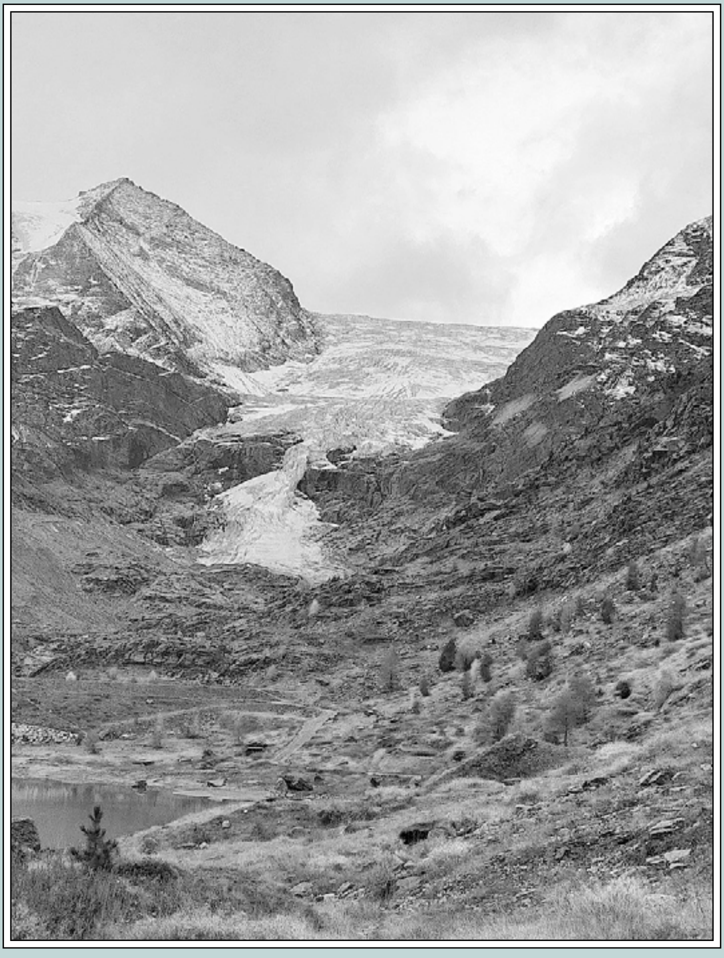
The Swiss Glaciers

2017/18 and 2018/19

Glaciological Report (Glacier) No. 139/140



2020

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Glaciological Report No. 139/140

Edited by

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Summary

During the 139th and 140th year under review by the Cryospheric Commission (EKK), Swiss glaciers continued to lose both in terms of length and mass. The two periods were characterized by partly strongly above-average snow accumulation during winter, and at the same time very high melt rates in summer resulting in major mass losses. Combined with the period 2016/17 they were higher than ever documented in three subsequent years in Switzerland since the beginning of the measurements. The results presented in this report reflect the weather conditions in the measurement periods 2017/18 and 2018/19 as well as the effects of ongoing atmospheric warming over the past decades.

In autumn 2018, a length variation was determined for 93 of the 114 glaciers currently under active observation, while one year later 84 glaciers were measured. In the two observation periods, 2017/18 and 2018/19, Swiss glaciers experienced further losses in length. Most of the measurement values lay between 0 and -30 m in both periods. For several glaciers a remarkably high retreat was found in a single year. This observation 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 acquired on ten glaciers: Basòdino, Findelen, Gries, Pizol, Plaine Morte, Murtèl, Rhone, Sankt Anna, Silvretta and Tsanfleuron, but measurements were also conducted on several additional glaciers. In the first period (2017/18), glaciers in all regions of Switzerland showed mass balances substantially more negative than the average of the last decade except for glaciers in the Southern Valais whose mass balance was only slightly more negative than normal due to extreme winter snow depths. In the second period under observation (2018/19), glacier mass losses were strongest at the border between Berne and Valais and in Eastern Switzerland but the mass balance was less negative than the average of the last decade in the Gotthard region and in Ticino.

Measurements of ice surface velocity were performed at eight glaciers throughout the Swiss Alps. The trend continued toward diminishing velocities reflecting the reduction in ice thickness due to the ongoing negative mass balances.

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

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 to 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 summary 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
A. Bauder, M. Huss and A. Linsbauer	139/140	2017/18 - 2018/19

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 the interest to gain insights into 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 variation, (2) mass balance, (3) volume change, (4) ice surface flow velocity, (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 and support by the Federal Office for Environment (BAFU), MeteoSwiss within the Global Climate Observing System (GCOS) Switzerland, the Swiss Academy of Sciences (SCNAT), and 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 annually to the World Glacier Monitoring Service (WGMS). This report is the new volume No. 139/140 in the series "The Swiss Glaciers" and presents the results of the two observational periods 2017/18 and 2018/19. 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

In this section the weather and climate conditions for the two periods 2017/18 and 2018/19 are described. We focus on the variables that are most relevant for glacier mass balance – temperature and precipitation. In general, glacier mass balance is largely determined by the amount of winter snow fall and air temperature during summer. High temperatures in April, May or June can reduce the winter snow pack rapidly and expose the much darker ice surface early. During July and August solar radiation receipts are high and melting of the unprotected ice is enhanced. On the other hand, summer snow down to the glacier termini protects the ice surface from melting.

We have selected the four high-elevation meteorological 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, Chateau-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 to document monthly anomalies in precipitation (Figure 2.2) for the two reporting periods. For annual precipitation and mean summer temperature (May-September), the long-term record since 1880 is shown in Figures 2.3 and 2.4 as a mean of 12 homogenized stations (Begert et al., 2005; Begert and Frei, 2018). 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 2017/18

After three winters with rather little snow, 2017/18 was characterised by high snow depths in the Swiss Alps. After an early winter start at the beginning of November and above-average snowfalls in December, January was rich in precipitation and warm. Snow depth below 1000 m a.s.l. was often strongly below the long-term average. At high altitudes, however, 2.5 to 6 m of fresh snow fell in some regions from the end of December to January 23 (Figure 2.2). It snowed most in the Valais – in the otherwise rather dry Visper valleys as much as only every 70 years. Up to the end of March, there was still twice as much snow as usual above 2000 m a.s.l., more than has ever been measured in the past two decades. In the very warm and dry months of April and May, however, the snow levels decreased significantly and returned back to normal values everywhere except for the southern Valais.

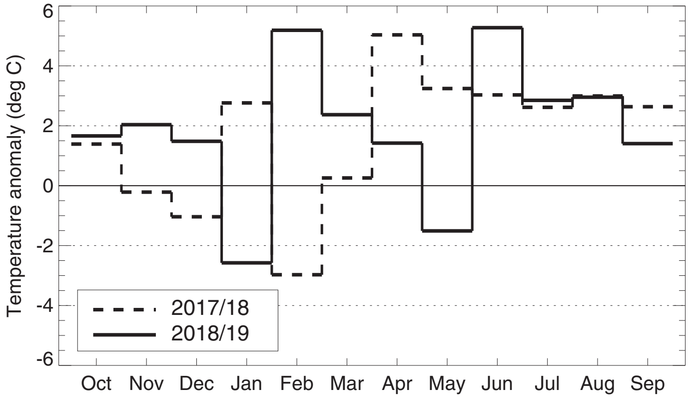

Figure 2.1: Mean monthly anomaly of temperature from the long-term climatic mean (period 1961-1990) for four selected stations at high elevation of the MeteoSwiss network. Anomalies in the two reporting periods 2017/18 and 2018/19 are shown.

According to MeteoSwiss, summer (June-August) was the fourth warmest since measurements began, after 2003, 2015 and 2019; the overall summer 2018 (May-September) is the second warmest on record only outmatched by 2003 (Figure 2.3). In addition to high air temperatures, the drought was a defining feature of the summer half-year. Hence, there were only very few and small fresh snow events on glaciers. This is exemplified by the fresh snow measurements from the Weissfluhjoch (2540 m a.s.l.), where not a single event with more than 1 cm of fresh snow was recorded between May 17 and September 4. Since the beginning of the measurements in 1937, there has never been so little fresh summer snow there. It was also significantly more in the hot summers of 1947 (60 cm) and 2003 (13 cm).

Compared to the reference period 1961-1990, summer air temperatures (May-September) were 3.1°C higher than the long-term mean evaluated for homogenized measurement series throughout Switzerland (Figure 2.3). This value ranks second after the summers of 2003 (+3.5°C). Annual precipitation amounts were 5% below average for the whole of Switzerland (Figure 2.4). Winter precipitation in particular strongly differed between the southern and the northern side of the Alps. The weather conditions during the period 2017/18 resulted in favourable accumulation for the glaciers, with a thick snowpack, at the end of the winter but strong and continuous melting throughout the summer season, extending into October.

2.2 Weather and Climate in 2018/19

The winter 2018/19 was characterized by a very cold and wet January (Figures 2.1 and 2.4), especially on the northern side of the Alps. Particularly in the East, record-breaking amounts of fresh snow fell. In mid-January, more snow was measured in many places in northern Grisons, parts

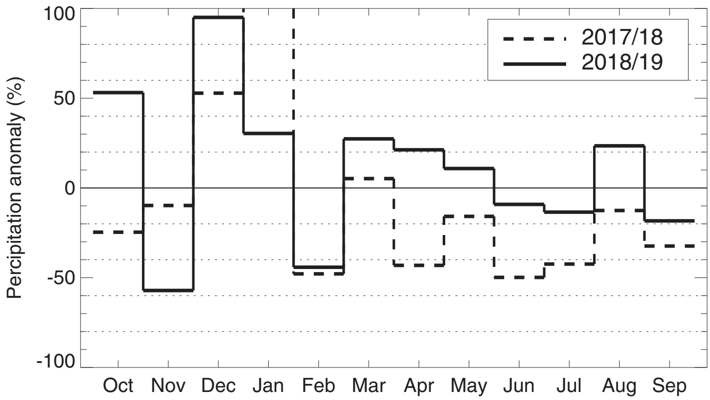

Figure 2.2: Mean monthly anomaly of precipitation from the long-term climatic mean (period 1961-1990) for 14 selected stations of the MeteoSwiss network. Anomalies in the two reporting periods 2017/18 and 2018/19 are shown.

of Central Grisons and in the northern Engadine than at any time before. After a sunny and dry February, the snow depths were only above average on the main Alpine ridge and in the east, and clearly below average in the South. Overall, the winter half-year 2018/19 (November to April) was characterized by high snow amounts. Especially along the main Alpine ridge, in the Valais, on the northern eastern slope of the Alps and in Grisons, the snow depths were partly strongly above average. Due to the relatively high air temperatures, this statement only applies to medium and high altitudes.

May was clearly too cold across Switzerland; it was the coldest May since 1991. Accordingly, it occasionally snowed down to the lowlands and the snow levels continued to increase at the elevation of the glaciers. In combination with the already large amounts of winter snow, snow depth reached two or three times the normal value at high elevation at the end of May (Figure 2.2). The snow, however, melted extremely quickly in the course of the second-hottest June since the start of the measurements and also a very warm July, so that at many places the snow depletion took place only a little later than normal. Air temperatures remained high throughout the entire summer. Especially during two heat waves in June and July, many long-standing temperature records were broken. In contrast to the hot summer of the previous year, there was sufficient rainfall, however, in most regions. With the exception of some precipitation in September, snowfall events were mostly only recorded above 3000 m a.s.l. due to the high temperatures.

Summer air temperatures were 2.2°C higher than the 1961-1990 mean (Figure 2.3). Annual precipitation was slightly below the long-term average (-3%, Figure 2.4), but winter and spring precipitation (December to May) was substantially above average (+26%, Figure 2.2). The summer heat waves resulted in massive glacier melt again, although overall mass losses were mitigated by the favourable conditions during winter with partly record snow depths at the end of May at high elevation.

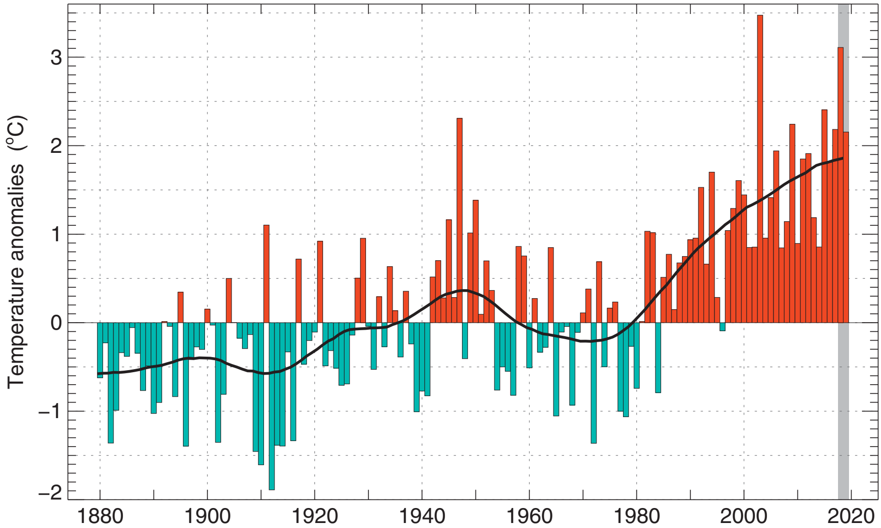

Figure 2.3: Anomalies of mean summer air temperature (May-September) from the mean value 1961-1990 in degrees Celsius for the period 1864-2019 based on 14 homogenized long-term stations of MeteoSwiss. The gray shaded area highlights the years of the current report.

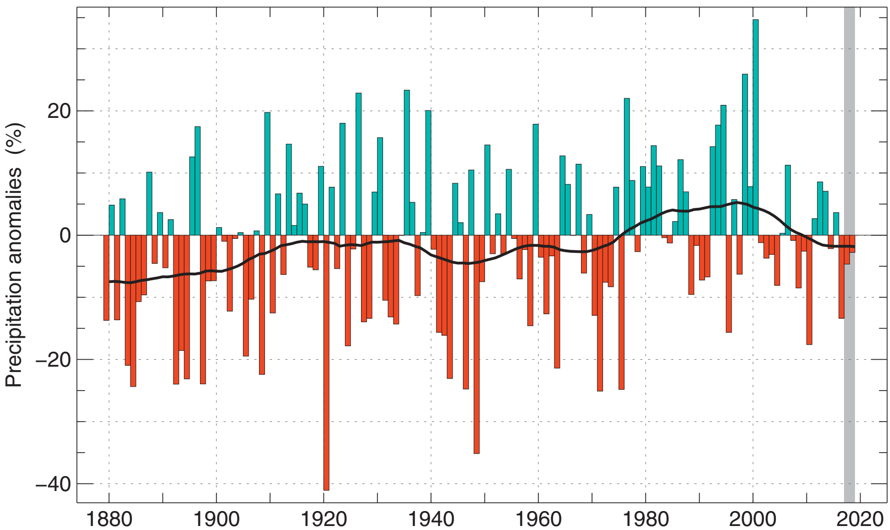

Figure 2.4: Anomalies of annual precipitation (hydrological year) from the mean value 1961-1990 in percentage for the period 1864-2019 based on 14 homogenized long-term stations of MeteoSwiss. The gray shaded area highlights the years of the current report.

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, or the measurements obtained were rather difficult to interpret, which does not justify reciting these figures in the charts and analyses.

During the two years under review, 2017/18 and 2018/19, Swiss glaciers suffered further losses in length. As in previous periods, most of the measurements were within the range of 0 to −30 m. 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 the result of a process extending over a longer period of time and thus are not unexpected.

3.2 Length Variations in 2017/18

Due to intensive melt during summer and good weather, generally optimal measurement conditions were present for the survey in autumn 2018. Changes in the terminus position as compared to the previous years were determined at 93 glaciers (Figure 3.1). Of these, 87 were found to be in recession, for three no change was observed, and another three glaciers showed a positive value. With the exception of six glaciers, the values ranged from a retreat of −70 meters at Gornergletscher to a slight advance of +29 meters at Vadret da Roseg. Nearly three-quarters of the measurements lay between −1 and −30 metres.

The six exceptions refer to the massive retreats ot the snout of Wildstrubelgletscher, Brunegg-gletscher, Vadret dal Cambrena, Turtmanngletscher, Glatscher da Lavaz and Scalettagletscher. 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 were melting irregularly without any major reduction in length over the previous years. At Wildstrubelgletscher large portions of the flat tongue broke into individual ice chunks during summer 2018 and terminus shifted back abruptly by 650 m at the onset of steeper terrain. The five other glaciers showed a similar behaviour with reduction in length between −100 meters and −140 meters. The timing of these events was rather arbitrary and only poorly reflects the overall and continuous change in these glaciers. Vadret da Roseg experienced a large retreat in the past decades and appears to be able to maintain its present terminus position. Under such conditions the glacier may advance slightly in certain years as has been observed during this period. Other positive values are the result of local changes at the terminus and do not stem from abundant ice flow from the accumulation area. Ice margins that are difficult to detect due to a thick and continuous coverage of debris may further cause erroneous interpretations. However, the cumulative length change is not affected by such uncertain individual results as they will cancel out in successive measurements.

3.3 Length Variations in 2018/19

Length variations were determined for 84 glaciers in autumn 2019 (Figure 3.2). Of these, 76 became shorter, six did not change their position, and another two were slightly in advance. With the exception of two glaciers, the values ranged from a recession of −80 meters at Grosser Aletschgletscher to a advance of +46 meters at Feegletscher. Again 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 and the widespread observations of retreat values are not unexpected.

Glacier de Tseudet and Vadret da Sesvenna were the exceptions featuring a very large reduction in length. As in the previous period, the high retreat values of several hundred meters for each is linked to a process that has been underway for many years. The tongue of both glaciers was detached at a break in the terrain where the ice was thinned out over last year due to high melt rates and the absence of ice supply from the accumulation area. In addition, the tongue of Tseudet is heavily debris-covered which favours irregular melt out. Eventually, the dynamic terminus shifted back abruptly. At the tongue of Feegletscher deposits from avalanches of winter 2017/18 did not melt entirely, have densified and transformed to ice. As they are completely connected with the main ice body in the meantime, the terminus is considered to have advanced, resulting in an increase in length.

3.4 Length Variations in 2017/18 and in 2018/19, Summary

No. [a]	Glacier	Ct. [b]	Length variation [c] (m)		Altitude [d] (m a.s.l.)	Date of measurements (Day, Month)		
			2017/18	2018/19	2019	2017	2018	2019
Catchment area of the river Rhone (II)								
1 [e,f]	Rhone	VS	−34.6	−36.2	2210.9 [16]	21.09.	11.07.	25.08.
2 [f]	Mutt	VS	−18.6	n	2667.4 [18]	01.09.	31.08.	n
3 [e,f]	Gries	VS	−26.8	−57.5	2430.4 [16]	07.08.	15.08.	25.08.
4 [f]	Fiescher	VS	n	n	1682 [15]	n	n	n
5 [e,f]	Grosser Aletsch	VS	−62.8	−80.3	1602.0 [16]	07.08.	27.09.	04.09.
6 [f]	Oberaletsch	VS	x	n	2142 [03]	n	17.10.	n
7 [e,f]	Kaltwasser	VS	−41.7	−17	2660 [12]	05.10.	19.09.	08.10.
173 [e]	Seewjinen	VS	−5.5	−3.5	2735.5 [16]	05.10.	11.09.	21.09.
10 [e,f]	Schwarzberg	VS	−26.7	−24.1	2663.2 [16]	05.10.	11.09.	21.09.
11 [e,f]	Allalin	VS	−7.2	−2.3	2676.7 [16]	05.10.	11.09.	21.09.
12 [e]	Chessjen	VS	−9.2	−5.8	2866.3 [16]	05.10.	11.09.	21.09.
174 [e]	Hohlaub	VS	−13.1	−4.6	2841.0 [16]	05.10.	11.09.	21.09.
13 [e,f]	Fee	VS	s	+45.9 [2a]	2170	05.10.	28.09.	11.10.
14 [f]	Gorner	VS	−70	−70	2211 [15]	13.10.	13.10.	13.10.
16 [e,f]	Findelen	VS	−11.7	−53.4	2555.8 [16]	05.09.	11.08.	03.09.
17 [e]	Ried	VS	−5	−8	2400	07.10.	14.10.	13.10.
18 [f]	Lang	VS	n	n	2045 [17]	n	n	n
19 [e,f]	Turtmann	VS	−127.5	n	2270 [10]	02.10.	11.10.	n
20 [e]	Brunegg (Turtmann)	VS	−136.5	−11.2	2500 [10]	02.10.	11.10.	01.10.
22 [e,f]	Zinal	VS	−26.3	n	2130 [18]	28.09.	27.09.	n
23 [f]	Moming	VS	n	n	2580 [13]	n	n	n
24 [e,f]	Moiry	VS	−44	n	2410 [18]	25.09.	27.09.	n
25 [e,f]	Ferpècle	VS	−24.2	−17.3	2205 [14]	12.10.	05.10.	14.10.
26	Mont Miné	VS	−27	−21.1	2090 [12]	12.10.	05.10.	14.10.
27 [e,f]	Arolla (Mont Collon)	VS	−17.2	−33.3		10.10.	20.09.	27.09.
28 [f]	Tsidjiore Nouve	VS	−6.2	−6.0	2320 [15]	10.10.	20.09.	27.09.
29 [e,f]	Cheillon	VS	−12.2	−12.3	2706	13.10.	21.09.	13.09.
30 [e,f]	En Darrey	VS	−18 [8a]	−7.3	2710 [17]	n	21.09.	13.09.
31 [e,f]	Grand Désert	VS	+1.5	−60	2810 [17]	13.09.	13.09.	12.09.
32 [e,f]	Mont Fort (Tortin)	VS	−39	+18.4	2785 [18]	16.09.	08.10.	13.09.
33 [e,f]	Tsanfleuron	VS	−24.4	−16.9	2550 [16]	11.10.	12.09.	20.09.
34 [e]	Otemma	VS	x	x	2480	n	05.09.	23.08.
35 [e]	Mont Durand	VS	−9	x	2380	30.08.	03.09.	26.08.
36 [e]	Breney	VS	−22	x	2575	24.08.	04.09.	26.08.
37	Giétro	VS	n	n	2718.6 [16]	n	n	n

No. [a]	Glacier	Ct. [b]	Length variation [c] (m) 2017/18	2018/19	Altitude [d] (m a.s.l.) 2019	Date of measurements (Day, Month) 2017	2018	2019
38	Corbassière	VS	n	n	2309.5 [16]	n	n	n
39 [e,f]	Valsorey	VS	−19.5	−25.6	2480	17.10.	19.09.	20.09.
40 [e]	Tseudet	VS	−1.7	−312	2625	17.10.	19.09.	20.09.
41 [e]	Boveyre	VS	−9.7	−17.2	2695	15.09.	19.09.	04.10.
42 [e,f]	Saleina	VS	−1.5	−16	1865	05.10.	04.09.	16.10.
43 [e,f]	Trient	VS	−13	−33	2166	07.10.	23.09.	12.10.
44 [f]	Paneyrosse	VD	−5.7	−8.4		07.09.	28.09.	20.09.
45 [e,f]	Grand Plan Névé	VD	−3.9	−1		08.09.	09.10.	27.09.
47 [e,f]	Sex Rouge	VD	−5	−4.6		08.09.	04.09.	15.09.
48 [e]	Prapio	VD	0	−1	2555	17.10.	11.09.	01.10.
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	−40.5	n	2130 [18]	28.09.	15.09.	n
53 [e,f]	Stein	BE	−30.5	−58	2220	08.09.	09.09.	26.08.
54	Steinlimi	BE	−19.5	−25.5	2530	08.09.	02.09.	26.08.
55 [e,f]	Trift (Gadmen)	BE	0.3	−1.4	2111.5 [16]	22.08.	20.09.	25.08.
57 [e,f]	Oberer Grindelwald	BE	−18.5	−23.3	2178.6 [16]	29.08.	15.08.	25.08.
58 [e,f]	Unterer Grindelwald	BE	−42.7	−35.9	1587.1 [16]	21.09.	15.08.	25.08.
59 [e]	Eiger	BE	−19	−13.4	2405.9	14.09.	19.09.	27.09.
60 [e]	Tschingel	BE	−1.8	−1.2	2310	22.09.	18.09.	14.10.
61 [e,f]	Gamchi	BE	−8	−9	2135	19.10.	03.10.	18.10.
109 [e]	Alpetli (Kanderfirn)	BE	−34	−26	2405	13.09.	21.09.	20.09.
63 [e]	Wildstrubel	VS	−655	−57	2690	08.09.	17.10.	20.09.
64 [e,f]	Blüemlisalp	BE	−18	−9	2394 [18]	27.09.	28.09.	01.10.
65 [e,f]	Rätzli	BE	−6.3	−11.3	2467.6 [16]	29.08.	28.08.	03.09.
111	Ammerten	BE	−1.6	−2.8	2350	07.10.	02.09.	21.09.
Catchment area of the river Reuss (Ib)								
66 [e,f]	Tiefen	UR	−7	−14	2650 [17]	05.10.	10.09.	19.09.
67 [e,f]	Sankt Anna	UR	−7	−10	2610 [17]	04.10.	10.09.	20.09.
68 [e,f]	Kehlen	UR	−13.6	−13	2400	08.09.	04.10.	11.10.
69	Rotfirn (Nord)	UR	n	n	2070 [17]	n	n	n
70 [e,f]	Damma	UR	−6.8	−9.7	2500	05.10.	04.10.	11.10.
71 [e,f]	Wallenbur	UR	−24	−0.2 [2a]	2295	29.09.	03.10.	01.10.
72 [e,f]	Brunni	UR	−0.6	−6.9	2570	25.08.	04.09.	20.09.
74 [f]	Griess	UR	−4.7	−25.1	2231	05.10.	25.09.	20.09.
75 [e,f]	Firnalpeli (Ost)	OW	−25 [2a]	x	2210	n	15.09.	26.10.
76 [e,f]	Griessen	OW	−12.3 [2a]	−6.5	2530	n	17.09.	27.09.

No. [a]	Glacier	Ct. [b]	Length variation [c] (m) 2017/18	Length variation [c] (m) 2018/19	Altitude [d] (m a.s.l.) 2019	Date of measurements (Day, Month) 2017	2018	2019
Catchment area of the river Linth / Limmat (Ic)								
77 [e,f]	Biferten	GL	−5.9	−21.6	1963.5	30.09.	15.09.	14.09.
78 [e]	Limmern	GL	−9.2	−3.6	2291	07.10.	13.10.	16.10.
114 [e]	Plattalva	GL	−15.3	−14	2629	07.10.	14.10.	16.10.
79 [e,f]	Sulz	GL	−1.5	−3.3	1810	28.09.	28.09.	24.09.
80 [e,f]	Glärnisch	GL	−14.7	−22.4	2346.1	01.11.	11.08.	31.08.
81 [e,f]	Pizol	SG	−47.9 [2a]	−13.5	2605	n	21.09.	19.09.
Catchment area of the river Rhine / Lake Constance (Id)								
82 [e,f]	Lavaz	GR	−111 [2a]	−12.6	2415 [18]	n	28.08.	27.08.
83 [e,f]	Punteglias	GR	+14	x	2370 [18]	12.10.	09.10.	12.09.
84 [e,f]	Lenta	GR	−11.9	n	2760 [18]	21.08.	28.08.	n
85 [e,f]	Vorab	GR	−22.2	−17.6	2618	15.10.	15.08.	15.09.
86 [e,f]	Paradies	GR	−39.9	−8.7	2710	07.09.	20.09.	20.09.
87 [e]	Suretta	GR	−4.3	−11	2619	24.08.	11.09.	27.08.
88 [e,f]	Porchabella	GR	−11.9	−17.4	2703	21.09.	04.09.	13.09.
115 [e]	Scaletta	GR	−100	−20	2731	31.07.	14.09.	20.09.
89 [f]	Verstankla	GR	−20.4	−8.3	2438	08.09.	19.09.	22.08.
90 [e]	Silvretta	GR	−13.7	−24.7	2471.8 [16]	25.08.	16.08.	29.09.
91 [e,f]	Sardona	SG	−8 [2a]	−0.7	2460	n	05.10.	11.09.
Catchment area of the river Inn (V)								
92 [e,f]	Roseg	GR	+28.7	x	2160 [09]	13.09.	26.10.	13.09.
93	Tschierva	GR	−32.3	−46.7	2312	13.09.	12.09.	13.09.
94 [e,f]	Morteratsch	GR	−37.9	−27.4	2034	06.10.	11.10.	10.09.
95 [e]	Calderas	GR	−9.1	−13	2798	28.08.	20.08.	01.10.
96 [e,f]	Tiatscha	GR	n	−21.6 [3a]	2671.5 [17]	n	n	29.09.
97 [e]	Sesvenna	GR	−15.1	−170	2840	31.08.	04.09.	29.08.
98 [f]	Lischana	GR	n	n	2810 [17]	n	n	n
Catchment area of the river Adda (IV)								
99 [e]	Cambrena	GR	−130	−12	2610	18.10.	18.10.	27.09.
100 [e,f]	Palü	GR	−6	−8.1	2590	12.10.	13.09.	20.09.
101 [e]	Paradisino (Campo)	GR	−9.8	−1	2850	18.10.	14.09.	13.09.
102 [f]	Forno	GR	−28.8	−26.7	2230	07.10.	05.09.	03.09.
116	Albigna	GR	−14.2	−13.4	2180	07.10.	23.08.	05.09.
Catchment area of the river Ticino (III)								
103 [e,f]	Bresciana	TI	−2.7	−2.7	2975	29.09.	07.09.	03.10.
352 [e]	Croslina	TI	−3.1	−0.1	2728.7	20.09.	06.09.	10.10.
118	Val Torta	TI	n	n	2525 [12]	n	n	n
117 [e]	Valleggia	TI	−12.2	−8.4	2420.8	24.09.	05.09.	18.09.
119 [e]	Cavagnoli	TI	−12.5	−10.8	2667.3	25.09.	04.09.	18.09.

No. [a]	Glacier	Ct. [b]	Length variation [c] (m)		Altitude [d] (m a.s.l.)	Date of measurements (Day, Month)		
			2017/18	2018/19	2019	2017	2018	2019
104 [e,f]	Basòdino	TI	−10.1	−5.7	2609	19.09.	03.09.	17.09.
120 [e]	Corno	TI	−2.0	−2.6	2667	09.10.	17.09.	26.09.

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 observational 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: −26 [5a] = Decrease of 26 meters within 5 years.

d If the altitude of the glacier tongue is not measured in 2019, the year of the last measurement is indicated: 2210.9 [16] = 2210.9 m a.s.l., measured in the year 2016.

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 Figure 3.4.

Wildstrubelgletscher after the splitting of the tongue in 2018 with previous snout in the foreground and the new ice margin in the back (Photo: KAWA/BE, A. L. Meier-Glaser)

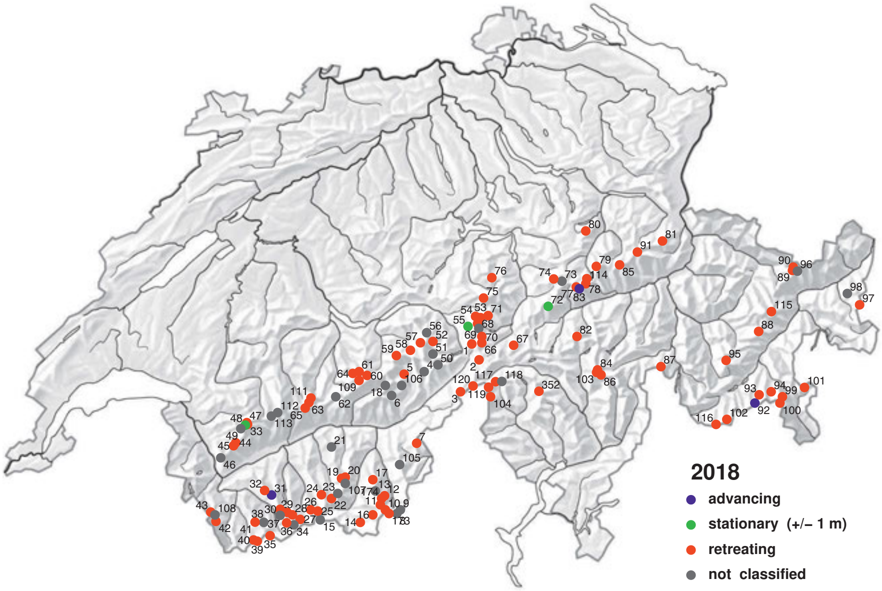

Figure 3.1: Observed glaciers in fall 2018.

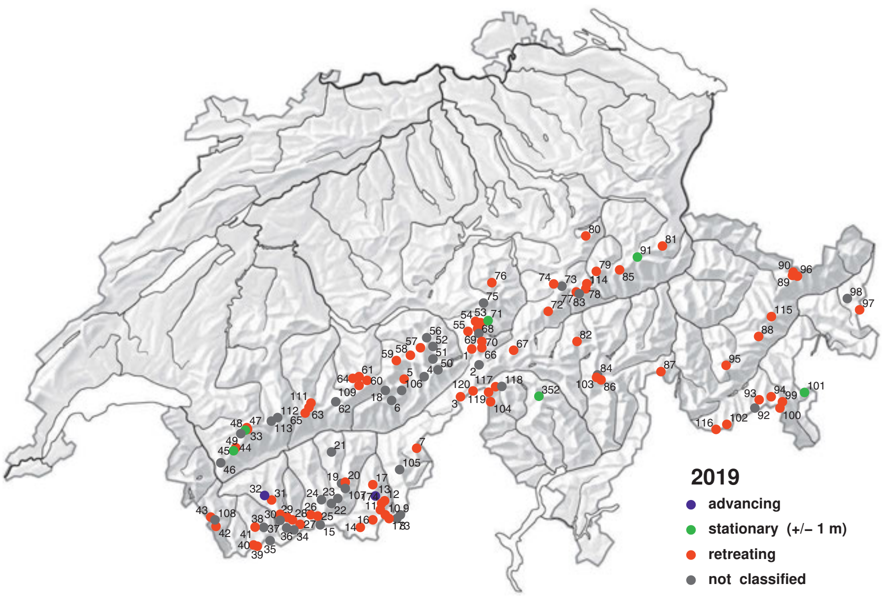

Figure 3.2: Observed glaciers in fall 2019.

3.5 Length Variations - Statistics for 1880-2019

The long-term development of glaciers in Switzerland is illustrated by using a selected sample of 73 glaciers (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 cumulative length changes (Figures 3.4 and 3.5 - 3.8) (Hoelzle et al., 2003). Such differences reflect the considerable effects of size and slope-dependent reaction of the delayed response of the glacier terminus with respect to the undelayed input (mass balance) signal (Zekollari et al., 2020).

In order to avoid a glacier sample whose scope changes annually, not all glaciers were considered for the analysis of the long-term evolution. Only continuous and long series are included. 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. Figure 3.3 presents absolute numbers of yearly measurements available in the database as well as for the selected glaciers. While in 2018 for 62 glaciers out of the reference sample a length variation was determined, in the following year 51 glaciers were measured. In 2018, 55 of the reference glaciers and in 2019, 46 glaciers were retreating, four and two glaciers, respectively, were advancing and in both years three glaciers showed no change.

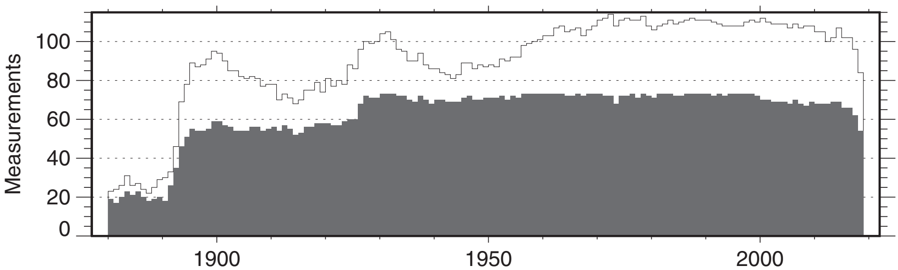

Figure 3.3: Yearly classification of glacier length variation in the data base (line) and of the 73 selected glaciers (grey area).

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 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, that has highly variable behavior.

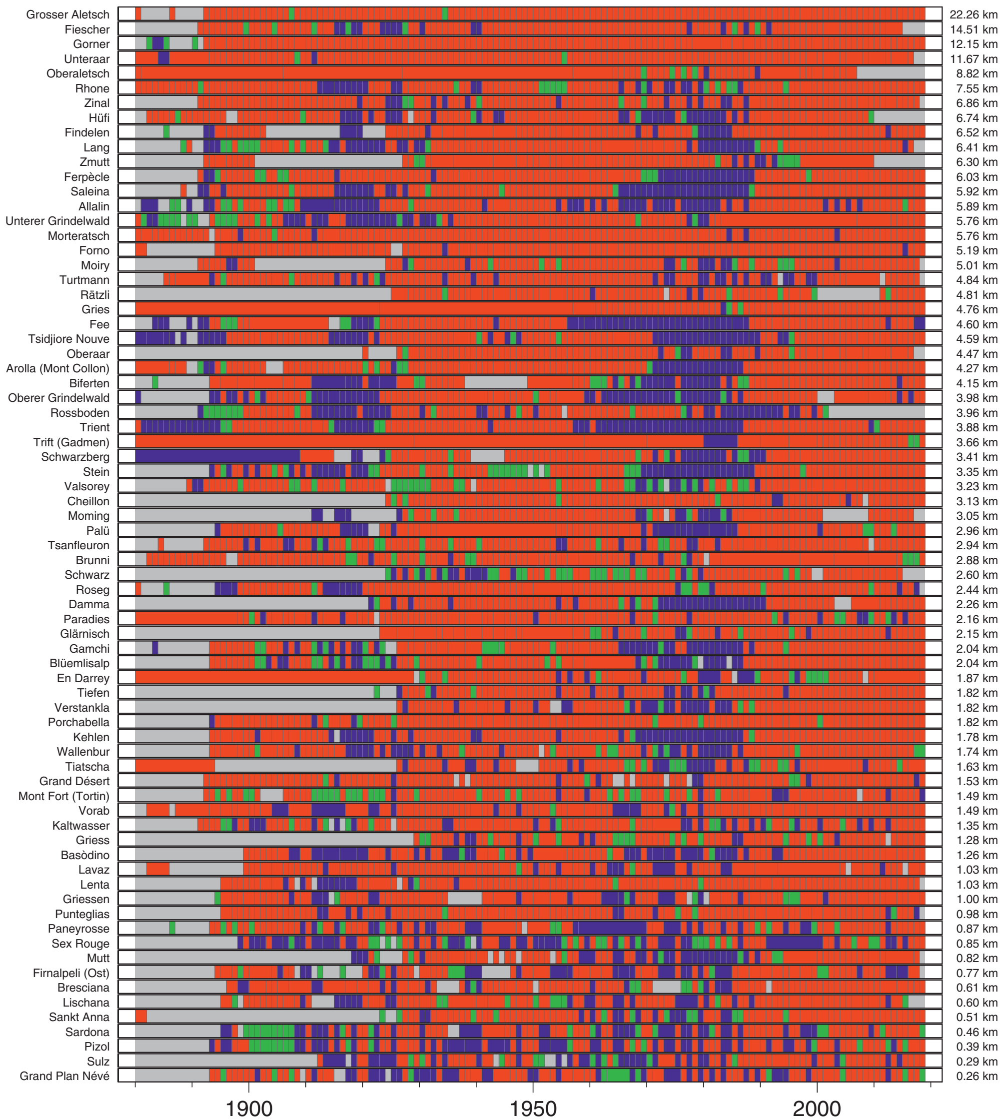

Figure 3.4: Individual pattern of advancing (blue), stationary (green) and retreating (red) length variation of the same 73 selected glaciers (displayed in the descending order of actual glacier length).

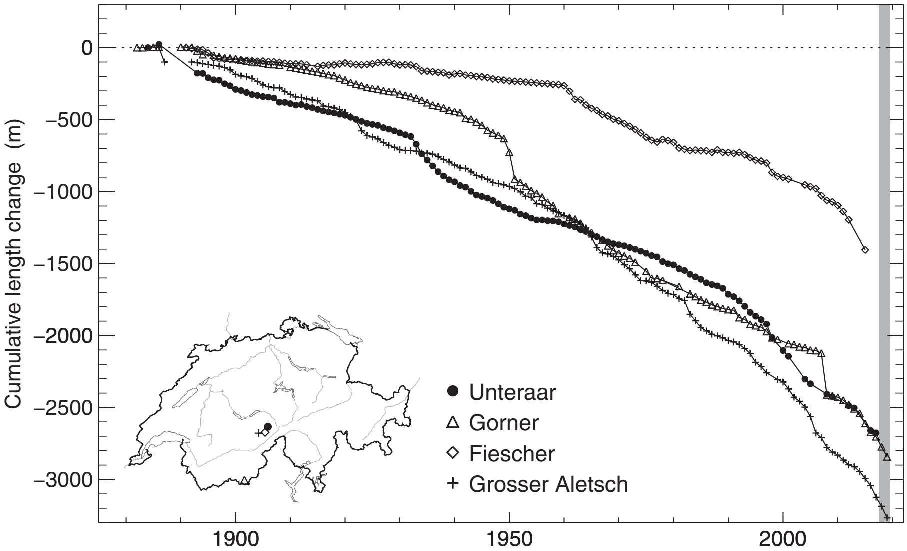

Figure 3.5: Large valley glaciers with a length of more than 10 km displaying a more or less continuous retreat over the entire time period. The gray shaded area highlights the years of the current report.

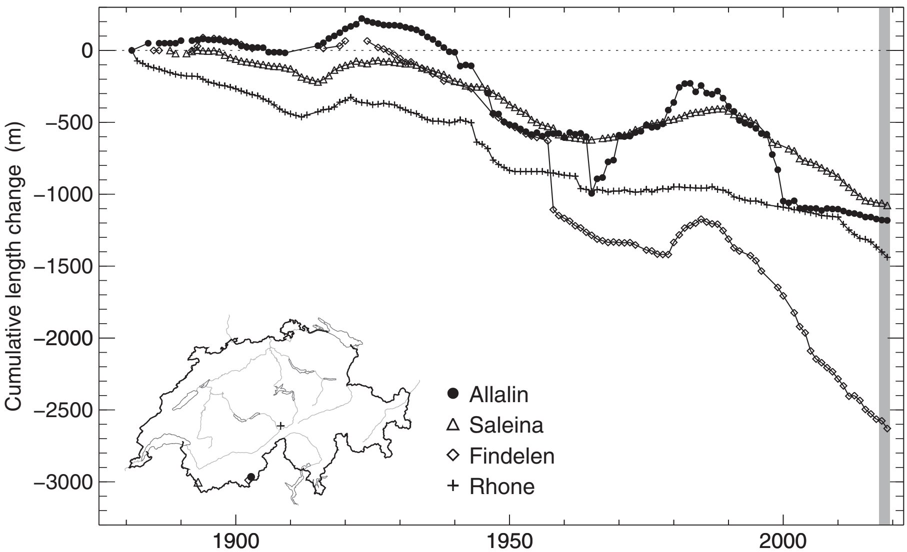

Figure 3.6: Mountain glaciers with a length of 5 to 10 km showing advance and retreat phases in two periods (around 1920 and 1970). The gray shaded area highlights the years of the current report.

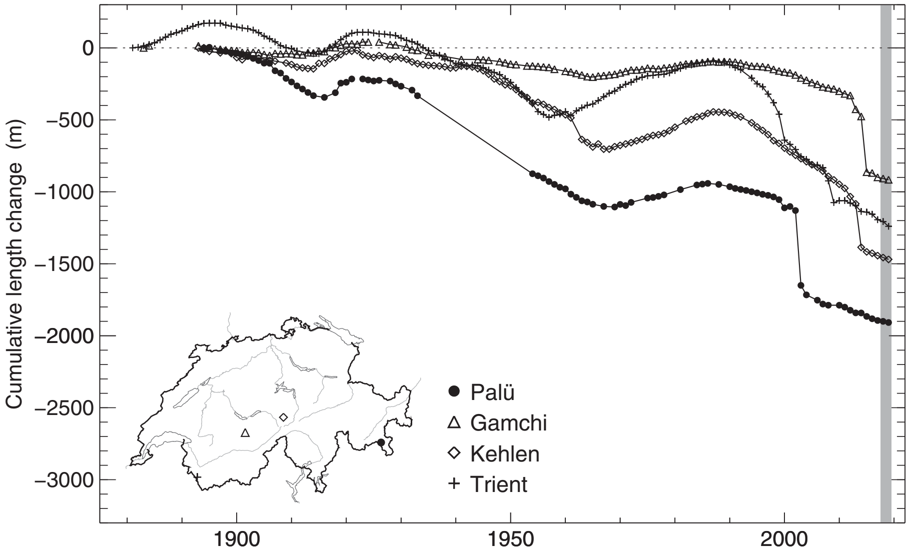

Figure 3.7: Small mountain glaciers with a length of 1 to 5 km showing two distinct advance and retreat phases. The gray shaded area highlights the years of the current report.

