

Observations of Slope Movements in Mountain Landforms using Permanent In-situ GNSS Instruments

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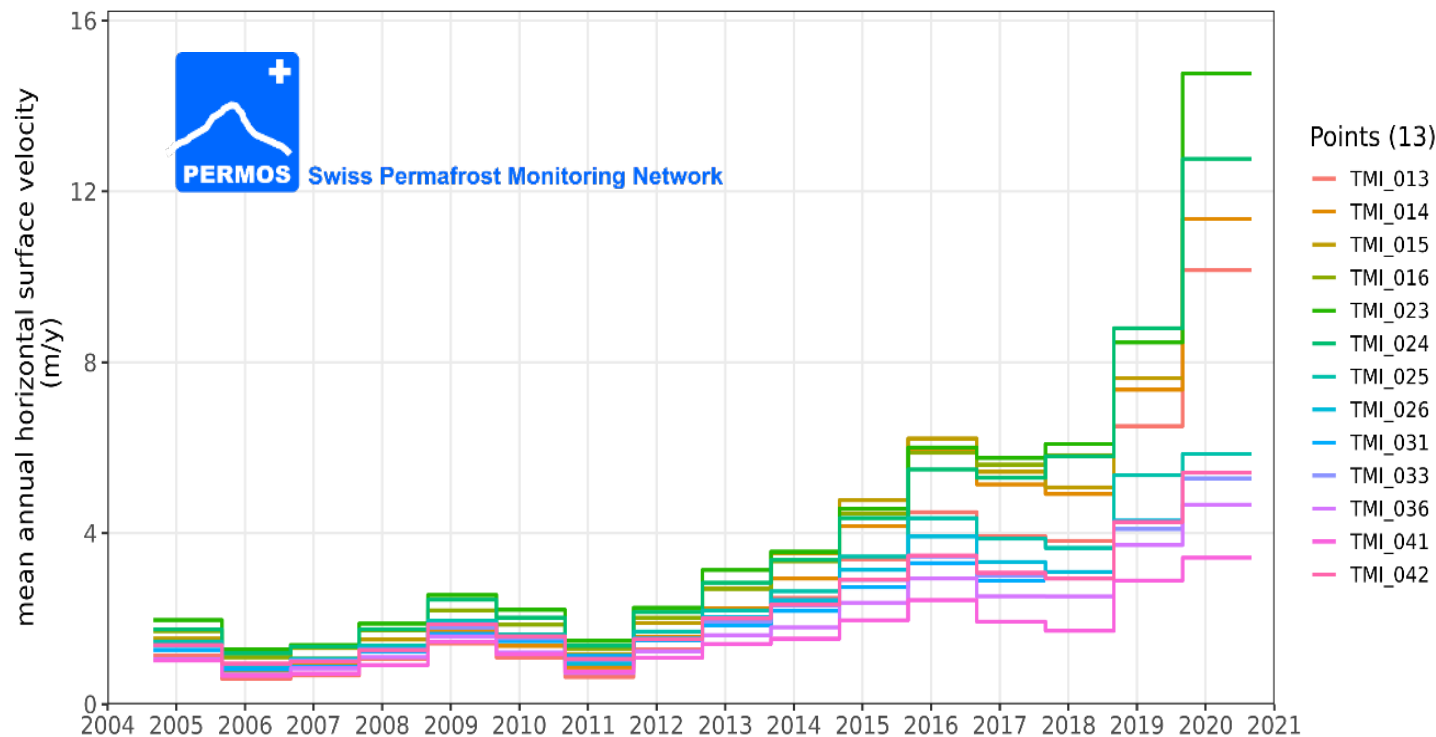


Increasing surface velocities are observed in the
mountain cryosphere

Grabengufer rock glacier, Randa VS

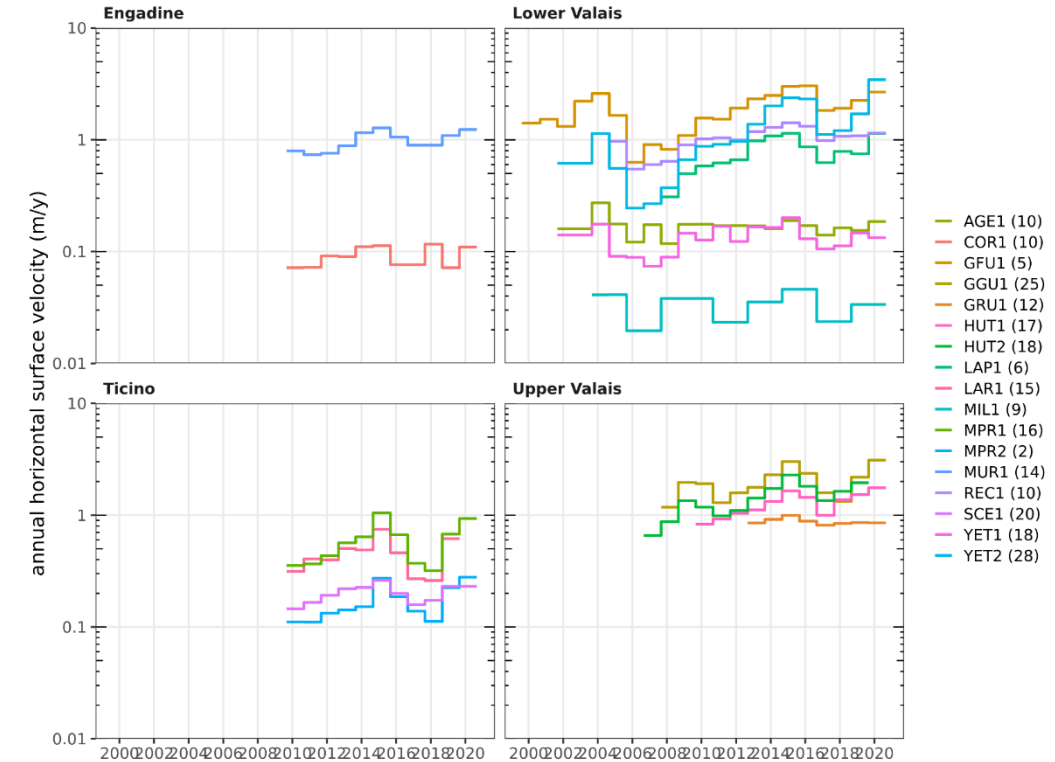
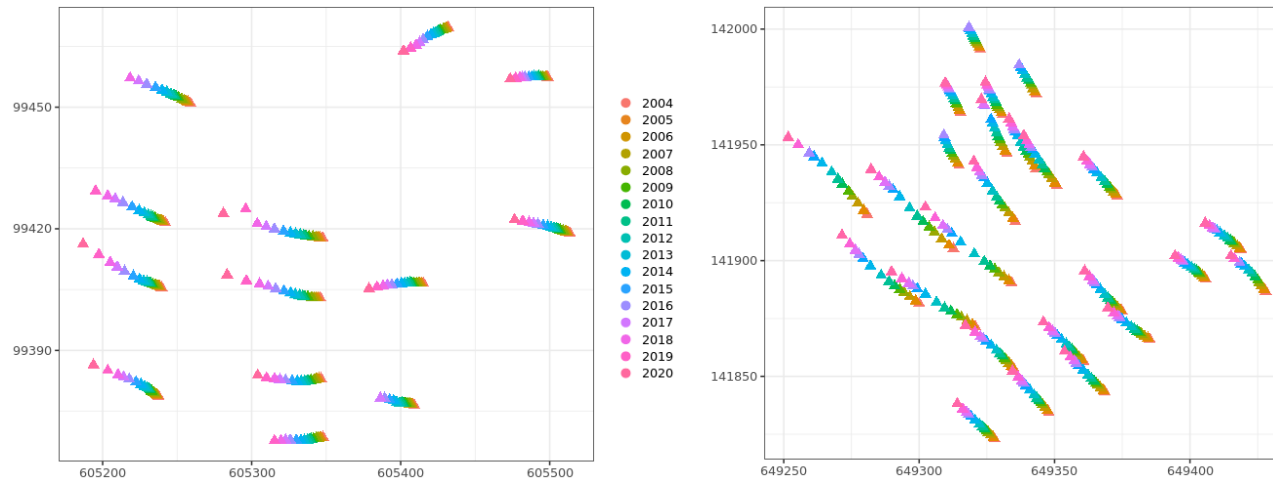
Traditional In-situ Assessment of Surface Deformations

