ETH zürich

Slope Monitoring in the Swiss Alps by GNSS: Velocity Determination and Time Series Analysis

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AHORN 2018, Veysonnaz, Switzerland

Motivation

- **Understand processes that could possibly trigger slope movements**

Temperature?
Precipitation?
Snow melt?
Seismic-induced?
…
… effect on slope movements?

Debris avalanche in Bondo, SUI in August 2017
(Source: infoticker.ch)

- **… and rapidly provide geodetic information for Early Warning Systems**

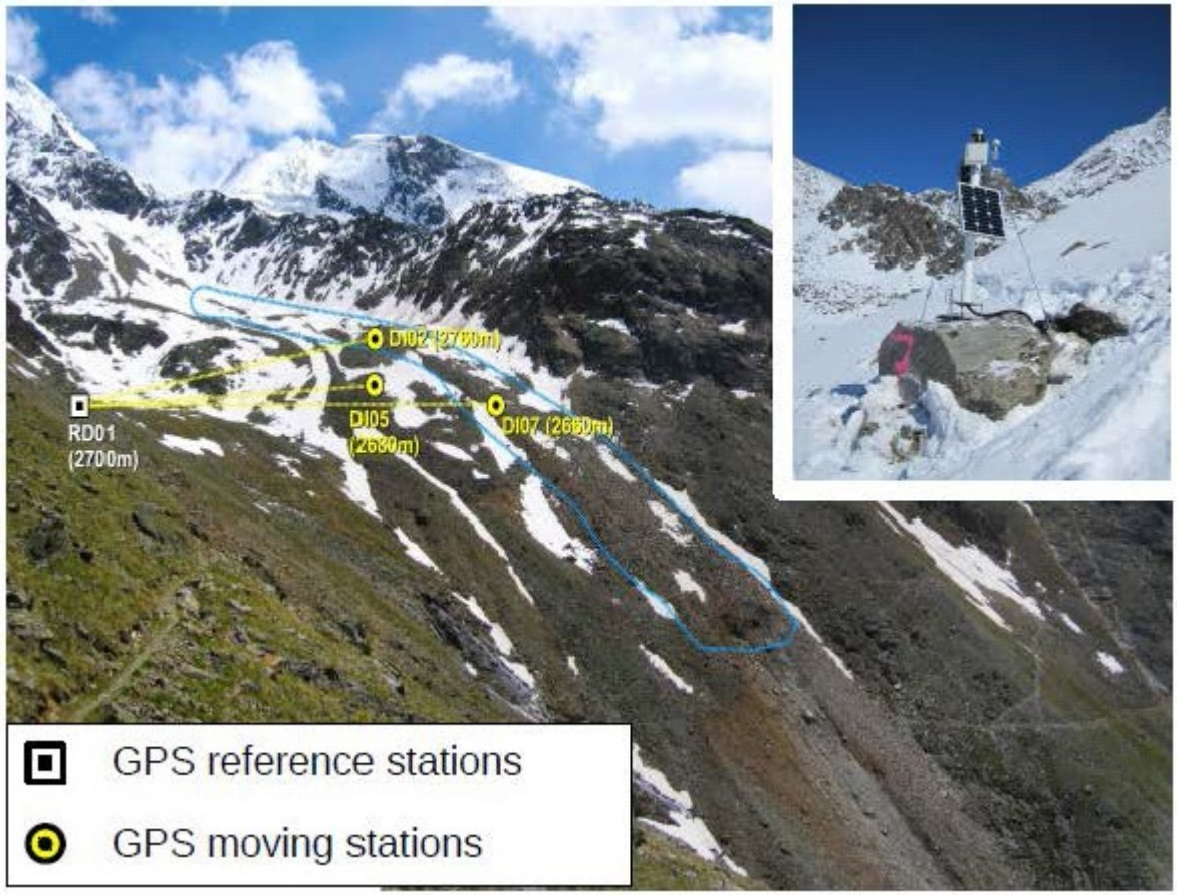
Overview

Geodetic **GNSS** (like GPS) can resolve ground movements ranging from
Millimeters per Year to Millimeters per Second

Long-term analysis
Based on static GNSS.
Possible application:
Landslide Monitoring

Short-term analysis
Real-time velocity estimation.
Possible application:
Lanslide Detection, Earthquake Early Warning

Long-Term Analysis



X-Sense and X-Sense2 (2009 – 2017)

Monitoring of slope movements and rockfalls in the Swiss alps

Long-Term Analysis

X-Sense and X-Sense2 (2009 – 2017)
Monitoring of slope movements and rockfalls in the Swiss alps (autonomous GNSS stations)

GNSS Geomonitoring and Processing @MPG
Monitoring stations at Great Aletsch glacier, Glarnerland …

[P. Limpach]

Long-Term Analysis

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Coordinate timeseries from more than 40 stations are available, spanning several years …

[P. Limpach]

Time Series Decomposition

- **Station Velocity: Time differentiation of coordinate series (from static sol.)**
- Decompose time series into individual contributions …

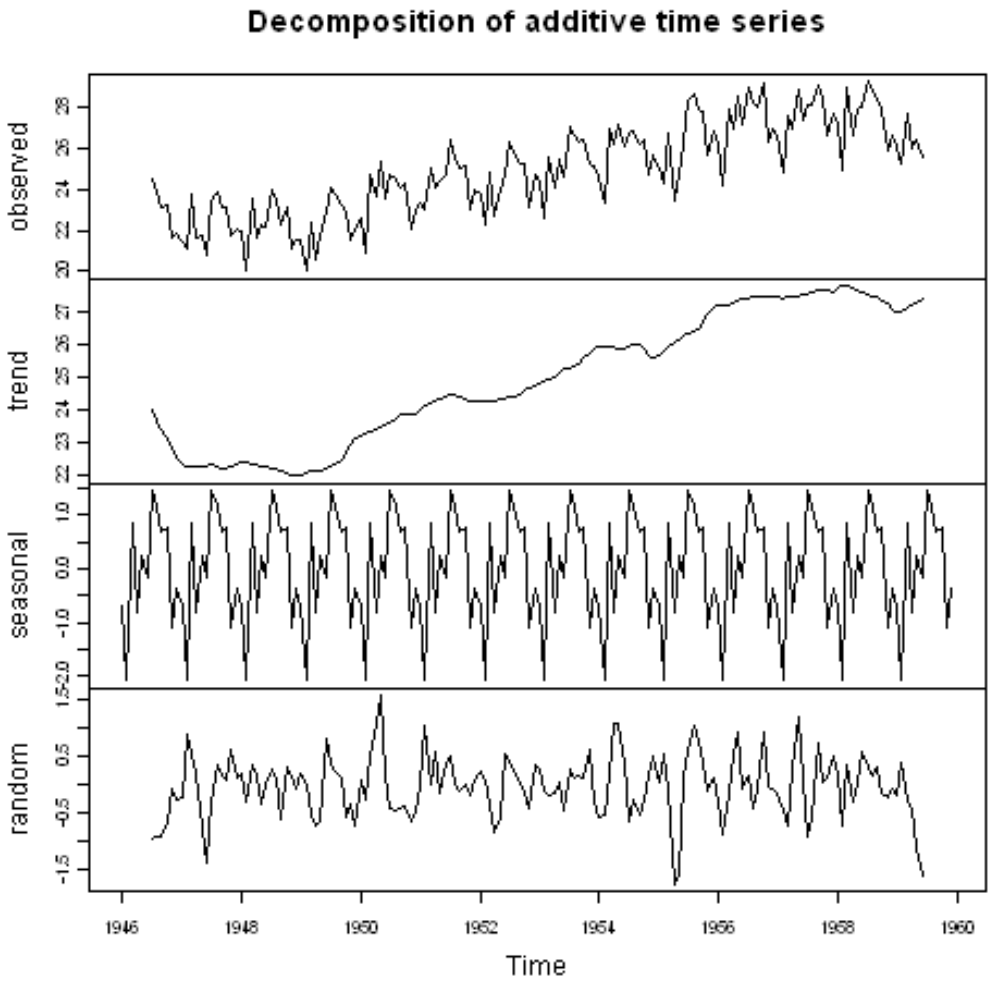
$$y_t = T_t + S_t + I_t$$

Trend

Seasonal component

Random (irregular) component

- Trend (T) and Seasonal (S) effects extracted by low-pass filtering



Source: https://a-little-book-of-r-for-time-series.readthedocs.io/en/latest/src/timeseries.html

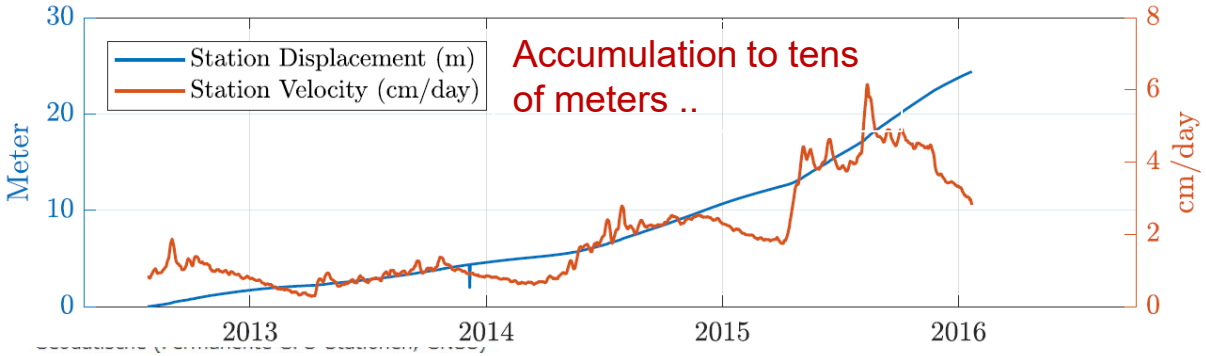
Station JAE1 (Univ. of Fribourg)

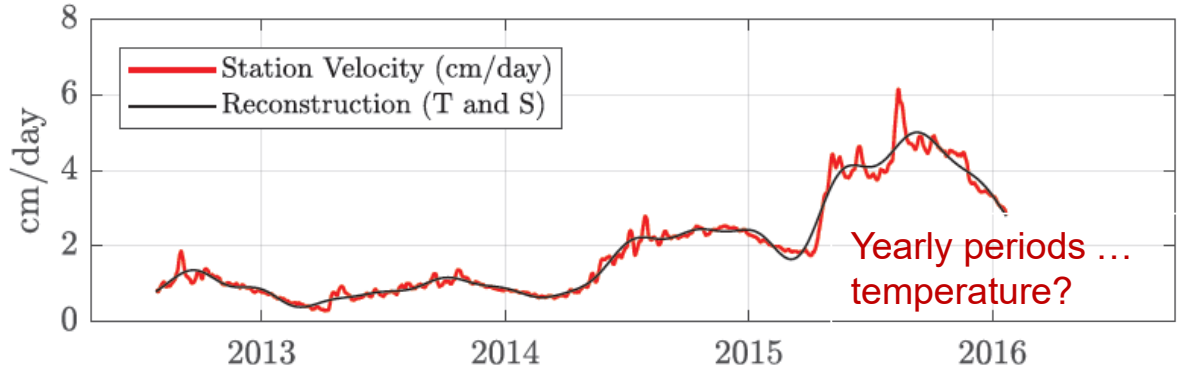
JEGI (VS)

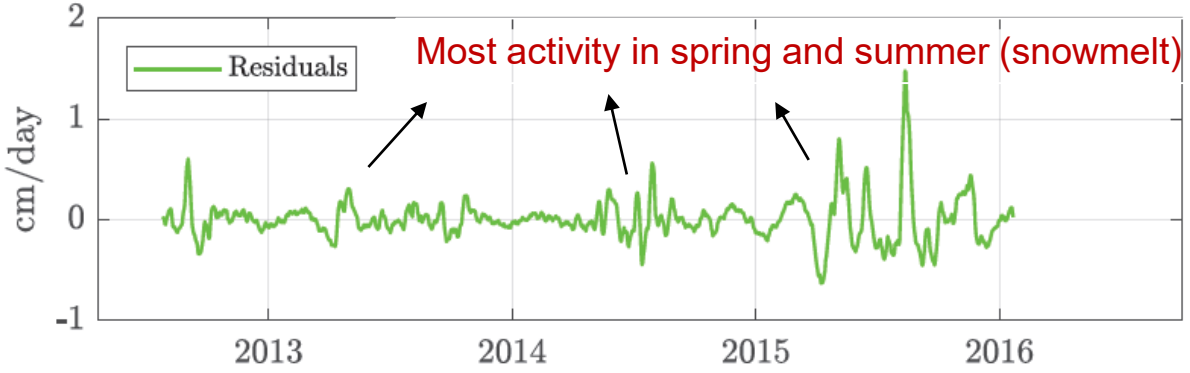
Aktive Blockgletscher
Active rock glacier

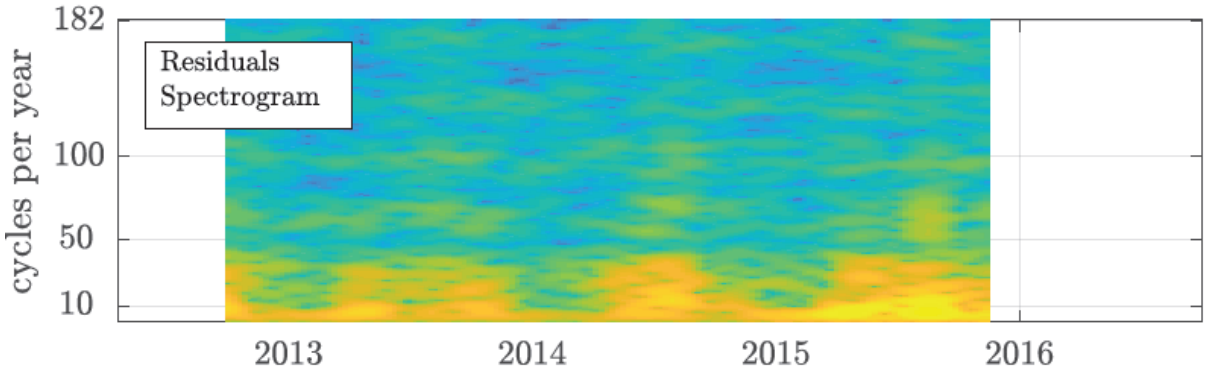
Lokalisierung

View larger map (all sites)

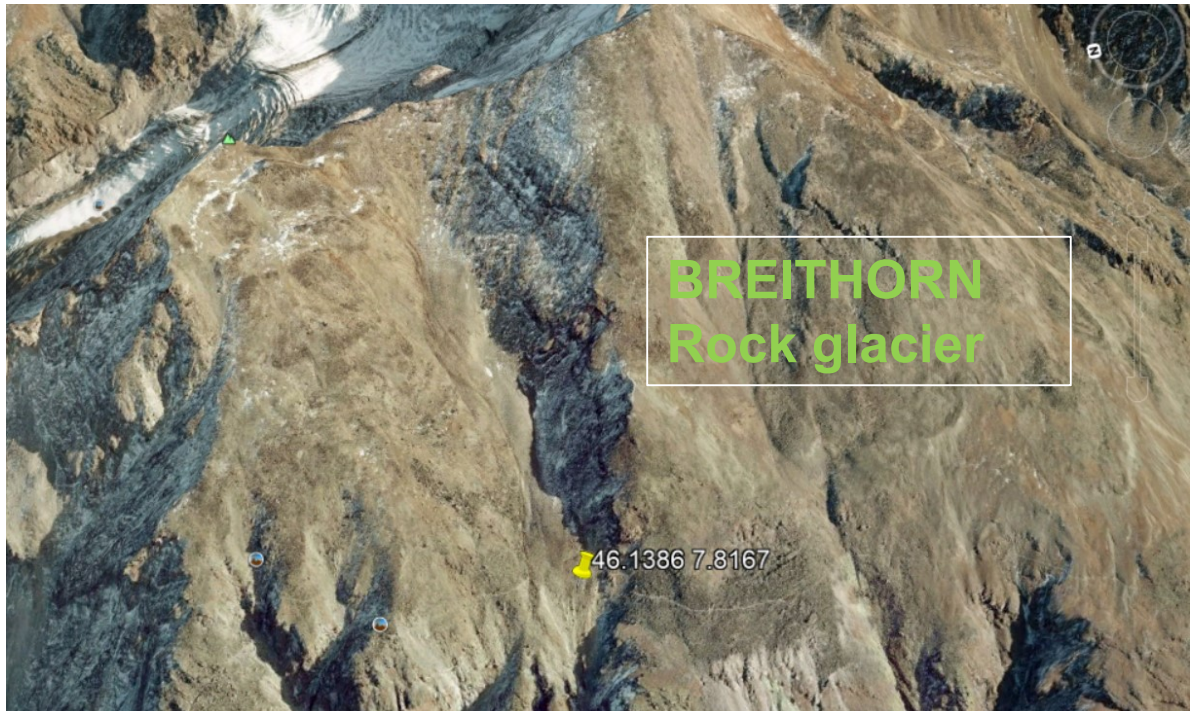


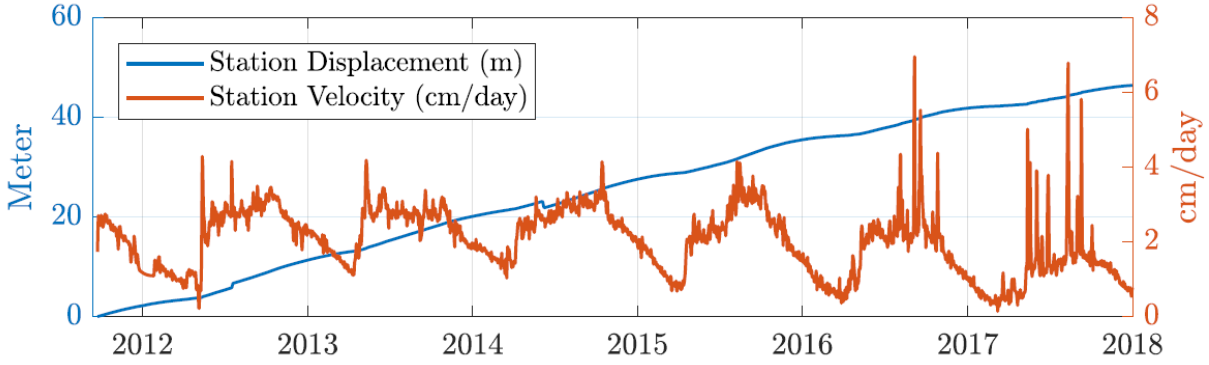


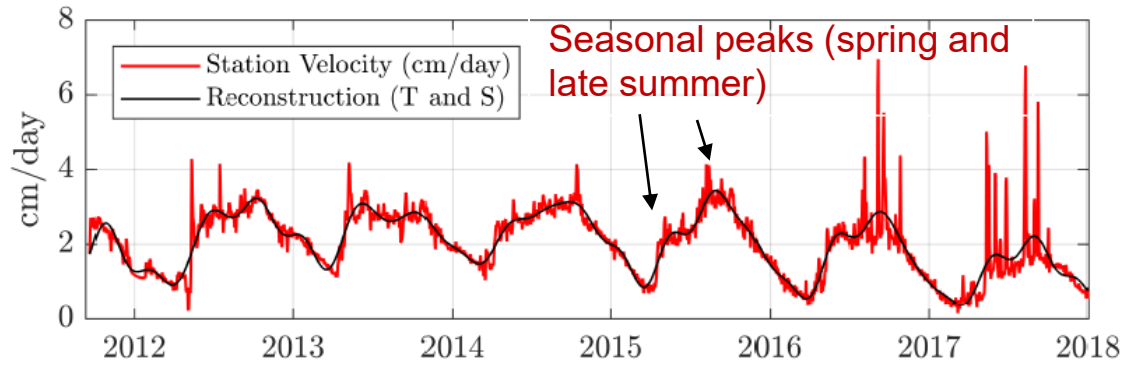


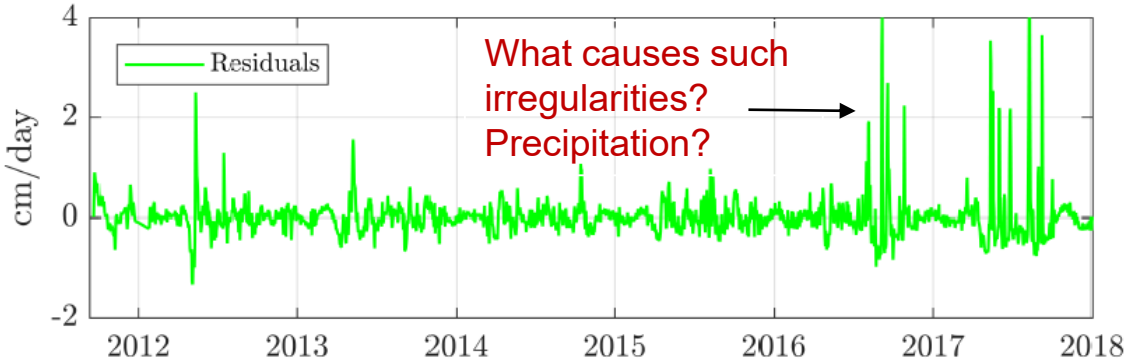


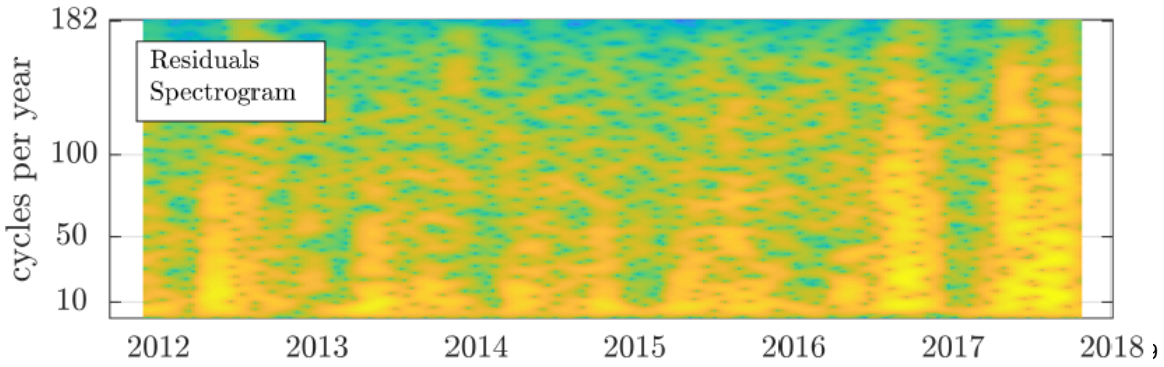
Station BH10 (X-Sense)





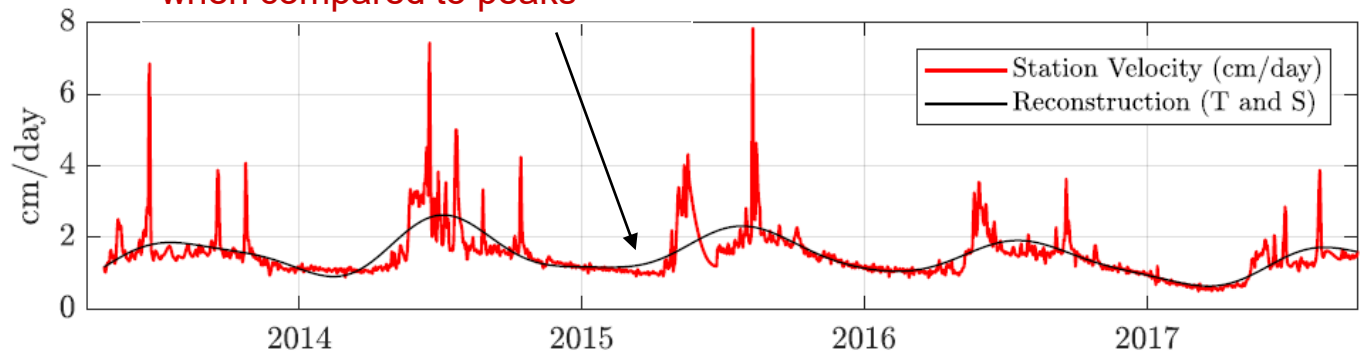


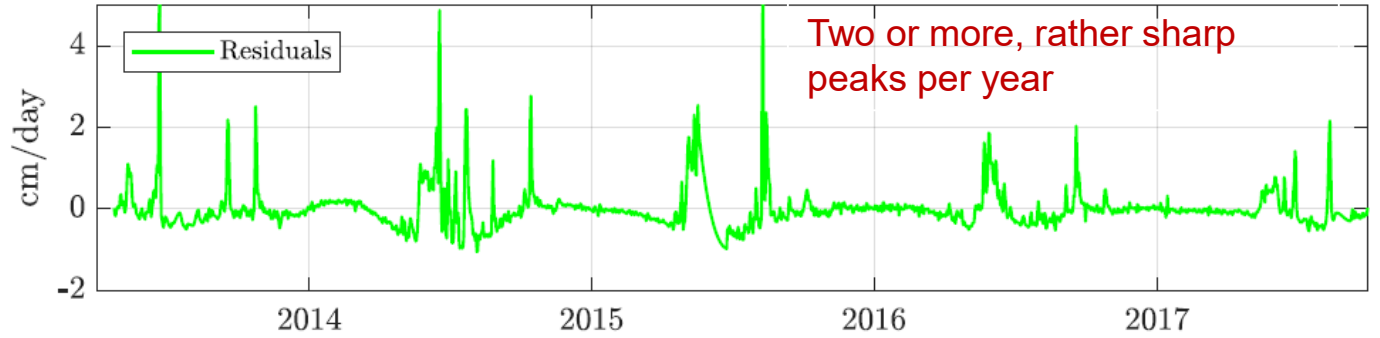




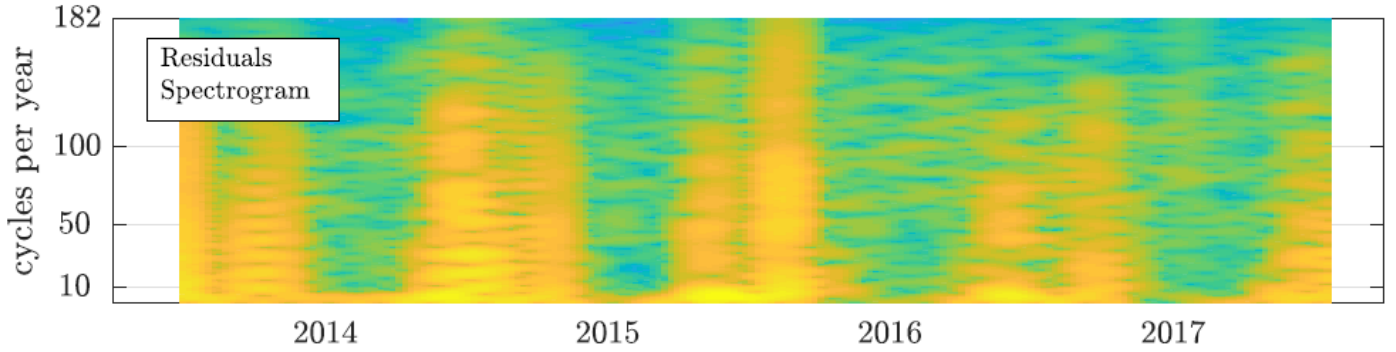
Station DI07 (X-Sense)

Rather low annual signals
when compared to peaks



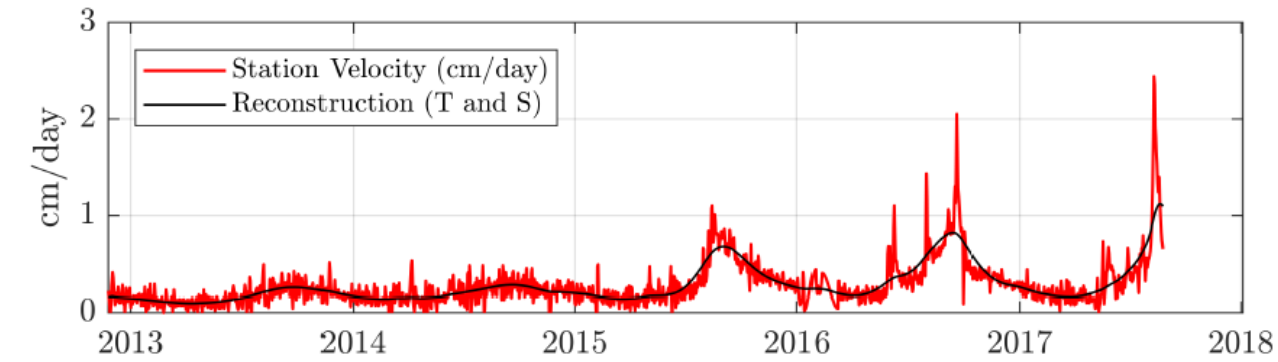


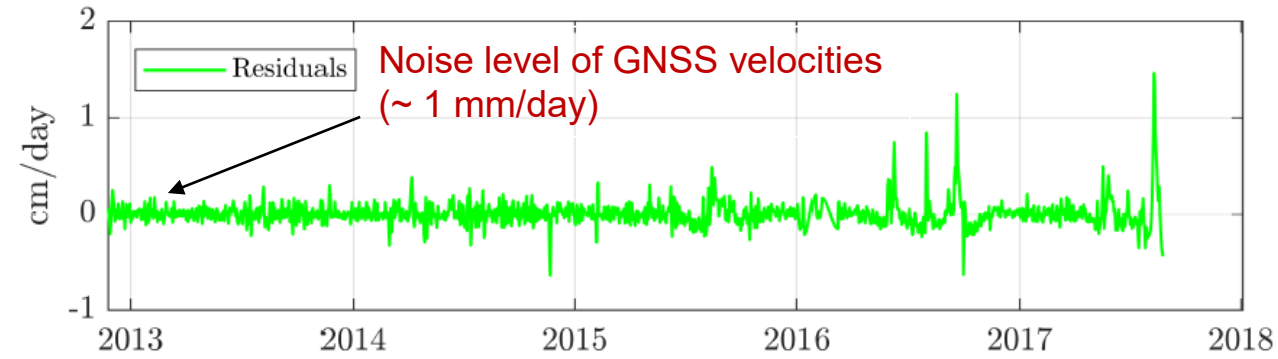
Two or more, rather sharp
peaks per year



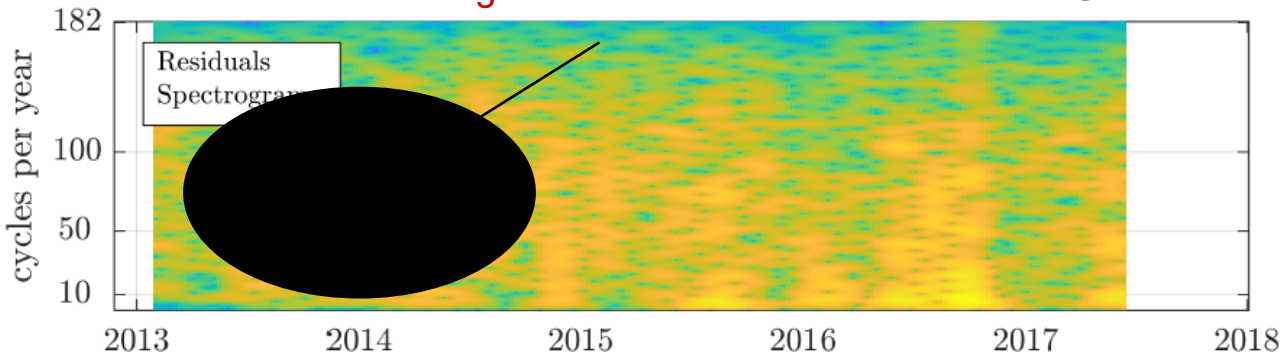
Station GG52 (X-Sense)

- **Grabengufer Rock Glacier**



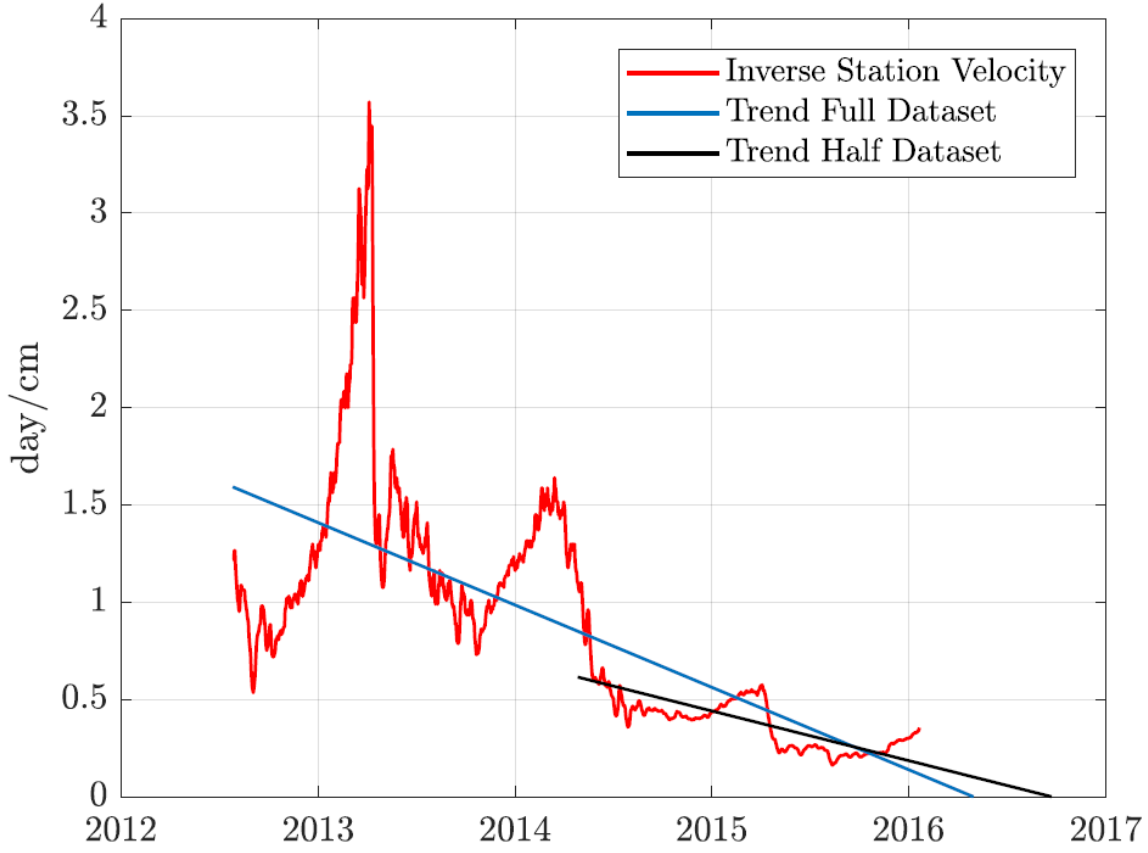


Movements might be too small to be resolved with GNSS here

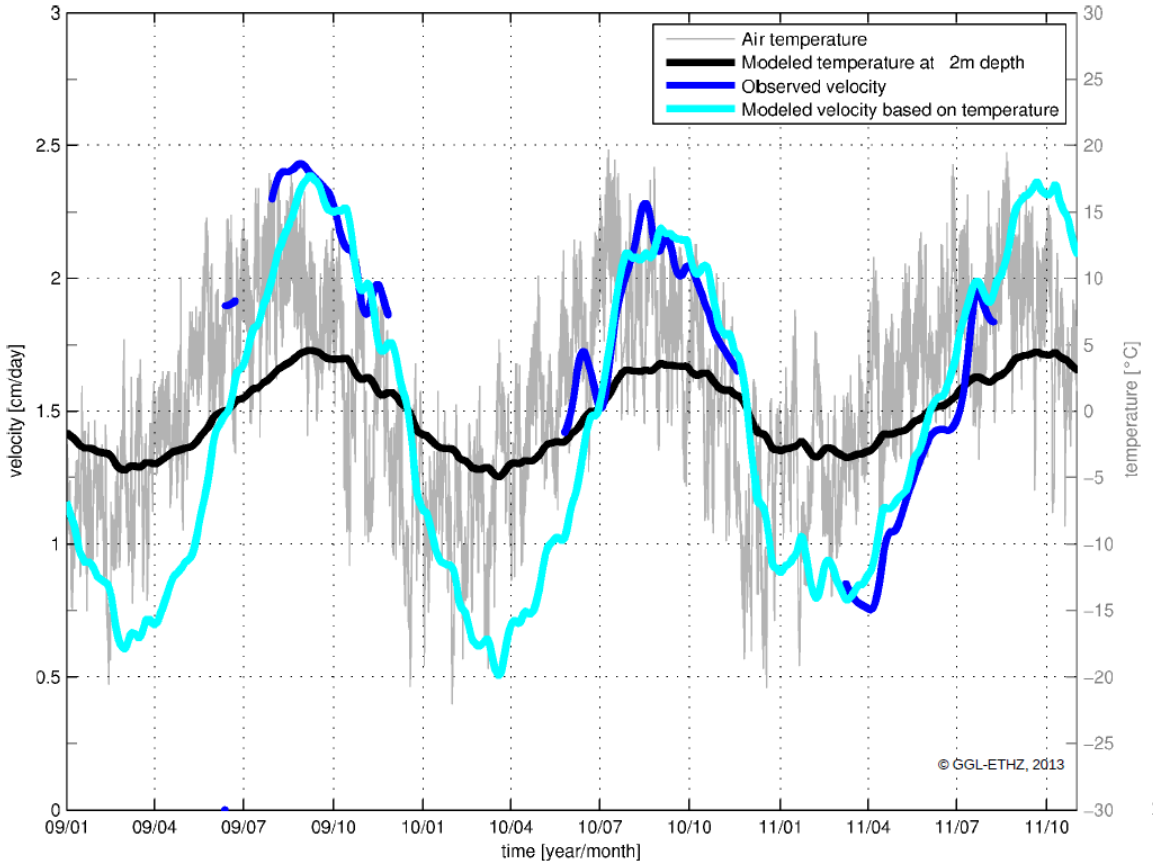


Predict Time-To-Failure | Temperature Correlation

- **Time-To-Slope-Failure: «Inverse Velocity» approach**

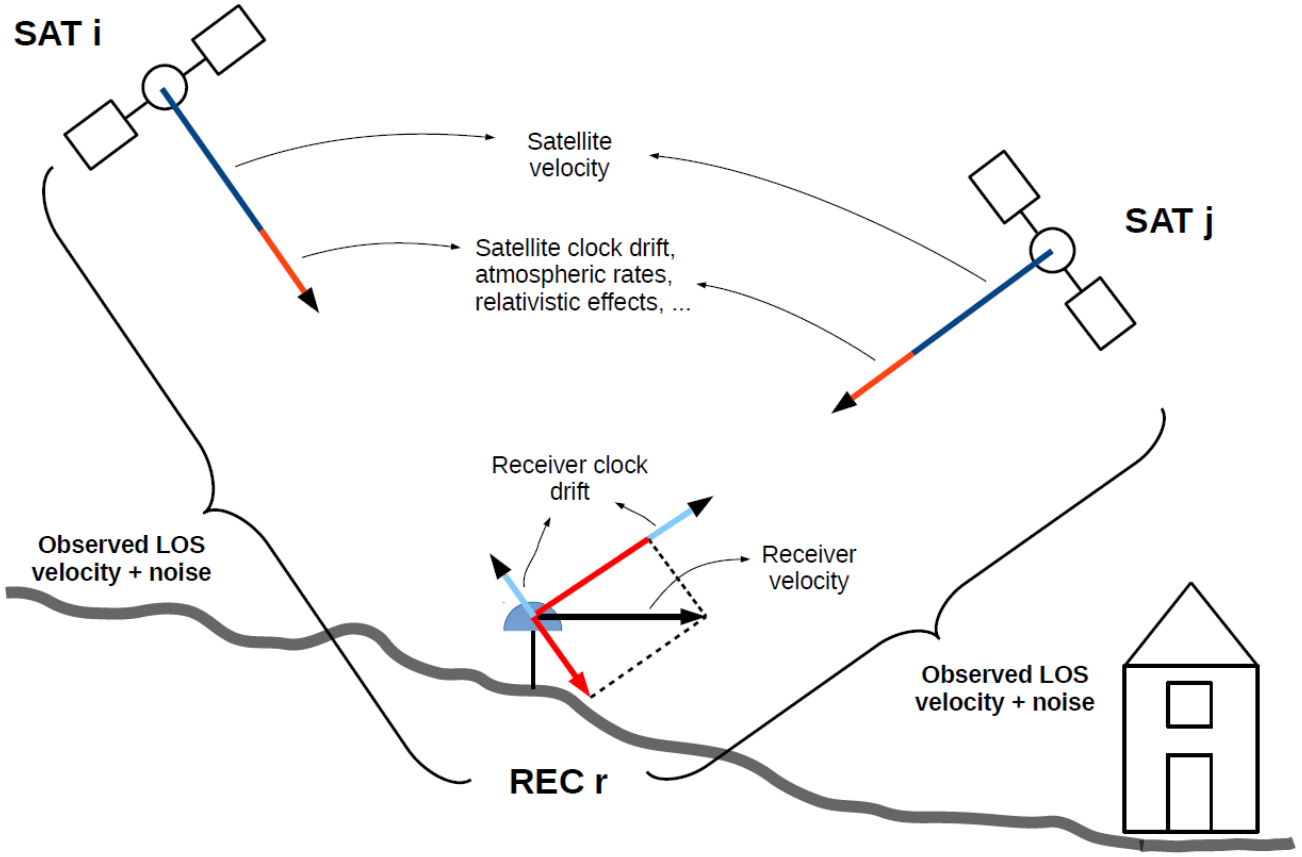


- **Link between slope movements and temperature variations**



Short-Term Analysis

- **Instantaneous Station Velocity Estimation**
  - Based on time-derivative of GNSS phase measurements – velocity accuracy down to sub-mm/s possible
  - **Standalone solution**
    No reference station data needed
  - **Goal:**
    Real-time movement detection based on velocity estimates – movement information within seconds



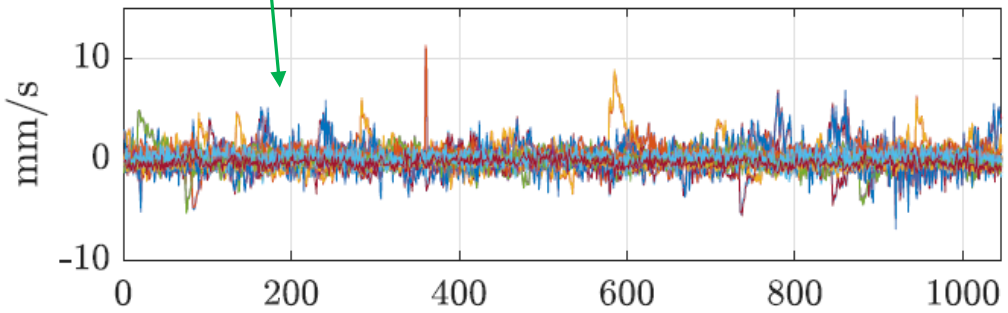
Results – Static and Dynamic Tests

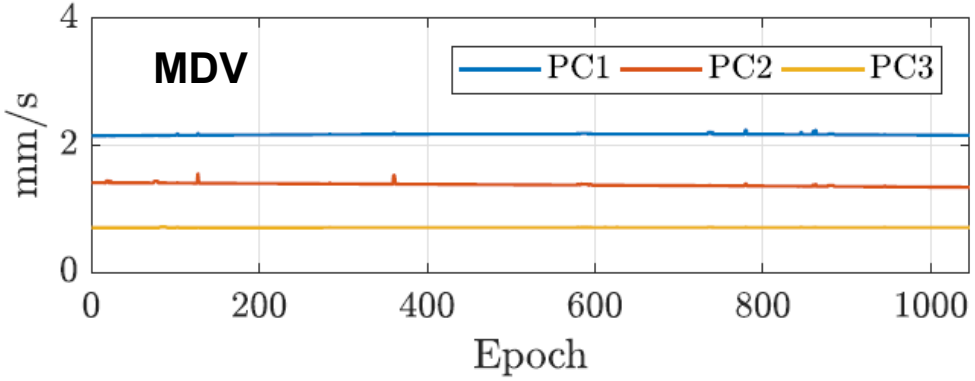
- **Static Tests**
  - Septentrio PolaRx receiver and choke ring antenna, 1 Hz Sampling Rate
  - Reveal observation characteristics
  - Minimum Detectable Velocity
- **Dynamic Tests (with a KUKA Robot)**
  - Very precise ground truth (robot)
  - Test data: Oscillation with T=100 s, A=10 cm, horizontal movement
  - Maximum Velocity ~ 6 mm/s
  - GPS and Galileo Observations

Figure: KUKA robot and GNSS equipment (LHS) and KUKA control unit (RHS)

Static Tests – Quality of Models and Observations

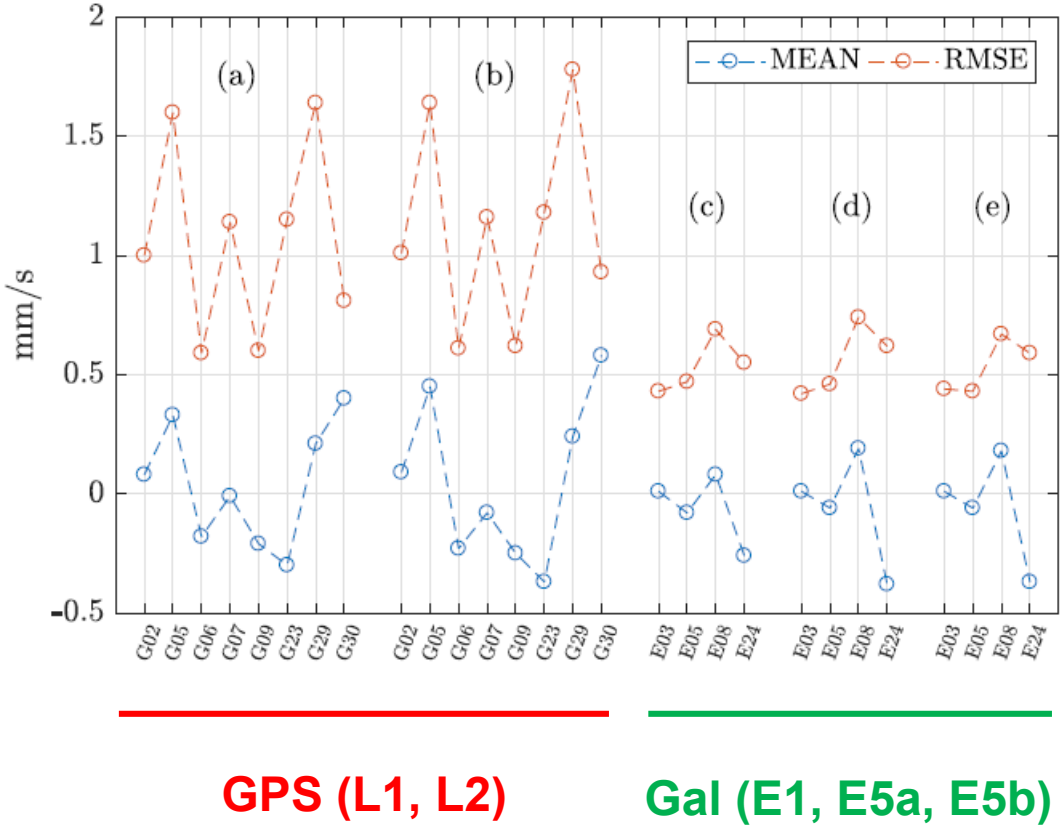
Observation Residuals





Statistics

MDV < 1 mm/s



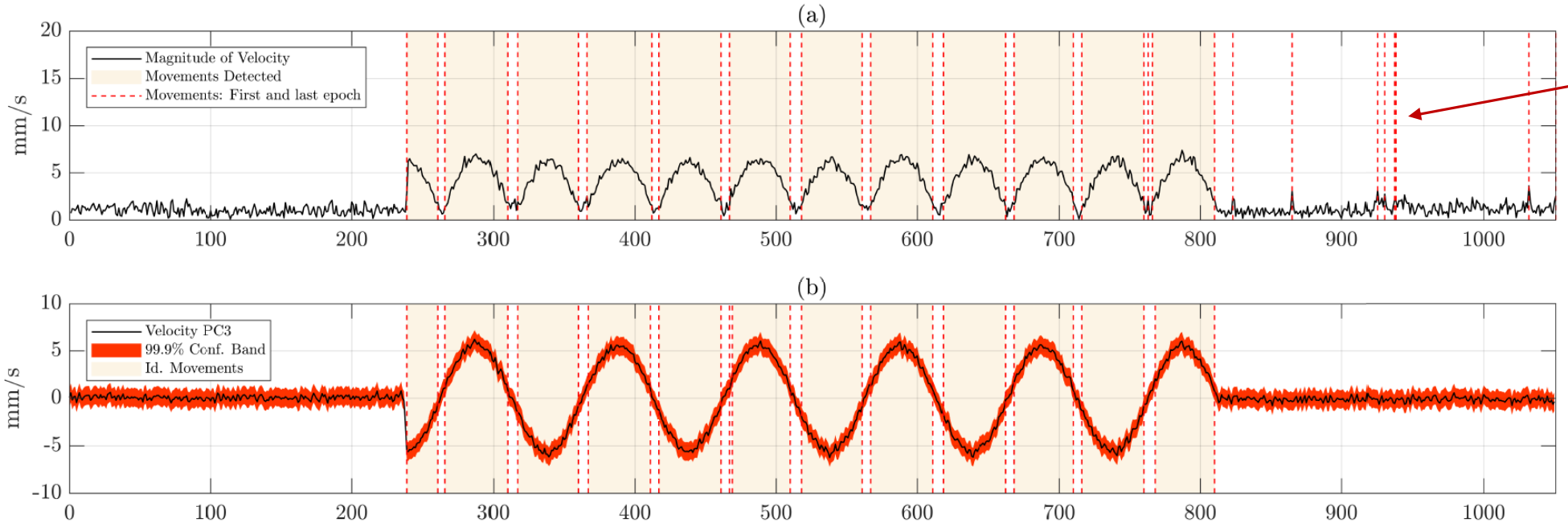
GPS (L1, L2)

Gal (E1, E5a, E5b)

"Minimum Detectable Velocity based on GNSS Doppler Observables". Proceedings of the European Navigation Conference (ENC), 2018, Gothenburg, Sweden

Dynamic Tests: Sinusoidal Movement

- **Results for a GPS+Galileo experiment**



False detections

Minimal detectable velocity ~ 0.95 mm/s

«Movement Detection based on High-Precision Estimates of Instantanteous GNSS Station Velocity», *Journal of Surveying Engineering,* in print

Application: GNSS Seismology

- **Earthquakes central Italy 2016**
- **Data from „RING“ GNSS network**
- Processing for Mw 6.5 earthquake near Norcia
- Station distance from epicenter:
  Few km up to ~180 km
- Processing:
  - 42 stations
  - Epoch-wise velocity estimation (batch mode)
  - Epoch-wise movement detection
  - Decision criterium: Cumulative relative frequency (7 out of 8 Epochs)

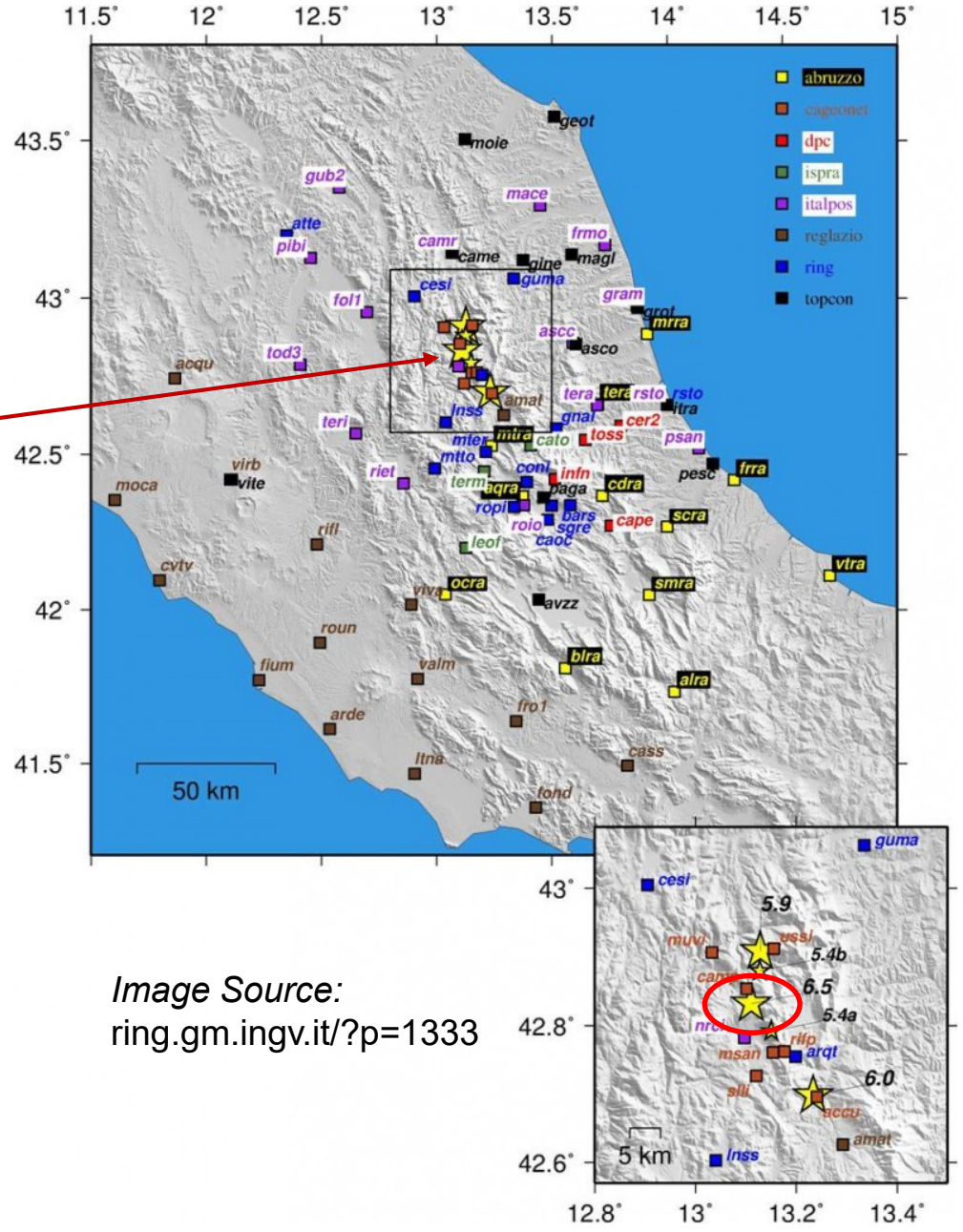
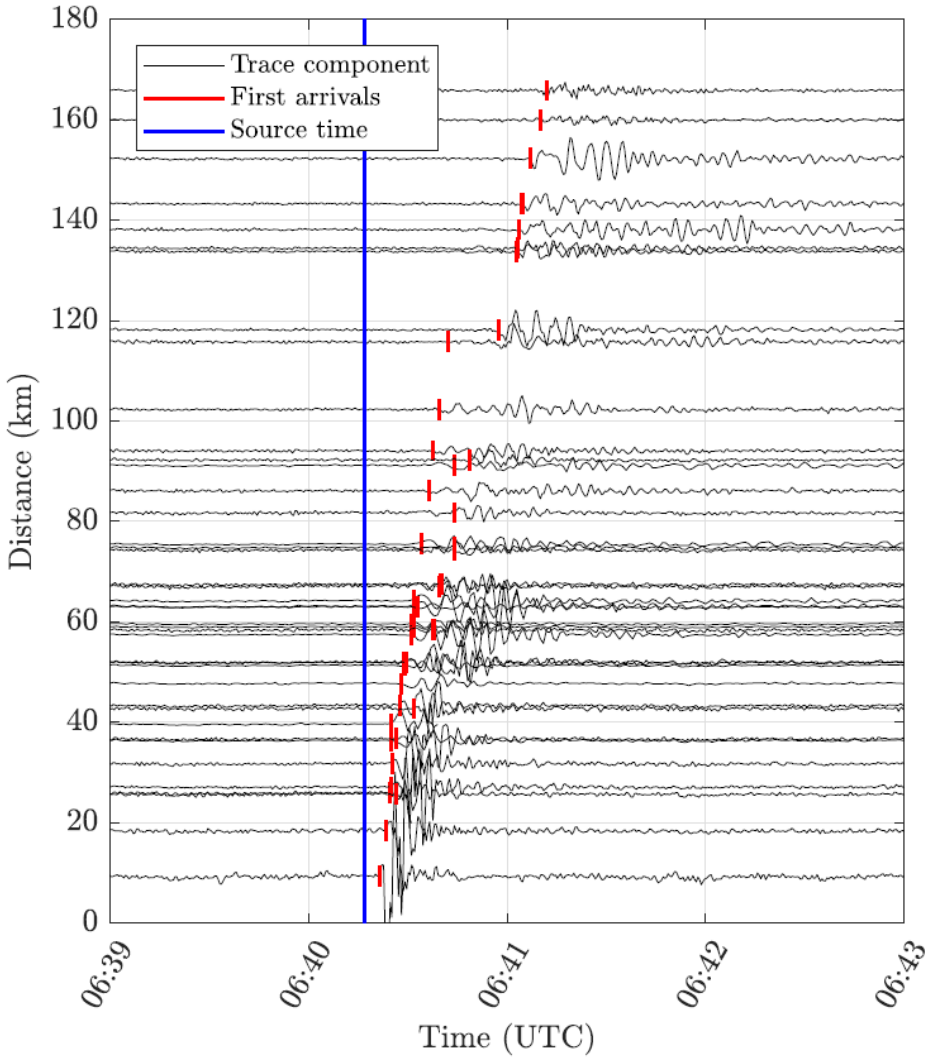
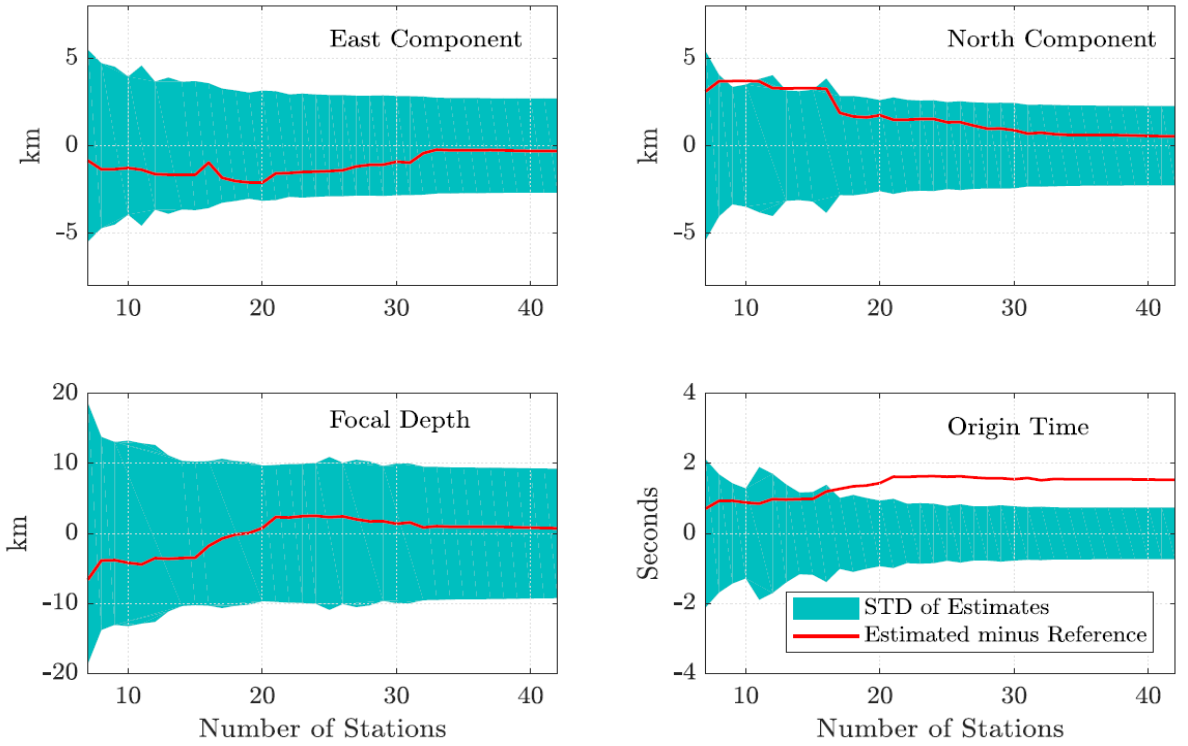


Image Source:
ring.gm.ingv.it/?p=1333

Results – Earthquake Detection and Localization



Earthquake was detected in all GPS stations -- Seismic P- and S-wave arrivals (left); Hypocenter localization comes very close to a official ('best') seismic solution (bottom)



Sensors «Stand-Alone GNSS Sensors as Velocity Seismometers: Real-Time Monitoring and Earthquake Detection"

Summary

- **GNSS is capable of monitoring slope movements from millimeters per year to millimeters per second**
- **Long-term analysis**
  Static GNSS; Understand processes that trigger slope movements
  Seasonal effects → Temperature? Cyclic and irregular components → Snow melt, precipitation?
- **Short-term analysis**
  Instantaneous Velocity Estimation; Contribute to real-time Early Warning System → Earthquake Early Warning
- **Effects causing slope movements need to be further investigated (master thesis planned)**

Thanks for your attention!