

Experiences with a Decade of Wireless Sensor Networks in Mountain Cryosphere Research

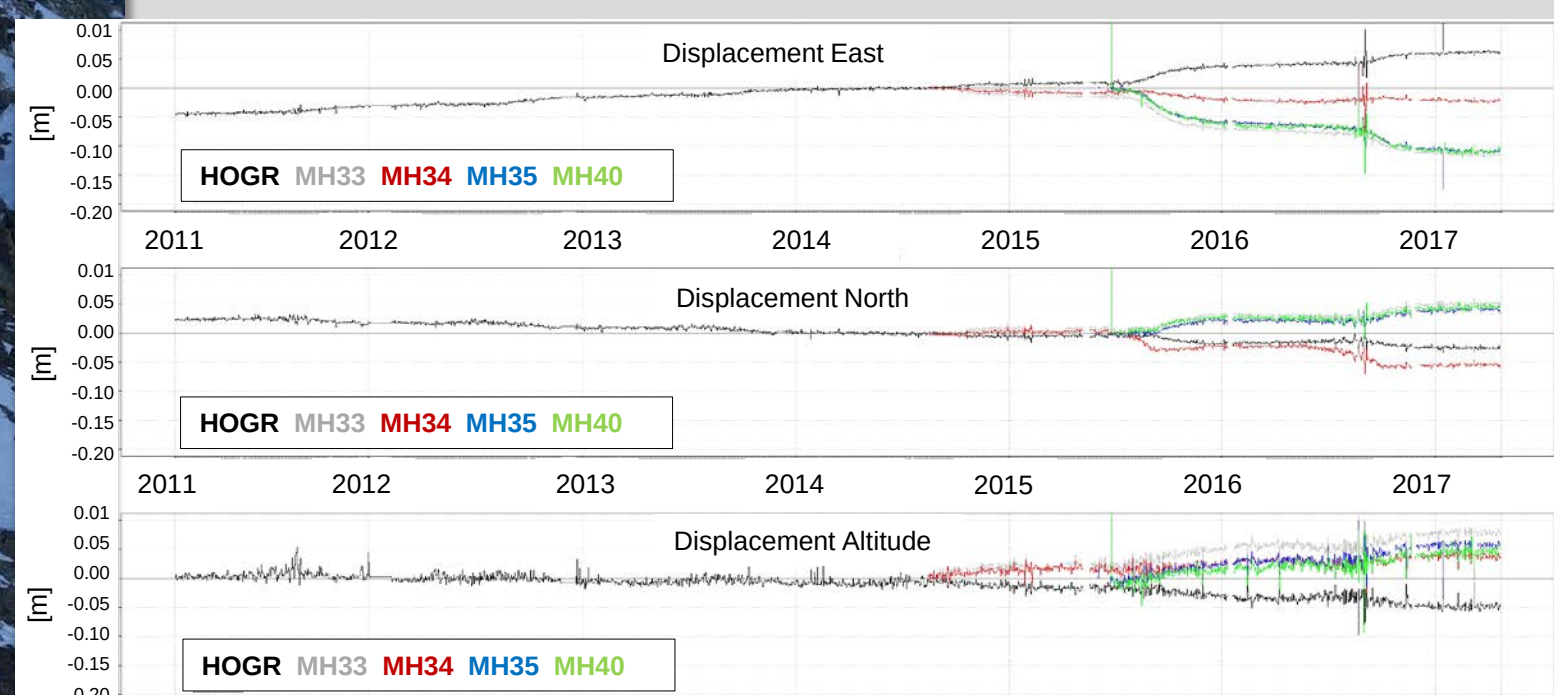
ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology ZürichJan Beutel¹, Reto Da Forno¹, Philip Deline⁹, Jérôme Failletaz², Alain Geiger¹, Tonio Gsell¹, Christofer Hierold¹, Roland Hohensinn¹, Romain Jacob¹, Roman Lim¹, Philippe Limpach¹, Michelle Müller¹, Fabian Neyer¹, Ludovic Ravanell⁹, Cosmin Roman¹, Felix Sutton, Tazio Strozzi⁶, Lothar Thiele¹, Andreas Vieli², Samuel Weber², Zhenzhong Su¹, Christoph Walser¹, Vanessa Wirz², Andreas Hasler², Stephan Gruber⁸, Lucas Girard², Bernhard Buchli¹, Matthias Keller¹, Stefanie Gubler², Jonathan Müller¹, Christian Plessl⁷, Sandro Schoenborn³, Igor Talzi³, Christian Tschudin³, Daniel Vonder Muehl¹, Karl Aberer⁴, Josua Hunziker¹, Mustafa Yuecel¹, Alessandro Cicoira, Dominic Bernath¹, Lukas Sigrist¹, Hugo Raetz⁵¹ETH Zurich; ²University of Zurich; ³University of Basel; ⁴EPF Lausanne; ⁵Federal Office of the Environment; ⁶Gamma Remote Sensing; ⁷University of Paderborn; ⁸Carleton University; ⁹Université Savoie Mont BlancUniversity of
Zurich

