



Ice shelf collapse

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What is an ice shelf?



NASA Dryden Flight Research Center Photo Collection
<http://www.dfrc.nasa.gov/Gallery/Photos/index.html>
NASA Photo: E204-0056-114 Date: March 13, 2004 Photo By: Jim Ross
The Larsen Ice Shelf in Antarctica viewed from NASA's DC-8 aircraft during the AirSAR 2004 campaign.

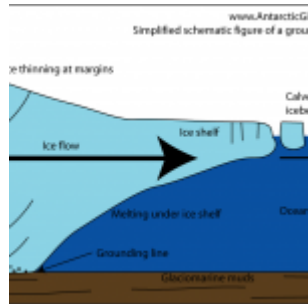
Larsen Ice Shelf in 2004

[Ice shelves](#) are floating tongues of ice that extend from grounded glaciers on land. Snow falls on glaciers, which flow downstream under gravity. Ice shelves are common around Antarctica, and the largest ones are the Ronne-Filchner, Ross and [McMurdo](#) Ice Shelves.

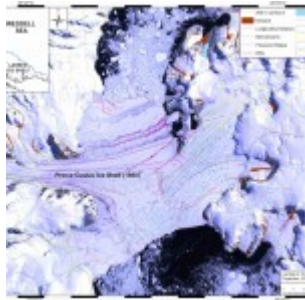
Ice shelves surround 75% of Antarctica's coastline, and cover an area of over 1.561 million square kilometres (a similar size to the Greenland Ice Sheet). Ice shelves gain mass from ice flowing into them from glaciers onland, from snow accumulation, and from the freezing of marine ice (sea water) to their undersides[1]. They lose mass by calving icebergs, and basal melting towards their outer margins, along with sublimation and wind drift on their surfaces. Ice shelves are important, because they play a role in the stability of the Antarctic Ice Sheet and the ice sheet's mass balance, and are important for ocean stratification and bottom water formation; this helps drive the world's thermohaline circulation. Melting from beneath ice shelves is one of the key ways in which the Antarctic Ice Sheet loses mass[1].

In the satellite image of Prince Gustav Ice Shelf below, you can see that the ice shelves have a very flat appearance. In fact, you can normally tell where the ice starts to float by a sharp break in slope at the *grounding line*. Ice shelves are therefore composed of ice derived from snowfall on land, but they also accrete marine ice from below[2]. Ice shelves are therefore distinct from sea ice, which form solely from freezing marine water. You can see an example from northern Antarctic Peninsula below. Prince Gustav Ice Shelf was situated between Trinity Peninsula and James Ross Island. It collapsed in 1995. You can see glaciological structures on the ice shelf, indicating that it flows out from its

tributary glaciers. You can also see abundant melt ponds on the ice shelf.



Schematic cartoon of a glacier flowing into an ice shelf, showing the grounding line and calving at the ice cliff at the edge of the ice shelf.



Glaciological structures in Prince Gustav Ice Shelf. Landsat 4 TM image from 1988.



Supraglacial meltwater lakes on McMurdo Ice Shelf. Credit: Neil Glasser.



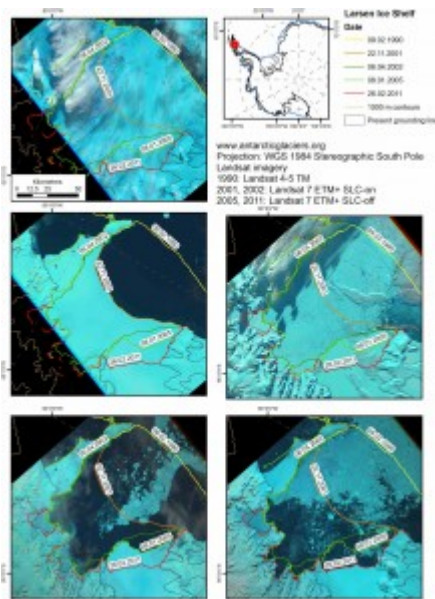
Meltwater lakes on McMurdo Ice Shelf

Ice shelves around Antarctica are up to 50,000 km² in size, and can be up to 2000 m thick. Their front terminus is often up to 100 m high. Ice shelves intermittently calve large icebergs, which is a normal part of their ablation. Around Antarctica, ice shelves form where mean annual temperatures are less than -9°C, with sequential break up of ice shelves as temperatures increase[3-5]. The geometry of the coastline is often important for determining where ice shelves will develop. The [Larsen Ice Shelf](#), for example, is formed in an embayment.

