Zeitschrift: Swiss bulletin für angewandte Geologie = Swiss bulletin pour la géologie appliquée = Swiss bulletin per la geologia applicata = Swiss bulletin for applied geology

Herausgeber: Schweizerische Vereinigung von Energie-Geowissenschaftern; Schweizerische Fachgruppe für Ingenieurgeologie

Band: 18 (2013)

Heft: 2

Artikel: Glaciers as indicators of changing climate from Little Ice Age to modern times

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DOI: https://doi.org/10.5169/seals-391148

Swiss Bull. angew. Geol. Vol. 18/2, 2013 S. 77-82

Glaciers as indicators of changing climate from Little Ice Age to modern times – SASEG field trip, 23 June 2013: «Mer de Glace, Chamonix – Mont Blanc»

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Lecture presented at the 80th SASEG Convention, June 2013, Chamonix (F)

Abstract
The Chamonix valley and the Mer de Glace glacier of the Mont Blanc Massif offer an insight into the relationship between recent glacial history and climate evolution from the Little Ice Age (about 1550 AD to 1890 AD) to now. Following the warm climate of the Middle Ages, the Little Ice Age starts with a rapid growth of glaciers and a first maximal extension in 1600 and 1640. After several fluctuations and maximum extension periods in 1820 and 1850, the melting of the glacier tongue, with interruptions between 1880 and 1930 and between 1970 and 1990, leads to a total shortening of the *Mer de Glace* glacier of more than 2,000 m. Glacial melting rates during this period vary between 20 and 40 m/year, and are of the same magnitude as melting rates at the end of the last Ice Age.

Zusammenfassung
Das Tal von Chamonix und der Gletscher Mer de Glace im Mont Blanc Massiv bieten einen Einblick in die Beziehung zwischen rezenter Vereisung und der Klimaentwicklung von der Kleinen Eiszeit (ungefähr 1550 AD bis 1890 AD) bis heute. Nach dem warmen Klima des Mittelalters begann die Kleine Eiszeit mit raschem Gletscherwachstum und ersten Maximalständen um die Jahre 1600 und 1640. Nach verschiedenen Schwankungen und einer Periode maximaler Ausdehnung zwischen 1820 und 1850 führte das Abschmelzen der Gletscherzunge zu einer Verkürzung des Mer de Glace-Gletschers um mehr als 2'000 m. Die Abschmelzraten variieren in dieser Periode zwischen 20 und 40 m/Jahr und sind in derselben Grössenordnung wie jene am Ende der letzten Eiszeit.

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1 Introduction

At the end of the 19th and the beginning of the 20th century, the spectacular alpine glacial landscapes of the outgoing Little Ice Age attracted numerous visitors, painters and photographers. This rush was at the origin of a rich iconographic documentation, presenting the mountain valleys with glacier tongues advancing into forests and pastures with a scarce vegetation. At that period, many scientists considered the repeated fluctuations of alpine glacier tongues as a possible announcement of the next glaciation. This was the main motivation for the foundation of the «Glacier Commission» (now: «Cryospheric Commission») of the Swiss Academy of Sciences in 1893, half a century after Agassiz (1837) and the scientific community admitted the existence of ice ages during the recent Earth history. Since then, length variations of about a hundred glacier tongues are regularly monitored as well as volume variations of a smaller number of glaciers (http://glaciology.ethz.ch/messnetz/monitoring.html?locale=en).

In the current debate on climate change and human impact on global warming, glacial variations and more particularly the variation in ice tongue and ice stream length are widely recognized as sensitive indicators of temperature fluctuations. According to Zemp et al. (2011) «the variations of a glacier front position represents an indirect, delayed, filtered and enhanced response to changes in climate over glacier specific response times of up to several decades...». The Chamonix valley and the Mont Blanc massif are a kind of an open-air museum of the impact of the Little Ice Age («Petit âge glaciaire», «Kleine Eiszeit») on landscapes from the middle of the 16th to the end of the 19th century, and of glacier retreat in modern times, either for natural reasons or resulting from human influence. Field observations on the extension of glaciers during the Little Ice Age and discussions on the modern human impact are particularly easy and instructive in this region. This is why SASEG has chosen glacier and climate history as one of the themes for its annual 2013 meeting and field trip in Chamonix.

