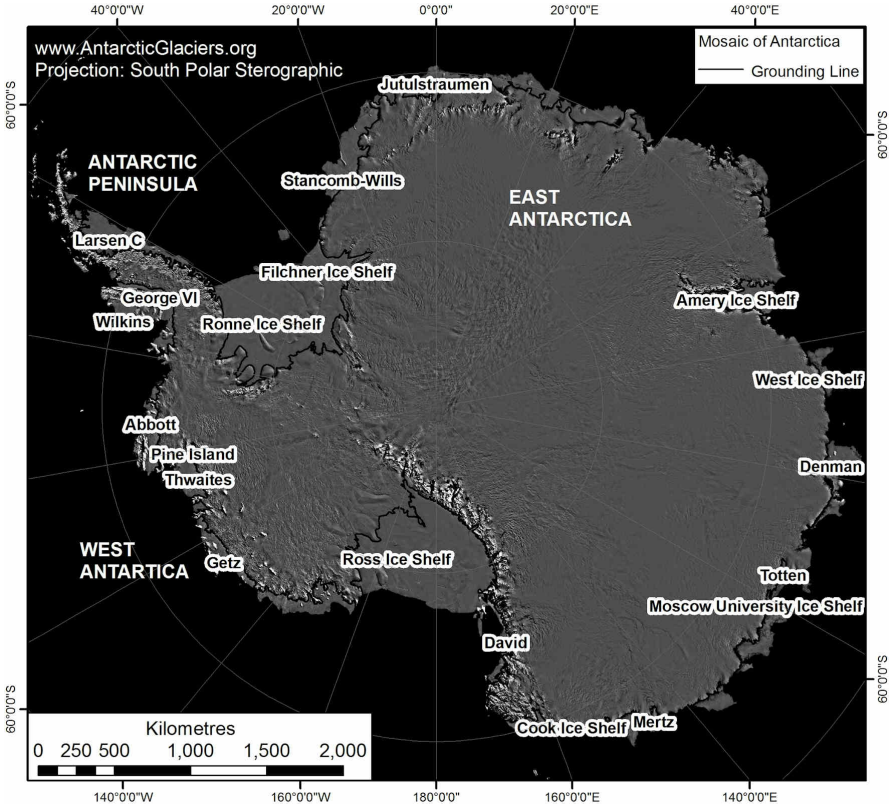
# Grounding Lines

## What is a grounding line?

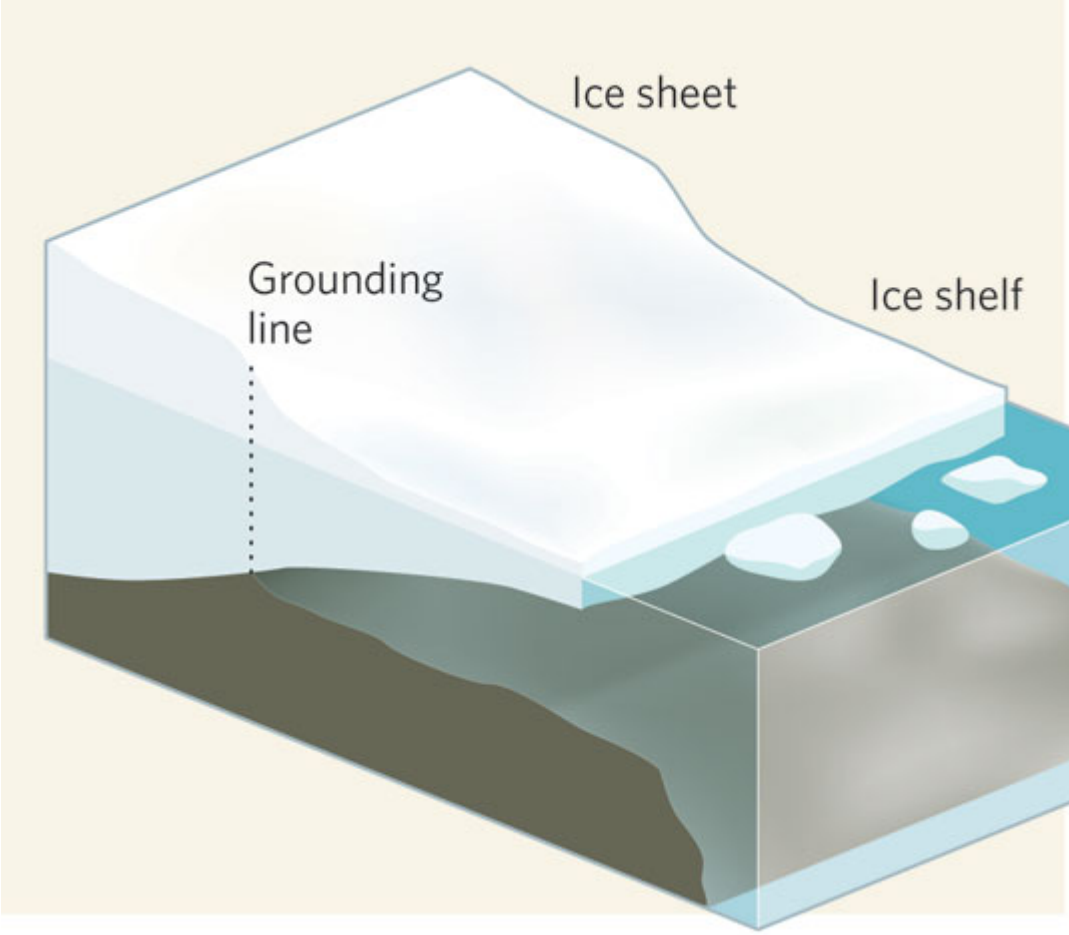
Almost all of Antarctica is covered in ice. Less than 1% its land area is ice free. This means that, across Antarctica, almost all glaciers end in the ocean, whereupon they calve icebergs. These glaciers can be grounded, or can end in floating ice tongues or larger ice shelves. These floating ice shelves move with the tide. Ice shelves fringe 75% of Antarctica's coastline, while collecting 20% of its snowfall over 11% of its area[1]. Basal melt from ice shelves is the largest melting process in Antarctica. Clearly, ice sheet – ocean interactions are extremely important for controlling ice sheet dynamics and rates of melting and recession.



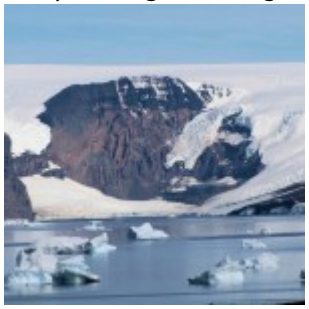
Landsat Image Mosaic of Antarctica (LIMA) showing location of key ice shelves.

Glaciers that end in the ocean like this are called **Tidewater Glaciers**. They may be **grounded** (the glacier is in contact with the bed entirely), or parts of the glacier terminus may be floating. Glaciers that flow into an ice shelf are **tributary glaciers.**

The point at which glaciers and ice shelves start to float is the **Grounding Line**. The location of the grounding line is important, because mass loss from Antarctica is strongly linked to changes in the ice shelves and their grounding lines[2, 3]. Change in the grounding line can result in very rapid changes in glacier and ice-shelf behaviour (for example, see Marine ice sheet instability).




Simplified grounding line image of an ice sheet. From: Huybrechts et al., 2009. Nature 458, 295-296.



