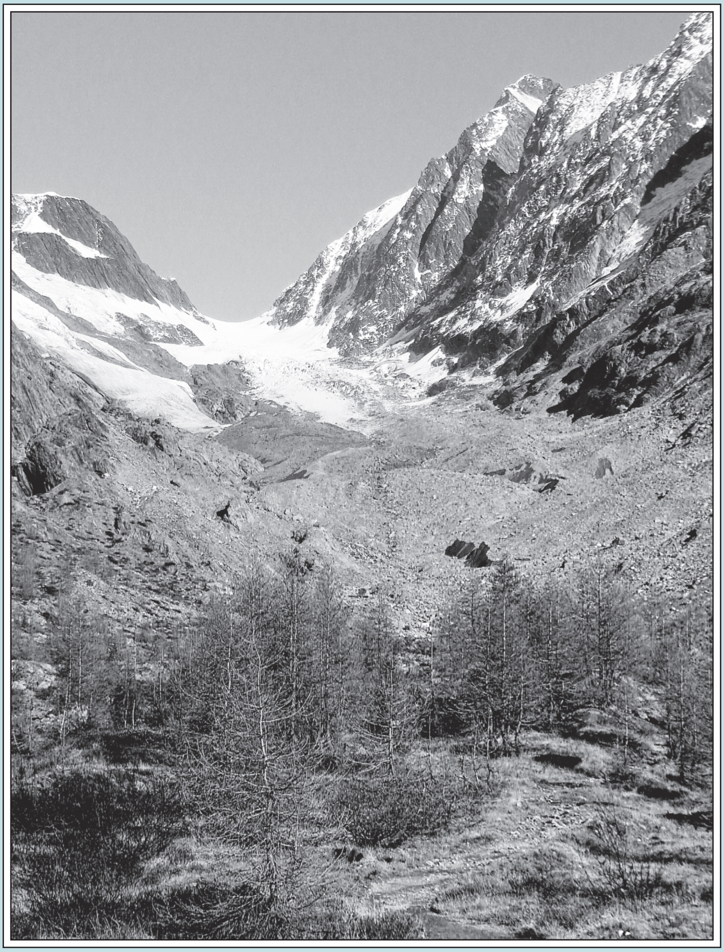
The Swiss Glaciers

2013/14 and 2014/15

Glaciological Report (Glacier) No. 135/136



2017

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Glaciological Report No. 135/136

Edited by

Andreas Bauder[1]

With contributions from

Andreas Bauder[1], Mauro Fischer[2], Martin Funk[1],

Jeannette Gabbi[1,4,*], Martin Hoelzle[2], Matthias Huss[1,2],

Giovanni Kappenberger[3], Urs Steinegger [4]

[1] Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich

[2] Department of Geosciences, University of Fribourg

[3] 6654 Cavigliano

[4] Meteodat GmbH, 8005 Zürich

* now at beffa tognacca sagl, 6702 Claro

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Andreas Bauder : Chapt. 1, 2, 3, 4, 5, App. A, B, C
Mauro Fischer : Chapt. 4
Martin Funk : Chapt. 1, 4, 7
Jeannette Gabbi : Chapt. 4
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Matthias Huss : Chapt. 1, 2, 4
Giovanni Kappenberger : Chapt. 4
Urs Steinegger : Chapt. 4

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Summary

During the 135th and 136th year under review by the Cryospheric Commission (EKK), Swiss glaciers continued to lose both length and mass. The two periods were characterized by average amounts of snow accumulation during winter, and moderate to very high melt rates in summer. The results presented in this report reflect the weather conditions in the measurement periods as well as the effects of ongoing atmospheric warming over the past decades.

In autumn 2014, a length variation was determined for more than 96 of the 114 glaciers currently under active observation, while one year later 99 glaciers were measured. In the two observation periods, 2013/14 and 2014/15, Swiss glaciers experienced further losses in length. Most of the measurement values lay between 0 and -30 m in both periods. Several glaciers displayed remarkably high retreat values in a single year. These can be attributed to the detachment of a mass of dead ice from the glacier snout, or to the melting of sections of the glacier that had been thinning constantly for many years.

Detailed mass balance observations at seasonal resolution were carried out at ten glaciers: Basòdino, Findelen, Gries, Pizol, Plaine Morte, Murtel, Rhone, Sankt Anna, Silvretta and Tsanfleuron, but measurements were also conducted at several additional glaciers. In the first period (2013/14), glaciers in the Southern Valais showed a balanced mass budget, whereas mass loss was for the most part moderate in the other regions. During the second period (2014/15), strong glacier mass losses occurred throughout the entire Swiss Alps. In addition to the results of new measurements, a homogenized 100-year series of point mass balance on Claridenfirn, as well as re-anaylzed long-term mass balance series of glacier-wide balance for nine glaciers are presented.

Measurements of ice surface velocity were performed at selected glaciers in the Mauvoisin and Mattmark regions. The trend continued toward diminishing velocities, reflecting the reduction in ice thickness due to ongoing negative mass balances.

Measurements of borehole firn temperature at Colle Gnifetti, Valais, showed further warming over the last pentade indicating a regime shift with melting occurring even at very high elevations in the Alps during summer.

An update of the inventory of hazardous glaciers documents known events that ocurred since 2003 in the Swiss Alps. The list also includes glaciers that are now considered as potentially hazardous and are under frequent observation.

Published Reports

Annual reports of the Swiss glaciers started in the year of 1880 by F.A. Forel (1841-1912). While the first two reports appeared in "Echo des Alps", reports 3 until 90 were published in the yearbooks of the Swiss Alpine Club (SAC). Starting from report 91, they appeared as separate publication of the the Swiss Academy of Sciences (SCNAT) and only a summery was published in the magazine of the Swiss Alpine Club (SAC).

Authors of the annual reports:	No.	Year
F.A. Forel	1 - 15	1880 - 1894
F.A. Forel et L. Du Pasquier	16 - 17	1895 - 1896
F.A. Forel, M. Lugeon et E. Muret	18 - 27	1897 - 1906
F.A. Forel, E. Muret, P.L. Mercanton et E. Argand	28	1907
F.A. Forel, E. Muret et P.L. Mercanton	29 - 32	1908 - 1911
E. Muret et P.L. Mercanton	33 - 34	1912 - 1913
P.L. Mercanton	35 - 70	1914 - 1949
P.L. Mercanton et A. Renaud	71 - 75	1950 - 1954
A. Renaud	76 - 83	1955 - 1961/62
P. Kasser	84 - 91	1962/63 - 1969/70
P. Kasser und M. Aellen	92	1970/71

Authors and editors of the glaciological two year reports:		
P. Kasser und M. Aellen	93/94	1971/72 - 1972/73
P. Kasser, M. Aellen und H. Siegenthaler	95/96 - 99/100	1973/74 - 1978/79
M. Aellen	101/102	1979/80 - 1980/81
M. Aellen und E. Herren	103/104 - 111/112	1981/82 - 1990/91
E. Herren und M. Hoelzle	113/114	1991/92 - 1992/93
E. Herren, M. Hoelzle and M. Maisch	115/116 - 119/120	1993/94 - 1998/99
E. Herren, A. Bauder, M. Hoelzle and M. Maisch	121/122	1999/00 - 2000/01
E. Herren and A. Bauder	123/124	2001/02 - 2002/03
A. Bauder and R. Rüegg	125/126	2003/04 - 2004/05
A. Bauder and C. Ryser	127/128	2005/06 - 2006/07
A. Bauder, S. Steffen and S. Usselmann	129/130	2007/08 - 2008/09
A. Bauder	131/132 - 135/136	2009/10 - 2014/15

Contents

1 Introduction

Systematic and long-term records of glacier changes in Switzerland started in 1880 with annual length change measurements of selected glaciers. At that time, these measurements were motivated by questions about past and future ice ages. In the meantime, the goals of worldwide glacier monitoring have evolved and multiplied. Glacier change data are necessary for investigations of the glacier-climate interaction, but the data are also important for the assessment of water resources, sea-level rise and natural hazards. Finally, the broad public manifests an increasing interest in glacier retreat as an element of the Alpine environment excellently illustrating climate change.

The main focus of the Swiss glacier monitoring network is to collect the following data: (1) length change, (2) mass balance, (3) volume change, (4) surface flow speed, (5) glacier parameters (e.g. surface area), and (6) englacial temperature. The programme for GLAcier MOnitoring in Switzerland (GLAMOS) has been adopted by the Cryospheric Commission in March 2007 and receives long-term funding by the Federal Office for Environment (BAFU), MeteoSwiss within the Global Climate Observing System (GCOS) Switzerland, the Swiss Academy of Sciences (SCNAT), and support by the Federal Office of Topography (swisstopo) since 1.1.2016. A detailed description of the aims, the current status and perspectives of the monitoring programme was presented in Chapter 1.1 of "The Swiss Glaciers" Volume 125/126.

The results of Swiss glacier monitoring contribute to the international efforts to document glacier fluctuations worldwide as part of global environmental monitoring initiatives of the Global Terrestrial Network for Glaciers (GTN-G) within the Global Terrestrial and Climate Observing System (GTOS/GCOS). Results are reported to the World Glacier Monitoring Service (WGMS).

This report is the new volume No. 135/136 in the series "The Swiss Glaciers" and presents the results of the two observational periods 2013/14 and 2014/15. It carries on the long tradition of yearbooks documenting monitored fluctuations of Swiss glaciers since 1880 (see page iv). Data and digital versions of the present and earlier volumes are available at http://glaciology.ethz.ch/swiss-glaciers. Thanks to the continuous efforts of many people, public and private organisations in Switzerland, long time-series of data related to glacier changes have been acquired and are highly valuable for scientific research, applied questions and outreach.

The present data-report expands the short overview of general outcomes published annually in German, French and Italian in the magazine "Die Alpen - Les Alpes - Le Alpi" of the Swiss Alpine Club with detailed facts and figures.

2 Weather and Climate

In this section the weather and climate conditions for 2013/14 and 2014/15, the two periods under review, are described. We focus on the two variables that are most relevant for glacier mass balance: temperature and precipitation. In general, glacier mass balance is determined largely by the amount of winter snowfall and by air temperature during summer. High temperatures in April, May or June can diminish the winter snowpack rapidly and expose the much darker ice surface as early as July. During July and August the amount of solar radiation is high, which enhances the melting of the unprotected ice surface. When these two factors are combined, very negative mass balances can be expected, as occurred during the heatwave of summer 2003. On the other hand, summer snow down to the glacier termini protects the ice surface from melting and leads to less negative mass balances.

We have selected the four high-elevation climate stations at Grand St-Bernard (2472 m a.s.l.), Jungfraujoch (3580 m a.s.l.), Säntis (2502 m a.s.l.) and Weissfluhjoch (2690 m a.s.l.) to illustrate the monthly anomalies in air temperature (Figure 2.1), and 14 stations (Airolo, Château-d'Oex, Disentis, Engelberg, Elm, Grand St-Bernard, Grimsel Hospiz, Montana, Lauterbrunnen, Säntis, Scuol, Sils-Maria, Weissfluhjoch, Zermatt) throughout all regions of the Swiss Alps for monthly anomalies in precipitation (Figure 2.2) during the two periods. For annual precipitation and mean summer temperature, the long-term record since 1880 is shown in Figures 2.3 and 2.4 as a mean of 12 homogenized climate stations (Begert et al., 2005). All stations belong to the observational networks maintained by MeteoSwiss. The description of the weather conditions in the two periods under review stems from the figures and the annual and monthly reports of the meteorological conditions found in the data provided by the observational networks maintained by MeteoSwiss.

2.1 Weather and Climate in 2013/14

Despite ample snowfalls in November 2013, mostly in the eastern Swiss Alps, snow depth remained well below average until Christmas in all regions of Switzerland. After that, the southern side of the Alps in particular was affected by extreme snow precipitation events that in some places experienced more than 100 cm of snowfall in 24 hours. Until February 2014, two to three times the normal amount of snow was recorded south of the main Alpine divide with snow depths of 2-2.5 m at 1500 m a.s.l. Since the beginning of the measurements, the Winter 2013/14 was the wettest on the south side of the Alps since measurements began. By contrast, frequent föhn led to mild temperatures, sparse precipitation and snow depth well below average in the north. At some low-

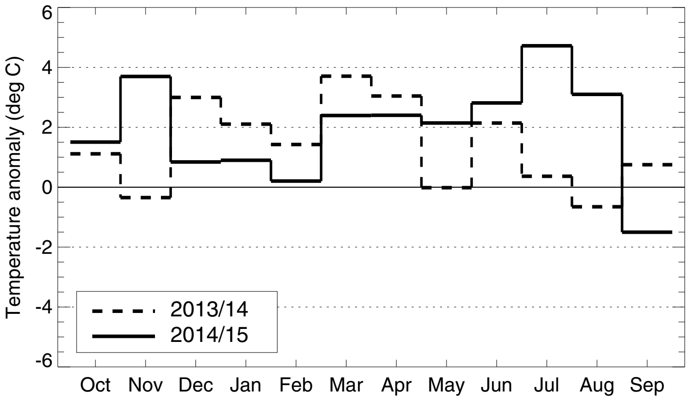

Figure 2.1: Mean monthly anomaly of temperature from the long-term climatic mean (period 1961-1990) for four selected stations in the MeteoSwiss network. Anomalies in the two reporting periods 2013/14 and 2014/15 are shown.

elevation stations not a single day with snow was observed. The warm and rather dry months of March and April contributed to an early onset of snowmelt on the glacier tongues. July and August were characterized by average air temperatures (Figure 2.1) but also by significant precipitations amounts, especially in July, when almost twice the typical amount was recorded at alpine stations (Figure 2.2). In combination, these weather conditions led to frequent fresh snowfalls at elevations of more than 3000 m a.s.l. and, hence, contributed to favourable conditions for the glaciers. In September, however, relatively high temperatures prolonged the melting of snow and ice well into autumn.

Compared to the period 1961-1990, summer air temperatures (May to September) were 0.9°C higher than the long-term mean (Figure 2.3). Annual precipitation amounts were 7% above average for the whole of Switzerland (Figure 2.4). Winter precipitation in particular strongly differed between the south and the north side of the Alps. For glaciers influenced by both large amounts of winter snow and, at sufficiently high elevations, by summer snow events (Engadine, Valais at the border to Italy), the particular weather conditions in 2013/14 resulted in the first year of slightly positive glacier mass balances for over a decade.

2.2 Weather and Climate in 2014/15

Early winter 2014/15 was characterized by record warm temperatures and very below-average amounts of snow (Figures 2.1 and 2.2). Until Christmas almost no snow was present in the Alpine valleys, while in the second half of January, several events brought a significant amount of snow, especially on the south side of the Alps. Considering the entire winter season, snow depth was close to average only above 2200 m a.s.l., which can be attributed to the relatively high air temperatures throughout the winter months. Significant differences in snow depth between the North and the

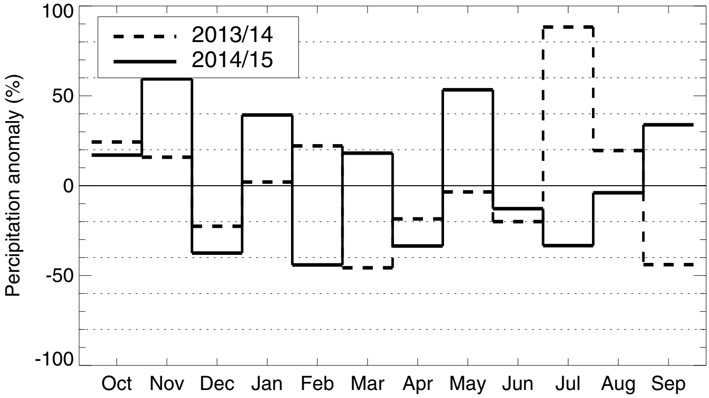

Figure 2.2: Mean monthly anomaly of precipitation from the long-term climatic mean (period 1961-1990) for 14 selected stations in the MeteoSwiss network. Anomalies found in the two reporting periods 2013/14 and 2014/15 are shown.

South persisted until April. In mid-May events with up to 1 meter of fresh snow in the North and East resulted in above average snow cover at high elevation. High air temperatures in early and late June contributed to a rapid melting of winter snow. Temperatures in July were almost 5°C above the long-term average (Figure 2.1). The extremely hot and dry weather persisted almost continuously until mid-August and resulted in fast depletion of the snow cover on glaciers and substantial ice melt. On Weissfluhjoch, not a single day with fresh snow was recorded in July and August 2015, which has occurred only one other time since observations began 80 years ago. Cooler temperatures and some snow at high elevation came in the second half of August. In early September, it snowed even down to 2000 m a.s.l. which put a rather early end to the melting season.

Summer air temperatures (May to September) were 2.4°C higher than the long-term mean (Figure 2.3). This value ranks second right after the heatwaves of summer 2003. Annual precipitation was 2% below average (Figure 2.4). The very high summer temperatures resulted in unfavorable conditions for the glaciers with one of the most intense melting periods in the 21st century. As the glaciers were relatively well-covered with winter snow at the beginning of the heatwave in late June, and September brought new snow, glacier mass loss did not reach values as extreme as in 2003.

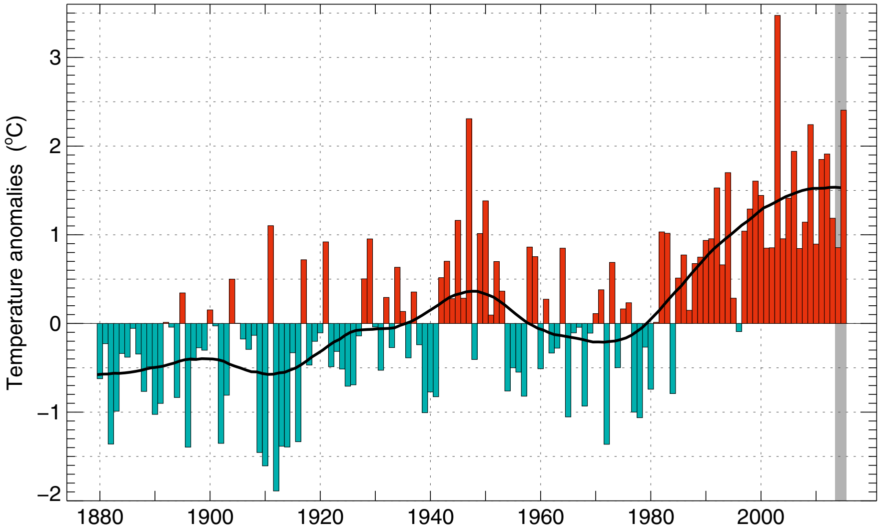

Figure 2.3: Anomalies of mean summer air temperature (May-September) from the mean value 1961-1990 in degrees Celcius for the period 1864-2015. The gray shaded area highlights the years of the current report.

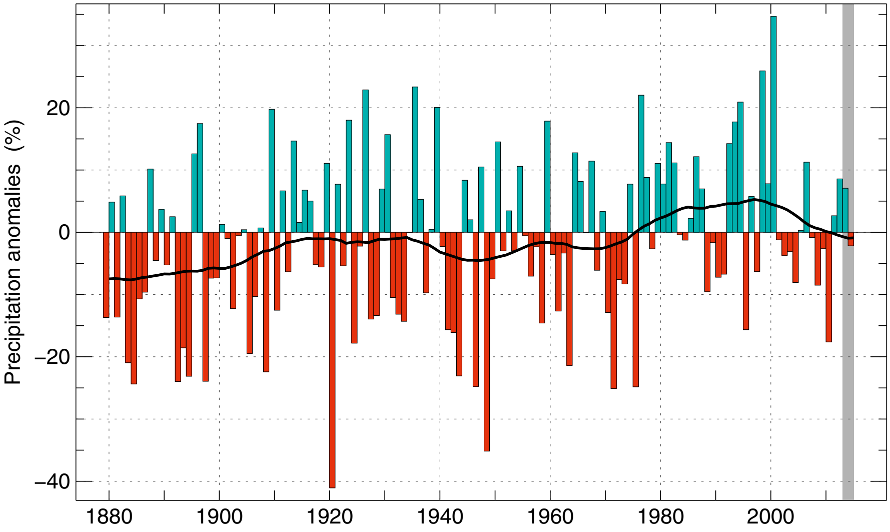

Figure 2.4: Anomalies of annual precipitation (hydrological year) from the mean value 1961-1990 in percentage for the period 1864-2015. The gray shaded area highlights the years of the current report.

3 Length Variation

3.1 Introduction

In the two periods covered this report, 114 of about 125 glaciers in the observational network were actively observed (Figures 3.1, 3.2 and Table 3.1). The other glaciers have melted back drastically and are often debris-covered, on one hand, with the result that it is simply not possible to carry out a proper survey at yearly intervals. On the other hand, a number of glaciers were observed only at irregular intervals, and the measurement values obtained were rather imprecise, which does not justify retaining these figures in the charts and analyses.

During the two years under review, 2013/14 and 2014/15, Swiss glaciers suffered further losses in length. As in previous periods, most of the measurements were within the range of 0 to -30 m for both periods. This overall trend was overshadowed in both years by a few very high retreat values, which could be traced to local influences as in previous years, or which relate to larger glaciers, and in some cases also pertain to a period of several years. They are usually also the result of a process extending over a longer period of time and thus are not unexpected.

3.2 Length Variations in 2013/14

In autumn 2014 changes in the terminus position as compared to the previous years were determined at 96 glaciers (Figure 3.1). Of these, 88 were found to be in recession, for four there was no change observed, and another four glaciers showed a positive value. With the exception of three glaciers, the values ranged from a retreat of -100 m at Blüemlisalpgletscher to a slight advance of +8 m at Firnalpelifirn. Approximately two-thirds of the measurement values lay between -1 and -30 m.

The three exceptions refer to the massive retreats of Schwarzgletscher, Unterer Grindelwaldgletscher and Kehlengletscher. The large retreat values are a result of the evolution of the glaciers over the past ten years. The heavily debris-covered tongue and the absence of ice supply from the accumulation area resulted in a gradual thinning of the flat tongues, while no change in length occurred. At all three glaciers, the dynamic terminus shifted back abruptly during the summer when a large portion of the tongue detached at a break in the terrain where the ice was thinned out. The timing of these events was rather arbitrary and only poorly reflects the overall and continuous change in these glaciers. The sporadic positive measurement values stem from the specific weather conditions in the year under review, and not from an advance due to a surplus of ice supply from the accumulation area after consecutive years of a positive mass balance. The increase in length resulted from local conditions in an individual year, with both firn deposits at the margin of the glacier and reduced melting at the terminus.

3.3 Length Variations in 2014/15

Length variations were determined for 99 glaciers in autumn 2015 (Figure 3.2). Of these, 91 became shorter, four did not change their position, and another four were slightly in advance. With six exceptions, the values ranged from a recession of barely 100 meters at Schwarzgletscher to an advance of 18 meters at Bifertenfirn. More than two thirds of the measurement values lay between -1 and -30 meters.

Unterer Grindelwaldgletscher, Gamchigletscher, Vadret da Morteratsch and Turtmanngletscher were the exceptions, together with two additional glaciers, where the length change was evaluated in a multi-year period. The high retreat values for each is linked to a process that has been underway for many years. Due to an increasingly thicker debris cover on the tongue or the continued absence of ice flow from the accumulation areas, the glaciers have been melting irregularly or have thinned out without any reduction in length. In an individual year such as the period under review, a large, flat area melted suddenly and completely, disintegrated into individual ice masses, or broke apart in a steep section of terrain. As a result, the active terminus shifted back abruptly and substantially.

3.4 Length Variations in 2013/14 and in 2014/15, Summary

No. [a]	Glacier	Ct. [b]	Length variation [c] (m)		Altitude [d] (m a.s.l.)	Date of measurements (Day, Month)		
			2013/14	2014/15	2015	2013	2014	2015
Catchment area of the river Rhone (II)								
1 [e,f]	Rhone	VS	−27.6	−6.2	2208.1	23.09.	23.09.	05.08.
3 [e,f]	Gries	VS	−44.7	−45.2	2427.0	21.08.	23.09.	31.08.
4 [e,f]	Fiescher	VS	n	−210 [3a]	1682	n	n	28.08.
5 [e,f]	Grosser Aletsch	VS	−31.9	−53.5	1598.5	21.08.	22.08.	26.08.
7 [e,f]	Kaltwasser	VS	−14.3	−6	2660 [12]	26.09.	26.09.	30.09.
173 [e]	Seewjinen	VS	−1.0	−12.8	2735.5	04.09.	02.10.	21.09.
10 [e,f]	Schwarzberg	VS	−16.4	−22.8	2663.2	04.09.	02.10.	21.09.
11 [e,f]	Allalin	VS	−8.6	−15.9	2681.2	04.09.	02.10.	21.09.
174 [e]	Hohlaub	VS	−1.6	−3.7	2839.4	04.09.	02.10.	21.09.
12 [e]	Kessjen	VS	−3.5	−3.3	2866.1	04.09.	02.10.	21.09.
13 [e,f]	Fee	VS	−21.1	−44.5	2259	26.09.	24.09.	02.10.
14 [e,f]	Gorner	VS	−30	−72	2211	21.10.	03.10.	21.09.
16 [e,f]	Findelen	VS	−33.3	−62.4	2553.2	20.08.	27.08.	05.08.
17 [e]	Ried	VS	x	−30	2319	20.10	14.09	10.10.
18 [e,f]	Lang	VS	−14	−16	2033	09.10.	04.09.	10.11.
19 [e,f]	Turtmann	VS	−13	−133.1	2270 [10]	03.10	08.09	07.10.
20 [e]	Brunegg (Turtmann)	VS	x	−21.8	2500 [10]	03.10	08.09	07.10.
22 [e,f]	Zinal	VS	−30.4 [2a]	−9.6	2178	n	12.09.	12.10.
23 [e,f]	Moming	VS	−7.9	−4.3	2580 [13]	25.10.	06.10.	29.09.
24 [e,f]	Moiry	VS	−5.5	−30	2390	25.10.	12.09.	23.09.
25 [e,f]	Ferpècle	VS	−12.9	−24.8	2205 [14]	25.10.	09.10.	22.10.
26	Mont Miné	VS	−14.6	−14	2090 [12]	25.10.	09.10.	22.10.
27 [e,f]	Arolla (Mont Collon)	VS	−15.1	−16.2		28.10.	29.09.	21.10.
28 [e,f]	Tsidjiore Nouve	VS	−8.1	−10.3	2320	28.10.	29.09.	21.10.
29 [e,f]	Cheillon	VS	−11.4	−15.2	2706	08.10.	31.10.	30.09.
30 [e,f]	En Darrey	VS	x	x	2510 [11]	n	31.10.	30.09.
31 [e,f]	Grand Désert	VS	−5.6	−13.4	2817	22.09.	20.09.	19.09.
32 [e,f]	Mont Fort (Tortin)	VS	−16.5	−14.5	2790	09.10.	28.09.	27.09.
33 [e,f]	Tsanfleuron	VS	−19.4	−20	2550	22.10.	02.10.	23.10.
34 [e]	Otemma	VS	−32.8	−24.3	2480	20.09.	08.09.	29.08.
35 [e]	Mont Durand	VS	x	−5	2380	13.09.	12.09.	27.08.
36 [e]	Breney	VS	−6	−35	2575	21.09.	03.09.	30.08.
37 [e]	Giétro	VS	−7.9	−17.4	2712.2	04.09.	02.10.	21.09.
38 [e]	Corbassière	VS	−36.8	−24.2	2306.7	13.08.	02.10.	21.09.
39 [f]	Valsorey	VS	−18.6	−18.5	2534	17.10.	14.10.	19.10.

No. [a]	Glacier	Ct. [b]	Length variation [c] (m) 2013/14	2014/15	Altitude [d] (m a.s.l.) 2015	Date of measurements (Day, Month) 2013	2014	2015
40 [e]	Tseudet	VS	−13.7	−11.4	2483.5 [11]	17.10.	14.10.	19.10.
41	Boveyre	VS	−27	−27.1	2680 [14]	17.10.	17.10.	19.10.
42 [f]	Saleina	VS	−29.7	−29.4	1835.3 [12]	16.10.	18.09.	01.10.
43 [e,f]	Trient	VS	−41	−4	2110	22.09.	06.09.	27.09.
44 [e,f]	Paneyrosse	VD	−8.7	−7.4		28.09.	17.09.	30.09.
45 [e,f]	Grand Plan Névé	VD	−3.5	−11.9		27.09.	12.09.	02.10.
47 [e,f]	Sex Rouge	VD	+1.1	−4.2		04.09.	11.09.	06.08.
48 [e]	Prapio	VD	+5.0	−1	2540	27.09.	27.09.	27.08.
Catchment area of the river Aare (Ia)								
50 [f]	Oberaar	BE	n	n	2306.9 [09]	04.09	n	n
51 [f]	Unteraar	BE	n	n	1930.3 [09]	04.09	n	n
52 [e]	Gauli	BE	−51	−13	2170	21.09.	12.09.	21.09.
53 [e,f]	Stein	BE	−88	−99	2125	22.09.	07.09.	13.09.
54 [e]	Steinlimi	BE	−88.5	−39	2390	22.09.	07.09.	13.09.
55 [e,f]	Trift (Gadmen)	BE	−1.2	−3.4	2114.0	22.08.	23.09.	05.08.
57 [e,f]	Oberer Grindelwald	BE	−11.6	+2.0	2177.1	23.09.	23.09.	05.08.
58 [e,f]	Unterer Grindelwald	BE	−471.7	−450	1491.6	23.09.	23.09.	05.08.
59 [e]	Eiger	BE	−7	−12	2397	20.09.	15.09.	25.09.
60 [e]	Tschingel	BE	−13.6	−7.9	2270	26.09.	16.09.	22.09.
61 [e,f]	Gamchi	BE	−50	−387	2140	28.09.	27.09.	01.10.
109 [e]	Alpetli (Kanderfirn)	BE	−24.3	−24.3	2305	21.09.	23.09.	29.90.
62 [e,f]	Schwarz	VS	−959 [2a]	−100	2540	n	30.09.	12.09.
63	Lämmern	VS	−12	−16	2550	14.09.	29.09.	11.09.
64 [e,f]	Blüemlisalp	BE	−100.7	−39	2360	23.09.	24.09.	21.09.
65 [e,f]	Rätzli	BE	−8.8	−3.8	2465.8	21.08.	23.09.	05.08.
111 [e]	Ammerten	BE	−0.1	−3.3	2350	22.09.	11.09.	20.09.
Catchment area of the river Reuss (Ib)								
66 [e,f]	Tiefen	UR	−29.5	−36.5	2520 [13]	22.09.	26.09.	02.10.
67 [e,f]	Sankt Anna	UR	−9.2	−12.9	2600 [13]	06.09.	26.09.	02.10.
68 [e,f]	Kehlen	UR	−302.6	−31.1	2380	05.09.	19.09.	21.09.
69 [e]	Rotfirn (Nord)	UR	−22	−14.3	2070	05.09.	19.09.	21.09.
70 [e,f]	Damma	UR	−9.4	−25.6	2380	06.09.	20.09.	22.09.
71 [e,f]	Wallenbur	UR	−43.4	−29.9	2290	08.10.	02.10.	29.09.
72 [e,f]	Brunni	UR	−3.9 [5a]	−3.5	2560	n	28.08.	26.08.
74 [e,f]	Griess	UR	−8.1	−13.0	2228	25.09.	03.10.	01.10.
75 [e,f]	Firnalpeli (Ost)	OW	+8.4 [2a]	+0.2	2220	n	28.08.	10.09.
76 [e,f]	Griessen	OW	−7.8 [2a]	−14.5	2525	n	19.08.	02.10.

No. [a]	Glacier	Ct. [b]	Length variation [c] (m)		Altitude [d] (m a.s.l.)	Date of measurements (Day, Month)		
			2013/14	2014/15	2015	2013	2014	2015
Catchment area of the river Linth / Limmat (Ic)								
77 [e,f]	Biferten	GL	−49.4	+17.6	1963.9	24.08.	04.10.	03.10.
78 [e]	Limmern	GL	−20.9	−10.3	2290	25.09.	05.10.	30.09.
114 [e]	Plattalva	GL	−17.8	−19.8	2625	24.09.	05.10.	01.10.
79 [e,f]	Sulz	GL	−8.2	+5.9	1796 [12]	02.10.	09.10.	12.10.
80 [e,f]	Glärnisch	GL	−7.4	−34.0	2347.2	17.08.	06.09.	29.09.
81 [e,f]	Pizol	SG	+1.3	−9.8	2610 [14]	09.10.	07.10.	09.10.
Catchment area of the river Rhine / Lake Constance (Id)								
82 [f]	Lavaz	GR	−3.4	−16.2	2413	30.08.	17.09.	21.08.
83 [e,f]	Punteglias	GR	−1	−26.6	2352	20.09.	16.09.	22.09.
84 [e,f]	Lenta	GR	−33.5	x	2700	30.08.	29.08.	25.08.
85 [f]	Vorab	GR	−10.3	−18.3	2636.8	20.09.	30.09.	09.10.
86 [f]	Paradies	GR	+1.8	−23.8	2705	11.09.	09.09.	05.10.
87 [e]	Suretta	GR	−9	+0.4	2563	20.09.	30.09.	08.09.
88 [e,f]	Porchabella	GR	−11	−15.3	2690	11.09.	23.09.	09.09.
115 [e]	Scaletta	GR	s	x	2605	07.09.	08.09.	10.09.
89 [f]	Verstankla	GR	−8.8	−18.3	2460	30.08.	04.09.	28.08.
90 [e]	Silvretta	GR	−7.1	−6.9	2466.9	22.08.	27.09.	07.08.
91 [e,f]	Sardona	SG	−10.2	−19.4	2460 [14]	25.09.	29.09.	29.09.
Catchment area of the river Inn (V)								
92 [f]	Roseg	GR	−39.6	+4.3	2160 [09]	10.09.	16.10.	14.10.
93 [e]	Tschierva	GR	−66.5	−27.9	2308	10.09.	16.10.	14.10.
94 [e,f]	Morteratsch	GR	−22.3	−163.9	2033	03.10.	13.10.	17.10.
95 [e]	Calderas	GR	−3.1	−6.3	2787	15.08.	25.08.	05.10.
96 [e,f]	Tiatscha	GR	−36.1	−0.5	2636.1	23.08.	11.09.	07.08.
97 [e]	Sesvenna	GR	−5.5	−15.0	2735	21.08.	25.08.	21.08.
98 [e,f]	Lischana	GR	n	−128.4 [2a]	2904	15.08.	n	15.09.
Catchment area of the river Adda (IV)								
99	Cambrena	GR	−6	−6.6	2488	26.09.	30.09.	18.08.
100 [e,f]	Palü	GR	−0.7	−23.8	2590	25.09.	29.09.	25.09.
101 [e]	Paradisino (Campo)	GR	−7.5	−16.8	2888	26.09.	30.09.	28.09.
102 [f]	Forno	GR	−14.6	−34.9	2230	09.09.	04.09.	02.09.
116	Albigna	GR	−15.3	−17	2180	27.09.	02.09.	04.09.
Catchment area of the river Ticino (III)								
120 [e]	Corno	TI	−16.4	−15.8	2648.5	02.10.	20.10.	01.09.
117 [e]	Valleggia	TI	−6 [2a]	−5.3	2421.6	n	11.09.	30.09.
352 [e]	Croslina	TI	−1.6 [2a]	−3.8	2723.6	n	15.09.	28.09.
103 [e,f]	Bresciana	TI	−29 [3a]	n	2941.7 [14]	n	03.10.	n

No. [a]	Glacier	Ct. [b]	Length variation [c] (m)		Altitude [d] (m a.s.l.)	Date of measurements (Day, Month)		
			2013/14	2014/15	2015	2013	2014	2015
119 [e]	Cavagnoli	TI	m	−13.0	2685.2	n	11.09.	30.09.
104 [e,f]	Basòdino	TI	−8.8 [2a]	−25.4	2602.7	n	09.09.	29.09.

Legend

+	advancing	x	value not determined
st	stationary, ±1 m	n	not observed
−	retreating	sn	snow covered

a Identification number of the glacier in the observation network.

b If a specific glacier is situated in more than one canton, the canton indicated in the table is the one where the observed glacier tongue lies.

c If the value given relates to more than one year, the number of years is indicated as follows: −23 [4a] = Decrease of 23 meters within 4 years.

d If the altitude of the glacier tongue is not measured in 2015, the year of the last measurement is indicated: 2522 [09] = 2522 m a.s.l., measured in the year 2009.

e Compare Appendix B: Remarks on individual glaciers.

f Glacier with nearly complete data series since the beginning of the measurements at the end of the 19th century and one of the 73 glaciers selected in Figures 3.3 and 3.4.

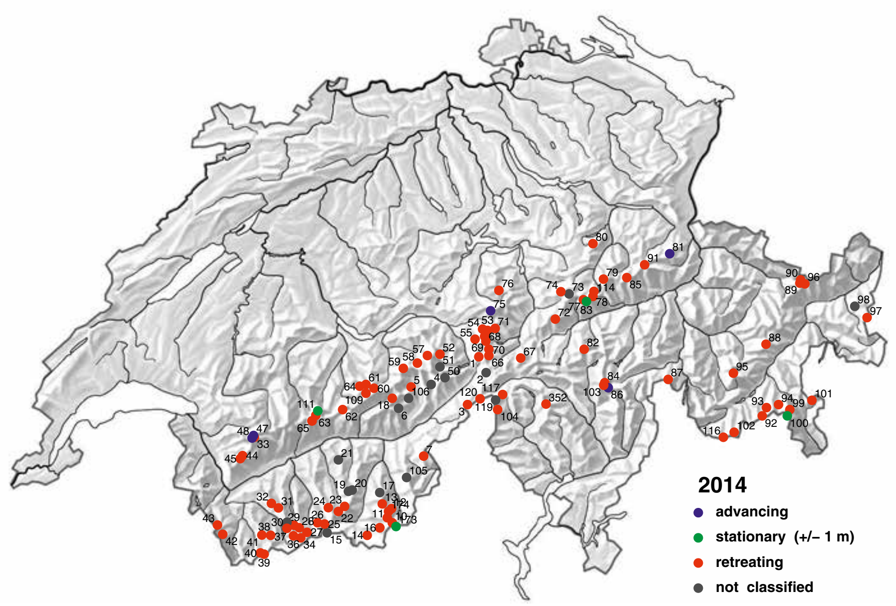

Figure 3.1: Observed glaciers in fall 2014.

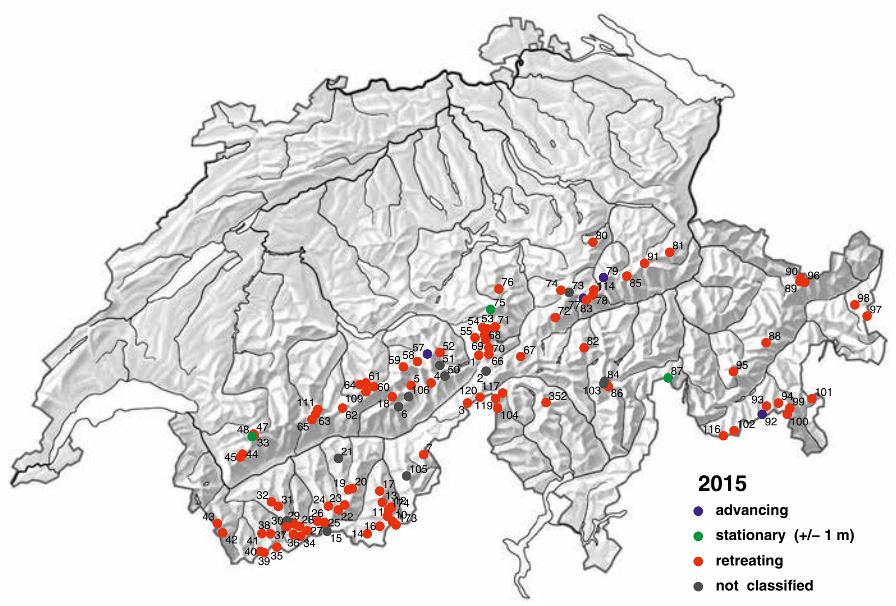

Figure 3.2: Observed glaciers in fall 2015.

3.5 Length Variations - Statistics for 1880-2015

The long-term development of glaciers in Switzerland is illustrated by using a selected sample from the Swiss glacier network (Figures 3.3 and 3.4), and the cumulative glacier length variations which have been classified according to length (Figures 3.5 - 3.8).

The dynamic response to climatic forcing of glaciers with variable geometry involves striking differences in the recorded curves (Figures 3.4 and 3.5 - 3.8) (Hoelzle et al., 2003). Such differences reflect the considerable effects of size-dependent reaction of the delayed tongue response with respect to the undelayed input (mass balance) signal. As a consequence, the overview figure of annual length-change data presented here as annual numbers or percentages of advancing and retreating glaciers should be interpreted carefully.

In order to avoid having a glacier sample whose scope changes annually, not all glaciers were included in Figures 3.3 and 3.4. From the entire dataset, 73 glaciers were selected as a sample with nearly complete series since the beginning of the measurements at the end of the 19th century. In Chapter 3.4, these 73 glaciers are indicated by a footnote f. The measured annual values are assigned to three classes: advancing, stationary and retreating. Figure 3.3 presents absolute numbers and percentages. The sample is dominated by medium-sized glaciers (length between 1 to 5 km) with a typical response time in the order of decades. The periods of advance, such as those in the 1910s to 1920s and the 1970s to 1980s, can be seen clearly. Figure 3.4 shows the annual and individual length change of all 73 selected glaciers sorted for length. For the purpose of intercomparison, values of cumulative length change are presented with respect to size categories chosen in a way

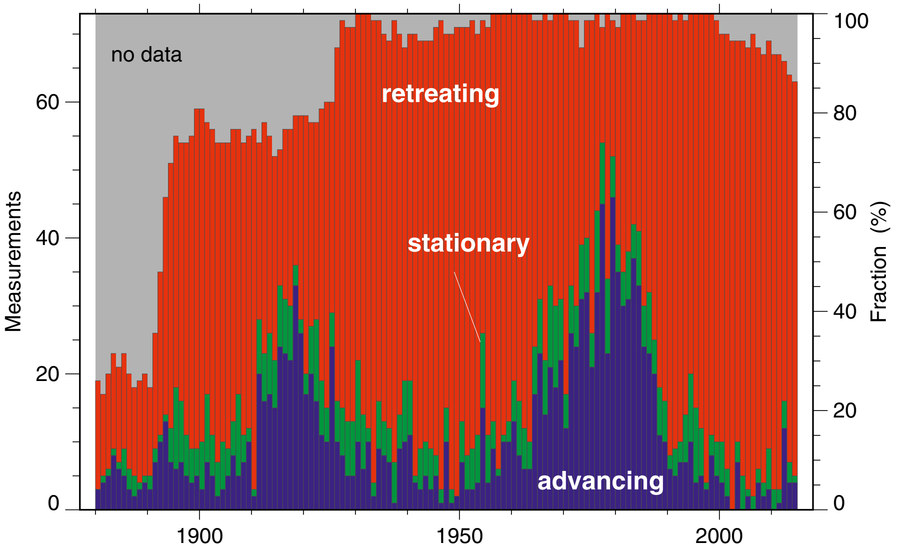

Figure 3.3: Yearly classification of glacier length behaviour (advancing, stationary and retreating) of 73 selected glaciers.

to optimally reflect common characteristics of the response signal at the glacier terminus. It is well recognized that large glaciers, such as Grosser Aletschgletscher, show continuous retreat since 1880, in contrast to the smaller glaciers such as Pizolgletscher, which has highly variable behavior.

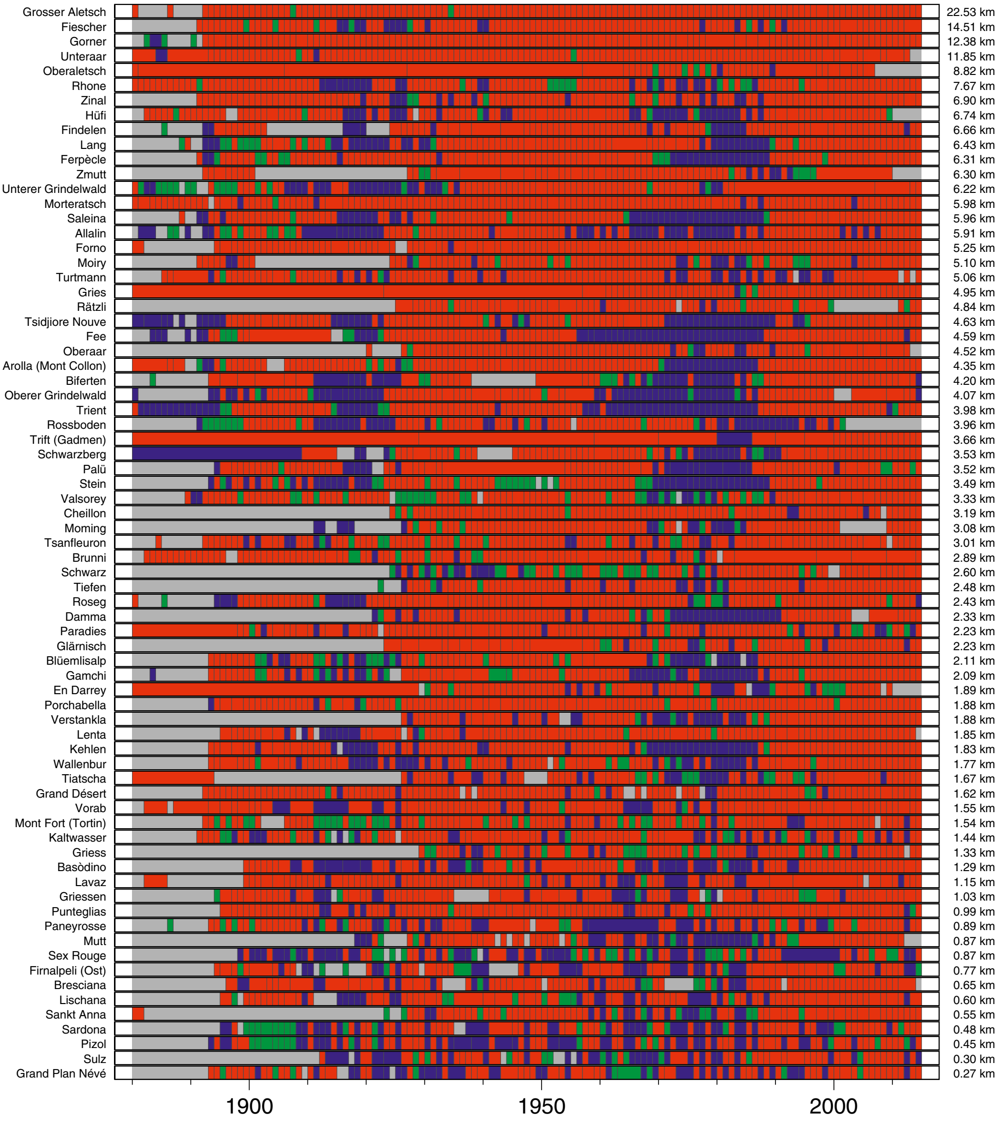

Figure 3.4: Individual yearly pattern of the same 73 selected glaciers (displayed in the descending order of actual glacier length).

