20 years of permafrost monitoring in the Swiss Alps: key results and major challenges

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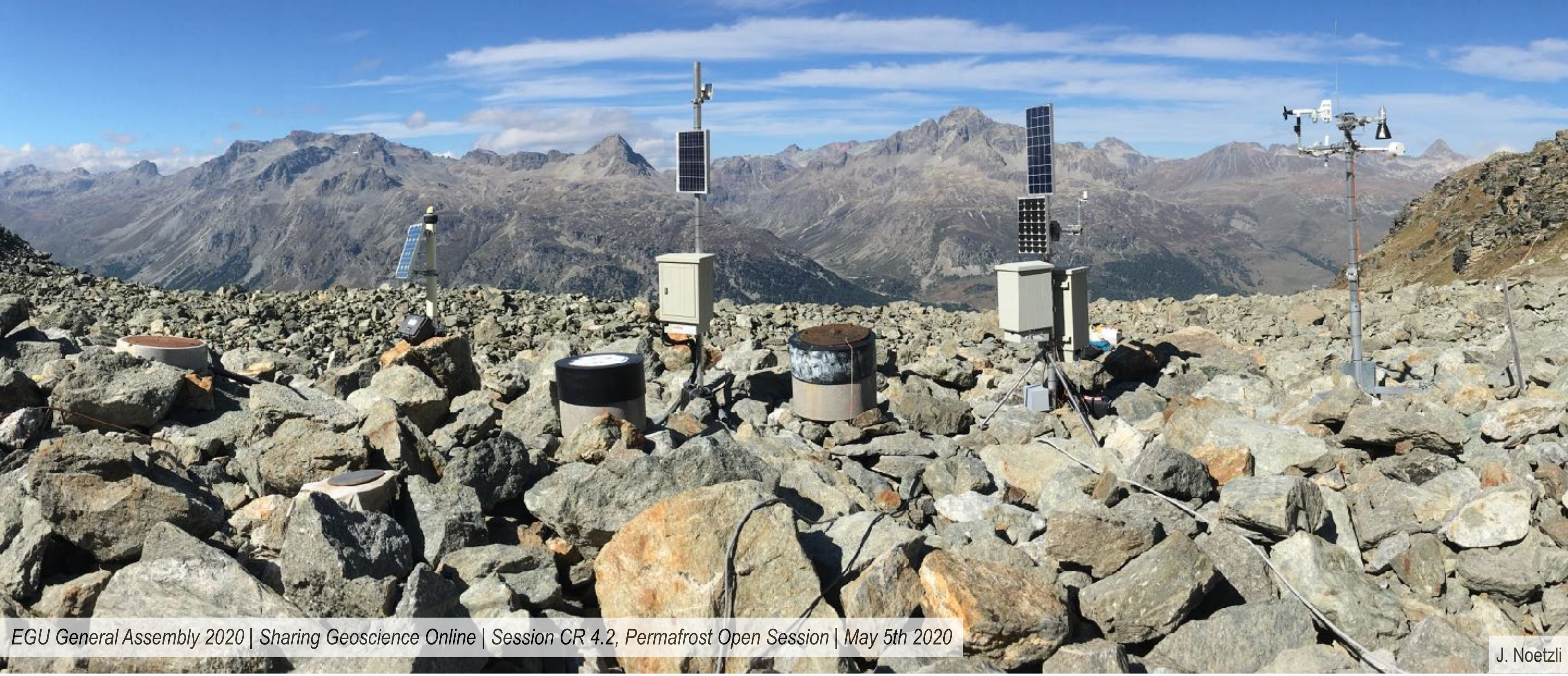

J. Noetzli

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Permafrost monitoring

- **Main objective**
  - Collection of long-term data documenting the state and changes of permafrost
  - Distinguish short-term variations and measurement errors from long-term trends
  - Provide baseline data (e.g., reference for time and locations devoid of data, model input and validation)

- **Permafrost is an ECV**
  - Global data collection by the Global Terrestrial Network for Permafrost (GTN-P)
  - Products are permafrost thermal state, active layer dynamics and (since 2020) rock glacier kinematics

- **Swiss Permafrost Monitoring Network PERMOS**
  - The first national long-term network for permafrost monitoring celebrates its 20th anniversary in 2020
  - PERMOS started in the year 2000 based on existing infrastructure from research and from the EU-Project PACE (Harris et al. 2001). It is funded by national agencies based on 4-year agreements and governed by a Scientific and Steering Committee
  - 6 research institutions carry the network and perform the fieldwork and maintenance
  - The PERMOS Office @ UniFR and @ WSL-SLF administrates and coordinates the network and observation strategies, analyses time series, writes reports, and manages and disseminates the data

Observation strategy for permafrost in the Swiss Alps

Landform-based approach

Differences in the thermal regime and its changes due to topography, temperature range, surface cover (incl. snow) and subsurface conditions (ice content) are considered more important those due to varying climate conditions.

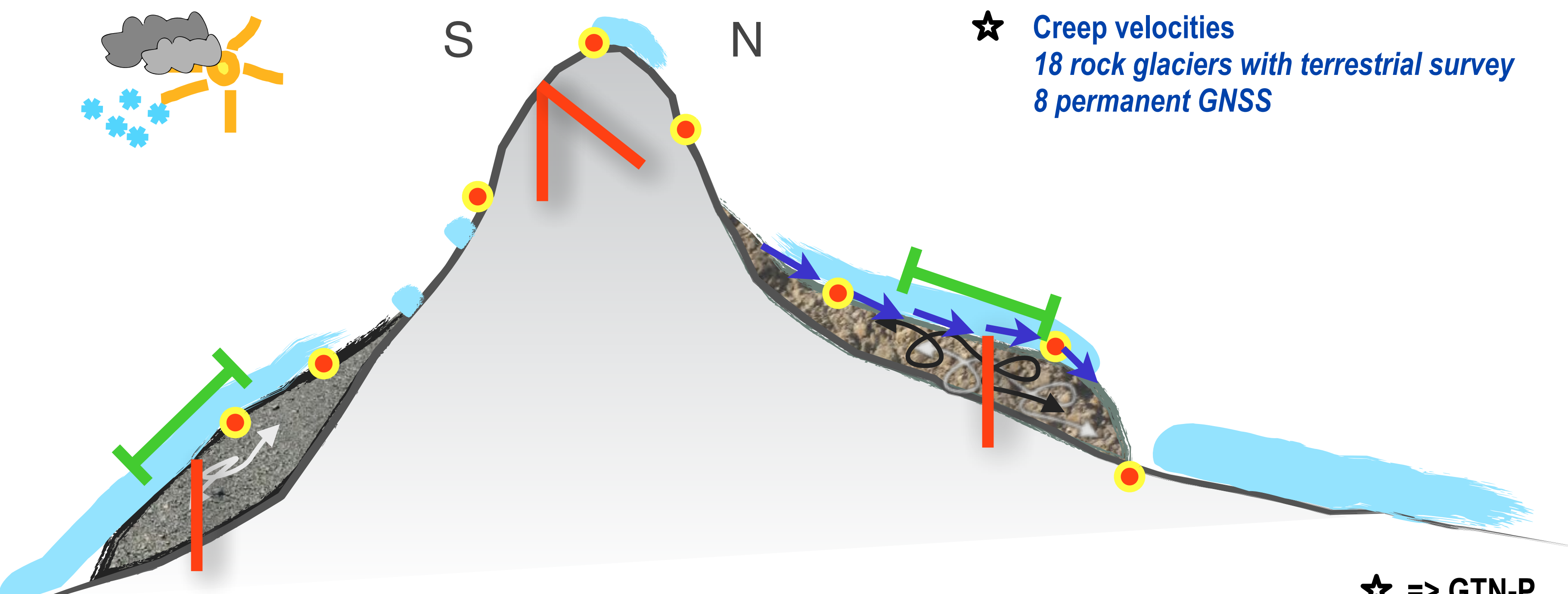
☆ **Borehole temperatures**
30 boreholes