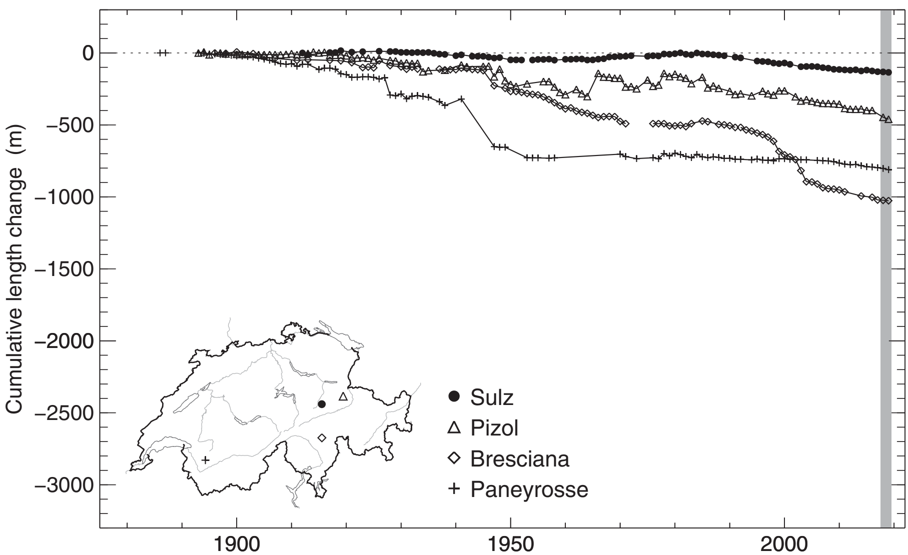

Figure 3.8: Very small cirque glaciers with a length of less than 1 km displaying generally small changes and a more irregular length change signal. The gray shaded area highlights the years of the current report.

Vadret da Sesvenna in 2009 (top) and 2019 (bottom) – the glacier experienced a large retreat in the past decade and the tongue finally disconnected from the firn area in a steep section in 2019 (Photos: AWN/GR G.C. Feuerstein and G. Renz)

4 Mass Balance

4.1 Introduction, cumulative mean specific mass balances

Detailed seasonal 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 performed at Claridenfirn, Grosser Aletschgletscher, Glacier du Giétro and Glacier de Corbassière, as well as in the Mattmark region (Allalin, Hohlaub, Schwarzberg). 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).

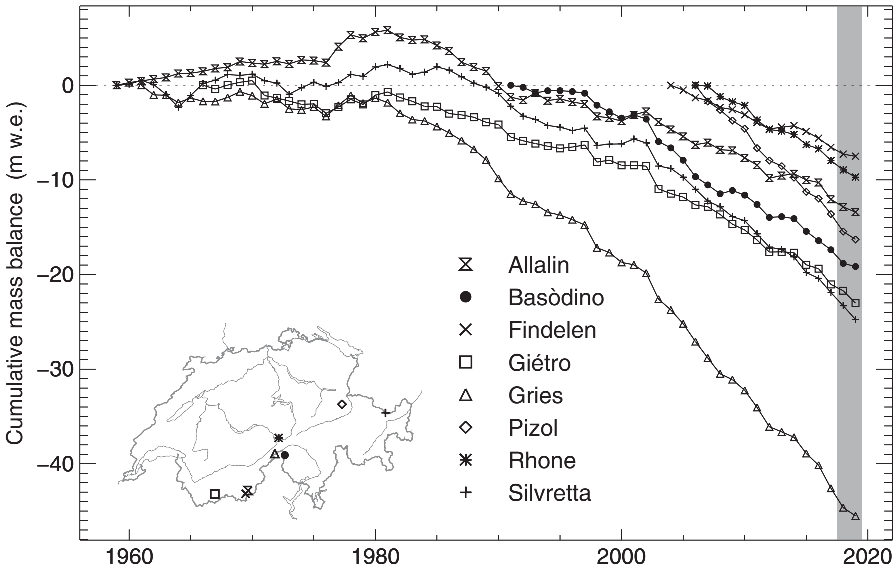

Figure 4.2: Cumulative mean specific mass balance over the whole observation period for the glaciers Allalin, Basòdino, Findelen, Giétro, Gries, Pizol, Rhone and Silvretta. The gray shaded area highlights the years of the current report.

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, 2015). Extrapolation from individual measurement points to the entire glacier surface was performed using a mass balance model constrained with all seasonal observations. The model includes 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 independent ice volume changes derived from digital elevation models is reported separately in five to ten year intervals after evaluation.

Field measurements were collected on 21 glaciers. The glacier-wide mass balance in seasonal resolution was determined by measuring snow accumulation during winter and melting in summer for the glaciers: Basòdino, Findelen, Gries, Murtèl, Pizol, Plaine Morte, Rhone, Sankt Anna, Silvretta and Tsanfleuron, including four smaller glaciers in the vicinity of the main observation

Table 4.1: Summary table with area, mean specific winter ($B_{w,meas}$) and annual ($B_{a,meas}$) balance, equilibrium line altitude (ELA) and accumulation area ratio (AAR) for the measurement periods (defined by the exact dates of field surveys) in 2017/18 and 2018/19.

Glacier	Period	Area (km^2)	$B_{w,meas}$ (mm w.e.)	$B_{a,meas}$ (mm w.e.)	ELA (m a.s.l.)	AAR (%)
Allalin	2017/18	9.646	1140	−801	3605	24
	2018/19	9.553	1000	−559	3445	41
Basòdino	2017/18	1.758	2121	−1440	3155	0
	2018/19	1.758	2418	−331	2975	30
Clariden	2017/18	4.389	1970	−1303	2945	22
	2018/19	4.321	2331	−1007	2925	29
Findelen	2017/18	12.778	1530	−723	3355	46
	2018/19	12.668	1477	−244	3295	56
Adler	2017/18	1.979	1304	−458	3475	44
	2018/19	1.979	1023	−831	3625	26
Giétro	2017/18	5.273	1460	−664	3245	45
	2018/19	5.280	1483	−1318	3355	13
Gries	2017/18	4.348	2067	−2045	3275	0
	2018/19	4.348	2000	−865	3095	7
Murtèl	2017/18	0.294	1215	−1233	3237	12
	2018/19	0.291	1179	−1299	3247	8
Corvatsch	2017/18	0.221	835	−1832	3352	5
	2018/19	0.221	854	−2083	3427	0
Pizol	2017/18	0.037	1994	−1847	2757	0
	2018/19	0.026	1622	−827	2727	5
Plaine Morte	2017/18	7.219	2303	−2101	2895	0
	2018/19	7.112	1619	−1769	2825	0
Rhone	2017/18	15.194	2171	−1000	3055	39
	2018/19	15.306	1941	−773	2935	55
St. Anna	2017/18	0.154	1955	−1077	2842	10
	2018/19	0.148	2503	−345	2817	23
Schwarzbach	2017/18	0.026	2569	−1838	2832	0
	2018/19	0.026	2541	−162	2797	46
Schwarzberg	2017/18	5.102	1778	−903	3165	32
	2018/19	4.891	1353	−776	3175	31
Silvretta	2017/18	2.616	1669	−1389	3025	1
	2018/19	2.582	2191	−1457	3015	2
Tsanfleuron	2017/18	2.466	2584	−2492	2975	0
	2018/19	2.451	2077	−1482	2975	0
Sex Rouge	2017/18	0.256	2110	−1658	2877	0
	2018/19	0.256	1817	−1890	2882	0

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

Table 4.2: Summary table with area, mean specific winter ($B_{w,fix}$) and annual ($B_{a,fix}$) balance, equilibrium line altitude (ELA) and accumulation area ratio (AAR) for fixed-date periods (1 October - 30 April - 30 September) in 2017/18 and 2018/19.

Glacier	Period	Area (km^2)	$B_{w,fix}$ (mm w.e.)	$B_{a,fix}$ (mm w.e.)	ELA (m a.s.l.)	AAR (%)
Allalin	2017/18	9.646	1127	−845	3575	27
	2018/19	9.553	981	−578	3495	35
Basòdino	2017/18	1.758	1865	−1476	3175	0
	2018/19	1.758	2330	−502	3055	10
Clariden	2017/18	4.389	2002	−1256	2935	24
	2018/19	4.321	1924	−1030	2925	29
Findelen	2017/18	12.778	1535	−737	3365	44
	2018/19	12.668	1475	−319	3295	56
Adler	2017/18	1.979	1332	−471	3485	43
	2018/19	1.979	1027	−903	3645	24
Giétro	2017/18	5.273	1271	−866	3315	22
	2018/19	5.280	1342	−1195	3345	15
Gries	2017/18	4.348	2061	−2069	3285	0
	2018/19	4.348	2185	−1188	3165	2
Murtèl	2017/18	0.294	1300	−1511	3237	12
	2018/19	0.291	1320	−1072	3227	19
Corvatsch	2017/18	0.221	892	−2093	3387	1
	2018/19	0.221	968	−1891	3377	2
Pizol	2017/18	0.037	1940	−1731	2757	0
	2018/19	0.026	1658	−930	2747	3
Plaine Morte	2017/18	7.219	2014	−2113	2915	0
	2018/19	7.112	1490	−1762	2835	0
Rhone	2017/18	15.194	2098	−1333	3105	33
	2018/19	15.306	2026	−718	2945	54
St. Anna	2017/18	0.154	1810	−1169	2832	15
	2018/19	0.148	2341	−296	2797	34
Schwarzbach	2017/18	0.026	2375	−1958	2832	0
	2018/19	0.026	2393	−105	2797	41
Schwarzberg	2017/18	5.102	1763	−927	3155	33
	2018/19	4.891	1327	−775	3165	33
Silvretta	2017/18	2.616	1533	−1881	3035	1
	2018/19	2.582	1747	−1003	3005	5
Tsanfleuron	2017/18	2.466	2317	−2373	2975	0
	2018/19	2.451	1826	−1875	2975	0
Sex Rouge	2017/18	0.256	1887	−2136	2877	0
	2018/19	0.256	1599	−1757	2872	0

and the analysis of the glacier-wide mass balance with an annual resolution were performed on Allalin, Corbassière, Giétro, Hohlaub and Schwarzberg, with an additional focus on the monitoring

of ice flow velocity.
The mean specific winter and annual balances are presented in Table 4.1 for the periods defined by the individual measurement dates and in Table 4.2 for comparable fied-date periods corresponding to the hydrological year. The mass balance for Adlergletscher, a former tributary of Findelengletscher, has 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. Additional measurements exist at Vadret dal Corvatsch in the vicinity of Vadret dal Murtèl, and at Schwarzbachfirn a neighbor of Sankt Annafirn. Only glacier-wide specific values are presented in the summary Tables 4.1 and 4.2 for these glaciers but no detailed figures. The long-term trends are clearly recognizable for Allalingletscher, Glacier du Giétro, Griesgletscher and Silvrettagletscher with very long and continuous time series (Figure 4.2). Notably, the accelerated 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 has also been submitted to the World Glacier Monitoring Service (WGMS) as a contribution to the efforts of international glacier monitoring (WGMS, 2020). Allalingletscher, Glacier du Giétro, Griesgletscher and Silvrettagletscher have been selected by WGMS as their reference glaciers, a list of glaciers that stand out for the length of their data series and the completeness of mass balance observations.

4.2 Mass Balance in 2017/18

Glacier-wide mass balance has once again been strongly negative according to measurements on 20 glaciers in all parts of Switzerland. This is particularly noteworthy because exceptionally high snow depths were measured on the glaciers in April and May. Especially in the Valais, the conditions for glaciers were excellent with up to 50% more snow than normal at the beginning of the melting season (Figure 4.3). In other regions of the Swiss Alps snow depths were also above average, in the East, however, less substantially (+20%). The protection provided by the thick snow cover was far from sufficient in view of the persistent heat phases during summer to ensure a balanced glacier mass budget. The glaciers declined massively in volume until the end of September. Summer balances more negative by 30% to 80% compared to the average of the previous decade were found (Figure 4.3). On several glaciers, an average glacier-wide mass balance of between -1.5 m to -2 m w.e. was measured. In the southern Valais, the thickness losses were less substantial with about 1 meter due to the large winter snow amounts (e.g. on Allalingletscher, Findelengletscher, and Glacier du Giétro).
For all roughly 1500 Swiss glaciers, a loss of around 1’650 million m^3 of ice is estimated for the hydrological year 2017/18. The current glacier ice volume has thus decreased by about 2.9% this year. Summed up over the past 10 years, almost a fifth of the glacier ice remaining has been

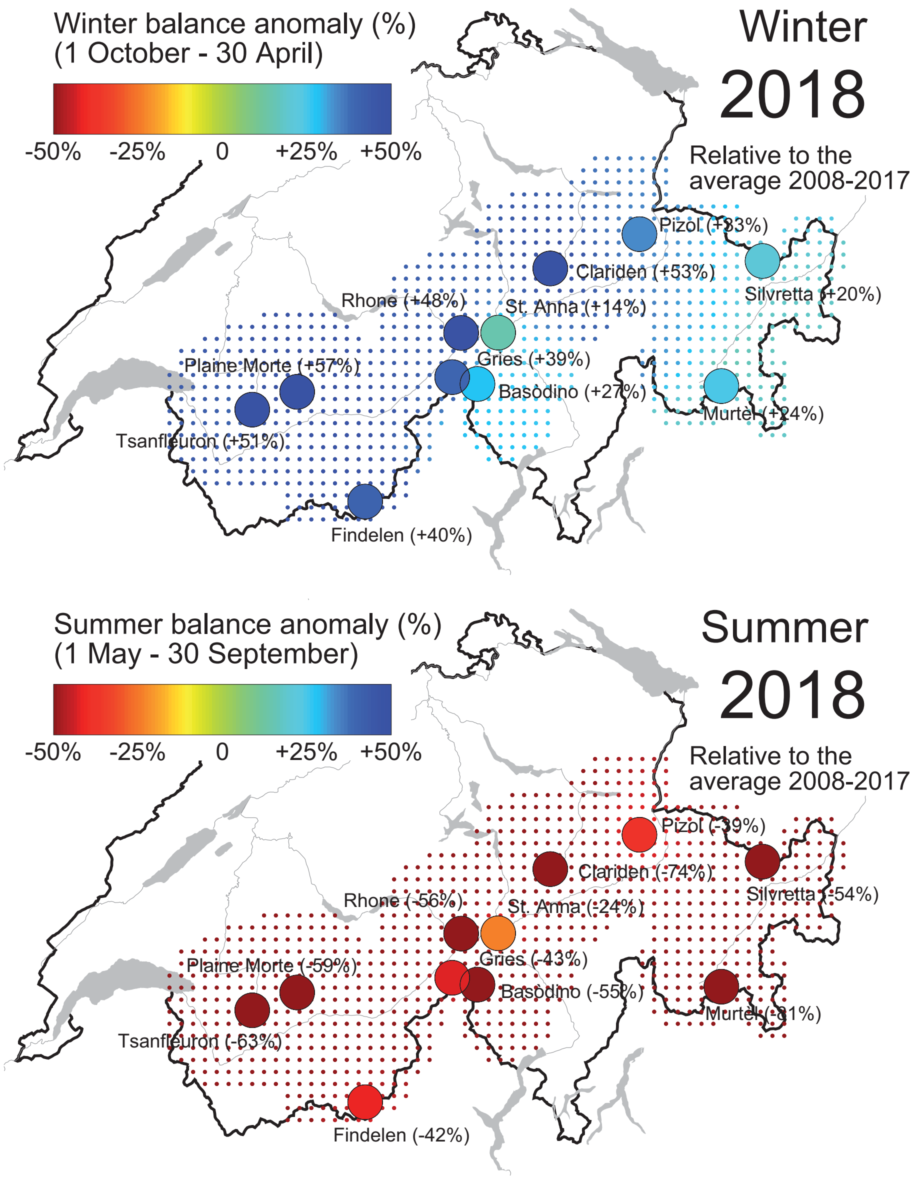

Figure 4.3: Anomaly of winter (top) and summer (bottom) mass balance in 2017/18 relative to the average 2007/08 to 2016/17 of all observed glaciers and extrapolated to the entire Swiss Alps.

lost. Glacier melt in the summer 2018 was extreme. It was only thanks to the enormous amounts of snow in the preceding winter that an absolute record loss was prevented. Glacier mass loss in 2017/18, roughly in line with the summers of 2015 and 2017, still ranks behind the year 2002/03.

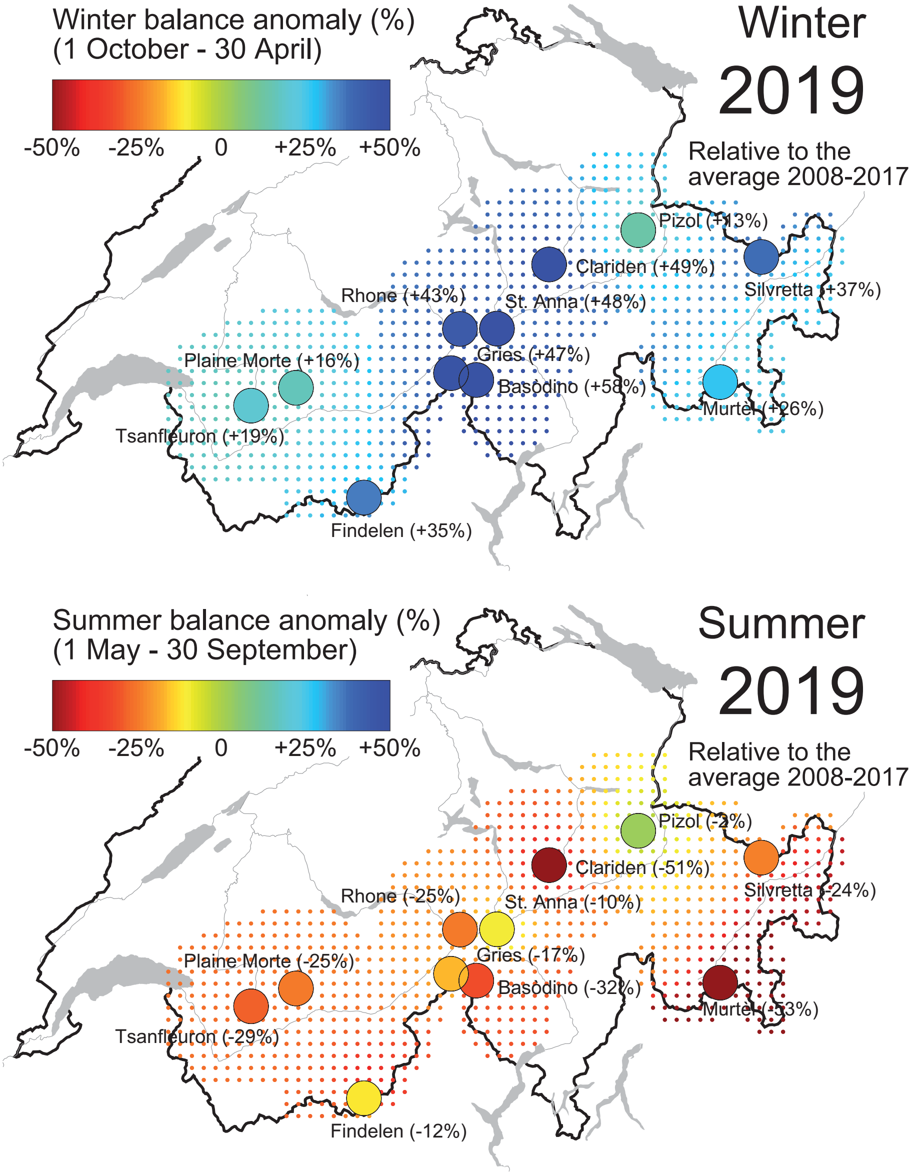

Figure 4.4: Anomaly of winter (top) and summer (bottom) mass balance in 2018/19 relative to the average 2007/08 to 2016/17 of all observed glaciers and extrapolated to the entire Swiss Alps.

4.3 Mass Balance in 2018/19

Observations of glacier-wide mass balance on the same 20 Swiss glaciers line up into the negative trend of the past years. However, the situation is less dramatic than in the first period of the present report. In April and May there was 10-40% more snow on the glaciers than on the average of the last decade (Figure 4.4). Highest snow depths were found in the central Swiss Alps, glaciers in the West were somewhat less above average. Since the melt started relatively late, there was hope until the first summer heat wave arrived that the glacier volume would decrease less than recently. During the two intense, one-week heat waves at the end of June and end of July, however, snow and ice masses corresponding to the annual national drinking water consumption melted on Swiss glaciers in just 15 days. The thick layer of snow was quickly gone, and the strong melt continued until early September. Summer melting was 10% to 50% more intense than on average of the previous decade (Figure 4.4). Extrapolated to all Swiss glaciers around 2.2% of the total glacier volume has been lost in the hydrological year 2018/19. The cumulated loss over the past five years is higher than has ever been observed in the data series on Swiss glacier mass change that reach until the beginning of the 20th century.

Glacier mass balance in 2019 is characterized by remarkable regional differences. In the east and on the north side of the Alps in particular, losses were greater than the average of the past decade. A reduction in the average ice thickness of 1 to 2 meters was measured for many glaciers (e.g. Silvrettagletscher, Glacier de Tsanfleuron). In the southern Gotthard region, however, the conditions were more favourable due to heavy snowfall at the beginning and the end of winter. On some glaciers relatively small losses were found (e.g. St. Annafirn, Ghiacciaio del Basòdino). The decay of small and very small glaciers continues: more than 500, mostly nameless glaciers, have disappeared since around 1900. Measurements of mass balance on Pizolgletscher have been abandoned as it is not regarded representative anymore due to its disintegration that has strongly accelerated during the two years of the present report.

4.4 Allalingletscher

Introduction

Allalingletscher is a temperate large mountain glacier located in the Southern Valais Alps. It currently covers an area of 9.6 km^2 flowing in north-eastern direction from 4180 m a.s.l. down to 2650 m a.s.l. Mass balance measurements started in 1955 as a part of investigations for the construction of the Mattmark reservoir for hydro-power production (VAW, 1999; Antoni, 2005). Initially, the measurement network was set up to better cover the entire surface area. Following an ice avalanche on 30th August 1965 when the construction site of the Mattmark reservoir was destroyed and 88 people died in the accident, the observation network was re-arranged in 1967 with a main focus on ice flow investigations at the glacier tongue (see Chapter 5). However, also the readings of local annual mass balance were continued. Data of point mass balance and geodetic ice volume changes since the beginning of the measurements in 1955 were re-analyzed and homogenized (Huss et al., 2015). The results of the glacier-wide mean specific annual balance for

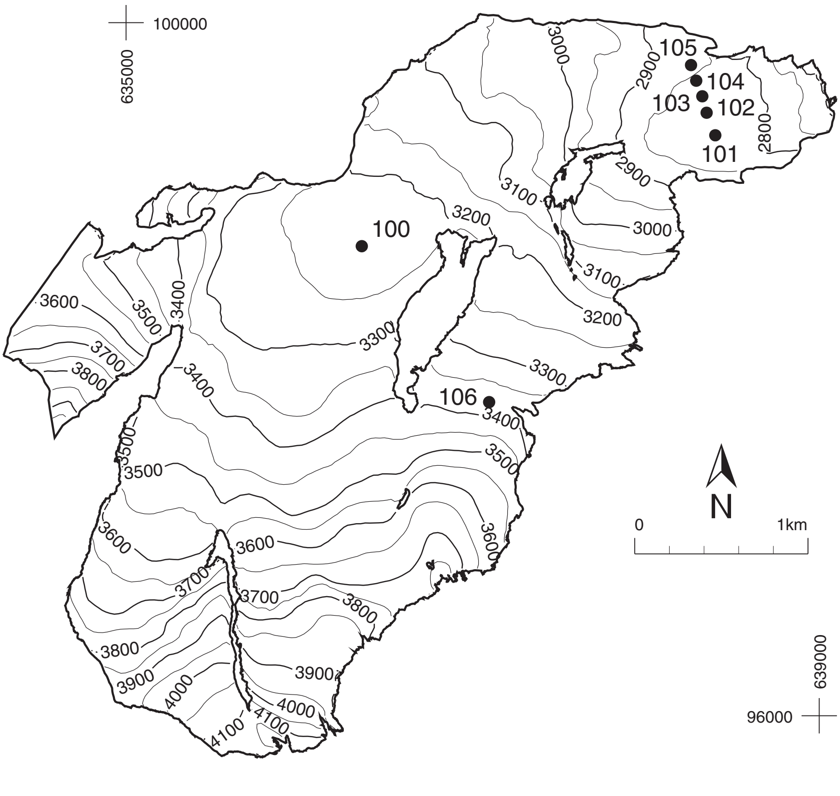

Figure 4.5: Surface topography and observational network of Allalingletscher.

comparable fixed-date periods were presented in Section 4.17 of Volume 135/136. Further details on long-term observations of ice flow velocities are shown in Section 5.6.

Investigations in 2017/18

Annual observations of mass balance with maintenance of the stake network were carried out on 9th September 2018. All seven stakes were located and set back to the initial position. Negative local mass balances have been registered for all stakes except for the highest stake on 3370 m a.s.l. where a slightly positive value was found. The higher area of the glacier was covered with remains of fresh snow accumulated in the days before the survey and it was difficult to determine the elevation of the end-of-summer snowline.

Investigations in 2018/19

Annual observations of mass balance with maintenance of the stake network were carried out on 30th August 2019. All stakes were located and set back to the initial position. As in the previous period negative local mass balances were measured for all but the highest stake. The transient snowline was found to vary in a range of 3400 m a.s.l. to 3600 m a.s.l.

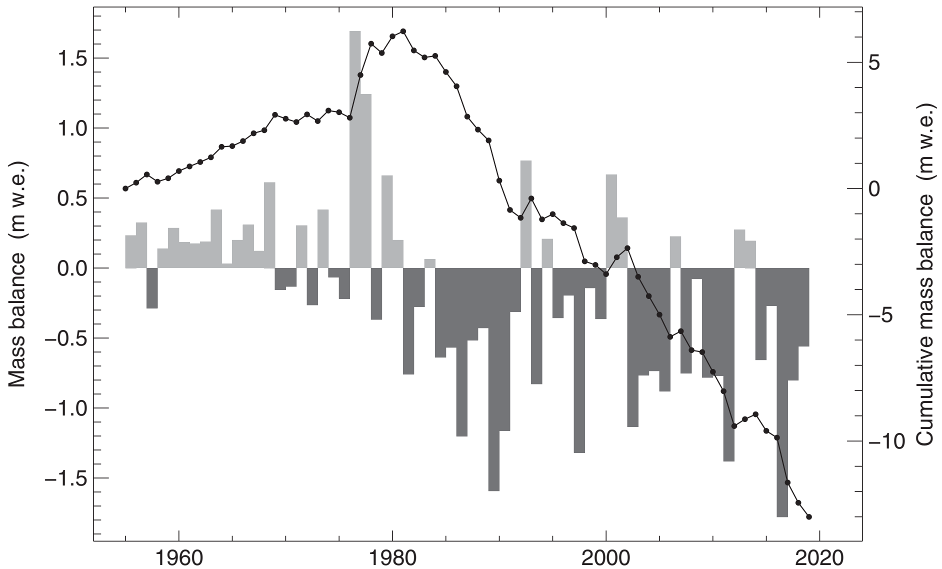

Figure 4.6: Allalingletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 1955-2019. Values refer to the measurement period.

Table 4.3: Allalingletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.002		−2797	0.001		−2247
2700 - 2800	0.154		−3140	0.134		−2724
2800 - 2900	0.573		−3155	0.528		−2540
2900 - 3000	0.486		−2648	0.463		−1922
3000 - 3100	0.717		−1946	0.713		−1545
3100 - 3200	0.739		−1343	0.739		−1291
3200 - 3300	1.592		−974	1.592		−1017
3300 - 3400	1.005		−202	1.005		−206
3400 - 3500	1.063		−259	1.063		−18
3500 - 3600	0.949		−83	0.949		186
3600 - 3700	0.838		44	0.838		324
3700 - 3800	0.517		197	0.517		465
3800 - 3900	0.449		183	0.449		460
3900 - 4000	0.291		232	0.291		483
4000 - 4100	0.181		232	0.181		462
4100 - 4200	0.091		160	0.091		389
2600 - 4200	9.646		−801	9.553		−559

Table 4.4: Allalingletscher - 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.)	
100	21.08.2017		06.09.2018	636510 / 98800 / 3222		−1476
101	21.08.2017		06.09.2018	638400 / 99360 / 2823		−3420
102	21.08.2017		06.09.2018	638351 / 99481 / 2826		−2790
103	21.08.2017		06.09.2018	638325 / 99577 / 2824		−3645
104	21.08.2017		06.09.2018	638290 / 99666 / 2839		−3600
105	21.08.2017		06.09.2018	638260 / 99753 / 2856		−4590
106	21.08.2017		06.09.2018	637097 / 97797 / 3372		72
100	06.09.2018		30.08.2019	636511 / 98802 / 3221		−1485
101	06.09.2018		30.08.2019	638400 / 99360 / 2820		−2700
102	06.09.2018		30.08.2019	638350 / 99480 / 2823		−2160
103	06.09.2018		30.08.2019	638325 / 99575 / 2822		−2340
104	06.09.2018		30.08.2019	638290 / 99665 / 2836		−2700
105	06.09.2018		30.08.2019	638259 / 99755 / 2854		−3780
106	06.09.2018		30.08.2019	637096 / 97792 / 3373		104

4.5 Ghiacciaio del Basòdino

Introduction

Ghiacciaio del Basòdino is a small north-east facing temperate mountain glacier in the southern Swiss Alps. The small branch descending to the north below Kastelhorn with a separate tongue and no longer connected is not considered part of the glacier, and is not included in the mass balance evaluation. The main body of the glacier presently covers an area of 1.8 km^2 and extends from 2600 to 3186 m a.s.l. Detailed mass balance investigations have been carried out since 1991. 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 since the beginning of the measurements in 1991. 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.

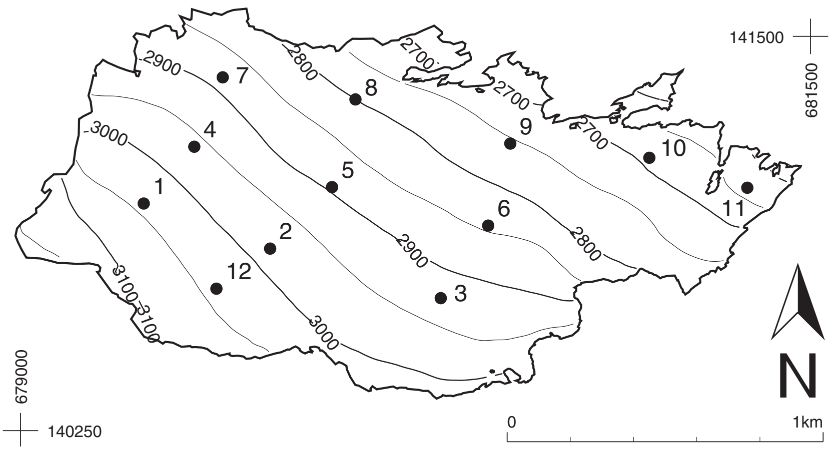

Figure 4.7: Surface topography and observational network of Ghiacciaio del Basòdino.

Investigations in 2017/18

The stake network was reorganized with the aim of a more even coverage of the entire surface (Figure 4.7). The measurement period extended from 8th September 2017 to 26th October 2018 with a field visit in spring, on 7th May 2018. The spring survey included snow depth probing at 27 locations and the determination of mean density of the snow pack with measurements in a snow pit in the center of the glacier at stake 5. The annual mass balance was observed at 11 stakes.

Additional field visits during the melting season were performed on 8th August and 3rd September 2018. The ablation season lasted over the whole of September.

Investigations in 2018/19

The measurement period was from 26th October 2018 to 17th September 2019. Winter balance was determined on 7th May 2019. Snow depth probing at 34 locations and measurement of the density in a snow pit were carried out in spring. An additional field visit during the melting season was conducted on 4 th September 2019 and annual mass balance was determined at all 11 stakes.

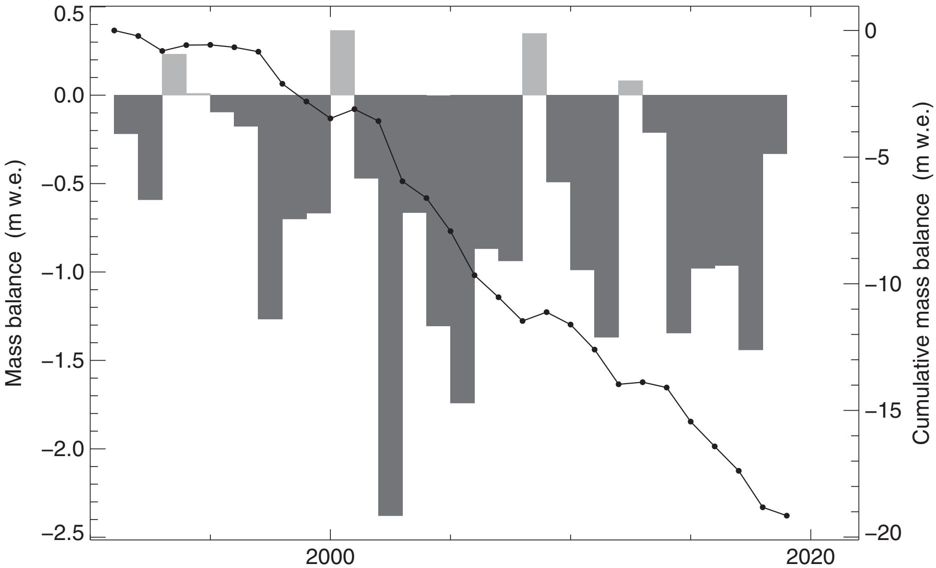

Figure 4.8: Ghiacciaio del Basòdino - Mean specific annual balance (bars) and cumulative mass balance for the period 1991-2019. Values refer to the measurement period.

Table 4.5: Ghiacciaio del Basòdino - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.108	2142.	−2067	0.108	2353.	−561
2700 - 2800	0.339	2073.	−1793	0.339	2449.	−689
2800 - 2900	0.422	2162.	−1698	0.422	2539.	−709
2900 - 3000	0.521	2261.	−1028	0.521	2508.	50
3000 - 3100	0.312	1976.	−1168	0.312	2212.	10
3100 - 3200	0.054	1586.	−1523	0.054	1756.	−320
2600 - 3200	1.758	2121	−1440	1.758	2418	−331

Table 4.6: Ghiacciaio del Basòdino - 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	08.09.2017	07.05.2018	26.10.2018	679391 / 140970 / 3035	1862	−1107
02	08.09.2017	07.05.2018	26.10.2018	679791 / 140828 / 2979	2107	−986
03	08.09.2017	07.05.2018	26.10.2018	680332 / 140672 / 2912	2512	−420
04	08.09.2017	07.05.2018	26.10.2018	679547 / 141159 / 2960	2125	−1479
05	08.09.2017	07.05.2018	26.10.2018	679987 / 141021 / 2886	1918	−1710
06	08.09.2017	07.05.2018	26.10.2018	680478 / 140906 / 2836	2222	−1068
07	08.09.2017	07.05.2018	26.10.2018	679639 / 141364 / 2882	1982	−2016
08	08.09.2017	07.05.2018	26.10.2018	680055 / 141291 / 2794	1982	−2289
09	08.09.2017	07.05.2018	26.10.2018	680551 / 141157 / 2748	1927	−2178
10	08.09.2017	07.05.2018	26.10.2018	680988 / 141117 / 2686	1936	−2052
12	08.09.2017	07.05.2018	26.10.2018	679620 / 140726 / 3026	2153	−1137
01	26.10.2018	07.05.2019	17.09.2019	679388 / 140962 / 3030	2075	−270
02	26.10.2018	07.05.2019	17.09.2019	679790 / 140825 / 2980	2507	148
03	26.10.2018	07.05.2019	17.09.2019	680333 / 140668 / 2930	2358	519
04	26.10.2018	07.05.2019	17.09.2019	679545 / 141155 / 2960	2444	77
05	26.10.2018	07.05.2019	17.09.2019	679981 / 141022 / 2880	2192	−648
06	26.10.2018	07.05.2019	17.09.2019	680476 / 140907 / 2840	2520	−144
07	26.10.2018	07.05.2019	17.09.2019	679634 / 141359 / 2860	2250	−689
08	26.10.2018	07.05.2019	17.09.2019	680050 / 141300 / 2790	2282	−995
09	26.10.2018	07.05.2019	17.09.2019	680553 / 141160 / 2740	2534	−414
10	26.10.2018	07.05.2019	17.09.2019	680992 / 141127 / 2685	2205	−1017
12	26.10.2018	07.05.2019	17.09.2019	679621 / 140719 / 3030	2480	334

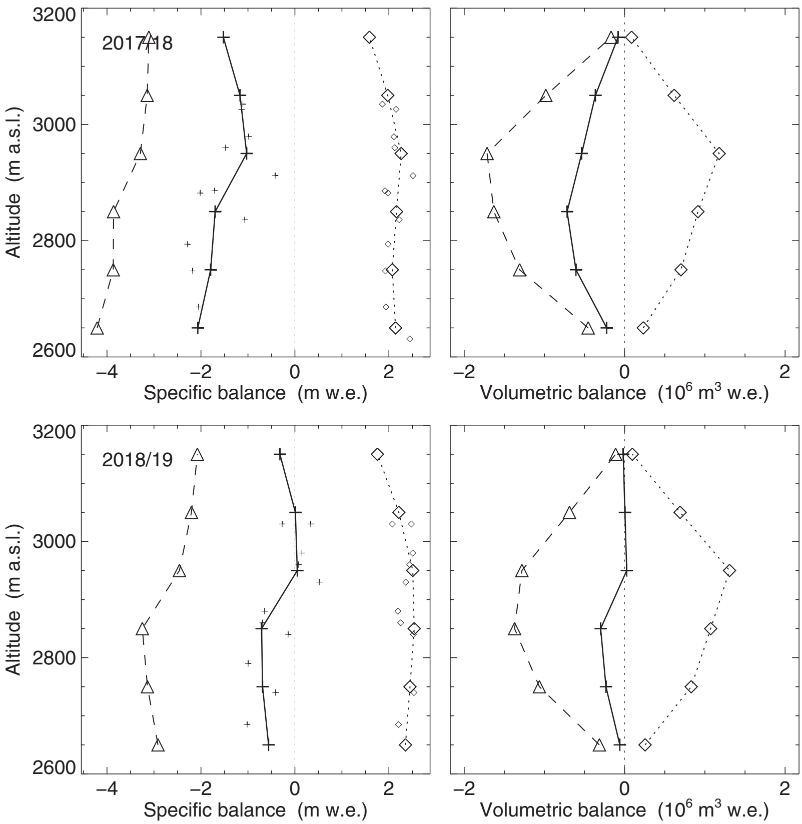

Figure 4.9: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

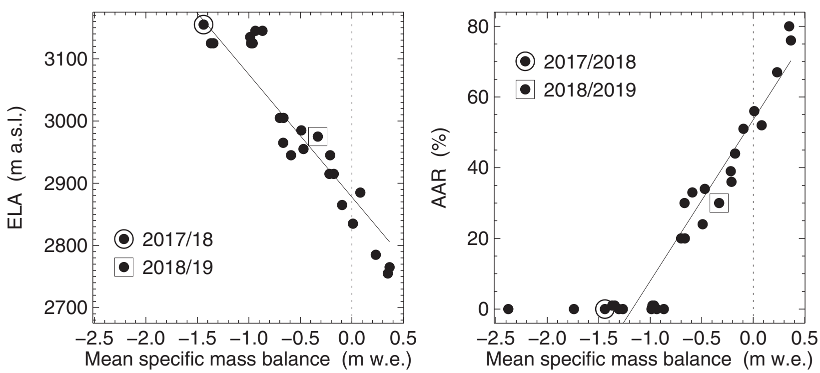

Figure 4.10: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.6 Claridenfirn

Introduction

Measurements of the snow and firn accumulation and melt, as well as of total precipitation 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 a marked horizon applied the previous autumn and measuring the water equivalent of the snow and firn layers. Annual point balances were determined every autumn since 1914 with very few data gaps 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). Observational techniques and the results for 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 drivers (see Section 4.10 of Volume 127/128). Values of the entire homogenized time series of point mass balance 1914-2015

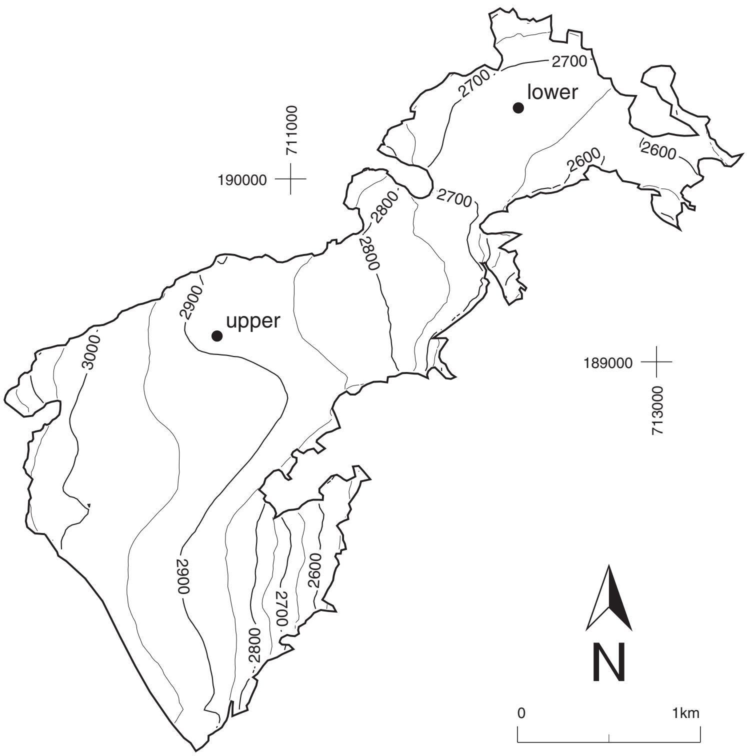

Figure 4.11: Surface topography and observational network of Claridenfirn.

are compiled in Section 4.16 of Volume 135/136 (Figure 4.12). In addition, Huss et al. (2015) calculated glacier-wide mass balance for the entire time series (Figure 4.13, 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 2017/18

Spring measurements were carried out on 11th and 12th May 2018. Only at the upper site the stake was visible. Detailed observations in a snow pit at the upper site were supplemented by 16 snow depth probings in the vicinity of both stakes. A distinct 5 cm thick ice lense was present at both sites in about 3.5 m depth. At the upper site the density of 493 kg m^{-3} was measured in the snow pit while at the lower site a value of 560 kg m^{-3} was determined using a core drill. Autumn measurements were carried out on 6th October 2018. At the lower site, snow accumulation during winter had melted completely with additional 1.5 m loss of ice. Also at the upper site a slight loss of 20 cm of firn was found, covered by 30 cm of fresh snow. In addition to the measurements of mass balance, surface lowering and horizontal displacement of the stakes was determined in autumn.

Investigations in 2018/19

The spring field survey was carried out on 5th June, and the late summer survey on 29th September 2019. The investigations included snow depth probing and density measurement using a core drill in spring. The observations were supplemented by additional snow depth probing between the two sites in a 200 m interval. A density of 515 kg m^{-3} at the lower and 535 kg m^{-3} at the upper site was found. At the end of September, a negative mass balance was registered at the lower site while a moderately positive mass balance was found at the upper site. A density of 567 kg m^{-3} of the accumulated layer was measured in a pit. Only the lower stake was redrilled at the original location.

Table 4.7: Claridenfirn - Individual stake measurements of winter and annual balance.2 Note that the lowermost elevation band also includes estimated mass losses by frontal break-off of ice.

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	23.09.2017	12.05.2018	06.10.2018	710596 / 189123 / 2890	2504	−33
lower	23.09.2017	11.05.2018	06.10.2018	712261 / 190406 / 2670	2384	−1342
upper	06.10.2018	05.06.2019	29.09.2019	710596 / 189123 / 2890	3157	449
lower	06.10.2018	05.06.2019	29.09.2019	712261 / 190406 / 2670	2524	−1125

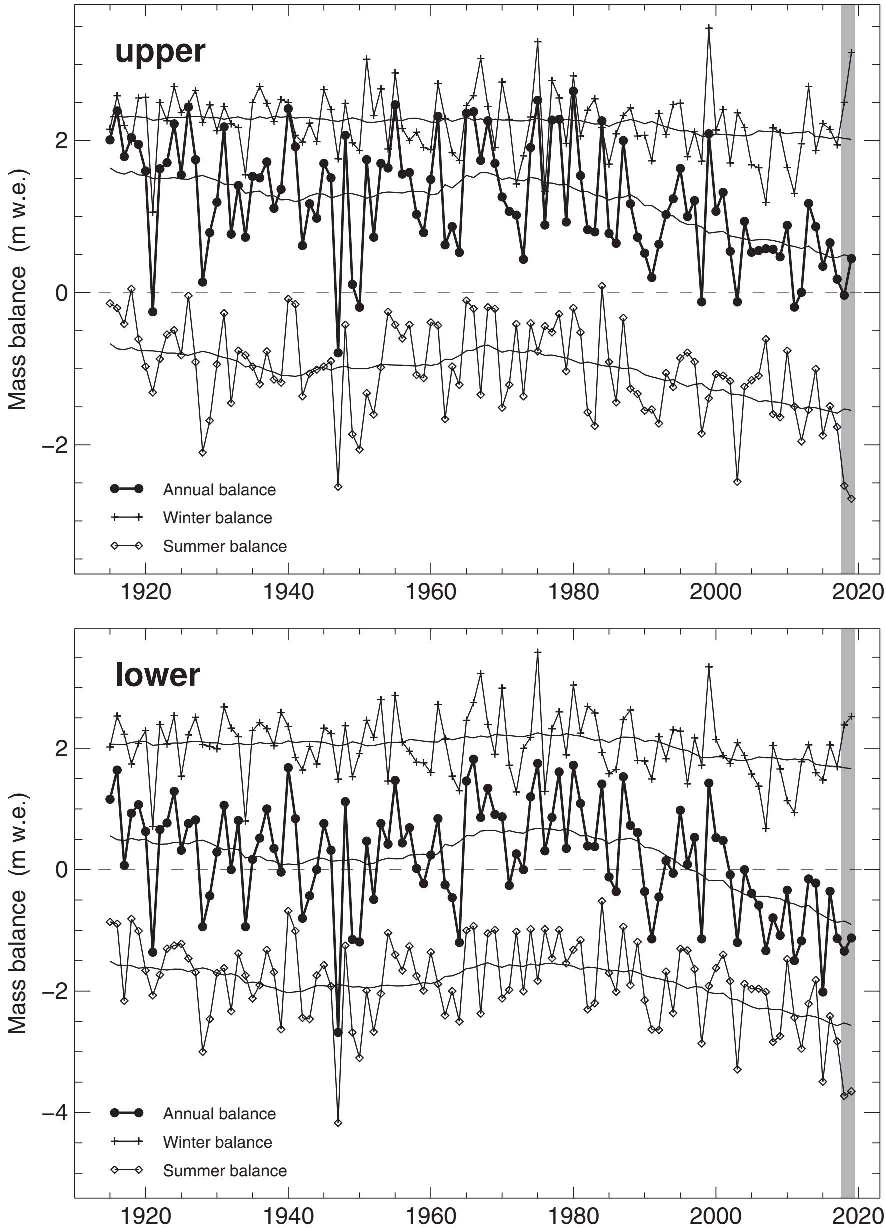

Figure 4.12: Mass balance of the upper (top) and lower (bottom) stake on Claridenfirn over the whole observation period. The gray shaded area highlights the years of the current report.

