Annual mass balance of Swiss glaciers in 2023/2024

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Summary

The annual ice loss was measured on 20 glaciers throughout Switzerland within the programme Glacier Monitoring Switzerland (GLAMOS) in September 2024. This data supports multi-decadal observational series that are essential to document the decline of mountain glaciers, and to understand the corresponding impacts. This year's results show a stark contrast between an exceptionally snow-rich winter, and intense summer melt rates that turned the tide rapidly. The melt-down of the massive snow layers was accelerated by the albedo effect of abundant Saharan dust accumulated at the surface. The highest mass loss for the month of August since the beginning of the measurements was registered in 2024. With an average mass balance of –1.3 meters water equivalent, the hydrological year 2023/2024 is slightly more negative than the average 2010-2020. Extrapolated to all glaciers, a reduction of the Swiss ice volume by 2.4% is found. This is less than in the two previous record-shattering years but still contributes to continued glacier disintegration and a reorganization of the Alpine landscape.

Zusammenfassung

Im Rahmen des Schweizer Gletschermessnetzes (GLAMOS) wurde im September 2024 der jährliche Eisverlust auf 20 Gletschern in der ganzen Schweiz gemessen. Diese Daten fügen sich in eine langjährige Beobachtungsreihe ein, die zentral ist, um den Gletscher-Rückgang zu dokumentieren und um die Auswirkungen zu verstehen. Die diesjährigen Ergebnisse zeigen einen starken Kontrast zwischen einem aussergewöhnlich schneereichen Winter und intensiven Schmelzraten im Sommer, die das Blatt rasch wendeten. Das Schmelzen der massiven Schneeschichten wurde durch den Albedo-Effekt des an der Oberfläche angesammelten Saharastaubs beschleunigt. Für den Monat August wurde die stärkste Schmelze seit Beginn der Messungen registriert. Mit einer durchschnittlichen Massenbilanz von –1,3 Metern Wasseräquivalent ist das hydrologische Jahr 2023/2024 etwas negativer als der Durchschnitt 2010-2020. Hochgerechnet auf alle Gletscher ergibt sich eine Abnahme des Schweizer Eisvolumens von 2,4%. Dies ist zwar weniger als in den beiden vorangegangenen Rekordjahren, führt aber dennoch zu einem weiteren Zerfall der Gletscher und zu einer Umgestaltung der Alpinen Landschaft.

(Left) Redrilling of a mass balance measurement stake on Griesgletscher. (Right) A team of glaciologists descending over the tongue of Findelgletscher towards the proglacial area. Photos: M. Huss

1. Measurements and basic approach

Within the standard observational programme of Glacier Monitoring Switzerland (GLAMOS) 20 glaciers were visited for end-of-summer measurements of ice melt and (where applicable) firn accumulation in September 2024 (Fig. 1). The aim of these surveys is to determine the glacier-wide annual mass balance, and thus to prolong multi-decadal observational series that are crucial for understanding the effects of shifts in climate on glacier change (Cogley et al., 2011). The annual mass balance refers to the total mass added to or removed from each glacier in the course of one year, and corresponds to the sum of winter snow accumulation and summer melting of snow/ice.

Long-term measurement programmes (>100 years in some cases) are ongoing on the surveyed glaciers that are distributed throughout all glacierized mountain regions of the Swiss Alps. The surveys were intensified with additional monitoring sites ca. 10-20 years ago, also with a more detailed measurements of winter snow water equivalent on glaciers (see GLAMOS, 2024) to infer seasonal mass balance. Insights into seasonal mass balance dynamics are crucial to disentangle the effects of snow accumulation (determined by variations in precipitation) and snow/ice melt (determined by variations in air temperature and solar radiation).

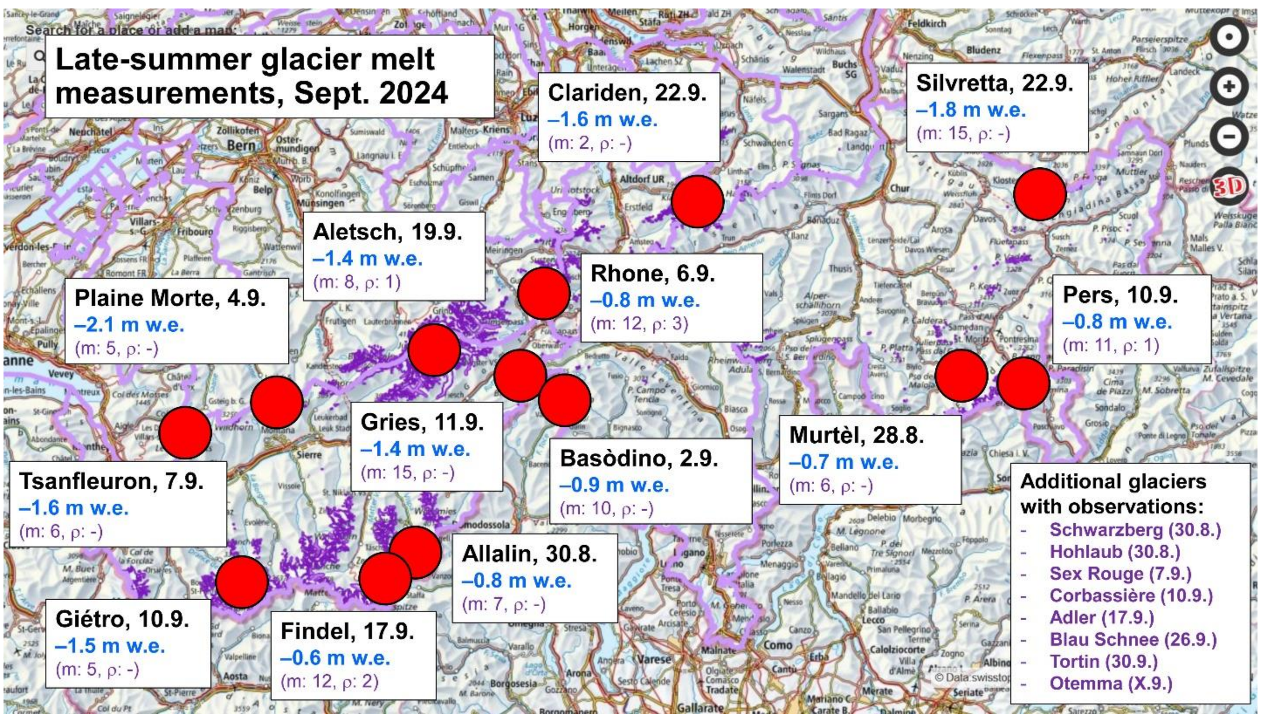

Figure 1: Overview of mass balance measurements performed on Swiss glaciers in September 2024. For all visited glaciers the date of the survey, as well as the glacier-wide annual mass balance (blue) in meters water equivalent (m w.e.) homogenized to the hydrological year (1.10.-30.9.) is given. The number of point mass balance measurements (*m*) and the number of firn density measurements (*ρ*), if applicable, is stated. Light purple boundaries show hydrological catchments.

On each glacier, a network of between 4 and 18 measurement sites allows estimating the glacier-wide annual mass balance. Aluminium or plastic poles are drilled into the ice and provide an accurate local observation of the ice layer removed at the specific location over time periods of about one year linking the end of subsequent melt seasons (GLAMOS, 2023a). These mass balance stakes are redrilled at their original location during the late-summer survey to compensate for local ice flow. In the accumulation area, mass balance stakes allow locating a snowed-in surface horizon marked by sawdust down to which the density of the accumulated snow is sampled (GLAMOS, 2021). Subsequently, all point measurements of ice ablation/firn accumulation are converted to water equivalent and are spatially extrapolated to the scale of the entire glacier using a model-based approach that is optimally taking the spatial variability and inhomogeneities in sampling into account (Huss et al., 2021; GLAMOS, 2023b, Appendix A.1). Furthermore, this approach resolves the daily glacier-wide mass balance, and thus allows homogenizing the results to common and thus comparable time periods, e.g. the hydrological year (1 October to 30 September).

Measurement conditions in late summer 2024 were characterized by relatively unstable weather with above-average temperatures at the beginning of September but a substantial cooling with significant amounts of fresh snow in some regions afterwards. This resulted in partly difficult conditions for fieldwork. Nevertheless, all glaciers could be visited until the end of September (Fig. 1). At some sites surveys may be repeated later in the year, depending on conditions, to complement the data set. In general, substantial ice ablation was measured, necessitating the redrilling of most stakes. While on smaller / low-lying glaciers all winter snow has disappeared, snow accumulation was present at the highest elevations, and measurements of firn density have been acquired on four glaciers.

2. Results

Summary figures for all investigated glaciers are shown and interpreted below. The Appendix contains glacier-specific figures allowing in-depth insights regarding different variables, such as the spatial distribution of annual surface mass balance over the glacier, the temporal dynamics of glacier mass change, or the relation of the year 2023/2024 with respect to previous periods.

Point observations of mass balance at the measurement sites were almost everywhere less negative than in the two previous extreme years of 2022 and 2023 (Appendix A.2). The most negative values observed reach around 7 meters of local ice loss for the annual period on glacier tongues extending to low elevation (e.g. Findel, Rhone) and even 11 meters for the lowermost site on Grosser Aletschgletscher (at 1980 m a.s.l.). Local snow accumulation, and thus formation of new firn has been observed above ca. 3100-3300 m a.s.l. (depending on the region). The highest measurement sites on Grosser Aletschgletscher, Findelengletscher and Rhonegletscher experienced accumulation rates of 2-3 meters. These relatively good conditions, however, only prevailed for the uppermost regions of large glaciers, while more than half of the monitored glaciers completely lost their snow coverage throughout the summer months and even the topmost measurement points experienced melt rates of 1 meter or more (e.g. Gries, Giétro, Otemma, Plaine Morte, Silvretta).

Glacier-wide annual mass balance observed for the hydrological year is for most glaciers close to or below the average of the period 2010-2020, considered here as a reference (Fig. 2). As absolute values of glacier-wide mass balance (Fig. 3) are difficult to be directly compared among glaciers due to differing long-term trends (e.g. Hugonnet et al., 2021), we here mainly discuss the individual glaciers' deviation from their mean. Very negative annual mass balance anomalies have been recorded for Silvrettagletscher and Claridenfirn (northeastern Switzerland), as well as for Glacier du Giétro. The observation of very negative mass balance in the Southwestern Valais is also supported by shorter measurement series on Glacier du Tortin and Glacier d'Otemma (not shown). For all other glaciers, annual mass balance anomalies are slightly more negative than the reference, with the exception of Griesgletscher, Rhonegletscher and Glacier du Tsanfleuron where marginally better conditions than on the 2010-2020 average have been observed. Even though the overall losses in 2024 are less dramatic compared to 2022 and 2023, they are noteworthy considering the exceptionally abundant snow cover on Swiss glaciers in spring (31% above the average; GLAMOS, 2024), indicating high melt rates during summer, as will be further elaborated below.

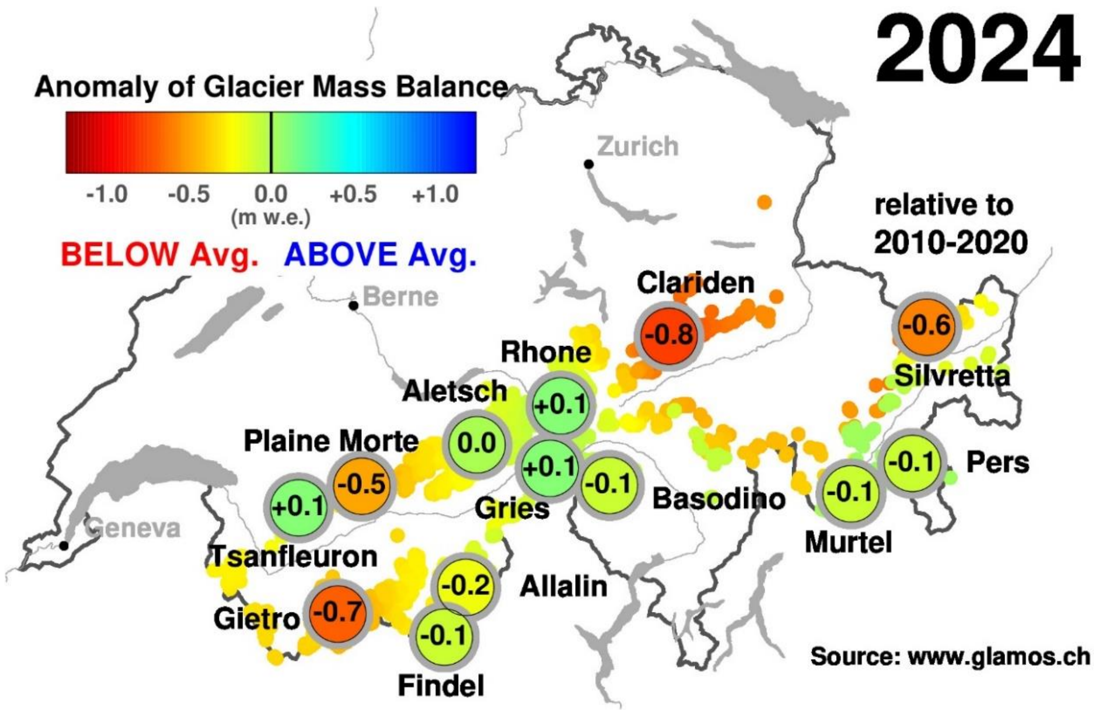

Figure 2: Anomaly of glacier-wide annual mass balance for the most important surveyed glaciers over the hydrological year (1 Oct. 2023 to 30 Sept. 2024) relative to the average of the period 2010-2020 in meters water equivalent (m w.e.). Smaller dots show the mass balance anomaly extrapolated to other glaciers in Switzerland for better visualizing the pattern. Yellow-red colours indicate below-average conditions with respect to glacier mass balance, and green-blue colours above-average conditions.