- Repeat manual surveys
- Displacements calculated through differencing



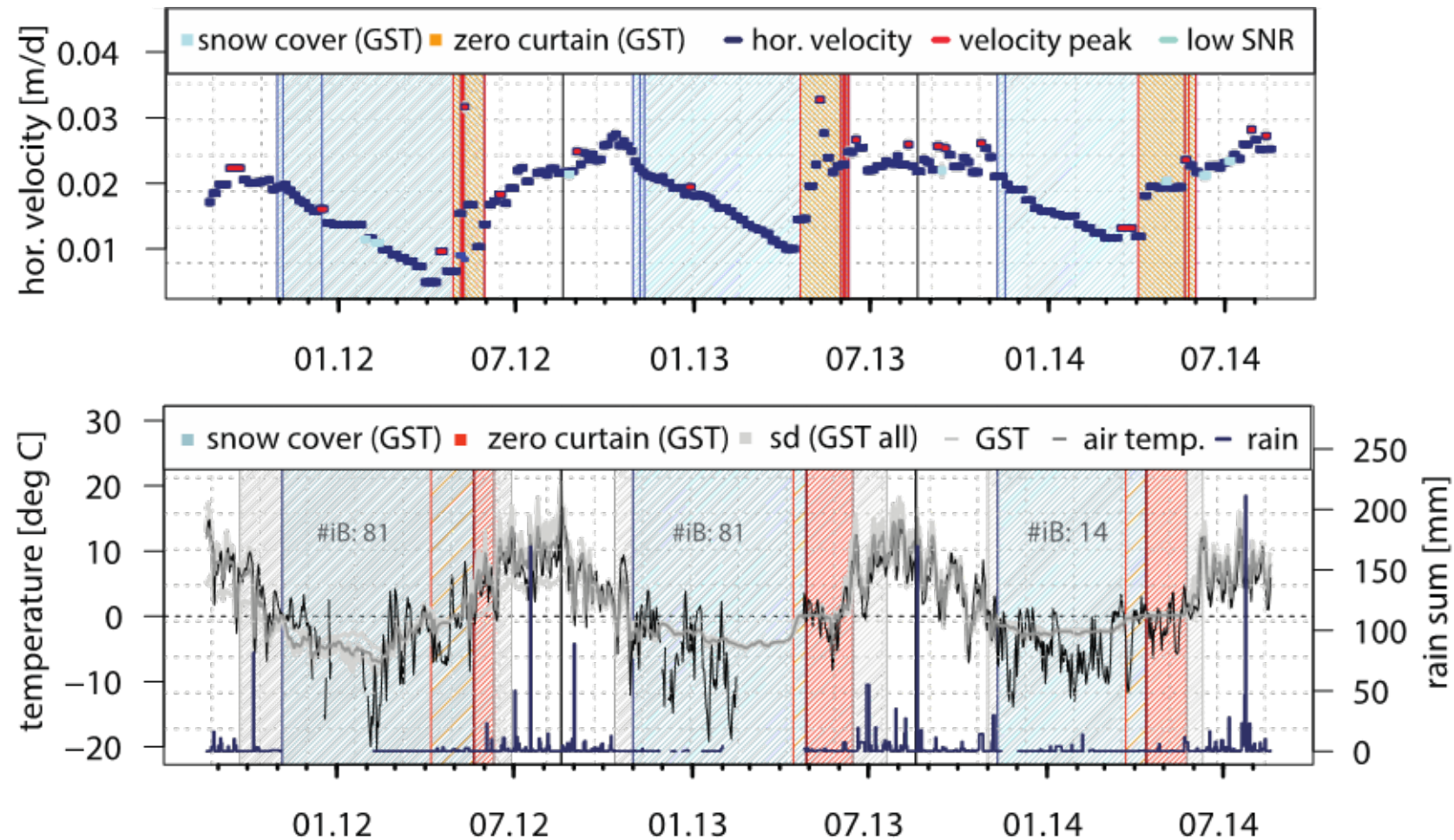
[Lambiel, and Delaloye: *Contribution of Real-time Kinematic GPS in the Study of Creeping Mountain Permafrost: Examples from the Western Swiss Alps*. Permafrost and Periglac. Process. 15: 229–241 (2004)]

Data Contributes to Long-Term Cryosphere Monitoring



- Some structural insights possible
- Severe limitations for detailed quantitative process understanding
- Strong limitations for hazard warning/mitigation

