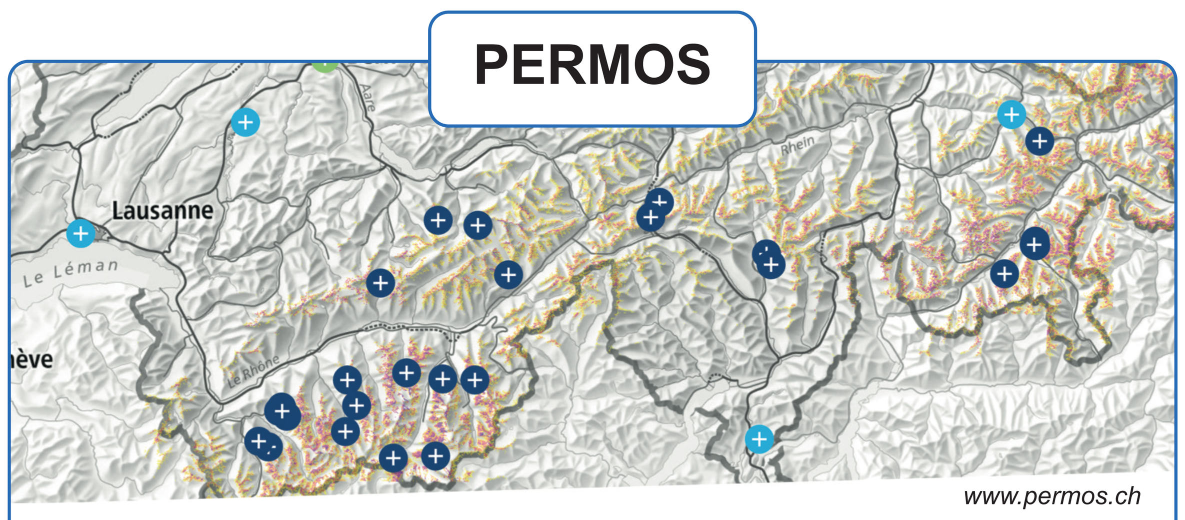
# Permafrost evolution in the Swiss Alps based on 25 years of coordinated observation

PERMOS Scientific Committee / J. Nötzli and C. Pellet

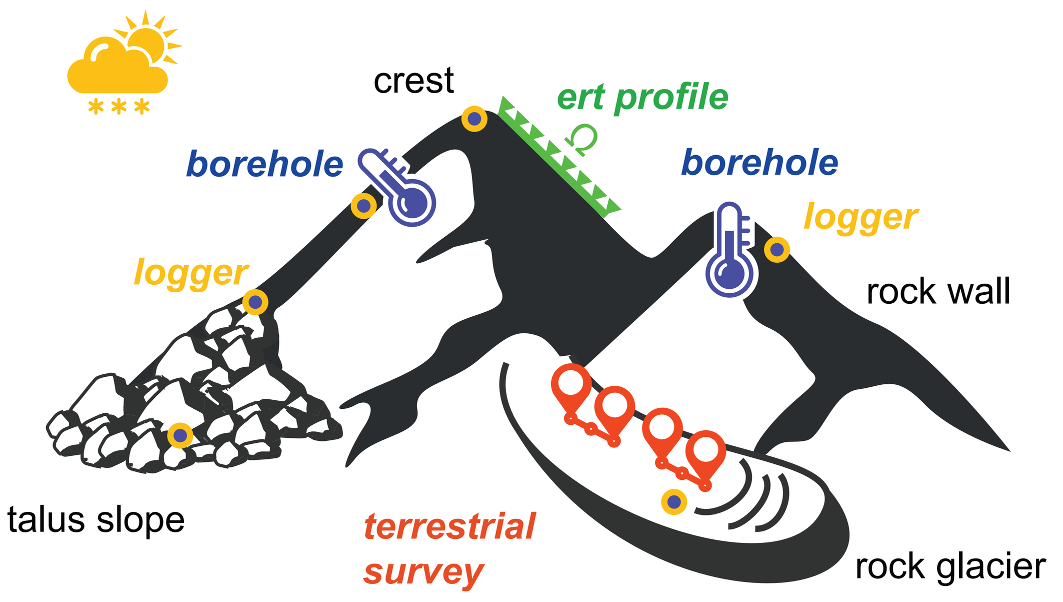
PERMOS is financially supported by MeteoSwiss/GCOS-CH, FOEN & SCNAT

