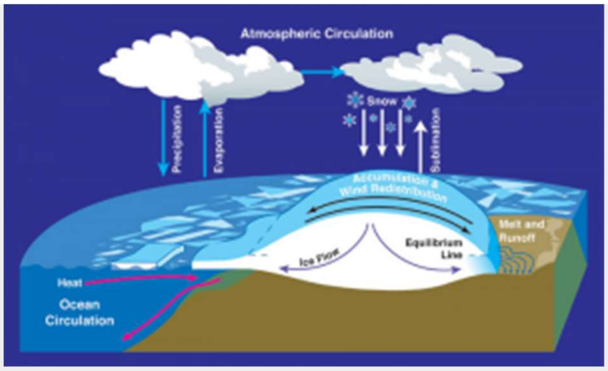
An introduction to Glacier Mass Balance

By Bethan Davies – Last updated 22/06/2017

Glacier mass balance | Measuring mass balance | Mass balance gradients | Mass balance through time | Further reading | References | Comments |

Glacier mass balance



Glacier mass balance and atmospheric circulation. By NASA. From Wikimedia Commons.

The mass balance of a glacier is a concept critical to all theories of glacier flow and behaviour. It is simple enough, really: mass balance is simply the gain and loss of ice from the glacier system[1]. A glacier is the product of how much mass it receives and how much it loses by melting. It can be thought of as the 'health of a glacier'; glaciers losing more mass than they receive will be in negative mass balance and so will recede. Glaciers gaining more mass than they lose will be in positive mass balance and will advance. Glaciers gaining and losing approximately the same amount of snow and ice are thought of as 'in equilibrium', and will neither advance nor recede. For clarification: when we talk about glaciers advancing, receding or being in equilibrium, we are talking about the position of their snout. Glaciers will continually flow under the force of gravity; ice is continually being moved from the upper reaches to the lower reaches, where it melts.

Accumulation zone


Unnamed Glacier, Ulu Peninsula, James Ross Island. The accumulation zone for this glacier extends from the plateau downwards.

The glacier system receives snow and ice through processes of **accumulation**. Surface accumulation processes include snow and ice from direct precipitation, avalanches and windblown snow. There may be minor inputs from hoar frost. The snow and ice is then transferred downslope as the glacier flows. Precipitation falling as rain is usually considered to be lost to the system. Internal accumulation may include rain and meltwater percolating through the snowpack and then refreezing. Basal accumulation may include freezing on of liquid water at the base of the glacier or ice sheet[2]. The snowline is often used to demarcate the equilibrium line on satellite images of glaciers.

