

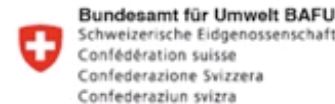
# Real-time Permafrost Monitoring in Matter Valley

Jan Beutel, ETH Zurich

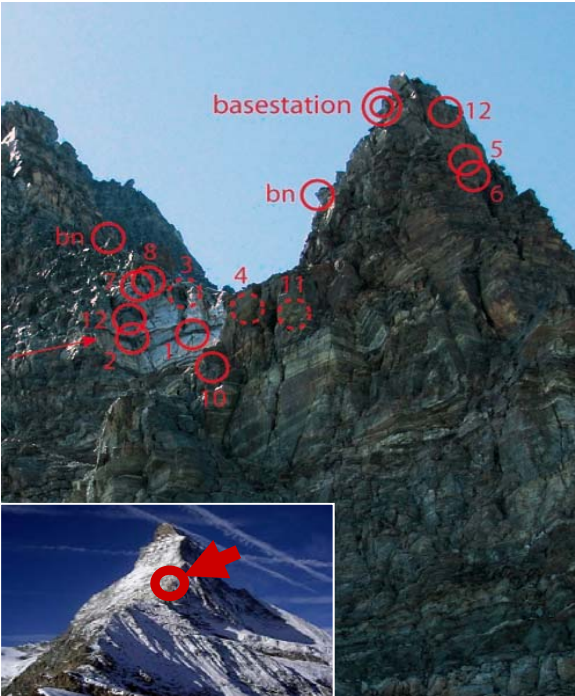
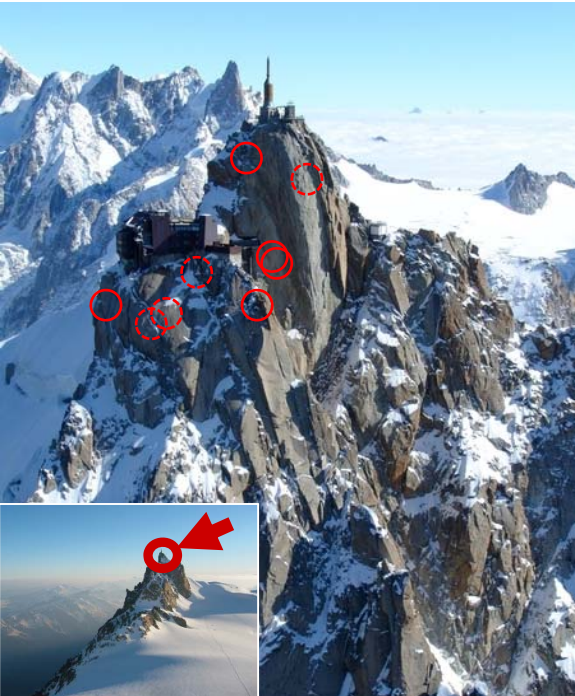
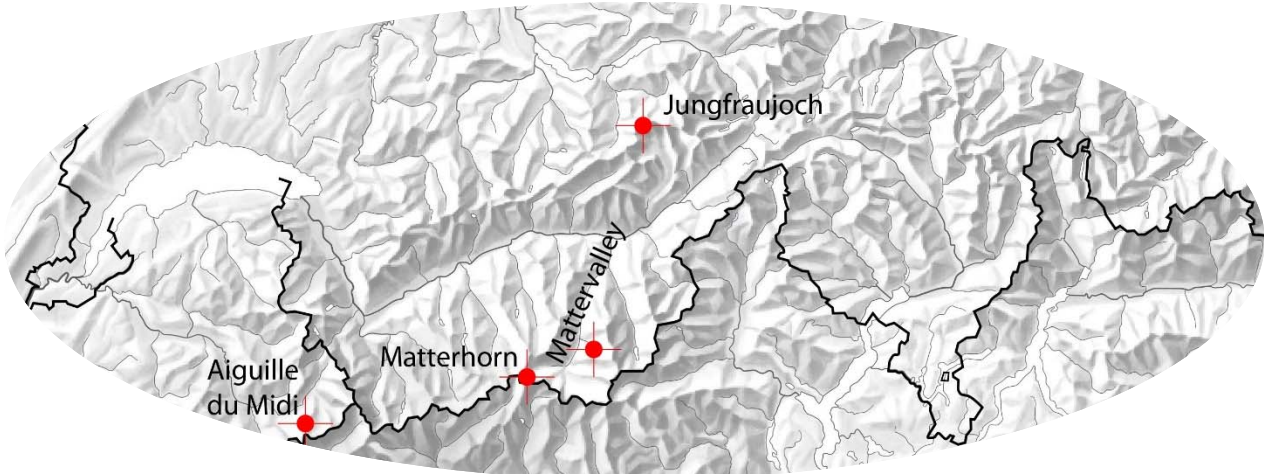


# PermaSense

- Interdisciplinary geo-science and engineering collaboration
- Consortium of several projects, start in 2006
- Fundamental as well as applied research
  - Long-term, high-quality sensing in harsh environments
  - Better quality data, obtained online
  - Measurements that have previously been impossible
  - Enabling new science, answering fundamental questions related to decision making, natural hazard early-warning
- More than 35 people, 17 PhD students



# Our Field Sites: Precision Scientific Instruments



# Miniature Low-Power Wireless Sensors

- Static, low-rate sensing (120 sec)
- Simple scalar values: voltages, resistivity, digital sensors
- 4-5 years operation ( $\sim 200 \mu\text{A}$  avg. power)
- $\sim 0.1$  Mbyte/node/day
- 6+ years experience,  $\sim 946,838,342$  data points




**Our patient does  
not fit into a  
laboratory**



So the laboratory  
has to go on the  
mountain





A base station  
collects and relays  
the data to the  
valley

[B. Buchli, F. Sutton, J. Beutel and L. Thiele: *Dynamic Power Management for Long-Term Energy Neutral Operation of Solar Energy Harvesting Systems*. Proc. SenSys 2014.

B. Buchli, F. Sutton, J. Beutel and L. Thiele: *Towards Enabling Uninterrupted Long-Term Operation of Solar Energy Harvesting Embedded Systems*. Proc. EWSN 2014

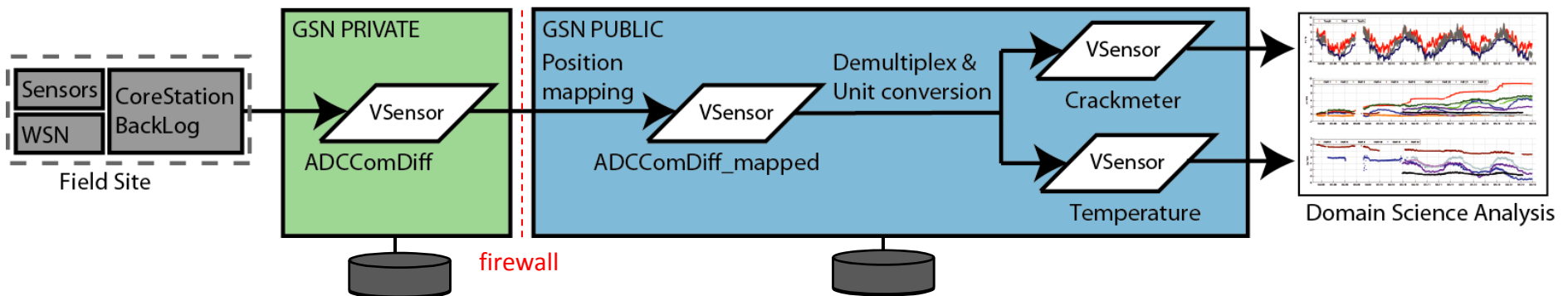
**M. Keller, J. Beutel and L. Thiele: *The Problem Bit*. Proc. DCOSS 2013 ★ Best Paper Award ★**

B. Buchli, D. Aschwanden and J. Beutel: *Battery State-of-Charge Approximation for Energy Harvesting Embedded Systems*. Proc. EWSN 2013.

M. Keller, J. Beutel and L. Thiele: *How Was Your Journey? Uncovering Routing Dynamics in Deployed Sensor Networks with Multi-hop Network Tomography*. Proc. SenSys 2012.]

# Online Data Management & Access

- Global Sensor Network (GSN)
  - Data streaming framework from EPFL (K. Aberer)
  - Organized in “virtual sensors”, i.e. data types/semantics
  - Hierarchies and concatenation of virtual sensors enable on-line processing
  - Dual architecture translates data from machine representation to SI values, adds metadata



Data from field site is received by the private GSN server “as is” and **stored** in a primary database.



Data is passed on to a public GSN server where it is **mapped** to metadata (positions, sensor types, calibration) and **converted** to convenient data formats.

