The Swiss Glaciers

2015/16 and 2016/17

Glaciological Report (Glacier) No. 137/138

2018

The Swiss Glaciers

2015/16 and 2016/17

Glaciological Report No. 137/138

Edited by

Andreas Bauder[1]

With contributions from

Andreas Bauder[1], Martin Funk[1], Matthias Huss[1,2],

Giovanni Kappenberger[3], Andreas Linsbauer[2,4], Urs Steinegger[5]

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

[2] Department of Geosciences, University of Fribourg

[3] 6565 San Bernardino

[4] Department of Geography, University of Zurich

[5] Meteodat GmbH, 8005 Zürich

2018

Publication of the Cryospheric Commission (EKK) of the Swiss Academy of Sciences (SCNAT)

c/o Laboratory of Hydraulics, Hydrology and Glaciology (VAW)
at the Swiss Federal Institute of Technology Zurich (ETH Zurich)

Hönggerbergring 26, CH-8093 Zürich, Switzerland

http://glaciology.ethz.ch/swiss-glaciers/

DOI: http://doi.org/10.18752/glrep_137-138

ISSN 1424-2222

Imprint of author contributions:

Andreas Bauder	:	Chapt. 1, 2, 3, 4, 5, App. A, B, C
Martin Funk	:	Chapt. 1, 4, 6
Matthias Huss	:	Chapt. 1, 2, 4, 6
Giovanni Kappenberger	:	Chapt. 4
Andreas Linsbauer	:	Chapt. 4
Urs Steinegger	:	Chapt. 4

Ebnoether Joos AG
print and publishing
Sihltalstrasse 82
Postfach 134
CH-8135 Langnau am Albis
Switzerland

Cover Page: Rossbodengletscher (Marco Gerold, 26.08.2016)

Summary

During the 137th and 138th year under review by the Cryospheric Commission (EKK), Swiss glaciers continued to lose both length and mass. The two periods were characterized by mostly 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 2016, a length variation was determined for 94 of the 114 glaciers currently under active observation, while one year later 93 glaciers were measured. In the two observation periods, 2015/16 and 2016/17, 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, Murtèl, Rhone, Sankt Anna, Silvretta and Tsanfleuron, and measurements were also conducted at several additional glaciers. In the first period (2015/16), glaciers between the cantons of Berne and Valais showed only small mass losses, whereas in the other regions of Switzerland mass balances were moderately to strongly negative. During the second period (2016/17), extreme glacier mass losses occurred throughout the entire Swiss Alps. Melt rates were close to those from the record years of 2002/03 and 2014/15.

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. In September 2017, an ice mass of 500,000 m^3 at the steep north face of Weissmies, clearly a threat to the village of Saas Grund below, became unstable and broke off. Fortunately there were no casualities and no damage to infrastructure.

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 - 137/138	2009/10 - 2016/17

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 inventories, 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. 137/138 in the series "The Swiss Glaciers" and presents the results of the two observational periods 2015/16 and 2016/17. 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://www.glamos.ch. 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

The weather and climate conditions for the two periods 2015/16 and 2016/17 are described in this section. We focus on the 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 reduce the winter snowpack rapidly and expose the much darker ice surface as early as July. During July and August, there is a significant amount of solar radiation and melting of the unprotected ice is enhanced. When these two factors are combined, very negative mass balances can be expected as during the heat waves of summer 2003 or 2015. 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 14 homogenized climate stations (Begert et al., 2005; Begert and Frei, 2018). All stations belong to the observational networks maintained by MeteoSwiss. The description of the weather conditions in the two reporting periods refer to the annual and monthly reports of the meteorological conditions by MeteoSwiss. Data are provided by the observational networks maintained by MeteoSwiss.

2.1 Weather and Climate in 2015/16

Winter 2015/16 started only in January due to exceptionally high air temperatures (Figure 2.1) and very dry conditions during fall. Many slopes up to high elevations were snow-free until the end of December. According to the 80-year time series at Weissfluhjoch (2540 m a.s.l.) the early winter of 1948 alone had experienced less snow to date. In the following period, weather conditions with westerly and southerly winds were dominant and in some cases brought large amounts of snowfall, most importantly to the western Swiss Alps. Average snow depths were reached in all parts of Switzerland during March, thus balancing the deficit of early winter (Figure 2.2). Between mid-April and the end of May cooler temperatures prevailed and the thickness of snow cover on

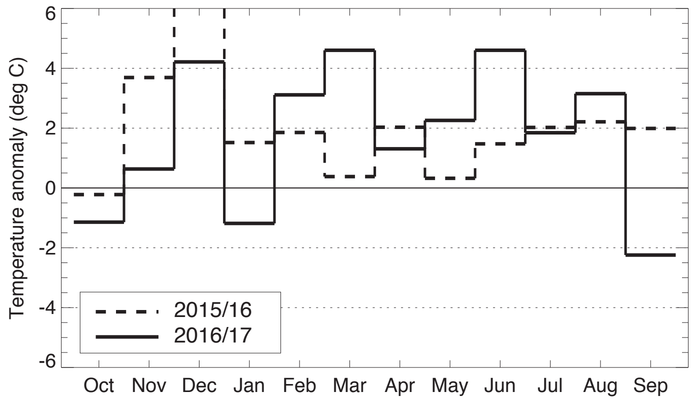

Figure 2.1: Mean monthly anomaly of temperature from the long-term climatic mean (period 1961-1990) for four mountain stations in the MeteoSwiss network. Anomalies in the two reporting periods 2015/16 and 2016/17 are shown.

glaciers continued to increase. At the beginning of June snow depth figures on the southern side of the Alps were close to the long-term average, whereas 50% above-average snow amounts were measured in the western Swiss Alps and about 20% in the east. Snowmelt slowly set in during June but also repeated snow fall events were registered. Consequently, the glaciers were still well protected by the winter snow cover at the onset of the first summer heat waves. Also in July, several cold spells occurred and glacier melting continued to be comparably slow despite above-average air temperatures. During August and the first half of September, however, very warm and stable summer weather prevailed and favoured a depletion of the snow cover, thus turning the situation from balanced conditions on many glaciers to a – once again – substantial mass loss.

Compared to the reference period 1961-1990, summer air temperatures (May to September) were 1.8°C higher than the long-term mean (Figure 2.3). Annual precipitation amounts were 4% 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. The weather conditions during the period 2015/16 resulted in a clear gradient with above-average winter snow accumulation in the northwest and smaller amounts in the south and east of Switzerland impacting on the pattern of mass losses throughout the summer season.

2.2 Weather and Climate in 2016/17

In mid-November 2016, substantial snowfalls occurred in the Swiss Alps which, however, soon melted away up to the elevation of the glacier termini. December was characterized by high air temperatures, as in the previous year, and even drier conditions, resulting in the smallest snow depths ever observed to the end of the year throughout Switzerland. Although the snow cover started building up in January and February, the conditions remained excessively dry throughout

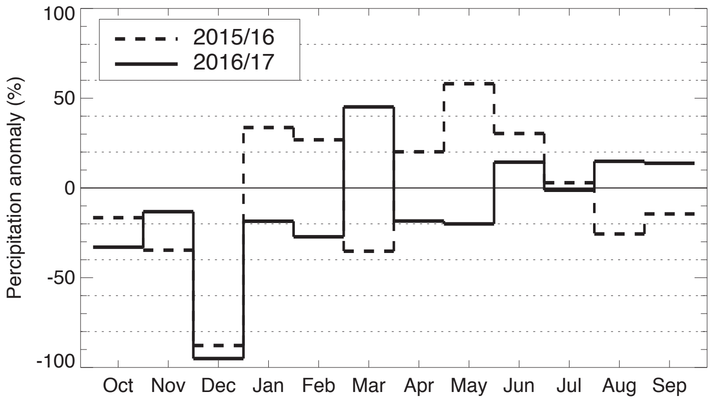

Figure 2.2: Mean monthly anomaly of precipitation from the long-term climatic mean (period 1961-1990) for 14 selected stations in the MeteoSwiss network. Anomalies in the two reporting periods 2015/16 and 2016/17 are shown.

the entire winter except for the month of March (Figure 2.1). Despite a number of significant snowfall events at the elevation of the glaciers in mid-April and early May, snow depths on the glaciers were mostly below average at the end of winter. Snowmelt intensified as early as late May, and particularly during the second-warmest June since records were begun (Figure 2.2). The combination of snow deficit in early winter, moderate amounts of precipitation until May, and rapid melting in early summer contributed to a depletion of the glacier snow cover that is among the earliest ever observed. The situation south of the Alps was even more dramatic than in the north, with the result that many smaller glaciers were completely snow-free already in July. In spite of two cold spells with fresh snow at high elevation, July remained too warm and was followed by repeated heat waves during August that were again responsible for substantial glaciermelt. A significant temperature drop came by the beginning of September. Throughout the entire month there were frequent fresh snowfalls at the elevation of the glaciers that stopped melting from occuring comparably early in the season, thus, preventing even higher glacier mass losses.
As an indicator of summer climate we analyzed average air temperatures between May and September. This is the period that is most relevant for glacier melting in the Alps. Summer air temperatures (May to September) were 2.2°C higher than the long-term mean (Figure 2.3). This value ranks third after the summers of 2003 (+3.5°C) and 2015 (+2.4°C). Annual precipitation was 13% 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 mostly poorly covered with winter snow at the beginning of the heatwaves in June, mass losses were strong and higher than those of 2015 on some glaciers, despite slightly lower average air temperatures. Due to a cool month of September with repeated snowfalls on the glaciers, the record glacier melt rates of summer 2003 were not matched.

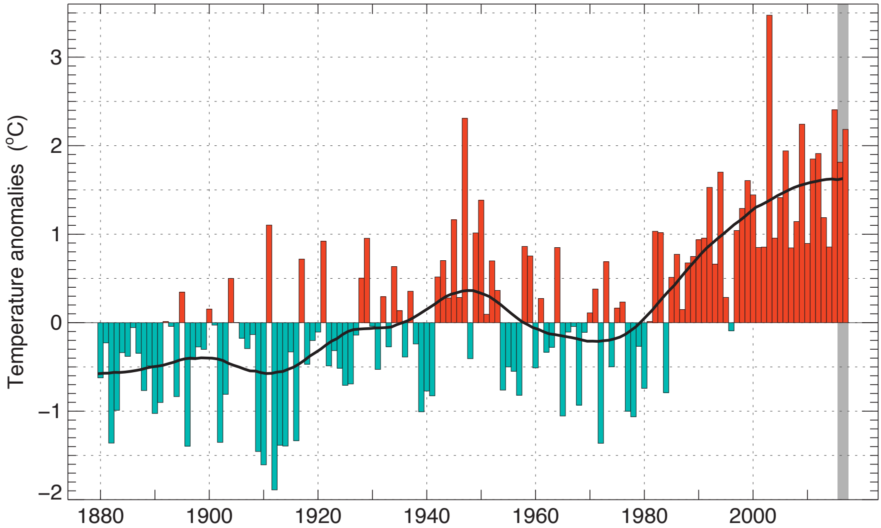

Figure 2.3: Anomalies of mean summer air temperature (May-September) from the mean value 1961-1990 in degrees Celsius for the period 1864-2017 based on 14 homogenized long-term stations of MeteoSwiss. The gray shaded area highlights the years of the current report.

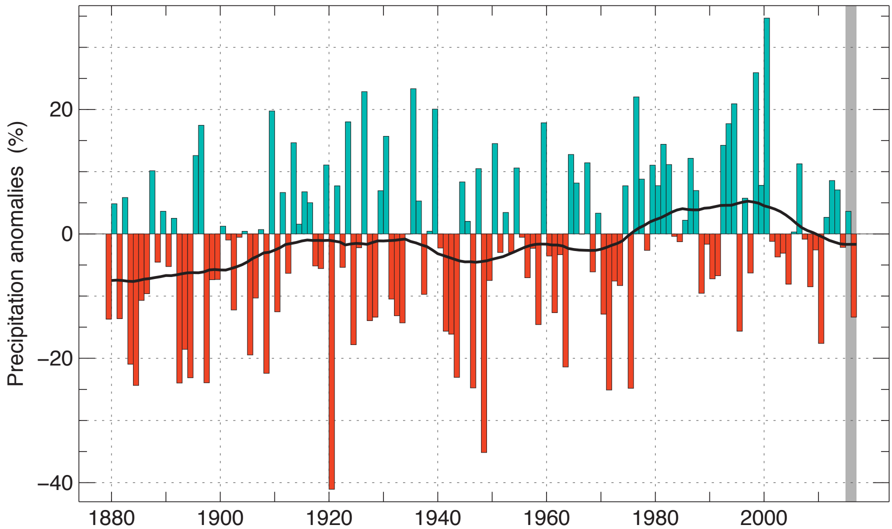

Figure 2.4: Anomalies of annual precipitation (hydrological year) from the mean value 1961-1990 in percentage for the period 1864-2017 based on 14 homogenized long-term stations of MeteoSwiss. The gray shaded area highlights the years of the current report.

3 Length Variation

3.1 Introduction

In the two periods covered by this report, 114 of 156 glaciers with documented length fluctuations have been 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 simply is 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 reciting these figures in the charts and analyses.

During the two years under review, 2015/16 and 2016/17, Swiss glaciers suffered further losses in length. As in previous periods, most of the measurements were within the range of 0 to -30 m. As in previous periods, this overall trend was once again overshadowed in both years by a few very high retreat values, which could be traced to local influences, 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 2015/16

In autumn 2016 changes in the terminus position as compared to the previous years were determined at 94 glaciers (Figure 3.1). Of these, 82 were found to be in recession, for seven there was no change observed, and five glaciers showed a positive value. With the exception of three glaciers, the values ranged from a retreat of -79 m at Glacier de Ferpècle to a slight advance of +28 m at Vadrec del Forno. More than two-thirds of the measurement values lay between -1 and -30 m.

The three exceptions refer to the massive retreats of Läntagletscher, Unterer Grindelwaldgletscher and Vadret da Morteratsch. The large retreat values are a result of the evolution of the glaciers over several years and were therefore expected.
Due to the continued absence of ice flow from the accumulation area or the increasingly thicker debris cover, the tongues of these glaciers were thinned out or melting irregularly without any major reduction in length. During summer 2016 the dynamic terminus shifted back abruptly. At Läntagletscher the tongue detached at a break in the terrain where the ice was thinned out, while at the other two glaciers large portions of the debris-covered tongue broke into individual ice chunks. The timing of these events was rather arbitrary and only poorly reflects the overall and continuous

change in these glaciers. Local changes at the terminus of the glacier were responsible for the sporadic positive values measured. This advance does not stem from abundant ice flows from the firn area after consecutive years of a positive mass balance when a length increase normally occurs over more than just one measurement period. The two causes of this advance were firn deposits at the margin of the glacier, and reduced melting at the terminus in an individual year.

3.3 Length Variations in 2016/17

Length variations were determined for 93 glaciers in autumn 2017 (Figure 3.2). Of these, 90 became shorter, two did not change their position, and another one was slightly in advance. With the exception of three glaciers, the values ranged from a recession of 80 meters at Grosser Aletschgletscher to a marginal advance of +1.3 m at Brunnifirn. About three-quarters of the measurement values lay between -1 and -30 meters. The survey at the glacier terminus benefited from optimal measurement conditions as a result of intensive melting during summer.

Tiefengletscher, Scalettagletscher and Glacier de Ferpècle were the exceptions. As in the previous period, the high retreat values for each is linked to a process that has been underway for many years. Both heavy debris cover on the tongue and the absence of ice supply from the accumulation area were involved. Eventually, 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. At Scalettagletscher, determination of the ice margin was rather difficult for several years due to increasingly thick debris cover. A distinct and clear margin formed only recently after the terminus retreated into steeper terrain and a reliable length change over a multi-year period could be evaluated. The tongue of Tiefengletscher broke off at a narrow and steep section forming a debris-covered dead ice body in the flat forefield. At Glacier de Ferpècle, the meltwater formed a large subglacial cavity over the past years, which ultimately collapsed. During the summer, remaining ice masses downglacier of the cavity melted completely and as a consequence the active terminus shifted back abruptly over a larger distance.

3.4 Length Variations in 2015/16 and in 2016/17, Summary

No. [a]	Glacier	Ct. [b]	Length variation [c] (m) 2015/16	2016/17	Altitude [d] (m a.s.l.) 2017	Date of measurements (Day, Month) 2015	2016	2017
Catchment area of the river Rhone (II)								
1 [e,f]	Rhone	VS	−18.0	−36.0	2210.9 [16]	05.08.	08.08.	21.09.
2 [f]	Mutt	VS	x	−26 [5a]	2665	n	02.09.	01.09.
3 [e,f]	Gries	VS	−22.9	−31.0	2430.4 [16]	31.08.	26.08.	07.08.
4 [f]	Fiescher	VS	x	x	1682 [15]	28.08.	13.09.	21.09.
5 [e,f]	Grosser Aletsch	VS	−49.5	−80.4	1602.0 [16]	26.08.	08.08.	07.08.
6 [f]	Oberaletsch	VS	x	x	2142 [03]	n	28.08.	15.10.
7 [e,f]	Kaltwasser	VS	−25.7	−9	2660 [12]	30.09.	05.10.	05.10.
173 [e]	Seewjinen	VS	−6.7	−13.6	2735.5 [16]	21.09.	29.09.	05.10.
10 [e,f]	Schwarzberg	VS	−28.1	−40.1	2663.2 [16]	21.09.	29.09.	05.10.
11 [e,f]	Allalin	VS	−0.3	−13.4	2676.7 [16]	21.09.	29.09.	05.10.
174 [e]	Hohlaub	VS	−13.2	−8.9	2841.0 [16]	21.09.	29.09.	05.10.
12 [e]	Chessjen	VS	−3.4	−3.6	2866.3 [16]	21.09.	29.09.	05.10.
13 [e,f]	Fee	VS	−19.9	−17	2267 [16]	02.10.	28.09.	05.10.
14 [f]	Gorner	VS	−61	−31	2211 [15]	21.09.	04.11.	13.10.
16 [e,f]	Findelen	VS	−31.2	−36.5	2555.8 [16]	05.08.	26.08.	05.09.
17 [e]	Ried	VS	−40	−6	2335	10.10.	09.10.	07.10.
18 [f]	Lang	VS	17	−38	2045	10.11.	30.11.	31.10.
19 [e,f]	Turtmann	VS	−30	−42.2	2270 [10]	07.10.	08.09.	02.10.
20 [e]	Brunegg (Turtmann)	VS	−18.7	−40.8	2500 [10]	07.10.	08.09.	02.10.
21 [e]	Bella Tola	VS	n	x		n	n	25.08.
22 [e,f]	Zinal	VS	−7.8	−10	2080	12.10.	22.09.	28.09.
23 [e,f]	Moming	VS	−20	−6.3	2580 [13]	29.09.	24.08.	25.08.
24 [e,f]	Moiry	VS	−28	−25	2410	23.09.	22.09.	25.09.
25 [e,f]	Ferpècle	VS	−79.2	−152	2205 [14]	22.10.	07.10.	12.10.
26 [e]	Mont Miné	VS	−13.5	−25.6	2090 [12]	22.10.	07.10.	12.10.
27 [e,f]	Arolla (Mont Collon)	VS	−13.2	−22.0		21.10.	10.10.	10.10.
28 [e,f]	Tsidjiore Nouve	VS	−9.2	−15.2	2320 [15]	21.10.	10.10.	10.10.
29 [e,f]	Cheillon	VS	−7.4	−22	2706	30.09.	06.10.	13.10.
30 [e,f]	En Darrey	VS	x	x	2710	n	06.10.	13.10.
31 [f]	Grand Désert	VS	−4.4	−26.8	2810	19.09.	25.09.	13.09.
32 [f]	Mont Fort (Tortin)	VS	−13.6	−15.4	2790	27.09.	19.09.	16.09.
33 [e,f]	Tsanfleuron	VS	−13.7	−18.9	2550 [16]	23.10.	05.10.	11.10.
34 [e]	Otemma	VS	−77.4	x	2480	29.08.	23.08.	29.08.
35 [e]	Mont Durand	VS	−27	−54	2380	27.08.	24.08.	30.08.
36 [e]	Breney	VS	−27.4	−37	2575	30.08.	22.08.	24.08.

No. [a]	Glacier	Ct. [b]	Length variation [c] (m) 2015/16	2016/17	Altitude [d] (m a.s.l.) 2017	Date of measurements (Day, Month) 2015	2016	2017
37 [e]	Giétro	VS	−7.5	−16.8	2718.6 [16]	21.09.	29.09.	05.08.
38 [e]	Corbassière	VS	−36.9	−17.2	2309.5 [16]	21.09.	29.09.	05.08.
39 [f]	Valsorey	VS	−8.3	−45.8	2600 [16]	19.10.	12.08.	17.10.
40 [e]	Tseudet	VS	−1.8	−8.1	2483.5 [11]	19.10.	12.08.	17.10.
41	Boveyre	VS	−10.3	−21.9	2731	19.10.	11.08.	15.09.
42 [f]	Saleina	VS	−3.7	−12.5	1900 [16]	01.10.	25.08.	05.10.
43 [e,f]	Trient	VS	−15	−38	2180	27.09.	25.09.	07.10.
44 [e,f]	Paneyrosse	VD	−1.8	−4.6		30.09.	13.09.	07.09.
45 [e,f]	Grand Plan Névé	VD	0.6	−11.6		02.10.	22.09.	08.09.
47 [e,f]	Sex Rouge	VD	+2.7	−8.9		06.08.	25.08.	08.09.
48 [e]	Prapio	VD	−3	−6	2555	27.08.	29.09.	17.10.
Catchment area of the river Aare (Ia)								
50 [f]	Oberaar	BE	n	n	2306.9 [09]	n	n	n
51 [f]	Unteraar	BE	n	n	1930.3 [09]	n	n	n
52	Gauli	BE	n	−19 [2a]	2170	21.09.	n	28.09.
53 [f]	Stein	BE	−28.5	−25.5	2220	13.09.	26.08.	08.09.
54	Steinlimi	BE	−42	−7	2500	13.09.	26.08.	08.09.
55 [e,f]	Trift (Gadmen)	BE	−1.4	0.0	2111.5 [16]	05.08.	08.08.	22.08.
57 [e,f]	Oberer Grindelwald	BE	−42.0	+1.3	2178.6 [16]	05.08.	26.08.	29.08.
58 [e,f]	Unterer Grindelwald	BE	−370	−16.3	1587.1 [16]	05.08.	26.08.	21.09.
59 [e]	Eiger	BE	−1	−13.4	2405.7	25.09.	13.09.	14.08.
60 [e]	Tschingel	BE	−2.3	−2.5	2300	22.09.	14.09.	22.09.
61 [e,f]	Gamchi	BE	−6	−30	2140	01.10.	11.10.	19.10.
109 [e]	Alpetli (Kanderfirn)	BE	n	−18.3	2405	n	n	13.09.
63 [e]	Lämmern	VS	−8	−18	2552	11.09.	22.09.	08.09.
64 [e,f]	Blüemlisalp	BE	−18	−21	2410	21.09.	30.09.	27.09.
65 [e,f]	Rätzli	BE	−6.3	−8.8	2467.6 [16]	05.08.	07.09.	29.08.
111 [e]	Ammerten	BE	−1.2	−3.1	2350	20.09.	11.09.	07.10.
Catchment area of the river Reuss (Ib)								
66 [e,f]	Tiefen	UR	−22.5	−620	2650	02.10.	08.10.	05.10.
67 [e,f]	Sankt Anna	UR	−12.5	−7.5	2610	02.10.	31.10.	04.10.
68 [e,f]	Kehlen	UR	−9.9	−16.3	2390	21.09.	08.09.	08.09.
69 [e]	Rotfirn (Nord)	UR	−20	−13.0	2070	21.09.	08.09.	08.09.
70 [e,f]	Damma	UR	−36.9	−23.5	2360	22.09.	09.09.	05.10.
71 [e,f]	Wallenbur	UR	−12.8	−17.5	2295	29.09.	07.10.	29.09.
72 [e,f]	Brunni	UR	−1	−0.9	2570	26.08.	26.08.	25.08.
74 [e,f]	Griess	UR	−5.9	−18.0	2230	01.10.	20.09.	05.10.

No. [a]	Glacier	Ct. [b]	Length variation [c] (m)		Altitude [d] (m a.s.l.)	Date of measurements (Day, Month)		
			2015/16	2016/17	2017	2015	2016	2017
75 [f]	Firnalpeli (Ost)	OW	+25.2 [2a]	n	2220 [15]	n	02.09.	n
76 [e,f]	Griessen	OW	−3.8	n	2525 [16]	02.10.	13.09.	n
Catchment area of the river Linth / Limmat (Ic)								
77 [e,f]	Biferten	GL	−9.3	−11.3	1963.7	03.10.	10.09.	30.09.
78 [e]	Limmern	GL	−2.9	−15.6	2291	30.09.	23.09.	07.10.
114 [e]	Plattalva	GL	−16.6	−14.6	2628	01.10.	24.09.	07.10.
79 [e,f]	Sulz	GL	−5.9	−5.2	1810	12.10.	28.10.	28.09.
80 [e,f]	Glärnisch	GL	−11.3	−31.3	2346.6	29.09.	31.10.	01.11.
81 [e,f]	Pizol	SG	0.3	n	2600 [16]	09.10.	16.09.	n
Catchment area of the river Rhine / Lake Constance (Id)								
82 [e,f]	Lavaz	GR	s	n	2369 [16]	21.08.	17.08.	n
83 [e,f]	Punteglias	GR	−3.1	−27.8	2355	22.09.	14.09.	12.10.
84 [e,f]	Lenta	GR	−786.7 [2a]	−21.7	2740	n	23.08.	21.08.
85 [f]	Vorab	GR	−9.9	−5.0	2620	09.10.	14.09.	15.10.
86 [e,f]	Paradies	GR	+6.6	−21.1	2706	05.10.	31.08.	07.09.
87 [e]	Suretta	GR	−0.4	−14.0	2530	08.09.	25.08.	24.08.
88 [e,f]	Porchabella	GR	−22.9	−14.8	2696	09.09.	07.09.	21.09.
115	Scaletta	GR	x	−240 [4a]	2670	n	15.09.	31.07.
89 [f]	Verstankla	GR	−13.5	−13.7	2431	28.08.	09.09.	08.09.
90 [e]	Silvretta	GR	−16.5	−16.8	2471.8 [16]	07.08.	07.09.	25.08.
91 [e,f]	Sardona	SG	−8	n	2545 [16]	29.09.	04.10.	n
Catchment area of the river Inn (V)								
92 [f]	Roseg	GR	−2	−13.8	2160 [09]	14.10.	06.10.	13.09.
93 [e]	Tschierva	GR	−20.7	−30.7	2322	14.10.	06.10.	13.09.
94 [f]	Morteratsch	GR	−135.2	−20.2	2035	17.10.	17.09.	06.10.
95	Calderas	GR	−7.2	−20.8	2797	05.10.	25.08.	28.08.
96 [e,f]	Tiatscha	GR	−21.7	x	2671.5	07.08.	07.09.	25.08.
97	Sesvenna	GR	−13.8	−20.3	2750	21.08.	31.08.	31.08.
98 [e,f]	Lischana	GR	0.5	x	2810	15.09.	02.09.	23.08.
Catchment area of the river Adda (IV)								
99 [e]	Cambrena	GR	−14.2	−27	2510 [16]	18.08.	18.08.	18.10.
100 [e,f]	Palü	GR	−16.2	−12.2	2590	25.09.	06.09.	12.10.
101 [e]	Paradisino (Campo)	GR	x	−13 [2a]	2845	28.09.	21.08.	18.10.
102 [f]	Forno	GR	+27.7	−31.4	2230	02.09.	09.09.	07.10.
116	Albigna	GR	x	−35.8 [2a]	2195	04.09.	08.09.	07.10.
Catchment area of the river Ticino (III)								
120 [e]	Corno	TI	−4	−11.4	2663	01.09.	09.09.	09.10.
117 [e]	Valleggia	TI	−9.4	−16.8	2421	30.09.	14.09.	24.09.

No. [a]	Glacier	Ct. [b]	Length variation [c] (m)		Altitude [d] (m a.s.l.)	Date of measurements (Day, Month)		
			2015/16	2016/17	2017	2015	2016	2017
352 [e]	Croslina	TI	−2	−5.5	2727	28.09.	07.09.	20.09.
103 [e,f]	Bresciana	TI	−8.8 [2a]	−18.9	2974	n	12.09.	29.09.
119 [e]	Cavagnoli	TI	−9.7	−14.3	2671.5	30.09.	14.09.	25.09.
104 [e,f]	Basòdino	TI	−10	−6.1	2607	29.09.	06.09.	19.09.

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 2017, 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.

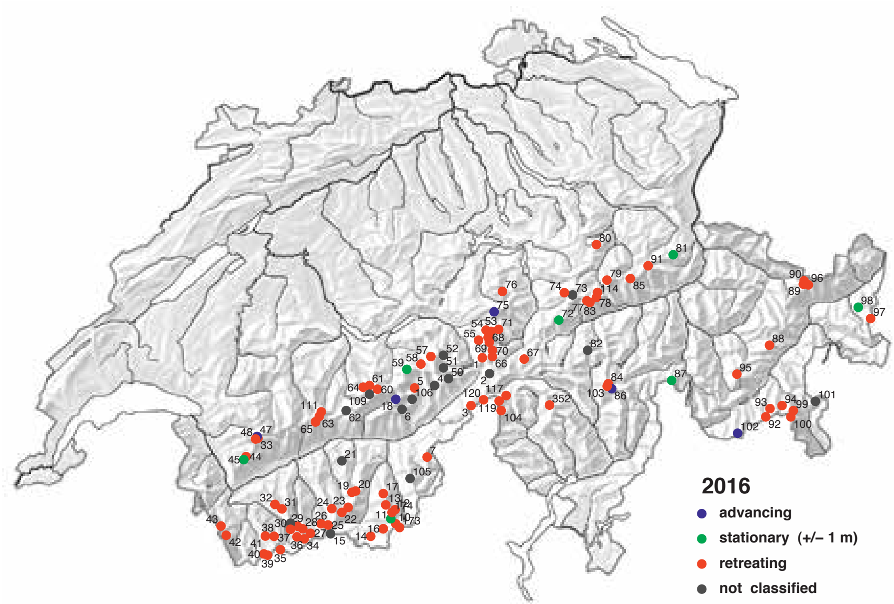

Figure 3.1: Observed glaciers in fall 2016.

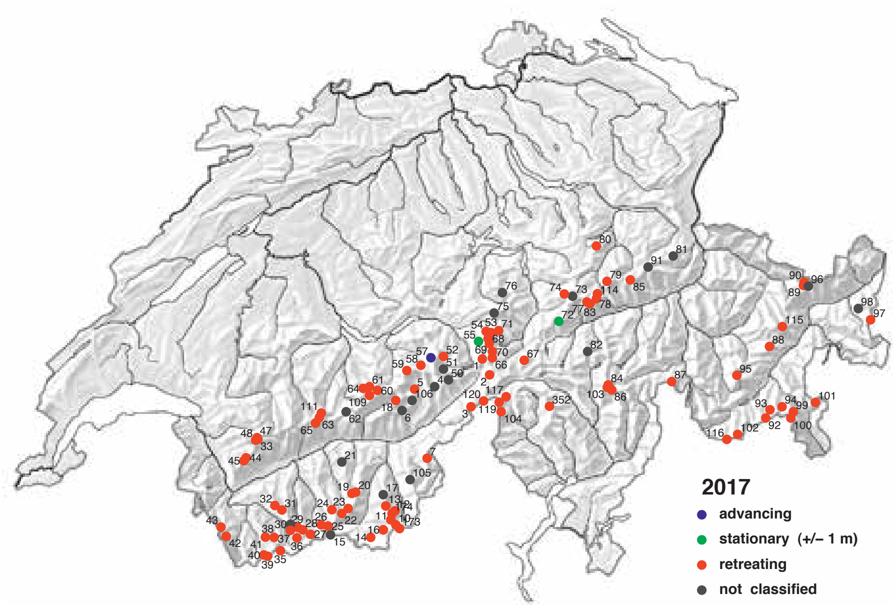

Figure 3.2: Observed glaciers in fall 2017.

3.5 Length Variations - Statistics for 1880-2017

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

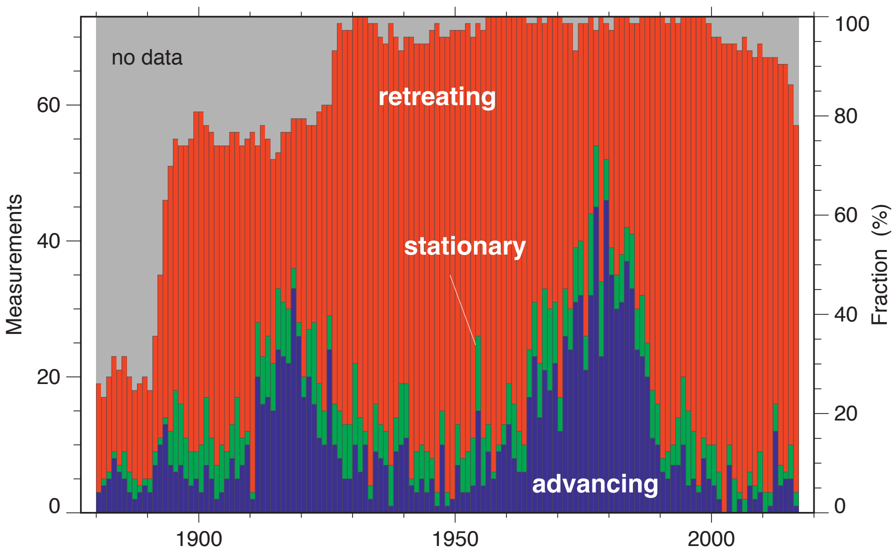

Figure 3.3: Yearly classification of glacier length behaviour (advancing, stationary and retreating) of 73 selected glaciers.

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.

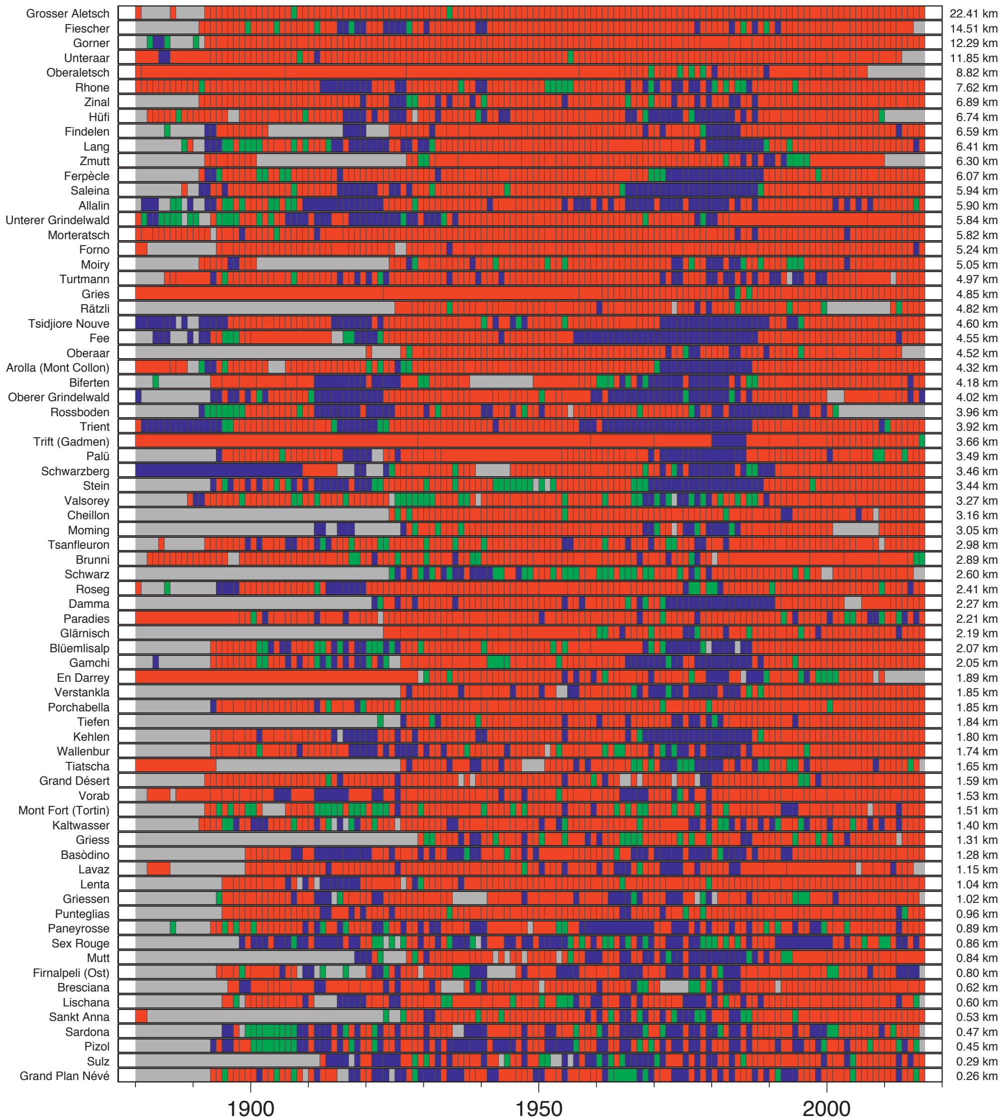

Figure 3.4: Individual yearly pattern of the same 73 selected glaciers (displayed in the descending order of actual glacier length).