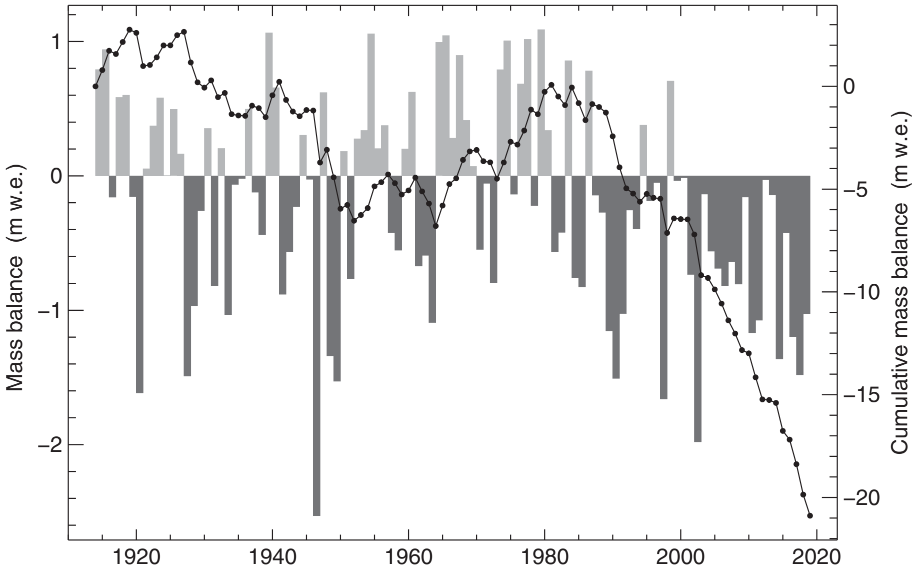

Figure 4.13: Claridenfirn - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1914-2019.

Table 4.8: Claridenfirn - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey. Note that the lowermost elevation band also contains mass loss contributions from estimated ice break-off at the glacier snout.

Altitude	2017/18			2018/19		
	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	0.002	1972.	−4924	0.000		
2500 - 2600	0.071	1550.	−4260	0.058	1873.	−3235
2600 - 2700	0.743	2099.	−1647	0.723	2517.	−1340
2700 - 2800	0.684	1925.	−1544	0.667	2292.	−1415
2800 - 2900	1.330	2029.	−1233	1.332	2396.	−854
2900 - 3000	1.378	1891.	−1066	1.363	2218.	−800
3000 - 3100	0.156	2031.	−80	0.152	2345.	−98
3100 - 3200	0.026	1545.	−271	0.026	1750.	−368
2400 - 3200	4.389	1970	−1303	4.321	2331	−1007

4.7 Glacier de Corbassière

Introduction

Since 1967, Glacier de Corbassière has been under observation by the Mauvoisin power company that exploits water from the catchment. Observations have been carried out on two profiles in the ablation area (Figure 4.14) where thickness change and ice flow was measured annually (see Chapter 5). Starting in 1996, stakes were maintained to measure annual quantities of ice flow velocity and local mass balance. Results of the glacier-wide mean specific annual balance for comparable fixed-date periods for 1996 to 2015 were presented in Section 4.17 of Volume 135/136. Here, we only present the results of annual point mass balance measurements. Glacier-wide mass balance estimates will be evaluated periodically when new observations of geodetic ice

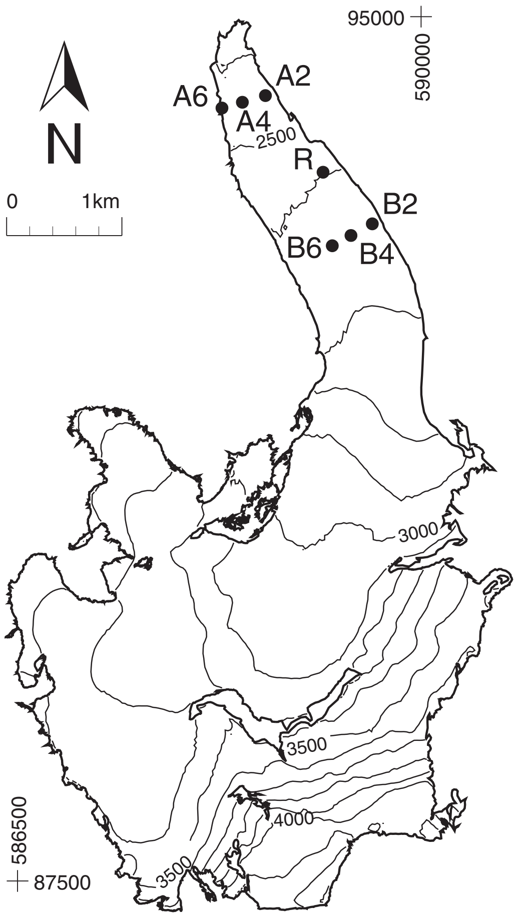

Figure 4.14: Surface topography and observational network of Glacier de Corbassière.

volume change will be available. Further details on the long-term observations of ice flow velocities are given in Section 5.3.

Investigations in 2017/18

Annual observations of mass balance with maintenance of the stake network were carried out on 17th and 18th September 2018. Negative local mass balances resulted at all stakes. Six out of seven stakes were located while A6 completely melted out. All stakes were set back to the initial position. Stake A2 is located in a depression that was filed with avalanche snow deposits during winter. This snow lasted throughout large parts of the melting season resulting in a less negative annual balance compared to neighboring stakes.

Investigations in 2018/19

The annual field survey took place on 27th and 28th September 2019. Six out of seven stakes were located. The missing stake R may have melted out completely and have been collected by tourists or was lost in a crevasse. At all stakes a negative local mass balance was determined. At site A6 the glacier has strongly receded in the last decade and is now heavily debris-covered, hence making it difficult to further maintain this measurement site.

Table 4.9: Glacier de Corbassière - 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.)	
B2	21.09.2017		16.09.2018	589577 / 93202 / 2619		−3690
B4	21.09.2017		16.09.2018	589392 / 93101 / 2623		−4005
B6	21.09.2017		16.09.2018	589230 / 93012 / 2628		−3933
R	21.09.2017		16.09.2018	589155 / 93651 / 2583		−4581
A2	22.09.2017		17.09.2018	588651 / 94315 / 2416		−6318
A4	22.09.2017		17.09.2018	588456 / 94259 / 2393		−2493
A6	22.09.2017		18.09.2018	588321 / 94217 / 2419		−3600
B2	17.09.2018		27.09.2019	589577 / 93202 / 2616		−3789
B4	17.09.2018		27.09.2019	589390 / 93100 / 2621		−4302
B6	17.09.2018		27.09.2019	589231 / 93007 / 2626		−3951
A2	18.09.2018		28.09.2019	588652 / 94311 / 2410		−6210
A4	18.09.2018		28.09.2019	588460 / 94257 / 2387		−3627
A6	18.09.2018		28.09.2019	588325 / 94198 / 2417		−4023

4.8 Findelengletscher

Introduction

Findelengletscher (12.7 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.

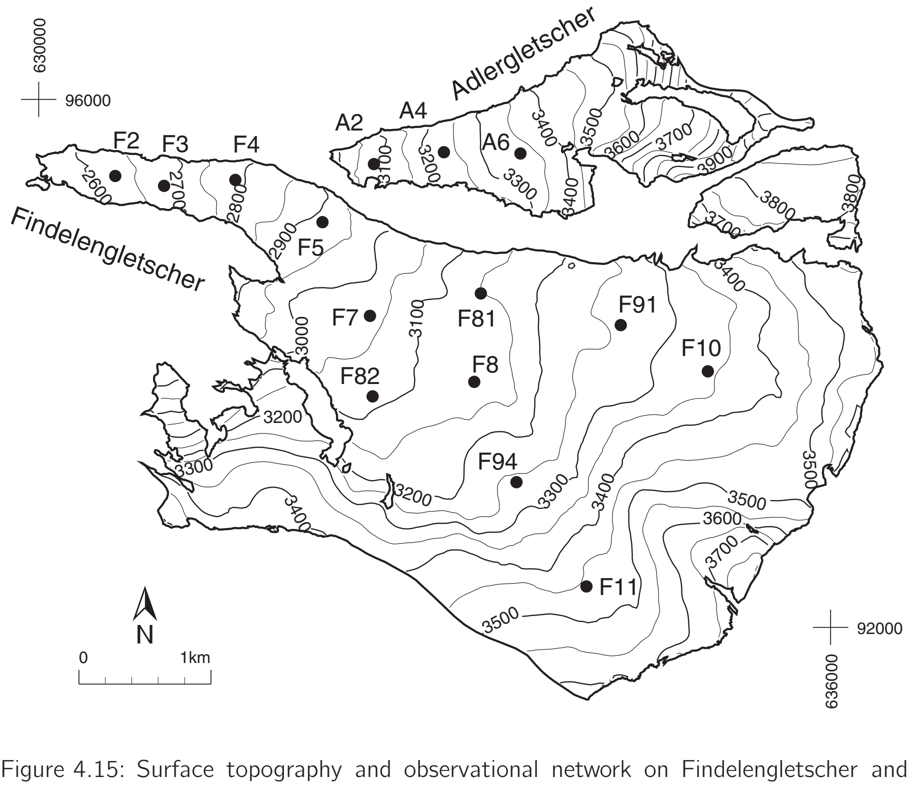

Figure 4.15: Surface topography and observational network on Findelengletscher and the former tributary Adlergletscher. Note that mass balance of Findelen- and Adlergletscher is evaluated over a homogenized perimeter that excludes some areas with very thick debris-coverage and unconnected tributaries below Stockhorn.

Investigations in 2017/18

Winter mass balance of Findelen- and Adlergletscher was determined on 18th April 2018. Snow probings were acquired for 252 locations and snow density was measured in five snow pits distributed over the entire elevation range of the glacier. Ground penetrating radar provided supplementary continuous data on snow depth with a total length of all profiles of 11 km. During a mid-summer field survey, the stakes in the ablation area were redrilled and a station to continuously measure ice ablation based on a webcam observing an ablation stake was installed. All mass balance stakes were visited and re-installed on 26th September 2018. The annual mass balance was determined for 11 locations on Findelen-, and three on Adlergletscher. No firn density measurement were performed as none of the observed stakes showed accumulation. Close to the long-term equilibrium line altitude a station was installed to continuously measure snow depth and snow water equivalent along with meteorological variables (Gugerli et al., 2019).

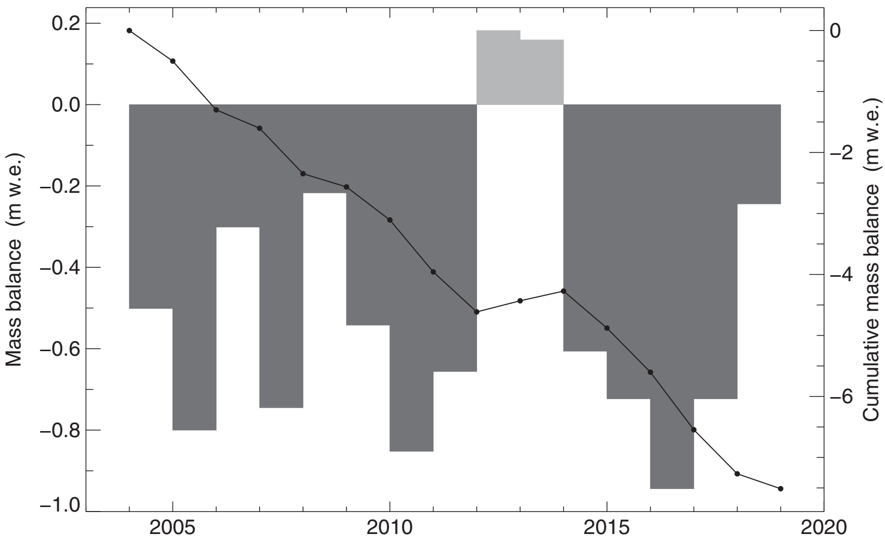

Figure 4.16: Findelengletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 2004-2019.

Investigations in 2018/19

The winter survey was performed on 17th April 2019. In total, 217 snow probings distributed over the entire surface of Findelen- and Adlergletscher were obtained, and snow density was measured in five snow pits. At one location an intercomparison of three different approaches to determine snow density was performed. In addition, snow depth was monitored using a ground-based radar with a total length of all profiles of 10 km. Two autonomous stations to continuously measure ice ablation were installed on 27th June 2019 related to a project for real-time monitoring of glacier mass loss. On 17th September 2019 all measurement sites were visited. Mass balance was determined at 13 stakes on Findelen- and at three stakes on Adlergletscher. Firn density was determined at two stakes in the accumulation area. The terminus area of Findelengletscher is undergoing rapid changes and fast retreat; a subglacial cavity has collapsed in 2019.

Table 4.10: Findelengletscher and Adlergletscher - 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.)
F2	21.09.2017	18.04.2018	26.09.2018	630462 / 95440 / 2605	760	−7170
F3	21.09.2017	18.04.2018	26.09.2018	630951 / 95346 / 2681	850	−6350
F4	21.09.2017	18.04.2018	26.09.2018	631522 / 95387 / 2794	1220	−4750
F5	21.09.2017	18.04.2018	26.09.2018	632136 / 95043 / 2915	1210	−3120
F7	21.09.2017	18.04.2018	26.09.2018	632537 / 94329 / 3039	1270	−2570
F8	21.09.2017	18.04.2018	26.09.2018	633311 / 93855 / 3122	1450	−1580
F81	21.09.2017	18.04.2018	26.09.2018	633367 / 94537 / 3150	1090	−2350
F82	21.09.2017	18.04.2018	26.09.2018	632565 / 93737 / 3091	1230	−2300
F91	21.09.2017	18.04.2018	26.09.2018	634444 / 94306 / 3264	1540	−1270
F94	21.09.2017	18.04.2018	26.09.2018	633617 / 93078 / 3258	1270	−1110
F10	21.09.2017	18.04.2018	26.09.2018	635096 / 93922 / 3345	1460	120
A2	21.09.2017	18.04.2018	26.09.2018	632544 / 95504 / 3081	1520	−2880
A4	21.09.2017	18.04.2018	26.09.2018	633082 / 95606 / 3236	1270	−2560
A6	21.09.2017	18.04.2018	26.09.2018	633672 / 95600 / 3340	1520	−880
F2	26.09.2018	17.04.2019	17.09.2019	630581 / 95422 / 2619	830	−5720
F3	26.09.2018	17.04.2019	17.09.2019	630950 / 95345 / 2681	700	−5880
F4	26.09.2018	17.04.2019	17.09.2019	631494 / 95392 / 2788	990	−3930
F5	26.09.2018	17.04.2019	17.09.2019	632162 / 95020 / 2921	1280	−2000
F7	26.09.2018	17.04.2019	17.09.2019	632510 / 94357 / 3036	1360	−1840
F8	26.09.2018	17.04.2019	17.09.2019	633306 / 93860 / 3122	1440	−1060
F81	26.09.2018	17.04.2019	17.09.2019	633367 / 94537 / 3150	1370	−1990
F82	26.09.2018	17.04.2019	17.09.2019	632550 / 93753 / 3088	1200	−1630
F91	26.09.2018	17.04.2019	17.09.2019	634408 / 94290 / 3258	1660	20
F94	26.09.2018	17.04.2019	17.09.2019	633625 / 93105 / 3255	1400	−580
F10	26.09.2018	17.04.2019	17.09.2019	635070 / 93939 / 3341	1620	440
F11	26.09.2018	17.04.2019	17.09.2019	634353 / 92285 / 3477	2050	1460
A2	26.09.2018	17.04.2019	17.09.2019	632543 / 95510 / 3081	1140	−2560
A4	26.09.2018	17.04.2019	17.09.2019	633059 / 95598 / 3231	1120	−2420
A6	26.09.2018	17.04.2019	17.09.2019	633652 / 95589 / 3339	1450	−850

Table 4.11: Findelengletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude (m a.s.l.)	2017/18 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	2018/19 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2500 - 2600	0.064	718	−7298	0.055	607	−6712
2600 - 2700	0.160	793	−6668	0.151	595	−6041
2700 - 2800	0.184	936	−5363	0.177	668	−4890
2800 - 2900	0.327	1044	−3854	0.287	985	−2972
2900 - 3000	0.578	1104	−3086	0.544	1142	−2060
3000 - 3100	0.996	1200	−2473	0.981	1246	−1841
3100 - 3200	1.716	1330	−1708	1.678	1357	−1242
3200 - 3300	1.833	1418	−999	1.857	1450	−394
3300 - 3400	1.951	1738	210	1.967	1634	550
3400 - 3500	2.357	1869	595	2.359	1790	979
3500 - 3600	1.609	1761	627	1.609	1655	915
3600 - 3700	0.439	1713	813	0.439	1399	790
3700 - 3800	0.301	1443	679	0.301	1222	742
3800 - 3900	0.252	1310	640	0.252	1167	783
3900 - 4000	0.011	1049	488	0.011	938	647
2500 - 4000	12.778	1530	−723	12.668	1477	−244

Table 4.12: Adlergletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude (m a.s.l.)	2017/18 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	2018/19 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2900 - 3000	0.006	1227.	−3709	0.006	1210.	−3035
3000 - 3100	0.086	1305.	−3105	0.086	1221.	−2616
3100 - 3200	0.123	1404.	−2474	0.123	1189.	−2428
3200 - 3300	0.253	1314.	−2003	0.253	1196.	−1949
3300 - 3400	0.399	1249.	−1013	0.399	1137.	−1122
3400 - 3500	0.315	1323.	−206	0.315	1021.	−732
3500 - 3600	0.246	1353.	411	0.246	933.	−278
3600 - 3700	0.208	1289.	723	0.208	843.	−15
3700 - 3800	0.177	1296.	1067	0.177	845.	300
3800 - 3900	0.103	1222.	1175	0.103	790.	406
3900 - 4000	0.046	1356.	1475	0.046	895.	639
4000 - 4100	0.014	1412.	1679	0.014	853.	684
4100 - 4200	0.004	1112.	1316	0.004	653.	452
2900 - 4200	1.979	1304	−458	1.979	1023	−831

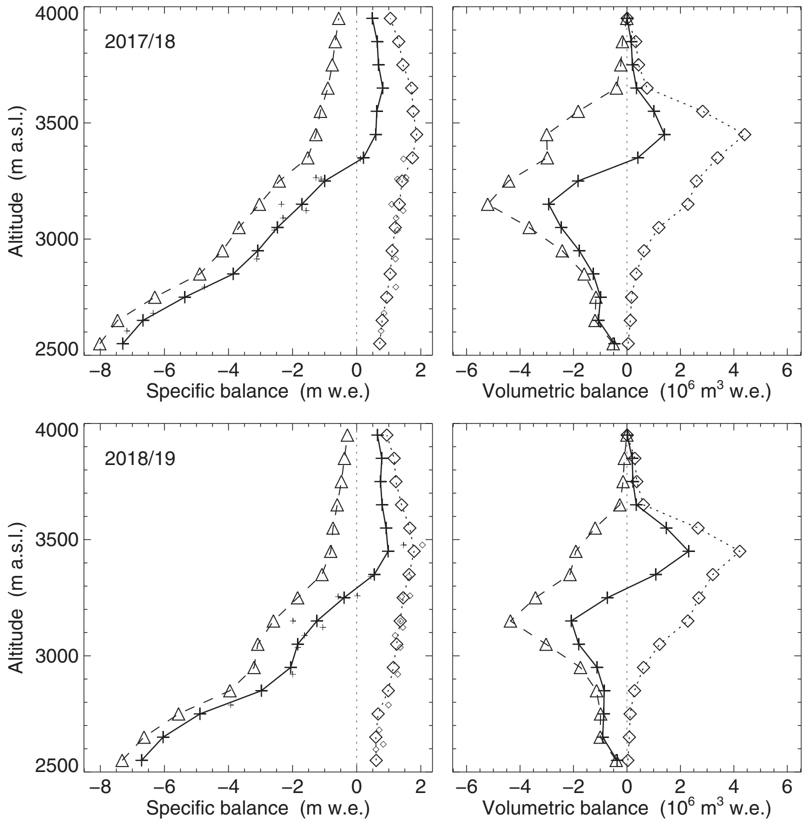

Figure 4.17: Findelengletscher - Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

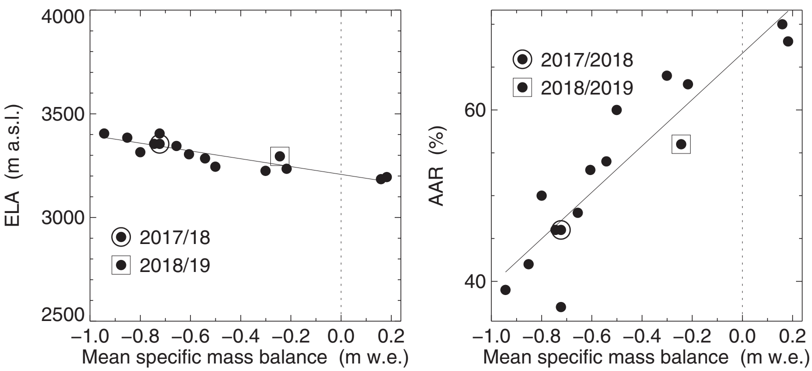

Figure 4.18: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.9 Glacier du Giétro

Introduction

Glacier du Giétro is a temperate mountain glacier in the Southern Valais Alps (Val de Bagnes). The glacier has been under observations for early recognition of glacier break-off, which can endanger the reservoir operated by the Forces Motrices de Mauvoisin SA located in the outreach of ice avalanches. The measurements carried out since the mid-1960s include glacier evolution, ice flow, as well as mass balance. The observations of more than half a century document periods of glacier growth and recession (VAW, 1997, 1998; Bauder et al., 2002; Raymond et al., 2003). Annual mass balance is measured at stakes and glacier-wide mean specific annual balance is determined (Figure 4.20). Data of point mass balance and volume changes since 1966 was re-analyzed and homogenized (Huss et al., 2015). 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. Further details on long-term observation of ice flow velocities are given in Section 5.4.

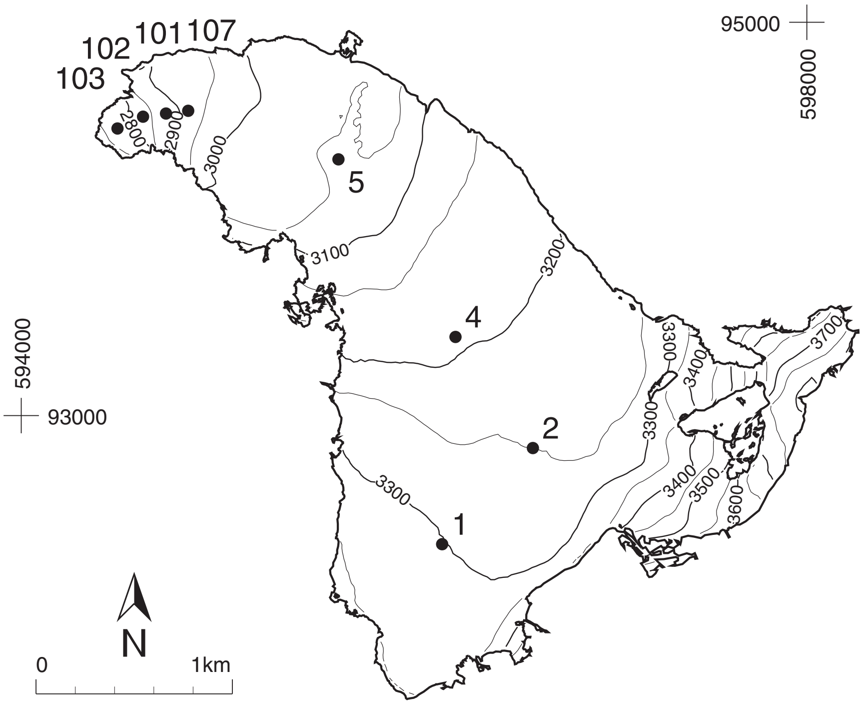

Figure 4.19: Surface topography and observational network of Glacier du Giétro.

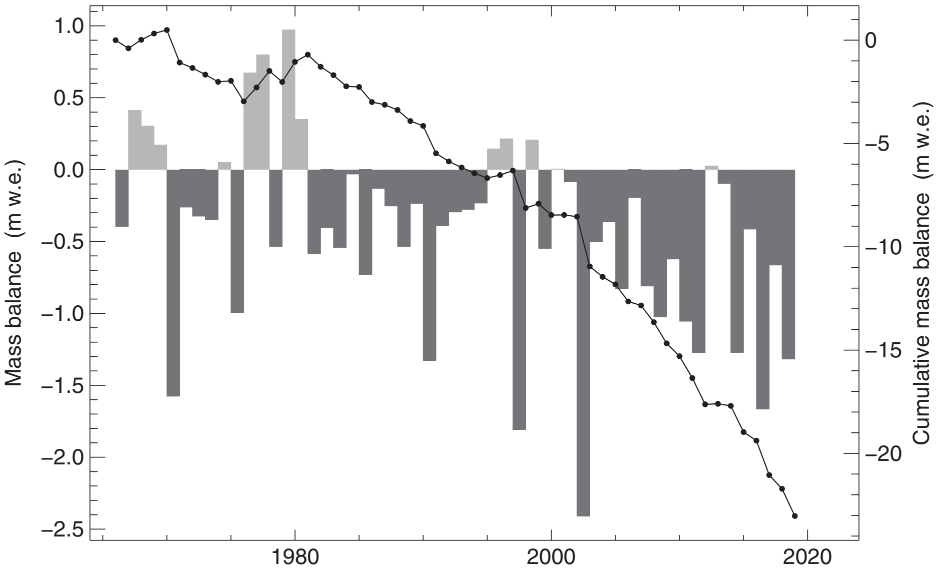

Figure 4.20: Glacier du Giétro - Mean specific annual balance (bars) and cumulative mass balance for the period 1966-2019. Values refer to the measurement period.

Investigations in 2017/18

Annual observations of mass balance with maintenance of the stake network were carried out on 17th September 2018. Negative local mass balances resulted at five stakes while the highest two sites 01 and 02 showed balanced or slightly positive balance. Due to the minimal amount of accumulation, no density measurement was performed.

Investigations in 2018/19

The annual field survey took place on 27th September 2019. At all stakes a negative local mass balance was determined. As there was no firn accumulation, no density measurement was performed. Noteworthy was the extraordinary high melt rates in the accumulation area, where mass balances varied between slight mass gains and moderate losses over the last decades. The mass balance difference between the lowest and highest sites was lower than in previous periods. On the glacier tongue the ice losses over the past few periods are enormous and the network was slightly modified. Due to the complete recession of the glacier snout, stake 103 was finally given up and replaced by stake 101 that was in use in earlier years already.

Table 4.13: Glacier du Giétro - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.030		−4991	0.027		−5843
2800 - 2900	0.071		−4623	0.066		−4768
2900 - 3000	0.225		−3644	0.221		−3681
3000 - 3100	0.869		−2252	0.881		−2644
3100 - 3200	0.985		−952	0.993		−1655
3200 - 3300	1.641		−34	1.641		−996
3300 - 3400	0.916		422	0.916		−378
3400 - 3500	0.172		613	0.172		396
3500 - 3600	0.117		668	0.117		554
3600 - 3700	0.121		680	0.121		571
3700 - 3800	0.116		725	0.116		600
3800 - 3900	0.009		747	0.009		599
2700 - 3900	5.273		−664	5.280		−1318

Table 4.14: Glacier du Giétro - Individual stake measurements of winter and annual balance.

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
01	21.09.2017		17.09.2018	596143 / 92346 / 3298		24
02	21.09.2017		17.09.2018	596605 / 92835 / 3246		186
04	21.09.2017		17.09.2018	596211 / 93400 / 3184		−666
05	21.09.2017		17.09.2018	595625 / 94165 / 3051		−2286
102	21.09.2017		17.09.2018	594625 / 94520 / 2817		−5184
103	21.09.2017		17.09.2018	594488 / 94462 / 2764		−2592
107	21.09.2017		17.09.2018	594836 / 94550 / 2907		−4563
01	17.09.2018		27.09.2019	596144 / 92348 / 3297		−1284
02	17.09.2018		27.09.2019	596603 / 92842 / 3246		−595
04	17.09.2018		27.09.2019	596205 / 93409 / 3183		−1584
05	17.09.2018		27.09.2019	595626 / 94166 / 3050		−2799
101	17.09.2018		27.09.2019	594737 / 94536 / 2866		−2241
102	17.09.2018		27.09.2019	594616 / 94515 / 2808		−4770
107	17.09.2018		27.09.2019	594860 / 94557 / 2917		−4122

4.10 Griesgletscher (Aegina)

Introduction

Griesgletscher is a temperate valley glacier located in the central Swiss Alps. The glacier currently covers an area of 4.3 km^2 flowing in north-eastern direction from 3305 m a.s.l. down to 2430 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 2015 (Huss et al., 2015) were presented in Section 4.17 of Volume 135/136.

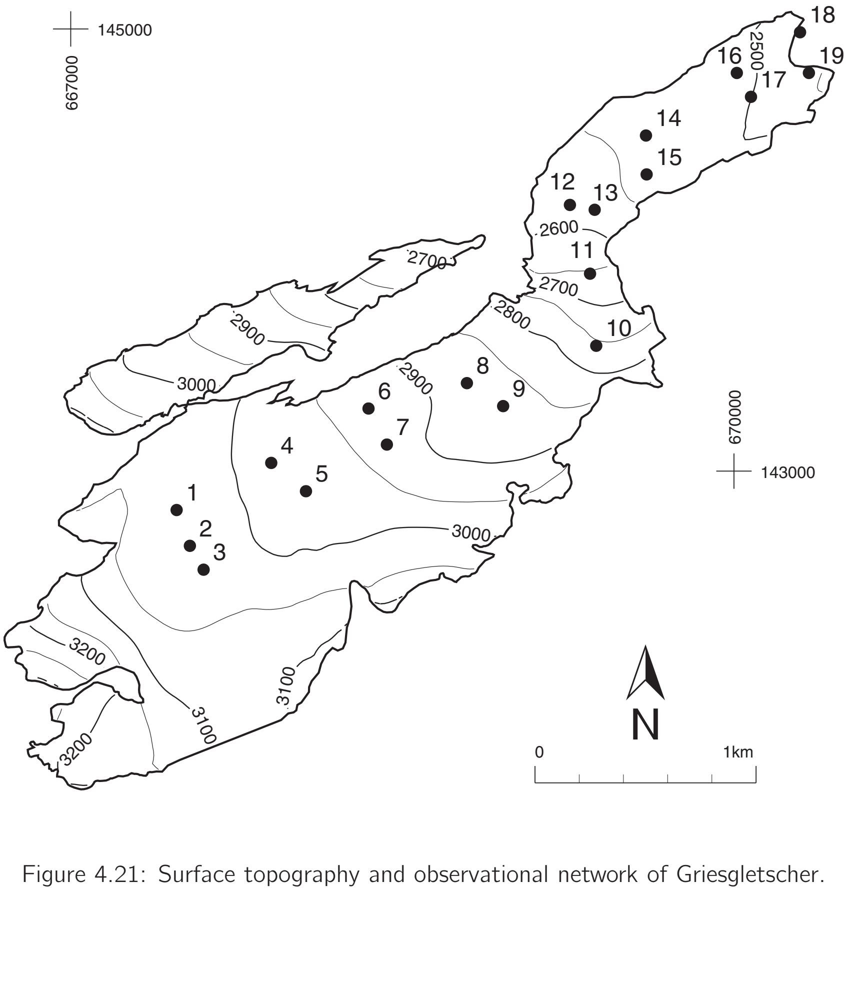

Figure 4.21: Surface topography and observational network of Griesgletscher.

Investigations in 2017/18

The measurement period extended from 7th September 2017 to 5th October 2018 with observations of winter mas balance on 17th April 2018. Snow depth soundings were collected at 19 stake locations and supplemented by two density profiles obtained by coring on the tongue and at 3000 m a.s.l. A negative annual mass balance was determined at all 19 stakes. Even in the accumulation area, firn coverage is completely depleted.

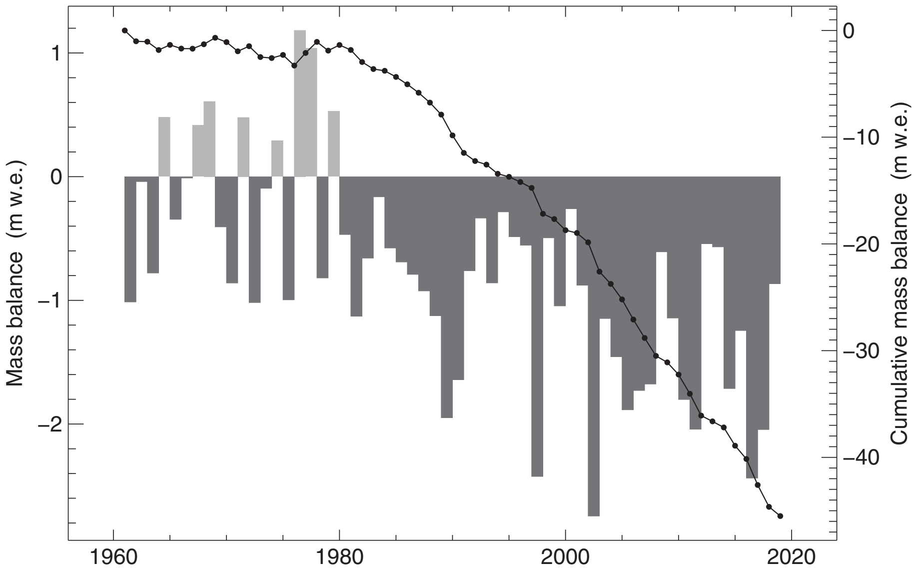

Figure 4.22: Griesgletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 1961-2019.

Investigations in 2018/19

Winter mass balance was determined on 15th April 2019. Snow soundings were performed at all 19 stakes and at 98 additional locations for better constraining the spatial distribution of snow depths. Snow density was measured by coring at two locations. The measurement period for the annual mass balance extended from 5th October 2018 to 9th September 2019. Despite of a substantial fresh snow layer on the entire glacier, annual balance was determined at 19 stakes. To account for the drastically declining area of the glacier tongue, the stake network in the lower reaches of Griesgletscher was reduced. In addition, three stakes were re-positioned in the upper area to reach a more comprehensive spatial coverage.

Table 4.15: Griesgletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.114	1482.	−5989	0.114	1465.	−3141
2500 - 2600	0.572	1593.	−4360	0.572	1530.	−2540
2600 - 2700	0.161	1830.	−3228	0.161	1789.	−1734
2700 - 2800	0.289	1949.	−2320	0.289	2021.	−1061
2800 - 2900	0.575	2022.	−1793	0.575	2174.	−704
2900 - 3000	0.992	2184.	−1609	0.992	2149.	−500
3000 - 3100	1.377	2346.	−1184	1.377	2137.	−279
3100 - 3200	0.196	2038.	−828	0.196	1888.	−108
3200 - 3300	0.071	1276.	−1514	0.071	1238.	−820
3300 - 3400	0.001	749.	−1350	0.001	723.	−941
2400 - 3400	4.348	2067	−2045	4.348	2000	−865

Rätzligletscher – the main tongue of Glacier de la Plaine Morte – in 2018 (Photo: M. Huss)

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

Stake	Period Start	Spring	End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	b_a
1	07.09.2017	17.04.2018	05.10.2018	667462 / 142815 / 3031	2330	−1990
2	07.09.2017	17.04.2018	05.10.2018	667542 / 142670 / 3025	2460	−1080
3	07.09.2017	17.04.2018	05.10.2018	667613 / 142556 / 3029	2400	−1130
4	07.09.2017	17.04.2018	05.10.2018	667911 / 143049 / 2989	2290	−1510
5	07.09.2017	17.04.2018	05.10.2018	668083 / 142926 / 2986	2160	−1530
6	07.09.2017	17.04.2018	05.10.2018	668340 / 143284 / 2935	2010	−2380
7	07.09.2017	17.04.2018	05.10.2018	668416 / 143124 / 2933	2270	−1800
8	07.09.2017	17.04.2018	05.10.2018	668777 / 143408 / 2886	1820	−2370
9	07.09.2017	17.04.2018	05.10.2018	668958 / 143284 / 2874	2010	−1850
10	07.09.2017	17.04.2018	05.10.2018	669377 / 143553 / 2768	1970	−1570
11	07.09.2017	17.04.2018	05.10.2018	669357 / 143879 / 2666	1760	−3590
12	07.09.2017	17.04.2018	05.10.2018	669253 / 144155 / 2601	1700	−3830
13	07.09.2017	17.04.2018	05.10.2018	669363 / 144139 / 2594	1910	−3530
14	07.09.2017	17.04.2018	05.10.2018	669587 / 144508 / 2551	1490	−4180
15	07.09.2017	17.04.2018	05.10.2018	669587 / 144508 / 2551	1490	−3750
16	07.09.2017	17.04.2018	05.10.2018	669985 / 144792 / 2524	1490	−4980
17	07.09.2017	17.04.2018	05.10.2018	670050 / 144674 / 2518	1590	−4730
18	07.09.2017	17.04.2018	05.10.2018	670249 / 144973 / 2493	1400	−5460
19	07.09.2017	17.04.2018	05.10.2018	670271 / 144785 / 2489	1490	−6070
1	05.10.2018	15.04.2019	09.09.2019	667421 / 142787 / 3032	1930	−790
2	05.10.2018	15.04.2019	09.09.2019	667537 / 142647 / 3026	2230	−200
3	05.10.2018	15.04.2019	09.09.2019	667620 / 142558 / 3029	2120	−130
4	05.10.2018	15.04.2019	09.09.2019	667869 / 143056 / 2991	2020	−360
5	05.10.2018	15.04.2019	09.09.2019	668068 / 142929 / 2986	2020	−460
6	05.10.2018	15.04.2019	09.09.2019	668347 / 143283 / 2935	1960	−1150
7	05.10.2018	15.04.2019	09.09.2019	668399 / 143136 / 2937	2070	−750
8	05.10.2018	15.04.2019	09.09.2019	668732 / 143408 / 2891	1910	−910
9	05.10.2018	15.04.2019	09.09.2019	668954 / 143309 / 2872	2210	−810
10	05.10.2018	15.04.2019	09.09.2019	669338 / 143551 / 2771	2190	−750
11	05.10.2018	15.04.2019	09.09.2019	669363 / 143862 / 2673	1520	−1970
12	05.10.2018	15.04.2019	09.09.2019	669233 / 144141 / 2601	1710	−1970
13	05.10.2018	15.04.2019	09.09.2019	669369 / 144124 / 2600	1570	−2270
14	05.10.2018	15.04.2019	09.09.2019	669521 / 144521 / 2553	1320	−2210
15	05.10.2018	15.04.2019	09.09.2019	669587 / 144340 / 2551	1430	−2650
16	05.10.2018	15.04.2019	09.09.2019	669944 / 144785 / 2526	1630	−2580
17	05.10.2018	15.04.2019	09.09.2019	669999 / 144672 / 2522	1430	−3180
18	05.10.2018	15.04.2019	09.09.2019	670205 / 144950 / 2502	950	−2520
19	05.10.2018	15.04.2019	09.09.2019	670226 / 144744 / 2498	1450	−3560

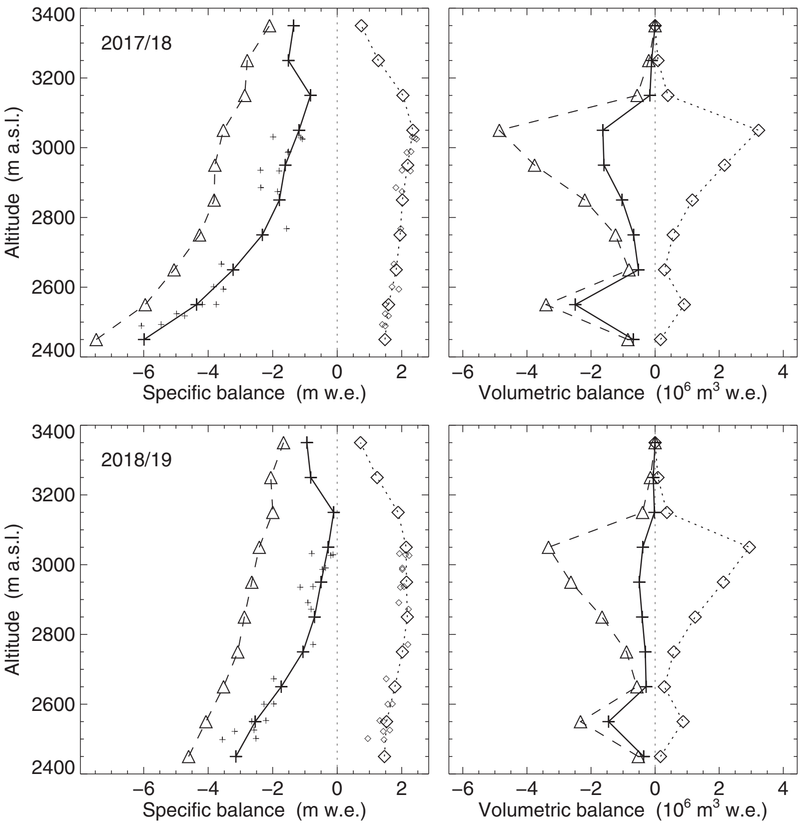

Figure 4.23: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

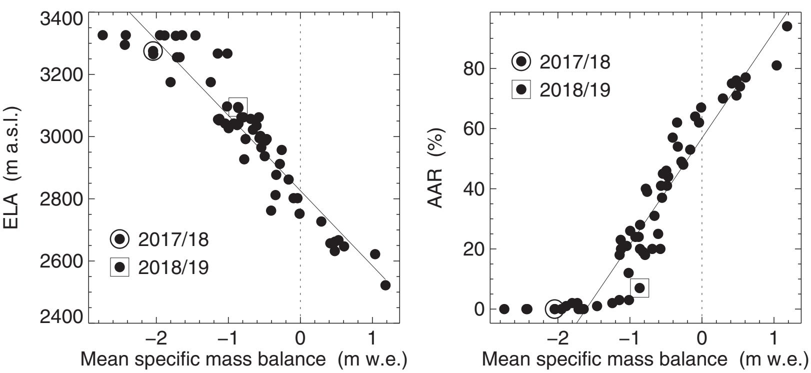

Figure 4.24: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.11 Grosser Aletschgletscher

Introduction

Grosser Aletschgletscher is the largest ice mass (84.4 km^2) 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 13 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 until today at site P3 (Figure 4.25). Huss and Bauder (2009) compiled and homogenized all existing measurements to provide a continuous time series of seasonal resolution (see Section 4.10 in Volume 127/128). Between the 1940s and 1990s a network of stakes on a longitudinal and several cross profiles was maintained with a focus on both mass balance and ice

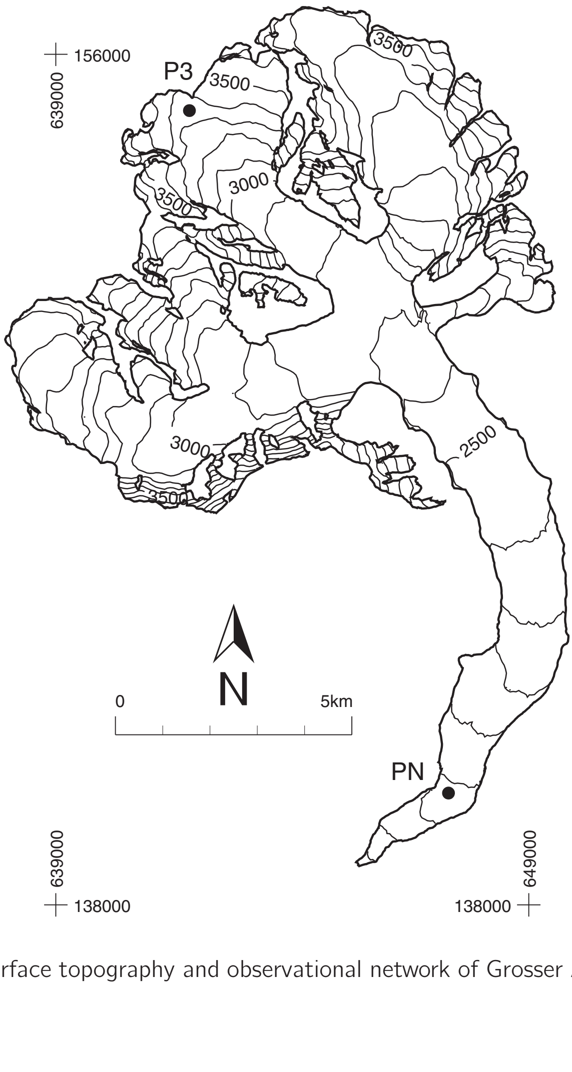

Figure 4.25: Surface topography and observational network of Grosser Aletschgletscher.

flow velocity (Zoller, 2010). As part of the educational activities of ProNatura, mass balance is measured at site PN on the glacier tongue. Starting in 1992, weekly readings have been carried out during the summer season, and since the year 1995/96 the annual balance has been 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. Results from additional investigations of ice flow velocities are given in Section 5.5.

