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GLACIER CHANGES IN THE EUROPEAN ALPS

In the densely populated European Alps, glaciers are an inherent component of the landscape, environment and culture. They represent a unique source of freshwater for agricultural, industrial and domestic use, an important economic component of tourism and hydro-electric power production, and are also a source of serious natural hazards. Our glaciers generally form where the winter snow is not entirely melted by the summer's strong insolation and warm temperatures. Because the Alpine ice is close to the melting point, glaciers react strongly to climate change, and thereby provide some of the clearest evidence for it.

Many of us remember the snowy winters of the 1970s and early 1980s, when winter sport activities were possible over many weeks even in the lowlands, and many glaciers, such as Argentière (FR), Oberer Grindelwald (CH), Pre de Bar (IT) or Waxegg (AT), pushed their icy tongues down-valley – what a different sight to the ice wasting away at present! However, how many still remember the strong glacier retreats of the 1940s, or the advances of the 1920s? Scientists have been systematically collecting information on glacier changes and carrying out regular measurements of glacier length changes since the 19th century. These early measurements together with dated moraines representing glacier maximum extents of past times, a complete inventory of all the Alpine glaciers compiled on the basis of maps and aerial photographs of the 1970s, annual glacier mass balance measurements – the annual thickness change of a glacier averaged over the glacier area – since the late 1940s, and numerous computer modelling studies provide us with a detailed picture of past, present and potential future glacier changes in the Alps.

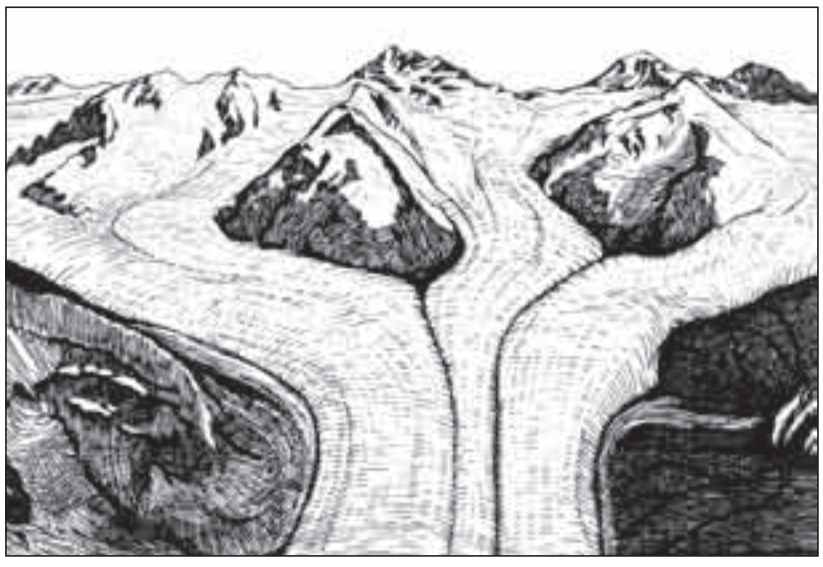
During the maximum extent of the last Ice Age, 20,000 to 25,000 years ago, Alpine glaciers covered an area of about 150,000 km^2. In the north the glacier tongues reached down to the pre-Alpine lowlands, in the south they advanced to the margin of the Padan Plain (in the Po Valley). In Zurich, for example, about 15 km upstream/up-glacier from the maximum front position, the Linth Glacier was still about 300 m thick. After this glacial maximum, Alpine glaciers started to retreat gradually with typical patterns of staggered sequences of moraines that testify to intermittent periods of glacier re-advances during the overall retreat. The moraines of the Younger Dryas (i.e., the period of 12,600–11,500 years ago are a conspicuous feature in many valleys and mark the last major re-advance of the Late Glacial period. After that last major re-advance, glaciers reached similar extents as today at the beginning of the Holocene (i.e., the period of the last 10,000 years). During the Holocene, glacier front variations fluctuated within relatively narrow margins as compared to the Late Glacial changes. Dated stumps of trees and peat as well as archaeological finds such as Ötzi, the 5300-year-old Iceman found on the Austrian-Italian border, document periods of reduced and expanded glacier states during that time. Periods of reduced glacier states were found during the Bronze Age (about 3800 to 2800 ago), at the transition from the Iron Age (about 2800–2450 ago) to the Roman Age (about 2450–1600 ago), and during the Middle Ages (about 1 500 to 500 ago); major glacier advances took place around 3 000–2 600, 1 500–1 400, 1 200–1 100, and 900–800 ago, as well as during the Little Ice Age (700–140 ago).