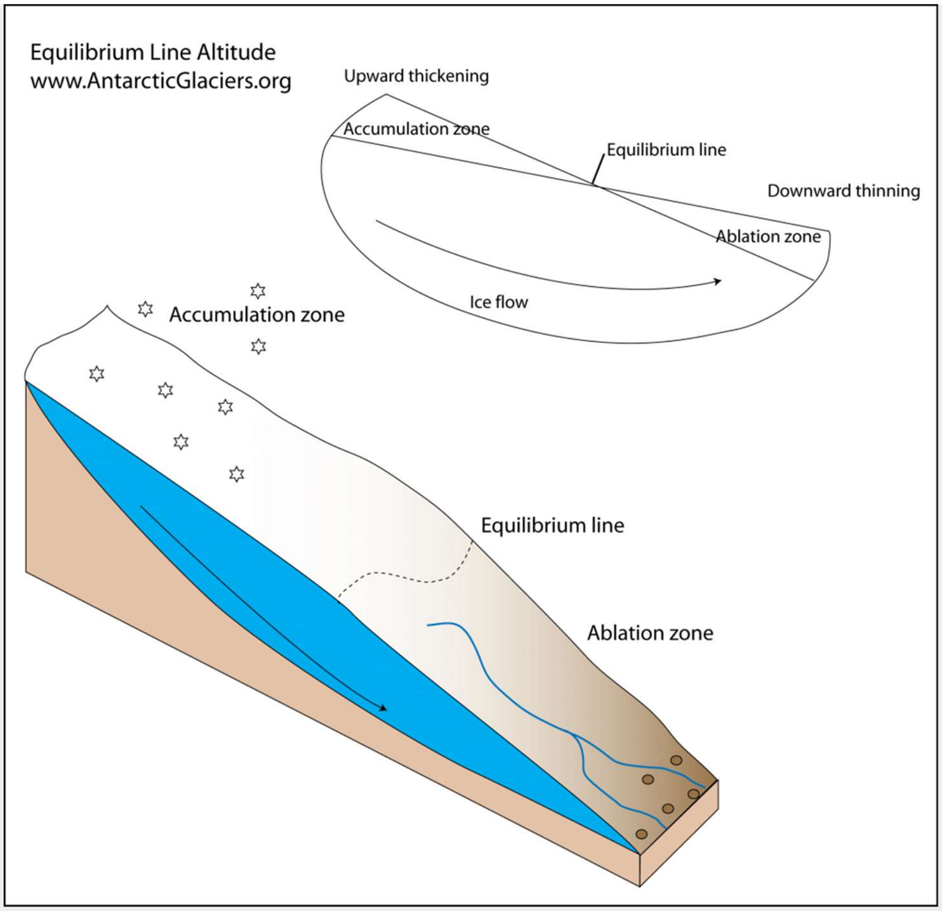
Ablation zone

Meltwater stream on Mendenhall Glacier, Alaska. From: Gillfoto, Wikimedia Commons

Glaciers lose mass through processes of **ablation.** Surface ablation processes include surface melt, surface meltwater runoff, sublimation, avalanching and windblown snow. Glaciers on steep slopes may also dry calve, dropping large chunks of ice onto unwary tourists below. Glaciers terminating in the sea or a lake will calve photogenic icebergs. Other processes of ablation include subaqueous melting, and melting within the ice and at the ice bed, which flows towards the terminus[2].

Equilibrium line altitude

Accumulation usually occurs over the entire glacier, but may change with altitude. Warmer air temperatures at lower elevations may also result in more precipitation falling as rain. The zone where there is net accumulation (where there is more mass gained than lost) is the **accumulation zone.** The part of the glacier that has more ablation than accumulation is the **ablation zone**. Where ablation is equal to accumulation is the **Equilibrium line altitude.**

