# Winter snow accumulation on Swiss glaciers in 2024

Matthias Huss, Andreas Bauder, Andreas Linsbauer (GLAMOS Office)


## Summary

The end-of-winter snow cover on 14 glaciers was measured within the programme Glacier Monitoring Switzerland (GLAMOS) in April and May 2024. Data on snow water equivalent on the glacier surface represents an essential variable to understand the potential impact of melting during the coming summer season. Snow depth soundings encompassing the entire glacier surface, and snow density measurements were performed. This year's results show strongly above-average snow cover on glaciers in all regions of Switzerland with average snow depths of 3 to 6 metres. Record values since the beginning of the series were registered for one third of the sites. Only in some parts of the Valais, the snow water equivalent is less substantially above average. Extrapolated to all Swiss glaciers, a surplus of 31% more winter snow compared to the period 2010-2020 is found. After the very dry winters 2022 and 2023, with corresponding extreme ice loss in summer, the abundant snow falls during winter 2024 represent a blessing for glaciers.



## Zusammenfassung

Im Rahmen des Schweizer Gletschermessnetzes (GLAMOS) wurde im April und Mai 2024 die Schneebedeckung zum Ende des Winters auf 14 Gletschern gemessen. Daten zum Schneewasseräquivalent auf der Gletscheroberfläche stellen eine wesentliche Variable dar, um die möglichen Auswirkungen der Schmelze während des kommenden Sommers zu verstehen. Es wurden Schneehöhenmessungen auf der gesamten Gletscheroberfläche sowie Schneedichtemessungen durchgeführt. Die Ergebnisse zeigen eine stark überdurchschnittliche Schneebedeckung der Schweizer Gletscher in allen Teilen des Landes mit mittleren Schneehöhen zwischen 3 bis 6 Metern. Rekordwerte seit Beginn der Messungen wurden auf einem Drittel der Gletscher festgestellt. Nur in einigen Regionen des Wallis liegt das Schneewasseräquivalent weniger deutlich über dem Durchschnitt. Für alle Schweizer Gletscher ergibt sich ein Überschuss von 31 % mehr Winterschnee im Vergleich zum Zeitraum 2010-2020. Nach den sehr trockenen Wintern 2022 und 2023 – mit entsprechend extremen Eisverlusten im folgenden Sommer – sind die reichlichen Schneefälle im Winter 2024 ein Segen für die Gletscher.


**Snow depth probing at 4000 m a.s.l. (Allalingletscher, left), and snow density measurements (Findelgletscher, right). Photos: M. Huss**

# 1. Measurements and basic approach

Within the standard observational programme of Glacier Monitoring Switzerland (GLAMOS) 14 glaciers were visited for end-of-winter measurements of the snow water equivalent in April and May 2024 (Fig. 1). The aim of these surveys is to determine the glacier-wide winter mass balance, and thus to prolong multi-decadal series of this quantity that is crucial for understanding the effects of shifts in meteorological forcing on glacier mass change (Cogley et al., 2011). Winter snow accumulation on glaciers refers to the protective layer of the ice and, hence, is an important quantity to estimate the potential impact of subsequent summer melting on annual mass balance, or overall ice volume loss.

Long-term measurement programmes (>100 years in some cases) are ongoing on all surveyed glaciers. The measurements of winter mass balance, with a spatial coverage of the entire glacier surface, has, however, only been intensified ca. 15-20 years ago. As snow depth shows strong spatial variability, a dense network of local measurements is needed to capture the total snow mass deposited on the glacier surface. Typically, between 50 and 200 individual snow depth measurements, consisting of 2-3 snow soundings at each point are acquired (GLAMOS, 2023a). In addition, density of the entire snow column down to the ice surface is determined at 1-5 sites per glacier (depending on the elevation range). These measurements are acquired by snow coring (GLAMOS, 2021). Subsequently, all snow depth observations 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). Furthermore, this approach resolves the daily glacier-wide mass balance, and thus allows determining the date of the late-summer minimum surface, as well as homogenization of the results to common and thus comparable dates, e.g. 30 April that is considered here as a reference date for the end of winter.

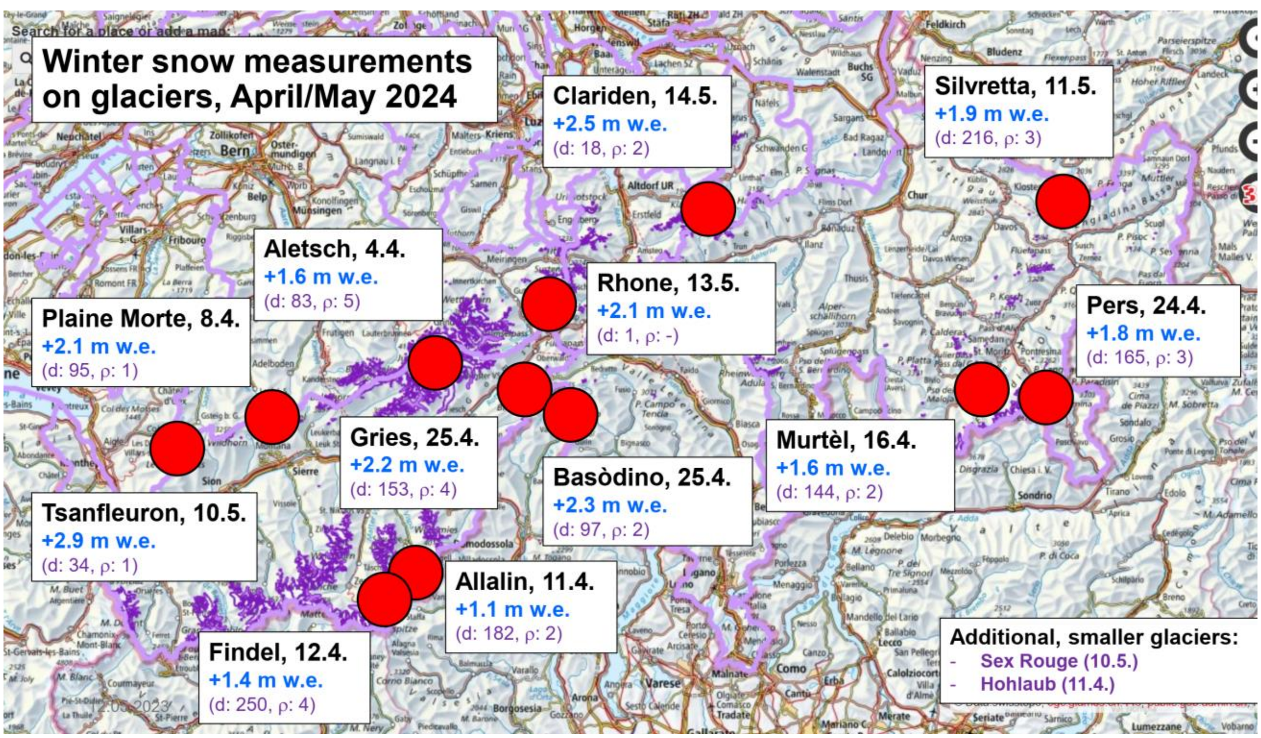


**Figure 1: Overview of winter snow accumulation measurements performed on Swiss glaciers in April/May 2024. For all visited glaciers the date of the survey, as well as the glacier-wide winter mass balance (blue) is given. The number of snow depth soundings (*d*) and the number of snow density survey points (*ρ*) is stated in purple.**

Measurement conditions in April/May 2024 were characterized by substantial amounts of dense snow frequently containing hard layers. This resulted in difficult and more labour-intensive conditions for snow observation on glaciers compared to the previous winters 2022 and 2023 with low snow depths. After a period with relatively stable and warm weather conditions in the first half of April 2024, instable weather with additional fresh snow falls made it difficult to find appropriate dates for completing the surveys. Until mid-May 2024 all but one of the glaciers could be visited (Fig. 1). So far missing detailed measurements on Rhonegletscher are supplemented by an automated in situ snow depth observation for this report.

## 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 winter snow across the glacier, or the temporal dynamics of glacier mass balance.

The snow water equivalent on glaciers is moderately to strongly above average for all measurement sites across the Swiss Alps at the end of April 2024 (Fig. 2). As absolute values of winter mass balance (see Fig. 1) are difficult to be directly compared among glaciers due to different local climates (i.e. precipitation totals), we compare the individual glaciers' deviation from the decadal average (2010-2020). These anomalies are expressed in standard deviations, which gives insights into the frequency of occurrence. For the winter mass balance homogenized to 30 April 2024 we find that glaciers are between 0.5 and 2.4 standard deviations above their mean values (Fig. 2). This corresponds to a surplus of winter snow of between 12% and 60%. In comparison to the last two years, end-of-winter snow is partly 2-3 times higher.

