Array analyses of the seismic noise wavefield at the possible corners of the Einstein Telescope in Sardinia (Italy)

C. Giunchi, D. Biagini, M. Capello, M. d’Ambrosio, G.Saccorotti,
INGV-PI

L. Naticchioni, M. Perciballi, V. Mangano
INFN-RM

D. D’Urso
UNISS, INFN

A. Cardini
INFN-CA

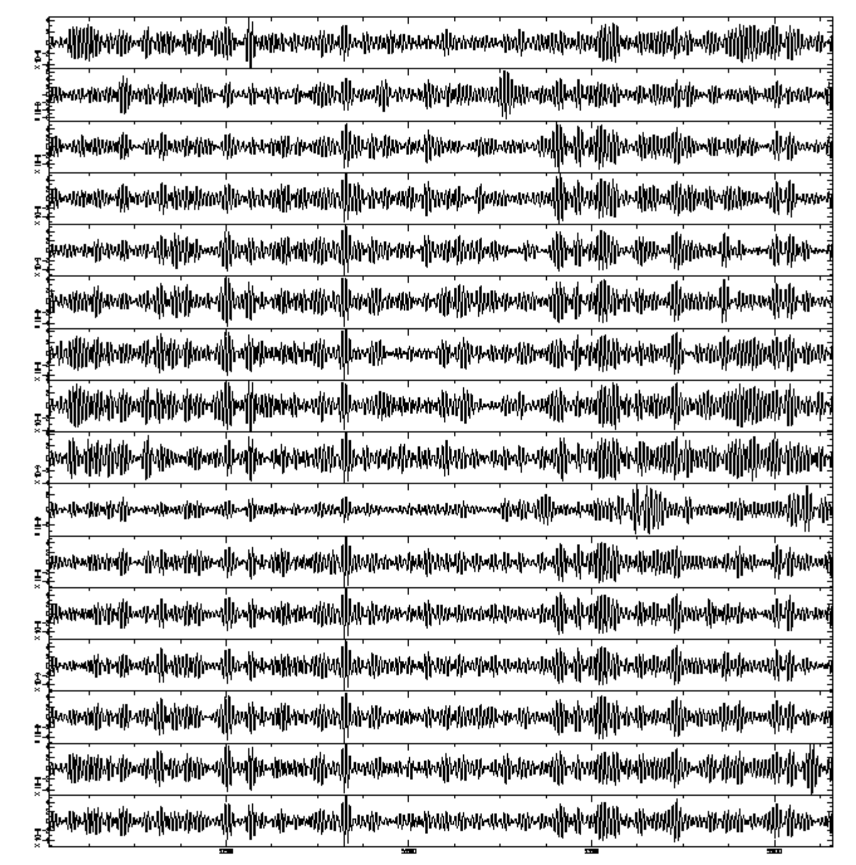
J. Ensing, M. Suchenek, B. Idźkowski
AstroCeNT

ET - Site Studies and Characterization Workshop. Nuoro, 8-11 November 2021

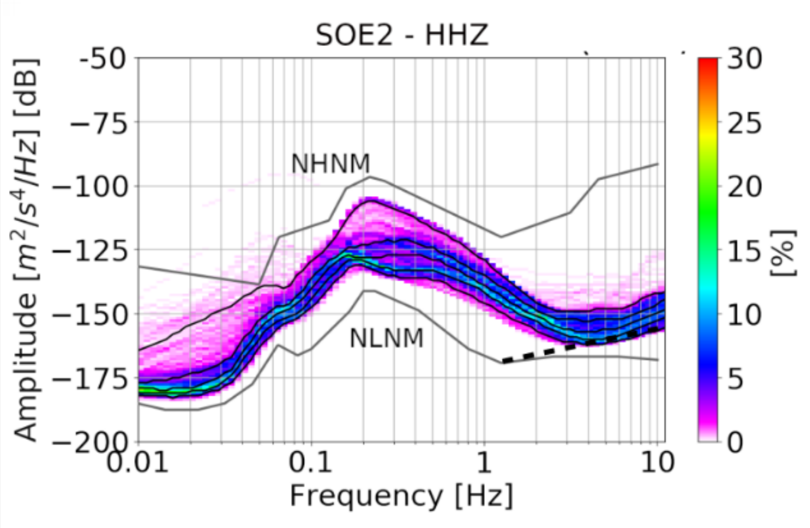
This Talk:

Overview of short-term, passive seismic surveys using dense deployments (*arrays*).

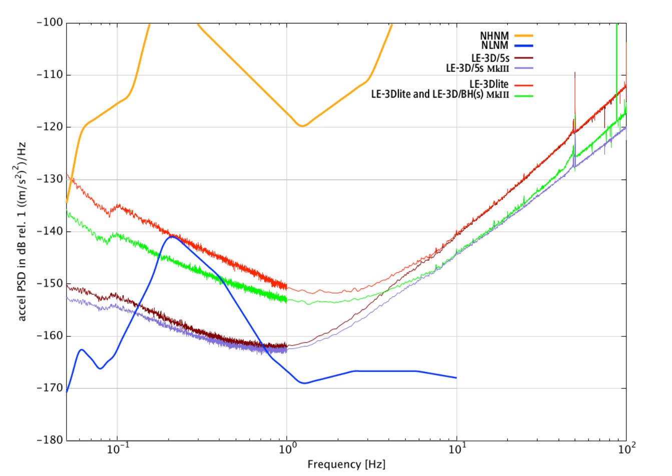
- Objectives
- Issues
- Methods & Techniques
- Best practices (?)