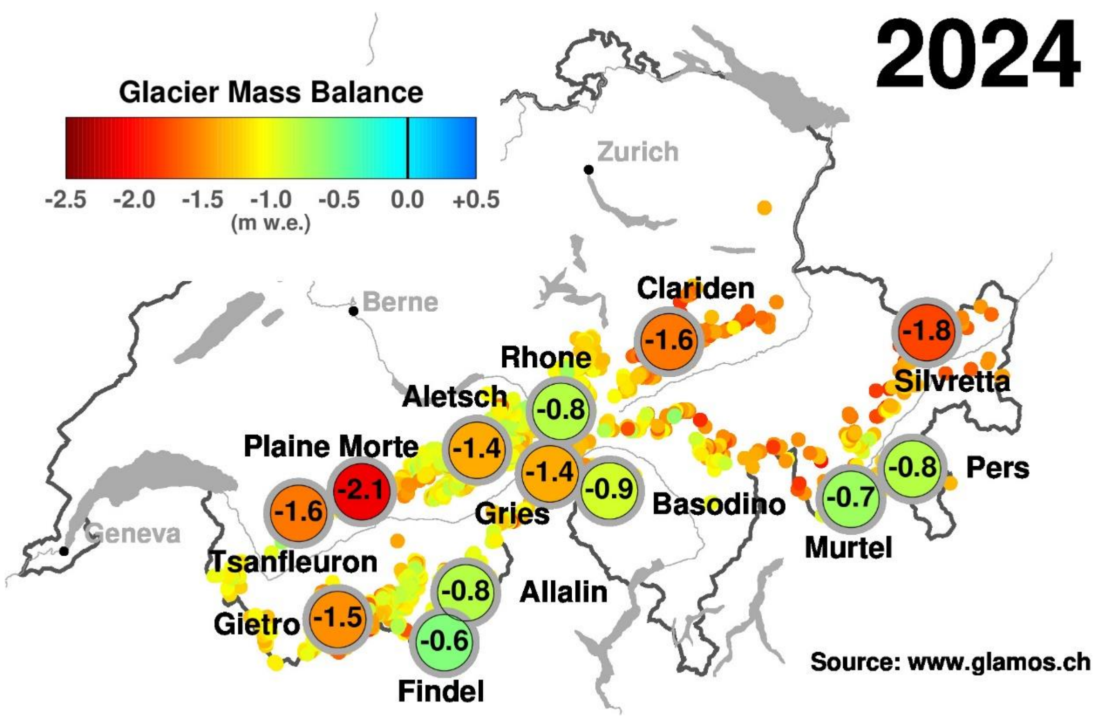

Figure 3: Glacier-wide annual mass balance for the most important surveyed glaciers over the hydrological year (1 Oct. 2023 to 30 Sept. 2024) in meters water equivalent (m w.e.). Smaller dots show the mass balance extrapolated to other glaciers in Switzerland. Note that the mass balance may strongly vary between neighbouring glaciers, and the monitored sites show different long-term average mass balance.

The observed pattern of mass balance anomalies does not appear to be directly related to the spatial variations in winter snow water equivalent that showed strongly above-average snow accumulation in the Ticino or nearby and the Engadin (Basòdino, Gries, Murtèl, Pers; see GLAMOS, 2024). Also, glaciers in the very west of Switzerland, as well as on the Northern flank of the Alps exhibited extremely high winter mass balances, resulting in record values for Glacier du Tsanfleuron and Claridenfirn. Nevertheless, annual mass losses were among the highest for these regions (Fig. 2, Fig. 3). Sites with very negative mass balances in the year 2024 are characterized by their relatively low elevation with most of the glacier surface located below 3000 m a.s.l.. This factor presumably made them more vulnerable to summer heat waves.

Three crucial factors were responsible for driving the substantial glacier mass losses in 2024 despite abundant winter snow coverage:

(1) Average air temperatures in July and August were very high. At the highest MeteoSwiss stations, values for August are even above the years 2003 and 2022 that are still remembered for their scorching heat.
(2) Throughout July and August good weather with high solar irradiance prevailed, and no fresh snow fall was registered in contrast to, for example, 2023.
(3) In winter and spring 2024, south-westerly winds brought substantial amounts of Saharan dust into the Alps during multiple events. This red-yellowish dust was first hidden by additional snow layers but accumulated at the surface with the start of the melting season. The albedo reduction on a dirty snow surface is substantial (e.g. Réveillet et al., 2022), and this effect accelerated the rate of snow depletion. This thus counteracted the benefit of the above-average snow depth on glacier mass balance. At this stage we are unable to quantify the net effect of the Saharan dust on the overall 2024 mass loss, but an increase in melt rates by 10-20% compared to normal conditions appears plausible.

Melting snow surface in August 2024 on Griesgletscher with important Saharan dust coverage. The reduced albedo resulted in a significant acceleration of snow melt rates, which explains the rapid disappearance of the partly record-high snow layer on glaciers in early summer. Photo: M. Huss

The evolution of glacier mass balance throughout the hydrological year 2023/2024 started with an exceptional melt event for autumn lasting until mid-October 2023, followed by a more rapid growth of the snow cover from late October until December 2023 than usual (Fig. 4). Towards the end of February 2024, snow cover almost tended back to the average again, while especially glaciers influenced by the meteorological conditions of the Southern side of the Alps showed substantially above-average snow accumulation from March to May (see Appendix A.3). The peak snow accumulation was reached on 3 June but melting only accelerated in early July. Until the second week of September melt rates were very high without any interruption. This is in contrast to previous summer seasons where glaciers could benefit from intermittent days of cooler weather. The “Glacier loss day” (Voordendag et al., 2023), i.e. the day when overall mass balance becomes negative and all snow mass added during winter is used up, happened on 11 August, a few days later than usual. On 15 August, the mass balance for the year 2023/2024 became more negative than the 2010-2020 average and remained below that level until the end of the year (Fig. 4). After the relatively late start of the melting season, it also ended early and abruptly in mid-September. Cooler weather and repeated snowfall events inhibited further losses until the end of the hydrological year.

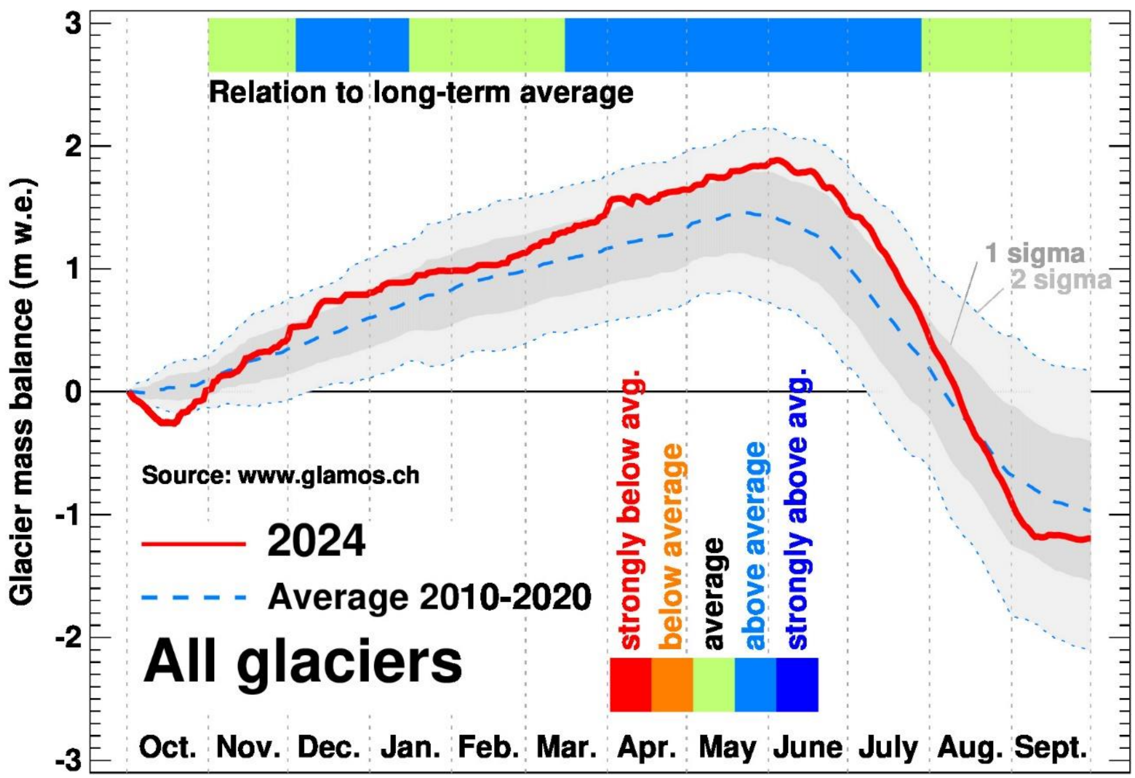

Figure 4: Cumulative daily mass balance in the hydrological year 2023/2024 (red) in comparison to the average and the spread of the years 2010-2020. The top bar indicates periods throughout the year with average (green), below- (orange/red) or above-average (light/dark blue) mass balance. The arithmetic average of the main surveyed glaciers (see Fig. 2 and 3) is shown.

For regionalizing the findings on glacier mass balance measured at the 20 sites throughout the Swiss Alps, we extrapolate annual mass balance anomalies homogenized to the hydrological year (1 Oct. - 30 Sept.) to all 1’400 glaciers in the Swiss Glacier Inventory SGI2016 (Linsbauer et al., 2021) according to an approach similar to Dussaillant et al. (2024). We thus account for differences in regional sampling density and include long-term trends of glacier-specific mass loss for all glaciers based on the geodetic mass balance (Fischer et al., 2015). The area of each glacier is updated based on a volume-area-scaling approach to the year 2024. Furthermore, measured seasonal and modelled daily mass balance variations are superimposed on computed annual glacier-specific mass changes, thus permitting long- and short-term dynamics of glacier mass change to be inferred at the scale of all Swiss glaciers.

For the hydrological year 2023/2024, an **average mass balance of –1.25 m w.e.** is found for all Swiss glaciers (Fig. 5). This pales against the values of –3.1 m w.e. and –2.3 m w.e. for 2022 and 2023. Annual losses in 2018, 2017, 2015 and 2011 were higher as well. Nevertheless, the glacier mass loss for 2024 is noteworthy considering the massive winter snow amounts: Evaluating summer mass balance anomalies (1 May - 30 Sept.) indicates that overall summer melting 2024 was 34% above the 2010-2020 average, despite the moderate air temperatures of June and September (Fig. 5). This value ranks fourth after 2022, 2003 and 2023.

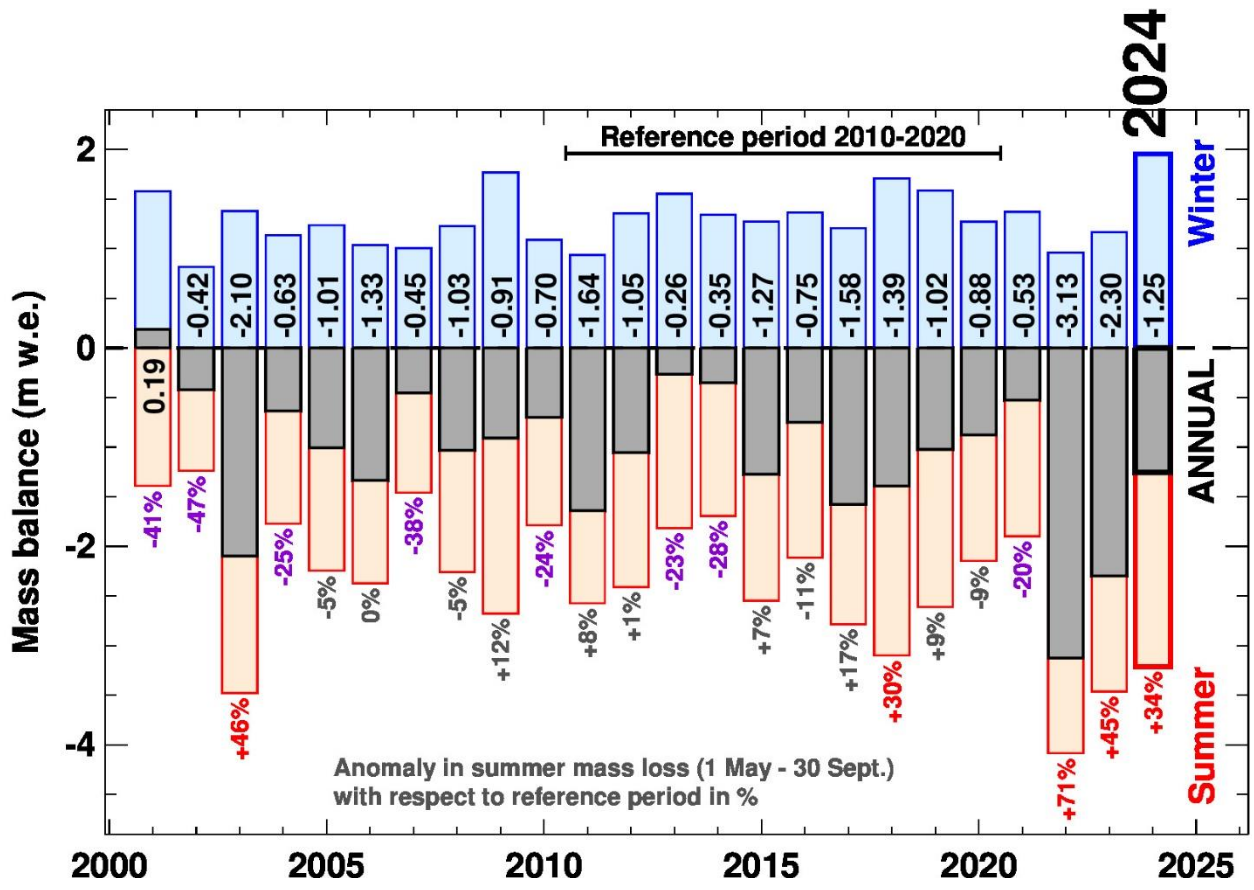

Figure 5: Seasonal mass balance extrapolated to all glaciers in Switzerland. Annual mass balance (1 Oct. - 30 Sept., dark grey / numbers), winter mass balance (1 Oct. - 30 April, light blue), and summer mass balance (1 May - 30 Sept., light red) is shown. Percentage numbers below the bars indicate the relative anomaly of summer mass balance relative to the period 2010-2020, coded with colours for years with strongly below-average melt (purple), average melt (grey) and strongly above-average melt (red).

When relating the annual mass balance 2023/2024 to the statistical distribution of previous measurements (Appendix A.4), the results indicate that this year is among the 10% most negative values for some glaciers (Clariden, Giétro, Silvretta). For most glaciers, however, 2024 ranks in or somewhat below the centre of the historical values. Seasonal mass balances at the level of individual monitoring sites (Appendix A.5) provide insights into the local anomalies in winter accumulation and summer melting. Whereas summer mass balance is clearly more negative than normal for all sites, results are not exceptional for most glaciers, probably due to the average air temperatures in May, June and September. Maybe most striking however is the very negative summer balance for Claridenfirn, where the second-most negative value (after 2022) in the 110-year long series has been found despite the record winter snow accumulation. This effect likely can only be explained by the effect of Saharan dust accelerating snow melt.

