



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

Jan Beutel, University of Innsbruck
+ PermaSense GNSS Team



Universität
Zürich^{UZH}



universität
innsbruck

The background image shows a vast, rugged mountain range under a clear blue sky. The mountains are covered in patches of white snow, particularly on the upper slopes and ridges, while the lower areas are exposed dark rock. The terrain appears steep and rocky, with deep shadows cast by the mountain faces.

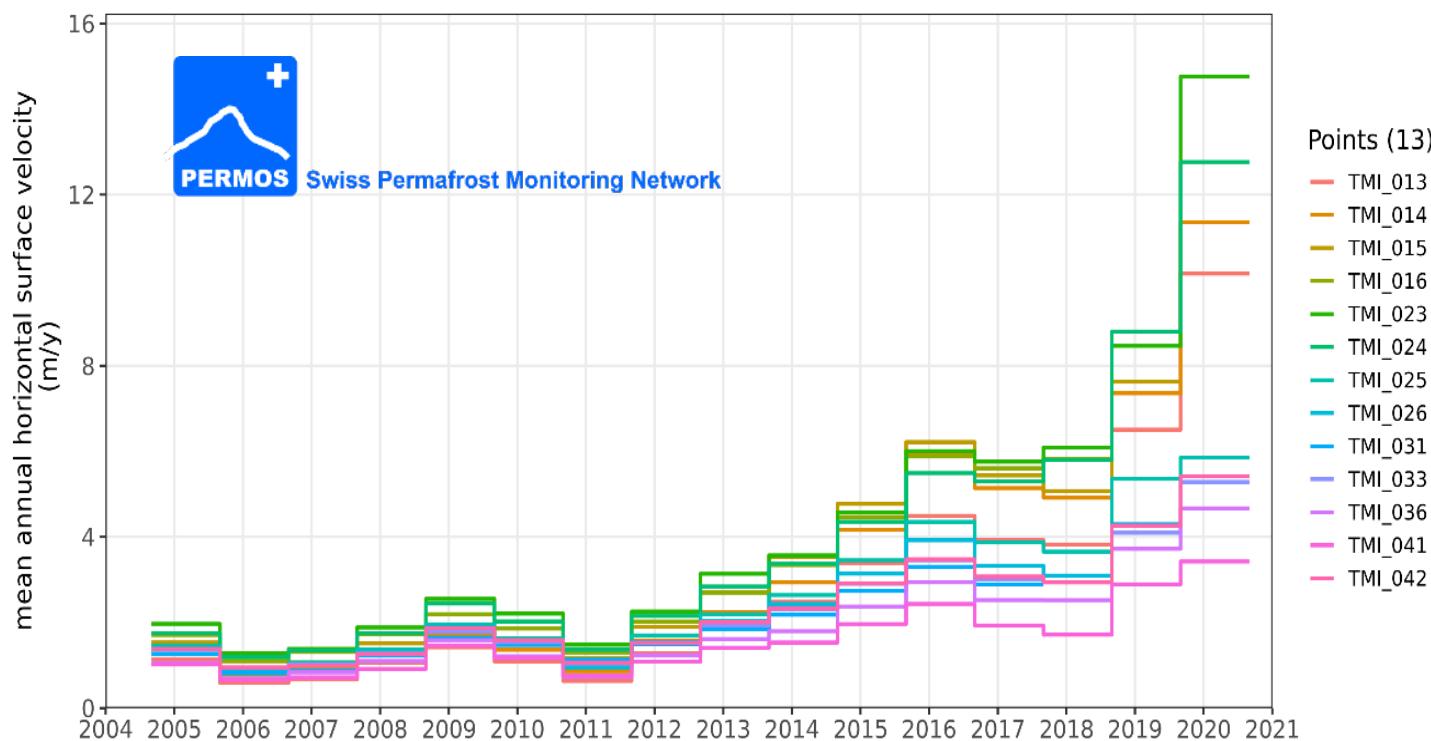
**Increasing surface velocities are observed in the
mountain cryosphere**

Grabengufer rock glacier, Randa VS

[© PermaSense Project]

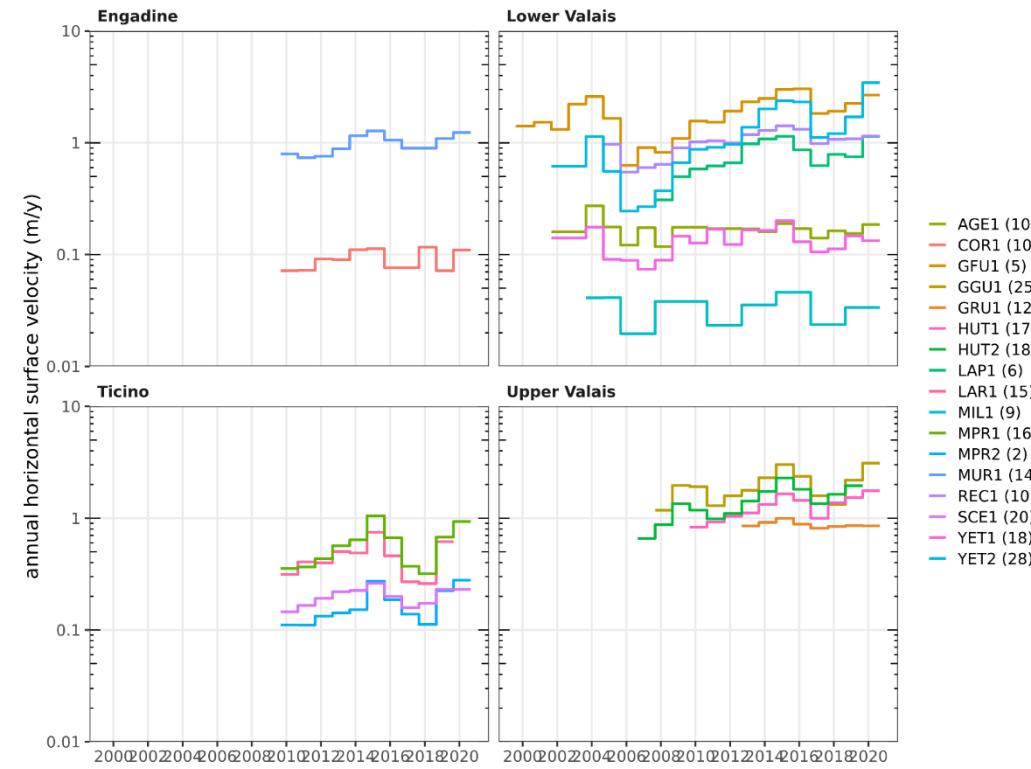
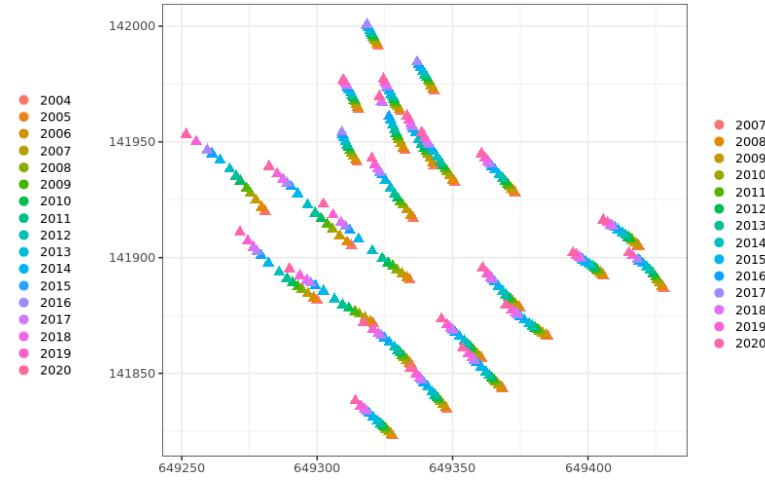
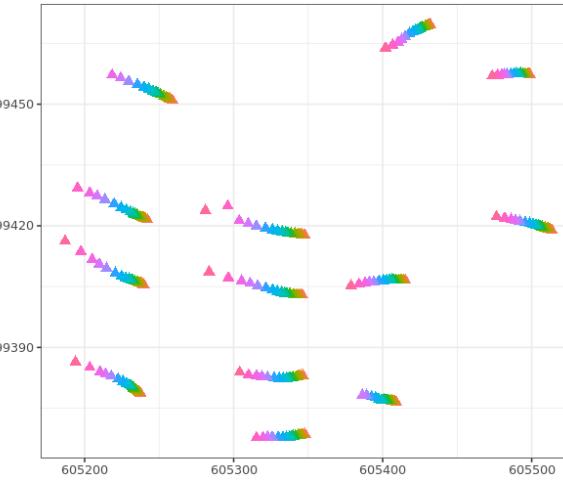
Traditional In-situ Assessment of Surface Deformations

- Repeat manual surveys
- Displacements calculated through differencing



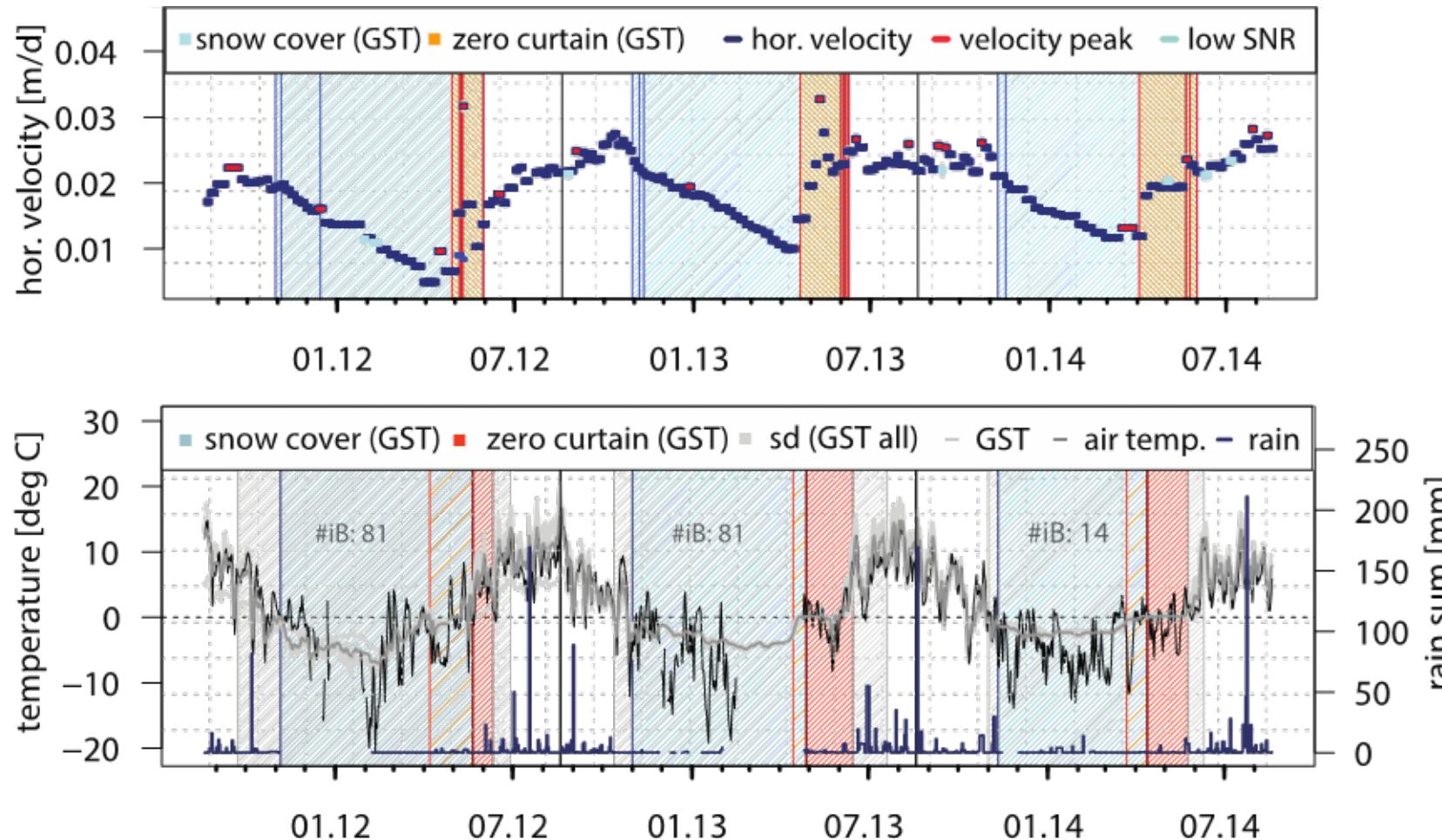
[Lambiel, and Delaloye: *Contribution of Real-time Kinematic GPS in the Study of Creeping Mountain Permafrost: Examples from the Western Swiss Alps.* Permafrost and Periglac. Process. 15: 229–241 (2004)]

Data Contributions 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,
Herbriggen, VS

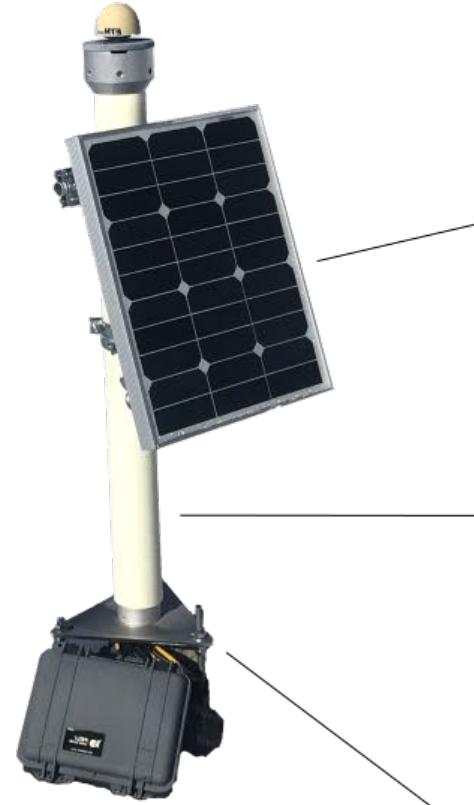
[V. Wirz et al: *Short-term velocity variations at three rock glaciers and their relationship with meteorological conditions*. Earth Surface Dynamics, 4, 1, p. 103-123, 2016.]

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



Mischabel group, Dom and Täschhorn viewed from Grossgufer, Randa, Switzerland

Continuous Observations Using Differential L1-GNSS

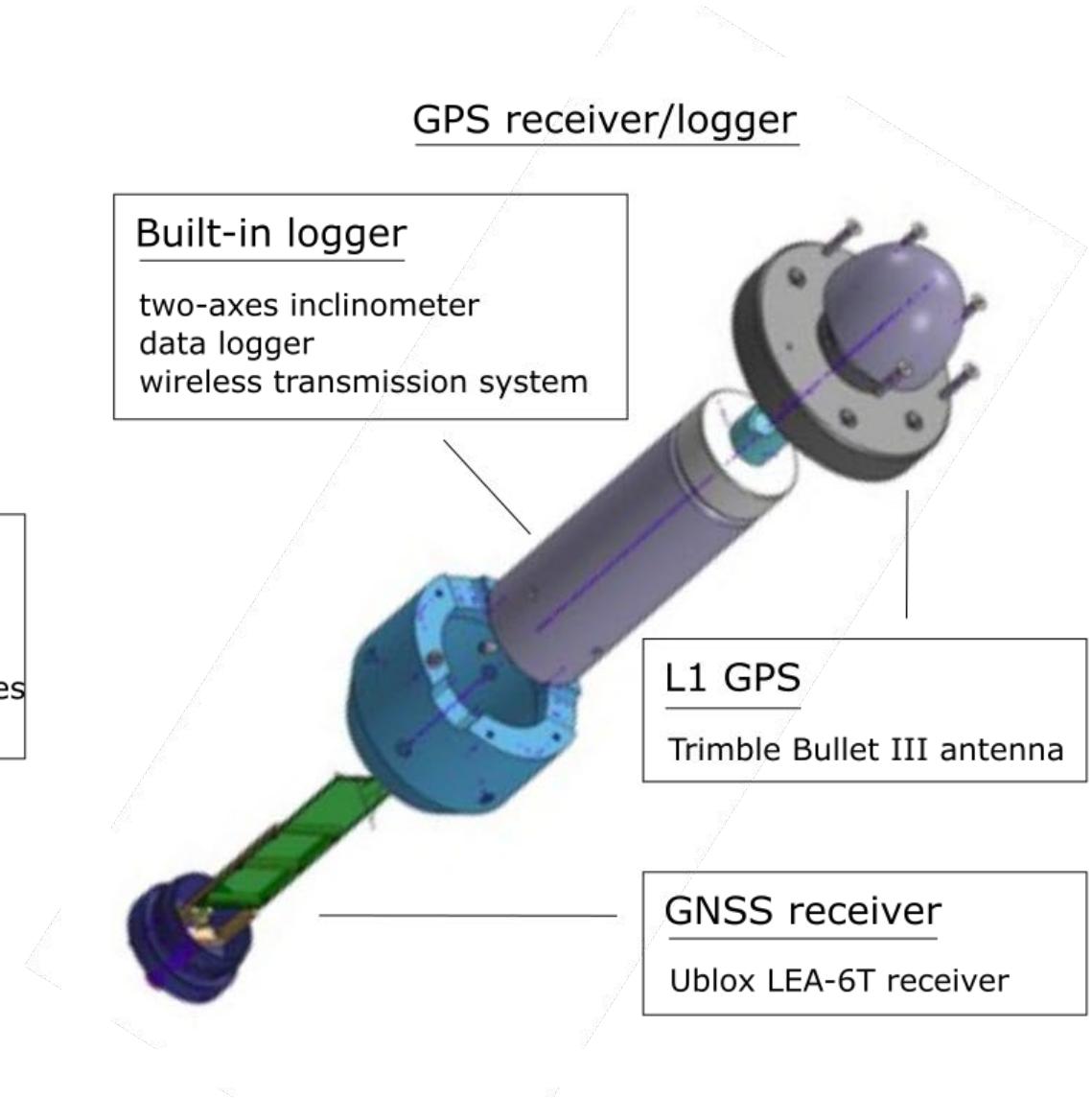


Power box
12.5 V battery
other info?

Solar panel
22 V panel
south exposed

Glas fiber mast
100mm fiber reinforced tube
Different heights
Protection for electronic and cables
Guy lines for stability

Rock anchors
3 x 10 mm glued screws
Triangular steel mast foot
Inclination adjustment



GPS receiver/logger

Built-in logger

two-axes inclinometer
data logger
wireless transmission system

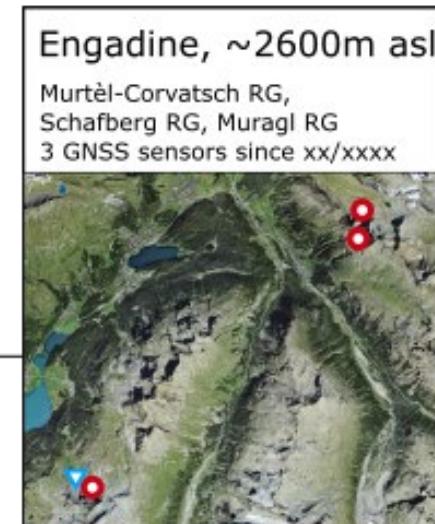
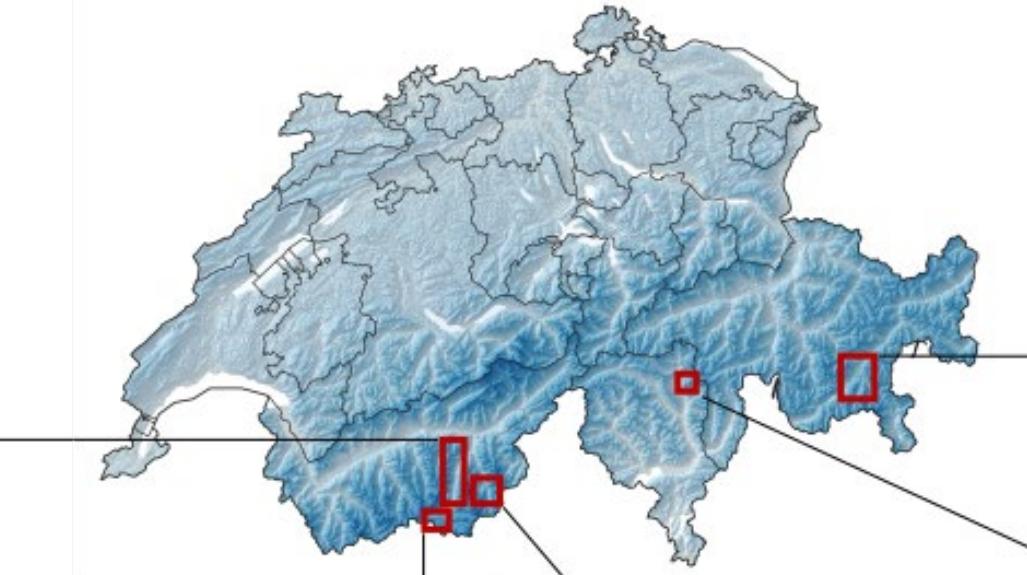
L1 GPS

Trimble Bullet III antenna

GNSS receiver

Ublox LEA-6T receiver

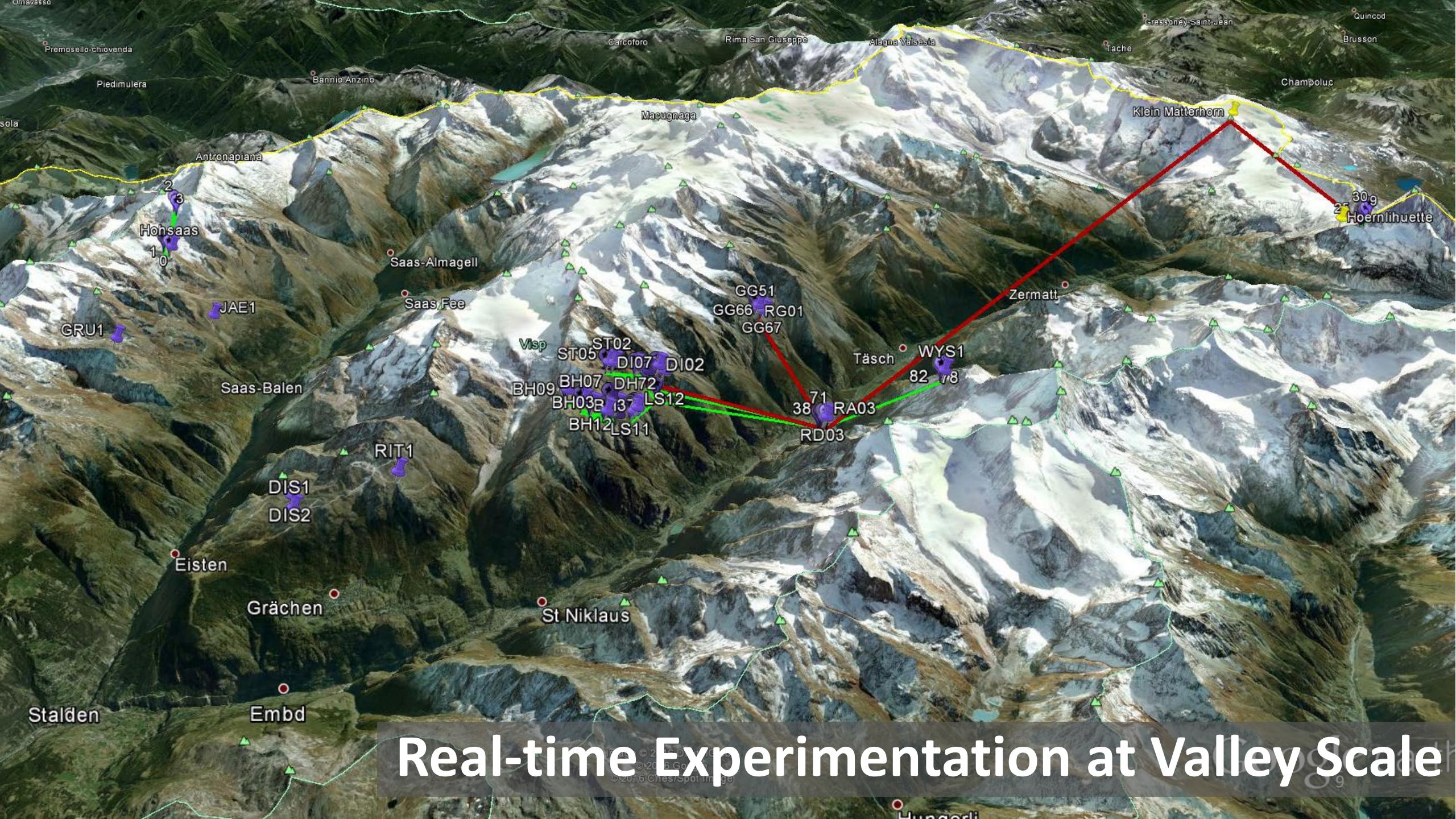
Key Field Sites in Switzerland



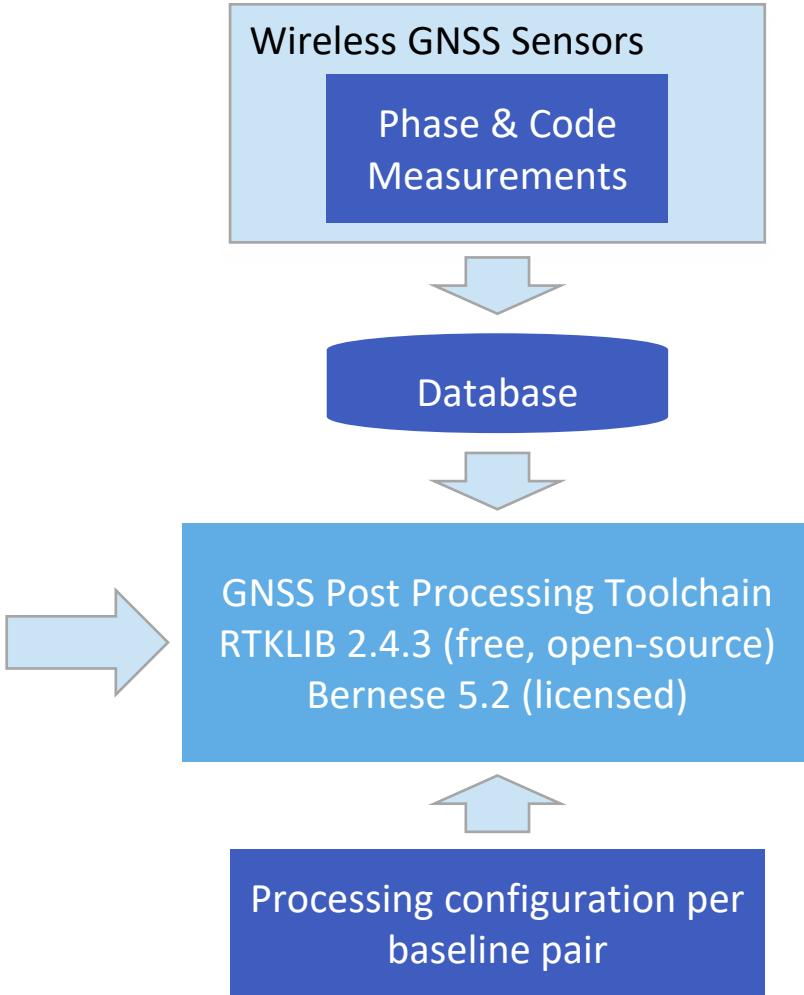
Legend

Landform type (multiple GNSS sensors):

● Rock Glacier ● Landslide ● Steep rock-wall ● Ongoing reference stations ▲ Weather station



Post-Processing of GNSS Data Within Hours



Solution accuracy depends on

- Measurement duration
- Baseline distance
- Availability of observation data

IGS Final – ~17 days

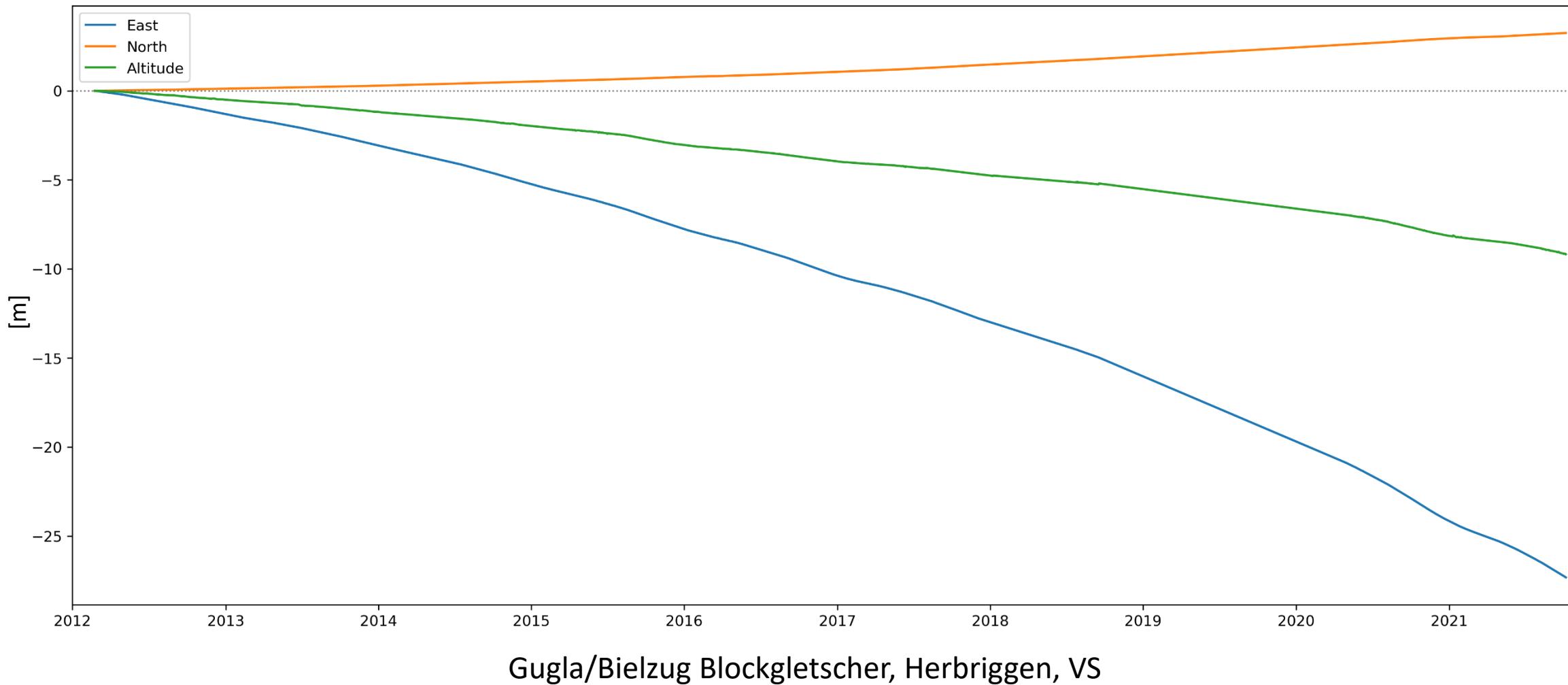
IGS Rapid – daily

IGS Ultra-rapid – 3 hourly

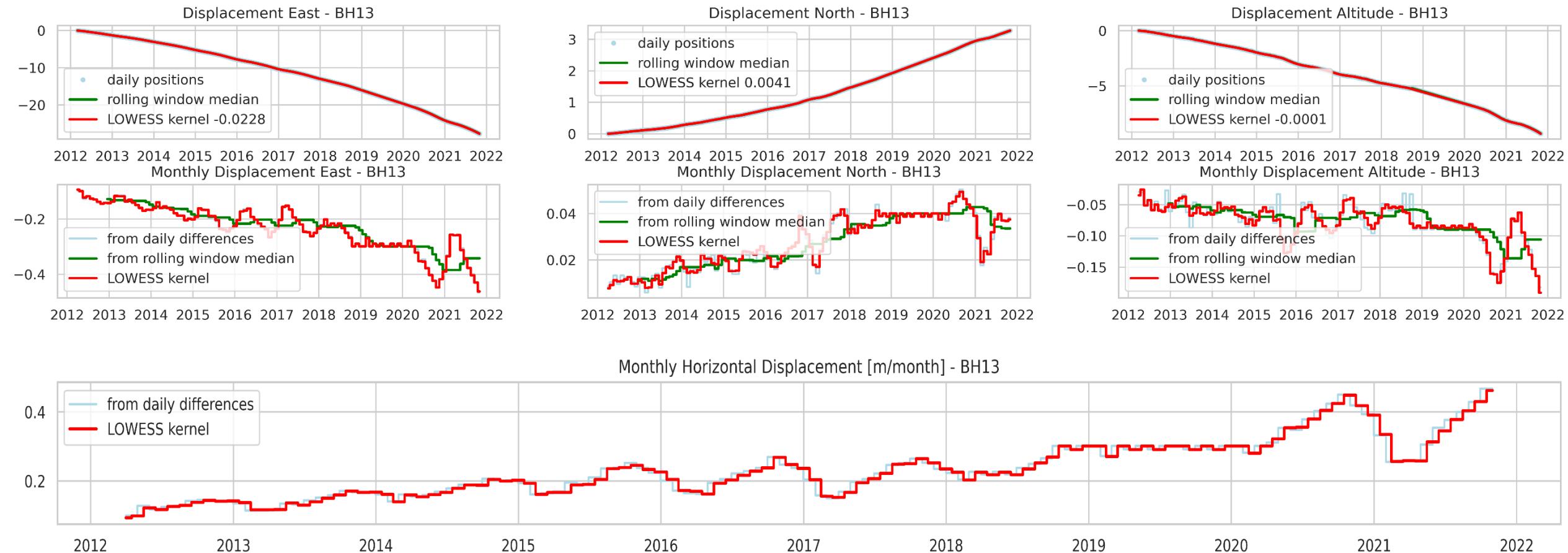
Typical pos. accuracy: Std. dev ~1-2 mm

YYYY	MM	DD	E [m]	N [m]	H [m]	VE	VN	VH
2015	06	11	2643766.990	1108779.430	3637.374	-3.83	1.68	-4.63
2015	06	12	2643766.953	1108779.446	3637.328	-4.21	2.35	-5.67
2015	06	13	2643766.907	1108779.476	3637.262	-4.57	2.62	-7.10
2015	06	14	2643766.861	1108779.499	3637.185	-4.31	2.13	-6.25
2015	06	15	2643766.821	1108779.519	3637.139	-4.27	2.13	-4.97
2015	06	16	2643766.763	1108779.553	3637.066	-5.22	3.47	-7.96
2015	06	17	2643766.718	1108779.589	3636.975	-5.53	3.05	-6.33

High-Resolution Coordinate Time Series

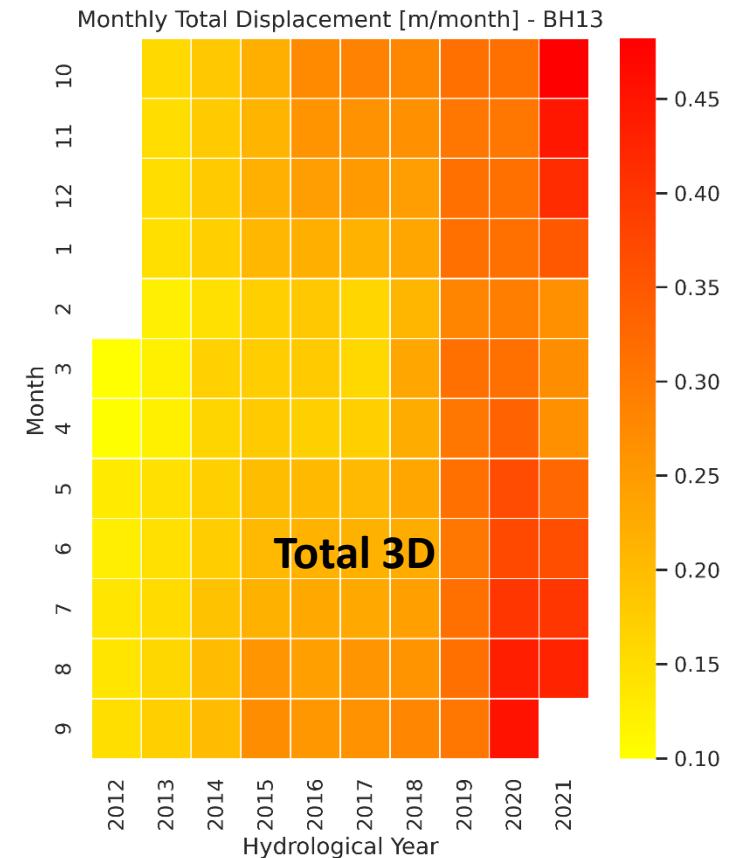
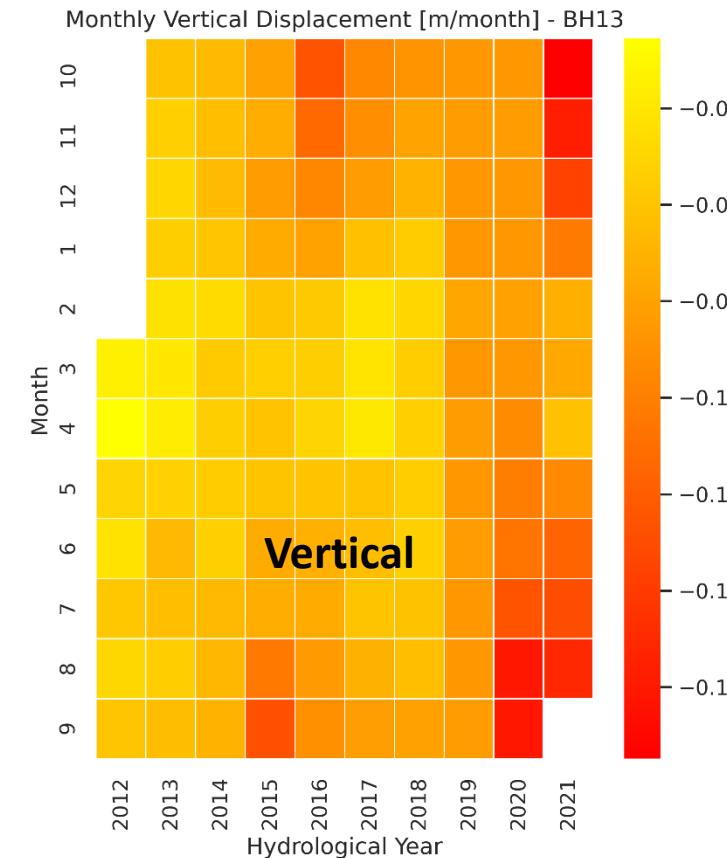
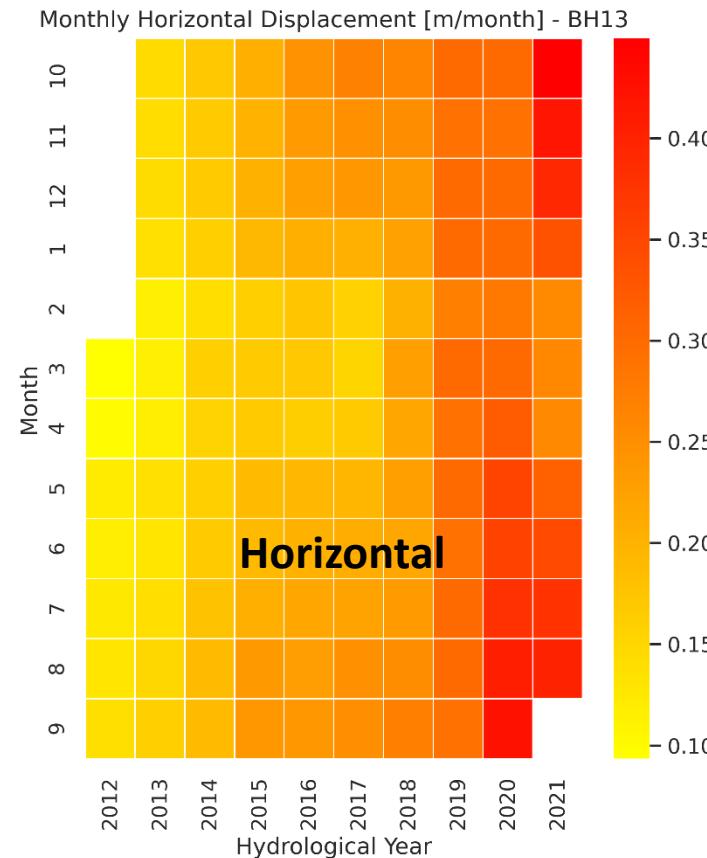


Derived Data Products: Displacement Rates



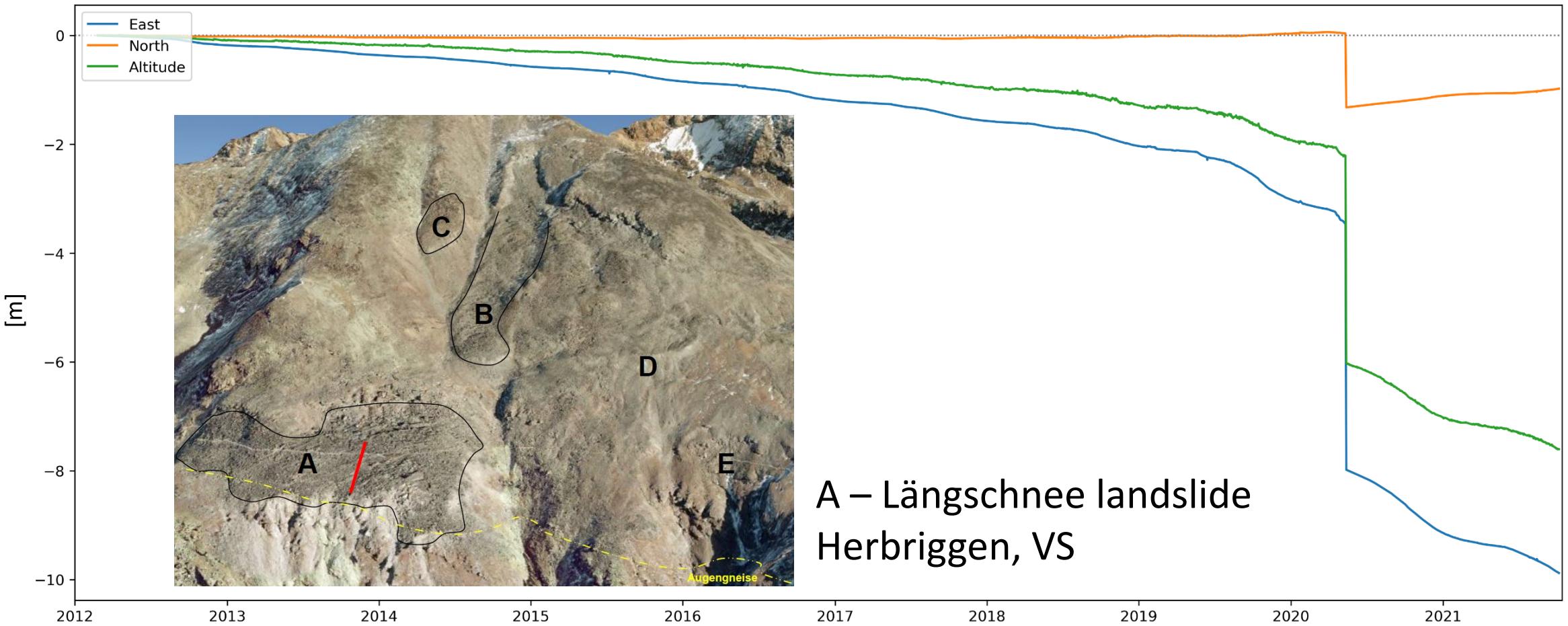
Gugla/Bielzug Blockgletscher, Herbriggen, VS

Alternative Presentation Using Heatmaps

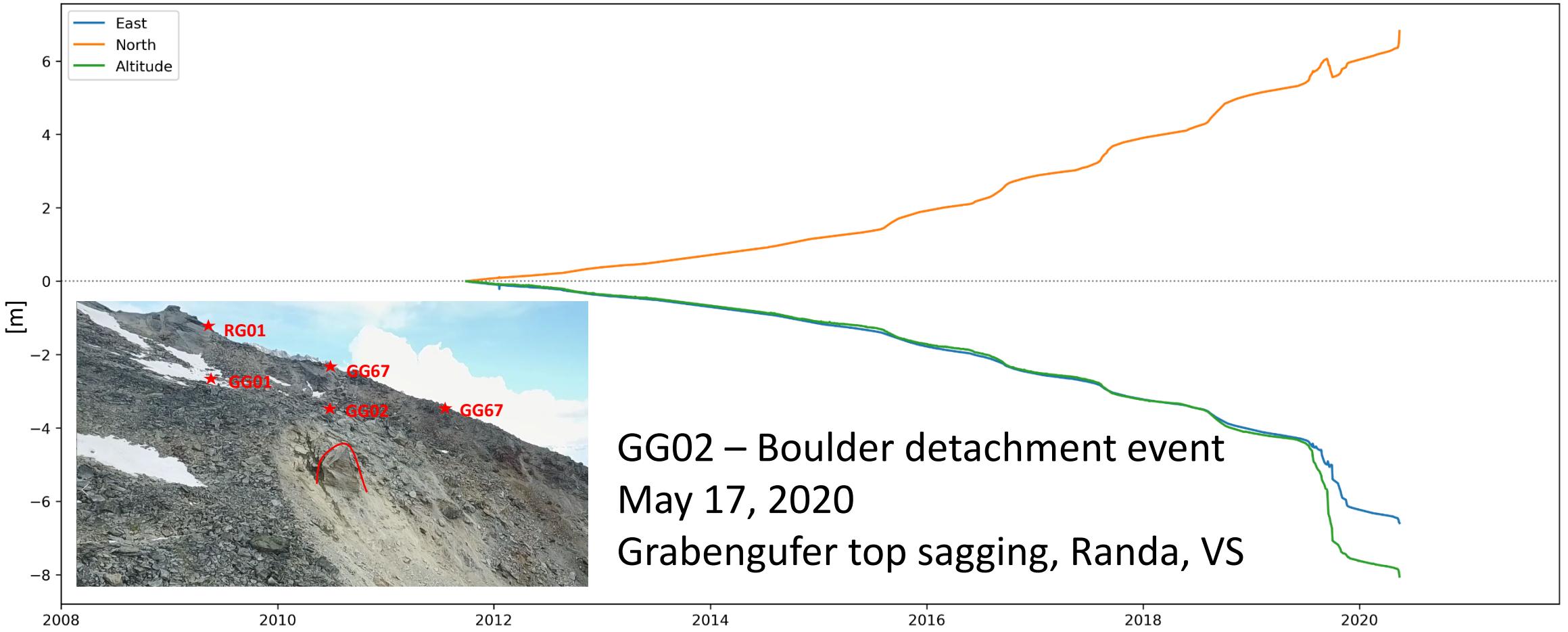


Gugla/Bielzug Blockgletscher, Herbriggen, VS

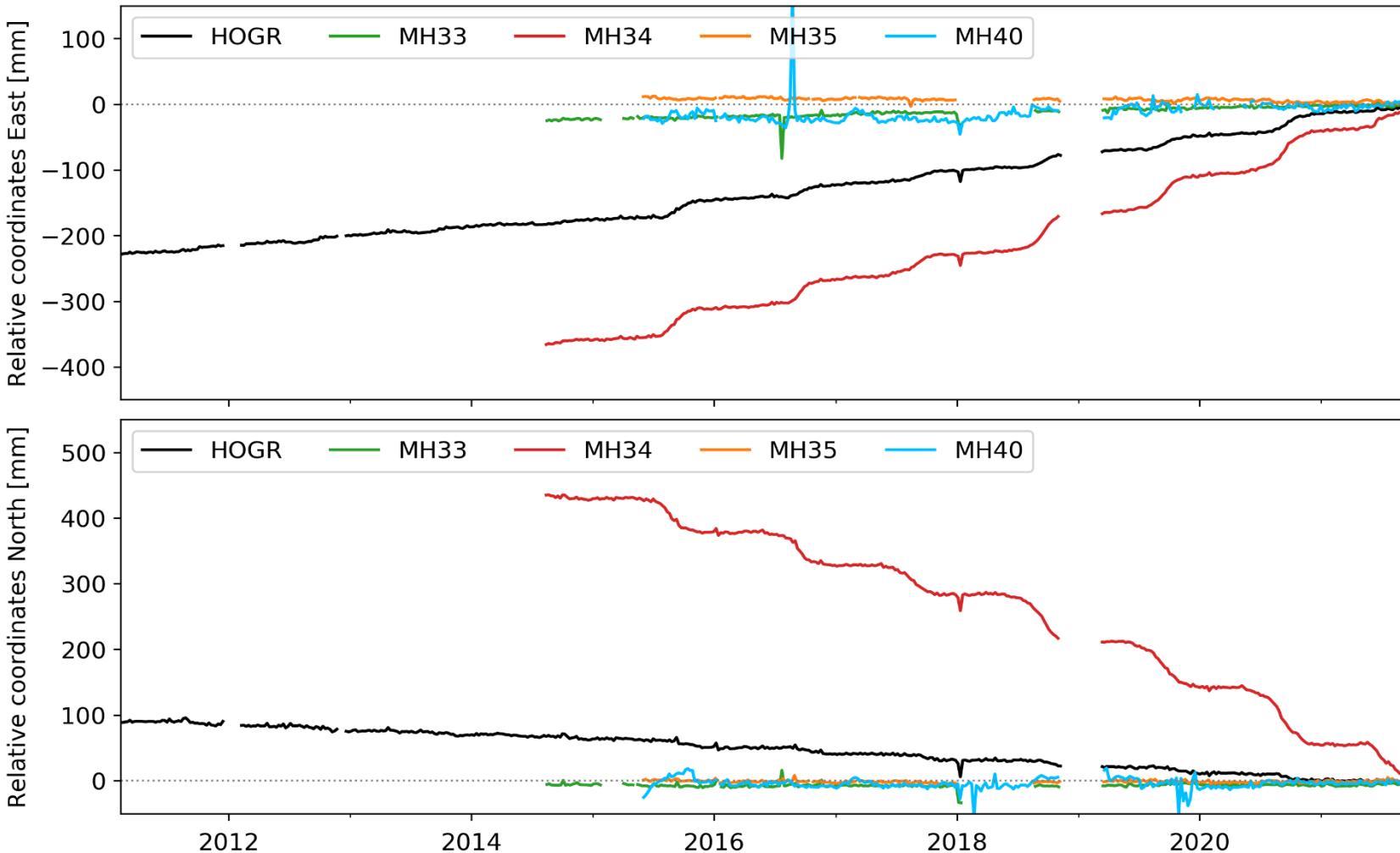
Capture of Stick-Slip Event: Timing, Magnitude



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 Hörnligrat (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 , Herbriggen, VS