## PERMOS




**The Swiss Permafrost Monitoring Network PERMOS documents the evolution of mountain permafrost in the Swiss Alps as a coordinated national monitoring network since 2000.**

Key tasks are data aquisition and long term maintenance at 27 field sites; mangement and curation of high-quality data; their analyses and synthesis to assess the permafrost evolution in Switzerland; dissemination of data, results and expertise to support permafrost monitoring, climate change impact studies, natural hazard assessment, education and public awareness.

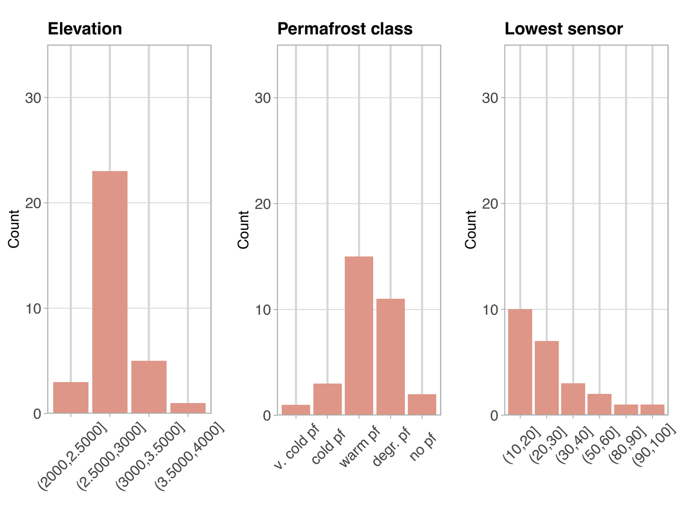



## Network challenges

- Changing conditions (e.g., increase in shearing, rock fall and water percolation) make data collection and site maintenance more demanding and increasingly put the continuation of the time series at risk !

*In September 2023, a rock fall hit the field site on rock glacier Murtèl-Corvatsch, severely damaged the instruments, and ended the longest mountain permafrost temperature time series. Photos: Drone Univ. Zurich (left), J. Noetzli (right).*

- Ongoing permafrost changes render the detection of ongoing changes more challenging and will require adaptation of the network in the mid- to long-term as permafrost will remain at higher elevation and at larger depths.




*Most PERMOS boreholes are located in warm permafrost <3000 m asl.*

- *Continuity of people, know-how and expertise (... and important in-kind funds!)*

