Comparison of a rotational sensor and an array on Piton de la Fournaise volcano, La Réunion

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This presentation participates in OSPP

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Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

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Overview

Piton de la Fournaise volcano

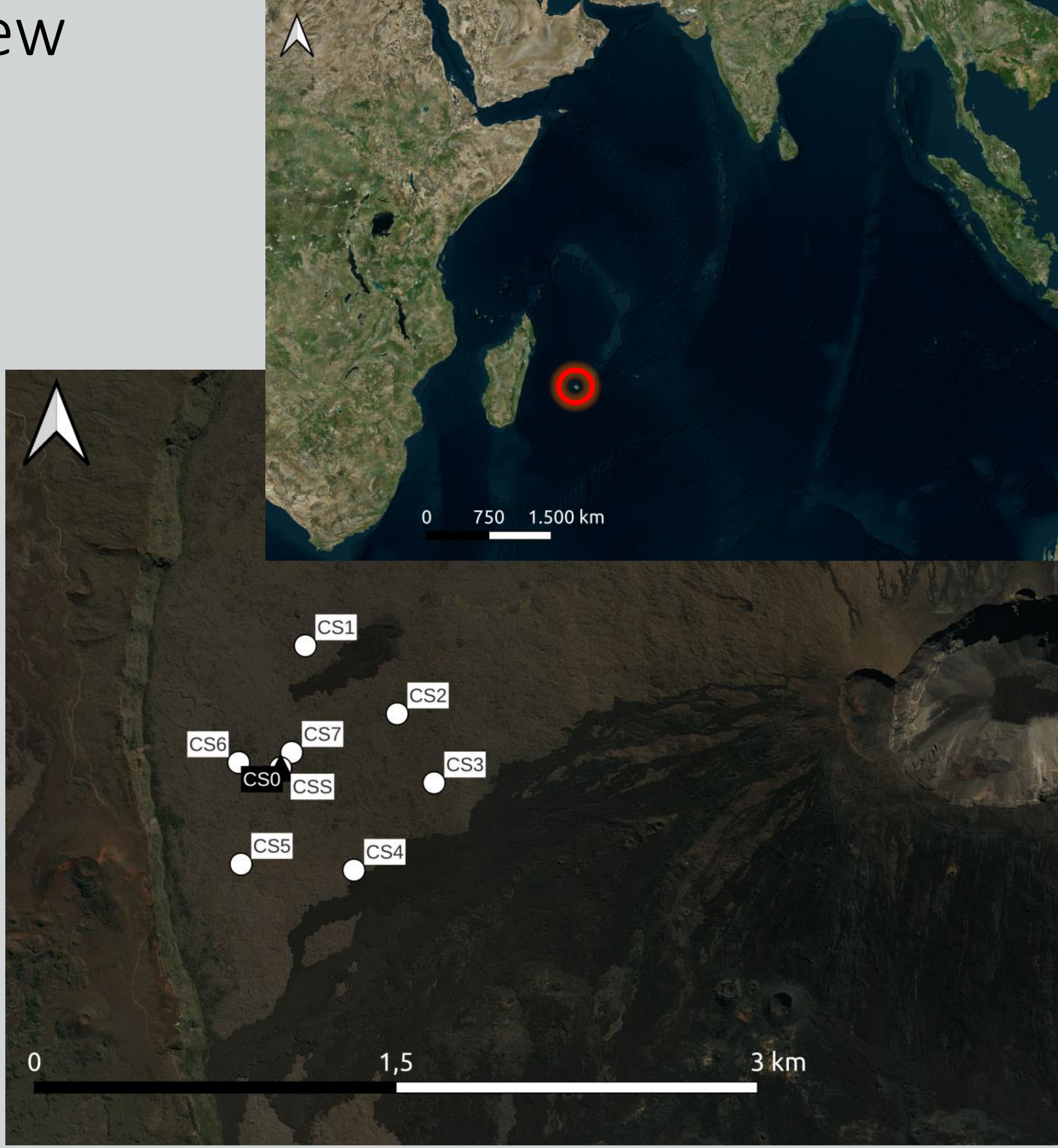
- recently 1-2 eruptions per year
- pre-eruptive signals: seismic swarm, tremor

Installation and methods

- rotational sensor, array (8 seismometers)
- ADR, SNR, BAZ for rockfall, local + summit EQ

Results

- array BAZ good for close & stronger events
- rotational sensor rockfall BAZ possibly true



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Methods

ADR	Array Derived Rotation
SNR	Signal to Noise Ratio
BAZ	Back azimuth calculation

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Array derived rotation (ADR)

- **displacement relation** between neighboring points assuming infinitesimal deformation to obtain rotation (Cochard et al. 2006, Spudich et al. 1995)
- rotation approximated by solving sampling points' linear equations; **finite difference approximation** by array stations (G) assuming uniformity of the strain tensor over array extent (Spudich et al. 2008, Suryanto 2006)

$$\mathbf{G} = \begin{bmatrix} u_{r,r} & u_{r,t} & u_{r,z} \\ u_{t,r} & u_{t,t} & u_{t,z} \\ -u_{r,z} & -u_{t,z} & -\eta(u_{r,r} + u_{t,t}) \end{bmatrix} \rightarrow \begin{bmatrix} \omega_r \\ \omega_t \\ \omega_z \end{bmatrix} = \begin{bmatrix} u_{z,t} \\ -u_{z,r} \\ -\frac{1}{2}(u_{r,t} - u_{t,r}) \end{bmatrix}$$

Donner et al. 2017

frequency (f) range limited by array aperture (h)

- here: 1 - 3.5Hz from 225m distance of 3 array stations and ground heterogeneities

$$\frac{0.00238 \cdot c}{h} < f < \frac{0.25 \cdot c}{h}$$

Donner et al. 2017

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Signal to noise ratio (SNR)

- Theoretical background:
  - calculation of averaged SNR as the **sum of the root mean square** (RMS) of all components' Signal (S) and divide by sum of RMS Noise (N)

$$SNR = \frac{\sqrt{\frac{1}{n}\sum_{i=0}^{n} S_{ei}^2 + S_{ni}^2 + S_{zi}^2}}{\sqrt{\frac{1}{n}\sum_{i=0}^{n} N_{ei}^2 + N_{ni}^2 + N_{zi}^2}}$$

Eibl et al. 2022

- Configuration here:
  - RMS of two **10s-time windows** before and during the event
  - gap of 5s between the signal and noise windows to avoid overlap

← methods

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Backazimuth (BAZ) – seismic array

- Theoretical background:
  - Fast Fourier Transform of real input
  - computing **covariances** of signal at different **array stations**
  - creating slowness maps
  - calculating **BAZ from slowness map**
- Output:
  - BAZ
  - slowness
  - power (real, absolute)
  - semblance
- obspy code from Van Driel & Bayreuther 2010

← methods

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BAZ – horizontal components of rotational sensor

- Theoretical background:
  - rotational sensor horizontal components for **orthogonal distance regression**
  - **ambiguity corrected** with co-located seismometer
  - assumption of only one source and planar incoming wavefield

$$\omega_x = \frac{1}{2} Ak \sin\phi \sin(\omega t - \mathbf{k}\cdot\mathbf{r} + \varphi),$$
$$\omega_y = -\frac{1}{2} Ak \cos\phi \sin(\omega t - \mathbf{k}\cdot\mathbf{r} + \varphi),$$
$$\omega_z = 0.$$

Sollberger et al. 2018

- Output: BAZ, standard error
- Configuration here: 1s sliding windows, overlap of 10%
- code from Wassermann et al. 2016 & Wassermann et al. 2020

← methods

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BAZ – 6C: vertical component of rotational sensor

- Theoretical background:
  - North and East seismometer components rotated around possible BAZ values
  - correlation of transverse and vertical rotation from rotational sensor
  - BAZ of highest correlation extracted
  - phase velocities estimated from amplitude ratios

$$\frac{a_T}{\dot{\omega}_z} = \frac{-k^2c^2 A \sin(kx - kct)}{\frac{1}{2}k^2 c A \sin(kx - kct)} = -2c$$

Hadziioannou et al. 2012

- Output: BAZ, phase velocities
- Configuration: 1s sliding windows
- code from Hadziioannou et al. 2012

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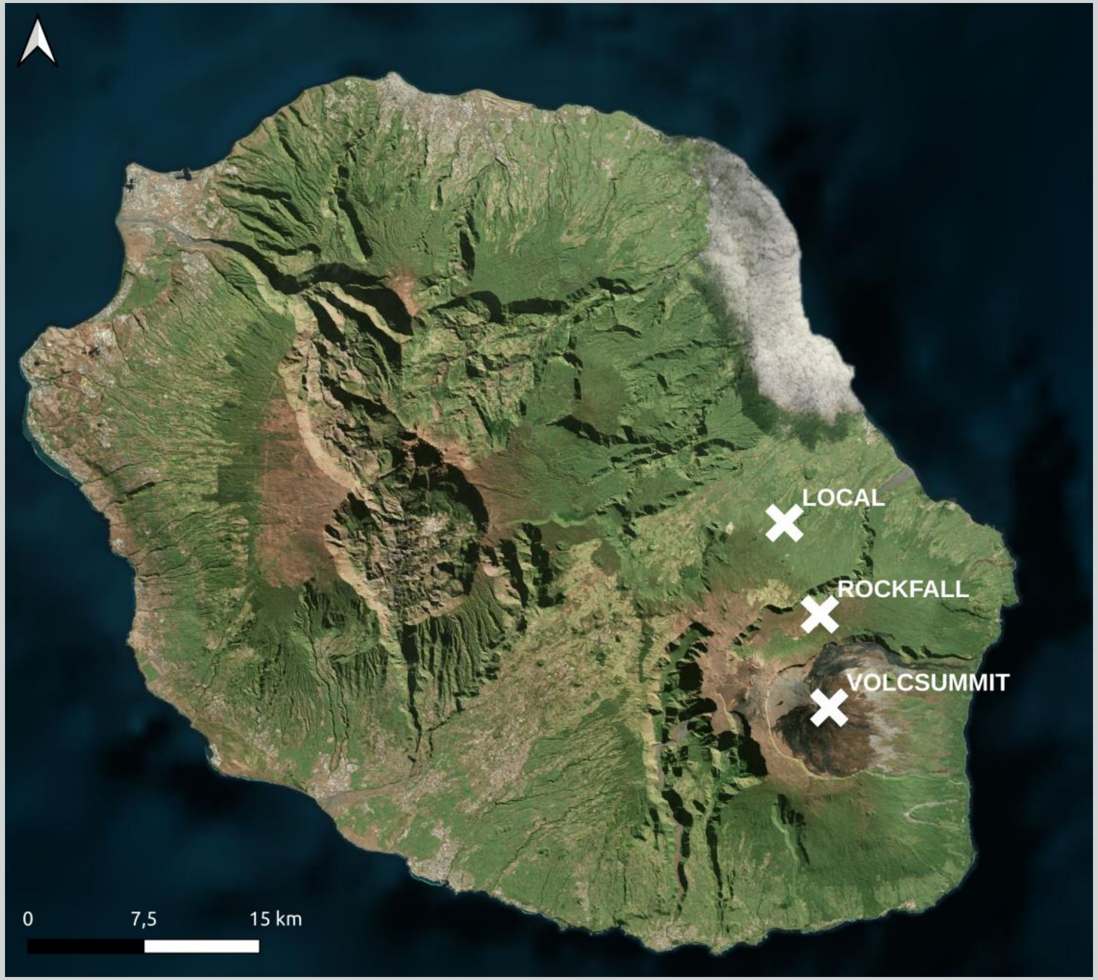
Results for events