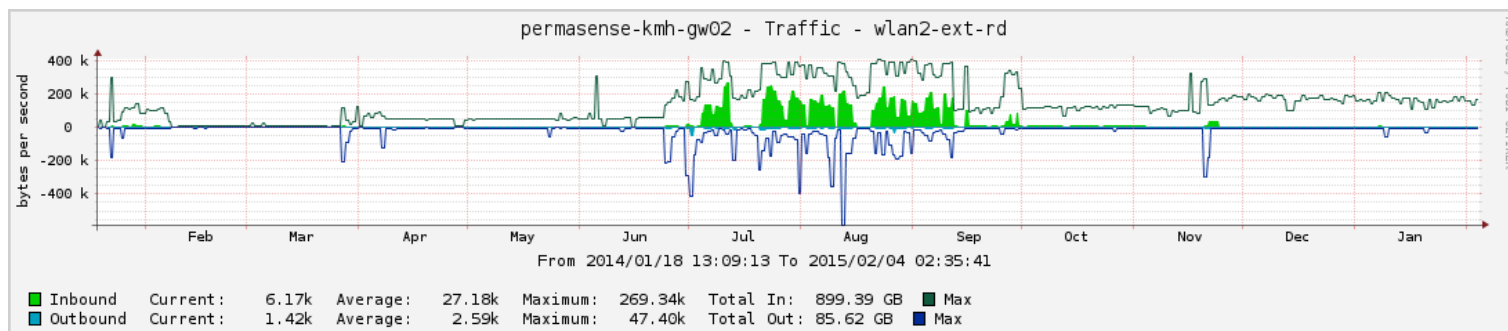
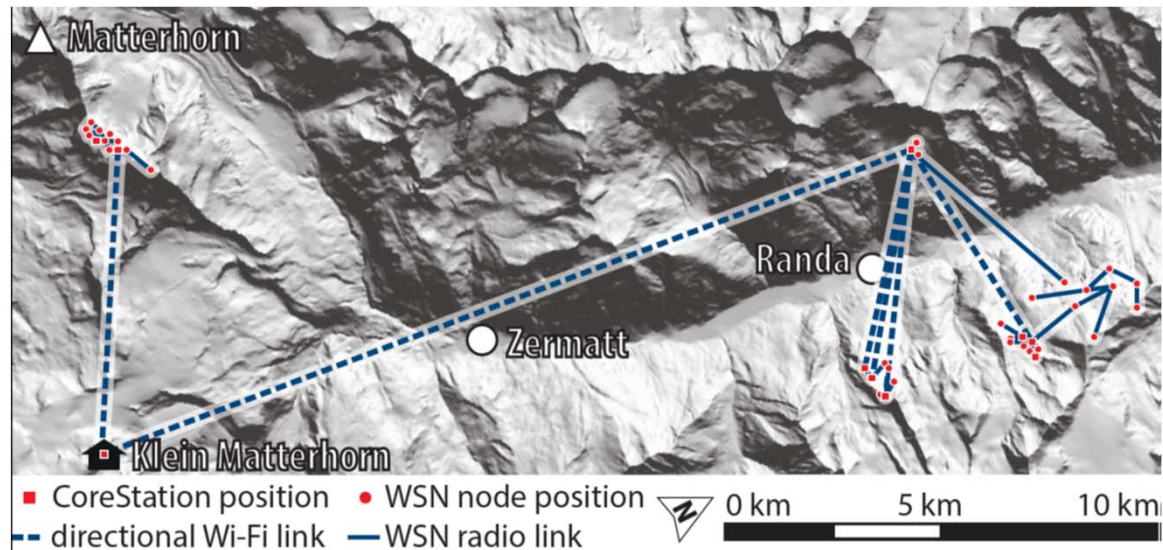


Data is available for download and analysis using **external tools**.



# WLAN Long-haul Communication

- WLAN (802.11a) backbone using directional links
- Leased fiber/DSL from Zermatt Bergbahnen AG to mountaintop



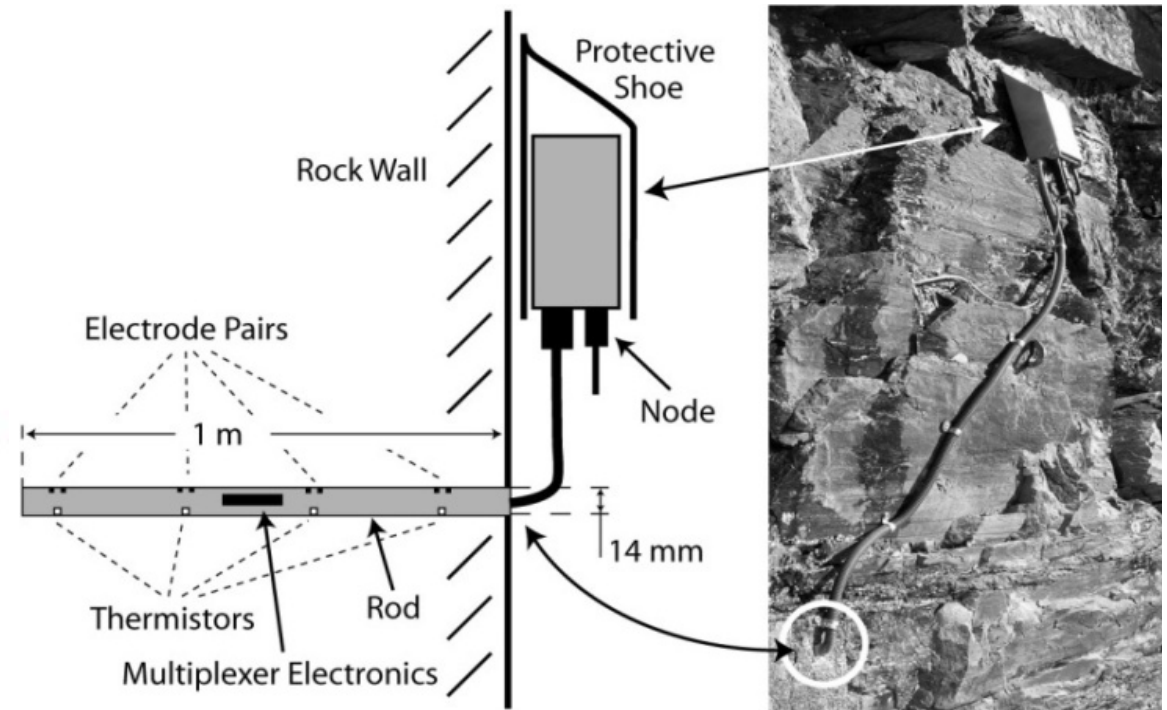
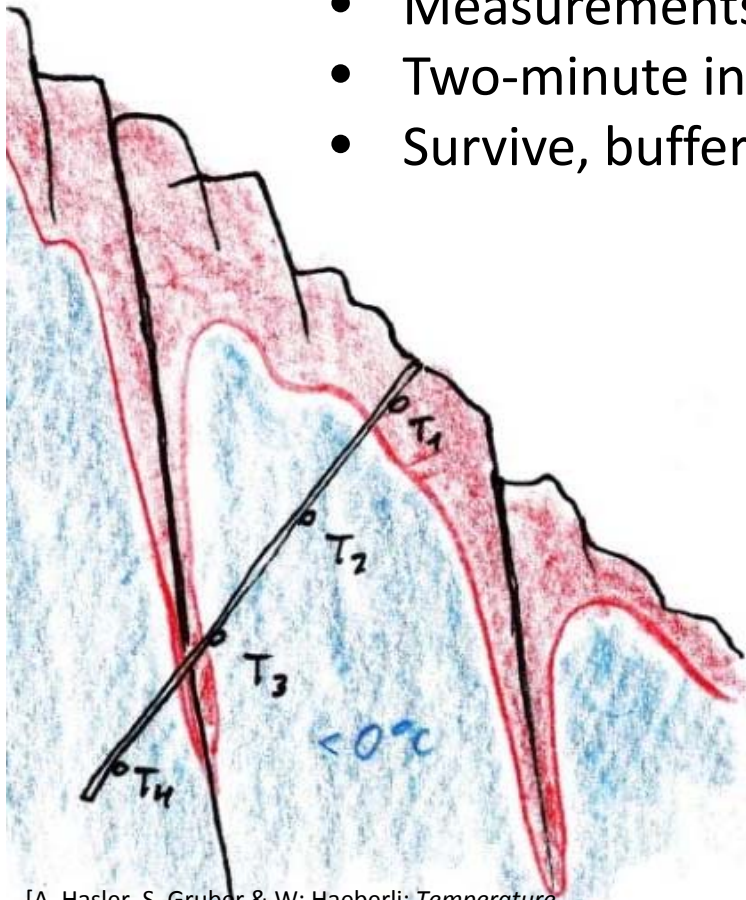
# Randa Grossguger Relay Station