Ground surface temperature
ca. 250 mini loggers

Climate at the site
6 meteo stations

Electrical resistivities
5 permanent ERT profiles

☆ **Creep velocities**
18 rock glaciers with terrestrial survey
8 permanent GNSS

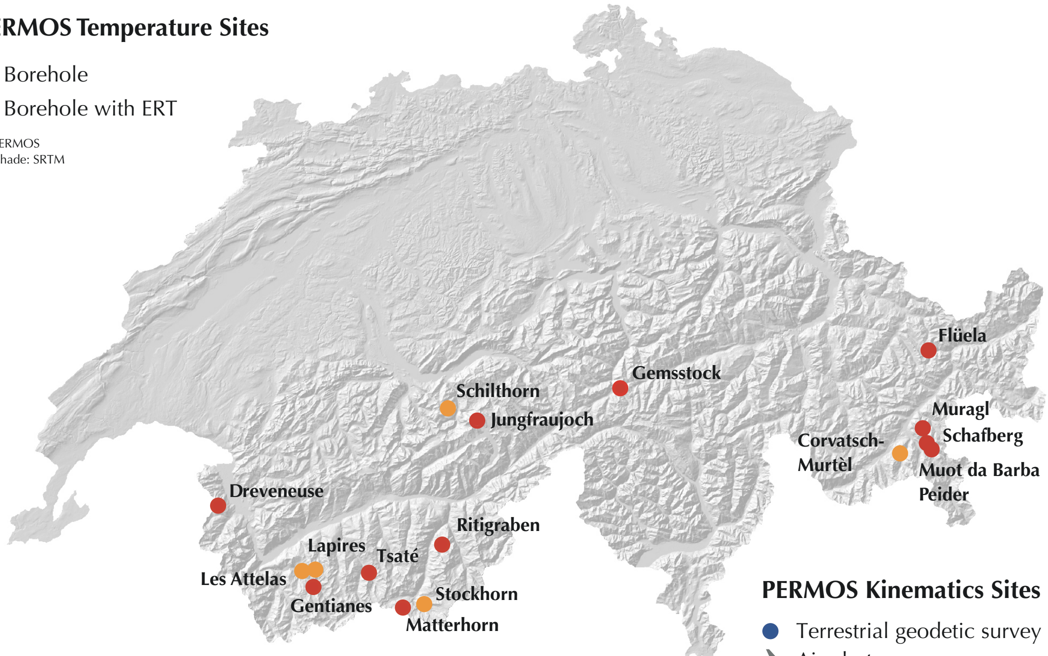


☆ => GTN-P

PERMOS monitoring sites

PERMOS Temperature Sites

- Borehole
- Borehole with ERT

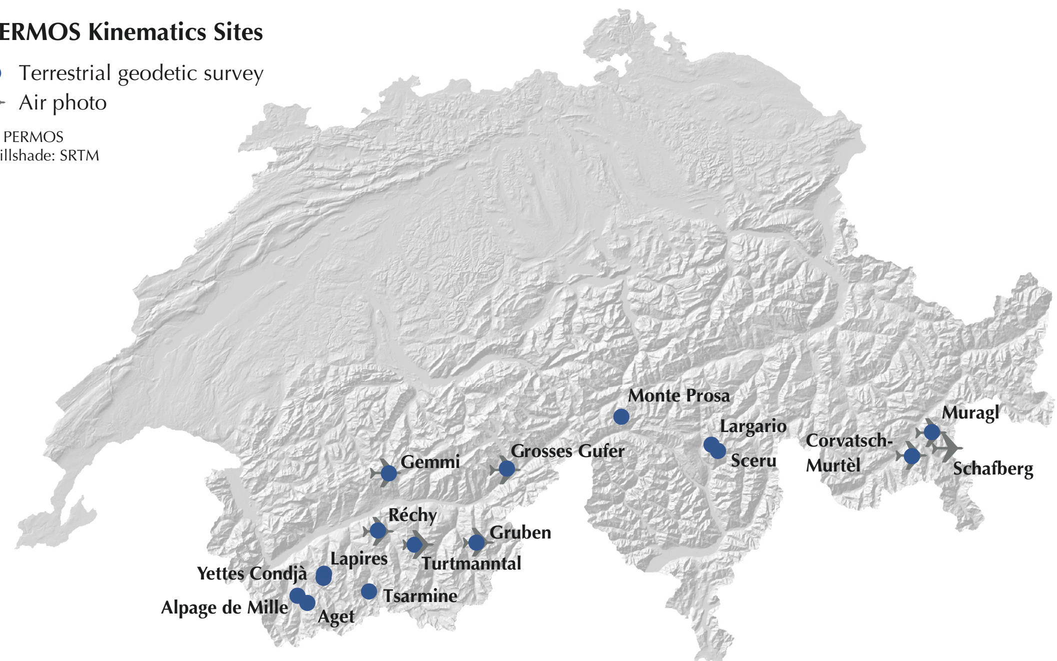


Site distribution

- 5 regions in the Swiss Alps
- crest (5), rock glacier (4), scree slopes (4), steep bedrock (2), moraine (1)
- 2400–3600 m asl.