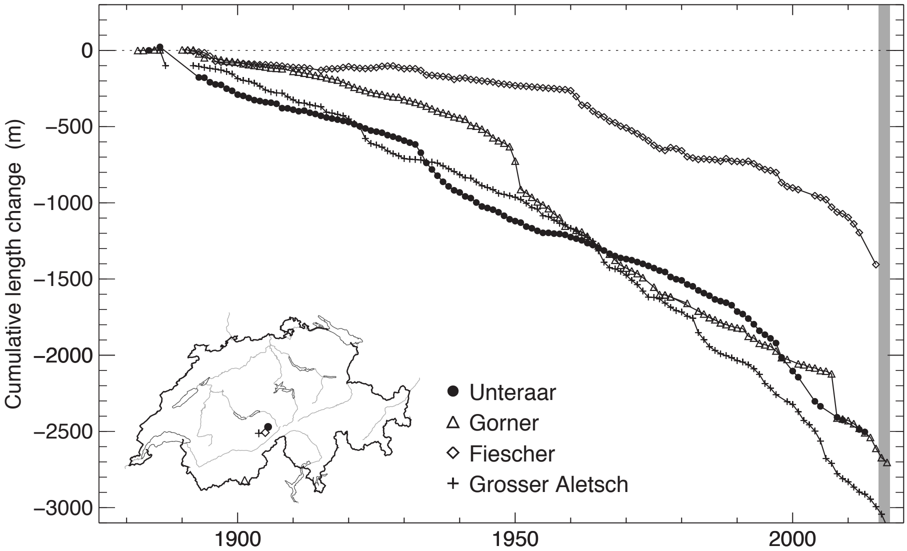

Figure 3.5: Large valley glaciers with a length of more than 10 km displaying a more or less continuous retreat over the entire time period. The gray shaded area highlights the years of the current report.

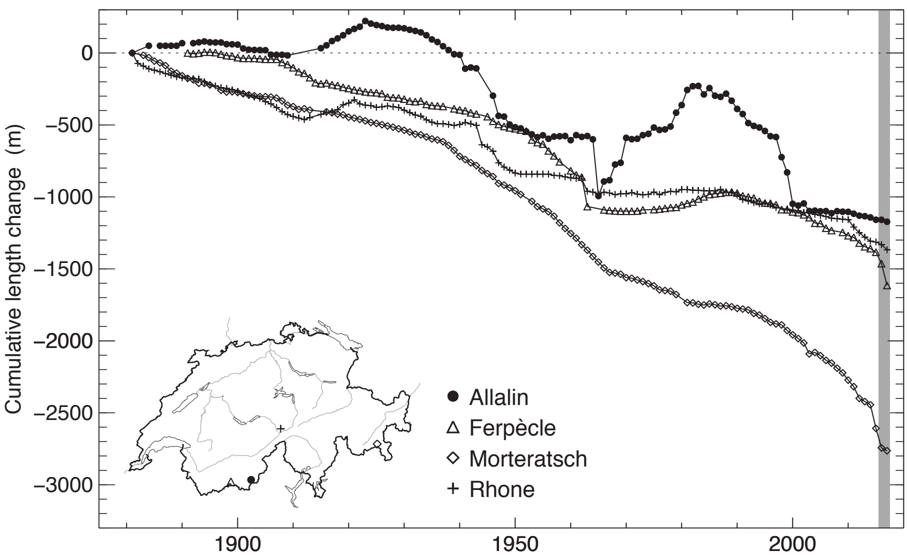

Figure 3.6: Mountain glaciers with a length of 5 to 10 km show advance and retreat phases in two periods (around 1920 and 1970). The gray shaded area highlights the years of the current report.

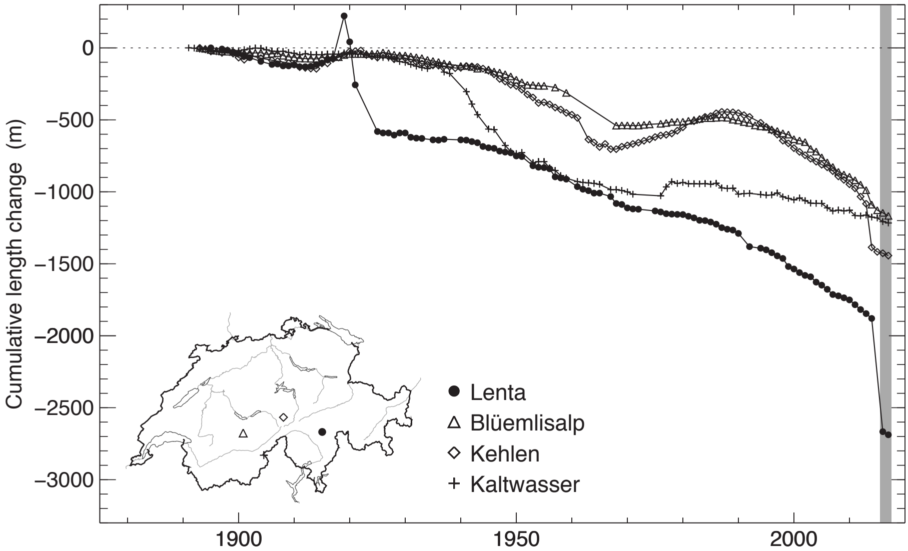

Figure 3.7: Small mountain glaciers with a length of 1 to 5 km show the two distinct advance and retreat phases. The gray shaded area highlights the years of the current report.

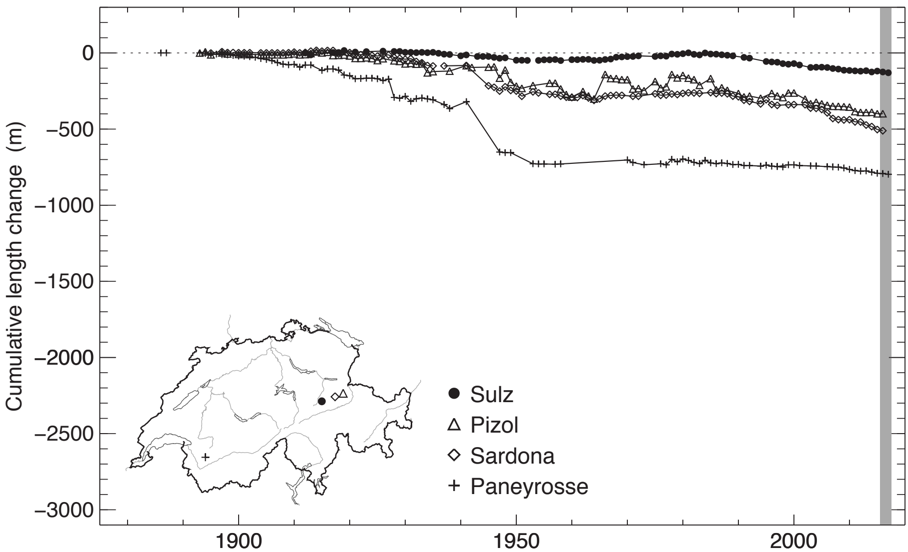

Figure 3.8: Very small cirque glaciers with a length of less than 1 km display generally small changes and a more irregular variability. The gray shaded area highlights the years of the current report.

Tiefengletscher in 2003 (top) and 2017 (bottom) – the glacier experienced a large retreat in the past decade forming a debris-covered tongue that finally disconnected in 2017 from the firn area in a steep section of the tongue (Photos: J. Marx and L. Eggimann)

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 (see 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.

Figure 4.1: Investigated glaciers for mass balance with a focus on spatial distribution and analysis of seasonal mass balance components (dark blue), and investigated glaciers with lower spatial sampling density and/or only annual components (light blue).

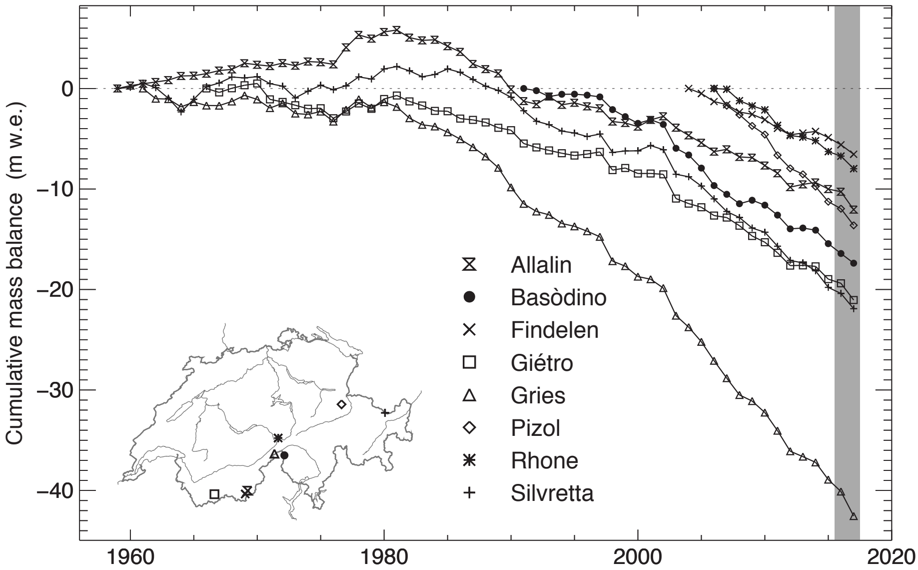

Figure 4.2: Cumulative mean specific mass balance over the whole observation period for the glaciers Allalin, Basòdino, Findelen, Giétro, Gries, Pizol, Rhone and Silvretta. The gray shaded area highlights the years of the current report.

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

Table 4.1: Summary table with area, mean specific winter and annual balance, ELA and AAR for the measurement periods 2015/16 and 2016/17.

Glacier	No.	Period	Area (km^2)	B_w (mm w.e.)	B_a (mm w.e.)	ELA (m a.s.l.)	AAR (%)
Allalin	11	2015/16	9.659	854	−269	3445	41
		2016/17	9.646	621	−1778	4165	0
Basòdino	104	2015/16	1.842	1877	−979	3125	1
		2016/17	1.758	1648	−963	3125	1
Clariden	141	2015/16	4.551	1694	−424	2875	49
		2016/17	4.551	1465	−1196	2935	25
Findelen	16	2015/16	12.880	991	−723	3405	37
		2016/17	12.893	1033	−944	3405	39
Adler	16	2015/16	1.989	677	−590	3485	38
		2016/17	1.979	692	−947	3605	28
Giétro	37	2015/16	5.322	1364	−414	3225	53
		2016/17	5.273	1084	−1666	3425	9
Gries	3	2015/16	4.431	1753	−1191	3135	3
		2016/17	4.407	1582	−2437	3295	0
Murtèl	377	2015/16	0.298	796	−462	3212	31
		2016/17	0.298	537	−1408	3252	5
Pizol	81	2015/16	0.061	1369	−699	2727	16
		2016/17	0.061	1099	−1652	2772	2
Plaine Morte	65	2015/16	7.549	1593	−248	2775	11
		2016/17	7.407	1421	−2277	2945	0
Rhone	1	2015/16	15.571	1402	−454	2875	63
		2016/17	15.523	1418	−1248	3105	32
Sankt Anna	67	2015/16	0.184	1339	−926	2822	22
		2016/17	0.184	1432	−1123	2857	7
Schwarzberg	10	2015/16	5.121	1304	−164	3055	48
		2016/17	5.102	986	−1768	3355	8
Silvretta	90	2015/16	2.684	1395	−606	2865	34
		2016/17	2.671	1351	−1513	3025	1
Tsanfleuron	33	2015/16	2.618	1914	−226	2795	41
		2016/17	2.466	1727	−2242	2975	0
Sex Rouge	47	2015/16	0.256	1780	−144	2817	35
		2016/17	0.256	1441	−2541	2882	0

ated mass loss since the mid-1980s is remarkable, as are the balanced mass budgets recorded in 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, 2017). Besides Griesgletscher and Silvrettagletscher, selected previously as reference glaciers by WGMS, Glacier du Giétro and Allalingletscher have now also been included in this global list of 41 glaciers that stand out for the length of their data series and the completeness of mass balance observations.

4.2 Mass Balance in 2015/16

Field measurements were collected on 20 glaciers. 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, including four smaller glacier in the vicinity of the main observation sites. On Claridenfirn and Grosser Aletschgletscher, detailed seasonal investigations were carried out on individual stakes in order to continue long-term series of point mass balance. Measurements and the analysis of the glacier-wide mass balance with an annual time-resolution were performed on Allalin, Corbassière, Giétro, Hohlaub and Schwarzberg, with an additional focus on the monitoring of ice flow velocity.
Due to mild temperatures and the absence of precipitation during fall and early winter, the accumulation season started late. In April and at the beginning of May, when the measurements were taken of winter snow accumulation on glaciers, mostly average snow depths were recorded with higher snow water equivalents in the northwestern part of the Swiss Alps as compared to the east. Abundant snowfalls in late May and June led to generally good conditions for the glaciers at the beginning of the summer. After an intense melt season in August lasting until September, a negative mass balance resulted on all observed glaciers. Substantial differences were observed between individual glaciers and regions. The glaciers Tsanfleuron and Plaine Morte glaciers, both located in the western Bernese Alps, showed minor losses of about -0.3 m w.e. The biggest losses were observed on glaciers located south of the main Alpine ridge. On Griesgletscher and Ghiacciaio del Basòdino average ice thickness was reduced by more than one meter. Also, the monitored glaciers in the Mattertal and Saastal showed significantly below-average mass balances. In this period, the differences between the glaciers and regions were caused by the spatial variation of snow amounts during winter.
By upscaling the measurements on individual glaciers to all glaciers and the main hydrological catchment in the Swiss Alps (see Section 4.16), a total loss in ice volume in the order of 900 million m^3 was estimated during this period. This amount corresponds to a reduction of about 1.6 % in the ice volume presently existing. Despite the substantial losses mass balance in the observation period 2015/16 was close to the average for the previous decade.

4.3 Mass Balance in 2016/17

The same 20 glaciers were investigated during this period as well. Once again, for the third year in a row, the accumulation season started late due to mild temperatures and the absence of snowfall.

Measurements from the end of the winter revealed lower snow accumulation than in the previous period, but, an average snow coverage overall except for glaciers in the Engadine. After an intense melting season lasting from June until early September, strongly negative mass balances were measured on all observed glaciers and in all regions in the Swiss Alps. Substantial fresh snowfalls in the second half of September stopped the melting relatively early, thus precluding even stronger losses.
The most negative mass balances, at -2.2 m to -2.5 m w.e. were found on Tsanfleuron and Plaine Morte in the western Bernese Alps, as well as on Griesgletscher. By contrast, the two glaciers Basòdino and Findelen experienced a relativly moderate reduction of only about -1 m w.e. Both glaciers are located in the southern Alps. At all other glaciers, between one and two meters of ice thickness loss were recorded.
Extrapolated over the entire glacierized area in Switzerland, there was a loss in ice volume of 1'500 million m^3. This corresponds to 3 % of the estimated current ice volume. In summary, the weather conditions during the period under review were unfavorable for the glaciers in Switzerland. The combination of a winter characterized by relatively low snow amounts and a very melt-intensive summer were responsible for the strong losses. In comparison to recent decades, as well as the period covering the last 100 years with systematic measurements on the glaciers, this period was amongst the most negative. Losses were similar to those in 2010/11 or 2014/15, but did not attain the record values of summer 2003.

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 extend 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 were presented in Section 4.17 of Volume 135/136.

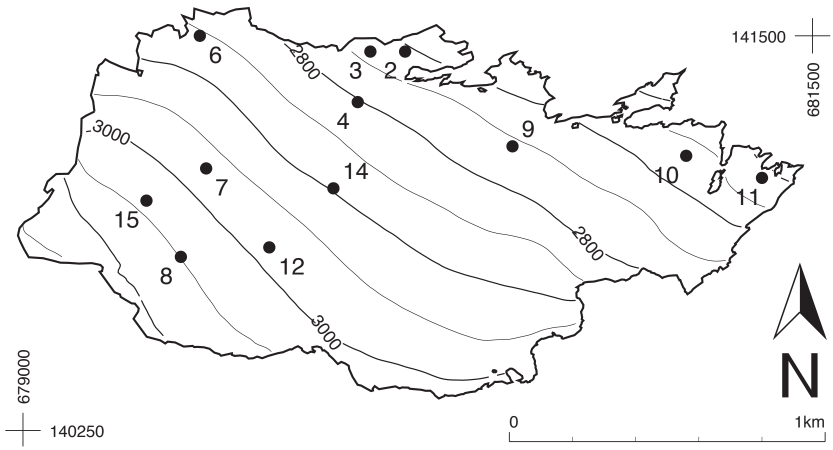

Figure 4.3: Surface topography and observational network of the Ghiacciaio del Basòdino.

Investigations in 2015/16

The measurement period extended from 31st August 2015 to 4th October 2016 with a field visit in spring, on 25th May 2016. Additional field visits during melting season were made on 12th August and 8th September 2016. Ablation season lasted over the whole of September, in October only the upper part was covered with minimal fresh snow.

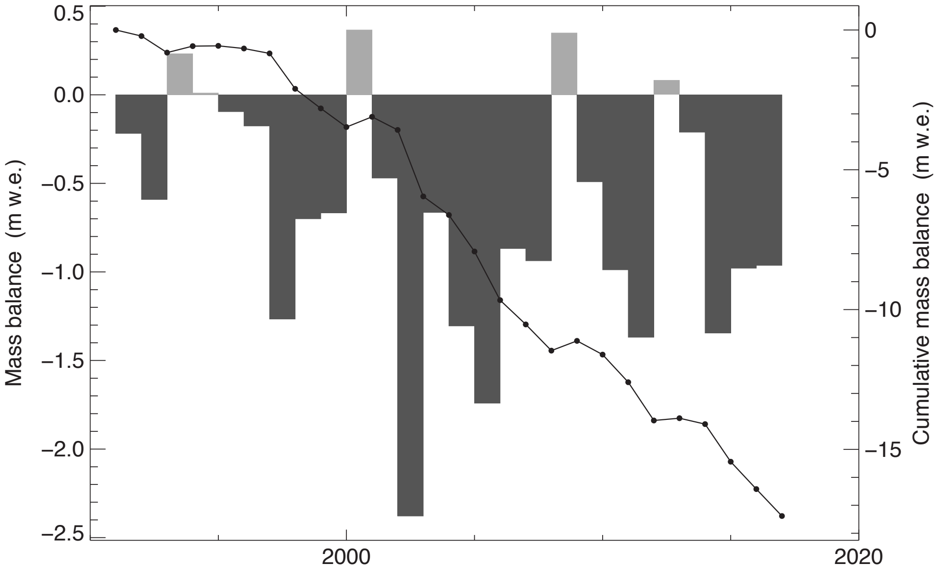

Figure 4.4: Ghiacciaio del Basòdino - Mean specific annual balance (bars) and cumulative mass balance for the period 1991-2017. Values refer to the measurement period.

Investigations in 2016/17

The measurement period was from 4th October 2016 to 8th September 2017. Winter balance was determined on 9th May 2017. Extensive snow depth sampling was carried out over the entire glacier at 107 individual locations. The density was measured in a snow pit in the center of the glacier at stake 14. Abundant snowfalls after the fall visit in September 2017 terminated the ablation season abruptly.

Table 4.2: Ghiacciaio del Basòdino - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	2104	−1202	0.000		
2600 - 2700	0.141	2011	−1242	0.108	1837	−1399
2700 - 2800	0.360	1914	−1284	0.339	1727	−1062
2800 - 2900	0.429	1853	−1363	0.422	1656	−1240
2900 - 3000	0.528	1936	−707	0.521	1709	−745
3000 - 3100	0.314	1790	−430	0.312	1471	−709
3100 - 3200	0.059	1422	−1015	0.054	1171	−882
2500 - 3200	1.842	1877	−979	1.758	1648	−963

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	31.08.2015	25.05.2016	08.09.2016	680067 / 141303 / 2792	1570	−1782
6	31.08.2015	25.05.2016	08.09.2016	679666 / 141432 / 2848	1711	−1827
8	31.08.2015	25.05.2016	04.10.2016	679618 / 140718 / 3020	2003	10
9	31.08.2015	25.05.2016	08.09.2016	680559 / 141158 / 2738	1720	−2079
10	31.08.2015	25.05.2016	08.09.2016	680990 / 141125 / 2680	1849	−2241
11	31.08.2015	25.05.2016	08.09.2016	681303 / 141021 / 2586	2288	−1449
12	31.08.2015	25.05.2016	04.10.2016	679790 / 140827 / 2970	1840	−700
14	31.08.2015	25.05.2016	08.09.2016	679986 / 141022 / 2874	1720	−1450
15	31.08.2015	25.05.2016	04.10.2016	679390 / 140974 / 3020	1699	−510
4	04.10.2016	09.05.2017	08.09.2017	680055 / 141291 / 2794	1333	−1359
6	04.10.2016	09.05.2017	08.09.2017	679651 / 141451 / 2865	1287	−1773
8	04.10.2016	09.05.2017	08.09.2017	679620 / 140726 / 3026	1558	−600
9	04.10.2016	09.05.2017	08.09.2017	680551 / 141157 / 2748	1587	−1377
10	04.10.2016	09.05.2017	08.09.2017	680988 / 141117 / 2686	1845	−1521
11	04.10.2016	09.05.2017	08.09.2017	681296 / 141021 / 2631	2399	−2025
12	04.10.2016	09.05.2017	08.09.2017	679791 / 140828 / 2979	1607	−704
14	04.10.2016	09.05.2017	08.09.2017	679987 / 141021 / 2886	1439	−1148
15	04.10.2016	09.05.2017	08.09.2017	679391 / 140970 / 3035	1402	−850

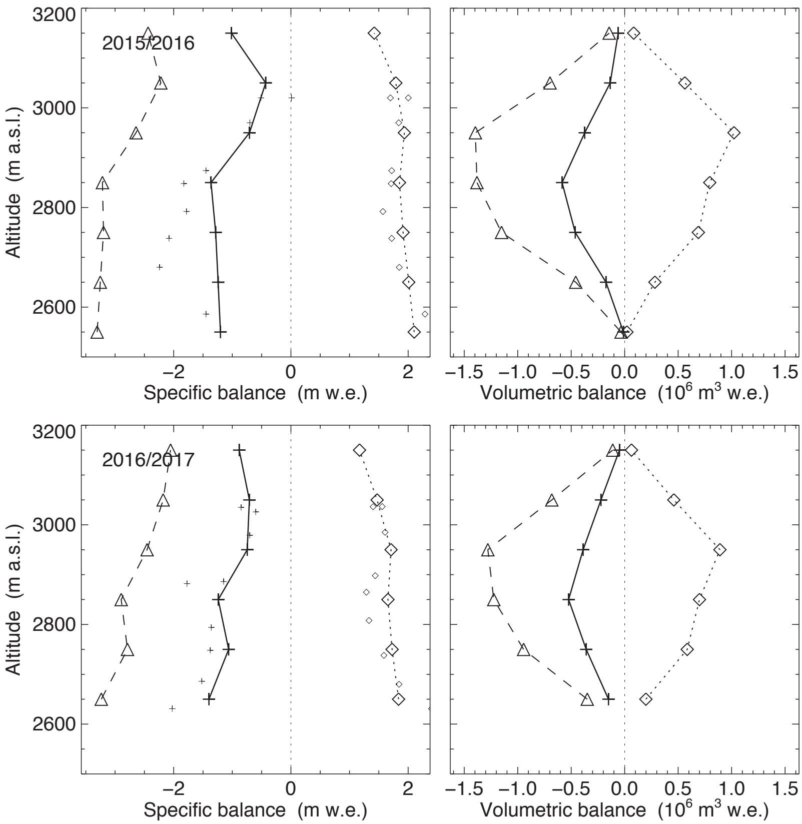

Figure 4.5: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

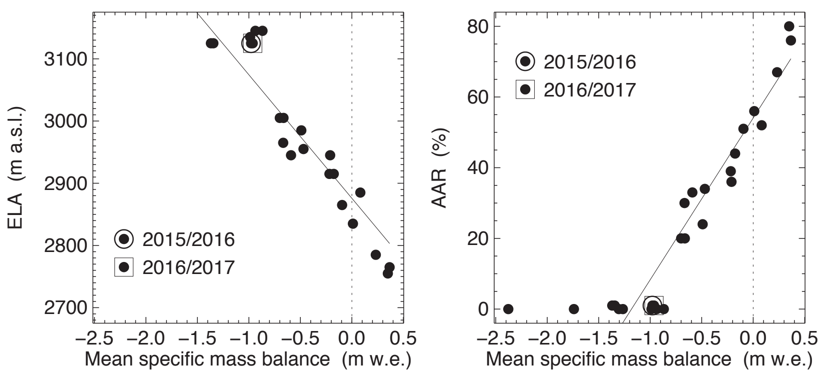

Figure 4.6: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

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 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. Sold et al. (2016) performed a complete re-analysis of all measurements after 2004.

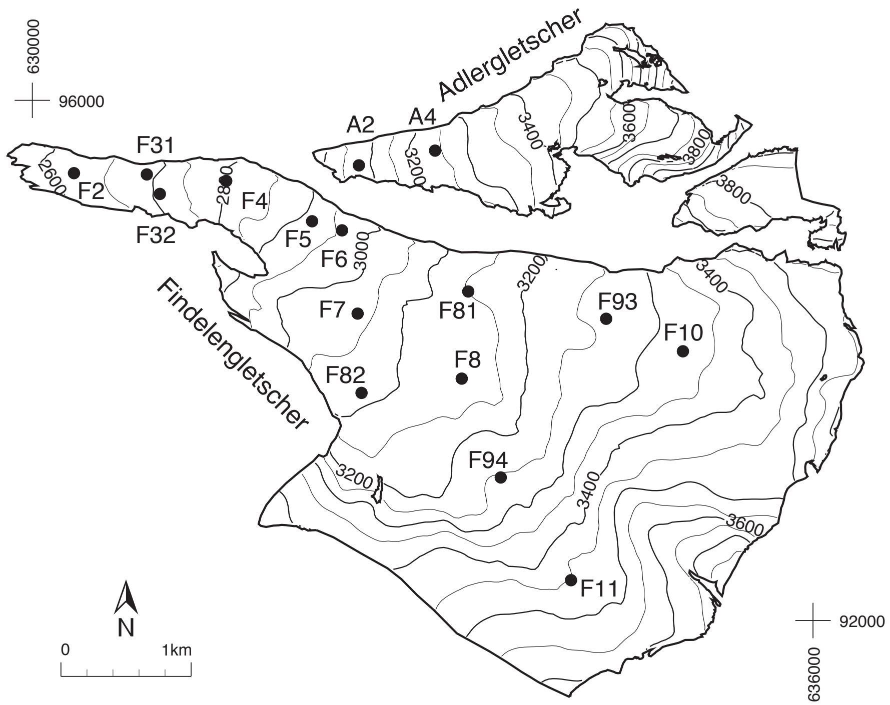

Figure 4.7: Surface topography and observational network on Findelengletscher and the former tributary Adlergletscher.

Investigations in 2015/16

The winter mass balance at Findelen- and at Adlergletscher was determined on 12th April 2016. Snow probings were acquired for 328 locations and snow density was measured in seven snow pits distributed over the entire elevation range of the glacier. Ground-based radar provided supplementary data on snow depth. All mass balance stakes were visited and re-installed on 22th September 2016. The annual mass balance was determined for 14 locations on Findelen-, and two on Adlergletscher. Firn density was measured in two snow pits. The terminus region of Findelengletscher showed signs of decay with a large depression forming close to the lowermost stake that had to be relocated.

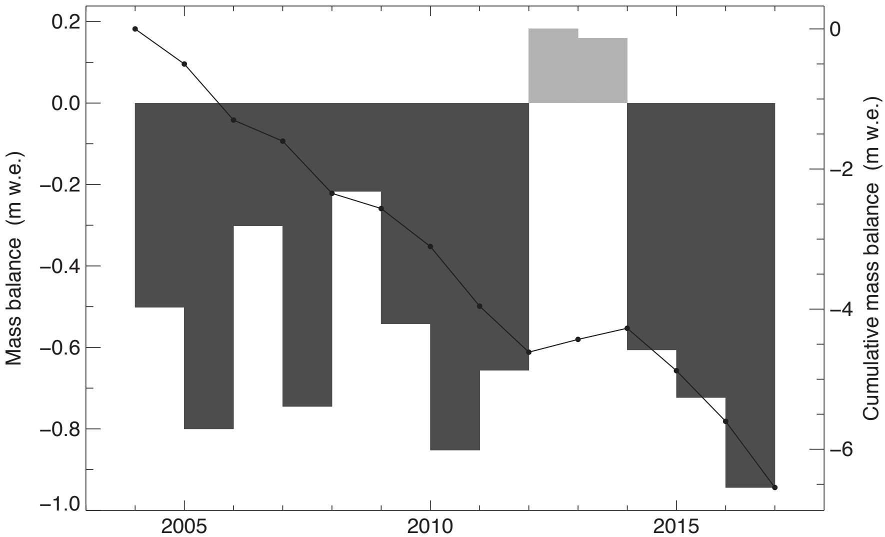

Figure 4.8: Findelengletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 2004-2017.

Investigations in 2016/17

The winter survey was performed on 12th April 2017. In total, 287 snow probings distributed over the entire surface of Findelen- and Adlergletscher were obtained, and snow density was measured in four snow pits. In addition, snow depth was monitored using a ground-based radar. On 21st September 2017 all measurement sites were visited. Mass balance was determined at 12 stakes on Findelen- and at two stakes on Adlergletscher. Due to limited winter snow and extreme summer heat waves the equilibrium line was at an elevation of up to 3500 m a.s.l. on Findelengletscher – higher than ever since the beginning of the measurements. None of the mass balance stakes experienced accumulation.

Table 4.4: Findelengletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	0.028	-42	−7303	0.082	202	−7301
2600 - 2700	0.259	94	−6530	0.192	255	−6502
2700 - 2800	0.217	205	−5112	0.237	368	−5380
2800 - 2900	0.338	484	−3916	0.341	555	−4062
2900 - 3000	0.578	643	−2784	0.578	690	−3290
3000 - 3100	0.977	718	−2101	0.996	777	−2852
3100 - 3200	1.736	777	−1457	1.715	910	−1857
3200 - 3300	1.834	823	−1063	1.833	1018	−1089
3300 - 3400	1.945	1051	−245	1.951	1192	−165
3400 - 3500	2.357	1338	512	2.357	1275	318
3500 - 3600	1.608	1431	1010	1.608	1248	638
3600 - 3700	0.439	1381	1135	0.439	1184	837
3700 - 3800	0.301	979	646	0.301	919	674
3800 - 3900	0.252	771	420	0.252	952	865
3900 - 4000	0.011	585	266	0.011	801	796
2500 - 4000	12.880	991	−723	12.893	1033	−944

Table 4.5: Adlergletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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.)
2900 - 3000	0.004	661	−2671	0.006	818	−3126
3000 - 3100	0.086	682	−2407	0.086	771	−2892
3100 - 3200	0.118	707	−2032	0.123	582	−2851
3200 - 3300	0.248	671	−1749	0.253	614	−2328
3300 - 3400	0.420	636	−1175	0.399	727	−1456
3400 - 3500	0.315	727	−371	0.315	770	−746
3500 - 3600	0.246	748	170	0.246	700	−254
3600 - 3700	0.208	708	388	0.208	675	131
3700 - 3800	0.177	655	568	0.177	677	437
3800 - 3900	0.103	574	598	0.103	634	545
3900 - 4000	0.046	544	644	0.046	664	686
4000 - 4100	0.014	490	656	0.014	661	778
4100 - 4200	0.004	454	643	0.004	531	603
2900 - 4200	1.989	677	−590	1.979	692	−947

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	21.09.2015	12.04.2016	22.09.2016	630331 / 95466 / 2622	300	−7180
F31	21.09.2015	12.04.2016	22.09.2016	630909 / 95416 / 2695	170	−5310
F32	21.09.2015	12.04.2016	22.09.2016	631010 / 95274 / 2708	610	−5060
F4	21.09.2015	12.04.2016	22.09.2016	631526 / 95379 / 2806	460	−4800
F5	21.09.2015	12.04.2016	22.09.2016	632181 / 94983 / 2934	720	−2700
F6	21.09.2015	12.04.2016	22.09.2016	632415 / 94970 / 2967	640	−3140
F7	21.09.2015	12.04.2016	22.09.2016	632534 / 94365 / 3036	790	−2220
F8	21.09.2015	12.04.2016	22.09.2016	633299 / 93862 / 3122	820	−1270
F81	21.09.2015	12.04.2016	22.09.2016	633279 / 94525 / 3139	790	−1860
F82	21.09.2015	12.04.2016	22.09.2016	632519 / 93787 / 3087	620	−1700
F93	21.09.2015	12.04.2016	22.09.2016	634295 / 94342 / 3255	870	−790
F94	21.09.2015	12.04.2016	22.09.2016	633648 / 93054 / 3264	840	−1360
F10	21.09.2015	12.04.2016	22.09.2016	635095 / 93918 / 3345	1020	100
F11	21.09.2015	12.04.2016	22.09.2016	634303 / 92288 / 3472	1510	380
A2	21.09.2015	12.04.2016	22.09.2016	632541 / 95502 / 3088	670	−2380
A4	21.09.2015	12.04.2016	22.09.2016	633064 / 95597 / 3239	490	−1940
F2	22.09.2016	12.04.2017	21.09.2017	630419 / 95449 / 2602	480	−7070
F31	22.09.2016	12.04.2017	21.09.2017	630934 / 95404 / 2679	90	−5920
F4	22.09.2016	12.04.2017	21.09.2017	631504 / 95374 / 2790	480	−4950
F5	22.09.2016	12.04.2017	21.09.2017	632160 / 95014 / 2921	960	−3060
F6	22.09.2016	12.04.2017	21.09.2017	632355 / 95012 / 2947	580	−3860
F7	22.09.2016	12.04.2017	21.09.2017	632473 / 94425 / 3031	780	−3170
F8	22.09.2016	12.04.2017	21.09.2017	633311 / 93855 / 3122	860	−1610
F81	22.09.2016	12.04.2017	21.09.2017	633338 / 94544 / 3149	510	−2890
F82	22.09.2016	12.04.2017	21.09.2017	632544 / 93756 / 3088	860	−2540
F94	22.09.2016	12.04.2017	21.09.2017	633596 / 93120 / 3250	720	−1570
F10	22.09.2016	12.04.2017	21.09.2017	635036 / 93958 / 3338	1200	−120
F11	22.09.2016	12.04.2017	21.09.2017	634291 / 92304 / 3472	980	0
A2	22.09.2016	12.04.2017	21.09.2017	632524 / 95504 / 3075	700	−3030
A4	22.09.2016	12.04.2017	21.09.2017	633046 / 95596 / 3231	760	−2500

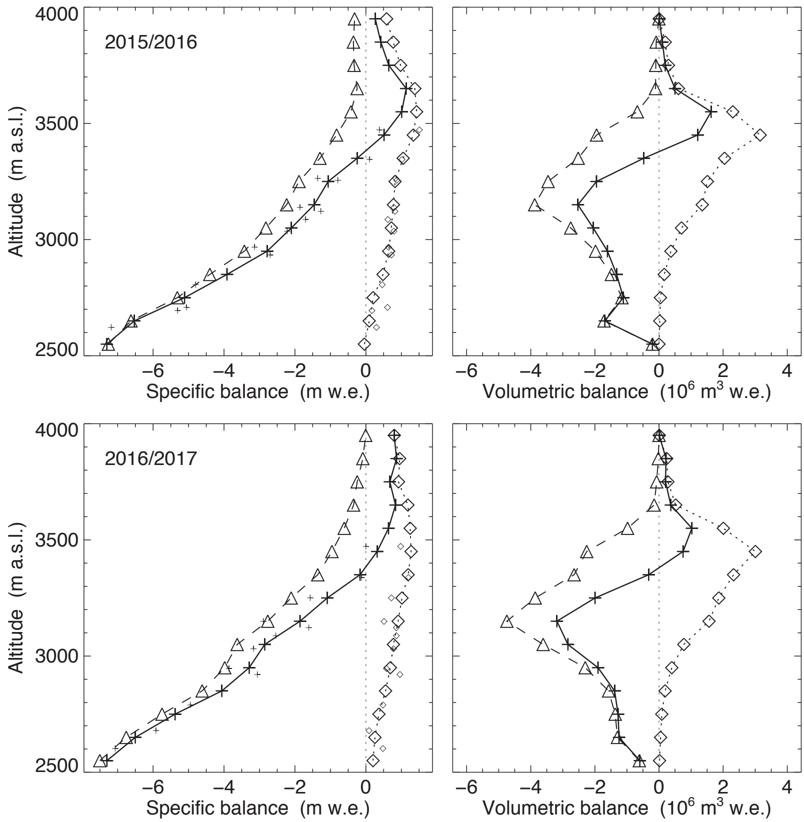

Figure 4.9: Findelengletscher - Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

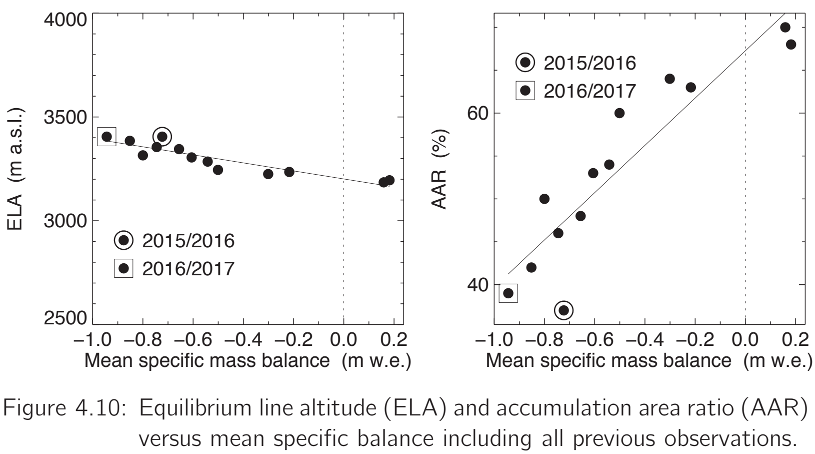

Figure 4.10: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.6 Griesgletscher (Aegina)

Introduction

Griesgletscher is a temperate valley glacier located in the central Swiss Alps. The glacier currently covers an area of 4.4 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, 2012 and every year since then. 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) were presented in Section 4.17 of Volume 135/136.