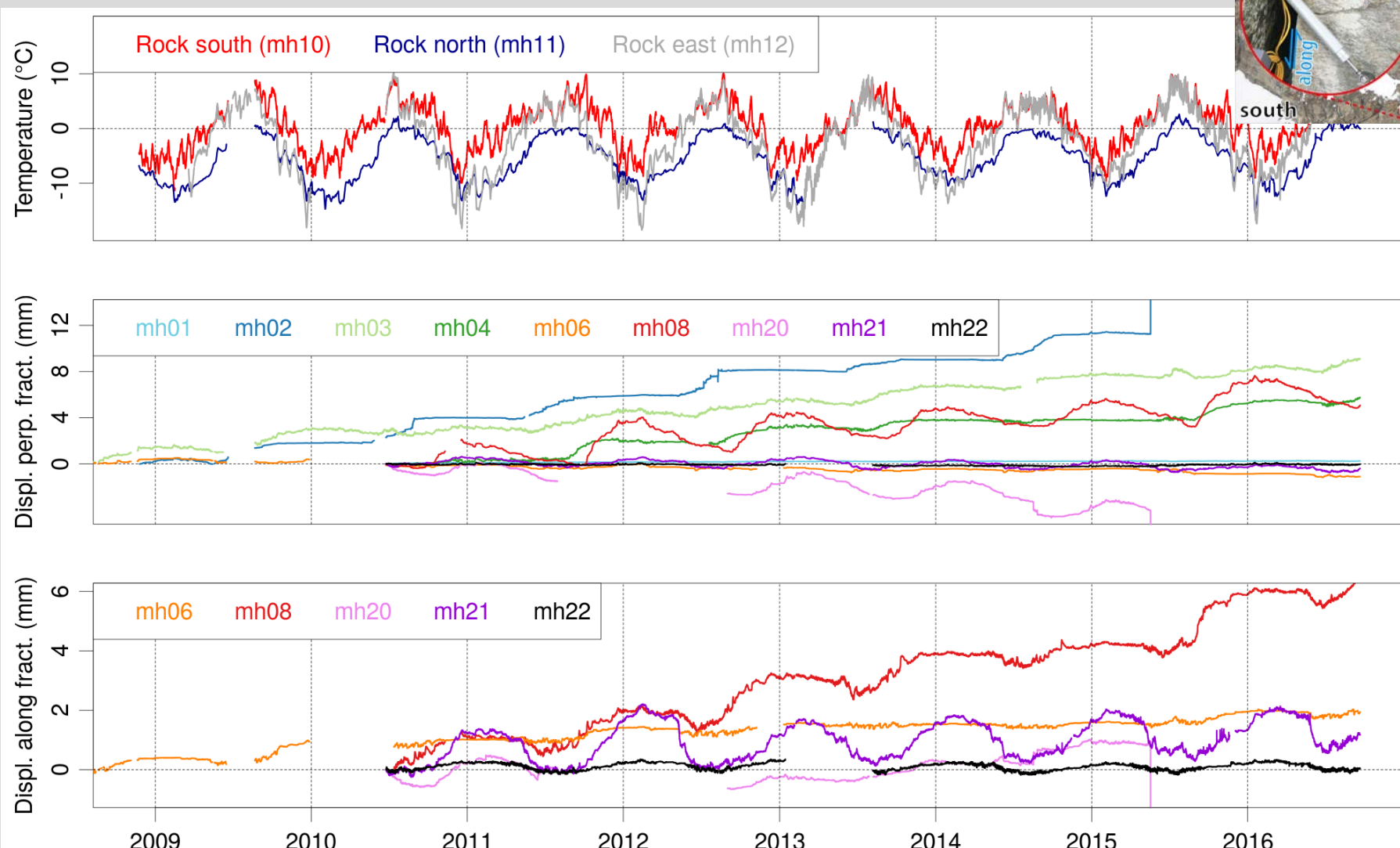
Our Field Sites: Precision Scientific Instruments