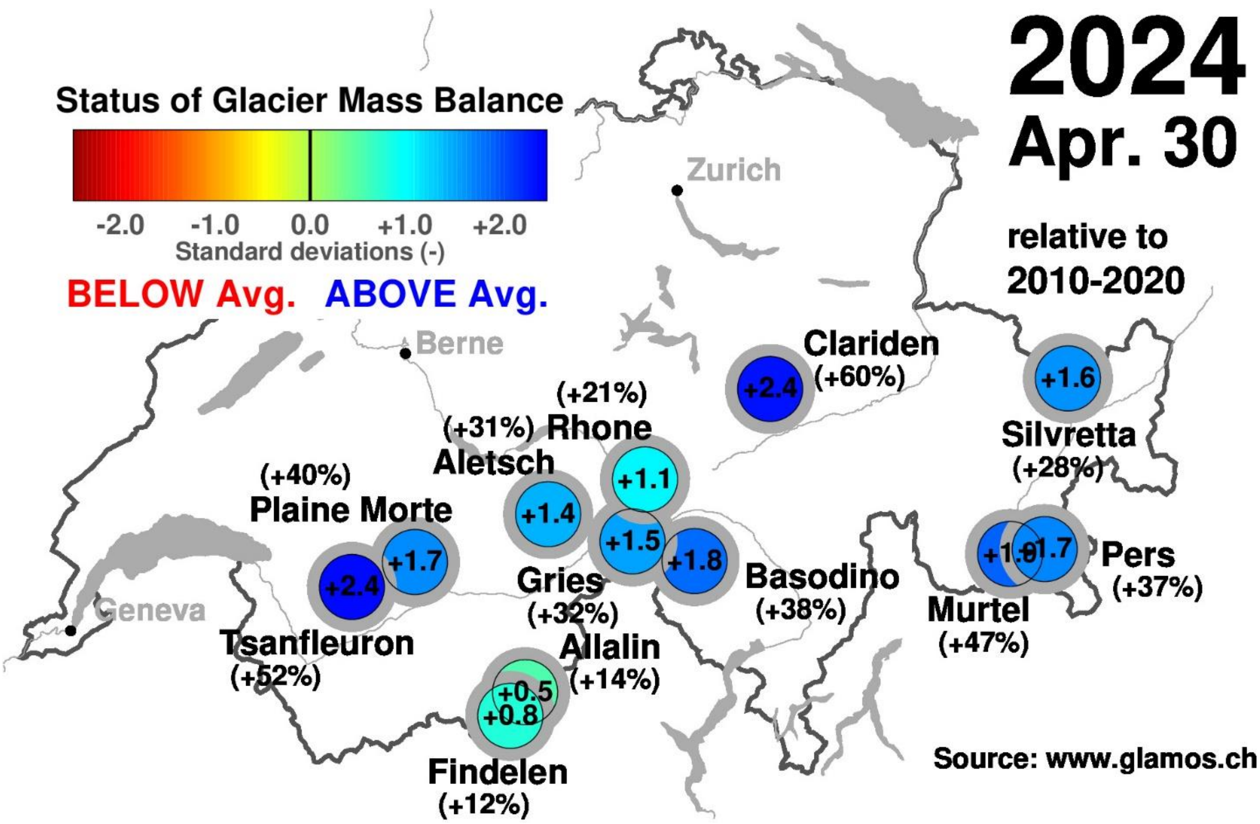


**Figure 2: Anomaly of winter mass balance for all surveyed glaciers homogenized to 30 April 2024 relative to the average of the period 2010-2020 expressed in standard deviations. The difference in percent is given. Yellow-red colours indicate below-average snow conditions, and green-blue colours above-average snow conditions.**

Whereas no clear North-South trend is visible, some clusters can be related to the prevailing weather patterns in the winter of 2023/2024. Glaciers in the Ticino or nearby and the Engadin (Basòdino, Gries, Murtèl, Pers) show strongly above-average mass balances, sometimes even the highest values that have ever been recorded since the beginning of the respective measurement series. Also, glaciers in the very west of Switzerland, as well as on the Northern flank of the Alps show extremely high winter mass balances, also resulting in record values for Tsanfleuron and Clariden. Glaciers in the Southern Valais, as well as Central Switzerland (Findelen, Allalin, Aletsch, Rhone) exhibit above-average winter balances. These are however not extraordinary.

The temporal evolution of the winter snow accumulation on glaciers is characterized by a more rapid growth of the snow cover from late October until December 2023 than normally (Fig. 3). 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.5). Note that Figure 3 is referenced to the start of the hydrological year (1 Oct). The exceptional ice melt until mid-October 2023 thus leads to an apparent dampening of the snow signal in overall cumulative mass balance in this visualization.

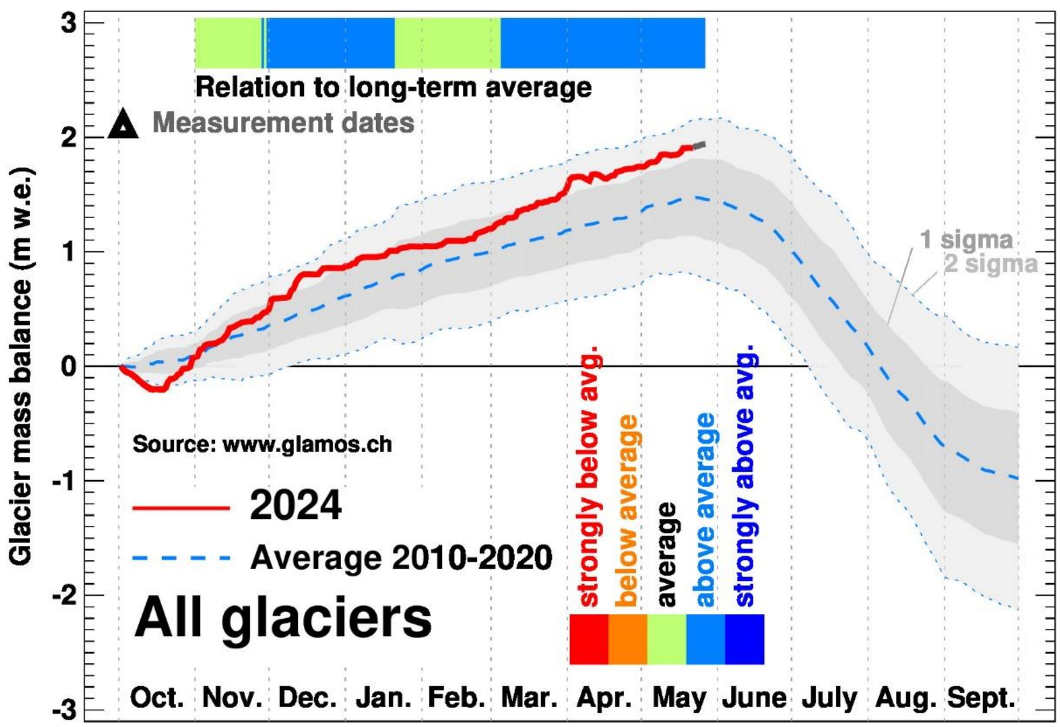


**Figure 3: Cumulative daily mass balance in the hydrological year 2023/2024 up to the date of the report (red) in comparison to the average and the spread of the years 2010-2020. Results based on the 6-day weather forecast are in grey. The top bar indicates periods throughout the year with below- or above-average mass balance. The arithmetic average of all surveyed glaciers (Fig. 1) is shown.**

When extrapolating the snow water equivalent anomalies homogenized to 30 April 2024 to all 1'400 glaciers in the Swiss Glacier Inventory SGI2016 (Linsbauer et al., 2021), thus accounting for differences in regional sampling density, we find the second-most positive winter mass balance on Swiss glaciers during the last two decades (Fig. 4). Even though for some glaciers, data are available going back to the early 1920s, we do not consider the spatial density to be sufficient to prolong this analysis beyond the year 2005. For 2024, the analysis indicates that 31% more winter snow was present on Swiss glaciers relative to the mean in the period 2010-2020, a value slightly smaller than 2019 and a bit larger than in 2018 or

2009. After the particularly dry winters of 2022 and 2023, this represents a major change that will unfold its impact on glacier mass balance during the coming summer. We also note that for many hydrological catchments of Switzerland (Rhine/Aare, Inn, Ticino/Maggia) the winter mass balance 2024 is even the highest values of the last 20 years, but the signal of all glaciers in Switzerland is dominated by glaciers in the Rhone basin where 2024 only ranks third.

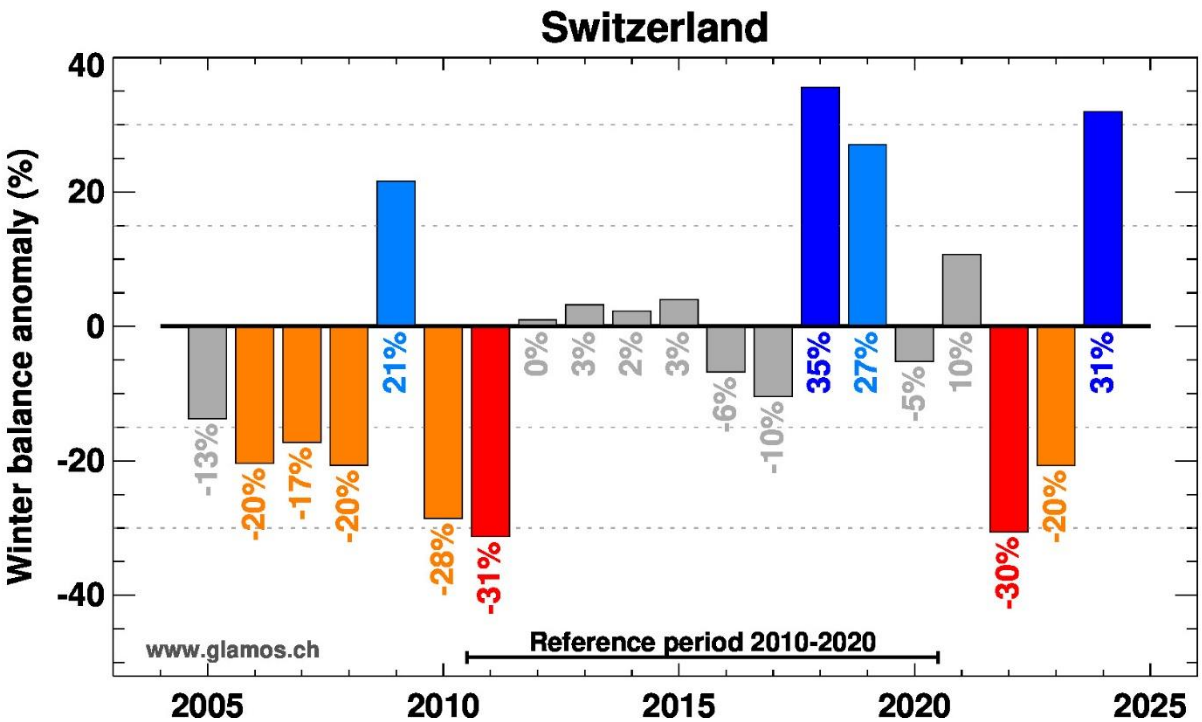


**Figure 4: Relative winter snow accumulation anomaly with respect to the period 2010-2020 at the reference date 30 April extrapolated to all glaciers in Switzerland over the last 20 years. Colours visualize average (grey), below-average (orange/red) and above-average (light blue/dark blue) years.**

Besides snow depth and its spatial distribution, snow density is an important variable to determine the winter mass balance of glaciers. Long-term records of end-of-winter snow density indicate substantial temporal variations even though the measurements have always been acquired at roughly the same time of the year (Fig. 5). Especially the years 2022 and 2023 with particularly small snow depth were characterized by record-low end-of-winter snow density. Measured snow densities in April/May 2024 are above the average, most likely due to stronger compaction and relatively warm weather conditions throughout the winter. A clear dependence of average snow density on the considered glacier is recognizable (Fig. 5). This is explained by differences in overall snow depth (that correlates with density), as well as differences in the typical dates of the field survey for the individual sites.

