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## Changing Views of Changing Glaciers

*Wilfried Haeberli*

Glacier changes have been observed for centuries. Throughout historical times, the perception of these often striking changes in high-mountain environments has shifted from legends about holy peaks and fear of punishment for worldly misbehavior via natural catastrophes to curiosity about movements from the “icy sea” of mountains and romantic enthusiasm for and realistic documentation of local phenomena to the discovery of past Ice Ages and the corresponding ideological disputes about the origin and evolution of the earth. Modern scientific investigation and worldwide coordination of glacier observations began toward the end of the nineteenth century, and the scientific observation of glacier fluctuations went through deep crises before evolving toward modern, integrated, multilevel concepts and advanced technologies. Today, glacier changes are increasingly recognized as a key phenomenon of global change in climate and living conditions on earth. Working Group 1 of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) lists the shrinking of mountain glaciers,

together with instrumentally measured sea-surface and land air temperatures, as the highest-confidence temperature indicators in the climate system (Figure 2.39a in Houghton et al. 2001).

This chapter concentrates on the increasing interest in the glacier during roughly the past three to four centuries in the European Alps, where rich material exists, where systematic monitoring programs were first initiated, and where discussions have sometimes been intense. The primary emphasis of this chapter is on the major directions of change rather than the details of a development that, in reality, has a great many facets. Unavoidably, therefore, it must remain a rather sketchy and somewhat subjective outline. A more detailed overview of early developments has been presented by Haeberli and Zumbühl (2003). Much more differentiated analyses would be not only possible but also worthwhile; the power of images and views profoundly influences our perception of environmental change in a critical period for human life on earth.

## CURIOSITY AND ROMANTIC ENTHUSIASM FOLLOWING ROUSSEAU AND VON HALLER

The early period of glacier perception is characterized by an antagonism between fear and fascination. The widespread advance of Alpine glacier tongues to their greatest Little Ice Age extent around AD 1600 was in places perceived as a threat to mountain dwellers (Zumbühl 1980). In fact, legends about glacier advances over flowering meadows as a heavenly punishment for the worldly misbehavior of humans exist in various high-mountain valleys and reflect the early religious or mythological attribution of causes and effects. The first scientific descriptions, those of J. Scheuchzer, J. Altmann, and G. Gruner, appeared in the eighteenth century (Haeberli and Zumbühl 2003). In the context of the contemporaneous call of J.-J. Rousseau (“back to nature”) for a new approach to life and the poetry of A. von Haller (which created the historical “myth of the Alps”), the growing scientific interest was accompanied by romantic views about the “pure,” “eternal,” and “untouched” firm fields and the water- and life-giving glaciers. The unique appeal of high-mountain scenery in the European Alps was the extreme contrast between glaciers, as an expression of “wild, indestructible” nature, and the carefully cultivated Alpine landscape, with its assumed “hard, simple, good, and healthy” living.

The painting by Pierre-Louis de la Rive depicting Mont Blanc (Figure 2.1) illustrates this notion of sustainable living in an intact high-mountain environment (cf. the extensive discussion of historical developments by Bätzing 2003). The view is upward through a green, garden-like landscape with open forest to the intact and “clean” white of firm and ice on a beautiful mountain peak. With the glacier-clad peak of the Eiger in the background and a cow in the foreground (Figure 2.2), Maximilien de Meuron portrays a combination of symbols that represents this paradise-like image and indeed became part of the reputation of Swit-



FIGURE 2.1. Mont Blanc, French Alps, from Sallenches in 1802. Painting by Pierre-Louis de la Rive (from Rasmø et al. 1981).

zerland as “a beautiful mountain/glacier country in the heart of Europe” for centuries. The detail of the tongue of the Unterer Grindelwald Glacier (Figure 2.3) from a painting by Caspar Wolf perfectly reflects the romantic enthusiasm and curiosity about the spectacular phenomenon of moving ice that led to much deeper-reaching questions about glaciers and life on earth.