L1-GPS Set Up Along the Fragile Ridge

Site of the Matterhorn Hörnligrat Rockfall
July 2003, ~2'500m³, 3500 m a.s.l., SE aspect

8+ Years Surface Temperatures and Crack Displacements

The clefts at Hörnligrat move
in distinct patterns

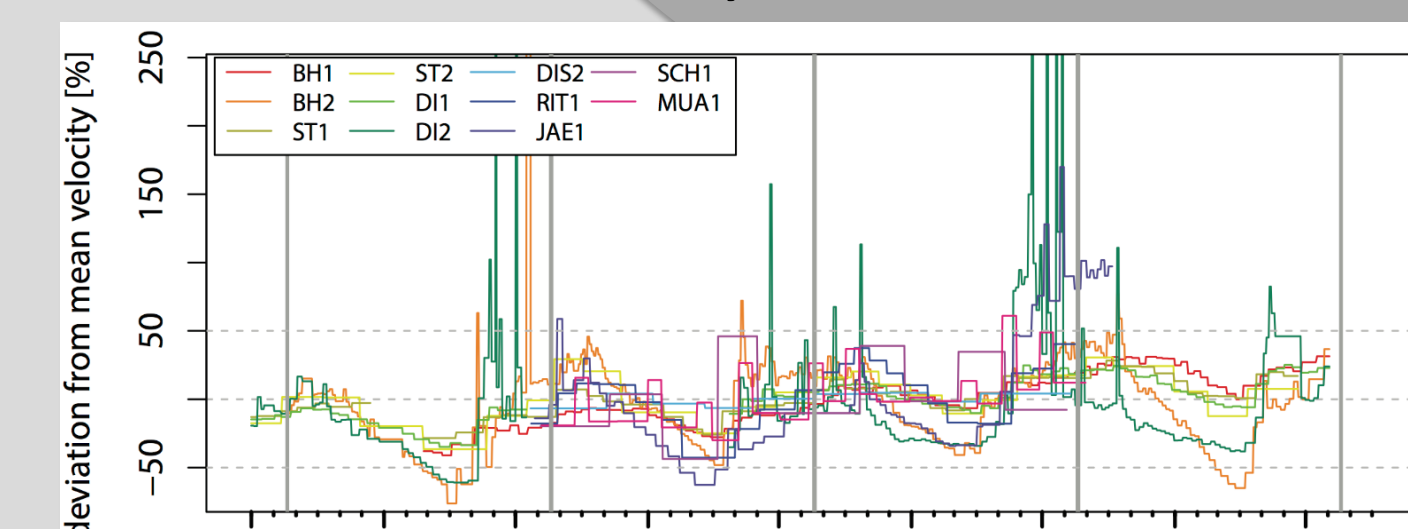
[1. Beutel et al: PermaDAQ: A Scientific Instrument for Precision Sensing and Data Recovery under Extreme Conditions. Proc. IPSN/SPOTS 2009.
A. Hasler, S. Gruber & W. Haeblerli: Temperature variability and thermal offset in steep alpine rock and ice faces. The Cryosphere, 5, 977-988.
A. Hasler, S. Gruber and J. Beutel: Kinematics of steep bedrock permafrost. J. Geophys. Res., 117, F01016.
Weber, S., Beutel, J., Failletaz, J., Hasler, A., Krautblatter, M., and Vieli, A.: Quantifying irreversible movement in steep, fractured bedrock permafrost on Matterhorn (CH), The Cryosphere, 11, 567-583, doi:10.5194/tc-11-567-2017.]

