Antarctica's Thwaites Glacier and sea-level rise

September 2025

Results from the International Thwaites Glacier Collaboration (ITGC)

Executive Summary

Change to Thwaites Glacier in West Antarctica, sometimes referred to as the "Doomsday Glacier", over the coming decades and centuries will have profound implications for global sea-level rise and coastal communities around the world. Over the past seven years, our research on the glacier has unveiled a complex and rapidly changing environment.

Thwaites Glacier's retreat has accelerated considerably over the past 40 years. Although a full collapse is unlikely to occur in the next few decades, our findings indicate it is set to retreat further, and faster, through the 21st and 22nd centuries, and general collapse of the West Antarctic Ice Sheet over this timeframe cannot be ruled out. Further research is urgently needed to refine this timeline.

Immediate and sustained climate change mitigation (decarbonisation) offers the best hope of delaying this ice loss and avoiding initiation of similar unstable retreat in marine-based sectors of East Antarctica.

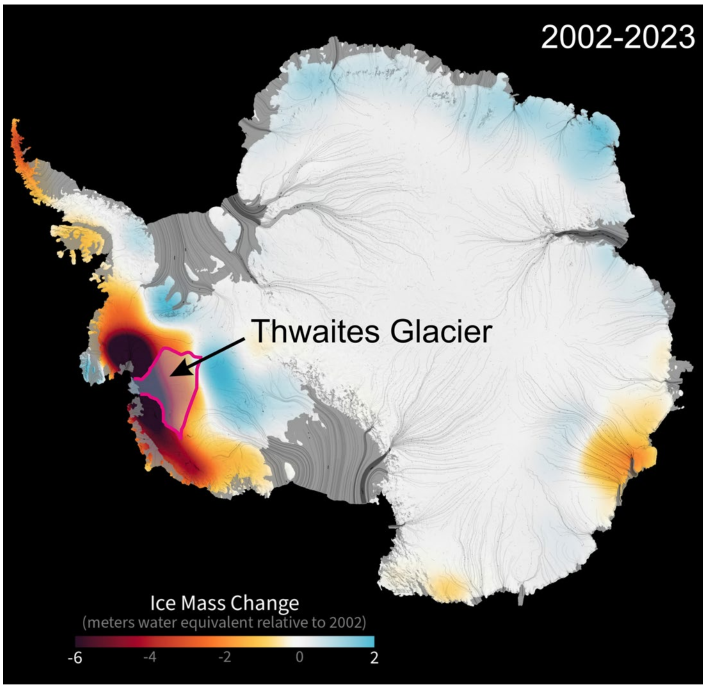
Introduction

West Antarctica has long been an area of interest and concern for scientists, because of its vulnerability to climate or ocean changes. The inherent instability of an ice sheet resting on bedrock deep below sea level was recognized early in the mapping of the region. If this part of the ice sheet collapses entirely it will raise sea levels by more than 3 metres. Satellite data since the mid-1990s have shown rapid ice loss from the Amundsen Sea sector of West Antarctica, centred on Pine Island, Thwaites, Pope, Smith, and Kohler glaciers, raising concerns about the possibility of a general collapse.

Antarctica remains the biggest wild card for understanding and forecasting future sea-level rise. The Intergovernmental Panel on Climate Change has said that, depending on future greenhouse gas emissions, global sea levels are likely to rise this century by between about 40-80 cm, and by up to almost two metres in a scenario where runaway ice-sheet instability processes take hold.

Following some key studies beginning two decades ago, it was widely recognised that Thwaites Glacier posed a potential threat of rapid contributions to sea level. Prior to our research, little was known about the mechanisms controlling the retreat of this enormous glacier - one of the largest and fastest-changing glaciers in the world. If it collapsed entirely, sea level would rise by 65 cm. Thwaites Glacier spans an area equal to the island of Great Britain or the US state of Florida, and in places is almost 4000 m (13,000 ft) thick. The amount of ice flowing into the sea from Thwaites Glacier and its neighbouring glaciers more than doubled from the 1990s to the 2010s, and the Amundsen Sea region now accounts for 8% of the current rate of global sea-level rise of 4.5 mm a year.