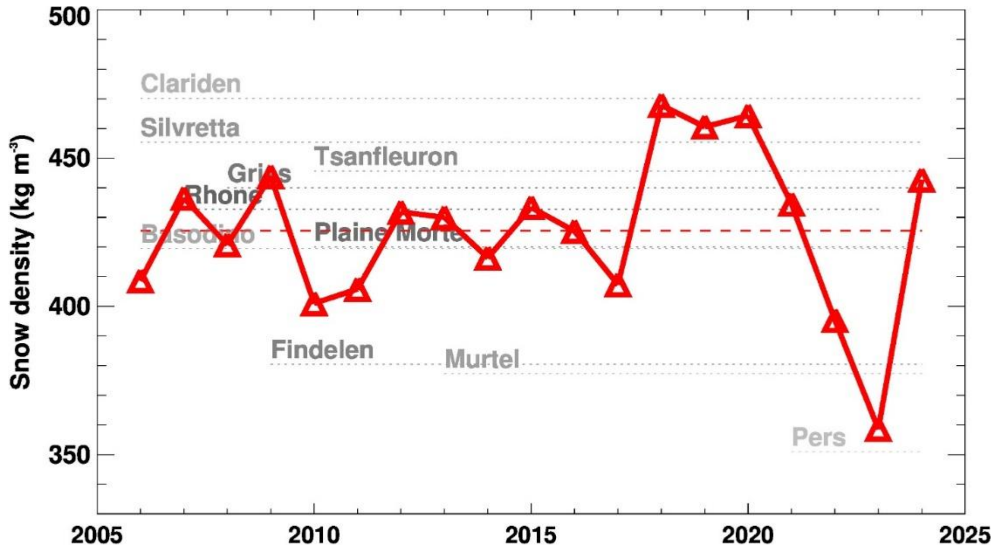


**Figure 5: Measured variations in average snow density over the last 20 years for selected glaciers. The red line/symbols show the mean of all glaciers, and the grey, dotted lines refer to the overall average density and the temporal data coverage of individual glaciers.**

## Funding

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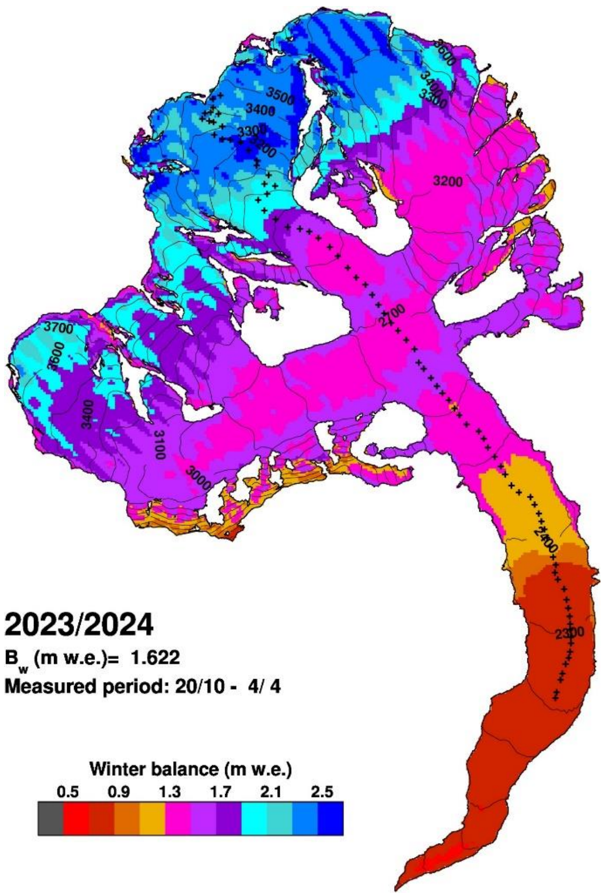
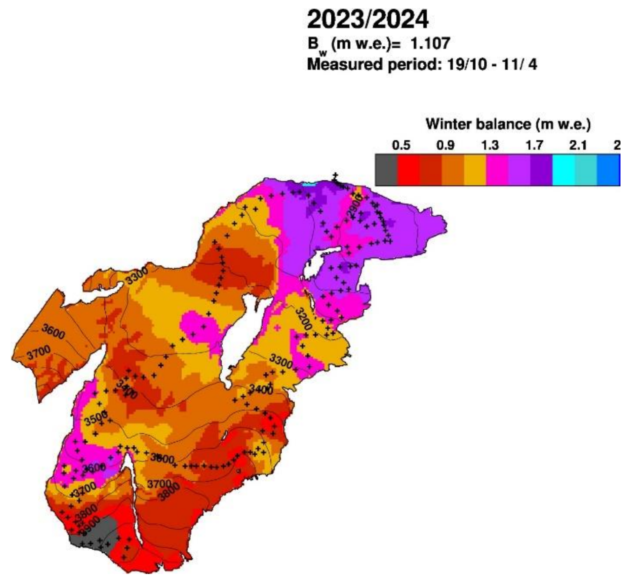
# 3. Appendix

## A.1 Spatial distribution of winter mass balance

The figures below show the extrapolated winter mass balance distribution in metres water equivalent (m w.e.) at the observation date. Measurement points of snow depth are indicated with black crosses. The spatial extrapolation accounts for processes of local snow redistribution. Glaciers are ordered alphabetically.




**Grosser Aletschgletscher**

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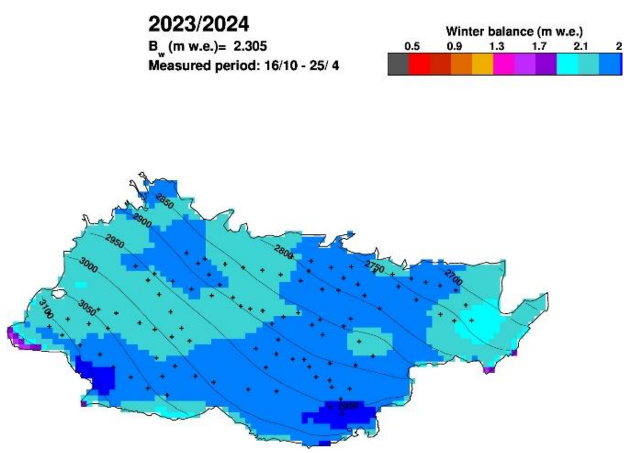
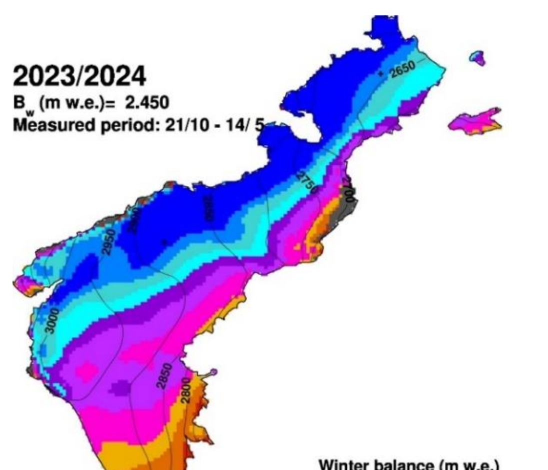
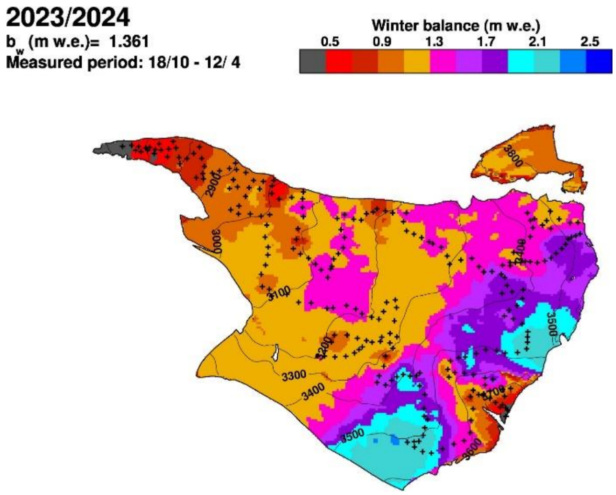



**Ghiacciaio del Basòdino**




**Claridenfirn**

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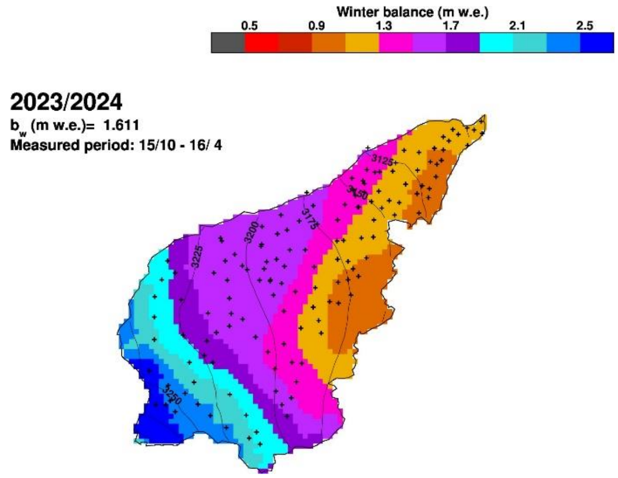
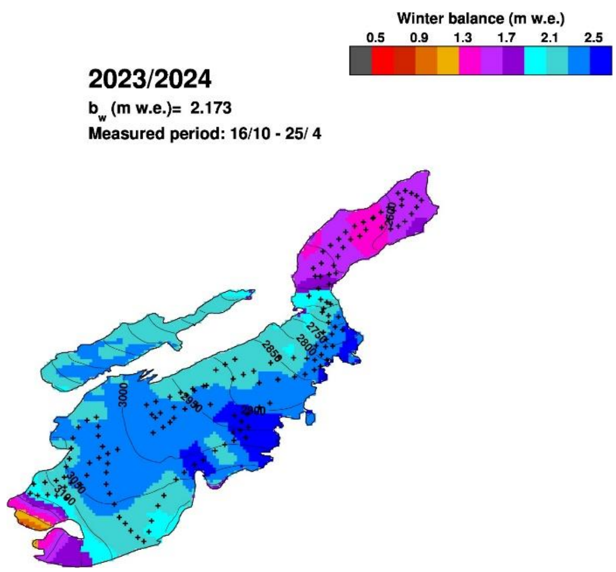
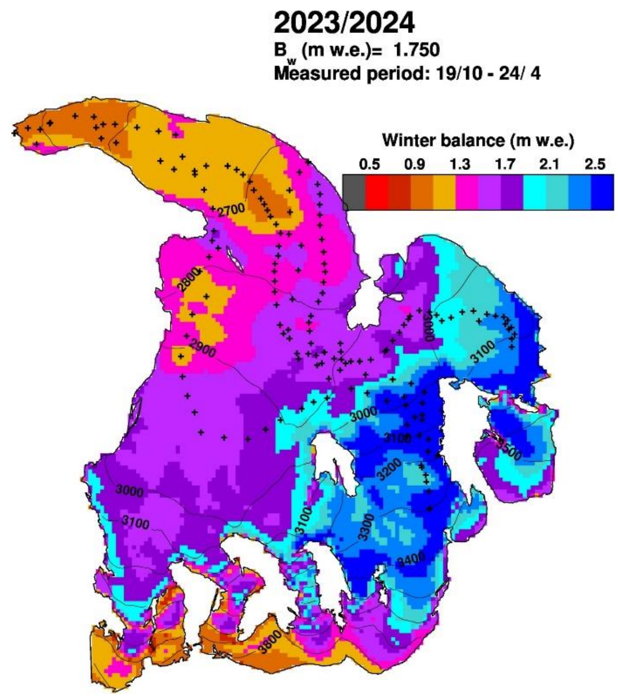