2 Alpine glaciers, climate and geomorphology

The ice balance of glaciers depends mainly on three major parameters (Fig. 1):

- Deep atmospheric temperatures to cool down and preserve snow and ice from melting.
- Precipitations (mainly as snow) to provide the necessary ice volume.
- Geothermal flux. This heat flow provides a modest, but still significant energy input at the base of the glacier, and guaranties conditions of a wet glacier basis.

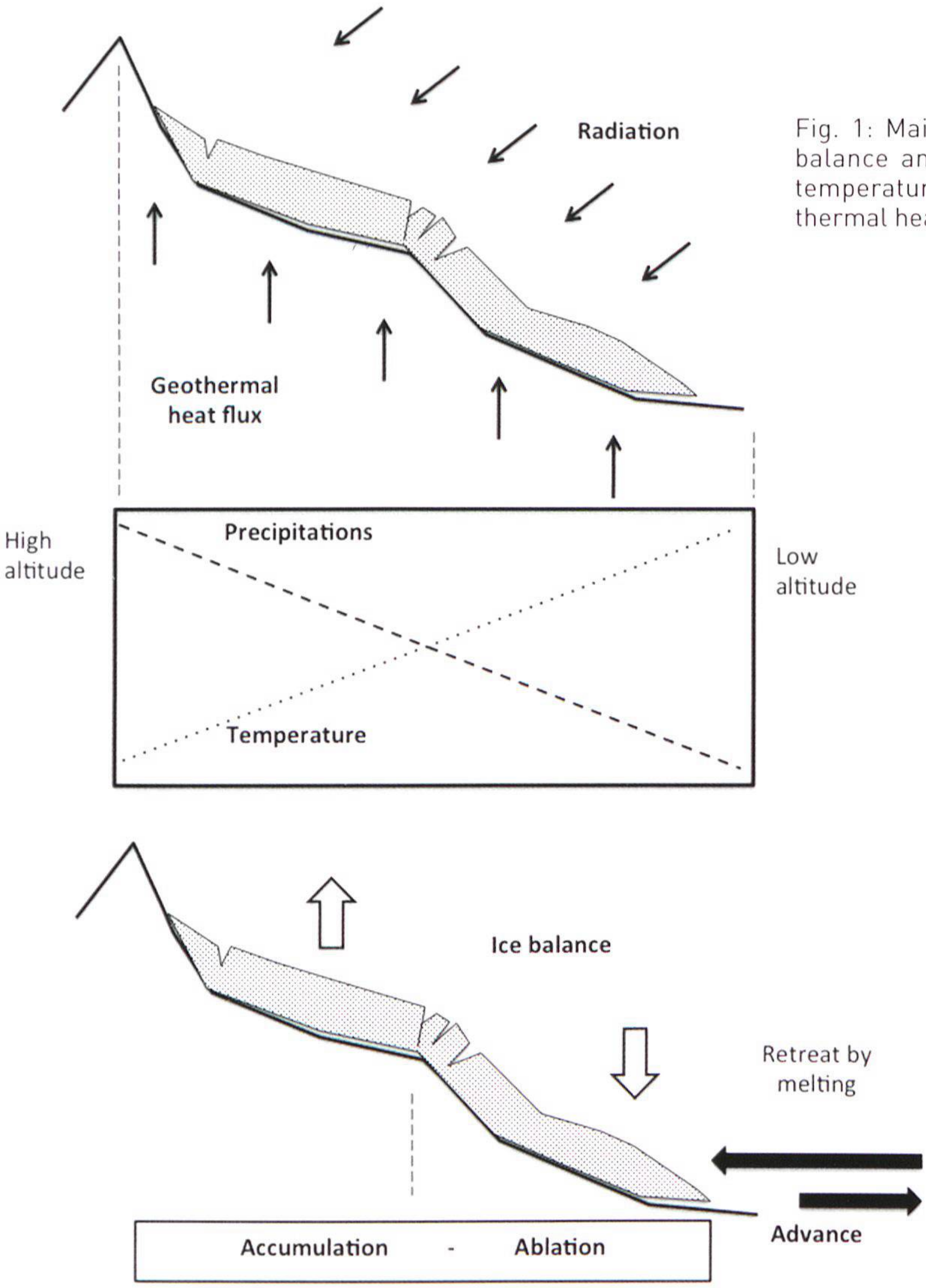

Fig. 1: Main parameters of the ice balance and glacier front position: temperature, precipitation and geothermal heat flow.