Spectrograms

SNR

ADR

BAZ

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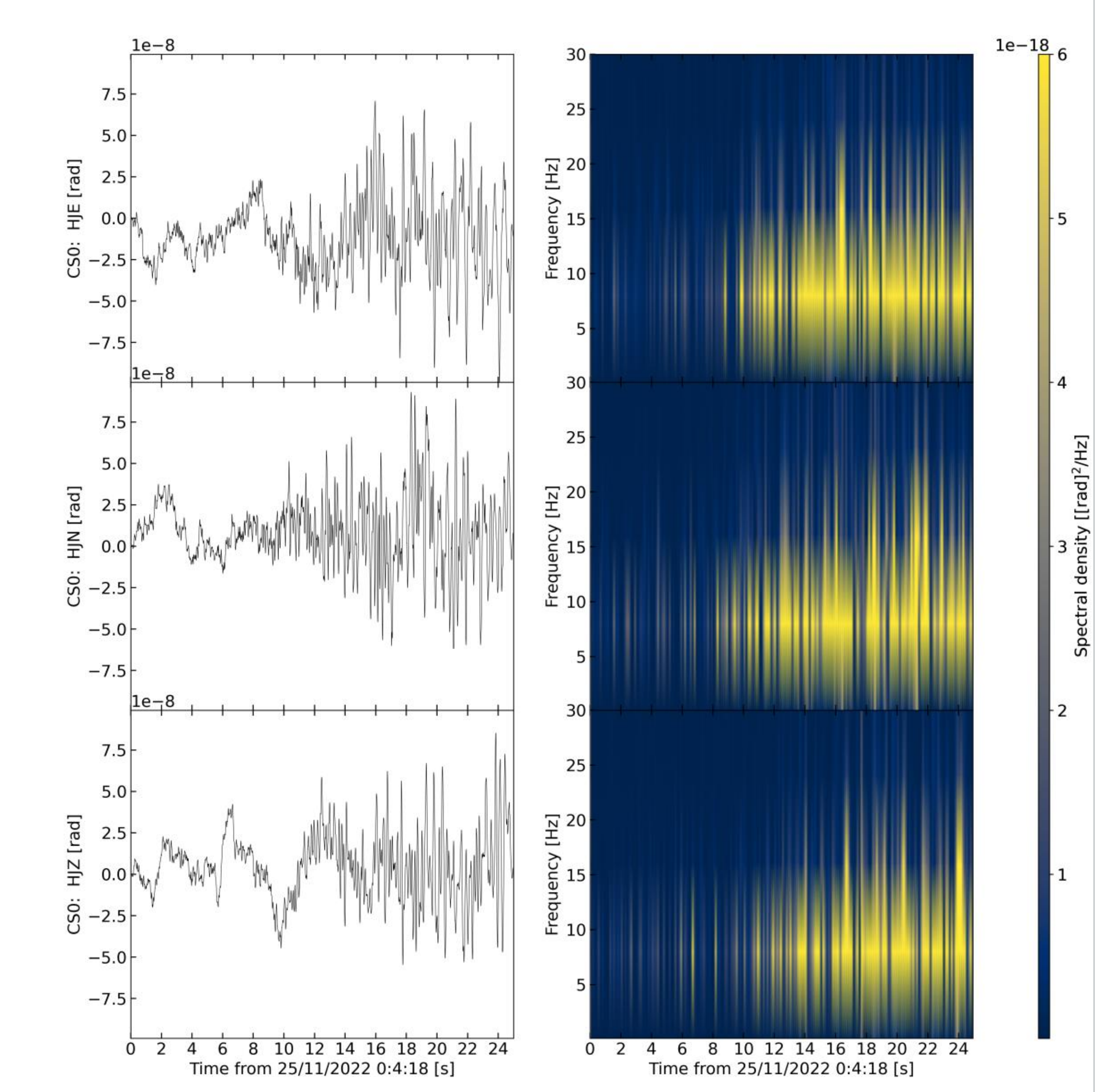
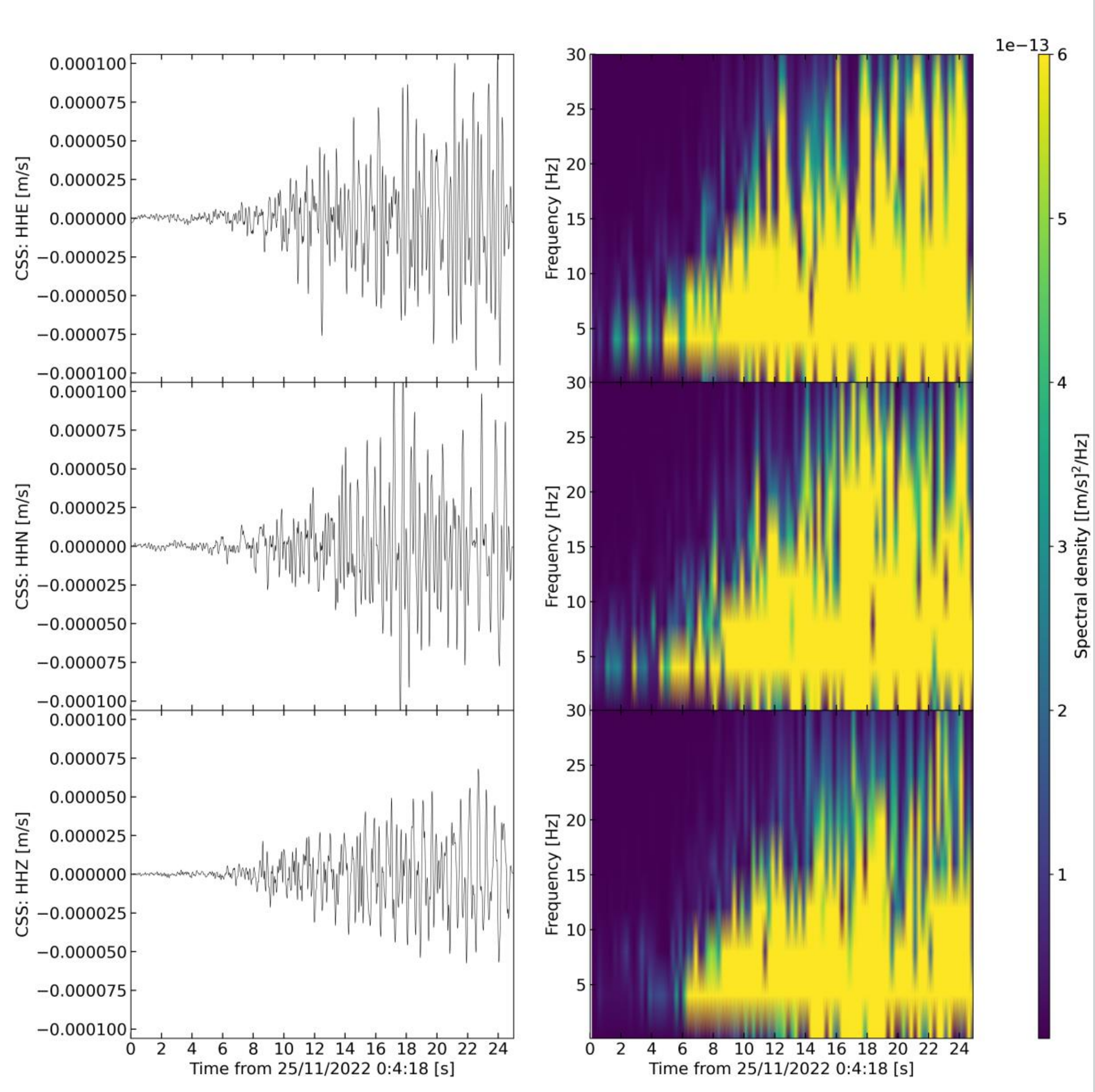
Spectrogram: Rockfall event 25.11.2022





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← results

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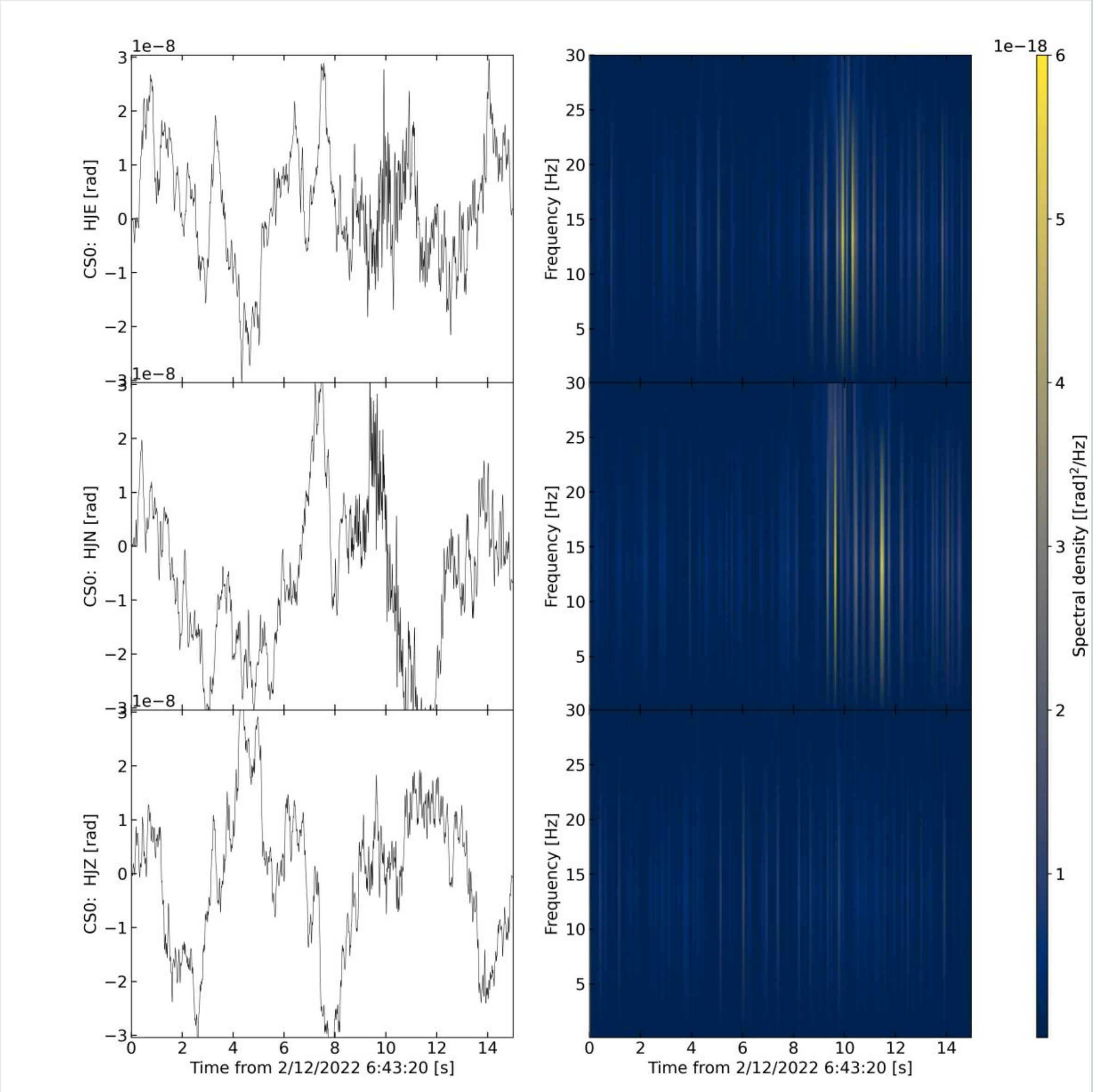
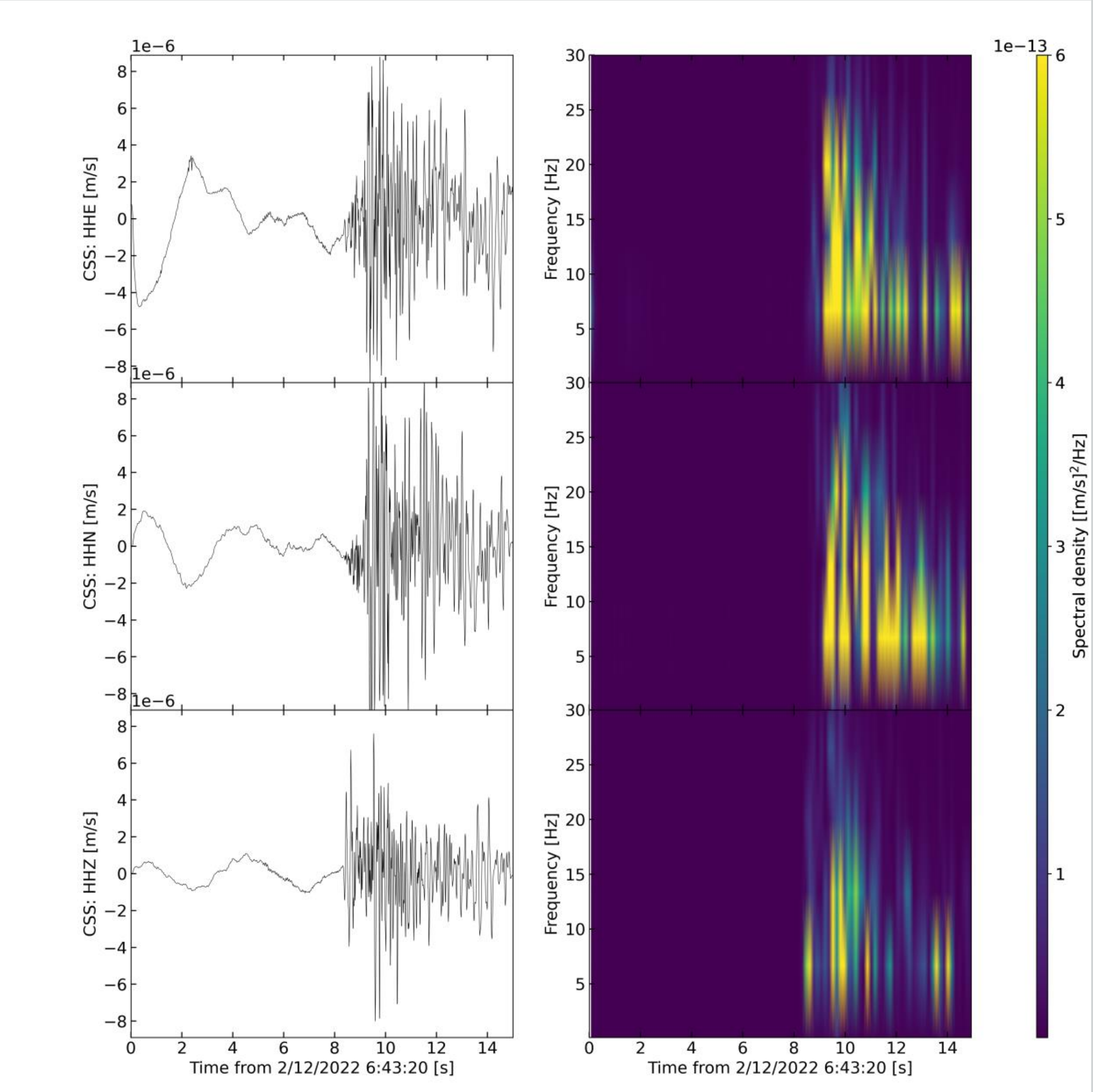
Spectrogram: Volcsummit 02.12.2022