Ice shelf collapse

Several of the ice shelves around Antarctica have recently collapsed dramatically, rather than retreating in a slow and steady manner. Larsen A collapsed in 1995[6], and Larsen B Ice Shelf

famously collapsed in 2002. It has shrunk from 12,000 km² in 1963 to 2400 km² in 2010[4]. During February 2002, 3250 km² were lost through iceberg calving and fragmentation. In the figure below, you can see the blue, mottled appearance of the ice shelf in the 2002 image, caused by the exposure of deeper blue glacier ice.



Landsat images showing the collapse of the Larsen Ice Shelf. Note the blue mottled appearance in 2002, resulting from the exposure of deep blue ice.

Several ice shelves have now collapsed around the Antarctic Peninsula (Table 1). Their collapse has made it possible to core the sub-shelf sediments to investigate whether these collapses are part of normal ice-shelf behaviour. It appears that the more northerly ice shelves, such as Prince Gustav Ice Shelf, have indeed previously collapsed, resulting in open-marine organisms living in Prince Gustav Channel for a short period 5000 years ago[7]. However, the more southerly Larsen B Ice Shelf appears to have remained a fixture throughout the Holocene[8]. This suggests that certain thresholds have been passed, with environmental changes throughout the Antarctic Peninsula now surpassing any that have occurred before.

In the video below, you can see an animation of the Larsen Ice Shelf collapse from Modis imagery:

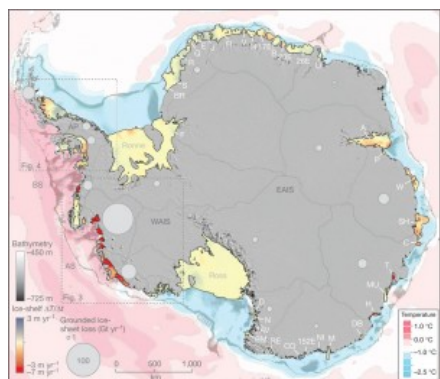
Table 1. Dates of ice shelf collapse

Ice shelf	Largest area (km ²)	Previous behaviour	Recent behaviour
Wordie	2000	???	1989 collapse
Larsen Inlet	400	Frequent removal throughout Holocene	1989 collapse
Prince Gustav	2100	Removal 5000 BP	1995 collapse
Larsen A	2500	Frequent removal throughout Holocene	1995 collapse
Larsen B	11,500	Stable throughout Holocene	2002 collapse
Jones	25	???	2003 collapse
Wilkins	16,577	Numerous large calving events	2008 collapse
Larsen C	60,000	Stable throughout Holocene	Thinning & retreating
Müller	50	Advance during the Little Ice Age	Gradual recession (50 % left)
George VI	26,000	Brief absence (9000 BP)	Still present & thinning. Confined, which may increase stability.

Mechanisms of ice shelf collapse

There are several reasons why ice shelves disintegrate rapidly rather than slowly and steadily shrinking. Ice shelves collapse in response to long term environmental changes, which cause on-going thinning and shrinking. When certain thresholds are passed, catastrophic ice shelf disintegration through iceberg calving is initiated. Before collapse, ice shelves first undergo a period of long-term thinning and basal melting, which makes them vulnerable. Meltwater ponding on the surface and tidal flexure and plate bending then all contribute to rapid calving events and ice shelf disintegration.