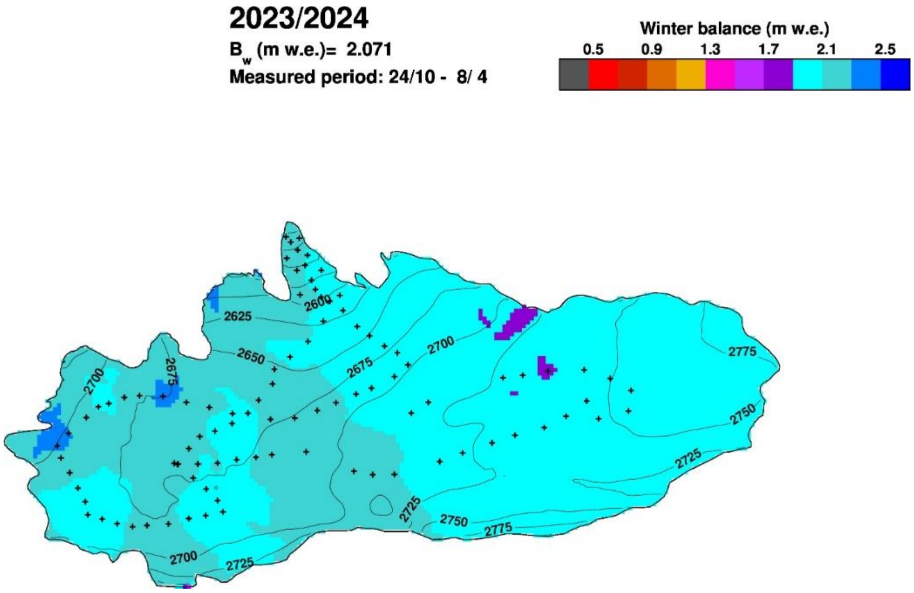

**Vadret dal Murtèl**



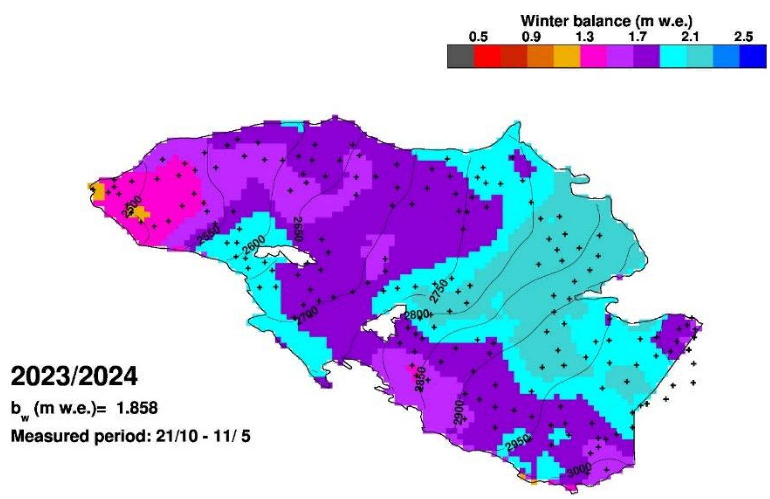

**Griesgletscher**



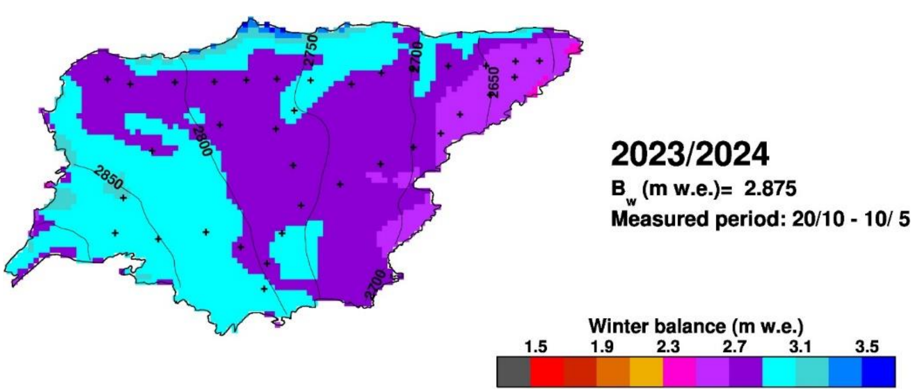

**Vadret Pers**




**Glacier de la Plaine Morte**



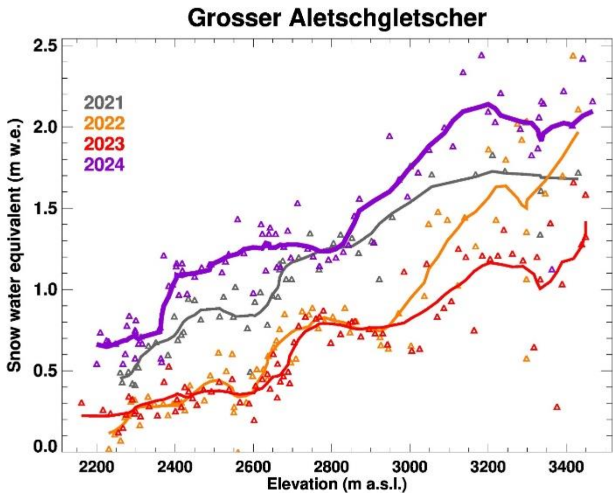

**Silvrettagletscher**

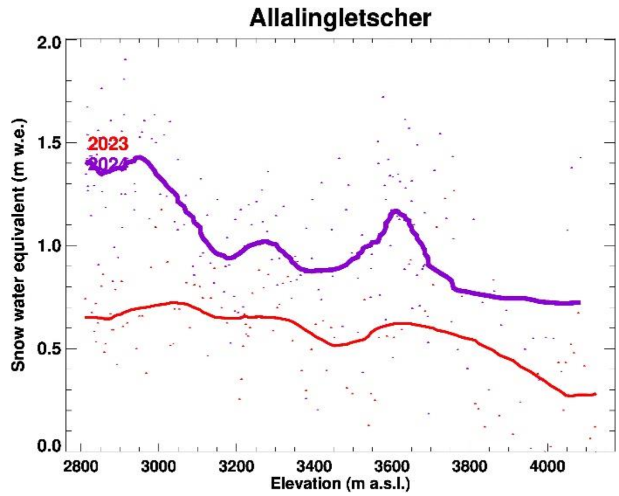


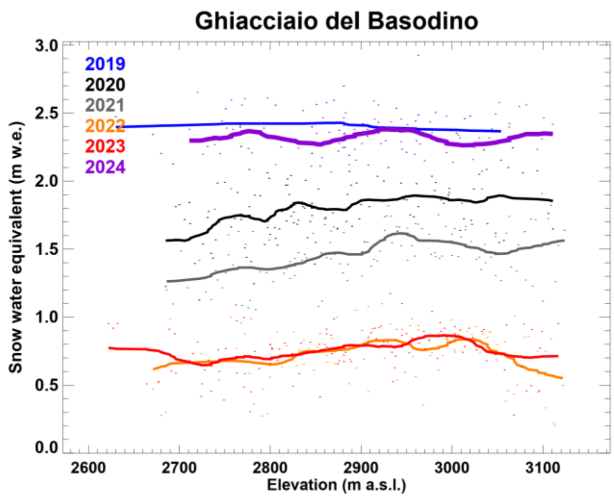

**Glacier de Tsanfleuron**

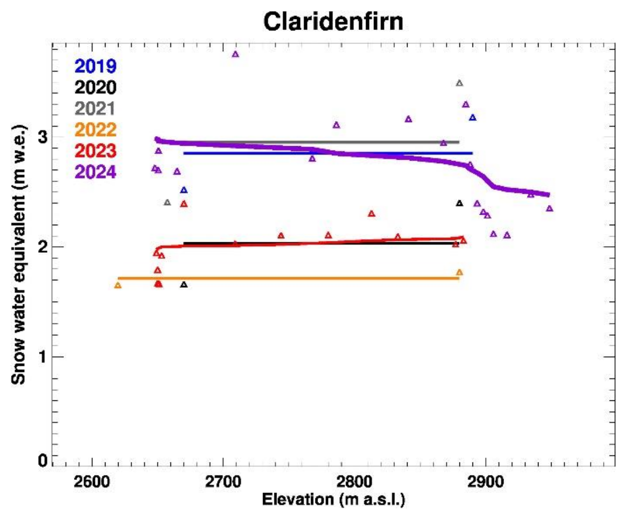
## A.2 Elevation distribution of observed winter snow water equivalent 2019 to 2024

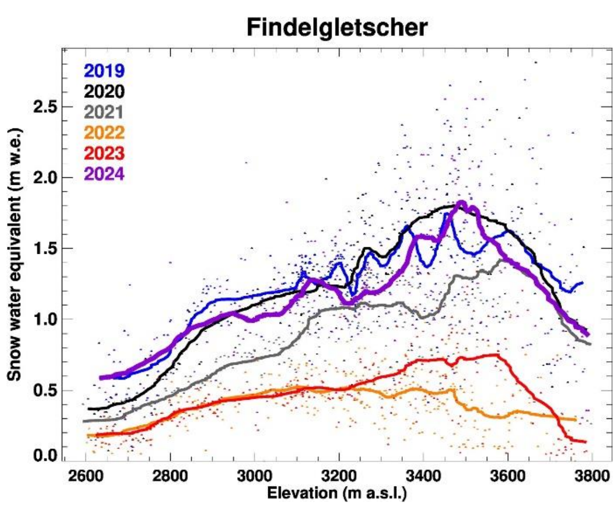
The figures below show measured local winter snow water equivalent on the glacier surface (symbols) depending on elevation over the last six years (2019-2024, if available), smoothed with a thick line. The measurements of April/May 2024 are shown in purple. The glaciers are alphabetically ordered.