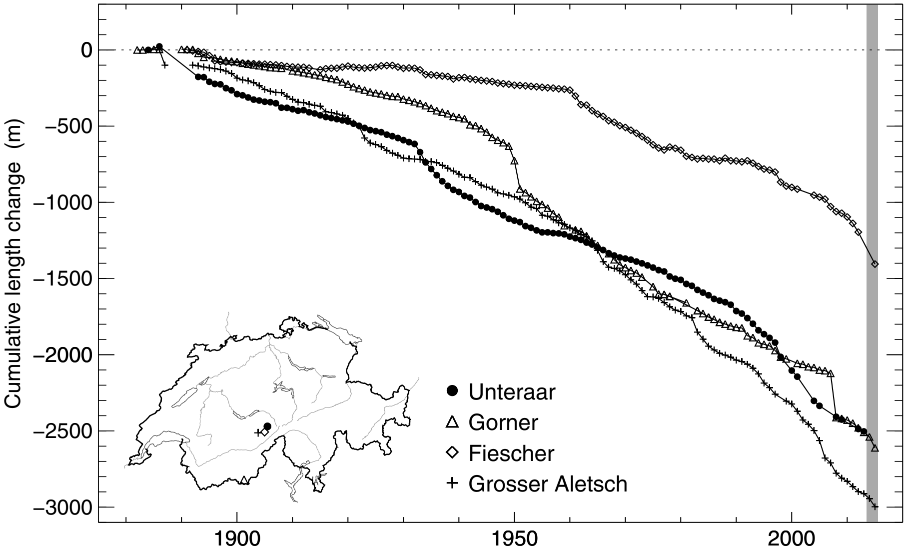

Figure 3.5: Large valley glaciers with a length of more than 10 km displaying a more or less continuous retreat over the entire time period. The gray shaded area highlights the years of the current report.

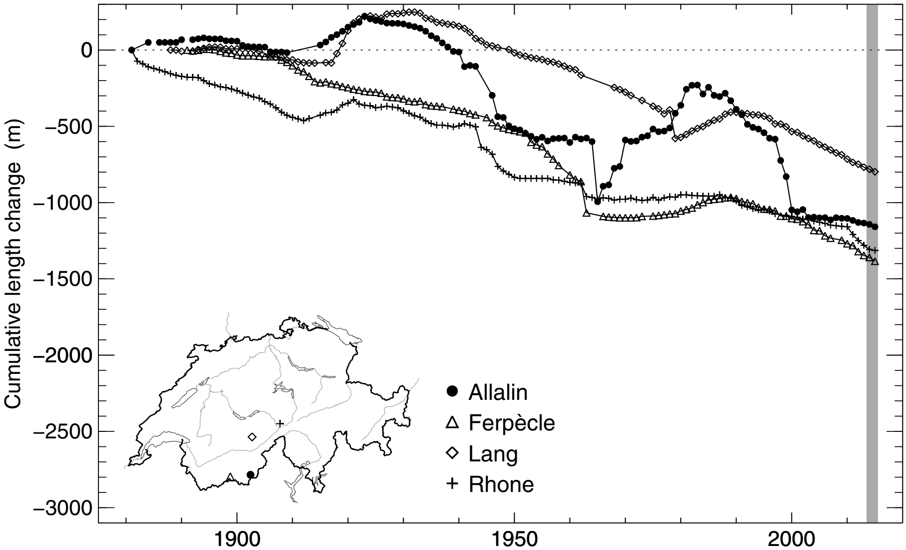

Figure 3.6: Mountain glaciers with a length of 5 to 10 km show advance and retreat phases in two periods (around 1920 and 1970). The gray shaded area highlights the years of the current report.

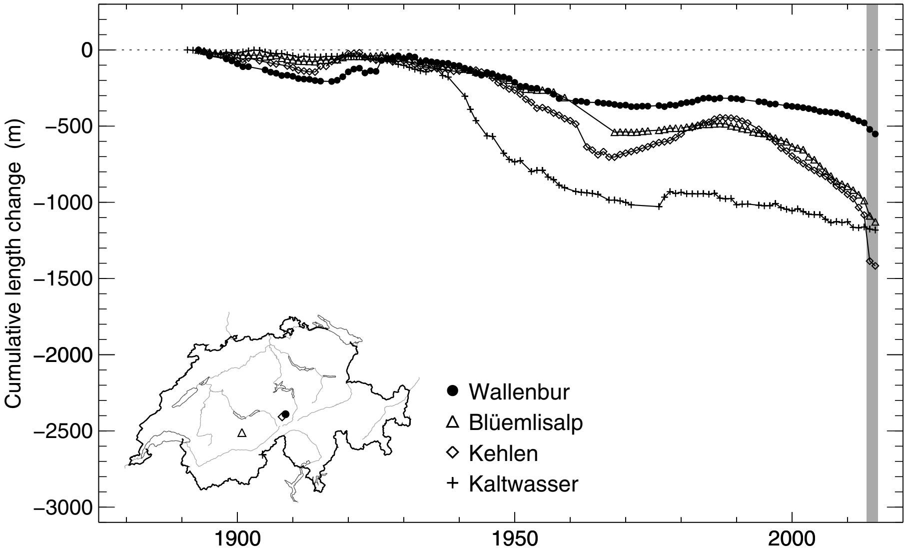

Figure 3.7: Small mountain glaciers with a length of 1 to 5 km show the two distinct advance and retreat phases. The gray shaded area highlights the years of the current report.

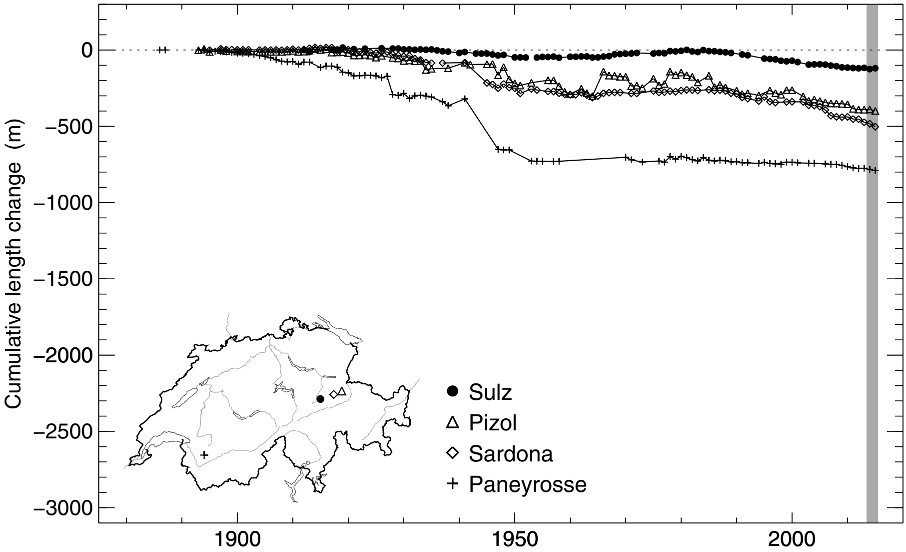

Figure 3.8: Very small cirque glaciers with a length of less than 1 km display generally small changes and a more irregular variability. The gray shaded area highlights the years of the current report.

Kehlengletscher in 2003 (top) and 2015 (bottom) – the terminus experienced a large retreat in 2014 when marginal ice completely disconnected (Photos: M. Planzer)

4 Mass Balance

4.1 Introduction, cumulative mean specific mass balances

Detailed mass balance data were collected using the glaciological method for Ghiacciaio del Basòdino, Findelengletscher, Griesgletscher, Vadret dal Murtèl, Pizolgletscher, Glacier de la Plaine Morte, Rhonegletscher, Sankt Annafirn, Silvrettagletscher and Glacier de Tsanfleuron in Switzerland. In addition to these investigations measurements of mass balance were also taken at Claridenfirn, Jungfraufirn (Grosser Aletschgletscher), Glacier du Giétro and Glacier de Corbassière (cf. Chapter 5), as well as in the Mattmark region (Allalin, Hohlaub, Schwarzberg, Chapter 5). In Figure 4.1 the location within Switzerland of all these glaciers is shown.

The mass balance measurements at stakes, in snow pits and extensive snow probing in spring were

Figure 4.1: Investigated glaciers for mass balance with the focus on spatial distribution and analysis of mean specific seasonal components of mass balance (dark blue) or point measurements (light blue).

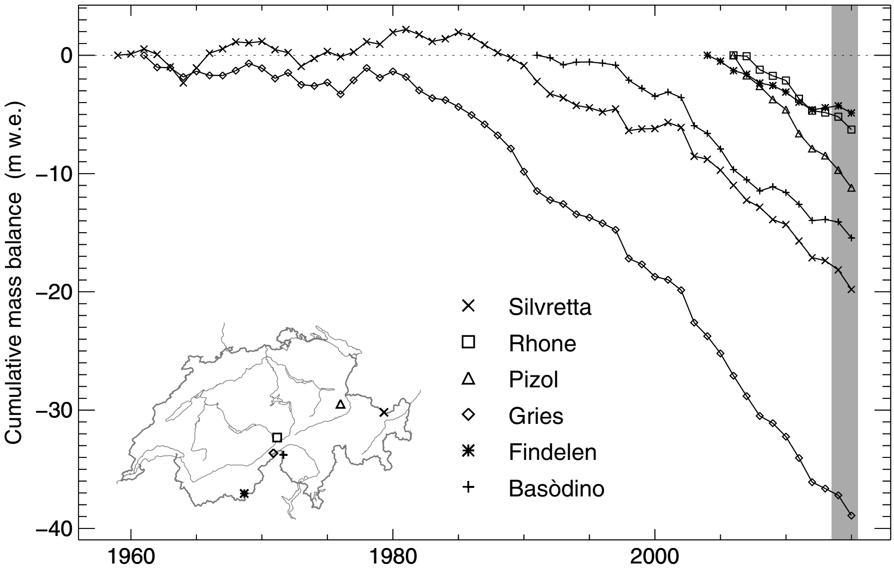

Figure 4.2: Cumulative mean specific mass balance over the whole observation period for the glaciers Silvretta, Rhone, Pizol, Gries, Findelen and Basòdino. The gray shaded area highlights the years of the current report.

used to calculate the mean specific components of mass balance following the methods described in Huss et al. (2009). Extrapolation from individual measurements to the entire glacier surface was performed using a mass balance model including the most important processes governing glacier mass balance distribution. The procedure is divided into two steps:

(1) The model is tuned such that both the measurements of winter accumulation and summer ablation are matched optimally over the periods defined by the exact dates of the in-situ measurements which are reported for the years of the current report. This allows extrapolation of mass balance based on a physical representation of the spatial variability, as well as the calculation of mass balance over fixed date periods (e.g. the hydrological year).

(2) A periodical final reanalysis and homogenisation with independently derived ice volume changes is reported separately in five to ten year intervals after evaluation.

The cumulative mean specific winter and annual balances of the glaciers with extensive observation series are presented in Table 4.1. Numbers for Adlergletscher as a former tributary of Findelengletscher have been evaluated separately but detailed figures are presented together with Findelengletscher. A similar situation exists at Glacier du Sex Rouge, a small glacier that is connected by an ice-divide to Glacier de Tsanfleuron. The long-term trends are very well recognizable for Griesgletscher and Silvrettagletscher with long time-series (Figure 4.2). Notably, the accelerated mass loss since the mid-1980s is remarkable, as are the balanced mass budgets recorded in

Table 4.1: Summary table with area, mean specific winter and annual balance, ELA and AAR for the measurement periods 2013/14 and 2014/15.

Glacier	No.	Period	Area (km^2)	B_w (mm w.e.)	B_a (mm w.e.)	ELA (m a.s.l.)	AAR (%)
Basòdino	104	2013/14	1.842	1896	−211	2945	36
		2014/15	1.842	1928	−1345	3125	1
Findelen	16	2013/14	12.880	1258	159	3185	70
		2014/15	12.880	1197	−606	3305	53
Adler	16	2013/14	2.011	975	230	3355	65
		2014/15	2.011	985	−378	3495	41
Gries	3	2013/14	4.431	1638	−568	2995	41
		2014/15	4.431	1764	−1713	3255	0
Murtèl	377	2013/14	0.301	1439	534	3157	74
		2014/15	0.302	1076	−902	3222	19
Pizol	81	2013/14	0.067	1148	−1222	2777	1
		2014/15	0.067	1856	−1501	2777	1
Plaine Morte	65	2013/14	7.549	1011	−991	2805	1
		2014/15	7.549	1235	−2395	2935	0
Rhone	1	2013/14	15.571	1197	−353	2915	57
		2014/15	15.571	1723	−1083	2995	45
Sankt Anna	67	2013/14	0.195	1881	−437	2792	33
		2014/15	0.193	1801	−1477	2917	0
Silvretta	90	2013/14	2.684	1202	−786	2925	21
		2014/15	2.684	1397	−1649	3025	1
Tsanfleuron	33	2013/14	2.618	1391	−610	2835	18
		2014/15	2.618	1565	−2744	2975	0
Sex Rouge	47	2013/14	0.270	1176	−613	2832	9
		2014/15	0.270	1447	−2213	2882	0

the 1960s and 70s. The point measurements of the mass balance are of particular significance with regard to answering questions related to climate change (Ohmura et al., 2007; Huss and Bauder, 2009; Gabbi et al., 2015). The four existing long-term time series (Claridenfirn, Grosser Aletschgletscher, Silvrettagletscher) start in the 1910s and cover almost the entire 20th century. Mass balance data of the present report have also been submitted to the World Glacier Monitoring Service (WGMS) as a contribution to the efforts of international glacier monitoring (WGMS, 2013).

4.2 Mass Balance in 2013/14

The glacier-wide mass balance in seasonal resolution was determined by measuring snow accumulation during winter and melting in summer for the ten glaciers: Basòdino, Findelen, Gries, Murtèl, Pizol, Plaine Morte, Rhone, Sankt Anna, Silvretta and Tsanfleuron. On glaciers located south of the main Alpine ridge and in Engadine (e.g., Findelen, Murtèl) a balanced or slightly positive mass balance was observed. Glaciers investigated on the north slopes of the Alps showed moderate mass losses. However, the reduction in average ice thickness between 0.3 and 0.6 m w.e. was relatively small compared with the values registered during the last decade. Most negative mass balances of a meter or more were found on the glaciers Plaine Morte in the western Swiss Alps and Pizol in the north-east. Regional differences in mass balance were considerable in this period. The main Alpine ridge acts as a weather divide and differences between north and south are common. In this period, they can be attributed to frequent damming of low pressure systems from the south in winter and spring. This resulted in large amount of snow on the south slopes, whereas dry conditions predominated in the north. These general conclusions drawn from the glaciers with focus on glacier-wide results are in accordance with the results on interannual variability revealed by the long-term point measurements at Claridenfirn and Jungfraufirn.

By upscaling the measurements on individual glaciers to all glaciers in the Swiss Alps, a total loss in ice volume in the order of 300 million m^3 was estimated during this period. This amount corresponds to a reduction of about 0.6 % in the ice volume presently existing. However, we conclude for this period that the weather conditions were relatively favorable for the glaciers. Only in the previous period 2012/13 were conditions over the last 10 years even more favorable. Even though the melting was less dramatic than previously, the mass loss was still substantial.

4.3 Mass Balance in 2014/15

The same ten glaciers were investigated during this period as well with regard to their mass balance. The differences in mass balance between these glaciers were higher than in previous periods. The most negative mass balance results were observed at glaciers in the western Swiss Alps. Extreme values of over -2.5 m w.e. were registered at Tsanfleuron and Plaine Morte. The least amount of mass loss for glaciers under detailed investigations, with average thickness changes at about -0.6 m w.e., was found on Findelen and Allalin in the southern Valais. All other glaciers ranged between one and two meters of mass loss. The very hot period in summer had an especially strong impact on the smaller glaciers with areas not extending to higher elevations. At the end of July, the winter accumulation on most of them had already disppeared completely. The 2015 calendar year is on record as one of the hottest year since systematic weather observation started in 1864. However, the slow melt-out in early summer as well as repeated snowfalls in mid-August and in September prevented a more intensive melt.

Extrapolated over the entire glacierized area in Switzerland, a loss in ice volume of 1300 million m^3 was found. This corresponds to 2.5 % of the estimated current ice volume. In summary, the weather conditions during the period under review were unfavorable for the glaciers in Switzerland. Snow accumulation during winter was about average, while the summer season turned out to be very melt-intensive. In comparison to recent decades, as well as the period covering the last 100 years with systematic measurements on the glaciers, this period was among the most negative.

4.4 Ghiacciaio del Basòdino

Introduction

Ghiacciaio del Basòdino is a small north-east facing temperate mountain glacier in the southern Swiss Alps. The small individual branch descending to the north with a separate tongue is not considered part of the glacier and not included in the mass balance determination. The main branch presently covers an area of 1.8 km^2 and extends from 2562 to 3186 m a.s.l. Detailed mass balance investigations have been carried out since 1990. Determination of volumetric changes in decadal resolution reach further back to 1929 (Bauder et al., 2007). Topographic maps or photogrammetrical surveys exist for 1929, 1949, 1971, 1985, 1991, 2002, 2008 and 2013. Huss et al. (2015) re-analyzed and homogenized the seasonal stake data and ice volume changes for the period 1991 to 2013. The results of the mean specific winter and annual balance for comparable fixed date periods are presented in Section 4.17 of this report.

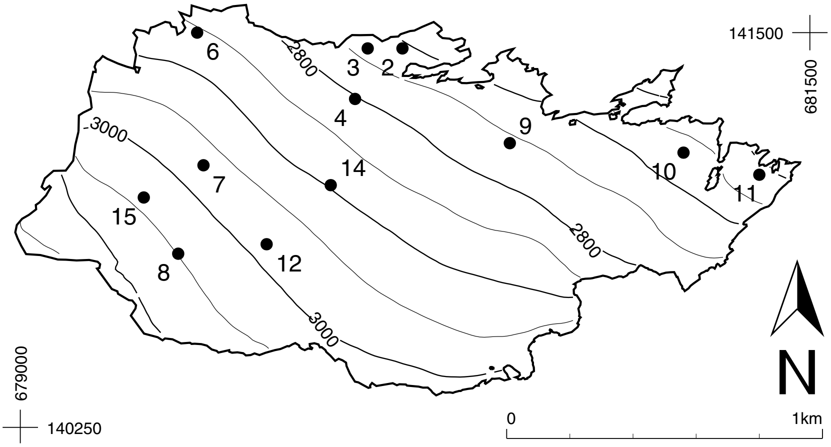

Figure 4.3: Surface topography and observational network of the Ghiacciaio del Basòdino.

Investigations in 2013/14

The measurement period extended from 13th September 2013 to 26th September 2014 with a field visit in spring on 16th May 2014. Abundant firn accumulation was present at the end of the balance year in September 2014. Snow depth was measured at about 16 locations during the spring measurement period and supplemented by a density profile from the central sector of the glacier.

Investigations in 2014/15

The measurement period was from 26th September 2014 to 31th August 2015 with a field visit in spring on 25th May 2015. Again snow depth was sampled at about 36 locations distributed over the entire glacier with a density profile at the center. An additional filed visit on 26th September 2015 at the lower stakes revealed substantial melt of 20-30 cm w.e. that occurred during September 2015 after the measurements had been taken.

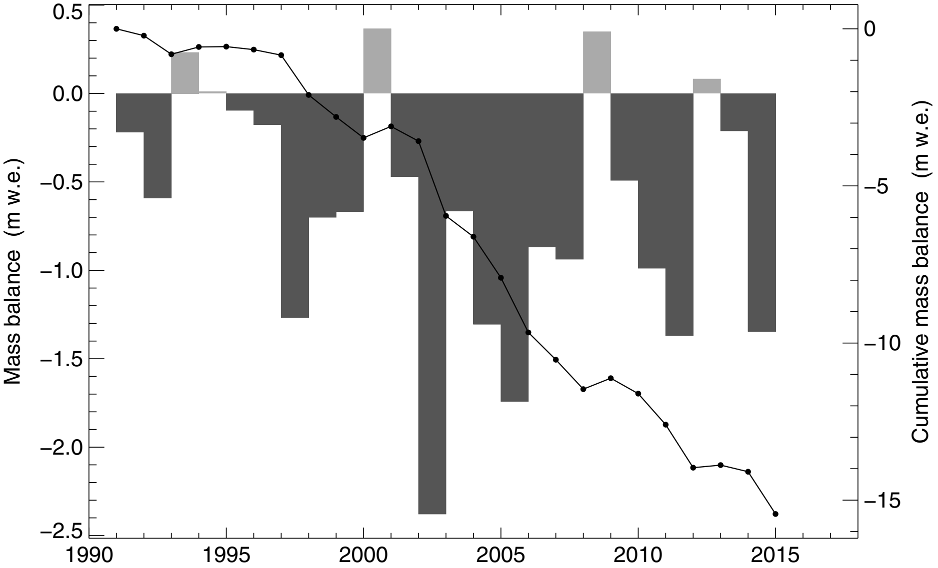

Figure 4.4: Ghiacciaio del Basòdino - Mean specific annual balance (bars) and cumulative mass balance for the period 1991-2015. Values refer to the measurement period.

Table 4.2: Ghiacciaio del Basòdino - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2500 - 2600	0.010	2049	−681	0.010	1980	−2114
2600 - 2700	0.141	1967	−377	0.141	1985	−1510
2700 - 2800	0.360	1903	−393	0.360	1982	−1534
2800 - 2900	0.429	1854	−542	0.429	1911	−2326
2900 - 3000	0.528	1960	3	0.528	1968	−744
3000 - 3100	0.314	1868	116	0.314	1882	−711
3100 - 3200	0.059	1526	111	0.059	1481	−1295
2500 - 3200	1.842	1896	−211	1.842	1928	−1345

Table 4.3: Ghiacciaio del Basòdino - Individual stake measurements of winter and annual balance.

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
4	13.09.2013	16.05.2014	26.09.2014	680061 / 141294 / 2819	1562	−864
6	13.09.2013	16.05.2014	26.09.2014	679650 / 141450 / 2890	1672	−816
8	13.09.2013	16.05.2014	26.09.2014	679500 / 140800 / 3040	2002	426
9	13.09.2013	16.05.2014	26.09.2014	680557 / 141167 / 2758	1786	−608
10	13.09.2013	16.05.2014	26.09.2014	681000 / 141130 / 2689	1782	−976
11	13.09.2013	16.05.2014	26.09.2014	681336 / 141054 / 2610	2433	−432
12	13.09.2013	16.05.2014	26.09.2014	679781 / 140828 / 2990	1870	168
14	13.09.2013	16.05.2014	26.09.2014	679983 / 141017 / 2904	1672	−140
15	13.09.2013	16.05.2014	26.09.2014	679391 / 140978 / 3040	1665	−196
2	26.09.2014	25.05.2015	31.08.2015	680067 / 141303 / 2792	1700	−2440
6	26.09.2014	25.05.2015	31.08.2015	679666 / 141432 / 2848	1850	−1728
8	26.09.2014	25.05.2015	31.08.2015	679618 / 140718 / 3020	2300	90
9	26.09.2014	25.05.2015	31.08.2015	680559 / 141158 / 2738	1700	−1292
10	26.09.2014	25.05.2015	31.08.2015	680990 / 141125 / 2680	2300	−1819
11	26.09.2014	25.05.2015	31.08.2015	681303 / 141021 / 2586	2250	−1080
12	26.09.2014	25.05.2015	31.08.2015	679790 / 140827 / 2970	1900	−140
14	26.09.2014	25.05.2015	31.08.2015	679986 / 141022 / 2874	1750	−1428
15	26.09.2014	25.05.2015	31.08.2015	679390 / 140974 / 3020	1900	−1440

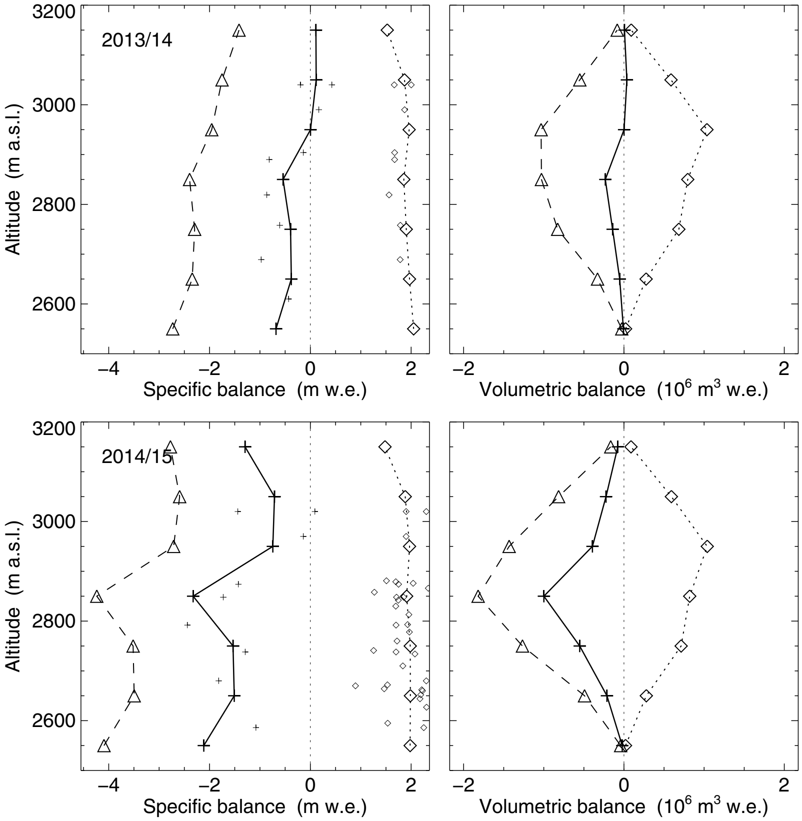

Figure 4.5: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

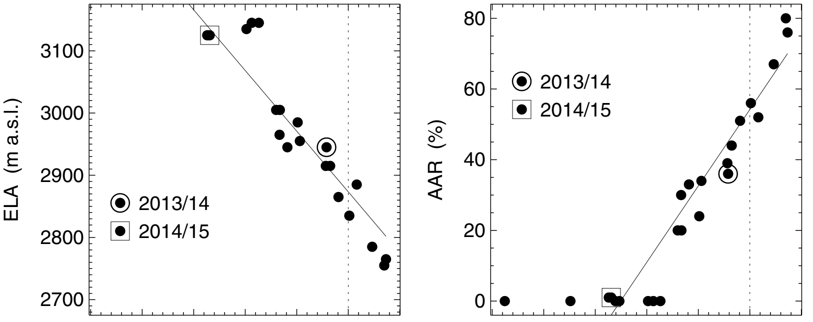

Figure 4.6: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.5 Findelengletscher

Introduction

Findelengletscher (12.9 km^2) and its former tributary Adlergletscher (2.0 km^2) are located in the southern Valais in the Zermatt area. The two glaciers cover an elevation range from 2580 m a.s.l. to 4120 m a.s.l. Findelengletscher is west-facing and is characterized by gently sloping high-elevation accumulation basins and a comparatively narrow glacier tongue. The region is relatively dry with equilibrium line altitudes being among the highest in the Alps. Mass balance measurements on Findelengletscher were initiated in fall 2004 and the observational network was extended to Adlergletscher one year later.

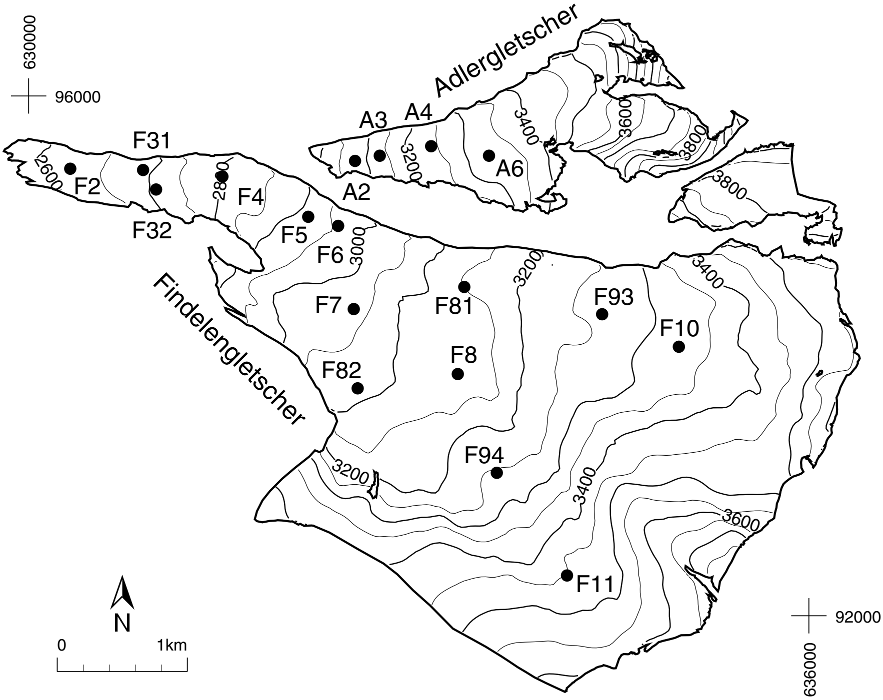

Figure 4.7: Surface topography and observational network on Findelengletscher and the former tributary Adlergletscher.

Investigations in 2013/14

Winter mass balance of Findelen- and Adlergletscher was determined on 9th April 2014. Snow probings were obtained for 321 locations and snow density was measured in five snow pits distributed over the entire elevation range of the glacier. Ground-based radar provided supplementary data

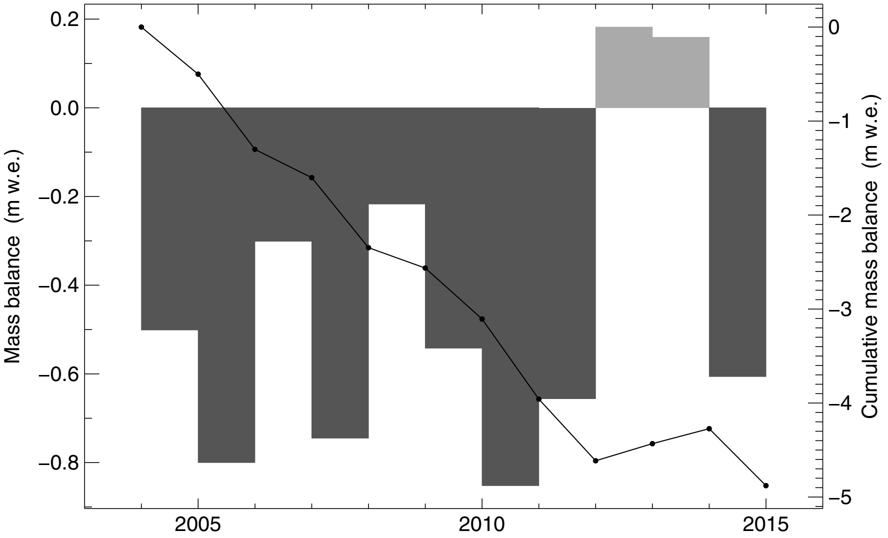

Figure 4.8: Findelengletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 2004-2015.

on snow depth. In addition, a survey based on a helicopter-borne ground penetrating radar system to record snow depth distribution was performed covering both Findelen- and Adlergletscher on a 500 m grid. The profiles had a total length of 55 km (Sold et al., 2016). All mass balance stakes were visited and re-installed on 27th September 2014. The annual mass balance was determined for 14 locations on Findelen-, and four on Adlergletscher. Firn density was measured in a snow pit. The equilibrium line was at about 3200 m a.s.l. on Findelen-, and 3350 m a.s.l. on Adlergletscher. The data indicate a slightly positive mass balance in this year, which is attributed to frequent summer snow fall events and the comparably high elevation of the glaciers.

Investigations in 2014/15

The winter survey was performed on 9th April 2015. In total, 142 snow probings distributed over the entire surface of Findelen- and Adlergletscher were obtained, and snow density was measured in five snow pits. Snow probing proved to be difficult in the accumulation area due to ice lenses and relatively large amounts of snow. In addition, snow depth was monitored using aground-based radar. On 21th September 2015 all measurement sites were visited. Mass balance was determined at 14 stakes on Findelen- and at three stakes on Adlergletscher. Firn density was measured in two snow pits. A complete re-analysis of the data series for Findelen- and Adlergletscher including all available data was performed, focussing on a better representation of snow accumulation distribution and consistency of annual mass balances with geodetic volume changes (Sold et al., 2016).

Table 4.4: Findelengletscher - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
(m a.s.l.)	Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2500 - 2600	0.028	363	−5841	0.028	462	−8229
2600 - 2700	0.259	454	−5417	0.259	623	−7198
2700 - 2800	0.217	583	−4006	0.217	619	−5988
2800 - 2900	0.338	726	−2790	0.338	825	−4410
2900 - 3000	0.578	839	−2190	0.578	892	−3576
3000 - 3100	0.977	991	−1212	0.977	982	−2558
3100 - 3200	1.736	1147	−329	1.736	1227	−1220
3200 - 3300	1.834	1329	440	1.834	1229	−230
3300 - 3400	1.945	1421	791	1.945	1360	345
3400 - 3500	2.357	1528	1201	2.357	1428	732
3500 - 3600	1.608	1464	1360	1.608	1266	765
3600 - 3700	0.439	1194	1120	0.439	1154	815
3700 - 3800	0.301	988	943	0.301	759	320
3800 - 3900	0.252	1059	1179	0.252	710	344
3900 - 4000	0.011	1030	1286	0.011	571	301
2500 - 4000	12.880	1258	159	12.880	1197	−606

Table 4.5: Adlergletscher - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
(m a.s.l.)	Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2900 - 3000	0.004	757	−1789	0.004	856	−3201
3000 - 3100	0.099	786	−1566	0.099	952	−2736
3100 - 3200	0.119	831	−1470	0.119	1030	−2055
3200 - 3300	0.248	850	−757	0.248	1027	−1387
3300 - 3400	0.421	926	−40	0.421	1015	−555
3400 - 3500	0.316	1042	435	0.316	945	−333
3500 - 3600	0.249	1159	951	0.249	986	200
3600 - 3700	0.209	1175	1221	0.209	878	343
3700 - 3800	0.177	1041	1219	0.177	1152	1083
3800 - 3900	0.104	872	1066	0.104	903	830
3900 - 4000	0.046	671	800	0.046	876	868
4000 - 4100	0.014	554	672	0.014	657	611
4100 - 4200	0.004	529	664	0.004	565	512
2900 - 4200	2.011	975	230	2.011	985	−378

Table 4.6: Findelengletscher and Adlergletscher - Individual stake measurements of winter and annual balance.

Stake		Period		Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
F2	25.09.2013	09.04.2014	27.09.2014	630313 / 95442 / 2624	370	−6120
F31	25.09.2013	09.04.2014	27.09.2014	630880 / 95426 / 2692	290	−4410
F32	25.09.2013	09.04.2014	27.09.2014	630987 / 95262 / 2705	490	−5260
F4	25.09.2013	09.04.2014	27.09.2014	631493 / 95381 / 2803	550	−3550
F5	25.09.2013	09.04.2014	27.09.2014	632115 / 95108 / 2909	830	−2350
F6	25.09.2013	09.04.2014	27.09.2014	632359 / 95025 / 2953	1150	−2110
F7	25.09.2013	09.04.2014	27.09.2014	632470 / 94383 / 3037	1000	−1320
F8	25.09.2013	09.04.2014	27.09.2014	633245 / 93889 / 3117	1020	−610
F81	25.09.2013	09.04.2014	27.09.2014	633346 / 94524 / 3150	780	−930
F82	25.09.2013	09.04.2014	27.09.2014	632557 / 93740 / 3088	980	−890
F93	25.09.2013	09.04.2014	27.09.2014	634374 / 94325 / 3259	1190	400
F94	25.09.2013	09.04.2014	27.09.2014	633576 / 93127 / 3250	1280	350
F10	25.09.2013	09.04.2014	27.09.2014	635070 / 93938 / 3341	1290	1010
F11	25.09.2013	09.04.2014	27.09.2014	634140 / 92337 / 3450	1900	1640
A2	25.09.2013	09.04.2014	27.09.2014	632509 / 95498 / 3076	780	−1700
A3	25.09.2013	09.04.2014	27.09.2014	632693 / 95539 / 3132	1130	−1450
A4	25.09.2013	09.04.2014	27.09.2014	633126 / 95617 / 3247	840	−750
A6	25.09.2013	09.04.2014	27.09.2014	633704 / 95584 / 3339	1010	50
A6o	25.09.2013	09.04.2014	27.09.2014	633522 / 95543 / 3331	940	−450
F2	27.09.2014	09.04.2015	21.09.2015	630323 / 95445 / 2624	630	−7780
F31	27.09.2014	09.04.2015	21.09.2015	630909 / 95418 / 2695	640	−5730
F32	27.09.2014	09.04.2015	21.09.2015	630984 / 95270 / 2705	630	−7030
F5	27.09.2014	09.04.2015	21.09.2015	632156 / 95069 / 2917	900	−3880
F6	27.09.2014	09.04.2015	21.09.2015	632392 / 94988 / 2961	1010	−3560
F7	27.09.2014	09.04.2015	21.09.2015	632497 / 94371 / 3036	1060	−2610
F8	27.09.2014	09.04.2015	21.09.2015	633320 / 93841 / 3123	1360	−1280
F8o	27.09.2014	09.04.2015	21.09.2015	633245 / 93889 / 3117	1310	−930
F81	27.09.2014	09.04.2015	21.09.2015	633326 / 94526 / 3147	1240	−2010
F82	27.09.2014	09.04.2015	21.09.2015	632540 / 93763 / 3087	970	−2330
F93	27.09.2014	09.04.2015	21.09.2015	634332 / 94322 / 3255	1370	−250
F94	27.09.2014	09.04.2015	21.09.2015	633542 / 93155 / 3247	1130	−170
F10	27.09.2014	09.04.2015	21.09.2015	635095 / 93918 / 3345	1330	660
F11	27.09.2014	09.04.2015	21.09.2015	634158 / 92339 / 3450	1300	1240
A2	27.09.2014	09.04.2015	21.09.2015	632502 / 95506 / 3076	900	−2790
A4	27.09.2014	09.04.2015	21.09.2015	633101 / 95610 / 3242	1000	−1600
A6	27.09.2014	09.04.2015	21.09.2015	633695 / 95575 / 3339	1150	−500

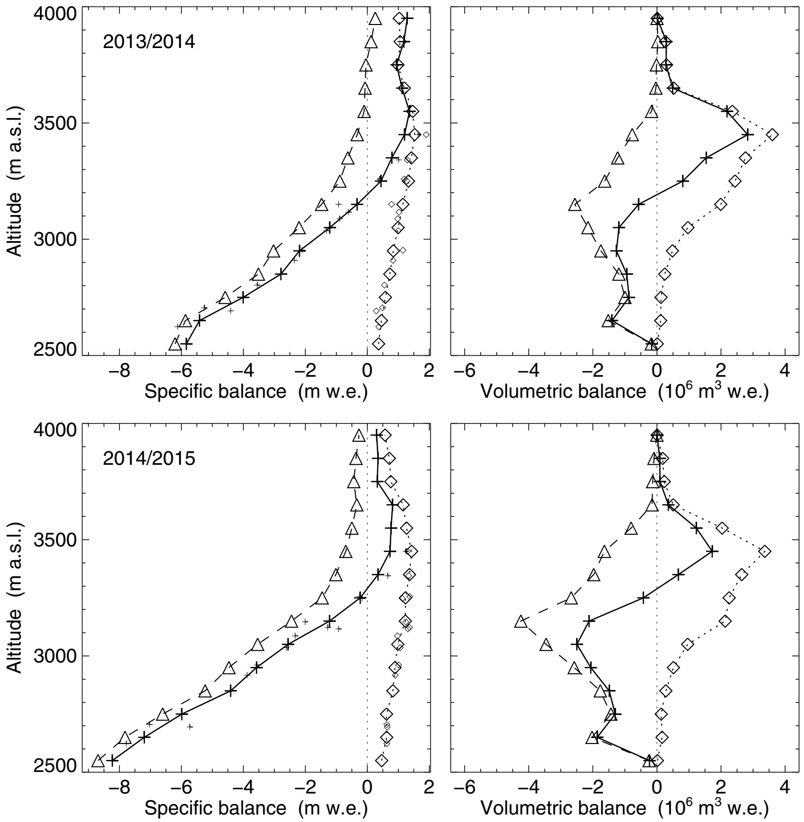

Figure 4.9: Findelengletscher - Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

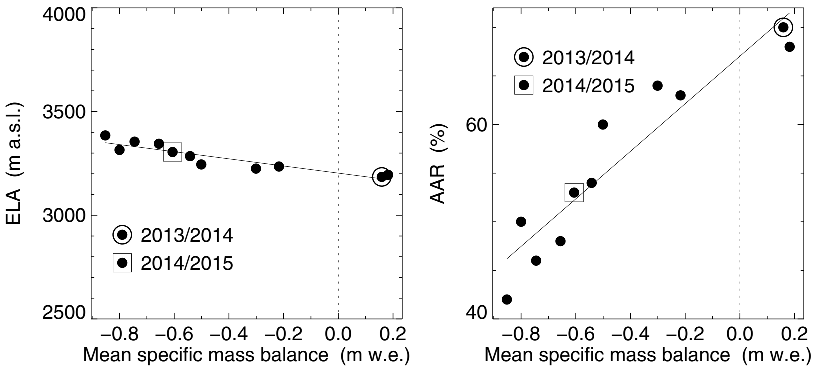

Figure 4.10: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.6 Griesgletscher (Aegina)

Introduction

Griesgletscher is a temperate valley glacier located in the central Swiss Alps. The glacier currently covers an area of 4.8 km^2 flowing in a north-east direction from 3305 m a.s.l. down to 2425 m a.s.l. Mass balance measurements started in 1961 in connection with the construction of a reservoir for hydro-power production. Determination of volumetric changes in decadal resolution extend further back to 1884 (Bauder et al., 2007). Topographic maps or photogrammetrical surveys exist for 1884, 1923, 1961, 1967, 1979, 1986, 1991, 1998, 2003, 2007 and 2012. Huss et al. (2009) re-analyzed and homogenized the seasonal stake data and ice volume changes for the period 1961-2007. The results of the mean specific winter and annual balance for comparable fixed date periods including a periodic update until 2012 (Huss et al., 2015) are presented in Section 4.17 of this report.

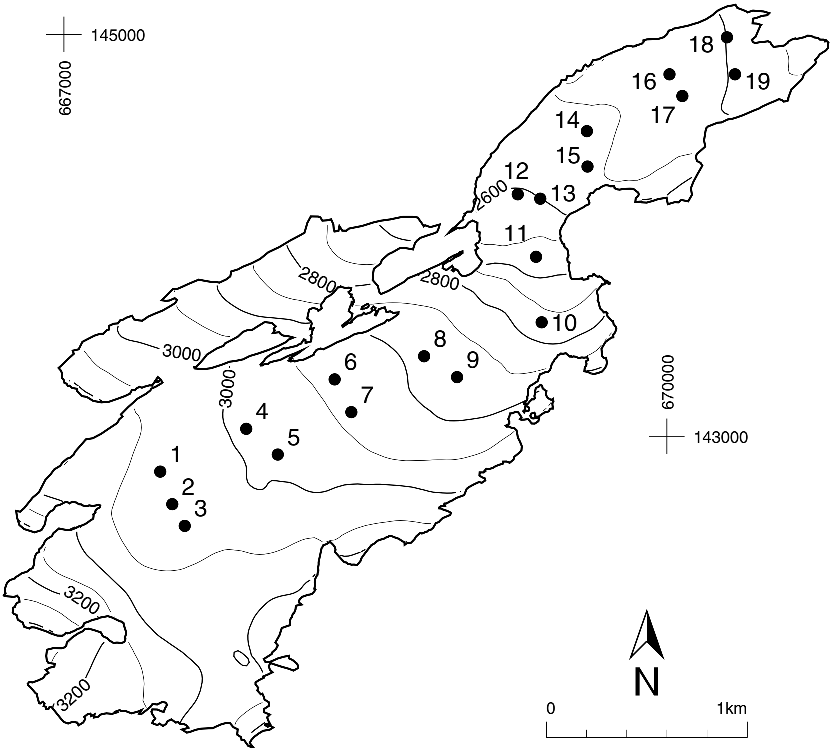

Figure 4.11: Surface topography and observational network of the Griesgletscher.

Investigations in 2013/14

The measurement period extended from 29th September 2013 to 10th September 2014 with a field visit in spring on 24th April 2014. Snow depth soundings were collected at 19 stake locations and supplemented by two density profiles obtained by firn drilling on the tongue and in the upper area. For only the second time in the last 15 years, the abundant snow which accumulated during winter remained into fall. This accumulation extended over the entire firn plateau above 3000 m a.s.l.