Considering glacier mass balances for individual months and their spread since the beginning of the available observational time series it becomes clear that the hydrological year 2023/2024 was exceptional both in terms of accumulation and melt (Fig. 6). The glacier mass losses in the month of August were never as pronounced as during this year. Results are on a par with the extreme summer of 2003 but clearly higher than in 2022 and 2023. Mass balance was also very low in July, but far from the record value of 2022. In contrast, the months November, March, and May of the hydrological year 2023/2024 showed mass balances that were among the most positive values (Fig. 6).

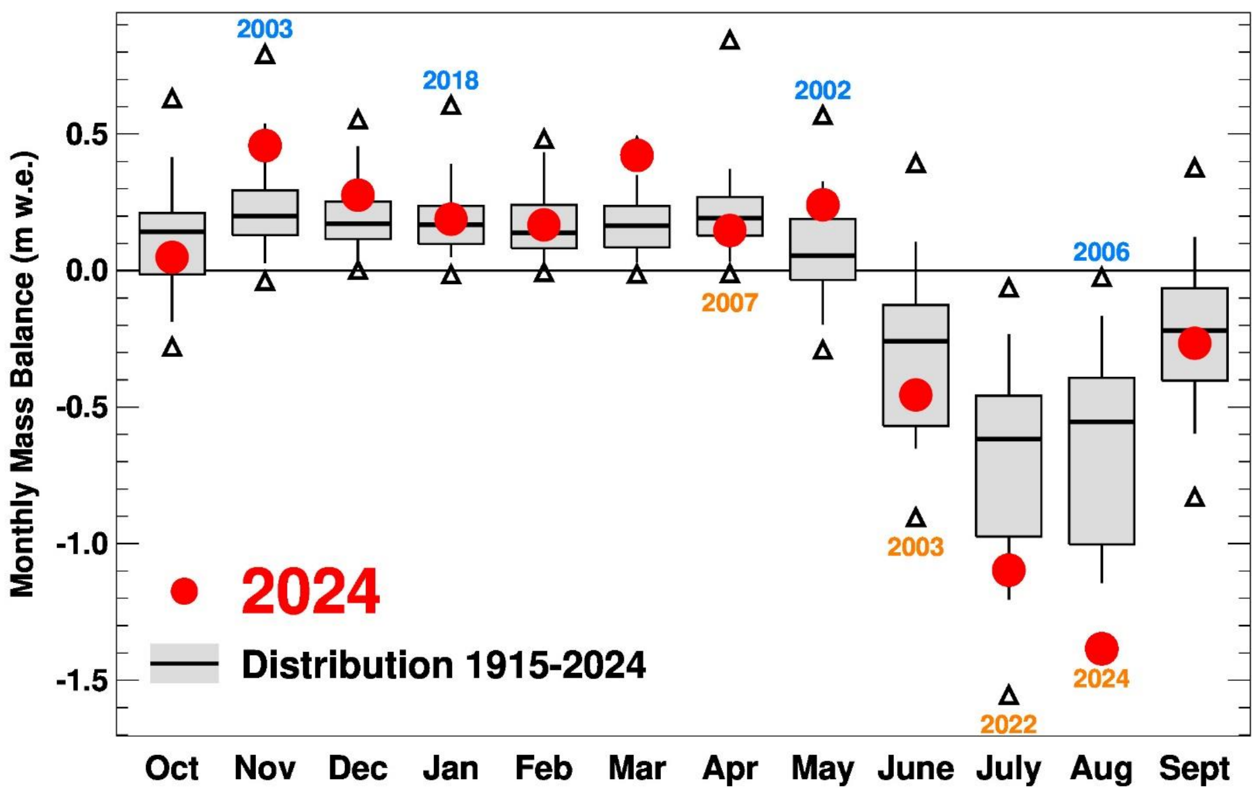

Figure 6: Spread in monthly glacier mass balance during 1915-2024. The results are based on a combination of direct measurements during this time period and modelling. Boxes contain 50%, and bars 90 % of the data, while the maximum and minimum value is marked with triangles. The years of monthly record values (positive/negative) in the 21st century are spelled out in light blue/orange.

By combining the extrapolated glacier mass change with a complete assessment of the glacier volume in Switzerland (Grab et al., 2021), ice volume time series can be prolonged up to today at the scale of individual glaciers, hydrological catchments and the whole of Switzerland. The results indicate that Switzerland still hosts ca. **46.4 km³ of glacier ice** by the end of 2024 (Fig. 7). This is almost 30 km³ less than in the year 2000. At present, Swiss glacier area is estimated to be 775 km², corresponding to a decline of 28% relative to 2000.

The annual reduction of glacier volume relative to the remaining volume fluctuated between –1% and –3% per year during the last two decades. The two extreme years 2022 (–5.9%) and 2023 (–4.4%) have completely changed the scene with unprecedented ice volume losses. The year 2024 exhibits a somewhat more moderate **ice volume reduction by –2.4%** (Fig. 7). The loss is still considerable though given the strongly above-average snow coverage at the end of winter.

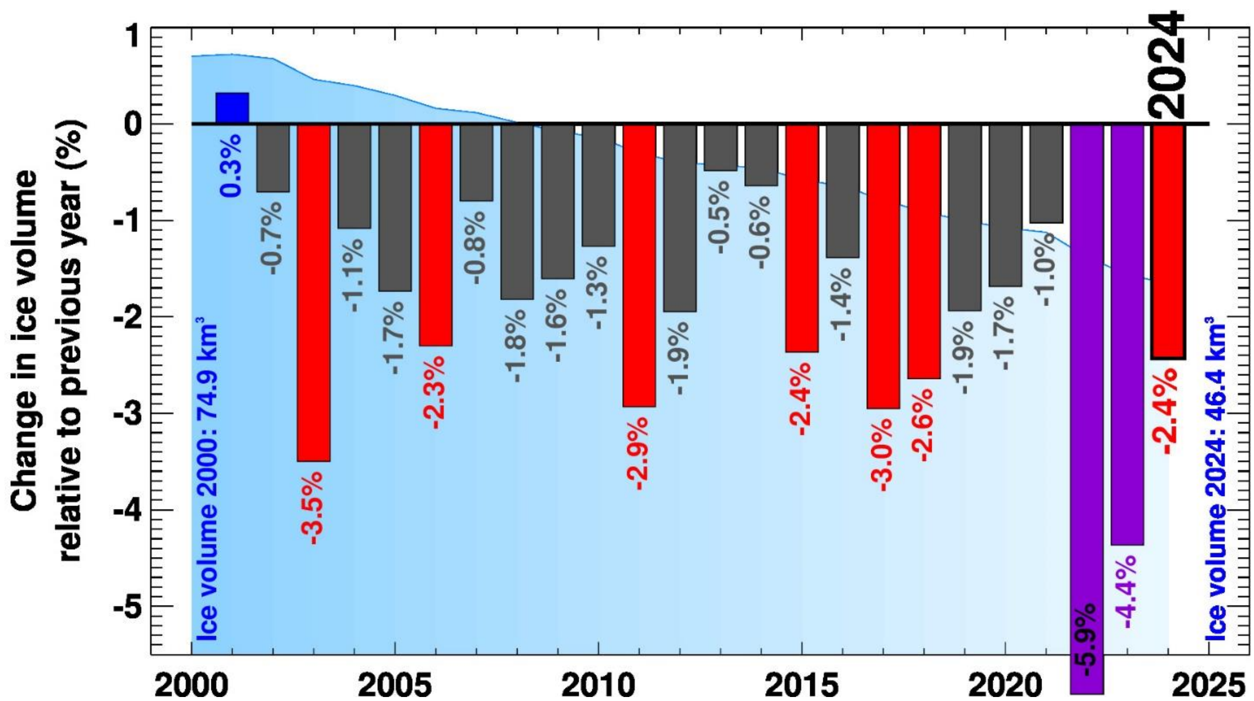

Figure 6: Swiss-wide annual change in glacier volume relative to the remaining ice volume of the previous year. Colours visualize moderate (dark grey), strong (red) and extreme losses (purple). 2024 is highlighted. The blue surface in the background visualizes the temporal evolution of total ice volume.

While the relative ice volume losses showed very high values in 2022 and 2023, far beyond previous extreme years such as 2003 (–3.5%) or 2017 (–3.0%) (Fig. 7), absolute ice volume changes indicate that the peak water release from Swiss glaciers has likely been passed with the recent extreme years (Fig. 8). With a **total ice volume loss of –1.2 km³**, the year 2024 is just average, similar as in 2019, but less than in 2017 and 2018. This is explained by the rapid decline in glacier area due to the major reduction in glacier volume of the last decades. Even with intense melt rates per unit area (Fig. 5), and major relative losses compared to the remaining ice volume (Fig. 7), glaciers can no longer provide very high quantities of melt water to downstream areas. This declining trend, despite increasing temperatures and snow/ice melt, is expected to pose important challenges for the future management of water resources (irrigation, hydropower production, ecology, transportation), especially during drought periods.

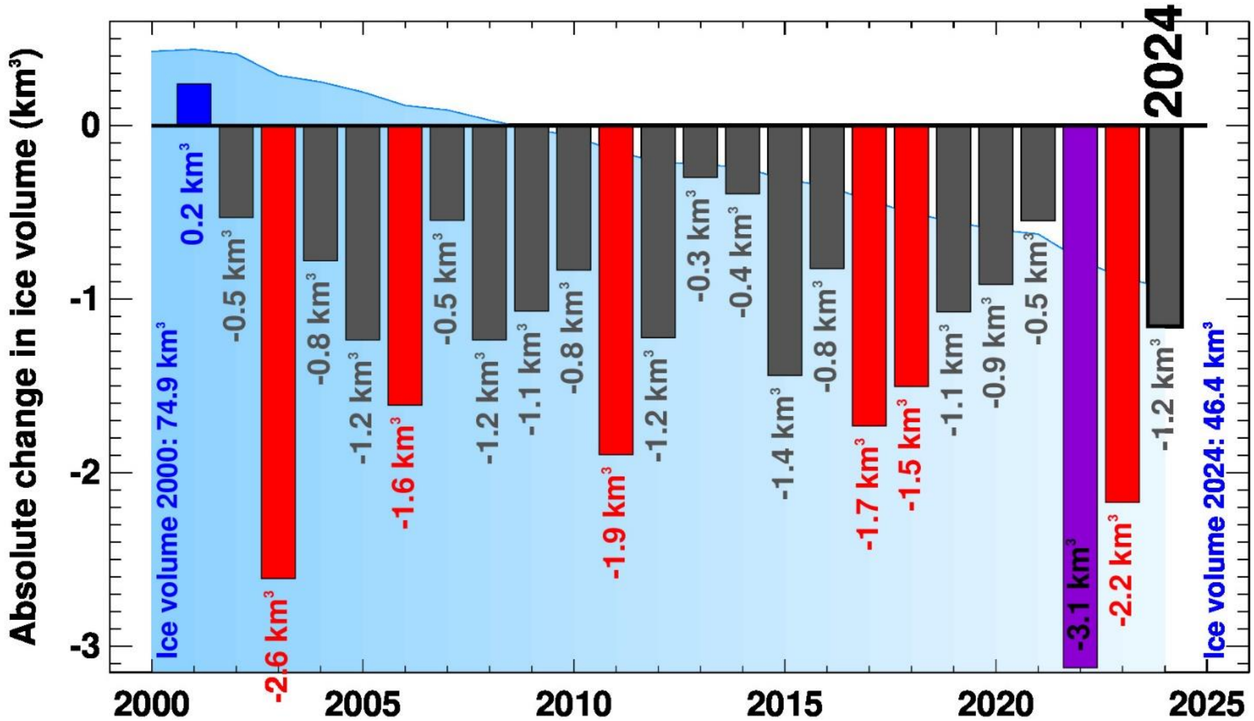

Figure 7: Swiss-wide annual change in absolute glacier ice volume. Colours visualize moderate (dark grey), strong (red) and extreme losses (purple). 2024 is highlighted. The blue surface in the background visualizes the temporal evolution of total ice volume.

Glacier mass balance measurement stake at Konkordiaplatz (2650 m a.s.l.), Grosser Aletschergletscher. Comparison of the observed melt rate in 2024 (right) with the extreme years 2022 and 2023, and the average from the observations performed in 1953-1983. Photos: M. Huss