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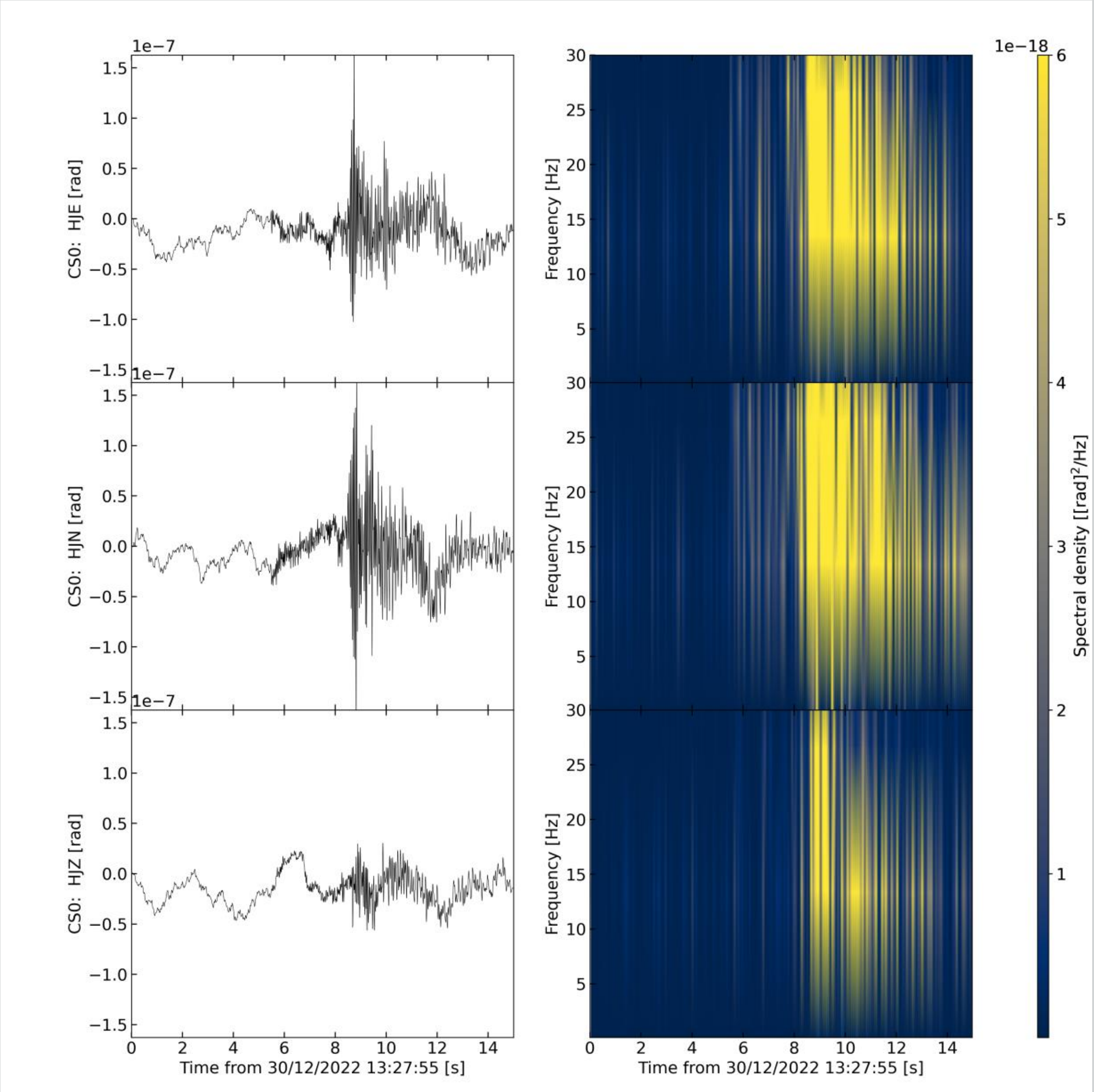
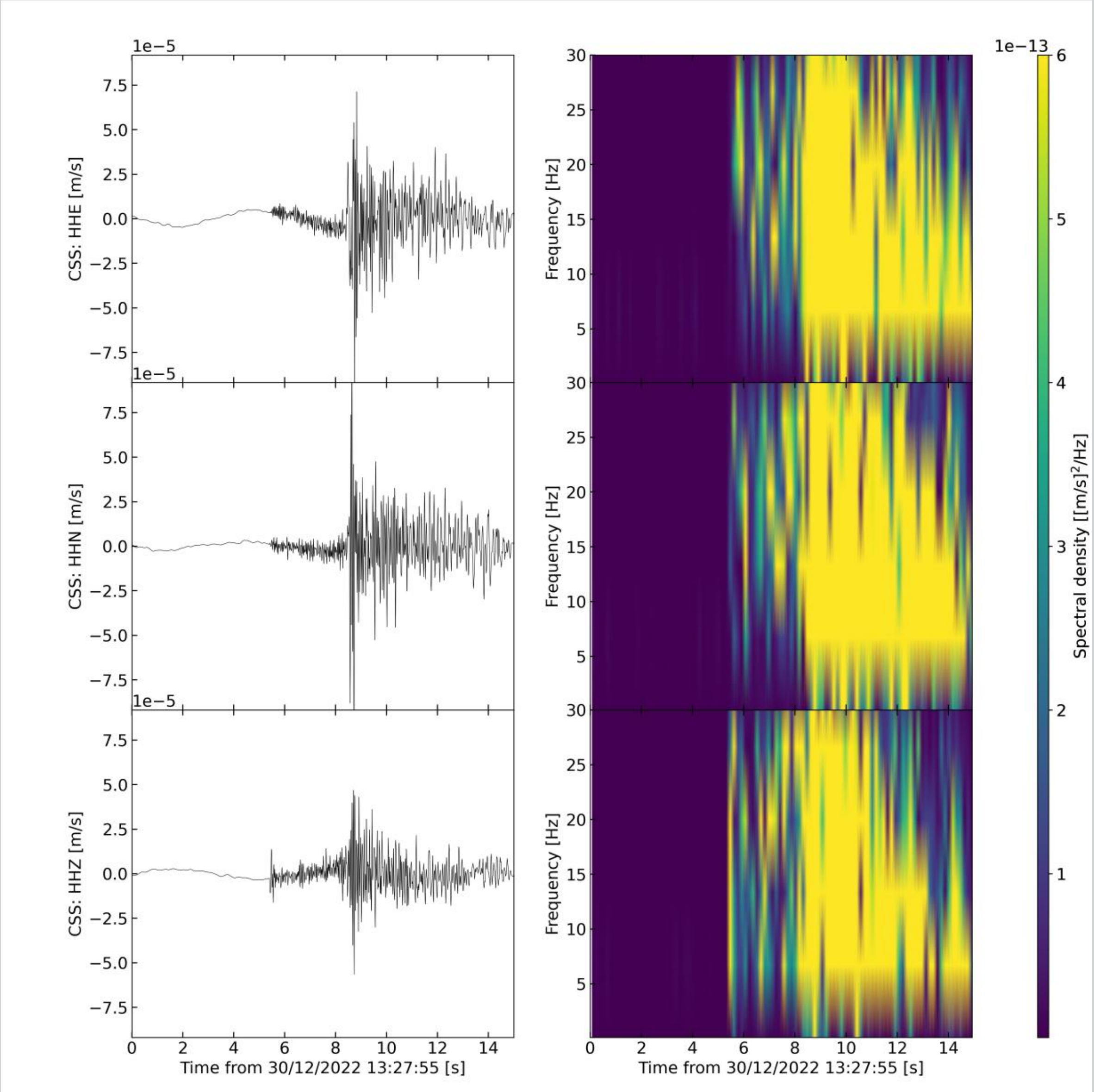
Spectrogram: Local event 30.12.2022





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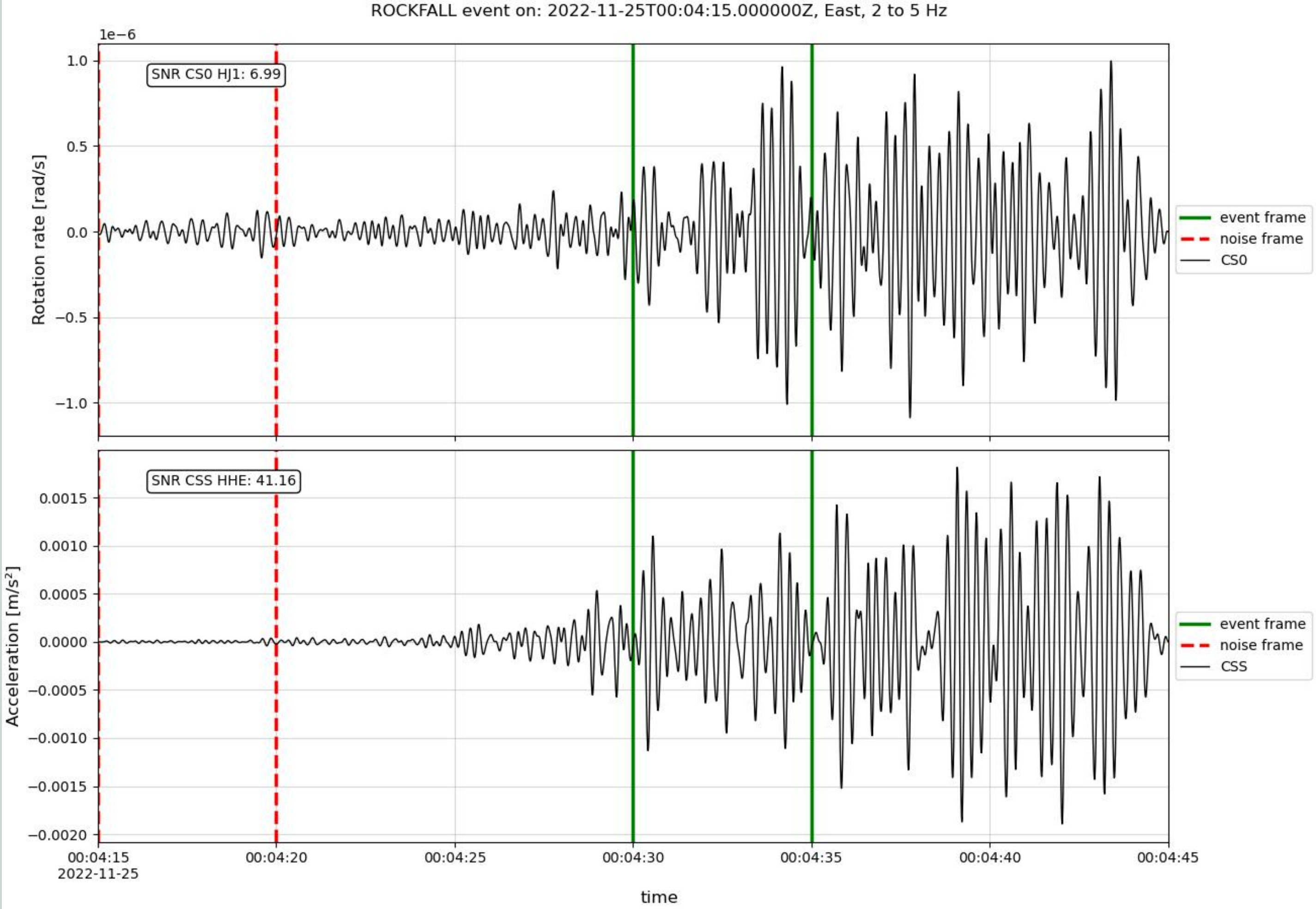
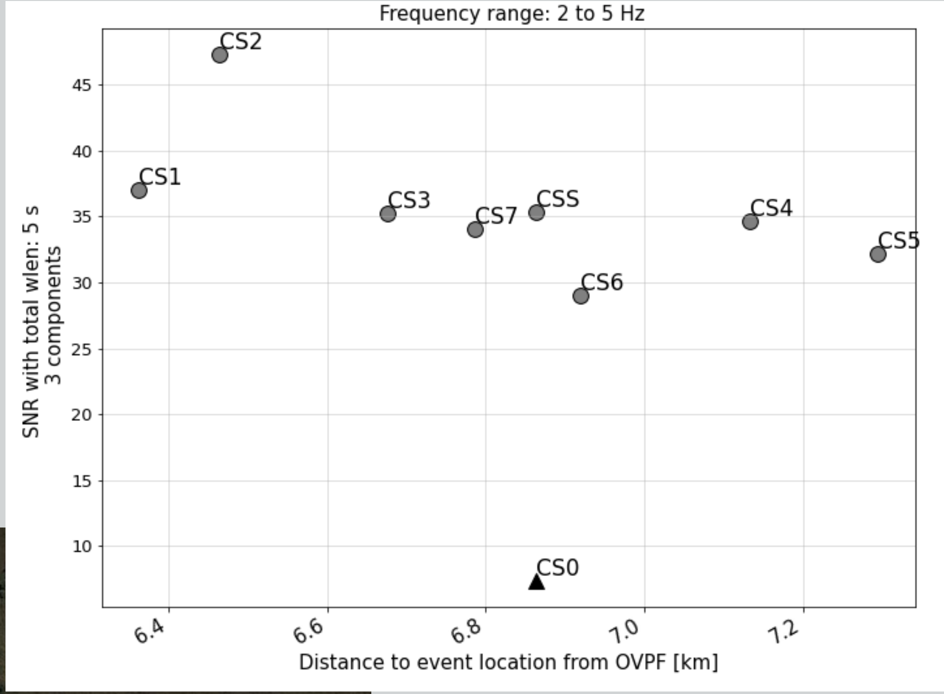
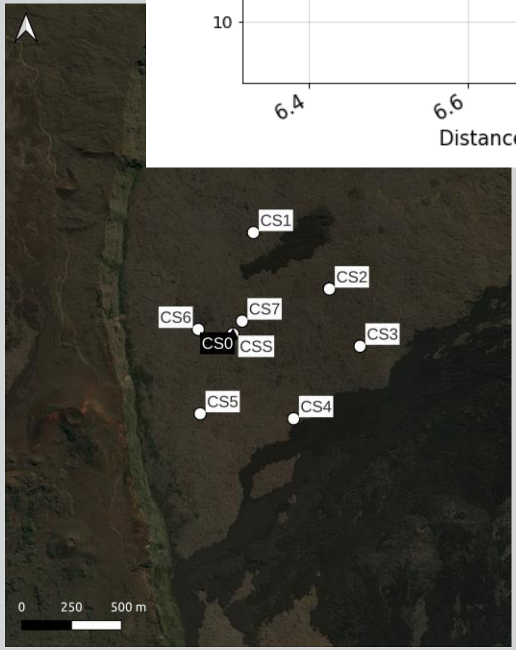
SNR: Rockfall event 25.11.2022