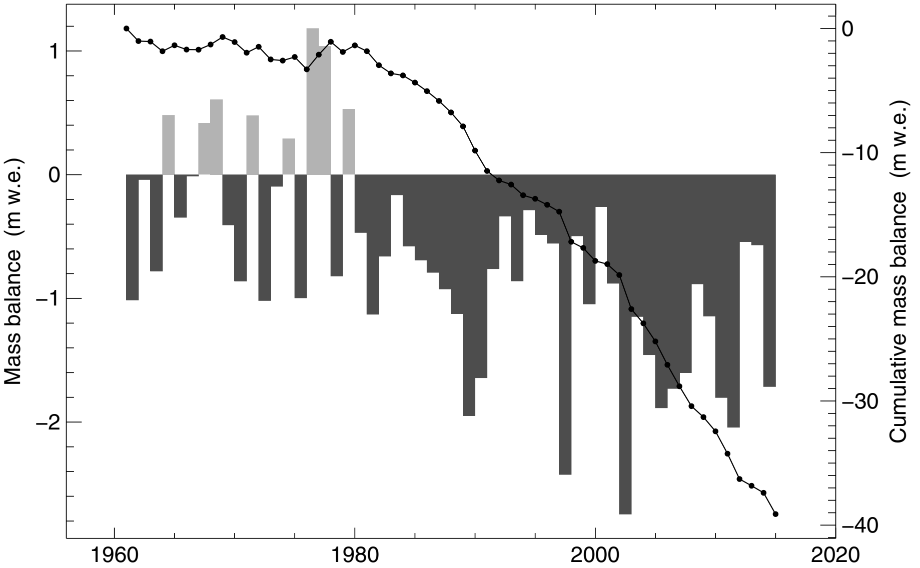

Figure 4.12: Griesgletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 1961-2015.

Investigations in 2014/15

The measurement period extended from 10th September 2014 to 8th September 2015 with a field visit in spring on 24th April 2015. The melt extent at the end of the summer covered the entire surface area, leaving only a few marginal firn patches. Snow depth was sampled at 19 stake locations and the density was determined at two locations using a firn drill.

Table 4.7: Griesgletscher - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2400 - 2500	0.106	1075	−2918	0.106	1479	−4512
2500 - 2600	0.613	1114	−2597	0.613	1452	−3865
2600 - 2700	0.178	1309	−1880	0.178	1660	−2978
2700 - 2800	0.296	1521	−985	0.296	1799	−2302
2800 - 2900	0.566	1646	−578	0.566	1861	−1864
2900 - 3000	0.977	1713	−196	0.977	1884	−1206
3000 - 3100	1.417	1928	315	1.417	1864	−760
3100 - 3200	0.206	1753	420	0.206	1619	−645
3200 - 3300	0.071	1121	−107	0.071	1000	−1255
2400 - 3300	4.431	1638	−568	4.431	1764	−1713

Table 4.8: Griesgletscher - Individual stake measurements of winter and annual balance.

Stake	Period Start	 Spring	 End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	 b_a
1	29.09.2013	24.04.2014	10.09.2014	667469 / 142819 / 3032	1980	210
2	29.09.2013	24.04.2014	10.09.2014	667536 / 142656 / 3029	1860	390
3	29.09.2013	24.04.2014	10.09.2014	667600 / 142557 / 3031	1930	360
4	29.09.2013	24.04.2014	10.09.2014	667911 / 143040 / 2992	1760	−70
5	29.09.2013	24.04.2014	10.09.2014	668070 / 142915 / 2989	1600	180
6	29.09.2013	24.04.2014	10.09.2014	668345 / 143283 / 2938	1420	−630
7	29.09.2013	24.04.2014	10.09.2014	668406 / 143110 / 2942	1650	−500
8	29.09.2013	24.04.2014	10.09.2014	668792 / 143397 / 2885	1580	−860
9	29.09.2013	24.04.2014	10.09.2014	668958 / 143294 / 2875	1640	−600
11	29.09.2013	24.04.2014	10.09.2014	669348 / 143882 / 2674	1270	−2040
12	29.09.2013	24.04.2014	11.09.2014	669245 / 144168 / 2608	1280	−2200
13	29.09.2013	24.04.2014	10.09.2014	669376 / 144157 / 2606	1260	−2130
14	29.09.2013	24.04.2014	11.09.2014	669602 / 144518 / 2560	1240	−2570
15	29.09.2013	24.04.2014	11.09.2014	669605 / 144342 / 2561	1040	−2660
16	29.09.2013	24.04.2014	11.09.2014	670013 / 144801 / 2534	1100	−2400
17	29.09.2013	24.04.2014	11.09.2014	670077 / 144693 / 2530	1040	−2880
18	29.09.2013	24.04.2014	11.09.2014	670299 / 144985 / 2499	1010	−3110
19	29.09.2013	24.04.2014	11.09.2014	670339 / 144801 / 2492	1200	−2990
4	10.09.2014	22.04.2015	08.09.2015	667919 / 143050 / 2990	1870	−1460
5	10.09.2014	22.04.2015	08.09.2015	667932 / 142931 / 2997	1900	−1150
1	10.09.2014	22.04.2015	08.09.2015	667598 / 142568 / 3030	1920	−1110
2	10.09.2014	22.04.2015	08.09.2015	667553 / 142639 / 3028	1920	−890
3	10.09.2014	22.04.2015	08.09.2015	667507 / 142762 / 3031	1680	−730
6	10.09.2014	22.04.2015	08.09.2015	668259 / 143224 / 2951	1750	−1160
7	10.09.2014	22.04.2015	08.09.2015	668270 / 143106 / 2958	1820	−1260
8	10.09.2014	22.04.2015	08.09.2015	668659 / 143401 / 2902	1780	−2370
9	10.09.2014	22.04.2015	08.09.2015	668983 / 143316 / 2871	1800	−1960
10	10.09.2014	22.04.2015	08.09.2015	669374 / 143558 / 2773	1700	−2070
11	10.09.2014	22.04.2015	08.09.2015	669444 / 143738 / 2714	1700	−3380
12	10.09.2014	22.04.2015	08.09.2015	669252 / 144187 / 2608	1510	−3550
13	10.09.2014	22.04.2015	08.09.2015	669372 / 144183 / 2601	1700	−2700
14	10.09.2014	22.04.2015	08.09.2015	669698 / 144428 / 2552	1490	−3990
15	10.09.2014	22.04.2015	08.09.2015	669698 / 144428 / 2552	1490	−4080
16	10.09.2014	22.04.2015	08.09.2015	669995 / 144720 / 2535	1540	−3740
18	10.09.2014	22.04.2015	08.09.2015	670301 / 144945 / 2499	1660	−4730
19	10.09.2014	22.04.2015	08.09.2015	670258 / 144769 / 2510	1440	−4870

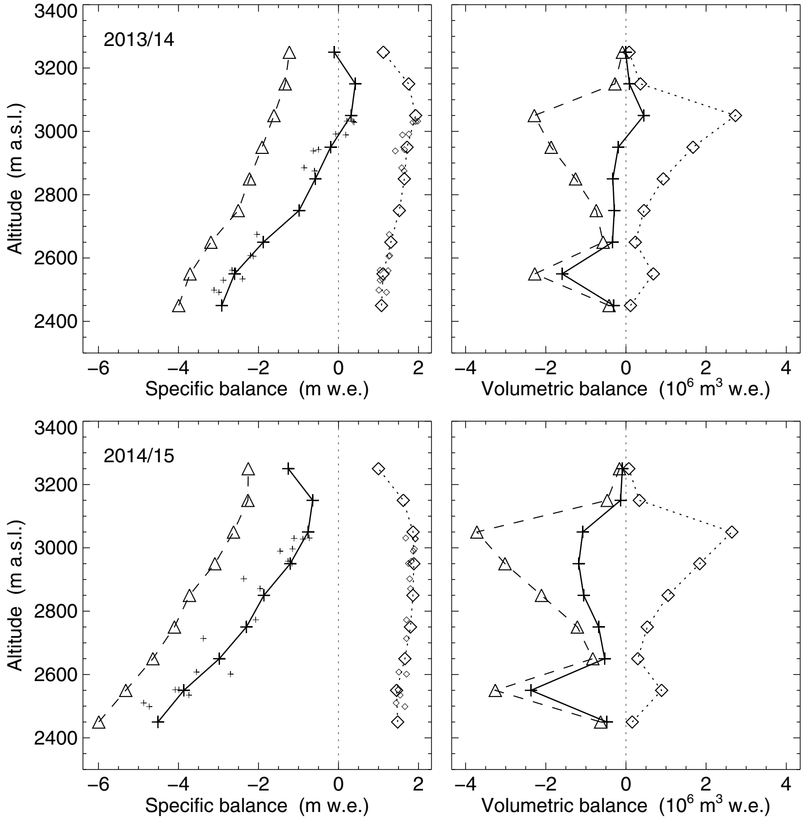

Figure 4.13: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

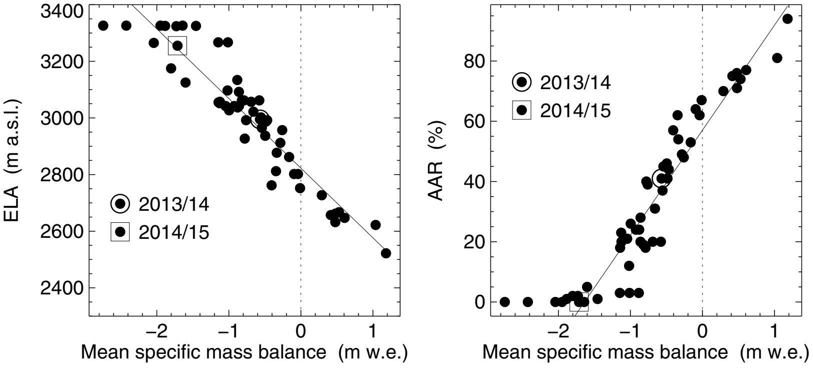

Figure 4.14: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.7 Vadret dal Murtèl

Introduction

Vadret dal Murtèl is situated in the inner-alpine Upper Engadine of south-eastern Switzerland. The east-facing cirque glacier next to Piz Corvatsch (3451 m a.s.l.) covers 0.3 km^2 and is still remarkably crevassed in its steeper middle part. Exhibiting only very little debris cover along the foot of steep headwalls confining the glacier to the north and west, Vadret dal Murtèl is a typical clean-ice glacier. Glaciological investigations were started in 2013, and also performed on the southern lobe of nearby Vadret dal Corvatsch. By 2010, Vadret dal Murtèl had retreated back to about two-thirds of its initial area in 1973. Observed volume and geodetic mass losses were comparatively large in recent decades. Between 1991 and 2009, the glacier lost more than half of its initial volume. Maximum measured ice thickness was 48 m in 2013, and 24 m on average (Fischer et al., 2014, 2015; Huss and Fischer, 2016).

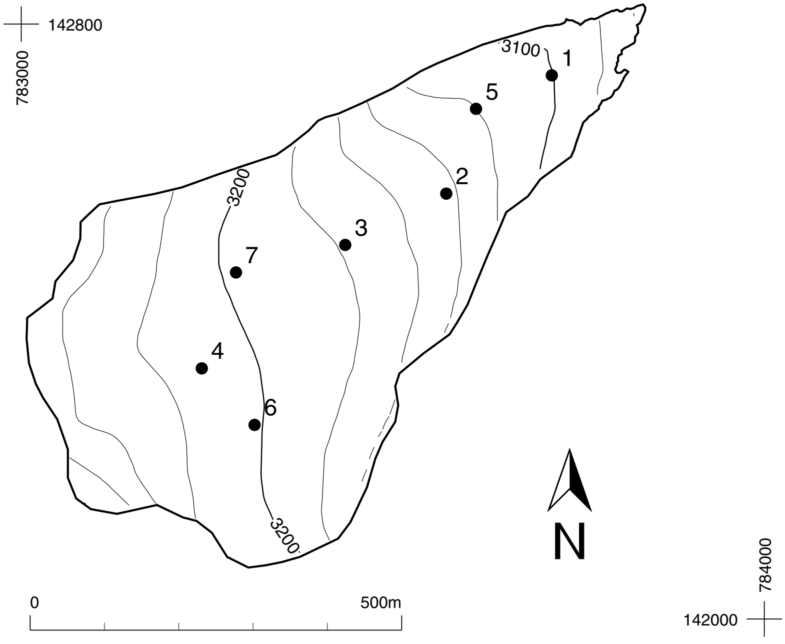

Figure 4.15: Surface topography and observational network of the Vadret dal Murtèl.

Table 4.9: Vadret dal Murtèl - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
3000 - 3050	0.001	1309	−255	0.000		
3050 - 3100	0.018	1149	−627	0.017	731	−2215
3100 - 3150	0.051	1203	48	0.054	786	−1841
3150 - 3200	0.114	1224	248	0.114	912	−1174
3200 - 3250	0.106	1755	1129	0.106	1393	−77
3250 - 3300	0.011	2215	2047	0.011	1702	659
3000 - 3300	0.301	1439	534	0.302	1076	−902

Investigations in 2013/14

Winter balance was determined on 15th April 2014. Snow probings at 304 locations were performed and snow density was measured in a snow pit. Above-average winter snow accumulation on the southern alpine slopes resulted in a slightly positive mass balance at Vadret dal Murtèl for 2013/14. A major part of the glacier surface showed net accumulation at the end of the melting season. A negative mass balance was measured at two stakes close to the glacier tongue on 4th October 2014. On Vadret dal Corvatsch, point mass balance between 31st August 2013 and 30th August 2014 was positive at six, balanced at one, and negative at three locations.

Table 4.10: Vadret dal Murtèl - Individual stake measurements of winter and annual balance.

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
1	01.09.2013	15.04.2014	04.10.2014	783714 / 142731 / 3100	1360	−650
2	01.09.2013	15.04.2014	04.10.2014	783572 / 142572 / 3143	1550	180
3	01.09.2013	15.04.2014	04.10.2014	783436 / 142503 / 3178	1490	350
4	01.09.2013	15.04.2014	04.10.2014	783243 / 142337 / 3211	1570	780
5	01.09.2013	15.04.2014	04.10.2014	783612 / 142686 / 3120	1360	320
6	01.09.2013	15.04.2014	04.10.2014	783314 / 142261 / 3202	1760	430
7	01.09.2013	15.04.2014	04.10.2014	783289 / 142466 / 3198	1450	810
1	04.10.2014	19.04.2015	19.09.2015	783714 / 142731 / 3100	740	−2210
2	04.10.2014	19.04.2015	19.09.2015	783572 / 142572 / 3143	1060	−1690
3	04.10.2014	19.04.2015	19.09.2015	783436 / 142503 / 3178	910	−1080
4	04.10.2014	19.04.2015	19.09.2015	783243 / 142337 / 3211	1170	−700
5	04.10.2014	19.04.2015	19.09.2015	783612 / 142686 / 3120	810	−2080
7	04.10.2014	19.04.2015	19.09.2015	783289 / 142466 / 3198	1230	−740

Investigations in 2014/15

The winter field survey was conducted on 19th April 2015. Snow probings at 185 locations were realized and snow density was measured in a snow pit. Strong melting in July and August contributed to significant mass loss on the glacier. On 19th September 2015, all of the four point mass balance measurements showed net ablation. The accumulation area was reduced to only the uppermost approx. 20% of the glacier surface. On Vadret dal Corvatsch, point mass balance between 4th October 2014 and 19th September 2015 was negative at all three measured stakes.

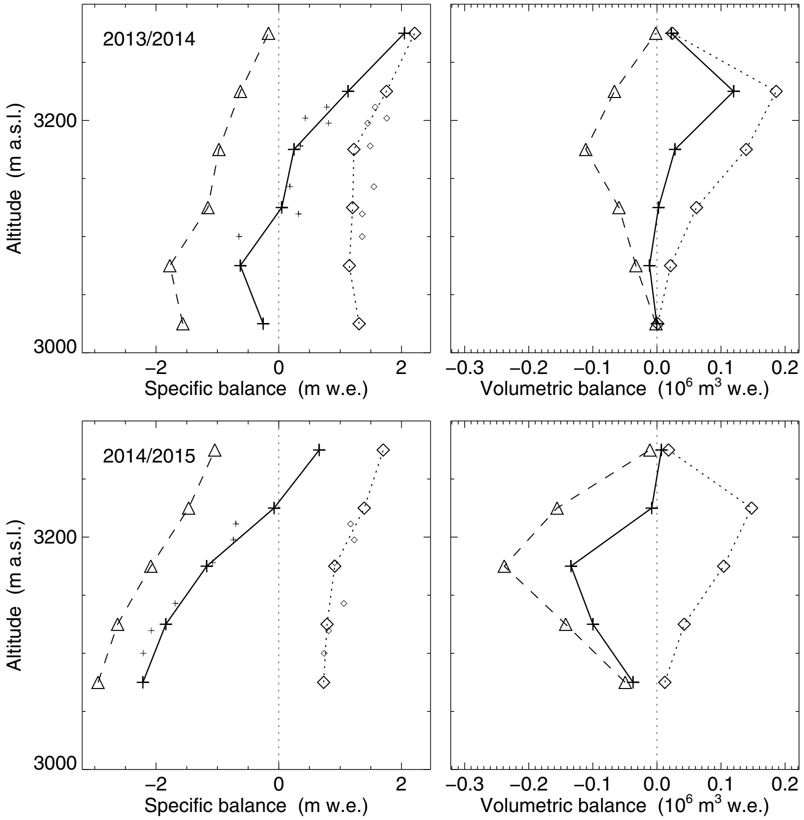

Figure 4.16: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

4.8 Pizolgletscher

Introduction

Pizolgletscher is a steep cirque glacier in the north-eastern Swiss Alps. With a surface area of about 0.06 km^2 Pizolgletscher represents the size class of glacierets that include almost 80% of the total number of glaciers in Switzerland (Fischer et al., 2014). Pizolgletscher is north-exposed and located at a relatively low elevation (2630-2780 m a.s.l.) which indicates that it depends on high quantities of winter accumulation. Seasonal mass balance measurements were started in 2006 (Huss, 2010).

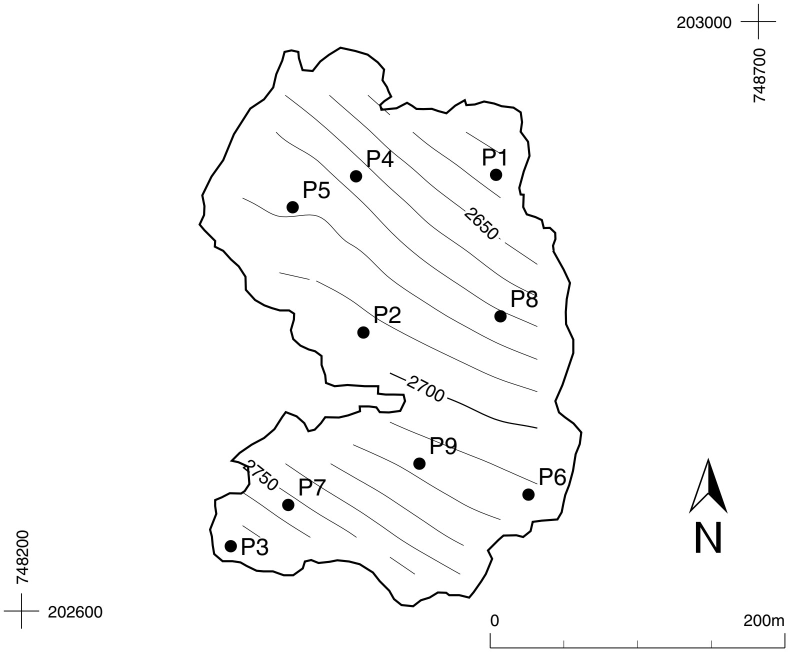

Figure 4.17: Surface topography and observational network of the Pizolgletscher.

Investigations in 2013/14

Winter balance was determined on 31st March 2014. Snow probings at 118 locations were performed and snow density was measured in a snow pit. During the late summer field survey on 20th September 2014 a negative mass balance was observed at eight stakes. Despite frequent summer snowfall events winter snow cover was completely depleted by the end of the ablation season, and

Table 4.11: Pizolgletscher - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2600 - 2650	0.011	1069	−1502	0.011	1679	−1966
2650 - 2700	0.032	1091	−1405	0.032	1812	−1841
2700 - 2750	0.018	1233	−870	0.018	2002	−836
2750 - 2800	0.005	1386	−727	0.005	1990	−743
2600 - 2800	0.067	1148	−1222	0.067	1856	−1501

debris coverage of the remaining ice accelerated. A surface elevation model was generated using a terrestrial laser scanner in order to determine annual geodetic mass balances (Fischer et al., 2016).

Investigations in 2014/15

The winter field survey was conducted later than in previous years (11.5.2015) because of adverse weather conditions in early April. Snow probings were conducted at 50 locations and snow density was estimated based on measurements on Claridenfirn performed in the same week. Strong melting in July and August contributed to significant mass loss on the glacier. On 9th September 2015 a

Table 4.12: Pizolgletscher - Individual stake measurements of winter and annual balance.

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
P1	23.09.2013	31.03.2014	20.09.2014	748521 / 202898 / 2629	1140	−1310
P2	23.09.2013	31.03.2014	20.09.2014	748432 / 202789 / 2692	1090	−1140
P3	23.09.2013	31.03.2014	20.09.2014	748342 / 202644 / 2777	1660	−950
P4	23.09.2013	31.03.2014	20.09.2014	748427 / 202906 / 2658	1050	−2310
P5	23.09.2013	31.03.2014	20.09.2014	748395 / 202879 / 2675	990	−1490
P7	23.09.2013	31.03.2014	20.09.2014	748381 / 202672 / 2753	1200	−1380
P8a	23.09.2013	31.03.2014	20.09.2014	748524 / 202792 / 2672	950	−1500
P8b	23.09.2013	31.03.2014	20.09.2014	748519 / 202799 / 2668	1050	−1710
P9	23.09.2013	31.03.2014	20.09.2014	748481 / 202701 / 2713	1010	−1170
P1	20.09.2014	11.05.2015	27.09.2015	748522 / 202896 / 2631	1530	−1860
P2	20.09.2014	11.05.2015	27.09.2015	748432 / 202789 / 2692	1860	−1300
P4	20.09.2014	11.05.2015	27.09.2015	748427 / 202895 / 2662	1550	−3280
P5	20.09.2014	11.05.2015	27.09.2015	748384 / 202874 / 2677	2000	−1750
P6	20.09.2014	11.05.2015	27.09.2015	748544 / 202679 / 2710	1970	−700
P8	20.09.2014	11.05.2015	27.09.2015	748525 / 202800 / 2667	1530	−2070
P9	20.09.2014	11.05.2015	27.09.2015	748470 / 202700 / 2715	2020	−1640

surface elevation model was generated using terrestrial laser scanning and all stakes were visited and re-installed during the late summer field survey on 27th September 2015. Mass balance was determined at seven stakes. No measurements at the two uppermost stakes were possible as they were hit by a rockslide. Ablation was above-average, with record melt rates of almost 4 m at one location.

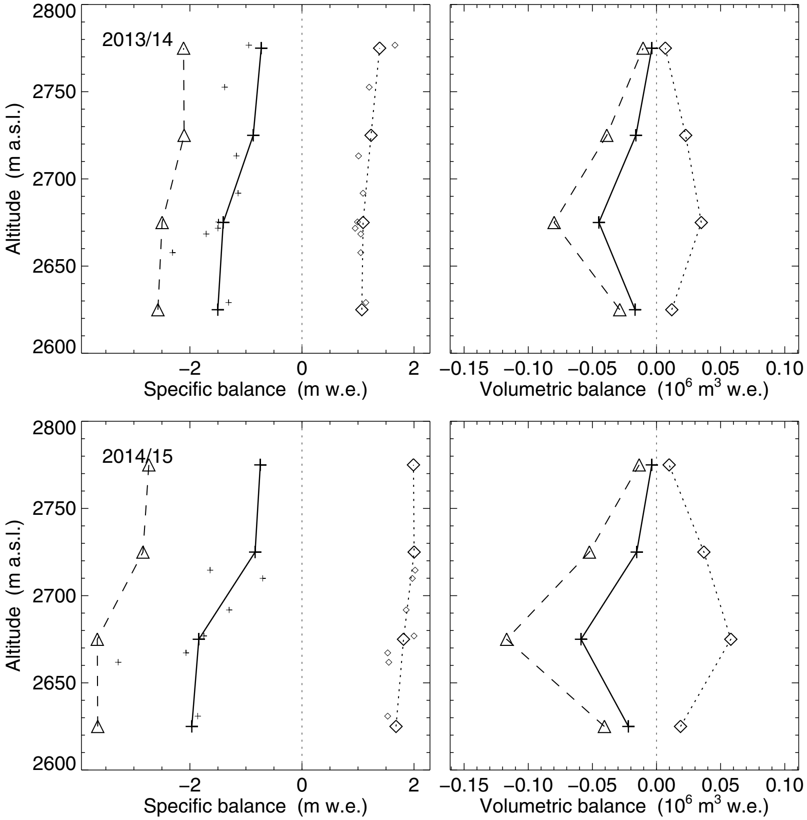

Figure 4.18: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

4.9 Glacier de la Plaine Morte

Introduction

Glacier de la Plaine Morte (7.5 km^2) is the largest plateau glacier in the European Alps and thus provides a particularly interesting site for studying the accelerating effects of climate change on Alpine glaciers. Plaine Morte is situated at the main Alpine divide between the cantons Berne and Valais. 90% of the glacier surface lies in a narrow altitudinal band between 2650 and 2800 m a.s.l. From the 5 km wide plateau with an average slope of less than four degrees, a small outlet glacier (Rezligletscher) flows northwards. In most years, the entire glacier is snow-covered or completely snow-free at the end of summer, i.e. the equilibrium line lies either above or below the glacier. Large circular depressions on the glacier surface, probably related to cryo-karst, are common features and have been stable over several decades. Three ice marginal lakes, notably Lac des Faverges with a water volume of more than 2 million m^3, are subject to annual drainage events. The seasonal mass balance at Glacier de la Plaine Morte has been determined since 2009 using the direct glaciological method (Huss et al., 2013). The spatial variability in melt is driven mainly by differences in ice surface albedo (Naegeli et al., 2015).

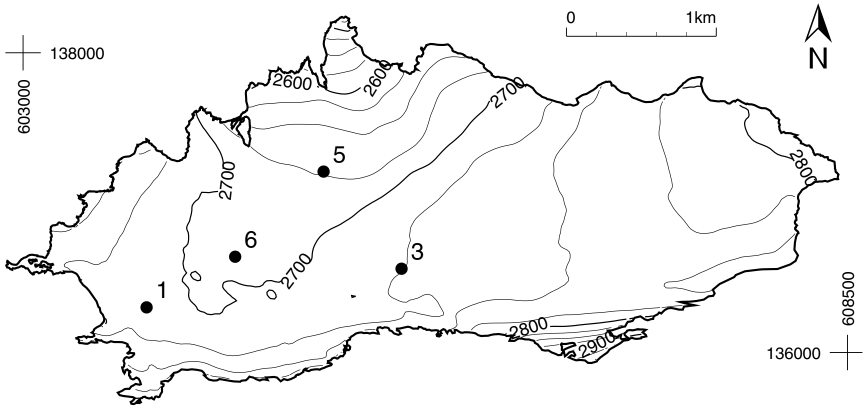

Figure 4.19: Surface topography and observational network of the Glacier de la Plaine Morte.

Investigations in 2013/14

Measurements of the winter mass balance were conducted on 28th March 2014. Snow probings at 94 locations distributed over the entire glacier were realized and snow density was determined in two snow pits. Snow depth was also measured using a ground-based radar system. Snow depth on the glacier was between 2-3 meters and thus below the long-term average. In early July an automatic weather station was installed on the western part of the glacier to record air temperature, precipitation, wind speed and direction, snow depth and all components of the radiation budget among other variables (Naegeli et al, in preparation). Surface albedo was determined repeatedly during the ablation season along three glacier cross-profiles using a pyranometer. Mass balance was measured at four stakes on 28th September 2014. Ablation was moderate but the entire glacier was snow-free between late July and the month of September. Lac des Faverges drained subglacially on 6th/7th August 2014 causing strongly elevated water levels in the Simme valley.

Table 4.13: Glacier de la Plaine Morte - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2400 - 2500	0.006	901	−1585	0.006	1229	−2709
2500 - 2600	0.152	928	−1532	0.152	1232	−2840
2600 - 2700	2.139	997	−1269	2.139	1248	−2613
2700 - 2800	5.106	1017	−886	5.106	1229	−2332
2800 - 2900	0.121	1087	−54	0.121	1241	−1043
2900 - 3000	0.026	1137	380	0.026	1253	−245
2400 - 3000	7.549	1011	−991	7.549	1235	−2395

Investigations in 2014/15

As part of the winter field surveysnow probings were acquired on 10th April 2015 at 38 locations distributed over the entire glacier, and snow density was measured in a snow pit. Snow depth was also determined along profiles using ground-penetrating radar. Winter accumulation exhibited small spatial variations and was around three meters. On 30th August 2015 an overflight with an imaging spectrometer allowed detailed mapping of surface impurities and the evaluation of spatially distributed bare-ice albedo (Naegeli et al., in press). A strongly negative mass balance was measured at all four stakes on 23th October 2015, with melt rates of three meters at individual sites. Over the summer season an automatic weather station on the glacier recorded various meteorological variables. The outburst event at Lac des Faverges was characterized by rather slow drainage of the water in this year and occurred between 27th July and 1th August 2015.

Table 4.14: Glacier de la Plaine Morte - Individual stake measurements of winter and annual balance.

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
1	02.10.2013	28.03.2014	28.09.2014	603819 / 136301 / 2704	1080	−1440
3	02.10.2013	28.03.2014	28.09.2014	605524 / 136559 / 2721	1200	−680
5	02.10.2013	28.03.2014	28.09.2014	605006 / 137212 / 2671	1070	−1160
6	02.10.2013	28.03.2014	28.09.2014	604417 / 136636 / 2691	1070	−1180
1	28.09.2014	10.04.2015	23.10.2015	603819 / 136301 / 2704	1260	−2890
3	28.09.2014	10.04.2015	23.10.2015	605524 / 136559 / 2721	1310	−2220
5	28.09.2014	10.04.2015	23.10.2015	605006 / 137212 / 2671	1390	−2620
6	28.09.2014	10.04.2015	23.10.2015	604417 / 136636 / 2691	1300	−2480

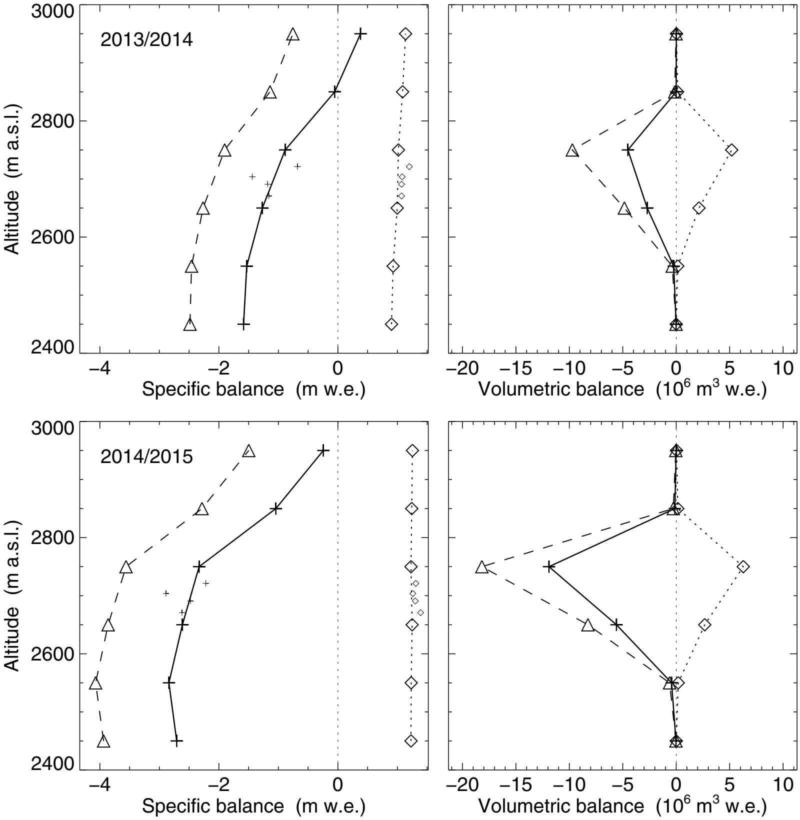

Figure 4.20: Specific (left) and volumetric (right) winter (dotted, ⋄), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

4.10 Rhonegletscher

Introduction

Rhonegletscher is a temperate valley glacier located in the central Swiss Alps, and is the primary source of water for the Rhone river. The glacier is easily accessible and therefore has been under observation since the 19th century. The total surface area of the glacier is 15.6 km^2 flowing in a southern direction from 3600 m a.s.l. down to 2200 m a.s.l. The first mass balance measurements were carried out in 1884 and are first ever recorded worldwide. After two periods of measurements between 1884-1910, and 1980-1982, the measurement series was resumed in 2006. Determination of volumetric changes in decadal resolution extend even further back to 1874 (Bauder et al., 2007).

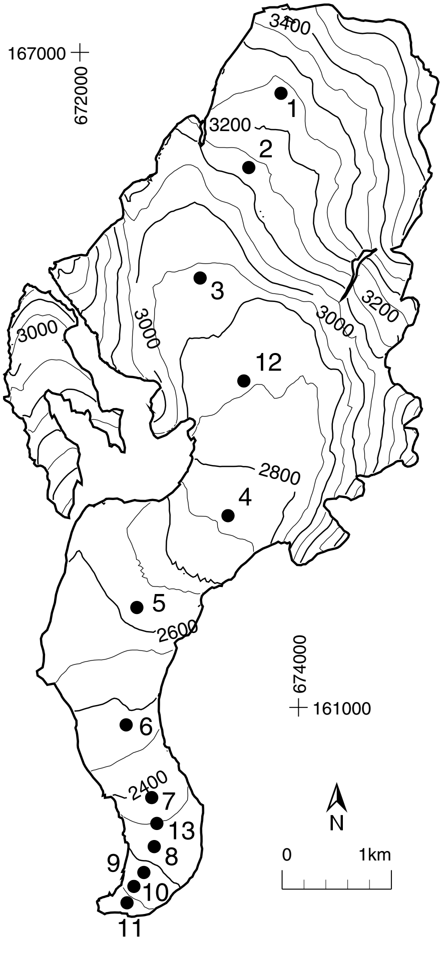

Figure 4.21: Surface topography and observational network of the Rhonegletscher.

Topographic maps or photogrammetrical surveys exist for 1874, 1929, 1959, 1980, 1991, 2000, and 2007.

Investigations in 2013/14

The measurement period extended from 27th September 2013 to 10th September 2014 with a field visit in spring on 10th April 2014. A total of 309 individual snow depth soundings were collected in April 2014. At the time of the field measurements in September 2014, the glacier was covered with snow above the icefall, and melt-out proceeded during summer up to about 2850 m a.s.l. with many of the exposed areas higher up becoming completely melted out. The density was acquired at stakes 3 and 13 in spring using a firn drill and in a snow-pit at stake 1 in fall.

Table 4.15: Rhonegletscher - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2200 - 2300	0.134	451	−4753	0.134	777	−5739
2300 - 2400	0.507	475	−4057	0.507	696	−5662
2400 - 2500	0.549	597	−3989	0.549	740	−5720
2500 - 2600	1.019	711	−3487	1.019	874	−4860
2600 - 2700	0.957	751	−2838	0.957	766	−4176
2700 - 2800	1.067	1023	−1625	1.067	1243	−2840
2800 - 2900	2.210	1244	−484	2.210	1803	−1208
2900 - 3000	2.171	1399	333	2.171	2014	−250
3000 - 3100	1.884	1378	659	1.884	2055	207
3100 - 3200	1.534	1359	884	1.534	2064	480
3200 - 3300	1.456	1478	1339	1.456	2198	925
3300 - 3400	0.951	1458	1540	0.951	2254	1271
3400 - 3500	0.795	1358	1583	0.795	2124	1355
3500 - 3600	0.334	1166	1392	0.334	1770	1059
2200 - 3600	15.571	1197	−353	15.571	1723	−1083

Investigations in 2014/15

The measurement period began on the 10th September 2014 and ended on the 10th September 2015 with a field visit in the spring on 2th April 2015. During the spring field visit, snow depth from 405 individual points were collected for measuring the winter accumulation. In September 2015, above the icefall the glacier was covered with 5-10 cm snow accumulated in the weeks before the survey. The limit of complete melt of winter accumulation was found at an elevation of about

2900 m a.s.l. Density measurements were carried out using a firn drill at stakes at 3 and 10 in spring and at all stakes where accumulation was registered (uppermost 3 stakes) in fall.

Table 4.16: Rhonegletscher - Individual stake measurements of winter and annual balance.

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
01	27.09.2013	10.04.2014	11.09.2014	673815 / 166615 / 3235	1508	1842
02	27.09.2013	10.04.2014	11.09.2014	673565 / 165925 / 3123	1348	1145
03	27.09.2013	10.04.2014	11.09.2014	673105 / 164929 / 2931	1304	948
04	27.09.2013	10.04.2014	10.09.2014	673358 / 162750 / 2748	1036	−1190
05	23.09.2013	10.04.2014	10.09.2014	672516 / 161935 / 2608	618	−3086
06	23.09.2013	10.04.2014	10.09.2014	672414 / 160851 / 2472	552	−4148
07	23.09.2013	10.04.2014	10.09.2014	672654 / 160180 / 2367	510	−3281
08	23.09.2013	10.04.2014	10.09.2014	672686 / 159724 / 2304	664	−3893
09	27.09.2013	10.04.2014	10.09.2014	672623 / 159516 / 2263	656	−4412
10	23.09.2013	10.04.2014	10.09.2014	672541 / 159387 / 2240	506	−3749
12	27.09.2013	10.04.2014	11.09.2014	673503 / 163990 / 2847	1184	−672
13	23.09.2013	10.04.2014	10.09.2014	672700 / 159945 / 2329	531	−4293
01	11.09.2014	22.04.2015	10.09.2015	673815 / 166615 / 3236	1995	1306
02	11.09.2014	22.04.2015	09.09.2015	673565 / 165925 / 3124	2104	1094
03	11.09.2014	22.04.2015	09.09.2015	673099 / 164929 / 2931	1948	894
04	10.09.2014	22.04.2015	10.09.2015	673364 / 162767 / 2748	1463	−2057
05	10.09.2014	22.04.2015	10.09.2015	672521 / 161920 / 2606	732	−4310
06	10.09.2014	22.04.2015	10.09.2015	672415 / 160846 / 2470	827	−5576
07	10.09.2014	22.04.2015	10.09.2015	672657 / 160175 / 2363	855	−5950
08	10.09.2014	22.04.2015	10.09.2015	672680 / 159725 / 2301	1340	−5109
09	10.09.2014	22.04.2015	10.09.2015	672605 / 159501 / 2254	1093	−5228
10	10.09.2014	22.04.2015	10.09.2015	672533 / 159390 / 2235	1012	−5296
12	11.09.2014	22.04.2015	09.09.2015	673497 / 163990 / 2845	1867	−1284
13	10.09.2014	22.04.2015	10.09.2015	672701 / 159936 / 2325	1121	−5627

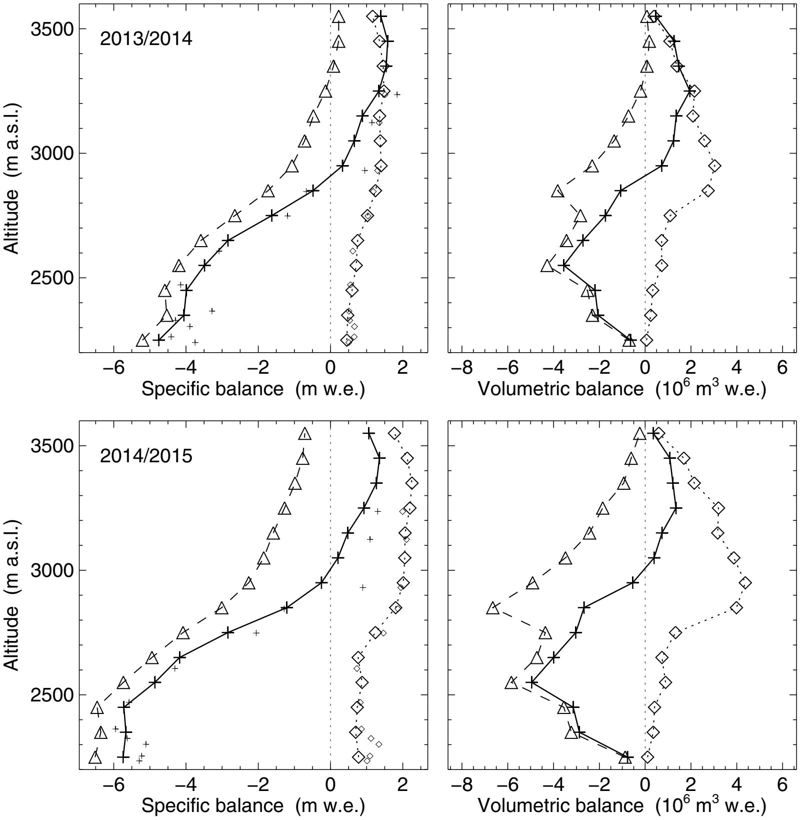

Figure 4.22: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

4.11 Sankt Annafirn

Introduction

Sankt Annafirn is a north-facing very small cirque glacier in the central Swiss Alps protected by steep rockwalls connecting Sankt Annahorn (2937 m a.s.l.) with Chastelhorn (2973 m a.s.l.). The glacier covers an area of 0.2 km^2. Glaciological investigations were started in 2012. Since 2013, measurements have been performed also on nearby Schwarzbachfirn. By 2010, Sankt Annafirn shrank to half its initial surface area from 1973, and lost about two-thirds of its volume since 1986 (Fischer et al., 2014, 2015). Measured maximum glacier thickness reached 42 m and was 16 m on average in 2013. According to a median climate scenario, Sankt Annafirn is expected to show ongoing and rapid shrinkage over the next 25 years. Only a tiny ice patch in a protected niche is predicted to survive until the middle of the 21st century (Huss and Fischer, 2016).

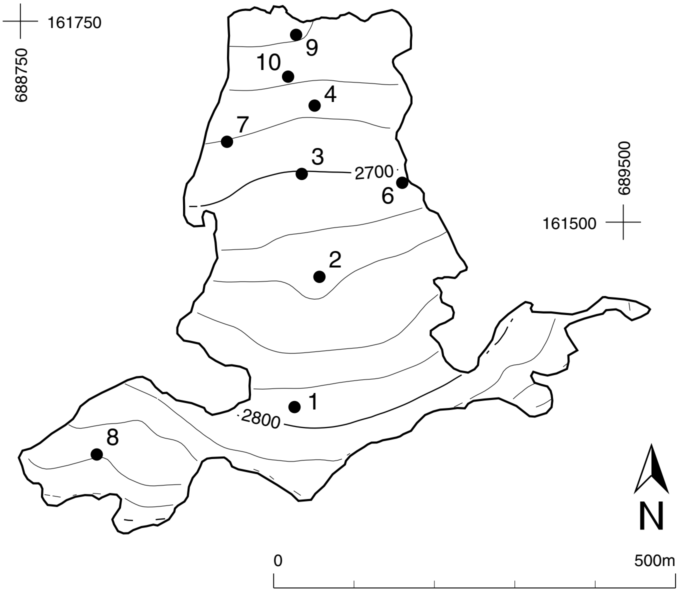

Figure 4.23: Surface topography and observational network of the Sankt Annafirn.

Investigations in 2013/14

The winter mass balance observations were conducted on 10th April 2014. Snow density was measured in a snow pit. Snow depth was determined based on 153 snow probings. Sankt Annafirn showed comparatively moderate mass losses during 2013/14. On 23rd September 2014, a negative mass balance for the measurement period was found at eight stakes. The uppermost third of the

Table 4.17: Sankt Annafirn - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2600 - 2650	0.014	1448	−1073	0.012	1594	−2494
2650 - 2700	0.037	1469	−1131	0.037	1501	−2402
2700 - 2750	0.046	1757	−619	0.046	1955	−1045
2750 - 2800	0.040	2231	127	0.040	1907	−1170
2800 - 2850	0.042	2196	49	0.042	1913	−1155
2850 - 2900	0.016	1902	−408	0.016	1667	−1448
2900 - 2950	0.001	1233	−1017	0.001	1145	−1470
2600 - 2950	0.195	1881	−437	0.193	1801	−1477

glacier surface showed net accumulation, the rates of which were determined based on three firn pits. Both during the winter and the late summer survey, digital terrain models of Sankt Annafirn and the nearby Schwarzbachfirn were acquired using terrestrial laser scanning (Fischer et al., 2016). At the end of September 2014, englacial temperature was measured in two approx. 10 m deep boreholes on Sankt Annafirn, indicating the co-existence of slightly cold and temperate ice (Huss and Fischer, 2016). On nearby Schwarzbachfirn, point mass balance between 7th September 2013 and 24th September 2014 was negative at two stakes.

Investigations in 2014/15

On 15th April 2015, end-of-winter snow depth was measured at 81 locations on Sankt Annafirn during the winter field survey, and snow density was determined in a snow pit. Due to the exceptionally high temperatures in July and August 2015, summer melt was above average and the mass balance on Sankt Annafirn was strongly negative for 2014/15. The whole glacier surface showed net ablation over this period. Mass losses were measured at nine stakes on 28th September 2015. Comparison of high-resolution digital elevation models for Sankt Annafirn and Schwarzbachfirn derived by terrestrial laser scanning indicated good agreement with direct mass balance measurements (Fischer et al., 2016). On Schwarzbachfirn, point mass balance between 24th September 2014 and 28th September 2015 was negative at all three measured stakes.