Wireless L1-GPS Sensors

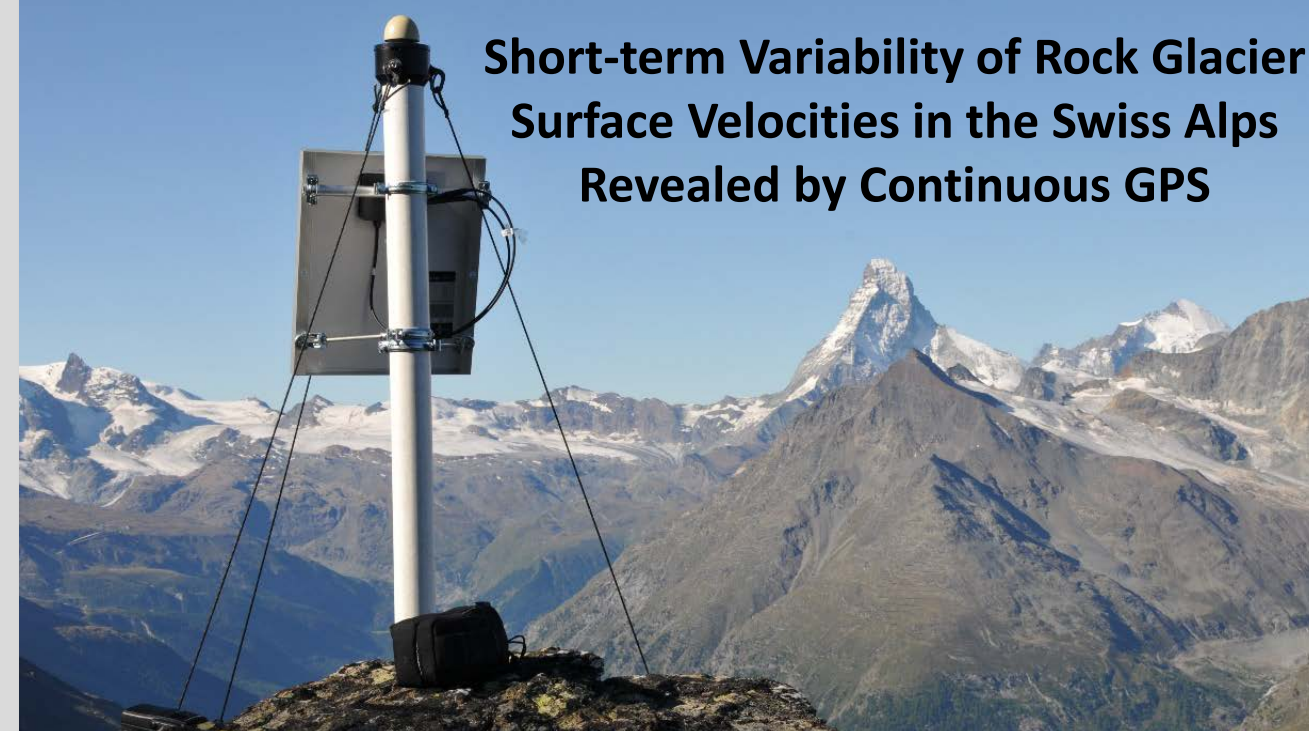
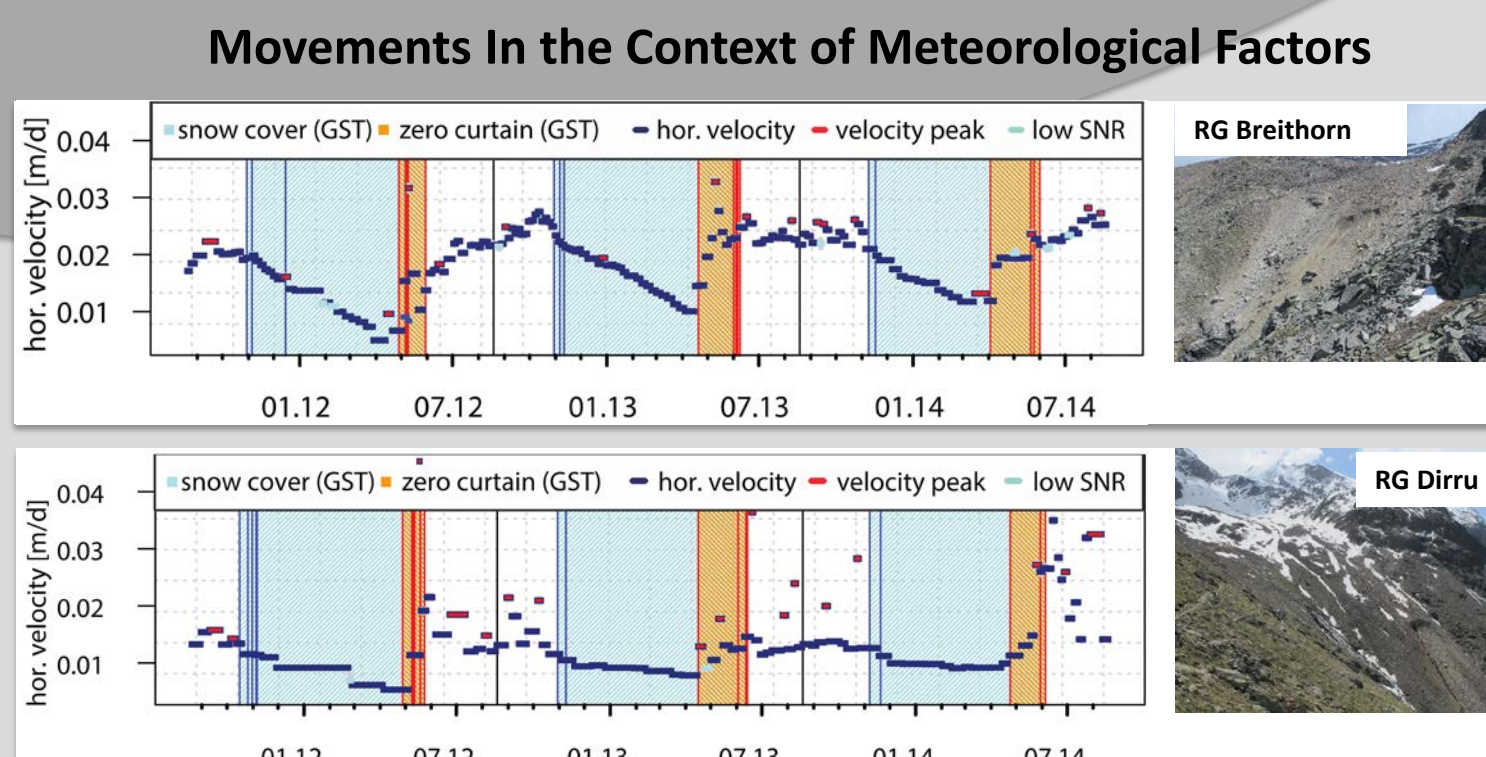