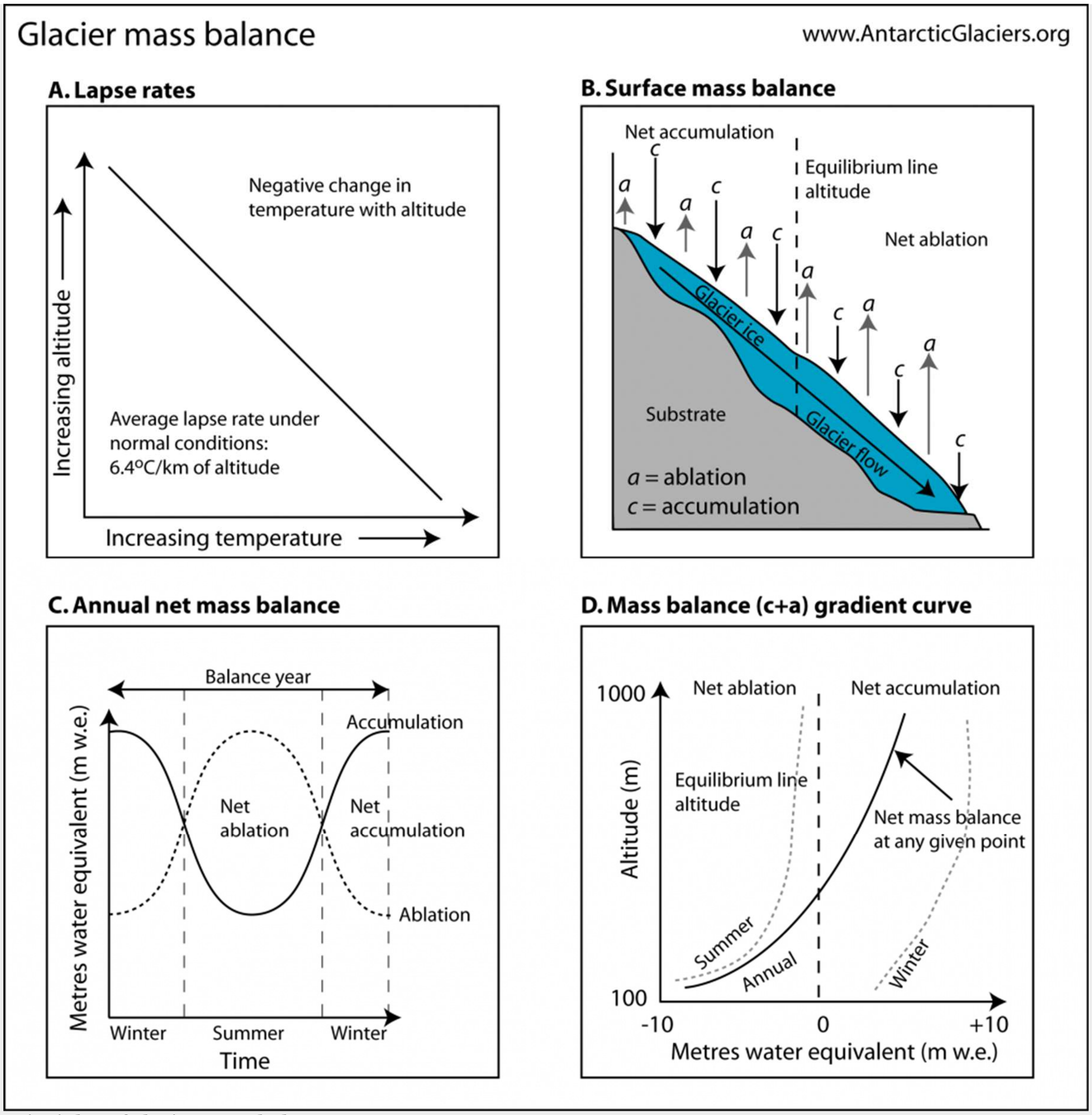


Equilibrium line altitudes in a hypothetical glacier

So what is Glacier Mass Balance?
So, glacier mass balance is the quantitative expression of a glacier's volumetric changes through time.In the figure below, Panel A shows how temperature varies with altitude. It is colder at the top than it is at the bottom of the glacier. This is crucial, as surface air temperature strongly controls melting and accumulation (as in, how much precipitation falls as snow or ice).

Mass balance (b) is the product of accumulation (c) plus ablation (a). Mass balance (b) $= c + a$ Mass balance is usually given in metres water equivalent (m w.e.). It varies over time and space; accumulation is greater in the higher reaches of the glacier, and ablation is greater in the lower, warmer reaches of the glacier (Panel B in the figure).

Mass balance also varies throughout the year; glaciers typically get more accumulation in the winter and more ablation in the summer (Panel C in the figure). Glacier mass balance therefore usually can therefore be expressed as a **mass balance gradient curve**, showing how $c + a$ varies attitudinally across the glacier (Panel D in the figure). The **balance gradient** is the rate of change of net balance with altitude[3]. A glacier's **net mass balance** is a single figure that describes volumetric change across the entire glacier across the full balance year.