# Shallow Rock/ice Temperature Profiles

Aim: Understand temperatures in heterogeneous rock and ice

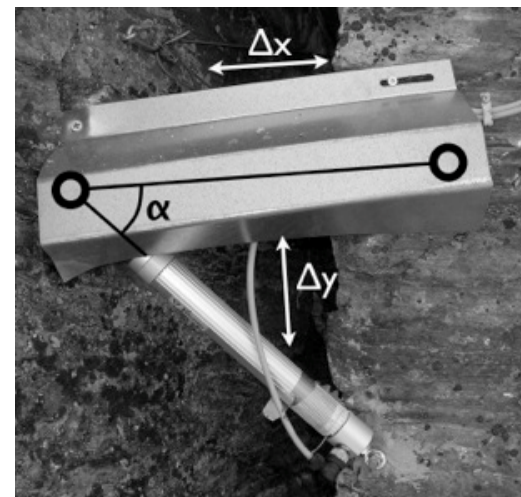
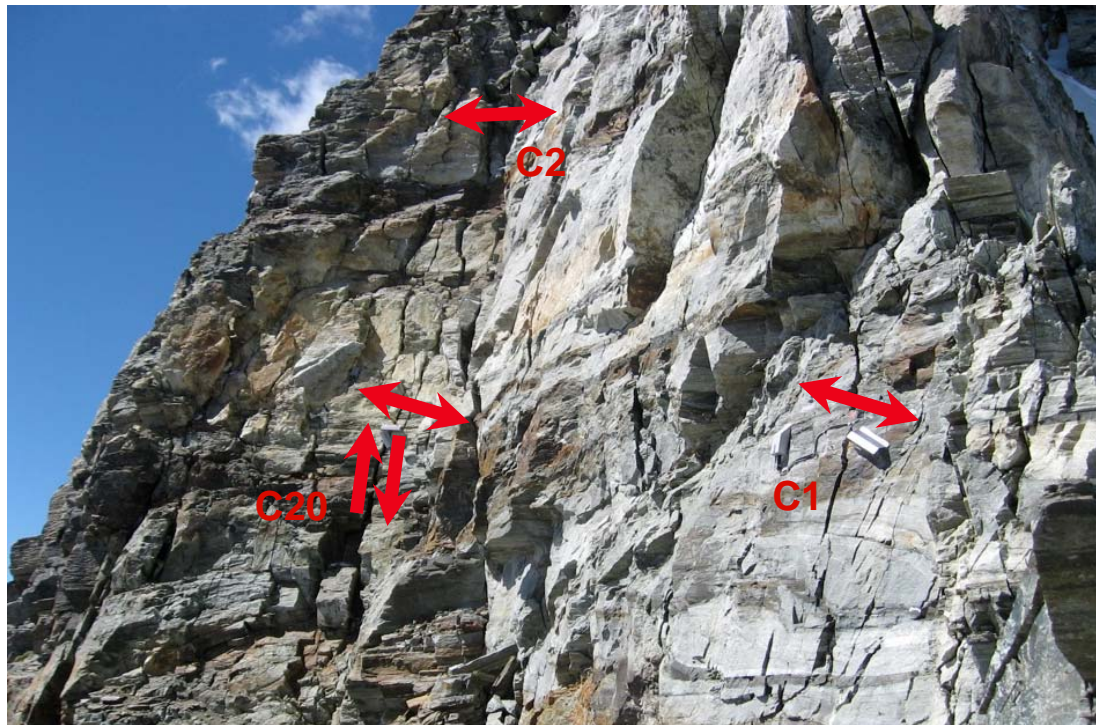
- Measurements at several depths
- Two-minute interval, autonomous for several years
- Survive, buffer and flush periods without connectivity



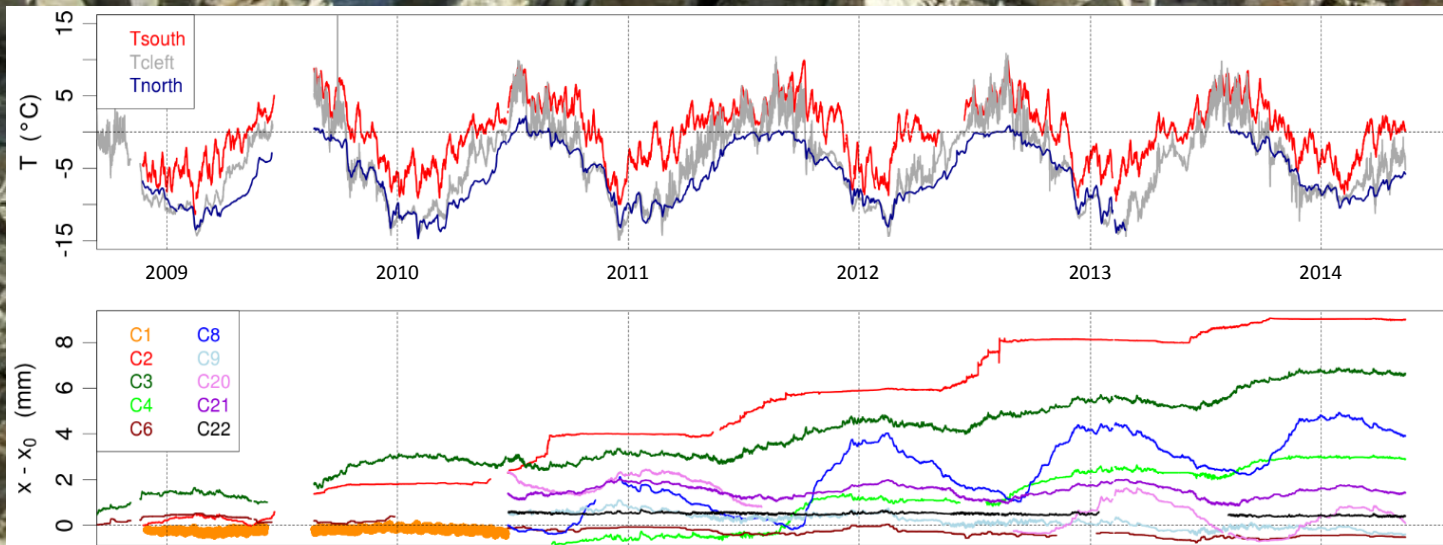
[A. Hasler, S. Gruber & W. Haeberli: *Temperature variability and thermal offset in steep alpine rock and ice faces*. *The Cryosphere*, 5, 977-988.]

# Assessment of Kinematic Behavior

- 1 and 2-dimensional crackmeter instrumentation in the 2003 rockfall detachment zone

