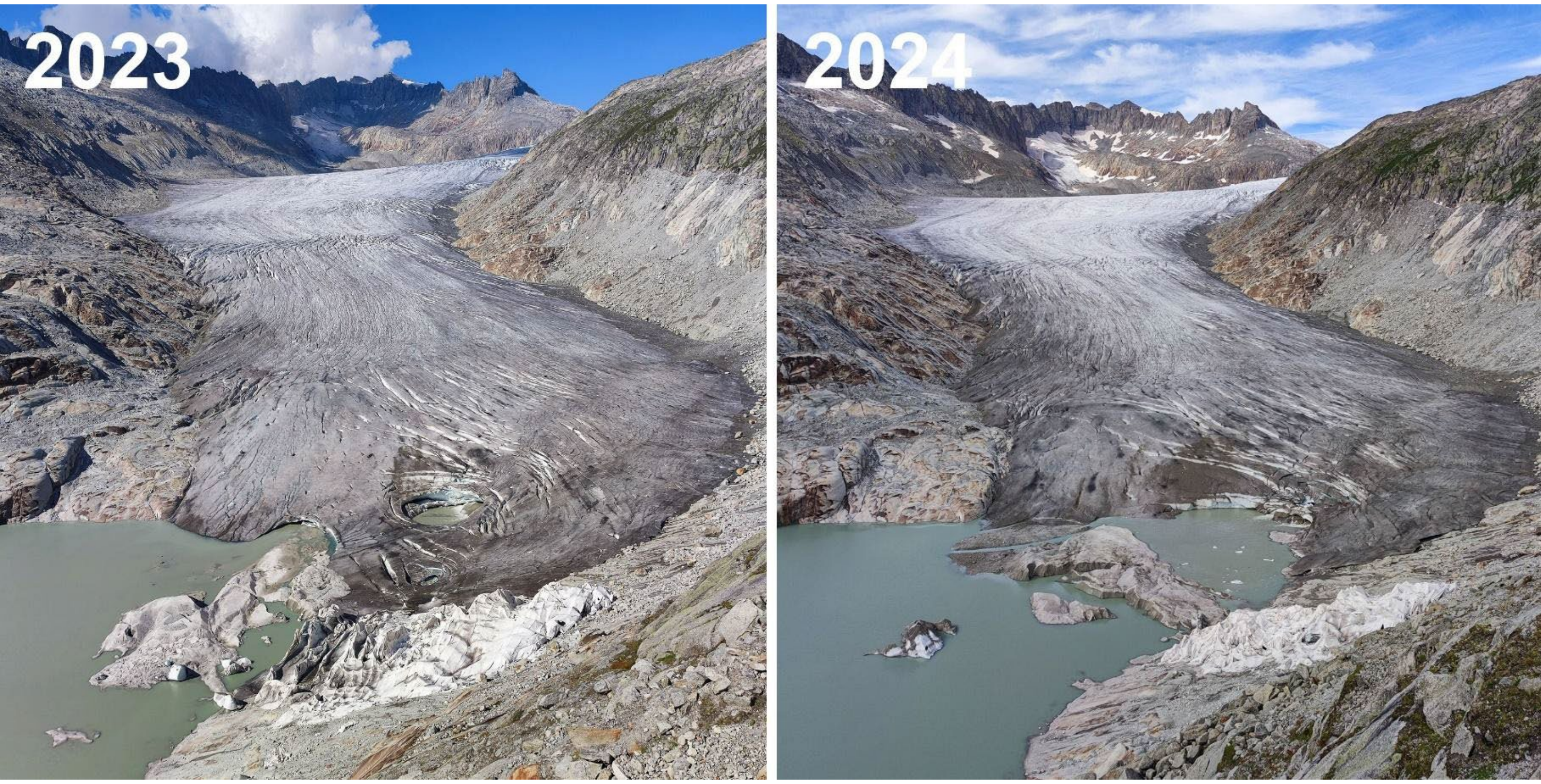
GLAMOS
Glacier Monitoring Switzerland



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Data availability

Cover page

Decay of the frontal part of Rhonegletscher between September 2023 and 2024. White geotextiles placed in front of the glacier are related to an artificial ice cave. Photos: M. Huss

Summary

The Glacier Monitoring in Switzerland (GLAMOS) programme documents, analyses and disseminates data on the state and changes of Swiss glaciers. The monitoring strategy is based on field measurements and remote-sensing products for different variables and observations: *Mass balance, Length change, Ice-flow velocity, Glacier inventory, Volume change, Englacial temperature* and *Special events related to glaciers*. This Swiss Glacier Bulletin provides an overview of the results with a focus on the hydrological year 2024, i.e. the period 1 Oct 2023 to 30 Sep 2024. For some variables, an extended period is covered related to periodical data acquisition and lagged data availability.

Meteorological conditions in the period of interest were extraordinary. For the hydrological year, air temperatures were 0.9°C above the 1991-2020 average. This was especially pronounced in the month of August, when new record values at high elevation were reached. Over the winter half-year, strongly above-average precipitation (+66%) was recorded, leading to very high snow depth in the Alps at the beginning of the melting season.

Direct measurements of winter mass balance on 14 glaciers throughout Switzerland indicated 31% higher snow mass by the end of April compared to the 2010-2020 average, and thus one of the highest values recorded during the last decades. At 21 glaciers, observations of annual mass balance were acquired in September. Very high melt rates, especially in July and August, contributed to a negative mass balance of –1.17 m water equivalent (w.e.) across all ca. 1400 Swiss glaciers. With respect to the last decade, this value is close to the average because of the favourable winter balance. At the Swiss-wide scale, 2.3% or 1.1 km^3, of the remaining ice volume was lost during 2024.

Length change of the glacier terminus was determined for 95 glaciers in 2023. Retreat/advance has already been measured on 49 glaciers for 2024, while data for additional sites are not yet available. The last years have shown a continued rapid retreat of all glacier snouts throughout Switzerland. 90% of the glaciers observed in 2023 retreated by between 4 m and 80 m. This retreat rate is 23% faster than the 2010-2020 average. Glacier length changes already observed in 2024 were between –2 m and –46 m.

Observations of local ice-flow velocity at a stake network on eight glaciers indicated a slow-down of ice motion in 2024 by 41% with respect to the 2010-2020 average. This is explained by persistently negative mass balance over the last decades and thus declining ice thickness and glacier flow. Preliminary updates of the Swiss Glacier Inventory based on aerial images of 2021 to 2023 acquired by the Federal Office of Topography swisstopo show a progression of glacier area losses. Rates of area change vary between –1.5 and –2.4% yr^{-1} depending on the region. At least 105 glaciers have ultimately disappeared in Switzerland between 2016 and 2022. The comparison of digital elevation models, available for 1- to 6-year intervals for all Swiss glaciers, allows the determination of recent ice volume change over multi-year periods. For 2015-2023, average geodetic mass balances were mostly between –1.2 m w.e. yr^{-1} and –1.7 m w.e. yr^{-1} indicating a noteworthy spatial variability.

Englacial temperatures measured at the high-elevation saddle of Colle Gnifetti indicated massive shifts due to substantial melting even occurring at almost 4500 m a.s.l. with a warming of 1.5°C over the last 30 years. For 2024, 11 special events related to glaciers (ice avalanches / glacier lake outburst events) have been documented. One fatality occurred and two additional events caused minor damages to infrastructure. A glacial/periglacial land movement related to the collapse of a large rock-ice mass at Piz Scerscen on 14 April 2024 did not entail damages though.

In summary, the decline of glaciers in Switzerland as documented by data acquired within GLAMOS continued unabated during the reporting period 2024 regarding all monitored variables. However, due to high winter snow accumulation, the resulting loss of glacier ice was less dramatic than in the two previous years 2022 and 2023.

Zusammenfassung

Das Schweizerische Gletschermessnetz (GLAMOS) dokumentiert, analysiert und publiziert Daten zum Zustand und den Veränderungen der Gletscher in den Schweizer Alpen. Das Messnetz basiert auf Feldmessungen und Fernerkundungsdaten für die folgenden Variablen, sowie ergänzende Beobachtungen: *Massenbilanz, Längenänderung, Eis-Fliessgeschwindigkeit, Gletscherinventar, Volumenänderung, Eistemperatur* und *besondere gletscher-bezogene Ereignisse*. Das *Swiss Glacier Bulletin* bietet einen Überblick mit Fokus auf die Ergebnisse des hydrologischen Jahres 2024, also die Periode 1. Oktober 2023 bis 30. September 2024. Bei einigen Variablen wird ein längerer Zeitraum abgedeckt, was mit der periodischen Datenerfassung und der verzögerten Datenverfügbarkeit zusammenhängt.

Die meteorologischen Bedingungen im untersuchten Zeitraum waren aussergewöhnlich. Für das hydrologische Jahr waren die Lufttemperaturen 0.9°C über dem Mittel von 1991-2020. Dies war im August besonders ausgeprägt, als in hohen Lagen neue Rekordtemperaturen erreicht wurden. Im Winterhalbjahr wurden klar überdurchschnittliche Niederschläge (+66%) verzeichnet, die zu Beginn der Schmelzsaison zu sehr grossen Schneehöhen in den Alpen führten.

Messungen der Winterbilanz auf 14 Gletschern ergaben für Ende April eine um 31% höhere Schneemenge als 2010–2020, und damit einen der höchsten Werte der letzten Jahrzehnte. Beobachtungen der jährlichen Massenbilanz wurden auf 21 Gletschern durchgeführt. Starke Schmelzraten, v.a. im Juli und August, führten zu einer Jahresbilanz von –1,17 m Wasseräquivalent (w.eq) für alle ca. 1400 Schweizer Gletscher. Bezogen auf das letzte Jahrzehnt ist dieser Wert aufgrund der grossen Winter-Schneemenge durchschnittlich. Schweizweit gingen im Jahr 2024 2,3% bzw. 1,1 km^3 des verbleibenden Eisvolumens verloren.

Die Längenänderung der Gletscherzunge wurde 2023 für 95 Gletscher bestimmt. Daten für 2024 liegen bereits für 49 Gletscher vor, während weitere Beobachtungen erst später verfügbar werden. Die letzten Jahre zeigten einen anhaltend schnellen Rückzug aller Gletscherzungen. 90% der im Jahr 2023 beobachteten Gletscher zogen sich zwischen 4 und 80 m zurück. Diese Rückzugsrate ist 23% schneller als im Durchschnitt der Jahre 2010–2020. Die 2024 bereits beobachteten Werte der Längenänderung liegen zwischen –2 m und –46 m (12 % über der durchschnittlichen Rückzugsrate von 2010–2020).

Beobachtungen der lokalen Eis-Fliessgeschwindigkeit an einem Pegel-Netzwerk auf acht Gletschern haben für 2024 eine Verlangsamung der Eisbewegung um 41% gegenüber dem Mittel von 2010-2020 ergeben. Dies ist auf die anhaltend negative Massenbilanz der letzten Jahrzehnte und die damit verbundene Abnahme der Eisdicke zurückzuführen. Vorläufige Aktualisierungen des Schweizer Gletscherinventars basierend auf Luftbildern des Bundesamtes für Landestopografie swisstopo aus den Jahren 2021 bis 2023 zeigen einen starken Verlust an Gletscherfläche. Die Raten der Flächenänderung variieren je nach Region zwischen –1,5 und –2,4% a^{-1}. Zwischen 2016 und 2022 sind in der Schweiz mindestens 105 Gletscher endgültig verschwunden. Der Vergleich digitaler Höhenmodelle, die für alle Schweizer Gletscher in Zeiträumen von 1 bis 6 Jahren verfügbar sind, ermöglicht die Bestimmung der Eisvolumenänderung über mehrjährige Perioden. Für den Zeitraum 2015–2023 liegen die so bestimmten geodätischen Bilanzen zwischen –1,2 m w.eq a^{-1} und –1,7 m w.eq a^{-1}, was auf eine bemerkenswerte räumliche Variabilität hinweist.

Am Colle Gnifetti gemessene Eistemperaturen deuten auf eine starke Erwärmung hin. Diese ist auf eine erhebliche Schmelze auf fast 4500 m ü. M. zurückzuführen, die in den letzten drei Jahrzehnten zu einer Erwärmung von 1,5 °C in 20 Meter Tiefe führte. Für das Jahr 2024 wurden 11 besondere Ereignisse im Zusammenhang mit Gletschern (Eislawinen/Gletscherseeausbrüche) inventarisiert. Ein Todesfall ereignete sich, und zwei weitere Ereignisse verursachten geringfügige Schäden an der Infrastruktur. Die glaziale/periglaziale Massenbewegung im Zusammenhang mit dem Abbruch einer grossen Fels-Eis-Masse am Piz Scerscen am 14. April 2024 verursachte jedoch keine Schäden.