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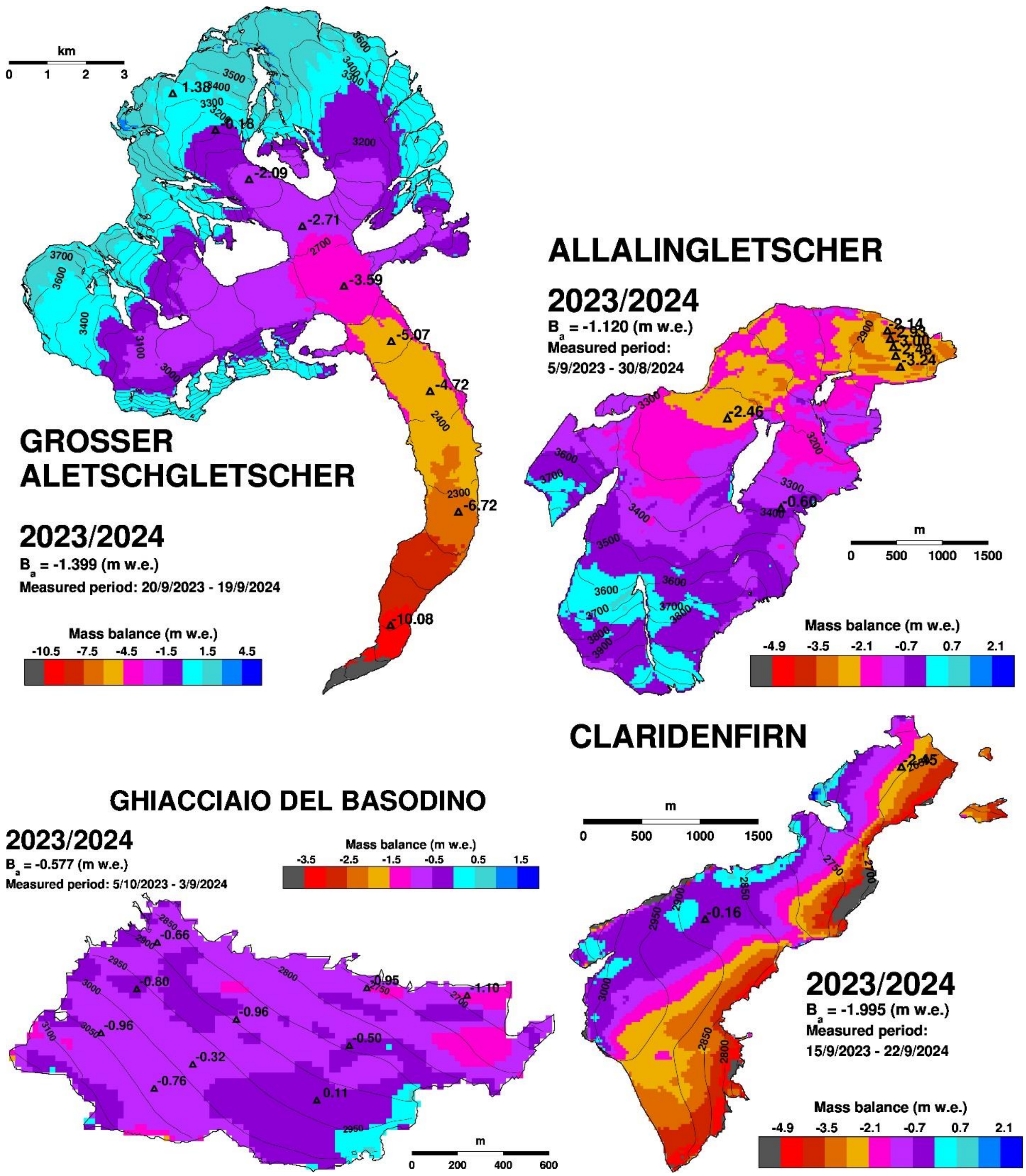
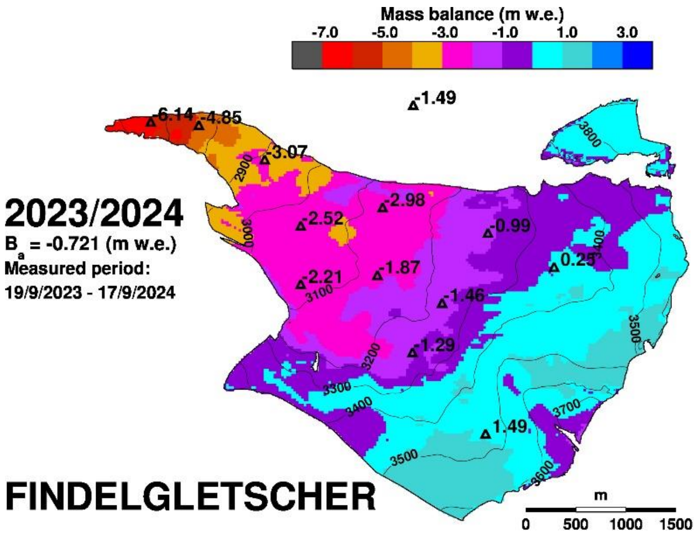
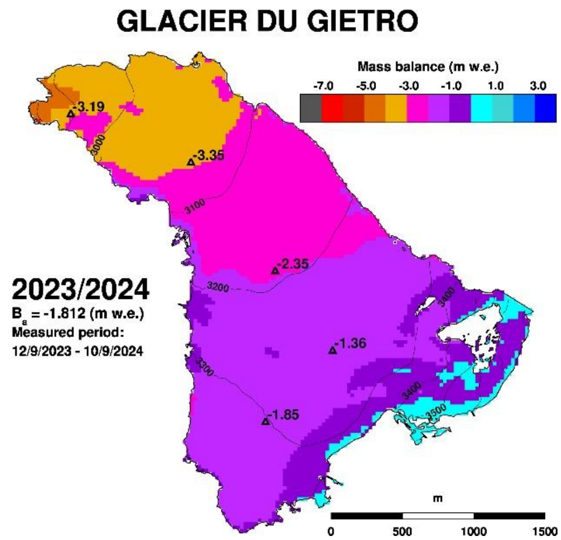
3. Appendix

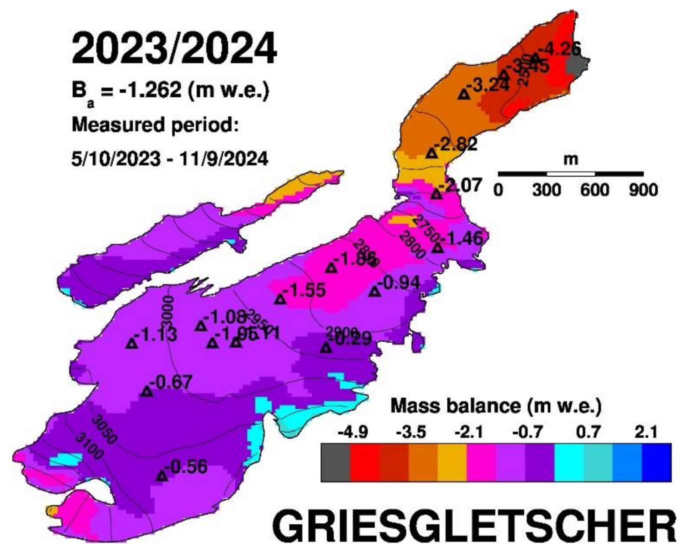
A.1 Spatial distribution of annual mass balance

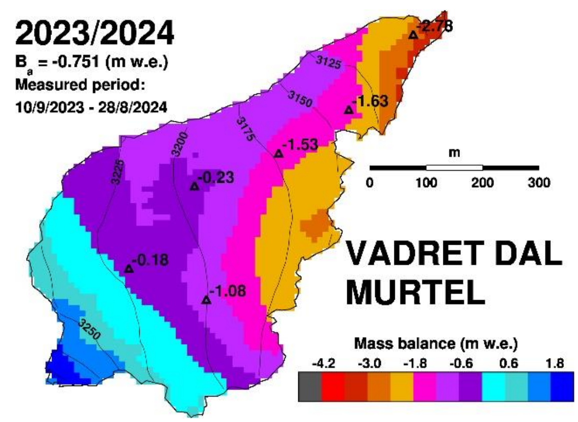
The figures below show the extrapolated annual mass balance distribution in metres water equivalent (m w.e.) during the measurement period (dates are given). Point surface mass balance measurements are indicated with black triangles, and the observed value for the respective period is stated. The spatial extrapolation accounts temperature and precipitation gradients, as well as for processes of local snow redistribution and topographic enhancement of solar radiation. Note that the scale of the maps and the range of displayed mass balances differs between the glaciers.

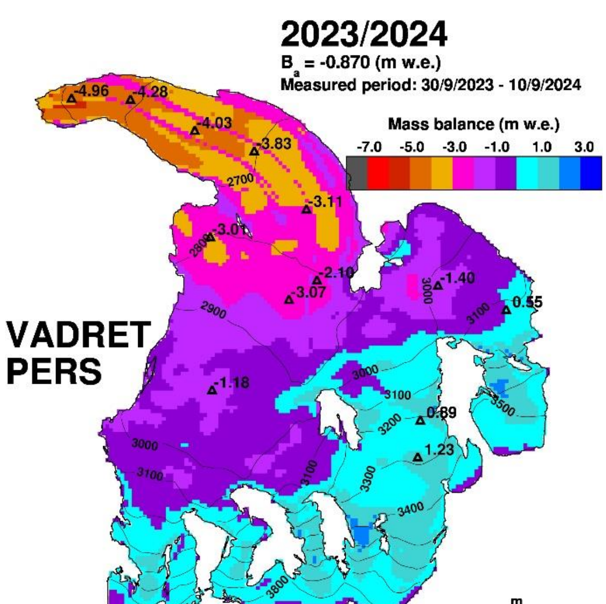


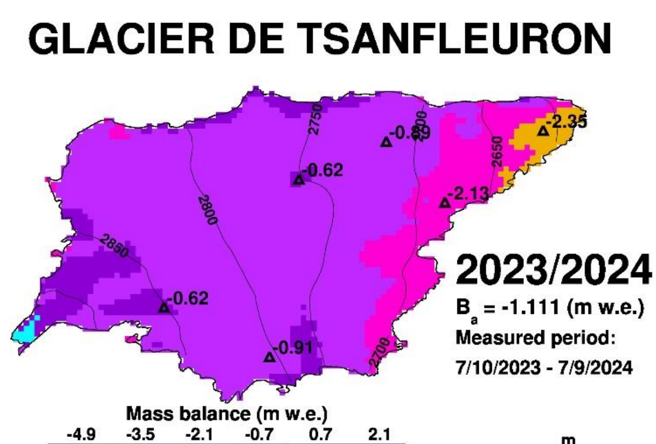

Mass balance (m w.e.)
-7.0 -5.0 -3.0 -1.0 1.0 3.0
2023/2024
B$_a$ = -0.721 (m w.e.)
Measured period:
19/9/2023 - 17/9/2024
FINDELGLETSCHER
m
0 500 1000 1500

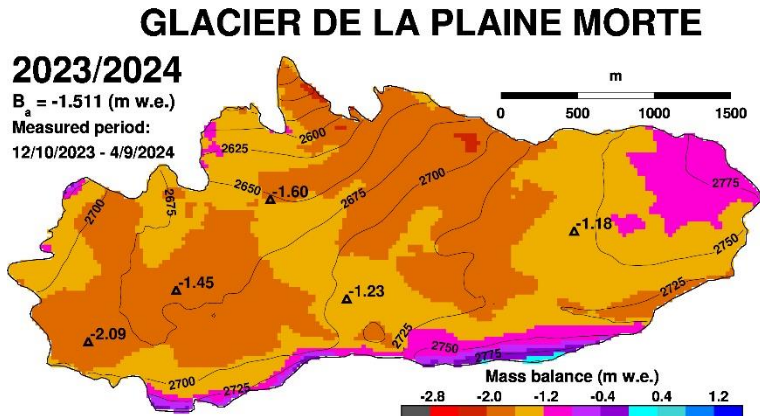

GLACIER DU GIETRO
Mass balance (m w.e.)
-7.0 -5.0 -3.0 -1.0 1.0 3.0
2023/2024
B$_a$ = -1.812 (m w.e.)
Measured period:
12/9/2023 - 10/9/2024
m
0 500 1000 1500

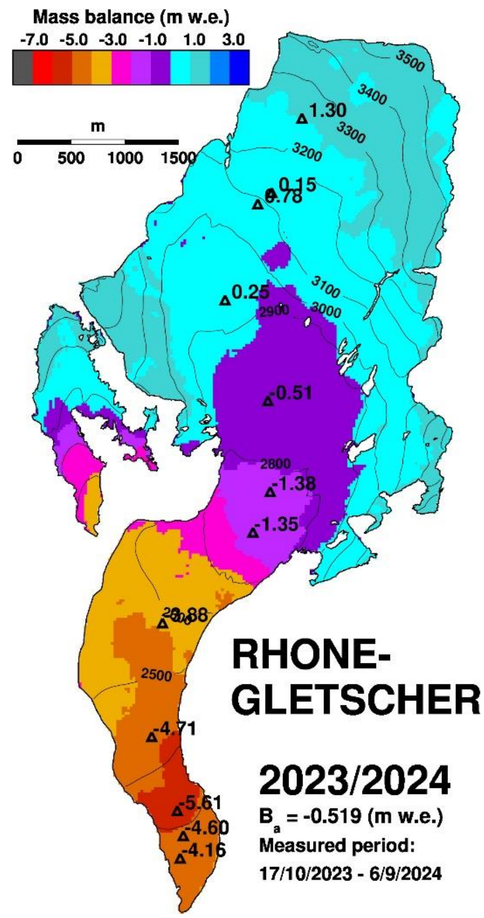

2023/2024
B$_a$ = -1.262 (m w.e.)
Measured period:
5/10/2023 - 11/9/2024
m
0 300 600 900
Mass balance (m w.e.)
-4.9 -3.5 -2.1 -0.7 0.7 2.1
GRIESGLETSCHER

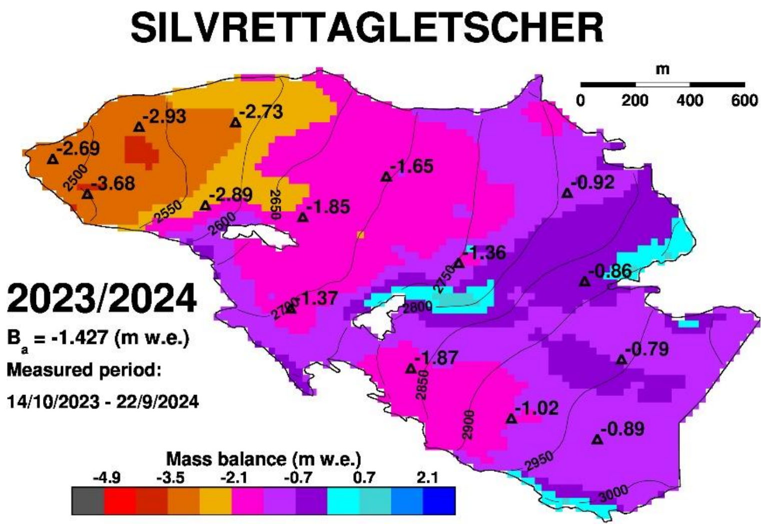

2023/2024
B$_a$ = -0.751 (m w.e.)
Measured period:
10/9/2023 - 28/8/2024
m
0 100 200 300
VADRET DAL MURTEL
Mass balance (m w.e.)
-4.2 -3.0 -1.8 -0.6 0.6 1.8


2023/2024
B$_a$ = -0.870 (m w.e.)
Measured period: 30/9/2023 - 10/9/2024
Mass balance (m w.e.)
-7.0 -5.0 -3.0 -1.0 1.0 3.0
VADRET PERS
m
0 300 600 900


GLACIER DE TSANFLEURON
2023/2024
B$_a$ = -1.111 (m w.e.)
Measured period:
7/10/2023 - 7/9/2024
Mass balance (m w.e.)
-4.9 -3.5 -2.1 -0.7 0.7 2.1
m
0 200 400 600