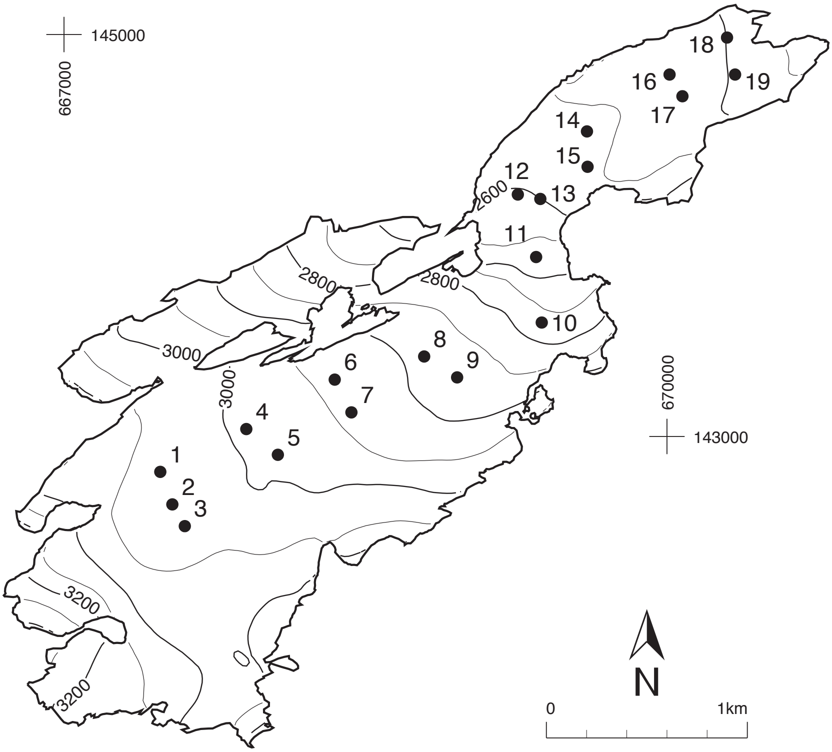

Figure 4.11: Surface topography and observational network of the Griesgletscher.

Investigations in 2015/16

The measurement period extended from 8th September 2015 to 7th September 2016 with a field visit in spring on 29th April 2016. 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. Mass balance was measured at 19 stakes.

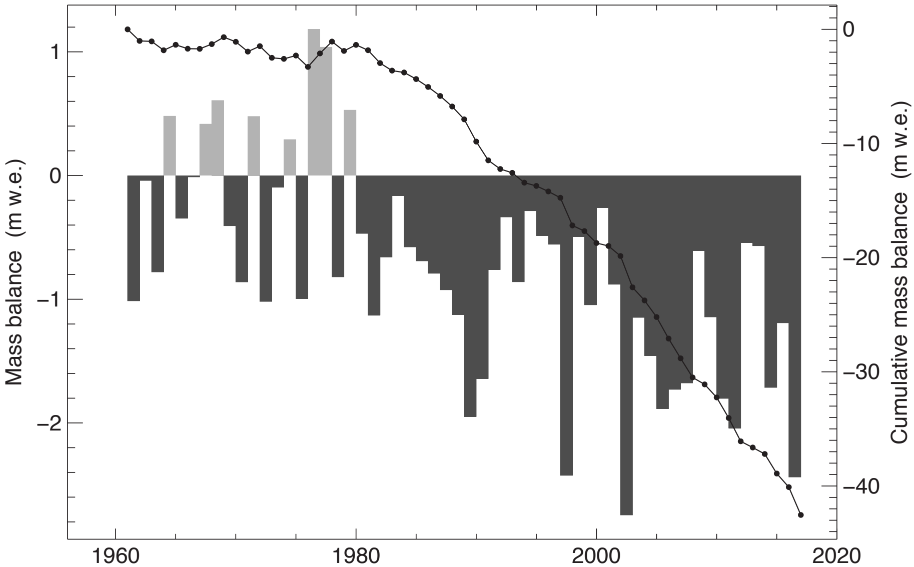

Figure 4.12: Griesgletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 1961-2017.

Investigations in 2016/17

The measurement period extended from 7th September 2016 to 7th September 2017 with a field visit in spring on 5th May 2017. Snow depth was sampled at 17 stake locations and the density was determined at two locations using a firn drill. Mass balance was measured at 17 stakes.

Table 4.7: Griesgletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	960	−3618	0.133	1108	−5085
2500 - 2600	0.613	975	−3283	0.594	1080	−4333
2600 - 2700	0.178	1449	−2319	0.165	1281	−3618
2700 - 2800	0.296	1674	−1380	0.292	1482	−2881
2800 - 2900	0.566	1811	−967	0.586	1616	−2293
2900 - 3000	0.977	1896	−787	0.993	1691	−2125
3000 - 3100	1.417	2088	−467	1.377	1838	−1626
3100 - 3200	0.206	1916	−99	0.196	1611	−1229
3200 - 3300	0.071	1212	−925	0.071	1006	−1714
3300 - 3400	0.001	806	−815	0.001	586	−1474
2400 - 3400	4.431	1753	−1191	4.407	1582	−2437

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

Stake	Period Start	Period Spring	Period End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	Mass balance b_a (mm w.e.)
1	08.09.2015	29.04.2016	07.09.2016	667462 / 142815 / 3034	1730	−850
2	08.09.2015	29.04.2016	07.09.2016	667542 / 142670 / 3027	1750	−1030
3	08.09.2015	29.04.2016	07.09.2016	667613 / 142556 / 3031	1930	−280
4	08.09.2015	29.04.2016	07.09.2016	667911 / 143049 / 2992	1760	−680
5	08.09.2015	29.04.2016	07.09.2016	668083 / 142926 / 2989	1660	−630
6	08.09.2015	29.04.2016	07.09.2016	668340 / 143284 / 2938	1480	−1310
7	08.09.2015	29.04.2016	07.09.2016	668416 / 143124 / 2937	1750	−1280
8	08.09.2015	29.04.2016	07.09.2016	668777 / 143408 / 2888	1540	−1490
9	08.09.2015	29.04.2016	07.09.2016	668958 / 143284 / 2877	1840	−940
10	08.09.2015	29.04.2016	07.09.2016	669377 / 143553 / 2773	1860	−830
11	08.09.2015	29.04.2016	07.09.2016	669357 / 143879 / 2674	1380	−2540
12	08.09.2015	29.04.2016	07.09.2016	669253 / 144155 / 2611	1450	−2870
13	08.09.2015	29.04.2016	07.09.2016	669363 / 144139 / 2606	1670	−2690
14	08.09.2015	29.04.2016	07.09.2016	669587 / 144508 / 2563	1200	−3080
15	08.09.2015	29.04.2016	07.09.2016	669587 / 144508 / 2563	1200	−3610
16	08.09.2015	29.04.2016	07.09.2016	669985 / 144792 / 2537	1100	−3400
17	08.09.2015	29.04.2016	07.09.2016	670050 / 144674 / 2531	1240	−3650
18	08.09.2015	29.04.2016	07.09.2016	670249 / 144973 / 2508	1450	−3720
19	08.09.2015	29.04.2016	07.09.2016	670271 / 144785 / 2506	1440	−3440
1	07.09.2016	05.05.2017	07.09.2017	667462 / 142815 / 3031	1720	−2070
2	07.09.2016	05.05.2017	07.09.2017	667542 / 142670 / 3025	1720	−1880
3	07.09.2016	05.05.2017	07.09.2017	667613 / 142556 / 3029	1740	−1400
4	07.09.2016	05.05.2017	07.09.2017	667911 / 143049 / 2989	1600	−2230
6	07.09.2016	05.05.2017	07.09.2017	668340 / 143284 / 2935	1520	−2750
7	07.09.2016	05.05.2017	07.09.2017	668416 / 143124 / 2933	1380	−2380
8	07.09.2016	05.05.2017	07.09.2017	668777 / 143408 / 2886	1430	−2790
9	07.09.2016	05.05.2017	07.09.2017	668958 / 143284 / 2874	1610	−2180
11	07.09.2016	05.05.2017	07.09.2017	669357 / 143879 / 2666	1370	−3980
12	07.09.2016	05.05.2017	07.09.2017	669253 / 144155 / 2601	1230	−4340
13	07.09.2016	05.05.2017	07.09.2017	669363 / 144139 / 2594	920	−3770
14	07.09.2016	05.05.2017	07.09.2017	669587 / 144508 / 2551	1140	−3820
15	07.09.2016	05.05.2017	07.09.2017	669587 / 144508 / 2551	1140	−4590
16	07.09.2016	05.05.2017	07.09.2017	669985 / 144792 / 2524	1080	−4070
17	07.09.2016	05.05.2017	07.09.2017	670050 / 144674 / 2518	1080	−4630
18	07.09.2016	05.05.2017	07.09.2017	670249 / 144973 / 2493	1330	−5190
19	07.09.2016	05.05.2017	07.09.2017	670271 / 144785 / 2489	1080	−5190

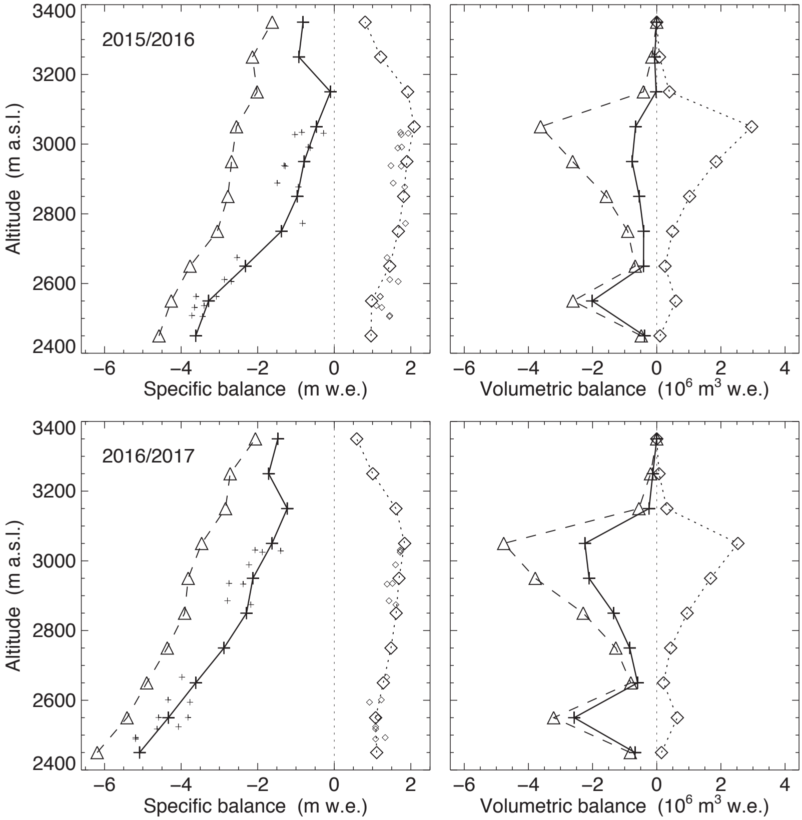

Figure 4.13: Specific (left) and volumetric (right) winter (dotted, $\diamond$), summer (dashed, $\triangle$) and annual (continuous line, $+$) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

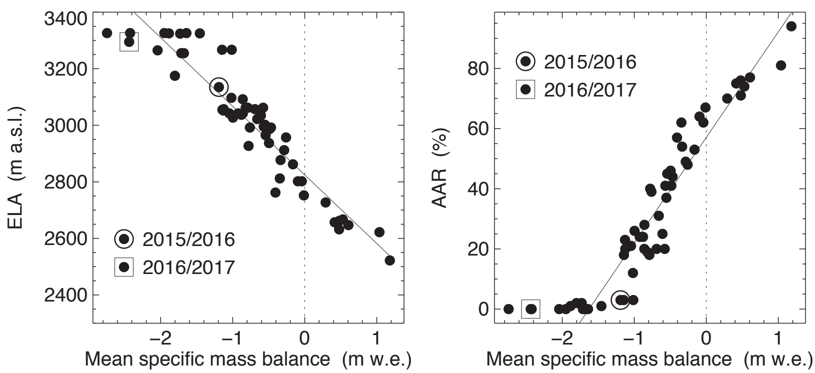

Figure 4.14: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

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.

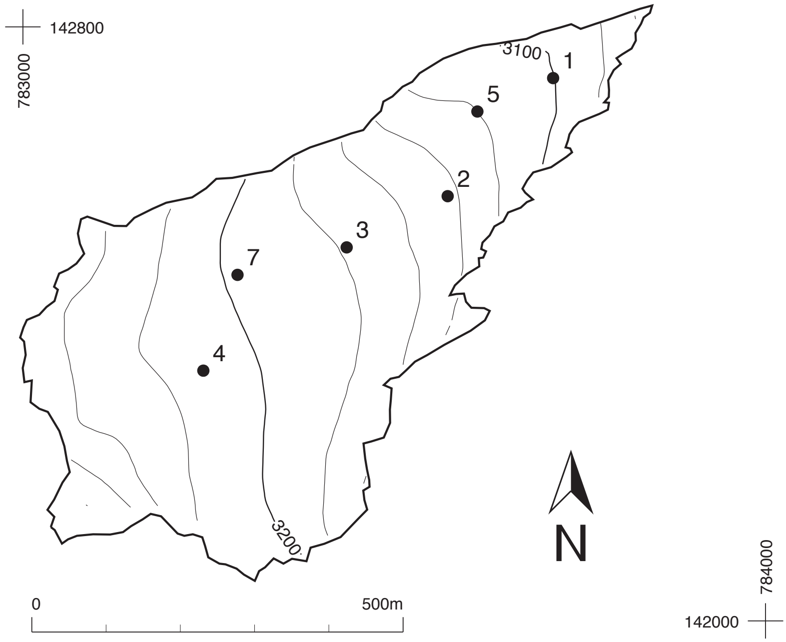

Figure 4.15: Surface topography and observational network of the Vadret dal Murtèl.

Investigations in 2015/16

Winter balance was measured on 10th April 2016. Snow depth was determined based on 131 snow probings on Vadret dal Murtèl and 30 on Vadret dal Corvatsch. Snow density was measured in two snow pits, in the lower and upper part of Vadret dal Murtèl, respectively. On 25th September 2016, measured point mass balance on Vadret dal Murtèl was negative at five stakes and balanced at the

Table 4.9: Vadret dal Murtèl - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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.)
3050 - 3100	0.015	580	−1818	0.015	350	−2945
3100 - 3150	0.052	624	−1162	0.052	352	−2196
3150 - 3200	0.109	648	−833	0.109	403	−1715
3200 - 3250	0.105	989	212	0.105	736	−741
3250 - 3300	0.016	1283	1073	0.016	914	175
3300 - 3350	0.001	1115	1223	0.001	814	584
3050 - 3350	0.298	796	−462	0.298	537	−1408

uppermost stake. On nearby Vadret dal Corvatsch, point mass balance between 19th September 2015 and 25th September 2016 was moderately negative at five measured stakes.

Investigations in 2016/17

Winter balance was determined on 24th April 2017. Snow probings were performed at 129 and 36 locations on Vadret dal Murtèl and Vadret dal Corvatsch, respectively. Snow density was measured in two snow pits. Snow depth was remarkably small, often less than one meter. Significant amounts of snow accumulation occurred, however, after the winter survey. A strongly negative mass balance was measured at four stakes on both glaciers on 13th September 2017. During the late summer

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	19.09.2015	10.04.2016	25.09.2016	783711 / 142736 / 3100	570	−1870
2	19.09.2015	10.04.2016	25.09.2016	783577 / 142572 / 3143	640	−950
3	19.09.2015	10.04.2016	25.09.2016	783436 / 142503 / 3178	690	−840
4	19.09.2015	10.04.2016	25.09.2016	783242 / 142337 / 3211	780	30
5	19.09.2015	10.04.2016	25.09.2016	783620 / 142686 / 3120	680	−1340
7	19.09.2015	10.04.2016	25.09.2016	783300 / 142467 / 3196	780	−410
1	25.09.2016	24.04.2017	13.09.2017	783715 / 142717 / 3101	240	−3190
2	25.09.2016	24.04.2017	13.09.2017	783577 / 142572 / 3143	520	−1970
3	25.09.2016	24.04.2017	13.09.2017	783443 / 142515 / 3175	370	−1750
7	25.09.2016	24.04.2017	13.09.2017	783293 / 142468 / 3196	550	−1310

field survey a thick fresh snow layer was already present. Nevertheless, ice ablation with values beyond -2m at an elevation of 3200 m a.s.l. during the summer of 2017 was extreme.

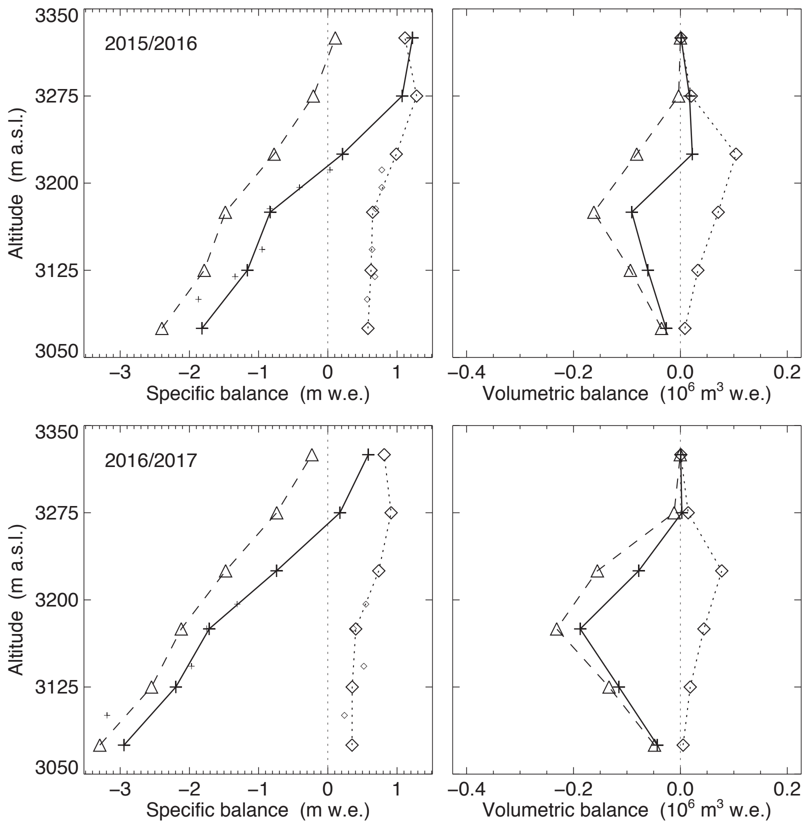

Figure 4.16: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

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 very small glaciers 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).

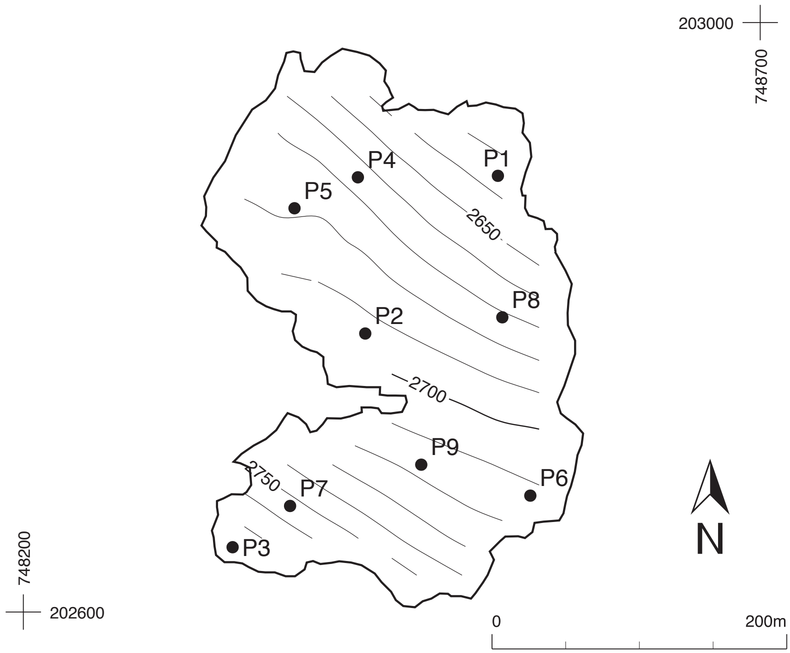

Figure 4.17: Surface topography and observational network of the Pizolgletscher.

Investigations in 2015/16

Winter balance was determined on 28th March 2016. Snow probings at 77 locations were performed and snow density was measured in a snow pit. During the late summer field survey on 24th September 2016 a negative mass balance was observed at eight stakes. Although the snow cover was almost fully depleted during this summer as well, melt rates were lower than in previous years.

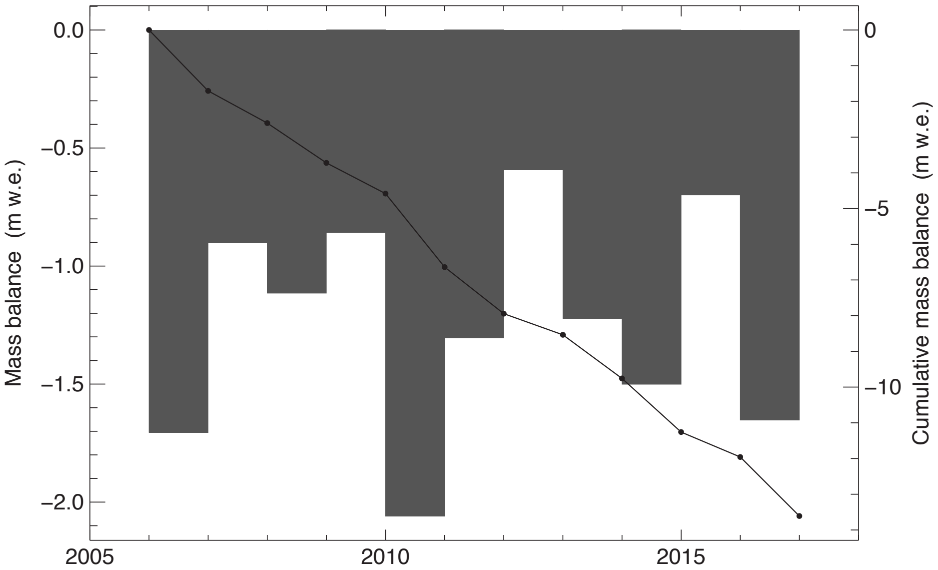

Figure 4.18: Pizolgletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 2006-2017.

The consistently negative mass balances of Pizolgletscher during the last decade have contributed to dramatic thinning of the glacier ice which is now becoming evident in the decay of remaining ice mass and rapidly increasing coverage of the glacier with blocks originating from the surrounding, destabilized rock flanks.

Investigations in 2016/17

The winter field survey was conducted on 16th March 2017. Snow probings at 87 locations were performed and snow density was measured in a snow pit. Due to below-average winter snow depth and frequent summer heatwaves, ice mass loss at Pizolgletscher was strong also in this year. On 29th September 2017 all stakes were visited and re-installed. A negative mass balance was determined at eight stakes. During the fall survey up to one meter of fresh snow was present on the glacier. The topmost part of the glacier immediately below Pizolsattel has almost completely disappeared and the last measurement site had to be abandoned due to objective danger (rockfall).

Table 4.11: Pizolgletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	0.010	1301	−1012	0.010	1043	−1931
2650 - 2700	0.032	1357	−835	0.032	1057	−1964
2700 - 2750	0.015	1374	−402	0.015	1190	−847
2750 - 2800	0.005	1569	−65	0.005	1215	−1457
2600 - 2800	0.061	1369	−699	0.061	1099	−1652

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	27.09.2015	28.03.2016	24.09.2016	748522 / 202896 / 2631	1180	−840
P2	27.09.2015	28.03.2016	24.09.2016	748430 / 202771 / 2697	1440	−500
P3	27.09.2015	28.03.2016	24.09.2016	748348 / 202657 / 2770	1630	−520
P4	27.09.2015	28.03.2016	24.09.2016	748426 / 202917 / 2654	1360	−1790
P5a	27.09.2015	28.03.2016	24.09.2016	748380 / 202867 / 2678	1260	−420
P5b	27.09.2015	28.03.2016	24.09.2016	748359 / 202852 / 2683	1650	260
P6	27.09.2015	28.03.2016	24.09.2016	748541 / 202669 / 2713	1280	−350
P8	27.09.2015	28.03.2016	24.09.2016	748524 / 202796 / 2670	1300	−1280
P9	27.09.2015	28.03.2016	24.09.2016	748464 / 202699 / 2715	1420	−290
P1	24.09.2016	16.03.2017	29.09.2017	748520 / 202890 / 2633	1090	−1740
P2	24.09.2016	16.03.2017	29.09.2017	748430 / 202771 / 2697	1040	−1670
P3	24.09.2016	16.03.2017	29.09.2017	748363 / 202652 / 2767	1220	−2180
P4	24.09.2016	16.03.2017	29.09.2017	748415 / 202903 / 2661	950	−2650
P5	24.09.2016	16.03.2017	29.09.2017	748380 / 202867 / 2678	1110	−2030
P6	24.09.2016	16.03.2017	29.09.2017	748541 / 202684 / 2709	1170	−1240
P8	24.09.2016	16.03.2017	29.09.2017	748500 / 202805 / 2672	970	−2600
P9	24.09.2016	16.03.2017	29.09.2017	748468 / 202697 / 2716	1370	−1100

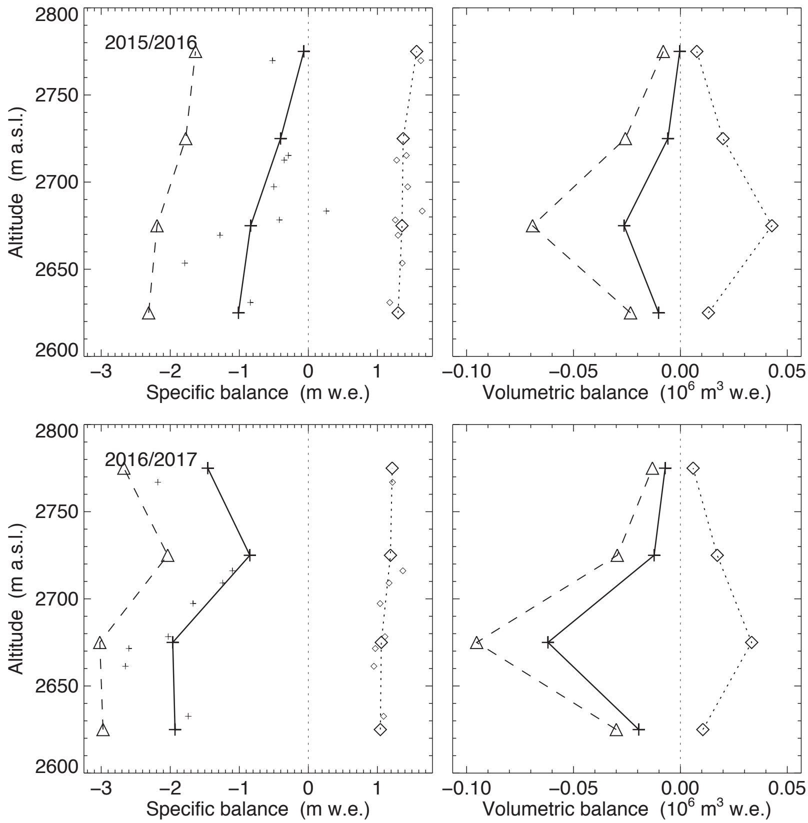

Figure 4.19: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

4.9 Glacier de la Plaine Morte

Introduction

Glacier de la Plaine Morte (7.4 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. Large circular depressions of the glacier surface, probably related to cryo-karst, are common features and are stable over several decades. Lac des Faverges, an ice marginal lake with a water volume of more than 2 million m^3 is subject to annual drainage events (see Chapter 6). The seasonal mass balance of 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 mainly driven by differences in ice surface albedo (Naegeli et al., 2015, 2017).

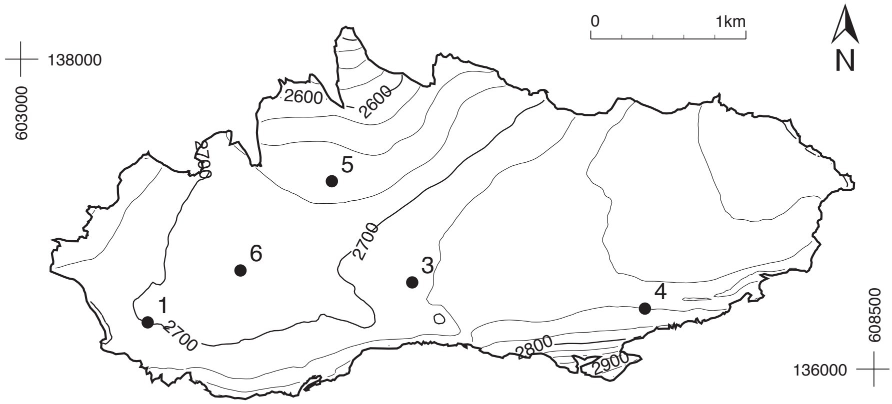

Figure 4.20: Surface topography and observational network of the Glacier de la Plaine Morte.

Investigations in 2015/16

Measurements of the winter mass balance were conducted on 30th March 2016. Snow probings at 51 locations distributed over most of glacier surface were performed and snow density was determined in a snow pit. In early July an automatic weather station was installed in the western part of the glacier recording air temperature, precipitation, wind speed and direction, snow depth and all components of the radiation budget among other variables during summer (Naegeli et al., 2017). Mass balance was measured at four stakes on 6th October 2016. As most of the glacier was snow-covered until the second half of August, ablation was moderate. However, by the end of

Table 4.13: Glacier de la Plaine Morte - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	1482	−1001	0.006	1539	−2304
2500 - 2600	0.152	1556	−854	0.152	1492	−2496
2600 - 2700	2.139	1583	−482	2.342	1450	−2277
2700 - 2800	5.106	1598	−155	4.792	1400	−2308
2800 - 2900	0.121	1603	480	0.089	1606	−790
2900 - 3000	0.026	1582	806	0.026	1588	−403
2400 - 3000	7.549	1593	−248	7.407	1421	−2277

the melting season the entire glacier was snow-free. Lac des Faverges drained subglacially on 27th August causing strongly elevated water levels in the Simme valley. In late October, a meteorological station was installed in the central part of Plaine Morte to investigate snow accumulation processes (Gugerli et al., 2017). Snow water equivalent is measured continuously using a cosmic ray sensor deployed at the snow-ice interface.

Investigations in 2016/17

During the winter field survey on 10th May 2017 snow probings at 130 locations distributed over the entire glacier were acquired and snow density was measured in a snow pit. Winter accumulation exhibited small spatial variations and was between three and four meters. The glacier surface was

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	23.10.2015	30.03.2016	06.10.2016	603819 / 136301 / 2704	1450	−790
3	23.10.2015	30.03.2016	06.10.2016	605524 / 136559 / 2721	1570	−40
5	23.10.2015	30.03.2016	06.10.2016	605006 / 137212 / 2671	1690	−690
6	23.10.2015	30.03.2016	06.10.2016	604417 / 136636 / 2691	1570	−700
1	06.10.2016	10.05.2017	11.10.2017	603819 / 136301 / 2700	1440	−2650
3	06.10.2016	10.05.2017	11.10.2017	605524 / 136559 / 2719	1640	−2010
4	06.10.2016	10.05.2017	11.10.2017	607024 / 136390 / 2749	1280	−2560
5	06.10.2016	10.05.2017	11.10.2017	605006 / 137212 / 2668	1460	−2170
6	06.10.2016	10.05.2017	11.10.2017	604417 / 136636 / 2688	1480	−2280

almost entirely snow-free already in the first half of July. During a mid-summer field survey, the automatic weather station for heat budget monitoring was re-installed in the western part of the glacier, maintenance of the winter station was performed and an additional mass balance stake was placed close to Lac des Faverges. A strongly negative mass balance was measured at all five stakes on 10th October 2017, with melt rates of three meters at individual sites. The outburst event of Lac des Faverges drained subglacially on 17th July 2017 with a volume slightly less than in the previous year.

