

# Is the ice burning?

The impact of global climate change is commonly illustrated by the media with images of retreating and melting glaciers. But what is the state of the world's glaciers, seen through the eyes of science?

By Kurt H. Kjær

■ The impact of climate change, is often dramatically portrayed by cascades of melt water gushing over the surface of glaciers to thunder off of its edge with large icebergs, or to disappear into deep crevasse in the ice. There is no doubt - the ice burns, while CO<sub>2</sub> is pumped into the atmosphere. The ice will dwindle away year after year on top of the world's mountains, while giant islands of ice tear themselves loose and drift away from the world's large ice sheets in Antarctica and Greenland, revealing never before seen fjords and valleys. According to the media, and opinion makers that is the world we and our children will experience in a time of global climate change. But what is the state of the world's glaciers, why are we so interested in them in a global perspective and do they react unexpectedly to the changing climate?

## Melting

The ominous predictions are to a large extent due to projections of the developments that have occurred within the last few decades. The evidence of which has been provided to us by new advanced aircraft and satellite monitoring, revealing the yearly development of glaciers in frozen regions. Since the early 1980s mass balance measurements have been done across the Greenland ice sheet

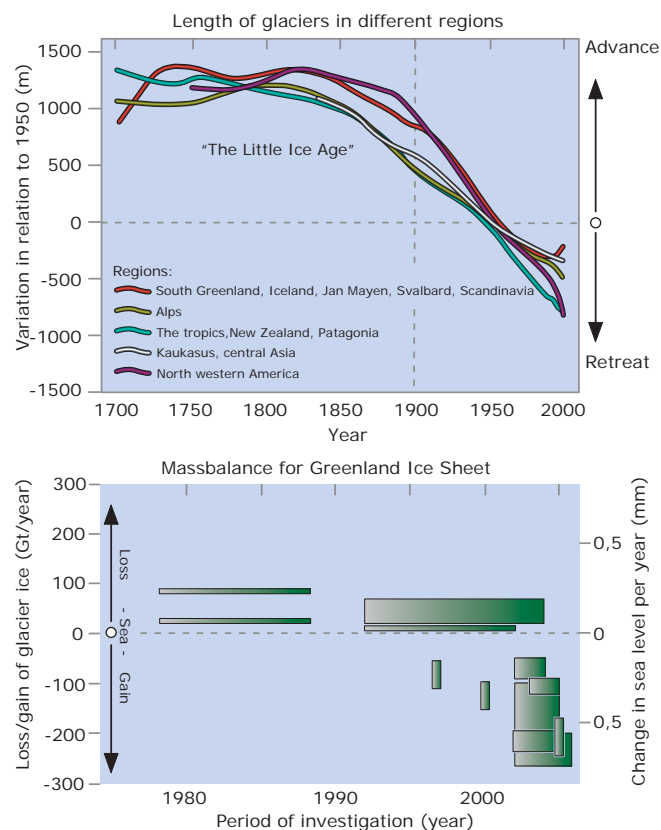


Figure 1. Top: Overview of the state of the world's glaciers during the last 300 years based on the length of glaciers in various regions. The vertical dashed line shows the end of the Little Ice Age.

Bottom: A comparison of decadal mass balance studies from the Greenland ice sheet. The boxes show the uncertainty of the period. Most of the latest studies find a gradually increasing loss that started back in the mid-1990s. Source: partially after the IPCCs AR4, 2007.

that calculate the loss or growth of glacier ice each year (Figure 1). These measurements indicate that within the last 15 years the overall loss of glacier ice is approximately 50-230 gigatons

per year, and while the central areas of the ice sheet are growing slightly in thickness, the ice in coastal areas is thinning at an even faster rate. The mass of the Antarctic ice sheets is also

changing by somewhere between +50 to -200 gigatons of glacier ice per year, but the uncertainty is of the same magnitude as the variation and changes over the last 10 years seem to be more modest than in Greenland. The total result represents a patchy collection of data from different methods and analyzed in different ways. This is because of the difficulties in collecting comprehensive datasets, so most of the investigations carried out have limited coverage over the ice sheets and the result must be extrapolated from a small study area for the entire mass of the ice, in order to provide an overall picture. That different survey methods yield different results is hardly surprising, when you take the huge areas of the ice sheets into account, but together with the short time interval of the investigations it does make it difficult to assess the stability of ice sheets in Greenland and Antarctica, when the natural variation cannot be discerned from the actual observed changes.

