Detection of convective storm signatures in GNSS-SNR: Two case studies from the summer of 2021 in Switzerland

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Author(s):
Aichinger-Rosenberger, Matthias; Aregger, Martin; Kopp, Jérôme; Soja, Benedikt

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Detection of convective storm signatures in GNSS-SNR

Two case studies from the summer of 2021 in Switzerland

Matthias Aichinger-Rosenberger[1], Martin Aregger[2,3], Jerome Kopp[2,3], Benedikt Soja[1]

[1]Institute of Geodesy and Photogrammetry, ETH Zurich, Zurich, Switzerland
[2]Institute of Geography, University of Bern, Bern, Switzerland
[3]Oeschger Center for Climate Change Research, University of Bern, Bern, Switzerland

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Motivation

GNSS = weather-independent system ???

- **GNSS signals are not weakened by the presence of (gaseous, liquid or solid) water in the atmosphere**
- Question: **Is this always true?**

Hydrometeors

Hönggerberg, Zürich, 13.07.2021

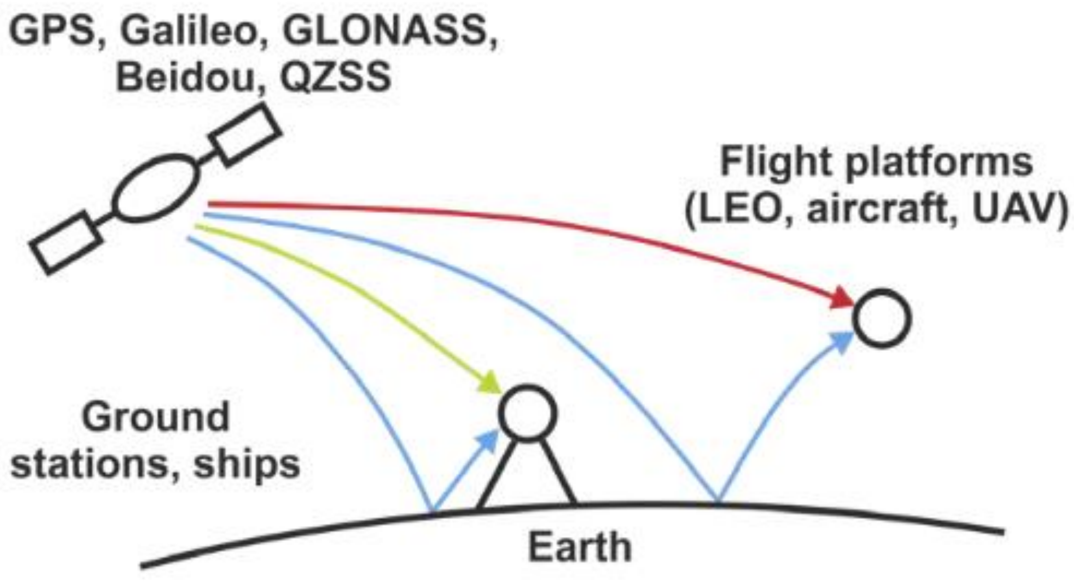
Foto: Urs Jaudas, https://www.derbund.ch/

GNSS remote sensing

- Global Navigation Satellite Systems (GNSS):
  - original purpose = positioning and navigation

- Number of "nuisance" parameters which contain information on:
  - Troposphere: Integrated water vapor (IWV) via signal delay
  - Ionosphere: Total Electron Content (TEC) via signal delay
  - Surface: surface properties via ground-reflected signals
    - Soil moisture
    - Snow height
    - Winds (Ocean)

- **Signal-to-noise ratio (SNR)?**

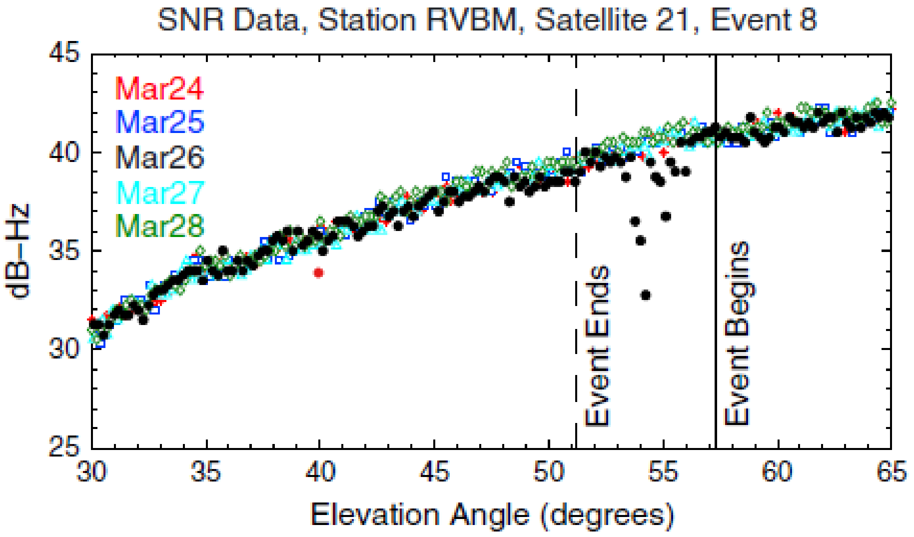


[Wickert et. al, 2020]