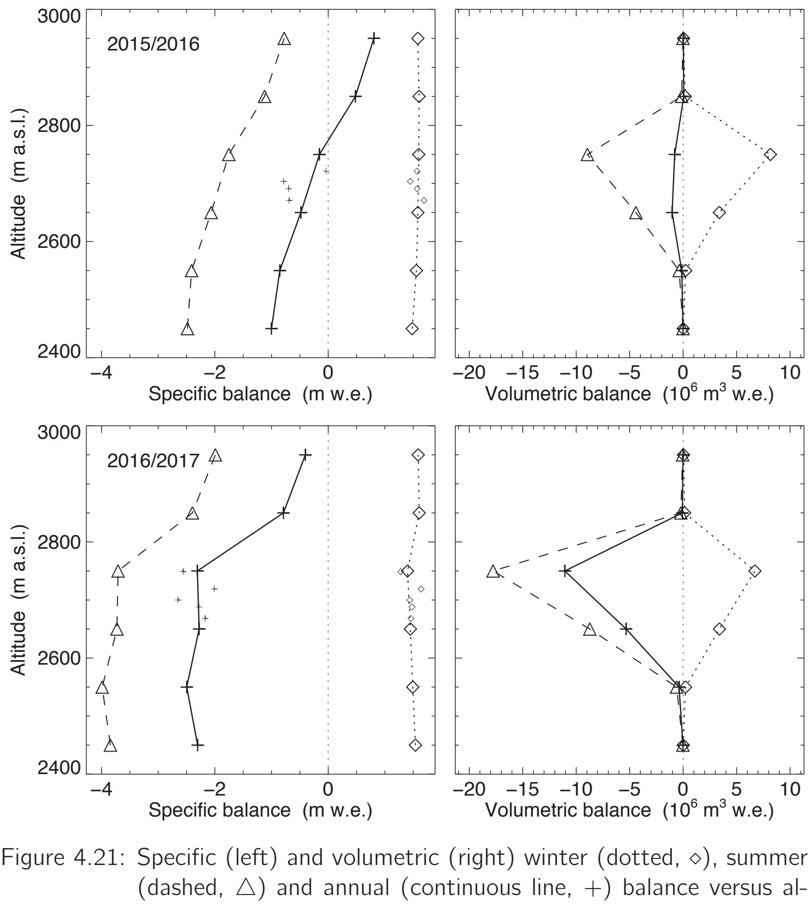

Figure 4.21: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

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 15.5 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 the 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 extends even further back to 1874

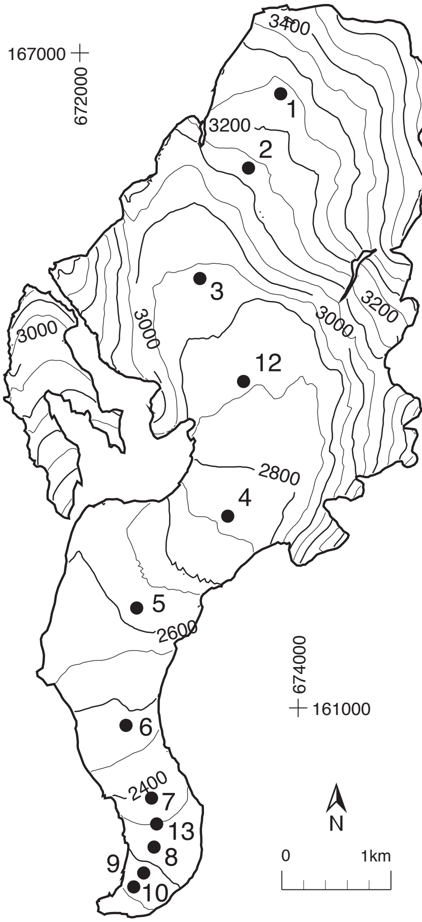

Figure 4.22: Surface topography and observational network of the Rhonegletscher.

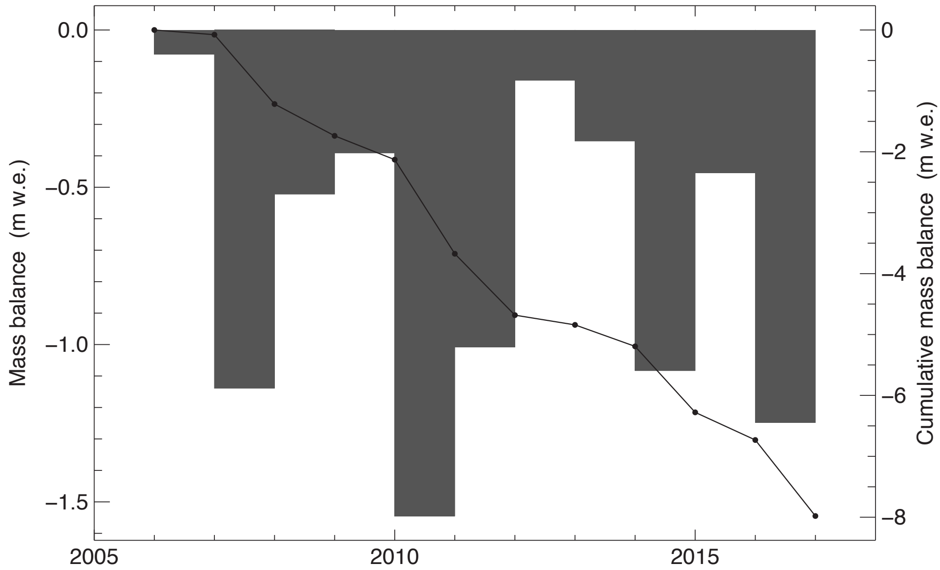

Figure 4.23: Rhonegletscher - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 2006-2017.

(Bauder et al., 2007). Topographic maps or photogrammetrical surveys exist for 1874, 1929, 1959, 1980, 1991, 2000, and 2007.

Investigations in 2015/16

The measurement period extended from 10th September 2015 to 20th September 2016 with a field visit in spring on 19th April 2016. A total of 405 individual snow depth soundings were collected in April 2016. At the time of the field measurements in September 2016, the glacier was covered with fresh 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 using a firn drill at stakes 3 and 13 in spring, and at stakes 1, 2 and 3 where net accumulation was recorded in fall.

Investigations in 2016/17

The measurement period began on the 20th September 2016 and ended on the 26th September 2017 with a field visit in the spring on 21st April 2017. During the spring field visit, snow depth from 317 individual points was collected for measuring the winter accumulation. In September 2017, the glacier was covered with 20-50 cm snow above 2600 m a.s.l., accumulated in the weeks before the survey. The limit of complete melt of winter accumulation was found at an elevation

Table 4.15: Rhonegletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	603	−5587	0.299	417	−6116
2300 - 2400	0.507	615	−5433	0.401	369	−5987
2400 - 2500	0.549	743	−5096	0.631	579	−5367
2500 - 2600	1.019	747	−4214	1.067	771	−4258
2600 - 2700	0.957	760	−3202	0.814	856	−3337
2700 - 2800	1.067	1292	−1460	1.068	1287	−2240
2800 - 2900	2.210	1671	−54	2.146	1570	−1264
2900 - 3000	2.171	1580	387	2.149	1615	−621
3000 - 3100	1.884	1571	741	1.876	1621	−216
3100 - 3200	1.534	1617	946	1.535	1621	−21
3200 - 3300	1.456	1709	1253	1.456	1715	374
3300 - 3400	0.951	1695	1499	0.951	1766	726
3400 - 3500	0.795	1483	1394	0.795	1810	1084
3500 - 3600	0.334	943	646	0.334	1508	826
2200 - 3600	15.571	1402	−454	15.523	1418	−1248

of about 3000 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 recorded (uppermost 2 stakes) in fall.

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

Stake	Period Start	Period Spring	Period End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	Mass balance b_a (mm w.e.)
01	10.09.2015	29.04.2016	20.09.2016	673815 / 166615 / 3235	2220	2148
02	10.09.2015	29.04.2016	20.09.2016	673552 / 165950 / 3125	1740	1236
03	10.09.2015	29.04.2016	20.09.2016	673100 / 164929 / 2929	1740	834
04	10.09.2015	29.04.2016	20.09.2016	673373 / 162787 / 2747	1440	−927
05	10.09.2015	29.04.2016	20.09.2016	672521 / 161915 / 2603	560	−3536
06	10.09.2015	29.04.2016	20.09.2016	672411 / 160849 / 2466	520	−4871
07	10.09.2015	29.04.2016	20.09.2016	672657 / 160173 / 2358	260	−5474
08	10.09.2015	29.04.2016	20.09.2016	672680 / 159724 / 2296	288	−5389
09	10.09.2015	29.04.2016	20.09.2016	672605 / 159500 / 2248	308	−5432
10	10.09.2015	29.04.2016	20.09.2016	672530 / 159390 / 2228	320	−4701
12	10.09.2015	29.04.2016	20.09.2016	673501 / 163994 / 2843	1620	6
13	10.09.2015	29.04.2016	20.09.2016	672704 / 159938 / 2321	240	−5287
01	20.09.2016	21.04.2017	26.09.2017	673815 / 166615 / 3235	1938	1350
02	20.09.2016	21.04.2017	26.09.2017	673552 / 165950 / 3125	1670	945
03	20.09.2016	21.04.2017	26.09.2017	673100 / 164928 / 2928	1640	−240
04	20.09.2016	21.04.2017	26.09.2017	673334 / 162736 / 2742	1262	−2131
05	20.09.2016	21.04.2017	26.09.2017	672519 / 161919 / 2601	370	−4689
06	20.09.2016	21.04.2017	26.09.2017	672410 / 160847 / 2464	−50	−5706
07	20.09.2016	21.04.2017	26.09.2017	672652 / 160175 / 2355	−130	−6237
08	20.09.2016	21.04.2017	26.09.2017	672680 / 159724 / 2291	−50	−6354
09	20.09.2016	21.04.2017	26.09.2017	672609 / 159494 / 2242	−120	−6453
10	20.09.2016	21.04.2017	26.09.2017	672530 / 159390 / 2221	80	−5922
12	20.09.2016	21.04.2017	26.09.2017	673517 / 163952 / 2840	1492	−1692
13	20.09.2016	21.04.2017	26.09.2017	672705 / 159937 / 2316	50	−5913

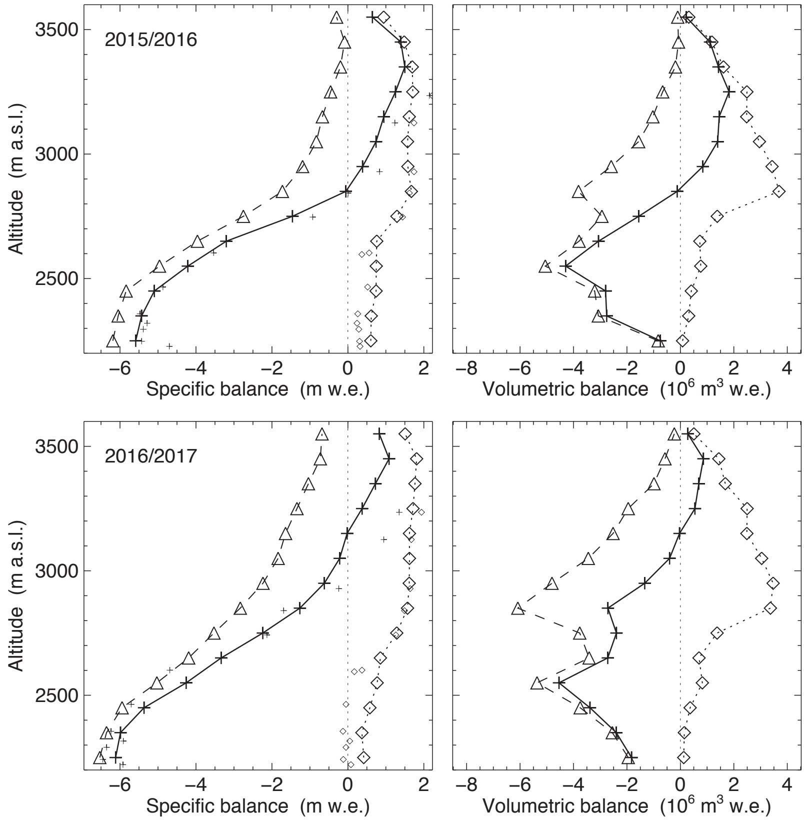

Figure 4.24: Specific (left) and volumetric (right) winter (dotted, ⋄), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

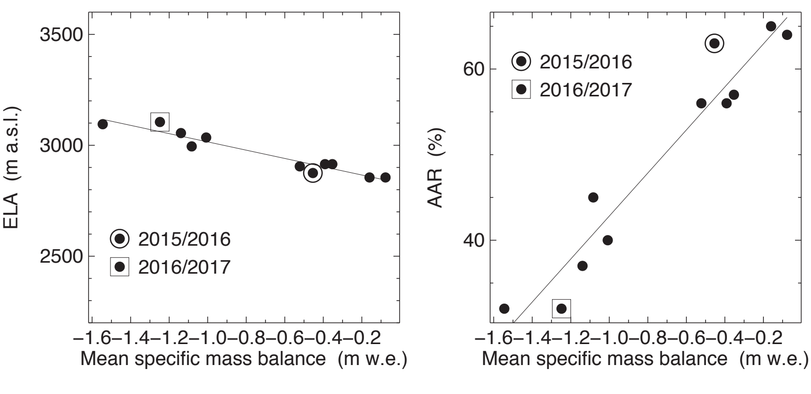

Figure 4.25: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

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 fast shrinkage over the next 25 years (Huss and Fischer, 2016).

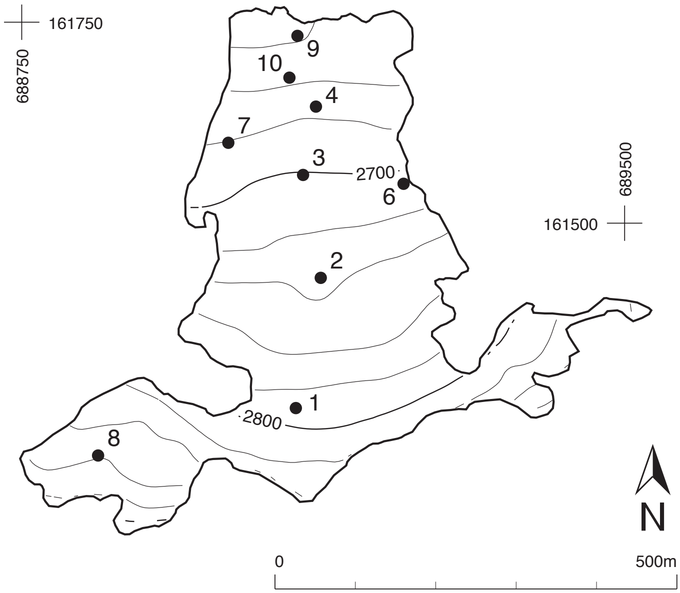

Figure 4.26: Surface topography and observational network of the Sankt Annafirn.

Investigations in 2015/16

Winter mass balance observations were conducted on 15th April 2016. Snow density was measured in a snow pit. Snow depth was determined based on 138 snow probings on Sankt Annafirn, and 80 probings on Schwarzbachfirn. On 3rd October 2016, a negative mass balance was measured at 11 stakes on Sankt Annafirn, and three stakes on Schwarzbachfirn. Most stakes were replaced but

Table 4.17: Sankt Annafirn - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	0.007	1080	−2085	0.007	1141	−2488
2650 - 2700	0.033	1036	−2074	0.033	1210	−2224
2700 - 2750	0.046	1190	−1615	0.046	1479	−1120
2750 - 2800	0.040	1489	−586	0.040	1408	−878
2800 - 2850	0.042	1581	166	0.042	1528	−515
2850 - 2900	0.016	1532	232	0.016	1728	−472
2900 - 2950	0.001	1036	685	0.001	1089	396
2600 - 2950	0.184	1339	−926	0.184	1432	−1123

the density of the monitoring network was somewhat reduced due to the limited size of the two glaciers. Both glaciers were snow-free except for some remnant snow patches below the headwalls.

Investigations in 2016/17

End-of-winter snow depth was measured at 73 locations on Sankt Annafirn, and at 30 locations on Schwarzbachfirn on 22^{nd} April 2017. Snow density was determined in a snow pit. For the first time, winter accumulation on the glacier was significantly affected by artificial snow relocation activities related to the ski run at Sankt Annafirn's margin. During the late summer field survey on 24^{th} September 2017, a negative mass balance was measured at eight stakes. High ablation rates of up to three meters were observed, however the maximum values of summer 2015 were not reached due to substantial snowfall in September 2017. Also on Schwarzbachfirn, a strongly negative mass balance was measured at two stakes.

Table 4.18: Sankt Annafirn - 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	28.09.2015	15.04.2016	03.10.2016	689091 / 161270 / 2791	1660	−530
2	28.09.2015	15.04.2016	03.10.2016	689122 / 161432 / 2735	1300	−1360
3	28.09.2015	15.04.2016	03.10.2016	689100 / 161560 / 2701	1320	−1530
4	28.09.2015	15.04.2016	03.10.2016	689116 / 161645 / 2676	990	−2340
5	28.09.2015	15.04.2016	03.10.2016	689238 / 161358 / 2765	1440	−1310
6	28.09.2015	15.04.2016	03.10.2016	689225 / 161549 / 2706	1100	−1940
7	28.09.2015	15.04.2016	03.10.2016	689007 / 161600 / 2681	1060	−1780
8	28.09.2015	15.04.2016	03.10.2016	688876 / 161215 / 2855	1300	−870
9	28.09.2015	15.04.2016	03.10.2016	689093 / 161733 / 2639	950	−2560
10	28.09.2015	15.04.2016	03.10.2016	689083 / 161681 / 2656	1040	−2280
11	28.09.2015	15.04.2016	03.10.2016	689386 / 161349 / 2816	1830	−340
1	03.10.2016	22.04.2017	24.09.2017	689081 / 161280 / 2787	430	−800
2	03.10.2016	22.04.2017	24.09.2017	689118 / 161433 / 2735	1580	−1270
3	03.10.2016	22.04.2017	24.09.2017	689102 / 161559 / 2701	1540	−1600
4	03.10.2016	22.04.2017	24.09.2017	689122 / 161640 / 2676	1070	−2540
7	03.10.2016	22.04.2017	24.09.2017	689016 / 161596 / 2682	1350	−2350
8	03.10.2016	22.04.2017	24.09.2017	688859 / 161212 / 2858	1990	−1560
9	03.10.2016	22.04.2017	24.09.2017	689089 / 161719 / 2641	1260	−2650
11	03.10.2016	22.04.2017	24.09.2017	689386 / 161349 / 2816	2110	−250

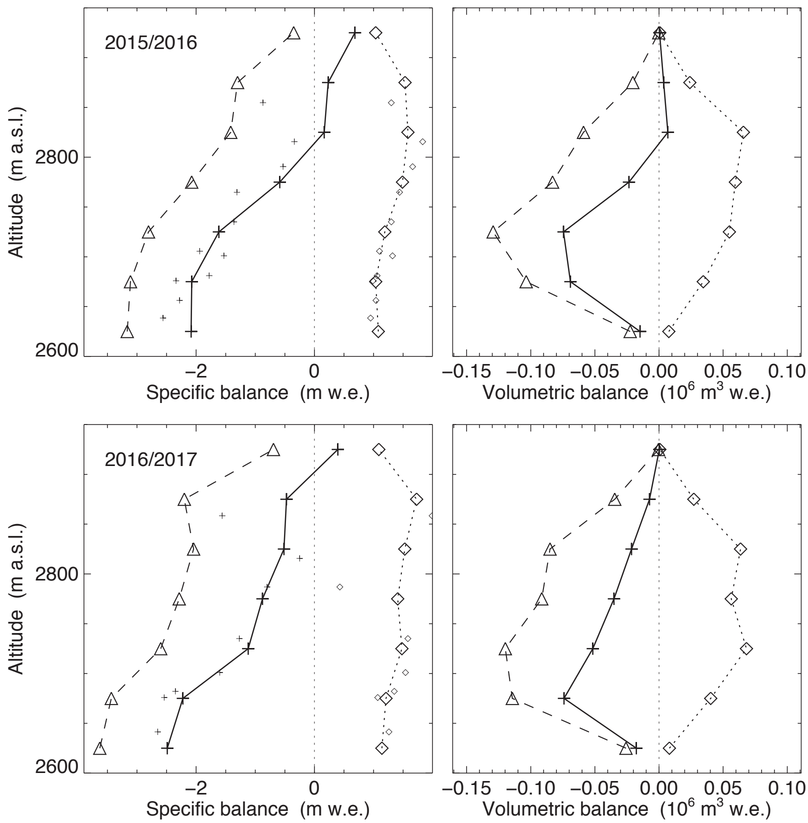

Figure 4.27: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

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, 1914–1978). 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, 2012 and every year since then. 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 2015 with corresponding values of the mean specific winter and annual balance for comparable fixed date periods was presented in Section 4.17 of Volume 135/136.

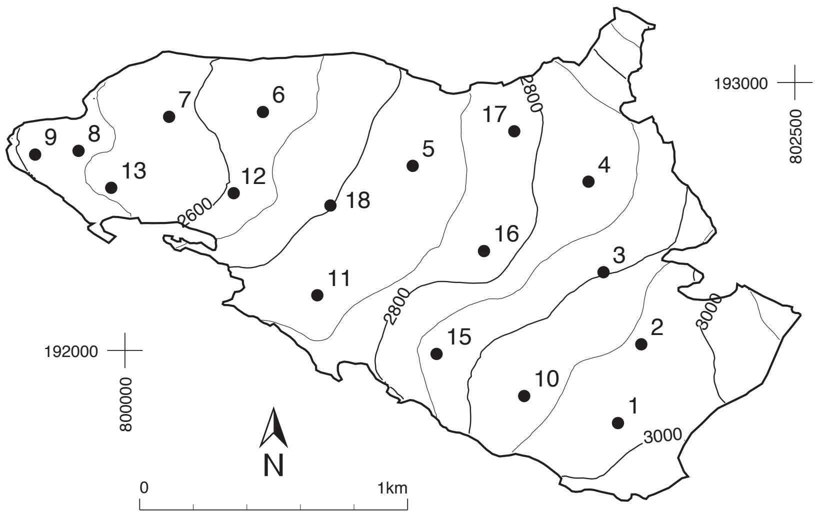

Figure 4.28: Surface topography and observational network of the Silvrettagletscher.

Investigations in 2015/16

Field measurements for winter mass balance were conducted on 7th May 2016. Snow depth samples were taken at 231 locations including all sites in the measurement network. Detailed

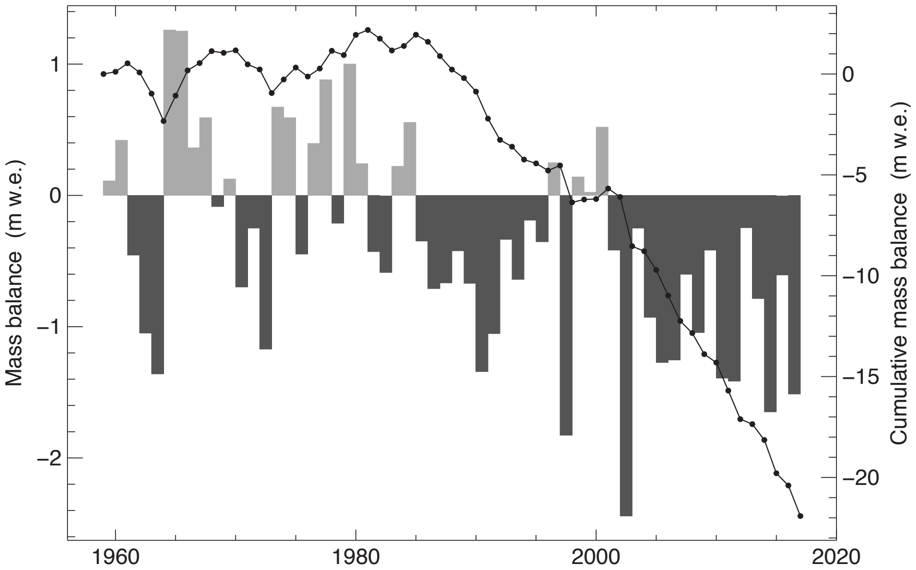

Figure 4.29: Silvrettagletscher - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1959-2017.

density profiles using the firn drill method were determined at two sites. A pronounced intermediate horizon most probably formed during a period of fair weather in January hindered the snow probings. Observations of mass balance in the fall with maintenance of the stake network were carried out on 23rd and 24th September 2016. The glacier was covered with 10-15 cm of fresh snow from previous days. Melt-out of the winter accumulation extended to almost the entire area and only limited accumulation at highest or shelterd areas and in depressions was left. The firn density was measured in a pit at one location (stake 02). Measurements at 16 stakes were available for the determination of the annual mass balance. Daily pictures from a time lapse camera taken from end of June until end of October document progressive melt-out and snowfall events during and at the end of the summer season.

Investigations in 2016/17

Winter mass balance was measured on 5th May 2017. Snow depth probings were collected at 209 locations distributed over the entire glacier surface. Snow density was determined at the same two locations as in the previous measuring periods using a firn drill. The field investigations in fall took place on 29th and 30st September 2017. Again the entire glacier was already covered with 25-60 cm snow accumulated during several snowfall events in September. Winter snow accumulation was completely depleted by the end of August on the entire glacier. A negative annual mass balance was determined at all 17 observation sites. Therefore only the density of fresh snow accumulation

Table 4.19: Silvrettagletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude (m a.s.l.)	2015/16 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	2016/17 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2400 - 2500	0.016	1051	−2818	0.026	1104	−3583
2500 - 2600	0.338	1113	−2472	0.333	1155	−3019
2600 - 2700	0.392	1343	−1172	0.411	1301	−1899
2700 - 2800	0.663	1450	−714	0.645	1376	−1520
2800 - 2900	0.576	1476	32	0.571	1424	−1087
2900 - 3000	0.583	1490	249	0.576	1433	−805
3000 - 3100	0.117	1239	176	0.109	1244	−909
2400 - 3100	2.684	1395	−606	2.671	1351	−1513

from September was determined at two locations. Investigations are again supplemented by the operation of a time lapse camera betweeen mid-June and end of October.

Silvrettagletscher at the beginning of August 2017 when the winter snow accumulation was already depleted to large extent (Photo: A. Bauder)

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

Stake	Period Start	Period Spring	Period End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	Mass balance b_a (mm w.e.)
01	26.09.2015	07.05.2016	24.09.2016	801841 / 191731 / 2976	1495	450
02	26.09.2015	07.05.2016	24.09.2016	801927 / 192023 / 2952	1495	255
03	26.09.2015	07.05.2016	24.09.2016	801780 / 192253 / 2900	1772	350
04	26.09.2015	07.05.2016	23.09.2016	801730 / 192630 / 2814	1659	30
05	25.09.2015	07.05.2016	23.09.2016	801074 / 192689 / 2711	1410	−837
06	25.09.2015	07.05.2016	23.09.2016	800515 / 192890 / 2610	1222	−1971
07	25.09.2015	07.05.2016	23.09.2016	800165 / 192872 / 2558	1231	−2385
08	25.09.2015	07.05.2016	23.09.2016	799833 / 192743 / 2514	1222	−2268
09	25.09.2015	07.05.2016	23.09.2016	799703 / 192736 / 2487	1208	−3015
10	26.09.2015	07.05.2016	24.09.2016	801525 / 191809 / 2931	1288	−81
11	25.09.2015	07.05.2016	23.09.2016	800720 / 192205 / 2715	1293	−1035
12	25.09.2015	07.05.2016	23.09.2016	800407 / 192586 / 2585	1368	−1971
13	25.09.2015	07.05.2016	23.09.2016	799974 / 192614 / 2529	963	−3015
15	25.09.2015	07.05.2016	23.09.2016	801163 / 191987 / 2849	1307	−594
16	26.09.2015	07.05.2016	23.09.2016	801341 / 192371 / 2761	1274	−999
17	26.09.2015	07.05.2016	23.09.2016	801446 / 192820 / 2768	1349	−1017
18	25.09.2015	07.05.2016	23.09.2016	800767 / 192541 / 2682	1419	−837
01	24.09.2016	05.05.2017	30.09.2017	801840 / 191729 / 2976	1500	−869
02	24.09.2016	05.05.2017	30.09.2017	801927 / 192023 / 2952	1560	−771
03	24.09.2016	05.05.2017	30.09.2017	801783 / 192252 / 2900	1440	−338
04	23.09.2016	05.05.2017	29.09.2017	801727 / 192631 / 2813	1312	−1287
05	23.09.2016	05.05.2017	29.09.2017	801070 / 192691 / 2710	1232	−1753
06	23.09.2016	05.05.2017	29.09.2017	800512 / 192890 / 2608	1082	−2609
07	23.09.2016	05.05.2017	30.09.2017	800166 / 192870 / 2556	1167	−2874
08	23.09.2016	05.05.2017	29.09.2017	799829 / 192747 / 2511	1093	−3084
09	23.09.2016	05.05.2017	29.09.2017	799704 / 192734 / 2484	1063	−3666
10	24.09.2016	05.05.2017	30.09.2017	801523 / 191810 / 2930	1280	−1047
11	23.09.2016	05.05.2017	29.09.2017	800721 / 192206 / 2714	1340	−1989
12	23.09.2016	05.05.2017	29.09.2017	800403 / 192587 / 2583	1309	−2546
13	23.09.2016	05.05.2017	29.09.2017	799965 / 192611 / 2524	905	−3962
15	23.09.2016	05.05.2017	29.09.2017	801163 / 191987 / 2849	1260	−1652
16	23.09.2016	05.05.2017	29.09.2017	801335 / 192374 / 2760	1452	−1460
17	23.09.2016	05.05.2017	29.09.2017	801453 / 192818 / 2768	1412	−1449
18	23.09.2016	05.05.2017	29.09.2017	800762 / 192543 / 2681	1372	−1789

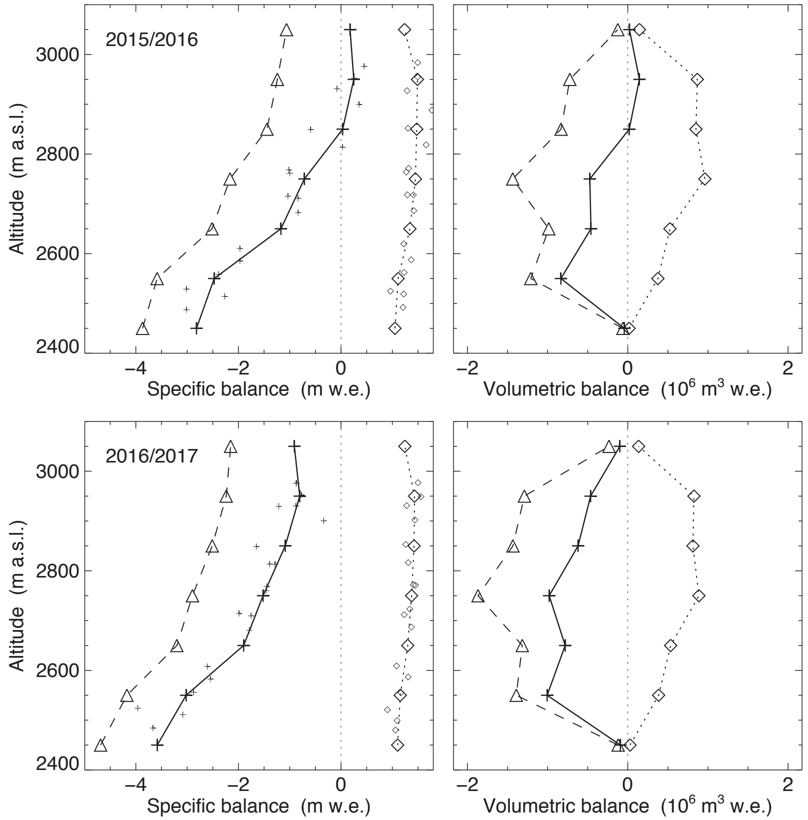

Figure 4.30: Specific (left) and volumetric (right) winter (dotted, $\diamond$), summer (dashed, $\triangle$) and annual (continuous line, $+$) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

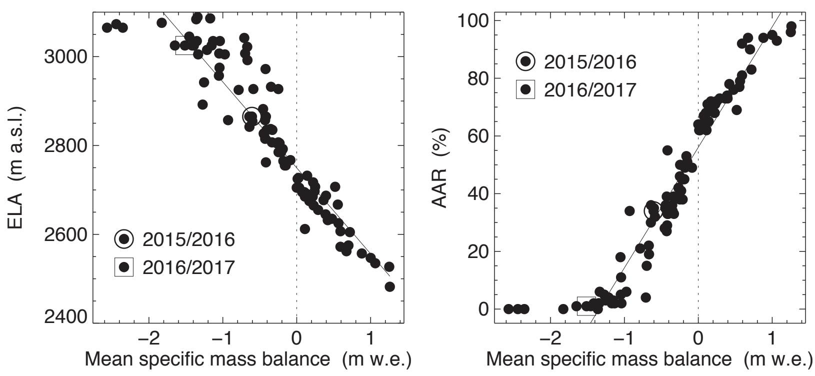

Figure 4.31: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.13 Glacier de Tsanfleuron

Introduction

Glacier de Tsanfleuron is an easily accessible medium-sized glacier at the border between 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 program in the western Swiss Alps. In addition, measurements are also performed on the very small Glacier du Sex Rouge connected to Tsanfleuron in its accumulation area. This permits comparing the mass balance response of neighboring glaciers of different size and characteristics.

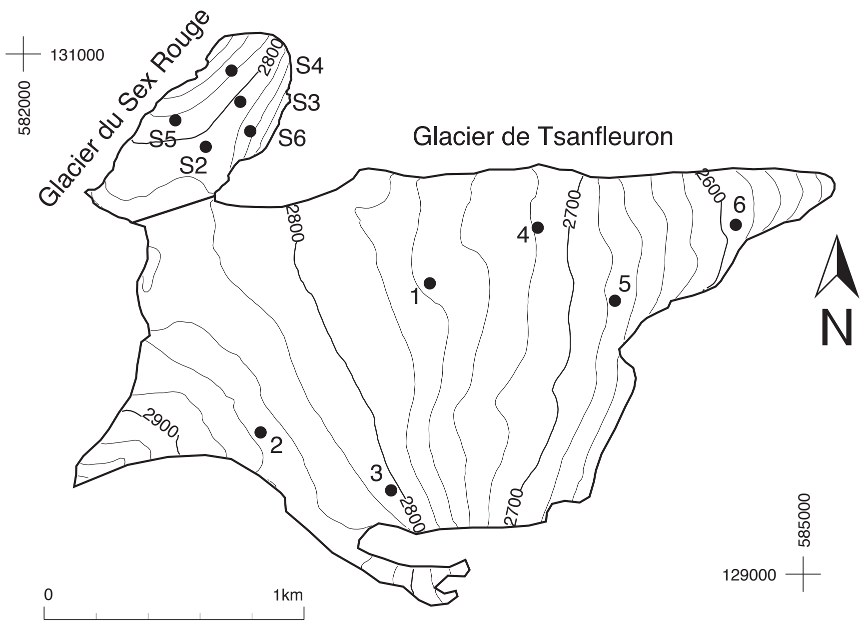

Figure 4.32: Surface topography and observational network of the Glacier de Tsanfleuron and the Glacier du Sex Rouge.

Investigations in 2015/16

The winter mass balance observations were conducted on 19th April 2016. Snow density was measured in a snow pit. Snow depth was determined based on 19 snow probings on Glacier du Tsanfleuron, supported by a 1.6 GHz ground-penetrating radar device. On Glacier du Sex Rouge, 85 snow probings were performed. During the late summer field survey on Glacier de Tsanfleuron on 14th September 2016 a negative mass balance was measured at three stakes, whereas three stakes

Table 4.21: Glacier de Tsanfleuron - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	1404	−1961	0.045	1381	−3841
2600 - 2700	0.457	1611	−1098	0.404	1550	−3052
2700 - 2800	1.126	1871	−280	1.097	1724	−2293
2800 - 2900	0.918	2144	329	0.863	1814	−1810
2900 - 3000	0.060	2017	565	0.057	1993	−794
2500 - 3000	2.618	1914	−226	2.466	1727	−2242

exhibited small mass gains. About 40% of the glacier surface was still snow-covered indicating that this year's meteorological conditions resulted in substantially smaller melt rates than, for example, the summer seasons 2015 or 2011. On Glacier du Sex Rouge, five stakes were measured of which four showed almost balanced conditions and one a negative mass balance. Repeated measurements of englacial temperature 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).