Within this context it is interesting to look further back in time - some 9000 - 6000 years ago, when the climate in Greenland was similar to or perhaps slightly warmer than it is today and the edge of the Greenland ice cap was in several places 20 kilometer farther inland than its current position.

By studying historic paintings and photographs, we can verify

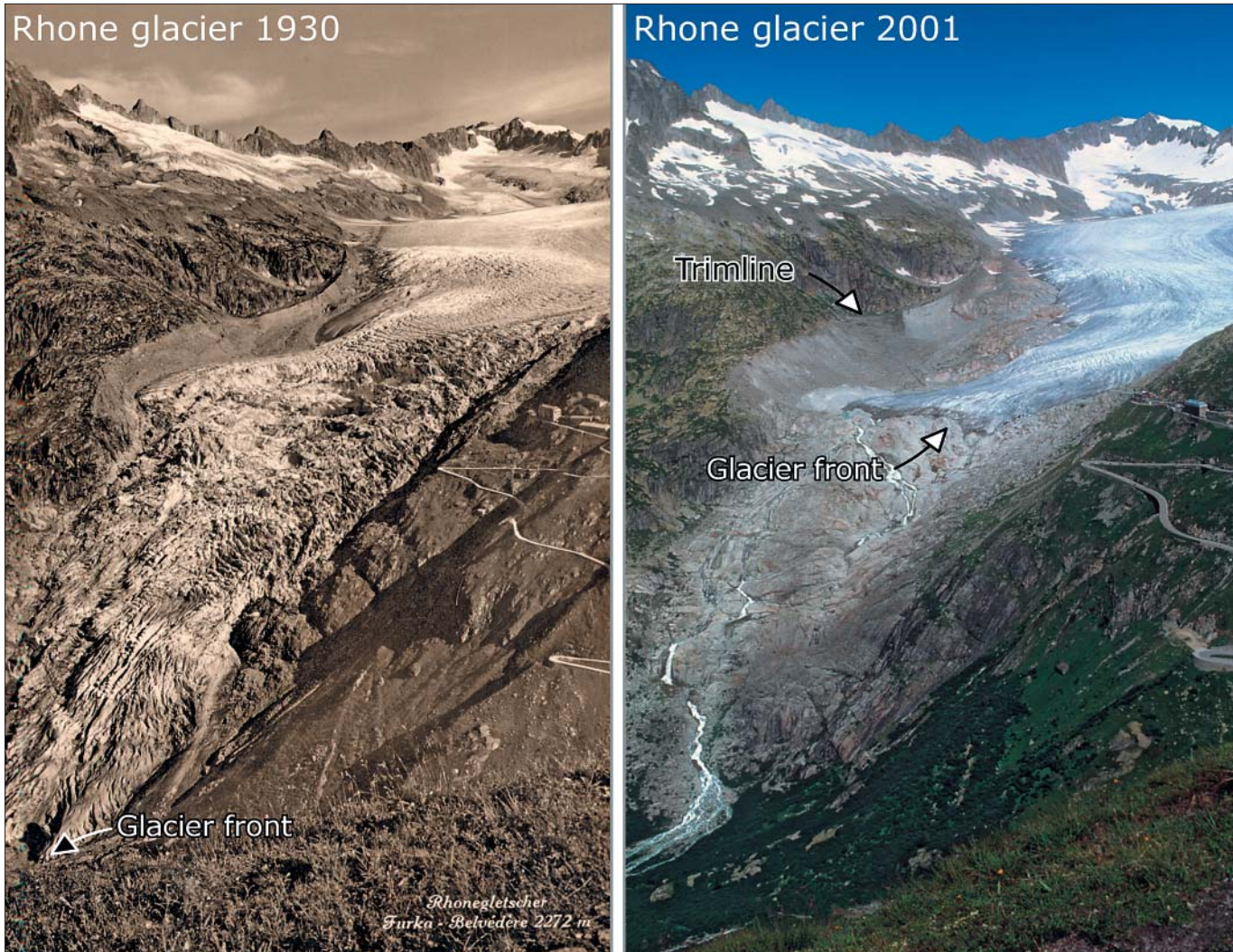


Figure 2. The Rhône Glacier in Switzerland - past and present. The sharp change in color on the mountain side shows where the glacier surface was during the Little Ice Age, in the period between the years 1500-1900. The glacier has had an overall negative mass balance since the end of the Little Ice Age.

that the volume of smaller glaciers has also changed in the past. During the Little Ice Age between year 1500 - 1900 AD, when the climate was colder, most of the world's glaciers grew and stopped several times in an advanced position (Figure 2). Also in the Alps, we can track the melting since the Little Ice Age and see how the length of glaciers was reduced year after year (Figure 1). Glaciers are thus sensitive and reliable indicators of climate change, and they adapt to and achieve balance when their size match the surrounding climate. The trend from the Alps can be recognized in most other valley glaciers around the world. The present change in glacier

frontal position is not just an extension of the withdrawal at the end of the Little Ice Age as many of these glaciers stopped their retreat or even advanced from 1950 to 1975, in response to a slightly cooler period in the 1940s. The present melting must therefore be coupled to the last 30 years of climate development. On the Antarctic Peninsula, a new survey shows that nine tenths of the glaciers there have retreated over the past half century.

But the story is even more interesting because it is not only the warming of the atmosphere, which causes changes in the glaciers' mass. The very symbol of global climate change – the Kibo Glacier atop Kilimanjaro

in East Africa – is apparently not affected by atmospheric warming, since the entire glacier is still far below the freezing line. At an altitude of 5000 meters, the temperature is around 32 °C colder than at sea level. Instead scarce precipitation in the form of snow appears to be starving the glacier, while at the same time it is losing mass by sublimation, which is when ice changes phase directly to water vapor because of strong solar radiation. The trend may be linked to a centuries-old change in the atmospheric circulation and precipitation patterns in the Indian Ocean. If global warming plays a role, it must be as an enhancer of a longer-term development

and not the only cause of the disappearance of “the snows of Kilimanjaro”.

### The global attention

The main interest in the state of the world's glaciers and the large ice sheets on Greenland and Antarctica is focused on their impact on oceanic sea levels and changes to water circulation in the North Atlantic. The relatively small glaciers that are typically found in the Scandinavian and North American mountains, as well as the Alps or the Himalayas, are without great global significance. However, their melting may have a significant impact on regional water resources and climate conditions. In the Himalayas melt water stored in large ice lakes can