In 2018, the United Kingdom and the United States launched a scientific and logistical partnership to study Thwaites Glacier. This effort aims to study and predict how Thwaites Glacier will contribute to global sea-level rise, potentially severely affecting coastal communities around the world, from Bangladesh and Pacific islands to Miami and London. The mission is to gain an understanding of the critical physical processes controlling the glacier, and to build a more reliable prediction of how the glacier will change in the near future. In the briefest terms, how much, and how fast, will this region respond to climate change and raise sea level?



Antarctic ice-sheet mass change from 2002-2023. Adapted from NASA/JPL CalTech graphic

More than 100 scientists are participating in the seven-year, $50 million International Thwaites Glacier Collaboration (ITGC), funded by the US National Science Foundation (NSF) and the UK Natural Environment Research Council (NERC), making huge progress in understanding the processes that control ice loss from the glacier. Additional important contributions have been made by partners in Sweden, Germany, and South Korea.

Results from the collaboration so far indicate that some potential scenarios for runaway glacier change, which suggested an abrupt increase in the rate of ice loss could occur within even the next couple of decades, are less likely than previously feared. However, our latest results and computer models indicate that rapid ice loss from the gigantic retreating glacier, which was initiated by climate and ocean changes, will continue and the rate of loss will accelerate. ITGC studies have also revealed previously unknown processes that could weaken the glacier and lead to more rapid future ice loss than currently projected.

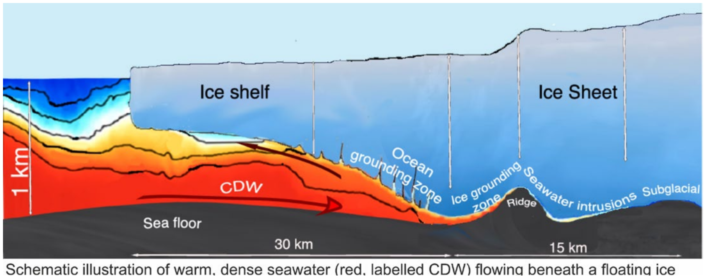
Key findings of the ITGC

The last remaining area of ice shelf in front of Thwaites is nearing break-up

The Thwaites Eastern Ice Shelf (TEIS), currently covering about half of the 120 km-wide front of the glacier, is likely to break up and drift away in the coming decade. Ice shelves, extensions of glaciers floating on the ocean, usually slow the flow of land-based ice by resisting the push from the ice upstream. However, observations and models show that TEIS already lost much of its capacity to resist flow and therefore its final breakup is not expected to cause a sudden, large acceleration of ice loss. It will, though, change how the ocean interacts with the newly-exposed ice front and may alter the retreat rate.

Underwater robots discovered a host of new melt processes and have shown us what the undersides of ice shelves look like

A torpedo-shaped robot known as Icefin, lowered through a 600 m-deep hole drilled through the ice shelf with hot water, found that a thin layer of cold water is surprisingly stable and effective in insulating much of the underside of the shelf. This slows the melt on the flat-lying parts of the floating ice. In places near where the ice begins to go afloat (the "grounding zone") and elsewhere beneath the floating ice, however, stronger melting occurs along vertical steps in the ice base and on the walls of crevasses. Under a nearby ice shelf, sonar mapping from a robotic submersible (autonomous underwater vehicle, or AUV) revealed terrace-like features and teardrop-shaped indentations indicative of episodic melting and uneven erosion of the floating ice. In general, melting underneath the ice was found to be far more varied spatially than was suspected prior to ITGC. This new understanding is important for forecasting how long ice shelves will provide an effective brake on the flow of glaciers feeding into them.



Schematic illustration of warm, dense seawater (red, labelled CDW) flowing beneath a floating ice shelf and being tidally pumped into a glacier grounding zone (from Rignot et al., 2024[1])

Tidally-driven seawater intrusions into the base of the glacier may hasten melting and retreat

New findings show how tides acting on the grounding zone are pumping warm sea water upstream under the ice. These areas draw in water from just above the seabed, and the flow of this water disrupts the cold insulating water layer at the ice base. The pumping process squeezes water at high pressure beneath the ice and pushes it upstream by as much as 10 km. This process, detected by both satellites and surface observations, will likely have a significant control on where and how fast the grounding zone retreats. Furthermore, ocean modelling and remote sensing data have suggested that the region of extended seawater intrusions may be the locus of the strongest melting of basal ice in the entire cavity system, which makes the exploration of this part of the ice shelf system a top priority for future research.