Investigations in 2016/17

During the winter field survey on 30th April 2017, snow probings at 86 locations on Glacier du Tsanfleuron, and at 42 locations on Glacier du Sex Rouge were performed. Snow density was determined in one snow pit. Due to below-average snow depth and extreme melting during the early summer the winter snow cover was already depleted over the entire glacier surface in the second half of July. On 8th September 2017, a strongly negative mass balance was measured at

Table 4.22: Glacier du Sex Rouge - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	0.004	1914	91	0.004	1601	−2214
2750 - 2800	0.080	1650	−298	0.080	1454	−2489
2800 - 2850	0.161	1790	−161	0.161	1405	−2692
2850 - 2900	0.011	2541	1101	0.011	1817	−861
2700 - 2900	0.256	1780	−144	0.256	1441	−2541

five stakes on Glacier du Tsanfleuron, and at two stakes on Glacier du Sex Rouge. Melt rates were, however, a bit less negative than during the 2014/15 measurement period.

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.)	
1	21.09.2015	19.04.2016	14.09.2016	583560 / 130158 / 2753	2280	210
2	21.09.2015	19.04.2016	14.09.2016	582918 / 129553 / 2851	2210	480
3	21.09.2015	19.04.2016	14.09.2016	583415 / 129322 / 2805	2120	170
4	21.09.2015	19.04.2016	14.09.2016	583979 / 130337 / 2719	2190	−410
5	21.09.2015	19.04.2016	14.09.2016	584264 / 130051 / 2685	1850	−1150
6	21.09.2015	19.04.2016	14.09.2016	584735 / 130346 / 2608	1490	−1770
S1	20.09.2015	19.04.2016	14.09.2016	582553 / 130486 / 2821	1820	−330
S2	20.09.2015	19.04.2016	14.09.2016	582702 / 130654 / 2805	1530	−250
S3	20.09.2015	19.04.2016	14.09.2016	582835 / 130816 / 2806	1720	−110
S4	20.09.2015	19.04.2016	14.09.2016	582795 / 130940 / 2775	1460	−840
S5	20.09.2015	19.04.2016	14.09.2016	582583 / 130742 / 2785	1760	50
S6	20.09.2015	19.04.2016	14.09.2016	582872 / 130709 / 2835	1530	150
S7	20.09.2015	19.04.2016	14.09.2016	582609 / 130602 / 2810	1730	40
1	14.09.2016	30.04.2017	08.09.2017	583527 / 130148 / 2756	1760	−1640
2	14.09.2016	30.04.2017	08.09.2017	582918 / 129553 / 2851	1810	−1370
3	14.09.2016	30.04.2017	08.09.2017	583416 / 129321 / 2805	1740	−2050
4	14.09.2016	30.04.2017	08.09.2017	583990 / 130341 / 2715	1810	−2340
6	14.09.2016	30.04.2017	08.09.2017	584735 / 130346 / 2608	1540	−3720
S3	14.09.2016	30.04.2017	08.09.2017	582833 / 130812 / 2806	1740	−2290
S5	14.09.2016	30.04.2017	08.09.2017	582583 / 130742 / 2785	1470	−2360

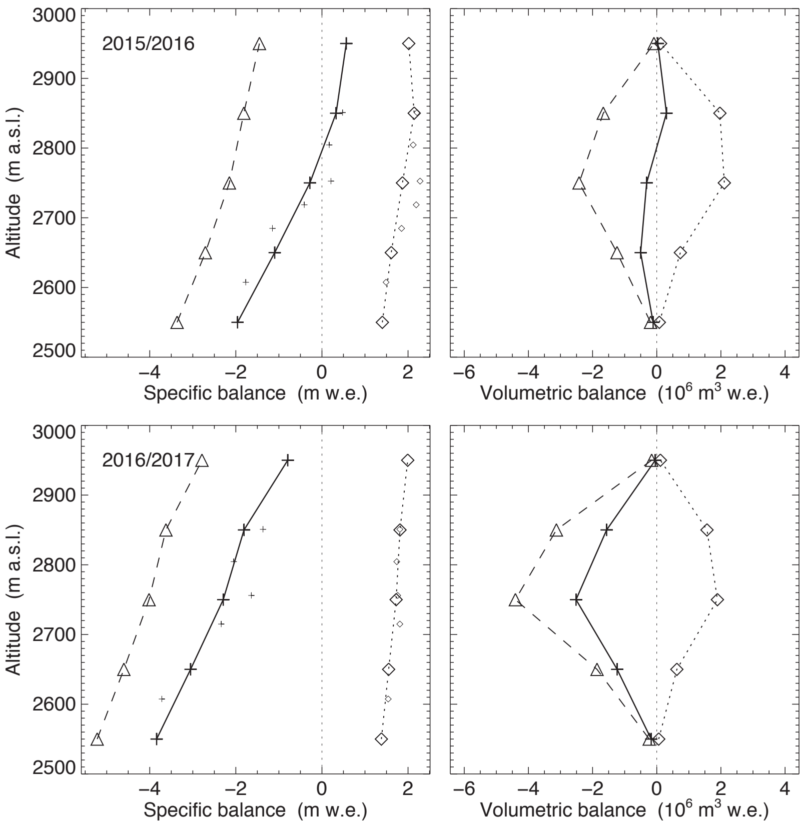

Figure 4.33: Glacier de Tsanfleuron - Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance versus altitude for 2015/16 (top) and 2016/17 (bottom). Small symbols mark the individual measurements.

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 snow pit 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 1914-2015 are compiled in Section 4.16 of Volume 135/136

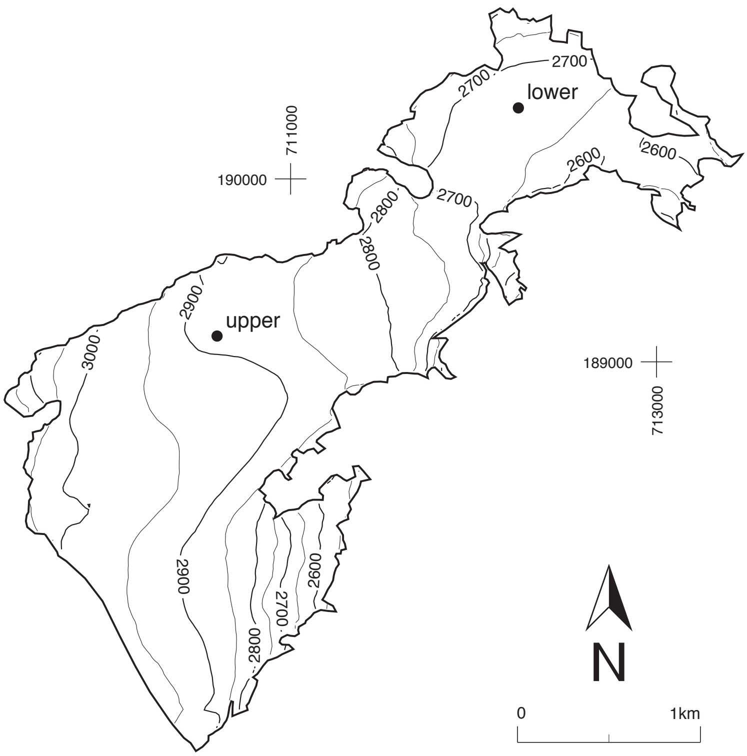

Figure 4.34: Surface topography and observational network of the Claridenfirn.

(Figure 4.35). In addition, Huss et al. (2015) calculated glacier-wide mass balance for the entire time series (Figure 4.36, see Section 4.17 of Volume 135/136). Investigations on the glaciers are complemented by measurements of two precipitation storage gauges at Claridenhütte (2475 m a.s.l.) and Geissbützistock (2710 m a.s.l.) situated in the close vicinity of the glacier. Readings are taken during both spring and fall visits.

Investigations in 2015/16

Spring measurements were carried out on 27th and 28th May 2016. Detailed observations in a snow pit at the upper stake were supplemented by 20 snow depth samples in the vicinity of both stakes. A distinct layer of sahara dust deposited at 2nd April 2016 was found at 1.6 m depth. Autumn measurements were carried out on 30th September 2016. At the lower site, snow accumulation during winter had melted completely with additional loss of ice. The upper site showed a moderate amount of 1.4 m of firn accumulation and the density was measured in a pit. In addition to the measurements of mass balance quantities, surface lowering and horizontal displacment of the stakes was determined in autumn.

Investigations in 2016/17

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 in fall. The spring field survey was carried out on 25th May, and the late summer survey on 23rd September 2017. In spring, two distinct ice lenses formed by percolation of meltwater were found at 1 m and 2.3 m depth. The temperature of the entire layer was still below melting, reaching a minimum of -3.9°C at the base. At the end of September, a substantial layer accumulated during September of 62 cm at the lower stake and 84 cm at the upper stake. Over the annual period, however, a substantial negative mass balance resulted at the lower site, where the winter accumulation completely melted and an additional large loss of ice occurred. At the end of August, melt-out of the snow accumulated during the winter season reached the upper site as well. The positive mass balance was due solely to the considerable amount of snow accumulation during September.

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

Stake	Period Start	Period Spring	Period End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	Mass balance b_a (mm w.e.)
upper	09.10.2015	28.05.2016	30.09.2016	710604 / 189127 / 2890	2148	655
lower	09.10.2015	27.05.2016	30.09.2016	712246 / 190397 / 2670	2054	−357
upper	30.09.2016	25.05.2017	23.09.2017	710596 / 189123 / 2890	1944	178
lower	30.09.2016	25.05.2017	23.09.2017	712261 / 190406 / 2670	1695	−1133

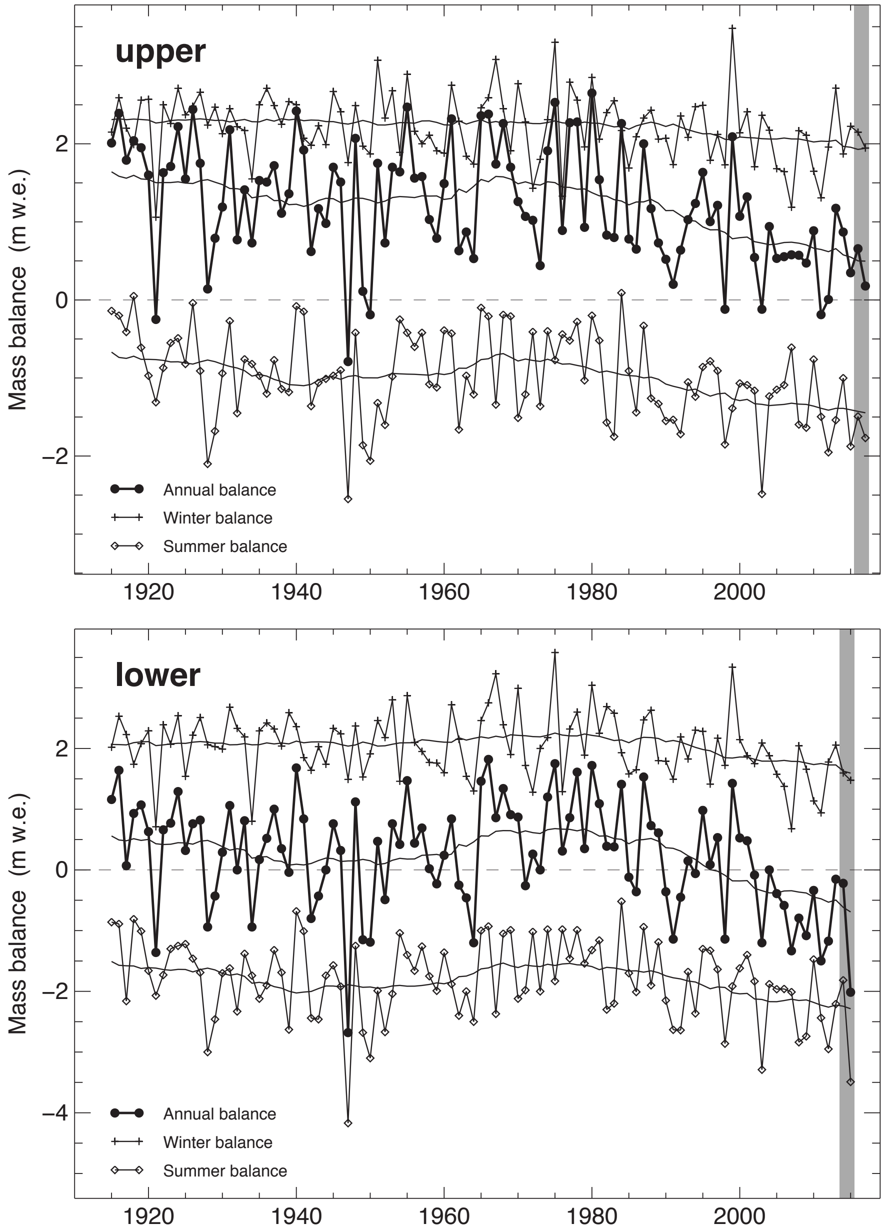

Figure 4.35: Mass balance of the upper (top) and lower (bottom) stake on Claridenfirn over the whole observation period. The gray shaded area highlights the years of the current report.

Table 4.25: Claridenfirn - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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	0.071	1263	−5664	0.071	1169	−5579
2600 - 2700	0.755	1690	−1576	0.755	1522	−1968
2700 - 2800	0.693	1691	−502	0.693	1488	−1181
2800 - 2900	1.304	1784	−100	1.304	1529	−948
2900 - 3000	1.498	1648	20	1.498	1396	−974
3000 - 3100	0.194	1755	497	0.194	1469	−198
3100 - 3200	0.031	1353	310	0.031	1116	−455
3200 - 3300	0.006	0	0	0.006	0	0
2500 - 3300	4.551	1694	−424	4.551	1465	−1196

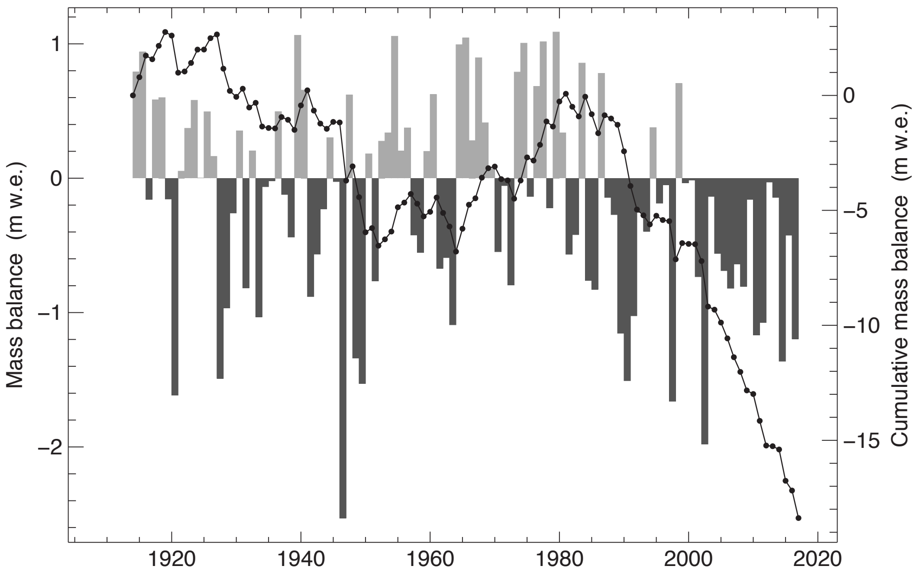

Figure 4.36: Claridenfirn - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1914-2017.

4.15 Grosser Aletsch

Introduction

Grosser Aletschgletscher is the largest ice mass in the Alps and borders the major northern Alpine crest. The three main tributaries converge 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 4.37). Huss and Bauder (2009) compiled and homogenized all existing measurements to form a continuous time series of seasonal resolution (see Section 4.10 in Volume 127/128). Between 1950 and 1985 a network of stakes on a longitudinal and several cross profiles

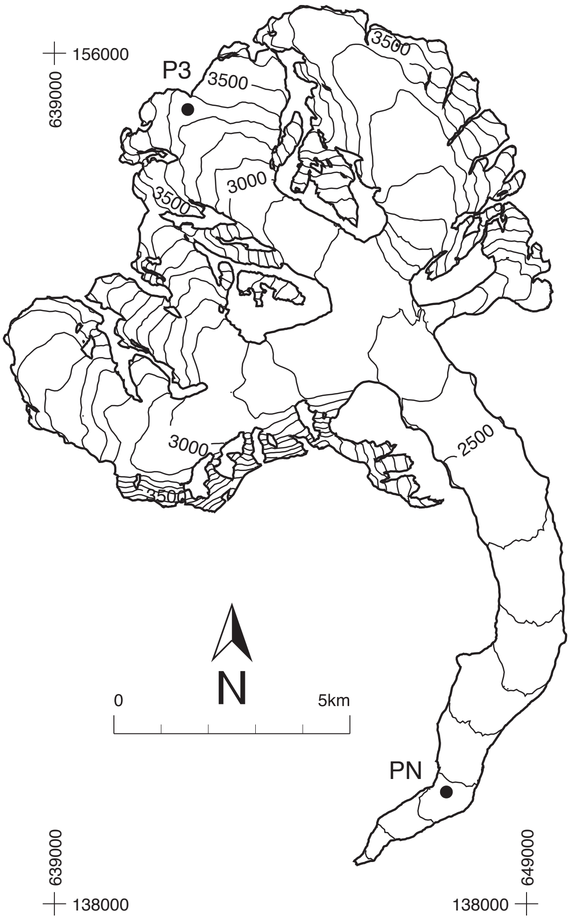

Figure 4.37: Surface topography and observational network of the Grosser Aletschgletscher.

was maintained, with a focus on both mass balance and ice flow velocity (Zoller, 2010). As part of the educational activities of ProNatura mass balance is being measured at a site on the glacier tongue (PN). Starting in 1992, weekly readings have been carried out during the summer season, and since the year 1995/96 the annual balance is being determined as well. The results of the glacier-wide mean specific winter and annual balance for comparable fixed date periods for 1939 to 1999 were presented in Section 4.17 of Volume 135/136. Afterwards the spatial sparsity of the observations did not permit determination of the glacier-wide balance.

Investigations in 2015/16

The investigations consisted of snow depth measurements and density profiling using a firn drill in spring and fall at site P3. The surface was marked the previous fall at the time of the measurement and could be retrieved in the density profiles. This monitoring program was supplemented by stake readings approximately twice a month. The measurements were taken in spring on 18th May 2016 and in fall on 29th September 2016. In spring a pronounced 10 cm thick layer of sahara dust was observed at about 2 m depth and still present in fall at 0.5 m depth. This layer was deposited at the beginning of April when the Alps experienced weather conditions of prevailing strong Föhn-winds. The distinct surface crust formed in summer 2015 could be identified clearly at both measurement events in May and September and was found half a meter below the surface marked during the previous fall visit. In spring, mean density was found to be 450 $\pm$15 kg m^{-3} of the layer accumulated in winter, and in fall it was 585 $\pm$5 kg m^{-3} of the annual layer. In addition to mass balance investigations, the position of the stake was surveyed using a high-precision differential GPS. An annual speed of 33.3 m a^{-1} was determined with only a slight increase from the winter to the summer season. Results of seasonal mass balance measurements at site PN were reported by ProNatura.

Investigations in 2016/17

The same set of measurements was conducted as in the previous period. At site P3, the spring field survey was carried out on 16th May 2017 and the fall survey on 12th October 2017. Snow depth measurement and firn coring in May showed a homogeneous layer of winter accumulation with one distinct intermediate horizon in 3 m depth. Corresponding measurements from stake readings, firn drilling, and snow depth measurements all delivered similar results. Mean density was found to be 430 $\pm$10 kg m^{-3} in spring of the layer accumulated in winter and 530 $\pm$10 kg m^{-3} in fall of the annual layer. A mean annual flow velocity of 31.6 m a^{-1} was recorded. Mass balance investigations at site PN were undertaken and results of winter, summer and annual balance reported by ProNatura.

Table 4.26: 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	29.09.2015	18.05.2016	29.09.2016	641825 / 154810 / 3340	2232	2334
PN	14.10.2015	06.06.2016	13.10.2016	647328 / 140403 / 1980	−1314	−9702
P3	29.09.2016	16.05.2017	12.10.2017	641825 / 154810 / 3341	1634	1002
PN	13.10.2016	07.06.2017	05.10.2017	647303 / 140366 / 1975	−2331	−10287

Stake P3 on Jungfraufirn in September 2016 with two marked patches for locating the reference surface during measurements in the subsequent year (Photo: A. Bauder)

4.16 Extrapolating local mass balance observations to the Swiss Alps

Background

Since 2011 a yearly report documenting the changes in glacier storage of the ten largest hydrological catchments of the Swiss Alps has been produced by GLAMOS for the Federal Office for the Environment (Huss and Bauder, 2012–2018). Changes in ice/water storage can significantly affect the overall water balance of drainage basins, especially during years with strong glacier melt. Estimating regional glacier mass change is, however, not trivial, as direct measurements at the annual scale are performed only on relatively few glaciers accounting for about 10% of the overall glacierized area of Switzerland, and only a bit more than 1% of the glacier count. A combination of methods is thus required to extrapolate in situ measurements to all glaciers, and to determine catchment-wide ice volume changes. Relating these changes to the remaining overall ice volume has proven to be beneficial in communicating the annual losses of Swiss glaciers during the last years to a broader public.

Methods

Substantial differences in the mass balance of neighboring glaciers documented in individual years might be due to local weather characteristics or, more importantly, due to different glacier geometries (average ice thickness, surface slope, etc.), resulting in different glacier response times (e.g. Kuhn et al., 1985; Huss, 2012). It is crucial to incorporate these effects into the extrapolation of single glacier mass balances to the regional scale as the in situ measurements (only 1-2 glaciers per hydrological drainage basin are monitored for the most part) are unlikely to be representative of the remaining glaciers. The computation of annual glacier storage changes for the large glacierized basins of Switzerland is structured in four steps:

1. For each individual glacier in Switzerland, the mass balance difference over the period 2006-2015 relative to the average over all glaciers is estimated based on the approach proposed by Huss (2012) who derived glacier-specific mass balance anomalies based on a comprehensive set of indices describing glacier geometry and a wealth of data on geodetic mass balance (Bauder et al., 2007; Fischer et al., 2015). This provides an estimate of the spatial variability in long-term mean mass balance for all glaciers.

2. The mass balance of the currently 20 glaciers, where annual balances are determined according to the direct glaciological method (see Section 4.1), are evaluated according to standard procedures (e.g. Huss et al., 2015) that also allow mass balance values referring to the hydrological year (1st Oct. to 30th Sept.) to be extracted. For each of the 20 monitored glaciers the mass balance deviation from the mean for 2006-2015 the period is determined and this anomaly, rather than the absolute mass balance, is extrapolated to the location of all glaciers in the Swiss Alps based on an inverse-distance weighting scheme. This scheme

also applies adjusted weights to glaciers lying on the same or on the opposite side of the main Alpine crest and takes into account, via reduced weights, a potential over-representation of observations in some regions.

3. Extrapolated anomalies in glacier mass balance (Step 2) over the analyzed hydrological year are superimposed on the glacier-specific long-term mass balance deviations (Step 1), thus combining temporal and spatial variabilities in mass balance at the single glacier scale.

4. Glacier storage changes are computed by multiplying extrapolated mass balances by the area of all glaciers provided by the 2010 Swiss Glacier Inventory (SGI2010, see Chapter 6 in Volume 131/132), updated for the respective year using observed area change rates for different glacier size classes between 2003 and 2010 (Fischer et al., 2014). Overall glacier mass changes are obtained for each hydrological drainage basin by summing up the results from all individual glaciers.

Overall glacier ice volumes in all hydrological catchments are estimated based on the approach of Huss and Farinotti (2012) applied to the SGI2010. The ice thickness model has been specifically calibrated for Switzerland using a wealth of direct ice thickness measurements on dozens of glaciers (e.g. Rutishauser et al., 2016). For each year, the remaining ice volume in each of the Swiss drainage basins is updated using the computed glacier storage changes from the above methodology.

Results

Anomalies in observed glacier mass balance extrapolated to the entire Swiss Alps for the two years covered in the present report are shown in Figures 4.38 and 4.39. The anomalies (deviation from the 2006-2015 average) show a spatially coherent pattern in both years despite some local-scale differences that might also be related to measurement uncertainties. During the 2015/16 hydrological year mass balances were substantially above average in the western Swiss Alps, and slightly above average in north-eastern Switzerland, whereas glaciers in the western Valais and south of the main Alpine crest experienced below-average mass balances (Figure 4.38). Mass balances during the 2016/17 hydrological year were strongly below average in all regions of Switzerland, most importantly in the south and the west, whereas losses in the north-east were somewhat less extreme (Figure 4.39).
Extrapolated to all Swiss glaciers, annual glacier mass losses of between 1.5 and 0.3 Gt a^{-1} have been found between in the 2010/11 to 2016/17 observation periods (Figure 4.40). As these losses are concentrated over the summer months, runoff is significantly increased due to glacier storage change during years with large melt rates. Relative to the remaining glacier ice volume, up to 3% of overall glacier mass was not eliminated until the summer of 2017 (Figure 4.40). Between October 2010 and 2017, more than 13% of the Swiss glacier ice volume disappeared. These high rates of storage change, with only slightly reduced losses during 2013 and 2014, are alarming and

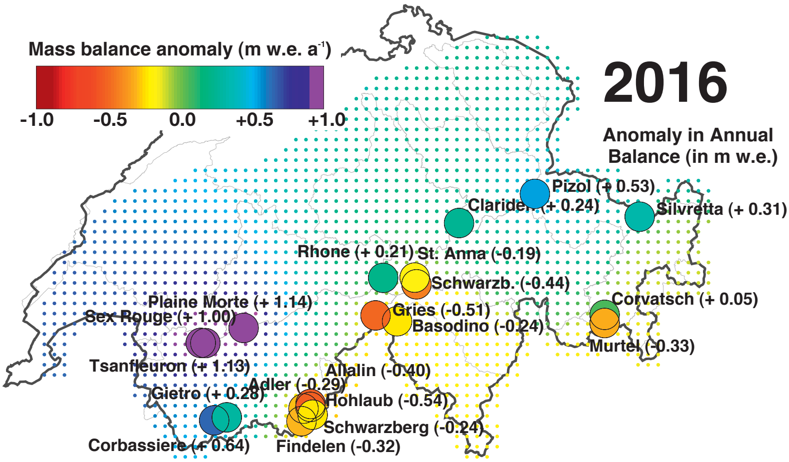

Figure 4.38: Anomaly in annual surface mass balance in the 2015/16 hydrological year relative to the average 2005/06 to 2014/15 period for all observed glaciers and extrapolated to the entire Swiss Alps.

indicate that an almost complete disappearance of Alpine glaciers by the end of the century is a realistic scenario.

New data sets will allow the uncertainties of these mass balance estimates for all Swiss glaciers to be reduced. The extrapolation to unmeasured glaciers according to the presently implemented

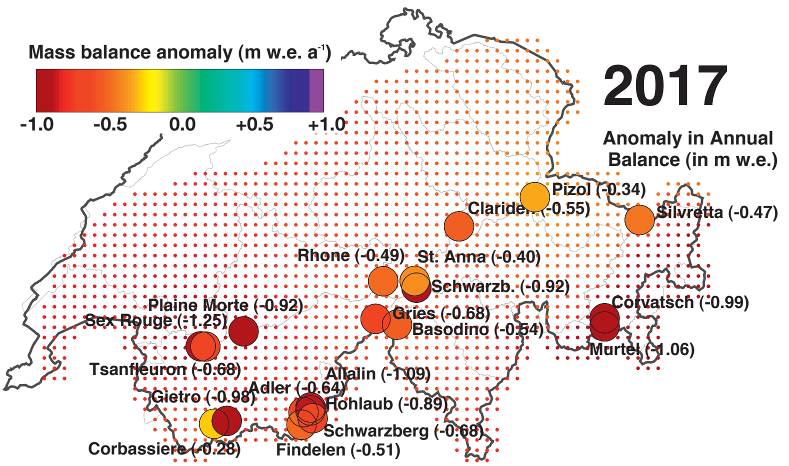

Figure 4.39: Anomaly in annual surface mass balance in the 2016/17 hydrological year relative to the average 2005/06 to 2014/15 period for all observed glaciers and extrapolated to the entire Swiss Alps.

approach remains rather restricted by the available observational evidence. Scheduled regularly updated digital elevation models for all glaciers in Switzerland produced by swisstopo (normally in a 6-year return cycle), including a consistent mapping of glacier extents, might permit a more accurate determination of long-term average mass balances of unmeasured glaciers. This could than be expected to improve the accuracy of the annually updated data set of nation-wide glacier mass changes.

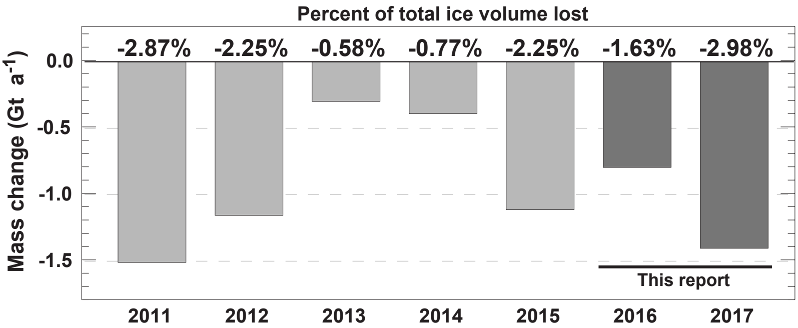

Figure 4.40: Overall glacier mass changes since the 2010/11 hydrological year extrapolated to the scale of Switzerland. The relative loss in ice volume in comparison to the remaining total Swiss ice volume is given (Huss and Bauder, 2018–2018).

Findelengletscher and the former tributary Adlergletscher (upper left) in fall 2017 (Photo: M. Huss)

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 from 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 measured at the stakes and glacier-wide mean specific annual balance determined (Figure 5.4). Huss et al. (2015) re-analyzed and homogenized the seasonal stake data and ice volume changes for the 1966 to 2014 period. The results of the glacier-wide mean specific annual balance for comparable fixed date periods were presented in Section 4.17 of Volume 135/136.

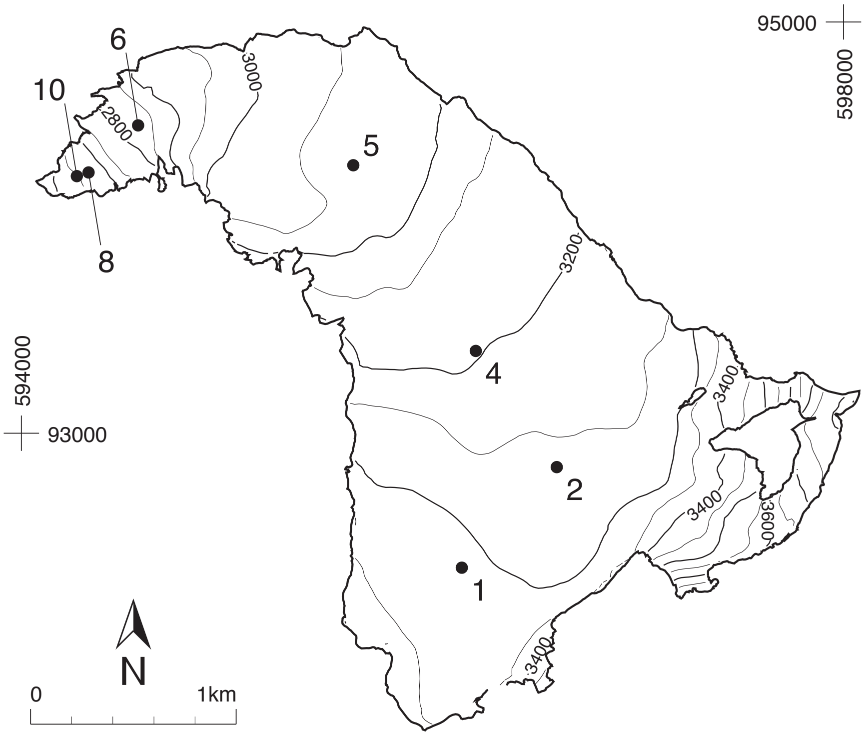

Figure 5.2: Surface topography and observational network of the Glacier du Giétro.

Figure 5.3 shows the surface flow velocity mesurements at seven stakes along the central longitudinal profile 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 2015/16 and in 2016/17

Five stakes provided measurements of velocity and local mass balance. The field survey in fall 2016 was carried out on 13th September. The position of the end-of-summer snowline was located on the firn plateau between 3250 m a.s.l. and 3350 m a.s.l. Some marginal accumulation of winter snow was observed at the the stakes 1 and 2. On 21st September 2017, the field measurements were taken for the second period. The melt had occurred over the entire extent of the firn plateau and well above, as never before observed in the last decade. Substantial mass loss was recorded even at the topmost stakes.

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

Stake	Period Start	Period End	Coordinates (m / m / m a.s.l.)	Thickness change (m)	Velocity ($m\ a^{-1}$)	Mass balance (mm w.e.)
1	08.09.2015	13.09.2016	596143 / 92346 / 3310	0.18	2.61	325
1	13.09.2016	21.09.2017	596143 / 92346 / 3310	−2.33	2.61	−1573
2	08.09.2015	13.09.2016	596605 / 92835 / 3255	0.10	8.26	187
2	13.09.2016	21.09.2017	596605 / 92835 / 3255	−2.19	8.09	−1488
4	08.09.2015	13.09.2016	596211 / 93400 / 3195	−0.33	11.73	−247
4	13.09.2016	21.09.2017	596211 / 93400 / 3195	−2.01	11.56	−1962
5	08.09.2015	13.09.2016	595615 / 94303 / 3060	−0.50	16.66	−1350
5	13.09.2016	21.09.2017	595615 / 94303 / 3060	−2.05	16.04	−2898
6	08.09.2015	13.09.2016	594568 / 94497 / 2830		21.81	−3186
6	13.09.2016	21.09.2017	594568 / 94497 / 2830	−4.05	18.79	−5112

Velocity in 2015/16 and in 2016/17

Due to the glacier retreat with complete ice melt at the glacier snout, the two sites 8 and 10 had to be abandoned already in 2010 and are no longer under observation. Large melt rates and associated changes of the surface hampered the measurements more and more at site 6 over the past periods. The decrease in speed over the past years did continue slightly during the two periods covered by this report. A moderate change was observed only at the lowest site (6), that may directly reflect the lowering of the surface elevation and the ever-increasing difficulties in maintaining a fixed position.