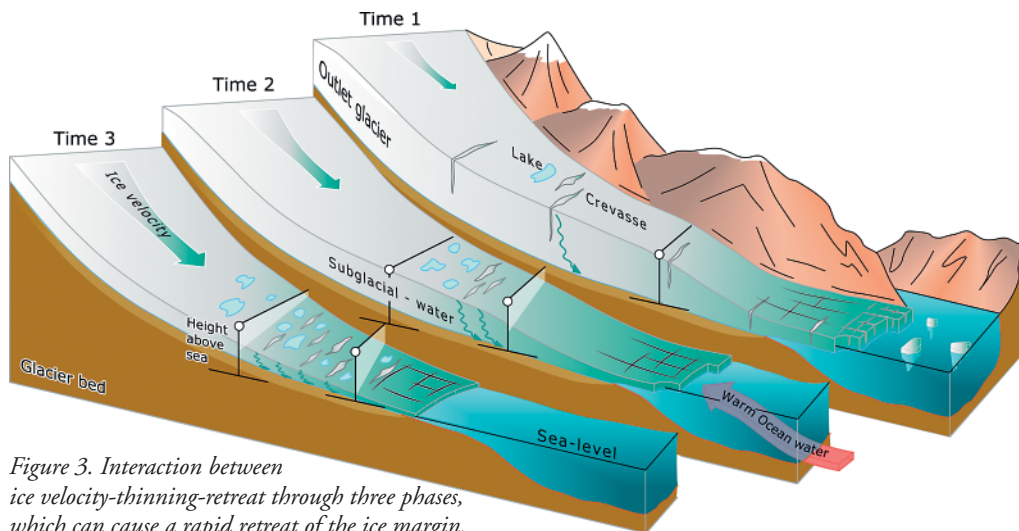
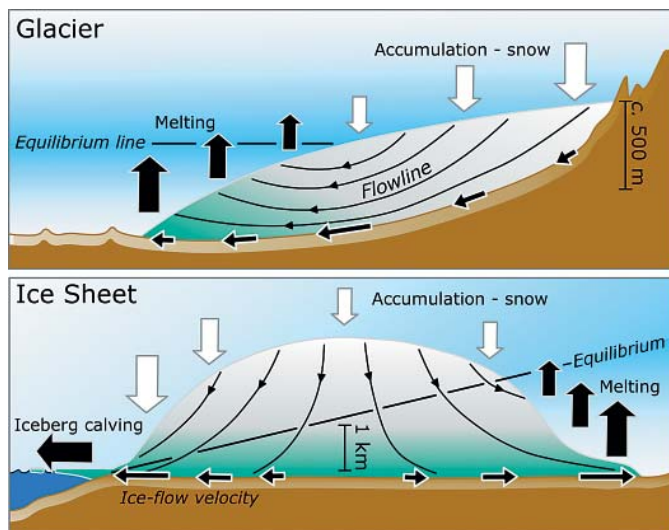


Figure 3. Interaction between ice velocity-thinning-retreat through three phases, which can cause a rapid retreat of the ice margin.



## Climate Balance – glaciers and ice caps

The size of valley glaciers and ice sheets is the product of the balance of the annual precipitation, that is snow accumulating on the glacier surface, and the annual loss of mass, which can be attributed to ice calving (icebergs), surface and bottom melting and in very cold climates, sublimation. In warmer climates and regions with less snowfall this mass balance becomes negative, and the glacier front retreats. However, if the climate becomes colder and/or snowfall increases the mass balance is positive and the glacier will advance. Usually, most snow falls in winter and more ice and snow melts in summer. The point at which the winter snow fall does not melt during summer, and where the snow does melt away completely is called the *equilibrium line*.

Above the equilibrium line, in the accumulation zone, snow is transformed into ice that slowly flows toward the bottom of the glacier and out toward the margin forced by gravity. A healthy glacier has slightly more than half of its area above the equilibrium line. If this is not the case the glacier will adapt to the new situation, but if the equilibrium line is very high or entirely above the glacier, no snow is accumulated on its surface and the melting becomes dominant.

suddenly be drained, with disastrous consequences for the local population living in low-lying valleys.

On a global scale, it is the Greenland ice sheet and ice sheets in Antarctica that can fundamentally affect Earth's climate system. A melting of the entire Greenland ice sheet would lead to a global sea level rise of 7 m, and if the Antarctic ice sheets all disappeared it would lead to a further increase of 50-60 m. The loss of mass from the Greenland ice sheet at the moment is equal to sea level rise in the oceans of up to 0.8 mm per year (Figure 1). But even a moderate sea level rise of less than 1 m will have serious consequences for low-lying coastal areas of economic importance. Huge amounts of fresh, cold melt water could change present ocean currents, which would inevitably change the climate in the countries around the North Atlantic. Climate changes normally only affect the large ice sheets after a certain period of time - the so-called response time. The Greenland ice sheet is expected to respond to climate changes over a period of several millennia, and a contribution of several meters to the global sea level rise in the foreseeable future is unlikely, although models suggest that, under current conditions, around a meter of sea level rise is expected by the end of the century from melting of the Greenland ice sheet alone. But predictions such as this depend

on our understanding of the processes controlling the stability of the ice sheet.