Small tidewater glaciers calving into Croft Bay

A grounded tidewater glacier at Point Wild, Elephant Island

Floating ice tongues at Trinity Peninsula, Antarctic Peninsula

The Larsen Ice Shelf

A tidewater glacier calving icebergs

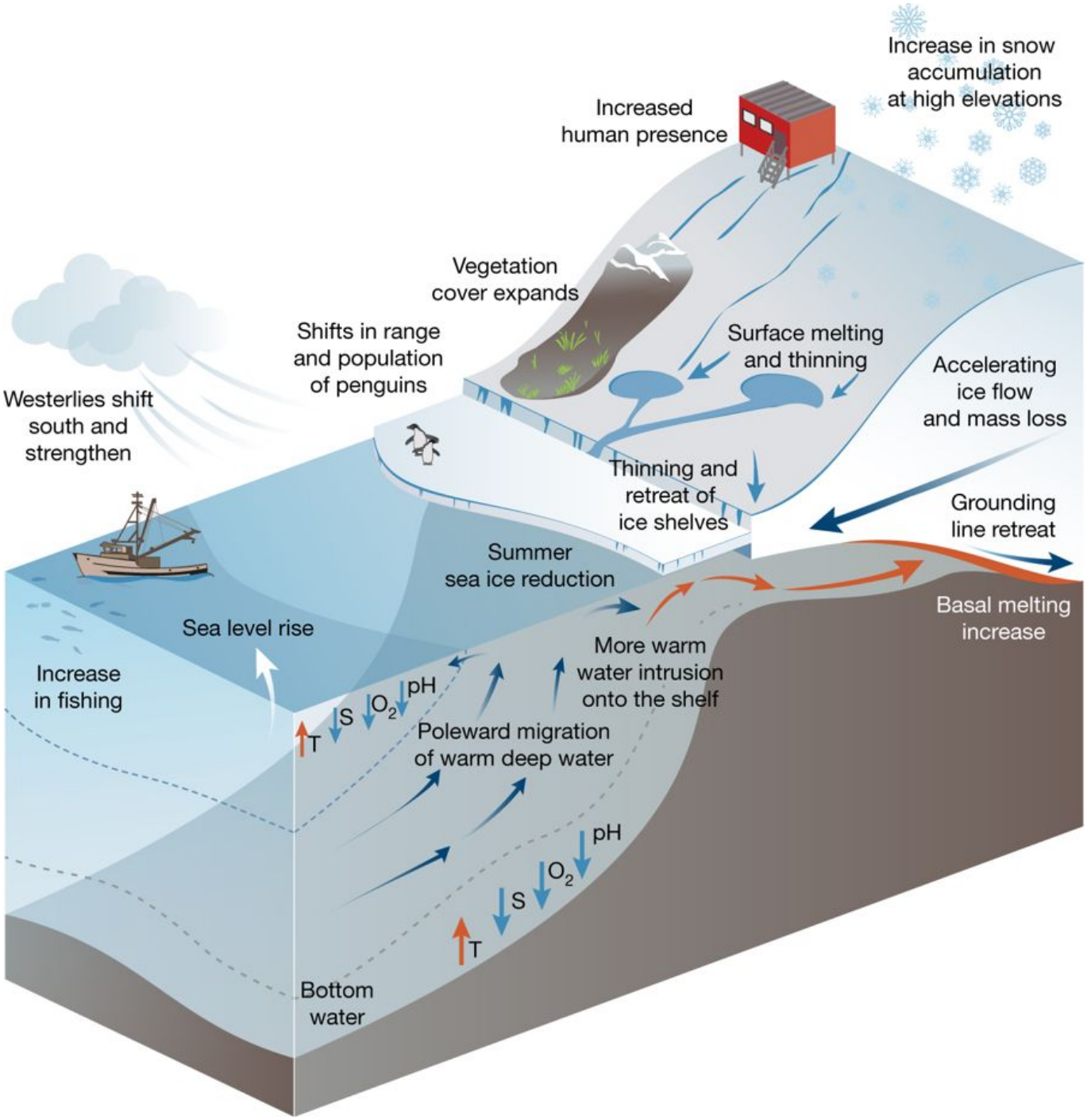
Crevasses on a glacier

Iceberg

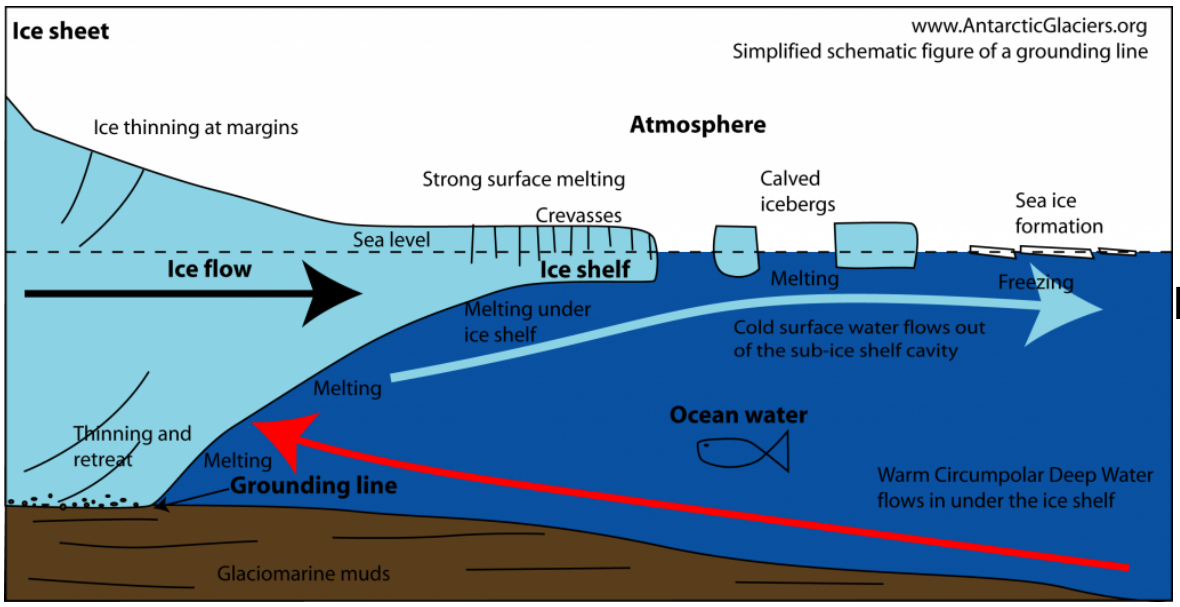
George VI Ice Shelf, looking towards Ablation Point. Note rifts and rumples in ice where a glacier flows into it.

A floating tidewater glacier on James Ross Island

The transition from grounded ice sheet to floating ice shelf plays an important role in controlling marine ice sheet dynamics, as it determines the rate at which ice flows out of the grounded part of the ice sheet[4]. This is because ice flux through the grounding line increases sharply with ice thickness at the grounding line. This means that grounding lines are unstable on reverse-bed slopes, such as those under Pine Island Glacier, because recession into deeper water increases ice flux and further encourages more glacier recession.