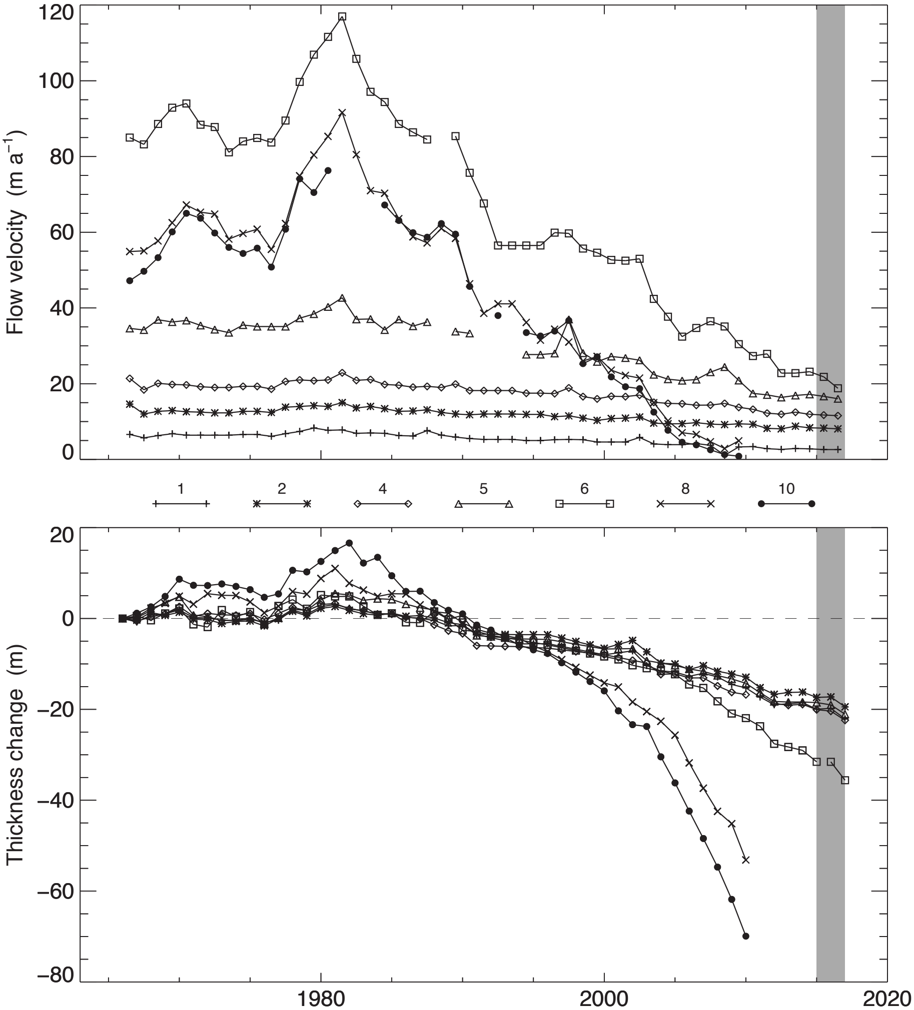

Figure 5.3: Surface flow velocities (top) and thickness change (bottom) of the Glacier du Giétro at all seven stakes. The gray shaded area highlights the years of the current report.

Table 5.2: Glacier du Giétro - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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 - 2800	0.046	556	−5298	0.030	491	−5108
2800 - 2900	0.076	929	−4015	0.071	577	−4416
2900 - 3000	0.234	1052	−3018	0.225	821	−3489
3000 - 3100	0.881	1296	−1652	0.869	973	−2785
3100 - 3200	0.993	1393	−544	0.985	1098	−2038
3200 - 3300	1.641	1440	192	1.641	1161	−1489
3300 - 3400	0.916	1445	375	0.916	1171	−893
3400 - 3500	0.172	1460	626	0.172	1176	88
3500 - 3600	0.117	1356	740	0.117	1090	320
3600 - 3700	0.121	1224	753	0.121	985	384
3700 - 3800	0.116	1211	806	0.116	975	439
3800 - 3900	0.009	1232	830	0.009	993	461
2700 - 3900	5.322	1364	−414	5.273	1084	−1666

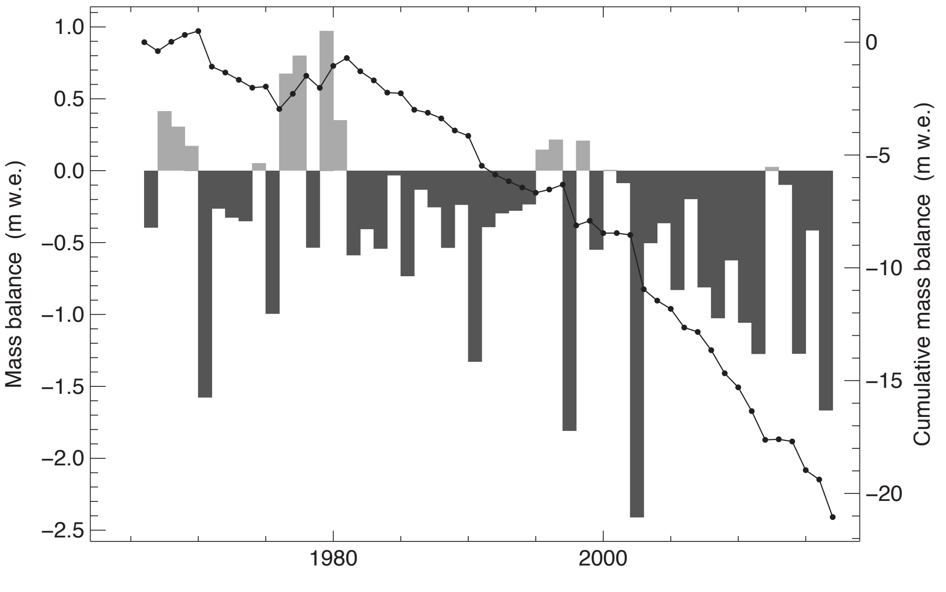

Figure 5.4: Glacier du Giétro - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1966-2017.

5.3 Glacier de Corbassière

Introduction

Since 1955, Glacier de Corbassière (Figure 5.5) 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 5.3). Figure 5.6 shows the surface flow velocities for the two profiles since 1967. Results of the glacier-wide mean specific annual balance for comparable fixed date periods for 1996 to 2015 are presented in Section 4.17 of Volume 135/136.

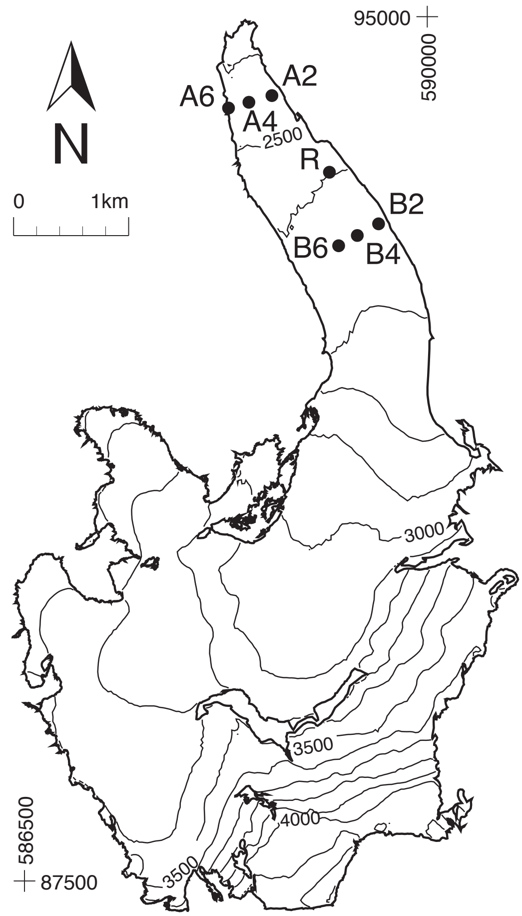

Figure 5.5: Surface topography and observational network of the Glacier de Corbassière.

Investigations in 2015/16 and in 2016/17

The field surveys were carried out on 13th/14th September 2016 and on 21st/22nd September 2017. 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. While during the first period a moderate mass loss was registered, extreme melt occurred in the second observation period.

Table 5.3: 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	08.09.2015	13.09.2016	589577 / 93202 / 2650	−2.45	8.92	−3060
B2	13.09.2016	21.09.2017	589577 / 93202 / 2650	−3.51	8.86	−4266
B4	08.09.2015	13.09.2016	589392 / 93101 / 2650	−2.12	15.52	−3402
B4	13.09.2016	21.09.2017	589392 / 93101 / 2650	−3.19	15.49	−4194
B6	08.09.2015	13.09.2016	589230 / 93012 / 2655	−1.76	16.22	−3105
B6	13.09.2016	21.09.2017	589230 / 93012 / 2655	−3.18	16.78	−4293
R	08.09.2015	13.09.2016	589150 / 93650 / 2620	−2.12	10.41	−3690
R	13.09.2016	21.09.2017	589150 / 93650 / 2620	−4.18	9.90	−5391
A2	08.09.2015	13.09.2016	588650 / 94315 / 2475	−5.32	5.87	−4797
A2	13.09.2016	21.09.2017	588650 / 94315 / 2475	−6.58	5.14	−6012
A4	08.09.2015	13.09.2016	588450 / 94257 / 2460	−6.37	4.13	−3618
A4	13.09.2016	21.09.2017	588450 / 94257 / 2460	−10.70	4.24	−5166
A6	08.09.2015	13.09.2016	588273 / 94207 / 2470	−1.75	1.53	−3159
A6	13.09.2016	21.09.2017	588273 / 94207 / 2470	−0.24	1.38	−3177

Velocity in 2015/16 and in 2016/17

The ice flow velocity decreased further during the two periods under review. The general long-term trend of decreasing speed accompanied by a lowering of the surface elevation was maintained. Stake A6 alone shows a stagnation of both. The site is debris-covered and has progressively migrated closer to the lateral margin due to shrinkage in width over the past few years. At sites A2 and A4, the extraordinarily high rate of surface lowering detected in 2014/15 continued with high rates during the two periods of this report.

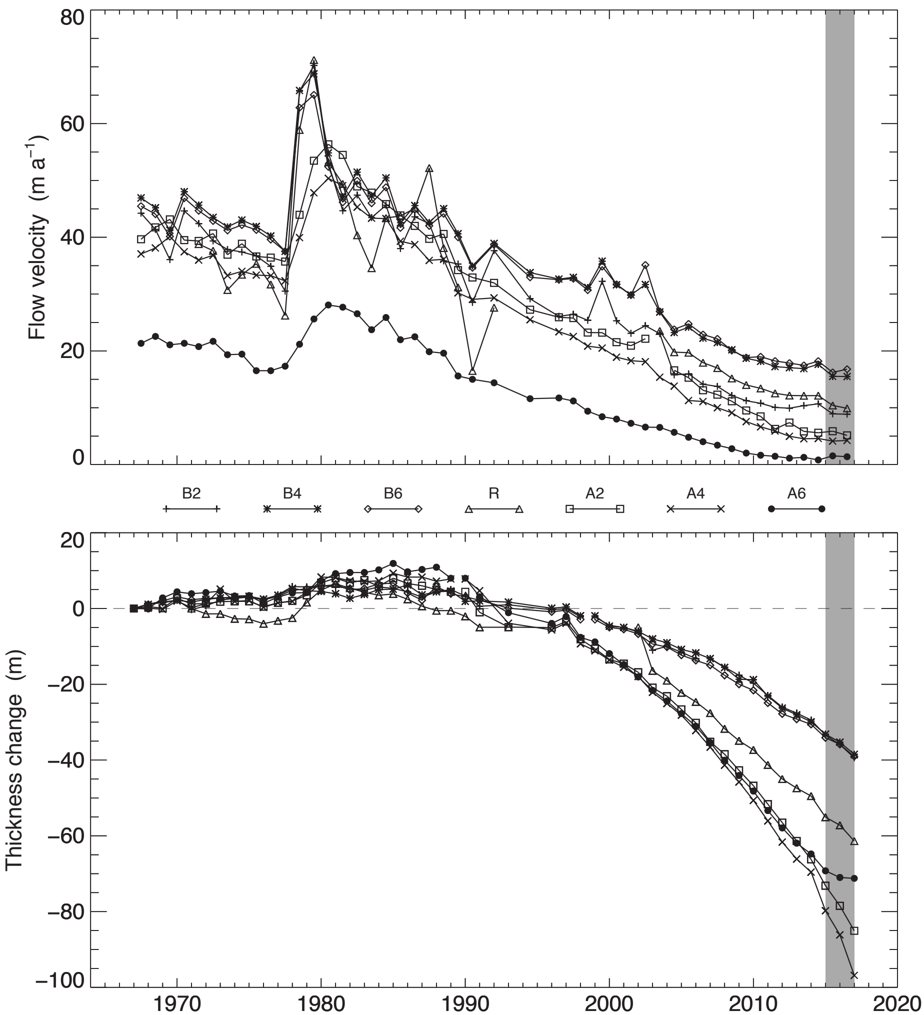

Figure 5.6: Surface flow velocities (top) and thickness change (bottom) of the Glacier de Corbassière at two profiles with three stakes each and the additional stake in between. The gray shaded area highlights the years of the current report.

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, Tälliboden and Ofental. Measurements are currently being continued on 11 selected stakes as part of the investigations by the VAW/ETHZ for the Mattmark hydro-power company (Figure 5.7). Figure 5.8 shows surface flow velocities on Allalingletscher. Huss et al. (2015) re-analyzed and homogenized the seasonal mass balance measurements and ice volume changes for the period 1955 to 2013. The results of the glacier-wide mean specific annual balance for comparable fixed date periods on Allalin and Schwarzberg are presented in Section 4.17 of Volume 135/136.

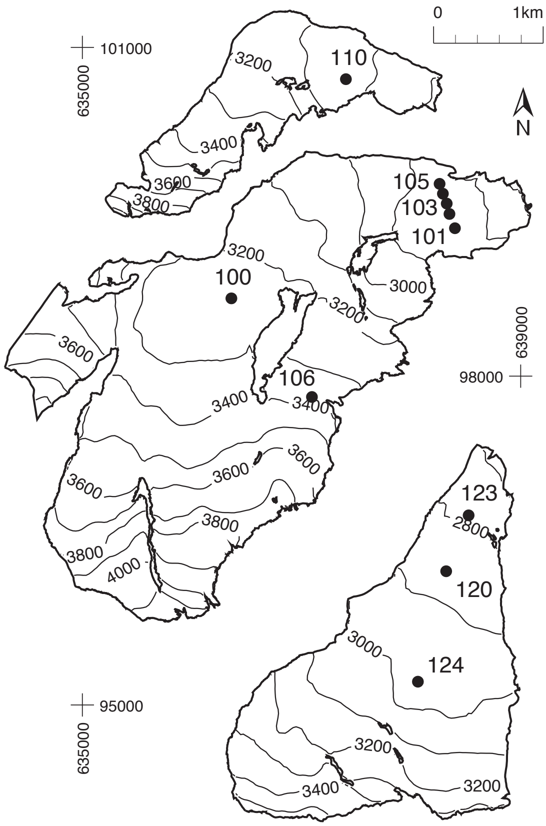

Figure 5.7: Surface topography and observational network of the Mattmark glaciers.

Investigations in 2015/16 and in 2016/17

The field surveys were carried out on 22nd August 2016 and on 21st August 2017. Two flow markers could not be located at the end of the second period probably due to extreme melt (105) and a crevasse opening (100). Results for horizontal flow velocity and thickness change for each glacier are given in Tables 5.4, 5.5 and 5.6. In addition, annual mass balance was measured at the stakes. Results of glacier-wide mean specific annual balance for Allalingletscher and Schwarzberggletscher are presented in Figure 5.9, Table 5.7 and Figure 5.10, Table 5.8, respectively.

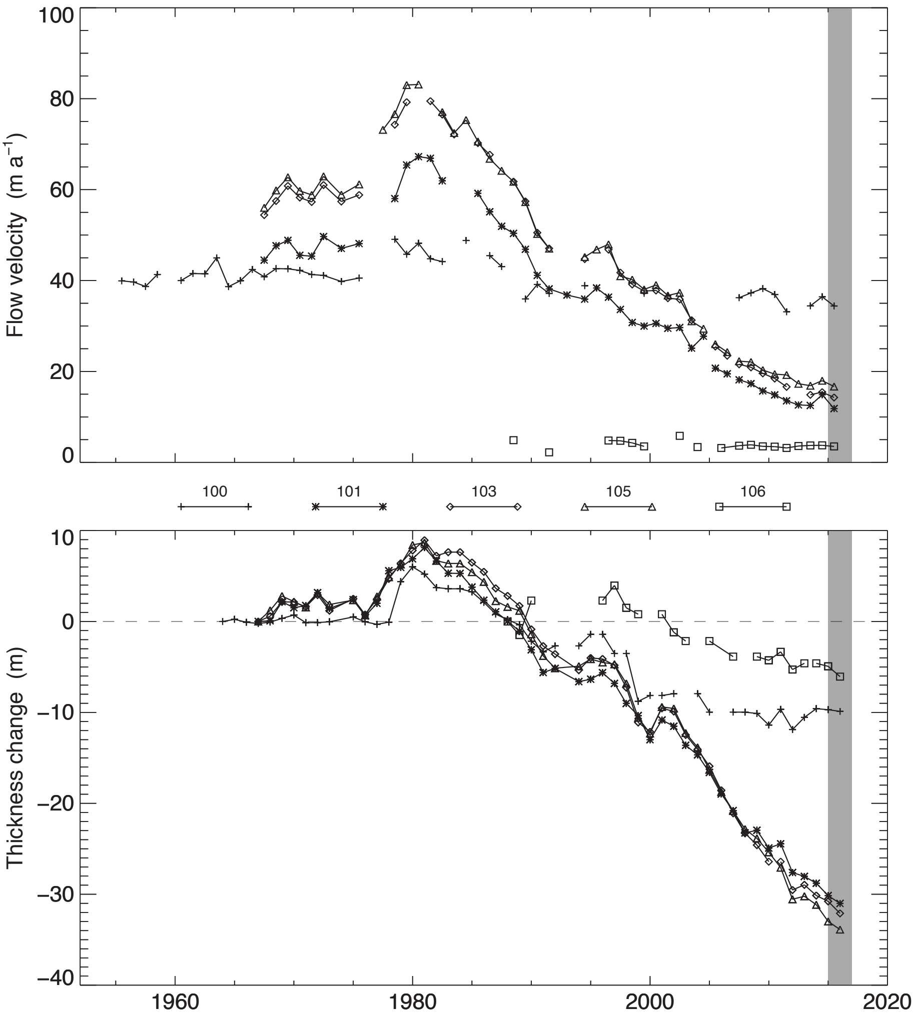

Figure 5.8: Surface flow velocities (top) and thickness change (below) of the Allalingletscher at five stakes. The gray shaded area highlights the years of the current report.

Table 5.4: 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	21.09.2015	22.08.2016	636360 / 98710 / 3230	−0.19	34.40	−657
100	22.08.2016	21.08.2017	636360 / 98710 / 3230		34.47	−2600
101	21.09.2015	22.08.2016	638400 / 99360 / 2850	−0.86	11.84	−1530
101	22.08.2016	21.08.2017	638400 / 99360 / 2850	−2.95	11.25	−3870
102	21.09.2015	22.08.2016	638350 / 99480 / 2850	−1.56	13.33	−1260
102	22.08.2016	21.08.2017	638350 / 99480 / 2850	−2.19	12.85	−3420
103	21.09.2015	22.08.2016	638325 / 99575 / 2855	−1.32	14.28	−1440
103	22.08.2016	21.08.2017	638325 / 99575 / 2855	−2.59	13.68	−3780
104	21.09.2015	22.08.2016	638290 / 99665 / 2865	−1.03	15.11	−1440
104	22.08.2016	21.08.2017	638290 / 99665 / 2865	−2.27	14.48	−3870
105	21.09.2015	22.08.2016	638260 / 99755 / 2885	−0.89	16.69	−1440
106	21.09.2015	22.08.2016	637095 / 97810 / 3375	−1.13	3.51	−77

Table 5.5: 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	21.09.2015	22.08.2016	637405 / 100710 / 3050	−0.05	9.74	−1530
110	22.08.2016	21.08.2017	637405 / 100710 / 3050	−2.52	9.13	−2700

Table 5.6: 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	21.09.2015	22.08.2016	638320 / 96220 / 2880	−0.68	6.20	−1332
120	22.08.2016	21.08.2017	638320 / 96220 / 2880	−2.12	6.18	−3258
123	21.09.2015	22.08.2016	638525 / 96730 / 2805	−1.73	4.52	−1800
123	22.08.2016	21.08.2017	638525 / 96730 / 2805	−3.17	4.34	−3267
124	21.09.2015	22.08.2016	638062 / 95212 / 2985	0.43	7.65	−522
124	22.08.2016	21.08.2017	638062 / 95212 / 2985	−1.29	7.40	−2160

Table 5.7: Allalingletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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 - 2800	0.046	556	−5298	0.030	491	−5108
2800 - 2900	0.076	929	−4015	0.071	577	−4416
2900 - 3000	0.234	1052	−3018	0.225	821	−3489
3000 - 3100	0.881	1296	−1652	0.869	973	−2785
3100 - 3200	0.993	1393	−544	0.985	1098	−2038
3200 - 3300	1.641	1440	192	1.641	1161	−1489
3300 - 3400	0.916	1445	375	0.916	1171	−893
3400 - 3500	0.172	1460	626	0.172	1176	88
3500 - 3600	0.117	1356	740	0.117	1090	320
3600 - 3700	0.121	1224	753	0.121	985	384
3700 - 3800	0.116	1211	806	0.116	975	439
3800 - 3900	0.009	1232	830	0.009	993	461
2700 - 3900	5.322	1364	−414	5.273	1084	−1666

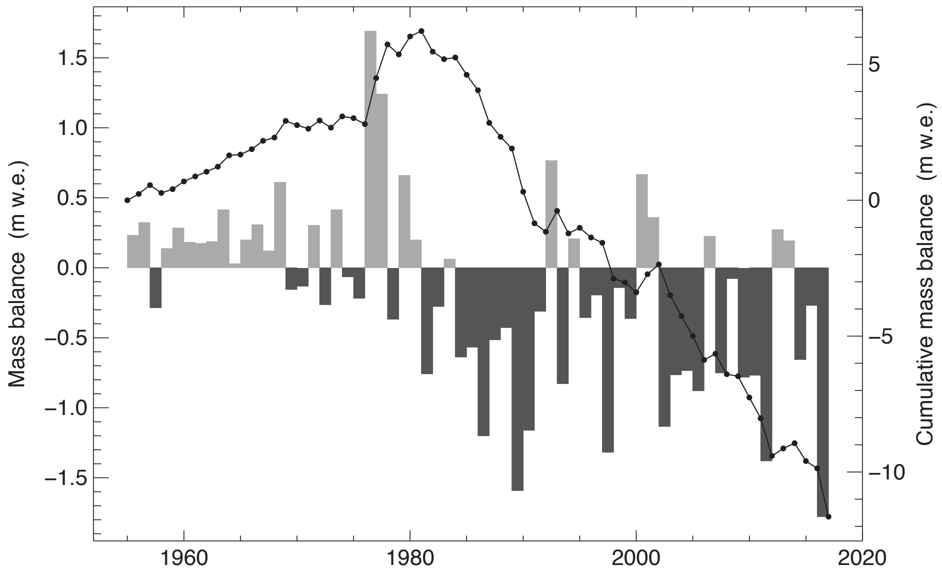

Figure 5.9: Allalingletscher - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1955-2017.

Table 5.8: Schwarzberggletscher - Specific winter and annual balance versus altitude in the two periods 2015/16 and 2016/17, evaluated for the measurement period defined by the dates of the field survey.

Altitude	2015/16			2016/17		
	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 - 2700	0.014	883	−2340	0.009	558	−4066
2700 - 2800	0.301	957	−2032	0.290	621	−3811
2800 - 2900	0.667	1100	−1323	0.666	760	−3186
2900 - 3000	1.188	1235	−612	1.188	896	−2556
3000 - 3100	0.854	1340	−24	0.854	1014	−1821
3100 - 3200	0.793	1415	348	0.793	1109	−1144
3200 - 3300	0.648	1474	715	0.648	1178	−511
3300 - 3400	0.367	1489	998	0.367	1197	−39
3400 - 3500	0.229	1458	1162	0.229	1172	281
3500 - 3600	0.058	1272	1026	0.058	1021	277
2600 - 3600	5.121	1304	−164	5.102	986	−1768

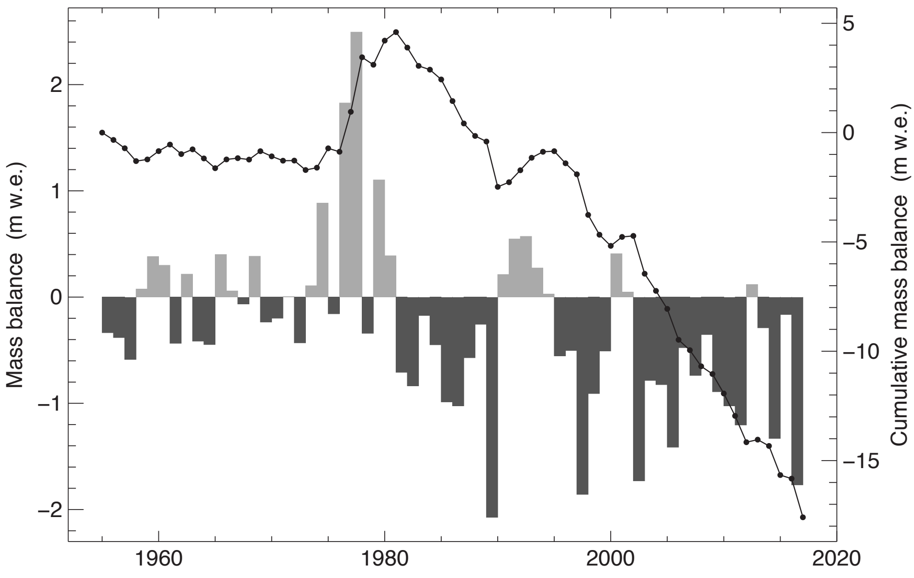

Figure 5.10: Schwarzberggletscher - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1955-2017.

Retreat of the tongue of Glacier du Giétro in 2005 (top) and 2016 (bottom) where two measurements sites had to be abandonend (Photos: A. Bauder)

6 Hazardous Glaciers in Switzerland

6.1 Introduction

As an update to the inventory of hazardous glaciers, three recent events that occurred during the two periods under review of this report are presented (Figure 6.1).

Figure 6.1: Glaciers with documented hazardous events in this report.

6.2 Recent instability of the glaciated Weissmies north face (above Saas Grund, Valais)

In summer 2014, the lower portion of the glacierized north face of Weissmies became unstable. This was due, on the one hand, to the diminishing thickness of the underlying Triftgletscher, causing the base of the hanging glacier on the north face to separate from Triftgletscher and its support function to be lost. On the other hand, the hanging glacier has become increasingly

Figure 6.2: Weissmies north face with the unstable portion (left, marked rectangle) on 8th September and after the break-off event (right) on 10th September 2017 (Photos: Geopraevent AG)

warmer due to climate change, whereby the ice that in former years had been frozen onto the rock could no longer, at least in some places, maintain a sufficiently strong hold on the rock bed.

In autumn 2014, the unstable zone consisted of approx. 750'000 m^3 of ice in danger of breaking off imminently (Figure 6.2). Simulations had revealed that ice avalanches could possibly advance as far as the valley floor, thus posing a potential risk to the village of Saas Grund. For this reason, a ground-based interferometric radar (GBIR) was installed at the Hohsaas cable car station in early October 2014 in order to perform continuous deformation measurements of the unstable zone. The initial rate of movement was approx. 20 $cm\,d^{-1}$, decreasing to 5 $cm\,d^{-1}$ in the following weeks. Subsequently, until early July 2017, the glacier surface motion remained below 10 $cm\,d^{-1}$, with no notable ice break-off events. However, in the course of August 2017 with repeated summer heatwaves, the flow velocity of the unstable zone accelerated considerably, and on the 9th September 2017, values of over 1 $m\,d^{-1}$ were recorded. Based on the increase in the ice flow velocity, the break-off event was predicted for the 10th September between 9 am and noon (Figure 6.3). On the evening of the 9th September, 200 villagers were evacuated from the danger zone as a precautionary measure. Shortly before 6 am on the 10th September the unstable zone with 500'000 m^3 of ice flowed at a rate of over 3 $m\,d^{-1}$ and broke off. Luckily, the ice avalanches came to a standstill in the upper portion of Triftgletscher without causing any damage for the sole reason that the immense volume of ice fell in the form of many small ice avalanches of less than 20'000 m^3 each between 5:50 and 6:00 am. As a result of this event, glaciation has diminished on the north face of Weissmies, and the western ice cliff now lies at an elevation 150 m higher than in early summer 2017 (Figure 6.2).

The remaining glacierized ice face between the Weissmies summit and the former position of the hanging glacier has been fractured with new, larger crevasses, which is an indication that basal motion due to warming at the ice/bedrock interface recently also started in this zone. Thus in the coming years, particularly in summer and fall, further ice break-off events at the north face of Weissmies are expected. The extent of these ice avalanches depends primarily on the volume of the mobilized material and the slope of the terrain. Even a relatively small volume of ice (greater than

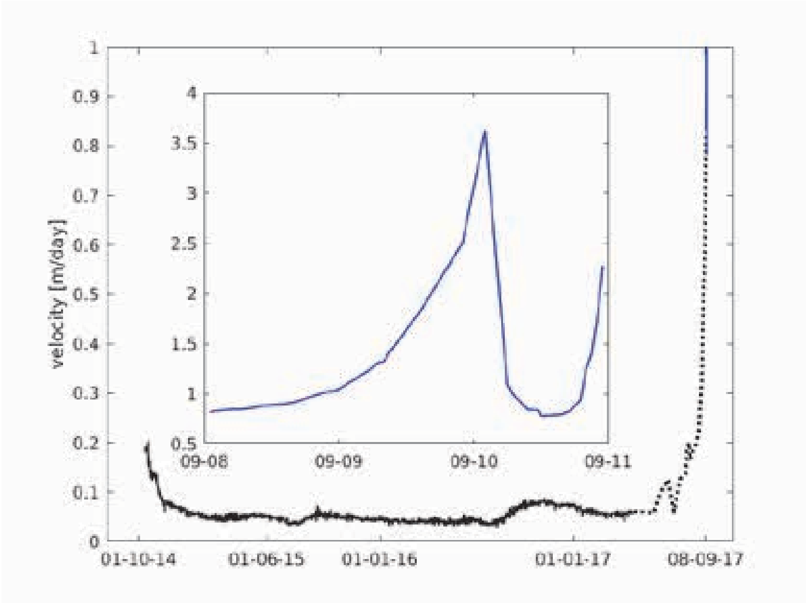

Figure 6.3: Mean flow velocities of the unstable portion from October 2014 to 11th September 2017 (solid line: results from GBIR records; broken line: surface velocities inferred from automatic camera image processing). The inset is a zoom of the last three days prior to the break off. On 10th September between 5:50 and 6:00 am two third of the whole unstable ice body (500'000 m^3) broke off (first peak in the blue broken curve). The remaining ice plummeted down on 11th September at 1:00 am (second peak in the blue broken curve).

approx. 20'000 m^3) is enough to reach the normal route of the ascent to the Weissmies summit. This situation will not return to normal until glacierization in the steep zone has almost completely ceased.

6.3 Sudden drainage of a subglacial water pocket at Feegletscher (above Saas Fee, Valais)

In early summer and winter of 2017 two drainage events of a subglacial water pocket were observed at the outflow of the easternmost branch of Feegletscher:

30-31 May 2017, 10:30-23:30: sudden release of at least 300'000 m^3 of water (Figure 6.4)

17-18 December 2017, 11:40-16:45: outflow of 24'000 m^3 of water

Thanks to the water gauge records at the Othmarhang reservoir the flood duration could be inferred, and the drained water volume could be roughly estimated (data provided by Rinaldo Andenmatten, Saas Fee). Due to the rather long drainage duration of these two events (13, and 15 hours), peak discharge values were relatively small. Such large volumes of water have the potential to cause major flooding. However, no damages were inccurred.

Figure 6.4: The flood triggered by the first event (31st May 2017) flowed very close to the Morenia cable car station (Photo: U. Andenmatten)

6.4 Drainage events of Lac des Faverges 2012-2017, Glacier de la Plaine Morte (above Lenk, Berne)

Since 2011, annual drainage events at Lac des Faverges, an ice-marginal lake on Glacier de la Plaine Morte (Figure 6.5), have been observed and lake levels monitored in detail as of late June 2012 by Geopraevent AG for early warning purposes. lake typically begins to fill in May/June, and up to 2 mio. m^3 drain in July/August within one to several days through englacial and subglacial channels (Kull and Fischer, 2014). Runoff from the Simme at Lenk has been reported to increase by a factor up to five during the lake outburst event. For example, on 28.8.2016 discharge rose from $5\,m^3\,s^{-1}$ to $27\,m^3\,s^{-1}$ within only 6 hours under dry weather conditions. So far, fortunately, no damage has occurred in the Simme valley due to glacier lake floods. Between 2012 and 2017 the lake basin grew substantially due to continuous glacier mass loss. The trend towards increasing volumes of Lac des Faverges is expected to persist over the coming decades (Huss et al., 2013).

Figure 6.5: Lac des Faverges on 13th July 2017, four days before the drainage occured (Photo: M. Huss)

The temporal evolution of water volume and lake discharge during the drainage event was computed (Figure 6.6) by intersecting observed lake levels at Lac des Faverges with annual digital elevation models of the ice surface (acquired as a part of GLAMOS). Thus justifying the following statements:

- Between 2012 and 2017, lake volume shows a significant trend towards increase at $+0.14\times10^6$ m^3 per year.
- The date of the drainage event depends on the meteorological conditions during the lake filling phase. Strong melt rates in early summer lead to a rather early drainage of Lac des Faverges, and vice versa.
- Peak lake discharge is well correlated with lake volume (except for the year 2015) and shows a general increase over time. Maximum water discharge from the lake was more than 40 $m^3\,s^{-1}$ in 2016.

Lake drainage typically initiates at moulins at the western end of Lac des Faverges as soon as they connect to the subglacial hydrological system. The triggering mechanism, however, varies from year to year. In 2016, for example, an overtopping of the ice dam towards the west took place for a few days before the drainage was observed. Whereas in 2015, peak discharges were low as a supraglacial channel had to be enlarged progressively in order to connect the lake to an active moulin. The likely increase in lake volume and peak discharge over the next years emphasizes the need for continued monitoring of Lac des Faverges to ensure early warning of the communities in the Simme valley.

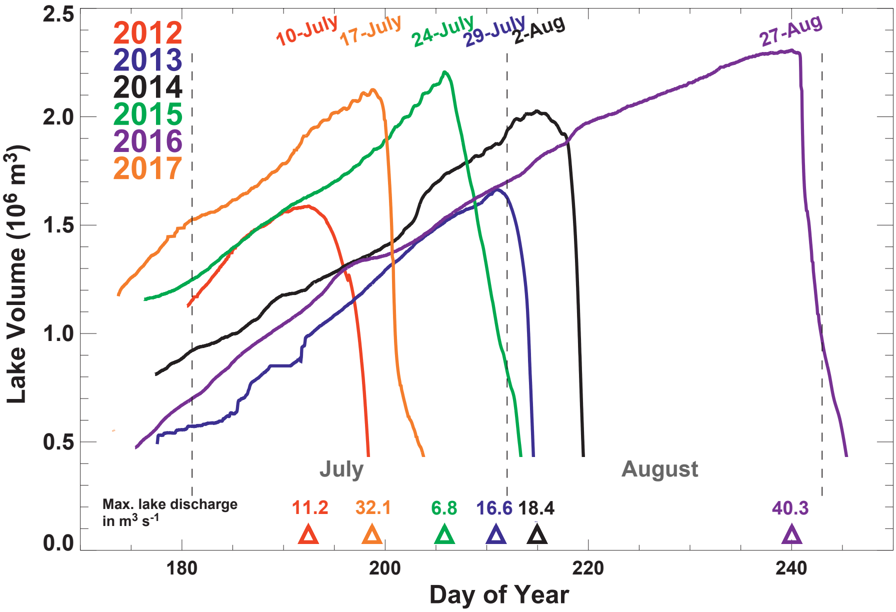

Figure 6.6: Temporal evolution of water volume at Lac des Faverges between 2012 and 2017. The date of the outburst event and the maximum lake discharge are given.

References

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. and Frei, C. (2018). Long-term area-mean temperature series for Switzerland – Combining homogenized station data and high resolution grid data. *International Journal of Climatology*, 38(6):2792–2807.

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.

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.

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.

Gugerli, R., Huss, M., and Salzmann, N. (2017). Using a cosmic ray sensor and weather radar composites to estimate the snow water equivalent on a Swiss glacier. 15th Swiss Geoscience Meeting.