## THE ONSET OF SCIENCE: FROM A NATURAL CATASTROPHE TO THE ICE AGE DEBATE

The initial impulse for thinking in a completely new dimension about humankind and nature originated at least partially outside scientific circles (Knight 2004). On the occasion of the 1818 Mauvoisin catastrophe, caused by the outburst of a lake dammed by ice avalanche debris from the advancing Giétro Glacier (Figure 2.4; Kasser and Haeberli 1979; Röthlisberger 1981), the farmer and mountain-goat hunter Jean-Pierre Perraudin met with the leading scientists of the time (Agassiz, de Charpentier, Escher von der Linth) and told them that the glaciers must have been much larger in the past to have been able to deposit large rocks far down the valley.

Such ideas may have been quite widespread among the “primitive” Alpine population living close to and experiencing glaciers, but they were new and astonishing in the academic circles



FIGURE 2.2. The Eiger near Grindelwald, Swiss Alps, painted from the alpine meadows of Wengernalp by Maximilien de Meuron, probably in 1821 (from Rasmø et al. 1981).

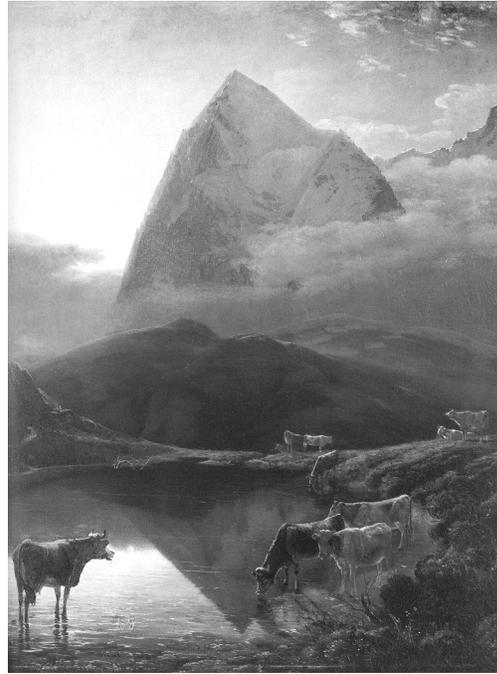


FIGURE 2.3. The advancing front of the Unterer Grindelwald Glacier, 1774–77. Detail of a painting by Caspar Wolf, the most important eighteenth-century painter of the Swiss Alps. (Photo H. J. Zumbühl)



FIGURE 2.4. Broken and collapsed debris cone of ice-avalanche deposits from the advancing Giétro Glacier after the sudden lake outburst and devastating flood wave at Mauvoisin/Bagnes, Swiss Alps, painted probably in 1818 by Hans Conrad Escher von der Linth (from Rasmø et al. 1981; cf. details in Kasser and Haerberli 1979).



FIGURE 2.5. The Agassiz team in the hut of Hugi, which later became the “Hôtel des Neuchâtelois” (the large boulder serving as shelter) on the medial moraine of Unteraar Glacier. Lithograph after a drawing by Joseph Bettanier published by Agassiz (1840–41) (from Rasmo et al. 1981).

developed in cultural centers in the lowlands. Louis Agassiz and his colleagues, detecting traces of glacier erosion and erratic boulders far from the Alps or other mountain chains, formulated the Ice Age theory, and this immediately excited a heated debate. Because the Bible contains no description of any smaller or larger glaciers, the idea of “Ice Ages” was widely considered offensive. The debate went on for decades and increasingly encouraged accurate field studies. The first paintings and illustrations showing scientists setting foot on and living or working on glaciers date from this time (Figure 2.5). The thorough investigations of the Unteraar Glacier by an interdisciplinary group of scientists led by Agassiz in the 1840s can be considered to constitute the beginning of modern experimental glacier research (Agassiz, Guyot, and Desor 1847). The results of such research on the geometry, material characteristics, and flow of a valley glacier and the first description of a large ice sheet in Greenland by E. Kane in the 1850s (cf. Bolles 1999) established the recognition of dramatic changes in climatic and environmental conditions for life in the most recent earth history. This revolution in our scientific understanding unavoidably led to questions of the physical causes and possible future repetitions of such events.