Table 4.18: Sankt Annafirn - Individual stake measurements of winter and annual balance.

Stake	Period Start	Spring	End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	b_a
1	02.10.2013	10.04.2014	23.09.2014	689091 / 161270 / 2791	2210	−70
2	02.10.2013	10.04.2014	23.09.2014	689122 / 161432 / 2735	1630	−170
3	02.10.2013	10.04.2014	23.09.2014	689100 / 161560 / 2701	1700	−740
4	02.10.2013	10.04.2014	23.09.2014	689115 / 161658 / 2667	1100	−1580
6	02.10.2013	10.04.2014	23.09.2014	689225 / 161549 / 2706	1630	−1100
7	02.10.2013	10.04.2014	23.09.2014	689007 / 161600 / 2681	1630	−960
8	02.10.2013	10.04.2014	23.09.2014	688863 / 161221 / 2856	1510	−960
9	02.10.2013	10.04.2014	23.09.2014	689093 / 161733 / 2639	1470	−1220
1	23.09.2014	15.04.2015	28.09.2015	689091 / 161270 / 2791	1830	−1170
2	23.09.2014	15.04.2015	28.09.2015	689122 / 161432 / 2735	1850	−850
3	23.09.2014	15.04.2015	28.09.2015	689100 / 161560 / 2701	1760	−1360
4	23.09.2014	15.04.2015	28.09.2015	689116 / 161645 / 2676	1270	−3000
6	23.09.2014	15.04.2015	28.09.2015	689225 / 161549 / 2706	1700	−1810
7	23.09.2014	15.04.2015	28.09.2015	689007 / 161600 / 2681	1660	−2090
8	23.09.2014	15.04.2015	28.09.2015	688845 / 161211 / 2858	1420	−1870
9	23.09.2014	15.04.2015	28.09.2015	689093 / 161733 / 2639	1620	−2920
10	23.09.2014	15.04.2015	28.09.2015	689083 / 161681 / 2656	1360	−2920

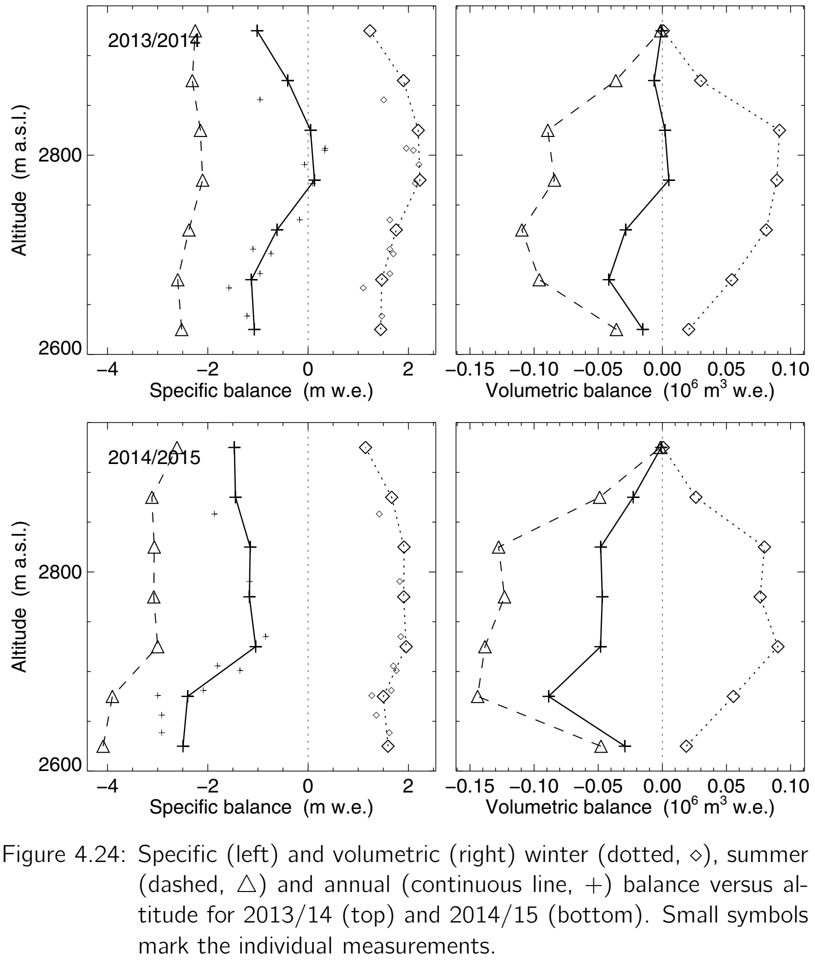

Figure 4.24: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

4.12 Silvrettagletscher

Introduction

Silvrettagletscher is a small temperate mountain glacier located in the north-eastern part of Switzerland in the Silvretta massif at the border to Austria. The present surface area is 2.7 km^2, extending from 3090 m a.s.l. down to 2470 m a.s.l. First mass balance measurements date back to the 1910s (Firnberichte, 1978). Seasonal observations at two stakes were conducted until 1959, when the stake network was increased to about 40 stakes. Huss and Bauder (2009) compiled and homogenized all existing measurements of stake 5 to a continuous time series of seasonal resolution for the period 1914 to 2007 (see Section 4.10 in Volume 127/128). Determination of volumetric changes in decadal resolution extends even further back to 1892 (Bauder et al., 2007). Topographic maps and photogrammetrical surveys exist for 1892, 1938, 1959, 1973, 1986, 1994, 2003, 2007 and 2012. Huss et al. (2009) re-analyzed and homogenized the seasonal stake data and ice volume changes for the period 1959 to 2007. An update for the period 1919 to 2012 with corresponding values of the mean specific winter and annual balance for fixed date periods is presented in Section 4.17 of this report.

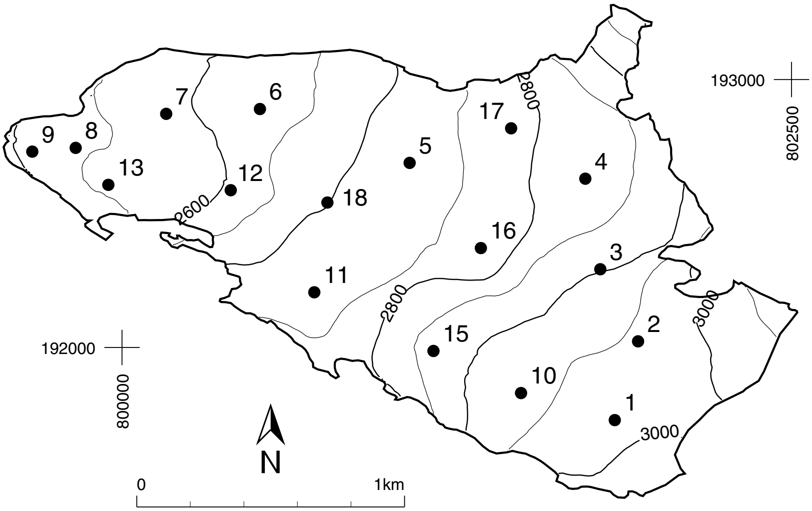

Figure 4.25: Surface topography and observational network of the Silvrettagletscher.

Investigations in 2013/14

The measurement period extended from 22nd September 2013 to 21st September 2014. The winter mass balance was determined during a field visit in spring, on 24th May 2014. Snow depth samples

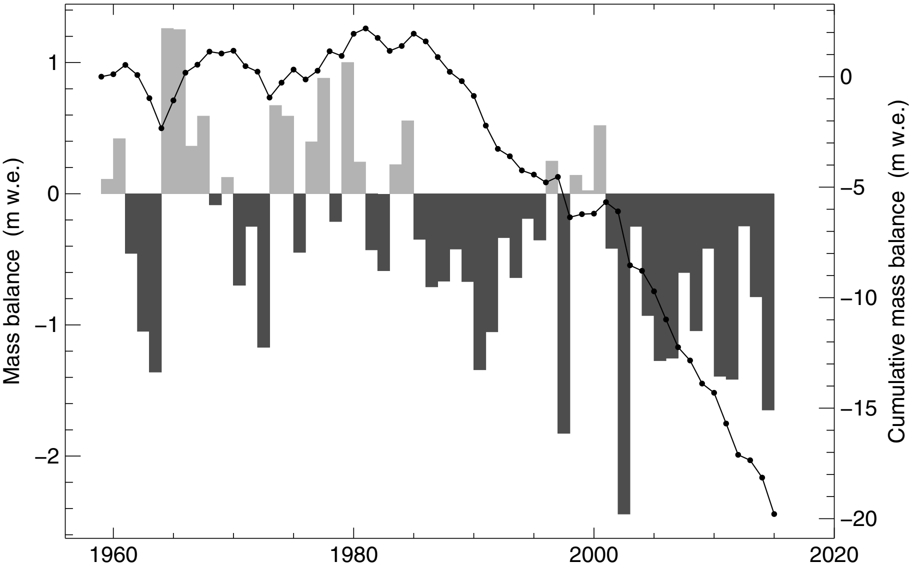

Figure 4.26: Silvrettagletscher - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1959-2015.

were taken at 196 locations and supplemented by density profiles in a snow pit at two sites. At the time of the measurements in autumn 2014, the tongue was free of snow from any recent snowfalls. Melt-out of the winter accumulation occurred up to an elevation of 2850 m a.s.l., and a larger area with accumulation remained, compared to previous years. Density measurements were taken in a snow pit at Stake 2, and measurements from 16 stakes were available for determining the annual mass balance.

Table 4.19: Silvrettagletscher - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2400 - 2500	0.016	934	−2495	0.016	1310	−3423
2500 - 2600	0.338	886	−2236	0.338	1378	−3220
2600 - 2700	0.392	1104	−1235	0.392	1365	−2552
2700 - 2800	0.663	1190	−960	0.663	1432	−1820
2800 - 2900	0.576	1293	−440	0.576	1404	−978
2900 - 3000	0.583	1371	54	0.583	1430	−671
3000 - 3100	0.117	1268	227	0.117	1184	−1049
2400 - 3100	2.684	1202	−786	2.684	1397	−1649

Investigations in 2014/15

The measuring period was from 21st September 2014 to 25th September 2015. During a spring field visit on 4th May 2015, snow depth probings from about 183 individual points were collected. Density was determined in snow pits at the same two locations as in previous years. The melt-out of winter accumulation extended to almost the entire area already by the end of August 2015. During the measurements in September 2015 the glacier was covered with 20-25 cm of fresh snow from the previous days. No density measurements were possible as no accumulation from the winter survived the melting season. Measurements of mass balance collected at 16 stakes were available for determining the annual mass balance. A short field visit at the end of October 2015 revealed some further melting on the glacier tongue after the field campaign in the order of 2 to 22 cm of ice, depending on the locations.

Installation of an ablation stake using a steam drill on Vadret dal Murtèl in September 2015 with Vadret dal Tschierva visible in the background. (Photo: M. Huss)

Table 4.20: Silvrettagletscher - Individual stake measurements of winter and annual balance.

Stake		Period		Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
01	22.09.2013	24.04.2014	20.09.2014	801840 / 191729 / 2978	1313	256
02	22.09.2013	24.04.2014	20.09.2014	801927 / 192023 / 2954	1339	360
04	21.09.2013	24.04.2014	20.09.2014	801738 / 192637 / 2817	1199	−655
05	21.09.2013	24.04.2014	20.09.2014	801069 / 192691 / 2714	1118	−1179
06	21.09.2013	24.04.2014	20.09.2014	800511 / 192891 / 2614	968	−1845
07	21.09.2013	24.04.2014	21.09.2014	800163 / 192871 / 2564	1043	−1728
08	21.09.2013	24.04.2014	21.09.2014	799826 / 192744 / 2519	1030	−1845
09	21.09.2013	24.04.2014	21.09.2014	799697 / 192736 / 2493	994	−2628
10	22.09.2013	24.04.2014	20.09.2014	801524 / 191808 / 2934	995	−357
11	21.09.2013	24.04.2014	20.09.2014	800734 / 192198 / 2720	961	−1161
12	21.09.2013	24.04.2014	21.09.2014	800406 / 192584 / 2590	893	−1980
13	21.09.2013	24.04.2014	21.09.2014	799966 / 192611 / 2534	629	−2772
15	21.09.2013	24.04.2014	20.09.2014	801163 / 191987 / 2852	910	−1116
16	21.09.2013	25.04.2014	20.09.2014	801333 / 192374 / 2763	922	−1332
17	21.09.2013	24.04.2014	20.09.2014	801453 / 192818 / 2772	1092	−900
18	21.09.2013	25.04.2014	20.09.2014	800762 / 192543 / 2685	1152	−1116
01	20.09.2014	04.05.2015	26.09.2015	801842 / 191731 / 2978	1344	−1160
02	20.09.2014	04.05.2015	26.09.2015	801927 / 192023 / 2954	1455	−960
03	20.09.2014	04.05.2015	26.09.2015	801783 / 192252 / 2902	1291	64
04	20.09.2014	04.05.2015	26.09.2015	801729 / 192626 / 2815	1242	−1528
05	20.09.2014	04.05.2015	25.09.2015	801064 / 192693 / 2712	1348	−1913
06	20.09.2014	04.05.2015	25.09.2015	800515 / 192890 / 2613	1308	−3026
07	21.09.2014	04.05.2015	25.09.2015	800168 / 192872 / 2562	1421	−3018
08	21.09.2014	04.05.2015	25.09.2015	799831 / 192743 / 2518	1299	−2882
09	21.09.2014	04.05.2015	25.09.2015	799700 / 192737 / 2491	1348	−3417
10	20.09.2014	04.05.2015	26.09.2015	801522 / 191810 / 2932	1411	−1360
11	20.09.2014	04.05.2015	25.09.2015	800721 / 192204 / 2718	1348	−1930
12	21.09.2014	04.05.2015	25.09.2015	800402 / 192585 / 2588	1322	−2244
13	21.09.2014	04.05.2015	25.09.2015	799974 / 192614 / 2533	1230	−3927
16	20.09.2014	05.05.2015	26.09.2015	801327 / 192377 / 2761	1362	−1989
17	20.09.2014	04.05.2015	26.09.2015	801450 / 192819 / 2770	1113	−1488
18	20.09.2014	05.05.2015	25.09.2015	800756 / 192545 / 2683	1313	−2159

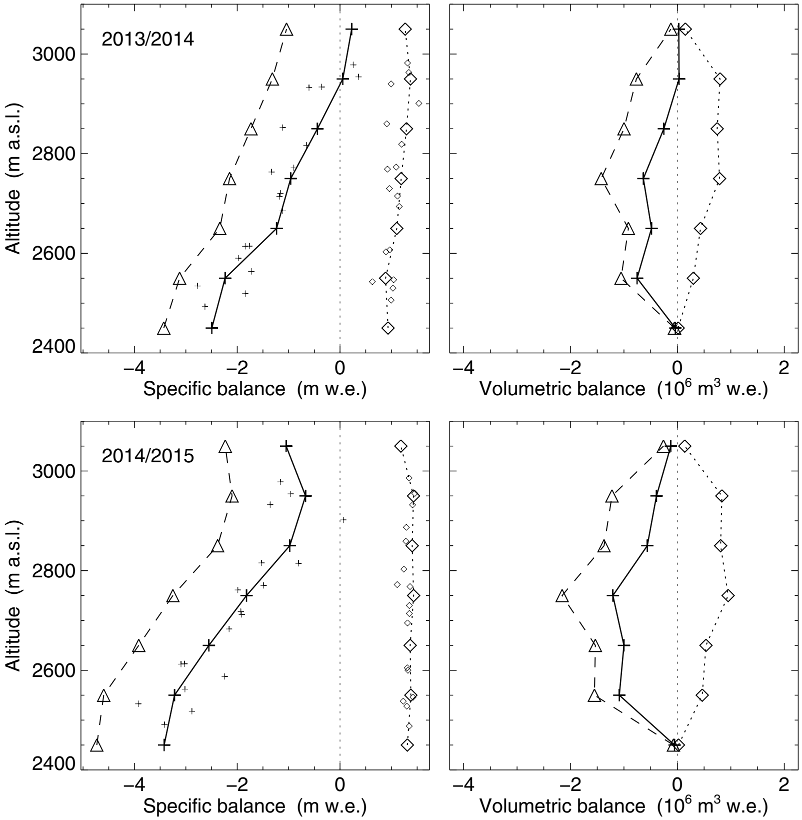

Figure 4.27: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

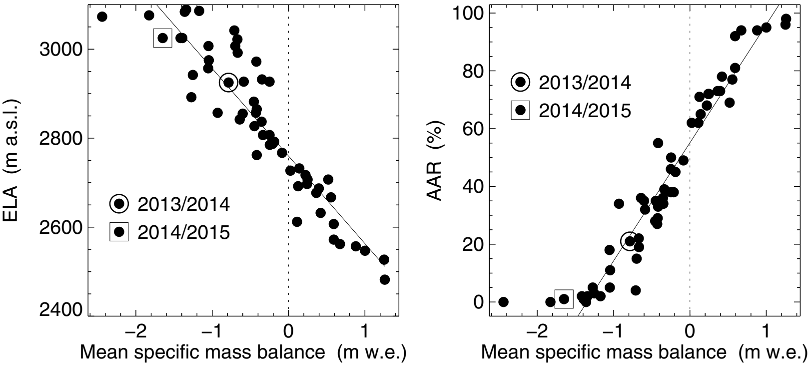

Figure 4.28: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.13 Glacier de Tsanfleuron

Introduction

Glacier de Tsanfleuron is an easily accessible medium-sized glacier located at the border shared by the cantons of Valais, Vaud and Berne. The glacier has an area of 2.6 km^2 and exhibits relatively small surface slopes. Glaciological investigations were started in 2009 with the aim of establishing a mass balance monitoring programme in the Western Swiss Alps. In addition, measurements are performed on the very small Glacier du Sex Rouge connected to Tsanfleuron in its accumulation area. This allows the mass balance response of neighbouring glaciers of varying sizes and characteristics, to be compared.

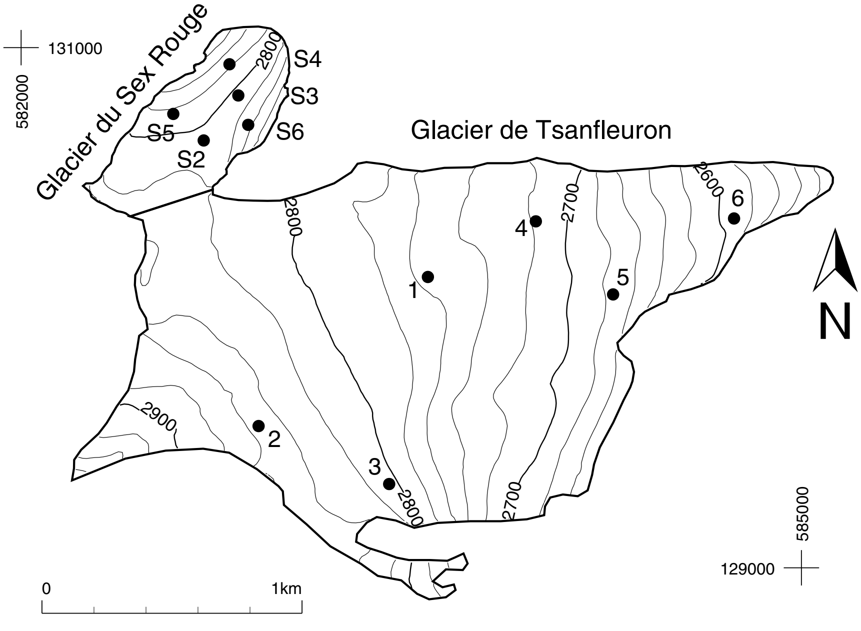

Figure 4.29: Surface topography and observational network of the Glacier de Tsanfleuron and the Glacier du Sex Rouge.

Investigations in 2013/14

Winter mass balance observations were conducted on 17th and 18th April 2014. Snow density was measured in a snow pit. Snow depth was determined based on 224 snow probings on Glacier du Sex Rouge, and using a 1.6 GHz ground-penetrating radar device on Glacier du Tsanfleuron. On 11th September 2014 a negative mass balance was found at four stakes on Glacier de Tsanfleuron. Only one measurement site exhibited slightly positive mass balance. For six stakes on Glacier du

Table 4.21: Glacier de Tsanfleuron - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2500 - 2600	0.058	1036	−2553	0.058	1405	−4176
2600 - 2700	0.457	1185	−1507	0.457	1490	−3665
2700 - 2800	1.126	1365	−593	1.126	1647	−2667
2800 - 2900	0.918	1545	−122	0.918	1520	−2361
2900 - 3000	0.060	1437	284	0.060	1439	−1633
2500 - 3000	2.618	1391	−610	2.618	1565	−2744

Sex Rouge a negative mass balance was measured on 22th September 2014. Digital terrain models of Glacier du Sex Rouge and the nearby small Glacier de Prapio were acquired, both during the winter and the late summer field surveys, based on terrestrial laser scanning (Fischer et al., 2016).

Investigations in 2014/15

During the winter field survey on 21st and 22nd April 2015, probings of the snow depth at 45 locations on Glacier du Tsanfleuron, and at 247 locations on Glacier du Sex Rouge were carried out and snow density was determined in a snow pit. Ground-penetrating radar provided additional information on snow depth distribution. Due to extreme melting and a complete depletion of the winter snow cover over the entire glacier surface by late July, several stakes had to be re-drilled in August. On 20th and 21st September 2015, a negative mass balance was measured at four stakes on Glacier du Tsanfleuron, and four stakes on Glacier du Sex Rouge with values being substantially more negative than in previous years. More than two meters of ablation were observed, even in the former accumulation area. Repeated measurements of englacial temperature

Table 4.22: Glacier du Sex Rouge - Specific winter and annual balance versus altitude in the two periods 2013/14 and 2014/15, evaluated for the measurement period defined by the dates of field survey.

Altitude	2013/14			2014/15		
	Area	$\overline{b_w}$	$\overline{b_a}$	Area	$\overline{b_w}$	$\overline{b_a}$
(m a.s.l.)	(km^2)	(mm w.e.)	(mm w.e.)	(km^2)	(mm w.e.)	(mm w.e.)
2700 - 2750	0.007	1245	−493	0.007	960	−2985
2750 - 2800	0.086	1096	−780	0.086	1144	−2648
2800 - 2850	0.166	1184	−601	0.166	1605	−2042
2850 - 2900	0.011	1633	434	0.011	1730	−909
2700 - 2900	0.270	1176	−613	0.270	1447	−2213

in a 35 m deep borehole on Glacier du Sex Rouge indicated ice at temperatures of around -1°C, and thus polythermal conditions in the ablation area (Huss and Fischer, 2016). Comparison of high-resolution digital elevation models for Glacier du Sex Rouge and Glacier de Prapio based on terrestrial laser scanning indicated good agreement with direct mass balance measurements (Fischer et al., 2016).

Table 4.23: Glacier de Tsanfleuron and Glacier du Sex Rouge - Individual stake measurements of winter and annual balance.

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
2	13.09.2013	17.04.2014	11.09.2014	582913 / 129545 / 2851	1750	130
3	13.09.2013	17.04.2014	11.09.2014	583415 / 129322 / 2805	1310	−230
4	13.09.2013	17.04.2014	11.09.2014	583979 / 130337 / 2719	1390	−640
5	13.09.2013	17.04.2014	11.09.2014	584261 / 130049 / 2689	1270	−1420
6	13.09.2013	17.04.2014	11.09.2014	584742 / 130347 / 2603	1280	−2470
S2	14.09.2013	16.04.2014	22.09.2014	582702 / 130654 / 2805	850	−1030
S3	14.09.2013	16.04.2014	22.09.2014	582835 / 130816 / 2806	1020	−520
S4	14.09.2013	16.04.2014	22.09.2014	582801 / 130936 / 2777	900	−1090
S5	14.09.2013	16.04.2014	22.09.2014	582585 / 130745 / 2785	1050	−800
S6	14.09.2013	16.04.2014	22.09.2014	582873 / 130703 / 2835	1350	−200
S7	14.09.2013	16.04.2014	22.09.2014	582609 / 130602 / 2810	1130	−670
1	11.09.2014	20.04.2015	21.09.2015	583527 / 130148 / 2756	1530	−2370
2	11.09.2014	20.04.2015	21.09.2015	582918 / 129553 / 2851	1350	−2100
5	11.09.2014	20.04.2015	21.09.2015	584264 / 130051 / 2685	1460	−3720
6	11.09.2014	20.04.2015	21.09.2015	584735 / 130346 / 2608	1570	−3970
S2	22.09.2014	21.04.2015	20.09.2015	582702 / 130654 / 2805	1430	−1950
S3	22.09.2014	21.04.2015	20.09.2015	582835 / 130816 / 2806	1380	−2020
S5	22.09.2014	21.04.2015	20.09.2015	582583 / 130742 / 2785	780	−2950
S7	22.09.2014	21.04.2015	20.09.2015	582609 / 130602 / 2810	1080	−2300

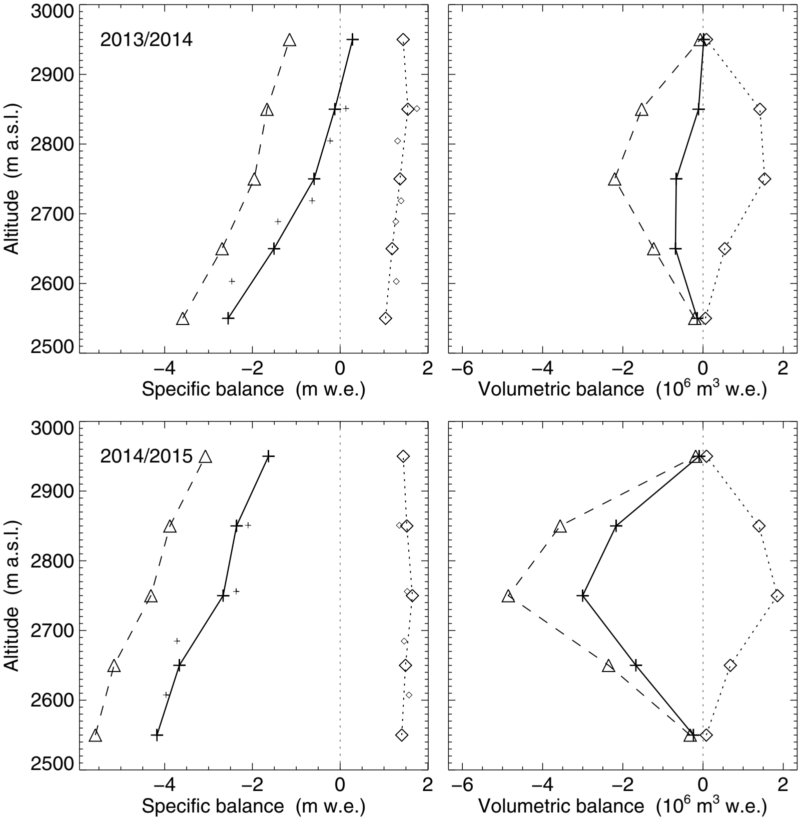

Figure 4.30: Glacier de Tsanfleuron - Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2013/14 (top) and 2014/15 (bottom). Small symbols mark the individual measurements.

4.14 Claridenfirn

Introduction

Measurements of the snow and firn accumulation and melt, as well as of precipitation values in the accumulation area of the Claridenfirn, have been undertaken by various researchers since 1914. The traditional glaciological method was applied by digging a snowpit down to the layer of ochre applied the previous autumn and measuring the water equivalents. Specific annual balances were determined every autumn since 1957 and also regularly in spring at two plateau locations at altitudes of 2700 and 2900 m a.s.l. The reports dealing with the years 1914 to 1978 are published in Kasser et al. (1986). The method of measurement and the results from the period 1914 to 1984 are published in Müller and Kappenberger (1991). A further update of the measurements until 2007 allowed Huss and Bauder (2009) to separate accumulation and melt and to interpret the entire time series in terms of climatic influences (see Section 4.10 of Volume 127/128). Values of the entire homogenized time series 1914-2014 are compiled in Section 4.16 of this report. In addition,

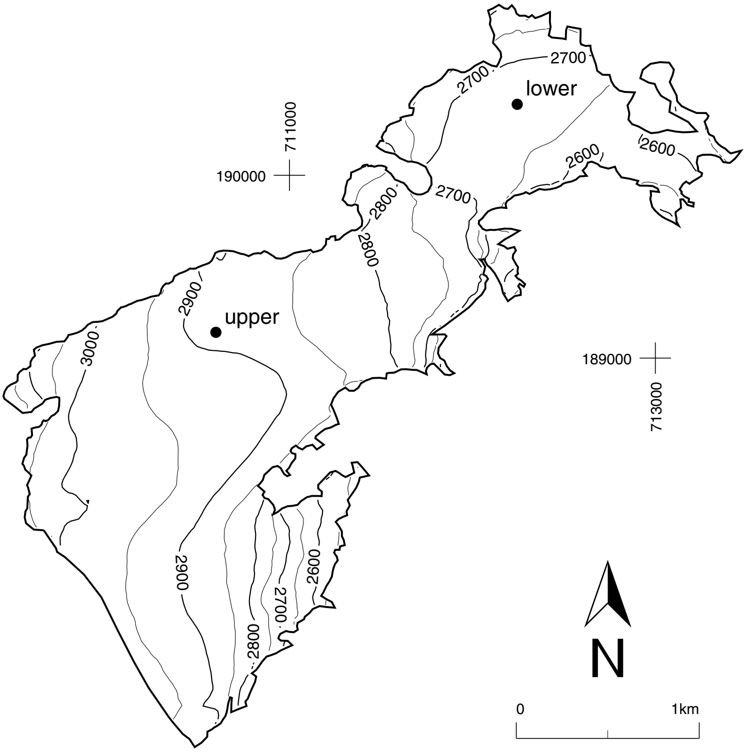

Figure 4.31: Surface topography and observational network of the Claridenfirn.

Huss et al. (2009) calculated glacier-wide mass balance for the entire time series (cf. Section 4.17).

Investigations in 2013/14

Spring measurements were carried out on 18th May 2014. Detailed observations in a snow pit at the upper stake were supplemented by 10-20 snow depth samples in the vicinity of both stakes. Percolation of meltwater was observed down to some ice lenses at 1 m depth. The temperatures in the lower column reached -2.7 °C. A distinct 20 cm thick layer of sahara dust deposited between 18th and 19th February 2014 was found at 1.3 m depth. Autumn measurements were carried out on 15th September 2014. The glacier was covered with 5-15 cm of fresh snow. At the lower site, snow accumulation during winter had melted completely with a small loss of ice. The upper site showed a moderate amount of 1.6 m of firn accumulation and the density was measured in a pit. Additional melt occurred after the field visit as confirmed by stake readings at the lower sites by tourists in mid October. In addition to the snow pits and depth probings, two precipitation storage gauges were monitered and readings taken during spring and fall visits at Claridenhütte and Geissbützistock.

Investigations in 2014/15

The investigations included snow depth measurements at both stakes, snow pit measurements in spring and fall at the upper site, stake readings, and determination of the position using a small theodolite in fall. The spring field survey was carried out on 14th May, and the late summer survey on 9th October 2015. In Spring, ice lenses formed by percolation of meltwater were found in the entire column. The accumulated snow from the winter season was completely melted at lower site with a substantial loss of ice, while at the upper site only a marginal layer survived the summer season.

Table 4.24: Claridenfirn - Individual stake measurements of winter and annual balance.

Stake	Period Start	 Spring	 End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	 b_a
upper	07.09.2013	18.05.2014	15.09.2014	710598 / 189141 / 2900	1870	869
lower	07.09.2013	18.05.2014	15.09.2014	712245 / 190388 / 2700	1596	−221
upper	15.09.2014	14.05.2015	09.10.2015	710598 / 189141 / 2900	2224	348
lower	15.09.2014	14.05.2015	09.10.2015	712245 / 190388 / 2700	1476	−2015

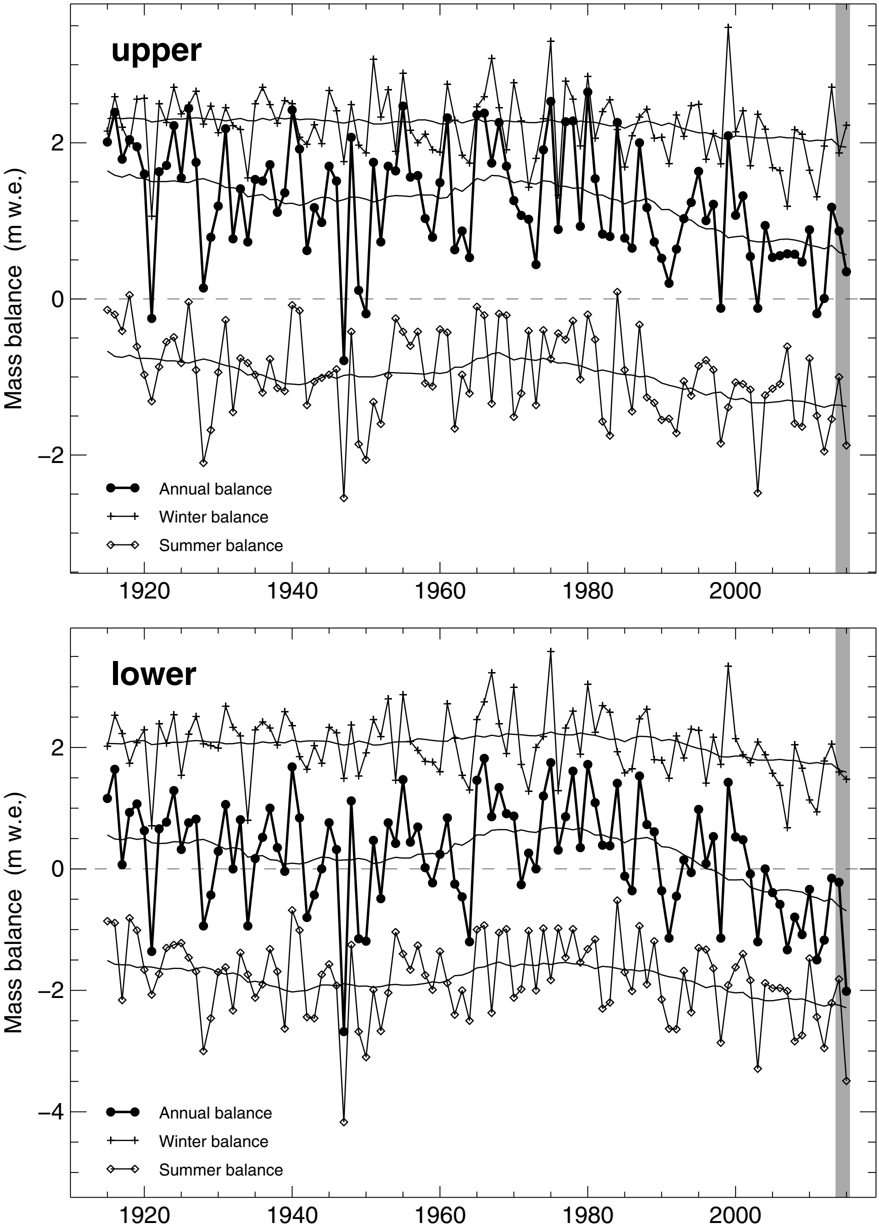

Figure 4.32: Mass balance of the upper (top) and lower (bottom) stake on Claridenfirn over the whole observation period. The gray shaded area highlights the years of the current report.

4.15 Grosser Aletsch (Jungfraufirn)

Introduction

Grosser Aletschgletscher is the largest ice mass in the Alps and borders to the main northern Alpine crest. The three main tributaries merge at the Konkordiaplatz and form the common tongue which extends southwards for about 15 km. Starting in 1918, the first stake was installed at 3350 m a.s.l. on Jungfraufirn and snow accumulation and annual mass balance was measured almost continuously at P3 (Figure 4.33). Huss and Bauder (2009) compiled and homogenized all existing measurements to a continuous time series of seasonal resolution (see Section 4.10 in Volume 127/128). The results of the glacier-wide mean specific winter and annual balance for

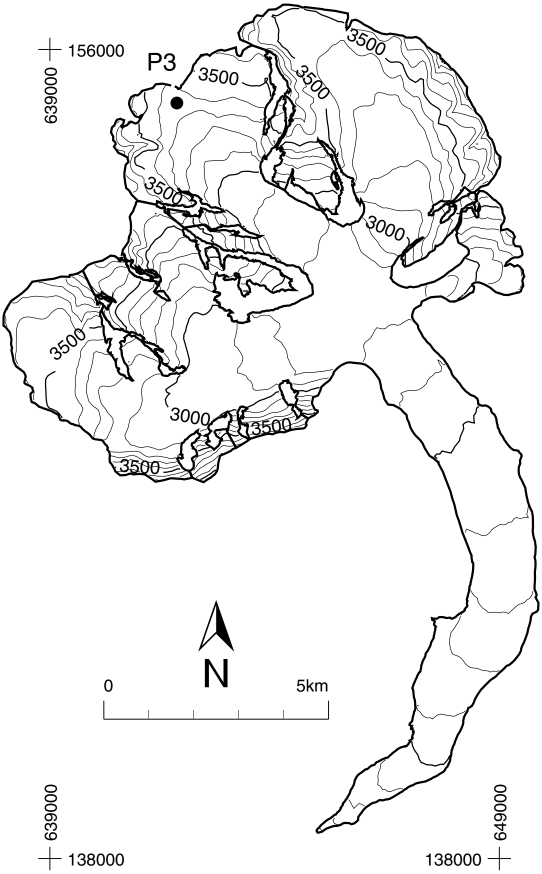

Figure 4.33: Surface topography and observational network of the Grosser Aletschgletscher.

comparable fixed date periods for 1939 to 1999 are presented in Section 4.17 of this report.

Investigations in 2013/14

The investigations consisted of snow depth measurements and density profiling using a firn drill in spring and fall. The surface was marked at the time of the measurement in the previous fall and could be retrieved in the density profiles. This monitoring programme was supplemented by stake readings approx. twice a month. The measurements were taken in spring on 3rd June 2014 and in fall on 29th September 2014. The layer of winter accumulation included one distinct ice lense detectable by snow depth probing. The distinct surface crust formed in summer 2013 could be identified clearly at both measurement events in May and September and is situated half a meter below the surface marked during the previous fall visit. In spring, mean density was found to be 460 ±10 $\text{kg}\,\text{m}^{-3}$ of the layer accumulated in winter, and in fall it was 565 ±5 $\text{kg}\,\text{m}^{-3}$ of the annual layer. While two sahara-dust layers formed on 18th February and 21st May 2014 were found in spring, only one was still present in the fall. In addition to mass balance investigations, the position of the stake was surveyed using a high-precision differential GPS. An annual speed of 34.1 $\text{m}\,\text{a}^{-1}$ was determined with only a slight increase from the winter to the summer season.

Investigations in 2014/15

The same set of measurements was conducted as in the previous period. The spring field survey was carried out on 18th May 2015 and the fall survey on 29nd September 2015. Snow depth measurement and firn coring in May showed a homogeneous layer of winter accumulation with no distinct ice lenses. Corresponding measurements from stake readings, firn drilling, and snow depth measurements all delivered similar results. Mean density was found to be 480 ±15 $\text{kg}\,\text{m}^{-3}$ in spring of the layer accumulated in winter and 560 ±5 $\text{kg}\,\text{m}^{-3}$ in fall of the annual layer. The flow velocity of 36.7 $\text{m}\,\text{a}^{-1}$ was slightly higher than in previous periods.

Table 4.25: Aletsch - Individual stake measurements of winter and annual balance.

Stake		Period		Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
P3	22.10.2013	03.06.2014	29.09.2014	641825 / 154810 / 3341	1582	2260
P3	29.09.2014	18.05.2015	29.09.2015	641825 / 154810 / 3342	1992	1540

4.16 Homogenized time series of Claridenfirn

The record of mass balance measurements at Claridenfirn, the longest time series of mass balances worldwide, celebrated its 100-year anniversary in 2014. On this occasion, the time series was re-analysed in order to provide consistent time series of seasonal mass balances for the period 1914 to 2014.

Already in an earlier analysis, the mass balance record from the period 1914 to 1984 was checked for consistency, and data gaps were filled based on the best possible estimates. Results from this review were published in Müller and Kappenberger (1991). A subsequent re-analysis and update until 2007 was done by Huss and Bauder (2009) and their results were reported in Section 4.10 of Volume 127/128 of the Glaciological Reports. In the present investigations, the evaluation has been extended to the years 1914 to 2015. Additionally, original field book notes were consulted to look for further, not yet published measurements and to clarify whether the declared values reflect true measurements or whether assumptions are involved.

The mass balance at Claridenfirn was measured twice a year, at the end of the accumulation period (May) and at the end of the ablation season (September) for a lower site (2700 m a.s.l.), situated close to the equilibrium line, and for an upper site (2900 m a.s.l.), located in the accumulation area. The mass balance was determined in three different ways, by (1) stake readings, (2) drilling or digging to the marked horizon of the previous fall and (3) snow depth probing. If available, snow pit data was used for the final mass balance time series, as they appear to provide the most reliable values, otherwise snow depth probing and, as a last option, stake readings were used. Snow density measurements have been carried out simultaneously, on a regular basis since the late 1950s. For years without density records, a density of 550 $\mathrm{kg\,m^{-3}}$ was assumed for one-year-old snow, 600 $\mathrm{kg\,m^{-3}}$ for two-year-old or older snow, 450 $\mathrm{kg\,m^{-3}}$ for winter snow and 320 $\mathrm{kg\,m^{-3}}$ for fresh snow. The resulting winter and annual mass balances in water equivalents for the two sites at Claridenfirn are presented in Tables 4.26 and 4.27. The tables also provide further information on the type and the quality of the mass balance measurements. Data for years with missing values, for the most part during the first half of the period, were determined based on best possible estimates (Müller and Kappenberger, 1991; Huss and Bauder, 2009).

Table 4.26: Time series of winter (b_w) and annual (b_a) mass balance in mm w.e. at the lower stake at Claridenfirn during the period 1914 to 2015. The type of mass balance measurements is indicated by the abbreviations P for stake reading, H for marked horizon and S for snow depth probing. The column ρ reports the availability of density (in kg m^{-3}) measurements. Regular font refers to measured values and italic font to estimated values or measurements which are subject to uncertainty.