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. (2012). Extrapolating glacier mass balance to the mountain-range scale: The european alps 1900-2100. *The Cryosphere*, 6(4):713–727.

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. and Bauder, A. (2012–2018). Gletscher-Speicheränderung in der Schweiz. Jährliche Berichte über die glaziologischen Messungen und Analysen der Gletscher-Speicheränderung bezogen aufs Hydrologische Jahr zuhanden des BAFU, Universität Fribourg.

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 Farinotti, D. (2012). Distributed ice thickness and volume of all glaciers around the globe. *Journal of Geophysical Research*, 117(4):F04010.

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.

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.

Kuhn, M., Markl, G., Kaser, G., Nickus, U., Obleitner, F., and Schneider, H. (1985). Fluctuations of climate and mass balance: different responses of two adjacent glaciers. *Zürcher Geographische Schriften*, 21:409–416.

Kull, I. and Fischer, L. (2014). Plaine Morte, Ausbruch Gletschersee Faverges 2013, Analyse und Prognose. unveröffentlichter Bericht Oberingenieurkreis I Kt. Bern, Thun, Gemeindeverwaltung Lenk.

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

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.

Naegeli, K., Damm, A., Huss, M., Wulf, H., Schaepman, M., and Hoelzle, M. (2017). Cross-comparison of albedo products for glacier surfaces derived from airborne and satellite (Sentinel-2 and Landsat 8) optical data. *Remote Sensing*, 9(2):110.

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.

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.

Rutishauser, A., Maurer, H., and Bauder, A. (2016). Helicopter-borne ground-penetrating radar investigations on temperate alpine glaciers: A comparison of different systems and their abilities for bedrock mapping. *GEOPHYSICS*, 81(1):WA119–WA129.

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.

WGMS (2017). Global Glacier Change Bulletin No. 2 (2014–2015). Technical report, ICSU(WDS)-IUGG(IACS)-UNEP-UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland.

Zoller, N. (2010). Fliessbewegung des Grossen Aletschgletschers. Bachelorarbeit, Departement Erdwissenschaften / Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW), ETH Zürich. pp. 45.

Acknowledgements

The Cryospheric Commission through its GLAMOS programme acknowledges long-term funding by the Federal Office for the Environment (BAFU), MeteoSwiss within GCOS Switzerland, the Swiss Academy of Sciences (SCNAT), and the support by the Federal Office of Topography (swisstopo). The Cryospheric Commission again received solid support in this 137th/138th measuring period from its reliable team of observers. Sincere thanks for their cooperation are extended to: the forestry services from the cantons of Berne, Glarus, Grisons, Obwalden, St. Gallen, Uri, Ticino, Vaud and Wallis, the staff of the hydro-power stations Aegina, Mattmark and, Mauvoisin, all the individual helpers, the Aerial Photography Flying and Coordination Service (CCAP) of the Swiss Federal Office of Topography swisstopo and Flotron AG (Thun). The Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the ETH Zürich, colleagues from the Geographical Institutes of the University of Fribourg and Zürich provided valuable contributions to the publication of this glaciological report. Barbara Bauder is acknowledged for typewriting the many remarks on the individual glaciers. A special vote of thanks goes to Susan Braun-Clarke for proof-reading the report.

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), swisstopo acquired routinely aerial photos for updating their standard products (National Maps, orthophoto or DEM). In the year 2016, pictures were taken for the sheets 1:50'000 nos. 236, 245, 246, 255, 256, 257, 263, 272, 273, 282, and 283 and in 2017 the areal of the Cantons VD and VS, respectively. More detailed information is available on swisstopo's webviewer http://www.luftbildindex.ch.

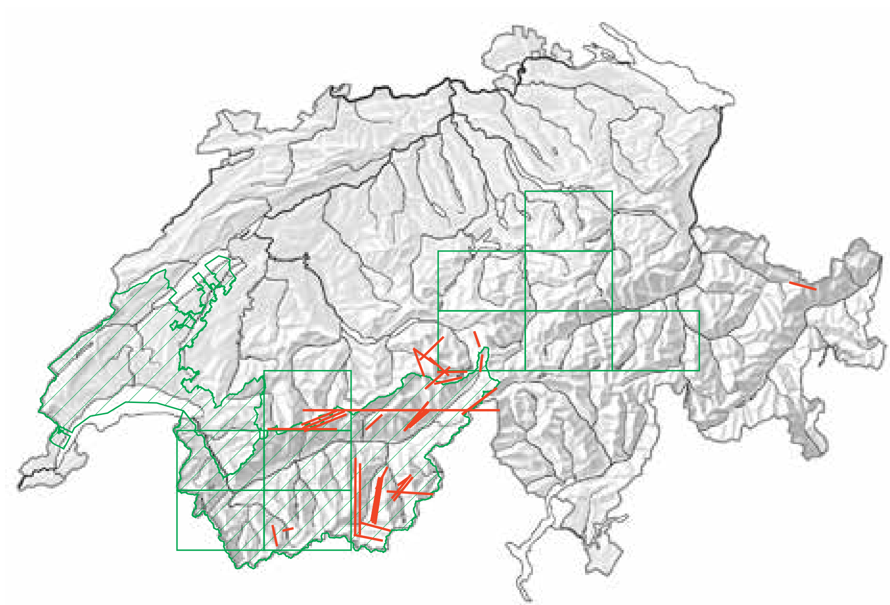

Figure A.1: Aerial photographs from the years 2016 and 2017.

Table A.1: Aerial photographs taken in 2016.

Glaciers	Ct.	Date	Line No.	Scale	Type
Allalin[p], Hohlaub[p], Chessjen[p]	VS	29.09.16			col
Birch[c], Nest[c], Stampbach[c], Bietsch[c], Joli[c], Üssere Baltschieder[p]	VS	07.09.16	30030201609071015	0.23	is
Bis[p], Schali[p], Hohlicht[p], Brunegg[p],Schölli[c], Stelli[c]	VS	26.08.16	30030201608261109	0.34	is
Corbassiere[p]	VS	29.09.16			col
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	26.08.16	30030201608261140	0.32	is
Eiger[p], Guggi[p], Giesen[p]	BE, VS	13.09.16			col
Findelen[p]	VS	26.08.16	30030201608261052	0.27	is
Finsteraar[p], Unteraar[p], Lauteraar[p]	BE	26.08.16	30030201608260939	0.28	is
Giétro[p]	VS	29.09.16			col
Gorner[p]	VS	08.08.16	30030201608080850	0.26	is
Gries[c], Corno[p], Blinnen[p]	VS	20.07.16	30030201607200957	0.28	is
Gries[c], Corno[p], Blinnen[p]	VS	26.08.16	30030201608260955	0.28	is
Grosser Aletsch (Mönch Süd)[p], Unt. Grindelwald[p], Guggi[p], Giesen[p]	BE, VS	13.09.16			col
Grosser Aletsch[p]	VS	29.07.16	30030201607291040	0.15	is
Grosser Aletsch[p]	VS	08.08.16	30030201608080939	0.30	is
Grosser Aletsch[p]	VS	29.07.16	30030201607291031	0.16	is
Grosser Aletsch[p]	VS	29.07.16	30030201607291022	0.15	is
Grosser Aletsch[p]	VS	07.09.16	30030201609071022	0.16	is
Grosser Aletsch[p]	VS	26.08.16	30030201608261204	0.30	is
Grosser Aletsch[p]	VS	26.08.16	30030201608261212	0.16	is
Grüebu[p], Mattwald[c], Gamsa[p]	VS	08.08.16	30030201608080910	0.19	is
Lauteraar[c], Ob. Grindelwald[p], Finsteraar[p], Unteraar[p]	BE	26.08.16	30030201608260932	0.29	is
Ob. Grindelwald[p], Lauteraar[p]	BE	26.08.16	30030201608260925	0.34	is
Ob. Grindelwasl[p], Chrinnen[c], Gutz[c], Hengsteren[c], Rosenlaui[p]	BE	26.08.16	30030201608261225	0.34	is
Oberaar[c], Finsteraar[p], Fiescher[p]	BE	26.08.16	30030201608260946	0.32	is
Plaine Morte[c], Wildstrubel[p], Lämmern[p], Steghorn[c], Tälli[c], Schwarz[p]	BE, VS	07.09.16	30030201609070951	0.30	is
Plaine Morte[p], Ammerten[c], Wildstrubel[c], Strubel[c], Steghorn[c], Tälli[c]	BE, VS	07.09.16	30030201609070943	0.31	is
Plaine Morte[p], Lämmern[c], Schwarz[p]	BE, VS	07.09.16	30030201609071000	0.32	is
Rhone[p]	VS	08.08.16	30030201608080956	0.22	is
Ried[p]	VS	08.08.16	30030201608080915	0.24	is
Ried[p], Hohbärg[p], Festi[p], Kin[p]	VS	26.08.16	30030201608261034	0.30	is
Ried[p], Hohbärg[p], Festi[p], Kin[p]	VS	26.08.16	30030201608261043	0.29	is
Ried[p], Hohbärg[p], Festi[p], Kin[p], Weingarten[p]	VS	26.08.16	30030201608261025	0.31	is

Schwarzberg [p]	VS	29.09.16			col
Seewjinen [p], Schwarzberg [p]	VS	29.09.16			col
Silvretta [c], Verstancla [c], Tiatscha [c], Plan Rai [c]	GR	07.09.16	30030201609070811	0.37	is
Trift [p]	BE	08.08.16	30030201608081002	0.22	is
Turtmann [p], Brunegg [p], Bis [p], Weisshorn [p], Schali [c], Moming [p], Hohlicht [p], Trift [p]	VS	26.08.16	30030201608261120	0.36	is
Unt. Grindelwald [p]	BE	26.08.16	30030201608260907	0.29	is
Unteraar [c], Lauteraar [p], Finsteraar [p]	BE	26.08.16	30030201608260900	0.23	is

c Glacier shown completely
p Glacier shown partially

Type of acquisition: col colour frames; is image stripe

Table A.2: Aerial photographs taken in 2017.

Glaciers	Ct.	Date	Line No.	Scale	Type
Blinnen [c]	VS	21.09.17	12504201709211200	0.25	is
Bluemslialp [c], Gamchi [c], Kanderfirn [p], Tschingel [c], Lang [p], Grosser Aletsch [p], Fischer [p], Minstiger [c], Chüebode [c]	BE, VS	21.09.17	12504201709211232	0.25	is
Eiger [p], Guggi [p], Giesen [p]	BE	05.10.17			col
Gries [c], Corno [p], Blinnen [p], Chüebode [c]	VS, TI	07.08.17	12501201708070948	0.15	is
Grosser Aletsch (Mönch Süd) [p], Unt. Grindelwald [p], Guggi [p], Giesen [p]	BE	05.10.17			col
Grosser Aletsch [p]	VS	07.08.17	12501201708071006	0.14	is
Grosser Aletsch [p]	VS	17.07.17	12501201707170934	0.14	is
Grosser Aletsch [p]	VS	07.08.17	12501201708071006	0.14	is
Grosser Aletsch [p], Mittelaletsch [p], Fiescher [p], Gries [p]	VS	21.09.17	12504201709211248	0.26	is
Grosser Aletsch [p], Mittelaltesch [p], Driest [c], Oberaltesch [p], Gries [p], Blinnen [c]	VS	21.09.17	12504201709211309	0.26	is
Grosser Aletsch [p], Oberaletsch [c], Bleich [c], Taelli [c], Steghorn [c], Strubel [c], Aemmerte [p], Schwarz [c],	VS	08.09.17	12504201709081012	0.26	is
Gruebu [p], Gamsa [p], Mattwald [c], Rossbode [p]	VS	22.08.17	12501201708221049	0.15	is
Grüebu [p], Fletschhorn [c], Rossbode [c]	VS	22.08.17	12501201708221043	0.15	is
Grüebu [p], Mattwald [c], Gamsa [p]	VS	22.08.17	12501201708221129	0.10	is
Gutz [c], Rosenlaui [p], Trift [p], Chelen [p], Rhone [p], Damma [p],	BE, VS	29.08.17	12504201708291126	0.26	is
Kanderfirn [p], Doldenhorn [c], Fründen [c], Tschingel [p], Tellin [p], Tal [c], Jegi [c] Anun [c], Breithorn [c], Lang [p], Grosser Aletsch [p]	BE, VS	08.09.17	12504201709081042	0.26	is
Kanderfirn [p], Tellin [c], Lang [p], Oberaletsch [p], Mittelaletsch [c], Grosser Aletsch [p], Fiescher [p], Gries [p]	BE, VS	08.09.17	12504201709081027	0.26	is

Mittelaletsch p, Grosser Aletsch p, Fiescher p, Gries p, Corno c	VS, TI	21.09.17	12504201709211258	0.26	is
Ob. Grindelwald p, Gutz c, Rosenlaui p, Gauli p, Trift p, Rhone p, Damma c	BE, VS	29.08.17	12504201708291137	0.27	is
Oberaar c, Finsteraar p, Fiescher p, Aletsch p, Tschingel p	BE	21.09.17	12504201709211134	0.24	is
Oberaar c, Finsteraar p, Fiescher p, Grosser Aletsch p, Tschingel p, Rottal c,	BE	21.09.17	12504201709211147	0.25	is
Plaine Morte c, Wildstrubel p, Lämmern c, Nest c, Baltschieder p	BE, VS	29.08.17	12504201708290919	0.26	is
Plaine Morte p, Ammerten c, Wildstrubel c, Strubel c, Steghorn c, Tälli c, Nest c, Birch c, Baltschieder c, Beich p, Oberaletsch p, Grosser Altesch p, Binnen c, Rappen c	BE, VS	29.08.17	12504201708290904	0.25	is
Plaine Morte p, Gelten c, Dungel c, Wildhorn c	BE, VS	21.09.17	12504201709211327	0.23	is
Plaine Morte p, Gelten c, Dungel c, Wildhorn c	BE, VS	29.08.17	12504201708290941	0.26	is
Plaine Morte p, Gelten c, Dungel c, Wildhorn c	BE, VS	05.10.17	12504201710051141	0.24	is
Rhone p, Unteraar c, Finsteraar p, Lauteraar p, Unt. Grindelwald p, Eiger c, Guggi c, Giesen p	BE, VS	21.09.17	12504201709211121	0.24	is
Ried p, Hohbärg p, Festi p, Kin p	VS	22.08.17	12501201708221025	0.15	is
Ried p, Hohbärg p, Festi p, Kin p	VS	22.08.17	12501201708221032	0.15	is
Ried p, Hohbärg p, Festi p, Kin p, Weingarten p	VS	22.08.17	12501201708221017	0.14	is
Silvretta c, Verstancla c, Tiatscha c, Plan Rai c	GR	25.08.17	12501201708251010	0.17	is
Trift p	BE	22.08.17	12501201708220953	0.22	is
Unt. Grindelwald p, Egier p, Lauteraar p, Unteraar p, Rhone p	BE, VS	21.09.17	12504201709211109	0.25	is
Unt. Grindwald p, Ob. Grindelwald p, Gauli c, Lauteraar p, Rhone p, Teifen c	BE, VS	29.08.17	12504201708291148	0.25	is

c Glacier shown completely
p Glacier shown partially

Type of acquisition: col colour frames; is image stripe

B Remarks on Individual Glaciers

1 Rhone

2016: Luftbildaufnahmen am 8.8.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 21.9.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

3 Gries

2016: Luftbildaufnahmen am 26.8.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 7.8.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

5 Grosser Aletsch

2016: Luftbildaufnahmen am 22.8.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 7.8.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

7 Kaltwasser

2016: Der Punkt 1 liegt in einem Graben mit Eisresten. (M. Schmidhalter)

2017: Im Graben bei Punkt 1 sind noch vereiste Stellen des Gletschers, welche nicht berücksichtigt wurden. (M. Schmidhalter)

10 Schwarzberg

2016: Luftbildaufnahmen am 29.9.2016, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.10.2017, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

11 Allalin

2016: Luftbildaufnahmen am 29.9.2016, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.10.2017, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

12 Chessjen

2016: Luftbildaufnahmen am 29.9.2016, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.10.2017, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

13 Fee

2017: Der untere Gletscherrand wurde zu Fuss vermessen. Der Rückzug ergibt sich jeweils aus der Verschiebung des Gletschertors. Der vordere Teil des Gletschers mit einer Länge von beinahe einem Kilometer ist überhaupt nicht mehr mit dem Nährgebiet verbunden und fällt stark zusammen. Evt muss in Zukunft der "neue" obere Gletschrrand gemessen werden. (U. Andenmatten)

16 Findelen

2016: Luftbildaufnahmen am 26.8.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.9.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

17 Ried

2016: Koordinaten von Referenzpunkt FP75 neu bestimmt mit Swiss Grid App auf iPhone: 630931 / 111065 (P. Rovina)

2017: Koordinaten von Referenzpunkt FP75 neu bestimmt mit Swiss Grid App auf iPhone: 630930 / 111062 (P. Rovina)

19 Turtmann

2016: Deutlicher Rückgang des Gletschers, am rechten Gletscherrand ist wieder eine neue Felsrippe zum Vorschein gekommen. (A. Brigger)

2017: Wiederum deutlicher Rückgang des Gletschers. Er fällt stark zusammen und ist nur noch mit einem schmalen Band mit dem Nährgebiet verbunden. (A. Brigger)

20 Brunegg

2017: Deutlicher Rückgang des Gletschers. Der Rückzug ergibt sich aus der Verschiebung des Gletschertors. (A.Brigger)

21 Bella Tola

2017: Premières mesures GPS sur le terrain. (P. Stoebener)

22 Zinal

2016: Epaisseur du front: ≈54 m. 2 points de mesure du recul ont été ajoutés pour être plus représentatif de l'ensemble de la ligne de front. (G. Chevalier)

2017: Epaisseur au front: ≈50 m. Le point de mesure 4 a été déplacé par rapport à 2016. (G. Chevalier)

23 Moming

2016: Formation d'un grand lac. (P. Stoebener)

2017: Hauteur front: 11.9 m. La partie sud-est de la mesure 2016 est probablement erronée. (P. Stoebener)

24 Moiry

2016: Epaisseur du front: ≈5 m. Glace morte en rive gauche recouverte de mat. morainique pas pris en compte, car détachée du front. Pas rajouté de points pour le recul, car le front est peu étendu. (G. Chevalier)

2017: Epaisseur au front: 0–3 m. Nouvelles lignes de calcul du recul (adapté au front). (G. Chevalier)

25 Ferpècle

2016: Nouveau calcul du retrait sur la base de 4 pts de référence (F. Fellay)

2017: Modification de l'azimut, ajout d'un point de référence. (F. Fellay)

26 Mont Miné

2016: Nouvelle mesure du recul sur la base de 4 pts de repère (F. Fellay)

2017: La langue est séparée du plateau glaciaire par une falaise entre 2500 m et 2600 m. Le glacier avance encore à cette altitude et "alimente" la langue par la chute de séracs. Mesure par Uni Genève: ligne d'équilibre calculée à 3100 m. Perte d'épaisseur de glace à la langue: 7–8 m. (F. Fellay)

27 Arolla

2016: Nouvelle mesure du recul sur la base de 4 pts de référence (F. Fellay)

28 Tsijdere Nouve

2016: Nouvelle mesure du recul sur la base de 4 pts de repère (F. Fellay)

29 Cheillon

2016: Le glacier continue de reculer principalement sur la partie Est. La méthode de mesures permet une bonne précision. (O. Bourdin)

2017: Point No 2: Langue glacière s'est retirée à l'Est. (O. Bourdin)

30 En Darrey

2016: Abandon de mesures sur glacier "mort". L'attaque devait se faire par le Nord, en remontant la moraine jusqu'aux parois rocheuses, puis traverser sur le plateau supérieur. En raison des conditions météos, l'eau de ruissellement transormé en glace a empèché cette approche sur la partie haute. Les conditions d'approche sont par ailleurs assez périlleuses dans ces grands versants à éboulis actifs. Nous n'avons pu prendre qu'un seul point en raison de la topographie. (O. Bourdin)

2017: Le point D* étant le plus bas mais également le plus inaccessible, la prochaine fois le retrait devra être contrôlé par la différence d'Azimut latéralement. Accès périlleux! (O. Bourdin)

33 Tsanfleuron

2016: Nouvelle mesure du recul sur la base de 4 points de repère (P. Fellay)

34 Otemma

2016: Nouveau pt. 20/16 car sur l'axe du pt. 19/13 la glace est bientôt inexistante. De plus il remplacera le pt. 4 dont l'axe se trouve maintenant dans le portail et le torrent glaciaire. (J.-J. Chabloz)

2017: Pt. 20/16 abandonné car plus de glace. Nouveau pt. 21/17. Tous les anciens pts ont étés emportés par l'effondrement de la moraine latérale gauche. (J.-J. Chabloz)

35 Mont Durand

2016: Toujours le même enchevêtrement de rochers parmi lesquels de très gros blocs. Le bras gauche du glacier se termine au niveau de la première barre rocheuse centrale. Rive droite le portail recule, mais reste au niveau du pied du verrou rocheux rive droite. L'axe de ma visée arrive au pied de la langue à gauche de la barre rocheuse centrale. (J.-J. Chabloz)

2017: Gros éboulement de rochers rive gauche au goulet avant le plateau glaciaire. Dans l'axe de visée rive gauche un torrent important est maintenant visible, puis disparaît à droite sous rochers et glace de la langue centrale. J'ai enfin pu voir et photograhier le portail principal de droite, gros débit d'eau, ainsi que la pente de glace qui le surplombe. Tassement marqué du front du glacier couvert de gros blocs rocheux entre lesquels la végétation prend place. (J.-J. Chabloz)

36 Brenay

2016: Portail principal rive droite au raz de l'eau, langue glaciaire à l'agonie, portail rive gauche béant à sec et la bordure rive gauche, pourtant ubac, est percée de trous et des gravats petits et gros se détachent sans arrêt. (J.-J. Chabloz)

2017: Le portail et la langue frontale très plate. Vers la rive gauche le torrent de surface creuse profondément la glace. En amont les deux bords tu glacier couverts de débris rocheux diminuent d'épaisseur. Au niveau de premier goulet une grande dépression est bien visible allant jusqu'à la séparation en deux bras au pied des séracs du Breney où le bedrock est bien apparent. (J.-J. Chabloz)

37 Giétro

2016: Luftbildaufnahmen am 29.9.2016, photogrammetrische Auswertung durch Flotron AG im Auftrag der Forces Motrices de Mauvoisin SA. Bestimmung der Längenänderung durch die VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.9.2017, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Forces Motrices de Mauvoisin SA. (VAW/ETHZ – A. Bauder)

38 Corbassière

2016: Luftbildaufnahmen am 29.9.2016, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Forces Motrices de Mauvoisin SA. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.9.2017, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Forces Motrices de Mauvoisin SA. (VAW/ETHZ – A. Bauder)

40 Tseudet

2016: Le bas du glacier est très irrégulier et est recouvert d'éboulis. Il est très difficile de déterminer où 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)

43 Trient

2016: La pointe de la langue glaciaire est toujours engagée dans le même sillon rocheux depuis 2004. Le recul est lent, mais la perte d'épaisseur est observable d'une année à l'autre, en comparant les photos prises du même point de vue. (J. Ehinger)

2017: Visite du samedi 7.10.2017; Buts: Evaluer visuellement l'état du glacier. Prendre des photos, en particulier depuis le point "alpha", pour continuer la série commencée en 1969 par Monsieur Pierre Mercier. Mesurer la position du front du glacier. Lever le plus grand nombre possible de points en bordure de la langue glaciaire. Le ciel est resté dégagé durant toute la journée, avec quelques cirrus en fin d'après-midi. La lumière n'était pas toujours favorable à la prise de photographies, en raison d'un soleil déjà assez bas sur l'horizon, générant un effet de contre-jour. Il y avait également une légère brume qui formait un voile ténu sur les reliefs. La fonte a été importante. Le débit du torrent émissaire a été particulièrement élevé durant l'été, selon le témoignage des responsables de la buvette. Par contre, le débit du torrent était plutôt ordinaire lors de notre passage. La fonte du glacier, initiée en 1987, se poursuit avec une intensité accrue depuis une dizaine d'années. En comparant les photographies des années précédentes, on remarque un amincissement de la langue glaciaire nettement perceptible et une ouverture des crevasses bien visible. La langue semble s'affaisser sur elle-même et l'on remarque un peu de glace éboulée en périphérie. Faute de mesures, il n'a pas été possible d'estimer le volume de glace perdu durant une année. La pointe de la langue glaciaire est bordée d'une importante masse de glace éboulée, en direction de l'aval. L'éboulement de cette année semblait très probable en 2016, compte tenu des larges fissures visibles lors de notre dernier passage. L'amincissement général de la langue glaciaire s'est poursuivi, de manière sensible. Photos du glacier ont été prises à partir du point "alpha". D'autres photos montrent les environs du point "alpha" et les traces encore visibles des dégâts occasionnées à la forêt par une avalanche de l'hiver 2009/10. Photos ont été prises à 230 mètres en aval de la buvette, à la hauteur de la prise d'eau du barrage. Ce secteur a été lourdement impacté par une avalanche survenue le 9.3.2017, sur la rive gauche du torrent. Les dégâts occasionnés à la forêt sont nombreux et impressionnants, car l'avalanche est remontée sur la rive droite du torrent. Le relevé du périmètre de la langue glaciaire a été réalisé à l'aide de jumelle laser LEICA, sans couplage GPS. Le reculé est déterminé dans l'extrémité la plus basse de la langue, engagée dans un sillon rocheux d'orientation approximative SW-NE. Le front se trouve à environ 2180 mètres d'altitude. (J. Ehinger)

44 Paneyrosse

2016: Refait la peinture des points. Pour 2017 pts 55 et 56 à déplacer côté sud sur une nouvelle base rocheuse. Reste encore de la neige de l'hiver 15/16. (J.-Ph. Marlétaz)

2017: En remplacement des pts 55 et 56 création de deux nouveaux pts 175 et 176 et 2 petits cairns de repérage (J.-Ph. Marlétaz)

45 Grand Plan Névé

2017: Posé 2 nouveaux pts 176 et 177 sur barre rocheuse à l'est des pts 81 à 85 et 2 petits cairns de repérage (J.-Ph. Marlétaz)

47 Sex Rouge

2016: Présence de névés persistants sur P2, P3 et P4. (J. Binggeli)

2017: (1) Pas de névés persistants sur P1,P2,P3 et P4 (glace morte sous les pierriers?) (2) Point le plus bas du glacier vivant se trouvant vraisemblablement beaucoup plus haut que P4 (3) Email envoyé à la Société "Glacier 3000" pour préservation de P1 à P3 (travaux de terrain à proximité) (J. Binggeli)

48 Prapio

2016: Les éboulis des pentes dominantes (rive droite) recouvrent le glacier dans sa partie inférieure, le point le plus bas est aujourd'hui juste décelable. Le recul s'explique par le détachement d'un gros bloc de glace de 3 m de l'avant du glacier. L'altitude 2025 indiquée au point P1 déterminé en 2001 est vraisemblablement inexacte (en fait 2501). Le glacier serait donc remonté de 50 mètres en altimétrie, de 2001 à 2016. (J. Binggeli)

2017: (1) Observation du 08.09.2017 depuis l'antecime du Sex Rouge: très forte altération! (2) Recul dû aux T^0 élevées (0° à 3800 m) et faible précipitations en neige; le point le plus bas du glacier est encore décelable malgré les éboulis de pente (photo) (3) Azimut: la mesure se fait dans l'axe du torrent depuis 2010 (4) Sous réserve de la précision des coord: l'altitude du point le plus bas du glacier déterminé à 2546 m en 2016 est trop basse, idem pour les années précédentes depuis 2010 (GPS altimètre!) (J. Binggeli)

55 Trift (Gadmen)

2016: Luftbildaufnahmen am 8.8.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 22.8.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

57 Oberer Grindelwald

2016: Luftbildaufnahmen am 26.8.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 29.8.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

58 Unterer Grindelwald

2016: Luftbildaufnahmen am 26.8.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 21.9.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

59 Eiger

2016: Messung mit Theodolit; Teilweise Rückgang, teilweise Vorstoss oder Vorrutschen. Der Gletscher ist sehr dünn. (R. Schai)

2017: Der Gletscher wird immer dünner. Messung teilweise mit Theodolit und Handleicadistanzmessung. Die Messung wird immer schwieriger, da die Distanzen sehr lang sind (über 800 m) und wir auch diagonal zum Gletscher messen. Unsere Instrumente sind am Limit. (R. Schai)

60 Tschingel

2016: Kein Gletschertor auszumachen, die Schuttbedeckung isoliert den Gletscher gut. (R. Schai)

2017: Kein Gletschertor auszumachen, die Schuttbedeckung isoliert den Gletscher gut. Die Referenzpunkte wurden näher zum Gletscher verschoben. (R. Schai)

61 Gamchi

2017: Der relativ dünne Ausläufer vom Vorjahr ist geschmolzen. Neu konnte wieder an einer dickeren Kante gemessen werden. (M. Schenk)

63 Lämmern

2016: Einmessung früherer Referenzpunkte mit GPS (E. Coleman Brantschen)

2017: Noch eingemessener, vorderer Teil des Gletschers dürfte bald den Kontakt zum Nährgebiet verlieren und zu Toteis werden. (E. Coleman Brantschen)

64 Blümlisalp

2016: Verhältnisse anspruchsvoll, eine genaue Messung wird zunehmends schwieriger. (U. Burgener)

2017: Zunehmend schwierigere Messbedingungen. (U. Burgener)

65 Plaine Morte

2016: Luftbildaufnahmen am 7.9.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 29.8.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

66 Tiefen

2016: Das Toteis am südlichen Gletscherrand ist sich stark am Auflösen. Lokal ist es ganz verschwunden und dahinter hat sich ein neuer Gletschersee gebildet. (L. Eggimann)

2017: Der Gletscher ist auf der Steilstufe auf Höhe ca. 2550 m Ende August 2017 ab- bzw. durchgeschmolzen. Somit verbleibt unterhalb dieser Steilstufe Toteis zurück und die neue aktive Gletscherzunge liegt rund 620 m weiter westlich als die ehemalige. (L. Eggimann)

67 St. Anna

2016: Am Messtermin lag bereis ca. 10 cm Schnee. Dadurch Gletscherfront nicht eindeutig bestimmbar. Pkt 2015 neu beschriften. (L. Eggimann)

2017: Der Gletscher weist in Steilstufe rund 50 m obehalb der Zunge erste Zerfallserscheinungen auf. (L. Eggimann)

68 Chelen

2016: Neuer Messpunkt eingerichtet. Die Gletscherzunge liegt im Moment am vordersten Rand eines flachen Geländebeckens. (M. Planzer)

2017: Neuer Messpunkt eingerichtet. (M. Planzer)

69 Rotfirn

2016: Die Verbindung der im Talboden liegenden Gletscherzunge mit dem Hauptgletscher besteht noch. (M. Planzer)

70 Damma

2016: Die westliche Gletscherzunge ist nicht mehr mit dem Hauptgletscher verbunden. (M. Planzer)

2017: Neuer Messpunkt angelegt. (M. Planzer)

71 Wallenbur

2016: Inzwischen ist der gesamte Gletscher im Talboden von Schutt bedeckt. (P. Kläger)

2017: Gletschermächtigkeit hat weiter stark abgenommen, am Zungenrand sind 5 kleinere bis mittlere Tore erkennbar. Vor allem die mittleren sind nur mit dünner Eisschicht überdeckt. Die Verbindung vom den Talgletscher speisenden Hängegletscher unterhalb des Sustenhorns ist weiter stark schmäler geworden - nur noch wenige Meter breites Band. (P. Kläger)

72 Brunnifirn

2017: Punkt 10 nach vorne verlegt / neu Punkt 10A (M. Planzer)

74 Griess

2017: Neuer Basispunkt 2017 eingemessen (B. Annen)

76 Griessen

2016: Bei Punkt 1 ist die gemessene Distanz sehr stark von der Genaugkeit des Azimut abhängig, weil die Messrichtung annähernd parallel zum Gletscher verläuft. Rückzug vermutlich gesamthaft etwas kleiner. (M. Meier)

77 Biferten

2016: Messung zusammen mit Roman und Susanne Müller. Wir steigen nach der obligaten Fahrt bis Hintersand, gespannt und bei angenehmen Temperaturen Richtung Gletscher, was uns da wieder erwarten wird. Etwas wusste ich bereits von Kurt Stüssi dem Chef des Bautrupp der KLL: an der Fassung 2 (Fassung bei Ausgangspunkt 2003) kommt kaum Wasser. Dafür fliesst an der Fassung 1 umso mehr, irgendwie ist da der Gletscherbach von Fassung 2 wohl eine neue Bindung eingegangen oder anders gesagt er hat sich einen andern Weg unter dem Gletscher gesucht. Der Service der KLL-Bautruppe in Sachen Stativtransport von der alten Fridolinshütte hinunter zur KLL Unterkunftshütte klappt einmal mehr tadellos! Herzlichen Dank. Beladen mit Sack und Pack geht es dann über den doch nicht ganz ungefährlichen Weg hoch zum Ausgangspunkt 2003. Trockene Kleider überziehen und auch ein kurzer Znünihalt gehört zum Startprozedere am Ausgangspunkt. Roman weiss bereits, dass er über den Punkt E als meinen Orientierungspunkt zum Gletscheranfang starten kann. Den Verlauf der Gletscherzunge mit 36 Punkten vermessen. Diese bestimme ich nach wie vor von den beiden Stationen 2003 und 20101, neu aber mit dem TCRA 1205+ einem Theodoliten der etwas neueren Generation, der auch Reflektorlos messen kann, was mir dann schliesslich beim Gletschertor 2 noch hilfreich ist. Der tiefste Punkt des Gletschers befindet sich am Anfang der Messung am ostseitigen Rand des Gletschers, dieser hat sich gegenüber dem Vorjahr nur unwesentlich verändert, nämlich von 1963.9 m.ü.M auf 1963.3 m.ü.M. Das Gletschertörchen das beim Gletscherbach zur Fassung 2 noch besteht liegt auf 1972.5 m.ü.M. Da ist klar ersichtlich, dass in dem Bereich das Vorgelände des Gletschers recht flach verläuft. Die Überquerung des Baches in dem Bereich ist einfach und ohne Schwierigkeiten zu meistern. Der Gletscherrand in dem Gebiet wie aus den Bildern ersichtlich nicht immer eindeutig und klar auszumachen. Der Abstand der Fassung 2 zum Gletschertor ist nun bereits bei 197.3 m, vor gut 40 Jahren im 1977 stand das Gletschertor auf der Fassung! und es musste ein Eisstollen gesprengt werden um das Wasser auch nützen zu können. Roman Müller kartiert die Gletscherzunge bis zum Punkt mit der Höhe 1999.3 m.ü.M, und ich erfasse diese Punkte ab der Station 2003. Danach wechsle ich hinauf zum Pt. 20101. Dann ist für den Gehilfen Pause angesagt. Ich versuche mit Susanne zusammen möglichst rasch unserem Gehilfen nachzueilen, um ihn dann zu überlaufen und mich dann bei Pt. 20101 wieder zu installieren und die Messung fort zu setzen. Doch dieses Jahr kommt es anders als gewohnt, so ist es unmöglich den Gletscherbach 2 zu überqueren und so ist eine Umgehung nur über den Gletscher möglich oder allenfalls zurück zur Unterkunftshütte und dann mit Gegenaufstieg über den KLL Bewirtschaftungsweg zum Pt. 20101. Da dies jedoch die umständlichere Variante ist, nehmen wir gemeinsam mit Roman den Weg über den Gletscher, der zum Glück mit viel Kies belegt ist, so dass wir dies ohne Steigeisen schliesslich schaffen. Für Susanne war dies wohl eine der grösseren Herausforderungen an diesem Tag, die sie aber ebenfalls bravourös meisterte. Wir liessen dann Roman am etwa ausgemachten Endpunkt unserer Messung zurück, während wir (Susanne und ich) uns zum Pt. 20101 vorkämpften und dort sofort den Theodoliten wieder installierten um die Messung fort zu setzen. Roman beginnt dann am Ende (der Messung) bei Punkt 2026.6 m.ü.M und arbeitet sich Richtung Gletschertor 2 vor. Bis zum Punkt 2004.7 m.ü.M kommt er mit dem Reflektor hin, danach versperrt ihm der Gletschersee den Zugang zur Gletscherzunge. Diese kann ich dann wie bereits angesprochen schliesslich "Reflektorlos" bis auf die Höhe 2005.7 m.ü.M erfassen und so schliesst sich die Aufnahmelinie der Gletscherzunge schliesslich nahtlos. Für den Gehilfen heisst dies; Ende der Messung und Aufstieg zum Punkt 20101, wo Susanne und ich das Instrument bereits in den Rucksack packen um dann über die Jakob Streiff-Becker Moräne gemeinsam auszusteigen. Dies tönt einfach und simpel, ist aber immer wieder eine Herausforderung; quer aufsteigend durch eine Moräne über Geröll und teilweise hart gepressten Untergrund mit Sack und Pack bringt das Adrenalin doch noch einmal etwas ins Fliessen. Aber mit dem Gedanken, dass oben in der Fridolinshütte die wohlverdiente Belohnung wartet (etwas "z'Bissä" und auch etwas Dünnes) beflügelt uns und so schaffen wir auch diese Klippe. Nach der Deponie des Statives in der alten Fridolinshütte geniessen wir die wohlverdiente Rast bei der Haupthütte und freuen uns ob der gelungenen Messung bei angenehmen Temperaturen. Das Resultat der Auswertung zeigt schliesslich wieder das gewohnte Bild, das mit Ausnahme des letzten Jahres doch bereits zur Gewohnheit wird: der Gletscher zieht sich zurück, im 2016 um 9.3 m. Eine Bestätigung der These, dass der Gletscherzuwachs vom Jahre 2015 der schwindenden Unteren Brüche und die genaue Fliessrichtung des Gletschers der durch diesen Druck an der Zunge nach vorne geschoben wird, kann ich nicht vollauf beweisen, (keine Fliessgeschwindigkeitsmessungen und keine Massenberechnungen) aber es könnte eine Erklärung sein, da der Zuwachs in diesem Bereich wohl das Resultat stark beeinflusste. Dass der Bifertengletscher noch eine Zeit bestehen wird bezweifle ich nicht, aber wie lange? Nach Verpflegung und Ausruhen auf der Fridolinshütte kommt noch der Abstieg über den Hüttenweg hinunter zum Vermessungsbus im Hintersand; müde aber glücklich kommen wir dort einmal mehr unfallfrei an und sinnieren bereits, was denn im 2017 alles passiert in Sachen Gletscher, Temperaturen und Schnee. (H. Klauser)