## THE BEGINNING OF SYSTEMATIC OBSERVATIONS: CLIMATIC PERIODICITIES AND CATASTROPHES

In 1893, François Alphonse Forel established the first systematic glacier observation network in Switzerland. Using this network as a model, the Sixth International Geological Congress in Zurich in 1894 initiated coordinated worldwide observation of glacier changes with the International Glacier Commission under Forel as the leading board of the newborn network. The goal was to learn more about the factors—whether internal or external to the earth system—that govern climate changes and cause Ice Ages to begin and end (Forel 1895).

The monitoring strategy consisted of regular and exact surveys at selected glacier tongues but also included indigenous knowledge about earlier glacier stages collected by scientists through communication with the mountain people. It was clearly oriented toward a better understanding of large-scale and long-term processes and therefore thought to require patience in order to bear fruit for future generations. It was this generous and “transdisciplinary” concept that helped develop one of the longest existing series of environmental observations, a real treasure of climate-related geoscience. During the twentieth century, the evolution of the international glacier-monitoring program and the corresponding views of glacier changes is marked by four distinct phases (see Haeberli, Hoelzle, and Suter 1998). The first phase of international glacier observation, around the turn of the century, was characterized by the search for regular oscillations in the climate/glacier-system, as is illustrated by the titles of the corresponding reports (“*Les variations périodiques des glaciers*”) issued by various members of the multilingual commission. The short glacier readvances in the Alps around 1890 and 1920 seemed to confirm the impression that climate and glaciers fluctuated in a periodic or at least quasi-periodic way. At the same time, a number of important glacier catastrophes in the Alps—a water outburst and devastating debris flow from the Tête Rousse

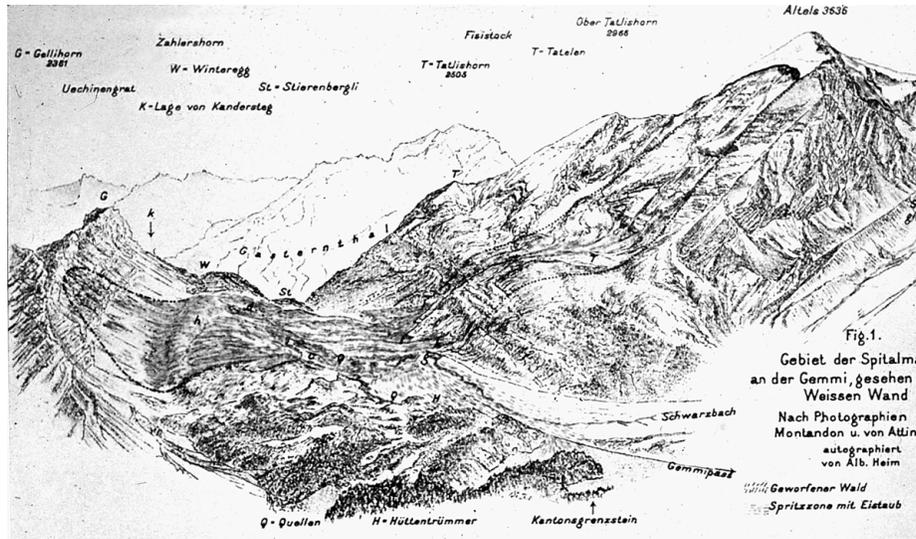


FIGURE 2.6. Drawing by the geologist Albert Heim of the traces of the large ice avalanche in 1895 at the Altels, Kandersteg, Swiss Alps (from Heim 1896).

Glacier on Mont Blanc in 1892, the large ice avalanche from the Altels in the Bernese Alps in 1895 (Figure 2.6), the large rock/ice avalanche from the Fletschhorn at Simplon Pass in 1901, the rapid advances of Vernagt Ferner in the Austrian Alps, and the massive disappearance of ice in Glacier Bay, Alaska—captured the interest of specialists as extraordinary events to be documented and analyzed. This first “golden” phase of worldwide glacier observation was unfortunately soon to be confronted with the dark shadows of global politics, economics, and even science.