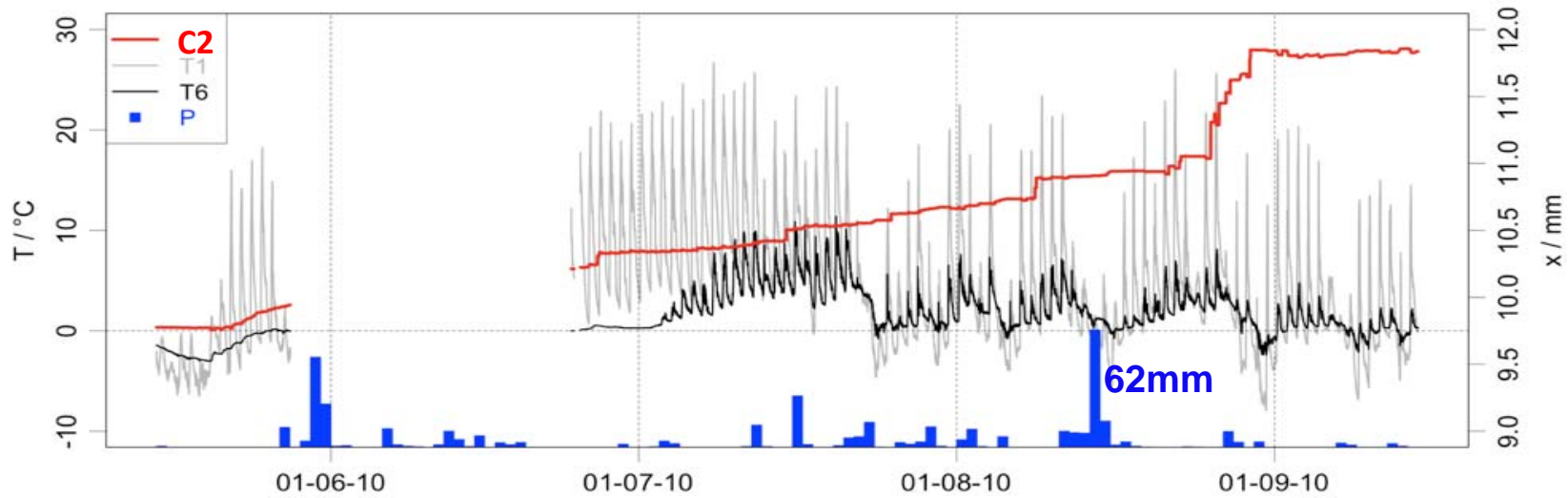


# The clefts at Hörnli ridge move in distinct patterns

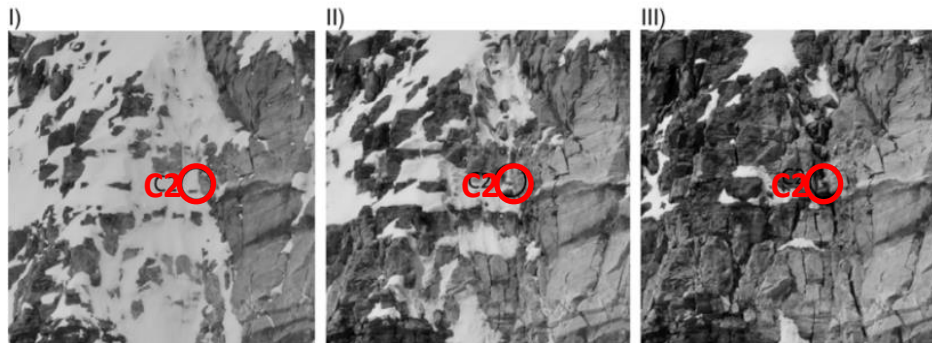
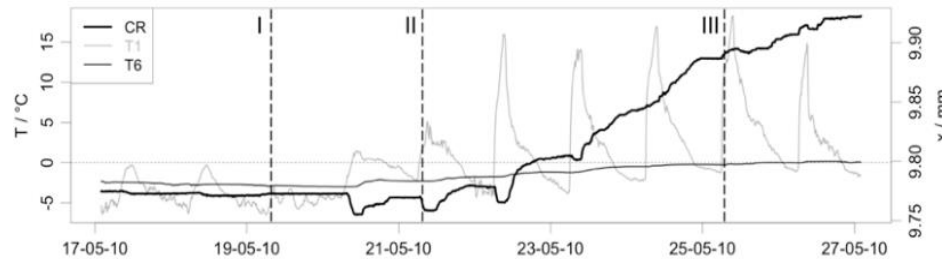


[A. Hasler, S. Gruber and J. Beutel:  
*Kinematics of steep bedrock permafrost.*  
*J. Geophys. Res.*, 117, F01016.]