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← results

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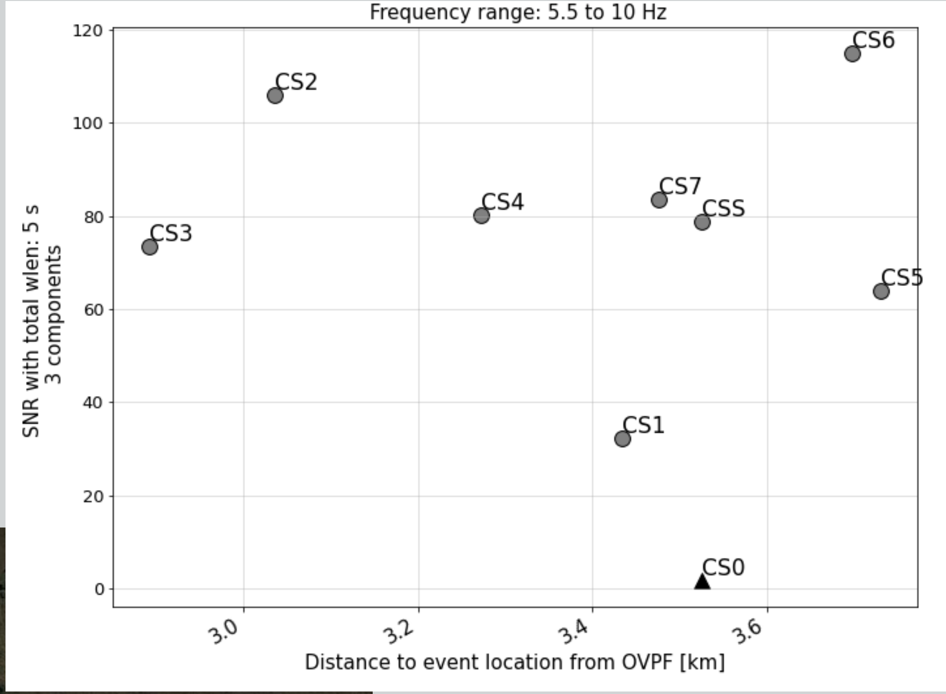
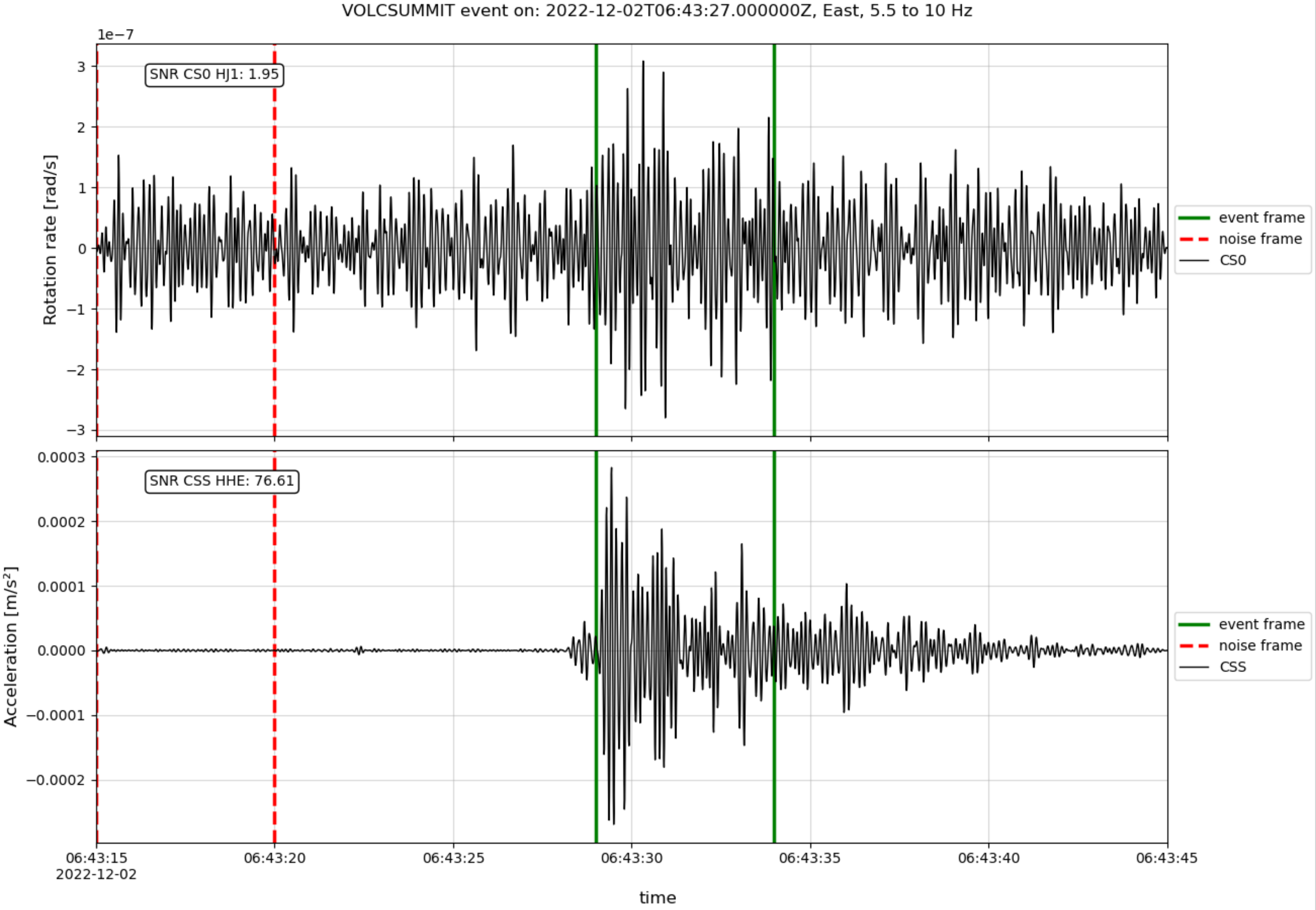
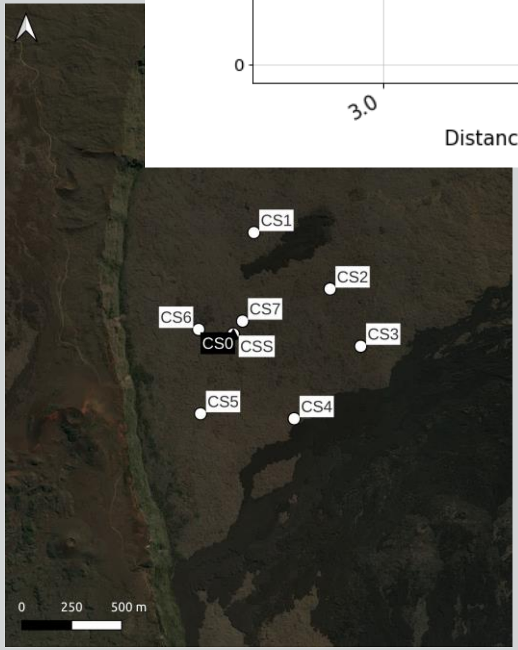
SNR: Volcsummit event 02.12.2022







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← results

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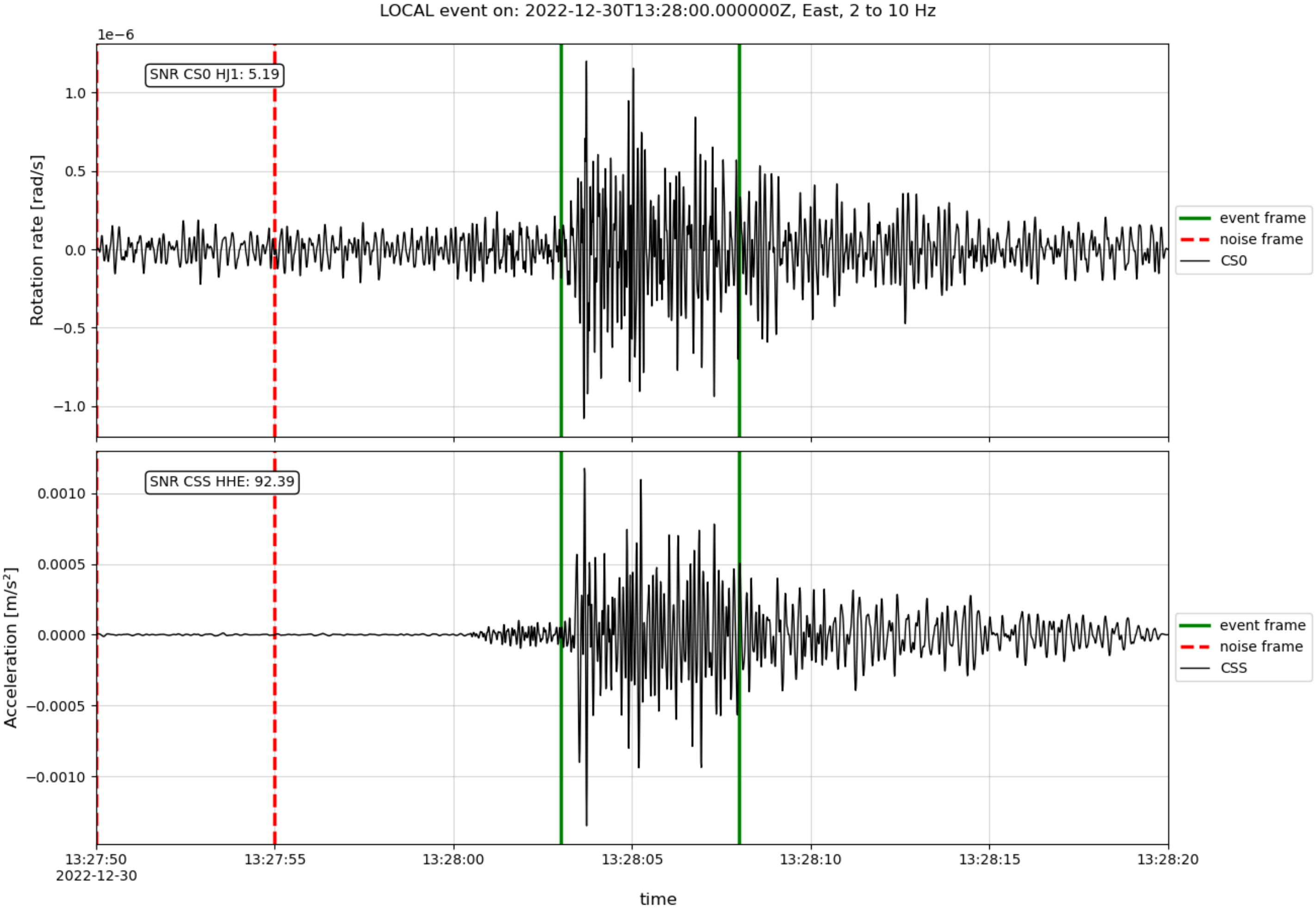
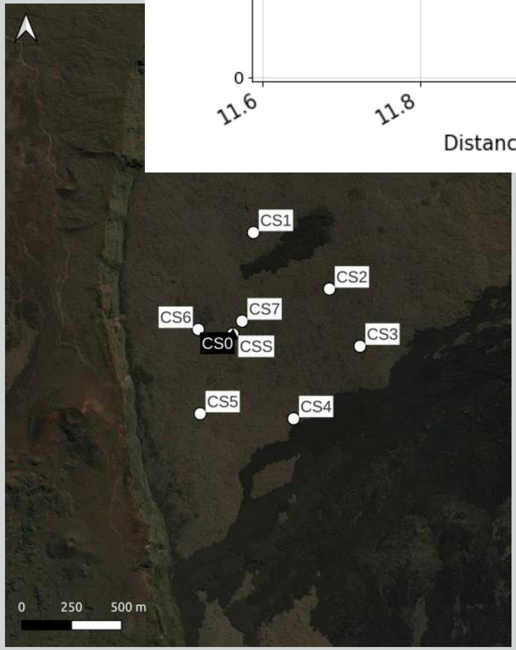
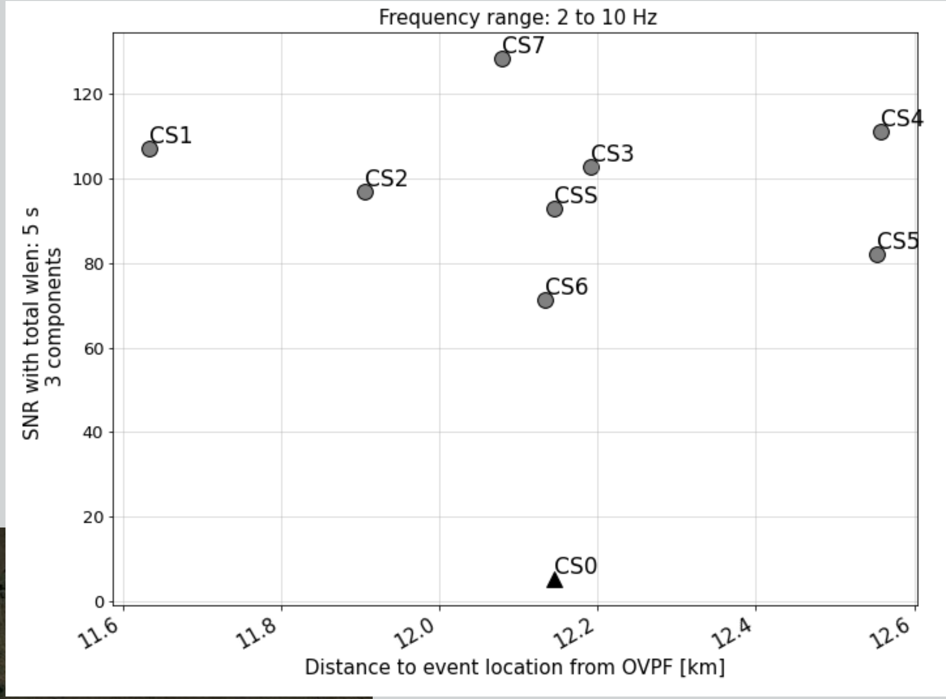
SNR: Local event 30.12.2022







← results

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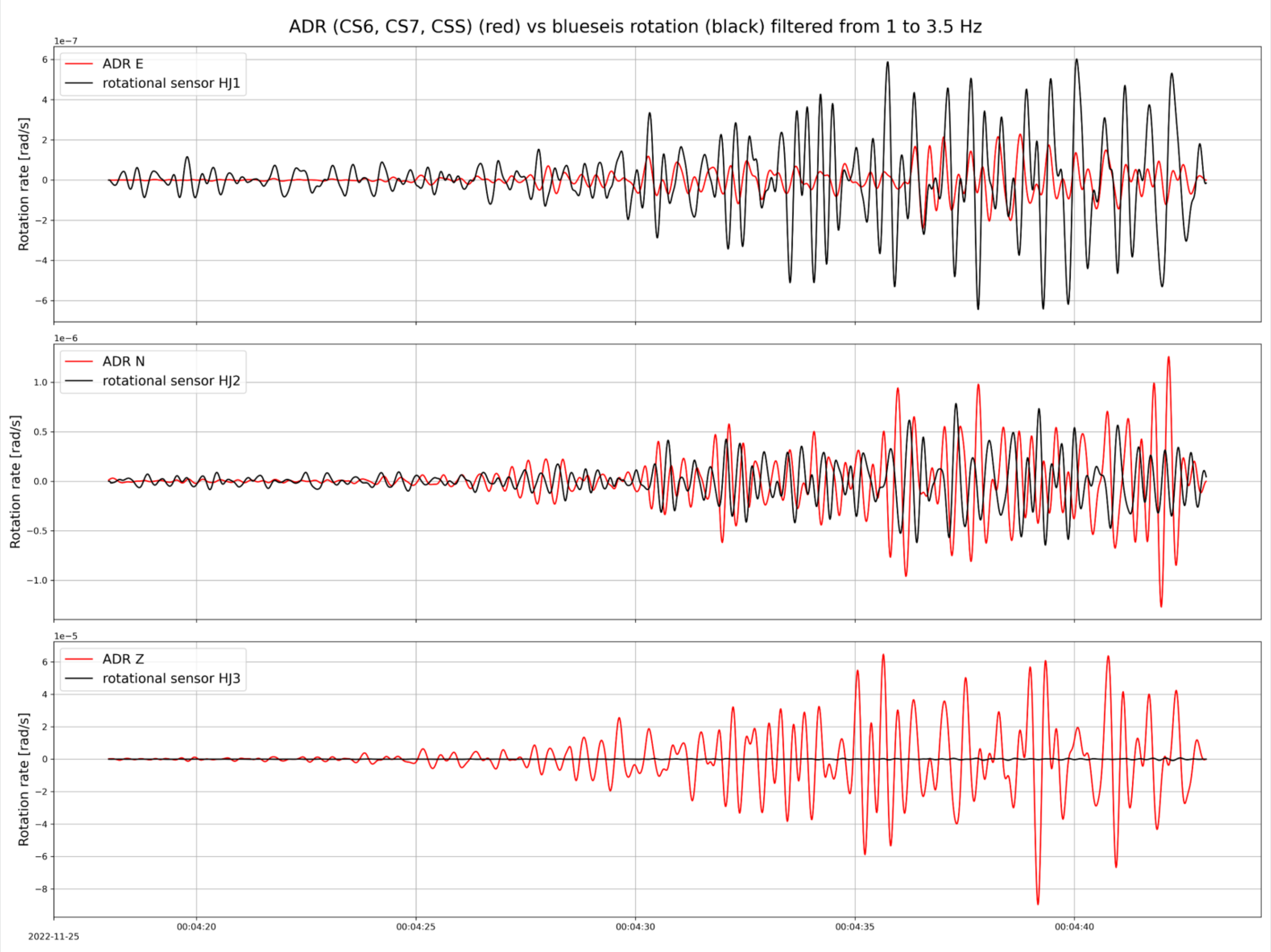
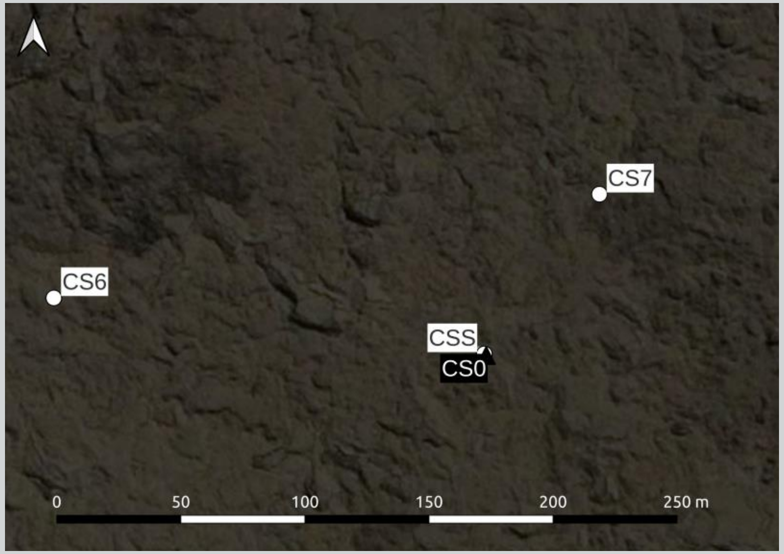
ADR: Rockfall event 25.11.2022