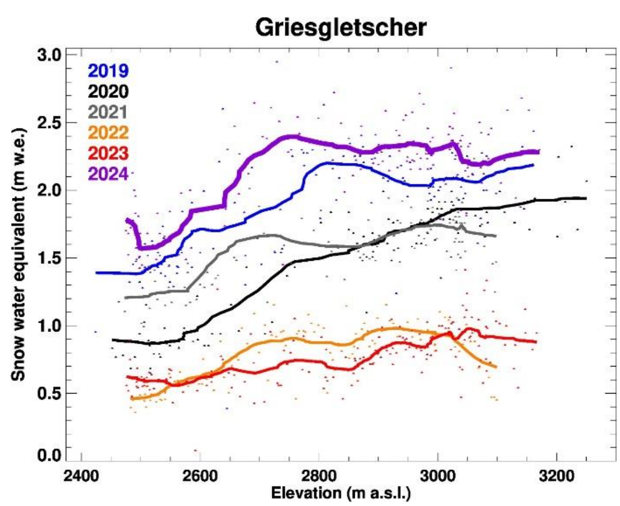


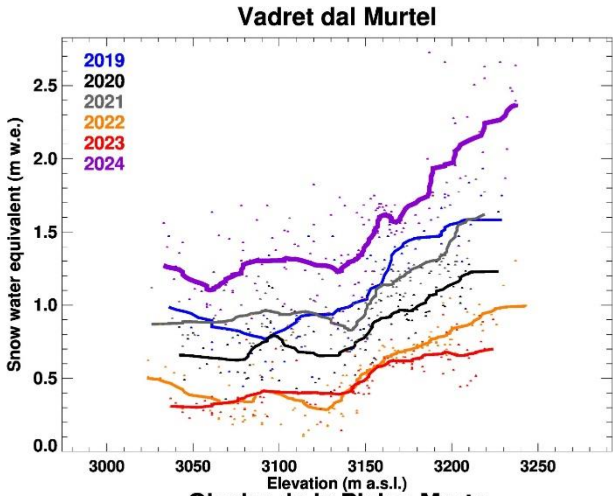



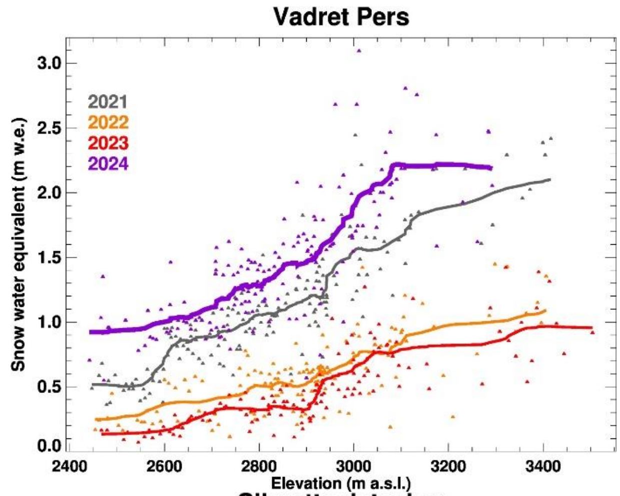



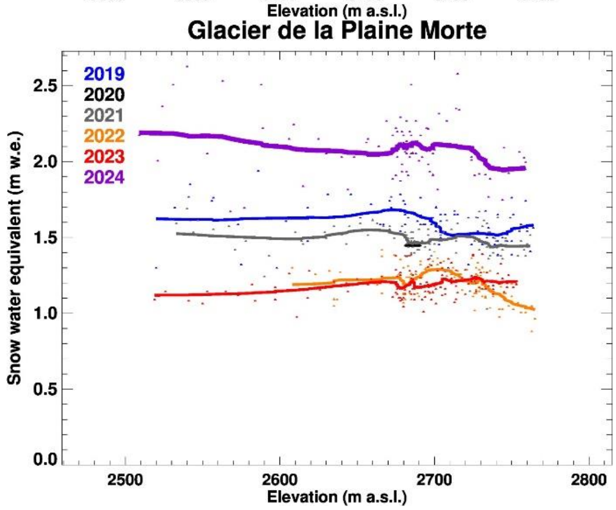



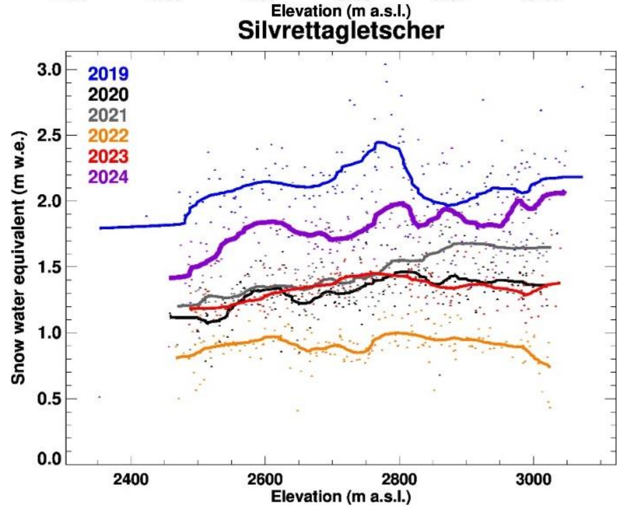



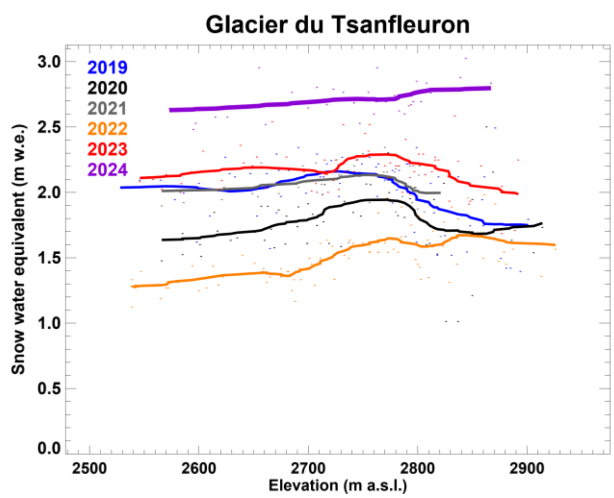




Vadret dal Murtel
2019
2020
2021
2022
2023
2024
Snow water equivalent (m w.e.)
Elevation (m a.s.l.)
0.0
0.5
1.0
1.5
2.0
2.5
3000
3050
3100
3150
3200
3250


Vadret Pers
2021
2022
2023
2024
Snow water equivalent (m w.e.)
Elevation (m a.s.l.)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2400
2600
2800
3000
3200
3400

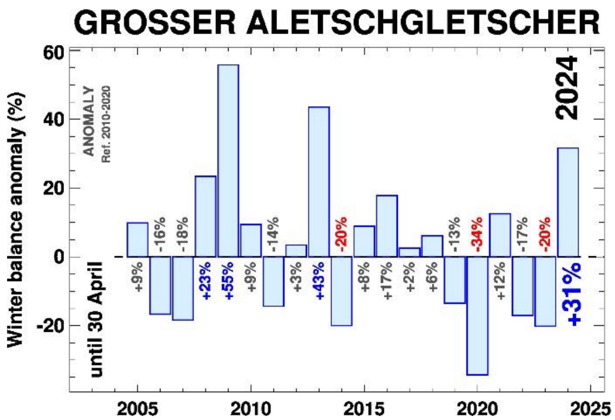

Glacier de la Plaine Morte
2019
2020
2021
2022
2023
2024
Snow water equivalent (m w.e.)
Elevation (m a.s.l.)
0.0
0.5
1.0
1.5
2.0
2.5
2500
2600
2700
2800

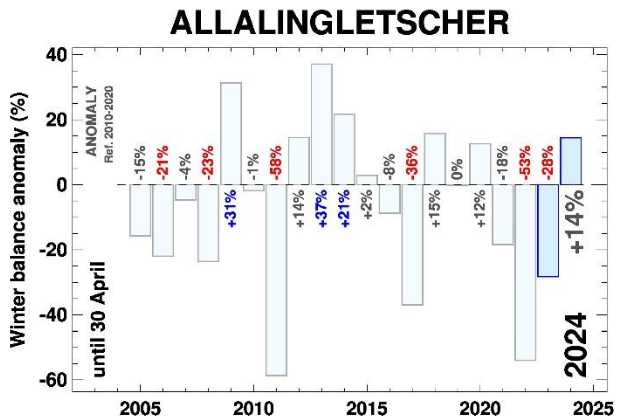

Silvrettagletscher
2019
2020
2021
2022
2023
2024
Snow water equivalent (m w.e.)
Elevation (m a.s.l.)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2400
2600
2800
3000

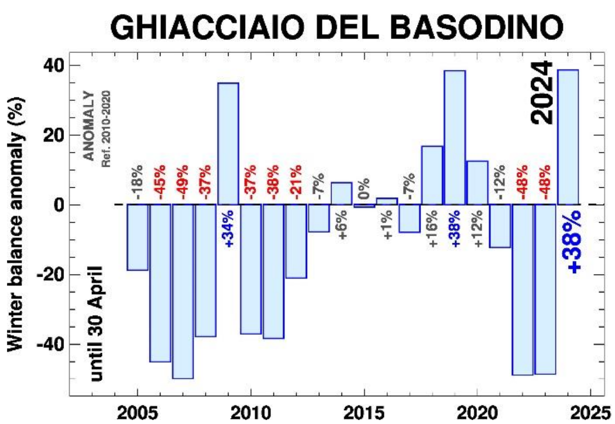

Glacier du Tsanfleuron
2019
2020
2021
2022
2023
2024
Snow water equivalent (m w.e.)
Elevation (m a.s.l.)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2500
2600
2700
2800
2900