1. Long term thinning and basal melting



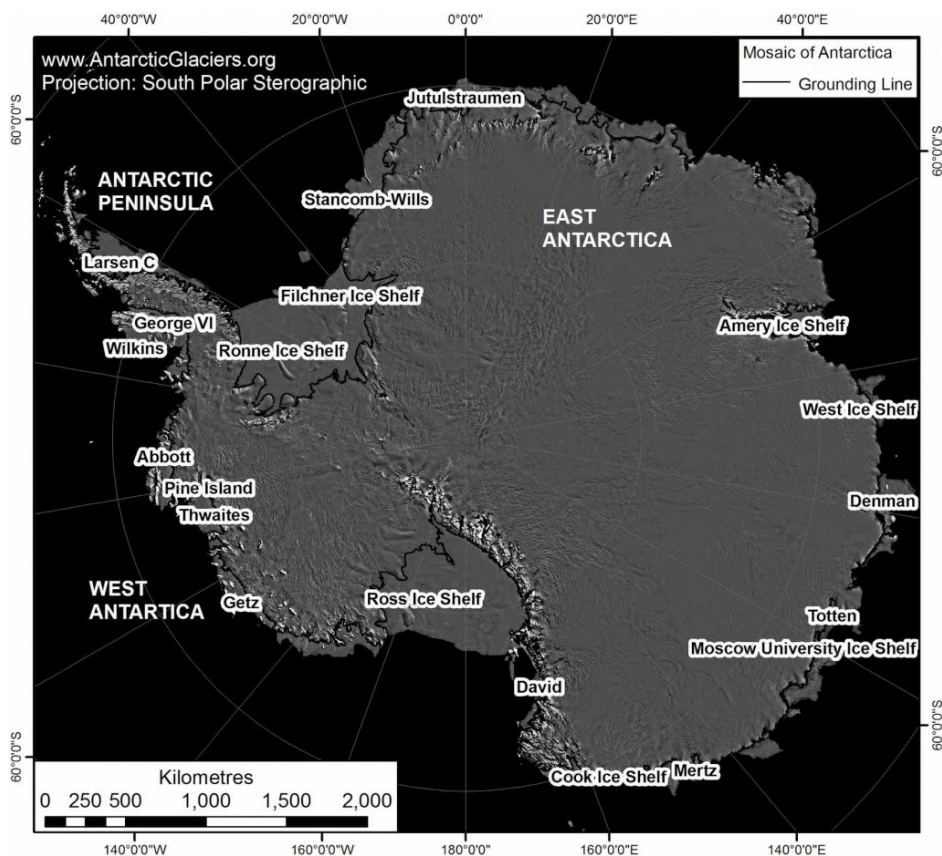
Antarctic ice shelf thickness changes. Note the rapid thinning of Pine Island Glacier ice shelf in West Antarctica. From Pritchard et al., 2012, Nature. Reprinted by permission from Macmillan Publishers Ltd: Nature (Pritchard et al. 2012), copyright (2012).

Long-term thinning from surface and basal melting preconditions the ice shelf to collapse. Negative mass balances on tributary glaciers can lead to thinning of the glaciers and ice shelves. The highest

rates of thinning are where relatively warm ocean currents can access the base of ice shelves through deep troughs[9,10]. Ice-shelf structure seems to be important, with sutures between tributary glaciers resulting in weaker areas of thinner ice, which are susceptible to rifting[11].

A recent analysis of ice shelves across Antarctica has shown that basal melt rates are around 1325 ± 235 gigatonnes per year, with an additional calving flux of 1089 ± 139 gigatonnes per year. Ice shelf melting is therefore one of the largest ablation processes in Antarctica[1]. However, this massive basal melting does not occur evenly distributed across all ice shelves; the massive Ronne, Filchner and Ross ice shelves cover two thirds of the total ice shelf area but account for only 15% of net melting. Instead, the highest melt rates occur around the Antarctic Peninsula and West Antarctica, from the northern end of [George VI Ice Shelf](#) to the western end of Getz Ice Shelf[1]. These ice shelves are also rapidly thinning rapidly[9]. On slow moving ice shelves (e.g., George VI, Abbot, Wilkins), almost all of the original land ice has melted away within a few kilometres of the grounding line. So, half of the meltwater produced comes from just ten small, warm-cavity ice shelves around the SE Pacific rim of Antarctica, and these ten ice shelves occupy just 8% of total ice shelf area. All this cold water being released into the ocean has a significant impact on the [formation of sea ice](#), resulting in higher rates of sea ice concentration around Antarctica.

Melting of ice shelves around Pine Island Glacier in West Antarctica is concerning, because the West Antarctic Ice Sheet is grounded below sea level. A collapse of this ice shelf could lead to [marine ice sheet instability](#) and rapid global sea level rise.



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

2. Surface melting and ponding

Increased atmospheric temperatures lead to surface melting and ponding on the ice surface. Catastrophic ice-shelf collapses tend to occur after a relatively warm summer season, with increased surface melting[12]. Based on the seasonality of ice shelf break up, and the geographic distribution of

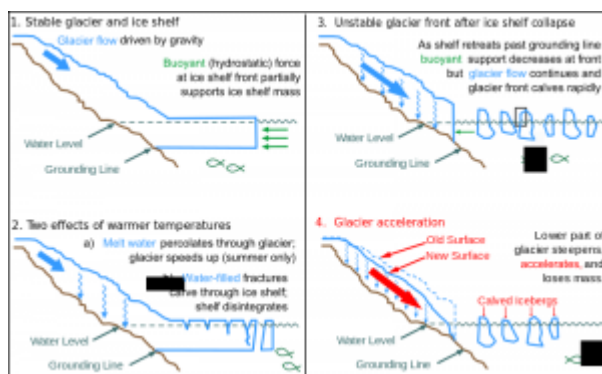
ice shelf collapse near the southerly-progressing -9°C isotherm, it appears that surface ponding is necessary for ice-shelf collapse[12]. This meltwater melts downwards into the ice shelf, causing fractures and leading to rapid ice-berg calving[5, 12]. Increased surface meltwater also leads to snow saturation, filling crevasses with water and increasing hydrostatic pressures. Brine infiltration can also cause crack over deepening.