The current position of a glacier front depends on the ice movement and the change in ice volume:

- Ice tongues are advancing by sliding and by internal flow deformation of the ice.
- A glacier tongue gets shorter, when melting of the glacier front is more rapid than the advance by sliding and internal flow.

On a glacier, the accumulation and ablation zones are the areas with respectively positive and negative ice balance from the point of view of ice formation and ice melting.
Glacial erosion is by far the most important landscape forming process in the Alps and the alpine foreland. Three different processes may be distinguished:

- Abrasion by friction of rock debris at the interface between the sliding ice masses. This process produces fine sand and silt, which is then evacuated as «glacier milk» by the melt-water of the sub-glacial river. Measured and calculated erosion rates are in the order of 1-2 mm/year. «Glacial polish» at the bedrock surface produces easily recognizable hummocky morphologies («roches moutonnées») that may last thousands of years of alteration and erosion.
- Plucking results from the stress of the glacial load on the bedrock. Along pre-existing faults and fractures this process produces rock debris and blocks of different shapes.
- Cavitation of the bedrock by sub-glacial water, carving vertical gorges and «moulins».

Gelifraction is responsible for landforms above the glacial surface. Outside the melt-water streams, erosion products of glaciers may be deposited in places as till (non sorted sediments) and moraines (term that designates morphologies due to till deposits). Lateral and frontal moraines of glaciers also contain material from slope deposits (screes and others) that may have been transported on the back of the glaciers.

3 Recent history of the *Mer de Glace* glacier

With an elevation of 4,810.45 m, the Mont Blanc is the highest mountain in the Alps and gives birth to a number of glaciers, as well on its southern, Italian slope as on the northern, French side. The town of Chamonix is located at 1,050 m above mean sea level. The *Mer de Glace* («Sea of Ice») is a glacier located in a lateral valley of the Arve River, on the northern slopes of the Mont Blanc Massif; it is the longest glacier in France. Its recent history was the focus of the SASEG field trip of 23 June 2013.
The last ice age, called Würm, started some 115,000 years ago, and glaciers were back in their present position about 10,800 BP ago. At least one major advance of the Arve and Rhone glaciers reached the Lyon area. During the «Last Glacial Maximum» (LGM), about 20,000 BP ago (Moscariello et al. 1998), the Rhone Glacier did not go further than the Lake Geneva basin. The maximum extension and limits of the Mont Blanc glaciers (Coutterand 2010) is well marked on both sides of the Arve Valley by the upper limit of glacial polish on the bedrock (Fig. 2). On the slopes of the Mont Blanc and Aiguilles Rouges Massif, south and north of the town of Chamonix, the surface of the Arve glacier reached an elevation of about 2,200 to 2,300 m. As a simplification, one can state that a glacier is stable in volume, as long as it remains in the area of an average annual temperature equal or lower than about 0 °C. This means that temperatures during the maximum extension of glaciers during the last ice age were about 10 °C lower than now. During the Holocene, alpine glaciers fluctuated from situations of strong melting and very little remaining ice to situations with glacier tongues up to about 1.5 to 2 km longer than now. These findings stem mainly from the analysis of trees and peat that appear nowadays under the melting glacier tongues, or that are expelled by the sub-glacial streams. These organic remains indicate

that, since the end of the last ice age, glacier tongues were clearly shorter than now during more than 5,400 years (Table 1; Schlüchter & Jorin 2004).

The last period of glacier progression was the so-called «Little Ice Age» (Matthes 1939) that followed the warm period of the Middle Ages. In the Alps, this period started with glacier advances in the late 16th century. According to Zemp et al. (2011), maximum lengths were reached at *Mer de Glace* in the Chamonix – Mont Blanc area in 1600 and 1640 AD, and other advances at around 1720, 1780, 1820 and 1850 AD.