PERMOS Kinematics Sites

- Terrestrial geodetic survey
- Air photo

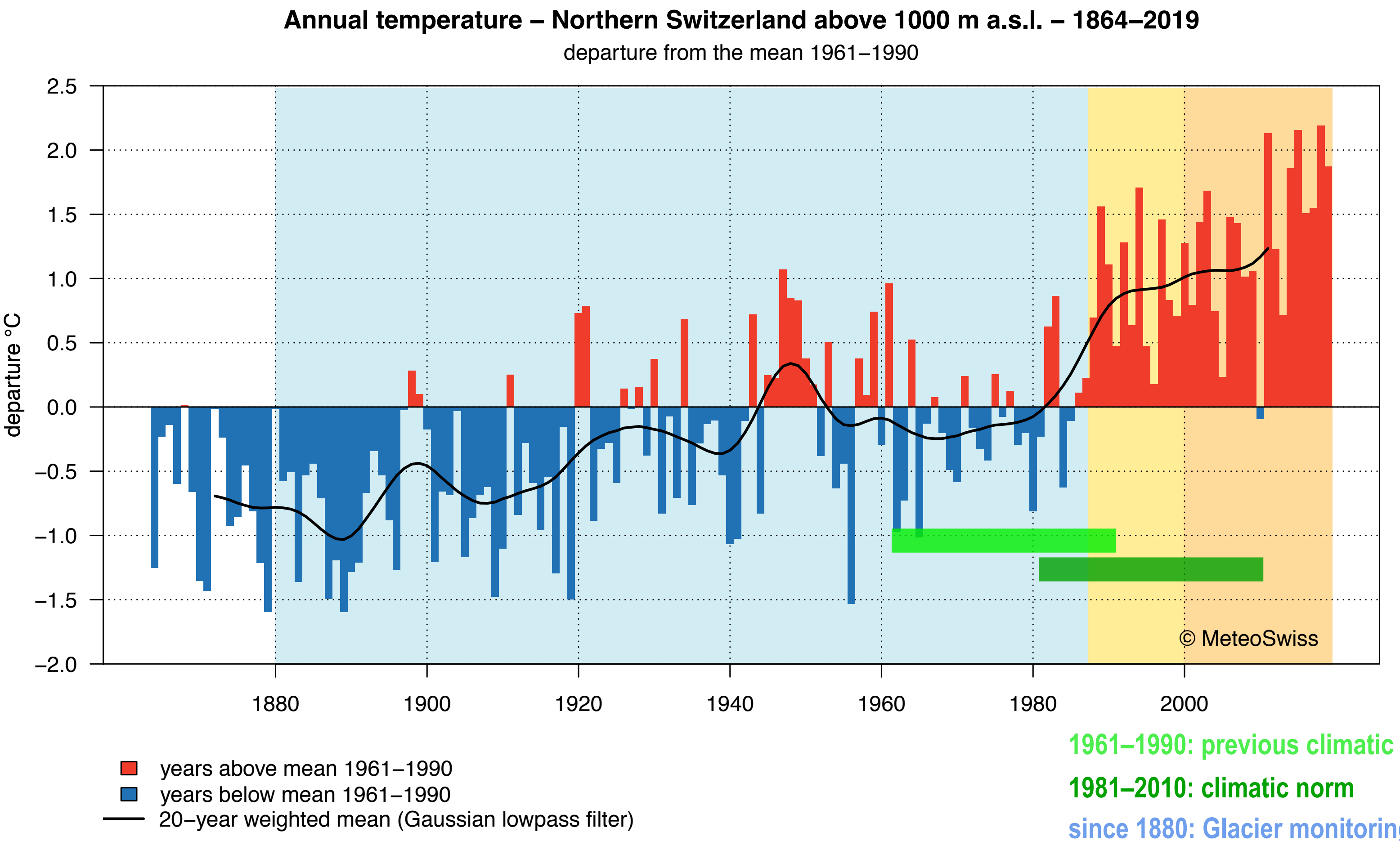


PERMOS sites today

- 16 Temperature sites with 30 boreholes
- 22 GST sites (ca. 250 GST loggers)
- 5 ERT profiles
- 15 Kinematics sites with 18 rock glacier lobes
- 8 Permanent GNSS
- 6 Meteo stations

Time scales and atmospheric conditions

- 2000–2019 was the warmest 20 year period in Switzerland since the start of the measurements in 1864
- 2010–2019 was the warmest decade in Switzerland since the start of the measurements in 1864



1961–1990: previous climatic norm

1981–2010: climatic norm

since 1880: Glacier monitoring in the Swiss Alps

since 1987: Borehole Corvatsch-Murtèl

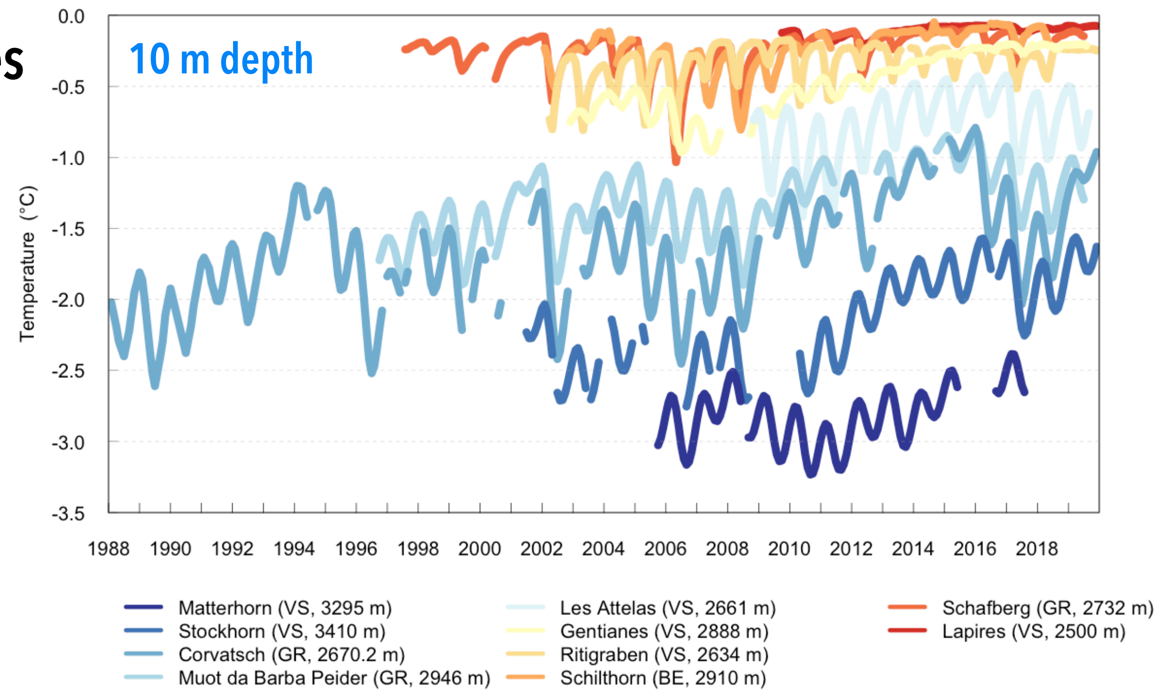
since 2000: Permafrost monitoring in the Swiss Alps