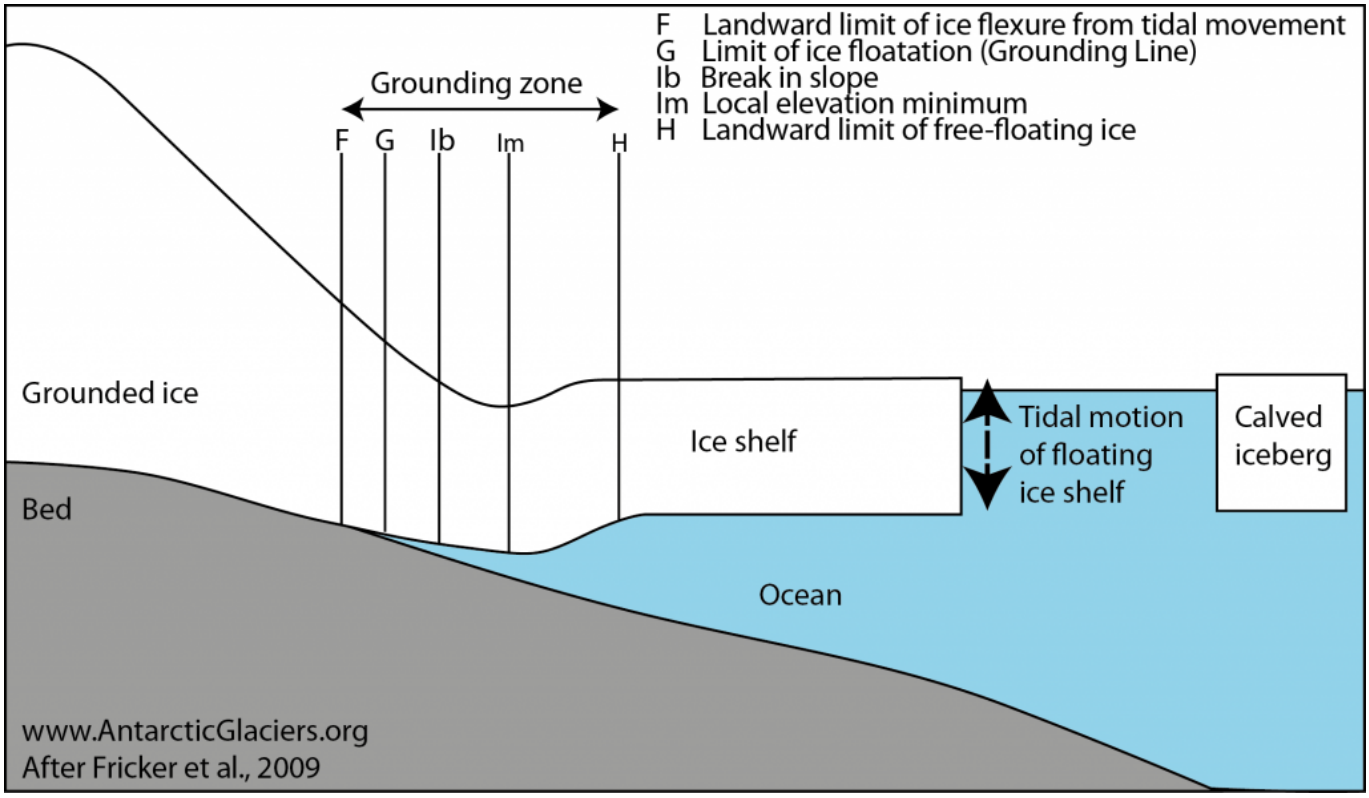

Summary of the impacts on Antarctica and the Southern Ocean in 2070, under a ‘high emissions’ scenario. Reprinted by permission from Nature [Nature Perspectives] [Choosing the future of Antarctica, S. Rintoul and colleagues] [Copyright 2018].




# Mapping the grounding line

Grounding lines are actually more of a *zone*. The grounding zone is the region where ice transitions from grounded ice sheet to freely floating ice shelf, typically over several kilometres. The floating ice shelf changes in elevation in response to tides, atmospheric air pressure and oceanic processes. Grounding occurs when the ice shelf comes into contact with the bedrock below.

The *grounding zone* is the region between point F on the figure below, where there is no tidal movement, and point H, which is the seaward limit of ice flexure, where the ice is free-floating.