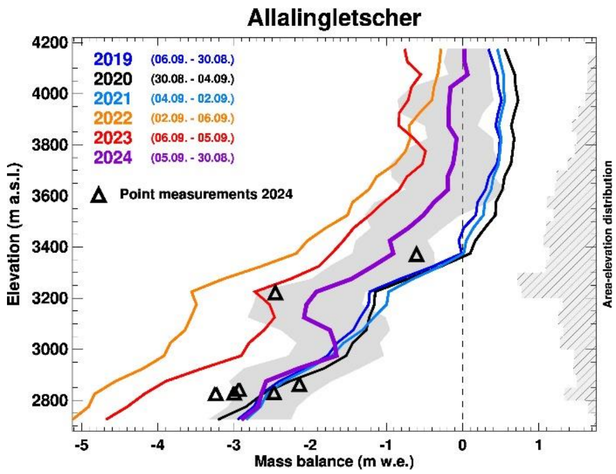

GLACIER DE LA PLAINE MORTE
2023/2024
B$_a$ = -1.511 (m w.e.)
Measured period:
12/10/2023 - 4/9/2024
m
0 500 1000 1500
Mass balance (m w.e.)
-2.8 -2.0 -1.2 -0.4 0.4 1.2
-1.60
-1.18
-1.45
-1.23
-2.09

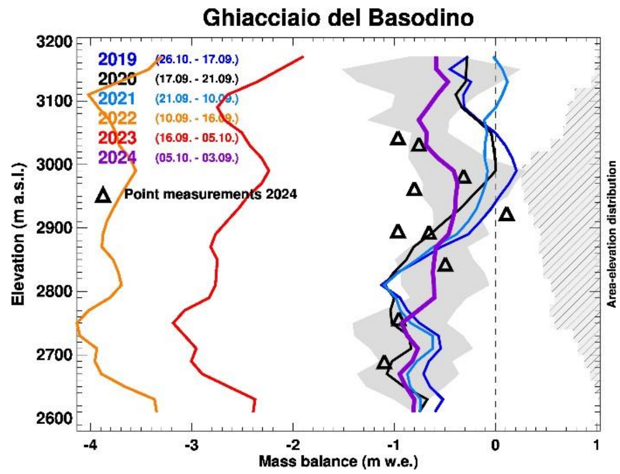

Mass balance (m w.e.)
-7.0 -5.0 -3.0 -1.0 1.0 3.0
m
0 500 1000 1500
RHONE-
GLETSCHER
2023/2024
B$_a$ = -0.519 (m w.e.)
Measured period:
17/10/2023 - 6/9/2024
1.30
0.15
0.25
-0.51
-1.38
-1.35
-4.71
-5.61
-4.60
-4.16

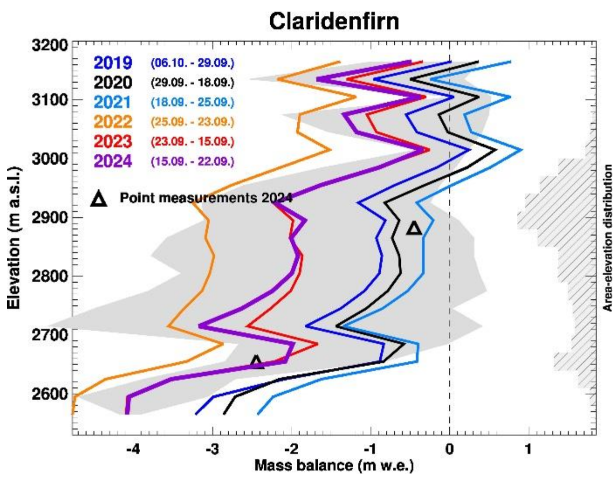

SILVRETTAGLETSCHER
m
0 200 400 600
2023/2024
B$_a$ = -1.427 (m w.e.)
Measured period:
14/10/2023 - 22/9/2024
Mass balance (m w.e.)
-4.9 -3.5 -2.1 -0.7 0.7 2.1
-2.69
-2.93
-2.73
-3.68
-2.89
-1.85
-1.65
-0.92
-1.36
-0.86
-1.37
-1.87
-0.79
-1.02
-0.89

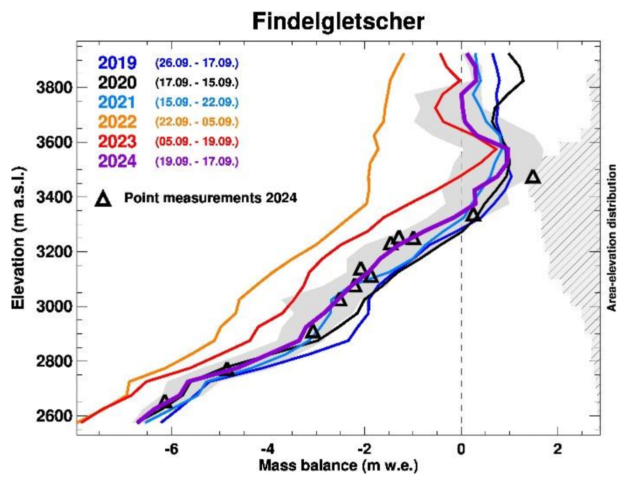
A.2 Elevation distribution of observed annual mass balance 2019-2024

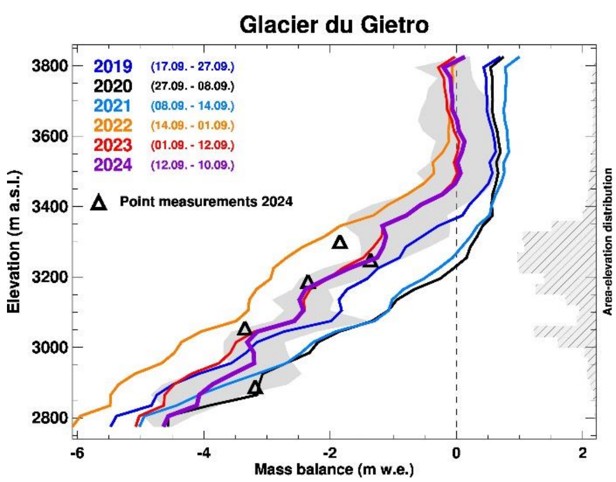
The figures below show the elevation distribution of annual mass balance during measurement period (respective dates are stated) extrapolated to the entire glacier surface over the last six years (2019-2024). The grey band shows the spread of mass balance per elevation band for the year 2024. Observed local mass balance is shown with triangles. Note that the x-axis scale differs between the graphs. The glaciers are alphabetically ordered.

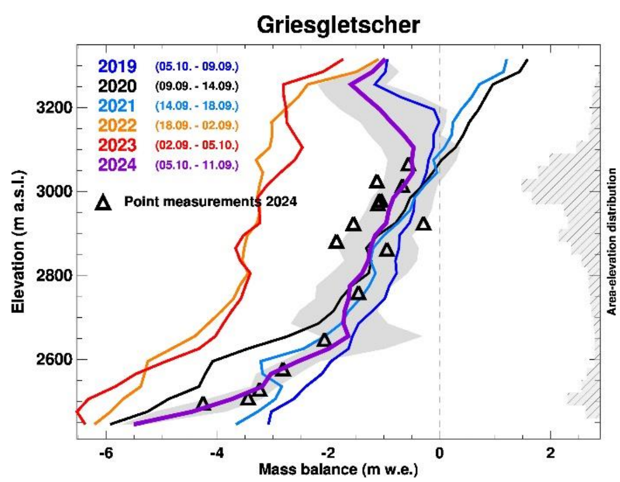


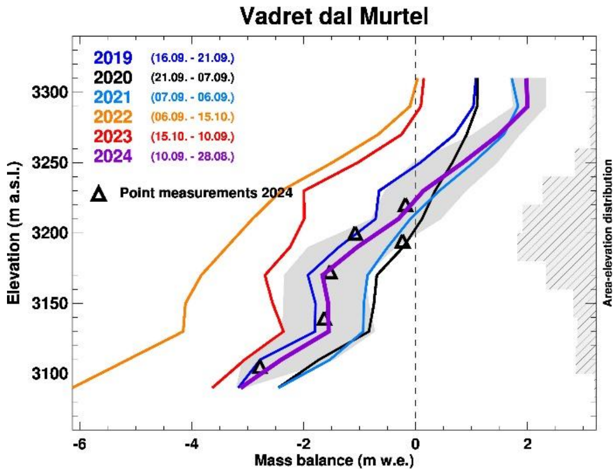


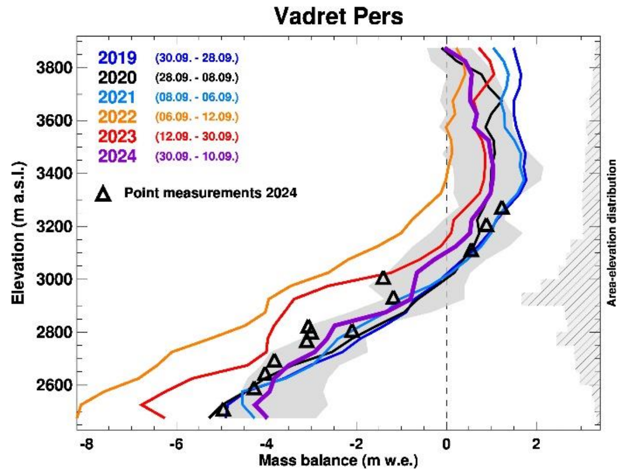


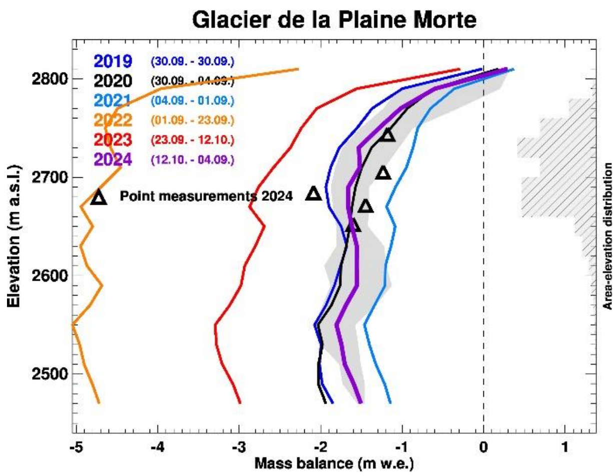


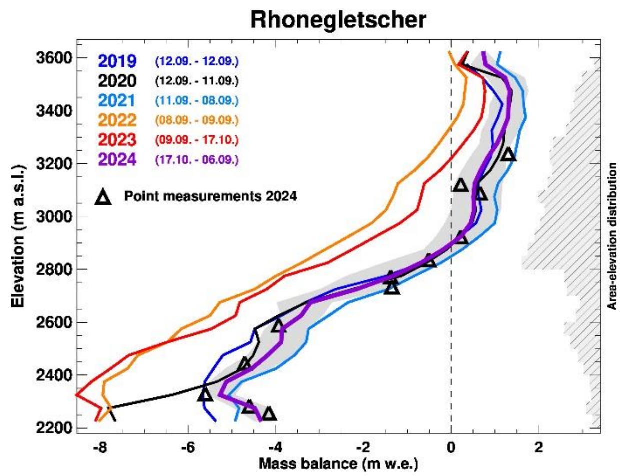


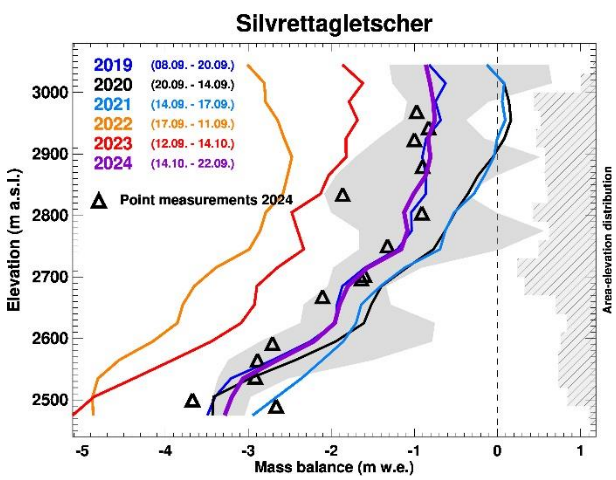


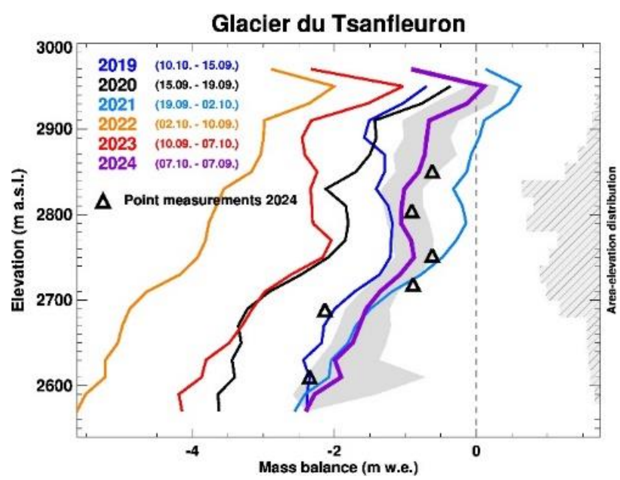

Vadret dal Murtel
2019 (16.09. - 21.09.)
2020 (21.09. - 07.09.)
2021 (07.09. - 06.09.)
2022 (06.09. - 15.10.)
2023 (15.10. - 10.09.)
2024 (10.09. - 28.08.)
Point measurements 2024
Elevation (m a.s.l.)
Mass balance (m w.e.)
Area-elevation distribution


Vadret Pers
2019 (30.09. - 28.09.)
2020 (28.09. - 08.09.)
2021 (08.09. - 06.09.)
2022 (06.09. - 12.09.)
2023 (12.09. - 30.09.)
2024 (30.09. - 10.09.)
Point measurements 2024
Elevation (m a.s.l.)
Mass balance (m w.e.)
Area-elevation distribution


Glacier de la Plaine Morte
2019 (30.09. - 30.09.)
2020 (30.09. - 04.09.)
2021 (04.09. - 01.09.)
2022 (01.09. - 23.09.)
2023 (23.09. - 12.10.)
2024 (12.10. - 04.09.)
Point measurements 2024
Elevation (m a.s.l.)
Mass balance (m w.e.)
Area-elevation distribution