Investigations in 2017/18

The investigations at site P3 consisted of snow depth measurements and density profiling using a core drill in spring and fall. The surface was marked at the time of the survey in the previous fall and could be located in the firn cores retrieved for density determination. This monitoring program was supplemented by stake readings approximately twice a month. The measurements were taken in spring on 6th June 2018 and in fall on 27th September 2018. In spring, mean density of the layer accumulated during winter was found to be 510 $kg\,m^{-3}$, and in fall a density of 575 $kg\,m^{-3}$ was found for the annual layer. At site PN an ablation stake is maintained and usually re-drilled twice during summer because of the high melt rate at this site. A first reading in spring was taken on 14th June 2018 and a last one in fall on 5th October 2018. Results of seasonal mass balance measurements were reported by ProNatura.

Investigations in 2018/19

The same set of measurements was conducted as in the previous period. At site P3, the spring field survey was carried out on 4th June 2019 and the fall survey on 3th October 2019. Snow depth measurements and firn coring in June showed a homogeneous layer of winter accumulation. Corresponding measurements from stake readings, firn drilling, and snow depth sounding delivered similar results. Mean density of the layer accumulated in winter was found to be 485 $kg\,m^{-3}$ in spring, and a density of 530 $kg\,m^{-3}$ in fall was found for the annual layer. Mass balance investigations at site PN were undertaken by ProNatura with measurement in spring on 22nd May 2019 and on 27th September 2019 with the determination of summer and annual balance.

Table 4.17: Grosser Aletschgletscher - 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.)
P3	12.10.2017	06.06.2018	27.09.2018	641825 / 154810 / 3340	1770	535
PN	05.10.2017	14.06.2018	19.10.2018	647260 / 140320 / 1980	−2250	−11471
P3	27.09.2018	04.06.2019	03.10.2019	641825 / 154810 / 3338	1717	790
PN	19.10.2018	05.06.2019	11.10.2019	647319 / 140491 / 1924	−1674	−12051

4.12 Hohlaubgletscher

Introduction

Hohlaubgletscher is a temperate mountain glacier located in the Mattmark area in the Southern Valais Alps. It currently covers an area of 2.1 km^2 flowing in east direction from 4020 m a.s.l. down to 2850 m a.s.l. Mass balance measurements started in 1955 as a part of investigations for the construction of the Mattmark reservoir for hydro-power production (VAW, 1999; Antoni, 2005). Initially a network of three stakes in the ablation area was maintained for mass balance and ice flow measurements (see Chapter 5). After 1967 measurements were continued at only one stake until present day. Data of point mass balance and geodetic ice volume changes since 1955 has been re-analyzed and homogenized (Huss et al., 2015). Here we only present the results of annual point mass balance measurements. Glacier-wide mass balance estimates will be evaluated periodically when new ice volume change data will be available. Further details on long-term observations of ice flow velocities are presented in Section 5.6.

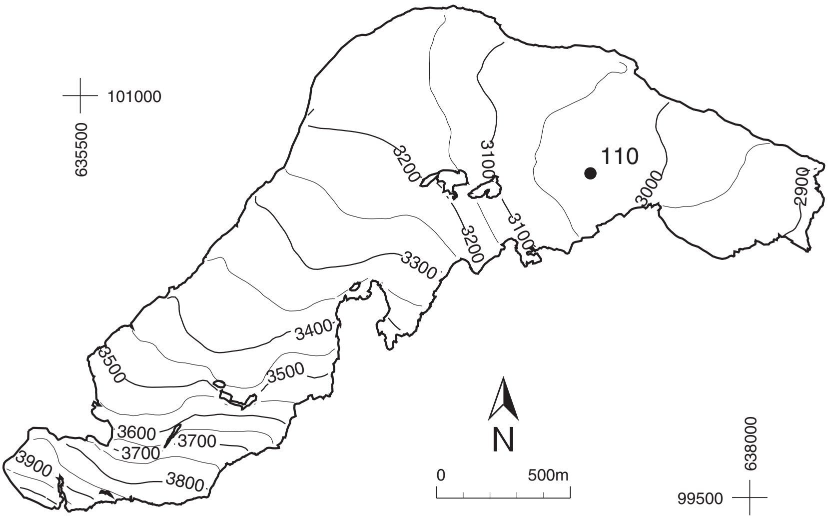

Figure 4.26: Surface topography and observational network of Hohlaubgletscher.

Investigations in 2017/18 and 2018/19

Annual observation of local mass balance at stake 110 was carried out on 9th September 2018. A negative local mass balances have been registered.

In the second observation period under review, the annual field measurements were carried out on 30th August 2019. Again, a negative local mass balance resulted at stake 110.

Table 4.18: Hohlaubgletscher - 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.)	
110	21.08.2017		05.09.2018	637404 / 100708 / 3026		−1638
110	06.09.2018		30.08.2019	637405 / 100710 / 3026		−2466

Marked horizon of the previous summer surface that melted out completely on Rhonegletscher at stake 3 in September 2018 (Photo: M. Huss)

4.13 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 shows some crevassing 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. Mass balance investigations were started in 2013, and are also performed on the southern lobe of nearby Vadret dal Corvatsch (0.2 km^2).

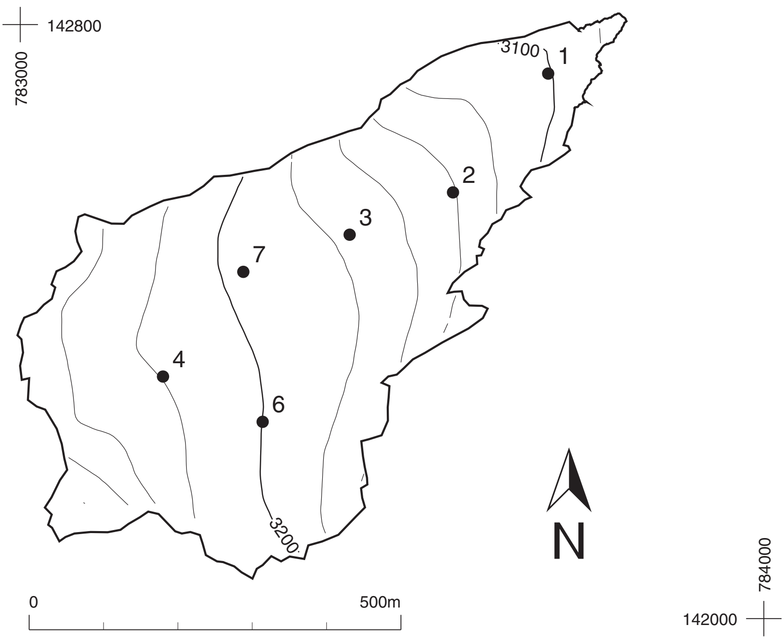

Figure 4.27: Surface topography and observational network of Vadret dal Murtèl.

Investigations in 2017/18

Winter balance was measured on 7th April 2018. Snow depth was determined based on 88 snow probings on Vadret dal Murtèl and 38 on Vadret dal Corvatsch. Snow density was measured in two snow pits, in the lower and upper part of Vadret dal Murtèl, respectively. On 16th September 2018, measured point mass balance on Vadret dal Murtèl was strongly negative at all six stakes.

Table 4.19: Vadret dal Murtèl - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.011	904.	−3001	0.008	866.	−3419
3100 - 3150	0.052	969.	−2116	0.052	763.	−2287
3150 - 3200	0.109	1083.	−1653	0.109	1071.	−1608
3200 - 3250	0.105	1436.	−452	0.105	1447.	−628
3250 - 3300	0.016	1665.	417	0.016	1653.	506
3300 - 3350	0.001	1555.	1114	0.001	1556.	1021
3050 - 3350	0.294	1215	−1233	0.291	1179	−1299

On nearby Vadret dal Corvatsch, a negative mass balance was measured at three stakes. On both glaciers, winter snow was fully depleted at the end of the melting season.

Investigations in 2018/19

Winter balance was determined on 22nd April 2019. Snow probings at 86 and 29 locations on Vadret dal Murtèl and Vadret dal Corvatsch, respectively. Snow density was measured in two snow pits. A strongly negative mass balance was measured at six stakes on Vadret dal Murtèl on 21st

Table 4.20: 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	13.09.2017	07.04.2018	16.09.2018	783710 / 142732 / 3102	1070	−3060
2	13.09.2017	07.04.2018	16.09.2018	783582 / 142575 / 3140	1220	−1820
3	13.09.2017	07.04.2018	16.09.2018	783439 / 142516 / 3177	1560	−1550
4	13.09.2017	07.04.2018	16.09.2018	783192 / 142327 / 3219	1330	−810
6	13.09.2017	07.04.2018	16.09.2018	783324 / 142266 / 3200	1250	−980
7	13.09.2017	07.04.2018	16.09.2018	783300 / 142467 / 3196	1310	−1030
1	16.09.2018	22.04.2019	21.09.2019	783711 / 142736 / 3100	750	−3370
2	16.09.2018	22.04.2019	21.09.2019	783582 / 142573 / 3140	1340	−1770
3	16.09.2018	22.04.2019	21.09.2019	783447 / 142519 / 3175	830	−1940
4	16.09.2018	22.04.2019	21.09.2019	783191 / 142325 / 3219	1530	−860
6	16.09.2018	22.04.2019	21.09.2019	783327 / 142264 / 3200	1360	−1160
7	16.09.2018	22.04.2019	21.09.2019	783300 / 142467 / 3196	1400	−790

September 2019. Also on Vadret dal Corvatsch mass balance was negative at all four stakes, with a loss of more than 2 m w.e. at an elevation of 3300 m a.s.l. The last years with strong mass losses have resulted more difficult accessibility of Vadret dal Murtèl and in disintegration of Vadret dal Corvatsch: the small lobe below Piz Murtèl with one measurement site has split off from the rest of the glacier.

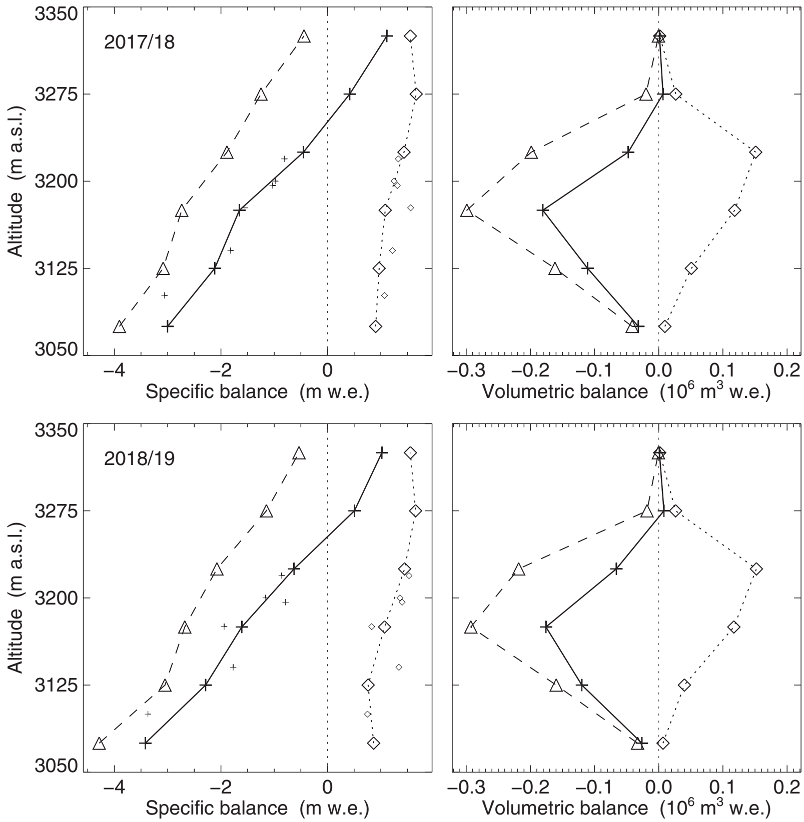

Figure 4.28: Specific (left) and volumetric (right) winter (dotted, ⋄), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

4.14 Pizolgletscher

Introduction

Pizolgletscher is a steep cirque glacier in the north-eastern Swiss Alps. With a surface area of about 0.03 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 relatively low elevation (2640-2760 m a.s.l.) indicating that it depends on high quantities of winter accumulation. Seasonal mass balance measurements were started in 2006 (Huss, 2010).

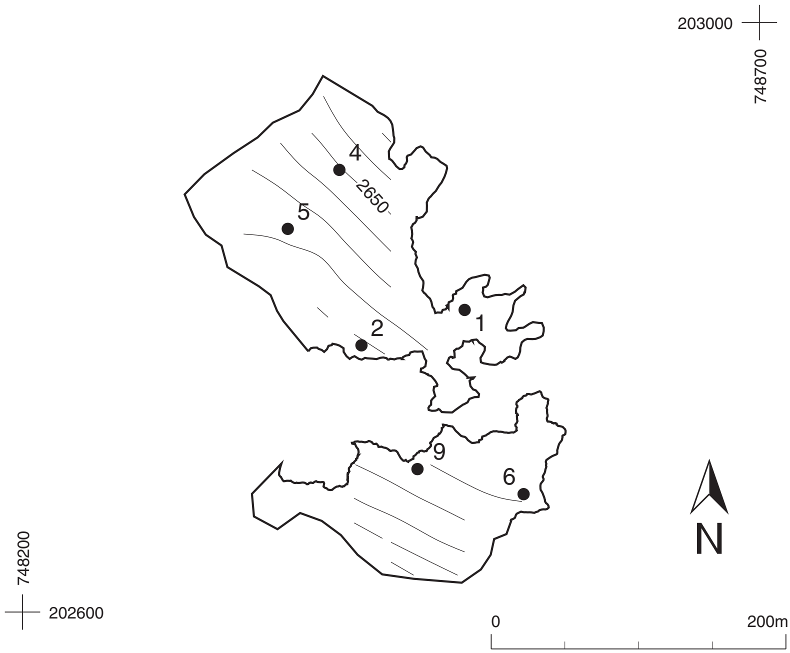

Figure 4.29: Surface topography and observational network of Pizolgletscher.

Investigations in 2017/18

Winter balance was determined on 24th March 2018. Snow probings at 63 locations were performed and snow density was measured in a snow pit. All stakes were visited on 23th August, 18th September and 16th October 2018 and a strongly negative mass balance over the annual period was observed at six stakes. The massive mass losses and the thinning of the last decade have

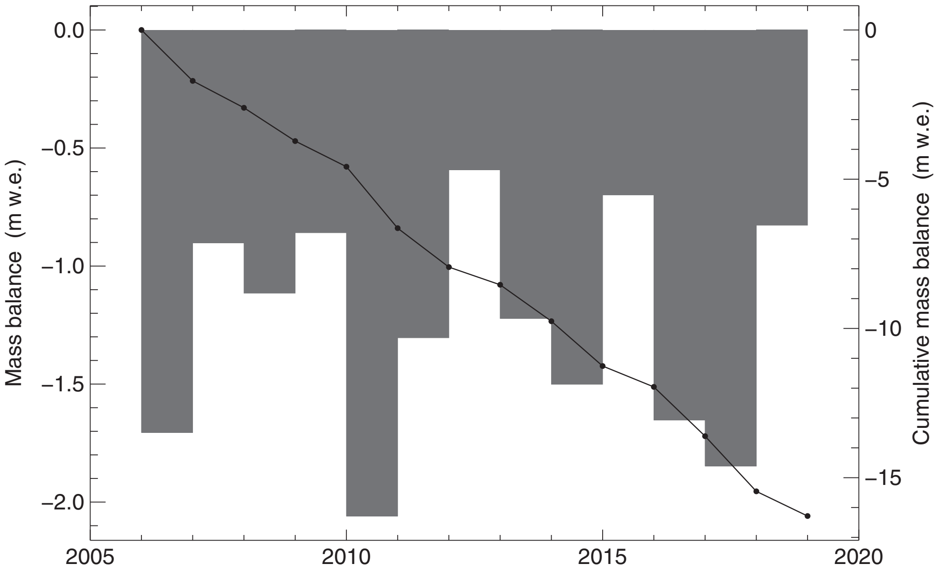

Figure 4.30: Pizolgletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 2006-2019.

manifested in the disintegration of the glacier during this year's extraordinarily hot summer. Glacier area has reduced by about 40% only in 2018, the connection between the upper and the lower part was lost, and the glacier terminus has substantially moved upwards. Five stakes have been redrilled but all except for one are in very shallow ice so that maintaining them any further will not be possible.

Investigations in 2018/19

The winter field survey was conducted on 30th March 2019. Snow probings at 48 locations were realized and snow density was measured in a snow pit. On 4th and 22nd September 2019 all stakes were visited, and one stake was re-drilled. Despite the massive winter snow amounts the glacier was again completely snow-free in September and the disintegration continued. The remnants of the glacier have split into five small ice bodies of which a significant share is covered by debris. Due to this evolution it was decided to officially stop the monitoring of the glacier-wide balance within GLAMOS although some observations will be performed also in the next years to document the complete demise of Pizolgletscher. In September 2019, a commemoration ceremony with about 250 hikers and international media coverage was organized by environmental organizations on Pizolgletscher to point to the fast wastage of Alpine glaciers.

Table 4.21: Pizolgletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.002	1779.	−2568	0.001	1432.	−1565
2650 - 2700	0.023	1888.	−2230	0.017	1640.	−853
2700 - 2750	0.011	2225.	−1061	0.007	1623.	−643
2750 - 2800	0.001	2217.	−677	0.001	1497.	−689
2600 - 2800	0.037	1994	−1847	0.026	1622	−827

Table 4.22: 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.)	
1	29.09.2017	24.03.2018	16.10.2018	748500 / 202805 / 2672	1730	−2760
2	29.09.2017	24.03.2018	16.10.2018	748430 / 202781 / 2694	2100	−2250
4	29.09.2017	24.03.2018	16.10.2018	748415 / 202903 / 2661	1710	−2680
5	29.09.2017	24.03.2018	16.10.2018	748380 / 202867 / 2678	2080	−2490
6	29.09.2017	24.03.2018	16.10.2018	748541 / 202684 / 2709	2370	−1220
9	29.09.2017	24.03.2018	16.10.2018	748468 / 202697 / 2716	2310	−1780
1	16.10.2018	30.03.2019	22.09.2019	748495 / 202799 / 2675	1300	−1270
2	16.10.2018	30.03.2019	22.09.2019	748433 / 202780 / 2694	1650	−1020
4	16.10.2018	30.03.2019	22.09.2019	748408 / 202901 / 2665	1920	−1480
5	16.10.2018	30.03.2019	22.09.2019	748370 / 202848 / 2683	1900	−550
6	16.10.2018	30.03.2019	22.09.2019	748532 / 202682 / 2711	1370	−480
9	16.10.2018	30.03.2019	22.09.2019	748468 / 202697 / 2716	1490	−580

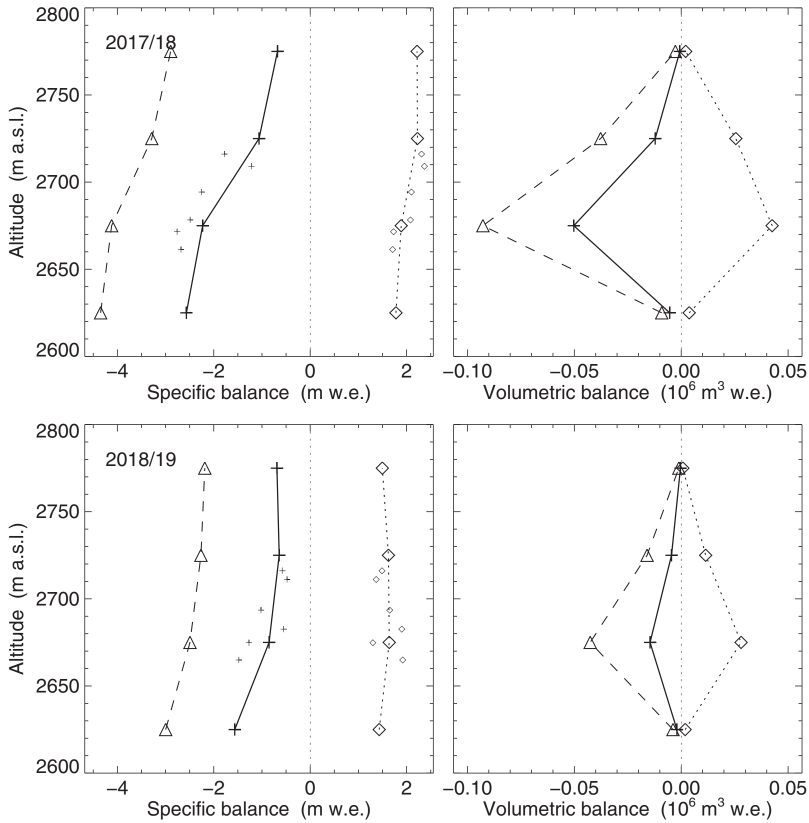

Figure 4.31: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

4.15 Glacier de la Plaine Morte

Introduction

Glacier de la Plaine Morte (7.1 km^2) is the largest plateau glacier in the European Alps and thus represents a particularly interesting site for studying 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 lie in a narrow altitudinal band of 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 (Lindner et al., 2020). The seasonal mass balance of Glacier de la Plaine Morte is 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).

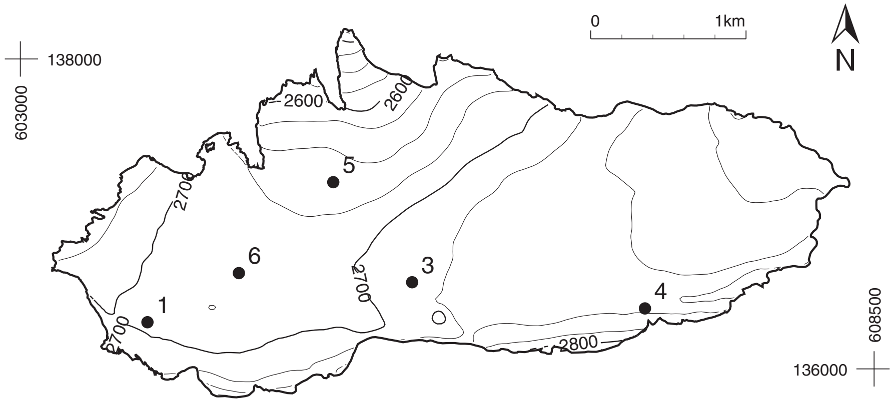

Figure 4.32: Surface topography and observational network of Glacier de la Plaine Morte.

Investigations in 2017/18

Measurements of the winter mass balance were conducted on 6th April 2018. Snow probings at 72 locations distributed over most of glacier surface were performed and snow density was determined in a snow pit. Snow measurements were challenging due to deep and strongly compacted snow. The stake network was maintained on 5th September 2018 and all five stakes were visited again on 30th September 2018. Due to above-average summer temperatures melt rates again were very high and the entire glacier was completely snow-free. Lac des Faverges drained subglacially on 27th July 2018 causing damages to infrastructure in the Simme valley. The glacier flood was by far the largest registered so far on Plaine Morte and the municipality of Lenk decided to take

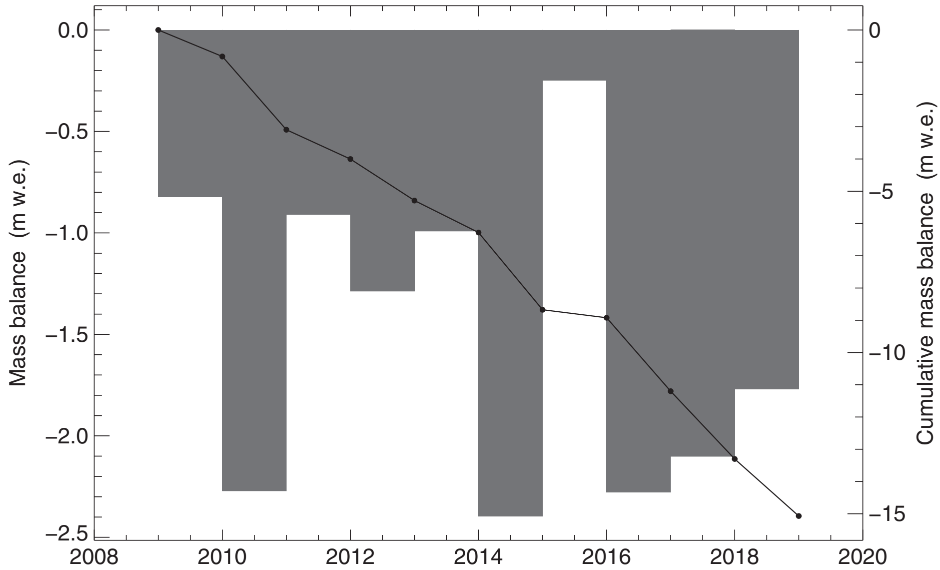

Figure 4.33: Glacier de la Plaine Morte - Mean specific annual balance (bars) and cumulative mass balance for the period 2006-2019.

preventive actions. A meteorological station in the central part of Plaine Morte is maintained and is designed to investigate snow accumulation processes (Gugerli et al., 2019). Snow water equivalent is continuously measured using a cosmic ray sensor deployed at the snow-ice interface.

Investigations in 2018/19

During the winter field survey on 2nd April 2019 snow probings at 90 locations distributed over the entire glacier were acquired and snow density was measured in a snow pit. An intercomparison of snow density devices was performed three additional times during the accumulation season next to direct snow water equivalent measurement using the cosmic ray sensor (Gugerli et al., 2019). During a mid-summer field survey, a station to continuously measure ice ablation was installed and is used in a project for real-time monitoring of Swiss glaciers. On 30.08.2019 all five stakes were re-installed and they were re-visited on 30th September 2019. Again, mass losses were around 2 metres at all stakes. In April 2019 large efforts by the municipality of Lenk were started to dig a more than 1 km long supraglacial trench in order to limit water volume of Lac des Faverges. After 11th July 2019 lake water flowed through the channel which subsequently further incised into the ice, thus slowly draining around half of the lake volume. On 25th August 2019 the remaining around 0.7 million m^3 drained subglacially without any impacts in the Simme valley.

Table 4.23: Glacier de la Plaine Morte - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	2226.	−2266	0.006	1651.	−1828
2500 - 2600	0.144	2232.	−2479	0.161	1659.	−1947
2600 - 2700	2.316	2307.	−2326	2.604	1668.	−1858
2700 - 2800	4.676	2304.	−2008	4.319	1589.	−1717
2800 - 2900	0.062	2272.	−362	0.021	1581.	−160
2900 - 3000	0.015	2243.	−3	0.000		
2400 - 3000	7.219	2303	−2101	7.112	1619	−1769

Table 4.24: 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	11.10.2017	06.04.2018	30.09.2018	603820 / 136298 / 2700	2350	−2450
3	11.10.2017	06.04.2018	30.09.2018	605524 / 136559 / 2719	2350	−1750
4	11.10.2017	06.04.2018	30.09.2018	607024 / 136390 / 2749	2230	−1680
5	11.10.2017	06.04.2018	30.09.2018	605017 / 137204 / 2668	2170	−2160
6	11.10.2017	06.04.2018	30.09.2018	604409 / 136617 / 2688	2270	−2340
1	30.09.2018	02.04.2019	30.09.2019	603818 / 136300 / 2695	1590	−2020
3	30.09.2018	02.04.2019	30.09.2019	605522 / 136561 / 2715	1630	−1530
4	30.09.2018	02.04.2019	30.09.2019	607000 / 137002 / 2753	1540	−1470
5	30.09.2018	02.04.2019	30.09.2019	605016 / 137206 / 2663	1590	−1690
6	30.09.2018	02.04.2019	30.09.2019	604408 / 136618 / 2683	1610	−1860

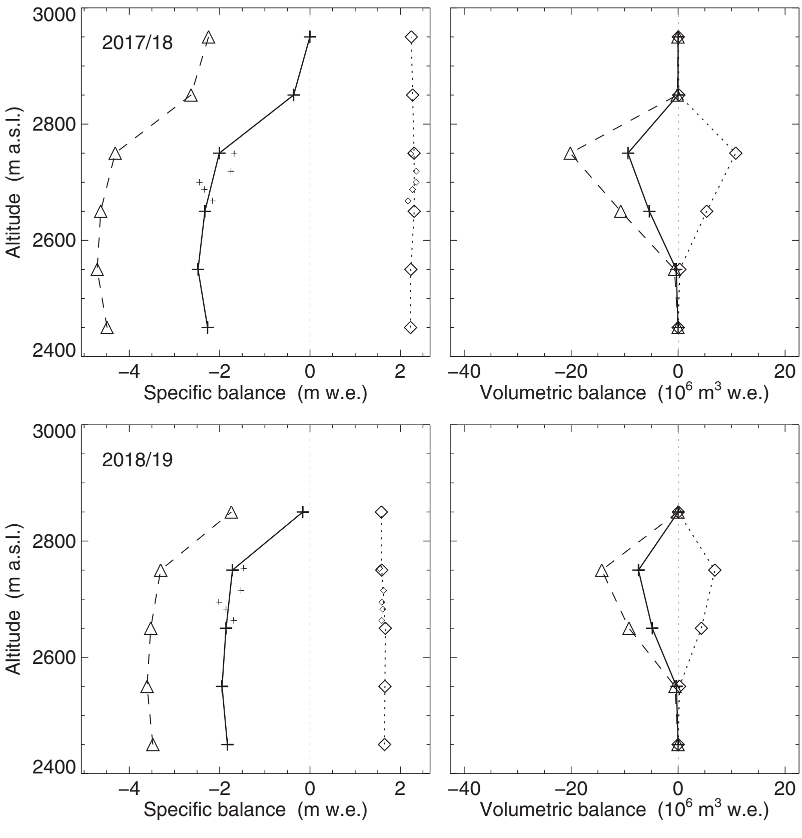

Figure 4.34: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

4.16 Rhonegletscher

Introduction

Rhonegletscher is a temperate valley glacier located in the central Swiss Alps, and is the source of 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 km² 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 such observations worldwide. After two periods of measurements between 1884-1910, and 1980-1982, the mass balance monitoring was resumed in 2006. Determination of volumetric changes in decadal resolution extends even further back to 1874 (Bauder et al., 2007).

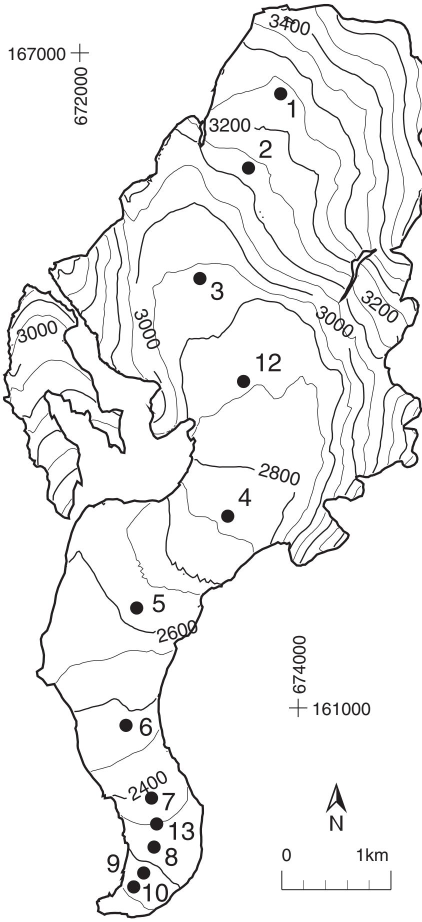

Figure 4.35: Surface topography and observational network of Rhonegletscher.

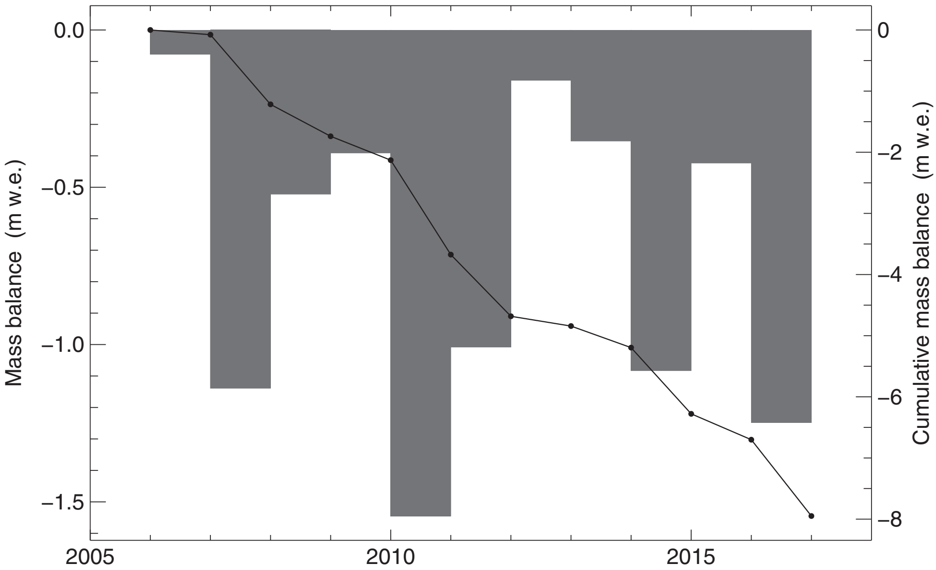

Figure 4.36: Rhonegletscher - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 2006-2019.

Topographic maps or photogrammetrical surveys exist for 1874, 1929, 1959, 1980, 1991, 2000, and 2007 and annually for the glacier tongue below 2700 m a.s.l. since 2012. Further details on observations of ice flow velocities are presented in Section 5.7.

Investigations in 2017/18

The spring survey for the determination of winter mass balance was performed on 24th April 2018. A total of 314 snow probings distributed over the entire area of Rhonegletscher were obtained. The density was measured at the two sites 3 and 13 based on coring. Investigations of snow depth probing were complemented with a ground penetrating radar survey along a longitudinal central profile from stake 1 down to stake 13. The ablation area was repeatedly visited in July and August for additional intermediate stake readings during the melting season. On 12 th September 2018 all measurement sites were visited for the determination of the annual mass balance. Density was measured using a core drill at sites 1, 2 and 3. Net accumulation was found only above 2900 m a.s.l. but with many exposed bumps that show complete melt-out even above.

Investigations in 2018/19

The winter mass balance was determined on 18st April 2019. Snow depth soundings were performed at 291 locations including all measurement sites. Snow density was measured by coring again at

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

Stake	Period			Coordinates	Mass balance	
	Start	Spring	End		b_w	b_a
				(m / m / m a.s.l.)	(mm w.e.)	
01	26.09.2017	24.04.2018	12.09.2018	673813 / 166616 / 3235	3105	1261
02	26.09.2017	24.04.2018	12.09.2018	673514 / 165899 / 3110	2985	484
03	26.09.2017	24.04.2018	12.09.2018	673109 / 164879 / 2924	2500	−629
04	26.09.2017	24.04.2018	12.09.2018	673363 / 162762 / 2743	1980	−2169
05	26.09.2017	24.04.2018	12.09.2018	672521 / 161920 / 2599	573	−4518
06	26.09.2017	24.04.2018	12.09.2018	672423 / 160843 / 2460	833	−3600
07	26.09.2017	24.04.2018	12.09.2018	672656 / 160173 / 2350	800	−5760
08	26.09.2017	24.04.2018	12.09.2018	672681 / 159725 / 2285	1125	−5238
09	26.09.2017	24.04.2018	12.09.2018	672606 / 159501 / 2235	1050	−6156
10	26.09.2017	24.04.2018	12.09.2018	672539 / 159391 / 2216	1150	−5724
12	26.09.2017	24.04.2018	12.09.2018	673500 / 163990 / 2841	2320	−1413
13	26.09.2017	24.04.2018	29.08.2018	672705 / 159937 / 2311	895	−5607
01	12.09.2018	18.04.2019	12.09.2019	673815 / 166615 / 3234	2414	1300
02	12.09.2018	18.04.2019	12.09.2019	673519 / 165923 / 3113	2059	428
03	12.09.2018	18.04.2019	12.09.2019	673100 / 164924 / 2925	2304	432
04	12.09.2018	18.04.2019	12.09.2019	673366 / 162771 / 2742	1852	−1602
05	12.09.2018	18.04.2019	12.09.2019	672522 / 161909 / 2595	661	−4347
06	12.09.2018	18.04.2019	12.09.2019	672423 / 160851 / 2458	192	−5805
07	12.09.2018	18.04.2019	12.09.2019	672656 / 160173 / 2345	331	−5715
08	12.09.2018	18.04.2019	12.09.2019	672678 / 159725 / 2280	677	−4932
09	12.09.2018	18.04.2019	12.09.2019	672608 / 159501 / 2229	517	−6318
12	12.09.2018	18.04.2019	12.09.2019	673497 / 163989 / 2839	2184	−747
13	12.09.2018	18.04.2019	12.09.2019	672704 / 159939 / 2306	329	−5760

the two sites 3 and 13. In addition, a ground penetrating radar was operated on a longitudinal transect for a continuous snow depth survey between stakes 1 and 13. Measurements at 12 stakes for annual mass balance were carried out on 12th September 2019. Density measurements were performed at the sites 1, 2 and 3. Most of the glacier was covered with 20-40 cm of fresh snow from the previous week. Summer melt out reached about 2850 m a.s.l. between site 12 and 3, but the snowline was significantly higher locally in more wind-exposed regions. Additional intermediate stake readings were obtained during the melting season as well as after the fall campaign in mid and end of October 2019.

Table 4.26: Rhonegletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.262	1190.	−5527	0.246	1389.	−5456
2300 - 2400	0.388	895.	−5511	0.383	1097.	−5682
2400 - 2500	0.610	1147.	−3866	0.608	1026.	−5360
2500 - 2600	0.988	1130.	−3731	1.030	1119.	−4602
2600 - 2700	0.799	1235.	−3921	0.808	1243.	−3845
2700 - 2800	1.062	1861.	−2676	1.047	1758.	−2244
2800 - 2900	2.107	2450.	−1289	2.104	2278.	−526
2900 - 3000	2.047	2540.	−679	2.126	2301.	283
3000 - 3100	1.859	2536.	7	1.864	2308.	658
3100 - 3200	1.535	2535.	565	1.542	2234.	678
3200 - 3300	1.456	2571.	905	1.462	2153.	928
3300 - 3400	0.951	2606.	1241	0.956	1972.	996
3400 - 3500	0.795	2327.	1202	0.795	1790.	1056
3500 - 3600	0.334	1555.	498	0.334	1338.	629
2200 - 3600	15.194	2171	−1000	15.306	1941	−773

Tongue of Rhonegletscher with proglacial lake and covered area of an ice cave in September 2019 (Photo: M. Huss)

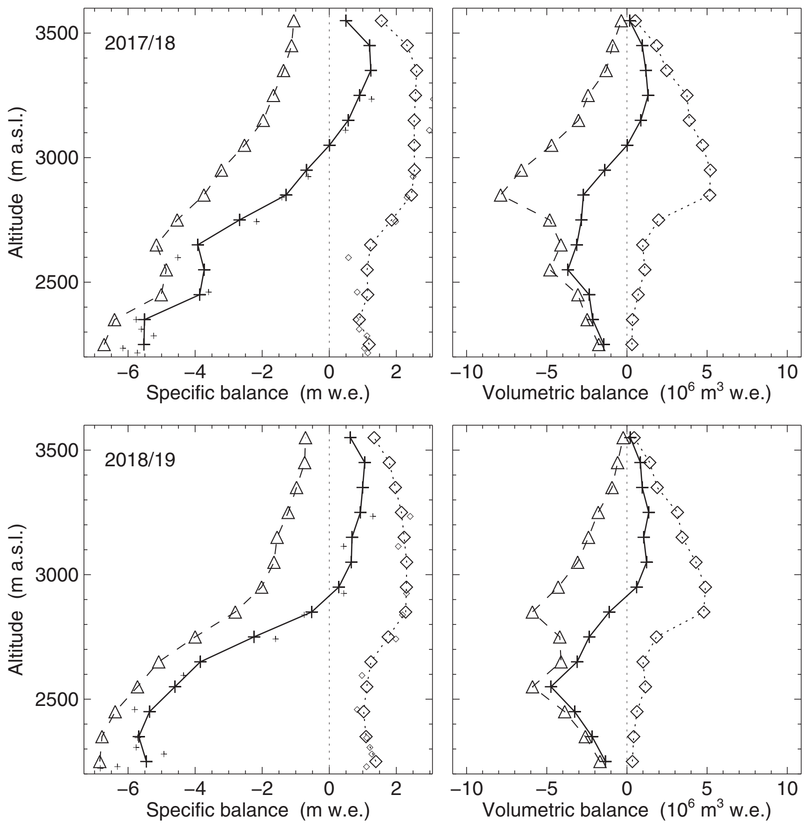

Figure 4.37: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

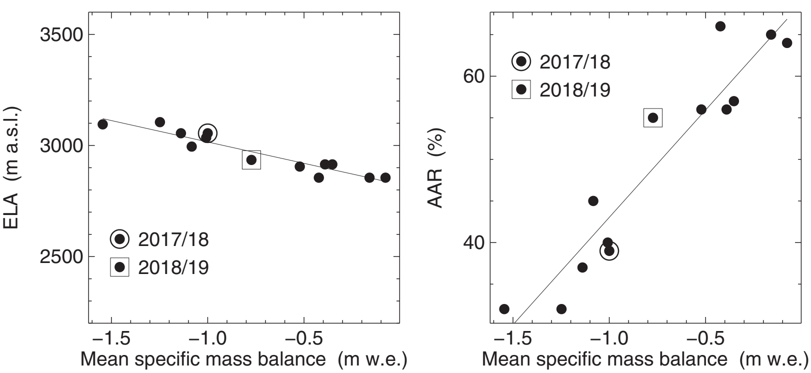

Figure 4.38: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.17 Schwarzberggletscher

Introduction

Schwarzberggletscher is a temperate mid-sized mountain glacier located in the Mattmark area in the Southern Valais Alps. It currently covers an area of 4.9 km^2 flowing in north direction from 3570 m a.s.l. down to 2690 m a.s.l. Mass balance measurements started in 1955 as a part of investigations for the construction of the Mattmark reservoir for hydro-power production (VAW, 1999; Antoni, 2005). Initially a network of seven stakes distributed over the entire area was maintained for mass balance and ice flow measurements (see Chapter 5). After 1967 measurements were continued at only four sites. Presently, annual observations at three sites are maintained. Collected data of point mass balance and geodetic ice volume changes since 1955 have been re-

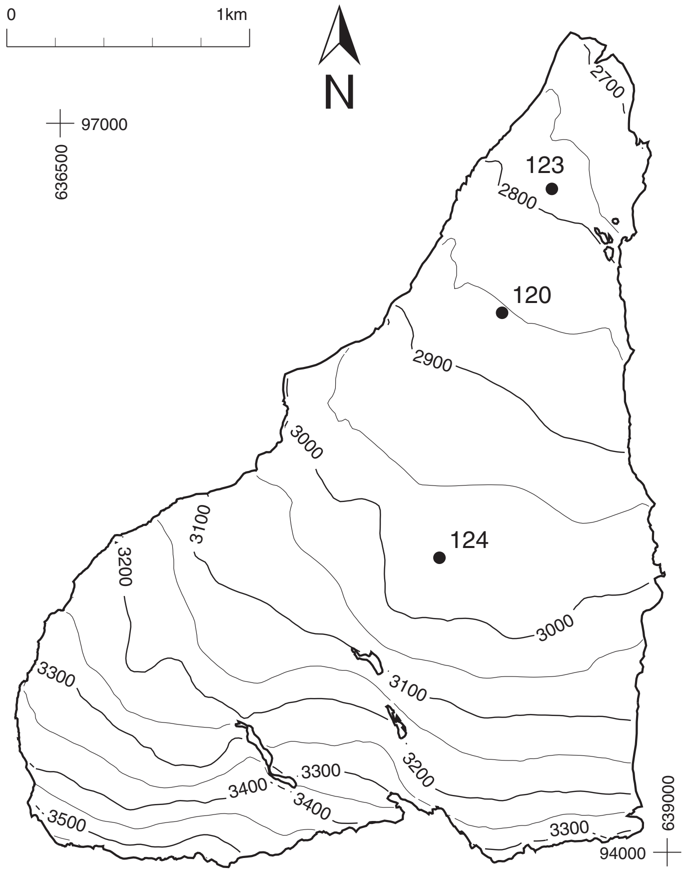

Figure 4.39: Surface topography and observational network of Schwarzberggletscher.

analyzed and homogenized (Huss et al., 2015). 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. Further details on long-term observations of ice flow velocities are in Section 5.6.