Der Gletscherrückgang in der Schweiz, wie er durch die im Rahmen von GLAMOS erfassten Daten dokumentiert wurde, setzte sich im Berichtszeitraum 2024 hinsichtlich aller überwachten Variablen unvermindert fort. Aufgrund der hohen Schneemengen im Winter war der daraus resultierende Verlust an Gletschereis jedoch weniger dramatisch als in den beiden Vorjahren 2022 und 2023.

Contents

1 Introduction

The programme Glacier Monitoring in Switzerland (GLAMOS, www.glamos.ch) documents the current state and the changes of Swiss glaciers in space and time. Systematic and long-term records of glaciological variables in the Swiss Alps started almost 150 years ago. Data on glacier changes are necessary for investigating the glacier-climate interaction, a better process-understanding related to natural hazards in high-alpine regions, and for the assessment and projection of present and future water resources and global sea-level rise. Finally, the broad public – nationally and internationally – manifests an increasing interest in glacier retreat as an element of the alpine environment excellently illustrating climate change.

The GLAMOS programme has been adopted by the Swiss Commission for Cryosphere observation (SKK) and receives long-term funding and support by the Federal Office for Environment (BAFU), the Federal Office of Meteorology and Climatology (MeteoSwiss) in the framework of GCOS Switzerland, the Swiss Academy of Sciences (SCNAT) and the Federal Office of Topography (swisstopo) since 1 January 2016. Operations are carried out by the three GLAMOS institutions, the Swiss Federal Institute of Technology (ETH Zürich), the University of Fribourg and University of Zürich, as well as external partners.

Results of Swiss glacier monitoring activities have been published in the Glaciological Reports since 1881 (GLAMOS, 1881-2024). While the next published volume of the Glaciological Report with detailed data on all observed variables will cover the four annual periods 2024-2027, the digital Swiss Glacier Bulletin provides an annual fast-track summary of the most important results of the monitoring programme. The present report focuses on the hydrological year 2024, i.e. the period from 1 October 2023 to 30 September 2024, and also provides results compiled throughout 2024 referring to periodical data acquisitions covering the years 2021-2023 (e.g. for the variables length change, inventory, volume change).

The focus of GLAMOS is to collect glaciological data following international standards according to the Essential Climate Variables (ECVs) as defined by the Global Climate Observing System (GCOS) of the World Meteorological Organization (WMO, 2022). Internationally, glacier monitoring is coordinated in the framework of the Global Terrestrial Network for Glaciers (GTN-G) and by the World Glacier Monitoring Service (WGMS). GLAMOS data are also reported to the international data centres (WGMS, GLIMS).

Wastage of the summit ice cap of Vadret dal Corvatsch, Eastern Switzerland, between 1969 and 2024. Glacier melting also substantially affected the topmost elevations of the Alps, as seen in the example of Piz Murtèl (3433 m a.s.l.). Photos: K. Morgenthaler / M. Huss.

Within GLAMOS, the following variables are regularly monitored both using *in situ* and remote-sensing data sets and corresponding results are reported in the present Swiss Glacier Bulletin:

- Mass balance (*seasonal to annual*),
- Length change (*annual*),
- Ice-surface flow speed (*annual*),
- Glacier area / inventory (*3-6 yearly*),
- Geodetic ice volume change (*1-6 yearly*),
- Englacial temperature (*annual*), and
- Documentation of special events related to glaciers (*annual*).

Figure 1.1 shows the spatial distribution of observation sites for the respective variables monitored in the current reporting period. Many measurement sites refer to long-term series, partly initiated over a century ago, related to scientific research questions relevant at that time (e.g. high-mountain water resources for hydropower production). Many of those glaciers have been continuously monitored until today. Sites that were more recently set up target an optimal spatial coverage across all climatological sub-regions of Switzerland, different glacier sizes and characteristics, as well as a focus on large glaciers that exhibit a higher resilience to climate change (GLAMOS, 2019). Data at high temporal resolution (sub-seasonal to annual) is acquired based on *in situ* observations on a representative set of glaciers, whereas data on multi-annual changes in glacier area and volume refer to all individual ca. 1400 Swiss glaciers and are based on the operational products of swisstopo.

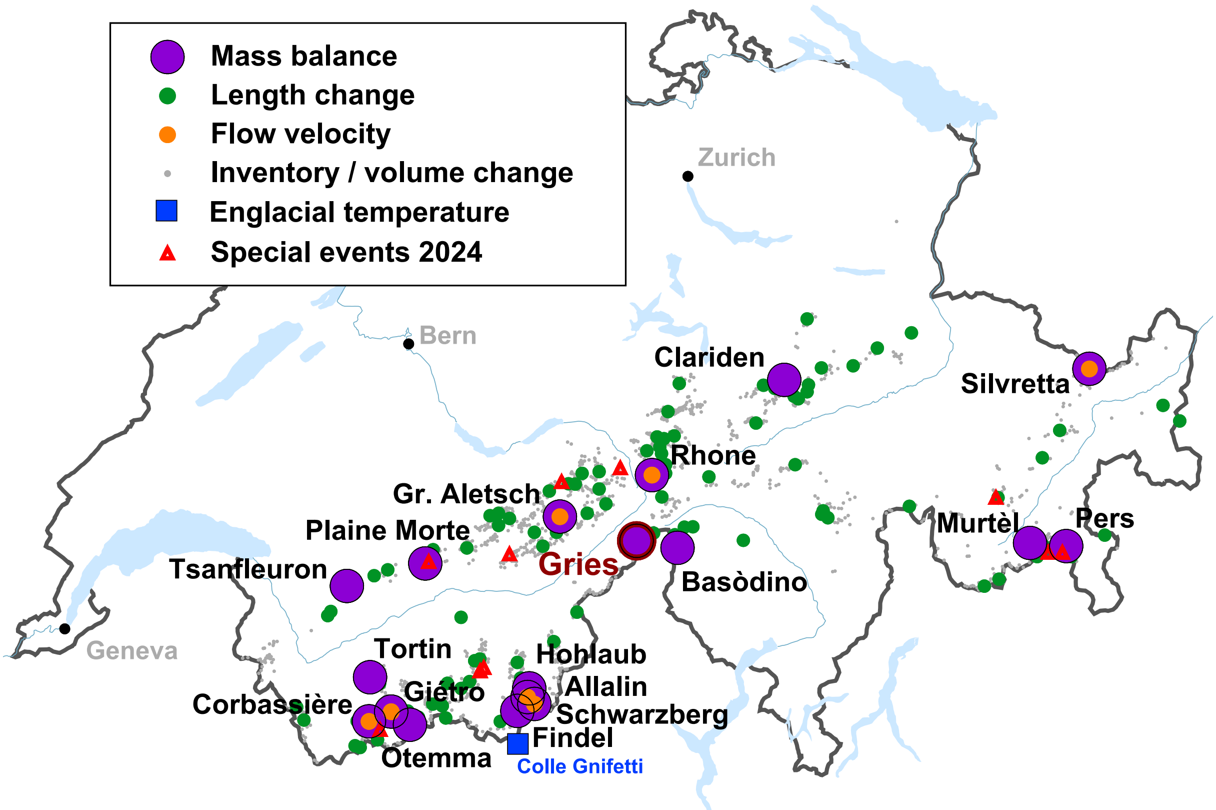

Figure 1.1. *Overview of GLAMOS field sites. Glaciers with in-situ observations of mass balance (see Chapter 3) and ice-flow velocity (see Chapter 5) are shown with purple/orange dots. This year's spotlight glacier (Griesgletscher) is highlighted in dark red. Sites with long-term glacier length change observations are in green (see Chapter 4). Remaining glaciers, covered by repeated inventories and geodetic ice volume change observations are indicated with small grey dots (see Chapters 6 and 7). The locations of englacial temperature measurements (blue square, see Chapter 8), and special events related to glaciers recorded in 2024 are marked (red triangles, see Chapter 9).*

2 Weather conditions in the hydrological year 2024

The meteorological forcing determines glacier mass loss or gain, where air temperatures and precipitation are key factors. The forcing results in the exchange of energy between the atmosphere and the glacier surface. Air temperature is influenced by two key components of the surface energy balance: incoming longwave radiation and turbulent sensible heat flux. Other elements of the surface energy balance, such as solar radiation, turbulent latent heat flux, and surface-specific characteristics like albedo, roughness, and emissivity, also play a role and therefore determine glacier melt (Vincent et al., 2004; Thibert et al., 2013). While the presently accelerated retreat of Alpine glaciers can mainly be attributed to increasing summer air temperatures, large year-to-year variations in snow precipitation without recognizable long-term trends may lead to reduced or enhanced glacier mass loss in individual years (Huss et al., 2021). Furthermore, interactions between temperature and precipitation are important: For example, high temperatures in May or June can reduce the winter snowpack rapidly and expose the darker ice surface early in the melting season when solar radiation receipts are maximal. In contrast, summer snowfall down to the glacier termini leads to an increase in surface albedo and reduces the melting intermittently. In the following, we summarize the meteorological conditions during the hydrological year 2024 based on long-term, homogenized weather station data from MeteoSwiss (Begert and Frei, 2018) and the Klimabulletin (MeteoSwiss, 2024, 2025).

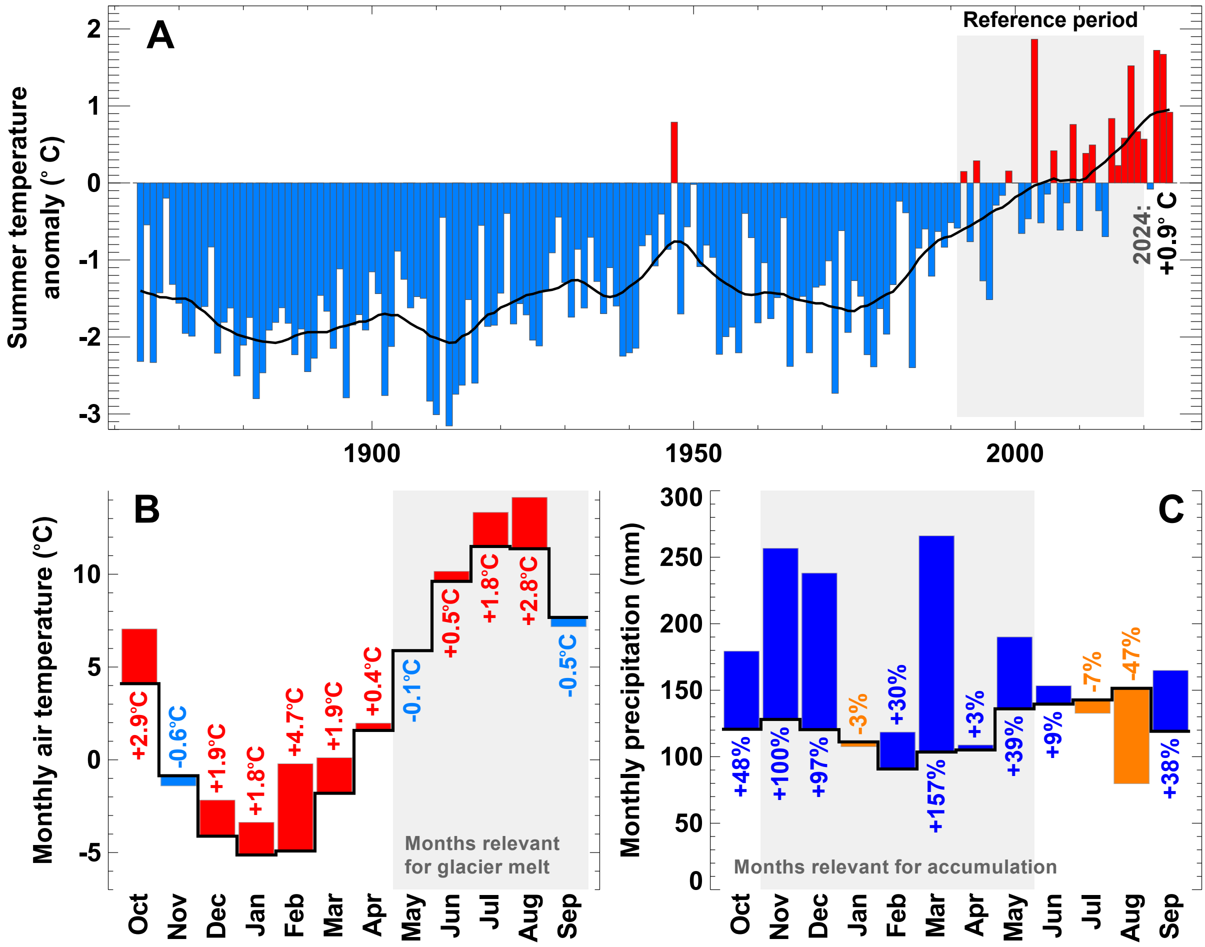

Figure 2.1. Weather conditions in the hydrological year 2024 with respect to the period 1991-2020. Data is based on the 13 homogenized MeteoSwiss stations (Begert and Frei, 2018) in the Alpine region (>1000 m a.s.l.). (A) Long-term evolution of summer air temperature (May to September). (B) Monthly anomaly of air temperature in the hydrological year 2024. (C) Monthly anomaly of precipitation in the hydrological year 2024. In panels (B) and (C), months relevant for glacier melt and snow accumulation, respectively, are underlain in grey. The colour of the bars indicates above- or below-average conditions with respect to the 1991-2020 baseline.