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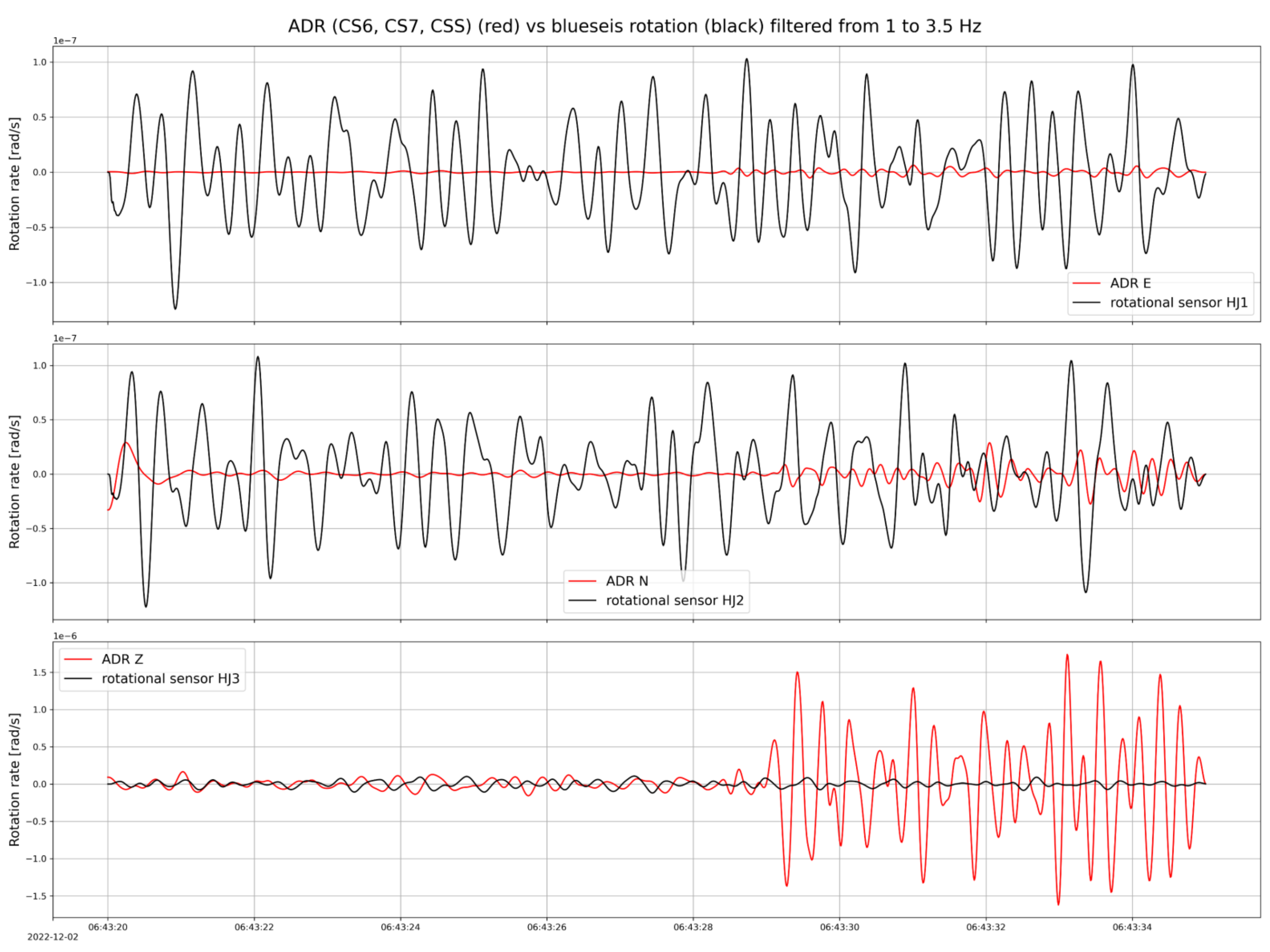
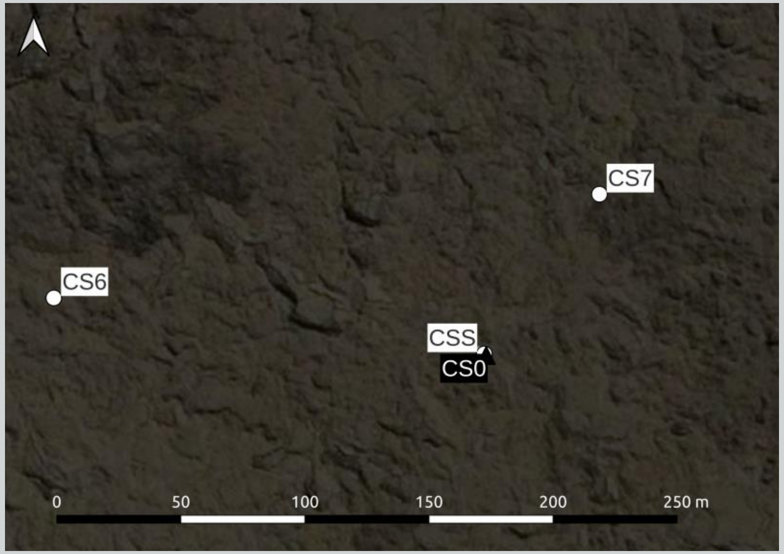
ADR: Volcsummit event 02.12.2022





← results

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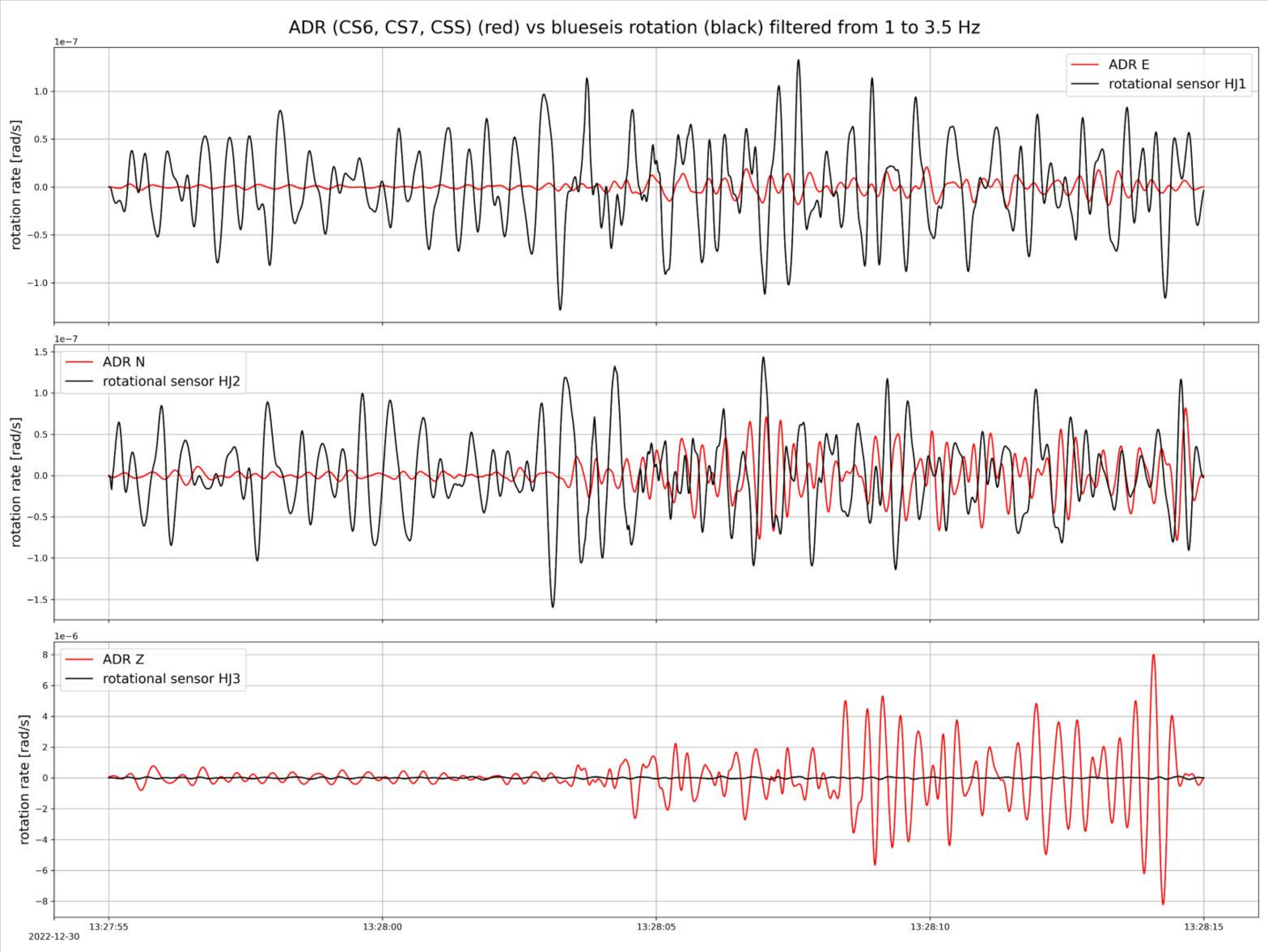
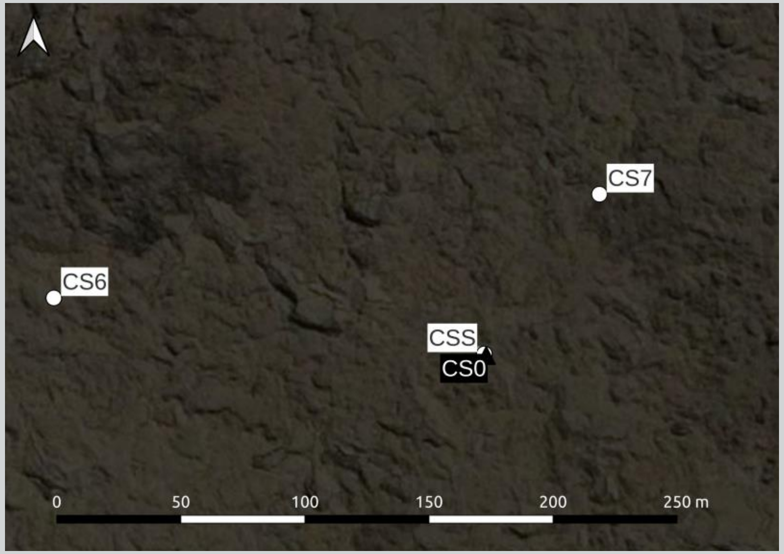
ADR: Local event 30.12.2022





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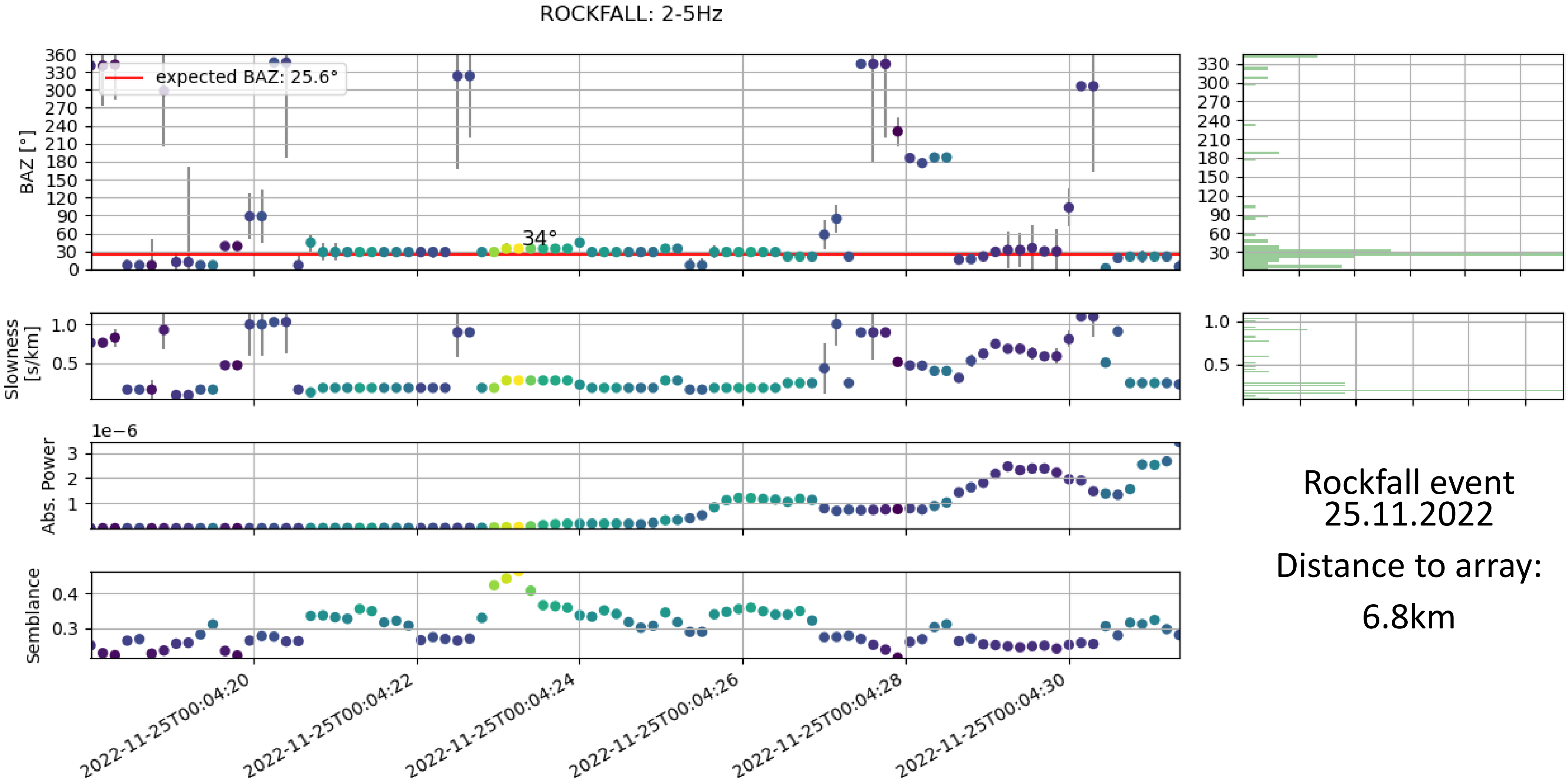
Back azimuth array