Seabed evidence shows past episode of retreat even faster than is seen today

The top of a seabed ridge near the front of Thwaites Glacier has imprinted patterns like an old-fashioned washboard. The size and spacing of the ridges show an unmistakable signal left by the glacier's grounding line as it interacted with tides during retreat across its bed several centuries ago. These features indicate a period when the retreat rate was more than 2 km per year, twice as fast as the retreat of Thwaites Glacier today. This documents that retreat rates when the front of the glacier loses contact with a seabed ridge can be even faster than has yet been observed.

[1]Rignot, E. et al., 2024. PNAS, 121, e2404766121

The modern retreat was initiated in the 1940s

Marine geological studies show the ice shelves in front of both Thwaites and Pine Island glaciers detached from seabed ridges ("pinning points") in the 1940s, initiating the modern retreat. A strong El Niño ocean and climate event and a series of rapid swings between El Niño and La Niña patterns in the Pacific Ocean at that time probably influenced the timing of detachment. Marine geological records also suggest a mid-20th century increase in the amount of warm water at depth in the ocean in front of the two glaciers, and this warm water has been the main driver of subsequent glacier retreat.

Past recovery from thinning took several millennia

Rock samples obtained by drilling through the ice near the edge of a nearby glacier show that the glacier was previously thinner than present, since the rocks were exposed at the surface a few thousand years ago. The glacier later thickened to cover them again. This indicates that slow recovery of the glacier was possible in a climate similar to today, although one that was not changing so fast. Current projections of future climate indicate further warming of water on the continental shelf, the main driver of ice loss, leading to very different conditions from those that prevailed over the past few thousand years. This makes recovery comparable to that documented from the past very unlikely.

Critical data to support improved modelling have been gathered

Mapping of the seafloor at the ice front and beneath the ice shelf has detailed the channels and troughs that route warm water beneath the ice shelf and to the grounding zone of the glacier itself. Combined with high-resolution mapping of the bed beneath the glacier by seismic and radar sounding, these data also show the size and spacing of bumps, ridges and rocky outcrops that affect the flow of Thwaites Glacier and other glaciers in the Amundsen Sea region. Other results from studies on the lateral edge of Thwaites Glacier allow us to better understand what controls the position of its boundaries and what could cause them to shift in the future. All these results provide critical information needed by computer models to predict future changes in ice flow and glacier retreat.

The arrangement of sediments and hard bedrock beneath the glacier can affect the rates of retreat. Mapping of the glacial bed by seismic profiling and three-dimensional surveys has shown large variations in the resistance of the bed layer to the flow of the overlying ice. This confirms assessments made by remote sensing and ice deformation modelling from many years earlier. New modelling efforts, however, indicate that the most rapid retreats occur when there is a distribution of resistant bedrock ridges and slick sediment patches beneath the ice – faster than if the bed were dominated by either resistant bedrock or sediments alone. Thus, further detailed mapping of the bed of Thwaites and adjacent areas will be important to detailing the longer-term variations in ice loss as the ice sheet deflates.

Major advances in modelling have been made

Work is also progressing rapidly to incorporate new discoveries into models to refine projections of sea-level rise. Recent modelling studies suggest that Thwaites Glacier is less likely to collapse in this century by processes that were identified prior to ITGC. One worst case scenario considers the formation of high, fast-retreating ice cliffs at the glacier front that would cause it to collapse rapidly, raising sea level by tens of centimetres in this century. Computer modelling studies have shown that this process, while real, will not always be sustained, as tall cliffs also lead to rapid internal deformation near the ice front, lowering the cliff. Even without ice cliff-driven retreat or tidal intrusions into the grounding zone though, our latest models predict continuing rapid ice loss during this century that will accelerate further through the next century, potentially leading to a general collapse of the West Antarctic Ice Sheet.