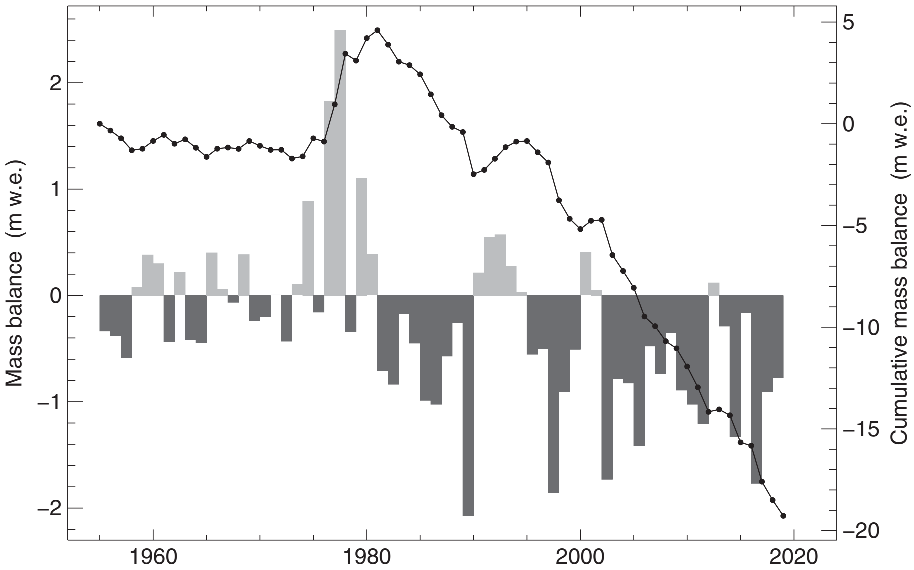

Figure 4.40: Schwarzberggletscher - Mean specific annual balance (bars) and cumulative mass balance for the period 1955-2019. Values refer to the measurement period.

Investigations in 2017/18 and 2018/19

Annual observations of mass balance with maintenance of the stake network were carried out on 9th September 2018. All three stakes were located and set back to initial position. Negative local mass balances have been registered for all stakes.

In the second observation period under review, the annual field measurements were carried out on 30th August 2019. Again, negative local mass balances resulted at all stakes.

Table 4.27: Schwarzberggletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.009		−4246	0.001		−3824
2700 - 2800	0.290		−3924	0.228		−3274
2800 - 2900	0.666		−2732	0.627		−2546
2900 - 3000	1.188		−1776	1.107		−1530
3000 - 3100	0.854		−808	0.838		−722
3100 - 3200	0.793		−26	0.788		−106
3200 - 3300	0.648		619	0.648		449
3300 - 3400	0.367		1114	0.367		878
3400 - 3500	0.229		1407	0.229		1116
3500 - 3600	0.058		1254	0.058		1005
2600 - 3600	5.102		−903	4.891		−776

Table 4.28: Schwarzberggletscher - 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.)	
120	21.08.2017		06.09.2018	638321 / 96220 / 2846		−2745
123	21.08.2017		06.09.2018	638526 / 96731 / 2765		−3636
124	21.08.2017		06.09.2018	638066 / 95202 / 2981		−1737
120	06.09.2018		30.08.2019	638319 / 96220 / 2844		−2655
123	06.09.2018		30.08.2019	638524 / 96729 / 2762		−2961
124	06.09.2018		30.08.2019	638061 / 95212 / 2979		−1359

4.18 Sankt Annafirn

Introduction

Sankt Annafirn is a north-facing 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. Investigations of the glacier mass balance were started in 2012. Since 2013, measurements are also performed on nearby Schwarzbachfirn (0.03 km^2). Both glaciers represent the size class of very small glaciers and deliver direct observations of seasonal glacier mass change in the hydrological catchment of the Reuss. Ice wastage in the region has been considerable over the last decades. By 2010, St. 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).

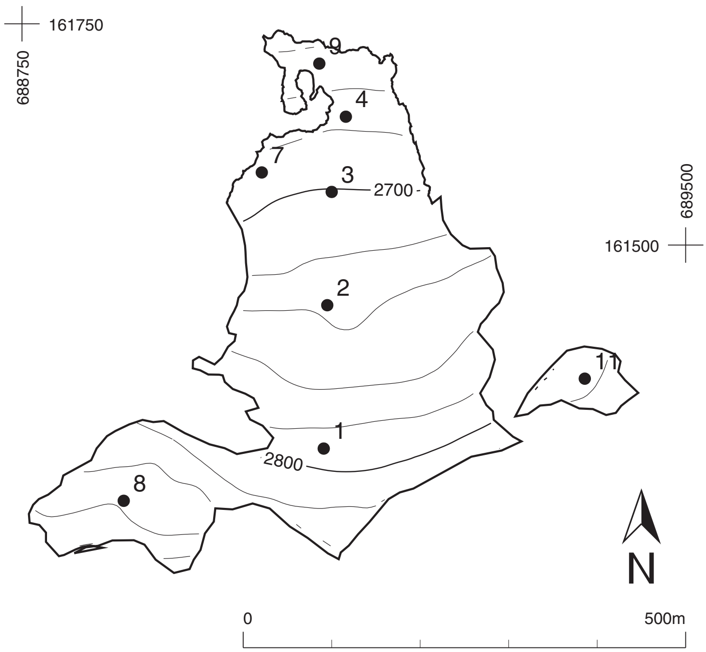

Figure 4.41: Surface topography and observational network of Sankt Annafirn.

Table 4.29: Sankt Annafirn - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude (m a.s.l.)	2017/18 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	2018/19 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2600 - 2650	0.003	1436.	−2532	0.001	2099.	−2302
2650 - 2700	0.022	1414.	−2604	0.018	2054.	−1368
2700 - 2750	0.043	1752.	−1205	0.043	2365.	−448
2750 - 2800	0.039	2056.	−876	0.039	2595.	−218
2800 - 2850	0.035	2310.	−425	0.034	2833.	131
2850 - 2900	0.012	2423.	−72	0.012	2471.	−64
2600 - 2900	0.154	1955	−1077	0.148	2503	−345

Table 4.30: Sankt Annafirn - Individual stake measurements of winter and annual balance.

Stake	Period Start	Spring	End	Coordinates (m / m / m a.s.l.)	Mass balance b_w (mm w.e.)	b_a
1	24.09.2017	19.04.2018	20.09.2018	689096 / 161286 / 2782	820	−1880
2	24.09.2017	19.04.2018	20.09.2018	689095 / 161432 / 2737	1630	−1190
3	24.09.2017	19.04.2018	20.09.2018	689102 / 161559 / 2701	1450	−2080
4	24.09.2017	19.04.2018	20.09.2018	689114 / 161635 / 2680	1490	−3280
7	24.09.2017	19.04.2018	20.09.2018	689021 / 161582 / 2689	1470	−2540
8	24.09.2017	19.04.2018	20.09.2018	688865 / 161221 / 2856	2550	−540
9	24.09.2017	19.04.2018	20.09.2018	689086 / 161705 / 2649	1240	−2860
11	24.09.2017	19.04.2018	20.09.2018	689386 / 161349 / 2816	2690	−1000
1	20.09.2018	10.05.2019	19.09.2019	689053 / 161241 / 2806	2650	−340
2	20.09.2018	10.05.2019	19.09.2019	689095 / 161432 / 2737	2480	−320
3	20.09.2018	10.05.2019	19.09.2019	689107 / 161558 / 2701	1910	−780
4	20.09.2018	10.05.2019	19.09.2019	689115 / 161643 / 2676	1820	−2030
7	20.09.2018	10.05.2019	19.09.2019	689021 / 161582 / 2689	2360	−1010
8	20.09.2018	10.05.2019	19.09.2019	688865 / 161221 / 2856	2480	−750
11	20.09.2018	10.05.2019	19.09.2019	689386 / 161349 / 2816	2680	−110

Investigations in 2017/18

The winter mass balance observations were conducted on 19th April 2018. Snow density was measured based on snow coring at one location. Snow depth was determined based on 62 snow probings on Sankt Annafirn, and 60 probings on Schwarzbachfirn, respectively. Snow depth was partly higher than 7 m. On 20th September 2018, a negative mass balance was measured at eight stakes on St. Annafirn, and two stakes on Schwarzbachfirn. Most stakes were redrilled. Due to the ice losses of the last years the area of Schwarzbachfirn has strongly reduced and the remaining ice is strongly covered by debris. The programme on this very small glacier will thus only be continued until the stakes have melted out. On St. Annafirn, annual mass balance has been affected by artificial snow relocation activities related to ski run.

Investigations in 2018/19

End-of-winter snow depth was measured at 61 locations on Sankt Annafirn, and at 22 locations on Schwarzbachfirn on 10th May 2019. Snow density was determined based on snow coring at one location. During the late summer field survey on 29th September 2019, a negative mass balance was measured at seven stakes. Melt rates were smaller than in previous years, however, which is attributed to very high snow depths in late winter. Also on Schwarzbachfirn, moderate overall mass loss was measured but the upper stake showed a balance mass budget for the first time since 2014.

Sankt Annafirn in September 2019 with some fresh snow (Photo: M. Huss)

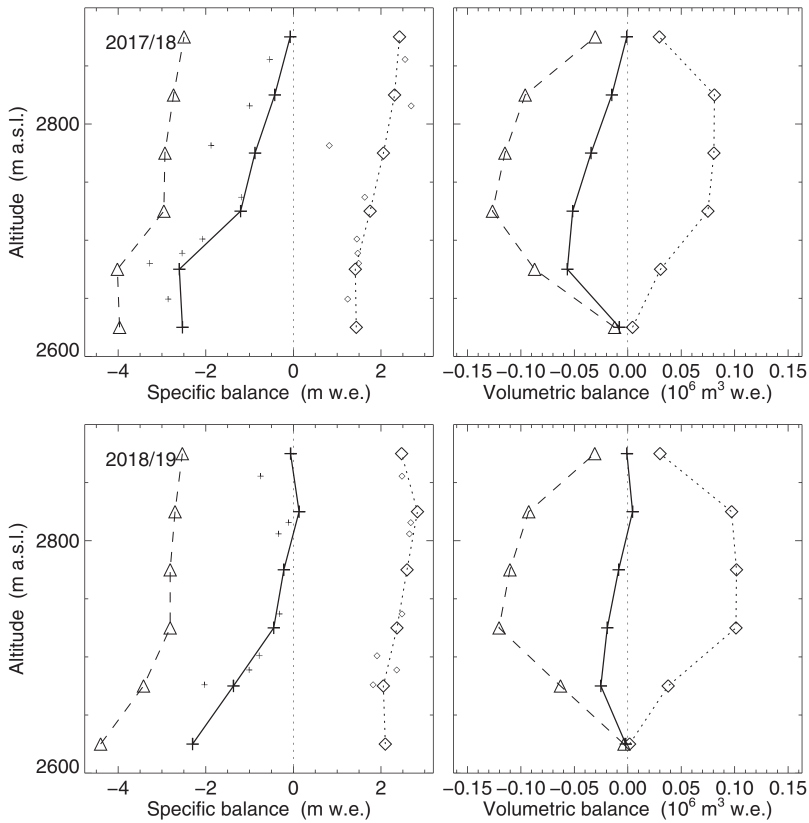

Figure 4.42: Specific (left) and volumetric (right) winter (dotted, ◇), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

4.19 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 2.5 km^2, extending from 3080 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 obtain a continuous time series of seasonal point mass balance 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 point mass balance data and geodetic ice volume changes for the period 1959 to 2007 to derive glacier wide mass balances. An update for the period 1918 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. Further details on observations of ice flow velocities are presented in Section 5.8.

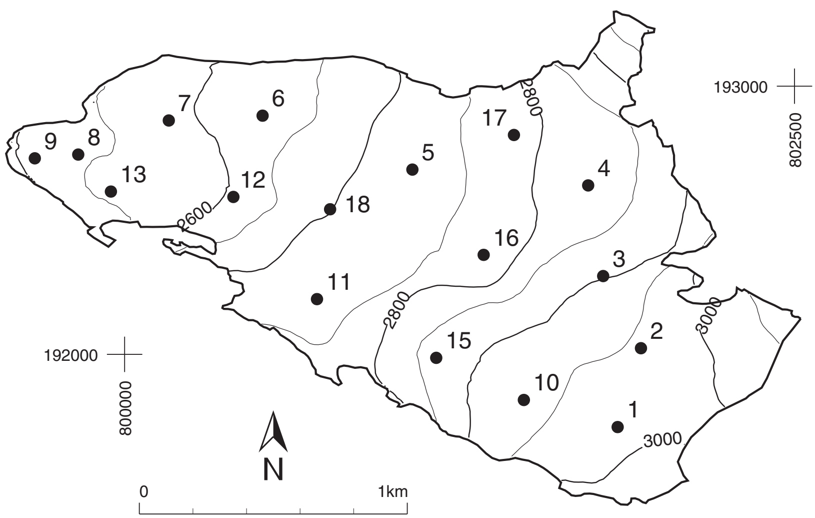

Figure 4.43: Surface topography and observational network of Silvrettagletscher.

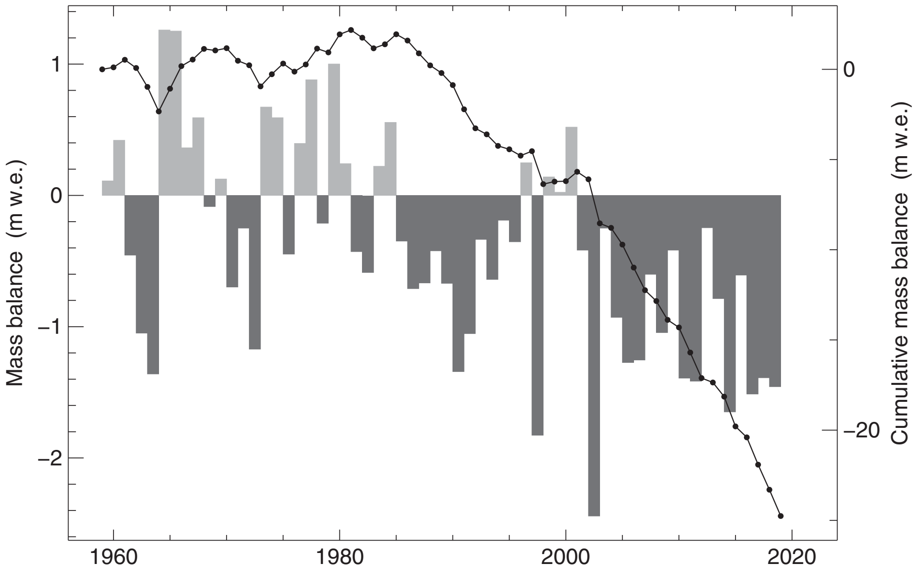

Figure 4.44: Silvrettagletscher - Mean specific annual balance (bars) and cumulative mass balance (line) for the period 1959-2019.

Investigations in 2017/18

Field measurements of winter mass balance were conducted on 19th May 2018. Snow depth probings were taken at 167 locations including all sites in the observational network. Density profiles using a core drill method were acquired at the sites 2 and 7. Out of eight individual density profiles a mean density of the accumulated winter layer of 490 ± 5 kg m^{-3} resulted, showing no difference between the two sites sampled. The glacier remained completely snow-covered until mid-June 2018. During the melting season intermediate readings of the stakes below 2700 m a.s.l. were taken twice in mid-June and mid-July. Observations of mass balance in the fall with maintenance of the stake network were carried out on 8th and 10th September 2018. Melt-out of the winter accumulation extended to almost the entire area and only limited accumulation at highest or sheltered areas and in depressions was left. No measurement of firn density was possible. At all but one stake a negative balance was registered. Measurements at 17 stakes were available for the determination of the annual mass balance. Below 2850 m a.s.l. substantial additional melt of 450 mm to 900 mm w.e. after the fall campaign was discovered during additional stake readings on 7th October 2018. Daily pictures from a time lapse camera taken from mid-June until early November document progressive melt-out and snowfall events during and after the summer season.

Table 4.31: Silvrettagletscher - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude	2017/18			2018/19		
	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	0.021	1295.	−3025	0.017	2008.	−3447
2500 - 2600	0.328	1363.	−2750	0.325	2109.	−3086
2600 - 2700	0.396	1558.	−1864	0.394	2208.	−1964
2700 - 2800	0.621	1631.	−1343	0.617	2336.	−1419
2800 - 2900	0.566	1834.	−851	0.551	2229.	−933
2900 - 3000	0.575	1832.	−916	0.565	2120.	−796
3000 - 3100	0.109	1568.	−813	0.113	1798.	−780
2400 - 3100	2.616	1669	−1389	2.582	2191	−1457

Investigations in 2018/19

The spring survey to evaluate the winter mass balance was performed on 25th May 2019. Snow depth probings were collected at 135 locations distributed over the entire glacier surface. An above-average mean snow depth of 420 cm was found. Snow density was determined at the same two locations as in the previous period using a core drill. A mean density of 497 kg m^{-3} at 2550 m a.s.l. and 507 kg m^{-3} at 2950 m a.s.l. was determined, respectively. First bare-ice patches on the glacier were only observed in the first half of July. Two visits during the melt season were carried out in July and August for intermediate readings of stakes on the glacier tongue. The late-summer field survey took place on 20th and 21st September 2019. Again, no accumulation of winter snow was observed on the entire glacier surface and no measurements of firn density was possible. A negative annual mass balance was determined at all 16 stakes. After an intensive snow event in the week after the fall measurements the glacier remained snow-covered except for some marginal areas of the tongue. The investigations are again supplemented by the operation of a time lapse camera between the end of June and mid-October.

Table 4.32: 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	30.09.2017	19.05.2018	10.09.2018	801840 / 191729 / 2975	1784	−804
02	30.09.2017	19.05.2018	10.09.2018	801922 / 192026 / 2950	1823	−1129
03	30.09.2017	19.05.2018	10.09.2018	801786 / 192292 / 2887	1793	426
04	29.09.2017	19.05.2018	10.09.2018	801723 / 192632 / 2812	1769	−1377
05	29.09.2017	19.05.2018	08.09.2018	801065 / 192693 / 2707	1548	−1667
06	29.09.2017	19.05.2018	08.09.2018	800515 / 192890 / 2606	1348	−2549
07	30.09.2017	19.05.2018	08.09.2018	800166 / 192870 / 2553	1318	−2715
08	29.09.2017	19.05.2018	08.09.2018	799831 / 192746 / 2508	1299	−2553
09	29.09.2017	19.05.2018	08.09.2018	799713 / 192737 / 2483	1235	−3044
10	30.09.2017	19.05.2018	10.09.2018	801517 / 191813 / 2928	1744	−974
11	29.09.2017	19.05.2018	08.09.2018	800720 / 192207 / 2712	1093	−1548
12	29.09.2017	19.05.2018	08.09.2018	800406 / 192587 / 2580	1485	−2513
13	29.09.2017	19.05.2018	08.09.2018	799971 / 192615 / 2521	1093	−3482
15	29.09.2017	19.05.2018	08.09.2018	801160 / 191988 / 2846	1460	−1756
16	29.09.2017	19.05.2018	08.09.2018	801340 / 192371 / 2759	1681	−1614
17	29.09.2017	19.05.2018	10.09.2018	801450 / 192819 / 2767	2078	−1044
18	29.09.2017	19.05.2018	08.09.2018	800758 / 192544 / 2678	1480	−1766
01	10.09.2018	25.05.2019	21.09.2019	801840 / 191729 / 2973	2222	−712
02	10.09.2018	25.05.2019	21.09.2019	801929 / 192021 / 2950	2086	−888
03	10.09.2018	25.05.2019	21.09.2019	801783 / 192296 / 2884	2065	−160
04	10.09.2018	25.05.2019	20.09.2019	801728 / 192632 / 2811	2454	−1264
05	08.09.2018	25.05.2019	20.09.2019	801075 / 192689 / 2707	2121	−1719
06	08.09.2018	25.05.2019	20.09.2019	800515 / 192891 / 2603	2010	−2835
07	08.09.2018	25.05.2019	20.09.2019	800165 / 192872 / 2550	2030	−2925
08	08.09.2018	25.05.2019	20.09.2019	799832 / 192745 / 2504	1995	−3258
09	08.09.2018	25.05.2019	20.09.2019	799717 / 192739 / 2479	1884	−5832
10	10.09.2018	25.05.2019	21.09.2019	801515 / 191814 / 2926	2187	−864
11	08.09.2018	25.05.2019	20.09.2019	800718 / 192206 / 2710	2222	−1854
12	08.09.2018	25.05.2019	20.09.2019	800408 / 192588 / 2578	2096	−2826
13	08.09.2018	25.05.2019	20.09.2019	799974 / 192614 / 2518	1843	−4095
15	08.09.2018	25.05.2019	20.09.2019	801163 / 191987 / 2845	1843	−1836
16	08.09.2018	25.05.2019	20.09.2019	801341 / 192371 / 2758	2237	−1548
17	10.09.2018	25.05.2019	20.09.2019	801447 / 192819 / 2765	2374	−1647
18	08.09.2018	25.05.2019	20.09.2019	800765 / 192538 / 2677	2045	−1683

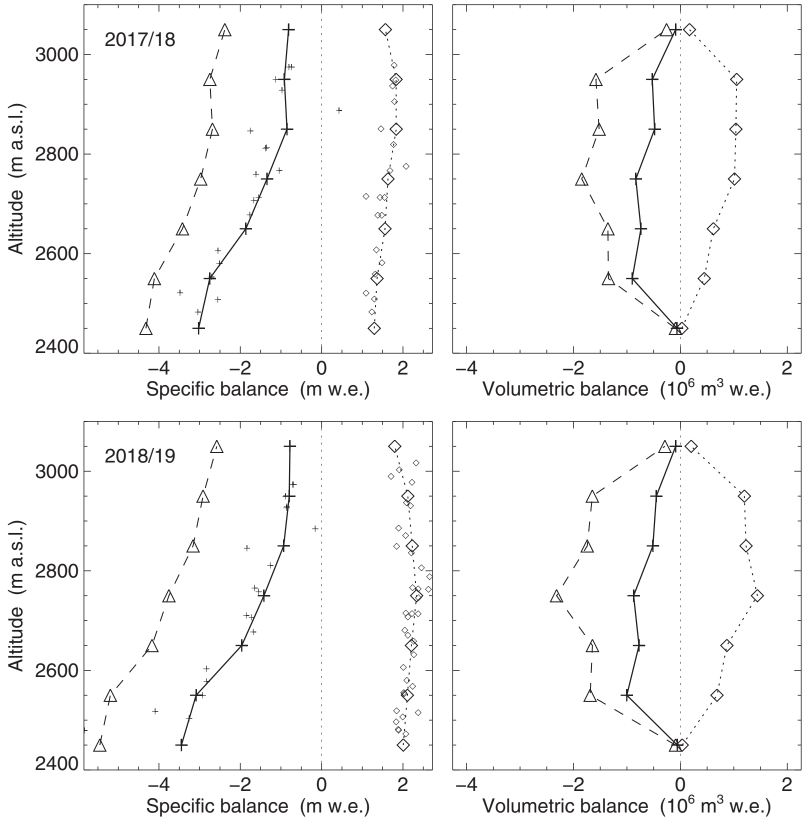

Figure 4.45: Specific (left) and volumetric (right) winter (dotted, ⋄), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

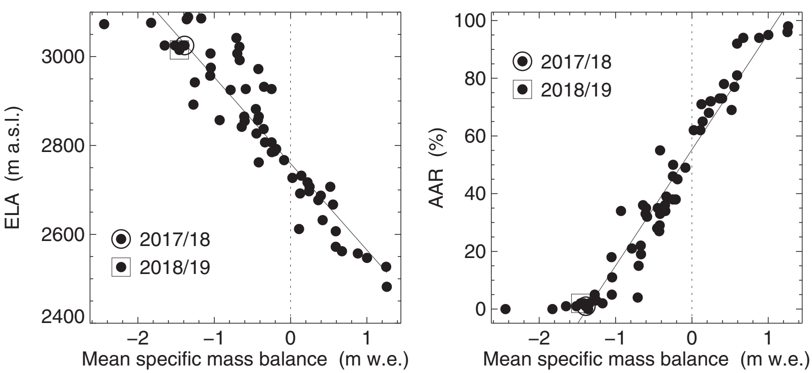

Figure 4.46: Equilibrium line altitude (ELA) and accumulation area ratio (AAR) versus mean specific balance including all previous observations.

4.20 Glacier de Tsanfleuron

Introduction

Glacier de Tsanfleuron is a well-accessible medium-sized glacier at the border between the cantons of Valais, Vaud and Berne. The glacier has an area of 2.5 km^2 and exhibits relatively small surface slopes. Glaciological investigations were started in 2009 with the aim of establishing a mass balance monitoring programme in the Western Swiss Alps. In addition, measurements are also performed on the very small Glacier du Sex Rouge (0.3 km^2) connected to Tsanfleuron in its accumulation area. This permits comparing the mass balance response of neighbouring glaciers of different size and characteristics.

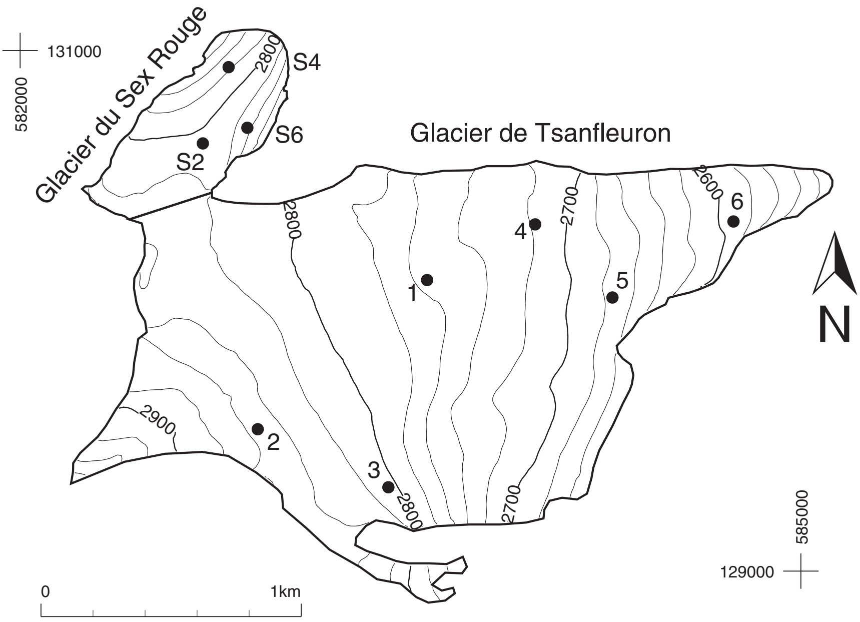

Figure 4.47: Surface topography and observational network of Glacier de Tsanfleuron and Glacier du Sex Rouge.

Investigations in 2017/18

The winter mass balance observations were conducted on 30th April 2018. Snow density was determined using snow coring at one location. Snow depth was measured based on 26 snow probings and totally 13 km of profiles using a 0.8 GHz ground-penetrating radar device. Despite very high winter snow amounts a strongly negative mass balance was measured at all six stakes on Glacier de Tsanfleuron and three stakes on Glacier du Sex Rouge during the late summer field

Table 4.33: Glacier de Tsanfleuron - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude (m a.s.l.)	2017/18 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	2018/19 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2500 - 2600	0.045	2478.	−3700	0.030	2071.	−2358
2600 - 2700	0.404	2541.	−3296	0.404	2067.	−2169
2700 - 2800	1.097	2670.	−2488	1.097	2203.	−1326
2800 - 2900	0.863	2531.	−2113	0.863	1955.	−1342
2900 - 3000	0.057	2147.	−1682	0.057	1597.	−1282
2500 - 3000	2.466	2584	−2492	2.451	2077	−1482

survey on 13th September 2018. The stakes on Glacier du Tsanfleuron were revisited after the melt-intense September on 10th October 2018.

Investigations in 2018/19

During the winter field survey on 1st May 2019, snow depth was measured based on snow probings on Glacier du Tsanfleuron, and 33 probings on Glacier du Sex Rouge and snow density was determined based on snow coring at one location. The traces of a landslide event with probably more than 100'000 m^3 on 28th April 2019 next to the snout of Glacier de Tsanfleuron were discovered. No direct impact on glacier mass balance was evident but the glacier forefield was completely reshaped. On 15th September 2019, a negative mass balance was measured at all six 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 previous period 2017/18.

Table 4.34: Glacier du Sex Rouge - Specific winter (b_w) and annual (b_a) balance according to elevation bands for the two periods 2017/18 and 2018/19. Results refer to the measurement period, defined by the dates of the field survey.

Altitude (m a.s.l.)	2017/18 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)	2018/19 Area (km^2)	$\overline{b_w}$ (mm w.e.)	$\overline{b_a}$ (mm w.e.)
2700 - 2750	0.004	2041.	−1982	0.004	1802.	−2137
2750 - 2800	0.080	1883.	−2042	0.080	1756.	−2151
2800 - 2850	0.161	2211.	−1528	0.161	1829.	−1823
2850 - 2900	0.011	2316.	−647	0.011	2112.	−883
2700 - 2900	0.256	2110	−1658	0.256	1817	−1890

Table 4.35: 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	08.09.2017	25.04.2018	10.10.2018	583536 / 130145 / 2756	2670	−2030
2	08.09.2017	25.04.2018	10.10.2018	582918 / 129553 / 2851	2440	−1560
3	08.09.2017	25.04.2018	10.10.2018	583422 / 129320 / 2805	2720	−1840
4	08.09.2017	25.04.2018	10.10.2018	583975 / 130342 / 2718	2770	−2550
5	08.09.2017	25.04.2018	10.10.2018	584264 / 130051 / 2685	2340	−3420
6	08.09.2017	25.04.2018	10.10.2018	584708 / 130371 / 2611	2420	−3800
S2	08.09.2017	25.04.2018	13.09.2018	582709 / 130670 / 2804	2370	−1160
S4	08.09.2017	25.04.2018	13.09.2018	582798 / 130943 / 2772	1320	−2450
S6	08.09.2017	25.04.2018	13.09.2018	582880 / 130703 / 2835	2390	−1390
1	10.10.2018	01.05.2019	15.09.2019	583536 / 130145 / 2756	2220	−900
2	10.10.2018	01.05.2019	15.09.2019	582918 / 129551 / 2851	1750	−1000
3	10.10.2018	01.05.2019	15.09.2019	583422 / 129320 / 2805	1700	−880
4	10.10.2018	01.05.2019	15.09.2019	583960 / 130341 / 2721	2220	−1180
5	10.10.2018	01.05.2019	15.09.2019	584234 / 130043 / 2692	1970	−2330
6	10.10.2018	01.05.2019	15.09.2019	584707 / 130366 / 2611	1950	−2630
S2	13.09.2018	01.05.2019	15.09.2019	582709 / 130670 / 2804	1870	−1800
S4	13.09.2018	01.05.2019	15.09.2019	582798 / 130943 / 2772	1450	−2460
S6	13.09.2018	01.05.2019	15.09.2019	582880 / 130703 / 2835	2100	−1530

Snout of Glacier de Tsanfleuron in October 2018 (Photo: M. Huss)

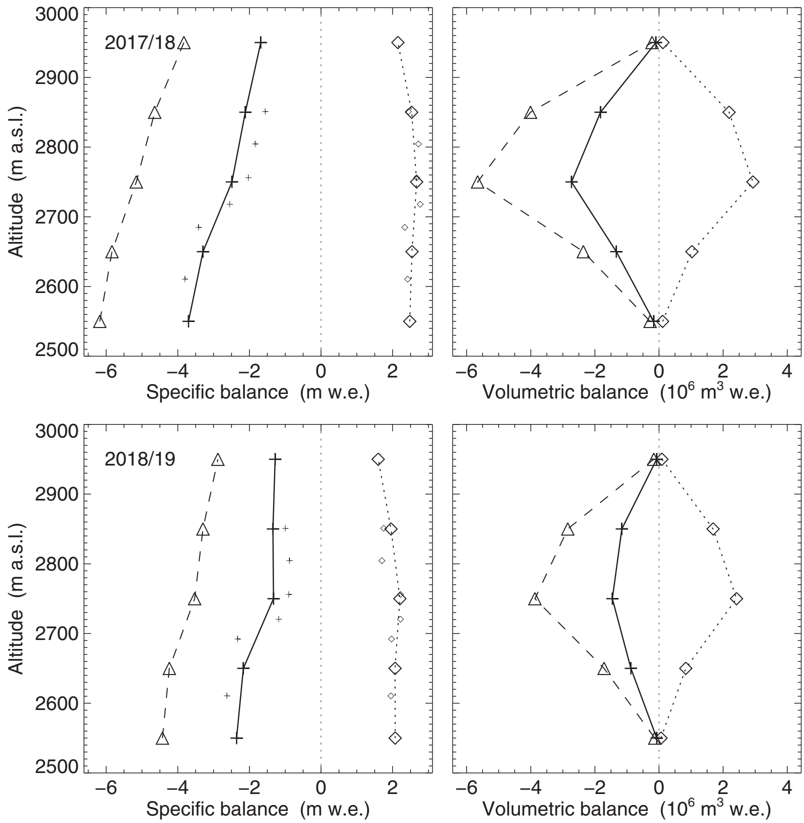

Figure 4.48: Glacier de Tsanfleuron - Specific (left) and volumetric (right) winter (dotted, ⋄), summer (dashed, △) and annual (continuous line, +) balance in elevation bands for 2017/18 (top) and 2018/19 (bottom). Small symbols mark the individual measurements.

5 Flow Velocity

5.1 Introduction

On ten glaciers (Figure 5.1) long-term investigations are carried out with measurements of the surface flow velocity. Presented numbers are annual velocities for a normalized period of 365 days to allow comparability, while corresponding thickness change is determined directly between successive surveys and are shown cumulatively. 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 these investigations is to observe the ice flow dynamics of the glaciers, particularly with regard to their potential threat to the buildings and the operation of the power station in the valley. The observations are mainly focused on the two glaciers Corbassière and Giétro 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.

Thanks to reduced efforts in surveying using global navigation satellite system (GNSS) technology, positions of stakes used for mass balance observations are available in necessary precision for evaluation of the surface flow velocity. As part of mass balance investigations on Grosser Aletschgletscher, Rhonegletscher and Silvrettagletscher (see Chapter 4) stakes have also been systematically surveyed in the last decades for the evaluation of annual surface flow velocity. For the first time, these results are now reported separatly in the present chapter in this report.
From 1924 until 1998 the ablation areas of the Aaregletscher (Figure 5.2) were geodetically surveyed and results were reported each year by Flotron AG on behalf of the Oberhasli hydro-electric power company (KWO). Starting in 2001, investigations were carried out only once every four years. Detailed information with annual ice flow velocities for 2016/17 and ice volume change for 2013-17 in the ablation area for the two glaciers Oberaar and Unteraar, is given in Flotron (2020). Though covering periods of previous reports, but only available with a certain delay, the main results are presented in this report (Tables 5.2 and 5.1) to carry on previous reporting of Volume 133/134.

5.2 Aaregletscher

Introduction

Ice flow velocity and thickness change have been systematically observed along transverse profiles since the 1920s on Unteraargletscher, and later additionally on Oberaargletscher (Figure 5.2). Starting in 1969, aerial photographs of the two glaciers were processed using photogrammetric analysis tools. In the meantime, generation of an orthophoto mosaic and a digital elevation model (DEM) of the glacier surface are standard products, opening new possibilities for the evaluation of glacier flow. Digital elevation models have been further refined since 1997, allowing the evaluation of glacier-wide thickness change. Using the method of simultaneous mono-plotting (Flotron, 1979; Kääb, 1996), horizontal displacement is determined with an estimated accuracy of 0.3 m. In order to continue the long-term time series the horizontal ice flow velocity and thickness change are determined along the same 17 profiles (Figure 5.3) with the original spatial resolution.

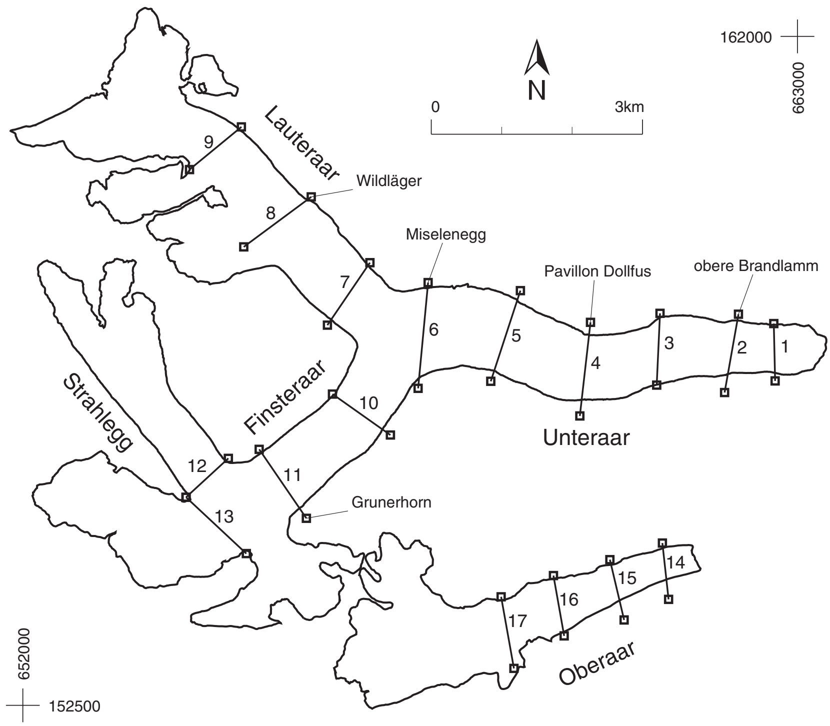

Figure 5.2: Outline and observational network of the Aaregletscher in 2001 with the original 17 profiles.

Investigations on ice flow velocities

Aerial photographs have been acquired on 29th September 2016 and 5th October 2017. The observation period for the determination of the surface displacement is thus 371 days, and values have been normalized to a period of one year. In accordance with a continued decrease in thickness, the horizontal flow velocities have also steadily decreased (Figure 5.3, Table 5.2).

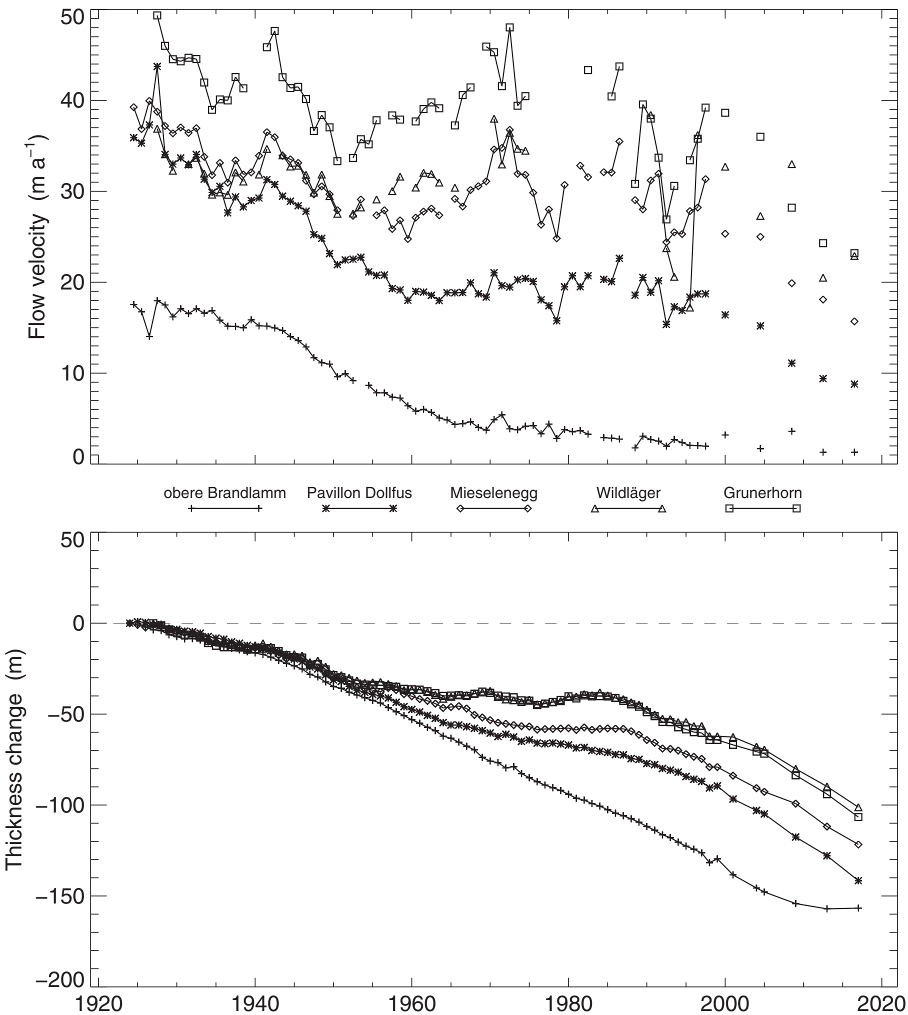

Figure 5.3: Surface ice flow velocities (top) and thickness change (bottom) at five selected transverse profiles on Unteraargletscher since 1924.

Investigations of thickness change

The observation period of 1492 days spans the interval since the previous report in fall 2013 and the most recent evaluation in fall 2017. The reduction in glacier extent in the terminus areas goes along with a mean thickness decrease in all the analysed profiles (Figure 5.3, Table 5.2) and an ice volume loss (Table 5.1) in all evaluated sections of the ablation area on the two glaciers. These changes can be observed clearly with the aid of ortho-photos, contour line maps and cross-sectional profiles. The mean lowering of Unteraargletscher and Oberaargletscher in the analysed regions between the glacier snout and the uppermost profiles amounts to 11.5 m and 12.7 m, respectively (Figure 5.2). The investigated areas correspond to 11.51 km^2 and 1.16 km^2. This results in a total ice volume loss of 132.3 million m^3 for Unteraargletscher, and 14.7 million m^3 for Oberaargletscher (Table 5.1), respectively. In comparison with the three previous four-year intervals (2001-05, 2005-09 and 2009-13), the total loss has stabilized on a high level, but is somewhat less pronounced than in the previous four years of 2009-13.

Table 5.1: Aaregletscher - Change in area and volume in the period 2013 - 2017 for individual sections between the profiles and totals of each glacier.

Section	Area change (m^2)	Volume change (m^3)
Unteraar		
Z - 2	-154'514	−539'175
2 - 3		−9'384'007
3 - 4		−10'323'948
4 - 5		−14'512'999
5 - 6		−15'815'522
6 - 7/10		−24'922'950
Lauteraar		
7 - 8		−16'808'598
8 - 9		−12'324'602
Finsteraar		
10 - 11		−15'121'054
11 - 12/13		−12'565'588

Section	Area change (m^2)	Volume change (m^3)
Oberaar		
Z - 15	-37'029	−1'963'541
15 - 16		−6'867'952
16 - 17		−5'906'642

Unteraar		−132'318'444
Oberaar		−14'738'136
total		−147'056'580

Table 5.2: Aaregletscher - Individual measurements of surface flow velocity and thickness change at the center of the profiles

Profile	Period		Coordinates	Thickness change	Velocity
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})
2	04.09.2013	05.10.2017	662085 / 157605 / 1934	0.4	
	29.09.2016	05.10.2017			1.3
3	04.09.2013	05.10.2017	661020 / 157500 / 2036	−7.0	
	29.09.2016	05.10.2017			7.2
4	04.09.2013	05.10.2017	659990 / 157335 / 2117	−13.7	
	29.09.2016	05.10.2017			8.8
5	04.09.2013	05.10.2017	658845 / 157710 / 2199	−14.4	
	29.09.2016	05.10.2017			12.9
6	04.09.2013	05.10.2017	657690 / 157815 / 2294	−9.9	
	29.09.2016	05.10.2017			15.7
7	04.09.2013	05.10.2017	656655 / 158385 / 2356	−13.2	
	29.09.2016	05.10.2017			16.0
8	04.09.2013	05.10.2017	655670 / 159405 / 2458	−11.4	
	29.09.2016	05.10.2017			22.9
9	04.09.2013	05.10.2017	654770 / 160440 / 2580	−12.1	
	29.09.2016	05.10.2017			26.5
10	04.09.2013	05.10.2017	656780 / 156650 / 2372	−13.7	
	29.09.2016	05.10.2017			17.1
11	04.09.2013	05.10.2017	655635 / 155730 / 2484	−12.6	
	29.09.2016	05.10.2017			23.2
12	04.09.2013	05.10.2017	654620 / 155735 / 2556	−11.8	
	29.09.2016	05.10.2017			9.2
13	04.09.2013	05.10.2017	654740 / 155060 / 2572	−7.8	
	29.09.2016	05.10.2017			43.1
15	04.09.2013	05.10.2017	660420 / 154215 / 2378	−19.9	
	29.09.2016	05.10.2017			5.6
16	04.09.2013	05.10.2017	659610 / 153930 / 2477	−17.7	
	29.09.2016	05.10.2017			6.3
17	04.09.2013	05.10.2017	658850 / 153710 / 2619	−11.4	
	29.09.2016	05.10.2017			5.8

5.3 Glacier de Corbassière

Introduction

Since 1967, Glacier de Corbassière (Figure 4.14) has been under observation regarding surface ice flow velocities. On two cross-profiles in the ablation area of the glacier flow markers were placed on the surface and annually moved back to the initial position. In 1996 the flow markers were replaced by ablation stakes. Annual surveying has been carried out to determine the ice flow velocities and local mass balance (Section 4.7, Table 4.9). Figure 5.4 shows the horizontal surface flow velocities for the two profiles since 1967.