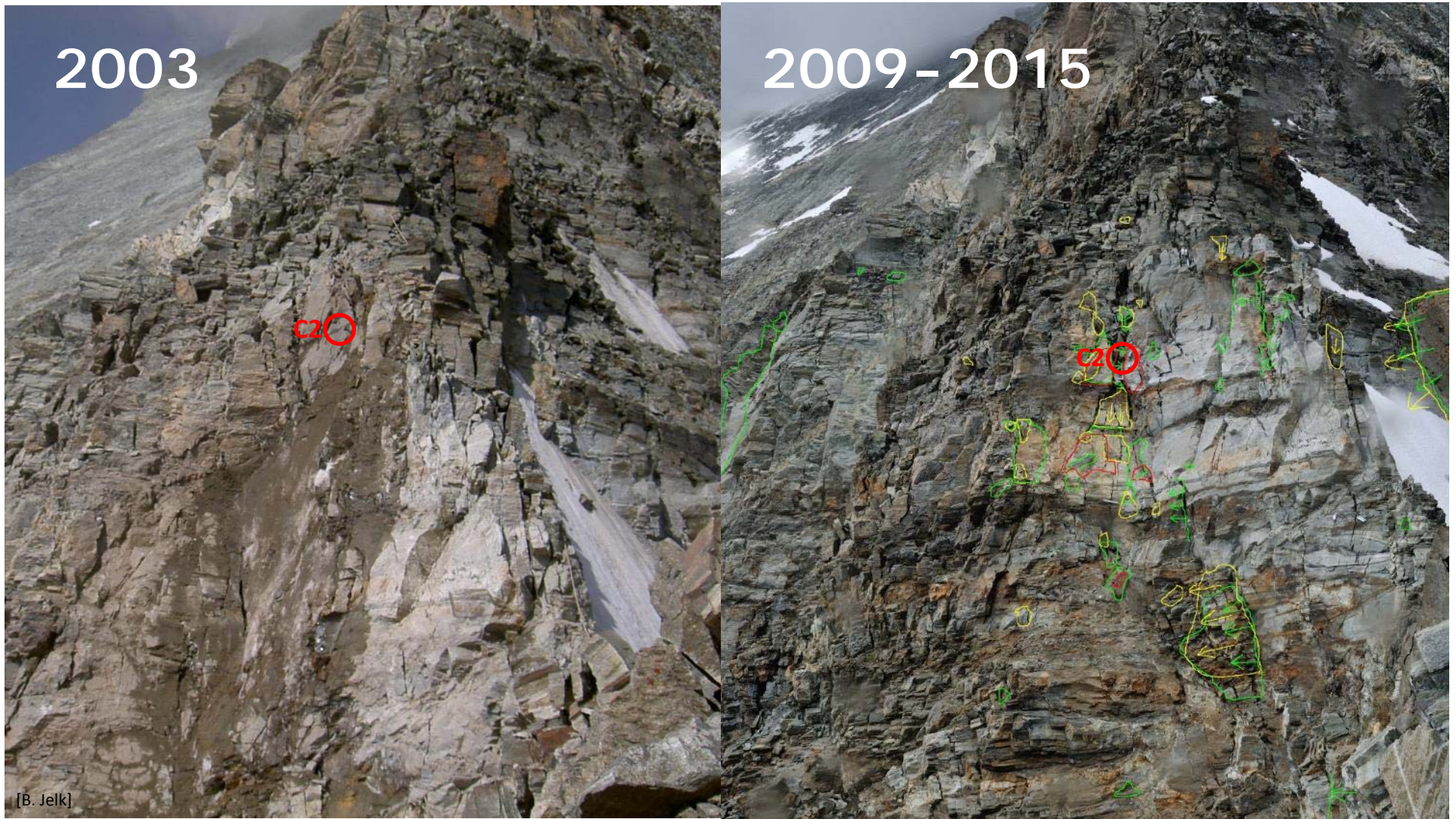
# Strong Stepwise Opening in Summertime



Reinforcement  
by snowmelt



# High-resolution Timelapse Photography



2009

c20





2010



2011

c20



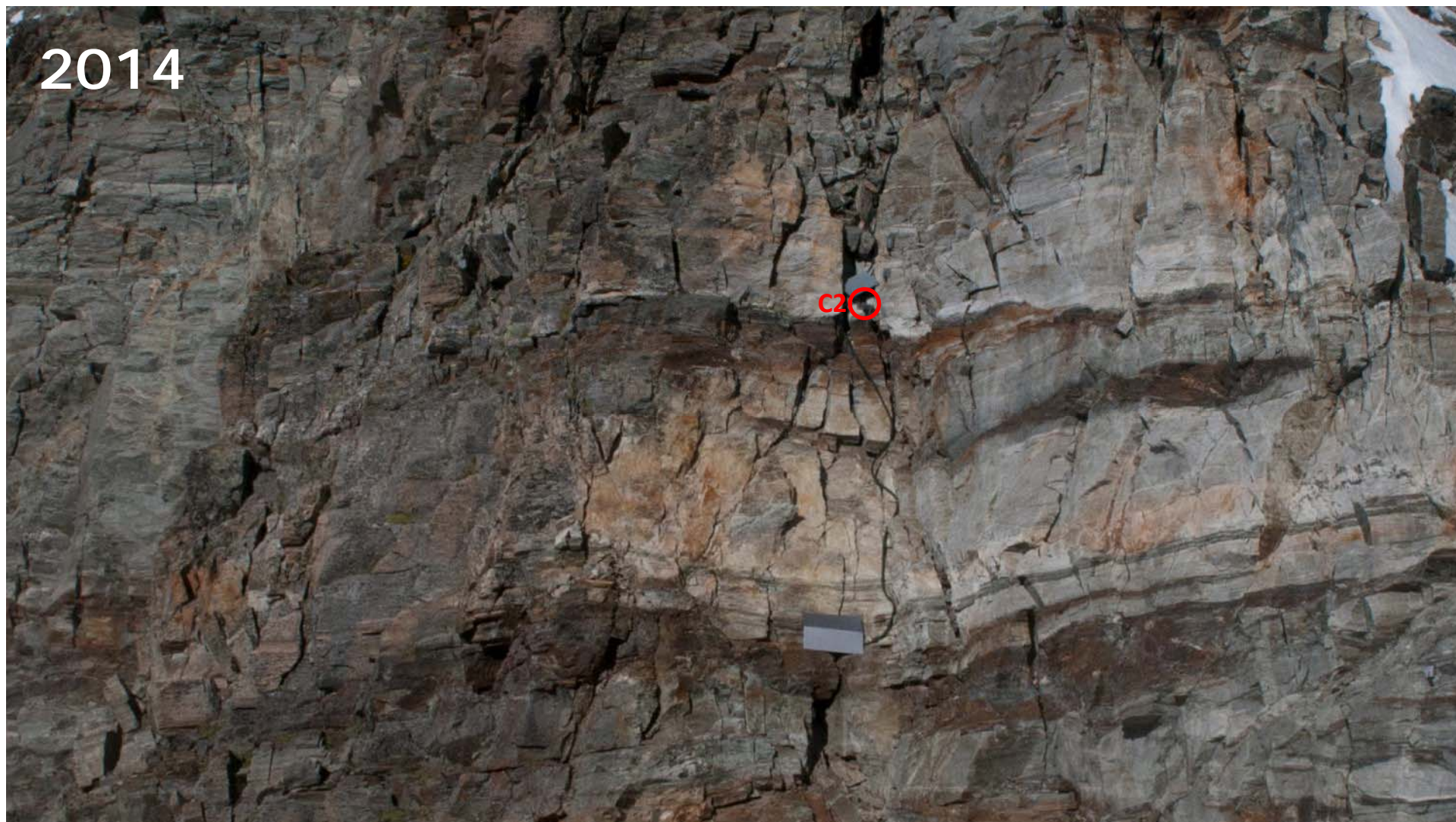
2012



2013



2014



18.05.2015

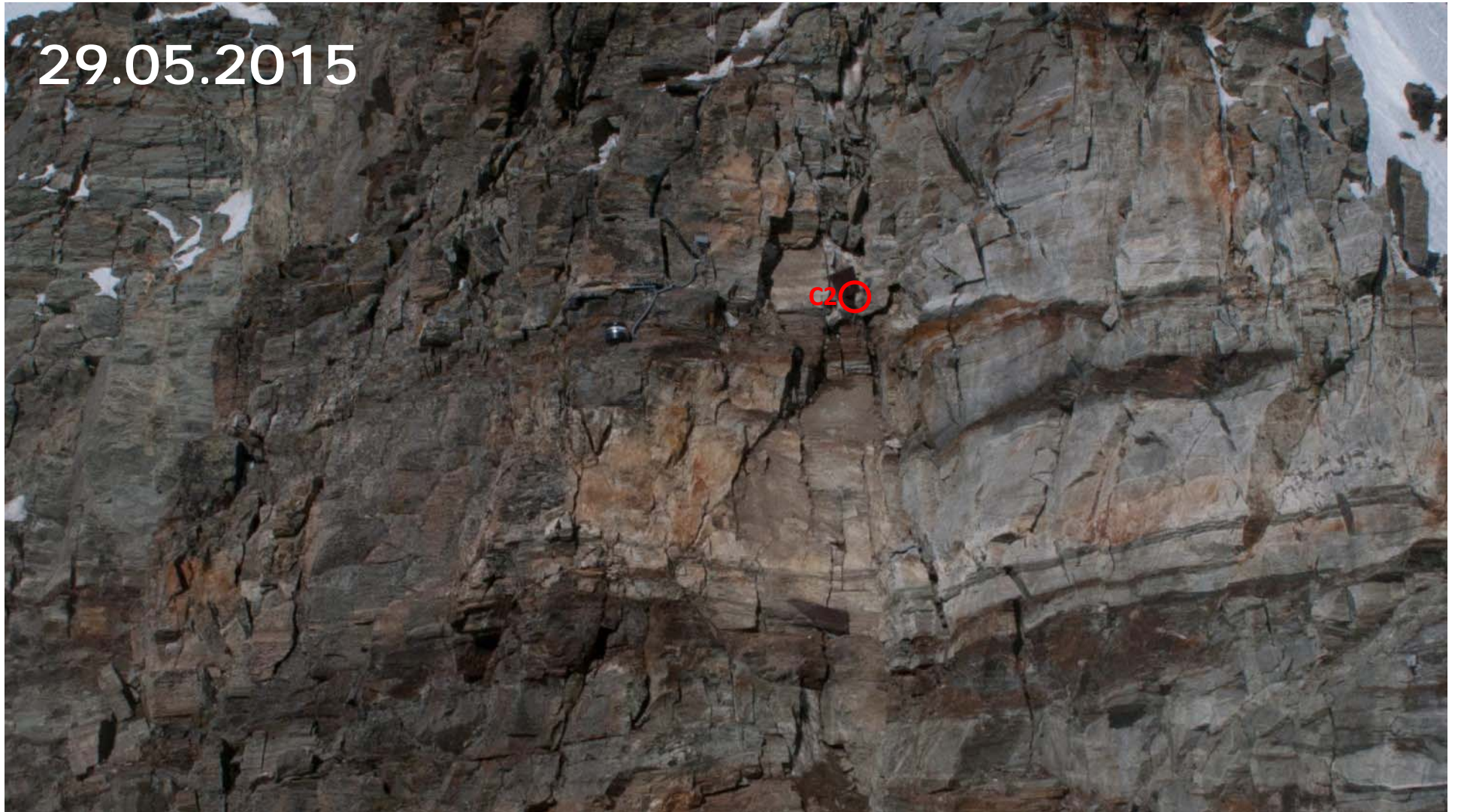


19.05.2015