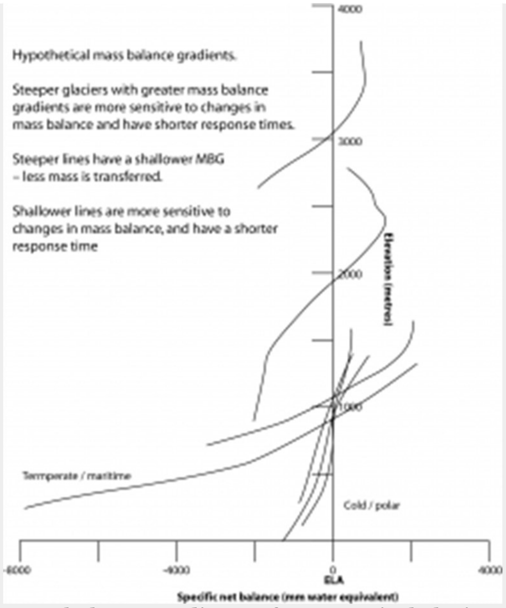
Principles of glacier mass balance

Measuring Mass Balance

Jonathan Carrivick prepares to stake out Glacier IJR45 on James Ross Island.

Glacier mass balance is normally measured by staking out a glacier. A grid of 'ablation stakes' are laid out across a glacier and are accurately measured. They can be made of wood, plastic, or even bamboo like you'd use in your garden. These stakes provide point measurements at the glacier surface, providing rates of accumulation and ablation. These methods are time consuming, logistically challenging and arduous; the stakes will need to be visited several times through the balance year. Accumulations and ablation are generally measured by reference to stakes inserted to a known depth into the glacier, and fixed by freezing and packing in[3]. The location is fixed with GPS. Automatic weather stations on the glacier surface are key to understanding energy fluxes on the glacier. Probing, snowpits and crevasse stratigraphy are also used to measure mass balance on glaciers, ideally supplemented with stakes. Remote sensing of glacier mass balance is obviously a good alternative, as it allows many glaciers to be assessed using desk-based studies. It is a cheap and simple alternative to arduous fieldwork, but ground truthing of mass balance measurements will always be necessary. Researchers from Aberystwyth University use satellite measurements to track changes in the mass balance of the Greenland Ice Sheet.

Mass balance gradients



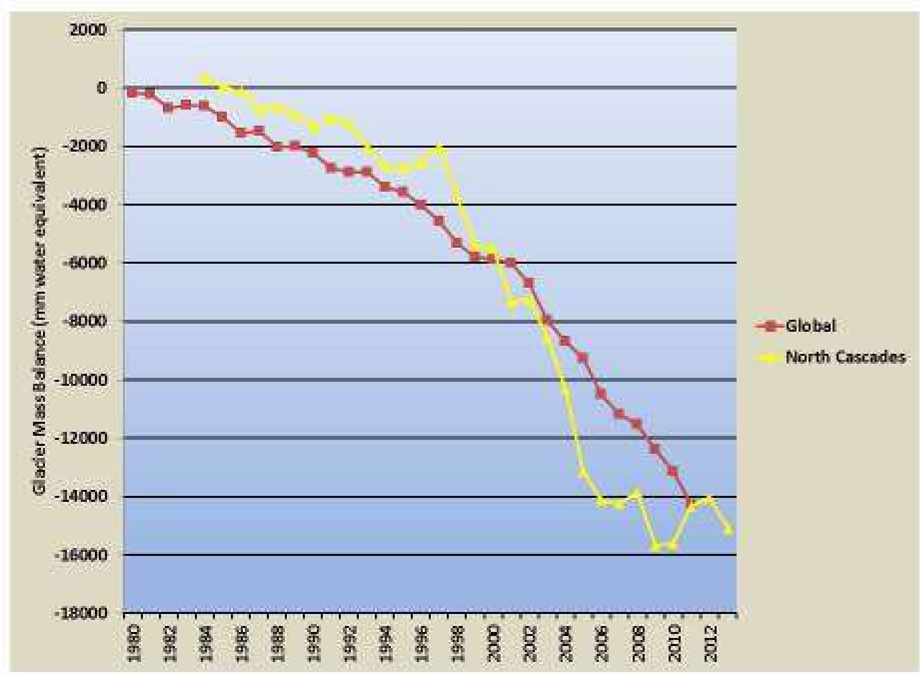
Mass balance gradients of some typical glaciers.