Investigations in 2017/18 and in 2018/19

The field surveys were carried out on 17th/18th September 2018 and on 27th/28th September 2019. As in previous years, seven stakes were maintained and surveyed on the glacier tongue. In addition, the surface elevation has been measured along the two cross profiles at additional points with fixed position to determine ice thickness change. 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.

Table 5.3: Glacier de Corbassière - Individual measurements of surface flow velocity and thickness change

Stake	Period		Coordinates	Thickness change	Velocity
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})
B2	21.09.2017	17.09.2018	589577 / 93202 / 2620	−3.16	8.74
B2	17.09.2018	27.09.2019	589577 / 93202 / 2615	−3.07	6.97
B4	21.09.2017	17.09.2018	589392 / 93101 / 2625	−2.84	14.90
B4	17.09.2018	27.09.2019	589392 / 93101 / 2620	−2.70	12.64
B6	21.09.2017	17.09.2018	589230 / 93012 / 2630	−2.24	16.00
B6	17.09.2018	27.09.2019	589230 / 93012 / 2625	−3.23	13.54
R	21.09.2017	17.09.2018	589150 / 93650 / 2585	−3.49	9.84
R	17.09.2018	27.09.2019	589150 / 93650 / 2580	−3.50	7.99
A2	21.09.2017	17.09.2018	588650 / 94315 / 2415	−6.99	4.84
A2	17.09.2018	27.09.2019	588650 / 94315 / 2410	−6.89	4.77
A4	21.09.2017	17.09.2018	588450 / 94257 / 2390	−6.66	3.93
A4	17.09.2018	27.09.2019	588450 / 94257 / 2385	−8.35	3.92
A6	21.09.2017	17.09.2018	588273 / 94207 / 2420	−4.61	1.63
A6	17.09.2018	27.09.2019	588273 / 94207 / 2415		0.74

Velocity in 2017/18 and in 2018/19

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 ice surface was maintained. The extraordinarily high rate of surface lowering in the lower profile (A2, A4, A6) observed in recent years continued during the two periods of this report.

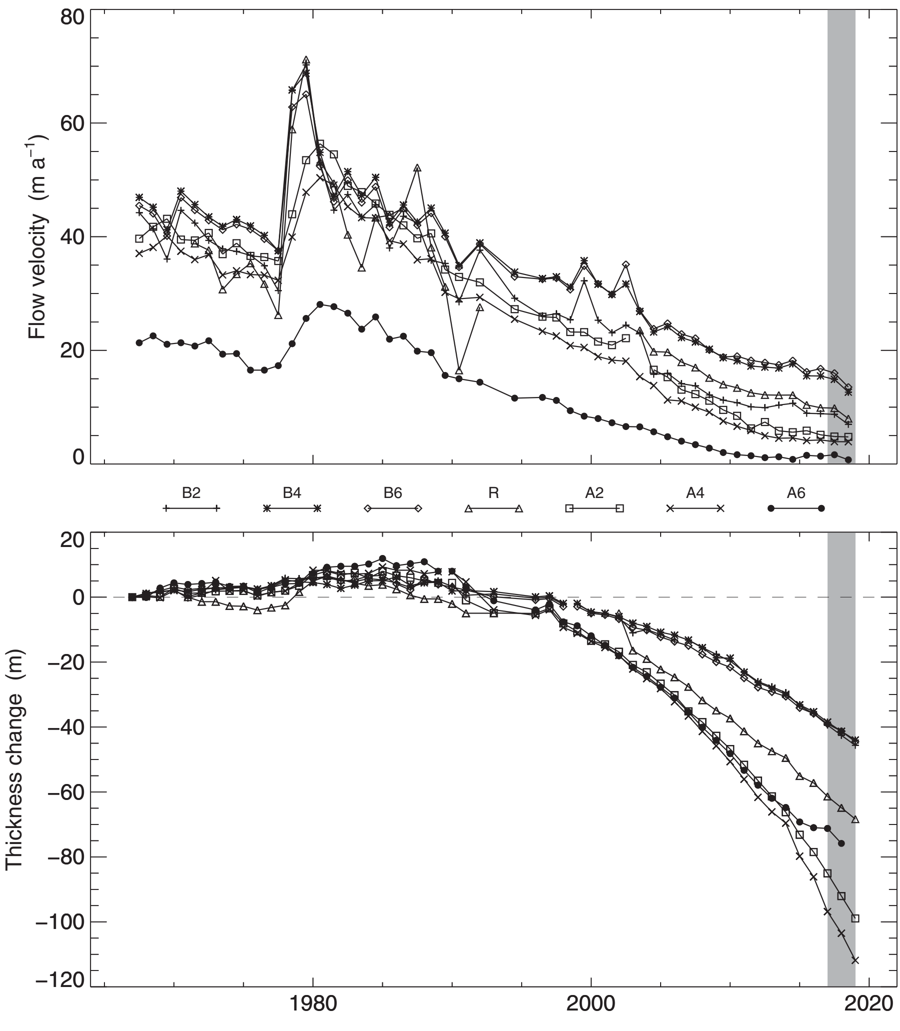

Figure 5.4: Surface flow velocities (top) and thickness change (bottom) of the Glacier de Corbassière at two profiles with three stakes each and the additional stake in between. The gray shaded area highlights the years of the current report.

5.4 Glacier du Giétro

Introduction

For Glacier du Giétro (Figure 4.19) in the Val de Bagnes (Valais) a very long measurement series of ice flow velocity is being maintained by VAW/ETHZ under contract with Forces Motrices de Mauvoisin SA. The aim of these annual observations was the early recognition of glacier break-offs, which could endanger the dammed lake located in the outreach of ice avalanches. The glacier tongue shrank drastically in recent years reducing the hazard potential substantially. 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 to ice flow velocity, annual mass balance is measured at the stakes (Section 4.9, Table 4.14).

Figure 5.5 shows the horizontal surface flow velocity measurements at seven stakes along the central longitudinal profile of the glacier, acquired since 1966. There are three distinct periods: in the first period (1966 to 1976), the velocities in the accumulation area (stakes 1, 2 and 4) were approximately 5-20 $\mathrm{m\,a^{-1}}$, in the central region of the glacier (stake 5) about 35 $\mathrm{m\,a^{-1}}$ and in the steep tongue area (stakes 102, 8 and 10) they were in the range of 50-90 $\mathrm{m\,a^{-1}}$. The second period (1977 to 1982) is marked by a distinct acceleration, in which the speeds (for example at stake 102) increased from 90 $\mathrm{m\,a^{-1}}$ to 120 $\mathrm{m\,a^{-1}}$. From the mid-1980s onward, the velocities decreased sharply, and in the last years reached the lowest values measured since 1966.

Investigations in 2017/18 and in 2018/19

Measurements of surface flow velocity and local mass balance were performed at five stakes. The field survey in fall 2018 was carried out on 17th September. All stakes have been located and moved back to the initial position. On 27th September 2019, the field measurements were carried out for the second period. Again, all stakes have been located and surveyed. Due to substantial ice loss and further retreat of the snout, the stake network had to be adapted at the lowest elevations. Site 103 was finally given up and replaced by site 101 that was in use in earlier years already. Thickness change could only be evaluated for stakes where initial position was not moved or that were abandoned.

Velocity in 2017/18 and in 2018/19

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 102 over the past periods. The decrease in ice flow velocity over the past years continued during the two periods covered by this report. The change observed at the lower sites directly reflects the lowering of the surface elevation and the ever-increasing difficulties in maintaining a fixed position.

Table 5.4: Glacier du Giétro - Individual measurements of surface flow velocity and thickness change

Stake	Period Start	End	Coordinates (m / m / m a.s.l.)	Thickness change (m)	Velocity (m a^{-1})
1	21.09.2017	17.09.2018	596143 / 92346 / 3300	−0.28	1.94
1	17.09.2018	27.09.2019	596143 / 92346 / 3300		2.37
2	21.09.2017	17.09.2018	596605 / 92835 / 3245	0.17	7.74
2	17.09.2018	27.09.2019	596605 / 92835 / 3245	−0.60	7.85
4	21.09.2017	17.09.2018	596211 / 93400 / 3185	−0.42	11.56
4	17.09.2018	27.09.2019	596211 / 93400 / 3185	−1.45	11.01
5	21.09.2017	17.09.2018	595615 / 94303 / 3050	−0.65	17.08
5	17.09.2018	27.09.2019	595615 / 94303 / 3050	−1.30	15.74
101	17.09.2018	27.09.2019	594737 / 94536 / 2866		26.06
102	21.09.2017	17.09.2018	594568 / 94497 / 2810		18.64
102	17.09.2018	27.09.2019	594568 / 94497 / 2810		18.47
103	21.09.2017	17.09.2018	594488 / 94462 / 2764	−4.26	12.16
107	21.09.2017	17.09.2018	594836 / 94550 / 2907		25.05
107	17.09.2018	27.09.2019	594860 / 94557 / 2917	−2.90	25.36

Tongue of du Giétro in 2018 and the area of the measurement site 103 that was given up due to nearly complete loss of ice. (Photo: A. Bauder)

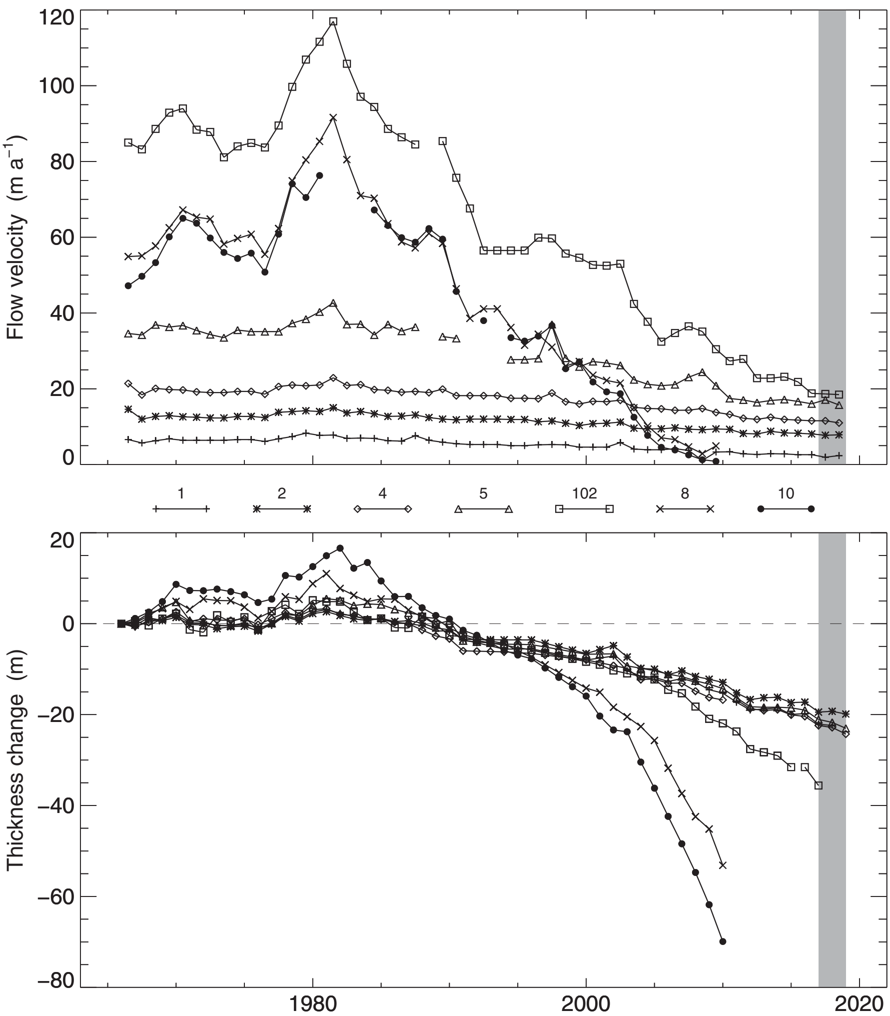

Figure 5.5: Surface flow velocities (top) and thickness change (bottom) of the Glacier du Giétro at all seven stakes. The gray shaded area highlights the years of the current report.

5.5 Grosser Aletschgletscher

Introduction

Grosser Aletschgletscher (Figure 4.25) has been under observation for surface ice flow velocities since several decades. Between 1940s and 1990s a network of stakes on a longitudinal and several cross profiles was maintained with a focus on both mass balance and ice flow velocity (Zoller, 2010). As a part of the ongoing mass balance investigations at stake P3 close to Jungfraujoch the position is surveyed systematically since 2004, thus allowing the determination of the surface flow velocity and thickness change. The results of the mass balance observations are presented in Section 4.11 and Table 4.17 of this report.

Investigations in 2017/18 and in 2018/19

Field surveys were carried out on a seasonal basis on 6th June and 27th September in 2018, and 4th June and 3th October in 2019, respectively. Using high-precision differential GNSS the position of stake P3 was surveyed. Each year in fall, the stake is moved back to the initial position. The results of the annual horizontal surface flow velocity and the change in ice thickness during the two measurement periods of this report are presented in Table 5.5.

Table 5.5: Grosser Aletschgletscher - Individual measurements of surface flow velocity and thickness change

Stake	Period		Coordinates	Thickness change	Velocity
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})
P3	12.10.2017	27.09.2018	641825 / 154810 / 3345	−1.96	31.85
P3	27.09.2018	03.10.2019	641825 / 154810 / 3345	−1.11	30.18

Velocity in 2017/18 and in 2018/19

In period 2017/18 an annual horizontal velocity of 31.9 m a^{-1} was determined without a variation between the winter and summer season. In the second measuring period, an annual flow velocity of 30.2 m a^{-1} was recorded with only a slightly higher velocity (+5%) in the summer season compared to the winter. The results of the annual horizontal surface flow velocity as well as the change in thickness since 2004 are shown in Figure 5.6. Only relatively small year-to-year fluctuations are evident. During the past 15 years with continuous observation the ice thickness decreased by about 7 m at site P3. In an evaluation of historical measurements at site P3 between 1957 and 1966, Zoller (2010) determined an annual surface flow velocities of 30 m a^{-1} to 40 m a^{-1} that was slightly higher than the observed values in the recent decade.

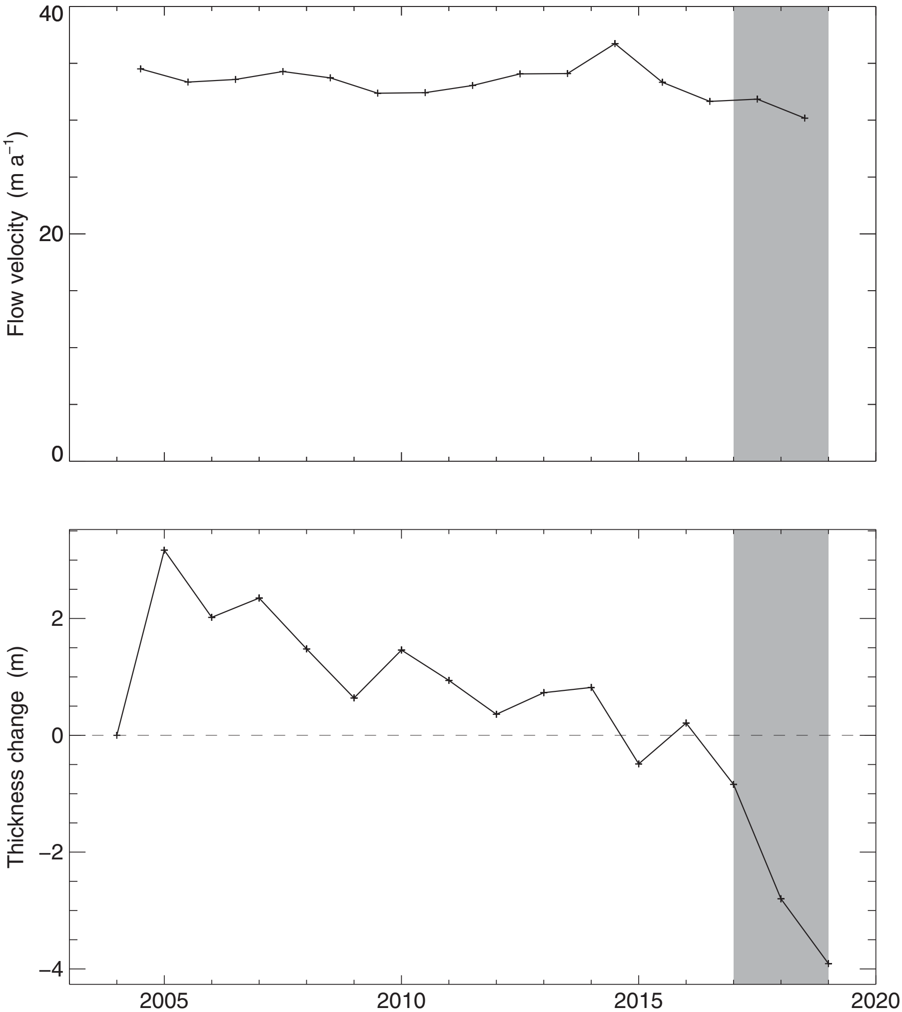

Figure 5.6: Surface flow velocities (top) and thickness change (bottom) at stake P3 on Grosser Aletschgletscher. The gray shaded area highlights the years of the current report.

5.6 Mattmark

Introduction

The first ice flow velocity measurements in the Mattmark area date back to 1955 (VAW, 1999). Initially, investigations were carried out at a network of up to 22 stakes on the glaciers Allalin, Hohlaub, Kessjen, Schwarzberg, Tälliboden and Ofental with the aim to determine glacier mass balance for planning and construction of the Mattmark reservoir for hydro-power production (VAW, 1999). In 1967 the observation network was re-arranged with a main focus for ice flow measurements. Measurements are currently being continued on 11 selected stakes (Figures 5.7) as part of the investigations by VAW/ETHZ for the Mattmark hydro-power company (VAW, 2010). Figure 5.8 shows the horizontal surface flow velocities on Allalingletscher. In addition to ice flow velocity, annual mass balance is measured at the stakes (Tables 4.4, 4.18 and 4.28).

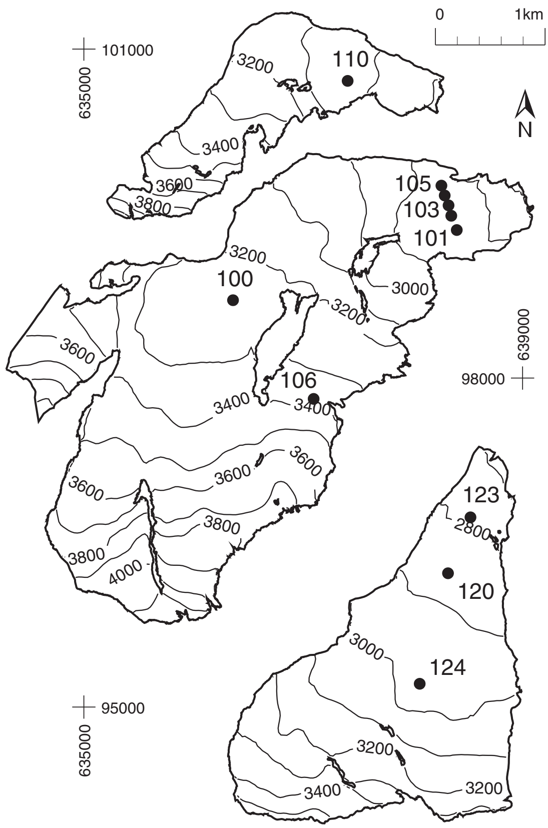

Figure 5.7: Surface topography and observational network of the Mattmark glaciers.

Investigations in 2017/18 and in 2018/19

The field surveys were carried out on 9th September 2018 and on 30th August 2019. During both field campaigns all stakes were located, surveyed and set back to their initial position. Results for horizontal flow velocity and thickness change for each glacier are given in Tables 5.6, 5.7 and 5.8.

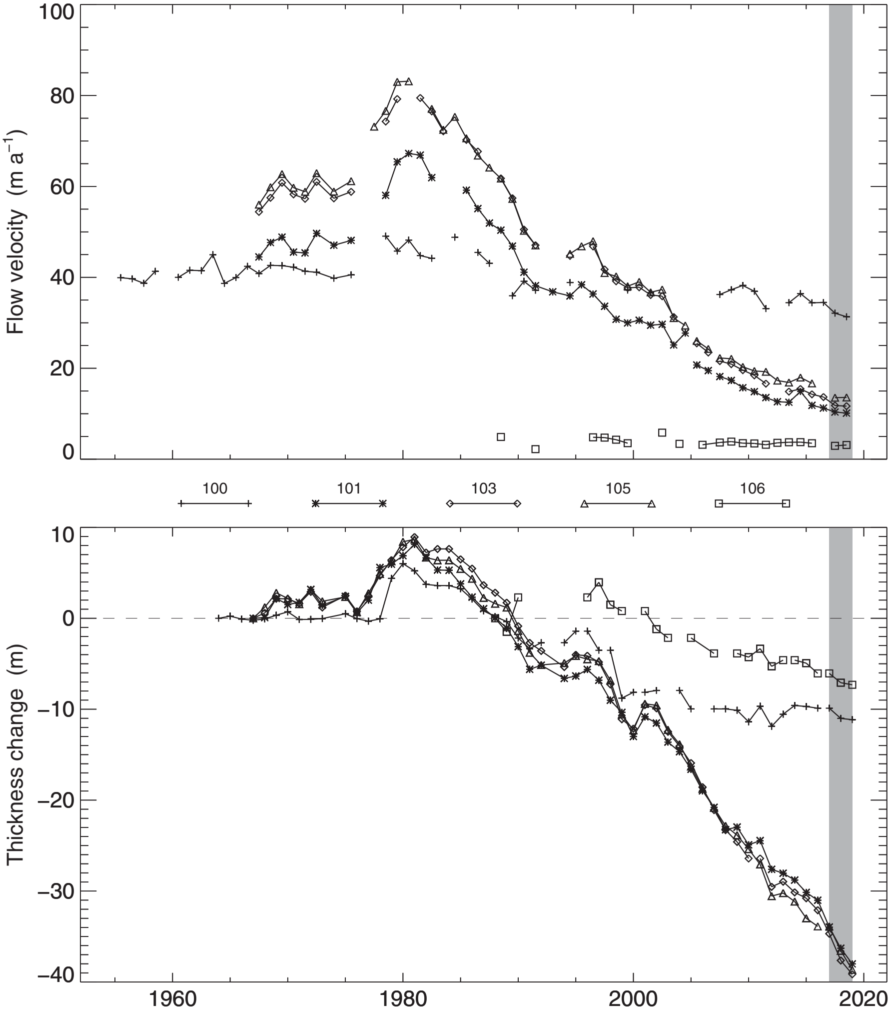

Figure 5.8: Surface flow velocities (top) and thickness change (below) of the Allalingletscher at five stakes. The gray shaded area highlights the years of the current report.

Table 5.6: Allalin - Individual measurements of surface flow velocity and thickness change

Stake	Period		Coordinates	Thickness change	Velocity
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})
100	21.08.2017	06.09.2018	636510 / 98800 / 3220	−1.12	32.11
100	06.09.2018	30.08.2019	636510 / 98800 / 3230	−0.14	31.32
101	21.08.2017	06.09.2018	638400 / 99360 / 2825	−2.33	10.37
101	06.09.2018	30.08.2019	638400 / 99360 / 2820	−1.72	10.14
102	21.08.2017	06.09.2018	638350 / 99480 / 2825	−2.24	11.39
102	06.09.2018	30.08.2019	638350 / 99480 / 2825	−1.47	11.06
103	21.08.2017	06.09.2018	638325 / 99575 / 2825	−2.94	11.81
103	06.09.2018	30.08.2019	638325 / 99575 / 2820	−1.52	11.68
104	21.08.2017	06.09.2018	638290 / 99665 / 2840	−2.81	12.36
104	06.09.2018	30.08.2019	638290 / 99665 / 2835	−1.25	12.02
105	21.08.2017	06.09.2018	638260 / 99755 / 2855	−2.69	13.54
105	06.09.2018	30.08.2019	638260 / 99755 / 2855	−2.09	13.59
106	21.08.2017	06.09.2018	637095 / 97810 / 3370	−1.02	2.94
106	06.09.2018	30.08.2019	637095 / 97810 / 3370	−0.23	3.13

Table 5.7: Hohlaub - Individual measurements of surface flow velocity and thickness change

Stake	Period		Coordinates	Thickness change	Velocity
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})
110	21.08.2017	06.09.2018	637405 / 100710 / 3025	−0.59	8.78
110	06.09.2018	30.08.2019	637405 / 100710 / 3025	−1.30	9.67

Table 5.8: Schwarzberg - Individual measurements of surface flow velocity and thickness change

Stake	Period		Coordinates	Thickness change	Velocity
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})
120	21.08.2017	06.09.2018	638320 / 96220 / 2845	−2.59	5.59
120	06.09.2018	30.08.2019	638320 / 96220 / 2845	−2.00	5.69
123	21.08.2017	06.09.2018	638525 / 96730 / 2765	−3.61	4.01
123	06.09.2018	30.08.2019	638525 / 96730 / 2860	−2.74	3.81
124	21.08.2017	06.09.2018	638062 / 95212 / 2980	−1.38	7.36
124	06.09.2018	30.08.2019	638062 / 95212 / 2980	−0.71	6.83

5.7 Rhonegletscher

Introduction

Starting in 2006, as part of the mass balance investigations at Rhonegletscher (Figure 4.35), the positions of all stakes are also surveyed for the evaluation of surface flow velocity. The substantial glacier melt and the associated retreat over the past two decades required modification of the observational network. However, several continuous time series of surface flow velocity distributed along a longitudinal profile have been acquired. The corresponding results of the mass balance observations are presented in Section 4.16 and Table 4.25 of this report.

Investigations in 2017/18 and in 2018/19

Measurement of surface flow velocity and mass balance were performed at 11 stakes. The field survey in fall 2018 was carried out on 11[th] September. All 11 stakes have been located and moved back to the initial position. On 12[th] September 2019, the field measurements were carried out for the second period. All but the uppermost stake in the accumulation area were found and surveyed. High-precision differential GNSS was used for surveying the positions of the stakes in both periods.

Table 5.9: Rhonegletscher - Individual measurements of surface flow velocity and thickness change

Stake	Period Start	End	Coordinates (m / m / m a.s.l.)	Thickness change (m)	Velocity (m a^{-1})
01	26.09.2017	11.09.2018	673815 / 166615 / 3235	−0.71	23.47
02	26.09.2017	11.09.2018	673552 / 165950 / 3125	−2.19	63.76
02	12.09.2018	12.09.2019	673552 / 165950 / 3125	−0.55	59.73
03	26.09.2017	11.09.2018	673100 / 164930 / 2930	−1.52	49.16
03	12.09.2018	12.09.2019	673100 / 164930 / 2930	−1.52	47.23
04	26.09.2017	11.09.2018	673357 / 162758 / 2745	−2.29	60.98
04	12.09.2018	12.09.2019	673357 / 162758 / 2745	−1.64	58.27
05	26.09.2017	11.09.2018	672521 / 161919 / 2605	−3.37	60.37
05	12.09.2018	12.09.2019	672521 / 161919 / 2605	−1.64	57.82
06	26.09.2017	11.09.2018	672423 / 160843 / 2465	−2.81	33.42
06	12.09.2018	12.09.2019	672423 / 160843 / 2465	−3.73	31.19
07	26.09.2017	11.09.2018	672657 / 160173 / 2360	−4.72	28.31
07	12.09.2018	12.09.2019	672657 / 160173 / 2360	−4.89	26.87
08	26.09.2017	11.09.2018	672680 / 159724 / 2295	−5.24	13.88
08	12.09.2018	12.09.2019	672680 / 159724 / 2295	−5.11	13.11
09	26.09.2017	11.09.2018	672605 / 159500 / 2250	−6.74	8.28
09	12.09.2018	12.09.2019	672605 / 159500 / 2250	−6.53	6.79
12	26.09.2017	11.09.2018	673500 / 163990 / 2845	−2.20	42.37
12	12.09.2018	12.09.2019	673500 / 163990 / 2845	−1.38	40.64
13	26.09.2017	11.09.2018	672705 / 159937 / 2320	−5.49	17.85
13	12.09.2018	12.09.2019	672705 / 159937 / 2320	−5.09	15.49

The results of annual horizontal surface flow velocity and change in ice thickness determined during the two measurement periods of this report are presented in Table 5.9.

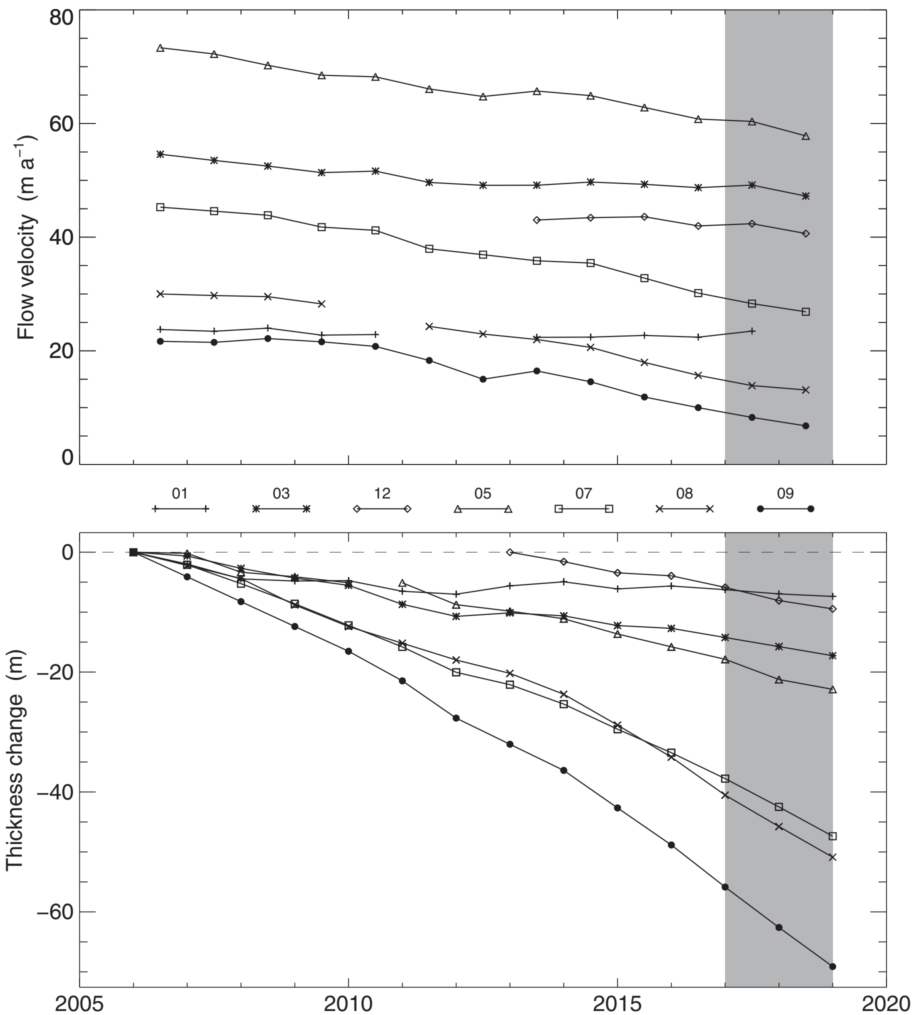

Figure 5.9: Surface flow velocities (top) and thickness change (bottom) of Rhonegletscher at selected stakes. The gray shaded area highlights the years of the current report.

Velocity in 2017/18 and in 2018/19

Observed flow velocities in the two measurement periods range from less than 10 m a^{-1} at the lowermost stake on the glacier tongue to about 60 m a^{-1} at three stakes at about 2600 m a.s.l., 2800 m a.s.l. and 3100 m a.s.l., respectively. With the exception of the uppermost stake, the flow velocities further decreased at all stakes in the two periods. The decrease in flow velocity is in direct relation with a decrease in the ice thickness observed over the last two decades. Figure 5.9 shows the results of the annual horizontal surface flow velocity as well as the change in thickness since 2006.

Experiment with stakes of different material: plastic, aluminum and wood (Photo: A. Bauder)

5.8 Silvrettagletscher

Introduction

Starting in 2003, as part of the mass balance monitoring programme at Silvrettagletscher (Figure 4.43), the positions of the available stakes are also surveyed for the evaluation of surface flow velocity. Until 2008 the observational network consisted of 11 stakes that were annually surveyed. Afterwards the network was extended to 16 stakes. The corresponding results of the mass balance observations are presented in Section 4.19 and Table 4.32 of this report.

Investigations in 2017/18 and in 2018/19

In the two periods under review in this report, measurements of surface flow velocity were performed at 16 stakes. The field survey in fall 2018 was carried out on 8th/10th September. All stakes have been located and surveyed. On 20th/21st September 2019, the field measurements were taken for the second period. Again, all stakes have been located and surveyed. Positions have been surveyed using high-precision differential GNSS. Some stakes are moved back annually to their initial position while maintenance of others is only needed every second year. The results of annual horizontal surface flow velocity and change in ice thickness determined during the two measurement periods covered by this report are presented in Table 5.10.

Velocity in 2017/18 and in 2018/19

Observed flow velocities in the two measurement periods were found to vary between one and several metres per year. A further decrease in flow speed was recorded. This decrease reflects the ongoing reduction of ice thickness registered over the past two decades at all sites. Figure 5.10 shows the results of the annual horizontal surface flow velocity as well as the change in thickness since 2003.

Table 5.10: Silvrettagletscher - Individual measurements of surface flow velocity and thickness change

Stake	Period		Coordinates	Thickness change	Velocity
	Start	End	(m / m / m a.s.l.)	(m)	(m a^{-1})
01	30.09.2017	10.09.2018	801840 / 191729 / 2980	−1.76	1.06
01	10.09.2018	21.09.2019	801840 / 191729 / 2980	−1.17	0.94
02	30.09.2017	10.09.2018	801927 / 192023 / 2955	−2.15	4.85
02	10.09.2018	21.09.2019	801927 / 192023 / 2955	−1.53	4.27
03	30.09.2017	10.09.2018	801783 / 192252 / 2900	−1.57	5.08
03	10.09.2018	21.09.2019	801783 / 192252 / 2900	−1.31	4.64
04	30.09.2017	10.09.2018	801730 / 192630 / 2820	−1.64	3.61
04	10.09.2018	21.09.2019	801730 / 192630 / 2820	−1.53	3.30
05	30.09.2017	10.09.2018	801074 / 192689 / 2720	−2.17	4.61
05	10.09.2018	21.09.2019	801074 / 192689 / 2720	−1.73	4.28
06	30.09.2017	10.09.2018	800515 / 192890 / 2625	−2.78	2.41
06	10.09.2018	21.09.2019	800515 / 192890 / 2625	−2.71	2.49
07	30.09.2017	10.09.2018	800165 / 192872 / 2580	−3.13	1.08
07	10.09.2018	21.09.2019	800165 / 192872 / 2580	−3.09	0.95
08	30.09.2017	10.09.2018	799827 / 192745 / 2535	−4.34	0.69
08	10.09.2018	21.09.2019	799827 / 192745 / 2535	−4.42	0.93
10	30.09.2017	10.09.2018	801530 / 191805 / 2940	−1.65	2.41
10	10.09.2018	21.09.2019	801530 / 191805 / 2940	−1.15	2.43
11	30.09.2017	10.09.2018	800718 / 192206 / 2725	−1.82	0.91
11	10.09.2018	21.09.2019	800718 / 192206 / 2725	−1.99	0.69
12	30.09.2017	10.09.2018	800406 / 192587 / 2600	−2.89	2.67
12	10.09.2018	21.09.2019	800406 / 192587 / 2600	−3.10	2.89
13	30.09.2017	10.09.2018	799949 / 192607 / 2545	−4.36	1.14
13	10.09.2018	21.09.2019	799949 / 192607 / 2545	−4.45	1.20
15	30.09.2017	10.09.2018	801163 / 191987 / 2855	−1.98	3.44
15	10.09.2018	21.09.2019	801163 / 191987 / 2855	−1.77	3.27
16	30.09.2017	10.09.2018	801340 / 192371 / 2765	−1.81	6.05
16	10.09.2018	21.09.2019	801340 / 192371 / 2765	−1.21	5.55
17	30.09.2017	10.09.2018	801453 / 192818 / 2775	−1.01	3.02
17	10.09.2018	21.09.2019	801453 / 192818 / 2775	−1.50	2.92
18	30.09.2017	10.09.2018	800767 / 192541 / 2695	−2.01	4.68
18	10.09.2018	21.09.2019	800767 / 192541 / 2695	−2.18	4.12

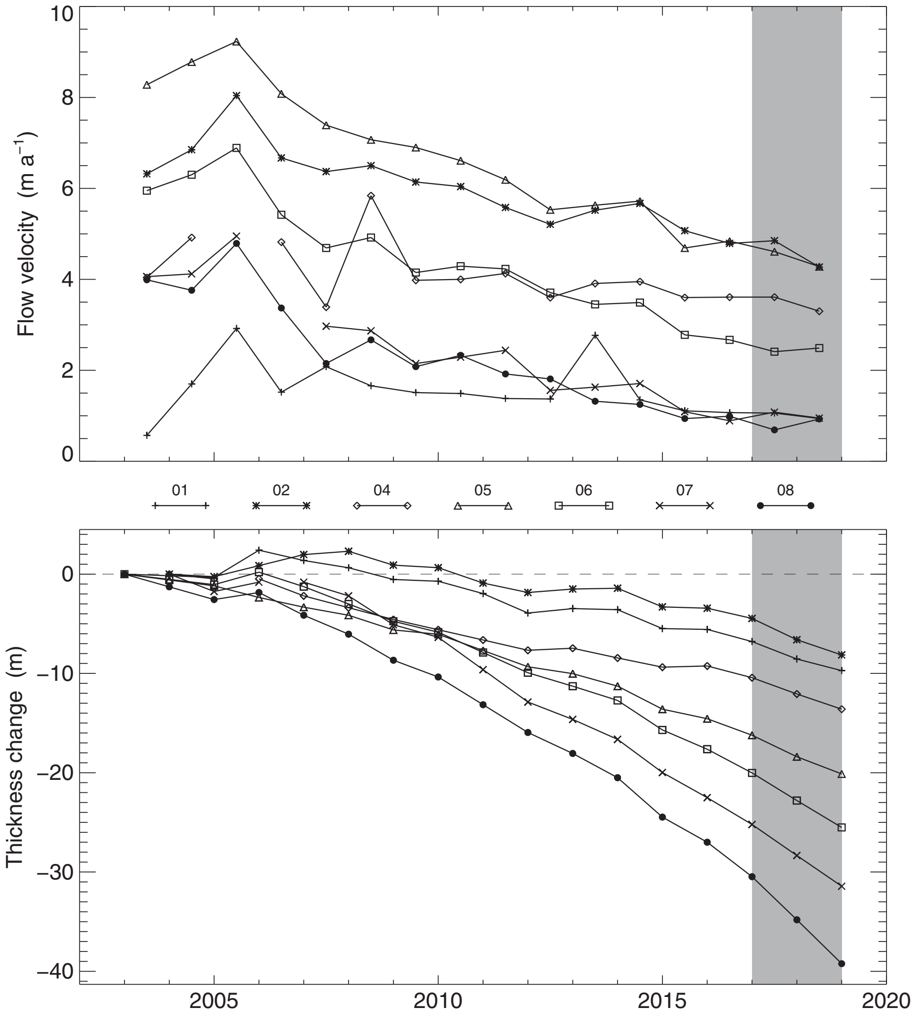

Figure 5.10: Surface flow velocities (top) and thickness change (bottom) of selected stakes at Silvrettagletscher. The gray shaded area highlights the years of the current report.

6 Englacial Temperature

6.1 Introduction

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

Measurements of englacial temperatures have been adopted by the Cryospheric Commission in 2007

Figure 6.1: Investigated site for englacial temperatures.

to be included to the GLAMOS monitoring programme (see Chapter 1.1 of Volume 125/126). The Colle Gnifetti site was selected for performing regular measurements to update the existing ones made in the years 1983, 1991, 1999, 2000. The results of measurements taken in the years 2018 and 2019 on Colle Gnifetti are presented in this report. The previous results of 2007, 2008, 2013, 2014 and 2015 have been reported in Volumes 129/130 and 135/136.

6.2 Colle Gnifetti (Monte Rosa)

Introduction

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

Investigations in 2018 and in 2019

Initially, it was considered to repeat the measurements every four to five years. However, a recent evaluation showed that more frequent measurements would be appropriate to account for shorter term changes. Therefore, in summer 2018, a fixed thermistor chain was installed at a repeatedly investigated site, for which measurements exist since 1982. This site is located close to the saddle point of Colle Gnifetti. In addition, in summer 2019, within a master thesis project at University of Fribourg, a second thermistor chain was installed to continuously monitor firn temperatures in real-time and to detect the thermal influence of percolating meltwater during and after strong heat events.

Data from this thermistor chain revealed that only shallow refreezing occurred, not exceeding 0.5 m in depth. Furthermore, the study by Mattea (2020) includes the application of a fully coupled high-resolution surface energy balance and thermal firn model based on van Pelt et al. (2012). The model is run for Colle Gnifetti and forced by long-term hourly meteorological data measured at the nearby Capanna Margherita weather station (4560 m a.s.l.). The data were corrected and gap-filled based on measurements from other high-altitude stations in the region. As the accumulation regime on Colle Gnifetti is especially complex, being dominated by wind scouring and sun consolidation, a particular focus of the study was laid on the precipitation input for the model. Therefore, a three-phase accumulation model including a climatological grid, an annual anomaly time series and a downscaling coefficient was set up. The coupled surface energy balance and firn model was then applied to simulate surface conditions and firn evolution at hourly resolution and down to a depth of 20 m between 2003 and 2018.

A trend of annual melt increase of around 40 mm w.e. $a^{-}1$ per decade was found for the modelled period. In Figure 6.2, measured temperature profiles at the saddle point with the borehole locations of CG82-1, CG08-1 and CG18-1) are shown, where also measurements in 2008 and 2018/19 exist. There appears to be a remarkable cooling between 2008 and 2018/19. This observation is in qualitative agreement with other measurements in the Mont Blanc area (Vincent et al., 2020). Nonetheless, the observed cooling is difficult to explain. It might be related to an enhanced formation of near-surface ice layers, blocking vertical percolation of meltwater to depth. This process would decrease the release of latent heat by refreezing (Reijmer et al., 2012). However, firn drilling in summer 2019 did not reveal such ice layers and erroneous measurements in the year 2008 have to be considered as possible. Figure 6.3 shows the modelled firn temperatures at various depths at the Colle Gnifetti saddle with a grid resolution of 100 m and 3-hourly time-steps. The measured and modelled firn temperatures at CG08-1, CG08-2 and CG18-1 are presented in Figure 6.4. Since 1982, a large number of englacial temperature measurements, some of them to depths of more than 60 m, has been acquired in the Monte Rosa area (Hoelzle et al., 2011). Mattea (2020) compares the model output to this data collection and demonstrates a relatively close correspondence, with deviations of max. 2°C to the observed measurements Figure 6.4).

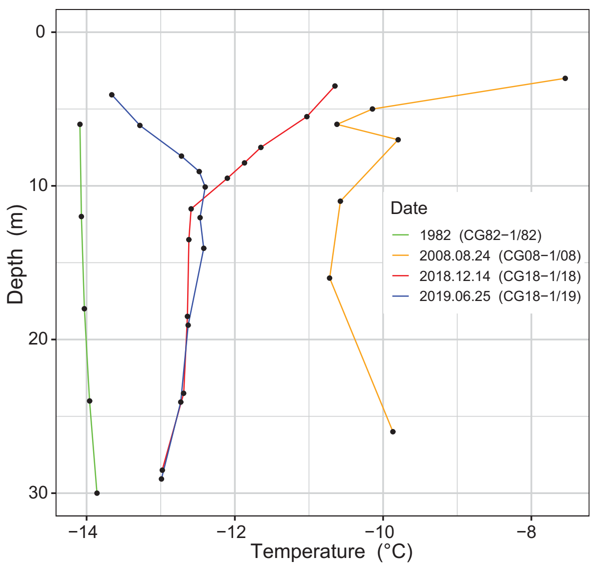

Figure 6.2: Firn temperature profiles at the Colle Gnifetti saddle, measured in 1982 (Haeberli and Funk, 1991), 2008 (Hoelzle et al., 2011) and 2018/2019 (Mattea, 2020). Boreholes CG82-1, CG08-1 and CG18-1 are loacatet at the same position.

Table 6.1: Borehole number, measurement date, total depth of the borehole, coordinates of the borehole location, and drilling technique.

number	date	depth	coordinates (m / m / m a.s.l.)	drill types
CG18-1/18	14.12.2018[a]	28.5	633798 / 86576 / 4455	steam
CG18-1/19	25.06.2019[a]	29.07	633798 / 86576 / 4455	steam
CG19-1/19	25.06 - 07.08.2019[b]	5.5	633797 / 86578 / 4455	mechanical

Type of thermistors: [a] YSI 44031; [b] http://u.nu/beadedstream

Table 6.2: Colle Gnifetti - Englacial temperature measurements in the years 2018 and 2019 in boreholes in two different boreholes CG18-1 and CG19-1.