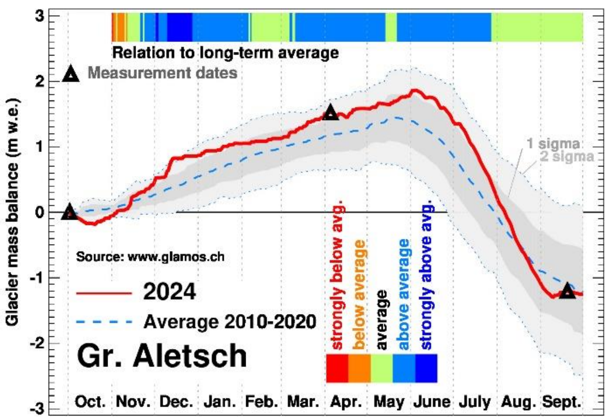

Rhonegletscher
2019 (12.09. - 12.09.)
2020 (12.09. - 11.09.)
2021 (11.09. - 08.09.)
2022 (08.09. - 09.09.)
2023 (09.09. - 17.10.)
2024 (17.10. - 06.09.)
Point measurements 2024
Elevation (m a.s.l.)
Mass balance (m w.e.)
Area-elevation distribution

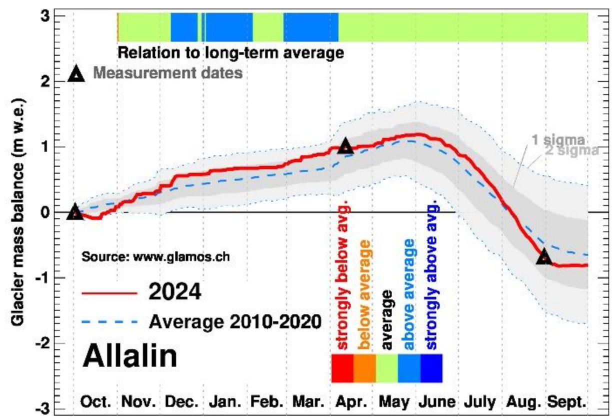

Silvrettagletscher
2019 (08.09. - 20.09.)
2020 (20.09. - 14.09.)
2021 (14.09. - 17.09.)
2022 (17.09. - 11.09.)
2023 (12.09. - 14.10.)
2024 (14.10. - 22.09.)
Point measurements 2024
Elevation (m a.s.l.)
Mass balance (m w.e.)
Area-elevation distribution

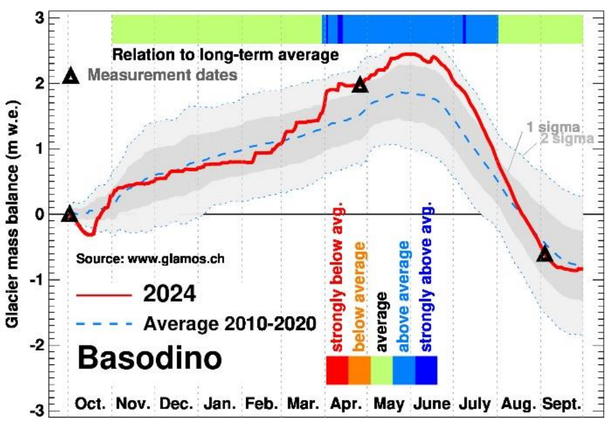

Glacier du Tsanfleuron
2019 (10.10. - 15.09.)
2020 (15.09. - 19.09.)
2021 (19.09. - 02.10.)
2022 (02.10. - 10.09.)
2023 (10.09. - 07.10.)
2024 (07.10. - 07.09.)
Point measurements 2024
Elevation (m a.s.l.)
Mass balance (m w.e.)
Area-elevation distribution

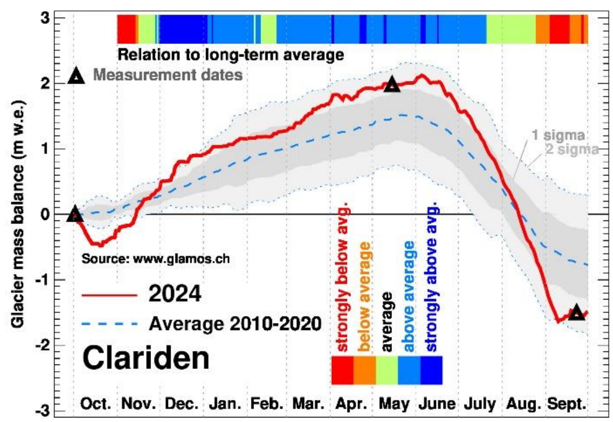
A.3 Temporal evolution of mass balance during the hydrological year 2023/2024

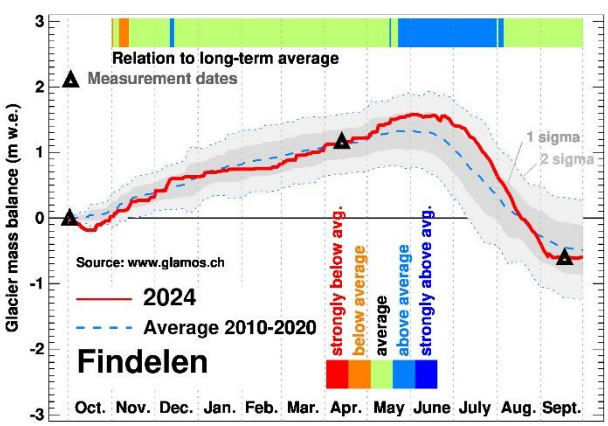
The figures below show the modelled daily cumulative mass balance during the hydrological year 2023/2024 in comparison to the average and the spread of the years 2010-2020. The measurement dates in late winter and late summer, by which the daily cumulative glacier-wide mass balance is constrained, is shown with black triangles. The top bar indicates periods throughout the year with below- or above-average mass balance. The glaciers are alphabetically ordered.

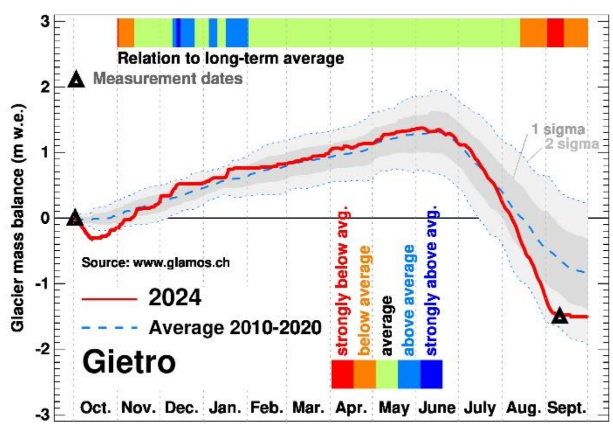


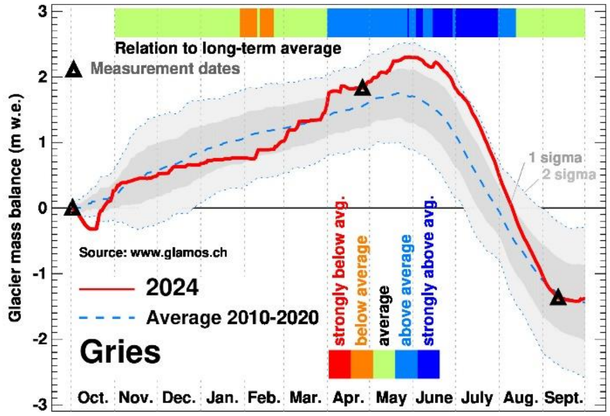


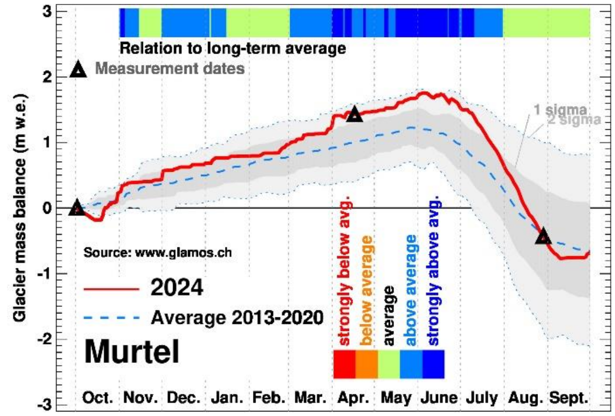


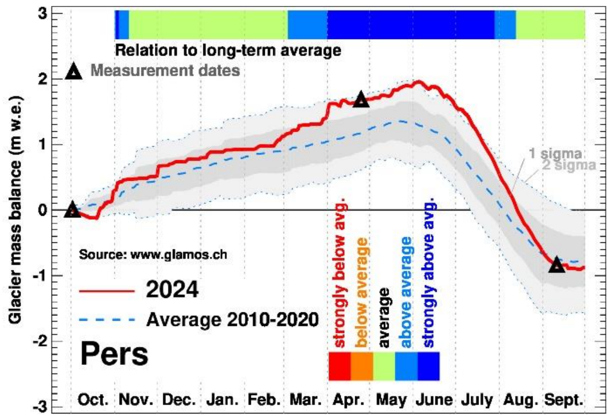


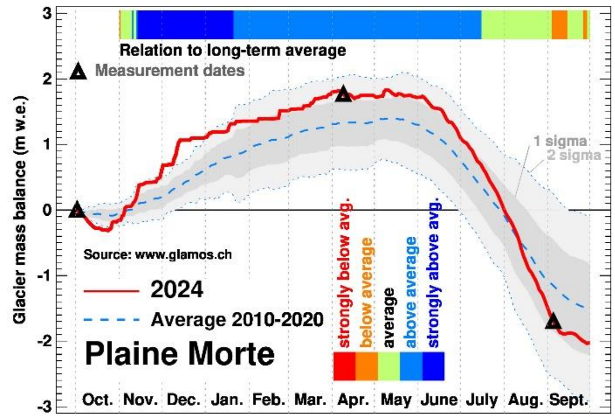


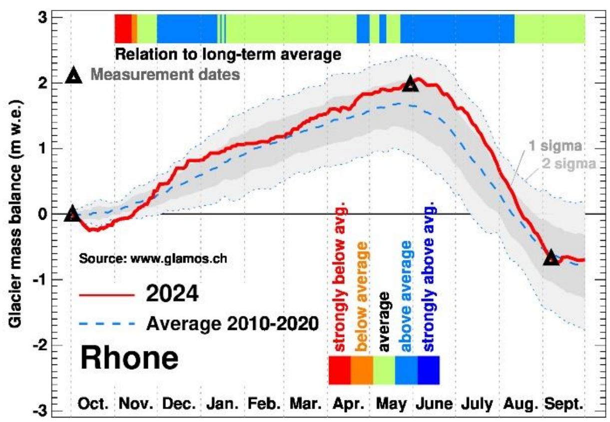


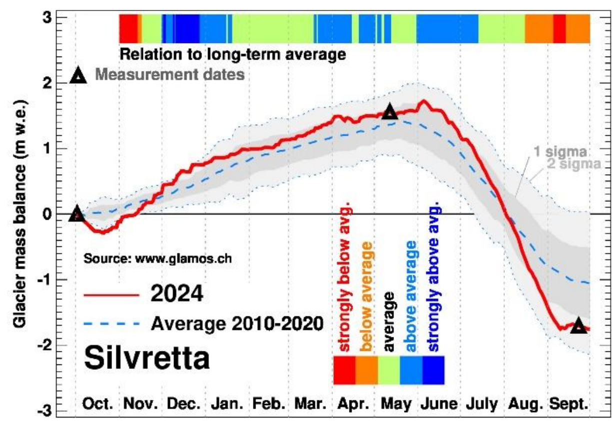

Relation to long-term average
Measurement dates
Glacier mass balance (m w.e.)
1 sigma
2 sigma
Source: www.glamos.ch
2024
Average 2010-2020
Gries
strongly below avg.
below average
average
above average
strongly above avg.
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept.

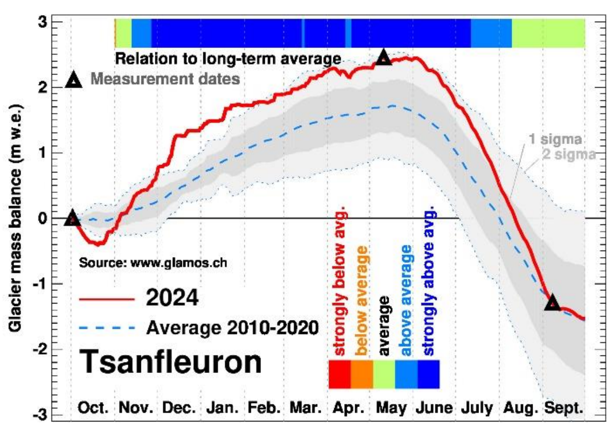

Relation to long-term average
Measurement dates
Glacier mass balance (m w.e.)
1 sigma
2 sigma
Source: www.glamos.ch
2024
Average 2013-2020
Murtel
strongly below avg.
below average
average
above average
strongly above avg.
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept.


Relation to long-term average
Measurement dates
Glacier mass balance (m w.e.)
1 sigma
2 sigma
Source: www.glamos.ch
2024
Average 2010-2020
Pers
strongly below avg.
below average
average
above average
strongly above avg.
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept.


Relation to long-term average
Measurement dates
Glacier mass balance (m w.e.)
1 sigma
2 sigma
Source: www.glamos.ch
2024
Average 2010-2020
Plaine Morte
strongly below avg.
below average
average
above average
strongly above avg.
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept.

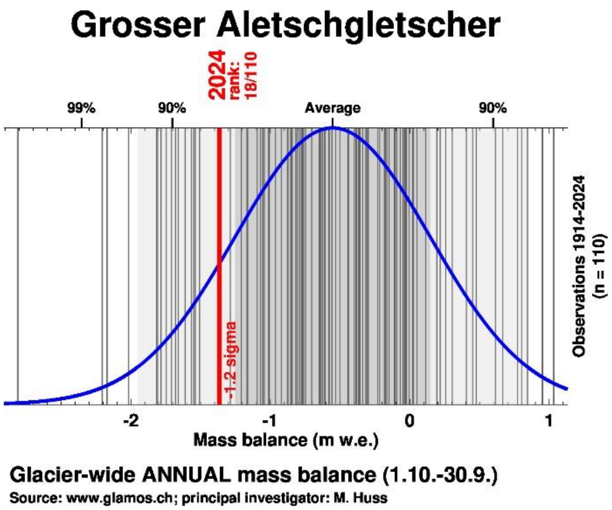

Relation to long-term average
Measurement dates
Glacier mass balance (m w.e.)
1 sigma
2 sigma
Source: www.glamos.ch
2024
Average 2010-2020
Rhone
strongly below avg.
below average
average
above average
strongly above avg.
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept.