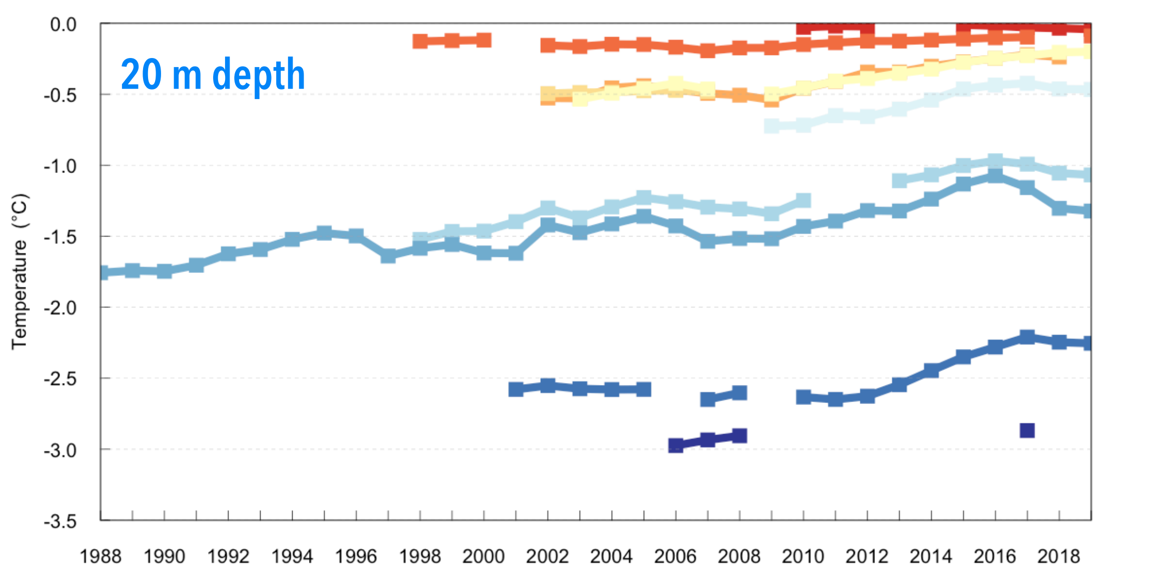

Permafrost temperatures
A. Hasler
CR800
YUASA
Valve Regulated Lead Acid Battery
NP65-12I
12V,65Ah
Pb
www.yuasaeurope.com

Key result – ground temperatures

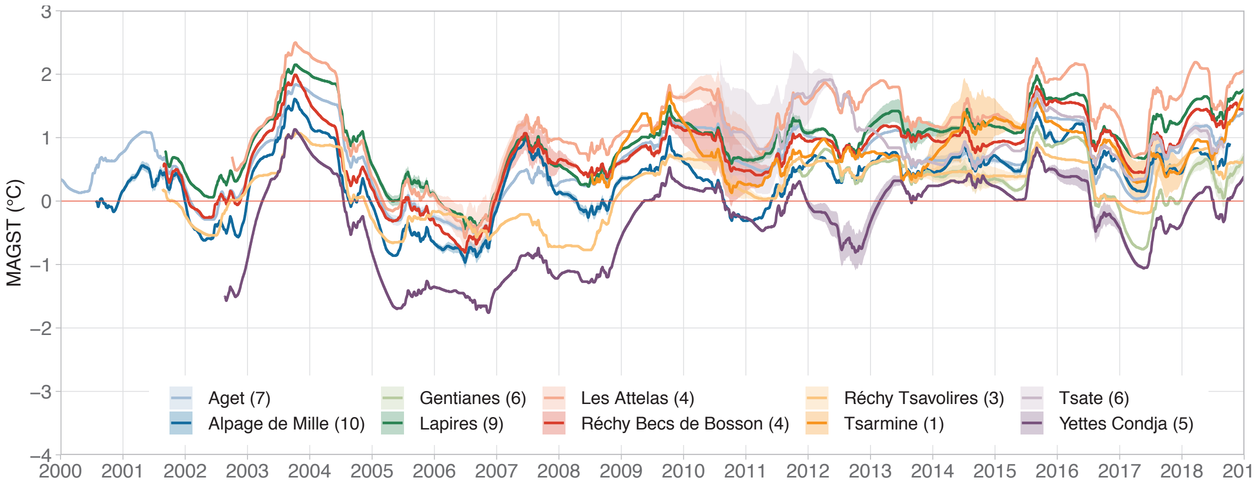
- **General warming of permafrost in the Swiss Alps**
  - Increased warming since 2010
  - Stronger warming at colder sites
  - Latent heat effects at sites little below 0 °C: small temperature signal
  - Corvatsch-Murtèl: temperature increase of ca. 1 °C at 10 m and ca. 0.5 °C at 20 m depth in 30 years

- **Seasonal effects**
  - Interruption of the warming trend after a snow poor winter 2016/2017
  - Warming resumed after hot summers 2018 and 2019