Real Movement Patterns Are Much More Complex



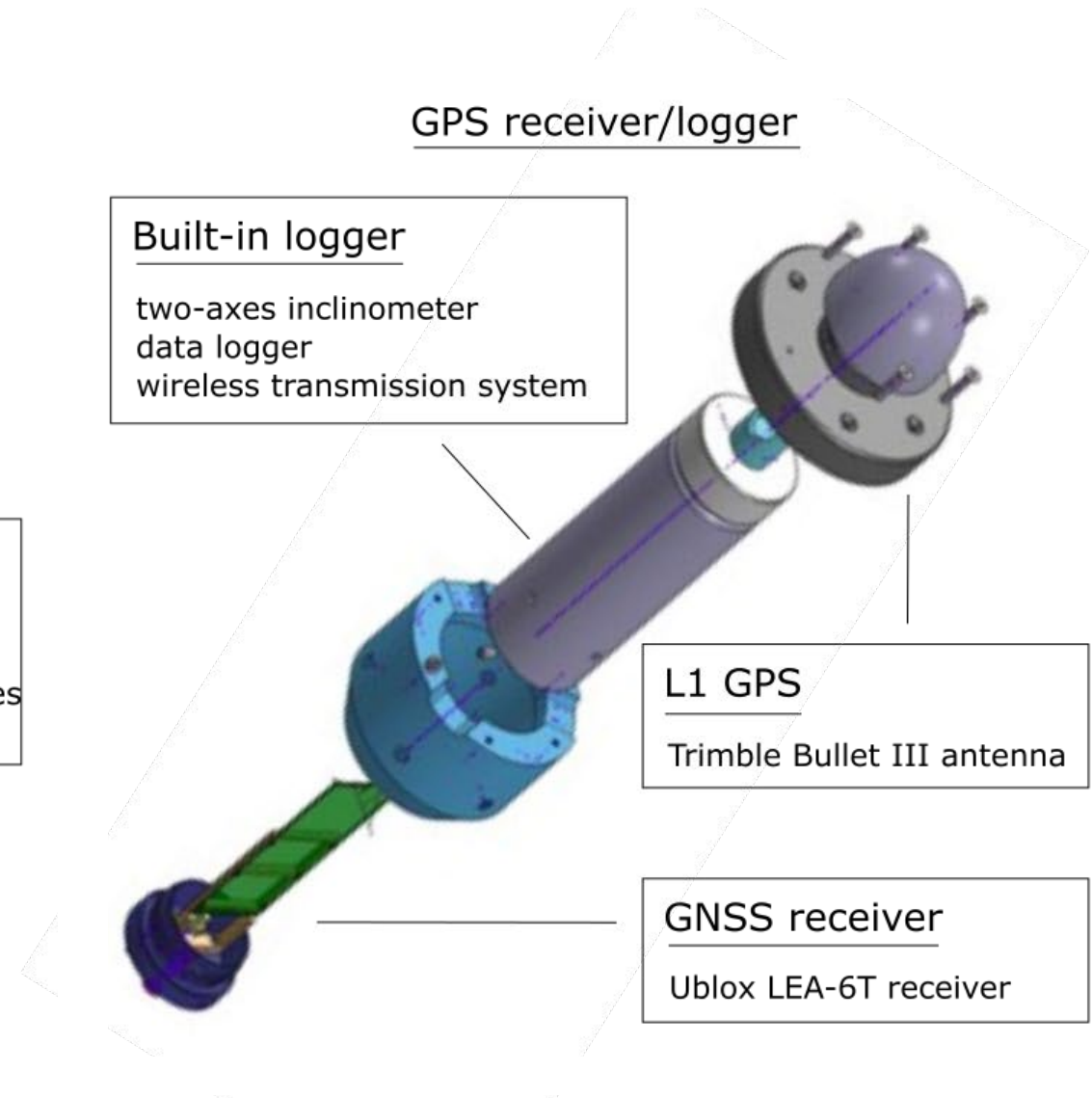
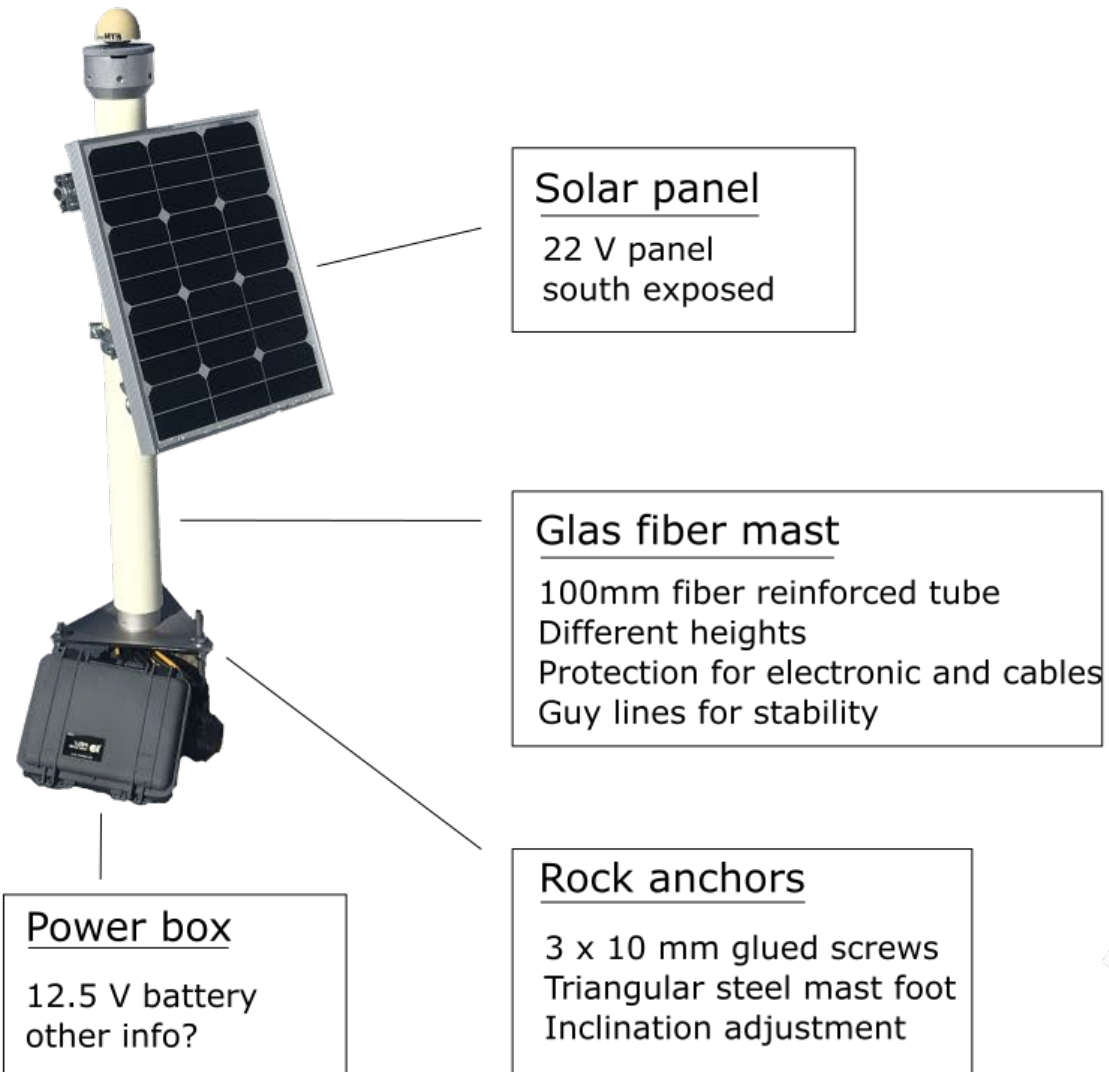
Gugla/Bielzug Blockgletscher,
Herbruggen, VS

[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.]