### It can quickly happen

A very surprising discovery of recent research is how quickly outlet glaciers from the inner part of the Greenland ice cap can change speed. Two of the big outlet glaciers in South-Greenland – Helheim and Kangerdlugssuaq doubled their speed in one year (around 2004) only to return to their initial speed two years later. The acceleration was so powerful that a number of smaller earthquakes triggered at the bottom of the ice could be registered as it quickly slid across the bedrock. These events showed one thing with certainty: We do not understand the dynamics behind these changes and their connection to climate.

The Antarctic ice also seems to respond more dynamically than expected. Over large areas the East and West Antarctic ice sheets are surrounded by floating glaciers known as ice shelves. Several times during the last 10 years huge ice shelves have broken off, and islands of ice the size of Fyn Island, Denmark (over 1000 sq. miles) have drifted away. The problem is not the floating ice in itself as it does not contribute to extra sea level rise, but rather that the outlet glaciers in the valleys behind are no longer held back by the ice shelf. The valleys are therefore drained of ice incredibly fast and more ice is pulled out to the sea from the inner part of the ice sheet. This does contribute to a rise in sea level and may also suggest that further collapse of ice shelves could put the ice sheet at risk of collapse.

Although the largest ice masses of the Greenland ice sheet are found in the interior, it is the local climatic conditions and drainage in the periphery, which determine how fast the ice responds to climate changes. It has also been discovered that melt from the ice surface can find its way to the bottom of the ice more quickly than was expected. In some areas, this creates a thin meltwater layer, which lubricates

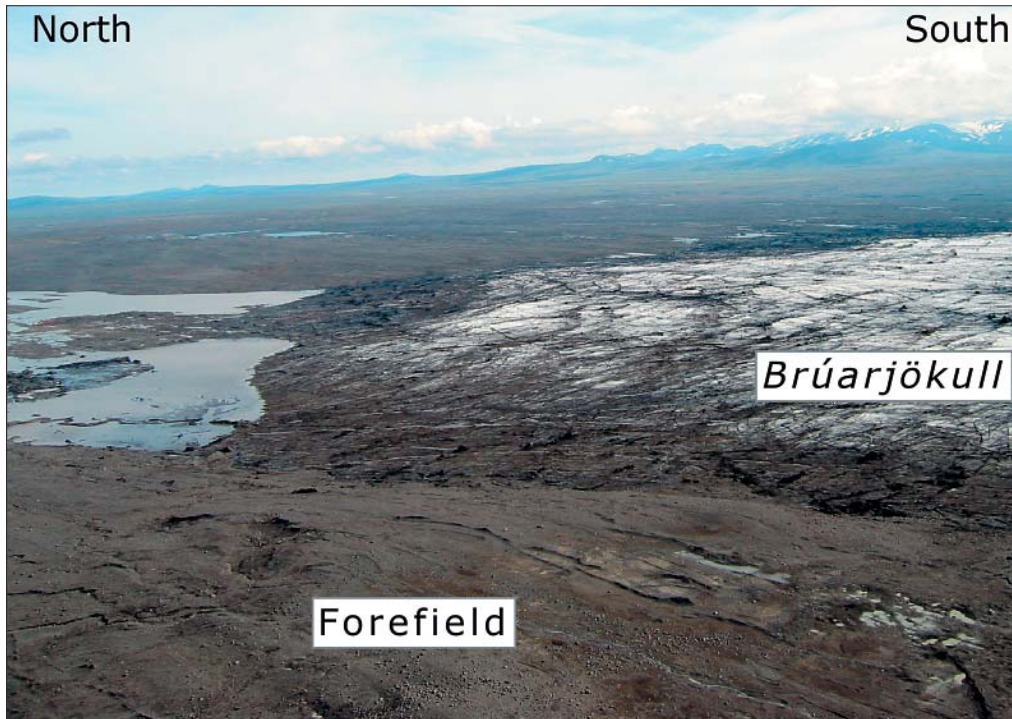
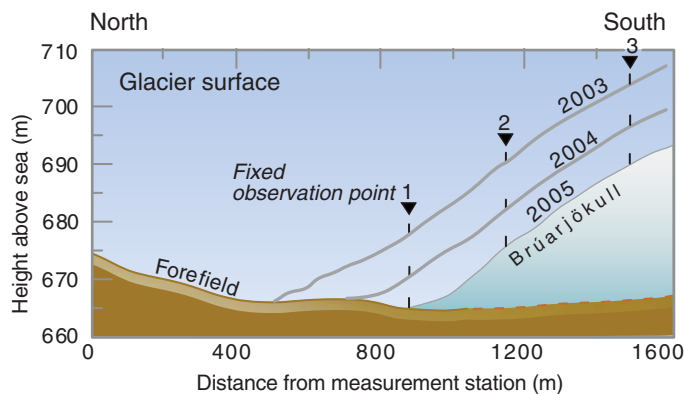