The history of the *Mer de Glace* fluctuations has been reconstructed in detail by Nussbaumer et al. (2007). As shown in Fig. 3, glacier growth is very rapid between the years 1550 and 1600, with an advance of approximately 1,000 m (ca. 20 m/year). From 1600 to

Warm periode (reduced glaciers, age of trees and peat)	Calendar year BP (before 1950)	Duration (years)
10	9,900 – 9,550	350
9	9,000 – 8,050	950
8	7,700 – 7,500	200
7	7,350 – 6,500	850
6	6,150 – 6,000	150
5	5,700 – 5,500	200
4	5,200 – 3,400	1,800
3	about 2,700	100
2	2,300 – 1,800	500
1	1.450 – 1,150	300
	Total	5,400

Tab. 1: Periods of reduced alpine glaciers, age of trees and peat (adapted from Schlüchter & Jorin 2004). The duration of 5,400 years corresponds to the dating of trees and peat by Schlüchter & Jorin (2004). However, after a glacier tongue melting, trees have first to start growing, and peat to form. Periods of shorter glacier tongues than now are therefore systematically underestimated.

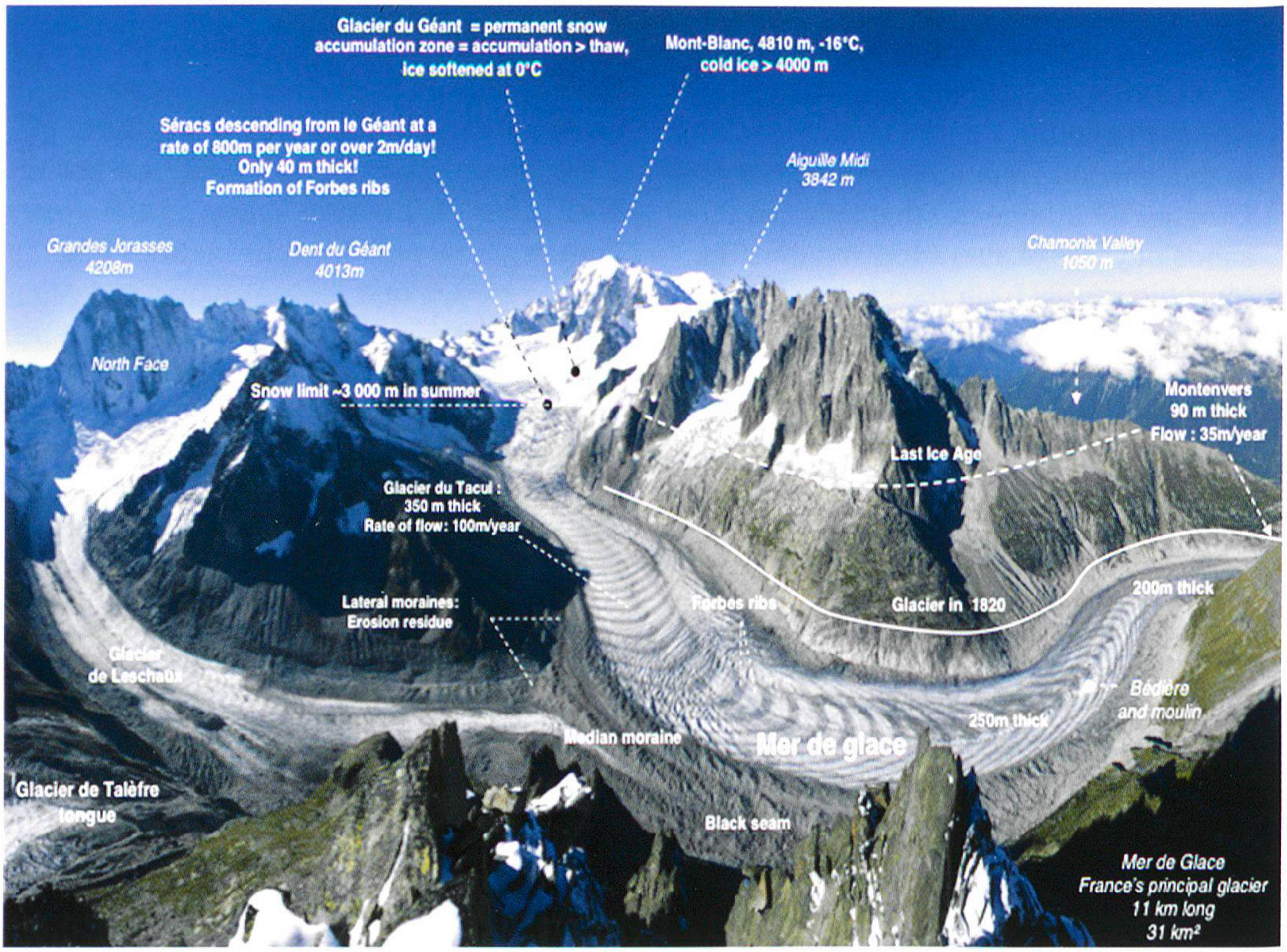

Fig. 2: The *Mer de Glace* glacier and Mont Blanc seen from the Le Moine summit (looking towards the West); ice limits during the last ice age Würm, and maximum ice extension during the Little Ice Age are indicated by glacial abrasion of the bedrock. Foto: Jean-François Hagenmuller [info@lumieresdaltitude.com], interpretation: Luc Moreau [Observatoire du Mont Blanc, 69 lacets du Benlédères, F-74400 Chamonix].

