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Geodätisches Monitoring von Massenbewegungen im alpinen Bereich

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Outline

- Motivation
- Velocity Classification of Mass Movements
- Monitoring of Mass Movements with GNSS
  - Overview: Processing Modes and Accuracy
  - Static Processing
  - RTK Processing
  - Doppler Velocity Processing
- Photogrammetric Monitoring of Mass Movements
- Summary

Motivation

- Rapidly provide geodetic information for integration in early warning systems
- Collect time series of data to gain insight into the physical mechanisms driving the mass movements

Figure left:

Mudflow in Pradella GR in July 2015

(Source: nzz.ch)

Figure right:

Debris avalanche, Felber Tauern (Austria) in May 2013 (Source: diepresse.at)

Velocity Classification of Mass Movements

- Which processing strategy for which type of hazard?
- Issues: Maintainance & infrastructural costs, computational & memory costs, …

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity	Probable Destructive Significance
7	Extremely Rapid			Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
		5×10^{3}	5 m/sec	
6	Very Rapid			Some lives lost; velocity too great to permit all persons to escape
		5×10^{1}	3 m/min	
5	Rapid			Escape evacuation possible; structures; possessions, and equipment destroyed
		5×10^{-1}	1.8 m/hr	
4	Moderate			Some temporary and insensitive structures can be temporarily maintained
		5×10^{-3}	13 m/month	
3	Slow			Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
		5×10^{-5}	1.6 m/year	
2	Very Slow			Some permanent structures undamaged by movement
		5×10^{-7}	15 mm/year	
	Extremely SLOW			Imperceptible without instruments; construction POSSIBLE WITH PRECAUTIONS

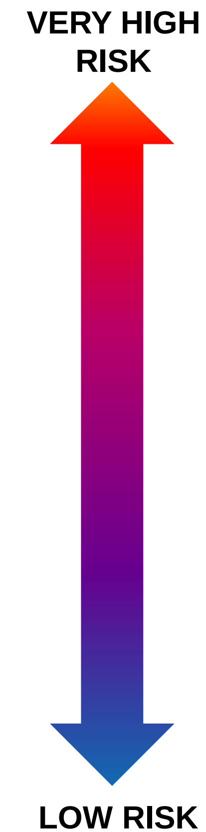
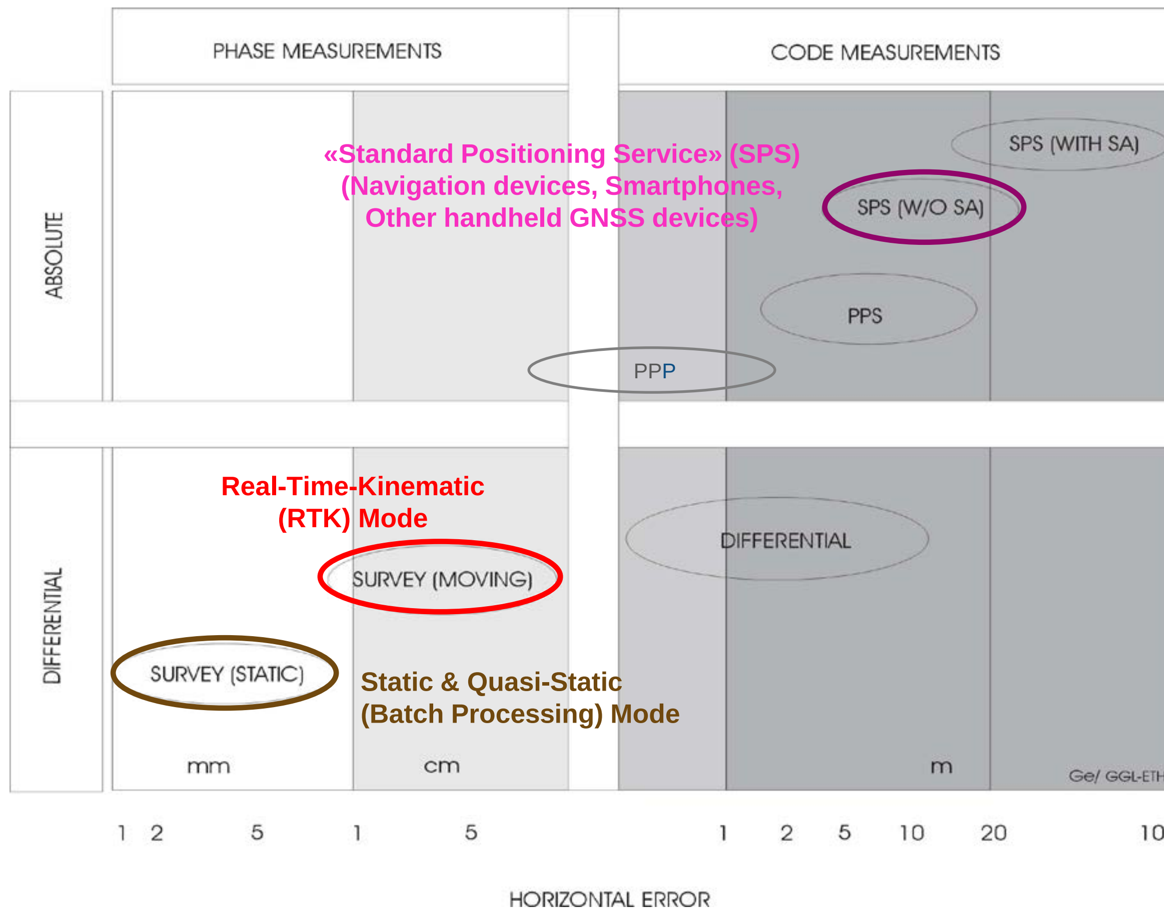


Image Source: Landslide Risk Management Concepts and Guidelines, Australian Geomechanics Society

GNSS Positioning Modes and Accuracy

- **Generally:** Quality of the solution depends on type/number of observables, mathematical/physical models for error mitigation, type of receiver/antenna, …

Mode	Characteristics
SPS	Horizontal Acc.: ~ 1 – 15 meters Sampling interval: (Sub) Seconds Initialization time: Seconds to minutes
Velocity (Doppler)	Horizontal Acc.: ~ 0.01 – 0.2 meters/s Sampling interval: (Sub) Seconds Initialization time: Seconds to minutes
RTK	Horizontal Acc.: ~ 0.01 – 0.2 meters Sampling interval: (Sub) Seconds Initialization time: Minutes
Static	Horizontal Acc.: ~ 0.001 – 0.05 meters Sampling interval: Seconds to minutes Solution provided: Days to hours (measurement stacking)



GNSS Processing and Landslide Velocity

- Which processing strategy for which type of hazard?
- Issues: Maintainance & infrastructural costs, computational & memory costs, …

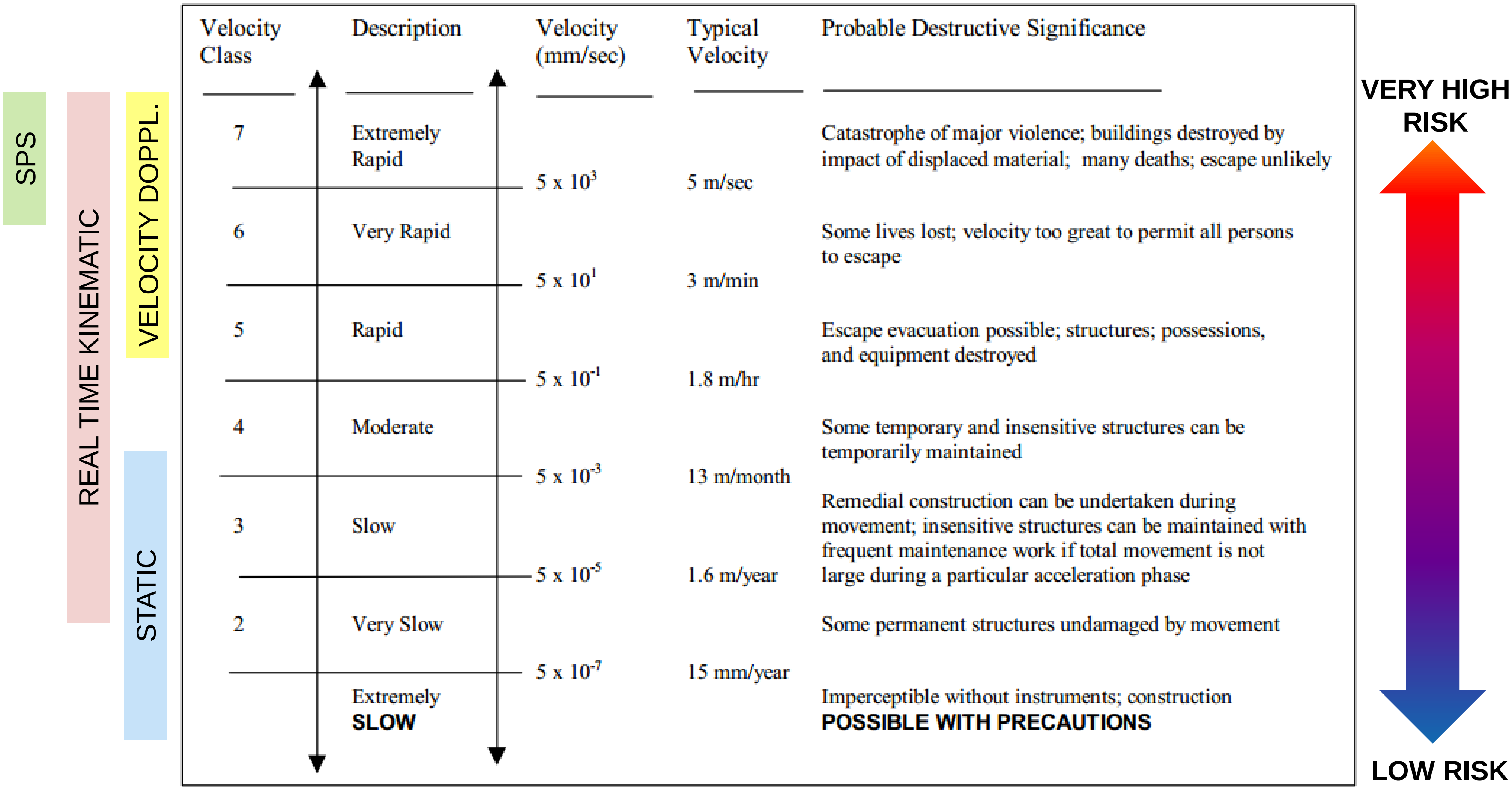


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Image Source: Landslide Risk Management Concepts and Guidelines, Australian Geomechanics Society

Geomonitoring in the Matter Valley, Switzerland

- **Projects *X-Sense, X-Sense2***
  - Part of *nano-tera* program of SNF
  - Collaboration of several institutes of ETHZ and UZH: Computer Engineering Lab TIK (ETHZ, lead), Institute for Micro- and Nanosystems (ETHZ), Institute for Geodesy and Photogrammetry (ETHZ), Institute for Geography (UZH)
  - **Goal:** Investigation of effects of climate change on alpine permafrost zones with a focus on the understanding of processes triggering natural hazards and early-warning

nano-tera.ch

FNS SNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

"Nano-tera: engineering complex systems for health, security, energy and the environment"

- **Our contribution:**
  - Monitoring of mass movements (e.g. rock glaciers) and velocities with permanently operating and energy-self-sufficient GPS stations and photogrammetric methods
  - Geodetic movement information as a contribution to an early warning system which shall be woken up by acoustic emissions of a hazardous event

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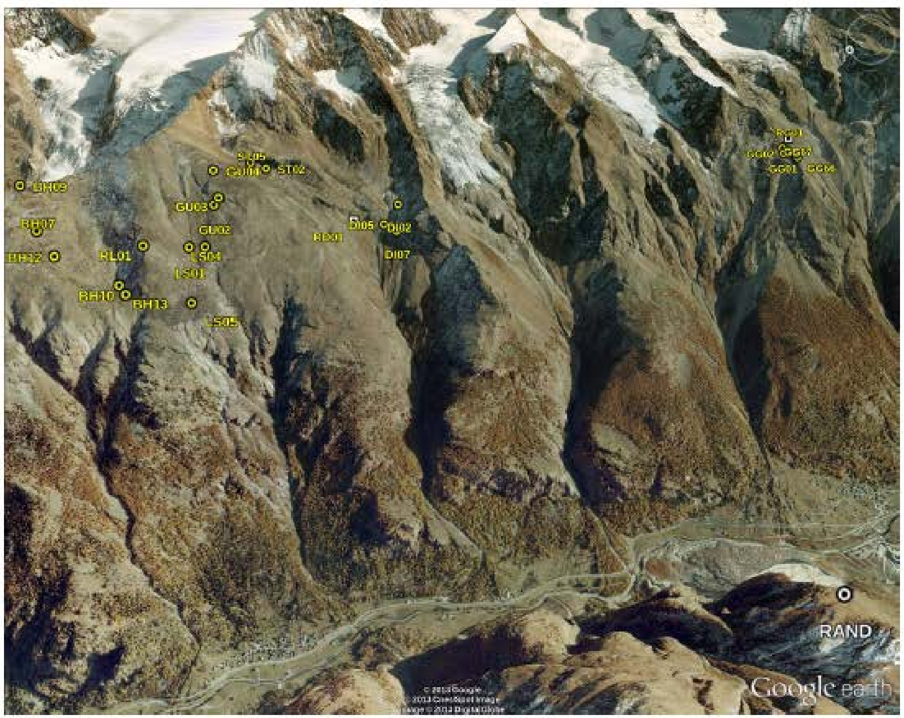
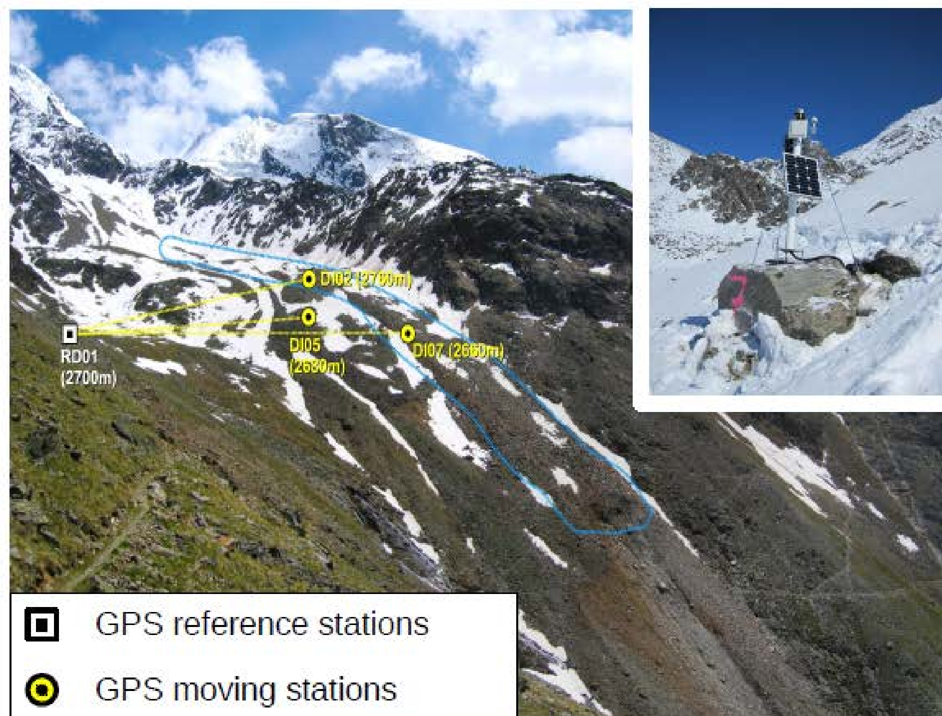
GNSS Monitoring Matter Valley, Switzerland

nano-tera.ch *X-Sense*

- **Differential carrier phase processing**
  - Single frequency, geodetic low-cost equipment
  - **Static (batch) processing:** Observation stacking over 24 hours/4 hours (30 s sampling)
    → One position solution per day/per 4 hours (mm-accuracy)
  - **Real-Time-Kinematic (RTK) processing**
    → Position solutions with 30 s intervals (cm-accuracy)

[Limpach et al 2013, EGU]





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Matter Valley: Results from Static Processing

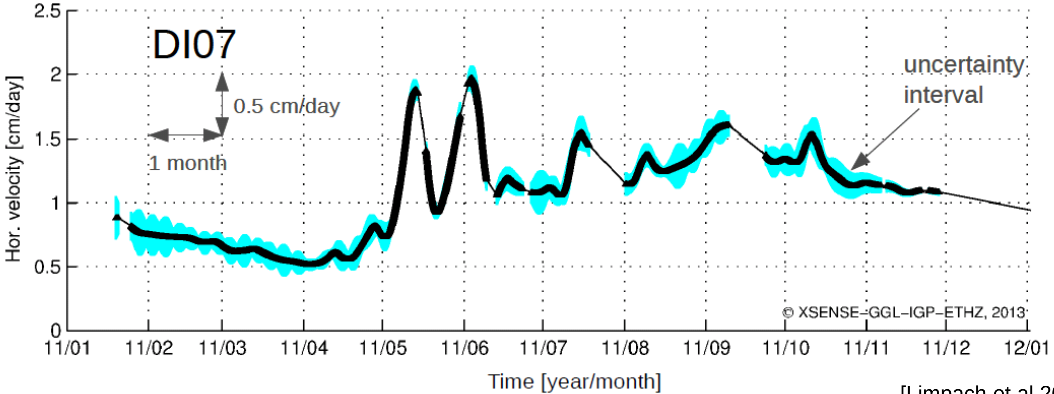
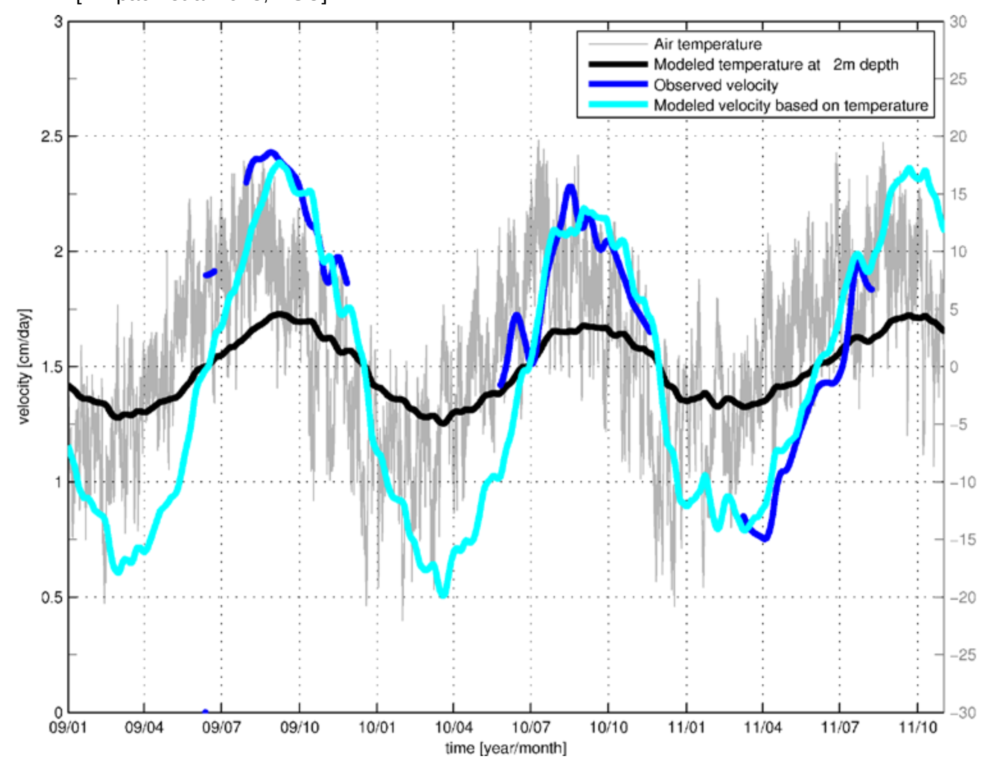


Figure left: *Horizontal velocity for station DI07 (located on the rock glacier) obtained from static solution. There is a general increase of the velocity during the summer months. The peaks in May and June are due to snow-melt.*

[Limpach et al 2013, EGU]

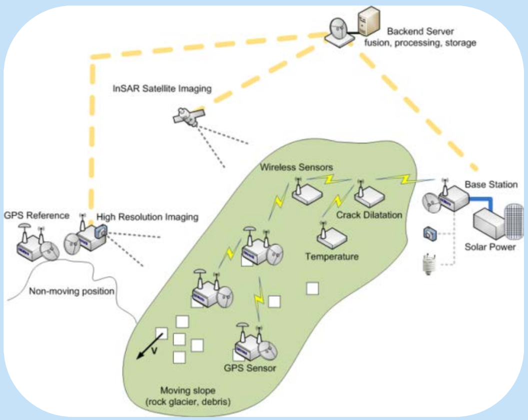
Figure right: *Analysis of the influence of temperature on the surface velocity of a rock glacier. The good agreement with the surface velocity obtained from GPS (blue line) with the modeled velocity (cyan line) shows the strong influence of temperature on seasonal velocity variations . A correlation between short-term velocity variations and water infiltration due to snow-melt and heavy rain was also observed (not shown here)*



RTK Processing

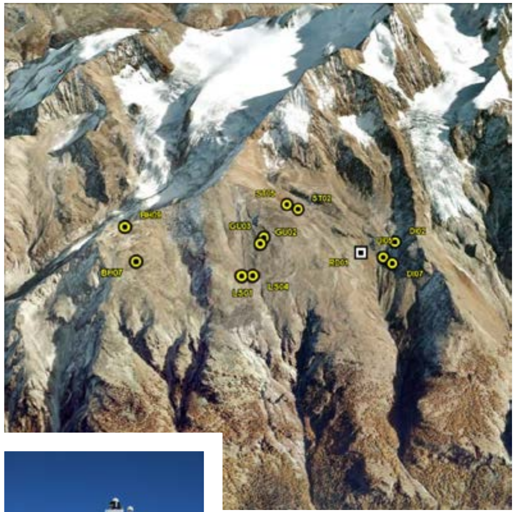
- Overview of the system architecture and overview of the RTK processing workflow of the X-Sense project:

System architecture overview



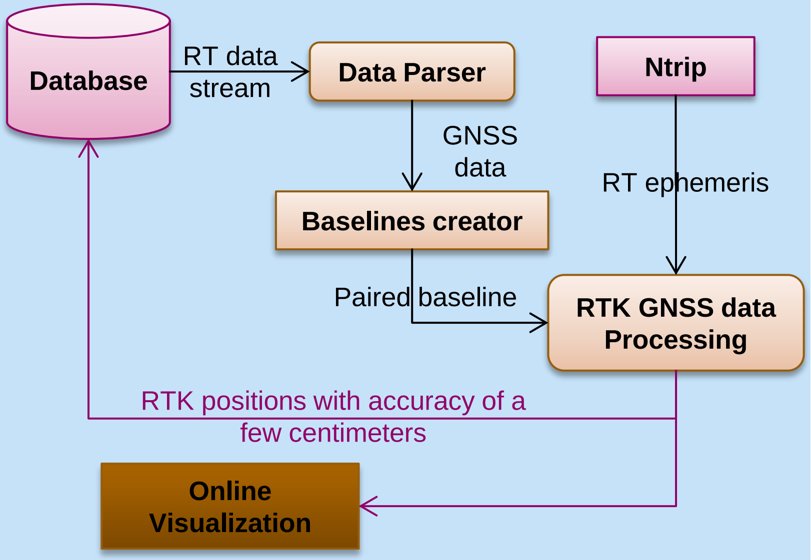
- L1 low-cost GNSS
- Wireless communication
- Solar power
- Real time data stream

GNSS stations in Swiss alps



20 RT stations; Motion Speed: 5cm/y ~ 7m/y

RTK GNSS process flow



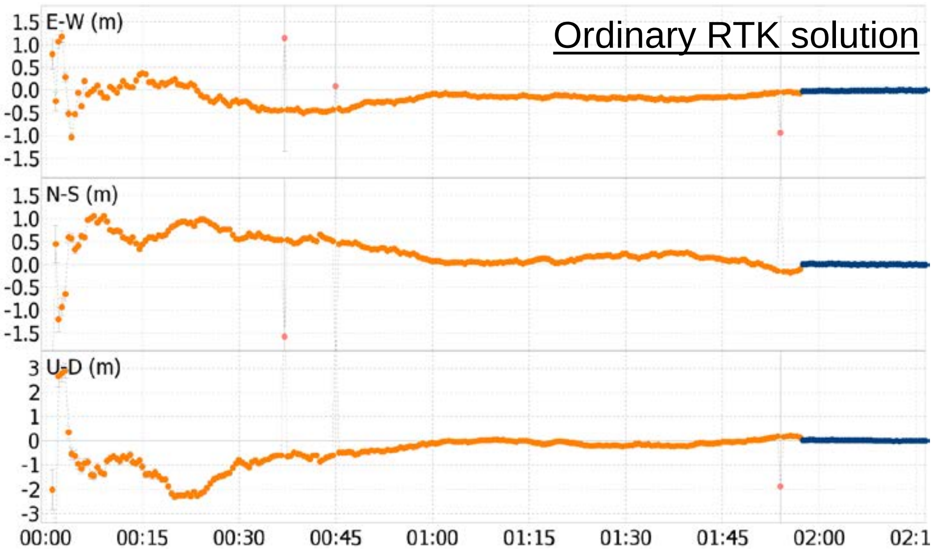
In the project X-Sense, a real time monitoring system has been developed based on wireless sensor network and RTK (Real Time Kinematic) GNSS positioning technique.

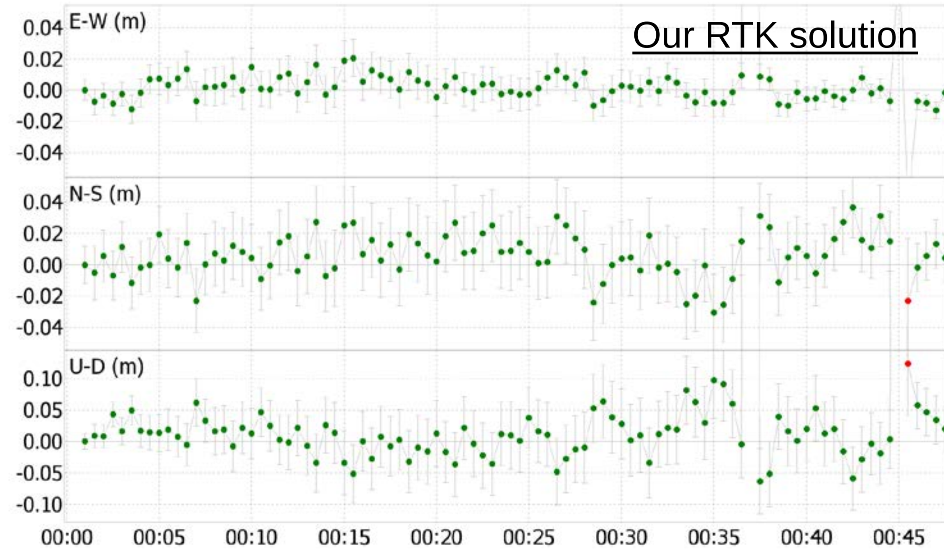
[Z. Su]

RTK Processing

- An aim of the RTK processing is to rapidly fix the integer ambiguities within few epochs

[Z. Su]





Comparison of a 5 km baseline RTK solution

Orange Points – float solution Green points – fixed solution

For the same 5 km baseline with 30s data sampling interval, the ordinary RTK processing takes 2 hours till the first ambiguities fixing. With our tailored processing strategy, the ambiguities are fixed at the first one or two epochs.

Matter Valley: Static and RTK Processing

- Static solutions (4 h stacking) for station BH10 for a timespan of one month

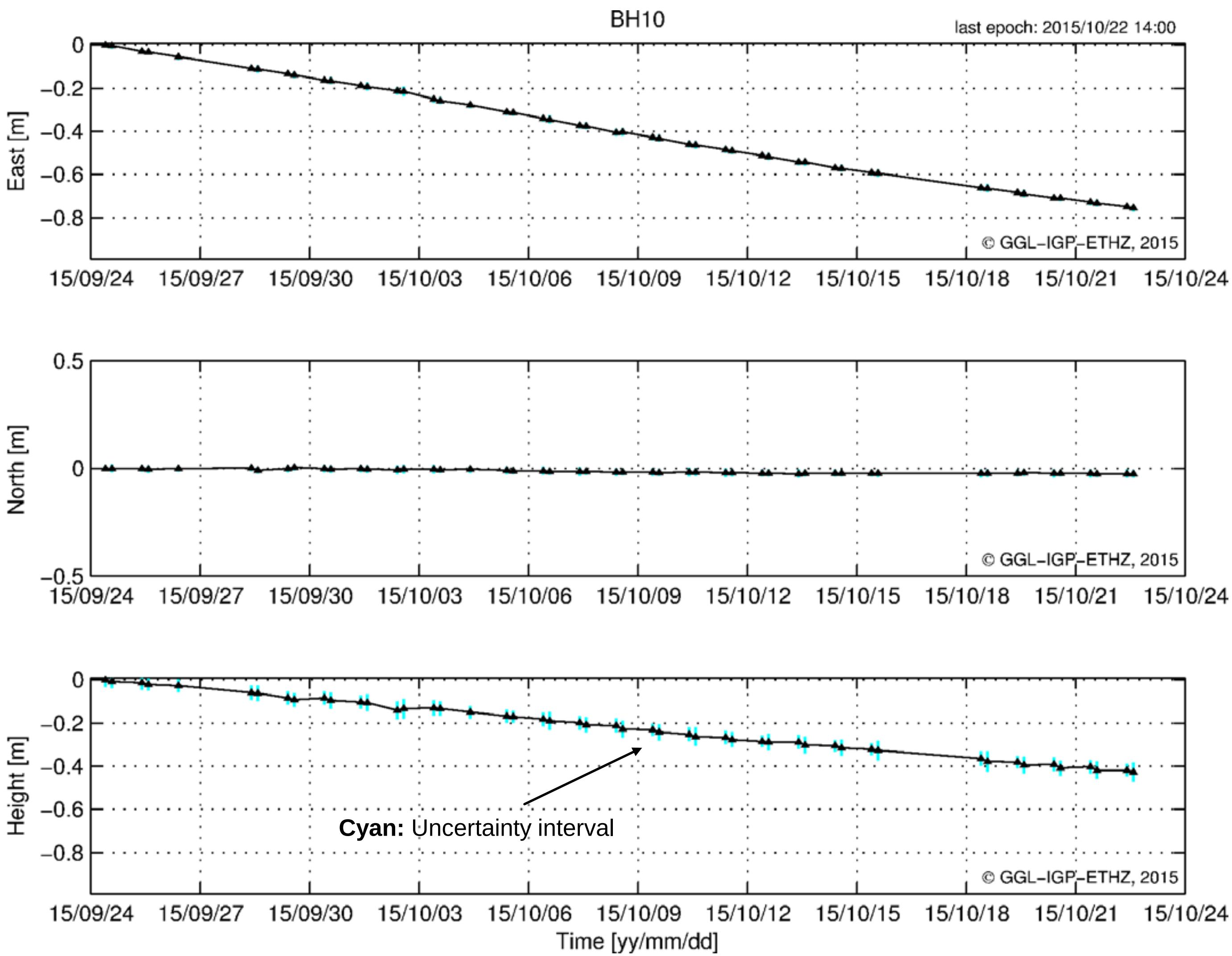
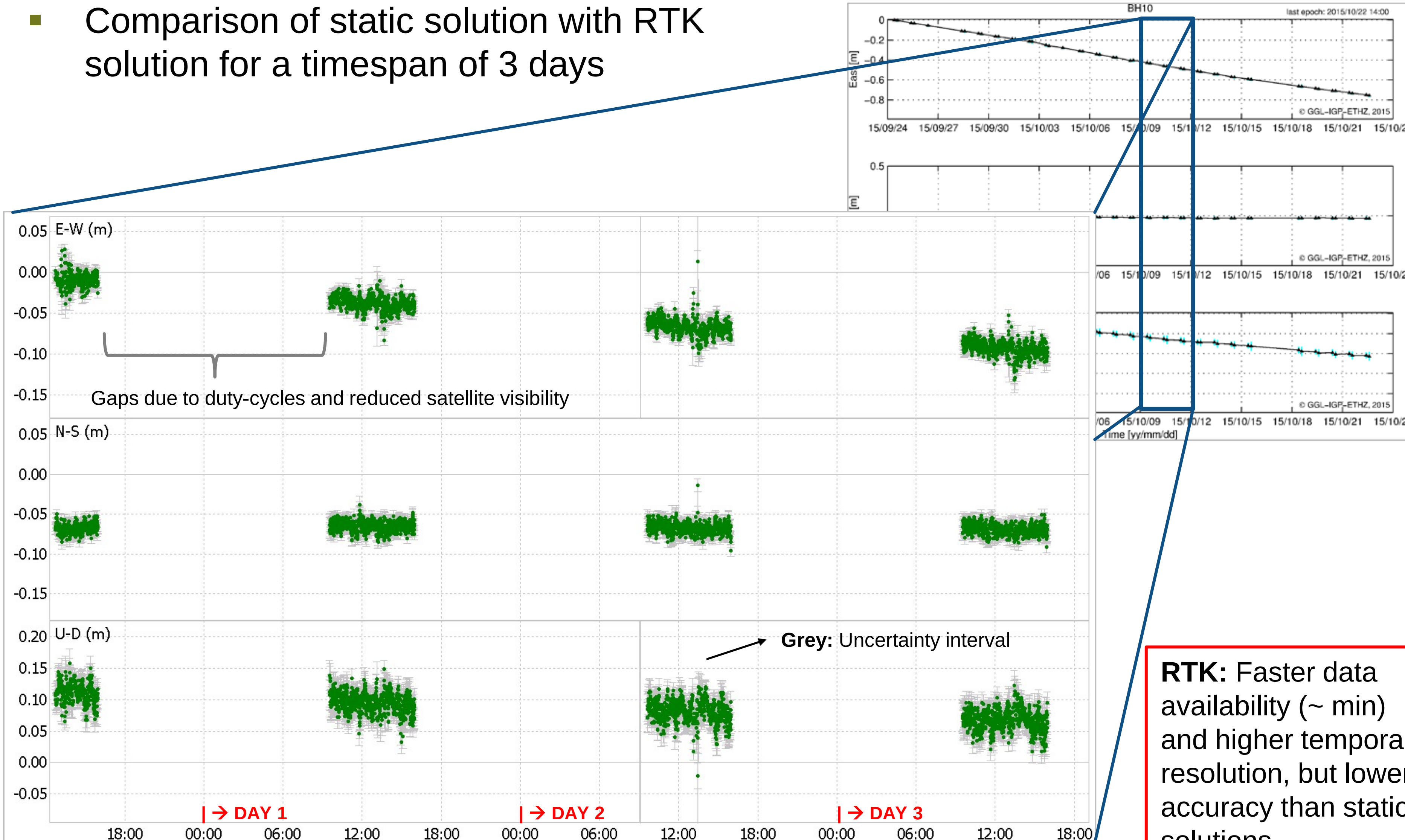


***Figure:** Change in East, North and Height coordinates of station BH10 wr.t. Sept 24. The triangles represent the static coordinate solutions. An almost linear movement of the station is visible in the east and the height component.*

Static solution: High accuracy, but lower time resolution and delayed data availability (~ hours to days) than RTK solution

Matter Valley: Static and RTK Results

- Comparison of static solution with RTK solution for a timespan of 3 days



RTK: Faster data availability (~ min) and higher temporal resolution, but lower accuracy than static solutions

[Z. Su]

Receiver Velocity from Doppler

X-Sense2

- **„Autonomous“:** No reference station information needed
- Fast availability of accurate movement information (within seconds)

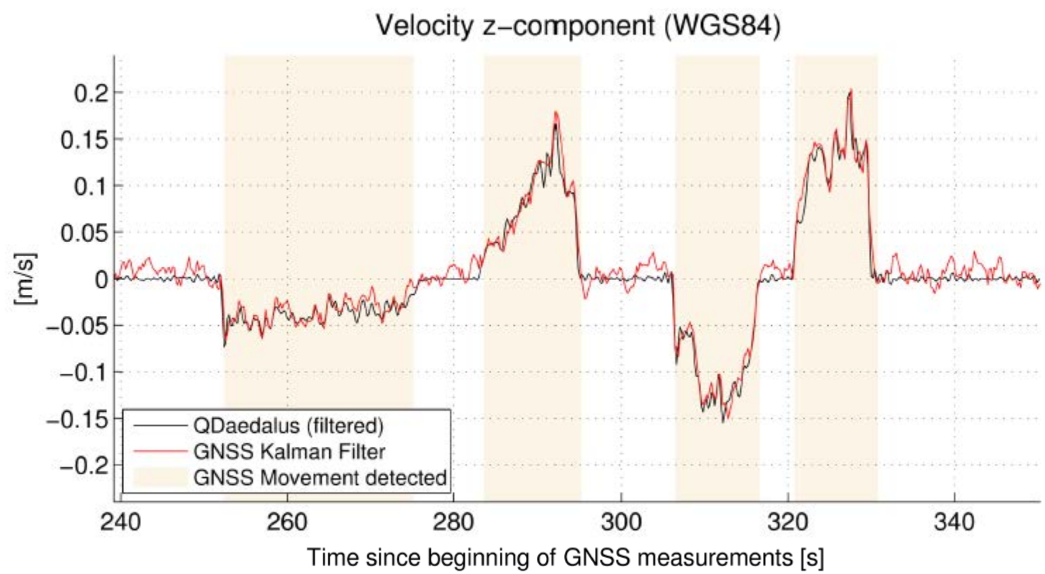
Figure right top:

Experiment setup with a guided slide on the roof of the institutes‘ building. Use of low-cost GNSS equipment . Tracking for ground-truth with high-accurate tachymetric surveying equipment

Experimental setup on roof of HPV building

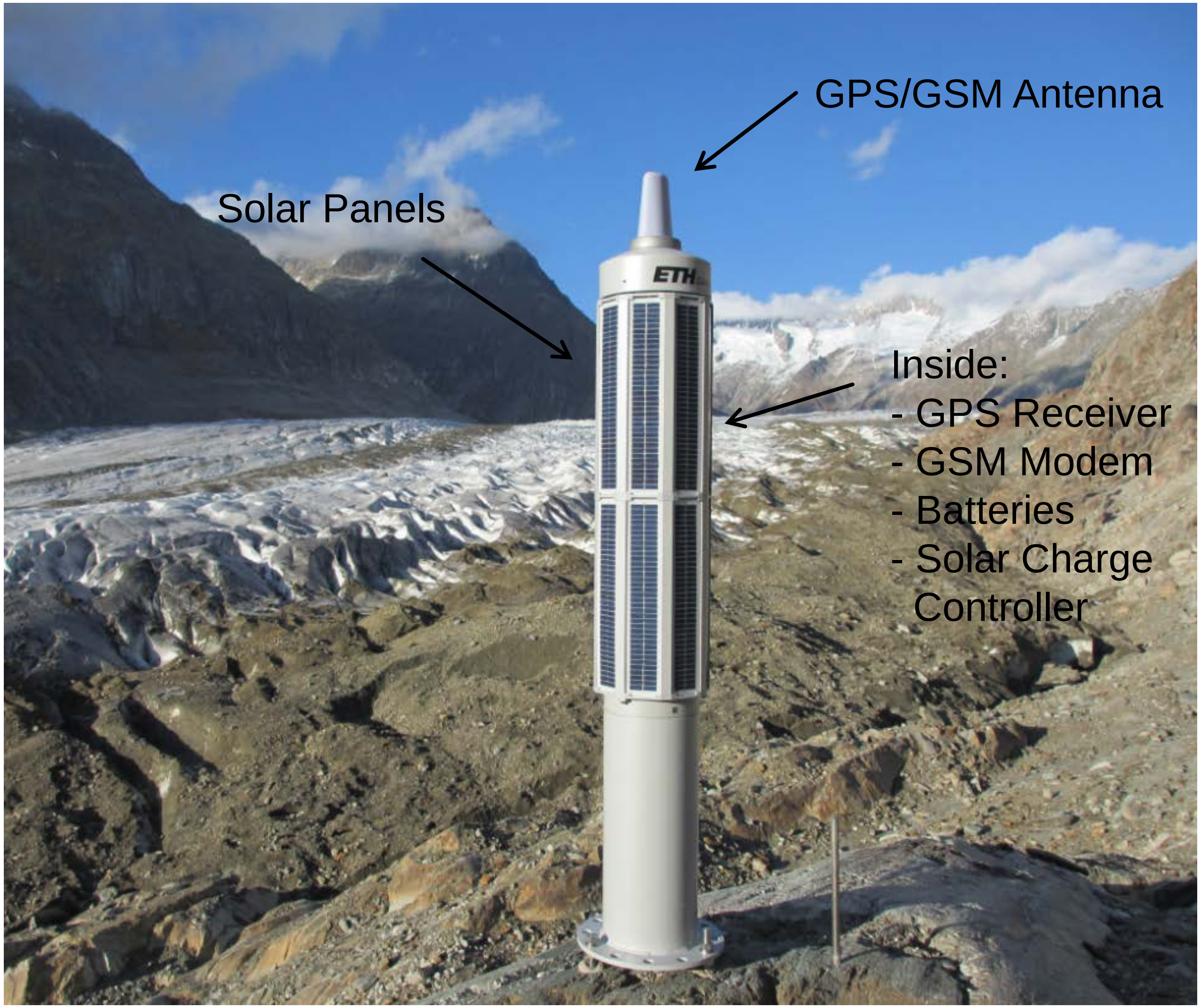
Figure right bottom:

Results for the estimated receiver velocity from GNSS Doppler observations. Based on statistical hypothesis testing, movements on the cm/s scale can be detected instantaneously.



GNSS Monitoring at Great Aletsch Glacier

- **Energy-self-sufficient station AL01**



[P. Limpach]

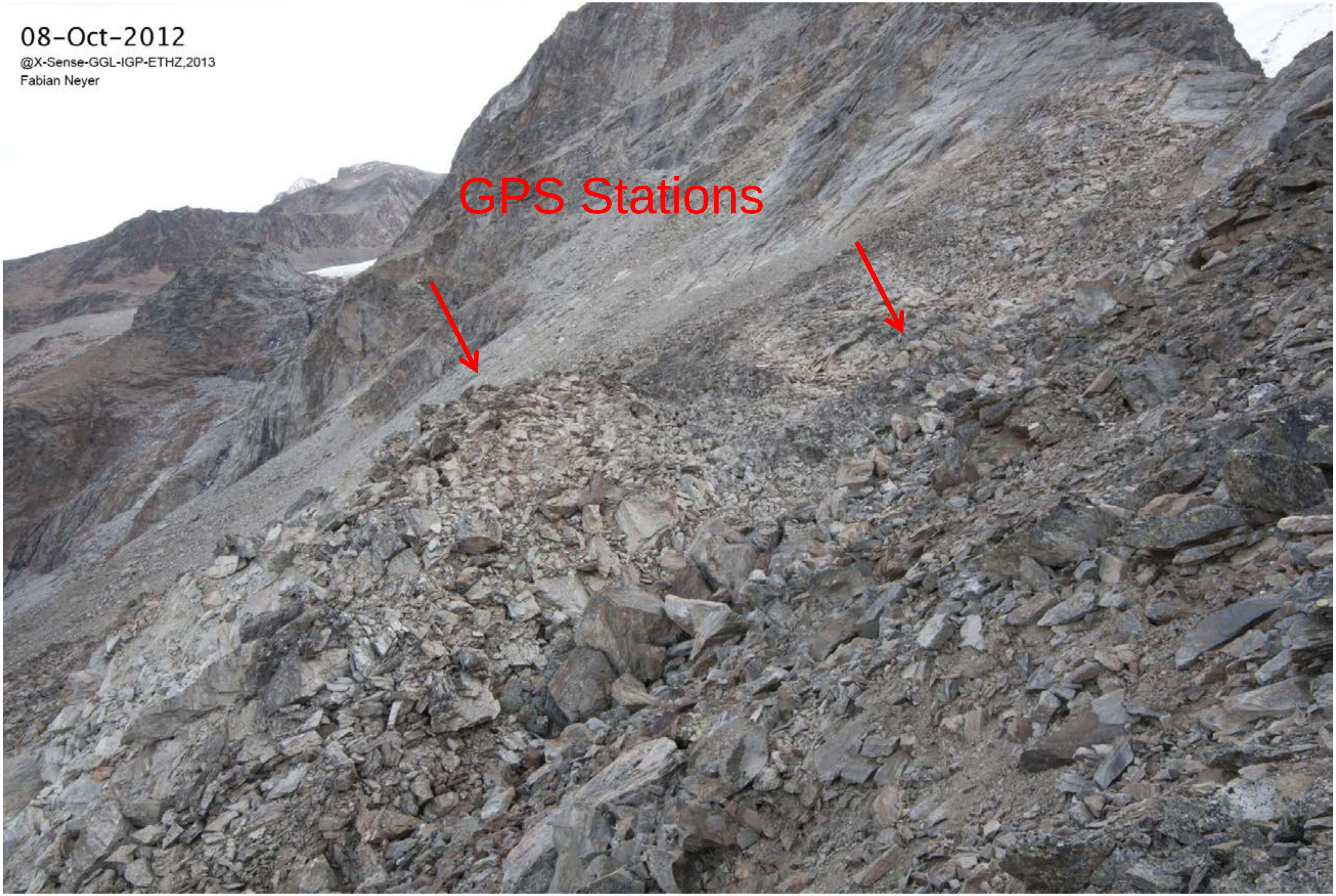
Matter Valley: Photogrammetric Monitoring

- **Grabengufer rock glacier:** Single-image processing (with use of DEM)

[F. Neyer]

Matter Valley: Grabengufer Rock Glacier

[F. Neyer]

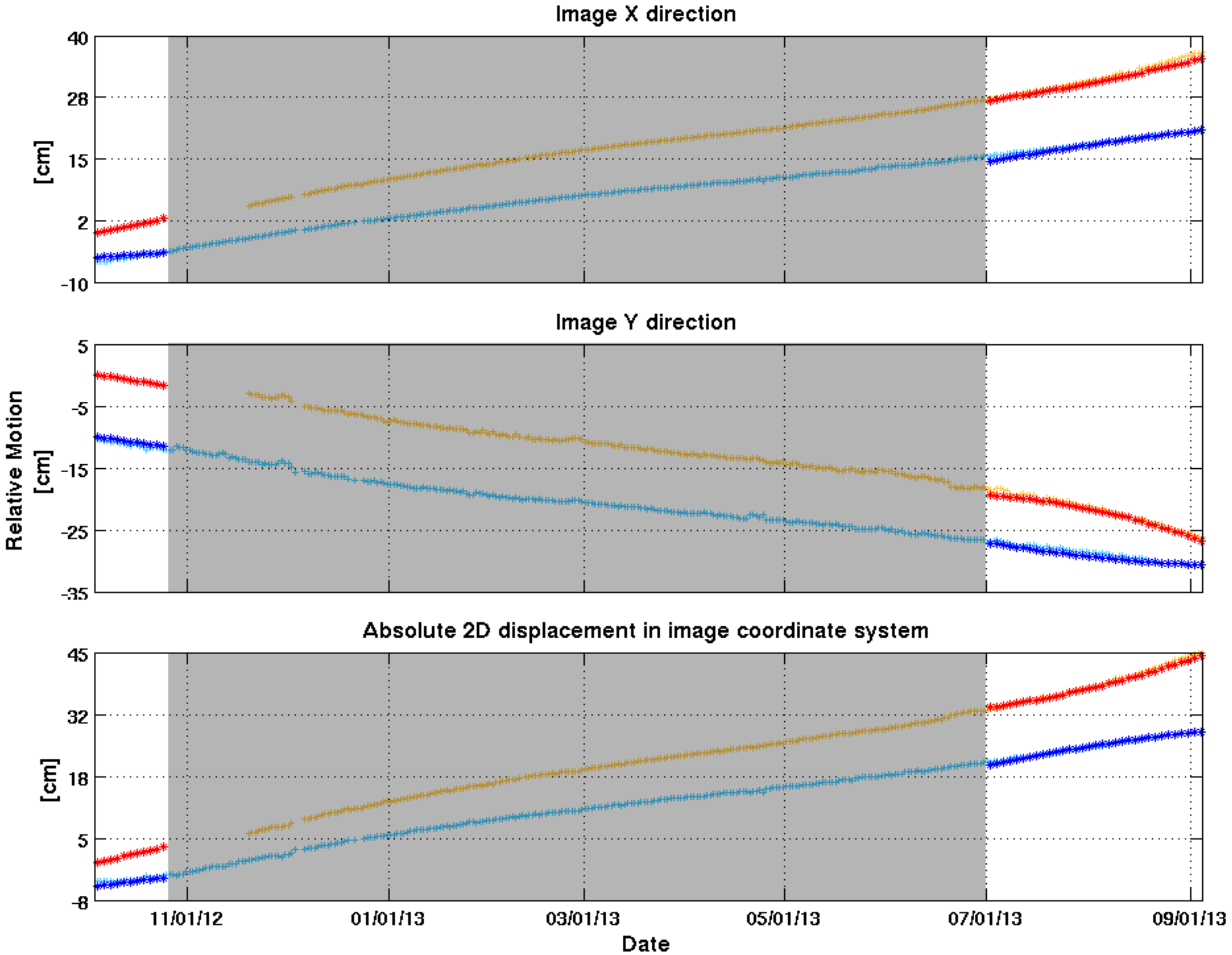


Grabengufer Rock Glacier: Results

[F. Neyer]

Grabengufer Rock Glacier: Results

- Photogrammetric determination of the motion of the GPS stations
  Grey area: Projection of GPS data in image coordinates (during snow cover)



Station 1 (in 103m distance):
$\sigma_x = 0.5cm$ and $\sigma_y = 0.6cm$

Station 2 (in 186m distance):
$\sigma_x = 0.8cm$ and : $\sigma_y = 0.7cm$

[F. Neyer]

Summary

- Geodetic observations can give valuable contributions to monitoring of mass movements on a broad band of landslide velocity classes
- Static GNSS processing for long-term analysis of slope movements and analysis of physical driving mechanisms
- RTK GNSS processing and Doppler velocity determination for near-real-time solutions
- Photogrammetric methods provide important areal information
- Furthermore: Low-cost equipment, on-line & energy-self-sufficient stations with low power consumption


Thanks for your attention!