Future outlook

Although ITGC research shows that the impending ice shelf collapse is unlikely to lead to an abrupt increase in the rate of ice loss within the next few decades, the medium-term outlook for Thwaites Glacier is grim. Warm water at depth from the Amundsen Sea continues to melt the front and underside of the glacier and ocean models show the temperature of this water will continue to increase through this century. The glacier is exceptionally vulnerable because it rests on a bed far below sea level that deepens towards the interior of the ice sheet and ice flow converges towards to modern glacier front, meaning that as the glacier retreats, ever more ice is exposed to warm ocean water. Furthermore, our research has also identified other processes driving melt that are not yet well understood and have the potential to significantly affect model forecasts of glacier change.

Our latest models predict continuing rapid ice loss that will accelerate. However, we have not yet quantified the amount of melt being driven by subglacial tidal pumping, or how change affecting the complex environment in grounding zones will affect glacier flow. New investments in research are needed to resolve these questions. The investment in ITGC has paid off already by answering many questions about Thwaites Glacier's behaviour in the years to come, while identifying critical new questions. Further investment in research, which is a trivial cost compared to the trillions of dollars that will need to be spent on adaptations to sea-level rise, is needed to answer these new questions and provide better constraints on what future to expect.

Even though accelerating ice loss from Thwaites Glacier and the wider Amundsen Sea region is now unavoidable, computer models indicate that reductions in greenhouse emissions in line with the 2015 Paris Agreement may yet delay runaway ice loss from West Antarctica, pushing the greatest acceleration later than the end of this century. Reductions in emissions will also reduce the risk of initiating similar unstable retreat in marine based sectors of East Antarctica and will mitigate ice loss from the Greenland Ice Sheet, smaller ice caps and mountain glaciers.

Key research questions for future studies

- How will conditions in the area evolve in the coming decades? Continued monitoring with ocean moorings, seismic, radar and GPS installations, and automatic weather stations is essential to obtain "ground truth" to validate and augment satellite observations of change. This requires a substantial logistic commitment. We cannot model what we cannot observe, especially for the ocean waters.
- Is the retreat of Thwaites Glacier now really unstoppable? Are there any mechanisms that might arrest or suspend retreat, and if so, what climate conditions would be required for them to occur? To what extent might increases in snow accumulation offset future ice loss? Why was previous ice thinning, thousands of years ago, reversible?
- How do ice-ocean interactions in the hidden world beneath ice shelves affect melt rates, and therefore control their ability to hold back glacier flow? The potential of ocean robotic devices to explore these environments has been demonstrated, but as yet they have not been able to explore the most critical region along the main trunk of Thwaites Glacier, which controls 80% of its ice discharge. Observations made with surface-based systems and borehole sensors are key to getting below the scale of what satellites or airborne systems can observe in such critical areas.
- How will the slope, irregularities and geology of the bed affect future ice flow and glacier retreat? This remains a priority because, despite collection of important data through ITGC, the detailed surveys obtained only cover a small portion of the glacier bed.
- How do tidal pumping, meltwater drainage, sediments and ice in grounding zones interact to affect melting, ice flow and glacier retreat? This newly appreciated process will need to be a major focus of further work and integration into models.
- Where and when might tall, rapidly-calving ice cliffs form during Thwaites Glacier's retreat? How effective would the resulting increases in ice flow and thinning rate near the ice front, and formation of ice mélange, be in slowing accelerated retreat?
- Where and when will glacier retreat accelerate? How, in detail, will the multiple metres of sea-level rise potential emerge from the West Antarctic Ice Sheet?
- How stable are the shear margins that bound Thwaites Glacier? Radar measurements show that the molecular properties of ice at these boundaries play a major role in their stability, and enables ice to flow at these boundaries, like sliding a standing deck of cards. Further measurements that reveal the geology and potential presence of meltwater at the bed, as well as deformational properties in the overlying ice, will inform and constrain future predictions.
- How much of what we have learnt about the Thwaites system can be translated to improve our understanding of other ice shelf/glacier systems globally? Is the Thwaites Glacier system typical of ice shelves and glaciers in West Antarctica? Can we use our knowledge about Thwaites Glacier to help constrain future contributions to sea level from other glaciers?