Year	Period			Measurements					
	Start	Spring	End	b_w	type	ρ	b_a	type	ρ
1914/15	28.09.1914	16.05.1915	08.08.1915	1913	P	*450*	1108	H	530
1915/16	08.08.1915	25.05.1916	15.08.1916	*2530*			*1640*		
1916/17	15.08.1916	25.05.1917	26.09.1917	1800	P	*450*	44	H	*550*
1917/18	26.09.1917	30.03.1918	18.09.1918	1845	P	*450*	1171	H	610
1918/19	18.09.1918	25.05.1919	17.09.1919	*2080*			1248	H	615
1919/20	17.09.1919	26.06.1920	25.09.1920	1800	P	*450*	840	H	600
1920/21	25.09.1920	31.03.1921	15.09.1921	855	P	*450*	-1410	P	*600*
1921/22	15.09.1921	25.05.1922	25.09.1922	*2390*			776	P	*550*
1922/23	25.09.1922	25.05.1923	12.09.1923	*2070*			714	H	*550*
1923/24	12.09.1923	06.07.1924	17.09.1924	1530	P	*450*	1220	H	464
1924/25	17.09.1924	06.06.1925	01.09.1925	1058	P	*450*	186	H	*550*
1925/26	01.09.1925	25.05.1926	11.09.1926	*2220*			765	H	*550*
1926/27	11.09.1926	25.05.1927	23.09.1927	*2510*			1032	H	*550*
1927/28	23.09.1927	08.04.1928	12.09.1928	1755	P	*450*	-1032	P	*600*
1928/29	12.09.1928	14.07.1929	15.09.1929	1071	P	*450*	-450	P	*600*
1929/30	15.09.1929	31.05.1930	26.09.1930	*1990*			385	H	*550*
1930/31	26.09.1930	08.07.1931	16.09.1931	1674	P	*450*	1067	H	*550*
1931/32	16.09.1931	13.06.1932	15.09.1932	1868	P	*450*	0	H	*550*
1932/33	15.09.1932	14.05.1933	12.09.1933	1958	P	*450*	935	H	*550*
1933/34	12.09.1933	25.05.1934	19.09.1934	630	P	*450*	-984	P	*600*
1934/35	19.09.1934	13.07.1935	16.09.1935	720	P	*450*	389	H	598
1935/36	16.09.1935	30.07.1936	20.09.1936	1328	P	*450*	523	H	*550*
1936/37	20.09.1936	25.07.1937	20.09.1937	1350	P	*450*	953	H	*550*
1937/38	20.09.1937	04.06.1938	14.09.1938	1868	P	*450*	352	H	*550*
1938/39	14.09.1938	11.06.1939	24.09.1939	*2590*			176	H	*550*
1939/40	24.09.1939	01.03.1940	25.09.1940	*2048*			*1590*	P	*550*
1940/41	25.09.1940	25.05.1941	18.09.1941	*1850*			842	H	*550*
1941/42	18.09.1941	28.06.1942	13.09.1942	1125	P	*450*	-870	P	*600*
1942/43	13.09.1942	25.05.1943	17.09.1943	*2030*			-480	P	*600*
1943/44	17.09.1943	25.05.1944	14.09.1944	*1740*			40	H	*550*
1944/45	14.09.1944	25.05.1945	12.09.1945	*2330*			849	H	*550*
1945/46	12.09.1945	13.07.1946	11.09.1946	1845	P	*450*	450	H	*550*
1946/47	11.09.1946	14.04.1947	12.09.1947	1598	P	*450*	-2346	P	*600*
1947/48	12.09.1947	25.05.1948	03.10.1948	*2370*			*1389*	H	*550*
1948/49	03.10.1948	06.06.1949	20.09.1949	1305	P	*450*	-1200	P	*600*
1949/50	20.09.1949	20.05.1950	14.09.1950	1530	P	*450*	-1002	P	*600*
1950/51	14.09.1950	15.06.1951	12.09.1951	2025	P	*450*	479	H	*550*

1951/52	12.09.1951	05.04.1952	28.08.1952	1950	P	*450*	*-702*	P	*600*
1952/53	28.08.1952	24.05.1953	18.09.1953	2250	P	*450*	715	P	*550*
1953/54	18.09.1953	07.06.1954	04.09.1954	1193	P	*450*	374	P	*550*
1954/55	04.09.1954	30.07.1955	18.09.1955	1733	P	*450*	1720	H	590
1955/56	18.09.1955	27.05.1956	17.09.1956	1845	P	*450*	534	H	*550*
1956/57	17.09.1956	18.05.1957	10.09.1957	1947	H	456	979	H	515
1957/58	10.09.1957	02.06.1958	10.09.1958	1771	H	499	-30	P	*600*
1958/59	10.09.1958	17.05.1959	08.09.1959	1756	H	456	-282	P	*600*
1959/60	08.09.1959	28.05.1960	27.08.1960	1603	H	462	605	H	550
1960/61	27.08.1960	12.03.1961	13.09.1961	1688	P	*450*	*798*	P	550
1961/62	13.09.1961	28.04.1962	13.09.1962	2173	H	448	260	H	491
1962/63	13.09.1962	25.05.1963	18.09.1963	1537	S	439	-474	P	*600*
1963/64	18.09.1963	25.05.1964	29.09.1964	1238	H	436	-990	P	*600*
1964/65	29.09.1964	04.06.1965	16.09.1965	2313	S	*450*	1573	H	501
1965/66	16.09.1965	15.06.1966	22.09.1966	2250	P	*450*	1850	H	591
1966/67	22.09.1966	21.06.1967	15.09.1967	2853	H	*450*	1170	H	498
1967/68	15.09.1967	25.05.1968	14.09.1968	1980	S	*450*	1551	H	550
1968/69	14.09.1968	18.05.1969	12.09.1969	1719	P	*450*	912	H	518
1969/70	12.09.1969	17.06.1970	22.09.1970	2430	P	*450*	1389	H	560
1970/71	22.09.1970	24.06.1971	27.09.1971	1431	P	*450*	-306	P	*600*
1971/72	27.09.1971	27.05.1972	23.09.1972	1296	S	*450*	264	H	382
1972/73	23.09.1972	26.05.1973	11.10.1973	1917	S	*450*	96	H	191
1973/74	11.10.1973	29.05.1974	14.09.1974	2430	S	*450*	1204	H	593
1974/75	14.09.1974	29.06.1975	20.09.1975	*3580*			1860	H	583
1975/76	20.09.1975	29.05.1976	25.09.1976	1202	S	*450*	387	H	387
1976/77	25.09.1976	07.05.1977	15.10.1977	2228	P	*450*	928	H	496
1977/78	15.10.1977	21.06.1978	15.09.1978	2070	S	*450*	1756	H	547
1978/79	15.09.1978	28.05.1979	16.09.1979	1637	H	423	456	H	536
1979/80	16.09.1979	08.06.1980	23.09.1980	*3040*			1789	H	568
1980/81	23.09.1980	15.05.1981	30.09.1981	2295	S	*450*	1170	H	470
1981/82	30.09.1981	26.05.1982	14.09.1982	2376	S	*450*	401	H	542
1982/83	14.09.1982	05.06.1983	08.09.1983	2309	S	*450*	570	H	548
1983/84	08.09.1983	27.05.1984	28.10.1984	1935	P	*450*	1410	H	473
1984/85	28.10.1984	25.05.1985	06.10.1985	1575	P	420	-105	P	523
1985/86	06.10.1985	17.05.1986	14.10.1986	1649	P	458	-360	P	*600*
1986/87	14.10.1986	25.05.1987	13.09.1987	2367	S	419	1547	H	571
1987/88	13.09.1987	28.05.1988	10.09.1988	2632	S	514	724	H	589
1988/89	10.09.1988	26.05.1989	19.09.1989	1814	S	529	607	H	552
1989/90	19.09.1989	25.05.1990	29.09.1990	1711	S	470	-360	P	*600*
1990/91	29.09.1990	21.05.1991	16.09.1991	1493	S	377	-1159	P	*610*
1991/92	16.09.1991	19.05.1992	19.09.1992	2208	S	480	-417	P	*600*
1992/93	19.09.1992	16.05.1993	20.09.1993	1814	S	468	311	H	457
1993/94	20.09.1993	13.05.1994	26.09.1994	2302	S	447	-360	P	*600*
1994/95	26.09.1994	28.05.1995	10.10.1995	2286	S	460	964	H	527
1995/96	10.10.1995	31.05.1996	17.09.1996	1328	P	455	-2	P	*600*
1996/97	17.09.1996	19.05.1997	16.09.1997	2198	P	444	532	H	585
1997/98	16.09.1997	24.05.1998	02.09.1998	1261	P	476	-1140	P	*600*
1998/99	02.09.1998	24.05.1999	03.09.1999	3338	S	470	1428	P	*560*

1999/00	03.09.1999	14.05.2000	17.09.2000	2100	H	473	538	H	555
2000/01	17.09.2000	13.05.2001	17.10.2001	1917	S	*450*	481	H	458
2001/02	17.10.2001	21.05.2002	14.09.2002	1751	P	449	-173	H	522
2002/03	14.09.2002	11.05.2003	17.09.2003	2090	S	474	-1150	P	*600*
2003/04	17.09.2003	20.05.2004	18.09.2004	1686	S	456	-65	P	*650*
2004/05	18.09.2004	15.05.2005	11.09.2005	1570	S	412	-423	P	*650*
2005/06	11.09.2005	15.05.2006	11.09.2006	1371	S	413	-585	P	*650*
2006/07	11.09.2006	22.04.2007	24.09.2007	1098	S	424	-1333	P	*650*
2007/08	24.09.2007	11.05.2008	21.09.2008	2044	S	413	-794	P	*700*
2008/09	21.09.2008	23.05.2009	13.09.2009	1658	S	477	-1082	P	*700*
2009/10	13.09.2009	23.05.2010	06.09.2010	1135	S	457	-338	P	*700*
2010/11	06.09.2010	01.05.2011	03.09.2011	939	S	419	-1498	P	*850*
2011/12	03.09.2011	27.05.2012	10.09.2012	1777	S	480	-1173	P	*850*
2012/13	10.09.2012	09.06.2013	07.09.2013	2141	S	480	-153	P	*850*
2013/14	17.09.2013	18.05.2014	15.09.2014	1596	S	420	-221	P	*850*
2014/15	15.09.2014	14.05.2015	09.10.2015	1476	S	490	-2015	P	*850*

Table 4.27: Time series of winter (b_w) and annual (b_a) mass balance in mm w.e. at the upper stake on Claridenfirn during the period 1914-2015. The type of mass balance measurements is indicated by the abbreviations P for stake reading, H for marked horizon and S for snow depth probing. The column ρ reports the availability of density (in kg m^{-3}) measurements. Regular font refers to measured values and italic font to estimated values or measurements which are subjected to uncertainty.

Year	Period			Measurements					
	Start	Spring	End	b_w	type	ρ	b_a	type	ρ
1914/15	28.09.1914	16.05.1915	08.08.1915	*2150*			*2010*		
1915/16	08.08.1915	25.05.1916	15.08.1916	*2590*			2349	P	550
1916/17	15.08.1916	25.05.1917	26.09.1917	1935	P	*450*	1815	H	*550*
1917/18	26.09.1917	30.03.1918	18.09.1918	1710	P	*450*	2361	H	610
1918/19	18.09.1918	25.05.1919	17.09.1919	*2560*			*1950*		615
1919/20	17.09.1919	25.05.1920	25.09.1920	*2570*			*1600*		
1920/21	25.09.1920	31.03.1921	15.09.1921	923	P	*450*	-390	P	*600*
1921/22	15.09.1921	25.05.1922	25.09.1922	*2500*			*1630*		
1922/23	25.09.1922	25.05.1923	12.09.1923	*2260*			*1710*		
1923/24	12.09.1923	06.07.1924	17.09.1924	2115	P	*450*	1730	H	388
1924/25	17.09.1924	10.04.1925	01.09.1925	1773	P	*450*	1661	H	*550*
1925/26	01.09.1925	02.04.1926	11.09.1926	2160	P	*450*	2283	P	*550*
1926/27	11.09.1926	25.05.1927	23.09.1927	*2660*			*1750*		
1927/28	23.09.1927	08.04.1928	12.09.1928	1620	P	*450*	155	P	*550*
1928/29	12.09.1928	14.07.1929	15.09.1929	2700	P	*450*	825	H	*550*
1929/30	15.09.1929	31.05.1930	26.09.1930	2025	P	*450*	1265	H	*550*
1930/31	26.09.1930	26.06.1931	16.09.1931	1935	P	*450*	2019	P	*550*
1931/32	16.09.1931	13.06.1932	15.09.1932	1890	P	*450*	770	H	*550*
1932/33	15.09.1932	05.06.1933	12.09.1933	2115	P	*450*	1513	H	*550*

1933/34	12.09.1933	25.05.1934	19.09.1934	1323	P	*450*	741	H	*550*
1934/35	19.09.1934	13.07.1935	16.09.1935	1485	P	*450*	1491	P	*550*
1935/36	16.09.1935	25.05.1936	20.09.1936	*2710*			*1510*		
1936/37	20.09.1936	30.07.1937	20.09.1937	1395	P	*450*	1681	P	*550*
1937/38	20.09.1937	04.06.1938	14.09.1938	2223	P	*450*	1118	H	*550*
1938/39	14.09.1938	11.06.1939	24.09.1939	2025	P	*450*	1511	H	*550*
1939/40	24.09.1939	25.05.1940	25.09.1940	*2500*			*2420*		
1940/41	25.09.1940	12.04.1941	18.09.1941	1935	P	*450*	2112	P	*550*
1941/42	18.09.1941	16.05.1942	13.09.1942	1845	P	*450*	715	H	*550*
1942/43	13.09.1942	25.05.1943	17.09.1943	*2230*			*1238*	H	*550*
1943/44	17.09.1943	16.07.1944	14.09.1944	2025	P	*450*	1007	H	*550*
1944/45	14.09.1944	25.05.1945	12.09.1945	*2670*			*1700*		
1945/46	12.09.1945	25.05.1946	11.09.1946	*2410*			1458	P	*550*
1946/47	11.09.1946	14.04.1947	12.09.1947	1508	P	*450*	-840	P	*600*
1947/48	12.09.1947	25.05.1948	03.10.1948	*2490*			*2292*	H	*550*
1948/49	03.10.1948	06.06.1949	20.09.1949	1755	P	*450*	110	H	*550*
1949/50	20.09.1949	20.05.1950	14.09.1950	1620	P	*450*	-240	P	*600*
1950/51	14.09.1950	13.07.1951	12.09.1951	2475	P	*450*	1705	P	*550*
1951/52	12.09.1951	05.04.1952	28.08.1952	2020	S	387	688	P	*550*
1952/53	28.08.1952	24.05.1953	18.09.1953	2610	P	*450*	1744	P	*550*
1953/54	18.09.1953	07.06.1954	04.09.1954	1800	P	*450*	1601	P	*550*
1954/55	04.09.1954	30.07.1955	18.09.1955	2318	P	*450*	2530	P	590
1955/56	18.09.1955	27.05.1955	17.09.1956	2025	P	*450*	1447	P	*550*
1956/57	17.09.1956	09.06.1957	10.09.1957	1926	P	*450*	1716	S	*550*
1957/58	10.09.1957	02.06.1958	10.09.1958	2305	S	499	1031	H	534
1958/59	10.09.1958	17.05.1959	08.09.1959	2079	S	459	940	H	599
1959/60	08.09.1959	28.05.1960	27.08.1960	1884	H	497	1447	P	*550*
1960/61	27.08.1960	25.05.1961	13.09.1961	*2750*			*2332*	S	*550*
1961/62	13.09.1961	28.04.1962	13.09.1962	2285	S	448	1039	H	574
1962/63	13.09.1962	25.05.1963	17.09.1963	1840	S	436	917	H	515
1963/64	17.09.1963	25.05.1964	29.09.1964	1746	H	447	623	H	448
1964/65	29.09.1964	03.06.1965	17.09.1965	2492	H	465	2426	H	513
1965/66	17.09.1965	15.06.1966	20.09.1966	2590	H	533	2381	H	563
1966/67	20.09.1966	21.06.1967	18.09.1967	3085	H	482	1989	H	496
1967/68	18.09.1967	25.05.1968	19.09.1968	2453	H	435	2430	H	517
1968/69	19.09.1968	18.05.1969	11.09.1969	1905	H	440	1700	H	533
1969/70	11.09.1969	17.06.1970	24.09.1970	2771	H	517	1644	H	548
1970/71	24.09.1970	24.06.1971	27.09.1971	2284	H	512	1118	H	535
1971/72	27.09.1971	27.05.1972	22.09.1972	1432	H	438	1024	H	459
1972/73	22.09.1972	26.05.1973	11.10.1973	1796	H	448	499	H	367
1973/74	11.10.1973	29.05.1974	12.09.1974	2313	H	458	1910	H	565
1974/75	12.09.1974	29.06.1975	19.09.1975	3305	H	549	2670	H	578
1975/76	19.09.1975	29.05.1976	24.09.1976	1312	H	457	963	H	430
1976/77	24.09.1976	07.05.1977	14.10.1977	2736	P	*450*	2336	H	518
1977/78	14.10.1977	20.06.1978	15.09.1978	2568	H	535	2409	H	582
1978/79	15.09.1978	28.05.1979	16.09.1979	1963	H	423	1006	H	541
1979/80	16.09.1979	08.06.1980	23.09.1980	2850	H	475	2699	H	588
1980/81	23.09.1980	15.05.1981	30.09.1981	2059	H	421	1580	H	473

1981/82	30.09.1981	25.05.1982	14.09.1982	2402	H	472	841	H	553
1982/83	14.09.1982	05.06.1983	08.09.1983	2551	H	468	949	H	565
1983/84	08.09.1983	27.05.1984	28.10.1984	2167	H	430	2261	H	480
1984/85	28.10.1984	25.05.1985	06.10.1985	1693	H	420	779	H	545
1985/86	06.10.1985	17.05.1986	14.10.1986	2093	H	458	654	H	579
1986/87	14.10.1986	25.05.1987	13.09.1987	2320	S	419	2083	H	595
1987/88	13.09.1987	28.05.1988	10.09.1988	2431	H	514	1166	H	569
1988/89	10.09.1988	26.05.1989	19.09.1989	2063	H	529	731	H	497
1989/90	19.09.1989	25.05.1990	29.09.1990	2068	H	470	519	H	481
1990/91	29.09.1990	21.05.1991	16.09.1991	1746	H	377	202	H	561
1991/92	16.09.1991	19.05.1992	19.09.1992	2419	H	480	722	H	531
1992/93	19.09.1992	16.05.1993	20.09.1993	1989	H	468	1193	H	499
1993/94	20.09.1993	13.05.1994	26.09.1994	2476	H	447	961	H	559
1994/95	26.09.1994	28.05.1995	10.10.1995	2479	H	460	1700	H	506
1995/96	10.10.1995	31.05.1996	17.09.1996	1801	H	455	1003	H	435
1996/97	17.09.1996	19.05.1997	16.09.1997	2109	H	444	1206	H	561
1997/98	16.09.1997	24.05.1998	02.09.1998	1740	H	476	-120	P	*600*
1998/99	02.09.1998	24.05.1999	03.09.1999	3477	S	470	2085	H	559
1999/00	03.09.1999	14.05.2000	17.09.2000	2127	H	490	1070	H	535
2000/01	17.09.2000	13.05.2001	17.10.2001	2453	S	*450*	1318	H	515
2001/02	17.10.2001	21.05.2002	14.09.2002	1706	S	449	544	H	523
2002/03	14.09.2002	11.05.2003	17.09.2003	2308	H	474	-14	P	*600*
2003/04	17.09.2003	20.05.2004	18.09.2004	2175	S	456	945	S	556
2004/05	18.09.2004	15.05.2005	11.09.2005	1677	S	412	537	S	532
2005/06	11.09.2005	15.05.2006	11.09.2006	1644	S	413	524	H	504
2006/07	11.09.2006	22.04.2007	24.09.2007	1272	S	424	578	S	498
2007/08	24.09.2007	11.05.2008	21.09.2008	2168	S	413	571	H	443
2008/09	21.09.2008	23.05.2009	13.09.2009	2108	S	477	472	H	583
2009/10	13.09.2009	23.05.2010	06.09.2010	1848	S	457	698	H	512
2010/11	06.09.2010	01.05.2011	03.09.2011	1307	H	419	-190	P	*650*
2011/12	03.09.2011	27.05.2012	10.09.2012	1957	H	467	431	H	539
2012/13	10.09.2012	09.06.2013	07.09.2013	2732	H	471	1179	H	564
2013/14	17.09.2013	18.05.2014	15.09.2014	1870	S	410	869	S	530
2014/15	15.09.2014	14.05.2015	09.10.2015	2224	S	470	348	H	435

4.17 Re-analyzed mass balance series

Background

Globally coordinated monitoring efforts have contributed to a comprehensive set of time series documenting variations in glacier-wide mass balance for more than a hundred glaciers (WGMS, 2012). However, only few series are longer than twenty years and even less start before the 1980s. Furthermore, only a fraction of the records yields seasonal mass budget components (Zemp et al., 2009), although these are of eminent importance for understanding glacier response to shifts in climatic forcing (Ohmura et al., 2007; Braithwaite, 2009).

The wealth of glacier mass balance data for the last decades – both in terms of spatial and temporal coverage as well as resolution (seasonal/annual) – can be increased by compiling and/or re-analyzing scattered measurements that have not yet been consistently evaluated. In fact, extensive mass balance observations with seasonal resolution, sometimes stretching over hundred years, have been performed on more than a dozen glaciers in the Swiss Alps and monitoring was partly pursued until today. No (or only incomplete) evaluations of glacier-wide mass balance have been performed so far.

The repeated uncertainty assessment and the re-analysis of mass balance series is an important concept of modern glacier monitoring (Zemp et al., 2013). It ensures that published mass balances are accurate, and thus are useful indicators of glacier change. Such efforts are based on a detailed re-assessment of the raw point measurements, the methods of inter- and extrapolation, and the validation against independent ice volume changes as obtained from the comparison of Digital Elevation Models (DEMs).

For the Swiss Alps, two mass balance series based on the direct glaciological method covering five decades are available (cf. Sections 4.6 and 4.6). Continuous long-term point measurements at a considerable number of additional glaciers have however been performed, often with a seasonal resolution. In some cases, the spatial point density of these monitoring programmes was not judged to be sufficient for calculating glacier-wide balance. In other cases, the measurements were just acquired as point balance series, or in connection to surveys of glacier flow speed (cf. Chapter 5). Huss et al. (2015) have derived nineteen new or re-analysed series of glacier-wide seasonal mass balance for the Swiss Alps based on in-situ observations (Figure 4.34). We present methods and results in this report. Two of the series cover a continuous period of (almost) 100 years. They thus represent the longest records of glacier-wide mass balance worldwide and provide the first direct information on seasonal/annual glacier mass change before 1946 (WGMS, 2012). Four additional series span six decades.

Methods

Various approaches are presently applied to calculate glacier-wide mass balance from point measurements ranging from the profile and contour line method (Østrem and Brugman, 1991; Kaser et al., 2003) to the application of kriging (Hock and Jensen, 1999). We rely on an alternative

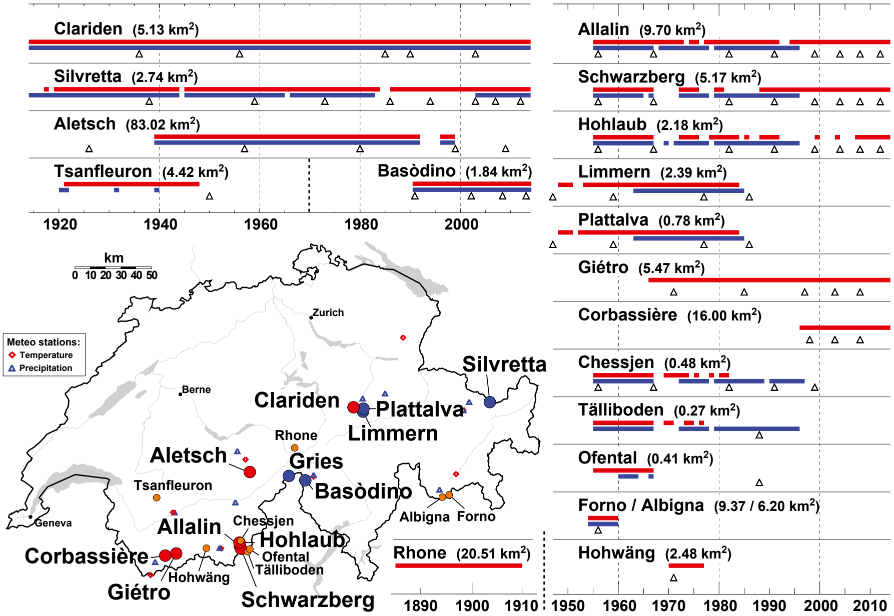

Figure 4.34: Data coverage and location of the re-analyzed glaciers in Switzerland. Previous long-term monitoring series are marked with blue circles; new long-term series are displayed with red circles. Small orange circles indicate shorter or less homogeneous new series. The availability of point mass-balance data for the annual period (red bars) and the winter period (blue bars) is visualized on a time axis. Years with DEMs are shown by triangles. Figure from Huss et al. (2015).

methodology which combines the point observations with mass balance modelling for inter- and extrapolation to unmeasured areas. The principle of our approach is the constraining of a distributed model with all available field data in every individual year (Huss et al., 2009). Modelling is thus used for spatial extrapolation of point mass balance; the seasonal/annual signal is given by the in-situ measurements.

The applied approach has several important advantages compared to traditional methods: (1) Extrapolation in space is based on an algorithm including the main processes governing mass balance distribution. This allows us to cope with a relatively small spatial density of surveyed points. (2) Data gaps, i.e. individual years with missing measurements, present for some of the series (Figure 4.34, Tables 4.28 and 4.30), can be filled in a consistent way. (3) Temporal differences between the hydrological year and the effective dates of the surveys can be corrected enabling the joint evaluation of mass balance over the fixed-date and the measurement period.

Glacier-wide mass balances calculated from the in-situ measurements are validated against independent ice volume changes provided by repeated geodetic surveys (Glaciological reports, 2016; Bauder et al., 2007) (Figure 4.35). A bias between glaciological and geodetic surveys can be explained by (i) internal and basal components not captured by surface mass balance measurements, (ii) erroneous extrapolation from the point measurements to the entire glacier, and (iii) uncertainties in both the direct field observations and geodetic mass changes (e.g. Zemp et al., 2013). We assume (i) to be negligible for temperate alpine glaciers and consider the uncertainties in both methods (iii) to be randomly distributed so that errors over long periods are small. If a difference >0.1 m w.e. a^{-1} between glaciological and geodetic balance was detected for an individual period defined by two subsequent DEMs, the model was re-calibrated to more realistically represent the mass balance in regions not covered by direct observations. The temporal and spatial variability of computed mass balance is thus given by the direct (seasonal) point measurements, whereas the long-term volume change, and hence the glacier-wide balance, is constrained by the geodetic surveys. This combination is expected to considerably reduce the uncertainties in evaluated glacier-wide mass balance, and reasonable results are possible even for glaciers with only relatively few point measurements, or occasional data gaps.

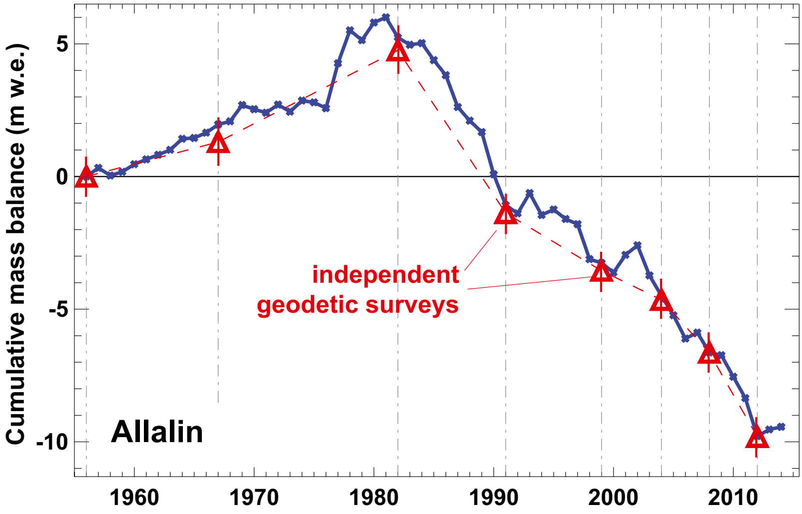

Figure 4.35: Comparison of cumulative glaciological mass balance for Allalingletscher with independent mass change from geodetic surveys (triangles). Figure from Huss et al. (2015).

Long-term mass balance series

The series for Clariden and Silvretta are the first glacier-wide mass balance records worldwide with a coverage of one century (Figure 4.36, Table 4.28). Mass balances were predominantly negative between 1920 and 1965, with accelerated mass loss in the 1940s. After a phase with moderate mass gains lasting until the late 1980s, persistently negative balances were observed until present.

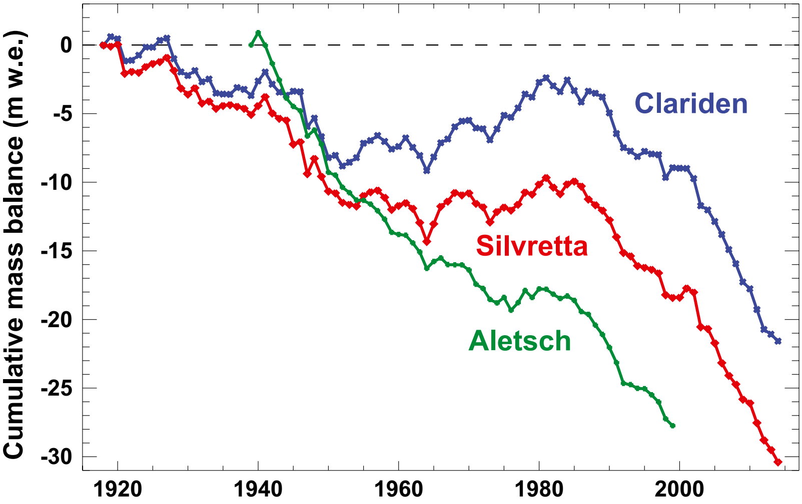

Figure 4.36: Cumulative mass balance for Claridenfirn, Silvretta- and Grosser Aletschgletscher. Figure from Huss et al. (2015).

Although Silvretta is subject to a slightly larger cumulative mass loss, the temporal variations are similar to Clariden. The long-term series of Aletsch show a different pattern with substantially more negative mass balances and smaller year-to-year variability (Figure 4.36). Mass gain was only recorded during a short period in the late 1970s. We explain the temporal mass balance evolution of Aletsch with its large area and, hence, long volume response time. All re-analyzed cumulative

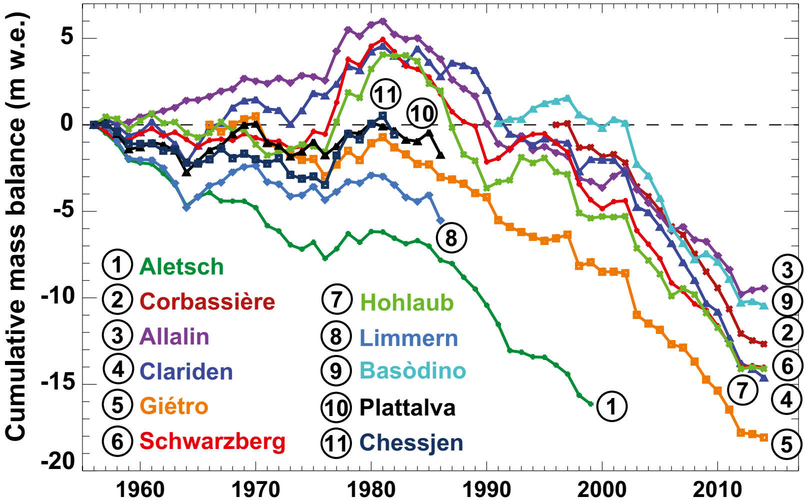

Figure 4.37: Cumulative mass balance since 1955 for selected long-term series. Glaciers are ordered according to their surface area. Figure from Huss et al. (2015).

long-term mass balance series show mass loss since the mid-1980s, the rates being similar for most glaciers (Figure 4.37). In the 1960s and 1970s, however, the differences are remarkable. Whereas some glaciers (Allalin, Clariden, Schwarzberg) gained mass, other glaciers (e.g. Aletsch) were subject to a reduction in ice volume (Table 4.28).

The uncertainty in the seasonal mass balance records depends on numerous factors. In general, we can qualitatively divide between two levels of uncertainty: (1) Long-term average balances, e.g. decadal means, are expected to be relatively accurate as they are partly constrained by observed ice volume changes (about $\sigma_{(1)}=\pm 0.05\text{-}0.15$ m w.e. a^{-1}). The accuracy of inferred long-term means of annual mass balance is expected to be higher with increasing length of the time interval considered. (2) Annual and seasonal mass balances are likely to be somewhat more uncertain. Year-to-year variability, as well as the seasonal components, are directly given by the field measurements. The results are thus prone to various uncertainties related to the acquisition and evaluation of in-situ mass balance data and are expected to range between $\sigma_{(2)}=\pm 0.15\text{-}0.40$ m w.e. a^{-1}.

After the re-analysis of the mass balance series of Silvretta and Gries for the period 1959/1961 to 2007 (Section 4.9 of Volume 125/126, Huss et al., 2009) this chapter provides a complete re-analyzed series for all other long-term glacier mass balance monitoring programs in Switzerland (Basòdino, Limmern, Plattalva, updated until 2015 for Silvretta and Gries; Tables 4.28 and 4.30). Glacier-wide annual mass balance for glaciers, for which only point measurements have been reported in the Glaciological Reports so far (Allain, Schwarzberg, Clariden, Giétro etc.) are evaluated regularly in the future and will be periodically published in "The Swiss Glaciers".

Table 4.28: Seasonal mass-balance time-series for selected glaciers: Grosser Aletsch, Clariden, Silvretta, Allalin and Schwarzberg for the period 1915-2015 and fixed date periods 1 Oct - 30 Apr (B_w) and 1 Oct - 30 Sep (B_a). Regular font refers to values where corresponding seasonal measurements were available and italic font to modelled values to fill gaps.

Period	Gr. Aletsch		Clariden		Silvretta		Allalin		Schwarzberg	
	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a
	(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)	
1914/15			1556	717						
1915/16			1607	1202						
1916/17			1505	-335						
1917/18			1390	645						
1918/19			1549	625						
1919/20			1761	-68	1950	-67				
1920/21			584	-1865	717	-2339				
1921/22			1476	343	909	14				
1922/23			1531	395	1385	-150				
1923/24			1668	514	1230	395				
1924/25			1414	247	998	224				
1925/26			1249	244	1857	-458				
1926/27			1811	605	1882	220				
1927/28			1066	-1764	1130	-2059				
1928/29			1519	-1066	1169	-1336				
1929/30			1072	-18	883	-382				
1930/31			2075	337	1347	478				
1931/32			1240	-1135	1034	-1247				
1932/33			1097	472	968	193				
1933/34			753	-1155	768	-445				
1934/35			1637	21	1744	233				
1935/36			1836	53	1474	116				
1936/37			1669	530	1784	55				
1937/38			1198	-300	899	-325				
1938/39			1475	-122	1258	-159				
1939/40	434	897	1724	1085	1280	429				
1940/41	482	-919	1277	534	1287	740				
1941/42	641	-1323	1180	-702	876	-1077				
1942/43	474	-1203	1366	-577	1164	-449				
1943/44	419	-1316	1150	-229	1072	-279				
1944/45	1202	-612	2030	407	*2330*	*-158*				
1945/46	963	-321	1561	-204	1199	76				
1946/47	413	-1838	1080	-2611	803	-2640				
1947/48	742	437	1825	967	1889	1091				
1948/49	316	-1039	1026	-1594	887	-1453				
1949/50	504	-2043	1268	-1317	1104	-1347				
1950/51	1056	-207	1933	54	1667	-260				
1951/52	890	-881	1602	-565	1198	-978				

Period	Gr. Aletsch		Clariden		Silvretta		Allalin		Schwarzberg	
	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a
	(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)	
1952/53	983	-396	1963	262	1418	-282				
1953/54	714	-542	976	339	975	-108				
1954/55	823	-12	1911	1085	1810	674				
1955/56	830	-283	1341	133	1386	4	1012	233	1139	-364
1956/57	665	-478	1370	583	1124	159	1012	333	828	-356
1957/58	927	-615	1513	-659	1320	-868	1190	-369	1266	-694
1958/59	645	-955	1289	-660	870	-1171	1172	75	1324	2
1959/60	775	-153	1295	668	808	286	1162	583	1219	756
1960/61	788	-56	1608	235	1211	203	1410	-295	1621	-298
1961/62	1212	-558	1535	49	1334	-404	1063	338	1305	-173
1962/63	804	-662	964	-662	867	-1042	1168	133	1445	154
1963/64	686	-1195	1068	-953	973	-1375	1091	404	1208	-453
1964/65	963	501	1580	1017	1323	1280	906	222	615	*-209*
1965/66	962	258	1798	1029	1338	1278	1146	18	1612	*158*
1966/67	820	-489	1745	295	1452	376	1076	350	1248	109
1967/68	369	-9	1431	1162	1311	631	*575*	179	*624*	*84*
1968/69	593	-5	1184	126	769	-175	1381	546	*1412*	*228*
1969/70	783	-371	1710	258	1286	145	794	-137	*1240*	*-202*
1970/71	565	-1038	1142	-426	944	-758	771	-121	*1179*	*-149*
1971/72	624	-313	732	-98	424	-259	988	303	*857*	*42*
1972/73	627	-799	1242	-817	969	-1102	824	-270	859	*-456*
1973/74	701	-249	1411	884	1055	763	1196	*501*	1226	*186*
1974/75	918	396	2385	965	1089	322	969	-242	1409	*753*
1975/76	421	-931	953	0	820	-218	924	36	974	*124*
1976/77	736	550	1764	806	1191	422	2153	*1730*	2362	*1870*
1977/78	1179	886	1581	957	1137	887	1807	1168	2911	*2452*
1978/79	983	-508	1162	-150	913	-149	*808*	-271	*921*	*-278*
1979/80	1231	624	1807	1116	1406	735	1526	576	1689	*1018*
1980/81	893	-22	1480	441	1395	479	1043	291	1333	*505*
1981/82	753	-361	1756	-946	1276	-697	1116	-873	1391	*-677*
1982/83	681	-317	1439	-221	1097	-487	1430	-407	1584	*-1091*
1983/84	517	180	1362	1036	*1011*	717	873	242	769	*44*
1984/85	433	-318	926	-1035	*1041*	*207*	1072	-900	1190	*-673*
1985/86	1004	-814	1238	-582	*1075*	*-367*	1622	-453	1484	*-787*
1986/87	769	-194	1244	885	*484*	-944	651	-1268	701	*-1040*
1987/88	786	-791	1815	-9	*1047*	-413	1165	-234	1264	*-460*
1988/89	850	-680	1398	-179	*917*	-393	970	-635	1234	*-525*
1989/90	546	-941	1430	-999	*1121*	-709	592	-1413	624	*-1842*
1990/91	594	-1106	759	-1685	*870*	-1238	1308	-1120	1486	*7*
1991/92	449	-1511	1654	-1029	*1883*	-1144	981	-311	1145	*598*
1992/93	*876*	*-93*	1439	-101	*1781*	-244	1380	*755*	1326	*665*
1993/94	*1048*	*-271*	1757	-315	*1609*	-708	1153	*-871*	1395	*201*
1994/95	*1277*	*-24*	1685	531	*1213*	-129	1239	620	955	*34*

Period	Gr. Aletsch		Clariden		Silvretta		Allalin		Schwarzberg	
	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a
	(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)	
1995/96	*335*	*-448*	509	-294	*471*	-143	542	-413	725	*-296*
1996/97	838	-520	1618	-313	*1500*	-263	*859*	-271	*939*	-971
1997/98	653	-1226	1207	-1248	*607*	-1591	*444*	-1201	*474*	-1714
1998/99	911	-502	2268	486	*2073*	-196	*1014*	-226	*1134*	-1087
1999/00			1725	363	*1752*	12	*834*	-64	*1086*	-51
2000/01			1698	314	*1587*	673	*800*	411	*1034*	61
2001/02			827	-1006	*1189*	-298	*933*	348	*1177*	26
2002/03			1726	-2245	*1140*	-2529	*1060*	-1244	*1398*	-1889
2003/04			1446	245	1396	-120	*496*	-724	*652*	-722
2004/05			1094	-764	1101	-1050	*828*	-761	*1064*	-878
2005/06			1092	-873	1235	-1449	*704*	-906	*881*	-1449
2006/07			545	-397	774	-916	*871*	299	*1056*	-304
2007/08			1549	-676	1430	-570	*672*	-730	*831*	-700
2008/09			1617	-841	1559	-1103	*1292*	-138	*1716*	-447
2009/10			875	-122	996	-279	*935*	-757	*1229*	-844
2010/11			826	-1545	965	-1507	*363*	-1026	*479*	-1384
2011/12			1353	-838	1527	-1336	*1054*	-1086	*1414*	-838
2012/13			1492	88	1231	-264	*1349*	237	*1767*	50
2013/14			1188	-151	1164	-715	*1179*	211	*1265*	-237
2014/15			1509	-1093	1223	-1577	*1002*	-571	*1099*	-1191

Table 4.30: Seasonal mass-balance time-series for selected glaciers: Gries, Giétro, Basòdino and Corbassière for the period 1962-2015 and fixed date periods 1 Oct - 30 Apr (B_w) and 1 Oct - 30 Sep (B_a). Regular font refers to values where corresponding seasonal measurements were available and italic font to modelled values to fill gaps.

Period	Gries		Giétro		Basòdino		Corbassière	
	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a
	(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)	
1961/62	*1008*	-984						
1962/63	*1269*	-180						
1963/64	*1666*	-688						
1964/65	*846*	445						
1965/66	*845*	-357						
1966/67	*1475*	29	*1031*	2				
1967/68	*1124*	379	*620*	592				
1968/69	*1503*	733	*901*	-129				
1969/70	*1471*	-758	*1056*	-57				
1970/71	*1449*	-527	*624*	-711				
1971/72	*1283*	408	*663*	-169				
1972/73	*771*	-1095	*778*	-1406				
1973/74	*1509*	-178	*704*	166				

Period	Gries		Giétro		Basòdino		Corbassière	
	B_w	B_a	B_w	B_a	B_w	B_a	B_w	B_a
	(mm w.e.)		(mm w.e.)		(mm w.e.)		(mm w.e.)	
1974/75	*1565*	378	*1220*	-198				
1975/76	*684*	-1021	*694*	-811				
1976/77	*1808*	1166	*1508*	753				
1977/78	*2165*	1056	*1464*	633				
1978/79	*1128*	-885	*1112*	-417				
1979/80	*1449*	570	*1255*	878				
1980/81	*952*	-324	*1302*	581				
1981/82	*1205*	-1304	*1404*	-757				
1982/83	*1314*	-779	*1347*	-541				
1983/84	*875*	-4	*687*	-37				
1984/85	*1070*	-526	*1015*	-499				
1985/86	*1767*	-947	*1315*	-586				
1986/87	*883*	-733	*1000*	-296				
1987/88	*1244*	-924	*1454*	-6				
1988/89	*1439*	-1071	*1190*	-559				
1989/90	*1167*	-1988	*974*	-145				
1990/91	*1186*	-1344	*1275*	-1528				
1991/92	*1198*	-1125	*979*	-297	1073	-38		
1992/93	*716*	-1052	*1369*	-109	1574	-242		
1993/94	1587	-209	*1305*	-388	1971	5		
1994/95	1185	-278	*1837*	-178	1544	260		
1995/96	632	-517	*518*	99	781	-366		
1996/97	1598	-1068	*1087*	58	1491	-471	*968*	-544
1997/98	962	-2053	*738*	-1567	1372	-992	*690*	-1215
1998/99	1676	-564	*1424*	166	1508	-861	*1250*	159
1999/00	1392	-985	*1105*	-859	1704	-1176	*974*	-343
2000/01	1802	-229	*1918*	385	2172	1018	*1583*	535
2001/02	876	-990	*520*	-148	661	-614	*494*	-414
2002/03	1558	-2711	*1222*	-2653	1436	-2403	*1066*	-1256
2003/04	1343	-1146	*1319*	-491	1452	-619	*1170*	-558
2004/05	1142	-1512	*937*	-530	1349	-1405	*827*	-894
2005/06	914	-1995	*829*	-757	953	-1686	*620*	-3565
2006/07	626	-1473	*849*	-76	812	-1172	*774*	-368
2007/08	1073	-1683	*767*	-820	951	-697	*710*	-998
2008/09	2156	-815	*1595*	-1247	2282	287	*1406*	-1056
2009/10	1138	-1060	*691*	-642	1011	-520	*661*	-866
2010/11	949	-2010	*803*	-1684	1070	-1307	*689*	-1419
2011/12	1597	-1849	*1093*	-671	1246	-986	*1021*	-789
2012/13	1502	-497	*1263*	-34	1552	8	*1134*	-309
2013/14	1601	-723	*1309*	-271	1820	-51	*1164*	-118
2014/15	1764	-1474	*678*	-1102	1608	-1278	*611*	-1330

5 Velocity

5.1 Introduction

On some specific glaciers (Figure 5.1) long-term investigations are carried out with measurements of the surface flow velocity. The VAW/ETHZ has been contracted by two hydro-electric power companies Kraftwerke Mattmark, and Forces Motrices de Mauvoisin SA to survey the glaciers in the operated catchments. The main objective of this research assignment is to observe the flow conditions of the glaciers, particularly with regard to their potential threat to the buildings and operation of the power station in the valley. The observations are mainly focused on the two glaciers Giétro and Corbassière in the Mauvoisin area (Val de Bagnes) and the two glaciers Allalin and Schwarzberg in the Mattmark area (Saastal).

Figure 5.1: Investigated glaciers for surface velocity measurements.

5.2 Glacier du Giétro

Introduction

One of the longest measurement series in existence, for Glacier du Giétro (Figure 5.2) in the Val de Bagnes (Valais), is being continued by VAW/ETHZ under contract of the Forces Motrices de Mauvoisin SA. The aim of these annual observations is the early recognition of glacier break-off, which can endanger the dammed lake located in the outreach of ice avalanches. The measurements, which have been carried out for more than 40 years, include periods of glacier growth and recession (VAW, 1997, 1998; Bauder et al., 2002; Raymond et al., 2003). In addition, annual mass balance is determined at the stakes. Huss et al. (2015) re-analyzed and homogenized the seasonal stake data and ice volume changes for the period 1966 to 2014. The results of the glacier-wide mean specific winter and annual balance for comparable fixed date periods are presented in Section 4.17 of this report.

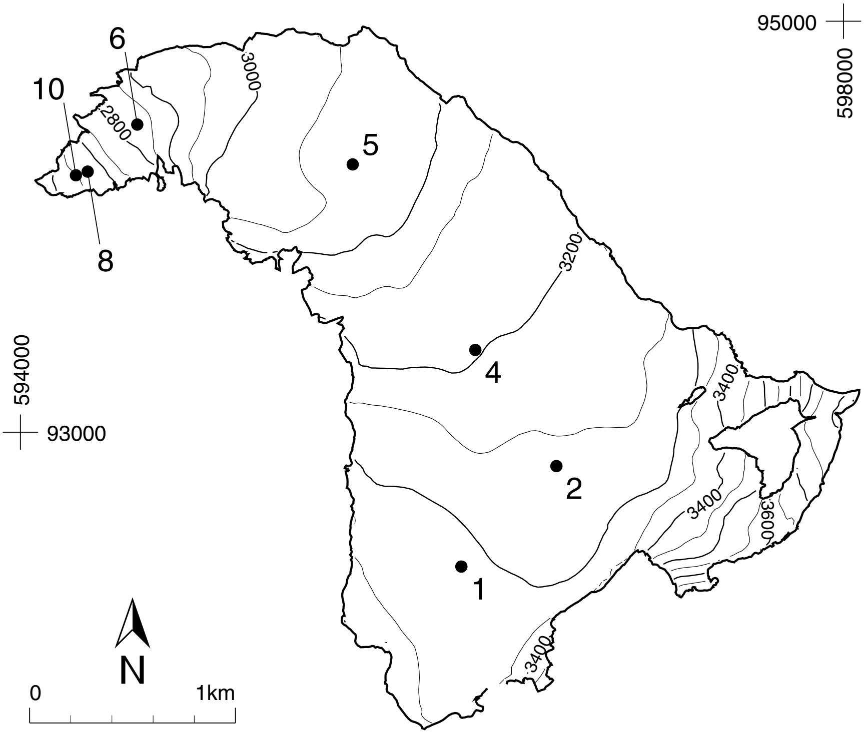

Figure 5.2: Surface topography and observational network of the Glacier du Giétro.

Figure 5.3 shows the surface flow velocity mesurements at 7 stakes along the central flow line of the glacier, taken since 1966. There are three distinct periods: in the first (1966 to 1976), the velocities in the accumulation area (Stakes 1, 2 and 4) were approximately 5-20 m per year, in the central region of the glacier (Stake 5) about 35 m per year and in the steep tongue area (Stakes 6, 8 and 10) they were in the range of 50-90 m annually. The second period (1977 to 1982) is marked by a distinct acceleration phase, in which the speeds (for example at Stake 6) increased from 90 m to 120 m per year. From the mid-1980s onward, the velocities decreased sharply again, and in the last years reached the lowest values measured since 1966.