## Outreach & data access

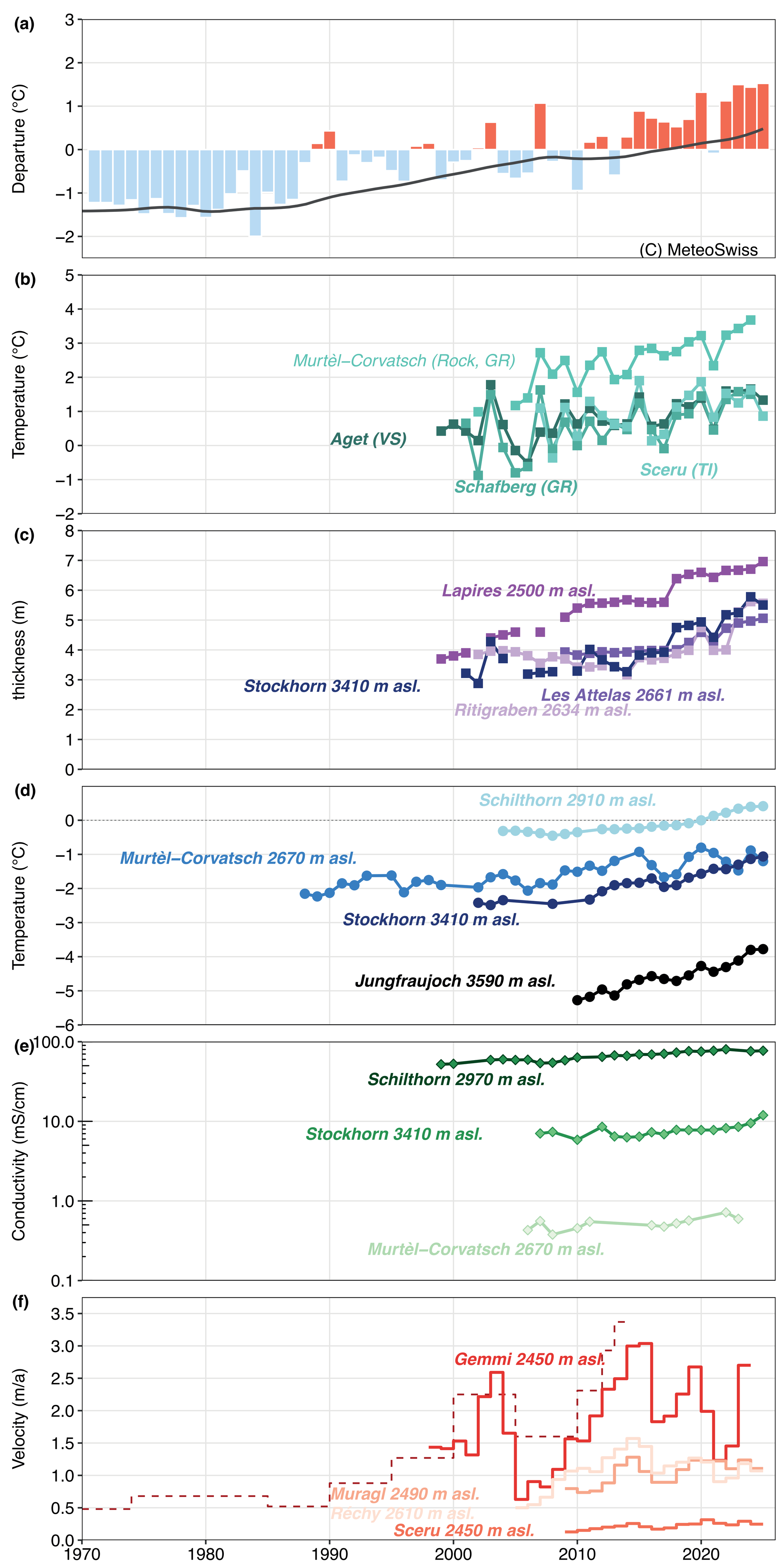
**www.permos.ch**


*New PERMOS website provided in three languages and including a self-designed data portal for all PERMOS field data.*

***PERMOS Data***
***doi.org/10.13093/permos-2025-01***

I. Altshuler (EPFL), D. Amschwand (UIBK), A. Bast (SLF), J. Beutel (UIBK), A. Cicoira (Geotest), C. Del Siro (SUPSI), R. Delaloye (UNIFR), T. Duvanel (UNIL), D. Farinotti (ETHZ, WSL), I. Gärtner-Roer (UZH), T. Gluzinski (UNIFR), N. Hählen (Canton BE), A. Hasler (SensAlpin), C. Hauck (UNIFR), C. Hilbich (UNIFR), M. Hoelzle (UNIFR), R. Kenner (SLF), C. Lambiel (UNIL), M. Lichtenegger (SLF), T. Mathys (UNIFR), C. Mollaret (UNIFR), S. Morard (UNIFR), R. Moser (ETHZ), J. Nötzli (SLF), C. Pellet (UNIFR), A. Peter (Canton BE), M. Phillips (SLF), H. Raetzo (BAFU), B. Robson (UNIL), N. Salzmann (SLF), C. Scapozza (SUPSI), L. Schmid (UNIFR), A. Vieli (UZH), S. Vivero Andrade (UNIFR), D. Vonder Mühll (SystemsX.ch), S. Walter (Canton BE), S. Weber (SLF)

## Permafrost changes




### A – Surface air temperature

- 30y warming rate at high elevations 0.4–0.5 °C $dec^{-1}$
- Warmest 4 years: 2022–2025
- Warmest hydrological year: 2025