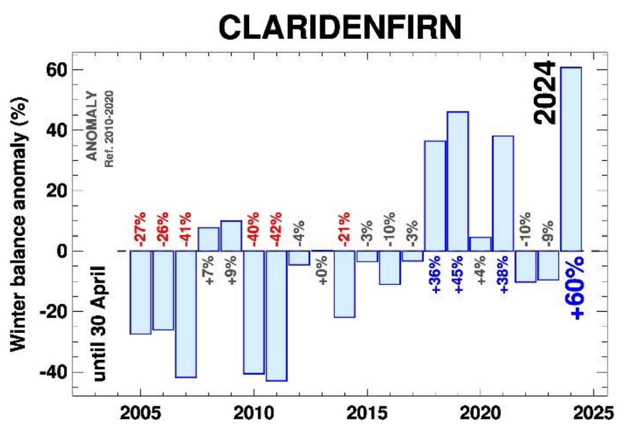
## A.3 Winter mass balance anomaly homogenized to 30 April

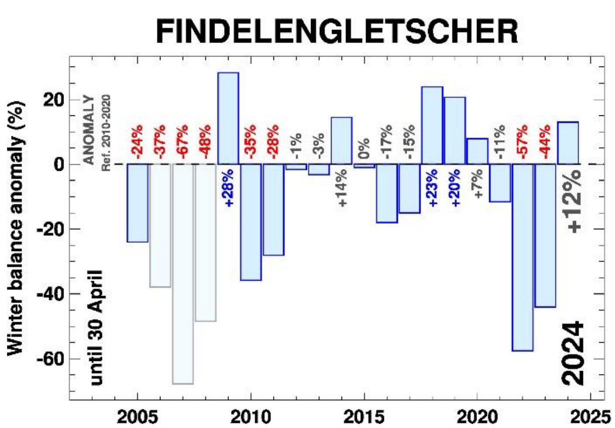
The figures below show the relative winter mass balance anomaly homogenized to 30 April of each year with respect to the measurements in the period 2010-2020. The last 20 years are displayed and the year 2024 is highlighted. Grey numbers refer to years relatively close to the average, blue numbers indicate strongly above-average years and red numbers strongly below-average years, respectively. Light bars for a few glaciers show years where results are not based on in situ measurements but modelling. The glaciers are alphabetically ordered.

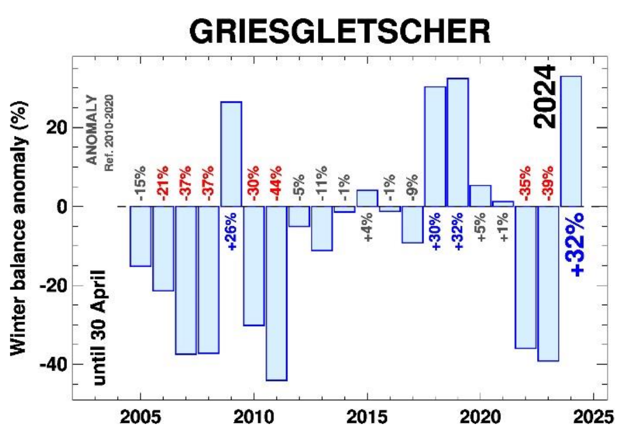


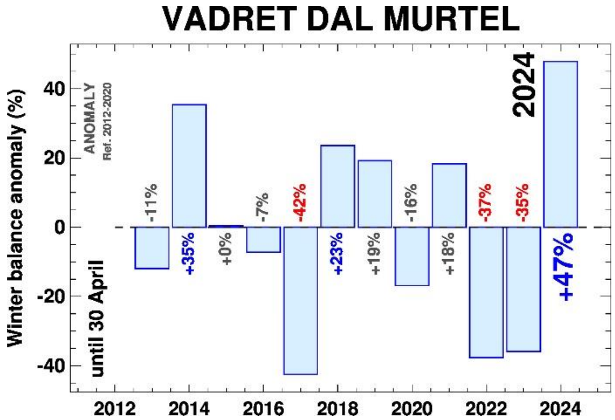



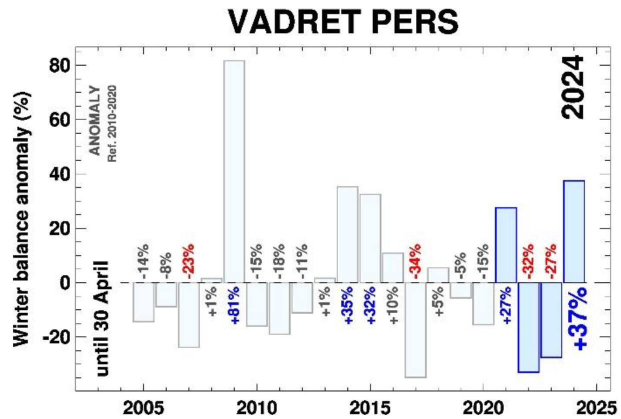



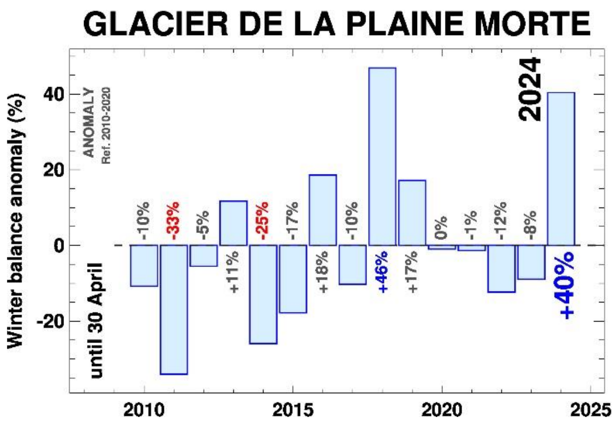



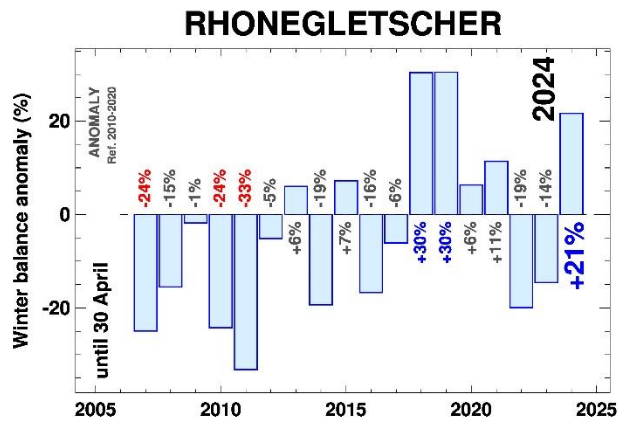



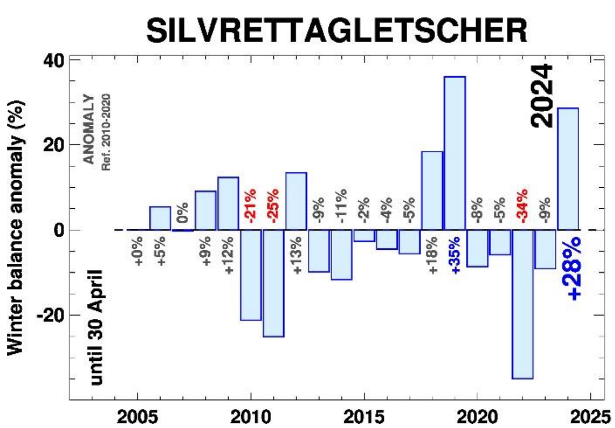



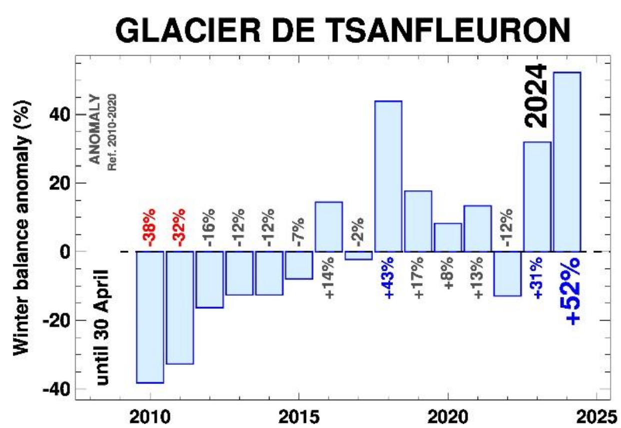

VADRET DAL MURTEL
Winter balance anomaly (%)
until 30 April
ANOMALY
Ref. 2012-2020
2024
-11%
+35%
+0%
-7%
-42%
+23%
+19%
-16%
+18%
-37%
-35%
+47%
2012
2014
2016
2018
2020
2022
2024


VADRET PERS
Winter balance anomaly (%)
until 30 April
ANOMALY
Ref. 2010-2020
2024
-14%
-8%
-23%
+1%
+81%
-15%
-18%
-11%
+1%
+35%
+32%
+10%
-34%
+5%
-5%
-15%
+27%
-32%
-27%
+37%
2005
2010
2015
2020
2025


GLACIER DE LA PLAINE MORTE
Winter balance anomaly (%)
until 30 April
ANOMALY
Ref. 2010-2020
2024
-10%
-33%
-5%
+11%
-25%
-17%
+18%
-10%
+46%
+17%
0%
-1%
-12%
-8%
+40%
2010
2015
2020
2025

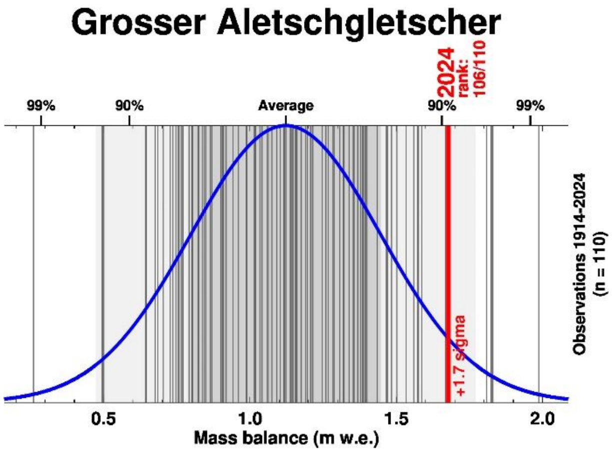

RHONEGLETSCHER
Winter balance anomaly (%)
until 30 April
ANOMALY
Ref. 2010-2020
2024
-24%
-15%
-1%
-24%
-33%
-5%
+6%
-19%
+7%
-16%
-6%
+30%
+30%
+6%
+11%
-19%
-14%
+21%
2005
2010
2015
2020
2025