Borehole: CG18-1

depth (m)	14.12.2018 temperature (°C)	25.06.2019 temperature (°C)
3.5	−10.65	
4.07		−13.66
5.5	−11.03	
6.07		−13.28
7.5	−11.65	
8.07		−12.72
8.5	−11.87	
9.07		−12.48
9.5	−12.10	
10.07		−12.40
11.5	−12.59	
12.07		−12.47
13.5	−12.62	
14.07		−12.42
18.5	−12.64	
19.07		−12.63
23.5	−12.69	
24.07		−12.73
28.5	−12.99	
29.07		−12.99

Borehole: CG19-1

depth (m)	26.06.2019 temperature (°C)
0.40	−4.94
0.65	−7.28
0.90	−8.61
1.15	−9.82
1.40	−10.77
1.65	−11.47
1.90	−12.10
2.15	−12.55
2.40	−12.93
2.65	−13.18
2.90	−13.25
3.15	−13.44
3.40	−13.50
3.65	−13.63
3.90	−13.63
4.15	−13.56
4.40	−13.56
4.65	−13.50
4.90	−13.50
5.15	−13.37
5.40	−13.25

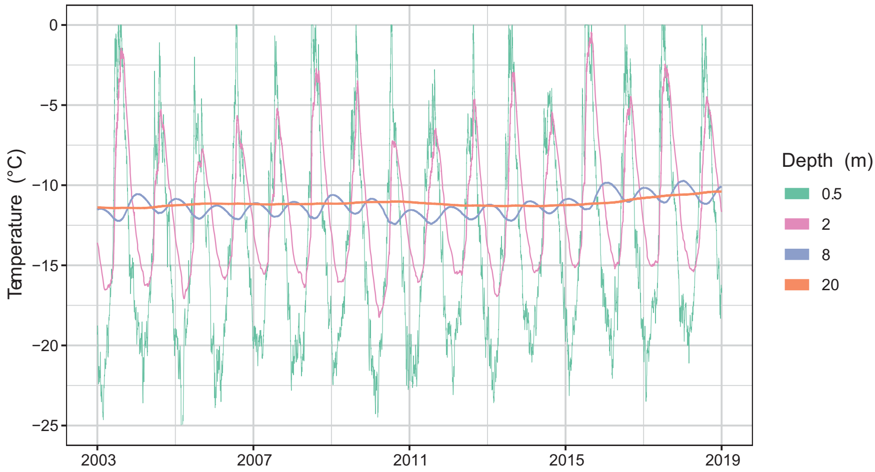

Figure 6.3: Modelled firn temperatures at various depths at the Colle Gnifetti saddle.

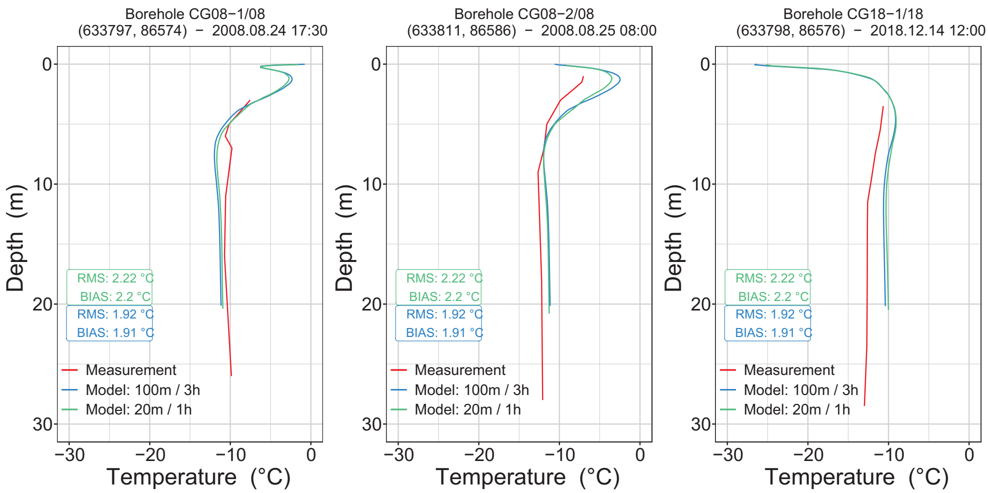

Figure 6.4: Boreholes CG08-1, CG08-2, CG18-1 with the measured and modelled temperature profiles in 2008 and 2018, respectively. Model results for two horizontal and temporal resolutions are shown and are characterized with their root-mean-square error and their bias in comparison to the observations.

Findelengletscher in 2018: accumulation area with Monte Rosa and Lyskamm in the background (top) and the glacier tongue with proglacial stream (bottom) (Photos: M. Huss)

7 GLAMOS data portal

The main tasks of GLAMOS are to document glacier changes in Switzerland, to maintain the long-term measurement series, and to collect relevant scientific information (see Chapters 3-6). However, an easily accessible, understandable and proper provision of the scientific data records to the public is equally essential. To GLAMOS, providing a representative and scientifically correctly processed data sample to a wide range of needs and audiences (research community, public administration, educational institutions like schools and universities and the interested general public) is thus crucial. To reach these different target audiences the best way is to maintain a publicly accessible data portal on the World Wide Web.

7.1 Background and requirements

At VAW/ETH, a database, containing all Swiss glacier monitoring data is maintained and is under ongoing further development. Access to this database can be granted to interested scientists, but is yet mainly limited to GLAMOS staff. To permit a broad public accessibility to all updated glaciological data, the data portal has to be built upon the GLAMOS database. Related to the database, a data and web server is already operational at VAW/ETH and the necessary interfaces can be provided. The database and the web and data server structure maintained at VAW/ETH are therefore an important basis for the development of a GLAMOS data portal.
The following requirements to an online data portal were thus formulated. The GLAMOS data portal has

- to be linked to the GLAMOS database,
- to present the most important GLAMOS data sets (length change, mass balance, glacier inventories),
- to include a map-browser based on swisstopo's map.geo.admin.ch environment,
- to present length change and mass balance data in interactive plots,
- to allow downloading of data, charts and tables,
- to have a News section (embedded Twitter account), and
- to provide the data in an understandable manner for all different target audiences.

In close collaboration with VAW/ETH and the University of Fribourg, the University of Zurich (UZH) was responsible for setting up a GLAMOS data portal that serves the above-mentioned criteria. Based on the defined requirements and thanks to additional funding provided by the Federal Office for Environment (BAFU), UZH was able to contract Meteotest, a private company from Bern (www.meteotest.ch), with whom UZH and GLAMOS staff developed and implemented the new GLAMOS data portal.

7.2 Development of the GLAMOS data portal

In order to optimally cover the various needs for a data portal, a user-, data- and use-case analysis was performed in a first step. Three main user categories were identified: (i) the general public interested in glacier changes, (ii) bodies of public administration and journalists, and (iii) scientists. As a next step, a storyboard for the website and a mock-up were developed. Based on the mock-up, Meteotest created a prototype of the website, which was then refined in several iterations following feedback from the GLAMOS Office and the GLAMOS Steering Committee.

The data portal can be accessed under the URL www.glamos.ch. For simplicity, the website's heading is *Swiss Glaciers* (*Schweizer Gletscher*, *Glaciers Suisses*, *Ghiacciai Svizzeri*), which is short and immediately understandable for a broader audience. Based on Meteotest's experience in web design, further requests regarding design and user guidance could be implemented. In the background, the GLAMOS database continuously provides up-to-date information to the data portal, which ensures that the two systems are connected but independent.

In February 2019, a first version of the GLAMOS data portal went online, satisfying already a majority of the articulated needs. However, further improvements were envisaged to fully respond to the expectations defined by the GLAMOS Office. Therefore, shortly after launching the first version, the process of further developing the portal had been started. Under the lead of UZH, but in close collaboration with all GLAMOS partners and numerous iterations with Meteotest, this process resulted in a next updated and enhanced version of the data portal that went online in June 2020.

7.3 Structure and functionalities of the website Swiss glaciers (www.glamos.ch)

Home: start page of data portal

On *Home*, the start page of the GLAMOS data portal (Figure 7.1), the most important elements are shown in a simplified manner. At the bottom, a welcome message is placed, where GLAMOS is explained in short. In a simple map viewer, markers in different colours, showing glacier length change or mass balance measurements, highlight the current observations. By default, a glacier with mass balance measurements is selected and the most important key values (area, annual mass

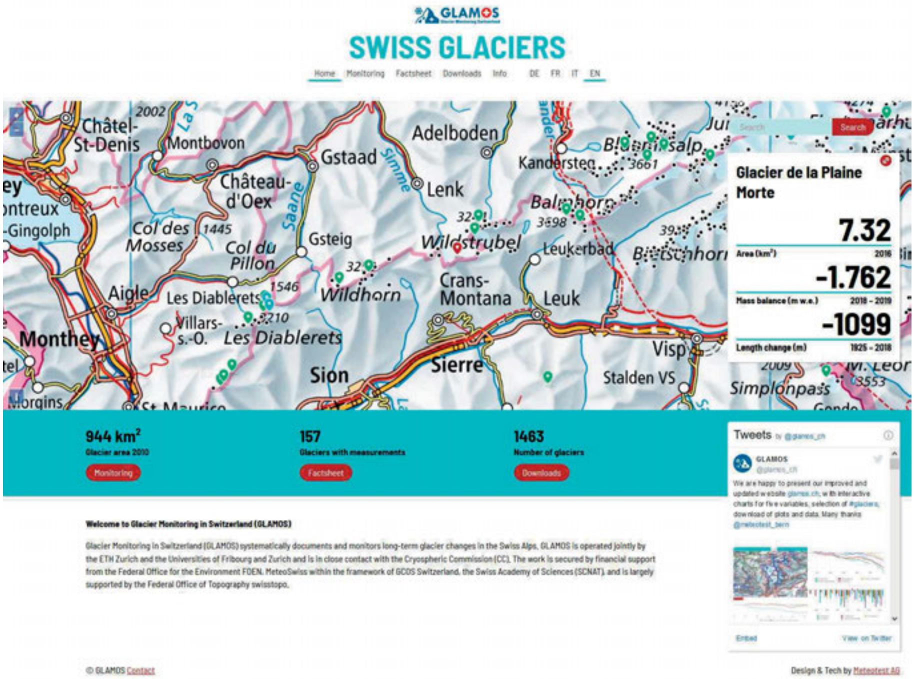

Figure 7.1: Start page of the GLAMOS data portal, presenting the most important elements in a simplified manner.

balance, long-term cumulative length change) is presented in an info box on the right. Just below the info box, as an integral part of the website, the GLAMOS Twitter feed is embedded to serve as a news ticker and archive for media articles related to GLAMOS. Within the prominent bar below the map, three key figures, derived from the last glacier inventory available, are used to direct the user to the three main pages of the portal:

- total glacier area → *Monitoring*
- number of glaciers with measurements → *Factsheets*
- number of glaciers → *Downloads*

Monitoring: map browser, charts and download

The *Monitoring*-page (Figure 7.2) is the core element of the GLAMOS data portal. This page builds upon an interactive map viewer based on swisstopo's map.geo.admin portal, where selected layers (e.g. current national map as the default, relief, aerial photos, last glacial maximum or the older Siegfried and Dufour maps) and the GLAMOS layers can be displayed. The GLAMOS layers

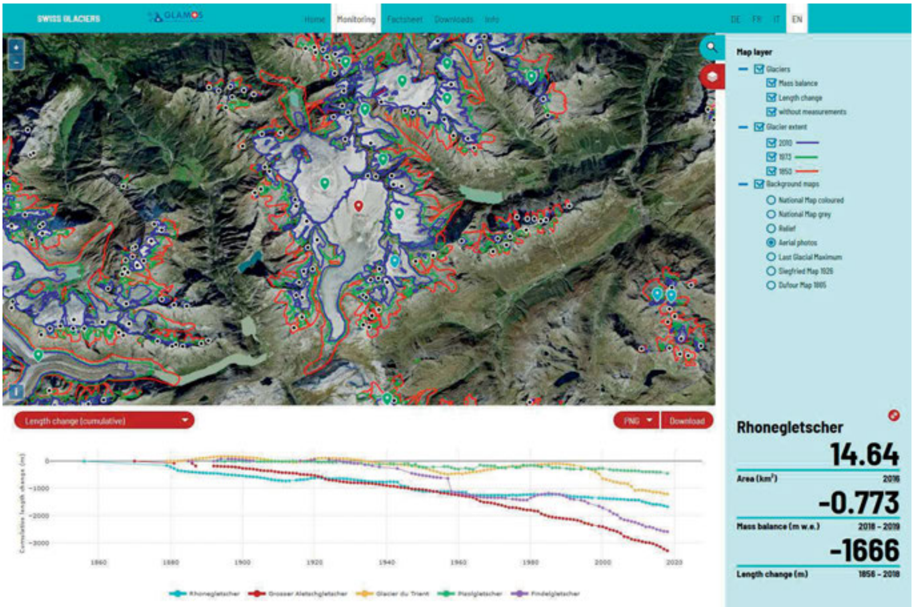

Figure 7.2: The core element of the data portal, where glaciers can be selected and be compared in charts based on five variables, which are downloadedable as .PNG or .SVG images or as a .CSV data file.

consist of three point layers (mass balance, length change, and glaciers without measurements) and three polygon layers with the glacier extent from the presently available inventories in 2010, 1973 and 1850. When entering the *Monitoring*-page, a mass balance glacier is selected per default and the corresponding info box displayed. Further glaciers can be added by using a search mask, or by browsing and clicking on a glacier. Up to a maximum of five glaciers can be selected and added to the plots at the bottom of the *Monitoring*-page. For a comparison, the data of all glaciers with measurements can be displayed in charts. This is possible for five variables: (i) cumulative length change, (ii) periodic length change, (iii) annual mass balance (observation period), (iv) winter mass balance (observation period), and (v) cumulative mass balance. The x-axis of the plots are adjusted based on the length of the measurement period of the selected glaciers. A mouse-over reveals further interactive elements (measurement value, time period, name of glacier). The plots can be downloaded as .PNG (picture) and .SVG (vector graph), but the data is also provided as a .CSV-file for more dedicated use of the data.

Factsheet: glacier info

The glacier *Factsheet* provides a compilation of all data and information available for glaciers with measurements. At the top of the page, a map for orientation, the glacier info box with the key observations, a short site description and a photo frame are shown. By clicking on the photograph, it is enlarged and a legend (date taken, photographer) appears. It is possible to browse through additional photographs of the glacier and the images can be downloaded. The glacier info text is stored within the GLAMOS database and can be easily updated. Below these four elements, the plots of the five variables are listed. These can also be selected on the Monitoring page. A suggestion for citing the data is given at the bottom of the page.

Download: access to raw data for experts

In the *Download*-section, the data of four categories can be downloaded. The inventory tab provides a list of all glaciers with measurements and the shapefiles of the Swiss Glacier Inventories 2010, 1973, 1850 together with the corresponding references. The length change, mass balance and volume change tabs are similarly structured. The downloadable dataset contains all available observations up to present and is delivered as a .CSV file. The following variables are provided: (i) glacier length change, (ii) glacier mass balance (observation period) for the entire glacier surface or elevation bins, (iii) glacier mass balance (hydrological year) for the entire glacier surface or elevation bins, and (iv) geodetic glacier volume changes. For all datasets, the references and doi-numbers are indicated.

Info pages: publications, glossary, organization and contact

The website is completed with static *Information*-pages: (i) publications, (ii) glossary, (iii) organization, and (iv) contact. These pages can be managed via a content management system (CMS), which allows updating, supplementing and linking content by the GLAMOS staff at any time and with limited effort.

The *Publication*-pages contains four categories: (i) press releases, (ii) annual reports on the state of the cryosphere published in the journal of the Swiss Alpine Club, (iii) yearbooks (detailed report of all measurements carried out by GLAMOS, published bi-annually by the Cryospheric Commission of SCNAT), and (iv) other publications. A menu on the right-hand side supports navigation between the categories. The *Glossary*-explains important basic glaciological terms. A menu allows selecting a specific term. On top, a selection of further glaciological links is provided. The *Organization*-page contains a description of the GLAMOS programme and its objectives. The participating institutions, partners and sponsors are listed and linked. The importance of the monitoring network is briefly explained. The ongoing, sedulous efforts of cantonal forestry services, federal offices, research institutes, hydropower companies, universities, and individuals are acknowledged and a note on how the GLAMOS data may be used, as well as recommended citations reference is given. Finally, the members of the GLAMOS Steering Committee and Scientific Committee are listed. The *Contact*-page reveals the main contact point (office@glamos.ch), the affiliations of the GLAMOS Office staff and the addresses of the institutions running GLAMOS.

7.4 Conclusion and outlook

The presentation of GLAMOS data on a graphically appealing and functional data portal provides a considerable benefit to all users addressed. With the multilingual structure, all content is provided in the four languages German, French, Italian and English. As the GLAMOS data portal is set up modularly, it can be expanded at any time, e.g. if further observational parameters should be added. Since the website is based on a CMS, the GLAMOS staff can easily perform smaller updates whenever needed. Most importantly, the data portal draws data from the GLAMOS database and will be updated annually. Information on how to cite the data is provided on the webpage but also within the downloadable data files.

Since this webpage is online (February 2019), the points of contact within GLAMOS are published. Especially via the general email-address (office@glamos.ch), GLAMOS has been approached with various requests: e.g. general information about a specific glacier, detailed questions about specific data, interview and media requests, pupils and students asking for assistance with data sets, artists making use of glaciological data, etc. Most feedback concerning the webpage from the public is very positive - apparently, the users are happy with the service provided. The current version of the GLAMOS data portal is in our view a functional and well-structured interface to communicate and distribute Swiss glacier data. However, there is always room for improvement and further ideas that could not be implemented this time are waiting to be developed.

References

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

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

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

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

Begert, M. 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.

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

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

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.

Flotron (2020). Vermessung der Aaregletscher - Beobachtungen 2017. unpublished report comissioned by Kraftwerke Oberhasli AG, Flotron AG, Meiringen.

Flotron, A. (1979). Verschiebungsmessungen aus Luftbildern. In *Festschrift Peter Kasser*, volume 41, pages 39–44. Mitteilungen der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, Gloriastrasse 37-39, CH-8092 Zürich.

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., Salzmann, N., Huss, M., and Desilets, D. (2019). Continuous and autonomous snow water equivalent measurements by a cosmic ray sensor on an alpine glacier. *The Cryosphere*, 13(12):3413–3434.

Haeberli, W. and Funk, M. (1991). Borehole temperatures at the Colle Gnifetti core drilling site (Monte Rosa, Swiss Alps). *Journal of Glaciology*, 37(125):37–46.

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

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

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

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

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

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

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

Kääb, A. (1996). Photogrammetrische Analyse zur Früherkennung gletscher- und permafrostbedingter Naturgefahren im Hochgebirge. Mitteilungen 145, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich, Gloriastrasse 37-39, CH-8092 Zürich. pp. 182.

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.

Lindner, F., Walter, F., Laske, G., and Gimbert, F. (2020). Glaciohydraulic seismic tremors on an alpine glacier. *The Cryosphere*, 14(1):287–308.

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

Mattea, E. (2020). Measuring and modelling changes in the firn at Colle Gnifetti, 4400 m a.s.l., Swiss Alps. Msc thesis, Faculty of sciences and medicine, Department of Geosciences. University of Fribourg. pp. 128.

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.

Reijmer, C. H., van den Broeke, M. R., Fettweis, X., Ettema, J., and Stap, L. B. (2012). Refreezing on the Greenland ice sheet: a comparison of parameterizations. *The Cryosphere*, 6(4):743–762.

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.

van Pelt, W. J. J., Oerlemans, J., Reijmer, C. H., Pohjola, V. A., Pettersson, R., and van Angelen, J. H. (2012). Simulating melt, runoff and refreezing on Nordenskiöldbreen, Svalbard, using a coupled snow and energy balance model. *The Cryosphere*, 6(3):641–659.

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

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

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

VAW (2010). Allalin-Gletscher – Bericht über die hydrologischen und glaziologischen Verhältnisse im Mattmarkgebiet 2018/2099. Bericht Nr. 7902-VAW-2020-03 (A. Bauder, unveröffentlicht), Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich. Im Auftrag der Kraftwerke Mattmark AG.

Vincent, C., Gilbert, A., Jourdain, B., Piard, L., Ginot, P., Mikhalenko, V., Possenti, P., Meur, E. L., Laarman, O., and Six, D. (2020). Strong changes in englacial temperatures despite insignificant changes in ice thickness at Dôme du Goûter glacier (Mont Blanc area). *The Cryosphere*, 14(3):925–934.

WGMS (2020). Global Glacier Change Bulletin No. 3 (2016–2017). ICSU(WDS)-IUGG(IACS)-UNEP-UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland.

Zekollari, H., Huss, M., and Farinotti, D. (2020). On the imbalance and response time of glaciers in the european alps. *Geophysical Research Letters*, 47(2):e2019GL085578.

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

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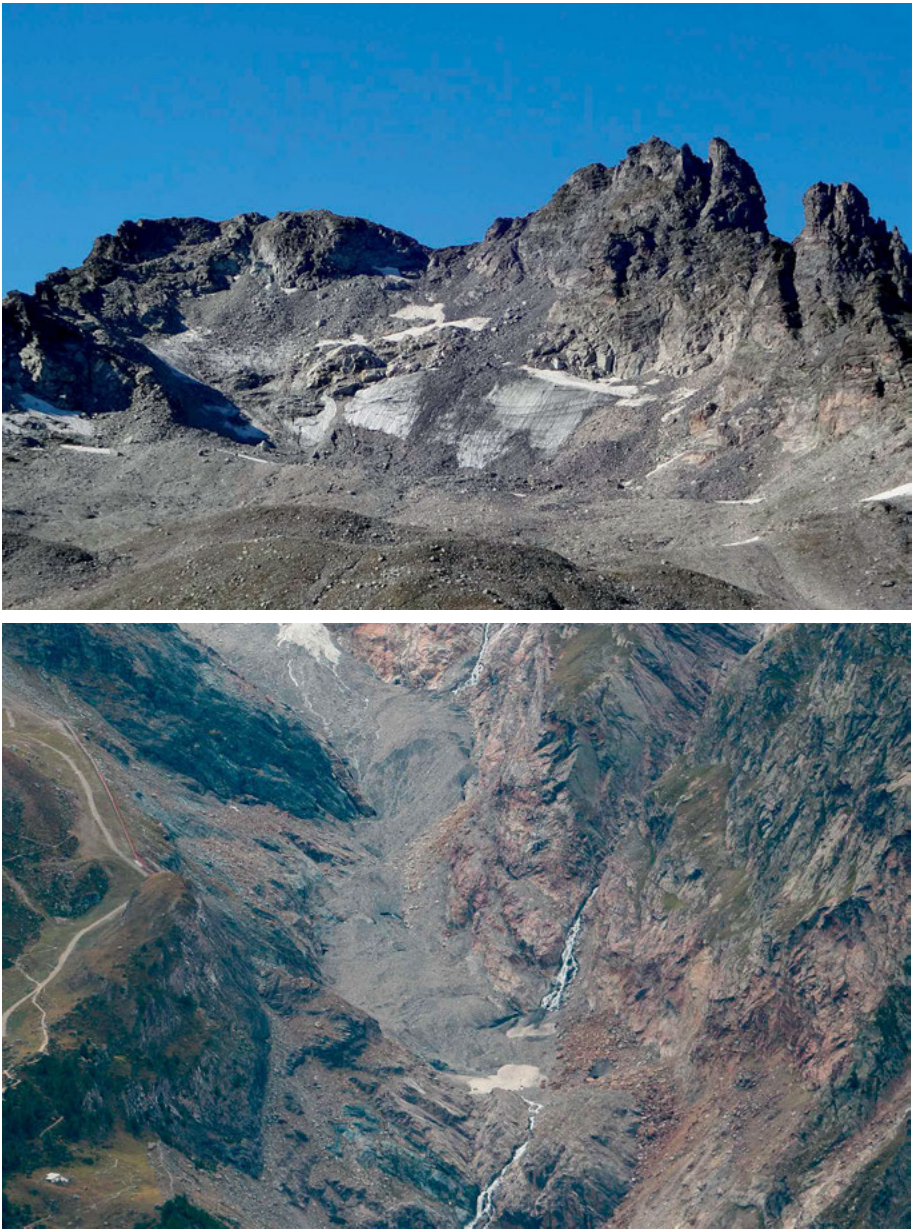

Debris covered remnant and discontinuous ice masses of Pizolgletscher in 2019 (top). Densified avalanche deposits that have been transformed to ice and are now completely merged with the glacier tongue (bottom) (Photos: M. Huss and DWL/VS, U. Andenmatten)

A Remote Sensing

A.1 Aerial photographs

Aerial photographs are taken at periodic intervals by Swiss Federal Office of Topography swisstopo in order to provide a baseline documentation for various applications (mapping, glacier change, natural hazards, etc). In addition to the periodical surveys, high resolution aerial photographs have been acquired which are designed in particular for glaciological applications. These are listed in the following tables (A.1 and A.2). Not listed are the routinely aerial photos by swisstopo for updating their standard products (National Maps, orthophoto or DEM). In the year 2018, pictures were taken for the areal of the Cantons BE, OW, TI and UR and in 2019 of the Cantons GL, GR and SG, respectively. More detailed information is available on swisstopo's webviewer http://www.luftbildindex.ch.

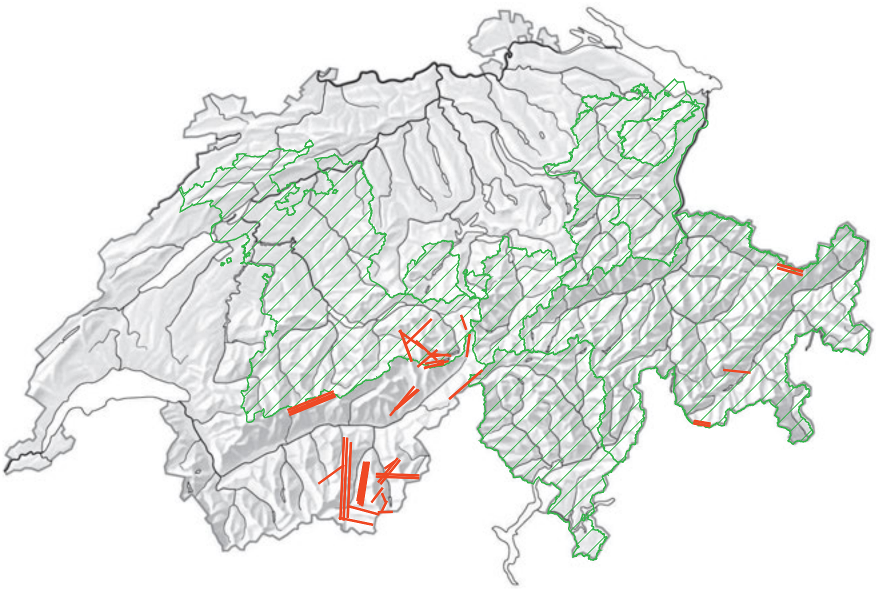

Figure A.1: Aerial photographs from the years 2018 and 2019 with specific surveys on glaciers (red) and coverage of swisstopo's periodic survey (green)

Table A.1: Aerial photographs taken in 2018.

Glaciers	Ct.	Date	Line No.	GSD	Type
Allalin p, Hohlaub p, Chessjen p	VS	11.09.18			col
Bis p, Schali p, Hohlicht p, Brunegg p,Schölli c, Stelli c	VS	11.09.18	12501201809111115	0.2	is
Bis p, Schali p, Hohlicht p, Brunegg p,Schölli c, Stelli c, Jung c	VS	11.09.18	12501201809111104	0.2	is
Bis p, Schali p, Hohlicht p, Turtmann p, Brunegg p, Schölli p, Piipji c	VS	11.09.18	12501201809111053	0.2	is
Cengal c, Bondasca c, Trubinasca c, Albigna p	GR	28.08.18	12501201808280903	0.1	is
Cengal c, Bondasca p, Trubinasca p, Albigna p	GR	28.08.18	12501201808280857	0.15	is
Diablons c, Turtmann p, Brunegg p	VS	11.09.18	12501201809111245	0.15	is
Fee p, Hohlaub p, Chessjen p	VS	11.09.18	12501201809111253	0.15	is
Findelen p	VS	11.09.18	12501201809111134	0.15	is
Gorner p	VS	11.09.18	12501201809111128	0.15	is
Gries c, Corno p, Blinnen p	VS	28.08.18	12501201808280929	0.15	is
Gries c, Corno p, Blinnen p	VS	15.08.18	12501201808150915	0.15	is
Grosser Aletsch p	VS	11.09.18	12501201809111150	0.1	is
Grosser Aletsch p	VS	11.09.18	12501201809111156	0.1	is
Grosser Aletsch p	VS	27.09.18	12501201809271059	0.15	is
Gruebu p, Gamsa p, Mattwald c, Rossbode p	VS	11.09.18	12501201809111039	0.15	is
Grüebu p, Fletschhorn c, Rossbode c	VS	11.09.18	12501201809111033	0.15	is
Grüebu p, Mattwald c, Gamsa p	VS	20.09.18	12501201809201008	0.1	is
Gutz c, Ob. Grindelwald p, Chrinnen c, Hengsteren p	BE	11.09.18	12501201809111345	0.2	is
Hohlaub p, Trift c, Mälliga c, Rottal c, Laggin p, Weissmies p, Tälli c, Zwischbergen p	VS	11.09.18	12501201809111016	0.15	is
Lagginhorn p, Hohlaub c, Trift c, Mälliga p, Laggin p, Weissmies c, Tälli c	VS	11.09.18	12501201809111024	0.15	is
Ob. Grindelwald p, Wächselberg c	BE	15.08.18	12501201808150906	0.2	is
Oberaar c, Fiescher p	BE	15.08.18	12501201808151004	0.15	is
Plaine Morte p, Lämmern c, Schwarz p	BE, VS	28.08.18	12501201808280950	0.1	is
Plaine Morte p, Tierberg c, Wildstrubel p, Steghorn c, Tälli c, Schwarz p, Altels c	BE, VS	28.08.18	12501201808281009	0.1	is
Plaine Morte p, Wildstrubel p, Lämmern p, Schwarz p	BE, VS	28.08.18	12501201808281000	0.1	is
Rhone p	VS	11.09.18	12501201809111002	0.15	is
Ried p, Hohbärg p, Festi p, Kin p	VS	11.09.18	12501201809111315	0.15	is
Ried p, Hohbärg p, Festi p, Kin p	VS	11.09.18	12501201809111323	0.15	is
Ried p, Hohbärg p, Festi p, Kin p, Weingarten p	VS	11.09.18	12501201809111307	0.15	is
Ried p, Hohbärg p, Festi p, Kin p, Weingarten p	VS	11.09.18	12501201809111259	0.15	is

Schwarzberg p	VS	11.09.18			col
Seewjinen p, Schwarzberg p	VS	11.09.18			col
Silvretta c, Verstancla p, Tiatscha p, Plan Rai p	GR	16.08.18	12501201808160819	0.15	is
Silvretta p, Verstancla c, Vernela c, Maisas p, Tiatscha c, Plan Rai c	GR	16.08.18	12501201808160826	0.15	is
Trift p	BE	20.09.18	12501201809201022	0.1	is
Unt. Grindelwald p	BE	15.08.18	12501201808150858	0.2	is
Unteraar p	BE	15.08.18	12501201808150958	0.15	is
Unteraar p	BE	15.08.18	12501201808150940	0.15	is
Unteraar p, Ob. Grindelwald p	BE	15.08.18	12501201808150949	0.15	is

c Glacier shown completely
p Glacier shown partially

GSD: Ground sampling distance in (m)
Type of acquisition: col colour frames; is image stripe

Table A.2: Aerial photographs taken in 2019.

Glaciers	Ct.	Date	Line No.	GSD	Type
Allalin p, Hohlaub p, Chessjen p	VS	21.09.19			col
Bis p, Schali p, Hohlicht p, Brunegg p,Schölli c, Stelli c	VS	03.09.19	12501201909031034	0.2	is
Bis p, Schali p, Hohlicht p, Brunegg p,Schölli c, Stelli c, Jung c	VS	04.09.19	12501201909041006	0.2	is
Bis p, Schali p, Hohlicht p, Turtmann p, Brunegg p, Schölli p, Piipji c	VS	03.09.19	12501201909031237	0.2	is
Cengal c, Bondasca c, Trubinasca c, Albigna p	GR	29.09.19	12501201909291043	0.12	is
Cengal c, Bondasca p, Trubinasca p, Albigna p	GR	29.09.19	12501201909291037	0.12	is
Fee p, Hohlaub p, Chessjen p	VS	03.09.19	12501201909031055	0.12	is
Findelen p	VS	03.09.19	12501201909031256	0.2	is
Gorner p	VS	03.09.19	12501201909031249	0.2	is
Gries c, Corno p, Blinnen p	VS	25.08.19	12501201908251003	0.2	is
Grosser Aletsch p	VS	04.09.19	12501201909041051	0.12	is
Grosser Aletsch p	VS	03.09.19	12501201909031208	0.1	is
Grosser Aletsch p	VS	03.09.19	12501201909031157	0.1	is
Gruebu p, Gamsa p, Mattwald c, Rossbode p	VS	04.09.19	12501201909041025	0.12	is
Grüebu p, Fletschhorn c, Rossbode c	VS	04.09.19	12501201909041018	0.12	is
Grüebu p, Mattwald c, Gamsa p	VS	04.09.19	12501201909041033	0.1	is
Gutz c, Ob. Grindelwald p, Chrinnen c, Hengsteren p	BE	25.08.19	12501201908251025	0.2	is
Güglia c	GR	29.09.19	12501201909291027	0.12	is
Hohlaub p, Trift c, Mälliga c, Rottal c, Laggin p, Weissmies p, Tälli c, Zwischbergen p	VS	03.09.19	12501201909031304	0.2	is
Lagginhorn p, Hohlaub c, Trift c, Mälliga p, Laggin p, Weissmies c, Tälli c	VS	03.09.19	12501201909031312	0.2	is

Ob. Grindelwald p, Wächselberg c	BE	25.08.19	12501201908250949	0.2	is
Oberaar p, Fiescher p, Minstiger p	BE	25.08.19	12501201908250923	0.12	is
Oberaar p, Fiescher p, Unteraar p	BE	25.08.19	12501201908250916	0.12	is
Plaine Morte p, Lämmern c, Schwarz p	BE, VS	03.09.19	12501201909031109	0.12	is
Plaine Morte p, Tierberg c, Wildstrubel p, Steghorn c, Tälli c, Schwarz p, Altels c	BE, VS	03.09.19	12501201909031125	0.12	is
Plaine Morte p, Wildstrubel p, Lämmern p, Schwarz p	BE, VS	03.09.19	12501201909031117	0.12	is
Rhone p	VS	25.08.19	12501201908250940	0.2	is
Ried p, Hohbärg p, Festi p, Kin p	VS	04.09.19	12501201909041130	0.12	is
Ried p, Hohbärg p, Festi p, Kin p	VS	04.09.19	12501201909041122	0.12	is
Ried p, Hohbärg p, Festi p, Kin p, Weingarten p	VS	04.09.19	12501201909041106	0.12	is
Ried p, Hohbärg p, Festi p, Kin p, Weingarten p	VS	04.09.19	12501201909041114	0.12	is
Schwarzberg p	VS	21.09.19			col
Seewjinen p, Schwarzberg p	VS	21.09.19			col
Silvretta c, Verstancla p, Tiatscha p, Plan Rai p	GR	29.09.19	12501201909291002	0.12	is
Silvretta p, Verstancla c, Vernela c, Maisas p, Tiatscha c, Plan Rai c	GR	29.09.19	12501201909291008	0.12	is
Trift p	BE	25.08.19	12501201908250849	0.12	is
Unt. Grindelwald p	BE	25.08.19	12501201908251014	0.2	is
Unteraar p	BE	25.08.19	12501201908250908	0.12	is
Unteraar p	BE	25.08.19	12501201908250931	0.12	is
Unteraar p, Ob. Grindelwald p	BE	25.08.19	12501201908250857	0.12	is

c Glacier shown completely
p Glacier shown partially

GSD: Ground sampling distance in (m)
Type of acquisition: col colour frames
is image stripe

B Remarks on Individual Glaciers

1 Rhone

2018: Luftbildaufnahmen am 11.7.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 25.8.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

3 Gries

2018: Luftbildaufnahmen am 15.8.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 25.8.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

5 Grosser Aletsch

2018: Luftbildaufnahmen am 27.9.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 4.9.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

7 Kaltwasser

2018: Die Gletscherzunge wurde erstmals mit GPS aufgenommen. Die diesjährige Messung wurde jedoch noch mit dem Messband ausgeführt. (M. Schmidhalter)

2019: Beim bisherigen Punkt 1 nur noch abgebrochene Gletscherzunge vorhanden. Neuer Punkt 1 bei der tiefsten Stelle eingerichtet. (M. Schmidhalter)

10 Schwarzberg

2018: Luftbildaufnahmen am 11.9.2018, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 21.9.2019, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

11 Allalin

2018: Luftbildaufnahmen am 11.9.2018, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 21.9.2019, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

12 Chessjen

2018: Luftbildaufnahmen am 11.9.2018, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 21.9.2019, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

13 Fee

2018: Der untere Gletscherteil ist mit dem Hauptgletscher am rechten Rand doch noch verbunden, jedoch mit viel Gestein und Geröll überdeckt. Das Gletschertor war Ende September nicht messbar, weil er an der Front mit Lawinenschnee aus dem Winter überdeckt war. (U. Andenmatten)

2019: Die Gletscherzunge ist weiterhin überdeckt mit dem Lawinenschnee aus dem Winter 2017/18. Im vergangenen Herbst wurde deshalb auf eine Vermessung verzichtet. Inzwischen ist der Lawinenschnee verfirnt und damit Teil der Gletscherzunge. Es ergibt sich deshalb auch eine Zunahme seit der letzten Messung im Herbst 2017. (U. Andenmatten)

16 Findelen

2018: Luftbildaufnahmen am 11.8.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 3.9.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

17 Ried

2018: Koordinaten von Referenzpunkt FP75 neu bestimmt mit Swiss Grid App auf iPhone: 630’938 / 111’062 (P. Rovina)

2019: Koordinaten von Referenzpunkt FP75 neu bestimmt mit Swiss Grid App auf iPhone: 630’930 / 111’061 (P. Rovina)

19 Turtmann

2018: Sehr grosser Rückzug, Gletscherrand zu Fuss und mit Drohne vermessen. Der Rückzug ergibt sich jeweils aus der Verschiebung des Gletschertors. (A. Brigger)

20 Brunegg

2018: Sehr grosser Rückgang des Gletschers. Vermessung erfolgte zu Fuss vor Ort und mit Drohne. Der Rückzug ergibt sich aus der Verschiebung des Gletschertors. Die genaue Lage des Gletschertors war nicht zugänglich und musste im Gelände abgeschätzt werden. (A.Brigger)

2019: Gletscherrand mit GPS und Laser vermessen. Der Rückzug ergibt sich aus der Verschiebung der Gletscherspitze (das Gletschertor liegt leicht seitlich und ist nicht zugänglich). (A.Brigger)

22 Zinal

2018: Précision GPS: ≈ 3.0 m. Epaisseur au front: 47 m. Vol drone avec 5 points de référence pour géoréférencement. (G. Chevalier)

24 Moiry

2018: Précision GPS: 2.5-3.0 m. Epaisseur au front: 0-5 m. Beaucoup de glace morte en rive gauche. Epaisseur: ≈ 20 m. Vol drone avec 4 points de référence pour géoréférencement. (G. Chevalier)

25 Ferpècle

2018: Points de référence 1 et 2 de 2017 abandonnés. Mesure du recul sur les points 3,4,5 de 2017 nommés 1,2,3 (F. Fellay)

2019: Depuis cette année il n'y a plus de lien entre la langue mesurée ici et la partie amont du glacier. La scission s'est produite environ 500 m en amont du front au niveau d'une barre rocheuse. Un accès sûr au nouveau front n'est plus possible. (F. Fellay)

27 Arolla

2019: Une très mince épaisseur de glace relie le plat à la langue. (F. Fellay)

29 Cheillon

2018: Recul mesuré sur la base de 4 nouveaux points de référence. L'avancée du glacier au centre de la langue résulte d'une différence de Méthode de mesure. Cette avancée n'existe pas en réalité. (O. Bourdin)

30 En Darrey

2018: 5 nouveaux points de référence ont été définis. (O. Bourdin)

31 Grand-Désert

2019: Nous avons fixé 3 nouveaux points de mesure pour 2020. (F. Bourban)

32 Mont Fort (Tortin)

2019: Le front glaciale est couvert de rochers et de materiel terreux, il est donc difficile de le situer précisement. En 2019 une fente bien visible a permis de localiser ces points plus précisément qu'en 2018 (F. Bourban)

33 Tsanfleuron

2019: Un éboulement important s'est produit au printemps 2019 au bas du glacier, sans toutefois le toucher. Il a par contre atteint le point B de prise de vue photo. Celui-ci a été déplacé. (P. Fellay)

34 Otemma

2018: Point 21/17 abandonné car emporté par suite d'un nouveau effondrement de la moraine latérale gauche. (J.-J. Chabloz)

35 Mont Durand

2018: Les deux bras du glacier sont maintenant bien séparés. (J.-J. Chabloz)

36 Brenay

2018: Point 24/15 abandonné, plus de glace. Nouveau axe de visée point 25/18 plus centré et un peu plus près du front. (J.-J. Chabloz)

39 Valsorey

2018: Grosse fonte en épaisseur (J. Médico)

40 Tseudet

2018: Forte fonte en épaisseur. La limite en rive droite est difficile à définir. Le glacier est entièrement recouvert de pierres. (J. Médico)

2019: Fort recul car fonte au milieu. Le point de mesure de l'an dernier est désormais coupé du reste du glacier (glace morte). (P. Stoebener)

41 Boveyre

2018: Forte fonte en épaisseur. Les limites en rive droite et gauche sont difficile à fixer. Le glacier est recouvert de pierres. (J. Médico) 2019: Le bord ouest du glacier n'a pas été délimité au même endroit. (P. Stoebener)

42 Saleina

2018: La langue du glacier a perdu beaucoup d'épaisseur et est passée d'une pente de 40° environ à une pente de 5°. En rive gauche, la délimitation du glacier est la plus exacte, la fonte de la glace a permis de délimiter mieux cette dernière. (J. Médico)

43 Trient

2018: La fonte de l'année 2018 a été importante. Le débit du torrent émissaire a été particulièrement élevé durant l'été, et c'était encore le cas lors de notre passage. L'amincissement de la langue glaciaire se poursuit inexorablement. La langue semble se recroqueviller, particulièrement sur sa marge Nord-Est. Faute de mesures, il n'a pas été possible d'estimer le volume de glace perdu durant une année. La masse de glace éboulée qui bordait la pointe de la langue glaciaire en 2017, en direction de l'aval, a presque entièrement disparu. La pointe de la langue abandonne peu à peu la pente la plus accentuée. On le remarque à la couleur sombre de la surface glaciaire, de moins en moins alimentée par l'écoulement gravitaire. Le relevé du périmètre de la langue glaciaire a été réalisé à l'aide de jumelle laser LEICA, sans couplage GPS, à partir du point de mesure "I". Coordonnées du point "I", en usage depuis 2004: 567'888 / 97'099 / 1'994m. Azimut principal du point "I" vers le font: 180°. L'extrémité la plus basse de la langue est toujours engagée dans un sillon rocheux d'orientation approximative SW-NE. Le front se trouve à environ 2'145 mètres d'altitude. Il s'agit de la base de la glace, au contact du rocher. (J. Ehinger)

2019: 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. La fonte de cette année a été importante, comme les années précédentes. Le débit du torrent émissaire a été élevé durant l'été, mais ce n'était plus le cas lors de notre passage. Comme exprimé dans les rapports précédents, la fonte du glacier, initiée en 1987, se poursuit avec une intensité accrue depuis une dizaine d'années. 2019 (+0,48°C, température annuelle moyenne) fait partie des cinq années les plus chaudes enregistrées au Grand-St-Bernard (la station météorologique de montagne la plus proche), avec 2018 (+0,56°C) et 2017 (+0,44°C). Les records depuis 1864 (-2,54°C) étant 2015 (+1,0°C) et 2011 (+0,76°C). L'amincissement de la langue glaciaire se poursuit inexorablement. La langue semble se recroqueviller, particulièrement sur sa marge Nord-Est. Faute de mesures, il n'a pas été possible d'estimer le volume de glace perdu durant une année. La pointe de la langue abandonne peu à peu la pente la plus accentuée. Dans quelques années il ne restera que le corps principal de la langue, orienté de 25° à l'Ouest d'un axe Nord-Sud. L'amincissement général de la langue glaciaire s'est poursuivi en 2019, de manière sensible. On le remarque à la couleur sombre de la surface glaciaire, de moins en moins alimentée par l'écoulement gravitaire. On remarque aussi l'augmentation de la largeur et de la profondeur des crevasses, allant parfois jusqu'à la roche. Année après année, on remarque la forte croissance des arbres autour du point "alpha", qui cachent de plus en plus la langue glaciaire. Le relevé du périmètre de la langue glaciaire a été réalisé à l'aide de jumelle laser LEICA, sans couplage GPS, à partir du point de mesure "I". Coordonnées du point "I". Azimut principal du point "I" vers le front: 180°. Le front du glacier dans l'extrémité la plus basse de la langue est toujours engagée dans un sillon rocheux d'orientation approximative SW-NE. Le front se trouve à environ 2'166 mètres d'altitude. Il s'agit de la base de la glace, au contact du rocher. (J. Ehinger)

45 Grand Plan Névé

2018: Points 1 et 11 pierres en surface = difficile de situer le glacier. (J.-Ph. Marlétaz)

2019: Recul du glacier faible car l'inclinaison de la langue glaciaire est importante = le glacier avance. Point 1 et 11 délicats a estimer car beaucoup de cailloux en surface. (J.-Ph. Marlétaz)

47 Sex Rouge

2018: (1) Les conditions météorologiques prévalant jusqu'à fin août induisent un recul sensible du glacier (2) Reliquats de neige fin août au point 2 ainsi que sur la nouvelle piste de ski (3) Le point 3 est recouvert par les remblais de la nouvelle piste de ski à Cabane CAS; ici le glacier étant soit définitivement recouvert par les éboulis de pente de la Becca d'Audon soit situé bien à l'amont (J. Binggeli)

2019: (1) Le glacier n'est plus apparent aux point 1 à 4 (mort ou reliquats enfouis sous les éboulis) (2) Aux points 500 et 51, agrandissement du plan d'eau résultant de la fonte du glacier (une ou deux flaques d'eau en 2013) (3) Faille longitudinale point 500-51 plus marquée (4) Outre le recul en situation mesuré, l'apparence générale du glacier laisse présager une perte de masse significative (J. Binggeli)

48 Prapio

2018: (1) Première observation du 04.09.2018 depuis l'antecime du Sex Rouge, glacier recouvert par fine couche de neige fraiche de fin août (2) Le point le plus bas est encore décelable sous les éboulis; pas de recul constaté, le bas du glacier est protégé par l'épaisse couche d'éboulis (≈ 10 m ou plus); glace vive (ou morte?) (J. Binggeli)

2019: (1) Première observation du 15.09.2019 depuis l'antecime du Sex Rouge: altération marquée du glacier en surface; trace d'une chute de blocs (déjà visible en 2018) des falaises de Prapio entaillant le glacier jusqu'au rocher; le torrent semble charrier des matériaux terreux (eau brune) (2) Nature de la glace apparente (mesurée): il n'est pas exclu qu'il s'agisse en fait de glace morte fractionnée recouverte par une couche d'éboulis (tentative avortée de traverser cette zone) (J. Binggeli)

53 Stein

2019: Zwei neue Referenzpunkte eingerichtet: No 6: 676'151 / 174 171 und No 7: 676'181 / 174'183.