- Sensors
 - ublox LEA-6T L1-GPS
 - Trimble Bullet III active antenna
 - 2-axis SCA830 inclinometer
 - Ambient temp/hum/battery
- Wireless communication
 - Wireless sensor network cluster
 - 868 MHz ultra low-power radios
 - Up to ~7km range
 - Remote configurable (duty-cycle, rate)

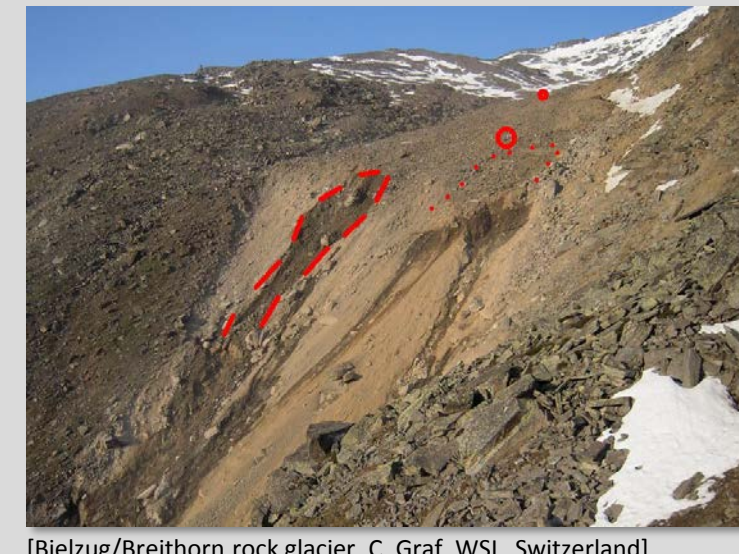
Intra-annual Variability of Horizontal Velocities