The mass balance gradient of a glacier is a key control in factors such as the glacier's response time. A glacier's mass balance gradient is critically determined by the climatic regime in which it sits; temperate glaciers at relatively low latitudes, such as Fox Glacier in New Zealand, may be sustained by very high precipitation. They will therefore have a greater mass balance gradient (more accumulation, more ablation). These wet, maritime glaciers may have a shorter response time and higher climate sensitivity than cold, polar glaciers that receive little accumulation but also have correspondingly low ablation. These cold, dry glaciers may respond more slowly to climate change.

In the figure on the left, temperate glaciers with greater mass balance gradients are represented by the *shallower* lines; more mass is transferred from the top to the bottom of the glacier. Cold, polar-type glaciers with smaller mass balance gradients are represented by the *steeper* lines.

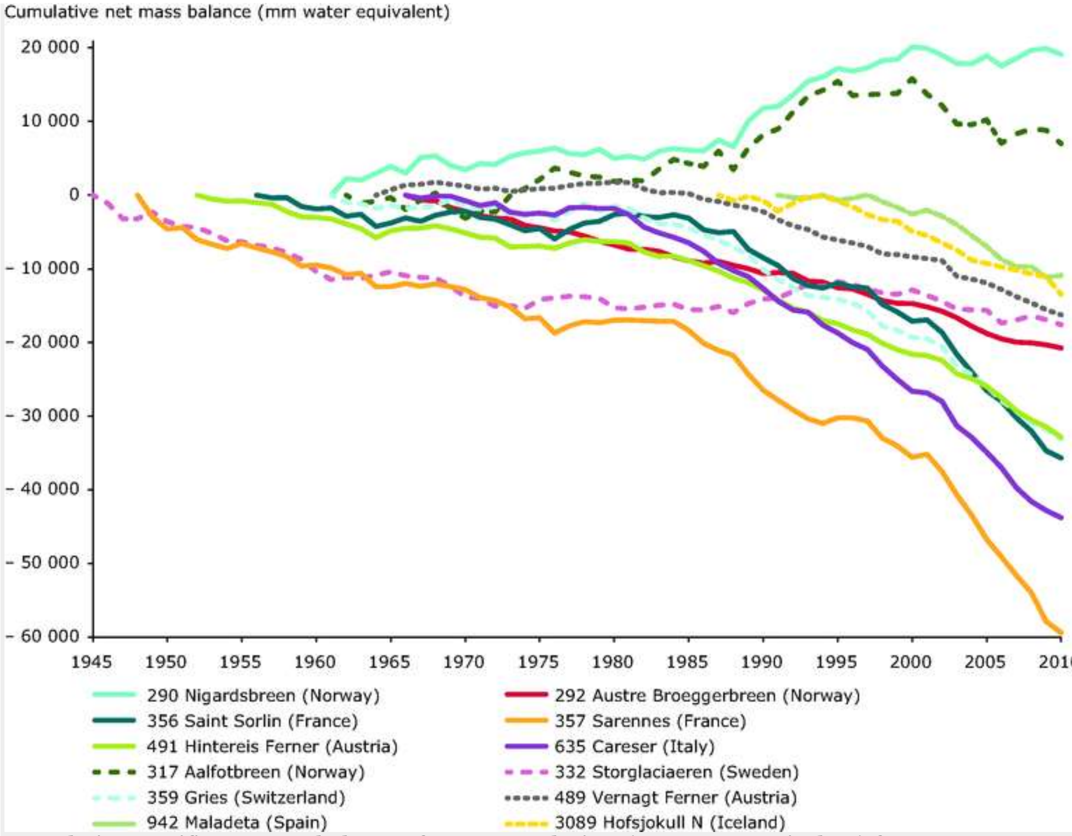
Mass balance through time

The **Cumulative mass balance** is the mass of the glacier at a stated time, relative to its mass at some earlier time. Some glaciers have mass balance measurements going back decades, which means that scientists can analyse how mass balance is changing over time. These measurements give us detailed information about climate change, as glaciers are sensitive 'barometers' to our changing world. Usually, the net mass balance over the balance year is plotted on a graph. There are several projects monitoring glaciers all over the world, and these analyses show that glacier mass balance is generally decreasing (becoming more negative) over time.