c20



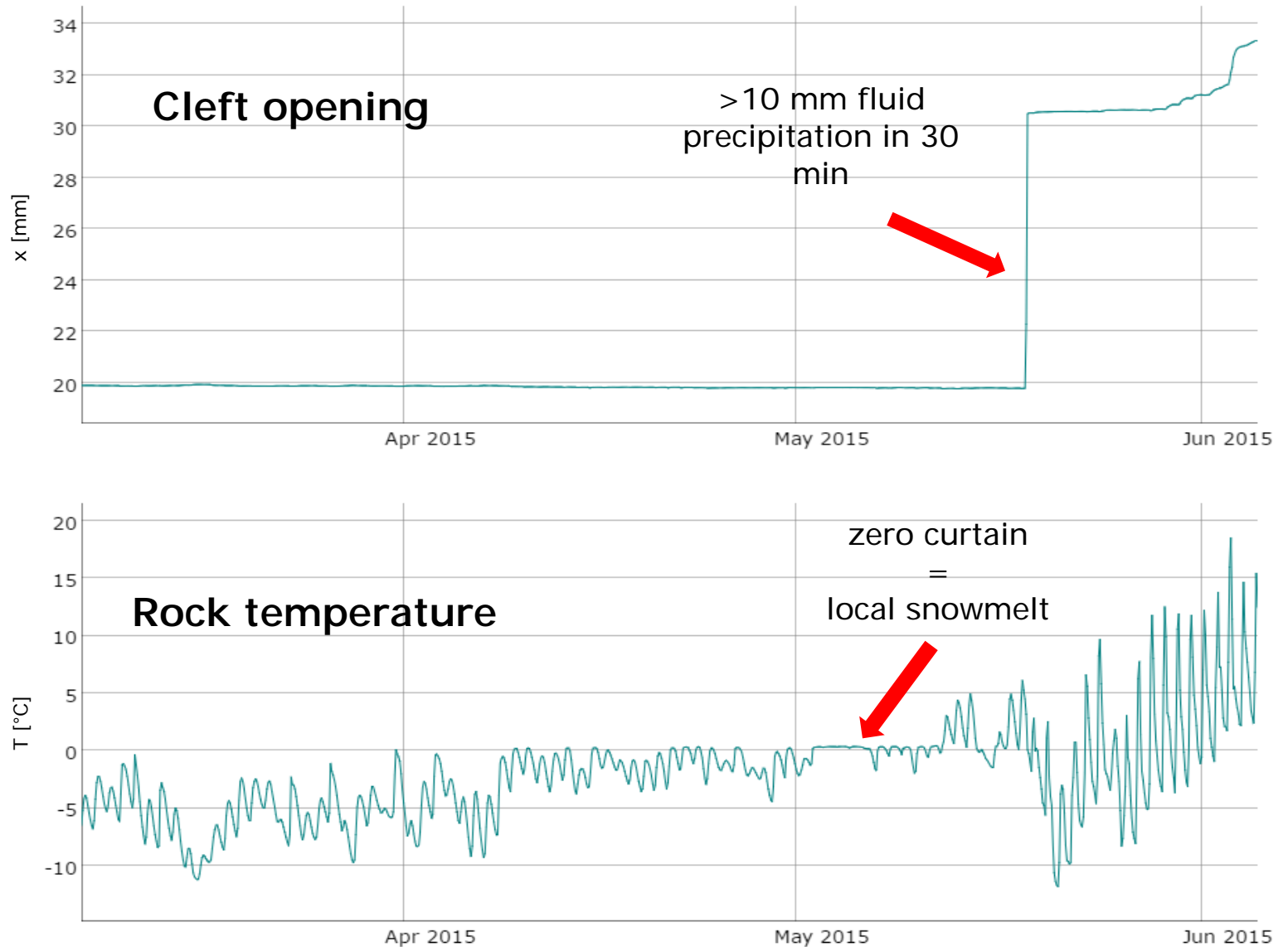
29.05.2015





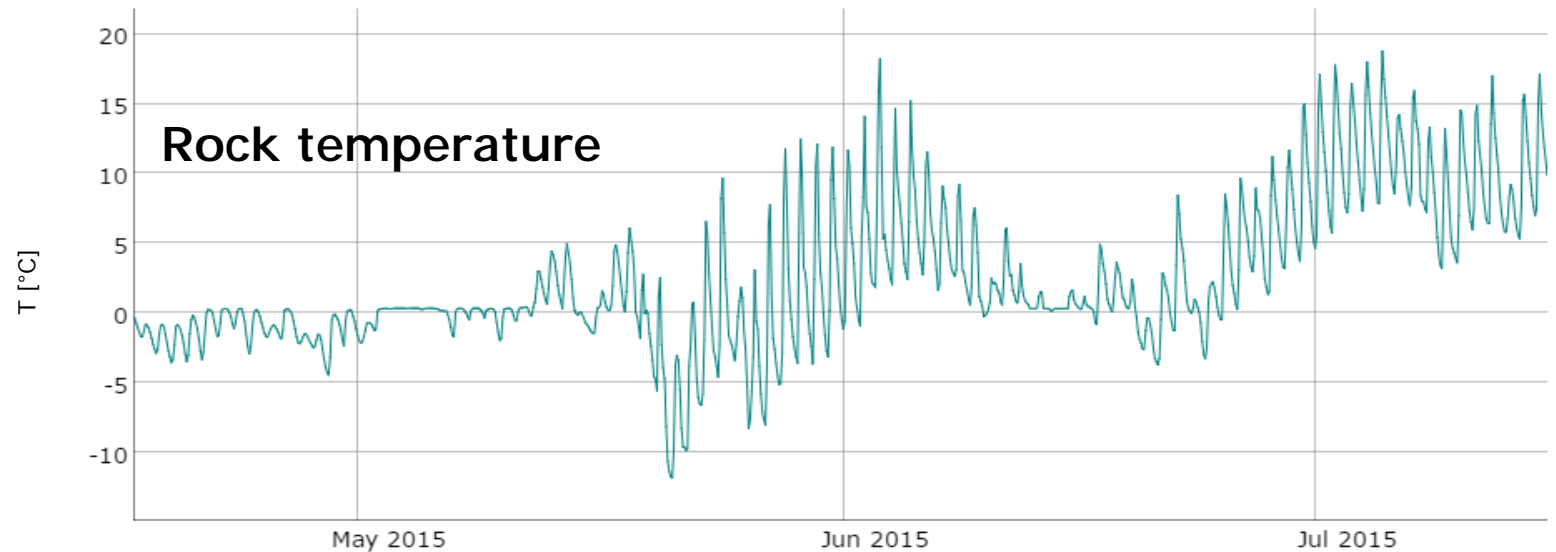
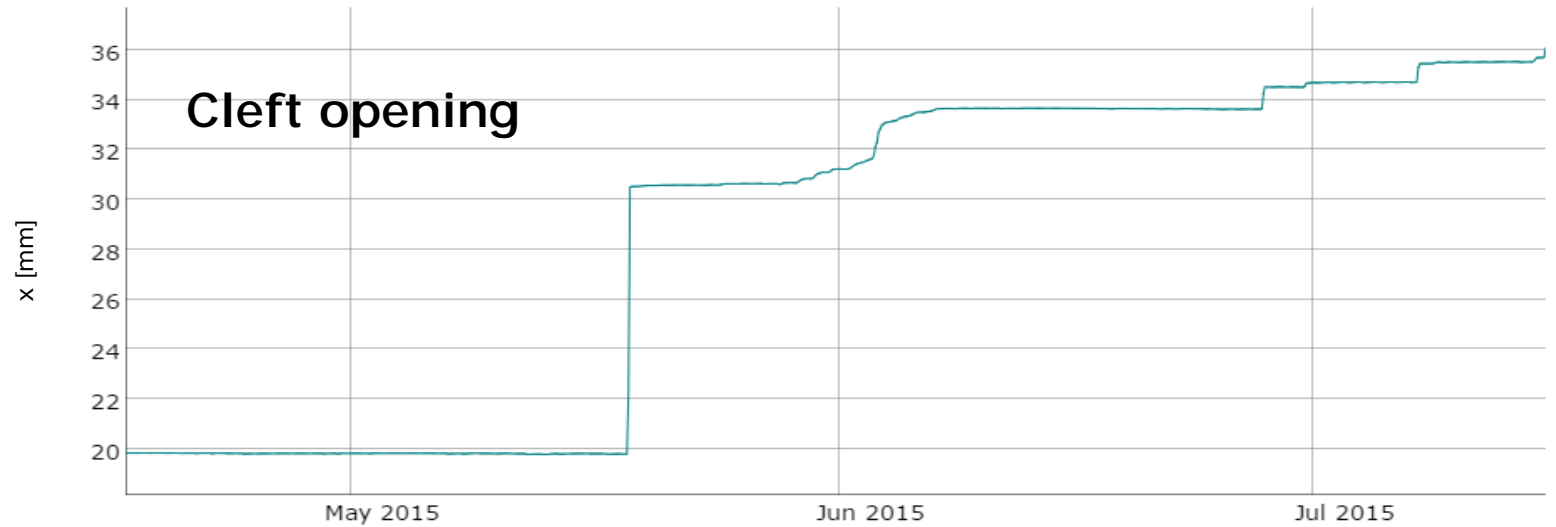
# Matterhorn Cleft Kinematic

Why did C2  
fail on  
18.05.2015?



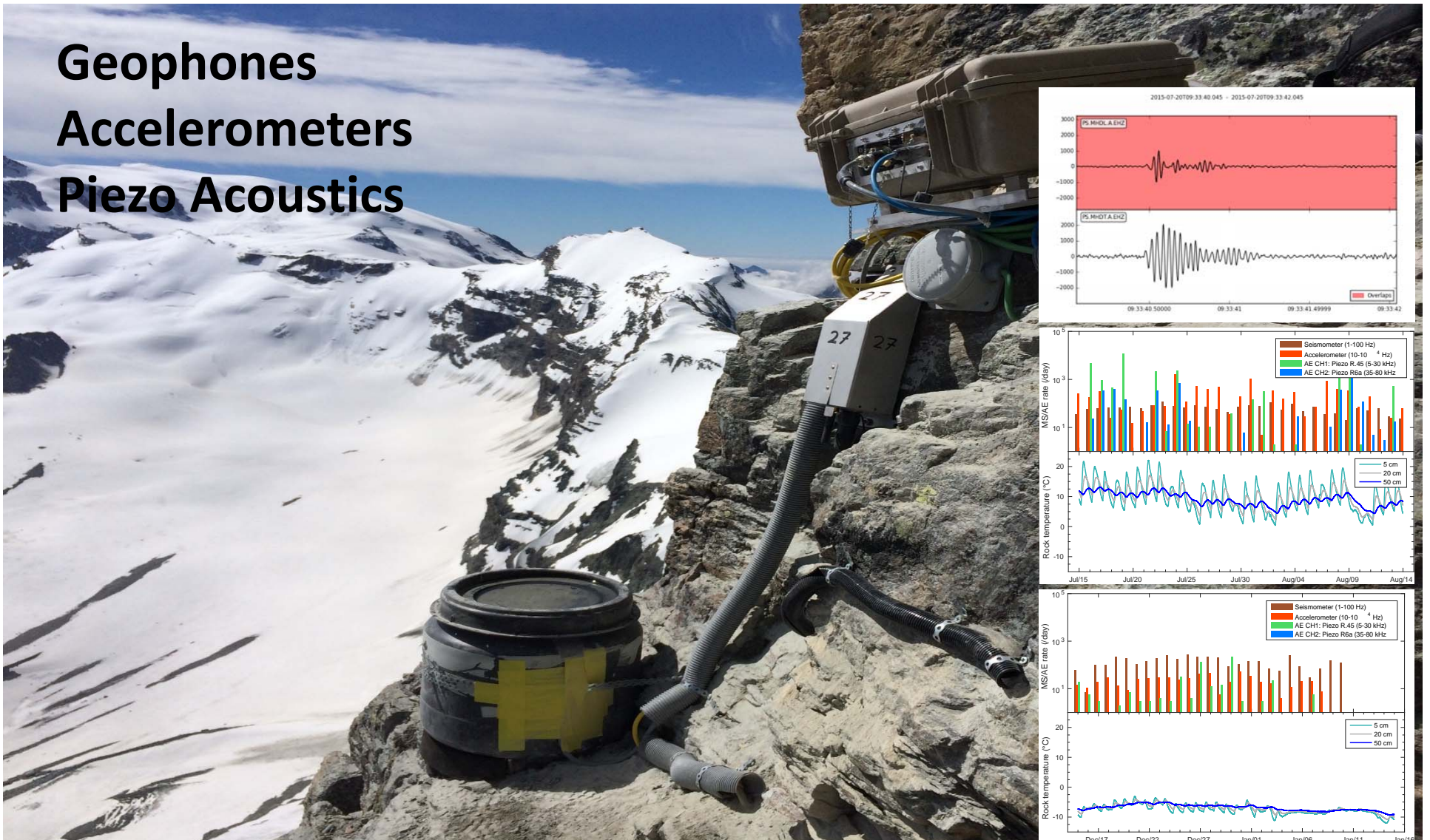
# Matterhorn Cleft Kinematic

How did C2  
behave  
since then?