SILVRETTAGLETSCHER
Winter balance anomaly (%)
until 30 April
ANOMALY
Ref. 2010-2020
2024
+0%
+5%
0%
+9%
+12%
-21%
-25%
+13%
-9%
-11%
-2%
-4%
-5%
+18%
+35%
-8%
-5%
-34%
-9%
+28%
2005
2010
2015
2020
2025

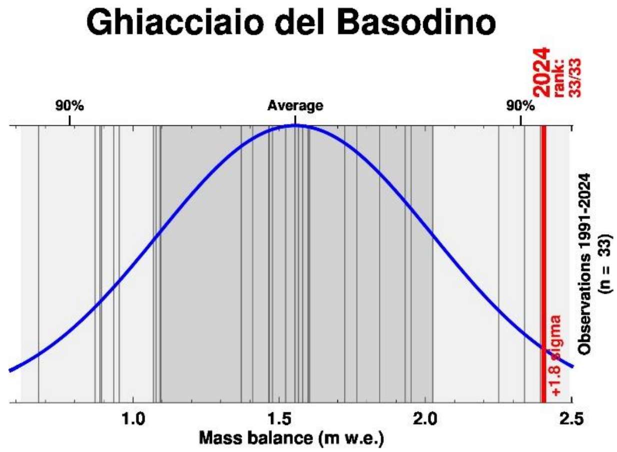

GLACIER DE TSANFLEURON
Winter balance anomaly (%)
until 30 April
ANOMALY
Ref. 2010-2020
2024
-38%
-32%
-16%
-12%
-12%
-7%
+14%
-2%
+43%
+17%
+8%
+13%
-12%
+31%
+52%
2010
2015
2020
2025

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

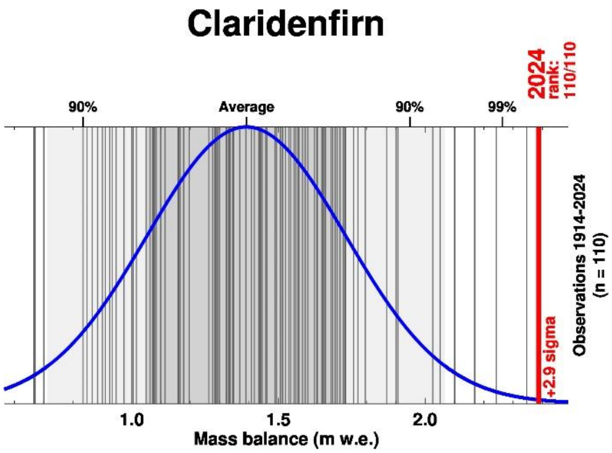
The figures below show the statistical distribution of all previously measured glacier-wide winter mass balances homogenized to 30 April (vertical lines). Ranges corresponding to 1 (dark grey) and 2 (light grey) standard deviations are shown, as are the boundaries encompassing 90% and 99% of the statistical distribution (ticks). The year 2024 is indicated with the thick, red line and the rank of 2024 starting from the least positive winter balance is given. The glaciers are alphabetically ordered.



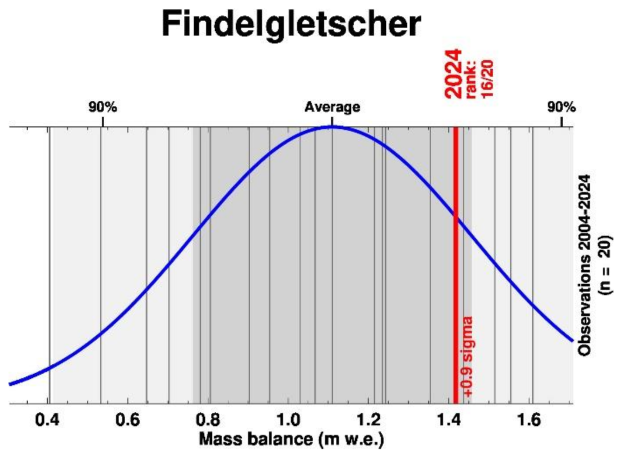

Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: M. Huss



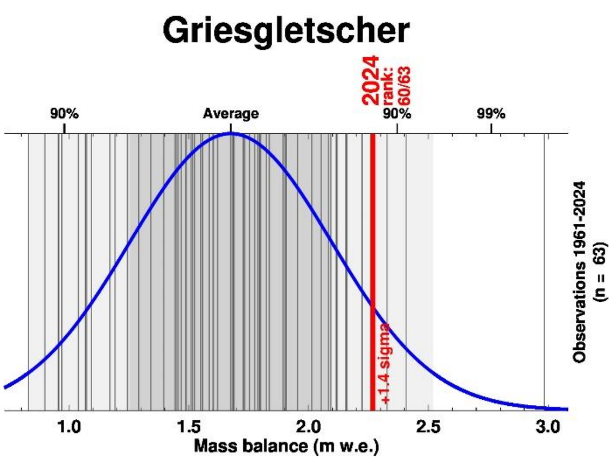

Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: G. Kappenberger



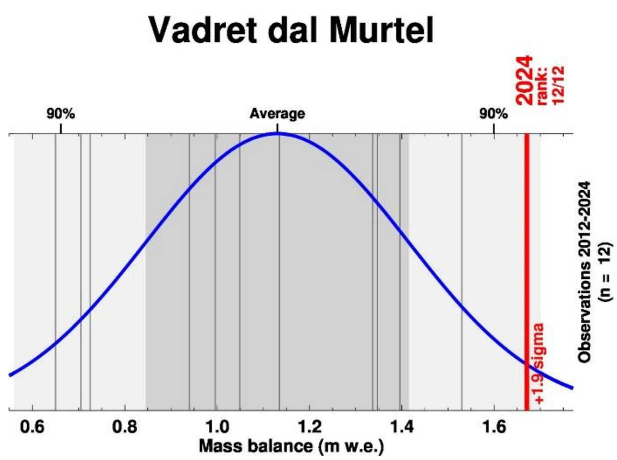

Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: U. Steinegger



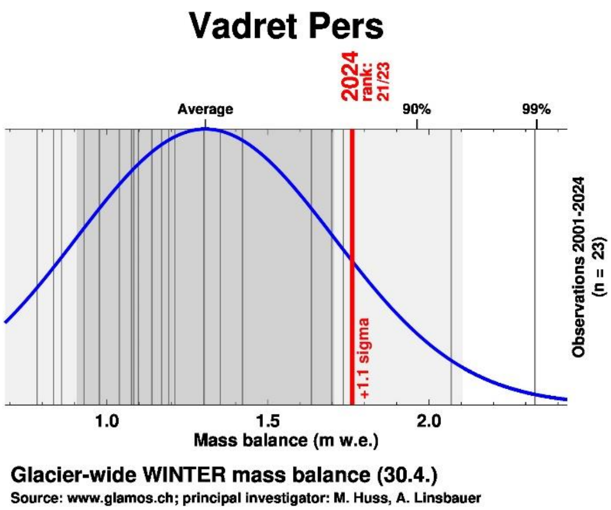

Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: M. Huss, A. Linsbauer

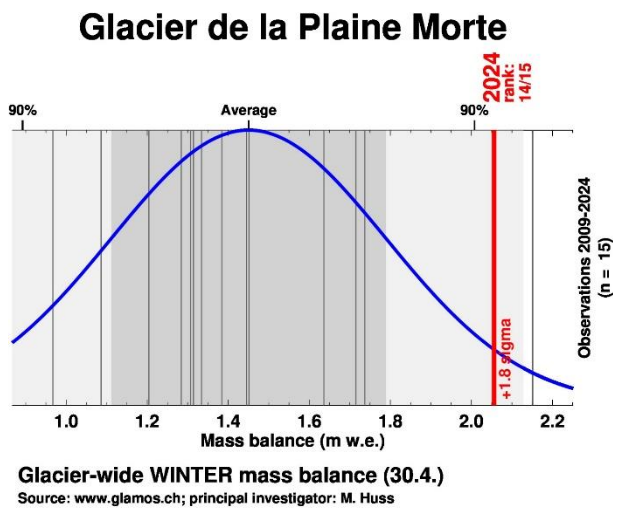


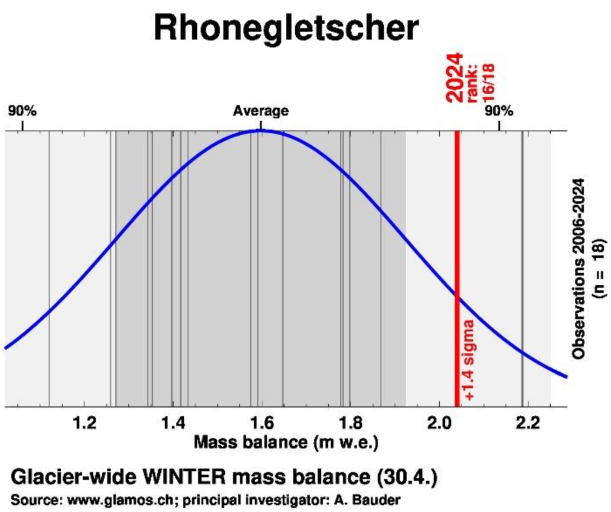

Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: M. Huss

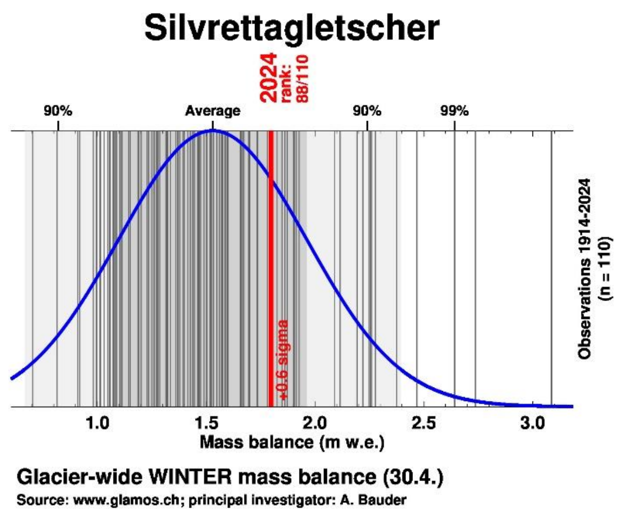


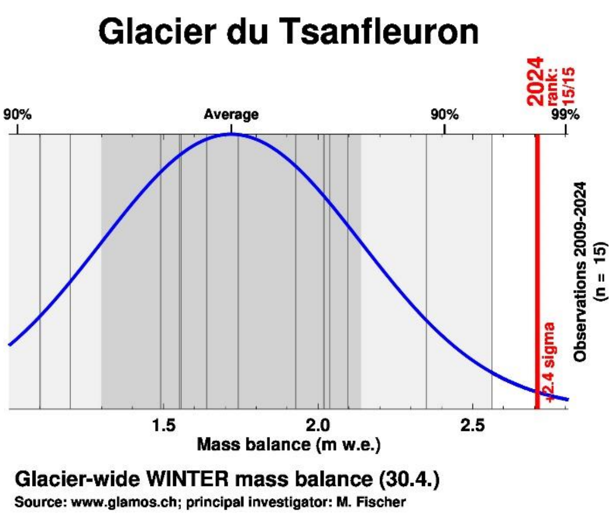

Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: M. Huss


Vadret Pers
2024
rank: 21/23
Average
90%
99%
+1.1 sigma
Observations 2001-2024
(n = 23)
1.0
1.5
2.0
Mass balance (m w.e.)
Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: M. Huss, A. Linsbauer