[Wirz, V., Beutel, J., Gruber, S., Gubler, S., & Purves, R. S.: Estimating velocity from noisy GPS data for investigating the temporal variability of slope movements. Nat. Hazards Earth Syst. Sci., 14, 2503-2520, 2014.
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.]

Short-term Variability of Rock Glacier
Surface Velocities in the Swiss Alps
Revealed by Continuous GPSAccess to Real-time Data for
Early Warning Decision-making

- Bielzug Debris Flow, June 2013
- Critical natural hazard event
- Herbrigen partial village evacuation
- Closure of road and railway to Zermatt



[Bielzug/Breithorn rock glacier, C. Graf, WSL, Switzerland]

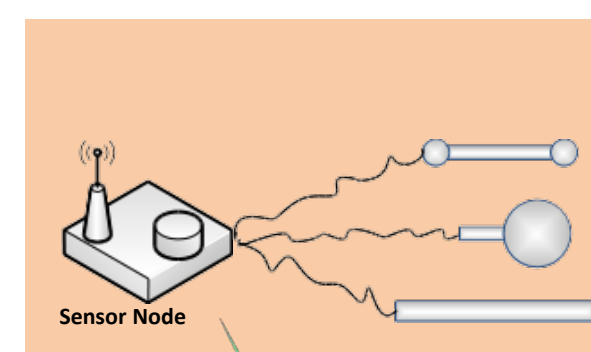
- Längschnee, Fall 2014
- Constructive measures securing rock boulders above Herbrigen
- Extension of sensor coverage in collaboration with authorities



[Willi Gitz, GF5, Stalden, Switzerland]

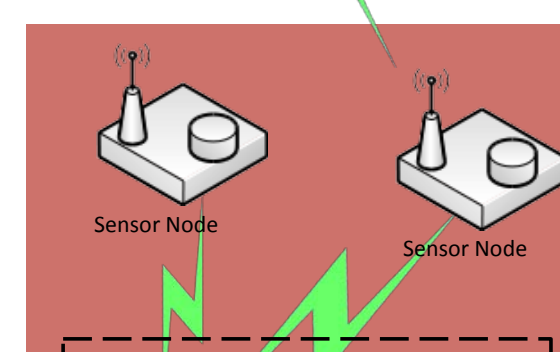
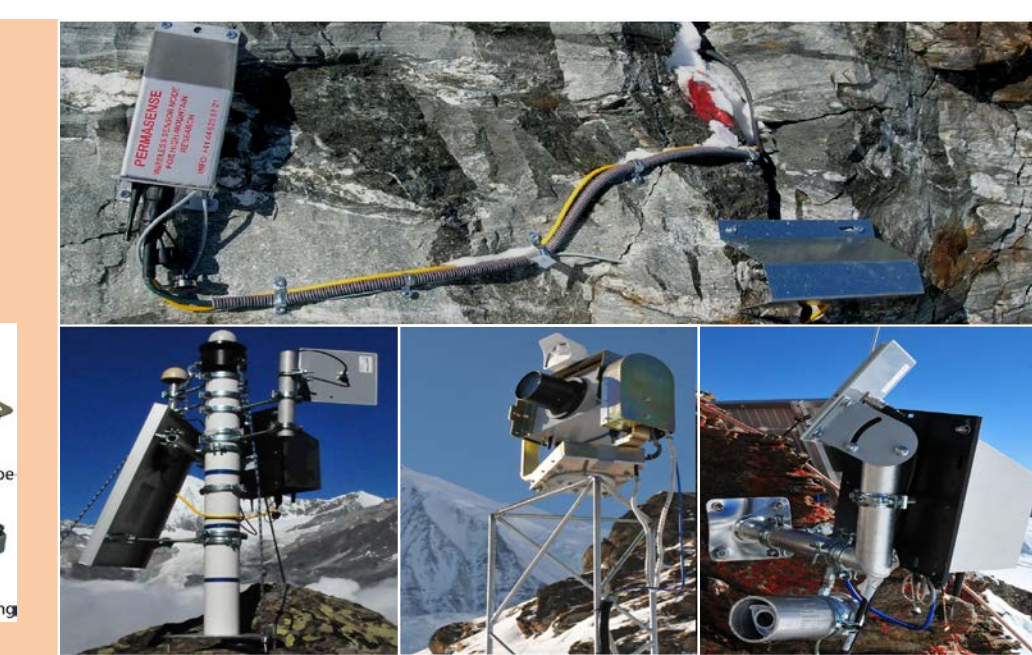
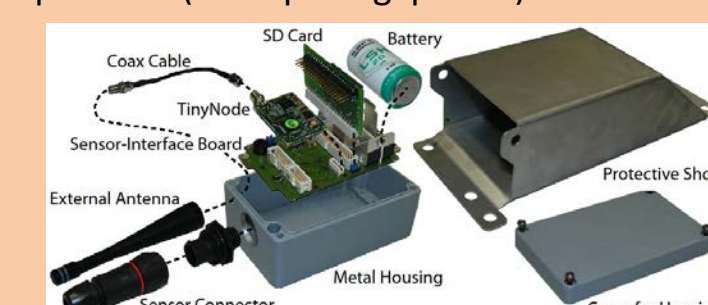
PermaSense System