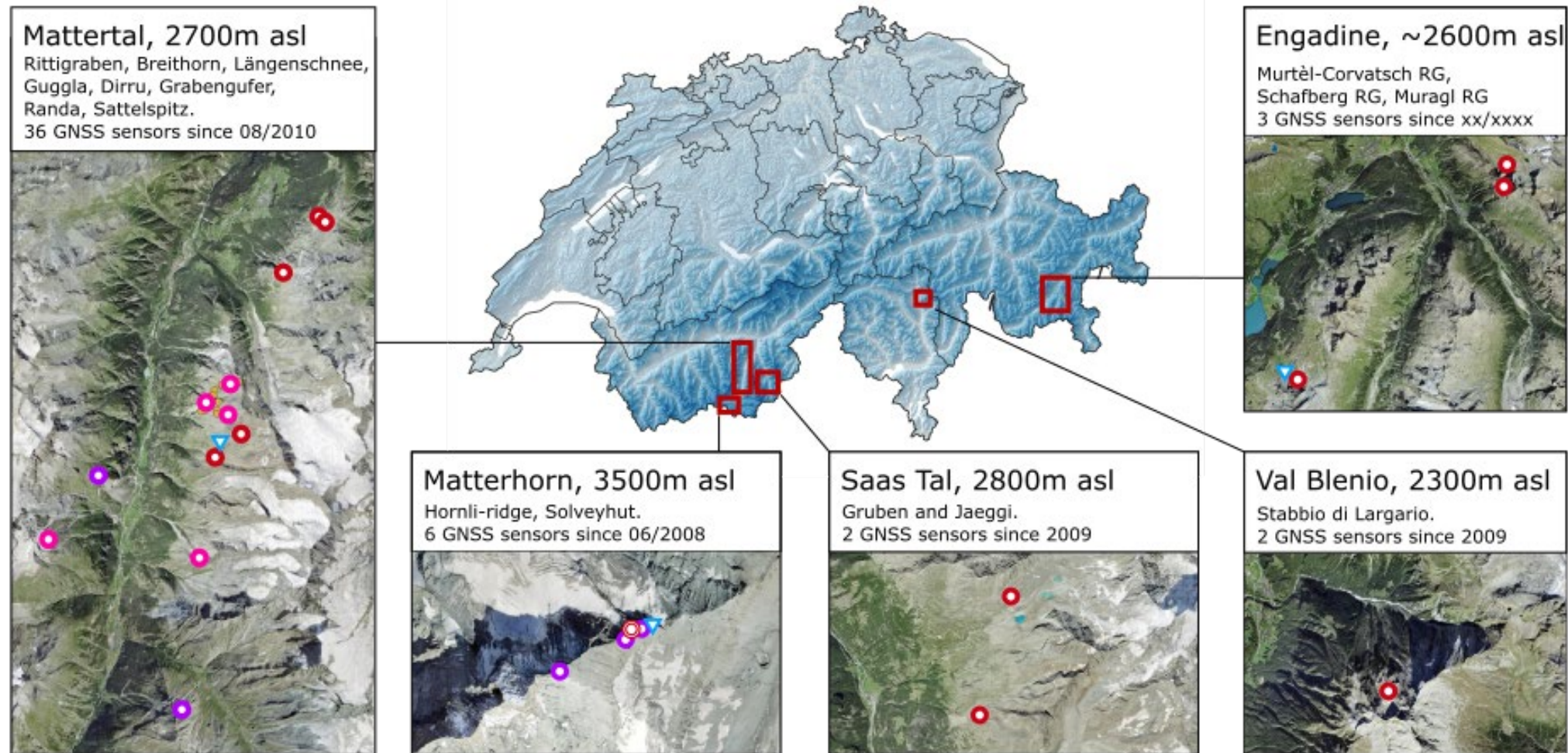
Towards More, Cheaper and Real-Time In-Situ Data Points



Continuous Observations Using Differential L1-GNSS



Key Field Sites in Switzerland



Legend

Landform type (multiple GNSS sensors):