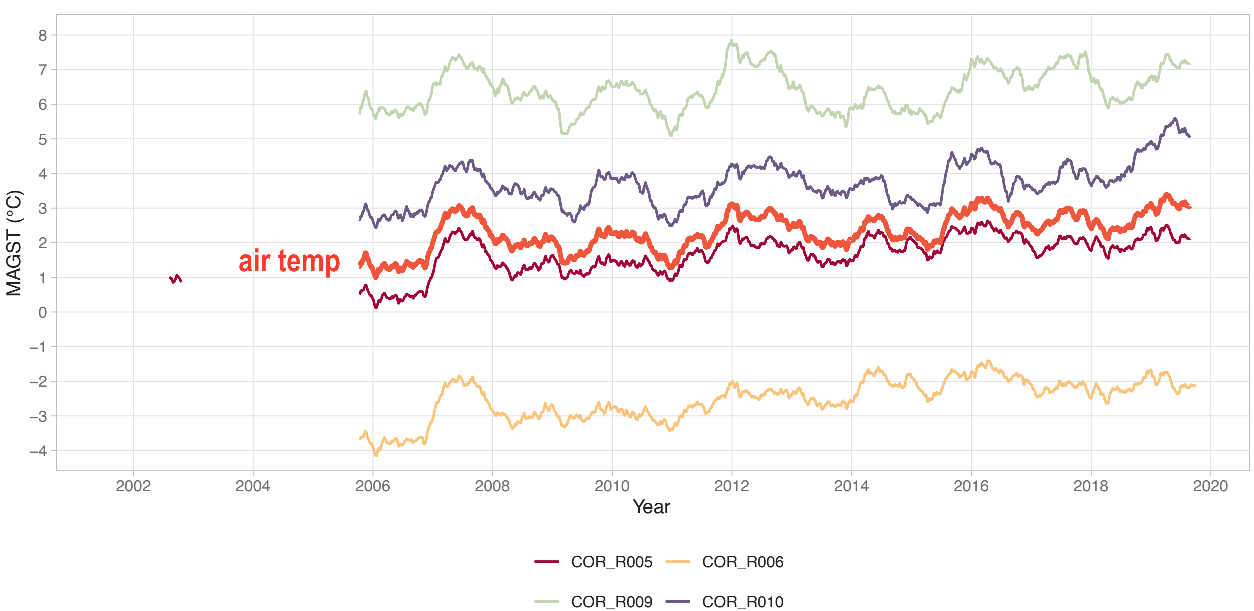


Key results – ground surface temperatures



- **GST in course blocks and debris**
  - strong influence of snow cover and summer air temperature

Running annual mean of GST in the lower Valais, site means (# of loggers in brackets)



- **GST in steep rock**
  - closely follow air temperature in their temporal evolution
  - strong influence of air temperature (all year)

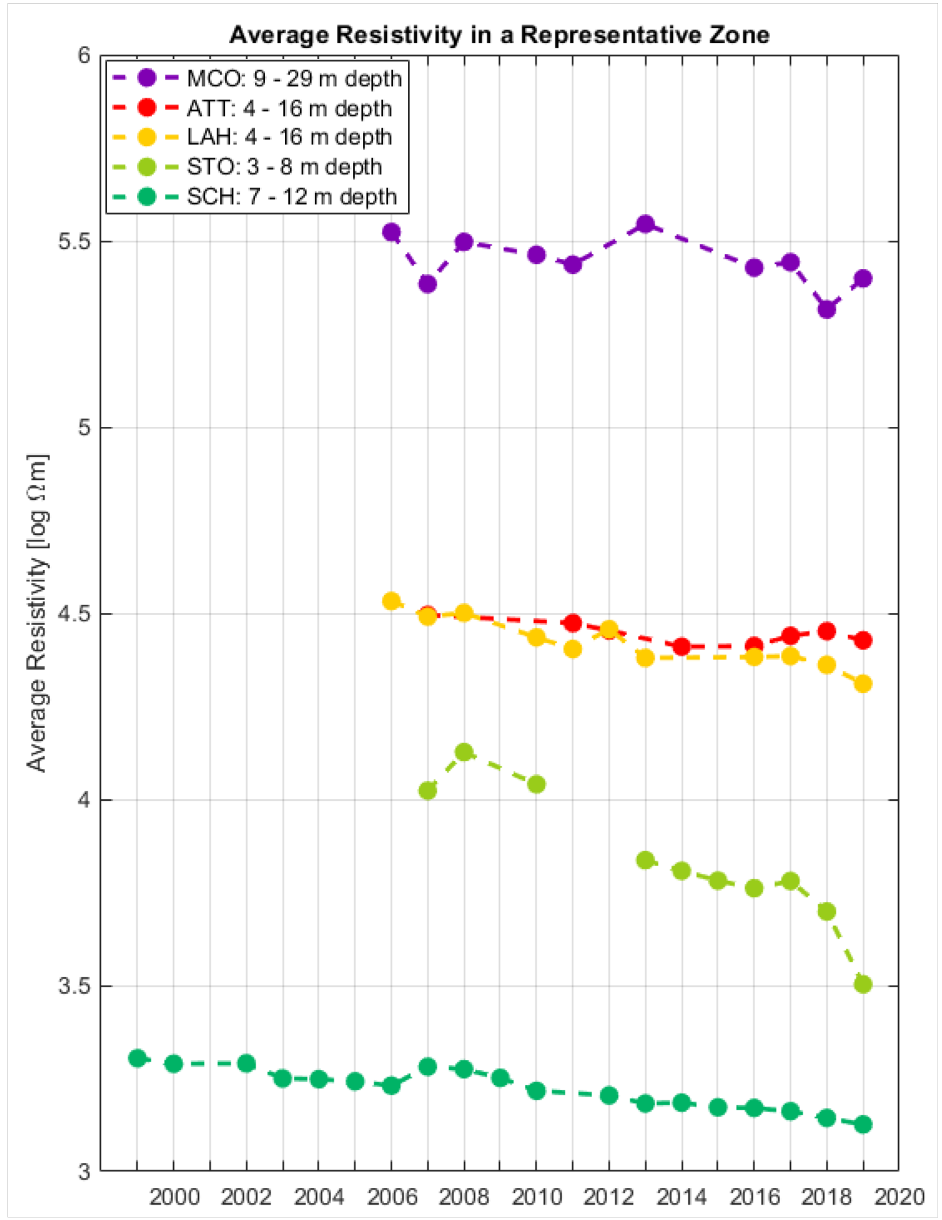
Running annual mean of GST in steep rock in the Corvatsch area (individual loggers), air temperature at the borehole station in thick red