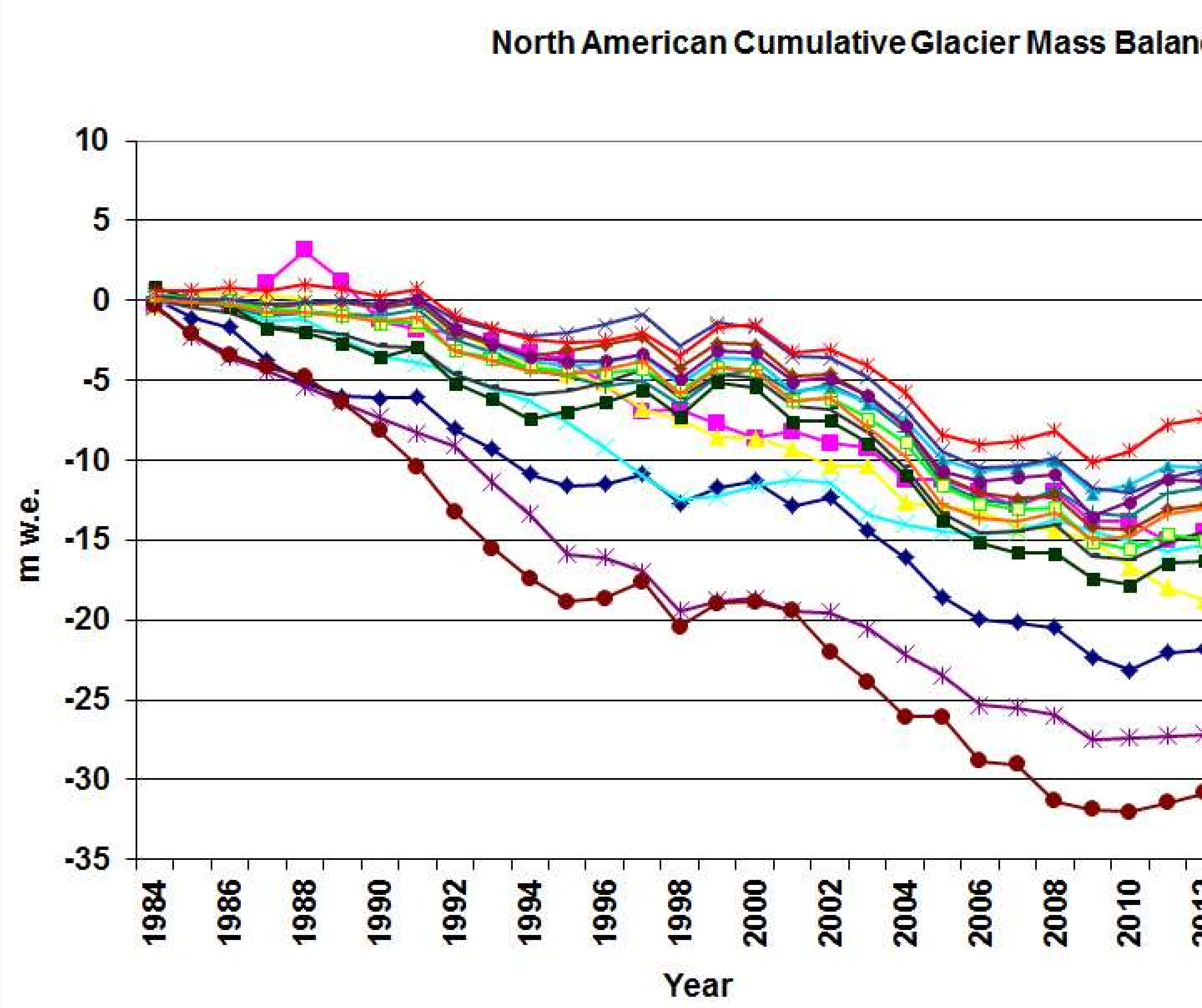
30 year glacier mass balance for 30 reference glaciers in the Alps. From the [World Glacier Monitoring Service](#)and [Alpine Glacier Mass Balance](#).