Rock Glacier



Landslide



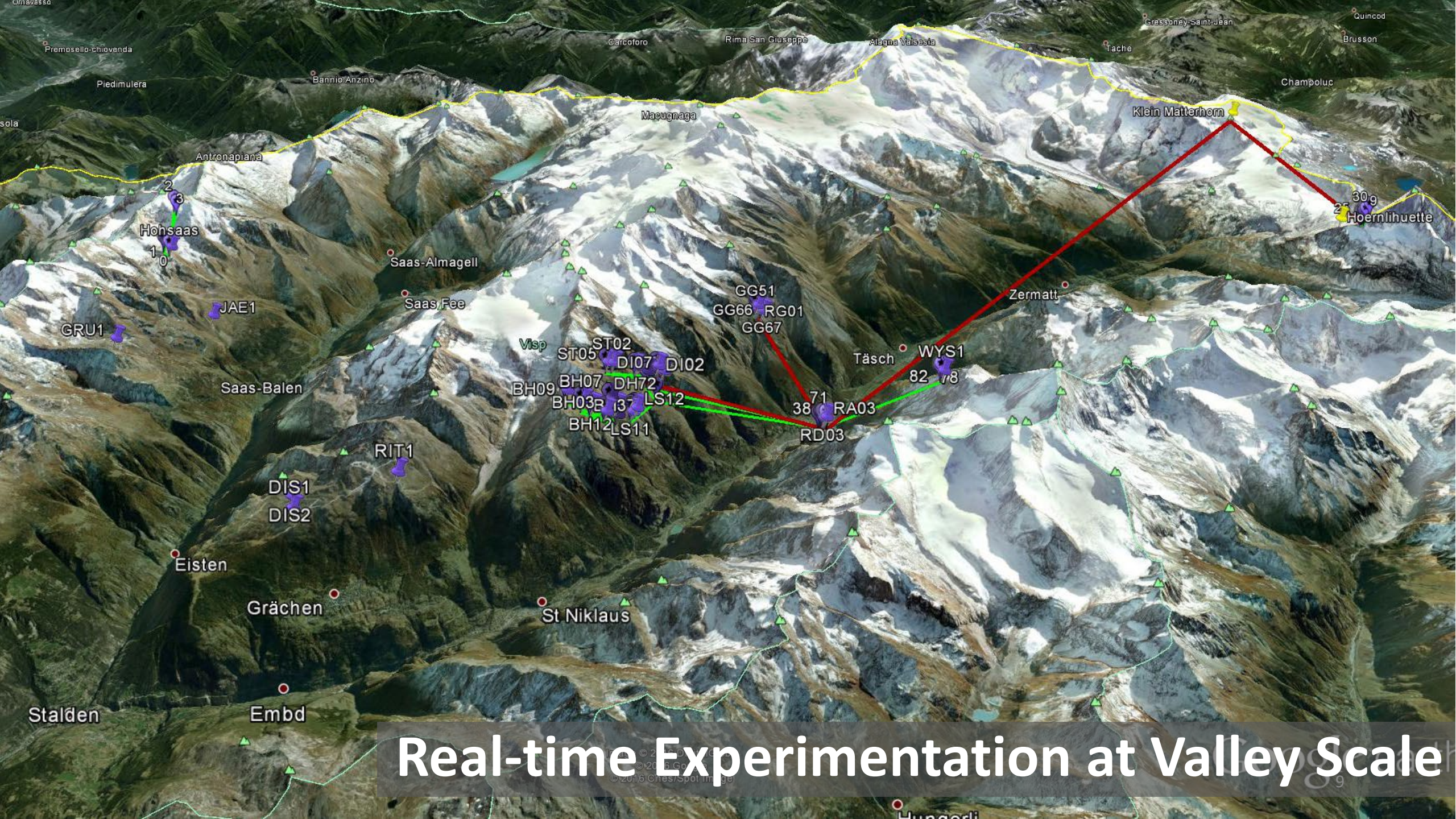
Steep rock-wall



Ongoing reference stations

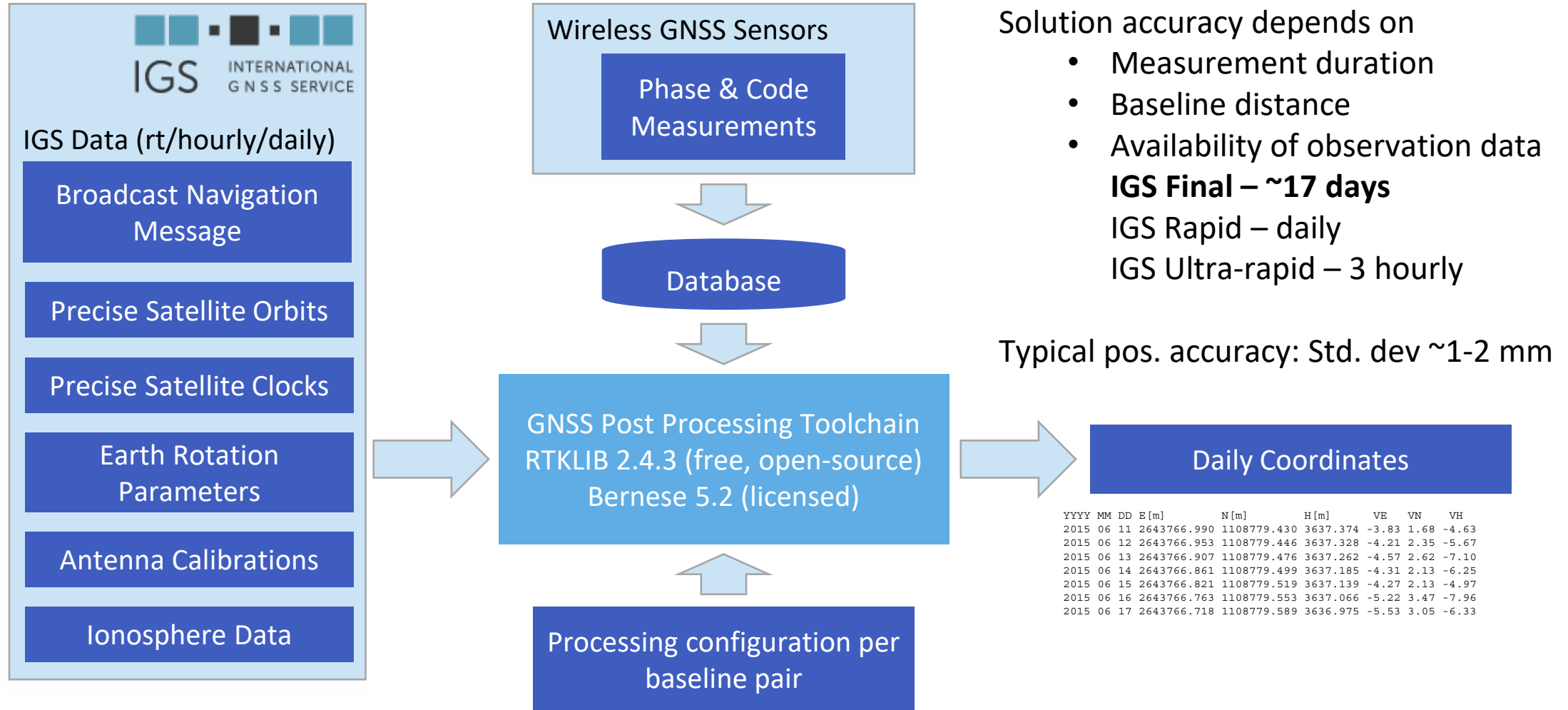


Weather station