#### HIGH TECHNOLOGY, WARS, AND A SCIENTIFIC CRISIS

One important product of the “golden” phase was the compilation of high-precision topographic maps, some specifically prepared for glaciers (Rhône, Vernagt, Guslar, Schnee, Hintereis; cf. Mercanton 1916) in the Swiss and Austrian Alps. These first maps are comparable in accuracy to modern topographic maps and can therefore be used to determine long-term volume and mass changes of the Alpine glaciers (Steiner et al., this volume). Thus high technology was used from the very beginning, and even today these maps

constitute a unique basis for scientific comparison. The mean century-scale mass balance estimates ( $-0.2$  to  $-0.6$  m water equivalent per year) derived from them and confirmed today by modern model calculations (Haeberli and Hoelzle 1995; Haeberli and Holzhauser 2003; Hoelzle et al. 2003) represent a standard against which glacier changes in other mountain ranges can be compared.

The second phase of international glacier observation spans the two world wars and the period of economic crisis between them, when glacier observations were reduced to a minimum. The number of glaciers observed in the Alps, for example, decreased by about 50% during each of the wars (see Zemp et al., this volume), with the Italian and Austrian glaciers being primarily affected. As a consequence, the intense global warming and glacier shrinkage of the 1930s and 1940s passed virtually unnoticed in the scientific literature. It was through the meritorious efforts of P. Mercanton in Switzerland that multiyear reports, though somewhat thin, continued, keeping the core of the worldwide network alive, albeit at a low level of intensity and scientific analysis. In addition to presenting numerical data on length changes of glaciers in the Alps and Scandinavia, these reports made



FIGURE 2.7. Synthetic oblique view of the Morteratsch Glacier, Bernina, Swiss Alps. The satellite image is a fusion of Landsat TM (1999, resolution 25 m) with the panchromatic channel of IRS 1C (1997, resolution 10 m). The retreat of the glacier tongue is 2 km from 1850 to 1973 and an additional 300 m to 1997. Since then, the glacier tongue has further retreated by more than 100 m. (Data and image processing by F. Paul; DHM25: © 2005. Reproduced by permission of swisstopo [BA057490]; satellite imagery © Eurimage/NPOC. 9.)

reference to various interesting national reports. Matthes (1934), for instance, reported a series of length variation measurements of the Nisqually Glacier since 1857. Signs of shrinking and glacier retreat clearly predominated, with the exception of a short but marked advance of glaciers in the Alps around 1920.

After this period of neglect, the third phase saw the reorganization of the international network under the umbrella of UNESCO by P. Kasser in Switzerland. In 1967, the Permanent Service on the Fluctuations of Glaciers (PSFG) was established as one of the services of the Federation of Astronomical and Geophysical Services (FAGS) of the International Council of Scientific Unions (ICSU). This resulted in the publication at five-year intervals of reports on the fluctuations of glaciers. Mass balance data from various countries, including the Soviet Union, the United States, and Canada, were included in these reports for the first

time, forming the essential link between climate fluctuations and glacier length changes. Length variation data from the United States, the Soviet Union, and other countries completed the corresponding records from the Alps, Scandinavia, and Iceland. Glacier readvances were reported from various parts of the world, especially from the Alps, where mass balances were predominantly positive in the late 1960s and 1970s. For the first time, therefore, empirical information about glacier responses to well-documented and strong signals in mass balance history started to become available.

This promising development, however, was soon faced with another crisis. Problematic theories about glacier mechanics (kinematic wave theory with unrealistic century-long reaction times [Nye 1960]) and the reporting of observed glacier changes as percentages of annually advancing/retreating glaciers (suppressing the essential cumulative effects so clearly visible in nature) reduced the credibility of these data in scientific, governmental, and public circles. This led to a brief interruption of the worldwide monitoring program when, after the sudden death of Fritz Müller (who had taken over the leadership of the program), the International Commission on Snow and Ice (ICSI), the responsible ICSU body for the network, did not immediately see the need to continue gathering worldwide glacier observations. This situation changed, however, with the growing interest in glacier fluctuations as a measure of ongoing climate change.