Investigations in 2013/14 and in 2014/15

Five stakes provided measurements of velocity and local mass balance. The field survey in fall 2014 was carried out on 8th September. The position of the snowline was just below of the lower edge of the firn plateau at an altitude of about 3200 m a.s.l. Accumulation of winter snow was observed at the the Stakes 1 and 2. On 8th September 2015, the field measurements were taken for the second period. At the end of August melt had occurred over almost the entire extent of the firn plateau, and only a few thin patches remained of the snow accumulated during winter.

Table 5.1: Glacier du Giétro - Individual measurements of surface flow velocity, thickness change and annual balance.

Stake	Period		Coordinates	Thickness change	Velocity	Mass balance
	Start	End	(m / m / m a.s.l.)	(m)	($m\ a^{-1}$)	(mm w.e.)
1	25.09.2013	08.09.2014	596143 / 92346 / 3300	0.26	2.88	313
1	08.09.2014	08.09.2015	596143 / 92346 / 3300	−1.45	2.80	−832
2	25.09.2013	08.09.2014	596605 / 92835 / 3250	0.09	8.77	243
2	08.09.2014	08.09.2015	596605 / 92835 / 3250	−1.16	8.36	−608
4	25.09.2013	08.09.2014	596211 / 93400 / 3185	0.21	12.48	−179
4	08.09.2014	08.09.2015	596211 / 93400 / 3185	−1.17	11.92	−1275
5	25.09.2013	08.09.2014	595615 / 94303 / 3055	0.02	16.90	−846
5	08.09.2014	08.09.2015	595615 / 94303 / 3055	−0.14	17.19	−2997
6	25.09.2013	08.09.2014	594568 / 94497 / 2820		22.80	−2610
6	08.09.2014	08.09.2015	594568 / 94497 / 2820	−3.72	23.18	−5076

Velocity in 2013/14 and in 2014/15

Due to the glacier retreat with complete icemelt at the glacier snout, the two sites 8 and 10 had to be abandoned in 2010 and are no longer under observation. The decrease in speed over the past years did not continued further during the two periods covered by this report. At the two lower sites (5 and 6) a slight increase during the second period may reflect the high melt rates that favored sliding.

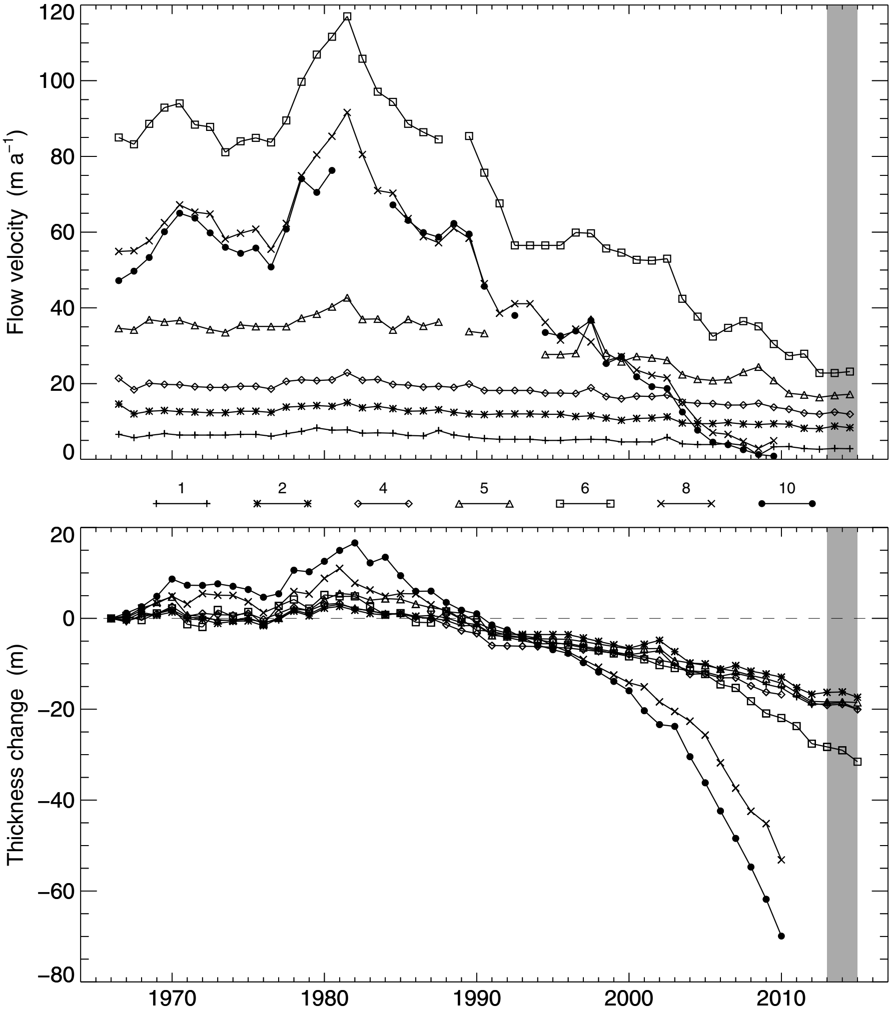

Figure 5.3: Surface flow velocities (top) and thickness change (bottom) of the Glacier du Giétro at all 7 stakes. The gray shaded area highlights the years of the current report.

5.3 Glacier de Corbassière

Introduction

Since 1955, Glacier de Corbassière (Figure 5.4) has been under observation by taking length change measurements. In the past, this glacier was threatening the water intake of the Mauvoisin power company at the front of the tongue. In the ablation area of the glacier, two profiles with stakes are being observed annually to determine the velocities and local mass balance (Table 5.2). Figure 5.5 shows the surface flow velocities for the two profiles since 1967. Results of the glacier-wide mean specific winter and annual balance for comparable fixed date periods for 1996 to 2015 are presented in Section 4.17 of this report.

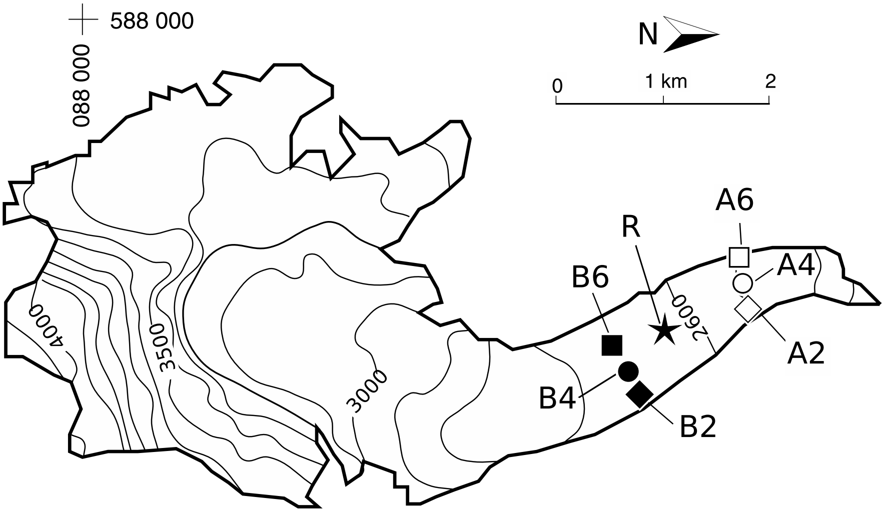

Figure 5.4: Surface topography and observational network of the Glacier du Corbassière.

Investigations in 2013/14 and in 2014/15

The field surveys were carried out on 8th/9th September 2014 and on 8th/9th September 2015. As in previous years, seven stakes were maintained on the glacier tongue. The continuous reduction in ice thickness and glacier width in the lower profile increasingly impeded surveying activities and efforts to restore the stakes to their initial position.

Velocity in 2013/14 and in 2014/15

During the two periods under review the general trend of decreasing speed did not continue. The stakes in the upper profile (B2 - B6) do show a slight increase lasting for the two consecutive periods. However, the lowering of the surface height at all stakes is sustained. Extraordinarily high rates of lowering have been observed at stakes A2 and A4 on the lower profile.

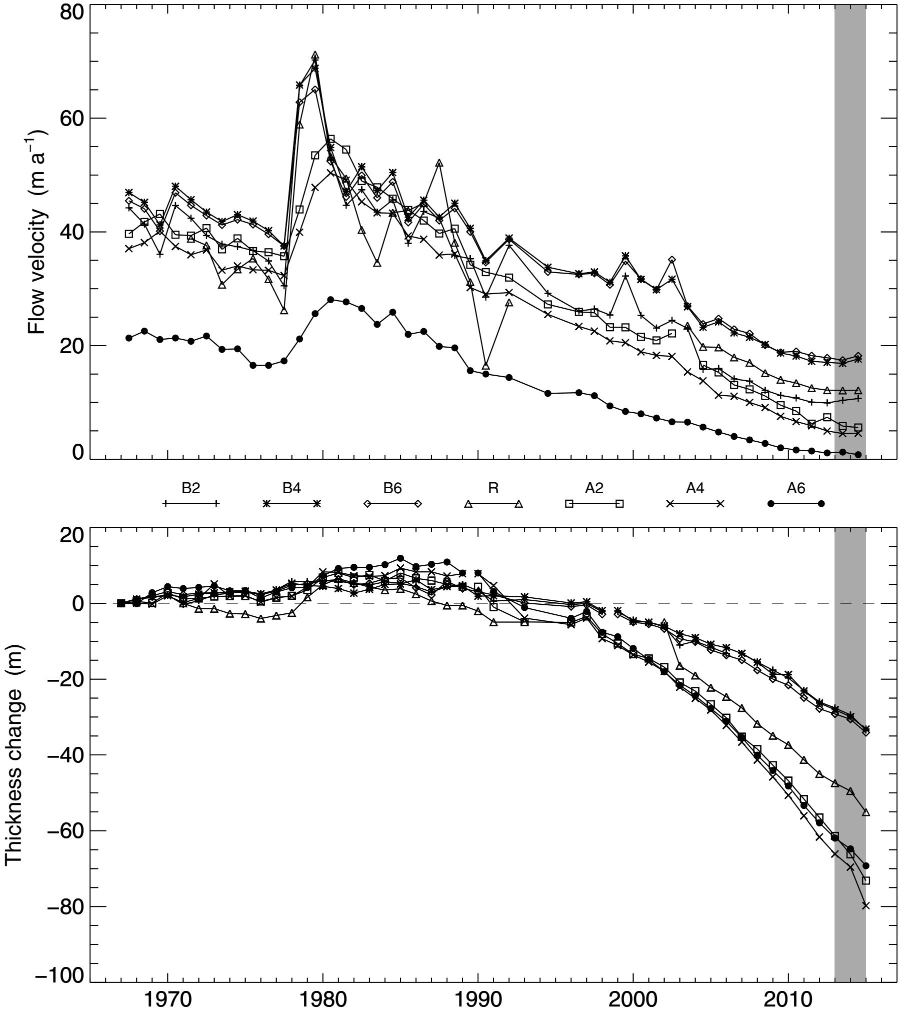

Figure 5.5: Surface flow velocities (top) and thickness change (bottom) of the Glacier de Corbassière at two profiles with 3 stakes each and the additional stake in between. The gray shaded area highlights the years of the current report.

Table 5.2: Glacier de Corbassière - Individual measurements of surface flow velocity, thickness change and annual balance.

Stake	Period		Coordinates	Thickness change	Velocity	Mass balance
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})	(mm w.e.)
B2	25.09.2013	08.09.2014	589577 / 93202 / 2630	−1.81	10.37	−2763
B2	08.09.2014	08.09.2015	589577 / 93202 / 2625	−4.03	10.68	−4752
B4	25.09.2013	08.09.2014	589392 / 93101 / 2630	−1.86	16.88	−2925
B4	08.09.2014	08.09.2015	589392 / 93101 / 2630	−3.25	17.64	−4284
B6	25.09.2013	08.09.2014	589230 / 93012 / 2635	−1.37	17.45	−2835
B6	08.09.2014	08.09.2015	589230 / 93012 / 2630	−3.53	18.21	−4635
R	25.09.2013	08.09.2014	589150 / 93650 / 2595	−2.09	12.12	−3447
R	08.09.2014	08.09.2015	589150 / 93650 / 2590	−5.57	12.14	−5175
A2	25.09.2013	08.09.2014	588554 / 94287 / 2430	−3.47	5.90	−4041
A2	08.09.2014	08.09.2015	588554 / 94287 / 2425	−6.92	5.60	−5967
A4	25.09.2013	08.09.2014	588450 / 94257 / 2420	−3.46	4.54	−3591
A4	08.09.2014	08.09.2015	588450 / 94257 / 2415	−5.19	4.59	−5256
A6	25.09.2013	08.09.2014	588273 / 94207 / 2430	−2.85	1.27	−2574
A6	08.09.2014	08.09.2015	588273 / 94207 / 2430	−4.45	0.81	−3735

5.4 Mattmark

Introduction

The first ice flow velocity and mass balance measurements in the Mattmark area date back to 1955 (VAW, 1999; Antoni, 2005). Investigations were carried out with a network of up to 22 stakes on the glaciers Allalin, Hohlaub, Kessjen, Schwarzberg and Tälliboden. Currently, measurements are continued on 11 selected stakes as part of the investigations by VAW/ETHZ for the Mattmark hydro-power company (Figure 5.6). Figure 5.7 shows surface flow velocities on Allalingletscher. Huss et al. (2015) re-analyzed and homogenized the seasonal stake data and ice volume changes for the period 1955 to 2013. The results of the glacier-wide mean specific winter and annual balance for comparable fixed date periods on Allalin and Schwarzberg are presented in Section 4.17 of this report.

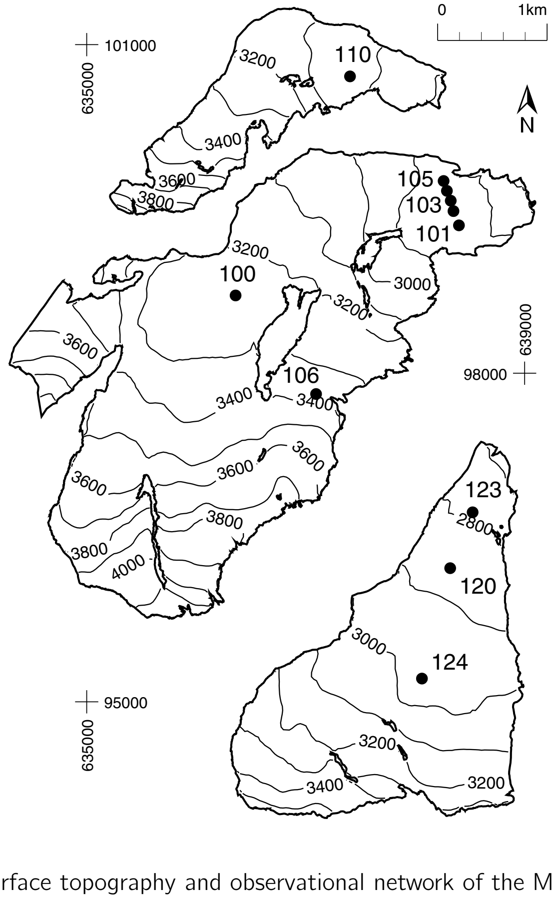

Figure 5.6: Surface topography and observational network of the Mattmark glaciers.

Investigations in 2013/14 and in 2014/15

The first measurement period at the stakes on Schwarzberggletscher, Hohlaub as well as those on Allalingletscher began on 29th August 2013 and ended on 2nd September 2014. The field survey of the second period was carried out on 21st September 2015. Results for horizontal flow velocity and thickness change for each glacier are given in Tables 5.3, 5.4 and 5.5.

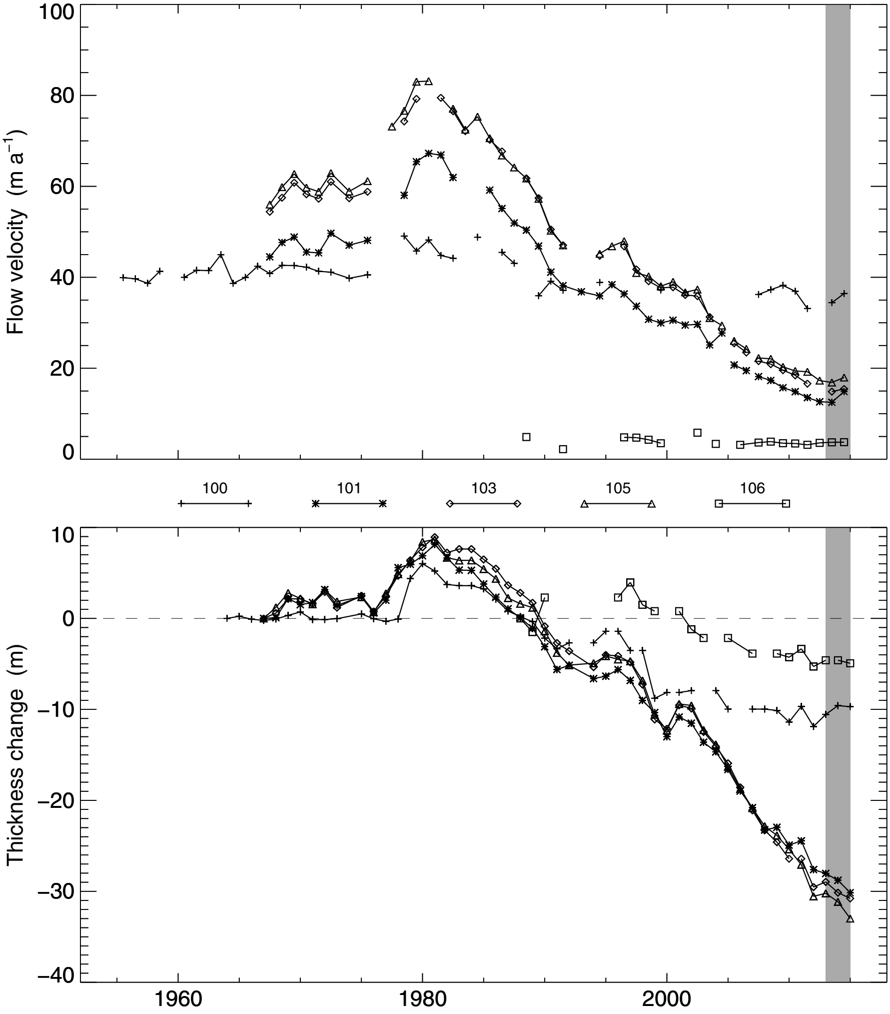

Figure 5.7: Surface flow velocities (top) and thickness change (below) of the Allalingletscher at 5 stakes. The gray shaded area highlights the years of the current report.

Table 5.3: Allalingletscher - Individual measurements of surface flow velocity, thickness change and annual balance.

Stake	Period		Coordinates	Thickness change	Velocity	Mass balance
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})	(mm w.e.)
100	29.08.2013	02.09.2014	636510 / 98800 / 3220	0.96	34.43	−417
100	02.09.2014	21.09.2015	636510 / 98800 / 3220	3.89	36.43	−666
101	29.08.2013	02.09.2014	638400 / 99360 / 2825	−0.75	12.52	−2700
101	02.09.2014	21.09.2015	638400 / 99360 / 2825	−1.36		−4500
102	29.08.2013	02.09.2014	638350 / 99480 / 2830	−0.85	14.10	−1530
102	02.09.2014	21.09.2015	638350 / 99480 / 2830	−0.82	14.53	−2970
103	29.08.2013	02.09.2014	638325 / 99575 / 2830	−1.18	14.87	−1980
103	02.09.2014	21.09.2015	638325 / 99575 / 2830	−0.64	15.45	−4500
104	29.08.2013	02.09.2014	638290 / 99665 / 2840	−0.41	15.73	−1980
104	02.09.2014	21.09.2015	638290 / 99665 / 2840	−0.69	16.51	−4140
105	29.08.2013	02.09.2014	638260 / 99755 / 2860	−0.93	16.88	−2700
105	02.09.2014	21.09.2015	638260 / 99755 / 2860	−1.84	17.97	−4500
106	29.08.2013	02.09.2014	637095 / 97810 / 3370	−0.50	3.73	534
106	02.09.2014	21.09.2015	637095 / 97810 / 3370	−0.33	3.75	348

Table 5.4: Hohlaubgletscher - Individual measurements of surface flow velocity, thickness change and annual balance.

Stake	Period		Coordinates	Thickness change	Velocity	Mass balance
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})	(mm w.e.)
110	29.08.2013	02.09.2014	637405 / 100710 / 3030	−0.54	10.13	−720
110	02.09.2014	21.09.2015	637405 / 100710 / 3030	−1.48	10.39	−2070

Table 5.5: Schwarzberggletscher - Individual measurements of surface flow velocity, thickness change and annual balance.

Stake	Period		Coordinates	Thickness change	Velocity	Mass balance
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})	(mm w.e.)
120	29.08.2013	02.09.2014	638320 / 96220 / 2850	−0.89	6.68	−1827
120	02.09.2014	21.09.2015	638320 / 96220 / 2850	−2.38	6.61	−2970
123	29.08.2013	02.09.2014	638525 / 96730 / 2770	−2.47	5.50	−2079
123	02.09.2014	21.09.2015	638525 / 96730 / 2770	−3.09	5.30	−3726
124	29.08.2013	02.09.2014	638062 / 95212 / 2980	−0.46	7.48	−801
124	02.09.2014	21.09.2015	638062 / 95212 / 2980	−0.87	7.71	−2016

6 Englacial Temperature

6.1 Introduction

Figure 6.1: Investigated site for englacial temperatures.

Besides glacier mass balance, firn and ice temperatures of ice bodies can be considered as a key parameter in detecting global warming trends. These temperatures have a sort of a memory function as they register short- and mid-term evolution of the energy balance at the surface. By looking at firn and ice temperature measurements it is possible to assess climate changes in areas where no direct measurement of common climatic parameters are available. Cold firn and ice in glaciers, ice caps and ice sheets occur when the firn and ice show permanently negative temperatures over the minimum time span of a year. If this is not the case, glaciers are temperate, thus their temperature is at the pressure melting point. Most of the existing cold ice bodies are not cold throughout. These ice bodies are called polythermal (Blatter and Hutter, 1991; Cuffey and Paterson, 2010).

Measurements of englacial temperatures have been added to the Swiss glacier monitoring programme (see Chapter 1.1 of Volume 125/126). The Colle Gnifetti site was selected for performing regular measurements to update the existing ones made in the years 1983, 1991, 1999, 2000, 2007 and 2008. The results of measurements taken in the years 2008, 2013, 2014 and 2015 on Colle Gnifetti are presented in this report. The previous results have been reported in Volume 129/130.

6.2 Colle Gnifetti (Monte Rosa)

Introduction

Colle Gnifetti is a small and very wind-exposed firn saddle at 4450 m a.s.l. in the region of Monte Rosa, Valais Alps, Switzerland. The saddle is situated between Zumsteinspitze and Signalkuppe with the famous Margerita hut, and belongs to the accumulation area of Grenzgletscher, a tributary of Gornergletscher. Strong wind erosion causes extraordinarily low annual accumulation of snow. Alean et al. (1983) and Lüthi (2000) showed accumulation rates of 0.1 $\mathrm{m\,a^{-1}}$ at the north-west slope of Signalkuppe to 1.2 $\mathrm{m\,a^{-1}}$ at the sunny south slope of Zumsteinspitze. Thus, Colle Gnifetti represents a unique Alpine key site for collecting long-term ice core records.

Investigations 2007 - 2015

In summer 2005, the University of Heidelberg (D. Wagenbach / O. Eisen) drilled the borehole CG05-1 to 62 m depth (measurements CG05-1/07 and CG05-1/08 also called KCI). Temperature measurements in this borehole were taken in November 2007 to a depth of 62 m and in August 2008 to a depth of 58 m. In the year 2007, a permanent thermistor cable was installed in the borehole CG07-1 by the University of Zurich (M. Hoelzle, M. Zemp), and the first measurement was taken in November 2007 (CG07-1/07), and a second in August 2008 (CG07-1/08). As a part of the major field campaign in 2008, the University of Zurich (G. Darms, M. Hoelzle) drilled seven additional boreholes on Colle Gnifetti, Grenzgletscher and Seserjoch (CG08-1, CG08-2, CG08-3, GG08-5, SJ08-6, SJ08-7 and SJ08-8) using the Heucke steam drill equipment. Since 2009, the University of Fribourg has been responsible for the long-term englacial temperature observations at Colle Gnifetti, which are in general performed every five years. In keeping with this plan, a major field campaign was carried out in 2013 by the University of Heidelberg (P. Bohleber, D. Wagenbach, C. Licciulli), who drilled a new core on the saddle (CG13-1/13 also called KCC) down to 71 m. In addition to this borehole, five other boreholes were drilled using a Heucke steam drill down to depths of around 20 m (CG13-2/13, CG13-3/13, CG13-4/13, GG13-5/13 and SJ/13-6/13) by the University of Fribourg. After 2007 and 2008 borehole CG05-1 was measured again in 2013 and 2015. Borehole CG13-1 was remeasured in 2014 and 2015. In 2015, the Paul Scherrer Institute drilled a new borehole with a depth of 76 m down to bedrock (CG15-1). The measured temperatures at a depth of around 20 m (corresponding roughly to the zero annual amplitude ZAA) were in a range of -2.5°C to -13.14°C. At the Seserjoch (SJ08-6/08, SJ08-7/08 and SJ08-8/08) and Grenzgletscher (GG08-5/08) sites, generally warmer temperatures were observed (Tables 6.1 and 6.2).

As a summary of the already existing measurements, it can be stated that a range of englacial temperature measurements, some with large depths, has been acquired in the Monte Rosa area at the border of Switzerland and Italy since 1982 (Figure 6.2). Especially, from 1999/2000 to 2015, a quite remarkable warming was observed, indicating that the amount of infiltrating and refreezing of meltwater at Colle Gnifetti has probably increased since 1999/2000. The measured temperatures give clear evidence of firn warming. This is confirmed by several boreholes with measured temperature down to bedrock (Figure 6.2), and also by the 20 m firn temperatures at selected borehole sites (Figure 6.3). However, the drilling sites on Colle Gnifetti are still located in the recrystallization-infiltration zone but could probably change soon in another firn facies zone. Measurements at Grenzgletscher and Seserjoch already show this change. Further detailed analyses can be found in Hoelzle et al. (2011).

Table 6.1: Borehole number, measurement date, total depth of the borehole, coordinates of the borehole location, and drilling technique. Type of thermistors used was YSI 44031, for a details of the measurement please consult Hoelzle et al. (2011)

number	date	depth	coordinates (m / m / m a.s.l.)	drill types
B05-1/13	20.08.2013	57.8	634002 / 86554 / 4452	mechanical
B05-1/15	25.09.2015	56.26	634002 / 86554 / 4452	mechanical
B13-1/13	20.08.2013	71.3	633950 / 86465 / 4468	mechanical
B13-1/14	25.09.2014	73.35	633949 / 86467 / 4468	mechanical
B13-1/15	24.09.2015	73.35	633948 / 86468 / 4468	mechanical
B13-2/13	22.08.2013	19	633808 / 86577 / 4455	steam
B13-3/13	23.08.2013	19.7	633922 / 86383 / 4482	steam
B13-4/13	22.08.2013	21.5	633747 / 86486 / 4451	steam
B13-5/13	22.08.2013	20.6	633500 / 85903 / 4253	steam
B13-6/13	22.08.2013	23.9	633748 / 85765 / 4295	steam
B15-1/15	27.09.2015	76	633860 / 86513 / 4462	mechanical

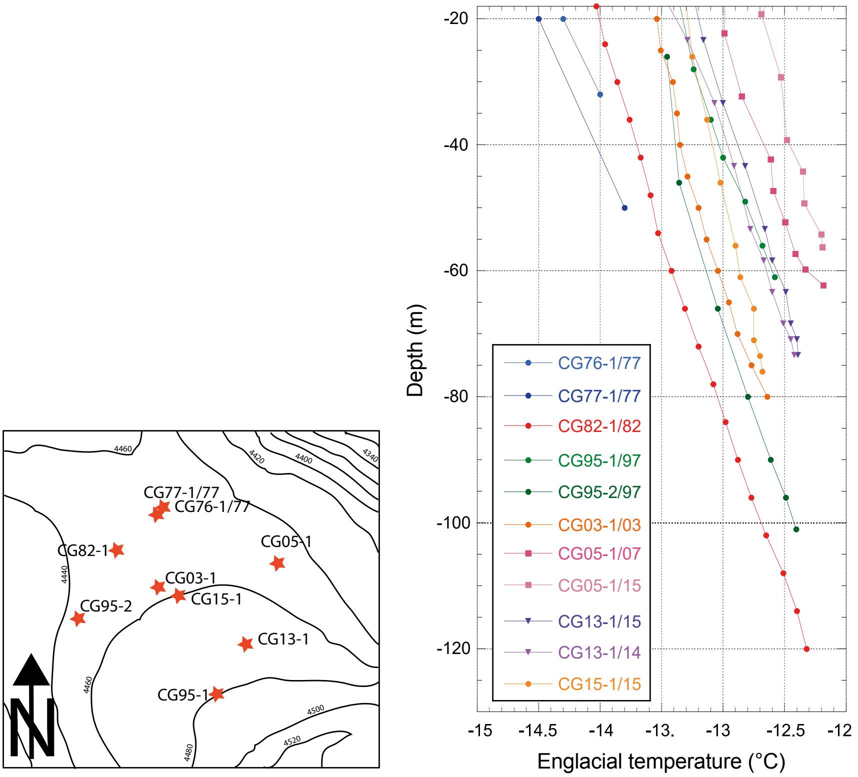

Figure 6.2: Englacial temperatures measured in all deep boreholes since 1977 on Colle Gnifetti.

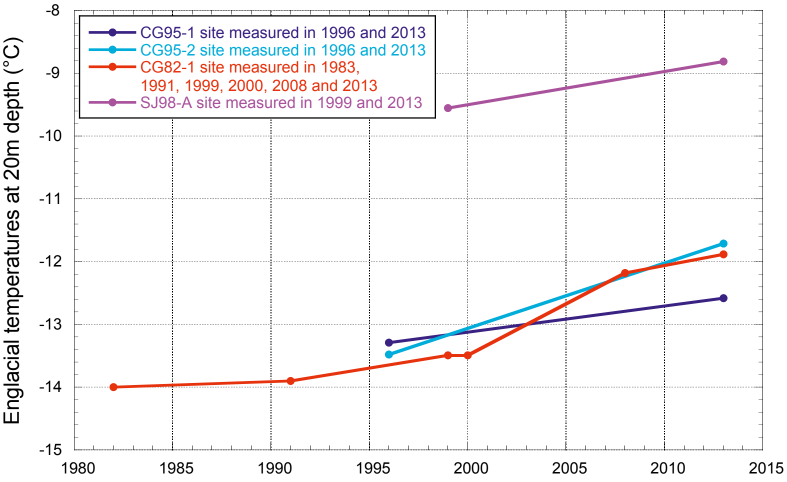

Figure 6.3: Englacial temperatures measured from 1982 to 2013.

Table 6.2: Colle Gnifetti - Englacial temperature measurements in the years 2013, 2014 and 2015 in boreholes.

Borehole: B05-1

depth (m)	20.08.2013 temperature (°C)	25.09.2015 temperature (°C)
0.1		−7.224
0.6		−6.84
1.1		−6.669
1.6		−6.58
2.1		−6.735
2.6		−7.074
3.6		−8.07
5.6		−10.3
7.6		−11.77
8.1	−13.411	
8.6		−12.12
9.6		−12.43
18.1	−12.87	
19.26		−12.69
22.6	−12.844	
24.6	−12.796	
25.6	−12.796	
26.6	−12.793	
28.1	−12.793	
28.6	−12.736	
29.26		−12.53
30.6	−12.731	
35.6	−12.63	
38.1	−12.626	
39.26		−12.48
40.6	−12.56	
43.1	−12.551	
44.26		−12.35
45.6	−12.448	
48.1	−12.41	
49.26		−12.34
53.1	−12.349	
54.26		−12.2
55.3	−12.302	
56.26		−12.19
57.8	−12.245	

Borehole: B13-1

depth (m)	20.08.2013 temperature (°C)	25.09.2014 temperature (°C)	24.09.2015
11.3	−13.64		
13.35		−13.57	−13.28
21.3	−13.26		
23.35		−13.29	−13.16
31.3	−12.99		
33.35		−13.07	−13
41.3	−12.82		
43.35		−12.91	−12.82
51.3	−12.68		
53.35		−12.78	−12.66
56.3	−12.71		
58.35		−12.67	−12.6
61.3	−12.49		
63.35		−12.6	−12.49
66.3	−12.51		
68.35		−12.51	−12.45
68.8	−12.43		
70.85		−12.45	−12.4
71.3	−12.41		
73.35		−12.42	−12.39

B13-2 22.08.2013		B13-3 23.08.2013		B13-4 22.08.2013	
depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)
0	−5.1	0.7	−7.25	0.5	−6.156
				1.5	−8.296
2	−9.8	2.7	−10.05	2.5	−10.093
4	−12.2	4.7	−11.81	4.5	−11.936
				6.5	−12.468
9	−12.55	9.7	−12.58	11.5	−12.35
14	−12.6	14.7	−12.34	16.5	−12.54
19	−12	19.7	−12.56	21.5	−11.352

B13-5 22.08.2013		B13-6 22.08.2013		B15-1 27.09.2015	
depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)
0.6	−0.1617	0.9	−3.094	16	−13.31
2.6	−4.436	2.9	−7.586	26	−13.25
		3.9	−8.806	36	−13.13
		4.9	−9.103	46	−13.02
5.6	−6.078	6.9	−9.646	56	−12.9
		8.9	−9.558	61	−12.86
10.6	−5.36	13.9	−9	66	−12.75
15.6	−4.25	18.9	−8.9	71	−12.75
20.6	−2.973	23.9	−8.453	73.5	−12.7
				76	−12.68

7 Hazardous Glaciers in Switzerland

7.1 Introduction

In 2003 the VAW published an inventory of hazardous glaciers (Raymond et al., 2003). An update of this inventory is presented including the hazardous events which have occurred in the meantime, as well as the glaciers which are now considered as potentially hazardous.

7.2 Canton of Valais

Minstigergletscher

21 August 2008: After the sudden release of a subglacial lake located immediately below the glacier surface at the left margin, a debris flow was formed which filled a safety reservoir

Figure 7.1: Glaciers with hazardous events (red) an potentially hazardous (yellow).

upstream of the village of Münster. Unfortunately, the front part of the reservoir was unable to withstand the tremendous pressure from the water/debris and the floodwaters inundated parts of the village resulting in major damage (http://glaciology.ethz.ch/glacier-hazards/).

Triftgletscher (Weissmies)

A large sector of the glacierized northwest face of Weissmies mountain in the Saas valley recently became unstable. This new development likely stems from a climate-induced glacier thinning of the supporting Triftgletscher and the steady progression from freezing to melting conditions at the ice/bed interface. Consequently, in the summer of 2014 a section of the glacierized face with 800'000 m^3 of ice reverted to an "active phase" with high surface flow velocities, thereby increasing the likelihood of a major icefall. In such an event, an ice/snow avalanche could threaten the population and infrastructure of the Saas valley. A monitoring campaign was initiated to detect warning signals of dangerous break-off events in order to enable timely evacuation of endangered areas. Interferometric and Doppler radar, seismic and acoustic sensors, optical imaging and GPS receivers were installed to provide real-time continuous surface displacement and ice fracture development data. A critical increase in surface velocities is a clear sign of an impending icefall. Thus it is possible to predict rupture time based on surface velocity data. Up to now, only minor icefalls have been observed (Preiswerk et al., 2016).

Feegletscher

15-20 September 2009: Several icefalls from the tongue of Feegletscher. In total, 300'000 m^3 of ice broke off in the course of several events. The ice avalanche resulting from three events (on the 15th, 19th and 20th September 2009) extended as far down as a hiking trail, but fortunately no damage or injuries occurred (DWL/VS, 2009).

Bisgletscher

23 and 31 March 2005: Part of the hanging glacier located immediately below the eastern ridge broke off in two events with a total ice volume of 460'000 m^3. A real-time monitoring system was installed for early warning purposes (Faillettaz et al., 2008; w/s/l, 2014). No damage occurred (http://glaciology.ethz.ch/glacier-hazards/).

24 January 2007: An ice avalanche from Bisgletscher reached the village of Randa at 10:50 pm, also releasing a great deal of powder snow (w/s/l, 2013).

28 February 2007: An avalanche originating at the eastern face of Weisshorn came down on "Sennjini" near Randa at 10:40 am. At 9:50 pm another avalanche reached the valley bottom. No damage occurred (w/s/l, 2013).

5 January 2012: An icefall from the steep part of Bisgletscher (approx. 3,300 m a.s.l.) triggered a large combined ice/snow avalanche which reached the road and railway leading to Zermatt.

Damage was incurred to trees, buildings and electricity conduits. Two cars and a truck (with persons inside) were displaced by the avalanche (w/s/l, 2013).

13 December 2012: A glacier break-off from the steep part of Bisgletscher (3300 m a.s.l.) caused an ice avalanche reaching down to an elevation of between 1450 and 1480 m a.s.l., immediately above the valley bottom. Powder snow extended down to parts of the village of Randa. No damage occurred (w/s/l, 2013).

21 February 2013: Part of the hanging glacier below the Weisshorn peak broke off (250'000 m^3 ice) and the avalanche moved down as far as the valley bottom. The village of Randa was covered by powder snow. No damage occurred (w/s/l, 2013).

Birchgletscher

22 March 2008, 7 am: Following heavy snowfall, a combined ice/snow avalanche reached the road between Ried and Blatten and covered it along a 30 m stretch, with more than 1 m of ice/snow. Luckily no damage occurred (A. Henzen, personal communication).

Mönch-Süd

24 May 2009, 1 pm: An ice lamella (50'000-70'000 m^3 of ice) broke off from the hanging glacier in the south face of Mönch on Grosser Aletschgletscher. A part of the avalanche reached the well-attended touristic facilities close to the tunnel entrance in the Sphynx mountain. By chance all tourists could timely leave the endangered area (VAW, 2009).

7.3 Canton of Berne

Hochfirn/Silberlouwena

30 January 2005: Large avalanche, probably triggered by an icefall. Damages caused to forest and the telephone lines to Steinberg (Lawinenkataster des Kantons Bern).

17 February 2011: Major ice avalanche with 500'000 m^3 of ice. Significant damage to the forest and to alpine cowsheds (http://glaciology.ethz.ch/glacier-hazards/).

26 June 2016: Ice avalanche reached Gletscherweid (1'100 m a.s.l.). No damage occurred (N. Hählen, personal communication).

Eiger (hanging glacier at the west face)

20 August 1990: Glacier break-off event and major ice avalanche (Lawinenkataster des Kantons Bern).

28 January 2012: Ice rupture triggered a ice/snow avalanche. A mixture of ice and powder snow invaded the cabin of a ski groomer through an open window at the Black Rock ski run. The windows (including the frames) of the uppermost building at Eigergletscher were pushed in by the pressure. The tables on the terrace were flattened against the wall, some of them flew over the rail. Never in the past 30 years has an ice avalanche come this far down (Lawinenkataster des Kantons Bern).

Ever since a crevasse began to form in the summer of 2015 behind the glacier front, an icefall with a maximum ice volume of 80'000 m^3 has been expected to occur. In order to secure the railway route to Jungfraujoch at the Eigergletscher station, a radar interferometry early warning system was installed in March 2016 by GEOPRAEVENT AG. Minor events only were detected shortly after the installation.

Unterer Grindelwaldgletscher

The tongue of Unterer Grindelwaldgletscher is covered with an uneven layer of debris. The layer is thicker towards the terminus due to the ongoing collapse of an unstable rock face located there, with the result that the surface lowering rates are higher upglacier than at the terminus. This led to the development of a topographical depression where a lake started to form in 2005. This basin increased in size in the following years and poses a growing threat to the downstream communities, as the lake, which it can contain, could potentially drain rapidly and cause floods.

30 May 2008: Subglacial drainage of a supraglacial lake occurred with a water volume of 750'000 m^3 and a peak discharge of 100 m^3/s in the Lütschine river. Pastureland as well as the golf course were flooded. The river channel was filled completely with debris, and damage totaling 400'000 Swiss francs (CHF) was caused to several protective structures (Hählen, 2013b).

In the years that followed, damages were expected to occur in the Lütschental as well as further downstream due to drainage of the glacier lake (Werder et al., 2010). An early warning system was installed in the glacier lake, which continuously recorded the lake water level by means of a water pressure sensor. As soon as a critical decrease in the lake level was recorded, a warning message was automatically sent to the person in charge of regional natural hazard prevention. This system functioned perfectly during the lake drainage flood which occurred on 30th May 2008.

To avert future destructive floods, the lake level should be kept as low as possible to keep potential overall lake water volume within a safe limit. To achieve this goal, in 2009 the Bernese authorities constructed a 2.1 km long drainage tunnel on the right side of the gorge from Marmorbruch to the lake. The tunnel exits onto the glacier surface behind the debris-covered ice dam at the lowest possible level, so that the water from the lake can drain through the tunnel. It is planned to adjust the tunnel exit level to the lowering glacier surface as required. After 2009, the glacier surface in the vicinity of the ice dam experienced a substantial thinning because huge amounts of debris were removed during tunnel construction in order to keep the tunnel entrance safe and the lake level low.

As a consequence, the glacier surface was largely debris-free in the vicinity of the ice dam, giving rise to high melt rates and subsequent surface lowering. Presently the glacier surface is 10-20 m below the tunnel entrance. The location of the glacier lake has moved some 500 m upstream, close to the confluence of Ischmeer and Unders Ischmeer. The lake is no longer supraglacial, it is proglacial. This means that rapid drainage through the ice is no longer possible with the present configuration.

Oberer Grindelwaldgletscher

14-15 July 2003: The Schwarze Lütschine river was temporarily dammed as a result of the collapse of the glacier terminus, triggering a number of floods. A bridge and several protective structures in the river were damaged (N. Hählen, personal communication).

26 August 2009: Sudden release of an ice-dammed water volume of 30'000 m^3 followed by a flood wave in the Schwarze Lütschine river. Two bridges were damaged (incurring costs of 70'000 CHF), and the damage caused by channel fill and destroyed protective structures came to 300'000 CHF (Ereigniskataster des Kantons Bern, Abteilung Naturgefahren).

29 June 2011: Sudden release of an ice-dammed water volume of 10'000 m^3, and entrainment of a significant volume of sediment (Hählen, 2011b).

23 August – 13 September 2011: Sudden drainage of several ice-dammed water bodies accompanied by major quantities of sediments (peak discharge up to 200 m^3/s and 100'000 m^3 of sediment). Damage estimated at up to 5 million CHF (Hählen, 2011a).

Glacier de la Plaine Morte

During the past decade, three glacier-dammed lakes formed around the Glacier de la Plaine Morte. These lakes, especially Lac de Faverges, represent a considerable hazard potential in the Simme Valley north of the glacier. With the expected further retreat of Glacier de la Plaine Morte, the potential water volume of Lac de Faverges will increase considerably in the coming decades (up to several million m^3 of water, Huss et al., 2013). The lake level has been monitored in real time since 2012 by GEOPRAEVENT AG for early warning purposes.

11 July 2011: Sudden drainage of Lac de Faverges (approx. 1 million m^3 of water) and Strubelsee (approx. 0.2 million m^3 water). No damage occurred (Hählen, 2013a).

16 July 2012: Sudden drainage of Lac de Faverges, approx. same water volume as in 2011. No damage occurred (Hählen, 2012).

2 August 2013: Sudden drainage of Lac de Faverges (approx. 1.3 million m^3 of water). The retention basin for debris filled up completely in the valley (Ereigniskataster des Kantons Bern, Abteilung Naturgefahren).

7 August 2014: Sudden drainage of Lac de Faverges (approx. 1.5 million m^3 of water), again the retention basin filled up completely (Ereigniskataster des Kantons Bern, Abteilung Naturgefahren).

1 August 2015: Sudden drainage of Lac de Faverges (approx. 1.8 million m^3 water), no damage occurred (Ereigniskataster des Kantons Bern, Abteilung Naturgefahren).

Rottalgletscher

31 July 2014: Outburst of an englacial water reservoir holding 1.2-1.8 million m^3 of water. 10'000 m^3 of sediment were deposited in the Weisse Lütschine river and then artificially removed in order to prevent inundations (GEOTEST AG, 2015).

Balmhorngletscher

9 July 2015: Ice avalanche almost reached the hiking trail to Balmhornhütte; no damage occurred (Ereigniskataster des Kantons Bern, Abteilung Naturgefahren).

Gutzgletscher

12 September 2015: Icefall from Gutzgletscher caused an ice avalanche over Wätterlouiwang (Ereigniskataster des Kantons Bern, Abteilung Naturgefahren).

Blüemlisalpgletscher

6, 18 and 26 August 2004: Icefall of 130'000 m^3 of ice; no damage (Ereigniskataster des Kantons Bern, Abteilung Naturgefahren).

7.4 Canton of Graubünden (Grisons)

Vadret da l'Alp Ota

11 July 2006: After the sudden release of a subglacial water pocket, a debris flow was formed in the proglacial area covered with unconsolidated sediments. This debris flowed across a hiking trail and killed one person (http://glaciology.ethz.ch/glacier-hazards/).

Vadret da Cambrena

Due to the retreat of the glacier, its terminus has ended in a steep slope since 2012. The glacier tongue covering this steep slope is potentially unstable. Should there occur a major break-off event, the ice avalanche could extend down to the Bernina reservoir and cause a dangerous flood wave (VAW, 2013). As an early warning measure, a time-lapse camera was installed next to glacier in July 2015 in order to detect a potentially dangerous icefall in advance.

References

Alean, J., Haeberli, W., and Schädler, B. (1983). Snow accumulation, firn temperature and solar radiation in the area of the Colle Gnifetti core drilling site (Monte Rosa, Swiss Alps): distribution patterns and interrelationships. *Zeitschrift für Gletscherkunde und Glazialgeologie*, 19(2):131–147.