Electrical resistivities

C. Hilbich

Key result – Electrical resistivity tomography

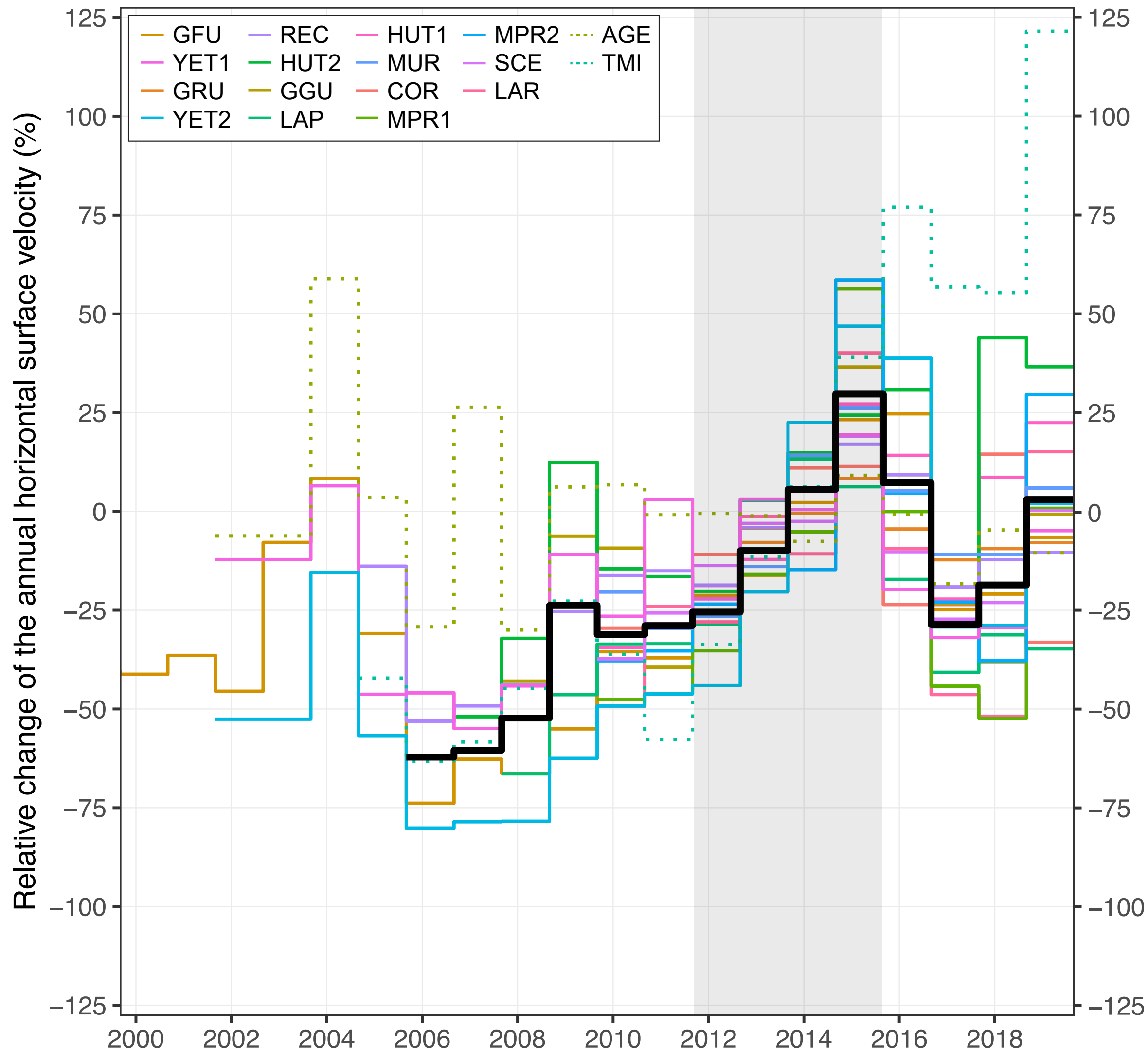
- **Overall decrease in electrical resistivities at the borehole sites with annual ERT survey**
  - Points to an increase in unfrozen water and a decrease of ground ice
  - No interruption of the trend following the snow poor winter 2016/2017
    => long lasting effects!



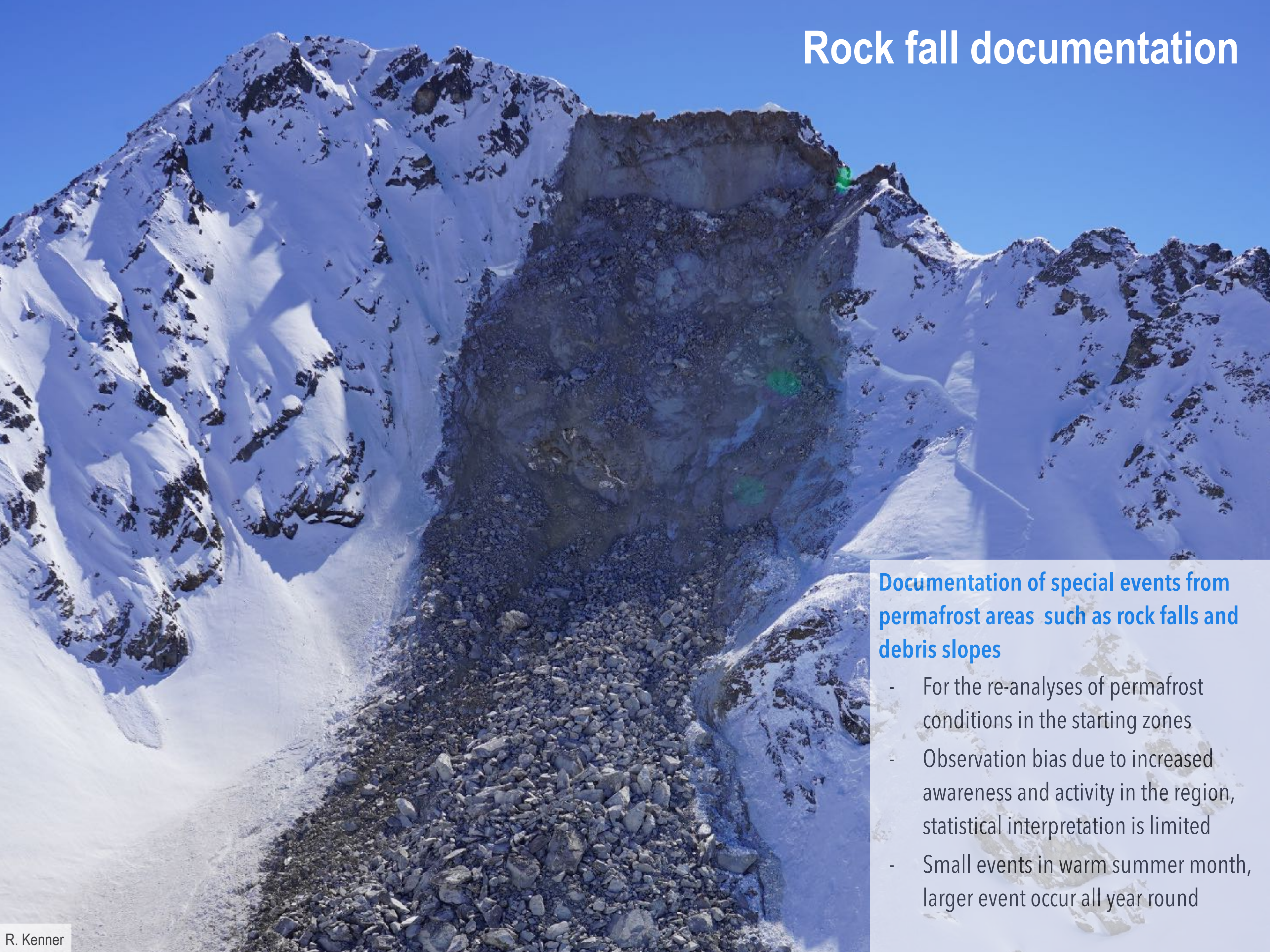

Creep velocities
J. Noetzli

Key results – Rock glacier kinematics

- **Creep velocities follow ground temperatures and generally increased**
  - Regional differences exist
  - Decrease in creep velocities together with temperature decrease following the snow poor winter 2016/2017
- **New observation element from 2019: automatic and continuous GNSS measurements**
  - Complement annual geodetic surveys at a larger number of points on a landform with continuous information
  - Describe intra-annual/seasonal variations