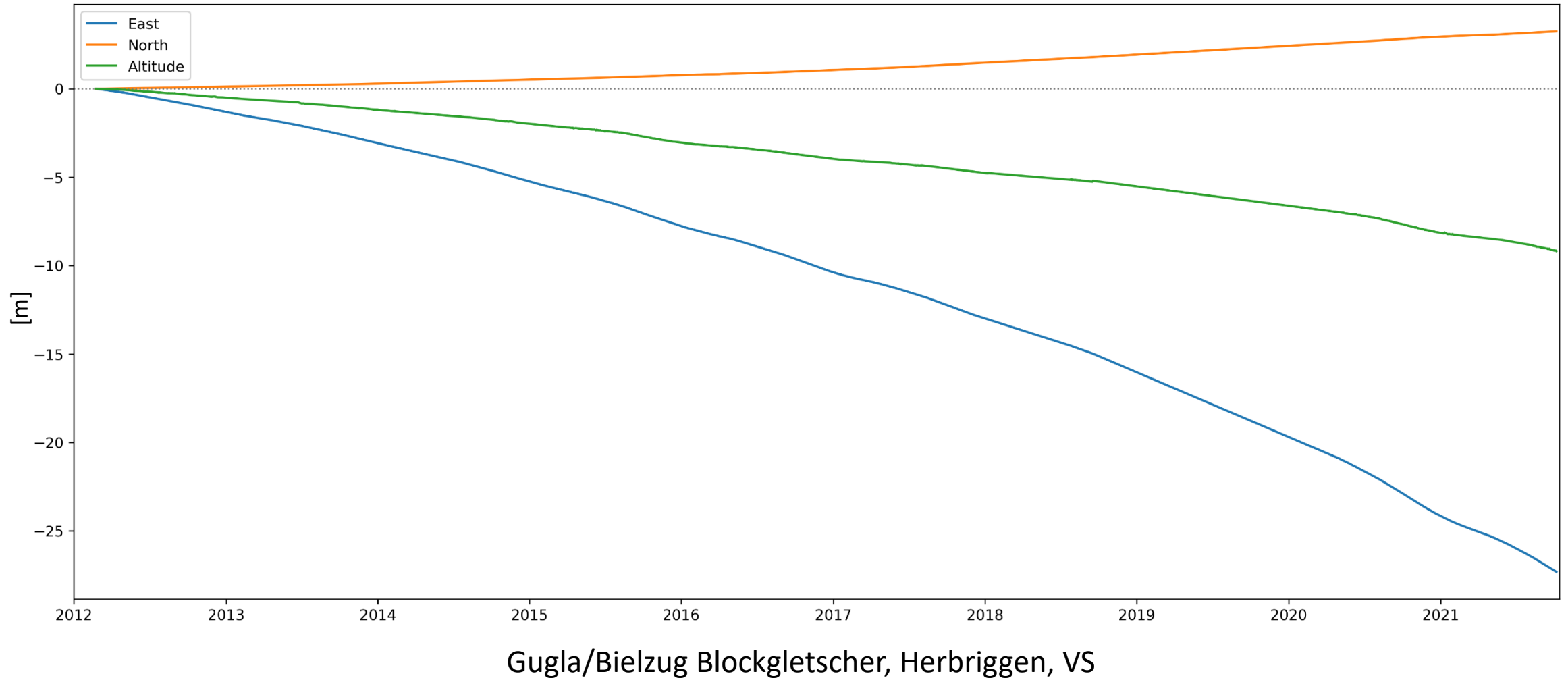


Real-time Experimentation at Valley Scale

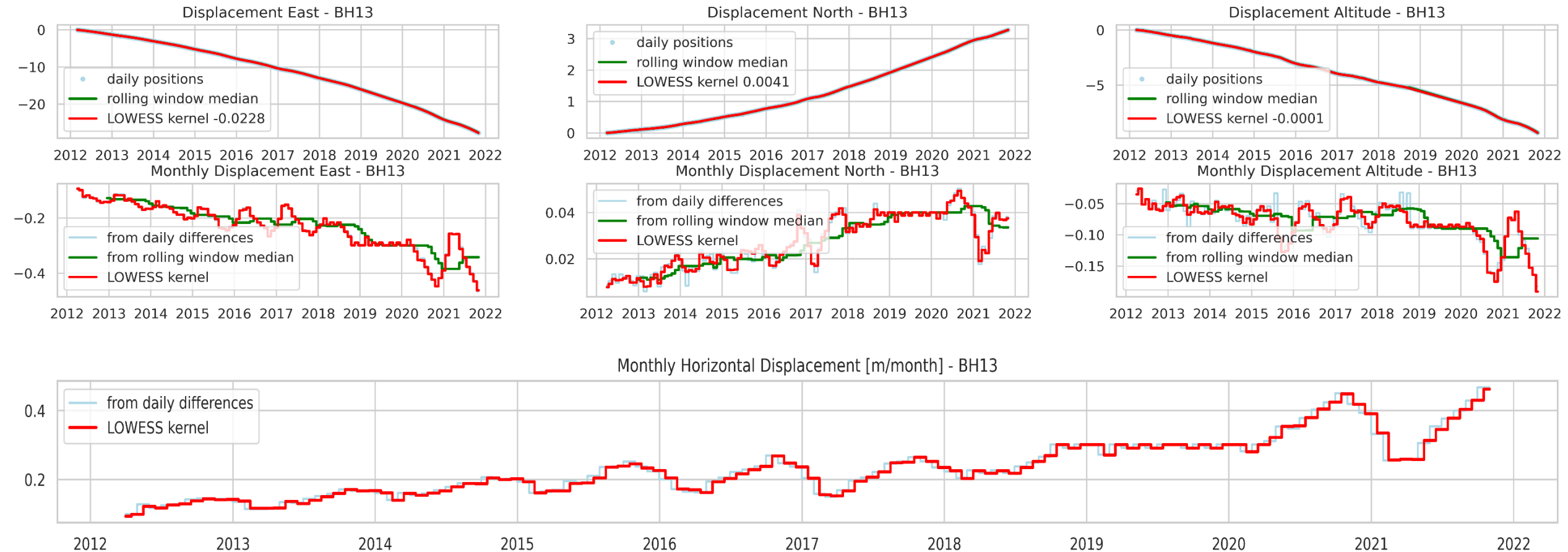
Post-Processing of GNSS Data Within Hours