*(Data source: MeteoSwiss)*

### B – Ground surface temperature

- 230 locations at 21 sites (40% cover >20y)
- Maximum running MAGST: May 2023–June 2024
- Warming rates during the past decade are 0.4–1 °C $dec^{-1}$

***GST increase !***

### C – Active layer thickness

- Derived from borehole temperature from 19 boreholes (cf. D)
- Increase up to several metres since the start of measurements
- Doubling of the ALT at many sites

***Active layer thickening !***

### D – Permafrost temperature

- 32 boreholes at 13 sites (12 cover >20y)
- Mean warming rate 2015–2024 (*Noetzli et al. 2025, Forum für Wissen*)
  at 10 m depth: 0.4 °C $dec^{-1}$ (–0.1 to 1.0 °C $dec^{-1}$)
  at 20 m depth: 0.2 °C $dec^{-1}$ (–0.1 to 1.0 °C $dec^{-1}$)

***Permafrost warming !***

### E – Permafrost resistivity

- 5 sites with annual ERT surveys (up to 25y)
- Permafrost resistivity is decreasing (incr. conductivity)
- Points to a considerable and irreversible ground ice loss

***Ground ice loss !***

### F – Rock glacier velocity

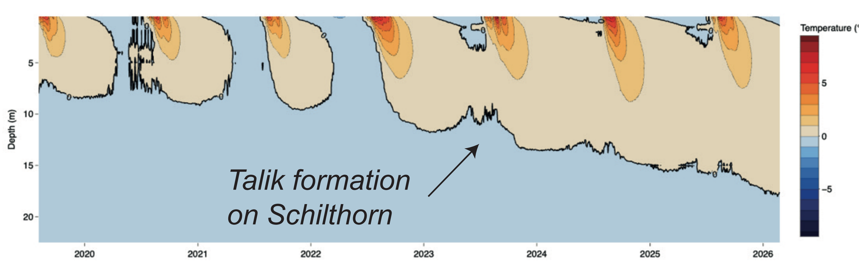
- >1000 points on 18 rock glaciers (up to 30y)
- RGV changed from decimetres to metres per year
- Large interannual variability (snow and thermal conditions)
- Grosses Gufer: 1974–90 0.32 $my^{-1}$ and 2008–23: 1.85 $my^{-1}$ ***x6 !***

***Increase in rock glacier velocity !***

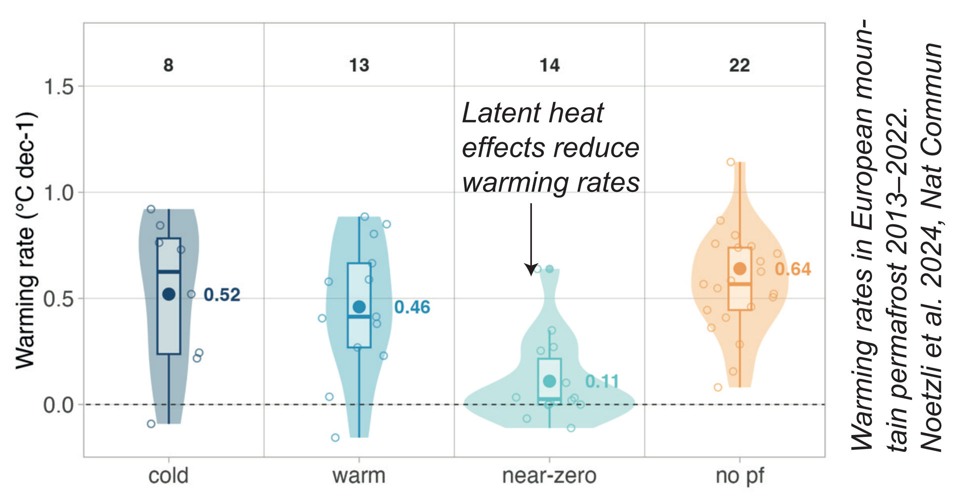
## Striking observations...!