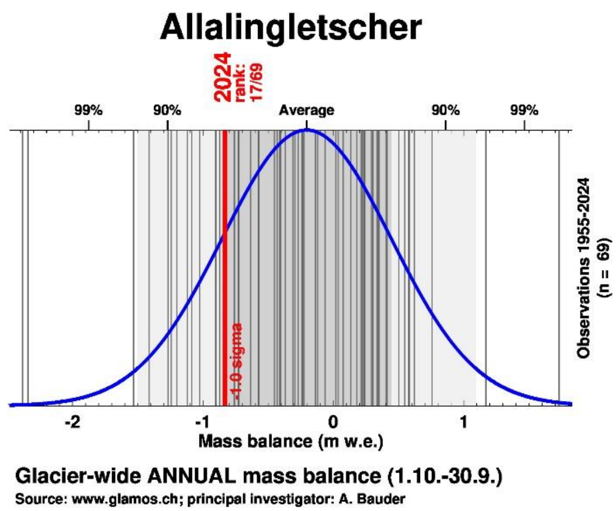

Relation to long-term average
Measurement dates
Glacier mass balance (m w.e.)
1 sigma
2 sigma
Source: www.glamos.ch
2024
Average 2010-2020
Silvretta
strongly below avg.
below average
average
above average
strongly above avg.
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept.

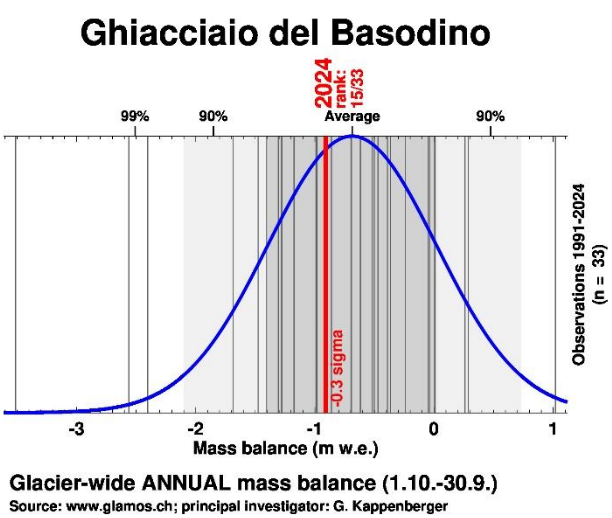

Relation to long-term average
Measurement dates
Glacier mass balance (m w.e.)
1 sigma
2 sigma
Source: www.glamos.ch
2024
Average 2010-2020
Tsanfleuron
strongly below avg.
below average
average
above average
strongly above avg.
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept.

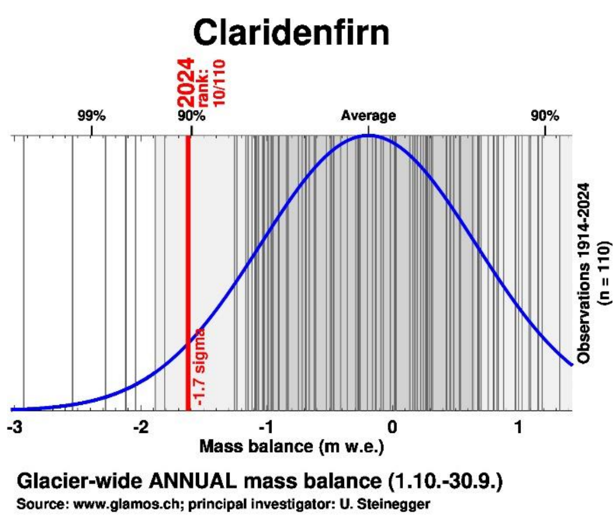
A.4 Annual mass balance 2024 compared to all years since initiation of the measurements

The figures below show the statistical distribution of all previously measured glacier-wide annual mass balances homogenized to the hydrological year (1 Oct - 30 Sept., vertical lines). The time period of observations is stated on the right. Ranges corresponding to 1 (dark grey) and 2 (light grey) standard deviations are shown, as are the boundaries encompassing 90% and 99% of the statistical distribution (blue line, ticks). The year 2024 is indicated with the thick, red line and the rank of 2024 starting from the most negative annual mass balance is given. Note that the x-axis scale differs between the graphs. The glaciers are alphabetically ordered.

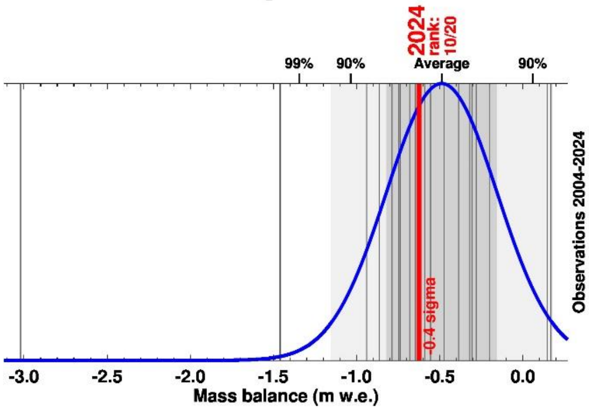






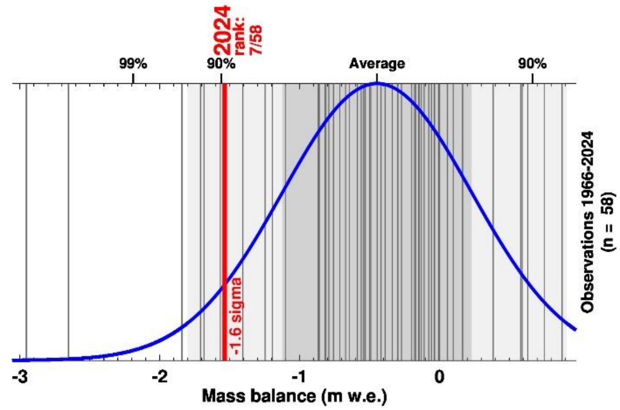


Findelgletscher



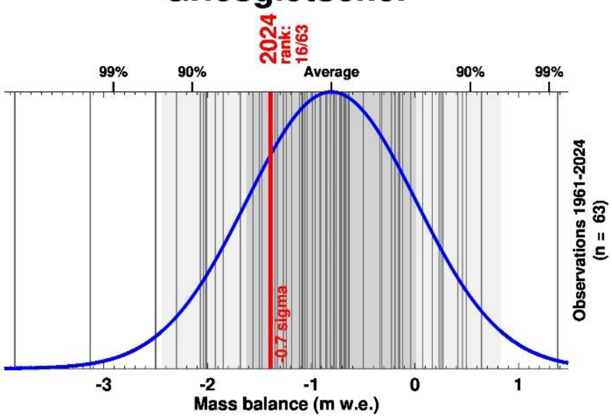
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: M. Huss, A. Linsbauer

Glacier du Gietro



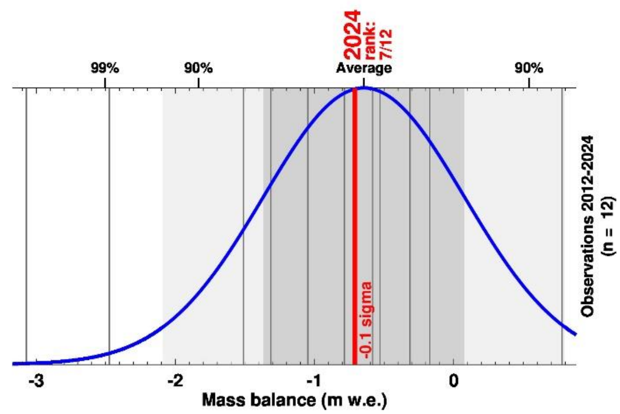
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: A. Bauder

Griesgletscher



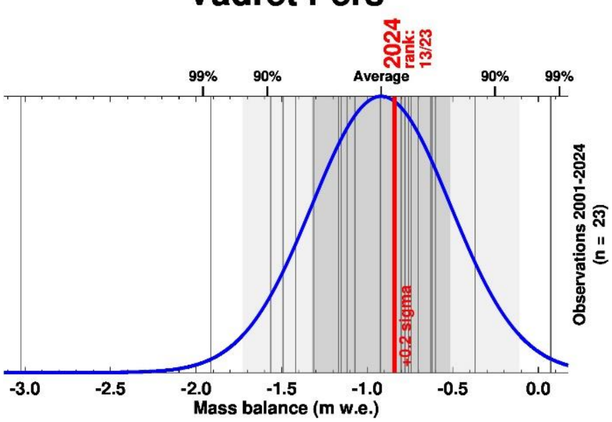
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: M. Huss

Vadret dal Murtel



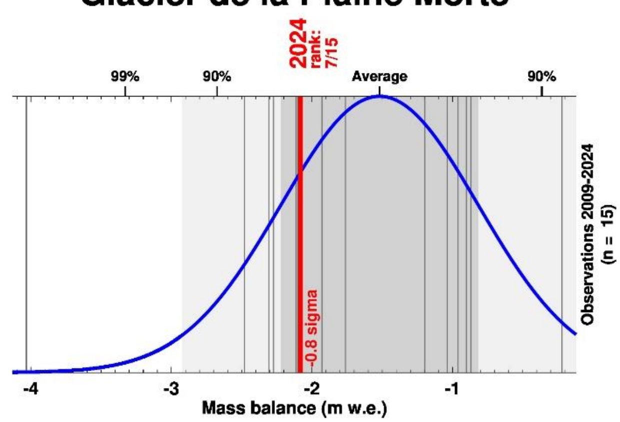
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: M. Huss

Vadret Pers

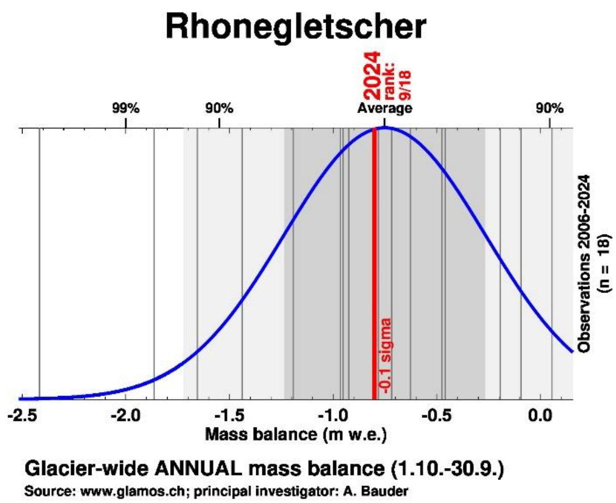


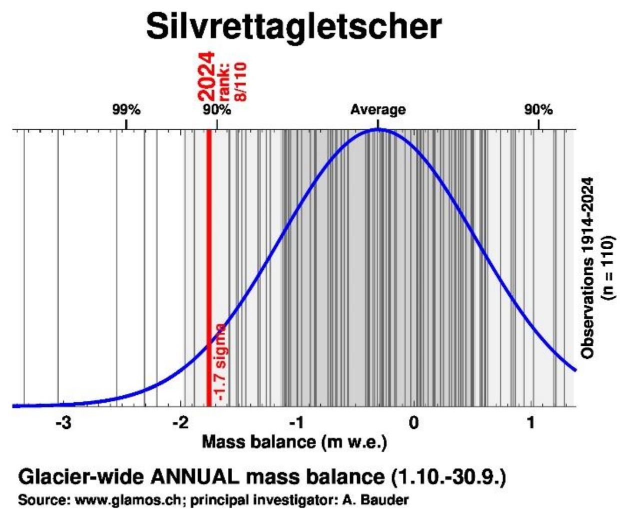
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: M. Huss, A. Linsbauer

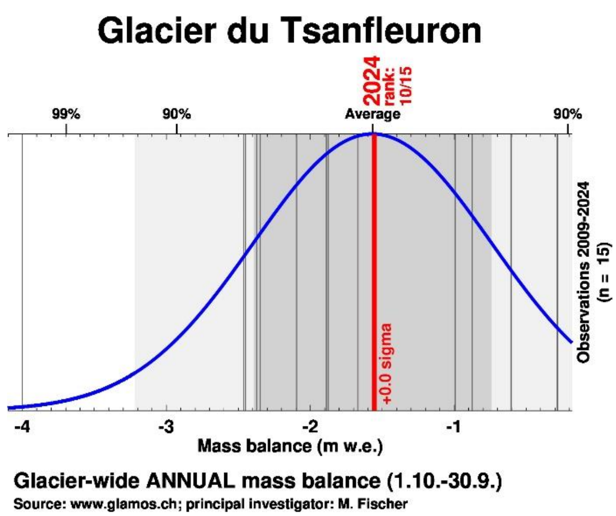
Glacier de la Plaine Morte



Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: M. Huss

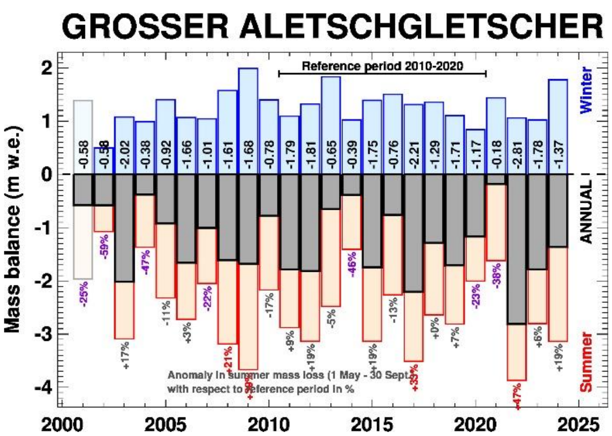

Rhonegletscher
2024
rank:
9/18
99%
90%
Average
90%
-0.1 sigma
Observations 2006-2024
(n = 18)
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
Mass balance (m w.e.)
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: A. Bauder

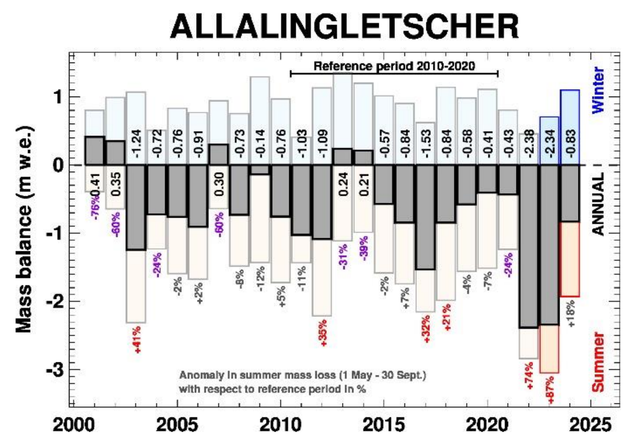

Silvrettagletscher
2024
rank:
8/110
99%
90%
Average
90%
-1.7 sigma
Observations 1914-2024
(n = 110)
-3
-2
-1
0
1
Mass balance (m w.e.)
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: A. Bauder

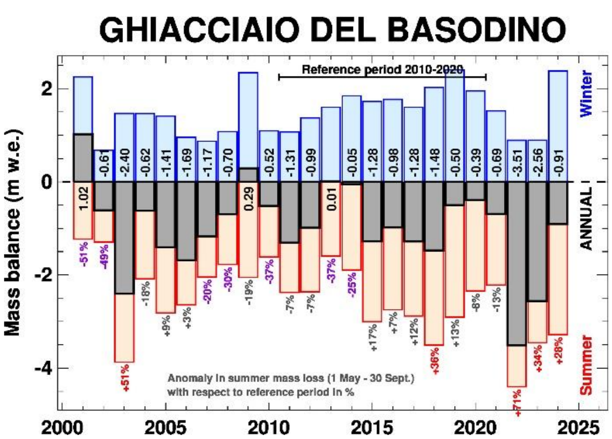

Glacier du Tsanfleuron
2024
rank:
10/15
99%
90%
Average
90%
+0.0 sigma
Observations 2009-2024
(n = 15)
-4
-3
-2
-1
Mass balance (m w.e.)
Glacier-wide ANNUAL mass balance (1.10.-30.9.)
Source: www.glamos.ch; principal investigator: M. Fischer

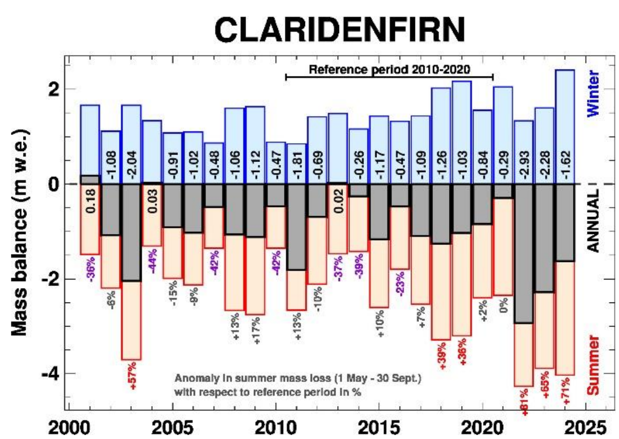
A.5 Seasonal mass balance time series (homogenized to fixed time periods)

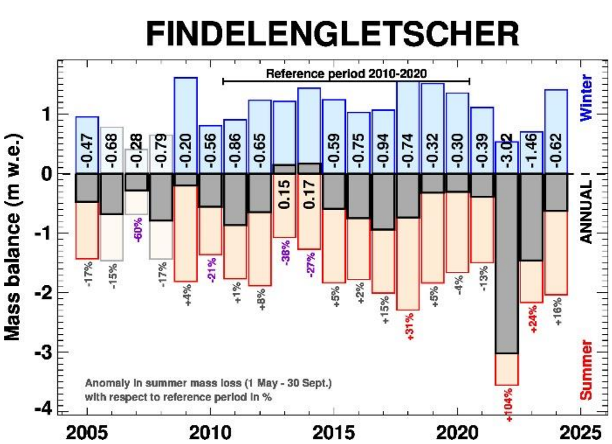
The figures below show measured seasonal mass balance homogenized to fixed time periods for the **annual mass balance** (1 Oct. - 30 Sept., dark grey / numbers), **winter mass balance** (1 Oct. - 30 April, light blue), and **summer mass balance** (1 May – 30 Sept., light red). All years since 2000 are displayed. Light bars for a few glaciers show years where the seasonal mass balance components are not based on in situ measurements but modelling. Measurements for the annual mass balance were available throughout the entire period shown. Percentage numbers below the bars indicate the relative anomaly of summer mass balance relative to the period 2010-2020, coded with colours for years with strongly below-average melt (purple), average melt (grey) and strongly above-average melt (red). Note that the y-axis scale differs between the plots. The glaciers are alphabetically ordered.

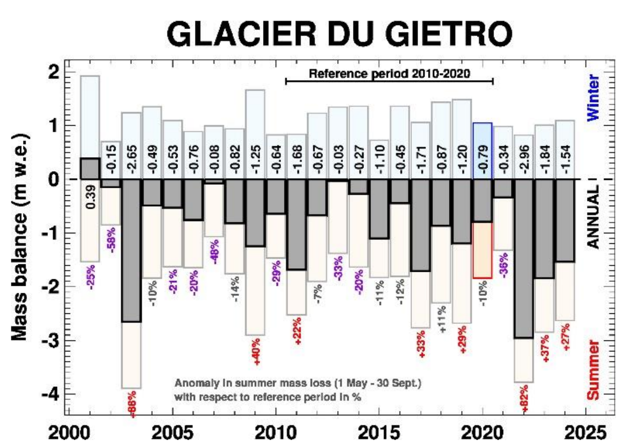


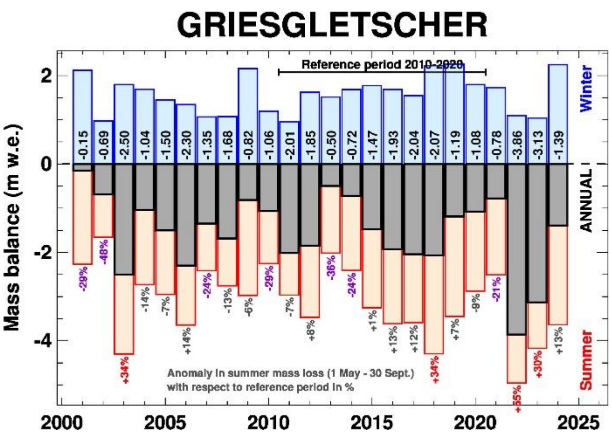


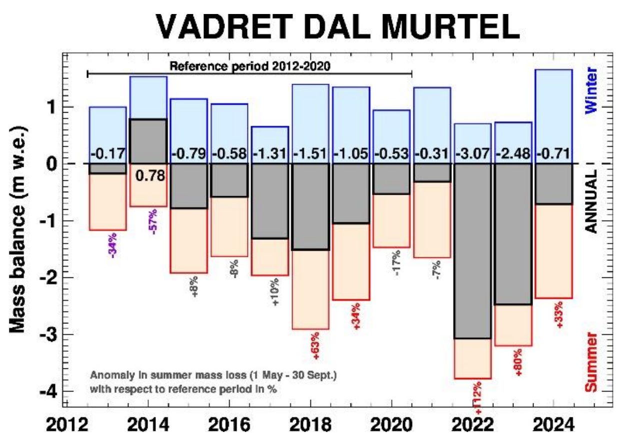


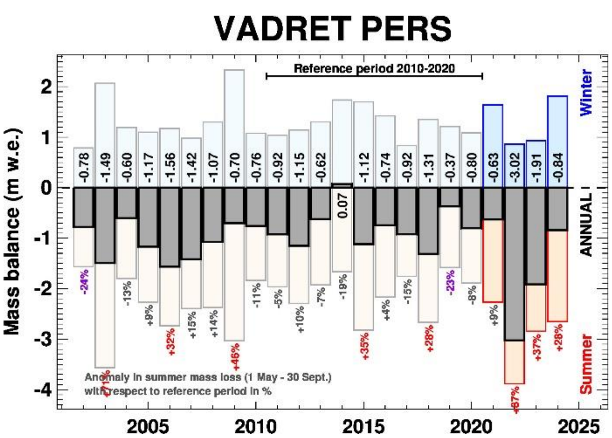


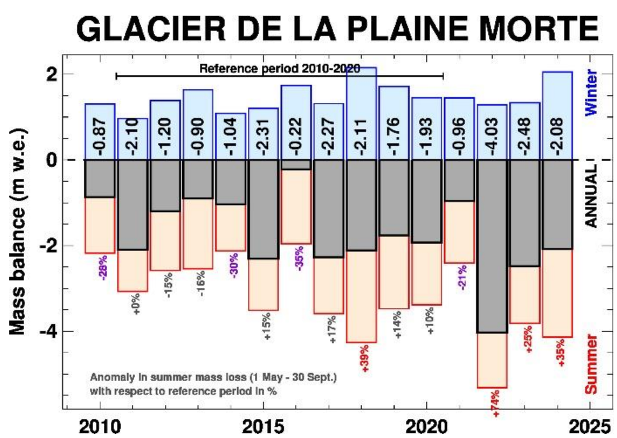


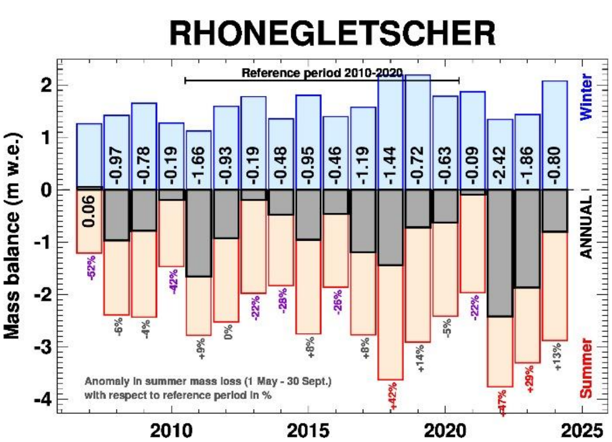


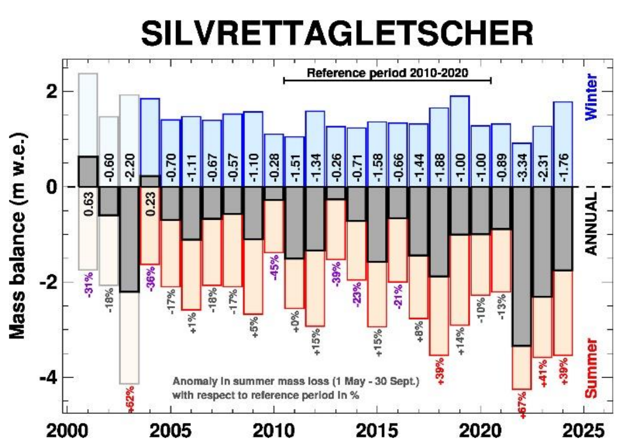

GRIESGLETSCHER
Reference period 2010-2020
Mass balance (m w.e.)
Winter
ANNUAL
Summer
-0.15 -0.69 -2.50 -1.04 -1.50 -2.30 -1.35 -1.68 -0.82 -1.06 -2.01 -1.85 -0.50 -0.72 -1.47 -1.93 -2.04 -2.07 -1.19 -1.08 -0.78 -3.86 -3.13 -1.39
Anomaly in summer mass loss (1 May - 30 Sept.)
with respect to reference period in %
2000 2005 2010 2015 2020 2025

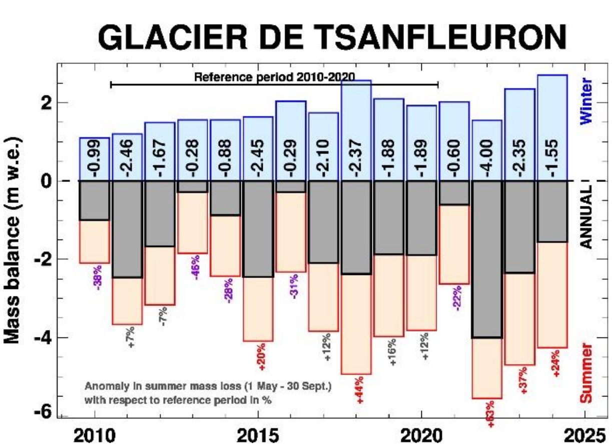

VADRET DAL MURTEL
Reference period 2012-2020
Mass balance (m w.e.)
Winter
ANNUAL
Summer
-0.17 0.78 -0.79 -0.58 -1.31 -1.51 -1.05 -0.53 -0.31 -3.07 -2.48 -0.71
Anomaly in summer mass loss (1 May - 30 Sept.)
with respect to reference period in %
2012 2014 2016 2018 2020 2022 2024


VADRET PERS
Reference period 2010-2020
Mass balance (m w.e.)
Winter
ANNUAL
Summer
-0.78 -1.49 -0.60 -1.17 -1.56 -1.42 -1.07 -0.70 -0.76 -0.92 -1.15 -0.62 0.07 -1.12 -0.74 -0.92 -1.31 -0.37 -0.80 -0.63 -3.02 -1.91 -0.84
Anomaly in summer mass loss (1 May - 30 Sept.)
with respect to reference period in %
2005 2010 2015 2020 2025


GLACIER DE LA PLAINE MORTE
Reference period 2010-2020
Mass balance (m w.e.)
Winter
ANNUAL
Summer
-0.87 -2.10 -1.20 -0.90 -1.04 -2.31 -0.22 -2.27 -2.11 -1.76 -1.93 -0.96 -4.03 -2.48 -2.08
Anomaly in summer mass loss (1 May - 30 Sept.)
with respect to reference period in %
2010 2015 2020 2025


RHONEGLETSCHER
Reference period 2010-2020
Mass balance (m w.e.)
Winter
ANNUAL
Summer
0.06 -0.97 -0.78 -0.19 -1.66 -0.93 -0.19 -0.48 -0.95 -0.46 -1.19 -1.44 -0.72 -0.63 -0.09 -2.42 -1.86 -0.80
Anomaly in summer mass loss (1 May - 30 Sept.)
with respect to reference period in %
2010 2015 2020 2025


SILVRETTAGLETSCHER
Reference period 2010-2020
Mass balance (m w.e.)
Winter
ANNUAL
Summer
0.63 -0.60 -2.20 0.23 -0.70 -1.11 -0.67 -0.57 -1.10 -0.28 -1.51 -1.34 -0.26 -0.71 -1.58 -0.66 -1.44 -1.88 -1.00 -1.00 -0.89 -3.34 -2.31 -1.76
Anomaly in summer mass loss (1 May - 30 Sept.)
with respect to reference period in %
2000 2005 2010 2015 2020 2025


GLACIER DE TSANFLEURON
Reference period 2010-2020
Mass balance (m w.e.)
Winter
ANNUAL
Summer
-0.99 -2.46 -1.67 -0.28 -0.88 -2.45 -0.29 -2.10 -2.37 -1.88 -1.89 -0.60 -4.00 -2.35 -1.55
Anomaly in summer mass loss (1 May - 30 Sept.)
with respect to reference period in %
2010 2015 2020 2025