Glacier de la Plaine Morte
2024
rank: 14/15
90%
Average
90%
+1.8 sigma
Observations 2009-2024
(n = 15)
1.0
1.2
1.4
1.6
1.8
2.0
2.2
Mass balance (m w.e.)
Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: M. Huss

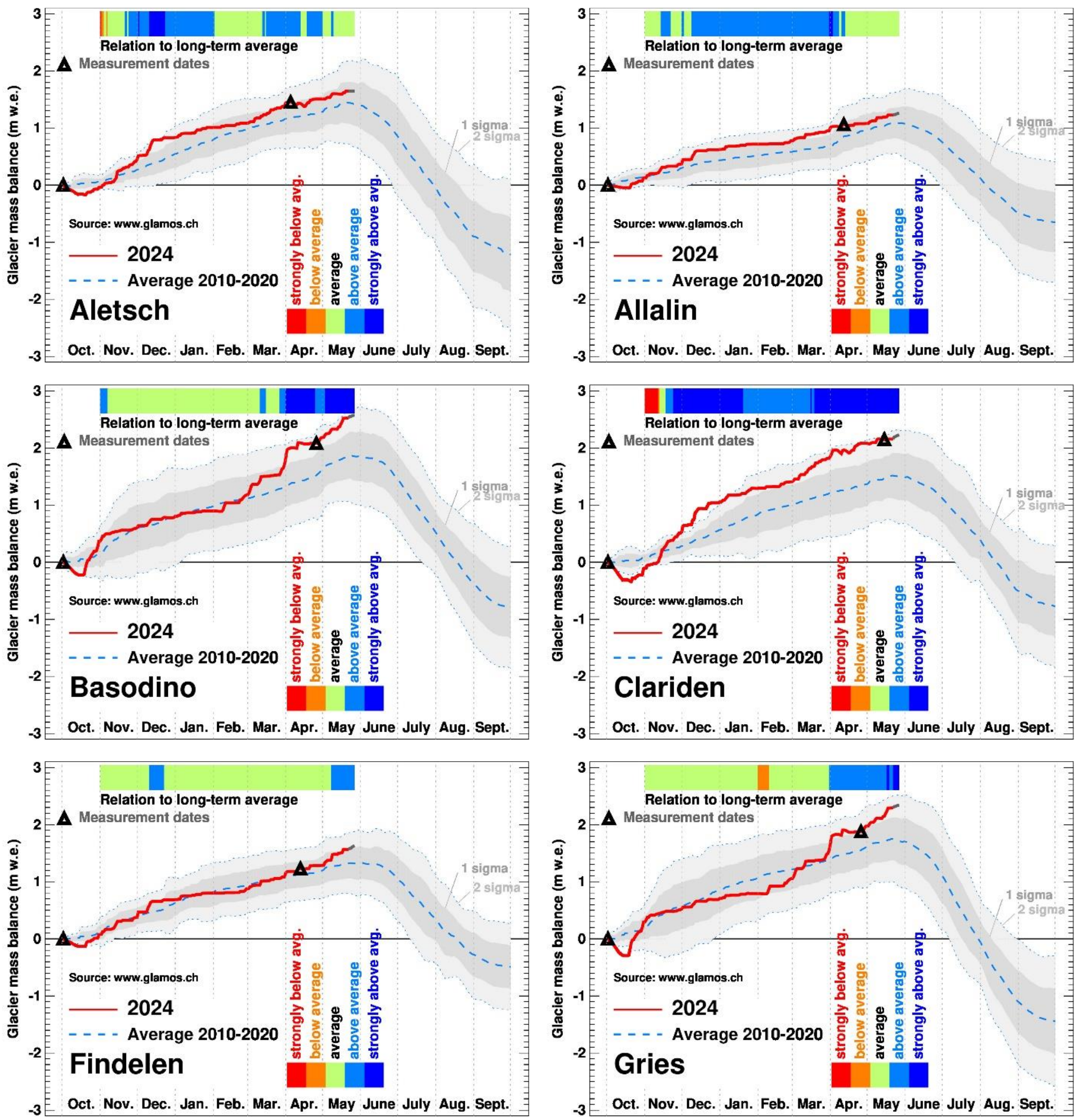

Rhonegletscher
2024
rank: 16/18
90%
Average
90%
+1.4 sigma
Observations 2006-2024
(n = 18)
1.2
1.4
1.6
1.8
2.0
2.2
Mass balance (m w.e.)
Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: A. Bauder

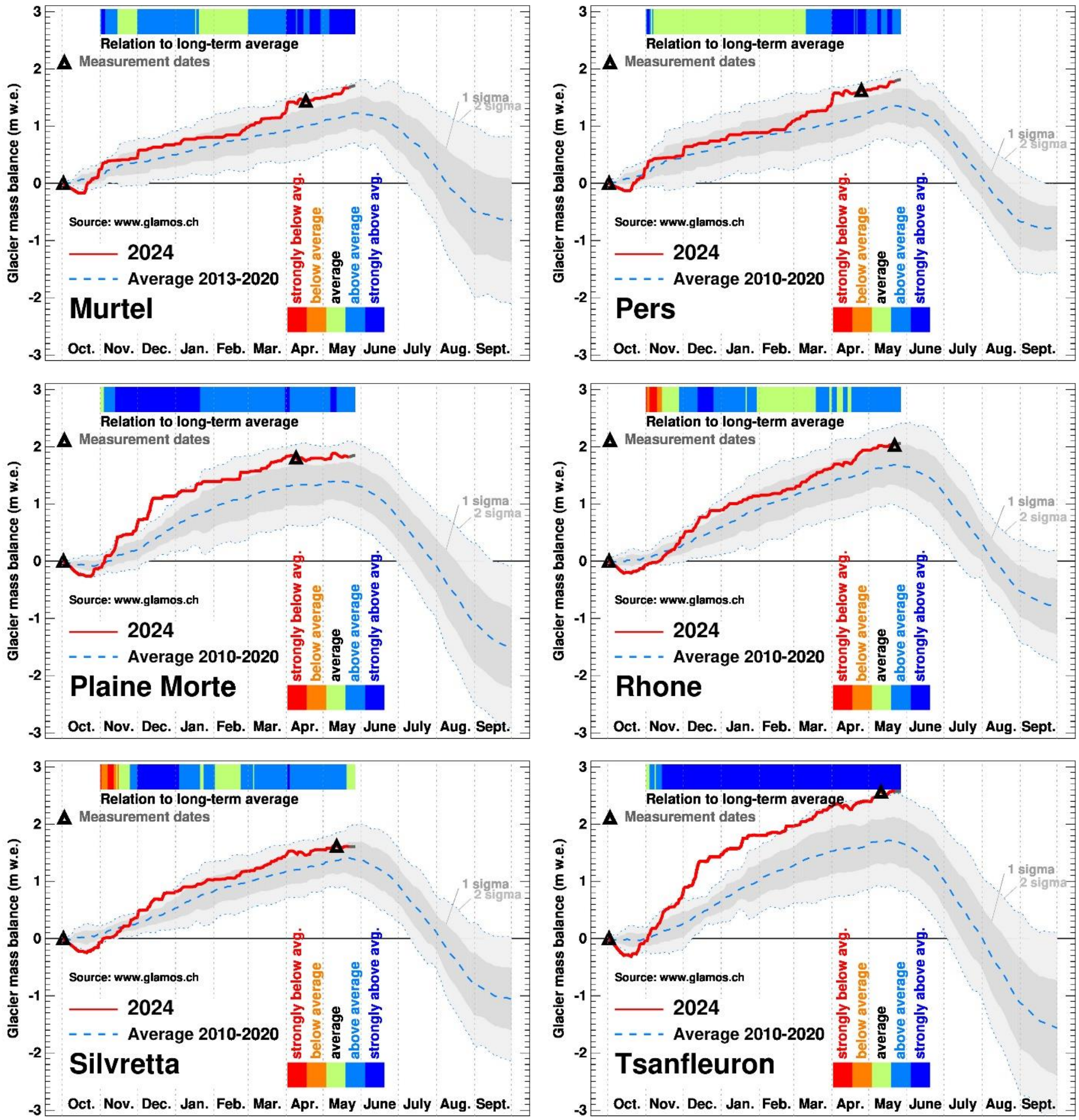

Silvrettagletscher
2024
rank: 88/110
90%
Average
90%
99%
+0.6 sigma
Observations 1914-2024
(n = 110)
1.0
1.5
2.0
2.5
3.0
Mass balance (m w.e.)
Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: A. Bauder


Glacier du Tsanfleuron
2024
rank: 15/15
90%
Average
90%
99%
+2.4 sigma
Observations 2009-2024
(n = 15)
1.5
2.0
2.5
Mass balance (m w.e.)
Glacier-wide WINTER mass balance (30.4.)
Source: www.glamos.ch; principal investigator: M. Fischer

## A.5 Temporal evolution of mass balance during the hydrological year 2023/2024

The figures below show the modelled daily cumulative mass balance in the hydrological year 2023/2024 up to the date of the report (red line) in comparison to the average and the spread of the years 2010-2020. Data based on the 6-day weather forecast are shown in dark grey. The measurement date, by which the daily cumulative glacier-wide mass balance is constrained, is shown with a black triangle. 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.)
Source: www.glamos.ch
2024
Average 2013-2020
Murtel
Average 2010-2020
Pers
Plaine Morte
Rhone
Silvretta
Tsanfleuron
strongly below avg.
below average
average
above average
strongly above avg.
1 sigma
2 sigma
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.