The moraines of the last Little Ice Age advance around 1850 mark Holocene maximum glacier extents in the Alps. From these positions, glaciers showed an overall dramatic retreat until the present day. Large valley glaciers such as Grosser Aletsch (CH), Morteratsch (CH) or Pasterze (AT) have retreated continuously, whereas mid-sized and steeper glaciers have reacted to somewhat wetter and cooler periods with intermittent re-advances in the 1890s, 1920s, and 1970-80s. A complete inventory of the Alpine glaciers was made in the 1970s.

5150 glaciers were identified with a total area of 2900 km^2; 90% of the glaciers were smaller than 1 km2 and together covered about one third of the total area; the largest seven glaciers make up one tenth of the total ice cover. Overall, the Alpine glacier cover is calculated to have diminished by about 35% from 1850 to the 1970s and by another 22% up to 2000. The corresponding loss in ice volume is estimated as

50% and 25% respectively. Mass balance observations over the past six decades reveal large ice losses in the first two decades, close to steady-state conditions between the mid 1960s and mid 1980s, followed by a fast and accelerated ice loss up to the present. According to these measurements, glaciers have thinned by more than 20 m over the past 25 years, with an annual average ice loss of more than one metre of ice per year since the turn of the century.

The onset of glacier retreat from their Little Ice Age moraines and the intermittent re-advances might at least partly be attributed to periods of increased snow accumulation. However, the main cause of the dramatic retreat of the Alpine glaciers over the past 150 years is to be found in the human-induced temperature increase. Alpine temperatures have increased by about 1.5 °C over the past 150 years – about twice as much as on the global average. In the same time half of the Alpine ice cover was lost. According to the current state-of-the-art climate scenarios, we are facing a potential additional temperature increase of 1 to 6 °C by the end of the 21st century depending on which of the plausible greenhouse gas emission scenarios is applied. Under such conditions we must expect a dramatic continuation of present glacier wasting. Glaciers will retreat well beyond their margins of the Holocene and the present day. In fact they would only be able to survive on some of the highest Alpine peaks, with impacts on our landscape, hydrological cycle and natural hazard potential that are beyond any historical analogy.



Aletsch glacier

Some facts and figures:

Number of glaciers (1970s): 5150

Estimated glacier cover:
around 1850: 4400 km^2, 200 km^3
around 1970: 2900 km^2, 100 km^3
around 2000: 2200 km^2, 75 km^3

The largest Alpine glaciers

#	Name	Country	Year	Area (km^2)	Length (km)
1	Grosser Aletsch	CH	1973	86.8	24.7
2	Gorner	CH	1973	68.9	14.1
3	Fiescher	CH	1973	33.1	16.0
4	Mer de Glace	FR	1967	33.1	12.3
5	Unteraar	CH	1973	28.4	13.5
6	Oberaletsch	CH	1973	21.7	9.1
7	Unterer Grindelwald	CH	1973	21.7	9.0
8	Pasterze	CH	1969	19.8	9.2
23	Forni	IT	1981	13.2	5.5
....	Schneeferner Nord	DE	1975	0.4	0.9

Source: Data from the World Glacier Inventory, hosted at the World Glacier Monitoring Service (www.wgms.ch).