Rock fall documentation



R. Kenner

Documentation of special events from permafrost areas such as rock falls and debris slopes

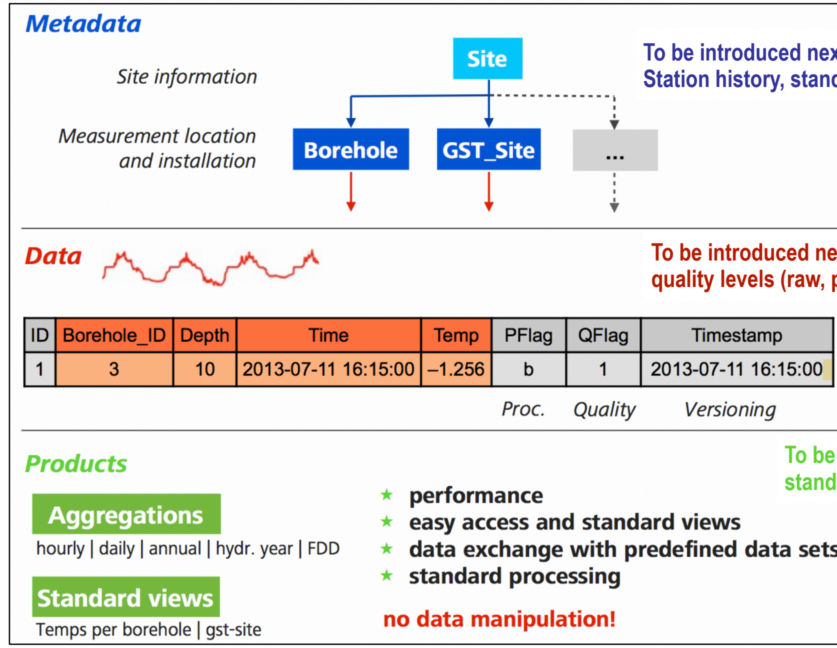
- For the re-analyses of permafrost conditions in the starting zones
- Observation bias due to increased awareness and activity in the region, statistical interpretation is limited
- Small events in warm summer month, larger event occur all year round

Data management

http://newshinypermos.geo.uzh.ch/app/DataBrowser/

- **PERMOS DMS**
  - Largest collection of permafrost data in mountain regions
  - Secure long-term data storage requires a robust and flexible data base system
  - Relational data base (PostgreSQL), in/out and processing based on R
  - Open data policy (for non-commercial use)
  - Continuous work on automatic reading, writing, flagging, processing and plotting of the data
  - Standards for the calculation of products are needed (e.g., aggregations)

- **PERMOS Data Portal**
  - Data publication via annual DOI and the PERMOS Data Portal
  - Raw data of online boreholes stored in raw data base and accessible in extra browser
  - Data exchange with GTN-P, Alpine Permafrost Database



To be introduced next: Station history, standardized field logs

To be introduced next: quality levels (raw, proc, corr, gap-filled)

To be introduced next: standardized routines

Access for advanced users via direct DB access

Main challenges and lessons learned

- **Boreholes**
  - Technical issues and unforeseen difficulties multiply with time
  - 4 boreholes re-drilled in the past 5 years due to blocked thermistor chains and no calibration/validation possibility
  - Measure small temperature changes near the melting point that are in the order of measurement uncertainties
  - Close gaps in geography and characteristics (e.g., high elevation cold permafrost, fractured rock between debris areas and steep rock)

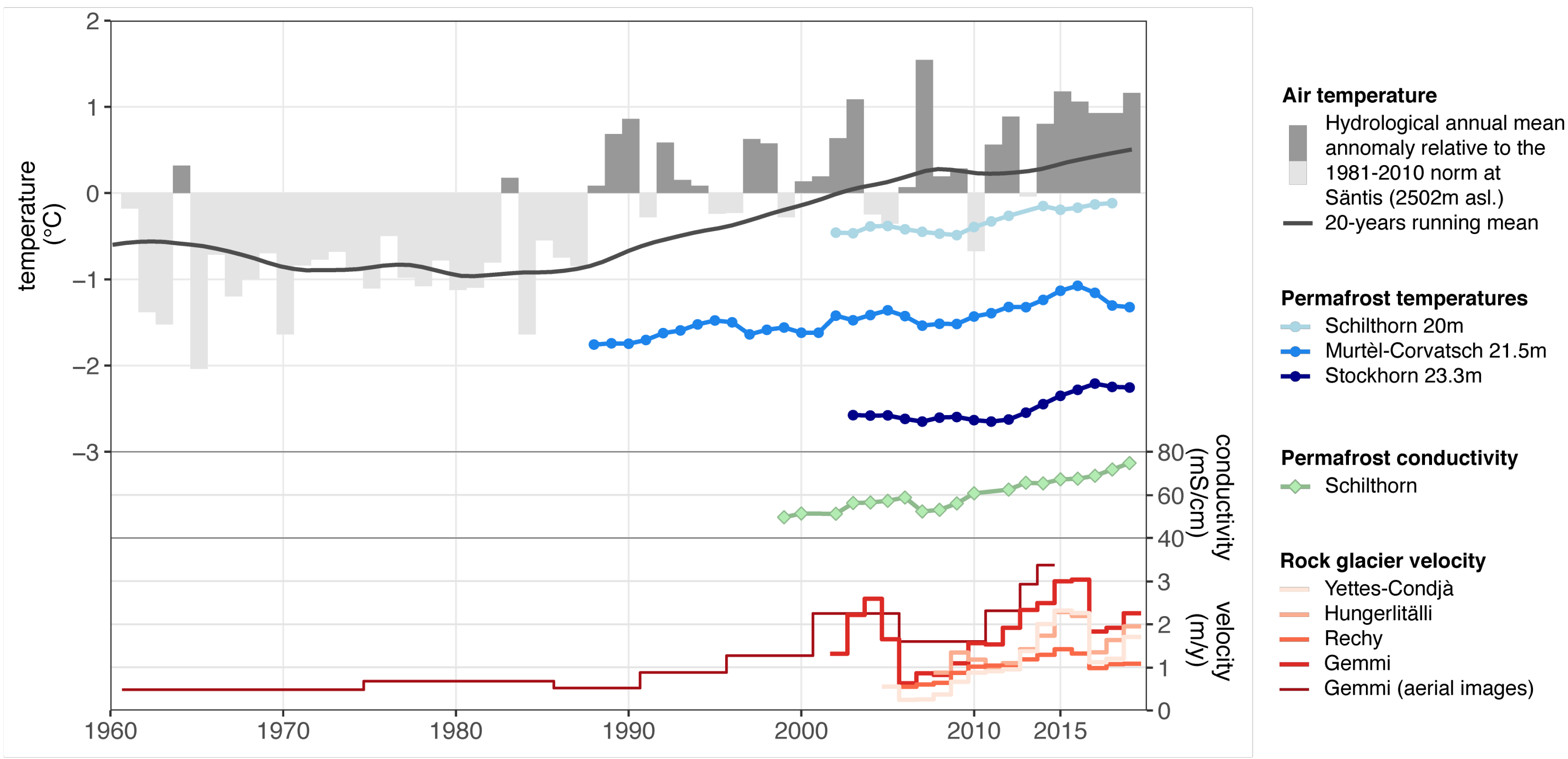
- **Rock glaciers**
  - Monitor rock glaciers that strongly advance: keep the same measurement points on a rock glacier with up to 25 m displacement in 25 years? Representativeness of the observed signal (e.g., topography changes)