Rockfall event
25.11.2022

Distance to array:

6.8km

← results

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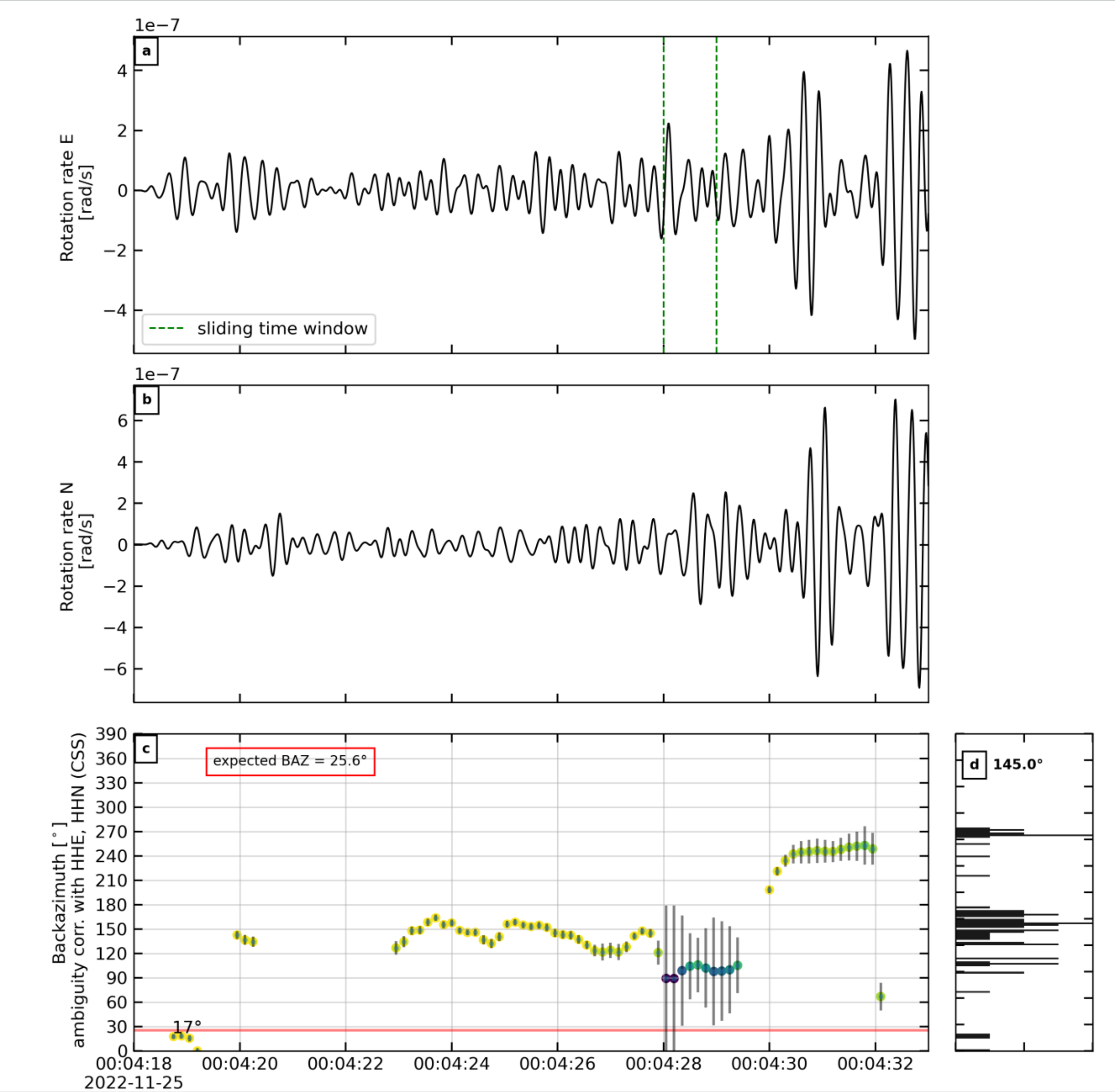
Back azimuth horizontal components

Rockfall event
25.11.2022

Distance to CS0: 6.9km



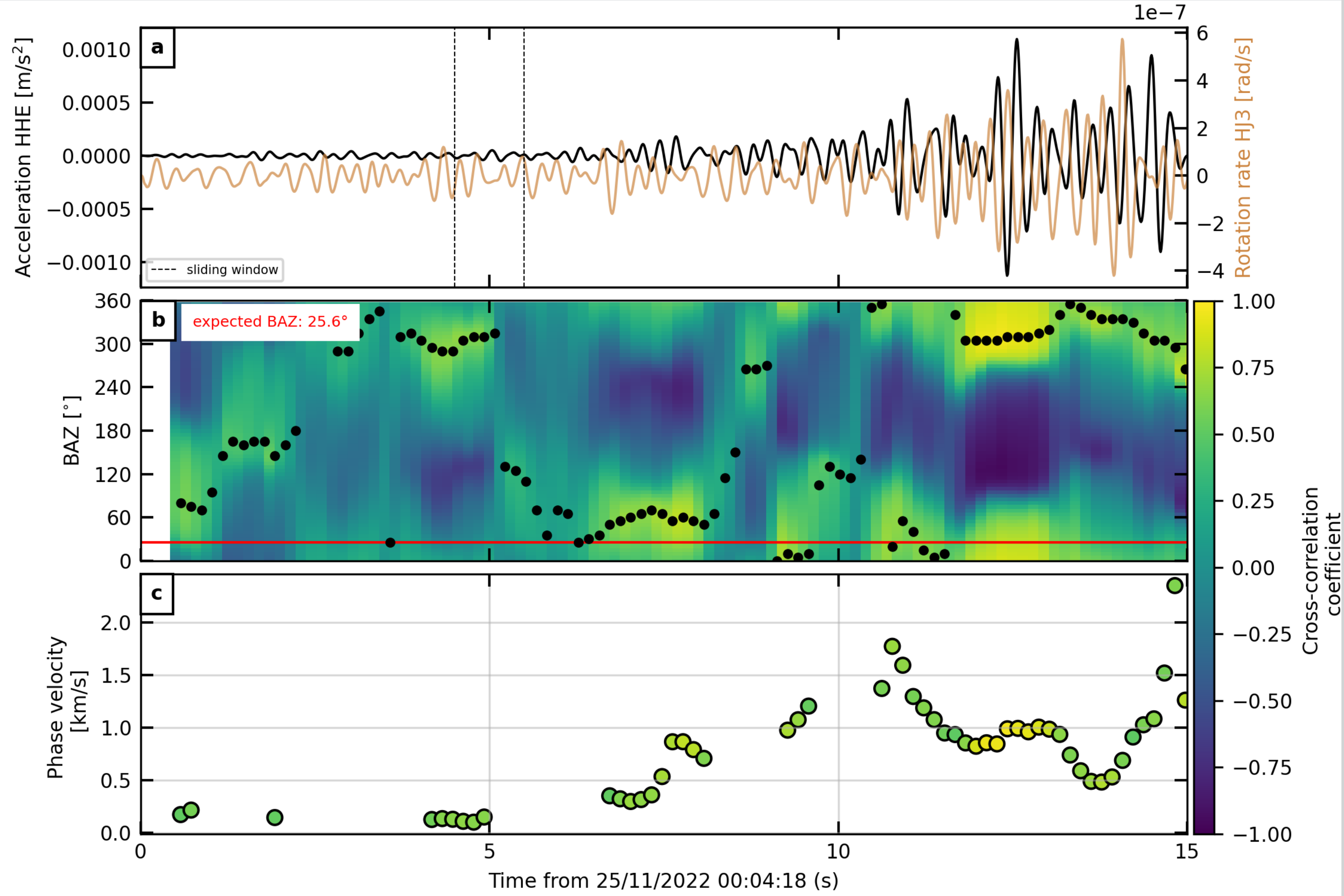
← results

← main slide

Back azimuth 6C method

Rockfall event 25.11.2022

Distance to CS0: 6.9km



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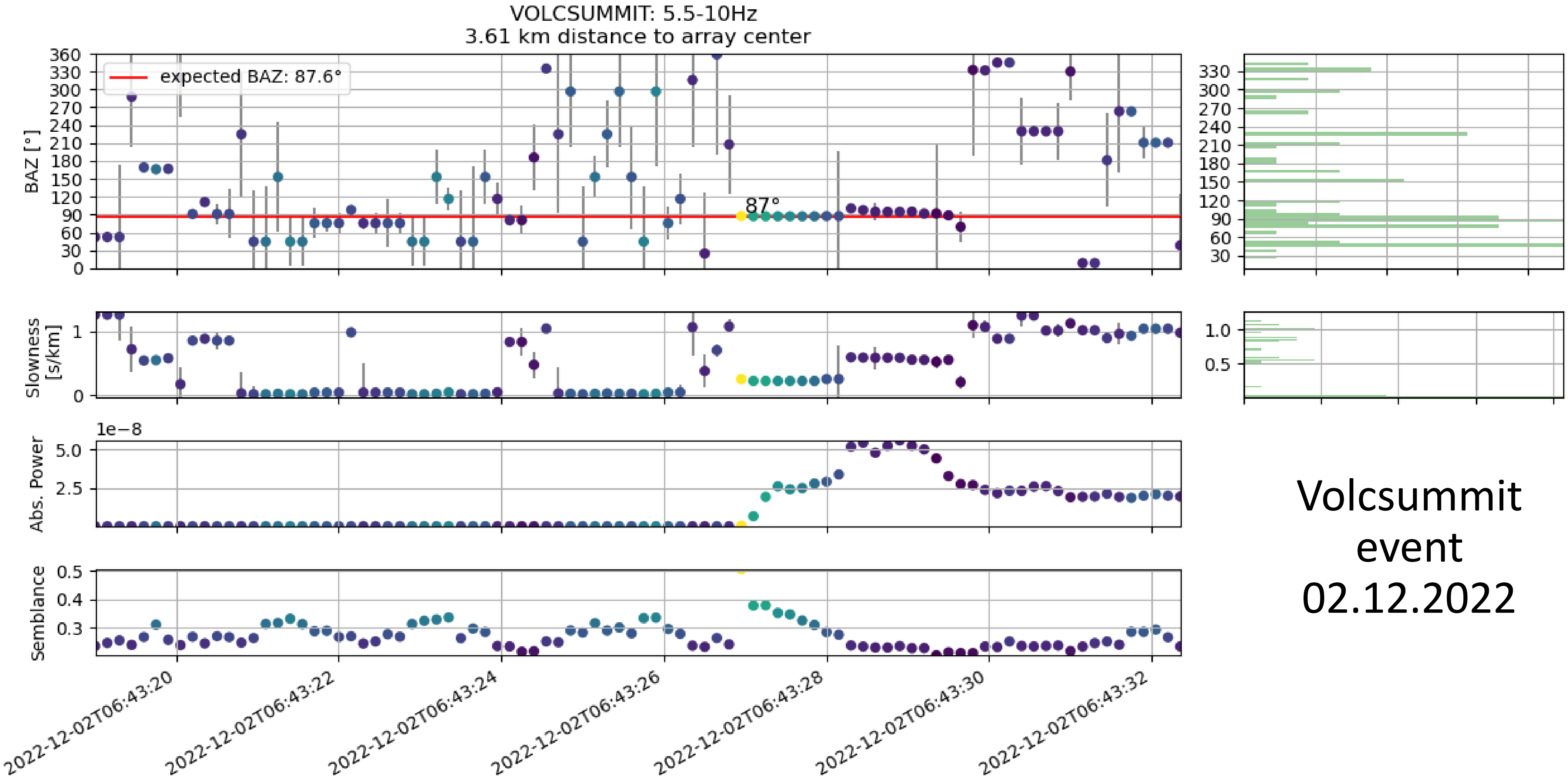
← results