Figure 4. Northern margin of Vatnajökull in eastern Iceland, summer 2003, seen from a helicopter over glacier. Brúarjökull – an outlet glacier of Vatnajökull surged 8 km during the winter of 1963/64 and is now rapidly melting again. Under the current climate the glacier fronts withdraw by up to 200 meters (600 ft.) per year – a perfectly natural situation, because the glacier ice has been brought down in an area with a climate which normally does not permit glaciers to exist.

the glacier bed and significantly enhances acceleration. This initiates a dynamic process: the acceleration depletes the ice reservoir and the surface loses elevation and is thus exposed to higher temperatures, which in turn leads to increased melting – more melt and even higher speeds (Figure 3). The outlet glacier will during this interaction move back periodically as dictated by the topography. The dynamic processes could potentially shorten significantly the response time to the changing climate of the Greenland Ice Sheet. Lately it has been documented that the penetration of warm subsurface waters to the margin of the Greenland ice sheet triggers a rapid dynamic response.

#### The unsuitable

In the climate debate before-and-after photos of glaciers, which have changed their size considerably over the past 100 years (Figure 2), are often shown as evidence. But in several cases the type of glaciers chosen are not suited for this kind of simplistic representa-



The melting of Brúarjökull from 2003 to 2005.

tions. These are the so-called surging glaciers that suddenly advance several kilometers in the course of weeks or months and then rapidly melt back (Figure 4). The cycle of rapid advance and slow retreat is partially a response to climate, but is mainly a result of internal processes in the glacier. By highlighting the melting phase only half of the truth is told, namely that glacier ice is transported disproportionately far and placed out of balance and quite naturally melts again to adjust to the surrounding climate.

It is clear that almost all the world's glaciers and large ice sheets are out of balance with today's climate. Most melt back, while other receives more snowfall as a product of warmer and more humid weather. The latter maintain their current position for the time being. The time scale of our experience with these rapid changes is not great and only future monitoring and reconstruction of earlier development dating thousands of years back in time can put them in the right perspective. ■

#### About the author



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#### Further Reading:

The Intergovernmental Panel on Climate Change (IPCC), Chapter 4: Observations: Changes in Snow, Ice and Frozen Ground. <http://ipcc-wg1.ucar.edu/wg1/wg1-report.html>

Das Gletscherarchiv. Glacier Archives from the Alps with comparative photographs from the end of the Little Ice Age and now. [www.gletscherarchiv.de](http://www.gletscherarchiv.de)

World Glacier Inventory. "The World Glacier Inventory contains information from more than 67,000 glaciers around the world." [www.nsidc.org/data/g01130.html](http://www.nsidc.org/data/g01130.html)

International Exhibition on Climate Change in the Botanic Garden <http://snm.ku.dk/english/udstillinger/climateexhibit/>