1850, three main short melting and growth periods are at the origin of 600–700 m of glacier front changes. After the last maximum in 1852, the glacier tongue collapses by a length of about 1'200 m within 30 years (40 m/year). A rather stable glacier tongue with minor fluctuations is reported from about 1880 to 1930. The next phase of rapid melting between 1930 and 1970 corresponds to a glacial retreat of 800 m (20 m/year). The following plateau is from about 1970 to 1995. In the current phase of rapid glacier melting, the tongue of the Mer de Glace is loosing an average of 35 m of length per year. Since the 1820 maximum, thickness reduction of *Mer de Glace* in the valley section of the Montenvers railway station is 180 m (Fig. 2).

4 Discussion

The climate history during the Little Ice Age has been investigated by several authors, and in particular by Le Roy Ladurie (1967). This author enumerates a number of exceptional climate events, at the origin of famine, social unrest etc. A diminished solar activity and repeated volcanic activity have been put forward as causes of this 350 years long climate crisis.

With respect to glacier melting, the rates of glacier tongue shortening from the end of the last maximum of the Little Ice Age until now may be compared with those of the Rhône glacier and other alpine glaciers at the end of the last ice age: The glacier position is near the city of Geneva in 18,600 BP (Moscariello et al. 1998). The glacier front is then back to its current position in Gletsch, about 180 km from Geneva, 8,000 years later. These data indicate an average rate of shortening of the glacier front of 22.5 m/year. The current rate of 35 m/year for the *Mer de Glace* is somewhat higher, but still in the same order of magnitude, and comparable with the rates from 1850 to 1880. Therefore, overall the current glacier melting is not an exceptional event in the recent history of the Alps.

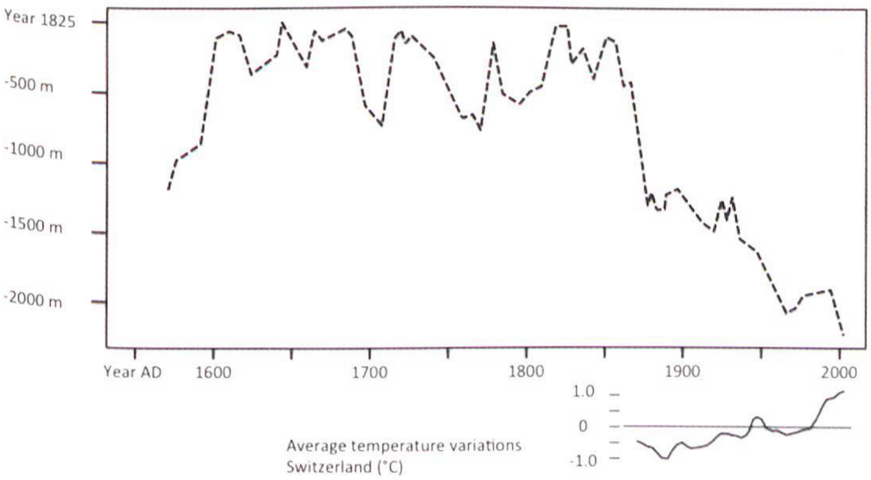

Fig. 3: Fluctuations of the *Mer de Glace* ice tongue from 1550 to 2001 AD (Nussbaumer et al. 2007, interpolated curve; the reference point of 1825 is an erratic block) and 20 year gliding average temperature variations (instrumental measurements) for Switzerland 1864–2012, reference period: 1961–1990 [http://www.meteoswiss.admin.ch/web/en/climateclimate_today/trends_in_switzerland.html.

Acknowledgements

The author would like to thank Jean-François Hagenmuller and Luc Morau for the authorisation to reproduce Figure 2. Georges Gorin made a careful revision of the paper.

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