At a global scale, the year 2024 was the warmest ever recorded (Copernicus, 2025). In Switzerland, air temperatures in 2024 were very high as well, only slightly below the warmest years observed so far. At some high-elevation stations, new annual records were even reached in 2024 (MeteoSwiss, 2025). In contrast to 2022 and 2023, the winter period was characterised by abundant precipitation at high elevation. For 13 long-term meteorological stations in the Alpine regions (>1000 m a.s.l.) a surplus of summer air temperatures (May to September) of +0.9°C with respect to the 1991-2020 average is indicated (Fig. 2.1). This value ranks 5th since the beginning of the observations in 1865 after 2003, 2022, 2023 and 2018. Throughout the year, all months except for November, May and September were above the 1991-2020 reference, partly substantially. This was especially pronounced in August and at alpine stations. For precipitation, however, especially the winter months were strongly above the average, most importantly November, December and March. Winter precipitation (November to April) was the maximum ever recorded at the 13 alpine stations since the onset of the records with a surplus of 66%. Clearly below-average precipitation was measured in August (Fig. 2.1).

The hydrological year started with strongly above-average temperatures and dry conditions in the first half of October 2023. This resulted in significant additional melting of the glaciers that were almost snow-free at that time. The winter was characterized by a stark contrast between mountain and valley on both sides of the Alps: At low elevations, snow depths were very low while they were significantly higher than normal above ca. 2000 m a.s.l.. This was due to the combination of large precipitation amounts but continuously high temperatures that resulted in rain at lower elevation. At snow monitoring stations, the average snow depths between November and May are among the highest since measurements began (Zweifel et al., 2024). However, these large winter snow masses disappeared surprisingly quickly with high temperatures in July and August. On Jungfraujoch, for example, August 2024 was warmer than in the extreme summer seasons of 2003 and 2022. The deposition of Saharan dust during repeated periods with southerly winds during late winter and spring 2024 was partly to blame for the intensive snowmelt. This meant that more solar energy was absorbed by the snow (e.g. Gabbi et al., 2015). In addition, even at 3000 m a.s.l. no significant snowfall was recorded between mid-June and mid-September. This is unusual but has been the case more and more frequently in recent years. Cooler conditions and, in some regions, relevant snowfalls brought the melting season 2024 to an early end even though mild weather in October and November 2024 resulted in continued ice ablation on glacier tongues.

In summary, the weather conditions in 2024 were again unfavourable to Swiss glaciers. Even though above-average winter snow intermittently indicated a better situation than in recent years, the substantially too warm and dry summer months July and August annihilated this benefit.

(Left) *Surface of Griesgletscher in August 2024. The accumulation of Saharan dust deposited on the snow surface during several events in late winter and spring resulted in a drastic albedo decrease and, thus, enhanced melting.* ***(Right)*** *Snowfall down to the elevation of the glacier termini in September locally put an early end to the melting season as observed during the late-summer measurements on Findelgletscher. Photos: M. Huss.*

3 Glacier mass balance

The seasonal to annual mass balance reflects the immediate glacier response to meteorological conditions. The monitoring of both winter snow accumulation and summer melting resolves the components of glacier mass change and thus allows investigating the drivers of mass gain or loss. Glacier mass change over annual periods is also directly linked to downstream impacts, such as contribution to the hydrological cycle and global sea level (Huss et al., 2025). Furthermore, the monitoring of glacier mass balance allows a near-time reporting, thus satisfying public requirements for insights into the current state of glaciers. Mass balance is therefore the most important GLAMOS variable and is presented in more detail in the Swiss Glacier Bulletin in comparison to other measurements that sometimes show a time lag in data availability or reveal a delayed climate change signal, such as length, surface elevation or glacier area change.

The method to determine *in situ* mass balance using the direct glaciological method has remained very similar since the first measurements at accumulation and ablation stakes initiated over 100 years ago (Firnberichte, 1914-1978; Müller and Kappenberger, 1992; WMO, 2023). A high temporal consistency for the reanalysis of long-term mass balance time series is thus reached (e.g. Zemp et al., 2013; Huss et al., 2015). The backbone of the direct observation of mass balance is the monitoring of point sites (Geibel et al., 2022). The method is based on stakes drilled into ice (ablation area) or snow pits/snow cores down to a marked horizon (accumulation area). During the winter surveys conducted in April or May, snow soundings to the last summer surface layer are used, complemented with density measurements (GLAMOS, 2021). Within GLAMOS, extrapolation from individual measurement points to the entire glacier surface is performed by relying on a distributed mass balance model tightly constrained with all observations acquired throughout the respective year. The model includes the most important processes governing spatial mass balance distribution (Huss et al., 2021). This approach is regarded as an advanced extrapolation tool to infer glacier-wide quantities from point measurements rather than a mass balance model in the conventional sense: the signal of seasonal and annual mass balance variability is purely given by the field measurements. The utilized approach allows extrapolation of mass balance into unmeasured regions based on a physical representation of the spatial variability, as well as the calculation of mass balance over arbitrary time periods, such as the hydrological year. The latter is relevant for the comparability of time series acquired on different glaciers.

Griesgletscher – chosen as a Spotlight glacier in this report – on 7 August 2024. Photo: M. Huss.

In the reporting period, field measurements documenting annual mass balance were collected on 21 individual glaciers throughout Switzerland (Fig. 1.1). The observations at a network of between 4 to 18 point sites per glacier permitted inferring glacier-wide quantities and the corresponding elevation distribution. A late-winter survey with 30 to 250 manual snow depth soundings per glacier and snow density surveys at 1 to 5 sites per glacier was conducted on 14 glaciers. For many glaciers, intermediate surveys of a part or the entire stake network during the summer season provided valuable insights into sub-seasonal dynamics of the mass loss. In addition, real-time observations of mass balance on seven glaciers were acquired using a webcam-based system (Landmann et al., 2021) providing daily accumulation and ablation at 1-2 selected sites per glacier. This data is used for weekly updates of the present state of Swiss glaciers.

3.1 Spotlight: Griesgletscher

In this Swiss Glacier Bulletin, we put a spotlight on Griesgletscher (Fig. 3.1) and provide more detailed insights into the monitoring programme, as well as some specific results for the reporting period. Griesgletscher is a global reference glacier of the WGMS and features detailed annual measurements based on a dense stake network since 1961 (GLAMOS, 1881-2024). With a coverage of 63 years, it is one of the longest continuous mass balance time series in the Alps. Winter balance observations are available since 1994. Over the last six decades, Griesgletscher has seen a dramatic retreat with a loss of 45% of its surface area and 65% of its ice volume. The decay of the glacier became particularly prominent since about 2012 (Fig. 3.1). In comparison to other Swiss glaciers with long-term data series, it exhibits the most negative cumulative mass balance (Huss et al., 2010). This is explained by a high sensitivity to climate change related to its particular surface geometry with a gently-sloping tongue and no high-elevation accumulation area.

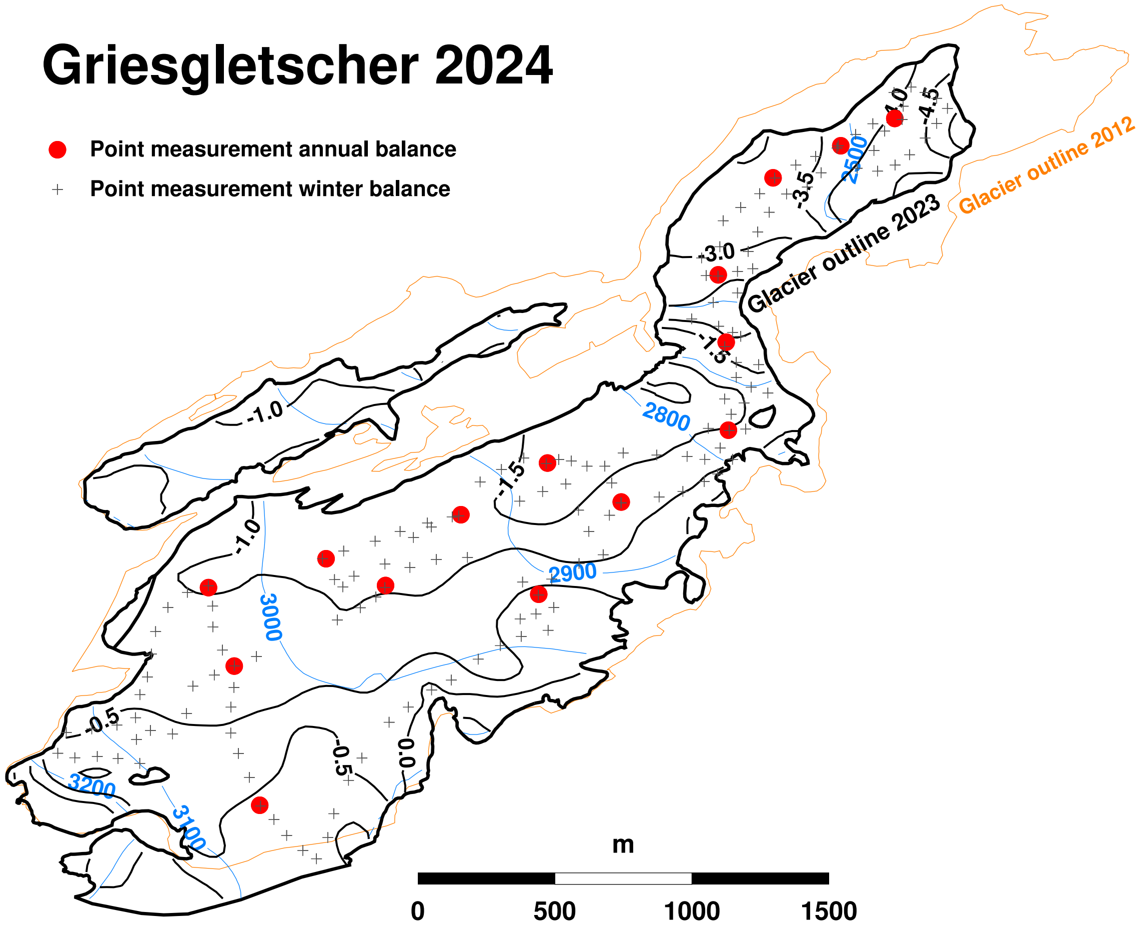

Figure 3.1. Overview map of Griesgletscher indicating the local measurements of winter snow accumulation (crosses) and annual mass balance (red dots) acquired in 2024. Glacier extent and surface contours are shown for the year 2023. The glacier outline in 2012 is depicted for comparison. Black contours show interpolated surface mass balance in the hydrological year 2024.

On Griesgletscher, a winter survey was carried out on 25 April 2024. In total 160 snow depth soundings and density measurements at four sites consisting of 2-4 snow cores each were acquired. Snow depth reached 5-6 metres over most of the glacier area which is exceptional in comparison to previous years. On 11 September 2024 the late-summer survey was conducted and the entire network of 16 stakes was visited and redrilled (Fig. 3.1). As in almost all years of the last two decades, the Griesgletscher's surface was completely snow-free except for a few firn patches in the most protected corners of the accumulation area. Despite the strongly above-average winter balance (+32% relative to 2010-2020, GLAMOS, 2024a), the annual balance was very negative with –1.32 m w.e., thus ranking in the lower third of values acquired since the beginning of the measurements. However, the value pales against the extreme losses of 2022 and 2023 (Fig. 3.2). The most positive mass balance was recorded in 1977 (+1.38 m w.e.). Since 1984, not a single year has experienced mass gain. The comparably limited loss of Griesgletscher despite one of the warmest summer seasons ever can be attributed to the effect of the extraordinary winter snow amount (GLAMOS, 2024b).