# Recent Avenues: Micro-seismic profiling

Geophones  
Accelerometers  
Piezo Acoustics



# Matter Valley: Detecting Large-Scale Mass Movements

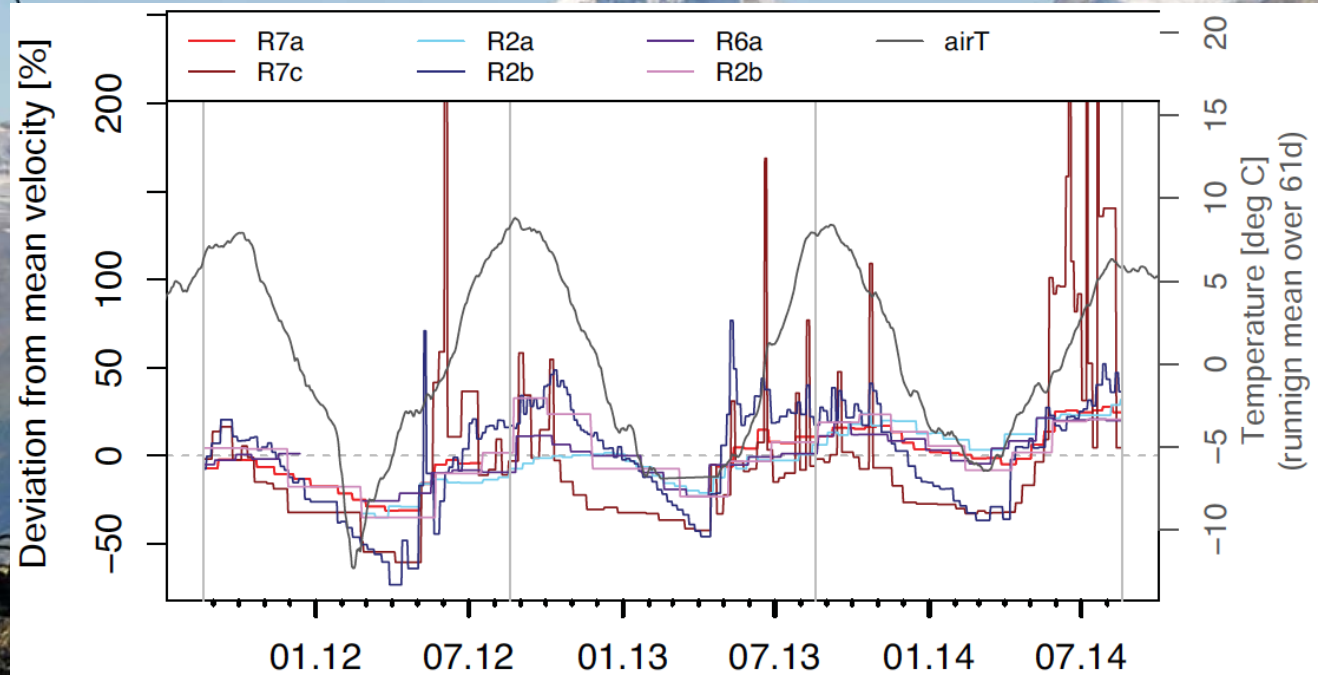


[J. Beutel et al: *X-Sense: Sensing in Extreme Environments*. Proc. Design, Automation and Test in Europe (DATE 2011)

V. Wirz et al: *Temporal characteristics of different cryosphere-related slope movements in high mountains*. Proc. Second World Landslide Forum, 2011.

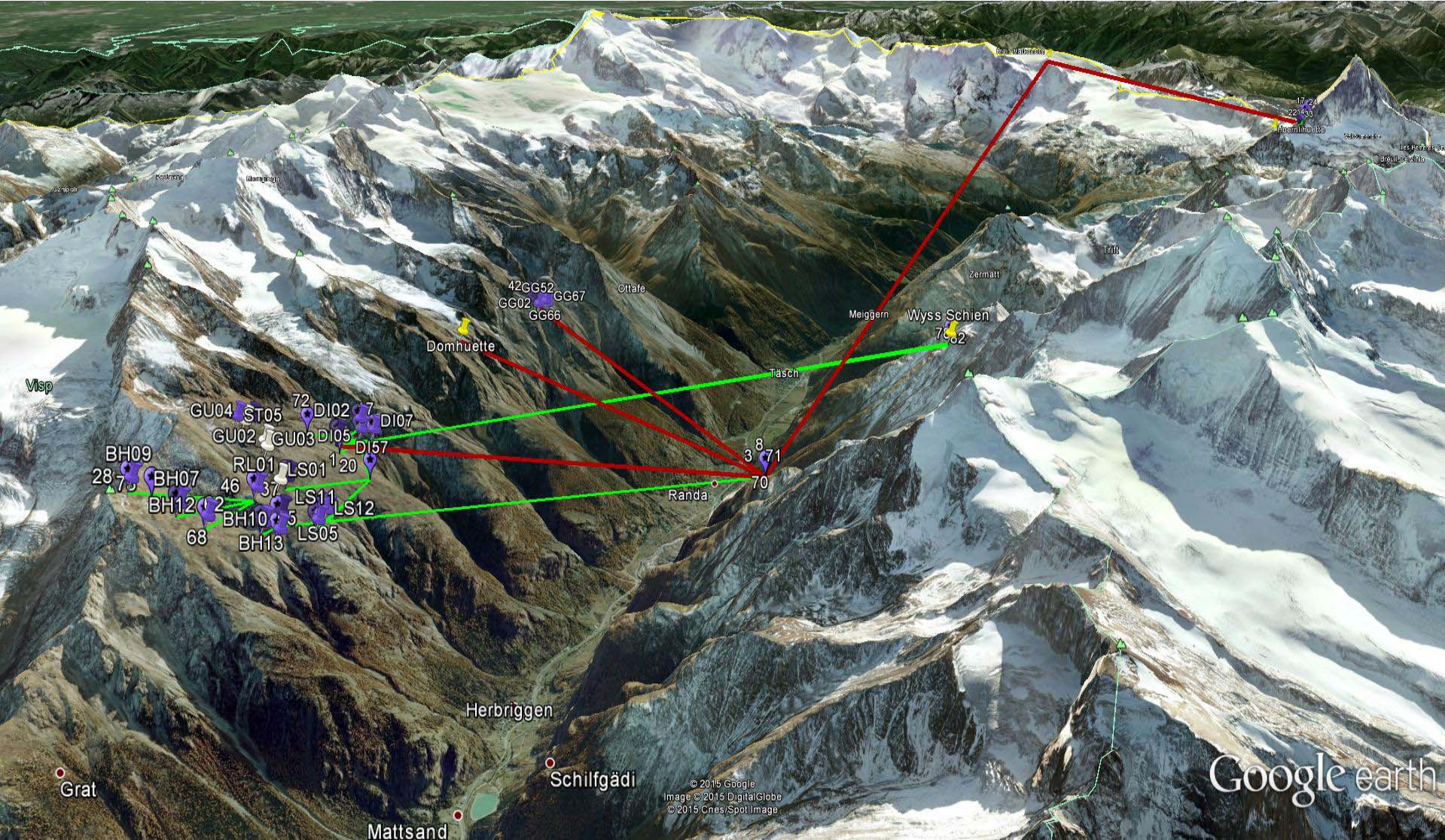
B. Buchli, F. Sutton and J. Beutel: *GPS-equipped Wireless Sensor Network Node for High-accuracy Positioning Applications*. Proc. EWSN 2012.]

# Wireless L1-DGPS sensors detect millimeter-scale process dynamics



[Wirz, V. et al: *Estimating velocity from noisy GPS data for investigating the temporal variability of slope movements*, Nat. Hazards Earth Syst. Sci., 14, 2503-2520, 2014.  
V. Wirz et al: *Short-term velocity variations at three rock glaciers and their relationship with meteorological conditions*. Earth Surface Dynamics, 4, 1, p. 103-123, 2016.]

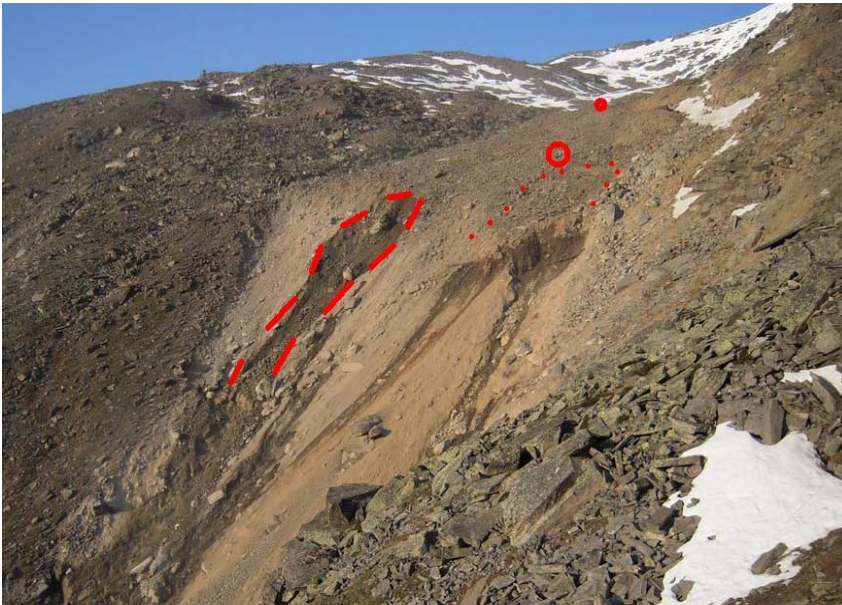
# Real-time Experimentation at Valley-Scale