Antoni, C. (2005). Langjährige Messreihen in den Schweizer Alpen. Praktikumsararbeit ausgeführt an der VAW, ETH Zürich, unter Anleitung von A. Bauder (unveröffentlicht).

Bauder, A., Funk, M., and Bösch, H. (2002). Glaziologische Untersuchungen am Glacier de Giétro im Zusammenhang mit der Sicherheit der Stauanlage Mauvoisin. In *Moderne Methoden und Konzepte im Wasserbau*, volume 175, (Band 2), pages 419–431. Mitteilung der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, ETH Zürich. Internationales Symposium 7.-9. Oktober 2002 in Zürich.

Bauder, A., Funk, M., and Huss, M. (2007). Ice volume changes of selected glaciers in the Swiss Alps since the end of the 19th century. *Annals of Glaciology*, 46:145–149.

Begert, M., Schlegel, T., and Kirchhofer, W. (2005). Homogeneous temperature and precipitation series of switzerland from 1864 to 2000. *International Journal of Climatology*, 25(1):65–80.

Blatter, H. and Hutter, K. (1991). Polythermal conditions in Arctic glaciers. *Journal of Glaciology*, 37(126):261–269.

Braithwaite, R. J. (2009). After six decades of monitoring glacier mass balance we still need data but it should be richer data. *Annals of Glaciology*, 50(50):191–197.

Cuffey, K. M. and Paterson, W. S. B. (2010). *The Physics of Glaciers*. Elsevier B.V., New York, forth edition. pp. 480.

DWL/VS (2009). Aktennotiz zum Abbruch Feegletscher. Sektion Naturgefahren, Dienststelle für Wald und Landschaft, Kanton Wallis (unveröffentlicht).

Faillettaz, J., Pralong, A., Funk, M., and Deichmann, N. (2008). Evidence of log-periodic oscillations and increasing icequake activity during the breaking-off of large ice masses. *Journal of Glaciology*, 54(187):725–737.

Firnberichte (1914–1978). *Der Firnzuwachs 1913/14–1976/77 in einigen schweizerischen Firngebieten*, number 1-64 in Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich. Jahresberichte herausgegeben von der Gletscher-Kommission der Physikalischen Gesellschaft Zürich, später Schweizerische Meteorologische Zentralanstalt und ab 1973 durch A. Lemans.

Fischer, M., Huss, M., Barboux, C., and Hoelzle, M. (2014). The new swiss glacier inventory SGI2010: Relevance of using high-resolution source data in areas dominated by very small glaciers. *Arctic, Antarctic, and Alpine Research*, 46(4):933–945.

Fischer, M., Huss, M., and Hoelzle, M. (2015). Surface elevation and mass changes of all Swiss glaciers 1980–2010. *The Cryosphere*, 9(2):525–540.

Fischer, M., Huss, M., Kummert, M., and Hoelzle, M. (2016). Application and validation of long-range terrestrial laser scanning to monitor the mass balance of very small glaciers in the Swiss Alps. *The Cryosphere*, 10(3):1279–1295.

Gabbi, J., Huss, M., Bauder, A., Cao, F., and Schwikowski, M. (2015). The impact of Saharan dust and black carbon on albedo and long-term mass balance of an Alpine glacier. *The Cryosphere*, 9(4):1385–1400.

GEOTEST AG (2015). Ereignisdokumentation Wasserausbruch 31. Juli 2014. Aktennotiz 5.8.2015 (I. Kull and D. Tobler).

Glaciological reports (1881–2016). The Swiss Glaciers, 1880–2012/13. Yearbooks 1-134, Cryospheric Commission of the Swiss Academy of Sciences (SCNAT). published since 1964 by Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of ETH Zürich, http://glaciology.ethz.ch/swiss-glaciers/.

Hählen, N. (2011a). Oberer Grindelwaldgletscher – Wasserwellen und Geschiebetrieb 25. August bis 13. September 2011. Ereignisbericht und erste Grobanalyse vom 16. Dezember 2011, 31 S. & Anhang.

Hählen, N. (2011b). Oberingenieurkreis I Kt. Bern 2011a: Oberer Grindelwaldgletscher – Wasserausbruch vom 29. Juni 2011. unveröffentlichter Bericht vom 30. Juni 2011, 10 S.

Hählen, N. (2012). Oberingenieurkreis I Kt. Bern 2012: Ausbruch Gletschersee de Faverges 16. Juli 2012. unveröffentlichter Bericht vom 25. Juli 2012, 10 S.

Hählen, N. (2013a). Oberingenieurkreis I Kt. Bern 2013a: Ausbruch Gletschersee Plaine Morte 11. Juli 2011. unveröffentlichter Bericht vom 15. Oktober 2013, 3 S.

Hählen, N. (2013b). Oberingenieurkreis I Kt. Bern 2013b: Unterer Grindelwaldgletscher 2006-2013, Ereignisse, Erkenntnisse und Entscheide rund um den Unteren Grindelwaldgletscher im Zeitraum 2006 bis 2013. unveröffentlichter Bericht, 126 S.

Hock, R. and Jensen, H. (1999). Application of kriging interpolation for glacier mass balance computations. *Geografiska Annaler*, 81A(4):611–619. in Methods of Mass Balance Measurements and Modelling.

Hoelzle, M., Darms, G., Lüthi, M. P., and Suter, S. (2011). Evidence of accelerated englacial warming in the Monte Rosa area, Switzerland/Italy. *The Cryosphere*, 5(1):231–243.

Hoelzle, M., Haeberli, W., Dischl, M., and Peschke, W. (2003). Secular glacier mass balances derived from cumulative glacier length changes. *Global and Planetary Change*, 36(4):295–306.

Huss, M. (2010). Mass balance of Pizolgletscher. *Geographica Helvetica*, 65(2):80–91.

Huss, M. and Bauder, A. (2009). 20th-century climate change inferred from four long-term point observations of seasonal mass balance. *Annals of Glaciology*, 50(50):207–214.

Huss, M., Bauder, A., and Funk, M. (2009). Homogenization of long-term mass-balance time series. *Annals of Glaciology*, 50(50):198–206.

Huss, M., Dhulst, L., and Bauder, A. (2015). New long-term mass balance series for the swiss alps. *Journal of Glaciology*, 61(227):551–562.

Huss, M. and Fischer, M. (2016). Sensitivity of very small glaciers in the Swiss Alps to future climate change. *Frontiers in Earth Science*, 4(34):1–17.

Huss, M., Voinesco, A., and Hoelzle, M. (2013). Implications of climate change on Glacier de la Plaine Morte, switzerland. *Geographica Helvetica*, 68(4):227–237.

Kaser, G., Fountain, A., Jansson, P., Heucke, E., and Knaus, M. (2003). A manual for monitoring the mass balance of mountain glaciers with particular attention to low latitude characteristics. Technical documents in hydrology 59, UNESCO, International Hydrological Programme. 137 p.

Kasser, P., Aellen, M., and Siegenthaler, H. (1986). Clariden. In *Die Gletscher der Schweizer Alpen, 1977/78 und 1978/79*, volume 99/100 of *Glaziologisches Jahrbuch der Gletscherkommission SNG*, pages 142–148. Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich.

Lüthi, M. (2000). Rheology of cold firn and dynamics of a polythermal ice stream: Studies on Colle Gnifetti and Jakobshavns Isbræ. Mitteilung 165, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich. pp. 212.

Müller, H. and Kappenberger, G. (1991). Claridenfirn-Messungen 1914-1984. Technical Report 40, Zürcher Geographische Schriften, Geographisches Institut der ETH Zürich. pp. 79.

Naegeli, K., Damm, A., Huss, M., Joerg, P., Wulf, H., Schaepman, M., and Hoelzle, M. (in press). Cross-comparison of albedo products for glacier surfaces in 2015. *Remote Sensing*.

Naegeli, K., Damm, A., Huss, M., Schaepman, M., and Hoelzle, M. (2015). Imaging spectroscopy to assess the composition of ice surface materials and their impact on glacier mass balance. *Remote Sensing of Environment*, 168:388–402.

Ohmura, A., Bauder, A., Müller, H., and Kappenberger, G. (2007). Long-term change of mass balance and the role of radiation. *Annals of Glaciology*, 46:367–374.

Østrem, G. and Brugman, M. (1991). Glacier mass-balance measurements – a manual for field and office work. Technical report, National Hydrology Research Institute. NHRI Science Report No. 4.

Preiswerk, L., Walter, F., Anandakrishnan, S., Barfucci, G., Beutel, J., Berkett, P., Canassy, P. D., Funk, M., Limpach, P., Marchetti, E., Meier, L., and Neyer, F. (2016). Monitoring unstable parts in the ice-covered Weissmies northwest face. In *INTERPRAEVENT*, pages 434–443. Internationales Symposium 2016, Lucerne, Switzerland.

Raymond, M., Wegmann, M., and Funk, M. (2003). Inventar gefährlicher Gletscher in der Schweiz. Mitteilungen 182, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich, Gloriastrasse 37-39, CH-8092 Zürich. pp. 368.

Sold, L., Huss, M., Machguth, H., Joerg, P. C., Vieli, G. L., Linsbauer, A., Salzmann, N., Zemp, M., and Hoelzle, M. (2016). Mass balance re-analysis of Findelengletscher, Switzerland; benefits of extensive snow accumulation measurements. *Frontiers in Earth Science*, 4(18):1–16.

VAW (1997). Gletscherveränderungen im Val de Bagnes 1966 – 1996. Untersuchungen im Zusammenhang mit den Anlagen der Kraftwerke Mauvoisin AG. Zusammenfassend dargestellte Hauptergebnisse der jährlichen Messungen. Bericht Nr. 7903.55.04 (M. Aellen, unveröffentlicht). Im Auftrag der Kraftwerke Mauvoisin AG.

VAW (1998). Mauvoisin – Giétrogletscher – Corbassièregletscher. Glaziologische Studien im Zusammenhang mit den Stauanlagen Mauvoisin. Bericht Nr. 55.05.7903 (M. Funk, unveröffentlicht). Im Auftrag der Elektrizitätsgesellschaft Lauffenburg AG.

VAW (1999). Mattmark – Zusammenfassender Bericht über die hydrologischen und glaziologischen Messungen im Mattmarkgebiet. Bericht Nr. 7902.52.45 (H. Bösch und M. Funk, unveröffentlicht), Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich. Im Auftrag der Kraftwerke Mattmark AG.

VAW (2009). Eisabbruch vom Hängegletscher Mönch-Süd. Bericht über die Feldbegehung vom 25. Mai 2009, Bericht Nr. 7902.52.56 (unveröffentlicht), Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich. Im Auftrag der Jungfraubahnen.

VAW (2013). Vadret dal Cambrena, Untersuchungen zur Gefahr von Eislawinen im Zusammenhang mit dem Projekt Lago Bianco. Bericht Nr. 70.03.2013 (unveröffentlicht) im Auftrag der REPOWER AG. pp. 20.

Werder, M. A., Bauder, A., Funk, M., and Keusen, H. R. (2010). Hazard assessment investigations in connection with the formation of a lake on the tongue of the Unterer Grindelwaldgletscher, Bernese Alps, Switzerland. *Natural Hazards and Earth System Sciences*, 10(2):227–237.

WGMS (2012). Fluctuations of Glaciers, 2005–2010, Vol. X. Technical report, ICSU(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland.

WGMS (2013). Glacier Mass Balance Bulletin No. 12, (2010–2011). ICSU(FAGS)–IUGG(IACS)–UNEP–UNESCO–WMO, World Glacier Monitoring Service, Zurich.

w/s/l (2013). Lawinenzug Bisbach, Überarbeitung der Lawinengefahrenkarte. Technical report, wasser/schnee/lawinen - Ingenieurbüro André Burkard AG, Brig. pp. 20.

w/s/l (2014). Sicherheitskonzept Bisgletscher, Mess- und Alarmsystem Bisbachlawine. Technical report, wasser/schnee/lawinen - Ingenieurbüro André Burkard AG, Brig. pp. 16.

Zemp, M., Hoelzle, M., and Haeberli, W. (2009). Six decades of glacier mass-balance observations: a review of the worldwide monitoring network. *Annals of Glaciology*, 50(50):101–111.

Zemp, M., Thibert, E., Huss, M., Stumm, D., Denby, C. R., Nuth, C., Nussbaumer, S. U., Moholdt, G., Mercer, A., Mayer, C., Joerg, P. C., Jansson, P., Hynek, B., Fischer, A., Escher-Vetter, H., Elvehøy, H., and Andreassen, L. M. (2013). Reanalysing glacier mass balance measurement series. *The Cryosphere*, 7(4):1227–1245.

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A Remote Sensing

A.1 Aerial photographs

Aerial photographs were taken at periodic intervals in order to provide a baseline documentation for various applications (mapping, glacier change, natural hazards, etc). In addition to the periodical surveys conducted by the Swiss Federal Office of Topography (swisstopo), high resolution aerial photographs have been acquired which are designed in particular for glaciological applications. In addition to the aerial photographs listed in the following tables (A.1 and A.2), other aerial photos for updating the National Maps are available from swisstopo. In the year 2014, pictures were taken for the sheets 1:50'000 nos. 237, 247, 248, 249, 264 and 274 and in 2015 for nos. 254, 258, 259, 265, 266, 267, 268, 269, 275, 276, 277, 278, 279, 284 and 294, respectively. More detailed information is available on swisstopo's webviewer http://www.luftbildindex.ch.

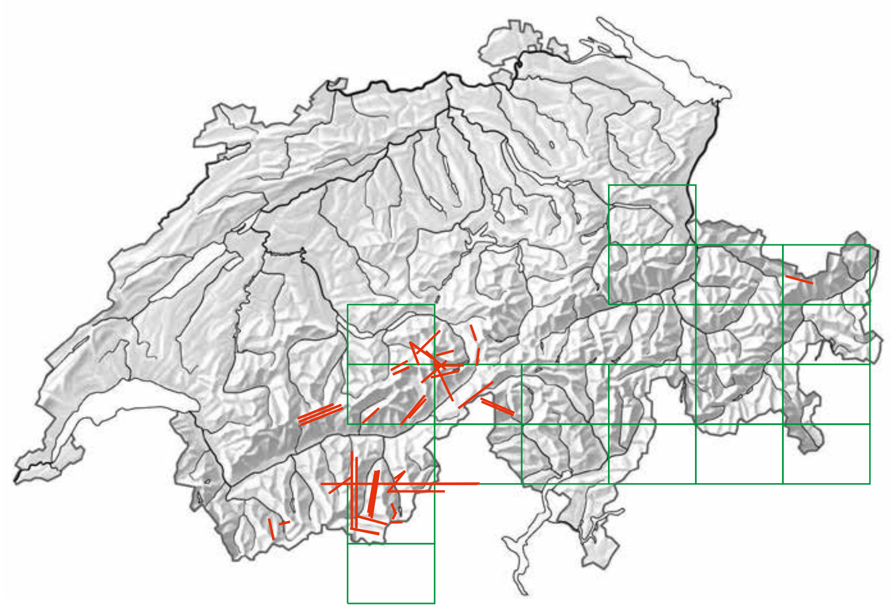

Figure A.1: Aerial photographs from the years 2014 and 2015.

Table A.1: Aerial photographs taken in 2014.

Glaciers	Ct.	Date	Line No.	Scale	Type
Allalin ^{p}, Hohlaub ^{p}, Chessjen ^{p}	VS	02.10.14			col
Basodino ^{c}	TI	23.09.14	1308201409230924	0.29	is
Basodino ^{c}	TI	23.09.14	1308201409230916	0.29	is
Bis ^{p}, Schali ^{p}, Hohlicht ^{p}, Brunegg ^{p},Schölli ^{c}, Stelli ^{c}	VS	23.09.14	1308201409231049	0.30	is
Corbassiere ^{p}	VS	02.10.14			col
Diablons ^{p}, Turtmann ^{p}, Brunegg ^{p}	VS	27.08.14	1308201408271019	0.26	is
Diablons ^{p}, Turtmann ^{p}, Brunegg ^{p}, Schölli ^{c}, Abberg ^{c}, Ried ^{p}, Balfrin ^{c}, Bider ^{c}, Lagginhorn ^{c}, Hohlaub ^{c}, Trift ^{c}, Rottal ^{c}, Holutrift ^{c}, Laggin ^{c}, Weissmies ^{c}, Tälli ^{c}	VS	02.09.14	30030201409020918	0.55	is
Eiger ^{p}, Guggi ^{p}, Giesen ^{p}	BE, VS	02.10.14			col
Findelen ^{p}	VS	27.08.14	1308201408270955	0.26	is
Finsteraar ^{p}, Unteraar ^{p}, Lauteraar ^{p}	BE	27.09.14	1308201409271119	0.27	is
Gauli ^{p}	BE	23.09.14	1308201409231138	0.20	is
Giétro ^{p}	VS	02.10.14			col
Gorner ^{p}	VS	27.08.14	1308201408271007	0.25	is
Gries ^{c}, Corno ^{p}, Blinnen ^{p}	VS	23.09.14	1308201409230934	0.26	is
Grosser Aletsch (Mönch Süd) ^{p}, Unt. Grindelwald ^{p}, Guggi ^{p}, Giesen ^{p}	BE, VS	02.10.14			col
Grosser Aletsch ^{p}	VS	22.08.14	1308201408221159	0.28	is
Grosser Aletsch ^{p}	VS	22.08.14	1308201408221208	0.17	is
Grüebu ^{p}, Mattwald ^{c}, Gamsa ^{p}	VS	23.09.14	1308201409231104	0.17	is
Grüebu ^{p}, Mattwald ^{p}	VS	23.09.14	1308201409231055	0.29	is
Gutz ^{c}, Ob. Grindelwald ^{p}, Rosenlaui ^{p}	BE	27.09.14	1308201409271129	0.34	is
Lauteraar ^{c}, Ob. Grindelwald ^{p}, Finsteraar ^{p}, Unteraar ^{p}	BE	27.09.14	1308201409271049	0.29	is
Minstiger ^{c}, Bächli ^{c}, Lauteraar ^{p}, Unteraar ^{p}, Finsteraar ^{p}, Galmi ^{p}, Oberaar ^{p}		27.09.14	1308201409271108	0.39	is
Ob. Grindelwald ^{p}, Lauteraar ^{p}	BE	23.09.14	1308201409231131	0.33	is
Oberaar ^{c}, Finsteraar ^{p}, Fiescher ^{p}	BE	27.09.14	1308201409271059	0.31	is
Plaine Morte ^{c}, Wildstrubel ^{p}, Lämmern ^{p}, Steghorn ^{c}, Tälli ^{c}, Schwarz ^{p}	BE, VS	23.09.14	1308201409231002	0.29	is
Plaine Morte ^{p}, Ammerten ^{c}, Wildstrubel ^{c}, Strubel ^{c}, Steghorn ^{c}, Tälli ^{c}	BE, VS	23.09.14	1308201409231010	0.30	is
Plaine Morte ^{p}, Lämmern ^{c}, Schwarz ^{p}	BE, VS	23.09.14	1308201409230954	0.31	is
Rhone ^{p}	VS	23.09.14	1308201409230858	0.21	is
Ried ^{p}, Hohbärg ^{p}, Festi ^{p}, Kin ^{p}	VS	27.08.14	1308201408271050	0.28	is
Ried ^{p}, Hohbärg ^{p}, Festi ^{p}, Kin ^{p}	VS	27.08.14	1308201408271058	0.28	is
Ried ^{p}, Hohbärg ^{p}, Festi ^{p}, Kin ^{p}, Weingarten ^{p}	VS	27.08.14	1308201408271042	0.30	is
Schwarzberg ^{p}	VS	02.10.14			col
Seewjinen ^{p}, Schwarzberg ^{p}	VS	02.10.14			col

Silvretta^{c}, Verstancla^{c}, Tiatscha^{c}, Plan Rai^{c}	GR	27.09.14	1308201409270933	0.37	is
Trift^{p}	BE	23.09.14	1308201409230849	0.21	is
Turtmann^{p}, Bis^{p}, Weisshorn^{p}, Schali^{c}, Hohlicht^{p}, Trift^{p}	VS	23.09.14	1308201409231039	0.33	is
Turtmann^{p}, Brunegg^{p}, Bis^{p}, Weisshorn^{p}, Schali^{c}, Moming^{p}, Hohlicht^{p}, Trift^{p}	VS	27.08.14	1308201408271031	0.34	is
Unt. Grindelwald^{p}	BE	23.09.14	1308201409231114	0.30	is
Unteraar^{c}, Lauteraar^{p}, Finsteraar^{p}	BE	27.09.14	1308201409271039	0.23	is

c	Glacier shown completely	Type of acquisition:	col	colour frames
p	Glacier shown partially		is	image stripe

Table A.2: Aerial photographs taken in 2015.

Glaciers	Ct.	Date	Line No.	Scale	Type
Allalin^{p}, Hohlaub^{p}, Chessjen^{p}	VS	21.09.15			col
Bider^{p}, Lagginhorn^{c}, Hohlaub^{c}, Trift^{c}, Rottal^{c}, Holutrift^{c}, Laggin^{c}, Weissmies^{c}, Tälli^{c}	VS	21.09.15	30030201509211000	0.58	is
Birch^{c}, Nest^{c}, Stampbach^{c}, Bietsch^{c}, Joli^{c}, Üssere Baltschieder^{p}	VS	09.09.15	1308201509091020	0.22	is
Bis^{p}, Schali^{c}, Hohlicht^{p}, Trift^{p}, Weisshorn^{p}, Brunegg^{p}, Turtmann^{p}, Schölli^{c}, Stelli^{p}	VS	26.08.15	1308201508261030	0.36	is
Bis^{p}, Schali^{p}, Hohlicht^{p}, Brunegg^{p}, Abberg^{c}, Schölli^{c}, Stelli^{c}	VS	07.08.15	1308201508070930	0.34	is
Corbassiere^{p}	VS	21.09.15			col
Eiger^{p}, Guggi^{p}, Giesen^{p}	BE, VS	21.09.15			col
Findelen^{p}	VS	05.08.15	1308201508051110	0.27	is
Finsteraar^{p}, Unteraar^{p}, Lauteraar^{p}	BE	05.08.15	1308201508051010	0.27	is
Gauli^{p}	BE	05.08.15	1308201508050920	0.21	is
Giétro^{p}	VS	21.09.15			col
Gorner^{p}	VS	05.08.15	1308201508051100	0.26	is
Gries^{c}, Corno^{p}, Blinnen^{p}	VS	31.08.15	1308201508310860	0.28	is
Grosser Aletsch (Mönch Süd)^{p}, Unt. Grindelwald^{p}, Guggi^{p}, Giesen^{p}	BE, VS	21.09.15			col
Grosser Aletsch^{p}	VS	26.08.15	1308201508261130	0.29	is
Gruben^{p}, Mattwald^{c}, Gamsa^{p}	VS	26.08.15	1308201508261120	0.18	is
Hohbärg^{p}, Ried^{p}	VS	26.08.15	1308201508261050	0.31	is
Lauteraar^{c}, Ob. Grindelwald^{p}, Finsteraar^{p}, Unteraar^{p}	BE	05.08.15	1308201508050960	0.29	is
Ob. Grindelwald^{p}, Lauteraar^{p}	BE	05.08.15	1308201508050950	0.34	is
Oberaar^{c}, Finsteraar^{p}, Fiescher^{p}	BE	26.08.15	1308201508261000	0.31	is
Plaine Morte^{c}, Wildstrubel^{p}, Lämmern^{p}, Steghorn^{c}, Tälli^{c}, Schwarz^{p}	BE, VS	05.08.15	1308201508051030	0.31	is

Plaine Morte[p], Ammerten[c], Wildstrubel[c], Strubel[c], Steghorn[c], Tälli[c]	BE, VS	05.08.15	1308201508051020	0.31	is
Plaine Morte[p], Lämmern[c], Schwarz[p]	BE, VS	05.08.15	1308201508051040	0.32	is
Rhone[p]	VS	05.08.15	1308201508050920	0.21	is
Ried[p], Hohbärg[p], Festi[p], Kin[p]	VS	05.08.15	1308201508051130	0.30	is
Ried[p], Hohbärg[p], Festi[p], Kin[p], Weingarten[p]	VS	05.08.15	1308201508051120	0.31	is
Schwarzberg[p]	VS	21.09.15			col
Seewjinen[p], Schwarzberg[p]	VS	21.09.15			col
Silvretta[c], Verstancla[c], Tiatscha[c], Plan Rai[c]	GR	07.08.15	1308201508070760	0.37	is
Trift[p]	BE	05.08.15	1308201508050930	0.21	is
Trift[p], Rottal[c], Weissmies[p], Tälli[c]	VS	21.09.15	30030201509211000	0.56	is
Unt. Grindelwald[p]	BE	05.08.15	1308201508050940	0.31	is
Unteraar[c], Lauteraar[p], Finsteraar[p]	BE	05.08.15	1308201508050910	0.23	is

c Glacier shown completely
p Glacier shown partially

Type of acquisition:
col colour
is image stripe

B Remarks on Individual Glaciers

1 Rhone

2014: Luftbildaufnahmen am 23.9.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 05.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

3 Gries

2014: Luftbildaufnahmen am 23.9.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 31.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

4 Fiescher

2014: Neuer Fixpunkt am Gletscherrand eingemessen. (P. Aschilier)

5 Grosser Aletsch

2014: Luftbildaufnahmen am 22.8.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 26.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

7 Kaltwasser

2014: Rückgang ca. 10 m, Graben/Schlund bei Punkt 1 noch teilweise vereist. (M. Schmidhalter)

2015: Rückgang ca. 6 m, bei Punkt 1 liegen in den Graben noch vereiste Stellen. (M. Schmidhalter)

10 Schwarzberg

2014: Luftbildaufnahmen am 2.10.2014, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 21.9.2015, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

11 Allalin

2014: Luftbildaufnahmen am 2.10.2014, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 21.9.2015, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

12 Chessjen

2014: Luftbildaufnahmen am 2.10.2014, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 21.9.2015, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

13 Fee

2014: Messungen erstmals mit GPS. (U. Andenmatten)

14 Gorner

2014: Gletschertor war nicht zugänglich,Lage/Distanz geschätzt. (S. Walther)

2015: Gletschertor war nicht zugänglich,Lage/Distanz geschätzt. (S. Walther)

16 Findelen

2014: Luftbildaufnahmen am 27.8.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 5.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

17 Ried

2014: Neuer Fixpunkt gesetzt. (P. Rovina)

18 Lang

2014: Erstmals Vermessung GPS. (H. Henzen)

19 Turtmann

2014: Messung mit GPS Kanton. Rückgang auf Karte herausgemessen. (A. Brigger)

2015: Markanter Rückgang des Gletschers. Bisherige Messung: Mittlung mehrerer Punktmessungen. Neue Messung: Rückzug Gletschertor. (A. Brigger)

20 Brunegg

2015: Gletscherfront von Messpunkt 2013 nicht mehr einsehbar und auch nicht zugänglich. Es muss ein anderer Zugang zum Gletscher gefunden werden. (A.Brigger)

22 Zinal

2015: Epaisseur max au front: 52.5 m. (G. Chevalier)

23 Moming

2014: (P. Stoebener)

24 Moiry

2015: Epaisseur max au front: 7.4 m. (G. Chevalier)

25 Ferpècle

2014: Altitude estimée (F. Fellay)

2015: A la sortie d'eau un pont de glace fait la jonction entre les langues latérales du glacier. Derrière ce pont une ouverture de 10 m x 30 m s'est ouverte. (F. Fellay)

27 Arolla

2014: Glacier noir en bordure est et ouest. Recul calculé à la sortie d'eau. (F. Fellay)

2015: Recul calculé à la sortie d'eau. (F. Fellay)

28 Tsijdere Nouve

2014: Recul mesuré sur 2 points, altitude estimée. (F. Fellay)

29 Cheillon

2015: Fort recul du point 1 consécutif à l'effondrement de cavernes glaciaires. (O. Bourdin)

30 En Darrey

2014: Le glacier se retire en rive droite. La séparation s'accentue entre l'amont et l'aval. (O. Bourdin)

31 Grand Désert

2014: Caverne s'est agrandie entre les points B et 3, hauteur env. 4 m, largeur 15 m, profondeur 6 m. (F. Vouillamoz)

32 Mont-Fort

2014: Le névé en aval de l'éperon rocheux est encore présent. (F. Vouillamoz)

2015: Entre les points 2-3 un petit lac en formation. (F. Vouillamoz)

33 Tsanfleuron

2014: Recul mesuré sur une moyenne de 2 points. Altitude estimée. (F. Fellay)

2015: Recul calculé à la sortie d'eau. (F. Fellay)

34 Otemma

2014: Toujours des signes de très grosses crues sur l'avant terrain. Le front du glacier est encore plus plat et un torrent sort maintenant à l'extrême droite du glacier. La rive droite complètement recouverte de rochers et gravats, se creuse très fortement. En bref un tassement et recul prononcé de tout le glacier. (J.-J. Chabloz)

2015: La couverture rocheuse des moraines gauche et droite en aval du glacier s'érode et laisse voir la glace et des ruisselets dévalent les pentes. Sur le glacier les torrents de surface ont creusé de profonds sillons et le front s'affaisse complètement. Les rives gauche et droite présentent de nombreux trous et crevasses. (J.-J. Chabloz)

35 Mont Durand

2014: Portail rive droite inaccessible: d'un côté bedrock presque vertical, de l'autre pente de glace du front raide et chutes de rochers et gravats constants. Rive gauche le glacier couvert de débris rocheux s'est tassé et a avancé. Le bedrock est apparu ce qui a permis de faire un nouveau Pt 10/14 dans le même axe de visée. En dépit des chiffres, grosse décrue, surtout visible à partir du trou bedrock central direction Tête Blanche. (J.-J. Chabloz)

2015: La rive gauche est percée de trous et crevasses. Juste au-dessus du front dans l'axe de mesure un seuil de bedrock sépare la langue du glacier en deux parties également couvertes de débris rocheux. Au plateau supérieur rive droite, le bedrock est toujours plus visible et un gros torrent le sépare du glacier. Au pied de Tête Blanche bedrock partout. (J.-J. Chabloz)

36 Brenay

2014: Recul peu marqué, mais la langue du glacier s'est complètement affaissée, surtout la rive gauche qui forme maintenant un vallon à l'extrémité duquel se trouve un faux portail désolidarisé du front. La rive droite couverte de débris rocheux qui se prolonge en aval du front se tasse fortement. Au niveau des séracs du Brenay, le bedrock rive gauche est bien apparent. Ici aussi décrue marquée. Un gros bloc abandonné par la dernière crue exactemnt dans l'axe principal a permis de marquer le Pt 23/15. (J.-J. Chabloz)

2015: Les rochers couvrants les moraines en aval du glacier se sont effondrés sur le plateau au devant du front. Le dernier Pt 23/15 se retrouve au milieu du torrent. Sur le glacier rive droite de gros trous et crevasses. Un torrent sous glaciaire à l'extrême bord rive droite rejoint le portail rive droite juste à la sortie du glacier et plusieurs petits bras de torrents sortent sous la langue rive gauche parmi un capernaüm de blocs, rochers et graviers. Au niveau des séracs du Brenay l'oeil rocheux n'est plus un oeil et le bedrock est lié à la rive droite. (J.-J. Chabloz)

37 Giétro

2014: Luftbildaufnahmen am 2.10.2014, photogrammetrische Auswertung durch Flotron AG im Auftrag der Forces Motrices de Mauvoisin SA. Bestimmung der Längenänderung durch die VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 21.9.2015, photogrammetrische Auswertung durch Flotron AG im Auftrag der Forces Motrices de Mauvoisin SA. Bestimmung der Längenänderung durch die VAW/ETHZ. (VAW/ETHZ – A. Bauder)

38 Corbassière

2014: Luftbildaufnahmen am 2.10.2014, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Forces Motrices de Mauvoisin SA. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 21.9.2015, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Forces Motrices de Mauvoisin SA. (VAW/ETHZ – A. Bauder)

40 Tseudet

2014: Le bas du glacier est très irrégulier et est recouvert d'éboulis. Il est très difficile de déterminer ou s'arrête vraiment le glacier (présence de langues glaciaires mais impossible de dire si c'est un mélange de blocs et de glace ou si c'est encore le glacier). (J. Médico)

2015: Situation gegenüber 2014 unverändert. (J. Médico)

43 Trient

2014: Une masse de glace s'est séparée de l'extrémité de la langue, mais est restée à proximité. La mesure de cette année ne l'a donc pas pris en compte. La fonte de la langue se poursuit, son épaisseur diminue. (J. Ehinger)

2015: La pointe de la langue est toujours engagée dans un sillon rocheux orienté approximativement SW-NE. La fonte de l'année a été importante, le glacier a perdu en épaisseur. Par contre le recul de la langue a été faible. (J. Ehinger)

44 Paneyrosse

2014: Refait peinture des points. (J.-Ph. Marlétaz)

2015: La neige fraîche n'a pas toute fondu, malgré cela les mesures sont fiables. Refait la peinture des points. (J.-Ph. Marlétaz)

45 Grand Plan Névé

2014: Refait peinture des points 83 à 85. (J.-Ph. Marlétaz)

2015: Les points 3,2,1,11 arrivent en fin de vie. Refait la peinture des points. (J.-Ph. Marlétaz)

47 Sex Rouge

2014: P1 à P3 ont été rafraîchi. (J. Binggeli)

2015: Le glacier n'est plus décelable sur P1, P3 et P4. Nous avons à nouveau mesuré P2 sans être à nouveau certain du matériau nivologique apparent (névé persistant, glacier sous-jacent, glace morte). (J. Binggeli)

48 Prapio

2014: L'été froid et pourri a favorisé la persistance d'un important névé compact, encore arrimé au glacier, obstruant la gorge en maints endroits. Ce phénomène est nettement plus marqué que l'année dernière, tant en longueur qu'en épaisseur. On note à nouveau le dépôt d'éboulis arrachés aux pentes dominantes. On constate la formation de matériau glace à l'avant du front sur une distance de 5 mètres. (J. Binggeli)

2015: On note à nouveau le dépôt d'éboulis arrachés aux pentes dominantes. (J. Binggeli)

52 Gauli

2014: Eine kleine Zunge des Gletschers reicht noch bis zum See, diese wird im nächsten Jahr vermutlich verschwinden. Am untersten Rand ist der Gletscher stark zerklüftet und noch einmal sichtbar dünner geworden. (D. Rohrer)

2015: Der Gletscher hat vor allem stark an Mächtigkeit verloren. (D. Rohrer)

53 Stein

2014: Der Gletscher ist wiederum stark zurückgegangen und hat vor allem an Mächtigkeit verloren. (D. Rohrer)

2015: Starker Rückgang auch in der Mächtigkeit. (D. Rohrer)

54 Steinlimi

2014: Gletscher hat sich gegnüber dem Vorjahr nicht stark verändert, ist aber wieder um mehr als 80 m zurückgegangen. (D. Rohrer)

55 Trift (Gadmen)

2014: Luftbildaufnahmen am 23.9.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 5.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

57 Oberer Grindelwald

2014: Luftbildaufnahmen am 23.9.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 5.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

58 Unterer Grindelwald

2014: Luftbildaufnahmen am 23.9.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 5.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

59 Eiger

2014: Der Rückzug des Eigergletschers hält an, besonders am rechten (östlichen) Rand und in Gletschermitte, wo Löcher zunehmen und die Eisdicke abnehmend aussieht. Eisablagerungen von höhergelegenen Gletscherteilen unter dem Mönch verursachten möglicherweise den Vorstoss links. (R. Zumstein)

2015: Messung mit Theodolit. Berührungslos gemessen. (R. Schai)

60 Tschingel

2014: Weiteres starkes Zurückweichen vor allem auf der sonnigen linken Seite (Wärmeabstrahlung von Fels/Moräne); dort auch flacher geworden. Gletscherfront bei G neu gut sichtbar. Eissporn zwischen den Punkten G und A, Kante zum höchsten Punkt des Gletschers. Wenig Wasseraustritt beim Gletschertor. (R. Zumstein)

2015: Rückgang besonders auf der sonnigen linken Seite. Leichter Vorstoss rechts bei Punkt G' könnte auch Moränenmaterial sein. Kein Gletschertor sichtbar. (R. Schai)

61 Gamchi

2014: Seitenarm bei E hat sich praktisch vom übrigen Gletscher gelöst, daher wurde der Messpunkt ohne Berücksichtigung aufgegeben. Der Gletscher löst sich in seinem unteren Bereich völlig und schnell auf, die Mächtigkeit beträgt oft nur noch wenige Meter. (R. Descloux)

2015: Messpunkt b aufgegeben, da Gletscher keine Verbindung mehr zum Nährgebiet hat. Punkt a direkt auf die Gletscherzunge neu gesetzt. (R. Descloux)

62 Schwarz

2014: Mit GPS wurde die Positition des Gletscherendes gemäss Triangulation von 2013 überprüft. Die beiden so erfassten Punkte liegen nah beieinander. Daraus wurde die Längenveränderun ab i_0 ermittelt. (E. Coleman Brantschen)

2015: Der 2014 gemalte Punkt ist nun weit ausser Reichweite: das Eis ist um ca. 2 m abgesackt. Das 2014 sichtbare Gletschertor ist weg, erkennbares Gletschertor ca. 100 m aufwärts. Auch oberhalb grossflächiges Auflösen des Gletschers. (E. Coleman Brantschen)

64 Blümlisalp

2014: Schmale Eiszunge in steilem Gelände - schwierige Messbedingungen (U. Burgener)

2015: Schwierige Messbedingungen. Einrichten neuer Basismesspunkte nötig. (U. Burgener)

65 Plaine Morte

2014: Ausbruch vom Lac des Faverges mit 1 bis 1.5 mio m^3 am 7.8.2014. Der ganze See hat sich innerhalb von etwas mehr als einem Tag subglazial entleert und in der Lenk zu einem Hochwasser ohne Schäden geführt. (M. Huss)

66 Tiefen

2014: Das Mass des Rückganges ist mit jenem des Vorjahres praktisch identisch. Im Vorfeld der Gletscherzunge liegt ein untiefer See. Die mit Schutt bedeckte Eismasse am südlichen Rand taut sehr schnell. Der Bach dürfte sich im Laufe der Zeit weiter in das Lockermaterial im Gletschervorfeld abteufen. (L. Eggimann)

2015: Rückgang ausgeprägter als in den letzten Jahren. Den See im Vorfeld der Gletscherzunge gibt es nicht mehr. Die südliche, weit vorragende Gletscherzunge dürfte nächstens vom Hauptgletscher abreissen. Die Messung von Pt. 8 wurde weggelassen, da das Messresultat zu stark verfälscht worden wäre. Neuer Messpunkt (Pt. 15) eingerichtet. (L. Eggimann)

67 St. Anna

2014: Der Rückgang liegt auch bei diesem Gletscher im Rahmen der letzten Jahre. Durch den leichten Schneefall am Vortag der Begehung liess sich der Rand des Gletschers sehr gut nachvollziehen. (L. Eggimann)

2015: Die Gletscherzunge ist gut 3 m mehr abgeschmolzen als im Vorjahr. Der Massenverlust dürfte sich dagegen verlangsamt haben. (L. Eggimann)

68 Kehlen

2014: Der Rückgang ist markant. Der Grund dafür liegt in einem Toteisfeld. 2013 war der Gletscher noch über eine dünne Eiszunge mit dem Eisfeld verbunden. Aber bereits damals nährte der Gletscher diese Eismasse nicht mehr. (M. Planzer)

2015: Markante Verminderung des Rückgangs: die Gletscherzunge liegt momentan am vorderen Rand eines grossen flachen Beckens. Bei mehreren Messpunkten war eine direkte Peilung wegen fehlender Sicht zum Gletscher nicht möglich. Daher wurden vier neue Messpunkte eingrichtet. (M. Planzer)

69 Rotfirn

2014: Die Messungen erfolgten wahrscheinlich an einer Toteismasse, welche von oben nicht mehr genährt wird. (M. Planzer)

2015: Dank der starken Schuttbedeckung hat sich der Rückzug der Gletscherzunge gegenüber dem Vorjahr verlangsamt. Die Verbindung des im Talboden liegenden Gletscherfeldes mit dem Hauptgletscher ist nur noch schwach und dürfte im nächsten Jahr abreissen. (M. Planzer)

70 Damma

2014: Rückgang ist ähnlich gross wie im Vorjahr. Gletscherzunge ist unbegehbar und konnte nicht mit dem GPS vermessen werden. (M. Planzer)

2015: Der Rückgang hat sich in diesem Jahr stark beschleunigt. Auch die Mächtigkeit des Gletschers ist stark am Schrumpfen. Die nordwestlich liegende Gletscherzunge ist nur noch durch ein schwaches Eisband mit dem Hauptgletscher verbunden. (M. Planzer)

71 Wallenbur

2014: Der Gletschertunnel auf der westlichen Seite ist eingebrochen und weggeschmolzen. Dadurch wurde der vorgelagerte Eisblock zu Toteis, und der Gletscher ist auf dieser Zungenseite stark zurückgegangen. (P. Kläger)

2015: Die unter Schutt liegende Eismasse hat deutlich weniger stark abgenommen als im Vorjahr. (P. Kläger)

72 Brunnifirn

2014: Bei den angegebenen Werten handelt es sich um den Rückgang in 5 Jahren. Der relativ kleine Distanzverlust dürfte darauf zurückzuführen sein, dass nachdem der Gletscher rasch über die steile Felsstufe weggeschmolzen ist er nun in flachem Gelände vorerst stark in seinem Volumen (Höhe) abnimmt, bevor er weiter zurückweicht. (M. Planzer)

2015: Der Rückzug der Gletscherzunge ist trotz des heissen Sommers erstaunlich gering. Da der Gletscher in einem flachen Becken liegt, erfolgt der Eisverlust ausschliesslich über die Höhe. (M. Planzer)

74 Griess

2014: Der ganze Zungenbereich liegt unter einer Schuttmasse aus Steinen und Blöcken, und der starke Zerfallsprozess schreitet weiter voran. Dauernde Eisabfälle in den Gletschersee. (B. Annen)

2015: Der Rückzug liegt leicht über dem der Vorjahre. Es lässt sich ein eigentlicher Schrumpfungsprozess beobachten. Der Zungenbereich hält sich dank Schuttauflage erstaunlich lang am Leben. (B. Annen)

75 Firnalpeli

2014: Unterschied zwischen verfirntem Schnee und blankem älteren Gletschereis nicht feststellbar. Deshalb ergibt sich hier ein "Vorstoss" der Zunge, welcher sich aber mit dem zweijährigen liegen gebliebenen Schnee erklären lässt. (M. Meier)

2015: Gletscherende weiterhin mit verfirntem Altschnee bedeckt. (M. Jäggi)

76 Griessen

2015: Gletscherende mit etwas Neuschnee bedeckt. (M. Jäggi)

77 Biferten

2014: Dieses Jahr war die Suche nach den Gehilfen für einmal das kleinste Problem. Hatte ich doch plötzlich Interessenten und Ehemalige die sich bereit erklärten mit mir den Bifertengletscher zu vermessen. Da war in diesem Sommer und Herbst eher der Wettergott der Spielverderber. Doch am Samstag 4. Oktober 2014 fand ich das ideale Wetterfenster um die Messung zu starten. Ein kurzes Telefon im Vorfeld an Kurt Stüssi, den Chef der Bautruppe im KLL, um abzuklären ob denn das Stativ wieder an seinem Startplatz deponiert war und wie er den momentanen Stand so einschätze sind meine wesentlichsten Vorarbeiten. Alles andere läuft beinahe wie von selbst, so kann ich zeitlich am Morgen meinen Gehilfen Hans-Rudolf Hösli alt Metzgermeister Ennenda, in Netstal abholen. Er hat sich bereits im 2013 bereits einmal mit mir an den Bifertengletscher gewagt, damals mit dem Resultat, dass wir ausser einer "Begehung" leider keine Messung heim brachten. Da war ja dann eine zweite Begehung nötig, dort aber mit Roman Müller, weil Hans-Rudolf "Ferien halber" weg war. Bis Linthal und ins Tierfehd sind die Strassen bestens fahrbar, ab Tierfehd bis hinauf nach Hintersand bin ich dann um den Vermesserbus mit hohem Radstand und Allradantrieb froh. So kommen wir ohne Probleme zu unserem Startpunkt, wo wir die Bergschuhe schnüren müssen, um an unsere Messpunkte zu gelangen. Bei der Sandrisi begrüsst uns diesmal mit einer kleinen Wolkenfahne der höchste Glarner der Tödi. Freudig "grüssen" wir zurück und halten den tollen Blick fotografisch fest. Steil und ohne flaches einlaufen steigen wir dem Bifertengletscher entgegen. Im Rucksack ausser dem Stativ, das übliche Vermessungsmaterial und auch Kleider zum Wechsel, nach dem schweisstreibenden Fussmarsch und etwas Proviant. Im Tentiwang ist die erste Rampe bewältigt und eine Ebene lässt uns etwas verschnaufen, bevor dann der zweite Teil hinauf zur KLL Schutzhütte folgt, um dort das Stativ zu fassen und zum Ausgangspunkt 2003 anzusteigen. Überall an den neuralgischen Punkten und Ausblicken werden