High-Resolution Coordinate Time Series

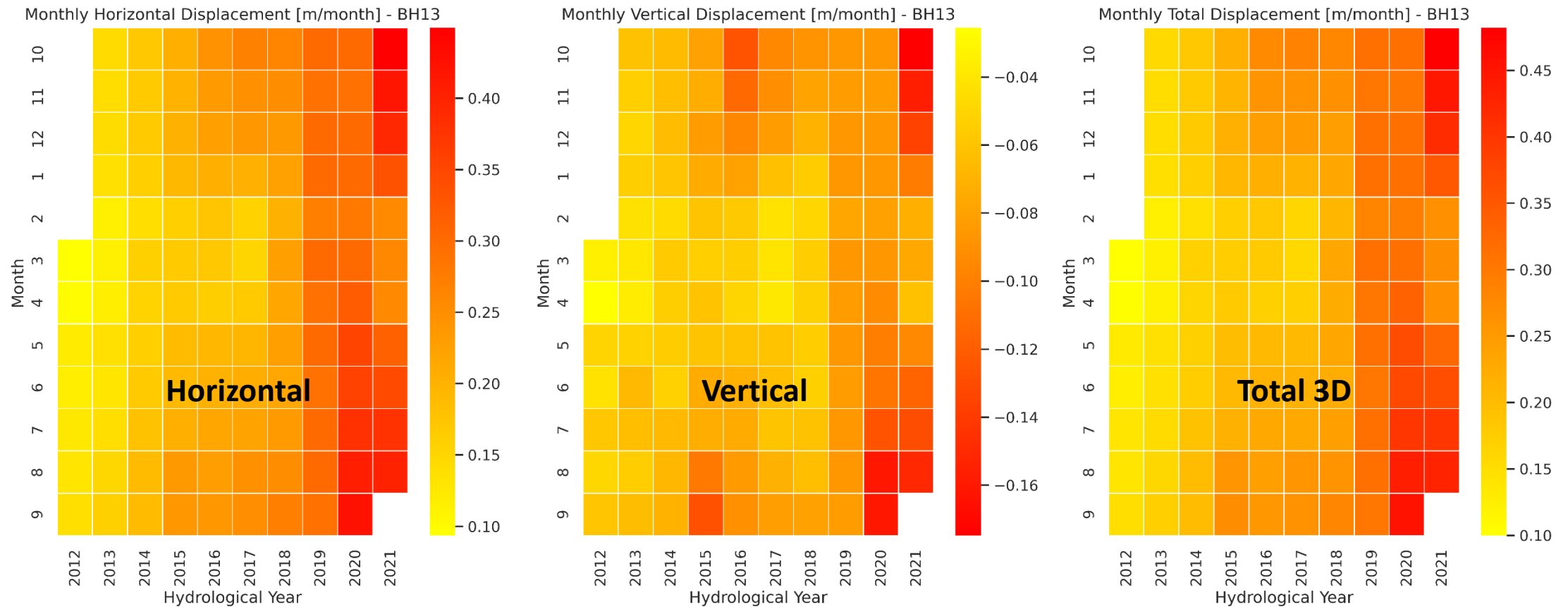


Derived Data Products: Displacement Rates



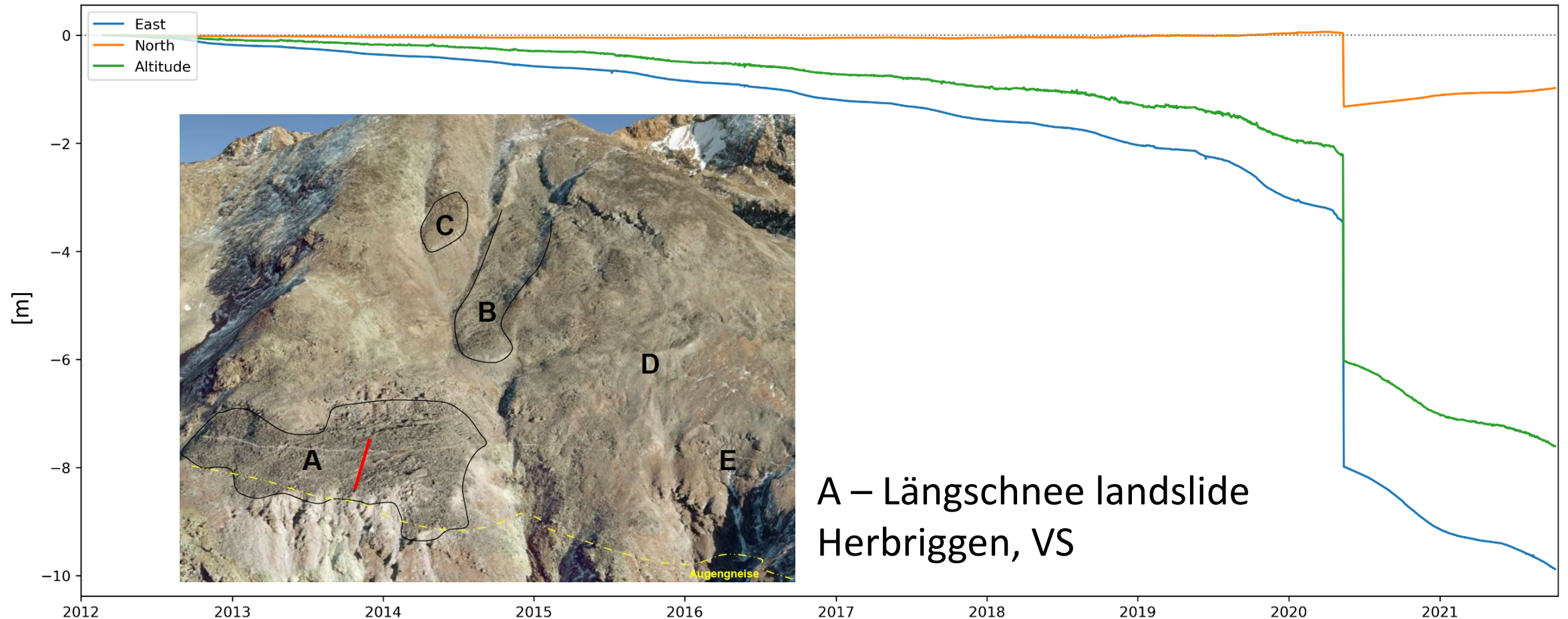
Gugla/Bielzug Blockgletscher, Herbriggen, VS

Alternative Presentation Using Heatmaps

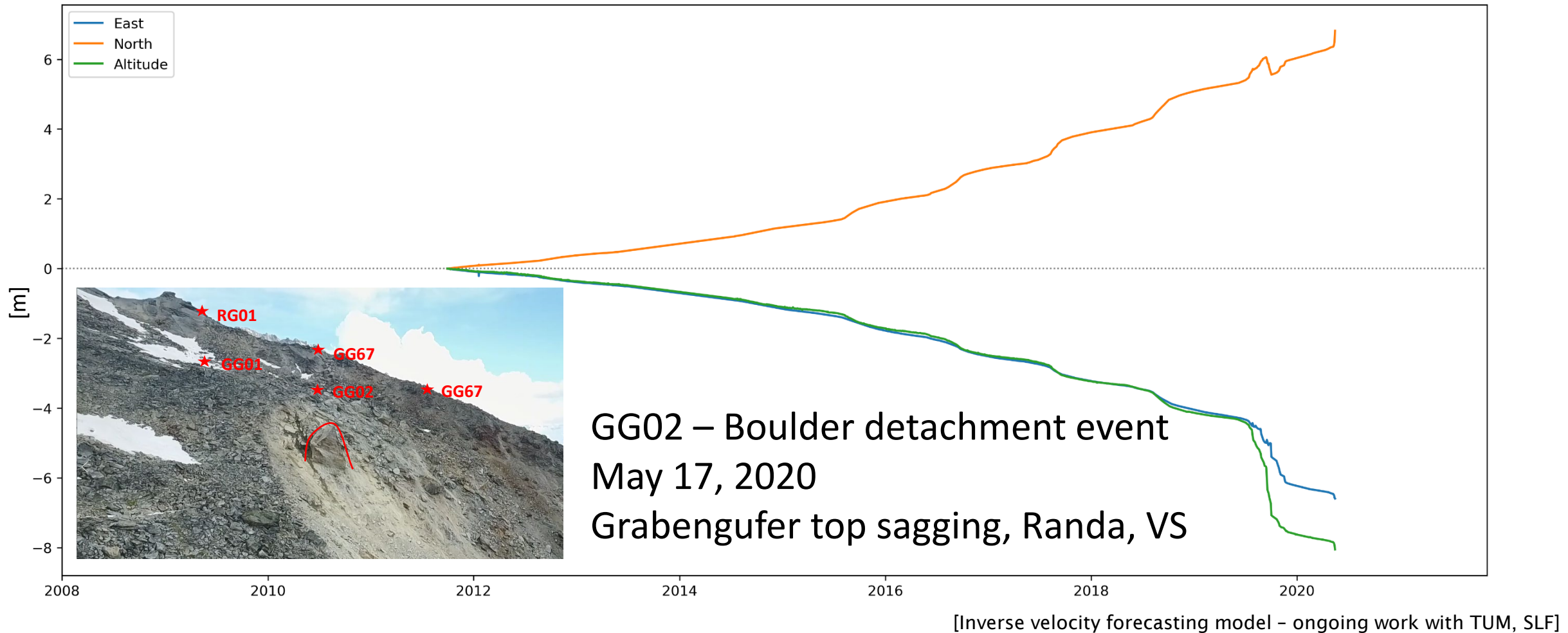


Gugla/Bielzug Blockgletscher, Herbriggen, VS

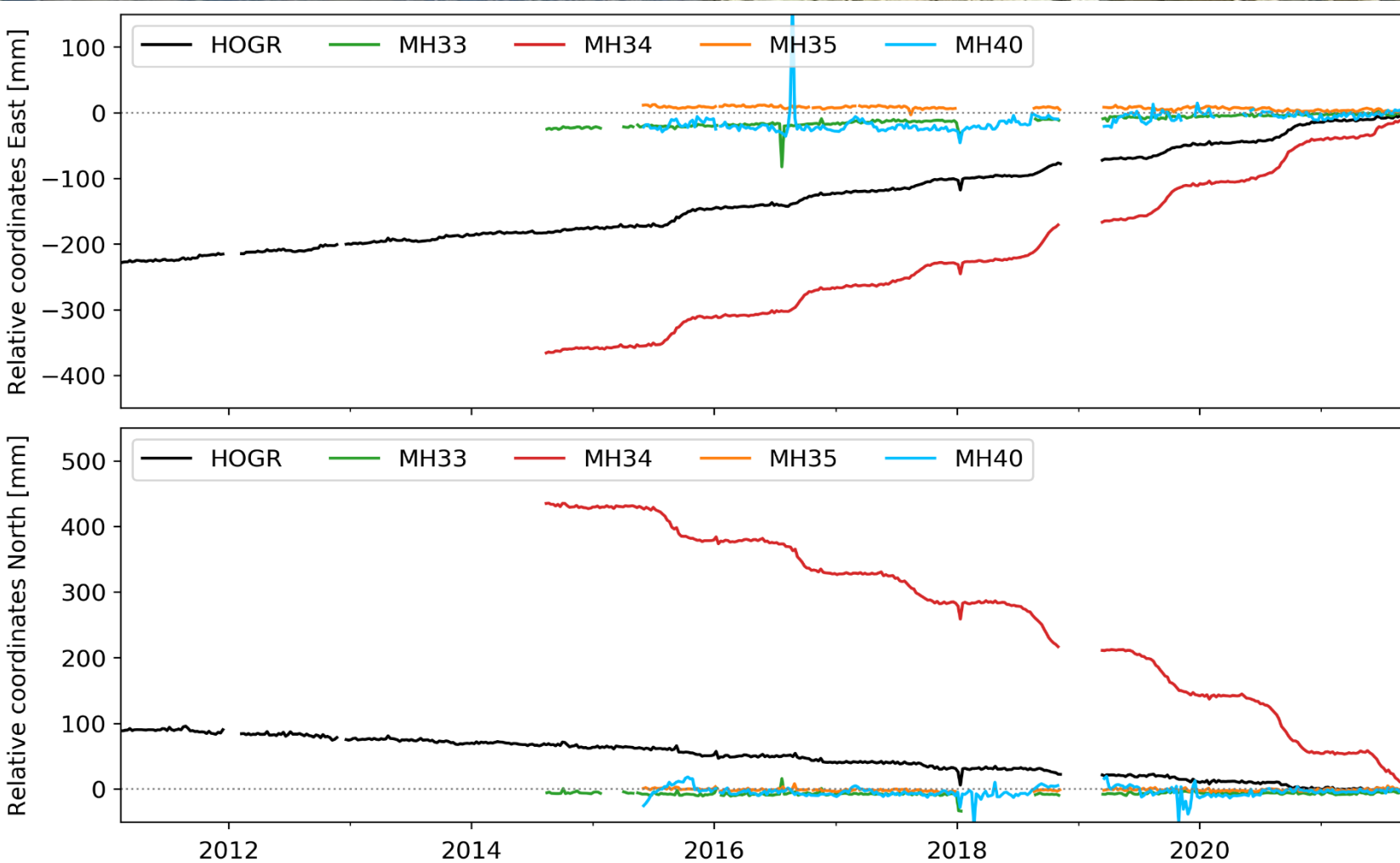
Capture of Stick-Slip Event: Timing, Magnitude



Accurate Capture of Total Collapse



Millimeter-Scale Motion Capture in Steep Bedrock



[Weber et al: A decade of detailed observations (2008–2018) in steep bedrock permafrost at the Matterhorn Hörnligat (Zermatt, CH). Earth Syst. Sci. Data, 11, 1203–1237, 2019. Impact Factor 10.951]

Limitations of Single In-Situ GNSS Measurement Points

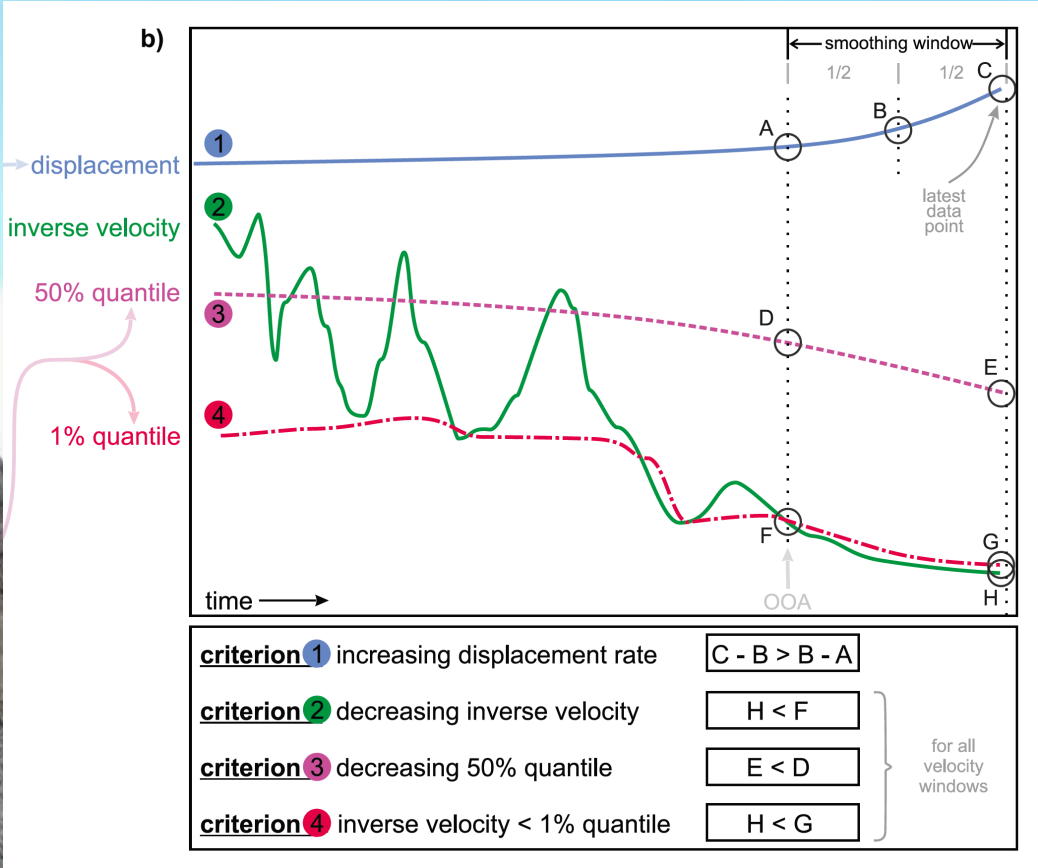


Largario Blockgletscher, Blenio, TI



Dirruhorn + Gugla/Bielzug Blockgletscher, Herbruggen, VS





Next: Application to Forecasting Models

Hazard Mitigation Measures, Grabengufer rock glacier, Randa VS