In Europe, [European Environment Agency](#) has records of many glaciers, and makes their cumulative mass balance measurements publically available. The Glaciers (CLIM 007) analysis shows that the vast majority of European glaciers are receding, with the rate of recession accelerating since the 1980s.



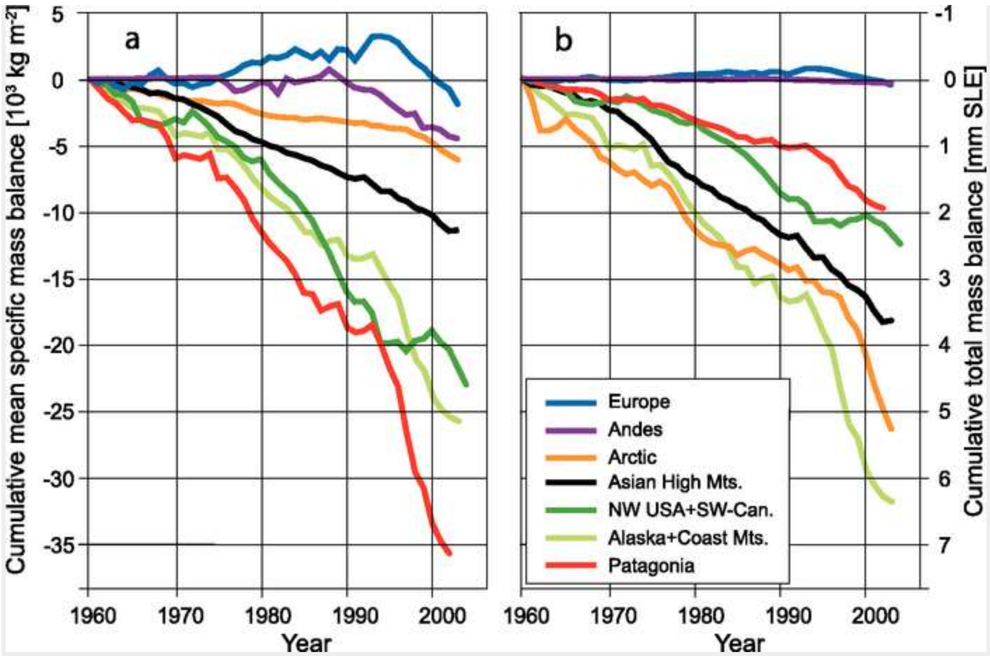
Cumulative specific net mass balance of European glaciers (mm water equivalent) from 1946 to 2010. From the Glaciers (CLIM 007) assessment.

The North American region shows a similar trend, with a generally declining mass balance each year.



North American glacier mass balance. Image courtesy of Mauri Pelto

Further afield, the IPCC AR4 shows cumulative specific net mass balance of glacierised regions worldwide. The differing behaviours of different regions shows the variable strength of climate change.



Cumulative mean specific mass balances (a) and cumulative total mass balances (b) of glaciers and ice caps, calculated for large regions (IPCC AR4)

Further reading

How glaciers flow:

- Deformation and sliding
- Stress and strain

Also of interest:

- Glacier thermal regime
- Glacier response time
- Antarctic Ice Sheet surface mass balance

Wider reading:

- Glossary of glacier mass balance and related terms (Cogley et al., 2011)
- Ice sheets and sea level: thinking outside the box (Van den Broeke et al., 2011)
- World Glacier Monitoring Service
- Glaciers (CLIM 007) Assessment
- Mass balance data 2011-2012
- North Cascade Glacier Climate Project (Mauri Pelto)