3. Plate bending and tidal flexure

However, meltwater ponding alone does not explain rapid ice-shelf fragmentation. We need to involve a third process. Bending at the frontal margin of the ice shelf as a result of tidal flexure may cause small cracks to form parallel to the ice front. When subject to the above conditions (thinning with abundant surface water), a threshold may be passed, causing rapid ice shelf disintegration[12].

When icebergs are formed through the above mechanisms, long, thin icebergs are formed at the ice front. These icebergs will capsize as they are thinner than they are deep. Iceberg capsize releases gravitational potential energy and increases tensile stress on the ice shelf. This may lead to a cascade of fragmentation, capsize, and iceberg break up[13].

Ice shelf buttressing



Glacier-ice shelf interactions: In a stable glacier-ice shelf system, the glacier's downhill movement is offset by the buoyant force of the water on the front of the shelf. Warmer temperatures destabilize this system by lubricating the glacier's base and creating melt ponds that eventually carve through the shelf. Once the ice shelf retreats to the grounding line, the buoyant force that used to offset glacier flow becomes negligible, and the glacier picks up speed on its way to the sea. Original Image by Ted Scambos and Michon Scott, National Snow and Ice Data Center.

Collapsing ice shelves do not directly contribute to global sea level rise. This is because they are floating, and so their melting does not result in sea level rise. To check this, put a few ice cubes in a glass and check the water level. Does the water rise when the "icebergs" melt?

However, ice shelves play a very important role in "buttressing" their tributary glaciers. Glaciers that feed into ice shelves are held back by the ice shelf in front of them[14, 15]. Even small ice shelves play an important role in regulating flow from ice streams that feed into them[14]. This has been

observed in several cases, most notably following the Larsen Ice Shelf [16-19] and Prince Gustav Ice Shelf collapses[20, 21]. In the Landsat image of Prince Gustav Ice Shelf above, you can see the rapid glacier recession from 1988 to 2009.

With glaciers thinning, accelerating and receding in response to ice shelf collapse[20, 21], more ice is directly transported into the oceans, making a direct contribution to sea level rise. Sea level rise due to ice shelf collapse is as yet limited, but large ice shelves surrounding some of the major Antarctic glaciers could be at risk, and their collapse would result in a significant sea level rise contribution[22]. See [Marine Ice Sheet Instability](#) for more information.

Further reading

- [Marine Ice Sheet instability](#)
- [George VI Ice Shelf](#)
- [Ice shelves: the hidden villain](#)
- [Sea level rise](#)
- [Glacier recession in Patagonia](#)
- [Glacier recession on the Antarctic Peninsula](#)
- [Glaciers and climate change](#)
- [Antarctica's contribution to global sea level rise](#)
- [The growing rift on Larsen C Ice Shelf](#)

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References

1. Rignot, E., Jacobs, S., Mouginot, J., and Scheuchl, B. (2013). Ice Shelf Melting Around Antarctica. *Science*.
2. Holland, P.R., Corr, H.F.J., Vaughan, D.G., Jenkins, A., and Skvarca, P., 2009. Marine ice in Larsen Ice Shelf. *Geophysical Research Letters*, 2009. **36**: p. L11604.
3. Morris, E.M. and Vaughan, A.P.M., 2003. Spatial and temporal variation of surface temperature on the Antarctic Peninsula and the limit of viability of ice shelves, in *Antarctic Peninsula climate variability: historical and palaeoenvironmental perspectives*, E.W. Domack, et al., Editors. American Geophysical Union, Antarctic Research Series, Volume 79: Washington, D.C. p. 61-68.
4. Cook, A.J. and Vaughan, D.G., 2010. Overview of areal changes of the ice shelves on the Antarctic Peninsula over the past 50 years. *The Cryosphere*, 2010. **4**(1): p. 77-98.
5. Scambos, T., Hulbe, C., and Fahnestock, M., 2003. Climate-induced ice shelf disintegration in the Antarctic Peninsula, in *Antarctic Peninsula climate variability: historical and palaeoenvironmental perspectives*, E.W. Domack, et al., Editors. American Geophysical Union, Antarctic Research Series, Volume 79: Washington, D.C. p. 79-92.
6. Rott, H., Skvarca, P., and Nagler, T., 1996. Rapid collapse of northern Larsen Ice Shelf, Antarctica. *Science*, 1996. **271**(5250): p. 788-792.
7. Pudsey, C.J. and Evans, J., 2001. First survey of Antarctic sub-ice shelf sediments reveals Mid-Holocene ice shelf retreat. *Geology*, 2001. **29**: p. 787-790.