Methodology

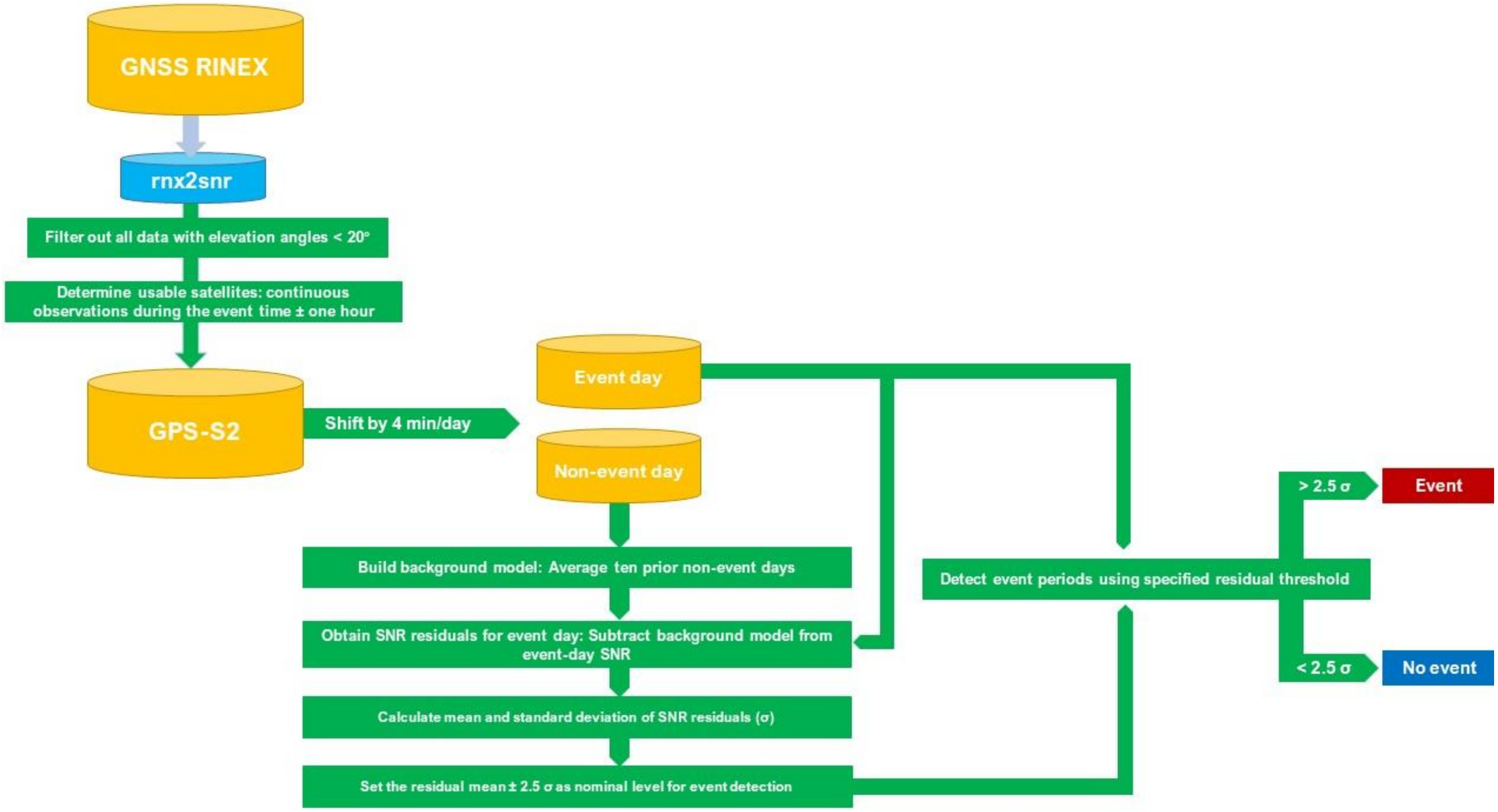
- Investigation on hydrometeor influence on GNSS signals
  - Tropospheric delays
  - Phase residuals
  - Raw phase observations
  - **Signal-to-noise ratio (SNR)**
- Former work on hydrometeor influence
  - Solheim et. al (1999):
    - Solid water particles have smaller influence than vapor
    - **Relevant only for extreme weather**
- Former work on SNR:
  - Detection of volcanic hail in GNSS SNR data (Larson et. al)
  - (In best case) allows for monitoring of the volcanic plume
  - **Idea:**

Try this approach for severe thunder- and hailstorms (here for Zurich 2021)