2017: Treue Messgehilfen sind ein Segen für den Gletschermesser. So durfte ich auf die Mithilfe von Roman Müller zählen. Da sich im Verlaufe des Tages der Föhn noch melden könnte, starten wir um 05.00 Uhr ab Glarus um möglichst sturmfrei die Messung zu bewältigen. Die Fahrt hinauf nach Hintersand mit kurzem Fotohalt an gewohnter Stelle bei der Sandrisi mit erstem imposantem Blick zum Tödi, können wir einmal mehr dank dem hochbeinigen Bus und Allradantrieb locker angehen. Der Aufstieg zum Gletscher, wie gewohnt noch bis zur Unterkunftshütte der KLL ohne Stativ, verläuft ebenfalls wie gewohnt rasch und ohne Probleme. Wiederum klappt die Deponie des Statives vor der KLL Unterkunft um es dort zu übernehmen einwandfrei und so steigen wir den "Jägersteig" hinauf zum Ausgangs- und Startpunkt der Messung im Osten dem 12003 und E. Natürlich werden dort zuerst trockene Kleider übergestreift und auch ein "Znünihalt", wenn auch kurz, gehört dazu. Auf der Station 12003 stationiere ich den Tachymeter (Leica Theodolit TCM 1201) um von dort bis ungefähr dem Beginn des Gletschersees die Gletscherzunge zu kartieren. Da Roman bereits ein alter Fuchs in Sachen Bifertengletscher Messung ist, findet er auch die Ausgangsrichtung E um mir diese für die Orientierung zu signalisieren. Nach diesen Vorarbeiten beginnt die eigentliche Vermessung des Gletschers. Wie seit längerer Zeit am Bifertengletscher, erleichtert uns das Geröll das dort liegt, nicht unbedingt die Arbeit, eine klare Linie der Gletscherzunge auszumachen. Doch das jahrelange Begleiten meines Messgehilfen, macht es etwas einfacher, sein Auge findet in etwa die Zunge, aber auch der unmittelbar vor unserer Messung gefallene Schnee zeichnet die Zunge ziemlich eindeutig und klar, dies weil wohl die kühlere Schicht sprich das Eis unter dem Geröll dazu beiträgt, dass der Schmelzprozess dort etwas verzögert ist. So kartiert mein Gehilfe Punkt um Punkt, mit 42 Punkten ist schliesslich der Gletscherrand erfasst. Das Tor am Gletscherbach zur Fassung 2 ist nur noch ein Türlein und der Bach ein Rinnsal, das da Richtung Tal fliesst. Die Höhe habe ich dort mit 1972.7 m.ü.M erfasst, da ist das Eis zum Vorjahr um 2 m nach oben geschmolzen. Der Abstand zur Fassung in der Horizontalen gemessen beträgt bereits 200.5 m. Im Jahre 1977 stand der Gletscher noch auf der Fassung 2, dies ist für mich immer ein eindrücklicher Referenzpunkt! Wie auch in den letzten Jahren verschwindet mein Gehilfe ungefähr im Bereich des Gletschersees und dem Abfluss des Gletscherbaches zur Fassung 1. Dies heisst für mich Standortwechsel und Aufstieg zur Station 20101, dabei kann ich noch einige Detailbilder knipsen, so dass da genügend Dokumentationsmaterial vorhanden ist. Die Überquerung des Gletscherbaches beim Gletschersee ist dieses Jahr mit einer guten Wahl der Steine im Wasser, gut machbar und so gelange ich recht schnell zu meiner zweiten Station. Nach Stationierung und Orientierung des Instrumentes setzen wir die Messung fort: ca. 11 Punkte kann ich im Bereich des Gletschersees, dort wo mein Gehilfe den Gletscher nicht begehen kann, diesen "reflektorlos" erfassen. Danach übernimmt Roman wieder mit dem Reflektor das Zepter und vermisst den Gletscher bis hinauf zur Höhe von 2047 m.ü.M. Das Tor beim Gletscherbach 2 liegt neu bei 2009.8 m.ü.M bereits wieder 4.3 m höher als im Vorjahr, der Gletscherbach selbst fliesst schliesslich auf einer Höhe von 2004.2 m.ü.M ab. Da ist zum Vorjahr bereits wieder eine starke Abplattung feststellbar. Was aber noch viel mehr zum Sinnieren gibt, ist das einfressen des Felsens am Fusse des Grünhornes in den Bifertenfirn, das ich in diversen Bildern dokumentiert habe. Da entsteht wohl in einigen Jahren eine riesige Toteismasse im unteren Teil des Gletschers und für mich demnach ein immer längerer Anstieg zur Zunge. Die Messung 2017 können wir dank dem frühen Start und der doch präzisen Wettervorhersage ohne negativen Witterungseinflüsse beenden. Der Ausstieg aus der Jakob Streiff-Becker Moräne als Dessert meistern wir auch noch mit Bravour und nach der Deponie des Statives in der alten Fridolinshütte für den Rücktransport durch Arbeiter der KLL gehört auch eine kurze Rast bei der Hütte dazu, bevor wir noch den Abstieg nach Hintersand unter die Füsse nehmen. Eine weitere Messung kann ich unfallfrei und mit vielen Eindrücken beenden. Das Resultat aus den Daten die ich im Büro verarbeite verwundern wohl niemanden mehr: ein weiterer Schwund von im Mittel -11.3 m lassen den Bifertengletscher immer mehr nach oben verschwinden. Was aber dennoch eindrücklich erscheint sind die gesamte Minusfläche über die gemessen Breite der Gletscherzunge nämlich 8693.4 m^2 : 772.7 m (gemessene Breite) ergibt eben den Schwund von -11.3 m. Aus der Höhe des tiefsten Punktes der im 2017 auf 1963.7 m.ü.M liegt und nur 0.4 m höher liegt zum Vorjahr wäre der Schwund nicht derart gross auszumachen, aber dies wirkt sich im flachen Vorgelände auch nicht so stark aus. Unaufhaltbar geht der Gletscher zurück, ich bleibe natürlich dran und beobachte das ganze Szenario! (H. Klauser)

78 Limmern

2016: Gletscherzunge aper, etwas Neuschnee ab ca. 2600 m, kaum Firnschnee; die Punkte 1 bis 3 sind stark schuttbedeckt. (U. Steinegger)

2017: Gletscherzunge eingeschneit (10–20 cm), kein Firnschnee; die Punkte 1, 2, 4 sind stark schuttbedeckt (U. Steinegger)

79 Sulz

2016: Der Gletscher ist etwas zurückgegangen und ein Teil der Gletscherzunge ist abgebrochen. Um das Gletschertor ist auch deutlich weniger Geschiebe vorhanden als im Vorjahr. Ansonsten sind visuell keine Änderungen sichtbar. (P. Köpfli)

80 Glärnisch

2016: Ich verabrede mich mit Hansruedi Hösli alt Metzgermeister aus Ennenda für die Messung. Die Fahrt von Glarus durchs Rossmattertal hinauf nach Wärben, alles im Schatten, ist ohne Zwischenfälle gemeistert, nun beginnt also der Aufstieg zu Fuss. In Anbetracht des Alters von Hansruedi übernehme ich nebst dem Instrument auch das Schultern des Stativs.

Das restliche Material wie Reflektor und Stab, Verlängerung und die Funkgeräte verschwinden im Rucksack meines Gehilfen. So steigen wir hinauf zu unserem Gletscher. Zuerst viele Serpentinen hoch bis zur ersten kurzen "Kraxelei" über die erste Felsstufe, dann weiter bei den Edelweissen vorbei, natürlich inklusive Foto, hinauf zur Hütte. Dort schalten wir eine kurze Verschnaufpause ein, leider ohne Hüttenkaffee, da der Hüttenwart bereits auf Winter umgeschaltet hat und somit nicht mehr vor Ort weilt. Erholt geht es dann weiter in Richtung Gletscher, nochmals mit kurzer Kletterei über eine kurze Felsbarriere. Für kurze Zeit begleitet uns die Sonne, bevor wir wieder "abtauchen" in Richtung Fels Band mit der Station 14 und 15, die im Schatten des Bächistockes liegen. Nun habe ich als Operateur mein Ziel vorerst erreicht, nun beginnt für den Gehilfen die "Knochenarbeit". Doch bevor wir damit beginnen, geniessen einen Cappuccino der Hansruedi liebevoll zubereitet. Die Besprechung unseres Vorgehens dauert nicht lange und bereits startet Hansruedi mit Funk und Reflektor sowie Stab und Verlängerung in Richtung südliches Ende des Gletschers. Ich positioniere wie letztes Jahr, den Theodoliten TCRA 1205 über der Station 15, dem HP den ich im Jahre 2014 bestimmt habe. Unterdessen hat sich mein Gehilfe behände und gewandt hinunter über die Felsbarriere zum Gletscher bewegt und ist bereit für die Messung. Ich orientiere das Instrument anhand der fernen Gipfelkreuze am Druesberg und Forstberg oberhalb des Pragelpasses sowie der Station 14. Nach diesen "Voreinstellungen" begleite ich nun Hansruedi der Gletscherzunge entlang und registriere anhand seiner Aufstellungen die Position der Gletscherzunge. Nach 10 Punkten auf Höhe von 2402.7 m.ü.M, die mir den südlichen Verlauf des Gletschers wiederspiegeln, muss ich meinen Standort wechseln, da der Gehilfe aus meinem Blickfeld verschwindet. So verschiebe ich den Theodoliten zur Station 14 von wo aus ich nun den restlichen Gletscherbereich vollumfänglich einsehen und erfassen kann. Früher war die eben erwähnte Stelle vielfach auch die Schlüsselstelle, klafften dort doch vielfach die grössten Spalten die dann dementsprechend vorsichtig zu begehen waren. Dies ist aber alles Vergangenheit: der immer mehr abflachende Gletscher ist nun einfach und ohne grosses Risiko begehbar. So kommt mein Gehilfe auch zügig voran und mit 30 Punkten ist der Gletscher schliesslich kartiert. Natürlich werden auch die Fixpunkte 12 und 13 noch in die Messung integriert, bevor Hansruedi seine wohlverdiente Rast einschalten darf. Eine weitere Messung kann erfolgreich abgeschlossen werden: nur wir zwei alleine, bei herrlichstem Wetter, absoluter Stille und für die Messung angenehmen Temperaturen. Der tiefste Punkt an dem wie letztes Jahr auch der Gletscherbach hervorfliesst, sich aber nach wie vor kein eigentliches Gletschertor bildet, liegt beinahe identisch in der Höhe zum letzten Jahr nämlich auf 2347.0 m.ü.M. Das Vorgelände ist da äusserst flach und unspektakulär, daher sind da momentan in der Höhe keine allzu grossen "Sprünge" zu erwarten. Die Berechnung der mittleren Veränderung des Gletschers ergibt wiederum eine Minusfläche von -4803.7 m^2, die ich dann mit der gemessenen Breite von 425.3 m dividiere. Das ergibt dann einen mittleren Schwund von doch wiederum -11.3 m. Der Eindruck am Gletscher hat also nicht getäuscht, die Schmelze geht weiter. Sämtliche Berechnungen und Aufzeichnungen führe ich im Geospro aus einem Vermesserprogramm auf GeoMedia Basis. Das Koordinatensystem ist nach wie vor LV03. Der Gletscher verabschiedet sich immer weiter Richtung Osten oder zum Schwandergrat. (H. Klauser)

2017: Als Gletschermesser kann man auch Geburtstagsgeschenk sein; so hat mich Katrin Egger im Sommer angefragt ob dies möglich sei, dass sie mich mit ihrem Vater Beat Stüssi als Geschenk zum 70. Geburtstag an den Gletscher begleiten dürfe. Mit den üblichen Hinweisen, dass sie ja eben selbst hochsteigen und dabei auch noch etwas Vermessungsmaterial tragen müssten und auch eine gewisse Bergerfahrung mitbringen sollten, willigte ich natürlich gerne ein. Das Wetter spielt vollends mit. Am Morgen noch kühl aber für den Aufstieg angenehm laufen wir nach der holperigen und "rütteligen" Fahrt bis Wärben mit dem Bus, unserem Ziel dem Gletscher entgegen. Wie immer ist der Rucksack nebst vielen warmen Kleidern und auch etwas Verpflegung und Trinksame, mit Vermessungsmaterial bis obenhin bepackt. Eine Last die man aber für diese Sache gerne auf sich nimmt. So steigen wir dann gespannt Richtung Glärnischhütte und dem Gletscher, was uns denn heute so erwartet: Können wir die Messung überhaupt ausführen, liegt vielleicht zu viel Schnee? Fragen die sich bald beantworten lassen. Der Jubilar Beat und auch die Tochter Katrin freuen sich auf das Erlebnis Gletschermessung und sind bereits beim Aufstieg interessierte Zuhörer meiner Erklärungen und Ausführungen zur Messung und zum Vorgehen oben am "ewigen Eis". In Anbetracht des hohen Alters von Beat passe ich das Aufstiegstempo etwas an. So kommen wir etwas langsamer in Richtung Glärnischhütte. Dabei bemerke ich, dass Beat immer mehr Pausen braucht und sich einfach nicht mehr vollauf erholen kann. Kurz oberhalb der Edelweissplatte von der auch nach erstem Schnee immer noch die Königin der Bergblumen grüsst, entscheiden wir gemeinsam, dass die Glärnischhütte für Beat leider, aber vernünftigerweise das heutige Ziel bleiben wird. Tochter Katrin übernimmt ab der Glärnischhütte dann die Gehilfenrolle, natürlich nach der obligaten Rast bei Glärnischhütte. Die Verpflegung ist diesmal auch nicht aus der Hüttenküche sondern aus dem eigenen Rucksack, da der Hüttenbetrieb bereits auf Winter umgestellt ist und daher die Hütte nicht mehr "bewartet" wird. Da wir dann doch etwas mehr Zeit aufwendeten um nur bis zur Hütte zu kommen, ist der Tag dann auch um das kürzer und so entscheide ich mich beim Erreichen des Gletschers, dass wir den nordöstlichen Teil des Gletschers erfassen, dies ab der Station 13 bis hinüber zur Station 14. Den Teil über dem Felsrücken mit der Station 14 und 15 in südlicher Richtung ist infolge der doch beachtlichen Schneemenge sowieso schwierig auszumachen und ein umstellen des Instrumentes hätte nochmals einiges an Zeit gekostet und in Anbetracht, dass unten bei der Hütte noch Beat wartet, war diese Entscheidung richtig. Nach Instrumenten-Stationierung und Orientierung über die Fernziele, beginnen Katrin und ich die Messung. Ich instruiere Katrin so, dass sie hinüber auf ungefähr die Höhe der Station 14 läuft, dort mit der ersten Messung beginnt und dann der Gletscherzunge in nördlicher Richtung bis zum Zungenende folgt. Dabei ist das Zungenende gut und eindeutig auszumachen. Katrin macht es sichtlich Spass und sie kartiert schliesslich mit 52 gemessenen Punkten den Zustand des Gletschers von 2017. Ein Gletscherbach ist wegen des Schnees nicht eindeutig auszumachen, aber dies war ja auch bei ausgeapertem Gletscher nicht immer klar und eindeutig. Eine Prognose bereits vor Ort zu stellen, ob denn der Gletscher weiter zurückgeschmolzen sei, war in Anbetracht der Situation vor Ort recht schwierig. Der Schnee verändert die Landschaft derart und lässt die Konturen viel weicher erscheinen, dass dies für einmal reine Mutmassung gewesen wäre. Aus dem Grunde verlasse ich mich lieber auf die Auswertung im Büro. Diese zeigt dann einen beträchtlichen Schwund im Mittelwert von -31.3ṁ über die gemessene Breite von 342.26 m. Der tiefste Punkt liegt diesmal 0.37 m tiefer auf 2346.6 m.ü.M (von 2347.0 m.ü.M im 2016). Dies ist auf das Vorgelände zurückzuführen, das in dem Bereich ziemlich flach ausfällt. Im Bereich der Höhe 2386.2 m.ü.M bis zum Punkt mit der Höhe 2385.2 m.ü.M (siehe Planbeilage), frisst sich der Fels immer mehr in den Gletscher und lässt ihn schmelzen. Da könnte auch in naher Zukunft eine grössere Abschmelzung passieren, wenn es zum Zusammenschluss der beiden Felspartien, die Angesprochene und diejenige die den Rand im Nordosten bildet, kommt. Die immer deutlichere Ausschmelzung an den beiden Bächicouloirs wird jedes Jahr noch verstärkt. Ein Aufstieg zum Gipfel des Bächistockes ist heute nur mehr über Fels möglich und war früher eine reine Firn und Eistour. (H. Klauser)

81 Pizol

2016: Die Messungen erfolgten durch Revierförster Urban Kühne und Regionalförster Thomas Brandes, Vorfeld und Gletscher waren aper. Schutt, Geröll und vorgelagerte Altschnee- und Eisflächen erschweren die Bestimmung des Eisrandes. Optisch scheint es aber grundsätzlich klar zu sein: die steil aufsteigende Gletscherfläche und die vorgelagerten flachen Toteis- und Altschneeflächen. In der Bestimmung waren wir der Meinung, dass in der Linie 2 das Gletschereis doch weiter vorne liegt, daher der Gletscher hier wieder "gewachsen" ist. In der Linie 3 rechnen wir die horizontale Fläche nicht mehr zum Gletscher (2015 noch dazu genommen). Der Rand in der Linie 5D ist am schwierigsten zu bestimmen: Überdeckung mit Geröll. Die Messung vom 2015 mit 68 m ist hier immer noch korrekt: Eis sicher festzustellen. Sowohl optisch als auch durch den ergleich der Übersichtsfotos ist kaum ein Veränderung wahrzunehmen, was auch die Messungen zeigen. Die Dicke hat sicher weiter abgenommen. (Th. Brandes)

82 Lavaz

2016: Die bisher erhobenen Höhenkoten basieren auf einem fehlerhaften Übersichtsplan. Die diesjährige Kote musste korrigiert werden und wird neu mit 2369 m.ü.M festgelegt. Aufgrund der teilweise vorliegenden Schneebedeckung konnte die Gletscherzunge nicht vollständig vermessen und die mittlere Veränderung somit nicht ermittelt werden. Ein Rückgang kann aber aufgrund der erfassten Messpunkte so oder so festgestellt werden. (R. Lutz)

83 Punteglias

2016: Die Gletscherzunge besteht immer noch aus drei Teilen, die alle in Richtung Südost fliessen. Der Mächtigste ist ganz im Osten von braunem Schutt bedeckt und immer noch mit dem Hauptgletscher oberhalb der Felsstufe verbunden. In der Mitte der Verbindung ist seit diesem Jahr eine Felsinsel sichtbar. Die mittlere Gletscherzunge wird immer schmäler. Beim Einsturztrichter im westlichen Teil sieht man bis auf den Untergrund. (Ch. Buchli)

84 Länta

2017: Beim tiefsten Punkt handelt es sich um den tiefsten gemessenen Punkt. Auf der linken, derzeit unzugänglichen Seite geht die Gletscherzunge bis auf ca. 2710 m.ü.M hinunter. (B. Riedi)

86 Paradies

2016: Messung des Polygonzuges mit GPS. Graphische Ermittlung der Veränderung des Zungenendes mittels Berechnung der Unterschiede im Beobachtungssektor im GIS (C. Fisler)

2017: Messung des Polygonzuges im GPS. Graphische Ermittlung der Veränderung des Zungenendes mittels Berechnung der Unterschiede im Beobachtungssektor im GIS. (C. Fisler)

87 Suretta

2016: Messung von Polygonzug via GPS sowie Distanzmessung. Mittlerer Rückgang des Beobachtungssektors in GIS berechnet. (C. Fisler)

2017: Messung von Polygonzug via GPS sowie Distanzmessung. Mittlerer Rückgang des Beobachtungssektors in GIS berechnet. (C. Fisler)

88 Porchabella

2016: Der Gletscherrand wurde an 99 Punkten aufgezeichnet. Das Felssturzmaterial aus der Nordwand des Piz Kesch von 2014 erschwert die Messung am westlichen Rand des Messsektors, da sich der Gletscherrand teilweie unter meterhohen Felsbrocken befindet. (C. Bieler)

2017: Zum Messzeitpunkt lag rund 30 cm Schnee auf dem Gletscher. Mittels einer Lawinensonde wurde der Rand bei Unsicherheit genau abgesteckt. Das Felssturzmaterial von 2014 überdeckt den Gletscherrand am westlichen Rand des Messsektors und verunmöglicht dadurch eine Messung in diesem Bereich. (C. Bieler)

90 Silvretta

2016: Luftbildaufnahmen am 7.9.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 25.8.2017, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

91 Sardona

2016: Die Messungen erfolgten durch Revierförster Stefan Nigg und Regionalförster Thomas Brandes begeleitet durch den Praktikanten Patrick Dietsch. Vorhandene Neuschneeresten auf Vorfeld und Gletscher behinderten nicht. Die Messung erfolgte ab den Punkten 1B, 2B, 3B, 4B und 5B mit dem Fadenmessgerät (Geländemass) im bisherigen Azimut 289 g (korrigierter Winkel). Den ehemaligen Zungenbereich links der Linie 1 haben wir nun nicht mehr als Gletscher angesprochen: Toteis und Schutt. Im Bereich des Schnittes der Linie 1B mit dem Gletscher ist die ehemalige Zunge deutlich abgesetzt. Auf die Distanz in Linie 1B hat diese keinen Einfluss (die Schnittlinie lag schon im Vorjahr deutlich weiter oben). Für die Höhe des tiefsten Gletscherpunktes dagegen schon. Diesen haben wir nun bei Linie 3B gemessen / festgelegt. Auf der Linie zwei haben wir einen Vorstoss gemessen. Durch Schutt und Abschmelzung ist nicht jedes Jahr gleich gut feststellbar, wo der 'wahre' Rand anzusetzen ist. Ist das gefundene Eis effektiv auch noch Gletscher oder bereits Toteis? Auf der Linie 4 ist der deutlichste Rückgang messbar. Im Gelände ist eine kleine Moräne erkennbar, welche sich vom Felsband 'vor' den Gletscher zieht. Vorgelagert ist noch Eis vorhanden. Wir haben aber den Eindruck, dass es sich bei den Steinen nicht nur um aufgelagertes Material handelt sondern dieses effektiv tiefer geht und daher trennend wirkt. Auf der Linie 5 findet neu kein Schnitt mit dem Gletscher mehr statt. (Th. Brandes)

93 Tschierva

2016: Weitere Holzfunde (G.-A. Godly)

96 Tiatscha

2016: Luftbildaufnahmen am 7.9.2016, photogrammetrische Auswertung durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

98 Lischana

2016: Wegen starker Schuttbedeckung Eisrand kaum auszumachen. (D. Könz)

2017: Schuttüberdeckung noch stärker als im Vorjahr. Es wurde versucht, so gut wie möglich den gesamten Gletscherumriss zu erfassen. Messungen 2015 und 2016 also nicht vergleichbar. (D. Könz)

99 Cambrena

2017: La parte inferiore del ghiacciaio si è separata dalla lingua e forma una piccola superficie isolata. La misurazione del bordo superiore della lingua terminale è pericolosa. (G. Berchier)

100 Palü

2016: Punto più basso del ghiacciaio: livello del nuovo laghetto (G. Berchier)

2017: Punto più basso: livello del laghetto (G. Berchier)

101 Camp-Paradisin

2016: Probabilmente pocchi giorni prima della misurazione, una parte della parete Nord del Corn da Camp è ceduta e scesa a valle proprio sul ghiacciaio, ricoprendo i punti fissi degli anni scorsi. I vecchi punti fissi del 2002 sono ancora visibili. Risulta impossibile definire il bordo del ghiacciaio sotto la massa rocciosa. (G. Berchier)

103 Bresciana

2016: Rilievo eseguito per la prima volta con il GPS. Profilo non esequito. Misura precedente risale al 2014 (nel 2015 un importante nevicata autunnale aveva ricoperto il fronte). (M. Soldati)

2017: Ghiacciaio coperto da ca. 30 cm di neve. Fronte comunque ben visibile. Il fronte è stato interamente rilevato con il GPS. Rilievo eseguito per la prima volta con il GPS. Profilo non eseguito. (M. Soldati)

104 Basòdino

2016: Rilievo del fronte eseguito per la prima volta con GPS. Rilevato l'intero fronte su tutta la lunghezza. (M. Soldati)

2017: Nonostante una copertura nevosa di ca. 30 cm, il fronte del ghiacciaio era ben visibile. Punti profilo non rilevati. Per la perdita di spessore si rimanda al bilancio di massa di Kappenberger. (M. Soldati)

107 Bis

2016: Am 13.1.2017 löst ein kleiner Eisabbruch vom Bisgletscher eine Schneelawine aus, die den Talgrund erreichte und deren Staubwolke kurzfristig die Strasse blockierte. (VAW/ETHZ – A. Bauder)

109 Alpetli (Kanderfirn)

2016: Neue Referenzpunkte installiert, welche die Vermessung deutlich erleichtern. Bildung kleiner Seen. Tatzenförmige Gletscherzunge. (U. Burgener)

2017: Bildung kleiner Gletscherseen im Vorfeld. Starker Massenverlust. (U. Burgener)

111 Ammerten

2016: Zum ersten Mal entsteht dieses Jahr auch auf der rechten Seite in der unteren Steilstufe langsam ein Loch und der Gletscher ist deutlich auseinandergerissen. Wie die Dicke oberhalb von Jahr zu Jahr dünner wird lässt sich sehr schön an dem mittleren Felsplateau vergleichen. (W. Hodel)

2017: Am Tag der Messung ist auffallend, dass die Nordflanke des Wildstrubel wieder einmal schön mit Schnee gefüllt ist. An der Zunge hatten wir dieses Jahr ein noch nie so grosses Gletschertor. (W. Hodel)

112 Dungel

2016: Das Zungenende war zum Zeitpunkt der Vermessung bis auf wenige Stellen ausgeapert. Die Gletscherzunge mündete an der tiefsten Stelle immer noch in den See und der Gletscherrand wurde entlang der Wasserlinie vermessen. (A. Wipf)

2017: Zum Zeitpunkt der Vermessung war der Gletscher fast vollständig ausgeapert. Einzig an den schattenexponierten Lagen nördlich des Wildhorn-NE-Grates war noch etwas Altschnee vorhanden. Erstmals war der See vor dem Zungenende ausgelaufen, sodass das effektive Zungenende ersichtlich war. Wegen der Unterhöhlung konnte der Gletscherrand nicht ganz exakt aber doch genügend zuverlässig abgeschritten werden. Die ehemalige Grösse des Sees war gut erkennbar und wurde ebenfalls vermessen. (A. Wipf)

113 Gelten

2016: Es wurde nur der östliche Teil des westlichen Zungenlappens vermessen. Der westliche Lappen (ehemalige Hauptzunge) endet noch immer in einer steileren Zone, deren Begehung als noch zu heikel eingestuft wurde. (A. Wipf)

2017: Die Zunge präsentierte sich grösstenteils ausgeapert. Erstmals konnte der ganze Bereich von südlich des Hüenerhürlis bis gegen Punkt 2545 vermessen werden, wobei das Abschreiten in der Steilstufe etwas heikel war. Damit steht nun erstmals eine durchgehende Vermessungslinie zur Verfügung. Die Fortführung der ununterbrochenen Vermessungslinie dürfte aber jeweils davon abhängen, ob die Steilstufe begehbar ist oder nicht. (A. Wipf)

114 Plattalva

2016: Gletscher mit etwas Neuschnee bedeckt, kaum Firnschnee; Bei Punkt 5 kreuzt die Messrichtung schleifend. (U. Steinegger)

2017: Gletscher mit 30 cm Schnee bedeckt (davon 20 cm Neuschnee, Rest Herbstschnee), kein Firnschnee; Bei Punkt 5 Verlauf des Gletscherrands unklar; schleifend zur Messrichtung sowie schuttbedeckt. (U. Steinegger)

117 Valleggia

2016: Rilievo esequito per la prima volta con GPS. Perdita media spessore calcolata in 2 punti corrisponde a 1.2 m. Copertura neve sul ghiacciaio praticamente assente. (M. Soldati)

2017: Rilievo eseguito interamente con GPS. Profilo non rilevato. (M. Soldati)

119 Cavagnoli

2017: Rilievo del fronte misurato con il GPS. Presenza di bedière molto profonde; particolarmente visibili i risultati dell'erosione dell'acqua di fusione. Perdita spessore medio ca. 2.5 metri. (M. Soldati)

120 Corno

2017: Perdita media spessore ghiaccio ca1.6 metri. Causa nebbia i punti più in alto del profilo 2016 non sono stati verificati. Il fronte si presentava completamente libero da neve. Si segnala che due importanti che due sottili lingue di ghiaccio che nel 2016 erano ancora collegate al resto del ghiacciaio, nel 2017 sono scomparse. (M. Soldati)

173 Seewjinen

2016: Luftbildaufnahmen am 29.9.2016, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.10.2017, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

174 Hohlaub

2016: Luftbildaufnahmen am 29.9.2016, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2017: Luftbildaufnahmen am 5.10.2017, photogrammetrische Auswertung durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

352 Croslina

2017: Nonostante la presenza di 30 cm di neve fresca sul ghiacciaio, il limite del fronte era ben visibile. Rilievo eseguito con GPS. La perdita media di spessore corrisponde a ca. 1.3 metri. (M. Soldati)

C Investigators

C.1 Length Variation (2017)

Glacier	No.	Investigator
Albigna	116	AWN/GR, Martin Keiser
Allalin	11	VAW/ETHZ, 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	DWL/VS, Pascal Stoebener
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
Chessjen	12	VAW/ETHZ, Bauder
Corbassière	38	VAW/ETHZ, Bauder
Corno	120	SF/TI, Mattia Soldati
Croslina	352	SF/TI, Mattia Soldati
Damma	70	AFJ/UR, Martin Planzer
Dungel	112	currently not observed
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	DWL/VS, Norbert Carlen
Findelen	16	VAW/ETHZ, Bauder
Firnalpeli (Ost)	75	AWL/OW, Miriam Jäggi
Forno	102	AWN/GR, Martin Keiser
Gamchi	61	KAWA/BE, Martin Schenk
Gauli	52	KAWA/BE, Daniel Rohrer

Glacier	No.	Investigator
Gelten	113	currently not observed
Giétro	37	VAW/ETHZ, Bauder
Glärnisch	80	Hanspeter Klauser
Gorner	14	DWL/VS, Leo Jörger & Stefan Walther
Grand Désert	31	DWL/VS, François Vouillamoz
Grand Plan Névé	45	FFN/VD, J.-Ph. Marlétaz
Gries	3	VAW/ETHZ, Bauder
Griess	74	AFJ/UR, Beat Annen
Griessen	76	AWL/OW, Miriam Jäggi
Grosser Aletsch	5	VAW/ETHZ, Bauder
Hohlaub	174	VAW/ETHZ, Bauder
Hüfi	73	currently not observed
Kaltwasser	7	DWL/VS, Martin Schmidhalter
Kehlen	68	AFJ/UR, Martin Planzer
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, Könz Duri
Lämmern	63	KAWA/BE, Adrian Meier-Glaser
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	VAW/ETHZ, Bauder
Oberaar	50	currently not observed
Oberaletsch	6	DWL/VS, Christian Theler
Oberer Grindelwald	57	VAW/ETHZ, 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, Thomas Brandes
Plattalva	114	Urs Steinegger
Porchabella	88	AWN/GR, Claudia Bieler
Prapio	48	Jacques Binggeli
Punteglias	83	AWN/GR, Christian Buchli
Rhone	1	VAW/ETHZ, Bauder
Ried	17	DWL/VS, Peter Rovina / (Bauder)
Roseg	92	AWN/GR, Gian Andri Godly
Rossboden	105	currently not observed
Rotfirn (Nord)	69	AFJ/UR, Martin Planzer

Glacier	No.	Investigator
Rätzli	65	VAW/ETHZ, 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	currently not observed
Schwarzberg	10	VAW/ETHZ, Bauder
Seewjinen	173	VAW/ETHZ, Bauder
Sesvenna	97	AWN/GR, Könz Duri
Sex Rouge	47	Jacques Binggeli
Silvretta	90	VAW/ETHZ, Bauder
Stein	53	KAWA/BE, Daniel Rohrer
Steinlimi	54	KAWA/BE, Daniel Rohrer
Sulz	79	AW/GL, Maurus Landolt
Suretta	87	AWN/GR, Cristina Fisler
Tiatscha	96	VAW/ETHZ, Bauder
Tiefen	66	AFJ/UR, Lukas Eggimann
Trient	43	Jacques Ehinger
Trift (Gadmen)	55	VAW/ETHZ, 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, Bauder
Val Torta	118	currently not observed
Valleggia	117	SF/TI, Mattia Soldati
Valsorey	39	DWL/VS, James Medico
Verstankla	89	AWN/GR, Peter Ebneter
Vorab	85	AWN/GR, Renato Deflorin
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	Urs Steinegger
Corbassière	38	VAW/ETHZ, Andreas Bauder
Findelen	16	DGUF / GIUZ, Matthias Huss, Nadine Salzmann, Andreas Linsbauer
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
Murtèl	377	DGUF, Matthias Huss
Pizol	81	VAW/ETHZ / DGUF, Matthias Huss
Plaine Morte	65	DGUF, Matthias Huss
Rhone	1	VAW/ETHZ, Andreas Bauder
Sankt Anna	67	DGUF, Matthias Huss
Schwarzberg	10	VAW/ETHZ, Andreas Bauder
Silvretta	90	VAW/ETHZ, Andreas Bauder
Tsanfleuron	33	DGUF, Matthias Huss

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