The fourth phase of international glacier monitoring took place during the past two decades, when improved theories and numerical models of changes in climate, energy and mass balance, ice thickness and flow, and glacier fluctuations finally became available (e.g., Jóhannesson, Raymond, and Waddington 1989; Haeberli and Hoelzle 1995; Oerlemans 2001; Hoelzle et al. 2003). Excellent international collaboration and advanced observational technologies (remote sensing, geoinformatics [see Bishop et al. 2004]) were now involved, but, more significantly, growing awareness of

the continued and accelerating loss of mountain glaciers in most parts of the world had finally led to the recognition that glacier changes were key indicators of global climate change and were therefore important to international assessments (the IPCC) and global observing systems (the Global Climate Observing System [GCOS]/Global Terrestrial Observing System [GTOS]) of the changing earth system.

Given these developments, attempts could now be made to build up a modern observational service. In the 1970s a World Glacier Inventory (WGI) had been planned under the guidance of Müller to be a snapshot of ice conditions on earth during the second half of the twentieth century. Within the framework of the Global Environment Monitoring System (GEMS) of the United Nations Environment Program (UNEP), a temporary technical secretariat began operations in 1976 as another service of ICSI. Detailed and preliminary regional inventories were compiled all over the world to update earlier compilations (see especially Field 1975; Mercer 1967) and to form a modern statistical basis for the geography of glaciers. The year 1986 finally saw the start of the World Glacier Monitoring Service (WGMS), combining and integrating the two ICSI services (PSFG and TTS/WGI). The *Glacier Mass Balance Bulletin* was issued at two-year intervals to speed up and facilitate access to information concerning mass balances of selected reference glaciers. International efforts were also made to collect and publish short abstracts on special events such as glacier surges, ice avalanches, glacier floods or debris flows, drastic retreats of tidewater glaciers, rock slides onto glaciers, and glacier-volcano interactions.

Modern glacier views (Figure 2.7) combine satellite imagery with digital terrain information; they show glaciers at high resolution from (virtual) elevated viewpoints and clearly document the striking ice losses and the bare ground left by the retreating and decaying ice. Recent and ongoing glacier changes are being documented through integrated multilevel strategies combining (1) information on mass balance, length



FIGURE 2.8. The retreating Stein Glacier, Sustenpass, Swiss Alps. The top two photographs are from 1947 and 2003; the bottom is a visualization of an assumed landscape in Roman times based on the hypothesis—in the strongest contradiction to existing scientific knowledge about Holocene climate, glacier, and forest fluctuations (see, e.g., Haeberli and Holzhauser 2003; Haeberli et al. 1999)—that glaciers had been almost completely replaced at that time by meadows and forests. The inherent message embedded in this third image (and understood by large parts of the public in central Europe) is that extremely warm temperatures (comparable to extreme IPCC scenarios for the twenty-first century) existed during historical times, remained unnoticed by contemporaneous people as well as by modern science, and did not cause any serious problems (from *Weltwoche*, August 12, 2004, based on Schlüchter and Jörin 2004).

change, and glacier inventories and (2) in-situ measurements with remote sensing for large/representative samples and GIS-based numerical modeling of distributed mass balance and flow for interpolation and extrapolation in space

and time (Haeberli 2004). Today wide public attention can be drawn to the accelerated disappearance of glaciers as dramatically documented in repeated glacier inventories (Paul et al. 2004). The spectacular find of the roughly 5,000-year-old and perfectly preserved body of the Oetztal ice man emerging from a small, probably cold (and now disappearing) miniature ice cap of the Austrian/Italian Alps confirmed that the “warm” or “high-energy” limit of Holocene, preindustrial glacier and climate variability may have been reached if not surpassed. The possibility can no longer be excluded that anthropogenic influences on the atmosphere could now, and for the first time, represent a major contributing factor to the observed glacier shrinkage (Haeberli et al. 1999; see also Houghton et al. 2001 for detailed discussion of anthropogenic influences on climate change). If these predictions are correct, many mountain ranges could lose their glacier covers within decades.