Fotos geschossen um die Verhältnisse im 2014 zu dokumentieren. Das Wetter spielt mit und ebenfalls die Temperatur, die natürlich für einen Gletscherzuwachs einmal mehr zu warm ist, aber von uns Vermesser als sehr angenehm empfunden wird. Der obligate "Znünihalt" bei der Station 2003 und eine kurze Instruktion für meinen Gehilfen und die Kartierung des Gletschers kann beginnen. Nach der Orientierung auf der Station E begibt sich mein Gehilfe mit Sack und Pack der Gletscherzunge entlang hinauf Richtung Süd um mir die einzelnen Eckpunkte der Gletscherzunge zu übermitteln. Dabei ist auch die Überquerung des Gletscherbaches 1 kein grosses Problem. Da sich das Tor immer weiter nach oben zurückzieht, ist der tiefste Punkt auch der erste Punkt der Messung. Er hat sich trotz des recht flachen Vorgeländes wiederum um 2.4 m hinauf bewegt, ebenfalls ein Indiz, dass sich der Gletscher zurück zieht. Der Gletscherbach und sein Tor liegen bereits auf 1972.3 m.ü.M. dies ist ebenfalls 1 Meter höher als im Vorjahr. Wie immer ist die Erfassung im nordöstlichen Teil des Gletscher eine Herausforderung: Geröll wie in einem Steinbruch lassen die Zunge nur erahnen, doch immer wieder kann man einzelne Kantenstücke erkennen und so den Verlauf in etwa festlegen. Mit 10 Mess-Punkten kann mir der Gehilfe dieses Teilstück übermitteln. Danach ist der Operateur gefragt, indem er einen Standortwechsel vorzunehmen hat. Also, Instrument einpacken, Stativ schultern und hinauf Richtung Station 20101 aufsteigen. Während dieser Zeit kann sich der Gehilfe etwas ausruhen, verpflegen und die Umgebung geniessen. Auf dem Weg nach oben, komme ich der Gletscherzunge natürlich ebenfalls sehr nahe, dies muss dann auch im Bild fixiert sein. So entsteht einmal mehr doch eine eindrückliche Dokumentation des Zustandes von 2014. Sobald die Stationierung auf dem Fixpunkt 20101 erfolgt ist und die Orientierung am Giebel der Grünhornhütte ausgeführt und mit dem Theodolit registriert ist, kann die Messung fortgesetzt werden. Nach wenigen Punkten gelangt Hans-Rudolf Hösli zum Gletschertor 2. Die Höhe dort beträgt 1992.0 m.ü.M. ist insgesamt um 12 m tiefer als im Vorjahr, trotz des grossen Rückzuges gerade auch in diesem Bereich. Der Höhenverlust rührt wohl daher, dass der Gletscher in diesem Bereich eine Mulde hinterlässt, die vorher nicht einsehbar war. Ab dem Gletschertor 2 wird eigentlich das Begehen des Gletschers erst so richtig spannend, obwohl dies eigentlich mehr als Wange statt als Zunge des Gletschers bezeichnet werden kann. Aber der Bifertengletscher wird mehr und mehr nur noch eine schlanke Figur die immer weniger Breite hat. Mit 27 Messpunkten haben wir im 2014 den Gletscher kartiert. Die Minusfläche ist dieses Jahr riesig, sie beträgt 37'744 m^2. Die gemessen Breite dazu ist mit 763.4 m doch recht lang. Trotzdem ergibt dies für den Rückgang des Gletschers eine erschreckende Zahl, nämlich -49.4 m. Dieses Resultat ist mit Abstand der höchste Rückzug seit ich die Messungen ausführe. Im 1994 hatte ich mit -38.6 m, dies aber über 3 Jahre, einen ähnlich hohen Schwund. Sicherlich hat sich im Bereich des Gletscherbaches 2 einiges getan, dass dies aber derart frappant ist, hätte ich doch nicht gedacht. Wenn dies so weiter geht, so bin ich dann bald unter dem Grünhorn und beobachte den Gletscher in diesem Bereich. Nach getaner Arbeit am Gletscher, steigen wir, nachdem der Gehilfe zu mir zur Station stösst, gemeinsam über die immer wieder knifflig zu begehende Dr. Streiff-Becker Moräne zur alten Fridolinshütte auf, um dort unser Stativ zu deponieren. Dieses wird in verdankenswerter Weise dann wieder von den KLL Mitarbeitern an den Startort bei der KLL Unterkunft befördert. Leider ist die Fridolinshütte nicht mehr bewartet und so steigen wir ohne gross zu rasten und ruhen, hinab ins Tal zu unserem Bus in Hintersand. Die Fahrt zurück ins Tierfehd verläuft ebenfalls ohne Probleme. Nach einem kurzen Umtrunk im Garten des Restaurant Rütihof endet die Messung unfallfrei und erfolgreich. Für Hans-Rudolf ein toller erster Messgehilfen-Einsatz, ohne diese Mithilfe wäre die beinahe ununterbrochene Messreihe kaum messbar, danke. Im 2015 wird sich dann weisen, was sich da am Bifertengletscher weiter tut. Ich hoffe, dass dies ein Ausreisser in Sachen Schwund ist, ansonsten wäre ja meine Arbeit wohl bald gefährdet?! Sicherlich steige ich gespannt auch im nächsten Jahr wieder zum Bifertengletscher hoch und beobachte ihn auf's Genauste. (H. Klauser)

2015: Beinahe genau 1 Jahr nach der Messung 2014, nämlich am 03.10.2015 machen wir uns wieder auf den Weg zum Bifertengletscher, einmal mehr der treue und bereits versierte Gehilfe Hansruedi Hösli alt Metzgermeister aus Ennenda und meine Wenigkeit. Die Verhältnisse für die Messung lassen uns zuversichtlich Richtung Linthal, Hintersand fahren um schliesslich zum Gletscher aufzusteigen. Der Wetterbericht verspricht mit etwas Föhn bis zum frühen Nachmittag trockene Verhältnisse. Die Bewölkung, die nach kurzer Phase mit blauem Himmel, bereits am Morgen den Himmel bedeckt, ist für unsere Arbeit nicht weiter tragisch, da diese hoch an den Gipfeln hängt. Die warmen Temperaturen zeigen deutlich, der älteste Glarner (Föhn) hat seine Hand im Spiel. Er vermag aber nicht "z'Bodä", dies zu unserem Glück, sonst hätten wir mit starken und unangenehmen Windböen zu kämpfen. Der Nebel der uns beim Zurückblicken im Tentiwang entgegenzüngelt wäre ein weiterer Spielverderber bei der Messung, dies passiert dann nur kurz vor Ende der Messung auf der Station 20101, er macht sich dann aber wieder aus dem Staub, vielmehr er wird durch den aufkommenden Regen verdrängt. Die Messung konnten wir aber trocken über die Runde bringen, schliesslich mussten wir nur das "ZMittag" an der "Tröchni" essen (in der alten Fridolinshütte, Winterraum, weil die Hüttenwärtin bereits eingewintert hat). Zum Abstieg hellte es dann nochmals auf und so konnten wir auch den Abstieg trocken bewältigen. Danach liess sich dann aber der Regen nicht mehr aufhalten, alle Schleusen öffneten sich. Es schien als sei dies der Weltuntergang; dies konnte uns zweien aber egal sein, wir hatten ja die Messung im Trockenen. Während des Zustieg zum Gletscher gehören wiederum diverse Fotohalte im Tentiwang und kurz vor der Unterkunftshütte dazu, um der Nachwelt die Verhältnisse an diesem Oktobertag im 2015 zu dokumentieren. Die warmen Verhältnisse und auch das bekannte Resultat am Glärnischgletscher lassen auch für den Bifertengletscher keine Euphorie in Sachen Wachstum aufkommen, aber ...?! Wiederum hat der Bautrupp der KLL das Stativ von der Deponie alte Fridolinshütte hinunter zum Ausgangspunkt Unterkunftshütte KLL befördert, dies klappt immer vorbildlich. Wir packen dieses noch zusätzlich zu unseren Lasten und steigen über den exponierten Weg hinauf zur Station 2003, wo wir wie gewohnt nach einem Znünihalt unsere Messung beginnen. Der erste Punkt am Gletscher ist auch der tiefste Punkt des Gletschers, 1963.9 m.ü.M gegenüber dem Vorjahr 1965.5 m.ü.M, da bereits 1.6m tiefer, etwas unüblich, wenn sich der Gletscher "aus dem Staub machen sollte"? Da in dieser Region aber immer viel Geröll liegt und der Gletscher recht schwer auszumachen ist, könnte dies auch auf dies zurückzuführen sei. Ein kleiner Gletscherbach auf der Höhe von 1969.1 m.ü.M bahnt sich den Weg zum eigentlichen Gletscherbach, der wiederum nicht beim eigentlichen Gletschertor (1973.7 m.ü.M) sondern etwas westlicher unter dem Gletscher hervortritt (1971.8 m.ü.M). Der für mich immer wieder interessante Messpunkt vom Austritt Gletscherbach hinunter bis zur Fassung 2 beträgt bereits 190.2 m. 1977 nochmals zur Erinnerung musste ein Stollen in den Gletscher gesprengt werden, damit das Wasser überhaupt in die Fassung floss. In diesem Bereich ist der Gletscher weiter im Rückzug. Im Bereich der Höhe 1984.0 m.ü.M ist die Gletscherzunge derart schwierig auszumachen, dass da Schwankungen seitens der Messung nicht auszuschliessen sind. Bis hinauf zur Höhe 2003.0 m.ü.M ist wieder klar Schwund auszumachen, was dann ab dieser Höhe die Messresultate hergeben, kann ich noch nicht schlüssig beurteilen, der Gletscher stösst hier doch beträchtlich vor. Die Messung dieses Bereiches habe ich wiederum von der Station 20101 ausgeführt und auch nachträglich im Büro noch überprüft. Das mächtige Gletschertor mit seinem unterliegenden fjordähnlichen See liegt auf einer Höhe von 2004.7 m.ü.M (12 m höher als im Vorjahr) In diesem Bereich muss ich mittels "Vorstellen" die Umrisse des Gletschers erfassen, da der grosse See wohl nur mit einem Boot zu befahren wäre, umso an die Gletscherzunge zu gelangen. Danach steigt der Gehilfe stetig bergan und schliesst auf 2043.5 m.ü.M die Messung 2015 ab. Bereits beim Rückweg zum Instrumentenstandort macht sich Petrus bemerkbar, indem er uns etwas Regen schickt. Dieser hindert uns jedoch nicht, über die Becker-Streiff Moräne hinauszusteigen und schliesslich zur alten Fridolinshütte aufzusteigen. Nach der Deponie des Statives, das wie bereits berichtet wieder von den treuen KLL Mitarbeitern zur Unterkunftshütte zurücktransportiert wird, nehmen wir das wohlverdiente Mittagessen in der Hütte ein, weil die Schleusen nun nochmals kräftig geöffnet werden. Der Regenbogen, den wir beim bereits wieder trockenen Abstieg bildlich festgehalten haben zeugt von der grossen Feuchtigkeit, aber gleichzeitig auch von der wärmenden Sonne. So steigen wir den Hüttenweg hinunter nach Hintersand, einmal mehr mit der Gewissheit, dass die Messung geglückt ist und dies wiederum unfallfrei. Dass der Gletscher dieses Jahr um 17.6 m gewachsen ist, verblüfft mich und ich bin immer noch auf der Suche nach einer plausiblen Erklärung. Diese werde ich wohl erst mit dem Vergleich der Messung im kommenden Jahr bekommen oder werden wir noch weiter überrascht? Bereits bei der Fahrt von Hintersand hinunter ins Tierfehd und nach Linthal giesst es wie aus Kübeln, zum Glück sind wir an der "Tröchni" und bald zu Hause. Die Auswertung im Büro braucht dieses Jahr viel mehr Zeit, da ich auf ein neues Vermessungsprogramm umsteigen muss und da noch einige Einstellungen vornehmen muss. Schliesslich glückt auch dies und so hoffe ich in den kommenden Jahren wieder speditiv das Büro zu erledigen umso das Resultat auch zeitig abliefern zu können. (H. Klauser)

78 Limmern

2014: Messrichtung nicht mehr parallel zur zentralen Fliessrichtung. Bei Punkt 5 besteht eine Eisbrücke. (U. Steinegger)

2015: Gletscherrand bei den Punkten 1 bis 4 stark schuttbedeckt. Gletscher mit etwas Neuschneebedeckt. Kaum Firnrücklagen vom vergangenen Winter übrig. (U. Steinegger)

79 Sulz

2014: Der Bereich des Gletschertores hat sich gegenüber 2013 deutlich verändert. Ein grösseres Stück der Gletscherzunge ist abgebrochen, liegt aber noch vor dem eigentlichen Gletscher. Der Verlauf des Gletscherbaches wurde durch Geschiebeablagerungen um mehrere Meter (ca. 20 m) nach Westen verlegt. (S. Kamm)

2015: Der Bereich des Gletschertores hat sich gegenüber 2014 wiederum deutlich verändert. (S. Kamm)

80 Glärnisch

2014: War es letztes Jahr noch August als ich mit meinen Gehilfen zusammen den Gletscher besuchte, so wird es dieses Jahr, Anfang September, nämlich der Samstag 06.09.2014. Dies rührt diesmal nicht daher, dass ich keinen Gehilfen fand, sondern vielmehr daran, dass der "flüssige" (nasse, feuchte) Sommer uns kaum Wochenende bescherte die uns nur im Geringsten eine Chance liessen den Gletscher zu vermessen. So machen wir uns an diesem Samstag mit dem Glauben an den doch vielversprechenden Wetterbericht auf zum Gletscher. (mindestens Trocken sollten wir über die Runde kommen) Einmal mehr begleitet mich dabei der bereits eingefleischte Gehilfe Roman Müller. Blauer Himmel und recht angenehme Temperaturen sind am Startort in Wärben unser "Begrüssungskommite". Nach der Verteilung der Lasten, nehmen wir den gut 1 1/2h Aufstieg in Angriff. Edelweissgruss und Kaffeehalt natürlich inbegriffen (Danke dem Hüttenwart-Team), kommen wir trotzdem zügig hinauf zum Gletscher. Wäschewechsel, damit der Operateur am Instrumentenstandort nicht friert, noch kurz einen Schluck aus der Wärmflasche und dann beginnt die Gletscher-Vermessung. Da bereits seit einigen Jahren die Messungen hin zum südlichen Ende des Gletschers recht mühsam von statten gehen, da sich der Gletscher hinter der Felsrippe in der Tiefe versteckt, entschliesse ich mich, mit einer temporären Hilfsstation (Nr. 15) auszuhelfen und somit besser und einfacher den Südteil des Gletschers zu erfassen. Nach kurzer Instruktion meines Gehilfen wie wir da vorgehen, kraxelt Roman behände und gewandt hinunter zur Zunge des Gletschers. Die Messung mit dem selbstspeichernden Theodoliten TCRM 1101 von Leica lässt uns rasch und doch äusserst präzise die Gletscherzunge im Süden für dieses Jahr erfassen. Sobald Roman aus meinem Wirkungskreis enteilt, wechsle ich zurück zur Station 14, von der aus der restliche Bereich des Gletschers hin zum Nordende noch erfasst werden kann. Dabei kann ich meinen Gehilfen immer bestens überwachen, da die Station 14 beinahe wie ein Adlerhorst hoch über dem Gletscher thront. Dies vielmehr um allfällige Stürze oder Probleme frühzeitig zu erkennen als dass er sich etwa aus dem Staub machen wollte. Gletscher vermessen ist ja nicht einfach ein Spaziergang, dies erfordert doch Trittsicherheit und überlegtes Gehen im Gelände. Einmal mehr meistert dies mein Gehilfe Roman bravourös und so können wir mit gut 50 Messpunkten den Gletscher wiederum bestens repräsentieren. Unser Gefühl, dass wohl auch dieses Jahr kein Wachstum zu erwarten ist, bestätigt sich dann bei der Auswertung im Büro. Einmal mehr zieht sich der Gletscher zurück und dies etwa in den nun bald gewohnten Grössenverhältnissen nämlich im Mittel um 7.4 m. Während der Messung ziehen Wolken auf, zwischenzeitlich habe ich bald Angst, es könnte uns noch der Nebel einen Streich spielen und auch ein nasser Abstieg könnte uns noch beschieden sein, doch dem ist nicht so, der Nebel verkriecht sich in höhere Gefilde und auch die Nässe bleibt aus, so dass ich noch ohne Probleme die Anschlussmessungen ausführen kann, die ich auf den Schluss hinausgeschoben habe, damit der Gehilfe nicht zu viele Wege zurücklegen muss und so ein "runder" Ablauf der Messungen gewährt ist. Der tiefste Punkt am Gletscher, der auch gleichzeitig der Austritt des Gletscherbaches ist befindet sich nur gerade 0.4 m höher als letztes Jahr auf 2345.2 m.ü.M. Die Ursache für diesen geringen Rückzug in der Höhe liegt darin, dass der Gletscher in diesem Bereich ein beinahe flaches Vorgelände ausweist. Ein zweiter Gletscherbach sucht sich ebenfalls noch den Weg ins Tal. Dieser tritt auf 2353.4 m.ü.M an die "frische Luft" aus dem Schlund des Gletschers. Nach getaner kann sich der Gehilfe in der Nähe der Station 12 ausruhen und sich verpflegen. Meine Wenigkeit baut die Station ab, verstaut das Instrument und die restlichen Messutensilien im Rucksack um zu meinem Gehilfen zu gelangen. Dabei bewege ich mich ebenfalls der Zunge entlang Richtung Nordende. Fotografisch halte ich da und dort noch Einzelheiten fest um dies schliesslich als Dokument diesem Bericht beizulegen. Eine kurze gemeinsame Rast am Ende der Mess-Strecke und dann nehmen wir den Abstieg ins Tal unter die Füsse. Glücklich, dass bereits ein Gletscher "im Kasten" ist, aber immer mit der nötigen Vorsicht, dass auch der Abstieg unfallfrei bewältigt werden kann. Der Schnitz Wähe und etwas Flüssiges bei der Glärnischhütte ist ein kleiner Vorschuss-Lohn an den Gehilfen und natürlich schmeckt der auch dem Operateur. Fachsimpeln vor der Hütte mit ankommenden Alpinisten könnten wir wohl noch lange, doch wir wollen ja noch bei Tageslicht das Tal erreichen und so eilen wir gestärkt unserem Bus in Wärben entgegen. Wohlbehalten erreichen wir diesen und können die Messung 2014 von der Feldseite her, als erledigt abhaken. Bereits sinnieren wir bei der Hinausfahrt aus dem Rossmattertal, was uns denn nächstes Jahr da oben wohl erwarten wird. Dass dabei ein müder Wandersmann unseren Taxidienst gerne in Anspruch nimmt sei hier nur am Rande erwähnt. So schliesse ich diesen Bericht, danke aber meinem treuen Gehilfen Roman für seine tolle Arbeit am Gletscher und hoffe, dass sich im 2015 der Gletscher doch endlich einmal erholen kann und wir nicht immer höher und höher steigen müssen. Dies ist aber wohl eher Wunschdenken, denn wenn da nicht die ganze Welt mithilft, der Klimaerwärmung Einhalt zu bieten so wird sich da wohl in nächster Zeit kaum etwas verändern, oder hat etwa die Natur noch einen Trumpf in der Hand?! (H. Klauser)

2015: Nach einem Jahr und 2 Wochen mache ich mich dieses Jahr auf, um den ersten Gletscher, den Glärnisch zu vermessen. Dabei begleiten mich erstmals am Glärnisch mein bereits eingearbeiteter Gehilfe vom letzten Jahr beim Biferten, Hansruedi Hösli alt Metzgermeister aus Ennenda und zusätzlich Brigitte Tiefenauer von der Südostschweiz (Regionalzeitung) als Reporterin um über dieses doch immer mehr Aufmerksamkeit auf sich ziehende Thema Gletscher haut nah zu berichten. Der bereits eine Woche frühere Termin viel dem doch garstigen Wetter zum Opfer. An diesem Samstag stimmt dann einfach alles, herrliches Wetter und beste Stimmung im Team. Wie gewohnt, nach Aufnahme meiner Begleiter im Bus ab Wohnort und Bahnhof (Brigitte), fahren wir holprig und geschüttelt hinauf nach Wärben. Bereits während der Fahrt diskutieren wir eifrig über den Zustand der Gletscher und die vorangegangenen Messungen: Was erwartet uns wohl dieses Jahr? Die Lasten werden aufgeteilt und los geht die Exkursion Gletscher 2015. Nach kurzem Halt bei der Edelweissplatte (was auch die Bilder belegen) streben wir der Hütte zu, wohl wissend, dass der Hüttenwart bereits abgezogen ist und er die Hütte auf den Winter vorbereitet hat. Trotzdem eine kurze Verschnaufpause an besagter Stelle, danach wollen wir endlich visuell wissen wie es denn "unserem" Gletscher so geht. Trotz Schneebedeckung lässt es einem wiederum Böses ahnen, was sich dann schliesslich auch in Zahlen bewahrheitet. Einmal mehr kann ich mit dem im letzten Jahr bestimmten HP 15 und der Station 14 die gesamte Gletscherzunge erfassen und kartieren. Nach "frischmachen" am Stationspunkt und einem kurzen "Znünihalt" kann ich Hansruedi los schicken um mir die Gletscherzunge von Süd nach Nord zu begehen und mir die Eckpunkte am Gletscher mittels Reflektor zu übermitteln. Gleichzeitig weihe ich auch Brigitte Tiefenauer in die Geheimnisse der Vermessung und der Gletschermessung ein. Beeindruckt begleitet sie dann in der ersten Hälfte vom südlichen Ende bis zur Felsrippe auf der ich mich installiert habe Hansruedi auf seinem Weg. Eindrückliches Bildmaterial und auch die Reportage zeugen von einer wirklich beindruckten Reporterin, die mit Begeisterung und Anerkennung für unsere Arbeit unterwegs war. Einmal mehr benütze ich den selbstspeichernden Theodoliten TCRM 1101 von Leica. Die Zielpunkte um das Azimut zu bestimmen sind ebenfalls wieder dieselben, nämlich Punkt 12 und 13, die mein Gehilfe am Schluss der Messung noch übermittelt, da sie ja gegenüber von Punkt 14 und 15 liegen. Daher hängt anfänglich alles am Gipfelkreuz, das ich als Fernziel immer mit messe. Mit gut 30 Messungen bestimmen wir dieses Jahr die Zunge und müssen einmal mehr einen grossen Schwund ausweisen: dieser beträgt im Mittel 34.0 m über die gemessene Breite von 428.6 m und einer "Schwundfläche" von 14'594.8 m^2. Die Höhenmessungen zeigen ebenfalls deutlich, dass sich der Gletscher aus dem Staub macht, ist doch in einem doch recht sanft ansteigenden Vorgelände der Unterschied von genau 2.0 m von 2345.2 m.ü.M vom Vorjahr auf 2347.2 m.ü.M ein deutliches Resultat. Der tiefste Punkt ist auch gleichzeitig am Austritt des Gletscherbaches der sich dann durch die Gletscherschliffe hinunter den Weg ins Tal sucht. Gut auszumachen sind auch die beiden Kessel in denen die Zunge sich noch hineinzwängt, getrennt durch die Felsrippe mit den Fixpunkten 14 und 15. Der Start im Norden (2396.0 m.ü.M) ist beinahe gleich hoch wie der Punkt oben an der Felsrippe 2406.0 m.ü.M) Der gesamte Kessel ab der Felsrippe gegen Norden ist dagegen allgemein tiefer gelegen. Bei der Höhe 2375.0 m.ü.M frisst sich ebenfalls eine weitere Felsrippe ins Eis und trägt weiter zum Schmelzen mittels "Bettflascheneffekt" bei (Wärmespeicherung am Fels unter Tag und Abgabe bis weit in die Nacht hinein, dann wenn der Gletscher eigentlich auskühlen sollte) Die Messung verläuft einmal mehr rationell und unfallfrei, dies dank meinem Gehilfen Hansruedi, der einmal mehr gewandt und sicher der Zunge entlang balanciert und die wichtigsten Punkte für die Kartierung übermittelt. Man sieht ihm die Freude bei dieser Arbeit so richtig an, er ist stolz ein Teil dieser doch interessanten Forschungen zu sein. Nach den Anschlussmessungen auf den beiden Punkten 13 und 12 hat der Gehilfe seine Arbeit getan und kann sich ausruhen und auch einmal verpflegen. Nun machen wir (Brigitte und der Operateur) uns auf den Weg ebenfalls der Zunge entlang zum Gehilfen, dabei wird das Erfasste noch genauer begutachtet und auch fotografisch festgehalten, dies alles bei herrlichstem Herbstwetter und mit nur wenigen Alpinisten die gegen das, oder vom "Gärtli" steigen. Klar scheint uns bereits vor Ort, dass der Glärnischgletscher wieder an Mächtigkeit verloren hat und sich mehr und mehr zurückzieht. Nach einer kurzen Mittagsrast zieht es uns dann den gewohnten weg wieder hinunter nach Wärben. Brigitte Tiefenauer mit vielem Bildmaterial und wohl tiefgehenden Eindrücken laden wir schliesslich beim Medienhaus in Glarus aus, jedoch wohl kaum noch um heute den Bericht auch noch zu verfassen, wohl vielmehr um das Bildmaterial abzulegen. Hansruedi führe ich noch nach Ennenda und ich bringe die Messutensilien ins Büro zurück, natürlich inklusive unsern doch so patenten Vermesserbus, der uns den Arbeitsweg doch um einiges verkürzt. So geht einmal mehr eine Messung unfallfrei zu Ende. Die Auswertung im Büro macht mir momentan bald mehr Kopfzerbrechen, da die ständige Änderung der Programme doch so einiges an Mehraufwand nach sich ruft. Schliesslich kann ich dann aber doch sämtliche Akten erstellen und so an die VAW übermitteln. Immer noch zuversichtlich, dass nach langer und warmer Periode auch wieder einmal eine Kältere folgt, steige ich auch nächstes Jahr wieder hinauf zum Glärnischgletscher um seine Veränderungen zu beobachten. (H. Klauser)

81 Pizol

2014: Im Bereich der Linien 2 und 3 fällt wie im Vorjahr die Schuttflächen auf. Von links (gegen den Gletscher gesehen) wird Material, mit viel Feinanteil eingeschwemmt. Es deckt Eisflächen ab, welche wohl auch mal zum Gletscher gehörten. Hinter diesem Vorfeld steigt der Gletscher immer noch mit einem markanten Geländeknick an. Aufgrund von viel Geröll ist der Rand in Linie 5 weiterhin nicht sicher bestimmbar. Die Felsen im oberen Teil des Glerschers sind 2014 etwas weniger stark freigelegt worden als in den Vorjahren, aber ein Absinken der Gletscheroberfläche ist immer noch erkennbar. (Th. Brandes)

2015: Der viele Schutt und das Geröll am unteren Gletscherrand machen eine genaue Messung immer etwas schwierig. Bei den Linien 3 und 5 ist ein Firnfeld vorgelagert, der Eisrand ist nicht eindeutig feststellbar. (Th. Brandes)

83 Punteglias

2015: Die mittlere Gletscherzunge wird schmäler. Der Gletscher hat sich im Vergleich zum Vorjahr verändert. Die Gletscherzunge drängt bergwärts, die Tälchen zwischen den einzelnen Gletscherkörpern wachsen, der Einbruchkrater auf dem Gletscherkörper wird grösser und am östlichen Gletscherkörper eröffnet sich ein neues Tälchen. Der Gletscher scheint vor allem im westlichen Teil stark an Mächtigkeit eingebüsst zu haben. (Ch. Buchli)

84 Lenta

2015: Der Gletscher ist auf einer Höhenkote von ca. 2700 m.ü.M auseinandergebrochen. (B. Riedi)

87 Suretta

2015: Die imposanten Eisblöcke, welche im Jahr 2014 abgebrochen sind und sich im Gletschervorfeld ablagerten, sind mittlerweile zu einer Einheit verschmolzen und wurden als Teil des Gletschers betrachtet. Dennoch hat der Gletscher auch in diesem Bereich an Mächtigkeit verloren. (C. Fisler)

88 Porchabella

2014: In Februar ist ein 110 m hoher Felsturm aus der Nordwand vom Kesch auf den Gletscher gefallen. Die Ablagerung betragen 150'000 m^3. Der Zeitpunkt kann auf die erste Hälfte Februar eingegrenzt werden. (M. Phillips/SLF)
Wegen den Felsablagerungen erwies sich die Ermittlung des Gletscherrandes im westlichen Bereich als sehr anspruchsvoll. (T. Bearth)

2015: Regelmässige Felsabbrüche aus der Nord-Ost-Flanke des Piz Kesch auf den Gletscher. Ermittlung des Gletscherrandes im westlichen Bereich erwies sich wegen abgelagerten Felsbrocken als sehr anspruchsvoll. (T. Bearth)

90 Silvretta

2014: Luftbildaufnahmen am 27.9.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 7.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

91 Sardona

2014: Die Messung erfolgte ab den Punkten 1B, 2B, 3B, 4B und 5B mit dem Fadenmessgerät (Geländemass) im bisherigen Azimut 289 g (korrigierter Winkel). Die Messung auf der Linie 1 streifte in den Vorjahren jeweils den Rand eines Zungenlappens. Diese Jahr berührte die Linien diesen Zungelappen nicht mehr sondern schneidet weiter oben den Gletscherrand wieder +/- senkrecht. Vermutlich liegt noch Eis im (ehemaligen) Zungenbereich, dieser wirkt jetzt aber mehr wie eine Mischung von Eis und Schutt. Die Seitentore der Vorjahre sind vollständig verschwunden. Links der Linie 1 findet sich auch noch immer der tiefste Punkt des Gletschers. Auf der Linie 4 konnte der Rand trotz Geröll relativ deutlich eruiert werden. (Th. Brandes)

2015: Neuschneeresten im Gletschervorfeld, Eisrand relativ stark schuttbedeckt und nur sehr schwer zu bestimmen. Der Tiefste Punkt befindet sich im Bereich von Linie 1. Dickenverlust zeigt sich deutlich. (Th. Brandes)

93 Tschierva

2014: 3 Stück Holz bei Zungenspitze gefunden. (G. Bott)

94 Morteratsch

2015: Fund Holzstück (791'786/144'080). (G.-A. Godly)

95 Calderas

2014: Gwäschtenabbruch von 2010 inzwischen mit Schnee verfüllt. Zunge wird immer dünner. (G. Bott)

96 Tiatscha

2014: Luftbildaufnahmen am 27.9.2014, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 7.8.2015, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

97 Sesvenna

2015: Es hat sich eine grosse Höhle am östlichen Rand gebildet. (G.-C. Feuerstein)

98 Lischana

2015: Neuer Felsriegel – der untere Teil ist nun grösstenteils vom Nährgebiet abgetrennt. (G.-C. Feuerstein)

100 Palü

2015: Gletscherende von See umgeben. (G. Bergier)

101 Paradisino

2014: Ghiacciaio in parte ricoperto da sassi caduti dalla parete del Corn da Camp (valutazione difficile). (G. Bergier)

2015: Difficoltà a definire il bordo del ghiacciaio sulla parte destra, tutta ricoperta da sassi e blocchi di grande dimensione. (G. Bergier)

103 Bresciana

2014: Occorre segnalare che una superficie di 1.33 ha situata vicino a un affioramento roccioso (vedi piano allegato) non è più considerata collegata al resto del ghiacciaio (ghiaccio morto), mentre lo era nel 2011. Sempre rispetto al 2011 si constata un arretramento medio lungo tutto il fronte di ca. 30.7 m. Se non si considera la superficie scomparsa, l'arretramento medio corrisponde a 4.2 m. L'arretramento più importante si è verificato nella parte centrale del fronte, quella più ripida. (M. Soldati)

2015: Le nevicate di settembre hanno ricoperto il fronte e hanno impedito la misurazione del 2015. (M. Soldati)

104 Basòdino

2014: Il rilievo del 2014 è risultato impegnativo per l'abbondante copertura nevosa del fronte. Proprio per questo motivo, rispetto all'ultima misura, è stato misurato un tratto inferiore del fronte. In generale, rispetto alla misura del 2012, si registra un arretramento medio di 9 m, con una perdita di spessore che varia da 30 cm a 1.20 m. La perdita di spessore massimo (3.2 m) si registra sul 3º punto del profilo longitudinale, che attualmente si trova in corrispondenza del fronte e che verosimilmente in occasione della prossima misura, sarà scomparso. Probabilmente in occasione della misura del 2015, verrà eseguito il rilievo lungo tutta la lunghezza del fronte. (M. Soldati)

2015: La misura del 2015 prevedeva il rilievo dell'intero fronte del ghiacciaio. Au causa della nebbia è però stato possibile rilevate unicamente la superficie già misurata negli scorsi anni. La linea del fronte misurato ha avuto un arretramento medio di ca. 25 metri. Sempre per la nebbia non è stato possibile eseguire il rilievo del profilo per misurare la perdita di spessore. (M. Soldati)

109 Alpetli (Kanderfirn)

2015: Drei neue Basismesspunkte eingerichtet: A 625'567/146'039, B 625'535/146'008 und C 625'666/146'015 (U. Burgener)

111 Ammerten

2014: Bei den Gletschertoren war jeweils noch Winterschnee vorhanden geblieben. Dementsprechend wurde die Gletscherzunge dieses Jahr wohl besser isoliert. (W. Hodel)

2015: Zum Zeitpunkt der Messung lag etwa 5-10 cm Neuschnee. Kein Altschnee vorhanden. (W. Hodel)

112 Dungel

2014: Im östlichen Teil erstreckte sich seitlich von den Felsen bei Pt 2875 südwestlich des Schnidejochs bis in den Zungenbereich ein Band von kompaktem Altschnee. Dies konnte in den letzten 15 Jahren nie beobachtet werden. Die Front der Zunge (die tiefste Stelle) endet auch dieses Jahr wieder in einem kleinen See. (A. Wipf)

113 Gelten

2014: Der Zungenbereich war gut ausgeapert. Die Vermessung beschränkte sich auf das Gletscherband oberhalb einer Felsstufe, die gegen Nordosten hinunterzieht. Die eigentliche Zunge auf der Westseite ist weiter zurückgeschmolzen, ihr östlicher Rand zieht steil südwärts gegen die erwähnte Felsterrasse hoch. (A. Wipf)

114 Plattalva

2014: Der Gletscher ist weitgehend Toteis und hat sich im oberen Bereich aufgetrennt. Punkt 5 bleibt schwierig zu messen, da die Messrichtung schleifend zum Rand verläuft. (U. Steinegger)

2015: Gletscher mit etwas Neuschnee bedeckt, kein Firnschnee vorhanden. Bei Punkt 5 Verlauf vom Gletscherrand weiterhin unklar (schleifend zur Messrichtung). (U. Steinegger)

115 Scaletta

2014: Gletscherende noch mit Winterschnee bedeckt. Keine sinnvolle Messung möglich. (B. Teufen)

2015: Wegen der starken Schuttbedeckung ist die Bestimmung des Eisrandes nach wie vor sehr schwierig. Am bisherigen Ort sind kaum noch Anzeichen von Eis ersichtlich. Die dort seit mehreren Jahren vorhandenen Reste von Lawinenschnee haben sich mittlerweile verfirnt. Das Gletscherende dürfte sich inzwischen deutlich weiter oben befinden. (B. Teufen)

117 Valleggia

2014: Quest'anno, il fronte si presentava completamente libero da neve. L'arretramento medio rispetto al 2012 corrisponde a 6 m; la perdita di spessore, misurata lungo i punti del profilo longitudinale varia tra 3.3 e 4.1 m. Da un confronto visivo con l'ortofoto del 2012, si nota molto bene che il lago proglaciale che si è formato negli scorsi anni, si è notevolmente ingrandito. (M. Soldati)

2015: L'arretramento medio del fronte è di ca. 5 m. La perdita di spessore nei punti rilavati varia da 3.20 a 4.20 m. Il laghetto proglaciale, ben visibile nel 2014, è quasi completamente riempito da depositi detritici (molto fini) trasportati dal ghiacciaio. (M. Soldati)

119 Cavagnoli

2014: Nel 2014 è stato cambiato il punto di misurazione in quanto un'importante superficie di ghiaccio è staccata dal corpo principale del ghiacciaio e non è più alimentata. Di conseguenza, il fronte del ghiacciaio è stato spostato di circa 860 metri in direzione (ovest)-sud-ovest (vedi piano allegato). (M. Soldati)

2015: La misura del 2015 è la seconda dopo lo spostamento della base. Per quanto concerne il fronte si registra un arretramento medio di ca. 13 metri. Di conseguenza il lago ha aumentato la sua superficie. La perdita di spessore è di circa 2.50 m per la parte basse e di 1.40-1.80 m per la parte alta. (M. Soldati)

120 Corno

2014: La misura svolta nel 2014 mostra un arretramento medio del ghiacciaio di 16.4 m. A differenza dello scorso rilievo, il ghiaccio ricoperto da detriti non è più stato considerato collegato al rimanente ghiacciaio. Questo spiega in parte l'aumento il forte arretramento registrato nel 2014. La perdita di spessore rispetto al 2012 (profilo non eseguito nel 2013) varia da 10 cm a 180 cm. (M. Soldati)

2015: Diminuzione spessore (in un solo punto) 183 cm. Un punto del profilo è scomparso, l'altro non è stato misurato a causa della nebbia. (M. Soldati)

173 Seewjinen

2014: Luftbildaufnahmen am 2.10.2014, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 21.9.2015, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

174 Hohlaub

2014: Luftbildaufnahmen am 2.10.2014, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2015: Luftbildaufnahmen am 21.9.2015, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

352 Croslina

2014: Nel 2014 è stato cambiato il punto di misurazione in quanto un'importante superficie di ghiaccio è staccata dal corpo principale del ghiacciaio e non è più alimentata. Di conseguenza, il fronte del ghiacciaio è stato spostato di circa 860 metri in direzione (ovest)-sud-ovest (vedi piano allegato). (M. Soldati)

2015: Rispetto al 2014 perdita spessore ghiaccio compresa tra 210 e 295 cm. (M. Soldati)

C Investigators

C.1 Length Variation (2015)

Glacier	No.	Investigator
Albigna	116	AWN/GR, Martin Keiser
Allalin	11	VAW/ETHZ, Andreas Bauder
Alpetli (Kanderfirn)	109	KAWA/BE, Ueli Burgener
Ammerten	111	Walter Hodel
Arolla (Mont Collon)	27	DWL/VS, François Fellay
Basòdino	104	SF/TI, Mattia Soldati
Bella Tola	21	currently not observed
Biferten	77	Hanspeter Klauser
Blüemlisalp	64	KAWA/BE, Ueli Burgener
Boveyre	41	DWL/VS, James Medico
Breney	36	Jean-Jacques Chabloz
Bresciana	103	SF/TI, Mattia Soldati
Brunegg (Turtmann)	20	DWL/VS, Alban Brigger
Brunni	72	AFJ/UR, Martin Planzer
Calderas	95	AWN/GR, Gian Andri Godly
Cambrena	99	AWN/GR, Gilbert Berchier
Cavagnoli	119	SF/TI, Mattia Soldati
Cheillon	29	DWL/VS, Olivier Bourdin
Corbassière	38	VAW/ETHZ, Andreas Bauder
Corno	120	SF/TI, Mattia Soldati
Croslina	352	SF/TI, Mattia Soldati
Damma	70	AFJ/UR, Martin Planzer
Dungel	112	Andreas Wipf
Eiger	59	KAWA/BE, Ralf Schai
En Darrey	30	DWL/VS, Olivier Bourdin
Fee	13	DWL/VS, Urs Andenmatten
Ferpècle	25	DWL/VS, François Fellay
Fiescher	4	VAW/ETHZ, Andreas Bauder
Findelen	16	VAW/ETHZ, Andreas Bauder
Firnalpeli (Ost)	75	AWL/OW, Miriam Jäggi
Forno	102	AWN/GR, Martin Keiser
Gamchi	61	KAWA/BE, Roland Descloux
Gauli	52	KAWA/BE, Daniel Rohrer
Gelten	113	Andreas Wipf

Glacier	No.	Investigator
Giétro	37	VAW/ETHZ, Andreas Bauder
Glärnisch	80	Hanspeter Klauser
Gorner	14	Stefan Walther
Grand Désert	31	DWL/VS, François Vouillamoz
Grand Plan Névé	45	FFN/VD, J.-Ph. Marlétaz
Gries	3	VAW/ETHZ, Andreas Bauder
Griess	74	AFJ/UR, Beat Annen
Griessen	76	AWL/OW, Miriam Jäggi
Grosser Aletsch	5	VAW/ETHZ, Andreas Bauder
Hohlaub	174	VAW/ETHZ, Andreas Bauder
Hüfi	73	currently not observed
Kaltwasser	7	DWL/VS, Martin Schmidhalter
Kehlen	68	AFJ/UR, Martin Planzer
Kessjen	12	VAW/ETHZ, Andreas Bauder
Lang	18	DWL/VS, Hans Henzen
Lavaz	82	AWN/GR, Renaldo Lutz
Lenta	84	AWN/GR, Bernard Riedi
Limmern	78	Urs Steinegger
Lischana	98	AWN/GR, G. C. Feuerstein
Lämmern	63	KAWA/BE, Evelyn Coleman Brantschen
Mittelaletsch	106	currently not observed
Moiry	24	DWL/VS, Gabriel Chevalier
Moming	23	DWL/VS, Pascal Stoebener
Mont Durand	35	Jean-Jacques Chabloz
Mont Fort (Tortin)	32	DWL/VS, François Vouillamoz
Mont Miné	26	DWL/VS, François Fellay
Morteratsch	94	AWN/GR, Gian Andri Godly
Mutt	2	currently not observed
Oberaar	50	currently not observed
Oberaletsch	6	currently not observed
Oberer Grindelwald	57	VAW/ETHZ, Andreas Bauder
Otemma	34	Jean-Jacques Chabloz
Palü	100	AWN/GR, Gilbert Berchier
Paneyrosse	44	FFN/VD, J.-Ph. Marlétaz
Paradies	86	AWN/GR, Cristina Fisler
Paradisino (Campo)	101	AWN/GR, Gilbert Berchier
Pizol	81	KFA/SG, Urban Kühne
Plattalva	114	Urs Steinegger
Porchabella	88	AWN/GR, Thomas Bearth
Prapio	48	Jacques Binggeli
Punteglias	83	AWN/GR, Christian Buchli
Rhone	1	VAW/ETHZ, Andreas Bauder
Ried	17	DWL/VS, Peter Rovina
Roseg	92	AWN/GR, Gian Andri Godly
Rossboden	105	DWL/VS, Marco Gerold
Rotfirn (Nord)	69	AFJ/UR, Martin Planzer

Glacier	No.	Investigator
Rätzli	65	VAW/ETHZ, Andreas Bauder
Saleina	42	DWL/VS, James Medico
Sankt Anna	67	AFJ/UR, Lukas Eggimann
Sardona	91	KFA/SG, Stefan Nigg
Scaletta	115	Bernardo Teufen
Schwarz	62	KAWA/BE, Evelyn Coleman Brantschen
Schwarzberg	10	VAW/ETHZ, Andreas Bauder
Seewjinen	173	VAW/ETHZ, Andreas Bauder
Sesvenna	97	AWN/GR, G. C. Feuerstein
Sex Rouge	47	Jacques Binggeli
Silvretta	90	VAW/ETHZ, Andreas Bauder
Stein	53	KAWA/BE, Daniel Rohrer
Steinlimi	54	KAWA/BE, Daniel Rohrer
Sulz	79	AW/GL, Stefan Kamm
Suretta	87	AWN/GR, Cristina Fisler
Tiatscha	96	VAW/ETHZ, Andreas Bauder
Tiefen	66	AFJ/UR, Lukas Eggimann
Trient	43	Jacques Ehinger
Trift (Gadmen)	55	VAW/ETHZ, Andreas Bauder
Tsanfleuron	33	DWL/VS, François Fellay
Tschierva	93	AWN/GR, Gian Andri Godly
Tschingel	60	KAWA/BE, Ralf Schai
Tseudet	40	DWL/VS, James Medico
Tsidjiore Nouve	28	DWL/VS, François Fellay
Turtmann	19	DWL/VS, Alban Brigger
Unteraar	51	currently not observed
Unterer Grindelwald	58	VAW/ETHZ, Andreas Bauder
Val Torta	118	currently not observed
Valleggia	117	SF/TI, Mattia Soldati
Valsorey	39	DWL/VS, James Medico
Verstankla	89	AWN/GR, Daniel Oertig
Vorab	85	AWN/GR, Matthias Kalberer
Wallenbur	71	AFJ/UR, Pius Kläger
Zinal	22	DWL/VS, Gabriel Chevalier
Zmutt	15	currently not observed

AFJ/UR	Amt für Forst und Jagd, Uri
AWN/GR	Amt für Wald und Naturgefahren, Graubünden
AW/GL	Abteilung Wald, Glarus
AWL/OW	Amt für Wald und Landschaft, Obwalden
DWL/VS	Dienststelle für Wald und Landschaft/Service des forêts et du paysage, Wallis/Valais
FFN/VD	Service des forêts, de la faune et de la nature, Vaud
KAWA/BE	Amt für Wald, Bern
KFA/SG	Waldregion 3 Sargans, St. Gallen
SF/TI	Sezione forestale, Ticino
VAW/ETHZ	Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, ETH Zürich

C.2 Mass Balance and Velocity

Glacier	No.	Investigator
Allalin	11	VAW/ETHZ, Andreas Bauder
Basòdino	104	Giovanni Kappenberger
Clariden	141	Giovanni Kappenberger, Urs Steinegger
Corbassière	38	VAW/ETHZ, Andreas Bauder
Findelen	16	DGUF / GIUZ, Matthias Huss, Nadine Salzmann, Gwendolyn Leysinger-Vieli
Giétro	37	VAW/ETHZ, Andreas Bauder
Gries	3	VAW/ETHZ, Martin Funk
Grosser Aletsch	5	VAW/ETHZ, Andreas Bauder
Hohlaub	174	VAW/ETHZ, Andreas Bauder
Murtel	33	DGUF, Mauro Fischer
Pizol	81	VAW/ETHZ / DGUF, Matthias Huss
Plaine Morte	65	DGUF, Matthias Huss
Rhone	1	VAW/ETHZ, Andreas Bauder
Sankt Anna	67	DGUF, Mauro Fischer
Schwarzberg	10	VAW/ETHZ, Andreas Bauder
Silvretta	90	VAW/ETHZ, Andreas Bauder
Tsanfleuron	33	DGUF, Matthias Huss

C.3 Englacial Temperature

Site (Glacier)	No.	Investigator
Colle Gnifetti (Gorner)	14	DGUF, Martin Hoelzle

VAW/ETHZ	Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, ETH Zürich
GIUZ	Geographisches Institut, Universität Zürich
DGUF	Département des Géosciences, Université de Fribourg