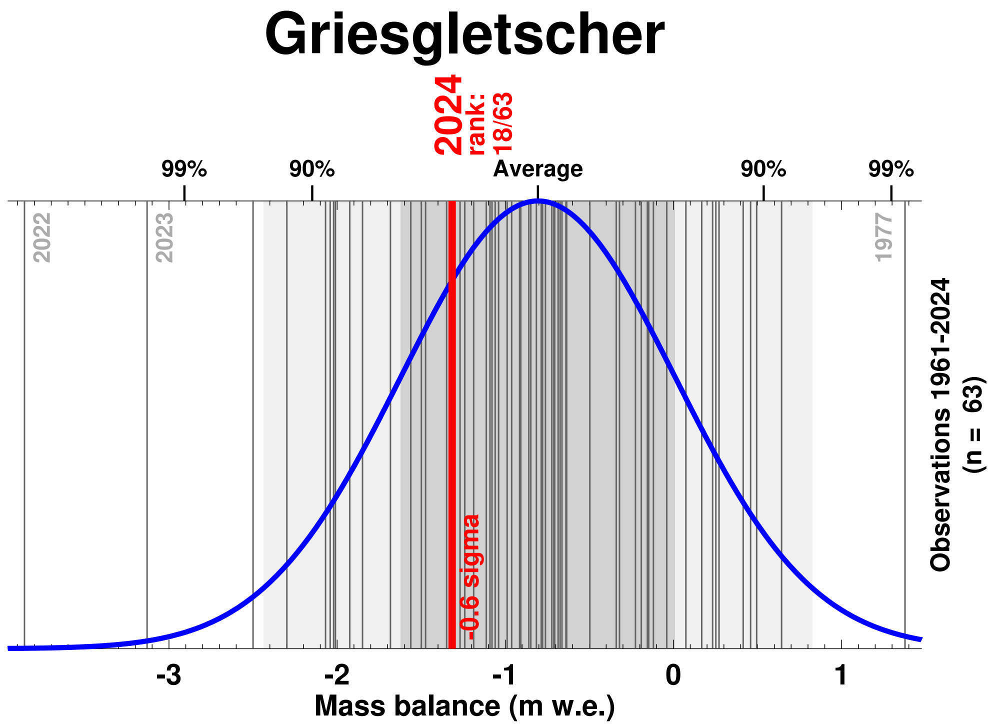

Figure 3.2. *Statistical distribution of glacier-wide mass balance of Griesgletscher since the beginning of the measurements (every year homogenized to 1 Oct to 30 Sep). The value and the rank of the current year is highlighted (red), and previous exceptional years (grey labels) are indicated. The blue line corresponds to a normal distribution fitted to all observations.*

3.2 Mass balance observations throughout Switzerland

Point observations of annual mass balance at measurement sites throughout Switzerland were less negative than in the two previous years almost everywhere. The maximum of local ice loss observed in September 2024 reached around 7 metres for the annual period on glacier tongues extending to low elevation (e.g. Findel, Rhone) and even 11 metres 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 (Grosser Aletsch, Findel, Rhone) experienced accumulation rates of 2-3 metres of snow. These 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 and even the topmost measurement points at elevations of between 2700 and 3300 m a.s.l. experienced ice melt rates of 1 meter or more (e.g. Gries, Giétro, Otemma, Plaine Morte, Silvretta).

Seasonal mass balance monitoring throughout all climatological regions of Switzerland indicated a similar pattern during the hydrological year 2024. Above-average winter snow depth partly mitigated the substantial melting in the summer season, still resulting in a strongly negative annual mass balance (Fig. 3.3).

Nevertheless, some regional differences emerge: Winter snow accumulation was most anomalous in the northern and eastern Swiss Alps with a surplus of 20-60% relative to the 2010-2020 average. For example, a snow depth of 6.2 m was measured in mid-May 2024 at 2880 m a.s.l. on Claridenfirn, which represents the highest snow water equivalent ever recorded at this site since the onset of measurements in 1914. Winter mass balance was only ca. 10% above the average in the Southern Valais though (Fig. 3.4).

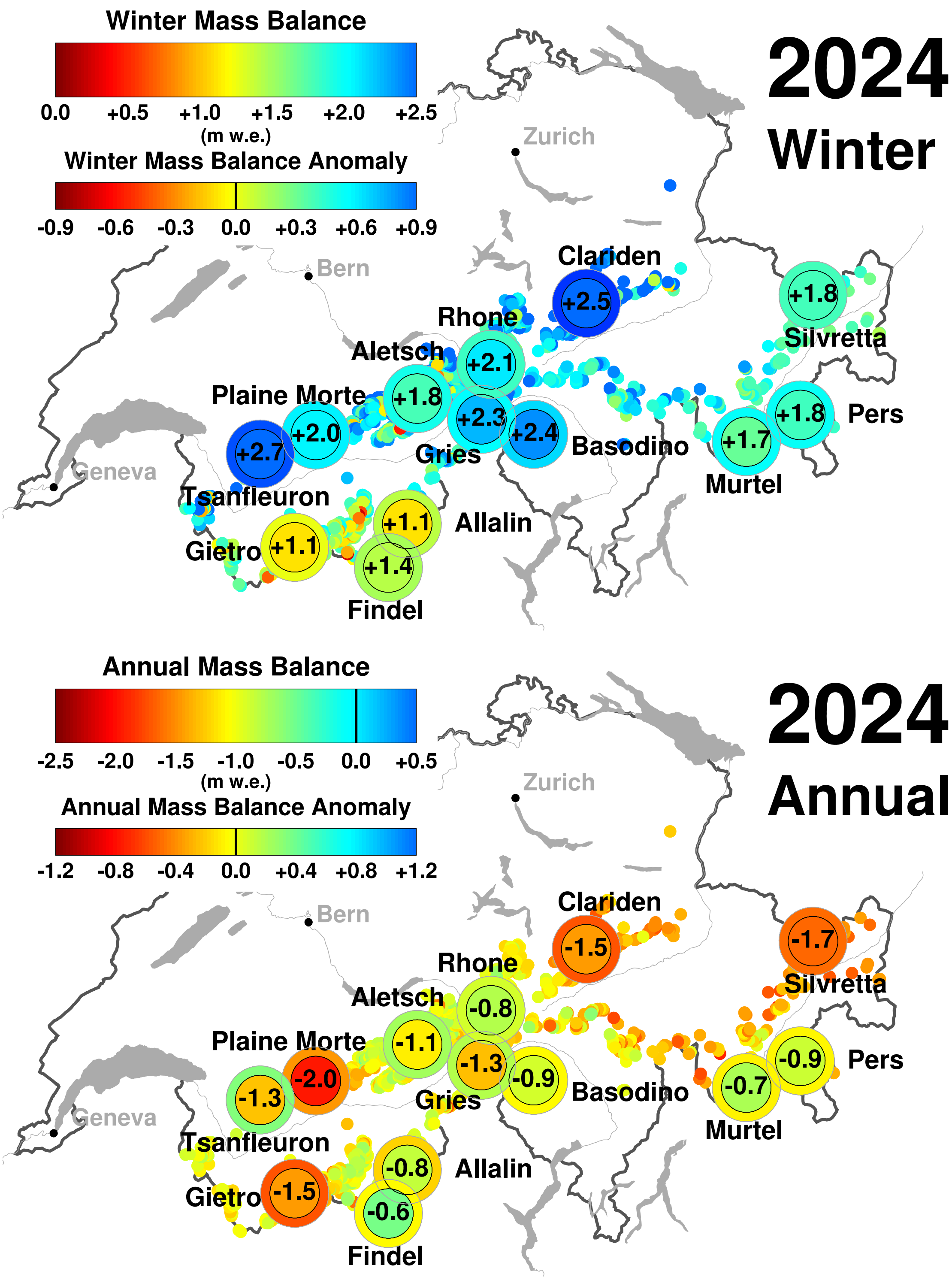

*Figure 3.3 Observed winter **(top)** and annual **(bottom)** glacier mass balance for the most important surveyed sites (large dots) in metres water equivalent (homogenized to 30 April 2024, and 30 Sep 2024, respectively). The colour of the outer circle indicates the anomaly with respect to 2010-2020 average mass balance of the respective glacier. For visualization, mass balance estimated by extrapolation is shown with small dots for the remaining glaciers.*

Values of between –2.0 to –0.6 m w.e. were measured for annual mass balance. No clear spatial pattern throughout Switzerland can be detected (Fig. 3.3). The annual loss corresponds to the average mass balance during the 2010-2020 period for most glaciers. Four glaciers (Clariden, Plaine Morte, Silvretta, Giétro) with anomalously negative mass balance are distributed throughout Switzerland. Their high losses for 2024 are likely explained by their limited altitudinal range with most of the glacier surface located below 3000 m a.s.l. presumably making them more vulnerable to summer heat waves. Correspondingly, the entire surface of these glaciers was snow-free by the end of August 2024.

Three factors were responsible for the substantial glacier mass loss in 2024 despite abundant winter snow:

1. Air temperatures in July and August were very high.
2. Throughout the summer season, fair weather with high solar irradiance prevailed, and no fresh snow at the elevation of the glaciers was registered until mid-September.
3. Saharan dust deposited in spring 2024 accumulated on the snow surface during the melting season, resulting in a substantial albedo reduction (a process described in e.g. Réveillet et al., 2022). This accelerated the rate of snow depletion.

The evolution of glacier mass balance throughout the hydrological year 2024 started with an exceptional melt event lasting until mid-October 2023 linked to high air temperature and widely snow-free conditions (Fig. 3.4). This was followed by a more rapid growth of the snowpack than usual from late October until December, and even more importantly between March and May. On average for 13 glaciers with detailed data, peak snow accumulation was reached on 3 June. Until the second week of September melt rates were very high without any interruption. This contrasts with previous summer seasons when 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 since all snow mass added during winter is depleted, happened on 11 August, four days later than in the 2010-2020 average here considered as the reference. On 15 August 2024, mass balance became more negative than the reference and remained below that level until the end of the year (Fig. 3.4). The melting season ended early and abruptly in mid-September. Cooler weather and repeated snowfall events inhibited further losses until the end of the hydrological year.

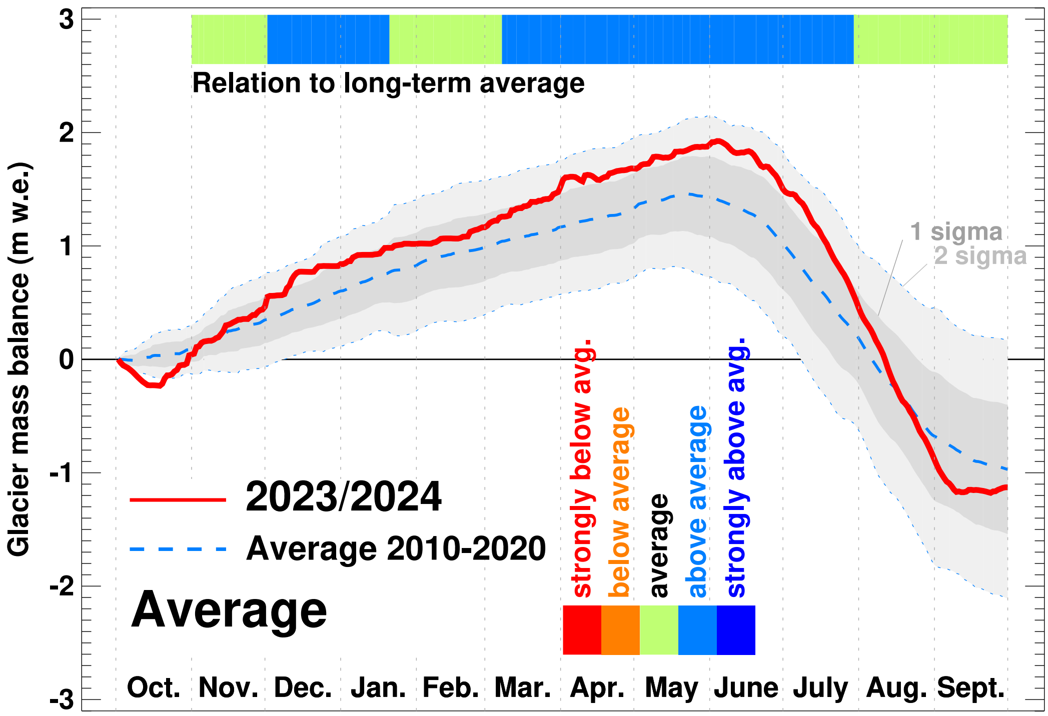

Figure 3.4 Cumulative daily mass balance in the hydrological year 2024 (red) in comparison to the daily average and the standard deviation of the years 2010-2020. The top bar indicates periods with average (green, +/–0.75 standard deviations σ), (strongly) below-average (orange/red, –0.75 / –1.5 σ) or (strongly) above-average (light/dark blue, +0.75 / +1.5 σ) mass balance. The graph shows the arithmetic average of the 13 main surveyed glaciers (see Fig. 3.3).