- Wireless sensor systems, low-latency data transmission
- Customized sensors and ruggedized equipment
- Cloud based data management, open data access
- Thermal profiles, surface displacement (crackmeter, L1-DGPS), radiation, high resolution imaging, acoustic and micro-seismic emissions



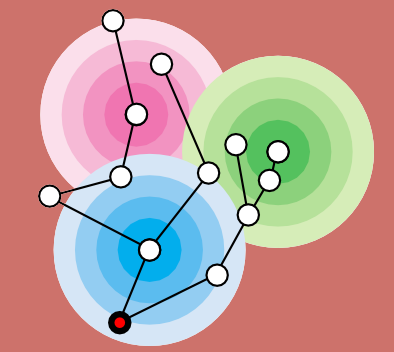
Wireless Sensor Nodes and Sensor Integration

- Optimized for ultra-low duty cycles
- Static, low-rate sensing (120 sec)
- Disconnected operation: 1 GB storage
- 4-6 years of independent operation (~150 µA avg. power)
- Ruggedized for alpine extremes
- < 0.1 MB/node/day
- Generic interface for analog and digital sensors



Wireless Sensor Networks (WSN)

- Reliable data acquisition in remote, inaccessible locations
- Self organizing multi-hop network
- Optimized for ultra-low duty cycles
- 8+ years experience, ~1'276'035'519 data points, 1.5+ TB