## PROSPECTS

Projections into the future can be based on simple extrapolation (with or without acceleration) of observed trends, on numerical model calculations of realistic scenarios, or on pure imagination. Extrapolation of developments documented by repeated glacier inventories for the Alps (Kääb et al. 2002; Paul et al. 2004) and provided by numerical models that combine glacier mass balance and flow (Oerlemans et al. 1998) both confirm that the disappearance of many mountain glaciers is quite likely to be a matter of a few decades. Pure imagination, of course, opens the possibility of optimism concerning such prospects (Figure 2.8). Such visualizations constitute a surprising revival of the romantic views originally developed during the eighteenth century: the Alps are again seen as a paradise-like white/green landscape with an open (probably cultivated) forest/meadow pattern surrounding some pretty remains of surface snow without any visible debris or moraines. Dreams of this type are obviously based on the hope that soils and vegetation will

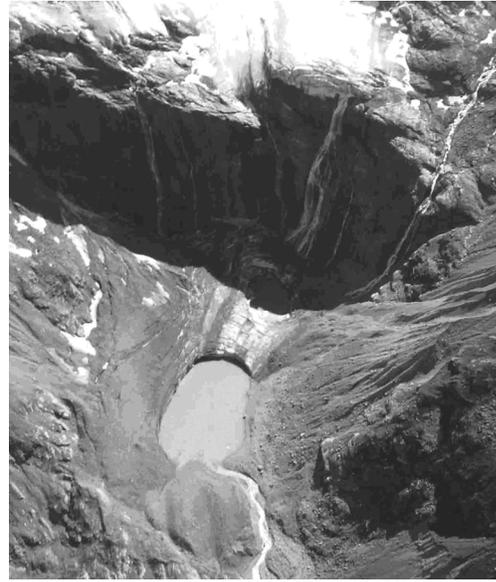


FIGURE 2.9. Two lakes (the upper one almost completely in shadow) filling collapse holes in the tongue of Paltü Glacier, Grisons, Swiss Alps, summer of 2005.

be able to immediately follow the disappearing ice, that high-mountain ecosystems will remain in equilibrium even with rapid climate forcing, and that changes in atmospheric temperatures of several degrees (causing timberline changes of many hundreds of meters) will occur without adverse effects on society. In reality, the developments of the coming decades may include the complete disappearance of small mountain glaciers and down-wasting rather than retreat for long valley glaciers. This already discernible trend may be accompanied by the development of extreme and long-lasting disequilibria in the abiotic as well as the biotic aspects of ecosystems and habitats, not only in high-mountain areas but elsewhere (Watson and Haeberli 2004).

The extreme summer of 2003 in the Alps removed an estimated 5–10% of the remaining glacier volume (Zemp et al. 2005). As a consequence, many glacier tongues have started to collapse rather than to retreat (Figure 2.9). The resulting dark and dusty mountain chains, free of snow and ice, provide an impression of the (summer) landscape that is likely to develop as a consequence of such a scenario of climate

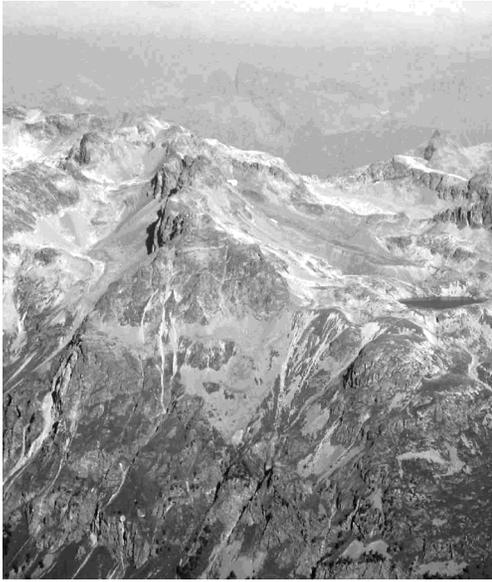


FIGURE 2.10. View from Piz Corvatsch to the Albula Mountains, Grisons, Swiss Alps, in the extremely hot, dry summer of 2003.

and glacier change (Figure 2.10). It is definitely no longer a question of “variations *périodiques* des glaciers.” Formerly glacierized mountains now becoming “black,” “dry,” and geomorphologically unstable may increasingly be perceived as primary testimony to general and very serious human impacts on the global environment (Watson and Haeberli 2004). In this sense, glacier observation is becoming an activity of ever-increasing socioeconomic and political importance. Accurate views of changing glaciers may therefore help to change our attitude toward accelerating changes in the global human environment, a challenge of historic dimensions.

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