commonly called a glacier.

In West Antarctica, the Thwaites and Pine Island Glaciers are recognized as locations of great vulnerability. These fast-moving glaciers overlay terrain that connects a large section of the entire WAIS, meaning that the acceleration of these glaciers could reach a tipping point in which much of the WAIS collapses rapidly into the Southern Ocean.

This has happened before, during the Last Interglacial (LIG) approximately 120,000 years ago, and as a result, the sea level was several meters higher than today.

One critical part of this system is the network of ice shelves at the edge of West Antarctica. An ice shelf is a floating extension of the glacier beyond the grounding line. Ice shelves are themselves anchored to adjacent land masses.

They, therefore, provide essential buttressing that slows down the glaciers' outflow, much like the flying buttresses of a medieval gothic cathedral allow the structure to bear the weight of the enormous roof. If the ice shelves are lost in a warming climate, glacial outflow and ice sheet mass loss will accelerate further.

An ice shelf is particularly vulnerable to a warming climate. Meltwater on its surface rapidly percolates downward throughout the structure, weakening it in a process called hydrofracturing. Eventually, the structure becomes weak enough that wind and wave motion break it apart.

This happened to the Larsen-B Ice Shelf on the Antarctic Peninsula in 2002, which largely disintegrated within 35 days, and is also happening now on the Larsen-C Ice Shelf farther south.

Where research is needed

To understand and project the future of the WAIS, research is needed in all aspects of this complex mechanical system the size of Western Europe. The structure of the ice sheet and its underlying terrain require better understanding. Glacier motion must be continuously monitored over the extent of all ice streams. Trends in ocean circulation and temperature beneath the ice shelves and at the grounding lines must be measured. Atmospheric impacts must be understood, including trends in precipitation that build up the ice sheets and warming episodes that damage the ice shelves.

The Polar Center at Scripps Oceanography makes important contributions to these research areas. The Center has led vital satellite remote sensing surveys using NASA's ICESat-2 (for which Center Director Prof. Helen Fricker is Science Team Lead), ICESat, and space-based radar missions, which reveal the extent of ice sheet and ice shelf loss, including details of the driving mechanisms.

The Polar Center also conducts atmospheric fieldwork in West Antarctica to measure the radiative energy inputs that either induce or inhibit ice shelf surface melting, and to discern how meteorological factors, from large-scale circulation to local cloud properties, influence this surface energy.

In 2018, the British Antarctic Survey and the United States Antarctic Program joined forces to send state-of-the-art geophysical equipment to Thwaites Glacier. This project, the International Thwaites Glacier Collaboration (ITGC) has deployed research vessels operating autonomous underwater vehicles and sediment coring equipment, and field parties operating ice-penetrating radars, seismic and meteorological instruments, and borehole drilling equipment, working in concert with modelers who develop advanced ice sheet simulations to synthesize the myriad observations and improve our fundamental understanding.

Revolutionize our understanding of the WAIS

Resources such as ITGC and NASA's space-based sensors are beginning to revolutionize our understanding of the WAIS response to a warming climate. Still, the extreme remoteness and harsh environment imposes many logistical and practical limitations for any single effort. West Antarctica will require ongoing research efforts over the next decade to reliably project its contribution to SLR throughout the 21st century.

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