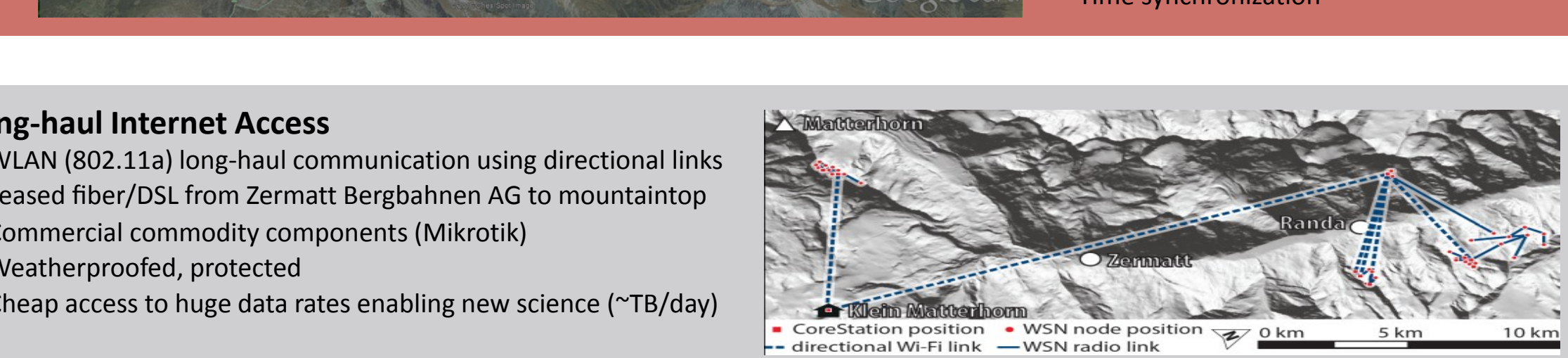
Advantages

- Spatially distributed field measurements
- Data all year-round available in near real-time
- No long cables, less problems with hazards, e.g. lightning
- Low maintenance

Challenges

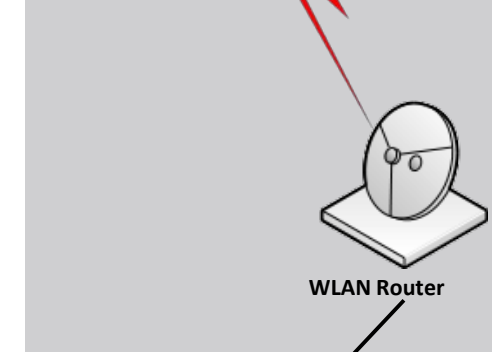
- Harsh environment
- Low power consumption
- Time synchronization

Real-time Experimentation at Valley-Scale



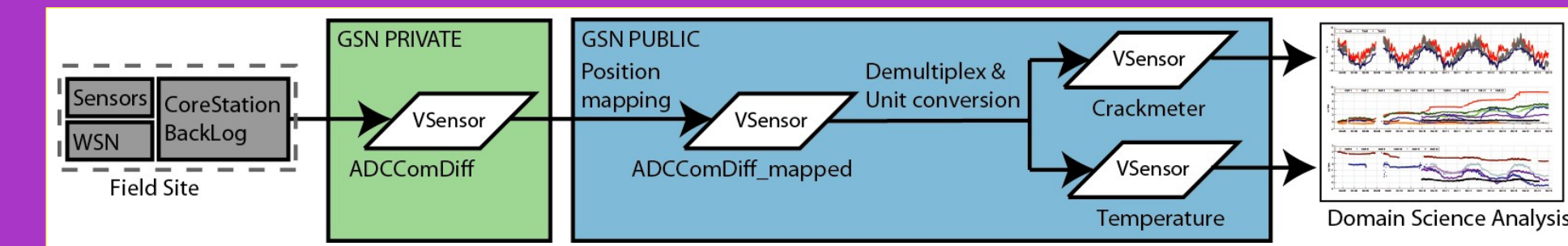
Long-haul Internet Access

- WLAN (802.11a) long-haul communication using directional links
- Leased fiber/DSL from Zermatt Bergbahnen AG to mountaintop
- Commercial commodity components (Mikrotik)
- Weatherproofed, protected
- Cheap access to huge data rates enabling new science (~TB/day)



Server Backend: Global Sensor Network (GSN)

- Dual architecture translates data from machine representation to SI values, adds metadata
- Organized in "virtual sensors", i.e. data types/semantics
- Hierarchies and concatenation of virtual sensors enable on-line processing



Data Access Portal

- Public, open data access in real time
- Tutorial available online

<http://data.permasense.ch>

PermaSense :: GSN - Public

HOME DATA NETWORK TOPOLOGY LOGS BACKEND SENSOR NETWORK SCIENCE ON-SITE WEATHER ACCESS RIGHTS LOGIN

HFSJG High Altitude Research Stations
Jungfrauoch & GornegratFNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHES NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATIONSchweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun Svizra
Bundesamt für Umwelt BAFU
Office fédéral de l'environnement OFEV
Ufficio federale dell'ambiente UFAMcces
Cooperation in Earth and Environmental Sciences

nano-tera.ch

MICS