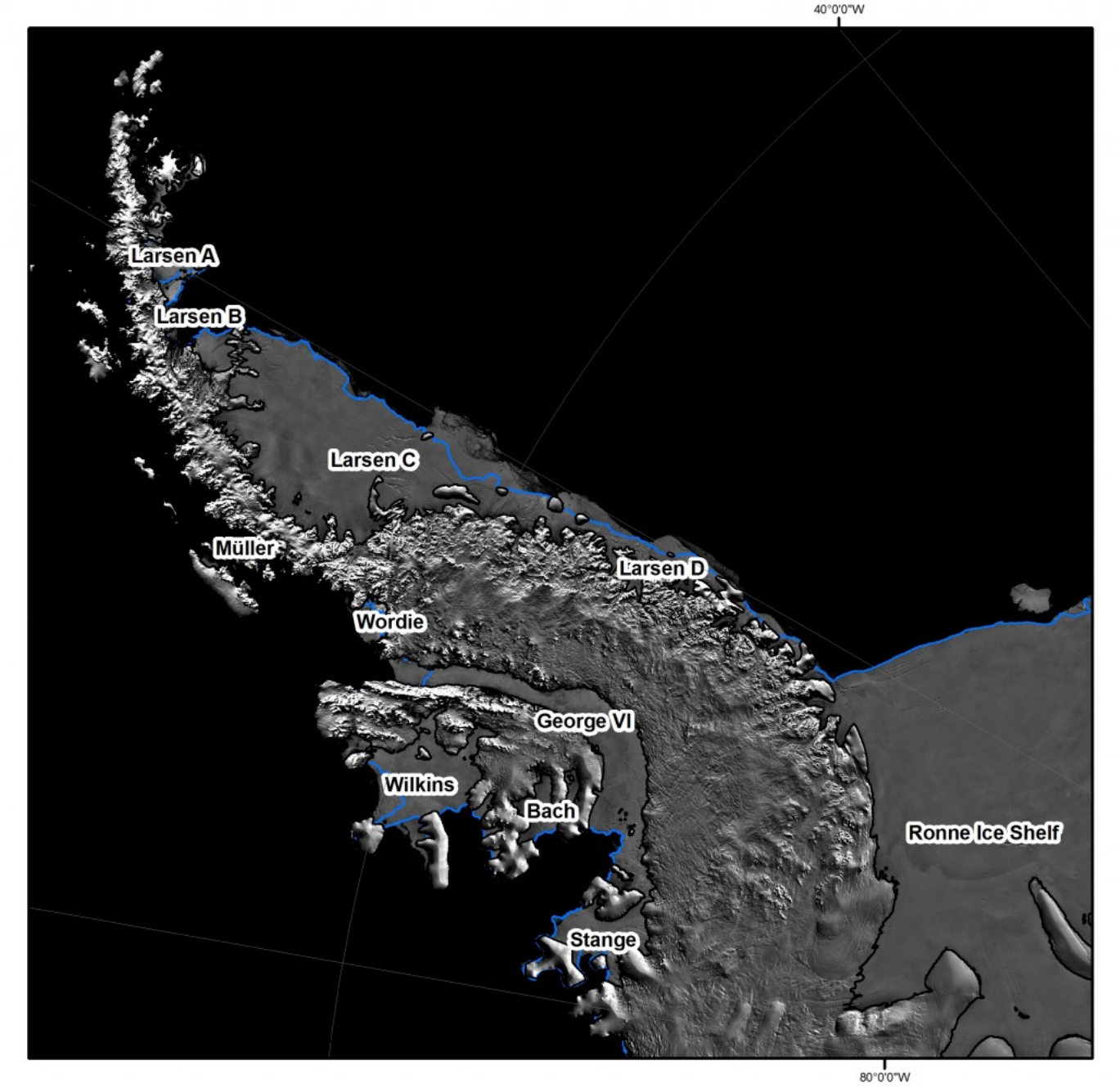



The grounding zone. After Fricker et al., 2009.

The grounding zone can be difficult to detect; it may take place over a wide area[5], and area can be remote and inaccessible and so difficult to monitor. Fortunately, there is a subtle feature that can be observed on satellite images. There is often an elevation minimum between points G and H (Point Im in the cartoon above). Elevation profiles across the grounding line will often show a break in slope

(Point Ib).