# Access to Real-time Data for Early Warning Decision-making

## Bielzug Debris Flow, June 2013

- Critical natural hazard event
- Herbriggen partial village evacuation
- Closure of road and railway to Zermatt



## Längschnee, Fall 2014

- Constructive measures securing rock boulders above Herbriggen
- Extension of sensor coverage in collaboration with authorities



# Technology Transfer

## PERMOS Continuous GPS Pilot

- Pilot program to make L1-DGPS sensors available on PERMOS partner field sites
- First sensor installation in summer 2013, extensions in 2014, 2015  
(Valais: Herbruggen Bielzug, Breithorn + Längschnee, Grächen Distelhorn + Ritigraben, Saas-Balen Gruben + Jägghorn, Wyss Schije, Randa Grossgufer)



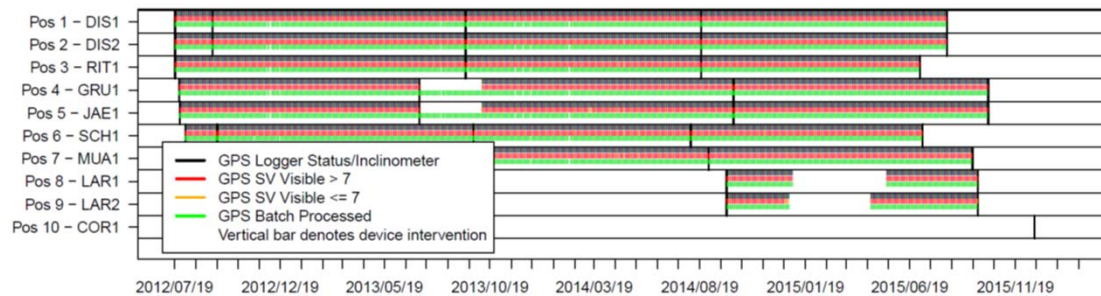
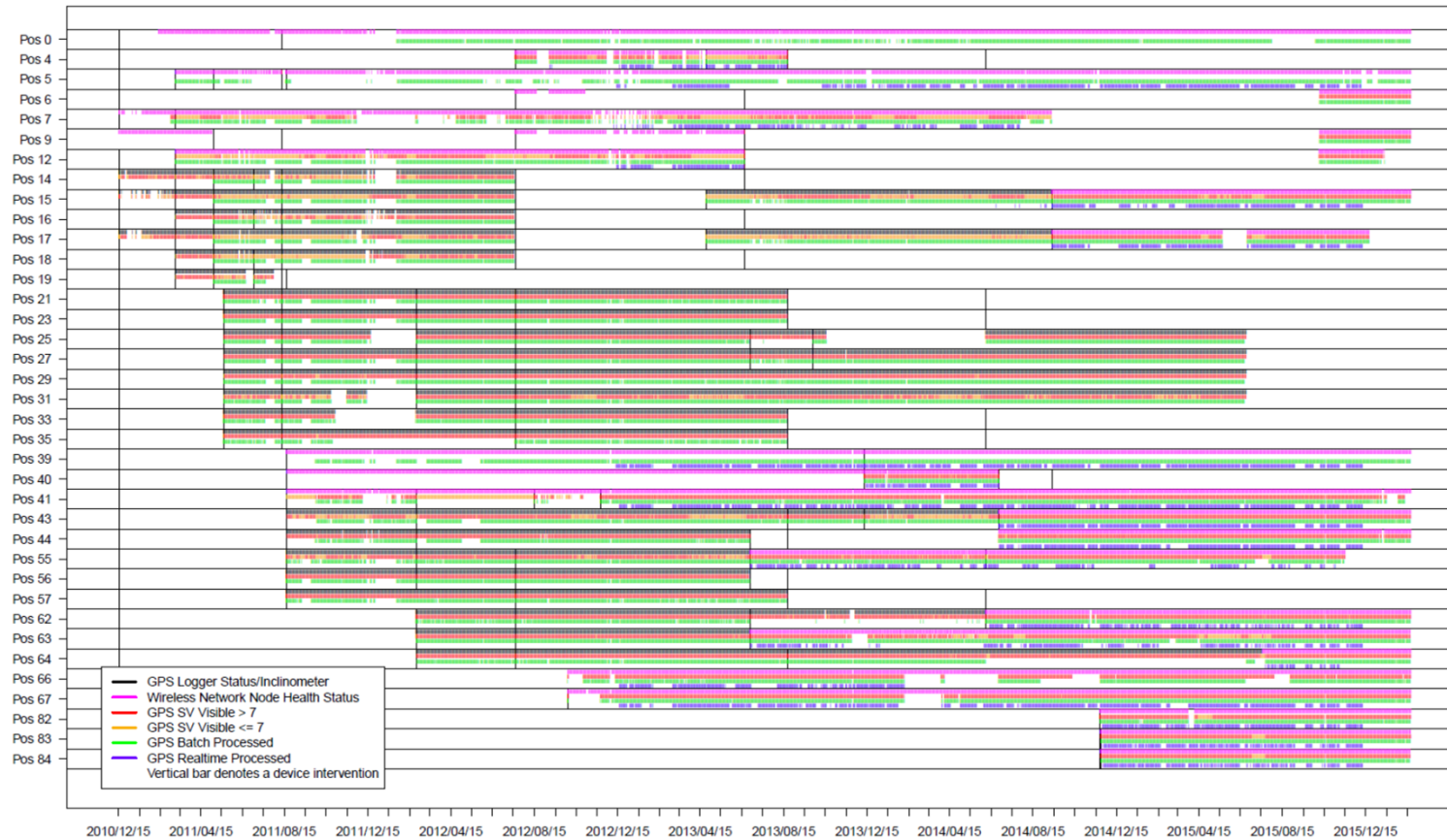
PERMOS site Largario rock glacier, Sept. 2014



Avalanche protection, Randa, Nov. 2014

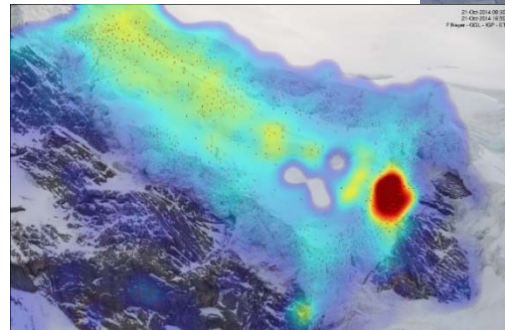


# L1-GPS Data Inventory

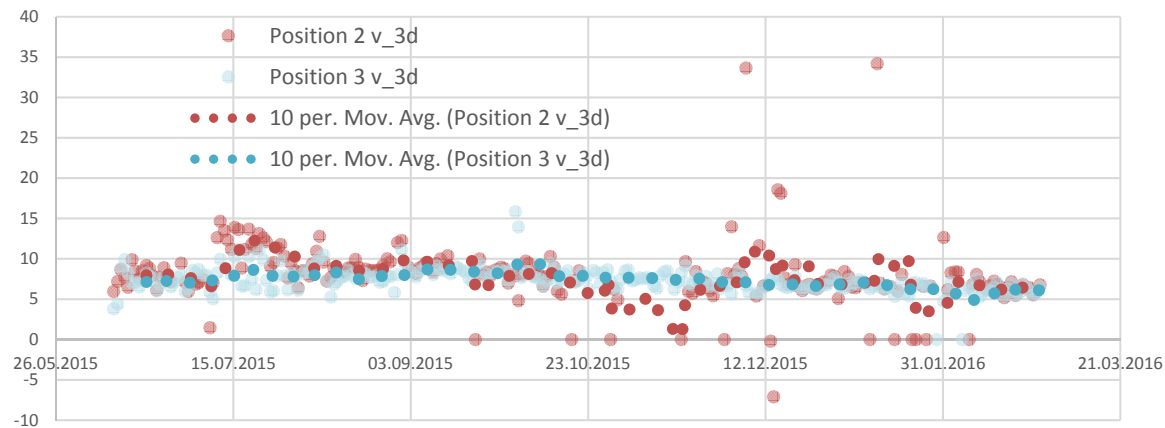


# Monitoring of Weissmies Hanging Glacier

- Multi-modal Monitoring of Hanging Glaciers
  - Ground-based radar (Geopraevent)
  - High-resolution imaging
  - In-situ wireless GPS installed from long-line

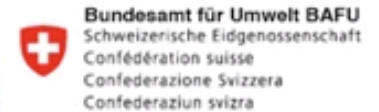


Triftgletscher 3D Velocity [cm/d]





- ETH Zurich
  - Computer Engineering and Networks Lab
  - Geodesy and Geodynamics Lab
  - Micro and Nanosystems
- University of Zurich
  - Department of Geography
- EPFL
  - Distributed Information Systems Laboratory
- University of Basel
  - Department Computer Science



Art of Technology



Interested in more?

<http://www.permasense.ch>