3.3 Swiss-wide glacier mass change

For regionalizing the findings on glacier mass balance measured at the 21 glacier throughout the Swiss Alps, annual mass balance anomalies homogenized to the hydrological year (1 Oct - 30 Sep) were extrapolated to all 1'400 glaciers of the Swiss Glacier Inventory SGI2016 (Linsbauer et al., 2021) according to an approach described in van Tiel et al. (2025) or 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 1980-2010 geodetic mass balance (Fischer et al., 2015). The area of each glacier is updated to the year 2024 based on a volume-area-scaling approach.

For the hydrological year 2024, an average mass balance of –1.17 m w.e. is found for all Swiss glaciers (Fig. 3.5). During the last decade, annual losses were higher in 2022, 2023, 2017, 2018, 2017 and 2015 (in this order). Nevertheless, the glacier mass change for 2024 is noteworthy considering the massive winter snow amounts: Evaluating summer mass balance anomalies (1 May - 30 Sep) indicates that overall summer melting 2024 was 31% above the 2010-2020 average, despite the moderate air temperatures of June and September (Fig. 2.1). This value ranks fourth after 2022, 2003 and 2023 since the beginning of homogeneous evaluations in the year 1915.

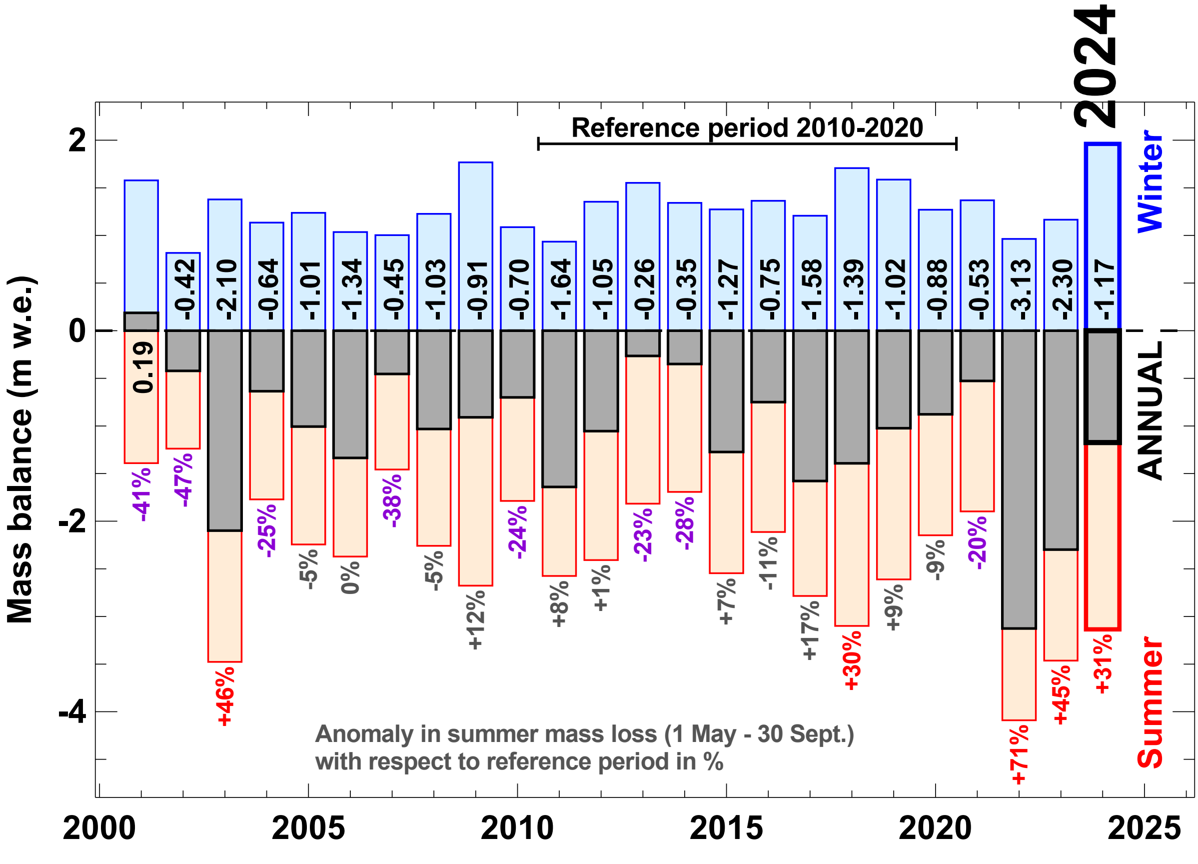

Figure 3.5. Seasonal mass balance extrapolated to all glaciers in Switzerland. Annual mass balance (1 Oct - 30 Sep, dark grey / numbers next to the zero-line), winter mass balance (1 Oct - 30 April, light blue), and summer mass balance (1 May - 30 Sep, orange) is shown. Percentage numbers below the bars indicate the relative anomaly of summer mass balance compared to the period 2010-2020, coded with colours for years with strongly below-average (purple), average melt (grey) and strongly above-average melt (red).

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 hosted ca. 46.5 km³ of glacier ice by the end of 2024 (Fig. 3.6). This is almost 30 km³ less than in 2000. For the end of the year 2024, Swiss glacier area is estimated to be 774 km², corresponding to a decline of 28% relative to 2000. The annual change of glacier volume relative to the remaining volume mostly 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 glacier ice volume reduction by –2.3% (Fig. 3.6), or 1.1 km³.

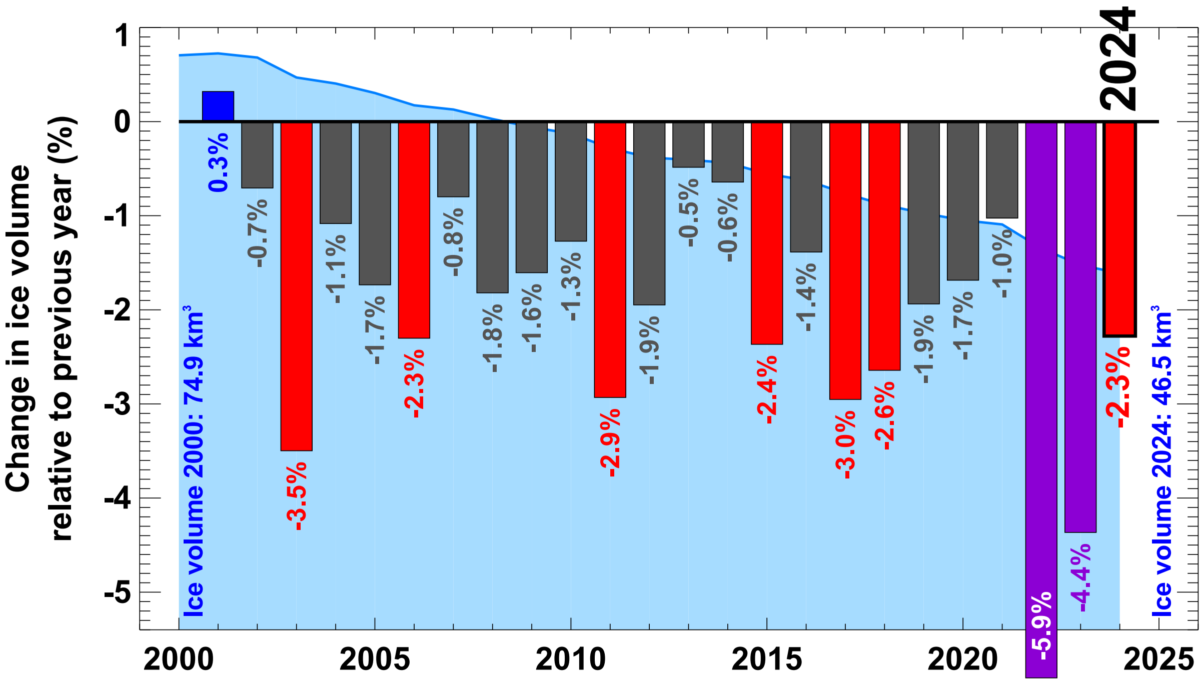

Figure 3.6. *Swiss-wide annual change in glacier volume relative to the remaining ice volume of the previous year. Colours visualize moderate (dark grey), strong (red) and extreme losses (purple). 2024 is highlighted. The blue surface in the background visualizes the temporal evolution of total ice volume.*

Snow depth probings on Grosser Aletschgletscher on 6 June 2024. Photo: A. Linsbauer.

4 Glacier length change

Systematic observations of glacier length change started in 1880, and many series have been continued until today (GLAMOS, 1881-2024). Since the beginning, surveys have been carried out by a collaborative network of contributors, often involving cantonal authorities and observers with local knowledge. The corresponding data are centrally collected and evaluated by GLAMOS. A variety of approaches is used to determine glacier length change, ranging from *in situ* observations using measuring tapes, theodolites or GPS, increasingly shifting to airborne measurements either based on drones or on the operational products of swisstopo (GLAMOS, 2020). However, remotely sensed data typically only become available with a time-lag of several months thus hampering near-time reporting. This is acceptable, as glacier length variations are an indirect response to climate change, determined by the meteorological conditions of the previous years, and strongly affected by the current terrain characteristics at the glacier snout (e.g. steep sections with thin ice or debris coverage). A complete assessment of length change until 2024 is thus not possible in this report as observations are only partly available up to the publication date. We focus instead on long-term variations and the complete data coverage of the previous year (2023).

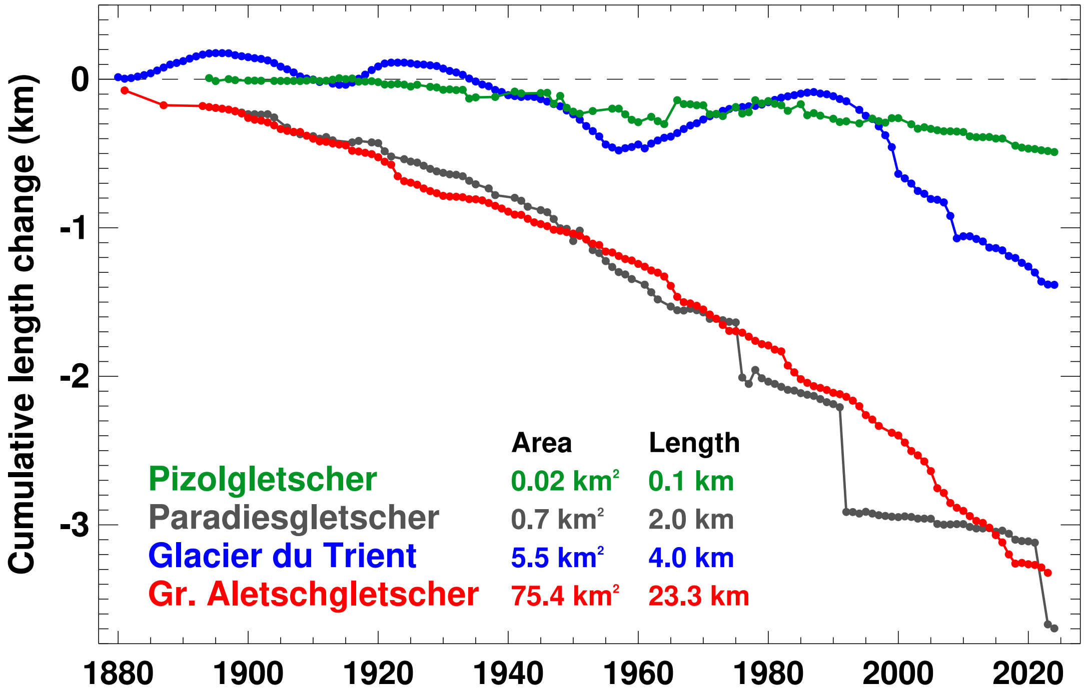

Figure 4.1. *Cumulative length change of four selected glaciers (see Fig. 4.2) with different characteristics or particular behaviour in the reporting period. Current glacier area and length are given in the lower part of the panel.*

In general, glaciers show strongly differing length variations in response to the same change in climate forcing. Large glaciers with a gently sloping tongue (e.g. Grosser Aletsch) exhibit a major and steady retreat, while glaciers with a steep glacier tongue have been able to react with an advance to intermittent short periods of positive mass balance (e.g. Trient in the 1980s, Fig. 4.1). In 2023, length change was measured for 95 glaciers (Fig. 4.2). Of these, 93 retreated. Two glaciers were stationary or slightly advanced which is explained by local conditions at the glacier snout with strong debris coverage, or observation uncertainties. 90% of the annual measurements show a length of between –4 m and –80 m (5% and 95% quantiles). Exceptions with a very large length reduction were observed at Paradiesgletscher and Vadret Calderas. The former retreated by 550 m in 2023 after three decades of limited changes at the snout with a cumulative retreat of just 207 m (Fig. 4.1). This is explained by effects of the glacier's shape and the subglacial terrain in the region of the glacier tongue. Long-term thinning can result in the wastage of the ice and the retreat over a steep rock step within a single year, unrelated to actual climate conditions in the respective year. Compared to the average glacier-specific length change rate between 2010 and 2020, retreat in 2023 was faster by 23% (median value), with 58% of the observed glaciers retreating at a higher rate than during the reference period.