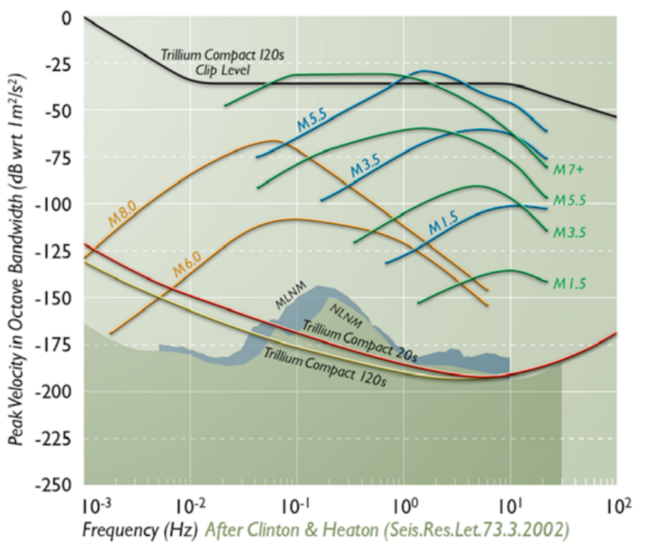


Motivations; Instrument choice and settings



Target: Investigate the noise wavefield at f > 1 Hz.





Problem 1: at those frequencies, observed noise is below the noise floor of SP seismometers.

Solution [1]: adopt low-noise BB seismometers

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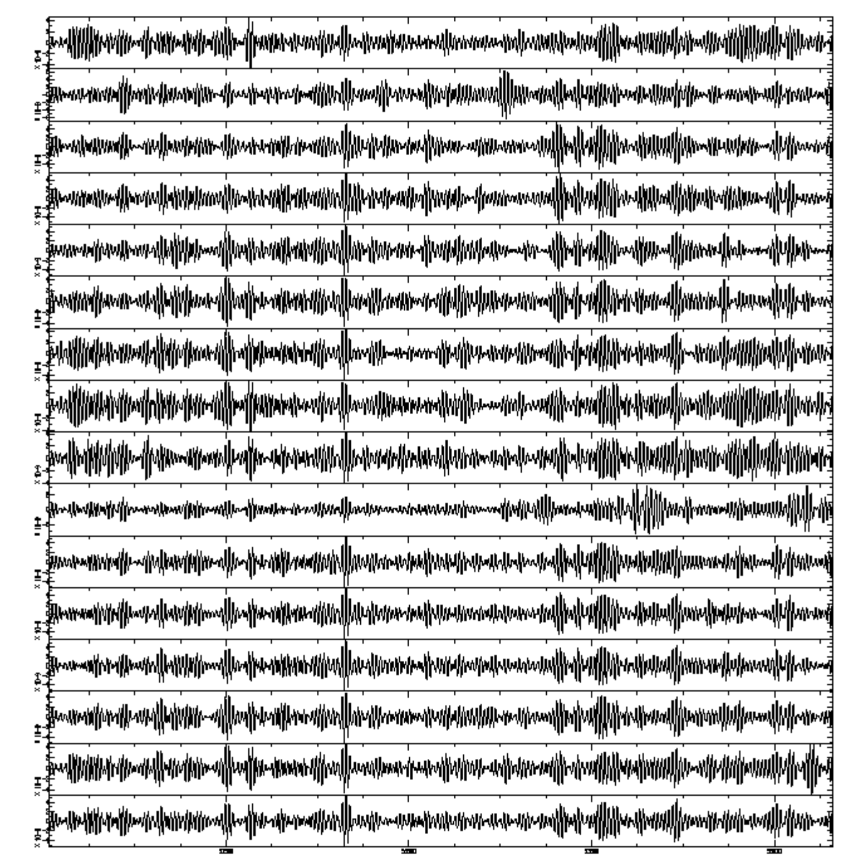
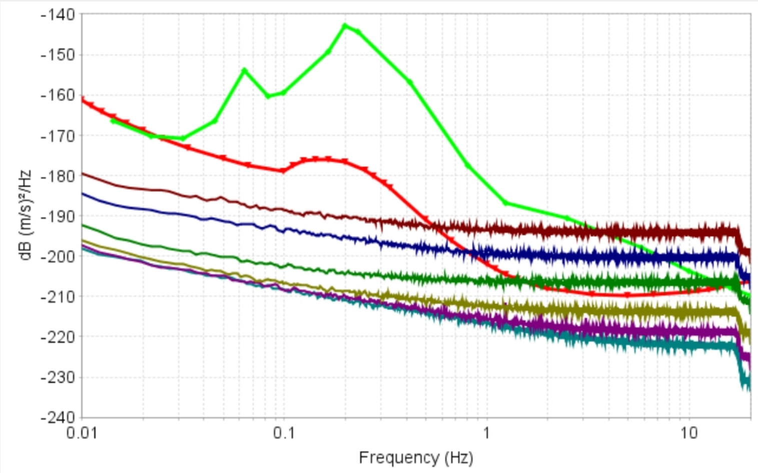