Back azimuth array



Volcsummit event 02.12.2022

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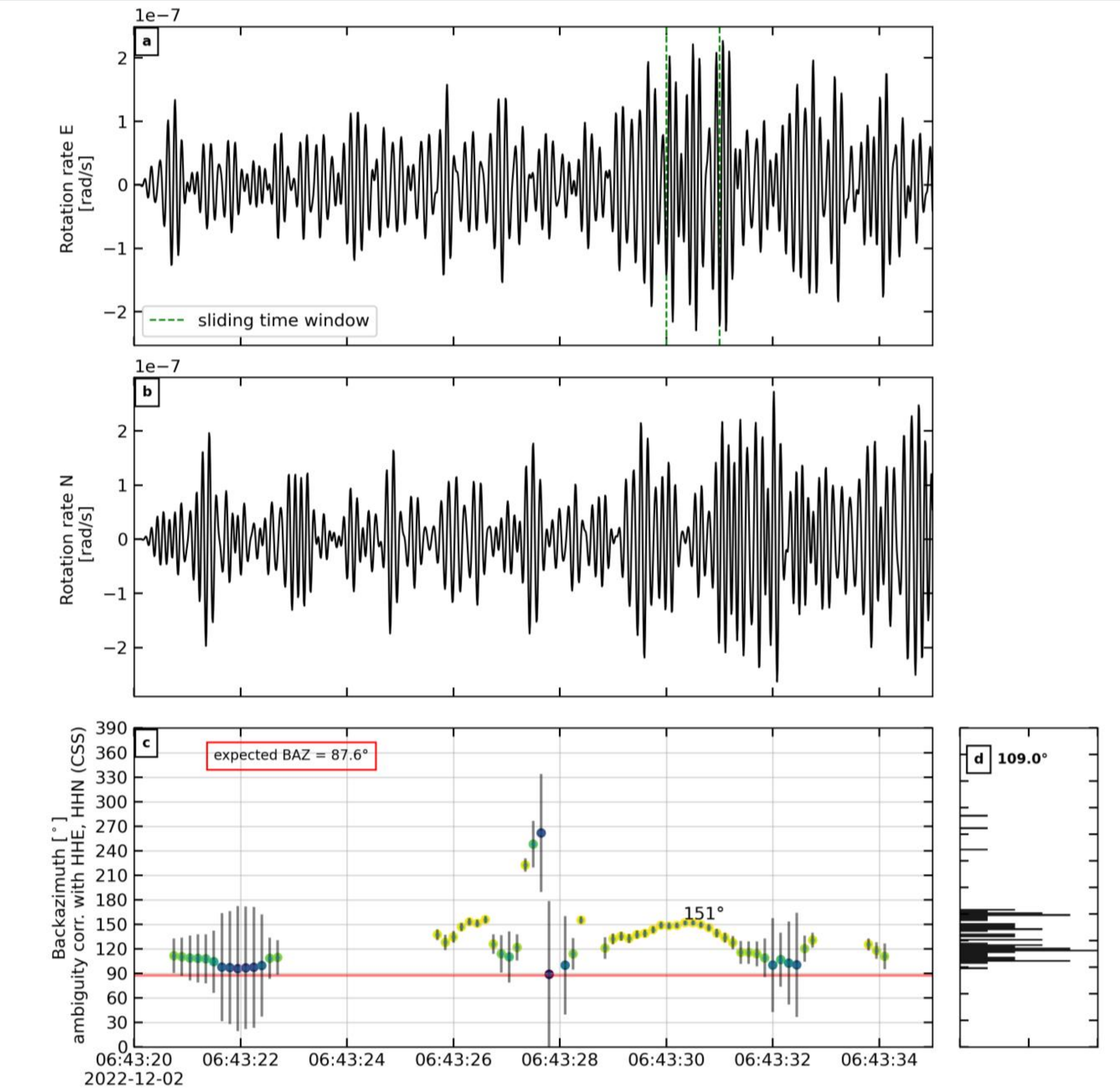
Back azimuth horizontal components

Volcsummit event
02.12.2022

Distance to CS0: 3.5km



← results

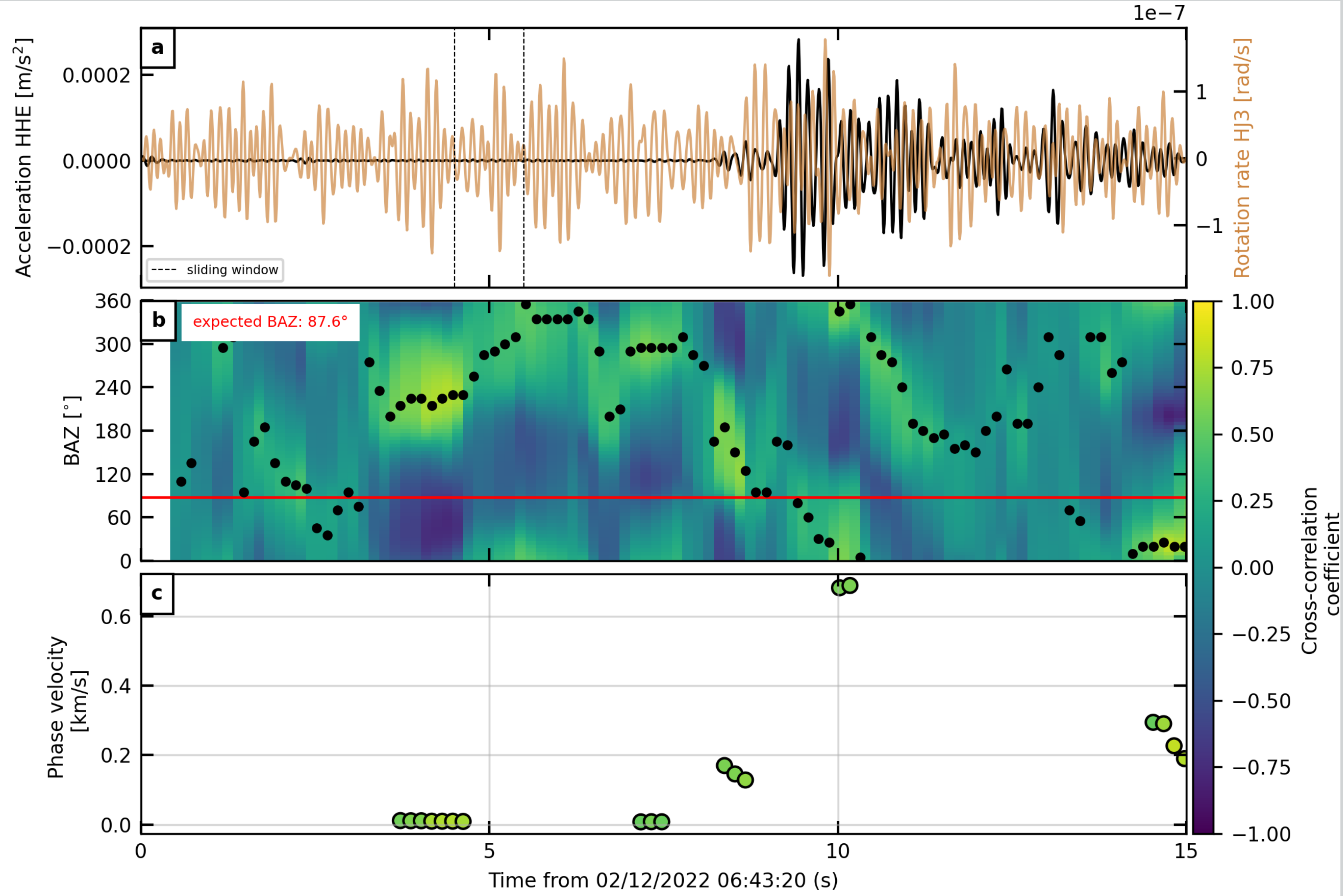
← main slide

Back azimuth 6C method

Volcsummit event 02.12.2022

Distance to CS0:

3.5km



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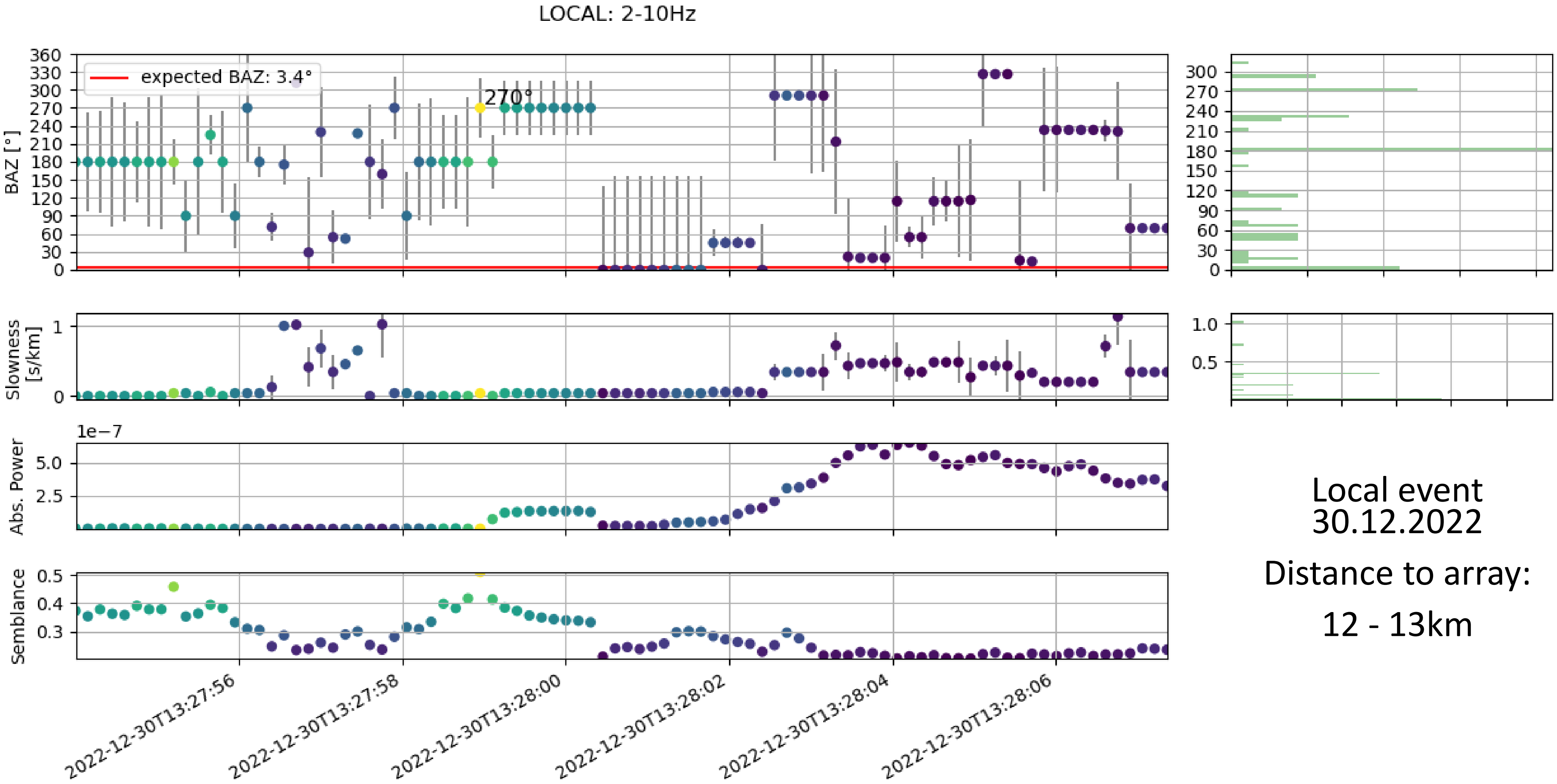
← results

Back azimuth array



Local event 30.12.2022

Distance to array:

12 - 13km

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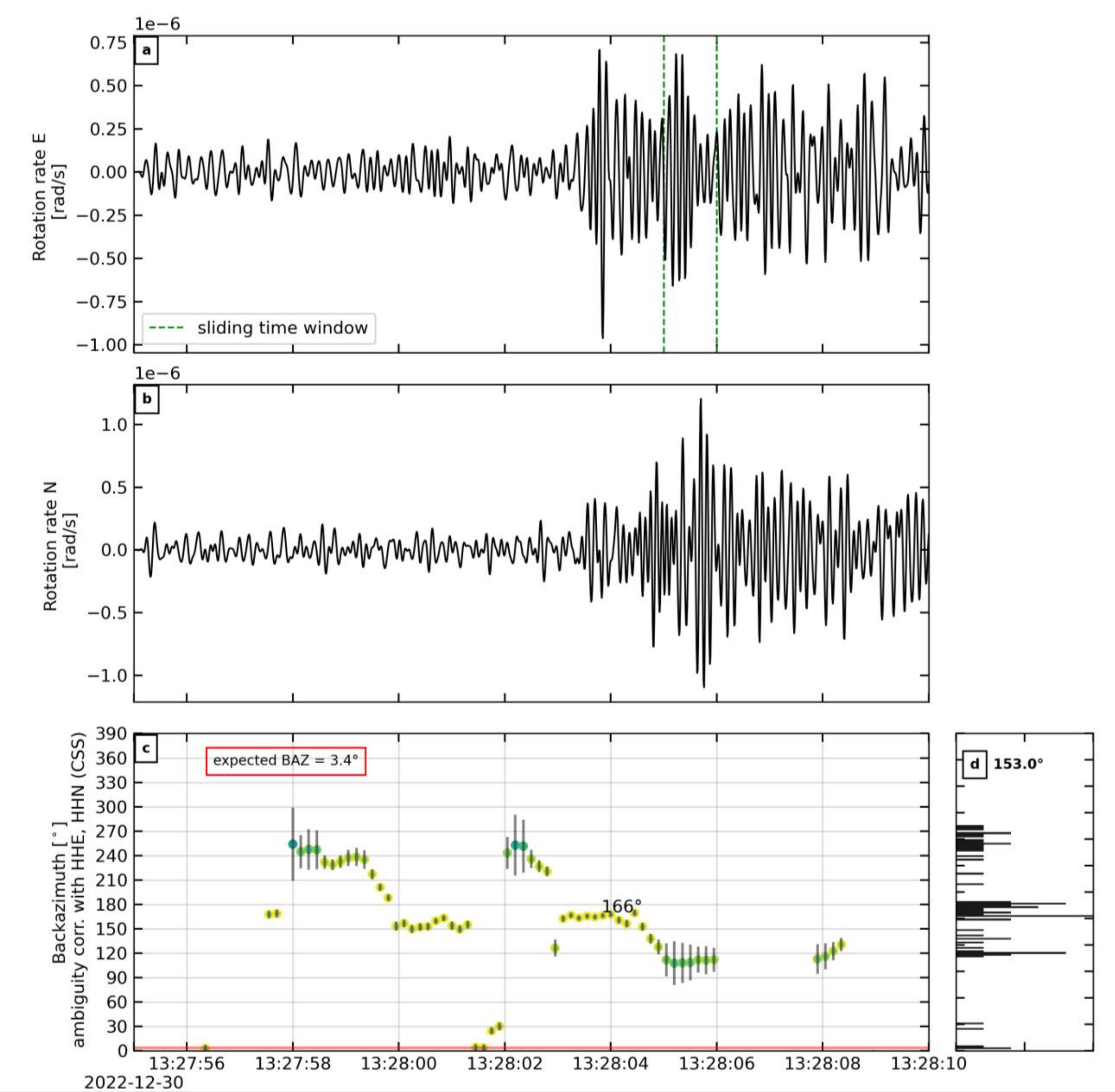
Back azimuth horizontal components