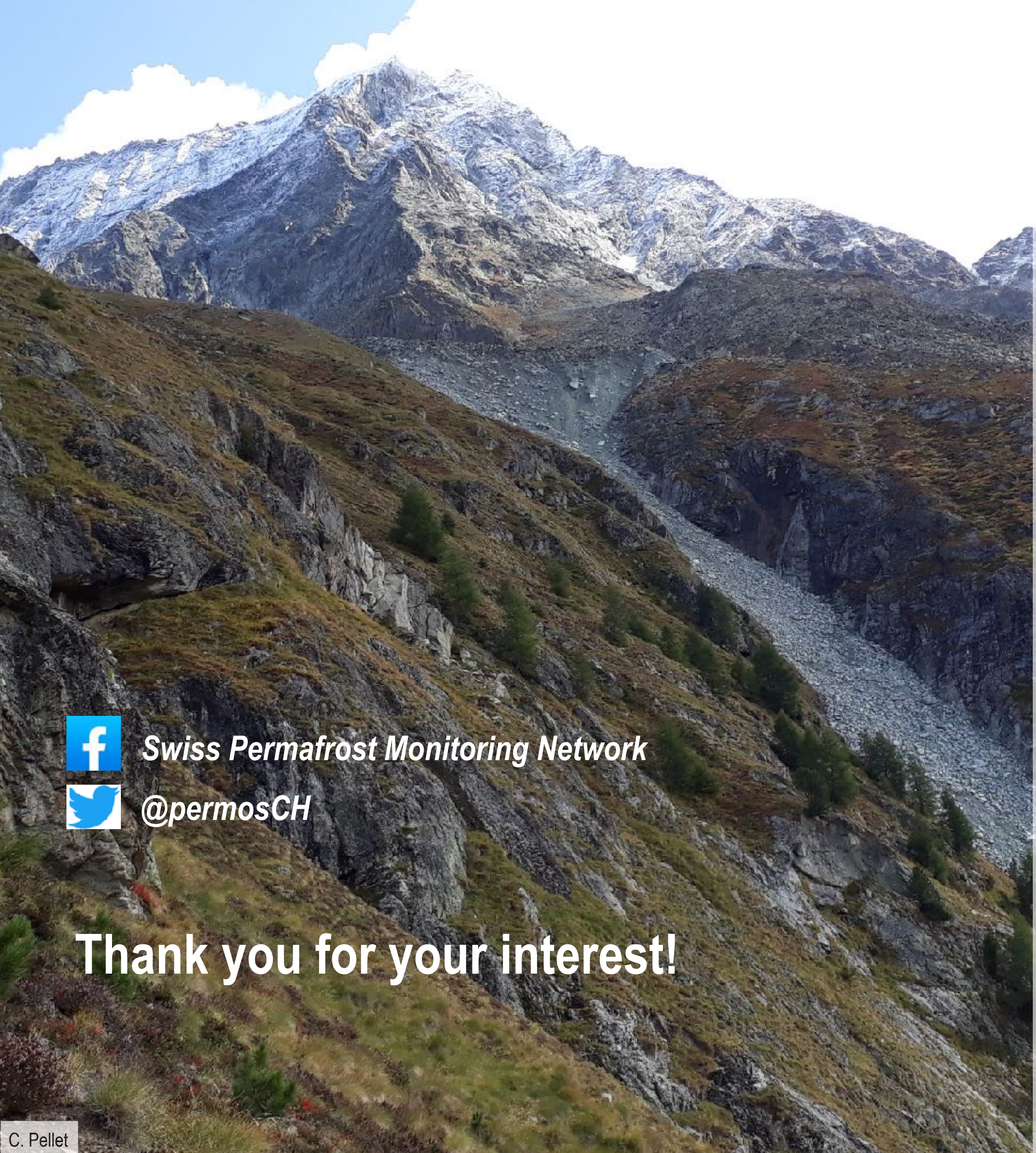
- **Standardization of measurements and data processing**
  - Further operationalize the science driven network grown based on available infrastructure
  - Reproducibility and traceability of the measurement and processing steps are key
  - Evolving monitoring techniques, new elements from 2019: meteo data for energy balance, continuous GNSS for seasonal creep velocity pattern
  - Securing and improving the long time series

- **Long-term monitoring is no easy task and needs staying power over decades!**
  - The core task is the main challenge: continue high quality measurements over decades
  - Technical issues and unforeseen difficulties multiply with time, plan renovation when infrastructure is getting older
  - Timely reporting (digital reports online), sound assessments and trend analyses (more quantitative statements)
  - Time, people, long-term commitment (funding, positions, knowledge, promoting young researchers)

Synthesis of the results

- **All observation elements describe a congruent picture of permafrost warming in the Swiss Alps**
  - The warming trend is more pronounced at cold sites and in steep bedrock slopes
  - Geophysics show a significant decrease in ice/water ratio
  - Rock glaciers are accelerating
  - Snow conditions can strongly impact the permafrost temperatures and creep velocities





C. Pellet

Swiss Permafrost Monitoring Network

@permosCH

Thank you for your interest!

The PERMOS Group

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…. and many more…. !!!

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