55 Trift (Gadmen)

2018: Luftbildaufnahmen am 20.9.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 25.8.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

57 Oberer Grindelwald

2018: Luftbildaufnahmen am 15.8.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 25.8.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

58 Unterer Grindelwald

2018: Luftbildaufnahmen am 15.8.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 25.8.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

59 Eiger

2018: Messung zusätzlich mit Hand-Distanzmesser (Leica) zur Kontrolle. Die Messung wird immer schwieriger, da die Distanzen sehr lang sind (über 800 m) und auch diagonal zum Gletscher gemessen wird. (R. Schai)

2019: Kein Gletschertor; viel Moränenmaterial, orographisch links ist es sehr schwierig den Gletscher unter dem Moränenmaterial zu finden. Es fällt auch viel Material von oben in diesen Trichter. Das Gletschervorfeld ist sehr matschig und mit Wasser durchtränkt. Die Punkte zusätzlich mit dem GPS erfasst. (R. Schai)

60 Tschingel

2018: Kein Gletschertor, Moränenmaterial isoliert den Gletscher gut, orographisch rechts liegt der Gletscher im Schatten der Berge und schmilzt langsamer. Auf der linken Seite ist er schon weiter nach hinten abgeschmolzen. Zum ersten Mal von den neuen Punkten gemessen. (R. Schai)

2019: Kein Gletschertor sichtbar, starke Schuttbedeckung, orographisch links ist es sehr schwierig den Gletscher unter dem Schutt auszumachen. Im Gletschervorfeld sumpfig. (R. Schai)

61 Gamchi

2018: Der Gletscher hat deutlich an Masse verloren. Das Vorfeld hat sich durch die grossen Abflussmengen stark verändert. Es sind viele neue Gräben entstanden und im mittleren Teil ist der Grossteil des Geschiebes bis auf den Fels weggeschwemmt worden. Der See im Geschiebefeld hat sich seit letztem Jahr deutlich vergrössert. Nach 1/3 der Gletscherlänge hat sich ein Gletschersee gebildet. (M. Schenk)

63 Lämmern

2019: Das Vorgelände ist felsdurchsetzt und nur schwierig begehbar. (A. Meier-Glaser)

64 Blümlisalp

2018: Der Blüemlisalpgletscher hat sich nun fast vollständig über die markante Felsstufe (2'500 m.ü.M) zurückgezogen. Vereinzelt hängen noch kleine Eisarme in die drei Couloirs hinunter. Eine relevante Längenmessung wurde hier während den letzten Jahren immer schwieriger, da das Gelände zunehmend unzugänglicher wurde und auch die Messrichtungen der alten Basismesspunkte nicht mehr auf Eis trafen. Nichtsdestotrotz konnte aber mittels elektronischer Distanzmessung eine Messung vorgenommen werden, welche noch annähernd relevant war. Dieses Jahr allerdings konnte mittels Distanzmesser keine relevante Messung mehr durchgeführt werden, da die Distanz schlichtweg zu gross war und sich keine "reflektierende" Fläche mehr fand. Augenscheinlich mittels diverser Anhaltspunkte zu vergangenen Messungen wurde der Längenverlust auf $\approx$9 Meter geschätzt. Allerdings ziehen sich die Arme in den Couloirs etwas langsamer zurück als die übrige Zunge oberhalb der Felsstufe. Hier ist der Massenverlust entsprechend gross und Flächen mit geringer Eisdicke über den Felsen verschwinden eindrücklich rasch. Mittels einiger Markierungen am Gletscherrand werden wir versuchen im nächsten Jahr die Messreihe oberhalb der Felsstufe weiterzuführen. (U. Burgener)

65 Plaine Morte (Rätzli)

2018: Luftbildaufnahmen am 18.8.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 3.9.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

66 Tiefen

2018: Im Vergleich zum Vorjahr an neuer Gletscherzunge massiv grösserer Wasserabfluss. (L. Eggimann)

2019: Im Bereich der Gletscherzunge starker Zerfall. Grosser Wasserabfluss. In der Ebene vor Toteis hat sich schöner Gletschersee gebildet. Toteis weist schönen, runden Einsturzkrater auf. (L. Eggimann)

67 St. Anna

2018: Im untersten Abschnitt ist der Gletscher am westlichen Rand stark abgeschmolzen. (L. Eggimann)

2019: Im untersten Teil Gletschereis sehr geringmächtig (<1 m), mit viel Schutt bedeckt. Teilweise bereits durchgeschmolzen. Übergang zu Toteis. (L. Eggimann)

68 Chelen

2018: Neuer Messpunkt 2018D eingerichtet. Punkt 2015A war unauffindbar. (R. Planzer)

70 Damma

2018: Zwei neue Messpunkte 2018 und 2018B eingerichtet (R. Planzer)

2019: Der Hauptgletscher hat sich stark zurückgezogen. Messungen vor allem an einigen Gletscherarmen. (M. Planzer)

71 Wallenbur

2018: Vor allem in der Mitte hat der Gletscher stark abgenommen (entlang Gletscherbach). Er hat weiterhin mehrere Tore. (P. Kläger)

2019: Der Gletscher hat in der Länge nicht abgenommen. Die Masse schwindet jedoch rapide. Vor allem entlang vom Gletscherbach ist der Gletscher mehrfach eingebrochen. Der Zubringer vom Eisfeld unterhalb des Gross Sustenhorns scheint definitiv unterbrochen. Der Gletscherteil Nord (unterhalb Klein Sustenhorn) scheint noch kompakt zu sein. (P. Kläger)

72 Brunnifirn

2019: Der Gletscher ist vor allem im Randbereich nicht sehr dick. Langsam bildet sich ein kleiner Gletschersee. (M. Planzer)

75 Firnalpeli

2018: Der Rückgang des Gletschers scheint relativ gross, Grund dafür ist die starke Schneebedeckung im 2016. Gegenüber 2015 ergäbe sich sogar ein Vorstoss von gemittelt fast 10 m. Die gemessenen Werte 2018 sind auch vergleichbar mit früheren Jahren. Nur im Bereich, wo sich der Gletscher wohl trennen wird, sind grössere Veränderungen ersichtlich. (M. Jäggi)

2019: Die beiden Teile des Gletschers sind nun komplett getrennt. Der untere Bereich hat sich gegenüber dem letzten Jahr kaum verändert, beim oberen Rand gab es bereits wieder einen Rückgang. Gemessen wurde nur der obere Bereich, mit GPS. (M. Jäggi)

76 Griessen

2018: Bei Punkt 1 ist die Messrichtung fast parallel zum Gletscher, weshalb der gemessene Wert recht ungenau ist. Insbesondere im Bereich von Punkt 4 war auch im Feld ein grosser Rückgang zu erkennen. Hier war vermutlich die Eisdicke bei der letzten Messung über eine längere Distanz nur noch sehr gering. (M. Jäggi)

2019: Bei Messpunkt 1 ist die Messrichtung nach wie vor fast parallel zum Gletscherrand, weshalb die Messung eher als ungenau zu werten ist. Teilweise ist die Gletscherzunge stark von Schutt bedeckt und nicht ganz eindeutig zu identifizieren. (M. Jäggi)

77 Biferten

2018: Zusammen mit Gabriela Schiesser können wir unsere Messung mit tollen Stimmungen in Angriff nehmen. Mystische Wolkengebilde und die einzigartig raue Bergwelt am Fusse des höchsten Glarners begleiten uns bei der Arbeit, aber dies ist keineswegs hinderlich für die Messung. Nach der holperigen Fahrt hinauf nach Hintersand, steigen wir mit Sack und Pack bis zur Unterkunftshütte der KLL auf. Verfolgt werden wir lediglich von einer Nebelschlange, die sich beinahe ins Tentiwang legt, wie vor vielen Jahrzehnten der Bifertengletscher. Gabi ist beeindruckt von der mächtigen Bergkulisse. Bei der KLL Unterkunftshütte fassen wir unser deponiertes Stativ und steigen zum Punkt 12003 auf, wo wir unsere Messung einmal mehr starten werden. Nach einem Znünihalt mit Kaffee aus der Thermosflasche und kurzer Anleitung, begibt sich Gabi zum Anschlusspunkt E und von dort zur Gletscherzunge um mit dem Reflektor die Zunge des Gletschers zu kartieren. Dies ist zugleich der tiefste Punkt am Gletscher der sich im Übrigen von 1'963.7 m.ü.M auf 1'964.7 m.ü.M zurückgezogen hat. Auch für meine Messgehilfin keine leichte Aufgabe, da eben in diesem Bereich der Gletscher nur sporadisch hervortritt und kaum auszumachen ist, aber der Gletschermesser kennt ja dieses Phänomen bereits lange und kann da mittels Funk auch etwas Einfluss nehmen, wenn es für Gabi zu schwierig wird den Verlauf zu erkennen. Bis zum Punkt mit der Höhe 2'002.8 m.ü.M kann ich alles von der Station 12003 aufnehmen. Danach ist ein Wechsel nötig, ich muss zu Punkt 20101 dislozieren und die Messgehilfin hat demnach etwas Pause. Dabei schaut sich Gabi nach einem geeigneten Übergang am Gletscherbach 2 um, dies scheint aber einmal mehr nicht direkt möglich zu sein. Da ist also die Überquerung und Umgehung über den Gletscher unumgänglich. Nachdem ich die Überquerung des Gletschers absolviert habe und das Instrument auf der Station positioniert und orientiert habe, können wir mit der Messung fortfahren. Dabei sind nur noch wenige Punkte aufzunehmen bis der Gletscherbach und See die Arbeit in diesem Bereich verunmöglichen. Gabi gibt mir diese Punkte noch und verschiebt sich dann ebenfalls über den Gletscher auf meine Seite um dort noch die restlichen Punkte zu kartieren. Sie kommt dabei bis zum Gletschertor 2 und übermittelt mir dabei die Daten. Nach dem Gletschertor kann ich leider mit der reflektorlosen Messung kein Resultat erzeugen, daher nehme ich die restlichen Punkte mit Längsverschiebungen (geschätzt) auf. Die starke Geröllbildung am Gletscher ist für uns beeindruckend wie auch die bildlichen Verschiebungen des Gletschers hinauf Richtung Tödi. Der Ausstieg über die Jakob Streiff-Becker Moräne gelingt uns recht passabel und so können wir nachdem wir das Stativ wiederum in der alten Fridolinshütte zur Zwischenlagerung abgelegt haben unsern wohlverdienten Z'Vesper bei Gabi Aschwanden der Hüttenwartin geniessen. Dabei sehen wir mit Schrecken, wie schnell im unteren Abbruch des Gletschers am Fusse des Grünhorns der Schwund verläuft und der unterste Teil des Gletschers allmählich zur Toteismasse werden wird. Dies bedeutet dann, dass ich meine Messungen wohl ab der Fridolinshütte vornehmen muss und im neuen Vorfeld neue Fixpunkte rund einen Kilometer weiter oben installieren muss. Der Abstand zur Fassung als doch eindrückliches Beweismittel wie sich der Gletscher bewegt, ist nun bereits auf 202.3 m gewachsen. Die Höhen an den Gletschertoren habe ich in diesem Jahre mit folgenden Metern festgehalten: Gletschertor 1 auf 1'972.3 m.ü.M und kaum mehr Wasserausfluss, Gletschertor 2 liegt auf 2'005.5 m.ü.M und hat einen grossen Gletschersee vor sich und speist daraus den jetzt mächtigen und reissenden Gletscherbach. (H. Klauser)

2019: Als ich mich um eine Begleitung umsah, sagte Hans Landolt aus Näfels (Stei Hans) spontan zu und so konnten wir bei besten Bedingungen den Gletscher messen. Nach Fahrt bis Hintersand und der Verteilung der Lasten und dem Aufschnallen der Rucksäcke geht es zu Fuss hinauf übers Tentiwang bis zur Unterkunftshütte der KLL und schliesslich über einen "Jägerpfad" hinauf zur Station 12003, wo wir mit der Messung beginnen wollen. Zügig erreichen wir unser erstes Ziel den Gletscherrand, dies wie gewohnt mit der nötigen Vorsicht, denn an gewissen Passagen ist Stolpern oder Straucheln nicht erlaubt. Natürlich wird auch "Stei Hans" in die Geheimnisse der Vermessung eingeweiht und mit den nötigen Utensilien und Instruktionen nach Wäschewechsel und einem kurzen Znüni auf den Weg geschickt. Ich stationiere auf dem Fixpunkt 12003 den Theodoliten TS16 von Leica, währenddem Hans mir die Ausgangsrichtung E signalisiert. Die restlichen Orientierungen sind der Giebel der Fridolinshütte und das Kirchlein in Braunwald. Nach der Orientierung, kann die Messung beginnen. Der erste Punkt der mir Hans am Gletscher übermittelt, ist zugleich der Tiefste: die Höhe beträgt dort 1'963.5 m.ü.M. Sie ist wieder um einen Meter tiefer als im Vorjahr, dies weil der Gletscher dort ziemlich schwierig auszumachen ist unter dem Geröll. Immer in Bewegung, läuft Hans gar in knielangen Hosen dem Gletscher entlang, ohne dabei ins Frieren zu kommen. Er macht seine Arbeit gewissenhaft und ohne Fehl und Tadel. Ein erstes sichtbares und eindeutiges Ausmachen des Gletschers ist beim Gletschertörchen am Gletscherbach 1. Kaum vorstellbar, dass da einmal derart Wasser floss, dass eine Überquerung unmöglich war und über den Gletscher umgangen werden musste. Die Höhe dieses ersten Referenzpunktes beträgt in diesem Jahr 1'972.7 m.ü.M. Dies ist nur gerade 40 cm höher als im Vorjahr, aber bei dem flachen Vorgelände kann da keine allzu grosse Höhenveränderung erwartet werden. Auch der Abstand zur Fassung ist nicht wesentlich verändert. Hans kann mir gut 10 Punkte ab der Station 12003 kartieren, danach ist wie bereits seit einiger Zeit, der Wechsel des Operateurs mit seinem Instrument unausweichlich. So kann Hans auf der Meereshöhe von 1'999.3 m.ü.M eine Rast einschalten. Bereits hat er aber bei meiner Ankunft auf seiner Position, einen Augenschein genommen, ob denn eine Gletscherbach 2 Querung möglich sei. Doch auch er findet keinen geeigneten und ungefährlichen Weg übers Wasser und so bleibt die Umgehung über den Gletscher die einzige Variante auf die andere Seite zu kommen. Dies ist dabei ohne Steigeisen und Pickel zu bewältigen, da das Eis derart mit Kies und Geröll übersät ist, dass dies gefahrlos möglich ist. So wechsle ich hinüber auf die Station 20101. Hans bleibt noch zurück und gibt mir dann noch die möglichen Punkte bis zum Gletschersee. Danach verschiebt er sich ebenfalls über den Gletscher zum Ende der Gletscherzunge. Von dort kämpft er sich dann bis zum Gletschertor 2 vor. Dieses kann ich nun sogar in der Höhe auswerten, da mir Hans die Höhe des Gletscherbaches mit dem Reflektor übermitteln kann und ich die Höhe und Lage des Gletschertores oben am Gletscher erfassen kann. Das 17.3 m hohe Tor ist doch eindrücklich, wenn man davor steht oder gar unter ihm! Danach kann Hans nicht mehr weiter, der Gletscherbach / See verwehrt ihm das Weiterkommen. Da ich mit der Funktion reflektorlos erfolgreich die restlichen Punkte bereits erfassen konnte, können wir die Messung abschliessen. Hans steigt nun vom Gletschersee zu mir empor und wir zusammen über die Jakob Streiff-Becker Moräne zur Fridolinshütte aufsteigen. Ein letztes Mal kehren wir bei der Hüttenwartin Gabi Aschwanden ein, um mit ihr über unsern Gletscher zu philosophieren. Es ist ihre letzte Saison auf der Fridolinshütte. Später steigen wir wieder zusammen ins Tal ab. Danke Hans für deine Mithilfe, es war wiederum ein erlebnisreicher Tag mit vielen Eindrücken. (H. Klauser)

78 Limmern

2018: Die Punkte 1 bis 3 sind stark schuttbedeckt. Gletscherzunge aper, etwas Neuschnee in höheren Lagen, kein Firnschnee. (U. Steinegger)

2019: Punkte 1 bis 3 stark schuttbedeckt, Gletscherzunge etwas Neuschnee (U. Steinegger)

79 Sulz

2018: Vermutlich ist im rechten Bereich ein Teil eingebrochen und abgesackt. (R. Zweifel)

80 Glärnisch

2018: Dieses Jahr begleitet mich Gabriela Schiesser zu den Messungen. Mit Sack und Pack ziehen wir hinauf zum Gletscher. Selbstverständlich übernehme ich die schwereren Lasten für den Aufstieg zum Gletscher. Ich möchte ja wieder einmal auf die Hilfe von meinen Freunden zurückgreifen. Rassig kommen wir bis zur Edelweissplatte voran, wo wir inne halten um die Pracht der Natur zu geniessen. Kaffeehalt und Fachgespräch mit dem Hüttenwartpaar lässt uns einmal mehr nichts Gutes ahnen, der Gletscher schwindet, bald ist es nur noch die Frage, gibt es einen neuen tragischen Rekord oder ist der Rückgang im Rahmen der Vorjahre. Gespannt ziehen wir weiter über die zweite Kraxelstelle hinauf zum Gletscherrand. Über die Station 12 und 13 führt uns der Weg zum Gletscher. Der Gletscherzunge entlang vom Norden nach Süden gelangen wir schliesslich zur Station 14 und 15. Dort instruiere ich meine Helferin und mit Funk und meinen Anweisungen ausgestattet, steigt Gabi zum Ende des Gletschers im Süden. Ich stationiere zuerst auf der vorverlegten Station 15, so dass ich meine Gehilfin gut verfolgen kann. Bis auf die Höhe von 2'401 m.ü.M kann ich die 22 Gletscherrandpunkte von der Station 15 erfassen. Zwischenzeitlich habe ich zur Station 14 gewechselt und nach der Orientierung mit den noch knapp ersichtlichen Fernzielen (Nebel) erfasse ich die restlichen 30 Punkte die mir Gabi von der Gletscherzunge übermittelt. Am Schluss der Messung sind noch die Kontrollpunkte Station 13 und 12 zu erheben, bevor die Gehilfin ihre Arbeit als erledigt betrachten kann. Ich baue dann das Instrument (TCRA 1201 von Leica) ab und verpacke alles wieder im Rucksack um schliesslich zu meiner Helferin abzusteigen. Nach einem kurzen Halt in der Glärnischhütte mit kurzem Rückblick auf die Messung und den angetroffenen Verhältnissen mit dem Hüttenwart bewältigen wir zusammen den Weg ins Tal. Einen Gletscherbach-Ausfluss war aber nur unklar erkennbar. (H. Klauser)

2019: Begleitet werde ich dieses Mal von Kurt Wegmann (alt Gärtnermeister) der sich auch viel mit der Natur beschäftigt und sein Interesse angemeldet hat, mich einmal zu begleiten. Zusätzlich werden wir zu Filmstaren, denn Saskia Huber von Tele Südostschweiz begleitet uns mit ihrer Filmkamera, um das in aller Munde liegende Thema der Klimaerwärmung und Gletscherschmelze aus erster Hand, mitzuerleben. Nach der Fahrt bis Wärben werden die zu schleppenden Materialien bereitgestellt: Stativ, Instrument, Reflektorstab, Reflektor, Farbe, Funkgeräte etc. Sobald alles in den verschiedenen Rucksäcken verstaut ist starten wir Richtung Glärnischhütte und Gletscher. Bei der Edelweissplatte, Halt und dann die erste Filmsequenz, um zu zeigen, dass eben eine Gletschermessung auch schweisstreibend sein kann, bis alle Messuntensilien am Berg und beim Gletscher sind. Dass dabei aber auch Naturschönheiten ganz nahe am Wegesrand blühen, auch dies gehört zu den bleibenden Eindrücken einer Gletschermessung. Flott steigen wir danach weiter und erreichen alsbald die Glärnischhütte, wo wir einmal mehr herzlich willkommen geheissen werden und mit einem Kaffee aus der Hüttenküche den Motor wieder auf Vordermann bringen. So steigen wir gestärkt weiter und erreichen nach einer zweiten Filmsequenz die für Saskia an einer weiteren interessanten Stelle am Aufstieg gedreht wird, endlich unser Ziel den Glärnisch-Gletscher. Bereits beim Aufstieg über die Station 12, 13 und dann an der Gletscherzunge entlang von Nord nach Süd, stellen wir mit Schrecken fest, dass der Gletscher wohl wieder einen beachtlichen Rückmarsch angetreten hat. Die zwei Stationen 12 und 13 zeige ich meinem Gehilfen, Kurt, damit er mir diese dann am Schluss noch als Kontrollpunkte übermitteln kann. Der Ablauf der ganzen Messung und die Bedienung der Messutensilien (Reflektorstab, Verlängerung, Höhen etc.) erkläre ich ihm dann bei der Station 14, wo natürlich auch Saskia erneut ihre Kamera positioniert, um die eigentliche Arbeit am Gletscher zu dokumentieren. Die vorgefundenen Verhältnisse am Gletscher lassen mich zum Entschluss kommen, dass ich eine neue Station bestimmen muss, daher stationiere ich zu Beginn auf der Station 15 und orientiere mein Instrument auf den Fernzielen Forstberg, Druesberg und Rigi. Unterdessen malt Kurt ein Kreuz am neuen Standort und positioniert den Reflektor für die Messung. Nach der Bestimmung wechsle ich meine Position und kartiere ab der Station 16 vor allem den südlichen Teil des Gletschers, den ich so wunderbar einsehen kann, nach dem Kurt behände und rasch, übrigens immer noch in kurzer Hose, zum Gletscherende im Süden ab- und dann wieder aufgestiegen war. Nachdem mein Gehilfe bis auf die Höhe der Felsrippe meiner Station den Gletscherrand erfasst hat, wechsle ich erneut zur Ausgangsstation 15 um von dort schliesslich noch den nördlichen Gletscherteil zu bestimmen. Kurt macht dies wie ein alter Vermesser und ist innert kurzer Zeit bereits am Nordende des Gletschers angelangt. Die Veränderung des tiefsten Punktes ist nur unwesentlich, dies eigentlich entgegengesetzt des Resultates von 2’346.6 m.ü.M im Vorjahr auf die neue Kote 2’346.1 m.ü.M gerückt. Dies ist aber nur eine unwesentliche Verschiebung, die auch mit dem äusserst flachen Vorgelände erklärt werden kann. Kurt verschiebt sich nach der Messung noch zu den Kontrollpunkten 13 und 12 und kann danach seine Arbeit als erledigt betrachten und auf den Gletschermesser und die Fernsehfrau als Begleiterin warten. Diese möchte noch ein Interview in den Kasten bringen, was ich natürlich gerne noch erledige. So können wir auch den Abstieg vorerst bis zur Glärnischhütte in Angriff nehmen. Bei der Hütte wird noch kurz ein Zwischenstopp eingeschalten, um den grössten Durst zu löschen und mit dem Hüttenwart das Gesehene zu analysieren. Danach zieht es uns dann endgültig ins Tal. Saskia ist von der Arbeit beeindruckt. Die Schlussbesprechung machen wir dann noch mit einer Sequenz im Büro dies aber gut eine Woche danach, nachdem ich die Auswertung auf dem PC bereits vollzogen habe. Saskia hat wirklich eine eindrückliche Sendung verfasst, die meine Arbeit mit allen Facetten vollumfänglich wieder gibt. Kurt mein Mess-Gehilfe hat seine Arbeit ebenfalls ausgezeichnet erledigt und auch er ist beeindruckt, vor allem vom diesjährigen Schwund. (H. Klauser)

81 Pizol

2018: Keine Schneeresten, jedoch erschweren Schutt und Geröll zum Teil die Festlegung des Eisrandes. Markante Veränderung im Bereich der Basispunkte 2 und 3. Der Gletscherrand hat sich in steiles Gelände zurückgezogen. (Th. Brandes)

82 Lavaz

2018: Aufgrund der Vermutung, dass das sichtbare Gletscherfeld von allen Seiten abgeschitten ist und als einziges Relikt vorherrscht, sollte der Gletschrrand vollständig aufgenommen werden. Dies geschah bei der diesjährigen Messung. Die Vermutung konnte dadurch bestätigt werden. Der Rückzug aus dem östlichen Gletscherteil war vorauszusehen, das Ausmass trotzdem eindrücklich. (R. Lutz)

2019: Die Eruierung des Randes war aufgrund der Überdeckung teils durch Blockschutt und teils durch Altschnee schwierig. Der Rückzug aus dem östlichen Gletscherteil ist weiter fortgeschritten. (R. Lutz)

83 Punteglias

2018: In der Mitte des Gletschers ist Eis und Schutt in Bewegung. Eine klare Linie ist nicht zu erkennen. Diese Bewegungen führen zu einem Zusammenfliessen des in den letzten Jahren geöffneten Tälchens. Darum ist die Gletscherlinie dort weiter vorne gewählt. Der letztjährige Krater mit See ist gegen Südosten geschmolzen und der See dort abgeflossen. Das Gletschertor ist noch vorhanden, jedoch viel kleiner. Es ist sehr eindrücklich wie schnell des Eis in diesem Bereich schmilzt. An der oberen Gletscherstufe (Fels) ist der Gletscher nur noch mit einem schmalen Band (≈ 10 m) mit dem Gletscher verbunden. (Ch. Buchli)

2019: Der Gletscher hat sich an der hinteren Steilstufe (unterhalb Bifertenstock) geteilt. Im flacheren Gelände davor bleibt ein grosser Toteiskörper zurück. Am orografisch linken Teil des Toteiskörpers hat sich erstmals ein Gletschertor gebildet. Erstmals hat sich auch in diesem Teil einiges bewegt und eine Eiskörperabnahme augenfällig. Es zeigt sich ein Zusammenfliessen des in den letzten Jahren geöffneten Tälchens in der Mitte. Eindrücklich ist vor allem auch die Volumenabnahme. Das Gletschertor der letzten Jahre ist verschwunden. (Ch. Buchli)

84 Länta

2018: Die orographisch rechte Hälfte des Gletschers weist aufgrund der geringen Eisdicke einen raschen Rückgang auf. Dieser wird sich auch in den kommenden Jahren fortsetzen. In der linken Hälfte verläuft der Rückzug deutlich langsamer, da die Eisdicke viel mächtiger ist. Die terrestrische Vermessung kann in dieser Form nicht mehr durchgeführt werden, da die Steinschlaggefahr im Auf- und Abstiegsweg, aber auch am Gletscherrand selber zu gefährlich ist. Eine valable Variante wäre die Vermessung des Gletscherrandes mittels einer Drohne. (B. Riedi)

85 Vorab

2019: Die einzelnen Ausläufer, vor allem im nordöstlichen Teil des Gletschers sind fast alle geschmolzen. (R. Deflorin)

86 Paradies

2019: Im mittleren Bereich des Gletschers hat die Breite massiv abgenommen. Ebenfalls ist über die letzten Jahre eine Abnahme der Mächtigkeit feststellbar. (C. Fisler)

87 Suretta

2018: Um die Gletscherzunge zu erreichen, muss man teilweise über Felsen klettern: nur bei guten Wetterbedingungen gewährleistet. Sie ist sehr steil mit losen Steinen auf der Oberfläche. Bei wärmeren Temperaturen können sie Steinschläge verursachen. Grosse Eisblöcke können sich von der steilen Gletscherzunge lösen. (C. Fisler)

2019: Zuviel Altschnee auf der Gletscherzunge verhindert den Gletscherrand eindeutig zu bestimmen. Am orographisch linken Rand des Gletschers herrscht eine erhöhte Steinschlaggefahr. (C. Fisler)

88 Porchabella

2018: Der Gletscherrand war schneefrei und gut erkennbar. Am westlichen Rand des Messsektor wird der Gletscher vom Felssturzmaterial aus dem Jahr 2014 verdeckt und der Rand ist nicht mehr genau erkennbar. Der Gletscherrand war sehr gut erkennbar und konnte mit dem GPS ermittelt werden. Wie bereits in den vergangenen Jahren wurde über den Messsektor hinaus gemessen. Insgesamt wurden 107 Punkte detailliert mit dem GPS aufgenommen. Abgesehen vom Rückgang sind keine auffälligen Veränderung (Risse, Abbrüche) erkennbar. Erwähnenswert ist die starke Abnahme der Eisdicke, diese ist aufgrund der jährlichen Markierungen am anstehenden Fels sehr gut erkennbar und zeigt sich nicht zwingend im Rückgang des Gletscherrandes. Bereits in diesem Jahr wurden die erreichbaren Markierungen aus den früheren Messungen übermalt. Es scheint uns wichtig, dass im nächsten Jahr auch die restlichen Markierungen neu gestrichen werden. Da diese teilweise schwer zugäglich sind, muss Abseilmaterial mitgebracht werden. (C. Bieler)

2019: Der Gletscherrand war gut erkennbar und konnte wegen Schneefällen gut vom Gletschervorfeld abgegrenzt werden. Am westlichen Rand des Messsektors verdecken Felssturzablagerungen aus dem Jahr 2014 den Gletscherrand. (C. Bieler)

90 Silvretta

2018: Luftbildaufnahmen am 16.8.2018 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 29.9.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

91 Sardona

2018: Die Messung erfolgte ab den Punkten 1B, 2B, 3B und 4B mit dem Fadenmessgerät (Geländemass) im bisherigen Azimut 289 g (korrigierter Winkel). Ab dem Punkt 5B erfolgte keine Messung mehr. Die Neuschneeresten im Vorfeld und auf dem Gletscher behinderten die Messung nicht. Gletschrrandpunkte zusätzlich mit GPS (iPhone) eingemessen. (Th. Brandes)

2019: Gletscher mit Neuschnee bedeckt. Tiefster Punkt des Gletschers liegt in Linie 1 und hat sich nicht verändert. (Th. Brandes)

92 Roseg

2019: Die Messung im Vorjahr ist nachträglich beurteilt nicht realistisch. (G.-A. Godly)

94 Morteratsch

2018: Holzfund bei 791’797 / 144’014 (G.-A. Godly)

95 Calderas

2018: Komplett ausgeapert. Viel Geröll darauf. Bäche führen stark Wasser. Sichtbare Massenabnahme im Vergleich zum Vorjahr. (G.-A. Godly)

96 Tiatscha

2019: Luftbildaufnahmen am 29.9.2019 und photogrammetrische Bearbeitung durch swisstopo, glaziologische Interpretation und Analyse durch VAW/ETHZ. (VAW/ETHZ – A. Bauder)

97 Sesvenna

2019: Der Gletscher hat sich in der Steilstufe beim Felsriegel auf einer Höhe von etwa 2'840 m.ü.M nun durchgetrennt. (G. Renz)

99 Cambrena

2018: Abgetrennter Teil aus dem Vorjahr ist ganz verschwunden. (G. Berchier)

100 Palü

2018: Tiefster Punkt entspricht dem Seespiegel des proglazialen Sees. (G. Berchier)

2019: Tiefster Punkt entspricht dem Seespiegel des proglazialen Sees. (G. Berchier)

101 Paradisino

2018: Der Gletscherrand konnte nur im oberen Bereich eindeutig bestimmt werden. (G. Berchier)

2019: Der Gletscherrand konnte nur im unteren Bereich eindeutig bestimmt werden. (G. Berchier)

103 Bresciana

2018: A causa della nevicata durante la notte, il rilievo del fronte è risultato difficoltoso e non sempre chiaro. Fronte rilevato interamente con GPS. Poca visibilità e copertura neve sul ghiacciaio quasi assente. La perdita di spessore al fronte corrisponde a $\approx$ 130 cm. (M. Soldati)

2019: Fronte rilevato interamente con GPS. Nella parte alta buona copertura del ghiacciaio con neve vecchia. Il confronto tra alcuni punti del fronte evidenzia una perdita di spessore compresa tra 80 e 160 cm. (M. Soldati)

104 Basòdino

2018: Il fronte del ghiacciaio durante la misura del 2018 si presentava pulito e completamente libero da neve. Il fronte è stato rilevato in maniera integrale. L'arretramento più importante ha avuto luogo nella parte ovest del fronte (verso il Kastelhorn). Punti profilo non rilevati. (M. Soldati)

2019: Il fronte, rilevato in maniera integrale, in alcune zone si presentava ricoperto da neve fresca, solo poche zone del ghiacciaio (verso sud-est) sono ancora ricoperte da neve vecchia. L'arretramento più importante ha avuto luogo nella parte ovest del fronte (verso il Kastelhorn). (M. Soldati)

109 Alpetli (Kanderfirn)

2018: Neben dem Längenverlust weist der Gletscher einen beeindruckenden Massenverlust auf. Im Gletschervorfeld hat sich ein See gebildet. Dieser fliesst über bereits bestehende Bäche ab und erreicht eine maximale Tiefe von einigen wenigen Metern. Der See ist geschätzte 100 Meter lang und zwischen 20-40 Meter breit. (U. Burgener)

2019: Die eigentliche Gletscherzunge im nördlichen Bereich kann infolge schlechter Zugänglichkeit und Steinschlaggefahr nicht gemessen werden. Gegenwärtig kann aber eine relevante Messung im südlichen Bereich gemacht werden. Diese liegt nur wenige Höhenmeter oberhalb der nördlichen Gletscherzunge. Hier wurden im 2014/15 auch neue Basismesspunkte installiert. Eindrücklich ist nach wie vor der Massenverlust des Gletschers. Der See ist trotz seiner stattlichen Fläche nicht besonders tief. (U. Burgener)

114 Plattalva

2018: Gletscher bedeckt mit etwas Neuschnee, kein Firnschnee. Bei Punkt 5 schneidet die Messrichtung den Gletscherrand nicht mehr. (U. Steinegger)

2019: Bei Punkt 5 liegt der Gletscherrand ausserhalb der Messrichtung, Gletscherzunge mit etwas Neuschnee bedeckt. (U. Steinegger)

115 Scaletta

2018: Nach mehreren Jahren konnte wieder eine gesicherte Messung gemacht werden. Es wurde ein neuer Referenzpunkt eingerichtet 792'063 / 175'068 / 2'667. Das neu entstandene Gletschertor auf der Ostseite befindet sich 115 m oberhalb der Basislinie von 2017. Das Eis ist dort sehr dünn. (B. Teufen)

2019: Im Sommer hat sich im zentralen Bereich eine steile Stirnfront ausgebildet. (B. Teufen)

117 Valleggia

2018: Rilievo eseguito interamente con GPS. Perdita media di spessore equivale a 230 cm. (M. Soldati)

2019: Rilievo eseguito interamente con GPS. Nella parte superiore del ghiacciaio (circa 1/3 superiore) è ancora presente neve vecchia dell'inverno. Il lago postglaciale che si è formato assume dimensioni sempre maggiori. Sono state notate delle zone ghiacciate ricoperte dai detriti nella lingua laterale sotto il Poncione di Val Piana, ghiaccio che gli scorsi anni non era visibile. Perdita media di spessore equivale a 230 cm. (M. Soldati)

119 Cavagnoli

2018: Rilievo del fronte misurato con il GPS. Presenza di bedière molto profonde; particolarmente visibili i risultati dell'erosione dell'acqua di fusione, in alcuni punti si intravede il fondo del ghiacciaio (roccia). In questi punti lo spessore complessivo del ghiaccio rimanente corrisponde a 4-5 metri. (M. Soldati)

2019: Rilievo del fronte misurato con il GPS. A causa del cattivo segnale GPS non è possibile determinare con precisione la perdita di spessore, ma si stima (in base alle nuove rocce affioranti) che sia superiore ai 150 cm. (M. Soldati)

120 Corno

2018: Molte zone del fronte sono ricoperte da detriti che rendono difficile determinare con precisione dove sia il ghiaccio. Questo spiega perché alcuni punti del fronte del 2017 siano più avanzati rispetti a quelli del 2018. (M. Soldati)

2019: Rilievo eseguito per la prima volta con GPS. Parte frontale del ghiacciaio ben visibile, tranne per il lato ovest, ricoperto dai detriti e non facilmente identificabile. (M. Soldati)

173 Seewjinen

2018: Luftbildaufnahmen am 11.9.2018, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 21.9.2019, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

174 Hohlaub

2018: Luftbildaufnahmen am 11.9.2018, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

2019: Luftbildaufnahmen am 21.9.2019, photogrammetrische Auswertung und Analysen durch VAW/ETHZ im Auftrag der Kraftwerke Mattmark AG. (VAW/ETHZ – A. Bauder)

352 Croslina

2018: Ghiacciaio praticamente privo di copertura nevosa. Oltre a un discreto arretramento del fronte, si segnala anche un "restringimento" della parte più a monte del ghiacciaio. La perdita media di spessore corrisponde a 130 cm. In alcuni punti si intravede il fondo del ghiacciaio, posto a circa 3-4 metri di profondità. (M. Soldati)

2019: Fronte del ghiacciaio stazionario. Alcuni punti sono addirittura più avanzati. Si ipotizza che la placca di ghiaccio scivoli leggermente verso valle. Questa ipotesi è confermata dal crepaccio sempre più largo nel centro del ghiacciaio. La perdita di spessore nelle zone adiacenti al fronte è compresa tra 80 e 100 cm. (M. Soldati)

C Investigators

C.1 Length Variation (2019)

Glacier	No.	Investigator
Albigna	116	AWN/GR, Martin Keiser
Allalin	11	VAW/ETHZ, Andreas Bauder
Alpetli (Kanderfirn)	109	KAWA/BE, Ueli Burgener
Ammerten	111	Walter Hodel
Arolla (Mont Collon)	27	DWL/VS, François Fellay
Basòdino	104	SF/TI, Mattia Soldati
Bella Tola	21	currently not observed
Biferten	77	Hanspeter Klauser
Blüemlisalp	64	KAWA/BE, Ueli Burgener
Boveyre	41	DWL/VS, Pascal Stoebener
Breney	36	Jean-Jacques Chabloz
Bresciana	103	SF/TI, Mattia Soldati
Brunegg (Turtmann)	20	DWL/VS, Alban Brigger
Brunni	72	AFJ/UR, Michael Planzer
Calderas	95	AWN/GR, Gian Andri Godly
Cambrena	99	AWN/GR, Gilbert Berchier
Cavagnoli	119	SF/TI, Mattia Soldati
Cheillon	29	DWL/VS, Sébastien Tremp
Chessjen	12	VAW/ETHZ, Andreas Bauder
Corbassière	38	VAW/ETHZ, A. Bauder & E. Hodel
Corno	120	SF/TI, Mattia Soldati
Croslina	352	SF/TI, Mattia Soldati
Damma	70	AFJ/UR, René Planzer
Dungel	112	Andreas Wipf
Eiger	59	KAWA/BE, Ralf Schai
En Darrey	30	DWL/VS, Sébastien Tremp
Fee	13	DWL/VS, Urs Andenmatten
Ferpècle	25	DWL/VS, François Fellay
Fiescher	4	DWL/VS, Norbert Carlen
Findelen	16	VAW/ETHZ, A. Bauder & E. Hodel
Firnalpeli (Ost)	75	AWL/OW, Miriam Jäggi
Forno	102	AWN/GR, Martin Keiser
Gamchi	61	KAWA/BE, Martin Schenk
Gauli	52	KAWA/BE, Martin Haider

Glacier	No.	Investigator
Gelten	113	Andreas Wipf
Giétro	37	VAW/ETHZ, A. Bauder & E. Hodel
Glärnisch	80	Hanspeter Klauser
Gorner	14	DWL/VS, Leo Jörger & Stefan Walther
Grand Désert	31	DWL/VS, Frédéric Bourban
Grand Plan Névé	45	FFN/VD, J.-Ph. Marlétaz
Gries	3	VAW/ETHZ, A. Bauder & E. Hodel
Griess	74	AFJ/UR, Beat Annen
Griessen	76	AWL/OW, Miriam Jäggi
Grosser Aletsch	5	VAW/ETHZ, A. Bauder & E. Hodel
Hohlaub	174	VAW/ETHZ, Andreas Bauder
Hüfi	73	currently not observed
Kaltwasser	7	DWL/VS, Martin Schmidhalter
Kehlen	68	AFJ/UR, René Planzer
Lang	18	currently not observed
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, Frédéric Bourban
Mont Miné	26	DWL/VS, François Fellay
Morteratsch	94	AWN/GR, Gian Andri Godly
Mutt	2	VAW/ETHZ, Andreas Bauder
Oberaar	50	Flotron AG, Meiringen
Oberaletsch	6	DWL/VS, Christian Theler
Oberer Grindelwald	57	VAW/ETHZ, A. Bauder & E. Hodel
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
Rätzli	65	VAW/ETHZ, A. Bauder & E. Hodel
Rhone	1	VAW/ETHZ, A. Bauder & E. Hodel
Ried	17	DWL/VS, Peter Rovina
Roseg	92	AWN/GR, Gian Andri Godly
Rossboden	105	currently not observed

Glacier	No.	Investigator
Rotfirn (Nord)	69	currently not observed
Saleina	42	DWL/VS, Pascal Stoebener
Sankt Anna	67	AFJ/UR, Lukas Eggimann
Sardona	91	KFA/SG, Thomas Brandes
Scaletta	115	Bernardo Teufen
Schwarz	62	currently not observed
Schwarzberg	10	VAW/ETHZ, Andreas Bauder
Seewjinen	173	VAW/ETHZ, Andreas Bauder
Sesvenna	97	AWN/GR, Giorgio Renz
Sex Rouge	47	Jacques Binggeli
Silvretta	90	VAW/ETHZ, A. Bauder & E. Hodel
Stein	53	KAWA/BE, Daniel Rohrer
Steinlimi	54	KAWA/BE, Daniel Rohrer
Sulz	79	AW/GL, Patrizia Köpfli
Suretta	87	AWN/GR, Cristina Fisler
Tiatscha	96	VAW/ETHZ, A. Bauder & E. Hodel
Tiefen	66	AFJ/UR, Lukas Eggimann
Trient	43	Jacques Ehinger
Trift (Gadmen)	55	VAW/ETHZ, A. Bauder & E. Hodel
Tsanfleuron	33	DWL/VS, François Fellay
Tschierva	93	AWN/GR, Gian Andri Godly
Tschingel	60	KAWA/BE, Ralf Schai
Tseudet	40	DWL/VS, Pascal Stoebener
Tsidjiore Nouve	28	DWL/VS, François Fellay
Turtmann	19	DWL/VS, Alban Brigger
Unteraar	51	Flotron AG, Meiringen
Unterer Grindelwald	58	VAW/ETHZ, A. Bauder & E. Hodel
Val Torta	118	SF/TI, Mattia Soldati
Valleggia	117	SF/TI, Mattia Soldati
Valsorey	39	DWL/VS, Pascal Stoebener
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
Oberaar	50	Flotron AG
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, Mauro Fischer
Unteraar	51	Flotron AG

C.3 Englacial Temperature

Site (Glacier)	No.	Investigator
Colle Gnifetti (Gorner)	14	DGUF, Martin Hoelzle, Enrico Mattea, Marlene Kronenberg, Horst Machguth

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