Local event 30.12.2022

Distance to CS0: 12.1km

← results

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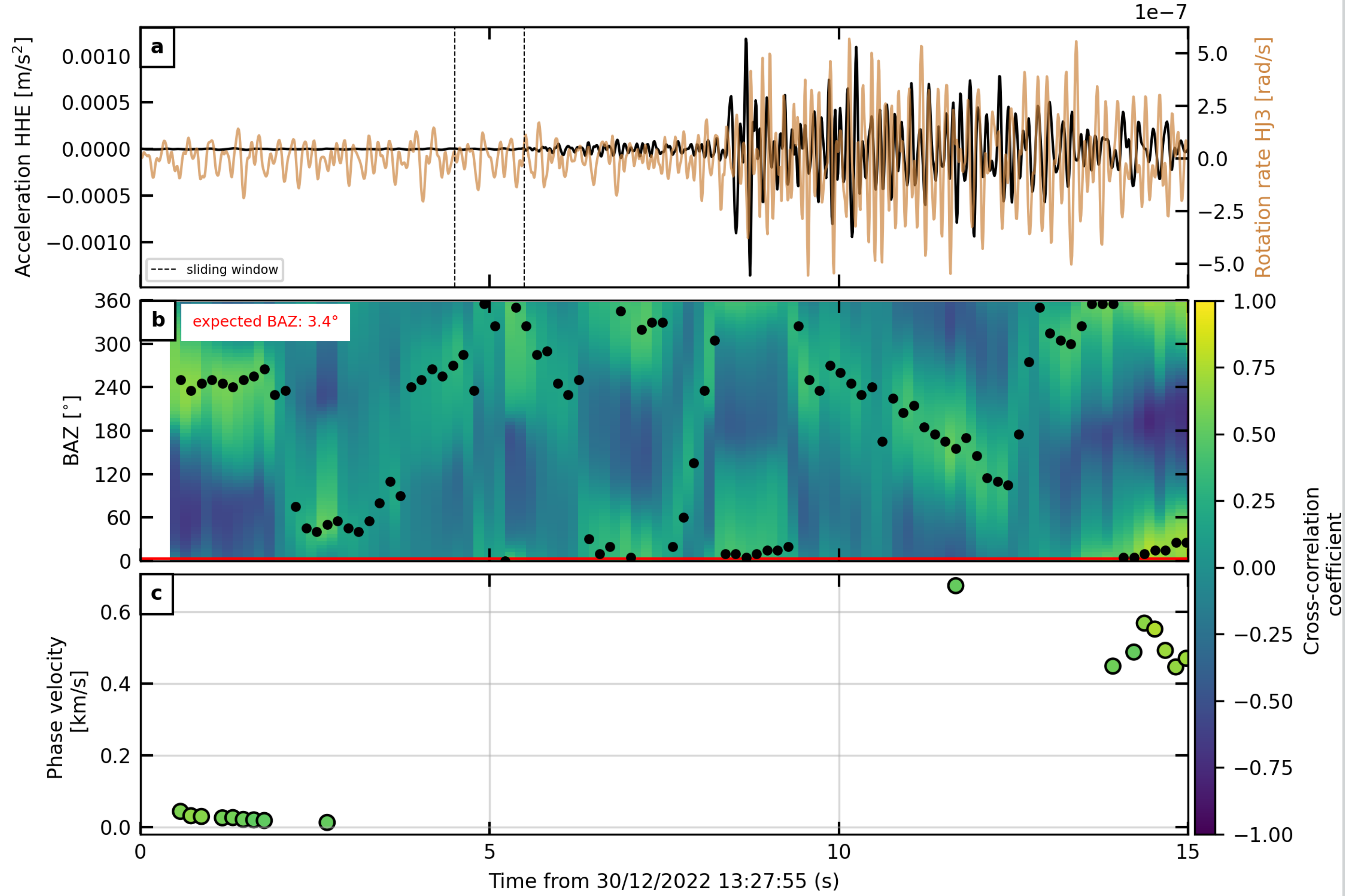
Back azimuth 6C method

Local event 30.12.2022

Distance to CS0:

12.1km



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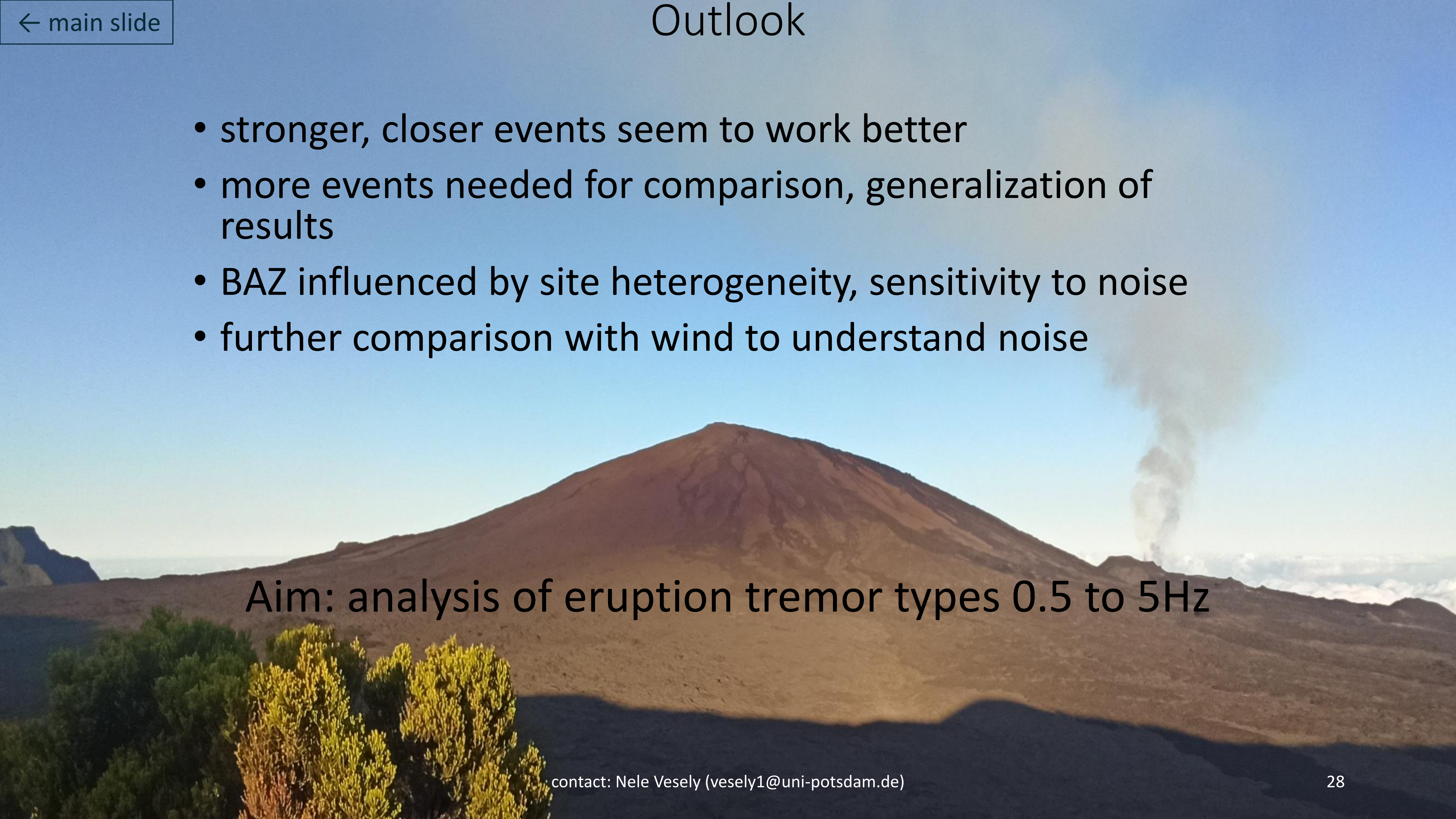
Outlook



- stronger, closer events seem to work better
- more events needed for comparison, generalization of results
- BAZ influenced by site heterogeneity, sensitivity to noise
- further comparison with wind to understand noise

Aim: analysis of eruption tremor types 0.5 to 5Hz

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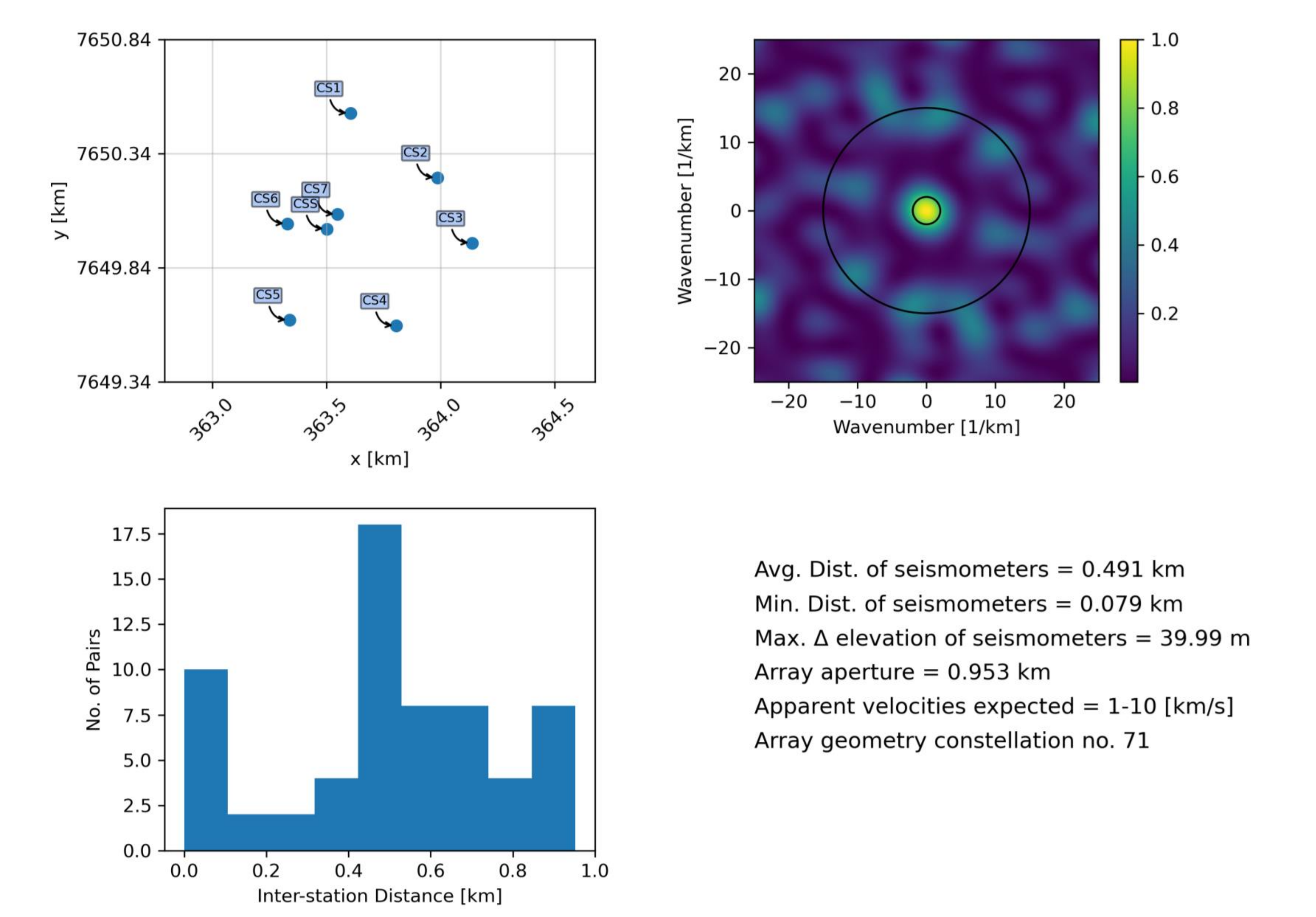
Appendix: Array response



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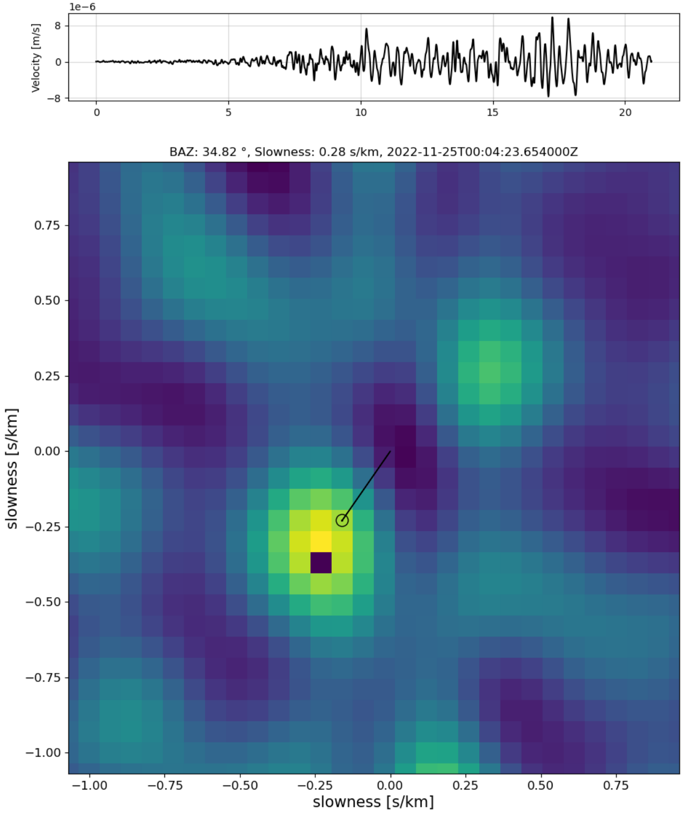
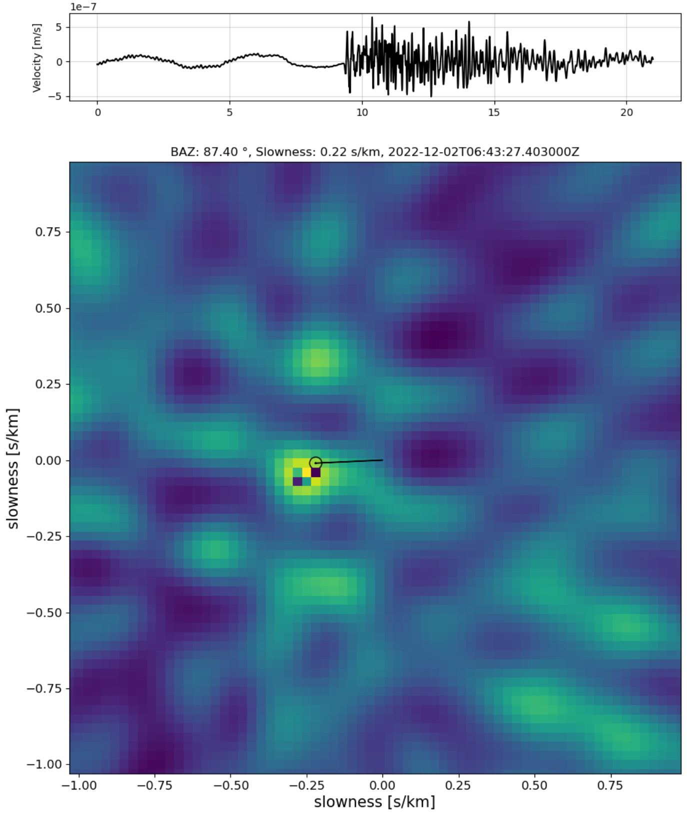
Appendix: Array responses as slowness maps

rockfall



volcsummit



local