8. Domack, E., Duran, D., Leventer, A., Ishman, S., Doane, S., McCallum, S., Amblas, D., Ring, J., Gilbert, R., and Prentice, M., 2005. Stability of the Larsen B ice shelf on the Antarctic Peninsula during the Holocene epoch. *Nature*, 2005. **436**(4): p. 681-685.
9. Pritchard, H.D., Ligtenberg, S.R.M., Fricker, H.A., Vaughan, D.G., van den Broeke, M.R., and Padman, L., 2012. Antarctic ice-sheet loss driven by basal melting of ice shelves. *Nature*, 2012. **484**(7395): p. 502-505.
10. Shepherd, A., Wingham, D., and Rignot, E., 2004. Warm ocean is eroding West Antarctic Ice Sheet. *Geophysical Research Letters*, 2004. **31**(23): p. L23402.
11. Glasser, N.F. and Scambos, T.A., 2008. A structural glaciological analysis of the 2002 Larsen B ice shelf collapse. *Journal of Glaciology*, 2008. **54**(184): p. 3-16.
12. Scambos, T., Fricker, H.A., Liu, C.-C., Bohlander, J., Fastook, J., Sargent, A., Massom, R., and Wu, A.-M., 2009. Ice shelf disintegration by plate bending and hydro-fracture: Satellite observations and model results of the 2008 Wilkins ice shelf break-ups. *Earth and Planetary Science Letters*, 2009. **280**(1-4): p. 51-60.
13. MacAyeal, D.R., Scambos, T.A., Hulbe, C.L., and Fahnestock, M.A., 2003. Catastrophic ice-shelf break-up by an ice-shelf-fragment-capsize mechanism. *Journal of Glaciology*, 2003. **49**(164): p. 22-36.
14. Dupont, T.K. and Alley, R.B., 2006. Role of small ice shelves in sea-level rise. *Geophys. Res. Lett.*, 2006. **33**(9): p. L09503.
15. Dupont, T.K. and Alley, R.B., 2005. Assessment of the importance of ice-shelf buttressing to ice-sheet flow. *Geophys. Res. Lett.*, 2005. **32**(4): p. L04503.
16. Scambos, T.A., Bohlander, J.A., Shuman, C.A., and Skvarca, P., 2004. Glacier acceleration and thinning after ice shelf collapse in the Larsen B embayment, Antarctica. *Geophysical Research Letters*, 2004. **31**: p. L18402.
17. Rott, H., Müller, F., and Floricioiu, D., 2011. The Imbalance of glaciers after disintegration of Larsen B ice shelf, Antarctic Peninsula. *The Cryosphere*, 2011. **5**: p. 125-134.
18. Hulbe, C.L., Scambos, T.A., Youngberg, T., and Lamb, A.K., 2008. Patterns of glacier response to disintegration of the Larsen B ice shelf, Antarctic Peninsula. *Global and Planetary Change*, 2008. **63**(1): p. 1-8.
19. Rott, H., Rack, W., Nagler, T., and Ieee. 2007. Increased export of grounded ice after the collapse of northern Larsen Ice Shelf, Antarctic Peninsula, observed by Envisat ASAR, in *Igarss: 2007 Ieee International Geoscience and Remote Sensing Symposium, Vols 1-12 - Sensing and Understanding Our Planet*. p. 1174-1176.
20. [Glasser, N.F., Scambos, T.A., Bohlander, J., Truffer, M., Pettit, E., & Davies, B.J., 2011. From ice-shelf tributary to tidewater glacier: continued glacier recession, acceleration and thinning following the 1995 collapse of the Prince Gustav Ice Shelf on the Antarctic Peninsula. *Journal of Glaciology* 57, 397-406.](#)
21. [Davies, B.J., Carrivick, J.L., Glasser, N.F., Hambrey, M.J., & Smellie, J.S., 2012. Variable glacier response to atmospheric warming, northern Antarctic Peninsula, 1988-2009. *The Cryosphere* 6, 1031-1048. doi:10.5194/tc-6-1031-2012](#)

22. Joughin, I. and Alley, R.B., 2011. Stability of the West Antarctic ice sheet in a warming world. *Nature Geosci*, 2011. **4**(8): p. 506-513.

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