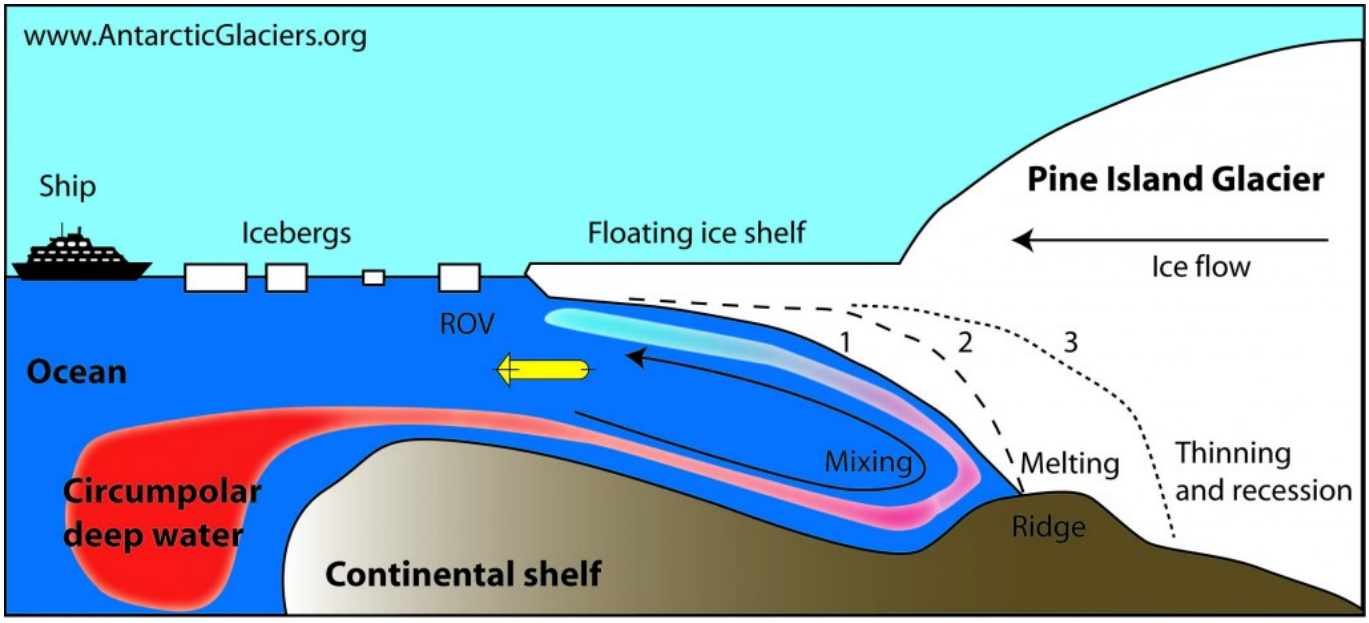
Other methods for detecting the grounding line rely on measuring changes in surface elevation during the tidal cycle, which can be measured by GPS or satellite synthetic aperture radar (eg., InSAR) or ICESat[2, 5, 6].




Antarctic Peninsula Ice Shelves. The grounding line is denoted by a thick black line.

## Current grounding line change

Across the Antarctic Peninsula and West Antarctica, increased upwelling of the relatively warm Circumpolar Deep Water is melting ice at the grounding line. In the Amundsen Sea, this has resulted in glacier acceleration, thinning, and grounding line recession. Circumpolar Deep Water, which is a key component of the Antarctic Circumpolar Current, is able to reach the undersides of the ice shelves and the grounding line by flowing through deep submarine troughs[7]. This has resulted in rapid grounding-line recession at Pine Island Glacier[8] – up to 31 km from 1992 to 2011.




1. Early 1970s. Pine Island Glacier is grounded at a bedrock ridge.
2. Warm, inflowing Circumpolar Deep Water melts the base of the glacier. The glacier steepens and accelerates.
3. Present day, observed by a remotely operated vehicle (ROV). Glacier is thinning and receding.

Warm Circumpolar Deep Water is penetrating beneath the ice shelves of Pine Island Glacier and Thwaites Glacier.

## Recognising grounding lines from the past

Grounding lines leave behind a distinct geomorphological and sedimentological record[9-14] on the continental shelf that scientists can use to map and date former grounding line positions. This crucial information can be used to reconstruct past ice-sheet extent; e,.g., [15, 16].

Grounding zone wedges form transverse to ice flow and can be mapped by ships equipped with swath bathymetry, which allows them to create a detailed topographical map of the sea floor[17]. These grounding zone wedges represent either past maximum ice-sheet extent, or recessional positions during deglaciation.

Grounding zone wedges (also known as ‘till deltas’ or ‘ice-contact submarine fan’[9]) build up under stable ice margins; they require the grounding line to remain in a stable position for long enough for enough sediment to accumulate to build a wedge or ridge[17]. Grounding zone wedges are sedimentary depocentres that form at the transition from grounded to floating ice. They typically consist of well-bedded foreset and bottomset deposits.

## Further reading

- Marine ice sheet instability
- Ice shelves

## References

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