### Degradation and thermokarst !

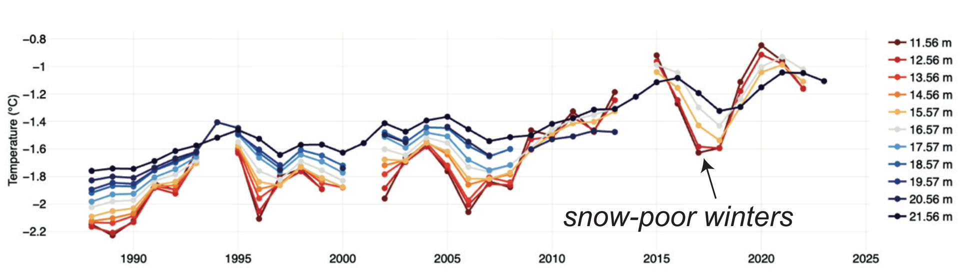
*Ground settlement next to the borehole station on Stockhorn (3400 m asl.). Photos: C. Pellet.*




### Temperature change patterns !

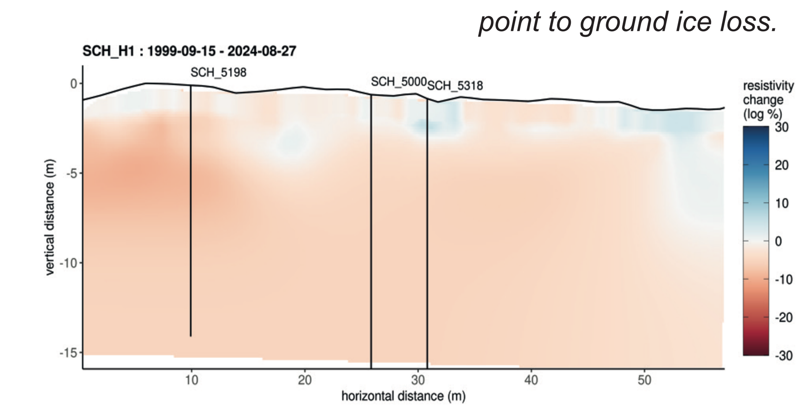



### Effect of the winter snow cover !




The timing of the snow cover can temporarily reduce or accelerate the general warming trend: annual permafrost temperatures at Murtèl-Corvatsch.

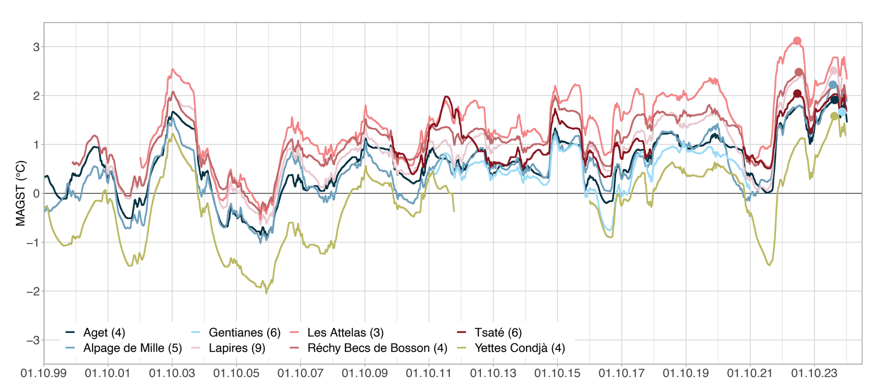
### Increasing amount of water !




*Resistivity changes on Schilthorn 1999–2024 point to ground ice loss.*

*Drilling in rock glacier Muragl (2400 m asl.) in Summer 2024: water coming out of the drill hole where ice was expected. Photo: J. Noetzli.*

### Is 2003 the new normal?



*Annual running mean GST at several PERMOS sites in VS.*

2003 record values have repeatedly been reached or broken in recent years for permafrost variables.

### Rock falls from permafrost !

*Rock fall of 5.5 mio m³ Volume from a permafrost slope, April 2024. Photos: D. Hunziker (left), M. Pasini (right).*

Ongoing permafrost changes alter the mechanical properties of the ground and make it more permeable to water => stronger deformation and decrease in the stability of frozen slopes.