49 glaciers for which observations are already available for late summer 2024 show a further progression of glacier terminus retreat. For example, at Bifertenfirn, a recession of around 1000 m was reported with respect to the year 2022 related to the split up of the glacier tongue in a steep section. For the already surveyed glaciers, 90% of the values lay between –46 m and –2 m.

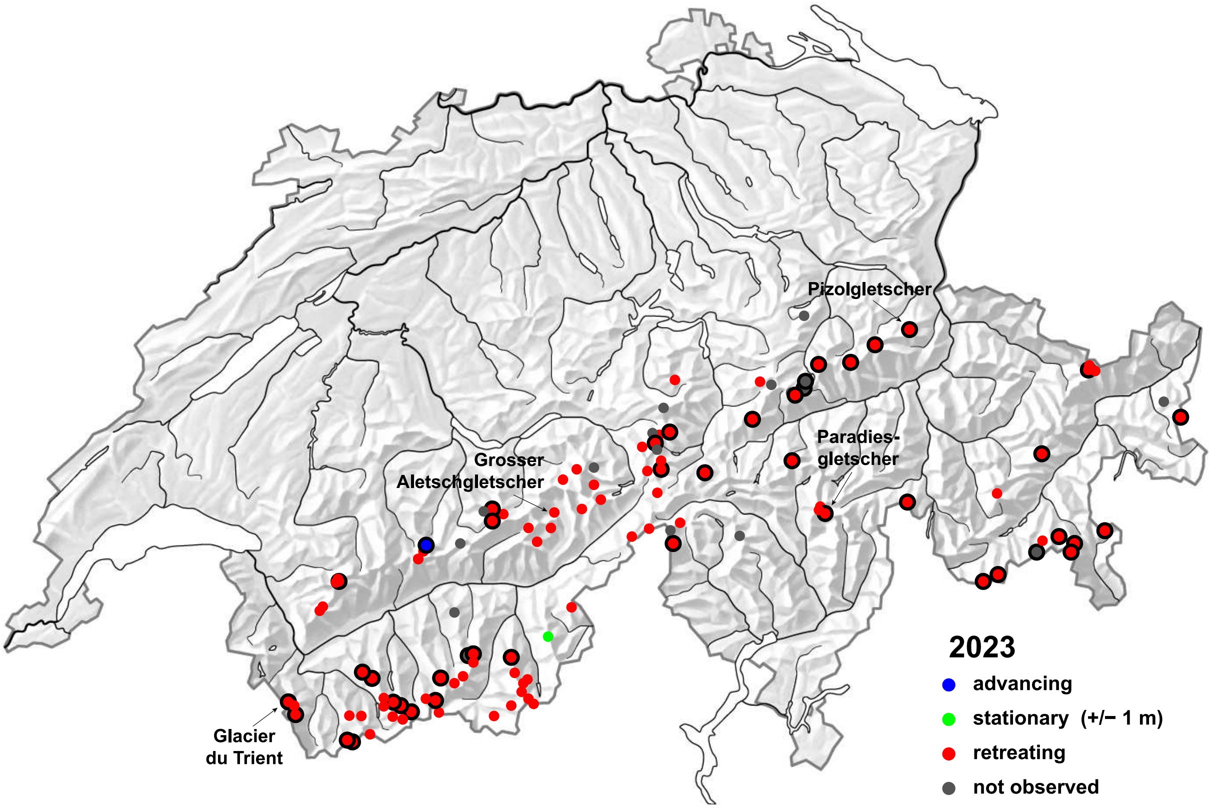

Figure 4.2. Length change measurements in 2023 classified into advancing (blue), stationary (green, +/–1 m) and retreating (red). Long-term series with no measurements in 2023 are grey. Glaciers with data already available for the 2024 reporting period are indicated with a black circle. The locations of glaciers depicted in Figure 4.1 are highlighted.

The terminus of Riedgletscher showing a retreat of 118 m in 2024 relative to 2020. Photo: A. Brigger (DN/VS)

5 Ice flow velocity

Surface ice-flow velocity of mountain glaciers provides insights into mass turn-over and changes in ice dynamics in response to shifts in surface mass balance (e.g. Millan et al., 2022). Long-term investigations of three-dimensional surface displacement are performed on eight Swiss glaciers (see Fig. 1.1) by monitoring the position of stakes using global navigation satellite system (GNSS) technology. The longest continuous series of local flow velocities go back into the 1960s when monitoring was started in relation to potentially hazardous glacier instabilities (Allalin, Giétro). Later, glaciers with long-term mass balance monitoring programmes were added (Grosser Aletsch, Rhone, Silvretta). Observations are acquired at a network of 1 to 16 stakes per glacier. Surface displacement is normalized to an annual period of 365.25 days for comparability.

Across all eight investigated glaciers, measured flow velocity in 2024 was 41% smaller than the respective average during the reference period 2010-2020. A decrease was found for all glaciers (average of all observed stakes) but varied between –16% (Grosser Aletsch) and –59% (Schwarzberg). Average flow velocity at the monitored sites ranged from 1.9 m yr^{-1} (Silvretta) to 31.7 m yr^{-1} (Rhone). Note that these mean flow velocities do not refer to the entire glacier but are determined from the observed points and are therefore influenced by their spatial distribution.

Here, we present the exemplary flow velocity time series for one particular glacier: On Allalingletscher, one measurement point in the accumulation area (3200 m a.s.l.) and one in the ablation area (2800 m a.s.l.) were selected (Fig. 5.1). The data indicates a striking difference between flow velocity in the accumulation and the ablation area. While flow speed significantly increased in the 1970s and 1980s to almost 80 m yr^{-1} in the ablation area due to a period of positive mass balance, the accumulation area was barely affected. In contrast, flow velocity close to the glacier terminus decreased to almost zero in 2024 because of ice thinning and a lack of mass supply from the accumulation area. Whereas flow velocity in the accumulation area only slightly decreased until ca. 2015, an important slow-down of more than 30% is seen over the last decade.

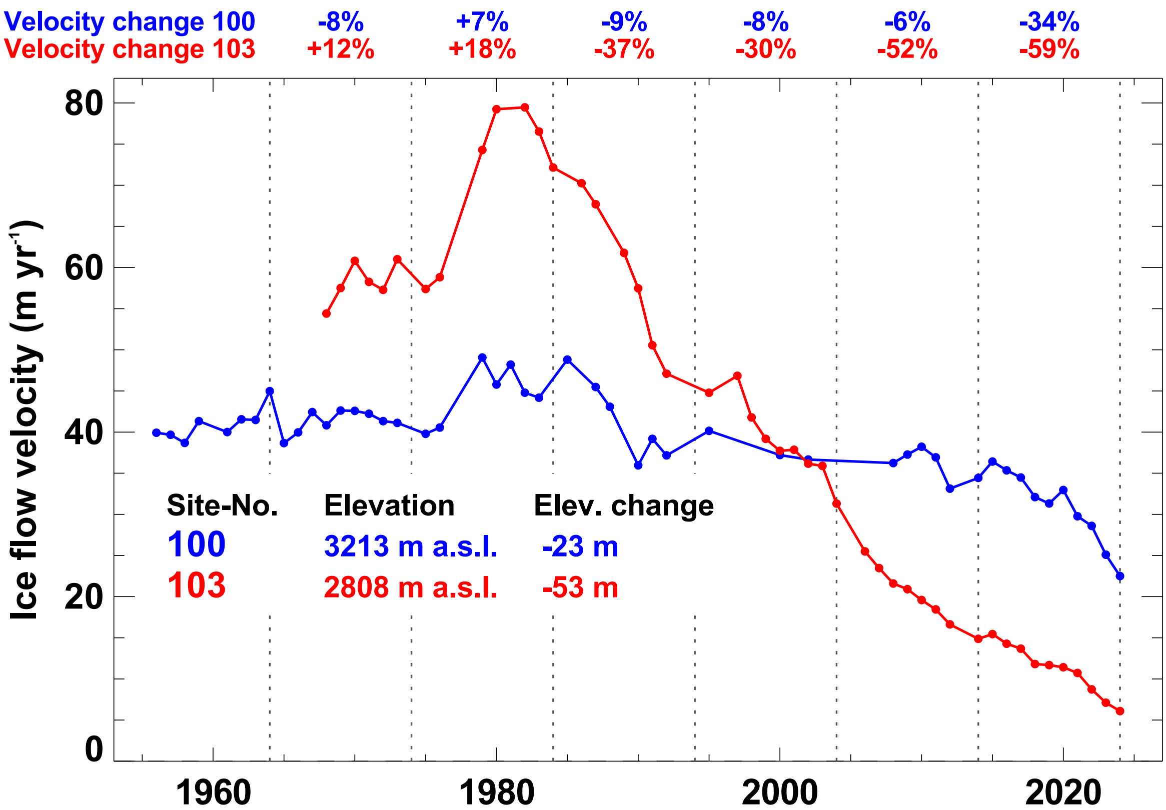

Figure 5.1. Long-term changes in ice flow velocity for two sites on Allalingletscher in the accumulation area (site 100) and close to the glacier snout (site 103). The change in flow velocity relative to the previous decade for each site is given on top. Total surface elevation change for both investigated sites since the onset of the respective series is indicated.

6 Glacier Inventory

Glacier inventories provide the extent of all glaciers in a region for a defined point in time (Paul et al., 2009). Several glacier inventories have been elaborated for Switzerland covering the last 170 years (Fig. 6.1). Since 2020, the Swiss Glacier Inventory (SGI) is being updated in an operational framework in close collaboration with swisstopo (Linsbauer et al., 2021). Within the process of generating the swissTLM^{3D} product (swisstopo, 2025), glacier outlines are manually digitized according to glaciological criteria on aerial orthoimages by swisstopo operators in 3- to 6-year time intervals. The spatial resolution of the imagery (10-20 cm) also allows accurate mapping of debris-covered ice and shadowed regions. Glacier outlines are then checked and potentially adjusted by GLAMOS to establish a glacier inventory including relevant attributes such as area, length, minimum/maximum elevation, and slope. As not all regions of Switzerland are covered by aerial imagery in a single year, completed inventories refer to a time range, with different glaciers being surveyed in different years. Here, we present intermediate results for the upcoming SGI2022 that will be completed in late 2025.

Table 6.1 shows a preliminary overview of glacier area changes between the last inventory (SGI2016) and the most recently mapped glacier extents in specific regions. In the years of 2022 and 2023, optimal mapping conditions and minimal snow coverage were encountered on the glaciers in the Grisons and the Valais. Thus, an update of glacier area has been obtained for 82% of the Swiss glacier area. A strong decrease in glacier area is seen in all regions, despite the short time interval of ca. 6 years considered. Regional area-change rates vary between –1.5 and –2.4 % yr^{-1}. However, we note that these values are difficult to compare as they depend on the average glacier size in the given region. A total glacier area of 873.2 km^2 is found for the center year 2022. As many as 105 glaciers have disappeared between 2016 and 2022, corresponding to 7.5% of the total count (Table 6.1). Glaciers that disappear are very small and are excluded from the inventory as soon as their area drops below the threshold of 0.01 km^2 (Linsbauer et al., 2021). The largest glacier that vanished between 2016 and 2022 (Vadrecc di Casletto, TI) still had an area of 0.11 km^2 in the SGI2016.

Table 6.1. Mapped glacier area according to the last inventory (SGI2016, Linsbauer et al., 2021) and updates in individual regions of Switzerland related to a preliminary version of the SGI2022. The median years of the inventories in the individual regions is given and the annual area change rate is evaluated. The last column refers to the number of individual glaciers that have disappeared since the SGI2016 (i.e. 2013-2018), including their percentage with respect to the total regional number.

Region	Reference years	Area SGI2016 (km^2)	Area SGI2022 (km^2)	Area change rate (% yr^{-1})	Glaciers disappeared
Valais	2017-2023	594.97	540.91	–1.51	63 (–10.6%)
Bernese Alps	2018-2021*	171.35	163.34	–1.56	1 (–0.4%)
Grisons	2016-2022	103.95	89.28	–2.35	24 (–8.0%)
Central Switzerland (UR, OW, SZ)	2015-2021	67.69	59.01	–2.13	10 (–6.1%)
Glarus Alps	2013-2019	15.28	13.70	–1.47	3 (–8.3%)
Ticino	2015-2021	4.56	3.98	–2.11	4 (–13.8%)
Others (AI, SG, VD)	2013/14-2019/20	3.47	3.00	–2.27	0 (0%)
Total	**2013-2018 to 2019-2023**	**961.27**	**873.25**	**–1.58**	**105 (–7.5%)**

* Values will be updated to 2024 by ca. Nov 2025.

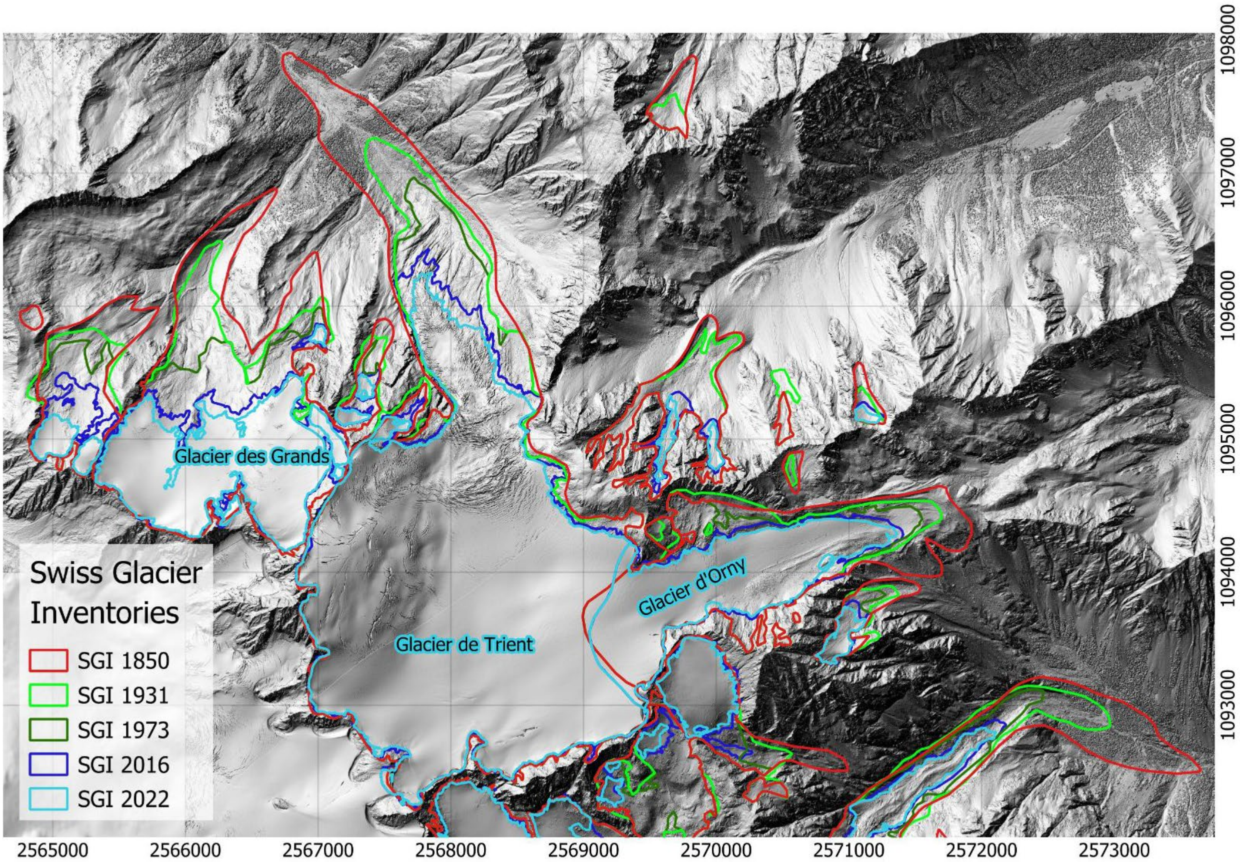

Figure 6.1. Glacier outlines for Glacier de Trient, Glacier d'Orny and Glacier des Grands, selected as an example to visualize past area changes. The Swiss Glacier Inventories of 1850, 1931, 1973, 2016 and 2022 are shown.

In the summer of 2024, the terminus of Grosser Aletschgletscher has shown a major retreat. As a result, a large glacier portal and a proglacial lake have developed. Photo: M. Oettli (Pro Natura Zentrum Aletsch).

7 Ice volume change

Ice volume change and geodetic mass balance can be inferred based on the comparison of repeated digital elevation models (DEMs) covering the entire glacier surface (e.g. Hugonnet et al., 2021, GlaMBIE, 2025). This approach allows obtaining data on multi-annual mass balance for every Swiss glacier (e.g. Fischer et al., 2015). Geodetic mass balance estimates for the Swiss Alps can also be extended to cover the entire last century (Bauder et al., 2007; Mannerfelt et al., 2022). Based on the operational data sets of swisstopo, most importantly the swissALTI^{3D} product (swisstopo, 2023), GLAMOS has access to DEMs acquired at 1- to 6-year intervals for all Swiss glaciers since about 2010. By combining DEMs with the temporally closest glacier outline from the multi-temporal inventories (see Chapter 6), a three-dimensional representation of every glacier through time is obtained. By differencing individual DEMs, surface elevation and volume changes can be computed over arbitrary time periods. Exemplarily, Figure 7.1 shows surface elevation change for Findelgletscher, Southern Valais, over the period 2015-2023. Rapid ice loss with a maximum of almost 80 m near the glacier terminus is visible. Surface lowering also extends to the highest regions of the glacier.

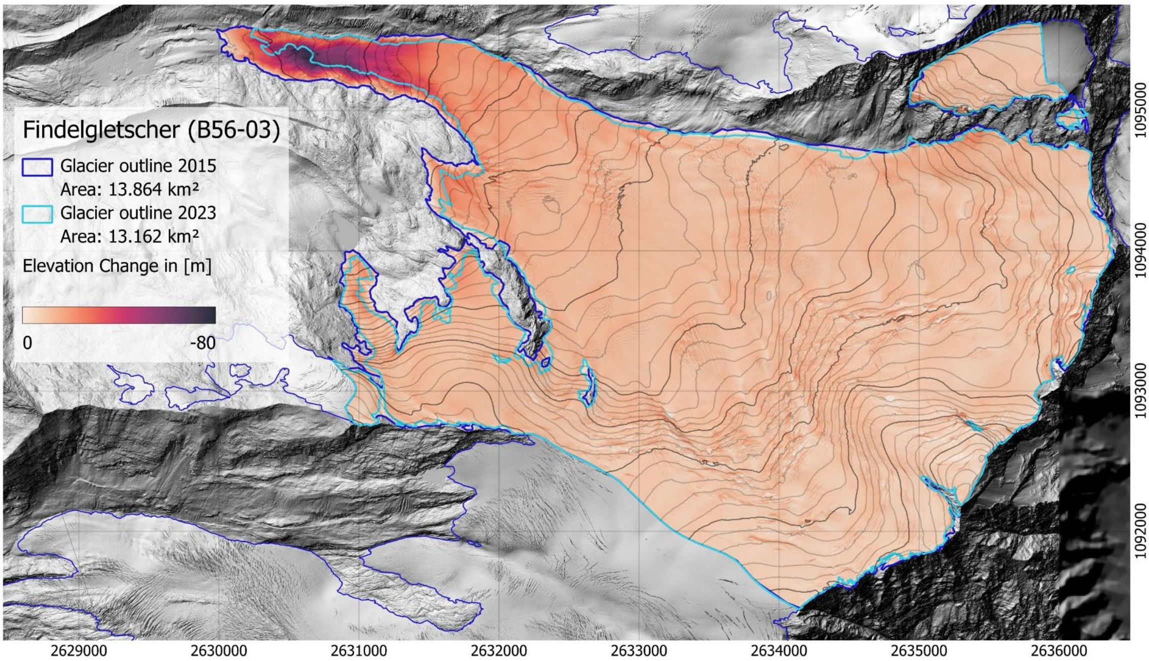

Figure 7.1. *Observed surface elevation change of Findelgletscher between 2015 and 2023. The glacier extent for the two points in time is indicated with the blue lines. The respective glacier area is given in the figure's legend.*

Resulting changes in ice volume are converted to a mass change and an annual geodetic mass balance using a density assumption (Huss, 2013). For regional-scale assessments, data on geodetic mass change need to be homogenized to refer to the same time period, as acquisition dates may vary by several months. This is achieved by relying on daily regional data products (see Chapter 3.3) and allows a Swiss-wide representation over the most recent years over consistent periods. These observations indicate average mass balance aggregated to medium-scale hydrological catchments throughout Switzerland of between –0.6 m w.e. yr^{-1} and –2.2 m w.e. yr^{-1} in the period 1 Oct 2015 to 30 Sep 2023, while most of the catchments exhibit values of between –1.2 m w.e. yr^{-1} and –1.7 m w.e. yr^{-1} (Fig. 7.2). The spatial variability is noteworthy and cannot be resolved with direct mass balance measurements only. The highest rates of mass loss are observed in the Grisons with a maximum for glaciers in the Val Bregaglia. Geodetic mass balance is somewhat less negative for glaciers in the Southern Valais. The most moderate losses occur in regions with relatively small glaciers but high precipitation rates in marginal regions of the Alpine arc. The spatial variations are driven by a combination of various factors, e.g. (1) regional differences weather conditions during the respective years, (2) the local sensitivity of glaciers to current warming trends, often related to overall precipitation amount and thus median glacier elevation, and (3) tendencies of glacier stabilization with major retreat due to increasing debris coverage and the loss of exposed low-lying ice surfaces.

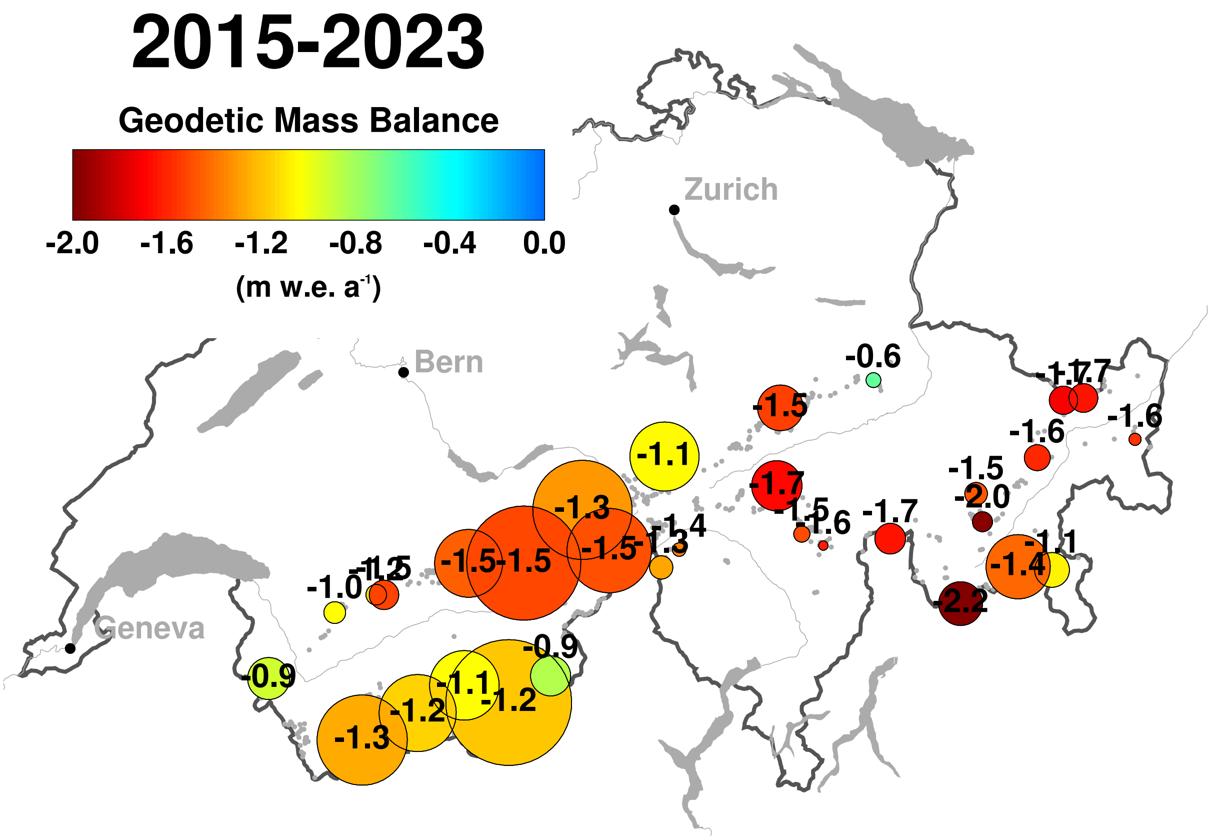

Figure 7.2. *Geodetic mass balance homogenized to the period 2015-2023 and aggregated for all glaciers in medium-scale catchments. Dot sizes scale with total glacier area per catchment. The position of the dots corresponds to the catchment's point of gravity. Values for the period average geodetic mass balance in m w.e.* a^{-1} *are given.*

Tiefengletscher in October 2024. The active glacier terminus retreated over a rock riegel and lost its connection to the underlying dead ice in 2017. Photo: L. Eggimann (AFJ/UR)

8 Englacial temperature

Firn and ice temperatures are a key parameter to detect global warming trends at the highest elevations of the Alps (Mattea et al., 2021). Englacial temperatures that constantly remain below the pressure melting point register short- and mid-term fluctuations of the surface energy balance. Firn temperature measurements on Colle Gnifetti (4450 m a.s.l.), down to a depth of up to 100 m, have been conducted at intervals of a few years since 1982 and annually since 2018, when a thermistor chain was permanently installed in a borehole (Gastaldello et al., 2024).

Differences in surface exposure result in strong firn temperature gradients across the Colle Gnifetti saddle (Mattea et al., 2021). However, several previous measurements are considered to be in sufficient proximity to each other to enable an assessment of englacial warming over the last 40 years. The last englacial temperature observations covered in this report were acquired in December 2023. Since 1991, firn temperatures at 20 m depth, isolated from annual variability, show a sustained warming trend of 0.046°C yr^{-1}, or +1.5°C (Fig, 8.1, Gastaldello et al., 2024). An inversion of the thermal gradient in the uppermost 30 m of the firn layer has become evident during the last decade compared to the profile from 1982 considered as representative of steady-state conditions. Particularly, the measurements acquired in 2023 indicate a strongly negative firn temperature gradient as a result of the influence of atmospheric warming and meltwater production at the surface during the previous summer season.

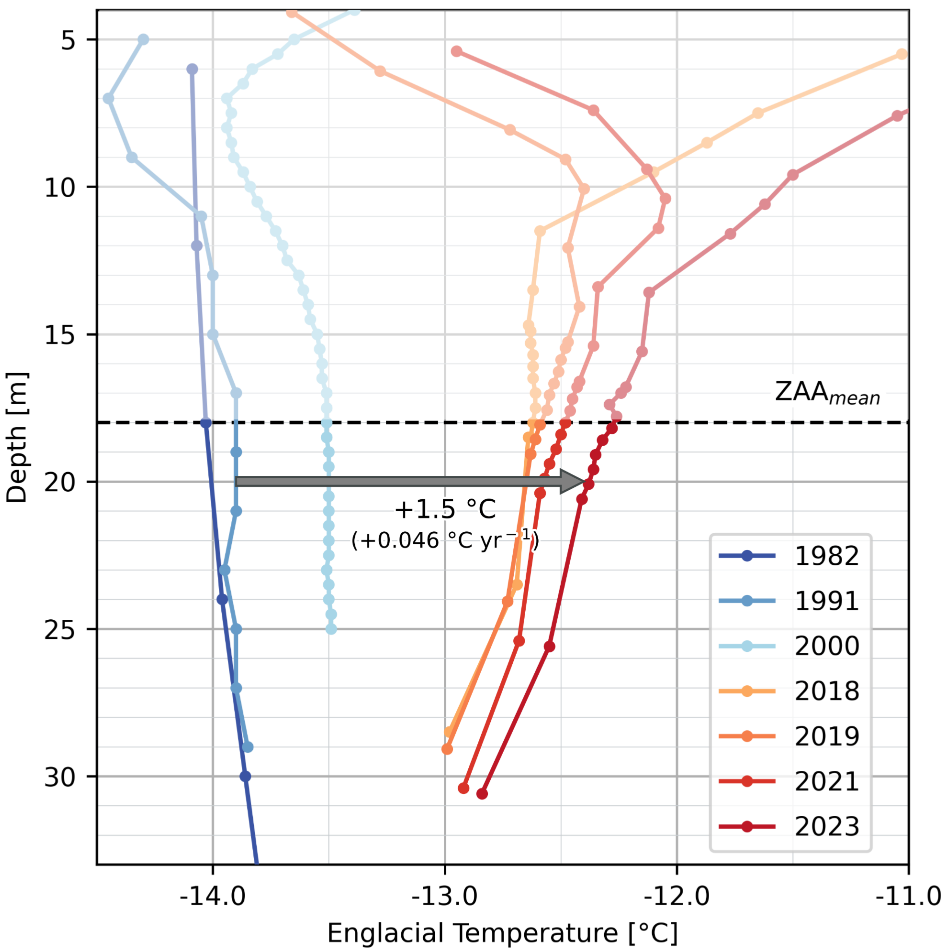

Figure 8.1. Firn temperature profiles at the Colle Gnifetti saddle, measured between 1982 and 2023 (Gastaldello et al., 2024). The firn temperature trend at 20 m depth is indicated. The mean Zero Annual Amplitude (ZAA$_{mean}$) is the depth at which the temperature is not influenced anymore by seasonal variability of air temperature. The temperature change below this depth shows the long-term firn warming trend.

9 Special events

GLAMOS annually documents special events related to glaciers. These events may either be hazardous to infrastructure, settlements, or mountain tourists, or simply represent unusual glacier behaviour worthy of notice even if not causing an immediate threat. Most of the special events are either glacier instabilities leading to ice break-off and subsequent processes such as ice avalanches (Jacquemart et al., 2024), or are linked to the outburst of water volumes stored in front, behind or beneath glacier ice (Zhang et al., 2024).

Table 9.1. Reported special events related to Swiss glaciers in the calendar year 2024. Events are ordered according to the date of occurrence. The respective canton is given. Date and (if known) time of the event are reported (time range in some cases). The estimated volume of a lake outburst event or an avalanche is given if sufficient evidence is available.

Glacier	Event type	Date / time (range)	Volume	Description
Birchgletscher (VS)	Glacier advance	2019-2024	unknown	The glacier tongue has become thicker and advanced since ca. 2019. The bulging of the front is associated with a thinning of the areas behind it, similar to a glacial surge. This change was probably triggered by increased rockfall activity from Kleines Nesthorn over the last two decades leading to the deposition of a 30-50cm thick debris layer on the tongue and thus greatly reduced melt rates.
Vadret da Tschierva / Piz Scerscen (GR)	Combined rock and ice avalanche	14 April 2024, 06:56	ca. 8 million m^3	Major rock and ice break-off at Piz Scerscen (ca. 3700 m a.s.l.). The deposits covered Vadret da Tschierva and the foreland down to the floor of Val Roseg (Pierhöfer et al., 2024). No damage reported.
Challifirn (BE)	Combined ice and snow avalanche	14 April 2024	ca. 100’000 m^3	Large ice and snow avalanche from Challifirn / Schlosslouwina. No damage reported.
Vadret da Morteratsch / Bellavista (GR)	Combined ice and snow avalanche	5 May 2024, 13:00	unknown	An ice break-off below Fuorcla Bellavista (ca. 3500 m a.s.l.) caused an avalanche that carried away a ski tourist, who died in consequence.
Vadret Calderas (GR)	Ice-dammed lake outburst	20 June 2024, 22:00	unknown	An ice-marginal lake on Vadret Calderas filled with snow melt water. The natural outflow towards Alp Flix was covered by snow, creating a dam. After failure, this resulted in an outburst flood that triggered a mudslide. This resulted in flooding on Alp Flix, causing damage to buildings, roads and meadows.
Glacier de la Tsessette (VS)	Moraine-dammed lake outburst	30 June 2024	ca. 8’000 m^3	Outburst of a small proglacial lake with damage to the Mauvoisin-Chanrion road.
Glacier de la Plaine Morte (BE)	Ice-dammed lake outburst	18 July – 24 July 2024	ca. 1.0-1.5 million m^3	Lac des Faverges drained subglacially over a period of 6 days. This annually recurring event is observed since 2011. A glacial moulin probably became active along the artificial drainage channel, which was filled with water before drainage. Discharge at the glacier snout rose continuously until 24 July 2024, 06:00. Hiking trails in the Simmental were closed as a precaution, but no damage was reported.
Bisgletscher / Weisshorn (VS)	Combined ice and snow avalanche	5 Jan - 31 Aug 2024	20'000 - 48'000 m^3	Documentation of 10 individual small ice break-off events from hanging glaciers on the Weisshorn NE-face (4000 m a.s.l.). No damage reported.
Aerlengletscher (BE)	Ice avalanche	Oct 2024	ca. 30’000 m^3	Slip of the glacier tongue on gently-inclined bedrock without damage.
Gorner-gletscher (VS)	Ice-dammed lake outburst	9 Oct - 13 Oct 2024	unknown	Filling and drainage of an ice-marginal lake at Gornergletscher without reported damages.
Bisgletscher (VS)	Ice avalanche	14 Mar - 29 Dec 2024	20'000 - 60'000 m^3	Documentation of 7 individual small ice break-off events from the altitude range around 3500-3600 or 3000-3400 m a.s.l.. No damage reported.

Table 9.1 compiles all events reported during the calendar year 2024 based on various sources, mostly cantonal authorities or entities involved in early warning (e.g. geoformer AG). In total, special events on 11 individual glaciers have been documented. While in one case, a fatality of a mountaineer has been reported, limited damages to infrastructure have occurred for two additional events. Most notable is the combined rock and ice avalanche at Piz Scerscen on 14 April 2024 leading to the largest high-alpine mass movement observed in Switzerland during the last decade (see extensive event documentation by Pierhöfer et al., 2024). Substantial quantities of water stored subglacially or in the rock were observed to exit from the break-out niche shortly after the event.

(Left) *Combined rock-ice avalanche at Piz Scerscen (14 April 2024). The avalanche eroded part of Vadret da Tschierva.* ***(Right)*** *Sediment deposition during a lake outburst on Vadret da Calderas (20 June 2024). Photos: M. Huss / AWN.*

Lac des Faverges, Glacier de la Plaine Morte, shortly before the outburst event (18 July 2024). Photo: Geopraevent AG.

10 Conclusions

The Swiss Glacier Bulletin provides an overview of field measurements and remote sensing products collected in the frame of the GLAMOS programme, and represents the 145th subsequent annual report on glacier change data in Switzerland. Observations of mass balance, length change, ice-flow velocity, glacier inventory, volume change, englacial temperature and special events related to glaciers are covered with a focus on measurements acquired in the hydrological year 2024. We note the following main findings:

- **Meteorological conditions were extraordinary**. Strongly above-average winter snow precipitation over glaciers was combined with high air temperatures throughout the entire year.
- **Direct mass balance observations** on 21 glaciers indicated **31% higher snow water equivalent by the end of winter** compared to the 2010-2020 average, but a significantly **negative annual mass balance of –1.17 m w.e.** at the Swiss-wide scale. **Overall, 2.3% or 1.1 km^3, of the remaining glacier volume was lost during 2024**.
- **Length change measurements** at 95 glaciers in 2023 demonstrate a **continued rapid retreat of almost all glacier snouts** throughout the Swiss Alps. Annual retreat rates are typically around 20 metres, but glacier terminus shifts by up to several hundred metres have been observed at a few sites with a contribution of non-climatic processes.
- **Local ice-flow velocity** at stake networks on eight glaciers indicated a **slow-down of ice motion in 2024 by 41%** with respect to 2010-2020.
- A preliminary **update of the Swiss Glacier Inventory** shows a rapid glacier area loss and a partial decay of some glaciers. **Between 2016 and 2022, 88 km^2 became ice-free, and at least 105 glaciers have ultimately disappeared**.
- Based on the differencing of digital elevation models across different regions of Switzerland, average **geodetic mass balances of mostly between –1.2 m w.e. yr^{-1} and –1.7 m w.e. yr^{-1}** were determined for the period 2015-2023.
- Monitoring of **englacial temperature** at 4450 m a.s.l. indicates important **shifts with a warming of 1.5°C over the last three decades** at 20 meter depth.
- 11 **special events related to glaciers** (ice avalanches / glacier lake outburst events) were documented in 2024. One fatality occurred and two additional events caused minor damage to infrastructure.

Overall, data acquired in the frame of GLAMOS clearly document the further decline of glaciers in Switzerland during the reporting period. This observation refers to all monitored variables, even though the resulting loss of glacier ice was less dramatic than in the two previous years due to high winter snow accumulation.

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