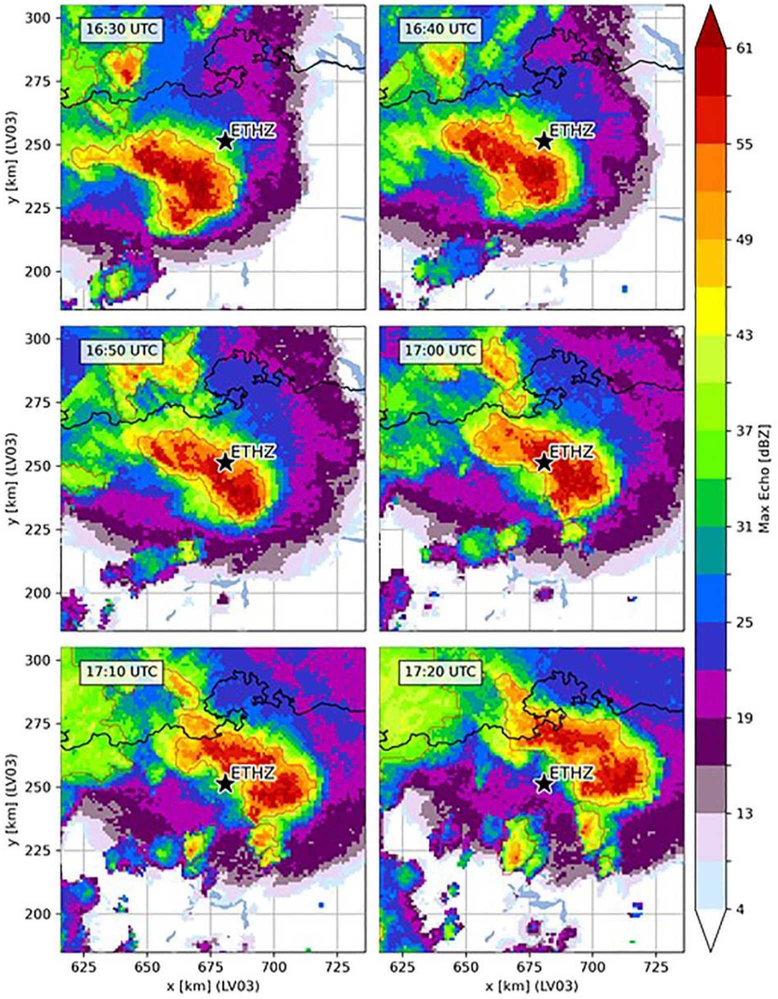
Larson, K. M. (2013). A new way to detect volcanic plumes. *Geophysical Research Letters*, 40(11), 2657–2660. https://doi.org/10.1002/grl.50556

SNR detection algorithm



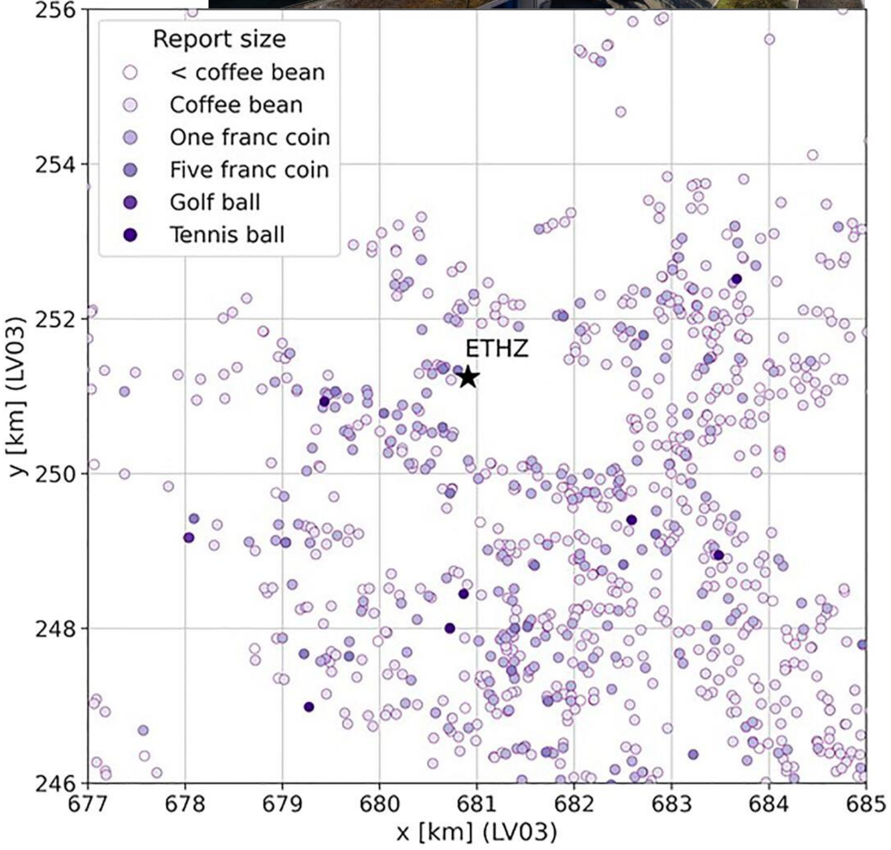
Case study 1: 28.06.2021

- ❑ Several supercell storms originated in Western Switzerland around 14:00 UTC
- ❑ Intense mesoscale convective system producing the second largest hail event in Switzerland since 2002
- ❑ Hailstones of up to 9 cm diameter
- ❑ Zurich: around 16:40 UTC maximum radar reflectivity (MAXRE) up to 60 dBZ



(a)

Images of MAXRE (dBZ) for the region surrounding the ETH Zurich station. Shown are images in 10 min intervals.

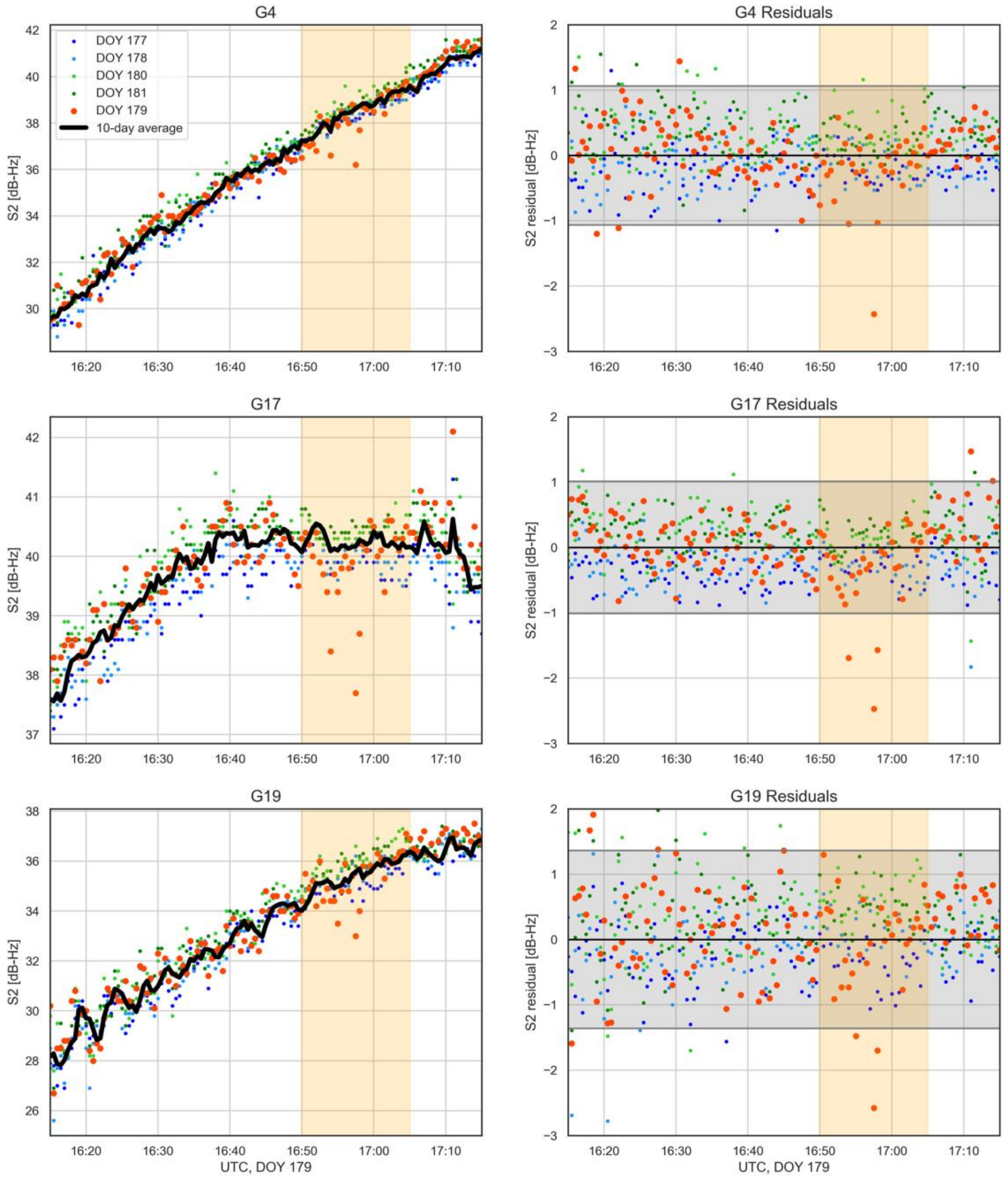


(b)

Hail observations for the region surrounding the ETH Zurich station: location of crowdsourced reports (purple dots, largest sizes are darker), location of the ETHZ GNSS station (black star).

Case study 1: 28.06.2021

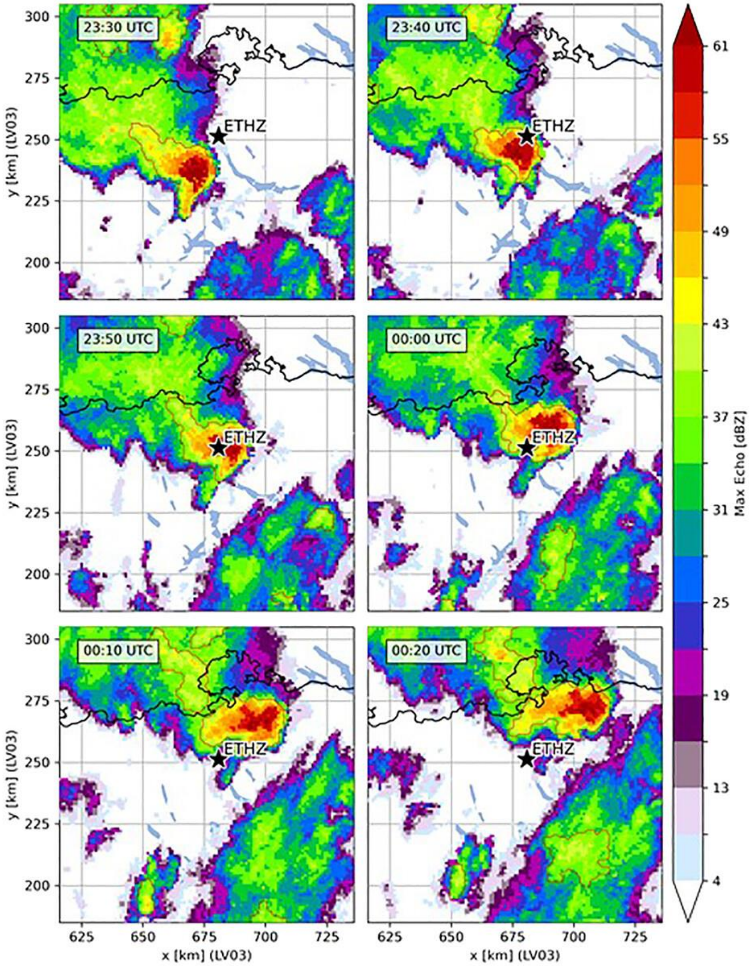
- Satellites G4, G17, and G19 selected
- During event period (orange):
  - All three satellites show degraded SNR levels compared to the background model
  - Largest degradation corresponding to the largest reflectivity values
  - Number of impacted observations is limited (1–3), but their degradation level is significant (2–3 db-Hz)
  - Some detections on non-event days for G17 and G19
  - Few event detections ahead of the actual event time for satellites G4 and G19
- Largest degradations during the period of most intense precipitation ➡ strong indication of the storm's impact on SNR levels



(a) (b)

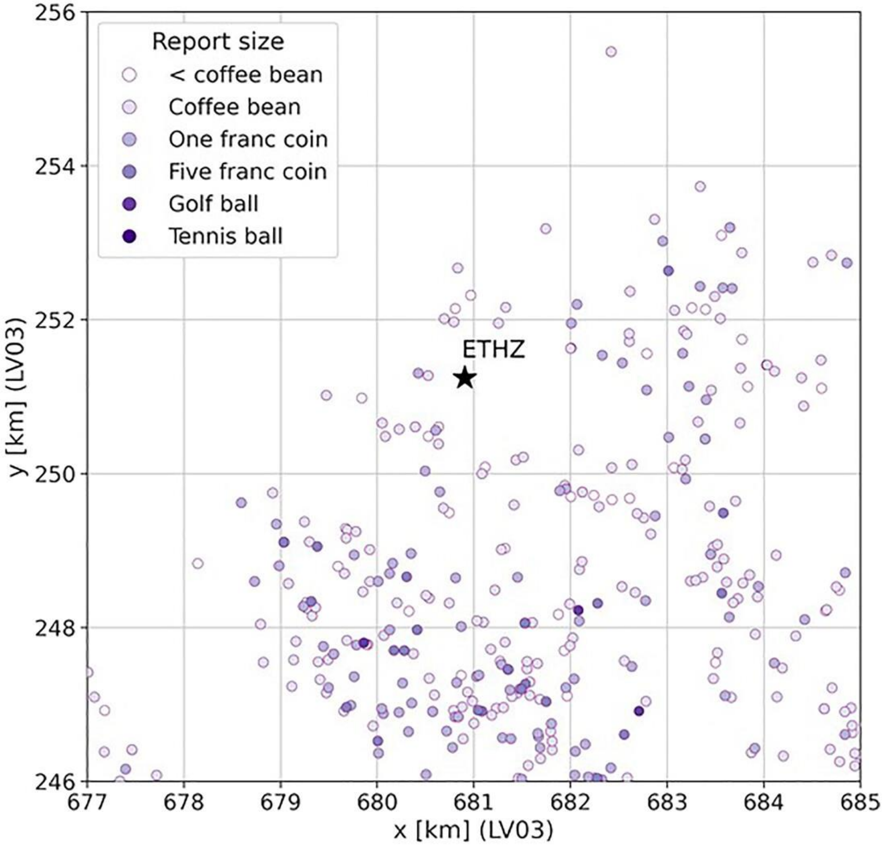
Case study 2: 12-13.07.2021

- Supercell thunderstorm ahead of an active cold front coming from the west
- Storm particularly intense when it approached the city of Zurich
- ETHZ hit around 23:40 UTC
- MAXRE values of up to 50 dBZ



(a)

Images of MAXRE (dBZ) for the region surrounding the ETH Zurich station. Shown are images in 10 min intervals.

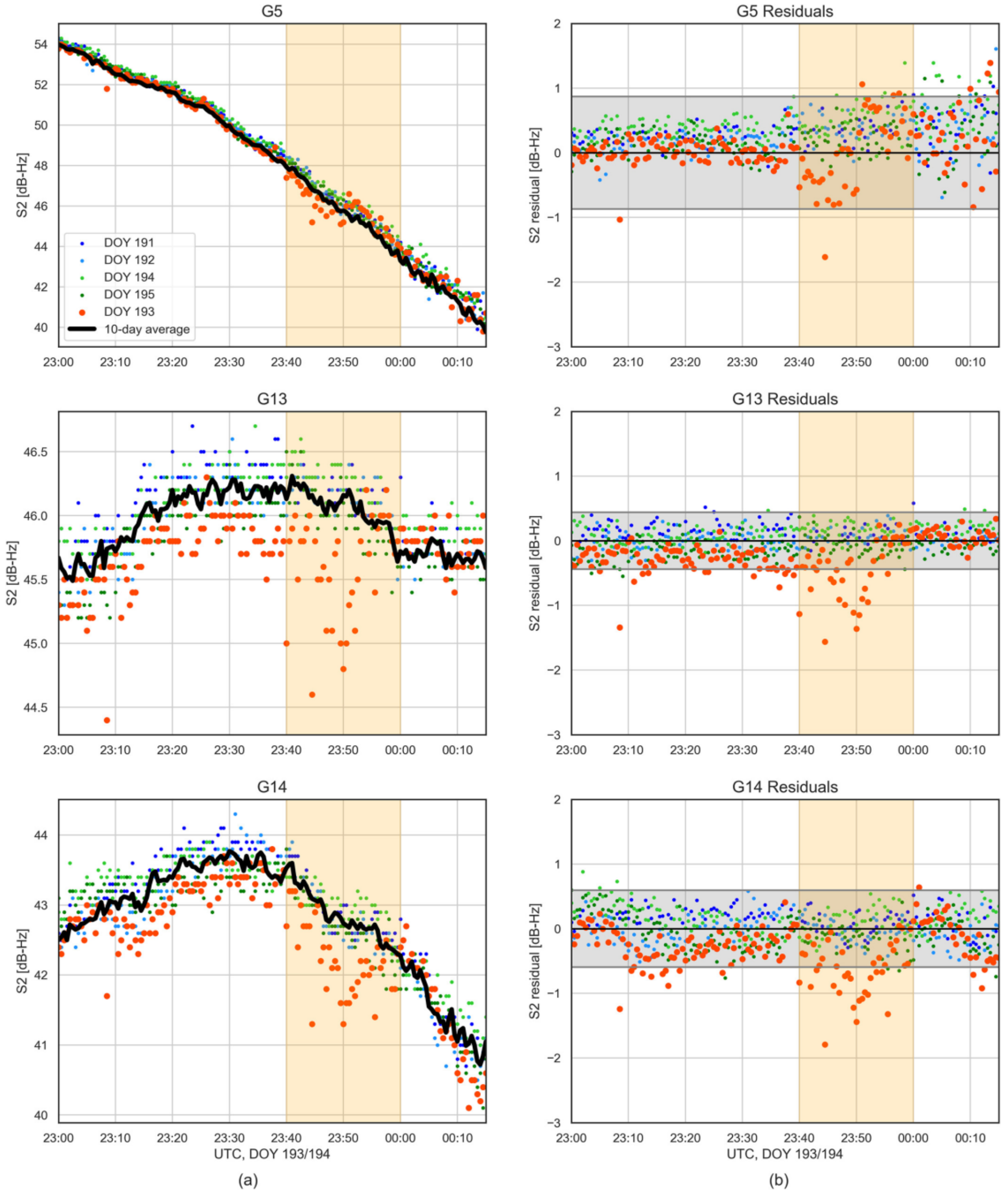


(b)

Hail observations for the region surrounding the ETH Zurich station: location of crowdsourced reports (purple dots, largest sizes are darker), location of the ETHZ GNSS station (black star).

Case study 2: 12-13.07.2021

- Satellites G05, G13, and G14
- Similar pattern as for CS1: clear degradation in SNR level during the period of most intense precipitation (23:40–00:00 UTC)
- Apart from event time:
  - observed values agree well with background model
  - Noise level similar throughout the five days shown
  - Some false detections prior and after the event, as well as on other days are again visible
- Comparison to CS1:
  - Residual levels are slightly lower (mostly 1–2 db-Hz)
  - Number of observations affected by the storm higher
  - G13 and G14: much larger number of detected events
  - Only one event detected for G5, but several residuals close to detection level
  - Stronger impact of this event than for CS1



Conclusions

- General conclusion:
  - → **Severe weather visible in GNSS-SNR**
  - → GNSS-SNR might be used as an additional proxy for detecting storm activity (point observation)
- Advantages:
  - High temporal (up to 1 Hz) and spatial coverage (5–10 km in dense networks)
  - Practically no additional costs for existing stations / only small costs for establishing new sites
  - Very simple and computationally efficient detection algorithm, allowing for real-time implementation
- Limitations:
  - Sensitivity of GNSS-SNR data is limited (L-band) → only severe storms could be detected
  - Storm must travel directly over the GNSS station to produce significant SNR degradation
  - GNSS-SNR = integral value along the ray path → horizontal resolution is restricted to the satellite tracks
  - Precise (sub-integer level) SNR observations are required, limiting the choice of GNSS receivers

Outlook

- At this stage, we can neither quantify:
  - Contribution of each hydrometeor type (rain vs. hail)
  - Influence of the size of the hydrometeors on the magnitude of the degradation
  - Contribution of other factors (such as lightning activity) to the SNR

- Future improvements:
  - Multi-GNSS : increase number of observations by factor 2-3
  - High-rate observations (e.g., 1 Hz): factor of 30
  - Machine-learning algorithms for separating the signatures of different hydrometeor types (rain and hail)
  - Highly complex task → combination of SNR observations with additional GNSS products (tropospheric signal delays and phase residuals) could be explored.

- **Future goal: Observing hailstorms with GNSS**
  - Difficult task due to their rarity and small spatial extent

  → Utilize existing and future networks of GNSS stations to detect hailstorms

ETH zürich

Questions???

Matthias Aichinger-Rosenberger
Post-Doc/Lecturer
maichinger@ethz.ch

ETH Zürich
Chair of Space Geodesy
Institute of Geodesy and Photogrammetry
Robert-Gnehm-Weg 15
8093 Zurich

www.space.igp.ethz.ch

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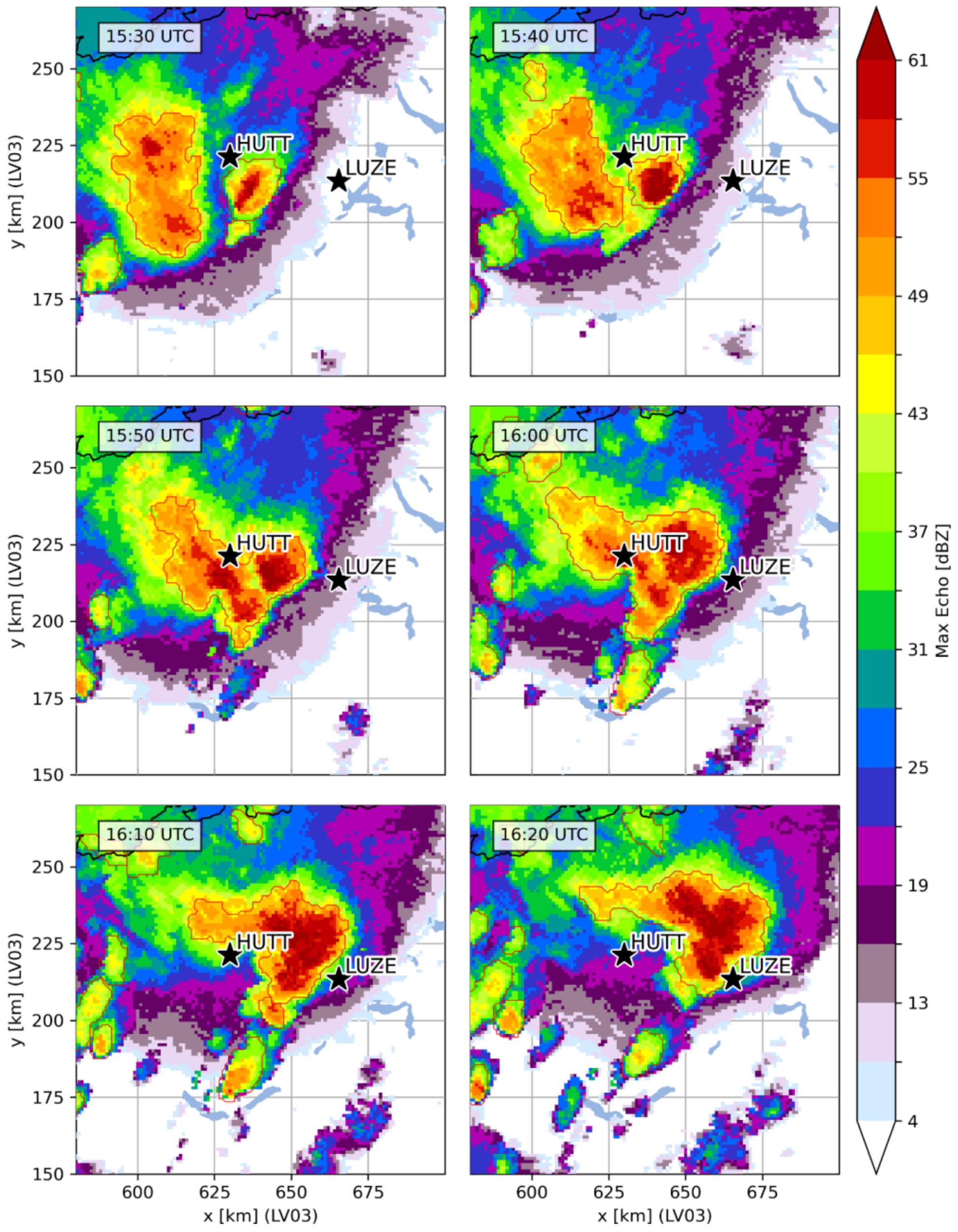
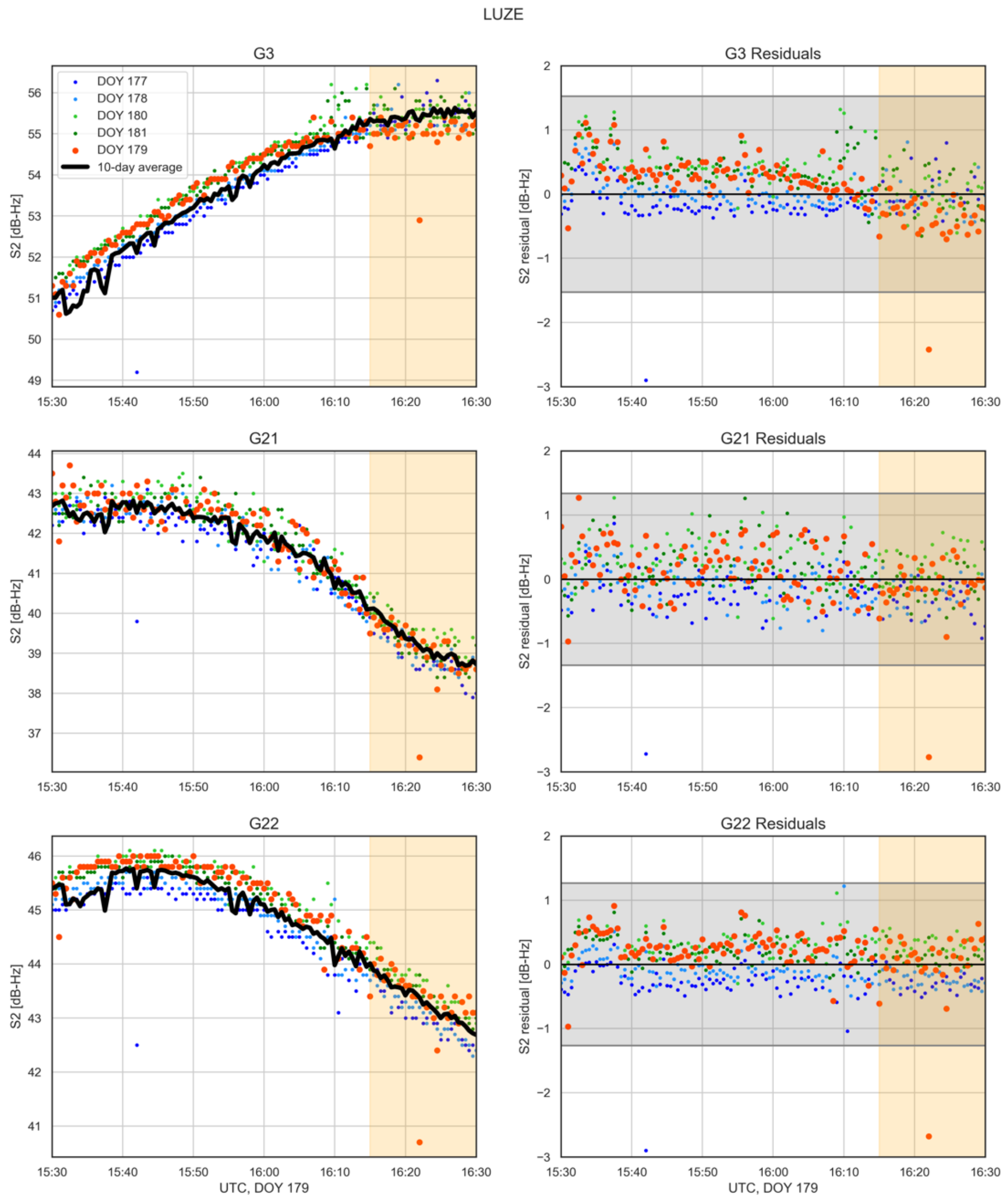
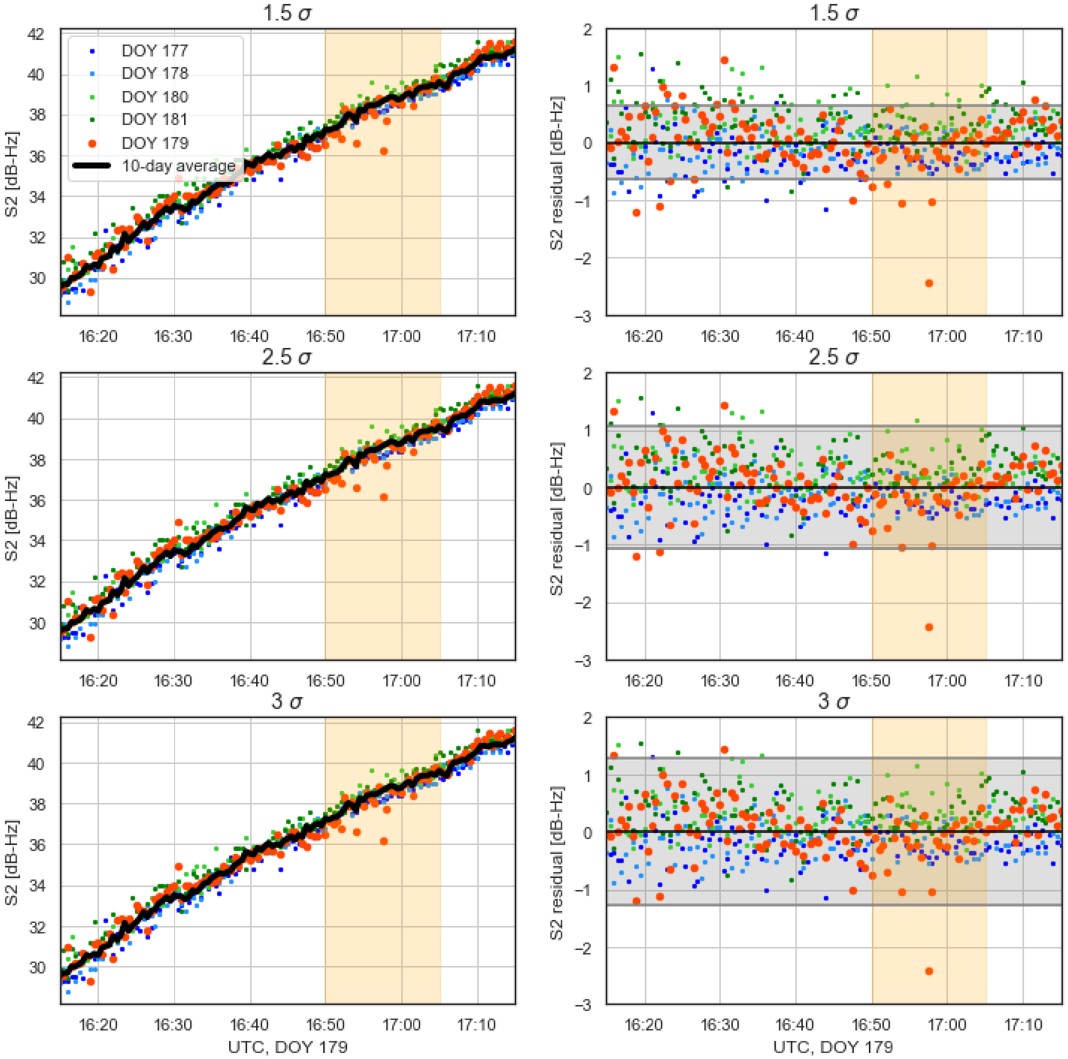
Influence of storm track: LUZE (Lucerne)





Influence of the set detection level

Different detection levels



Different averaging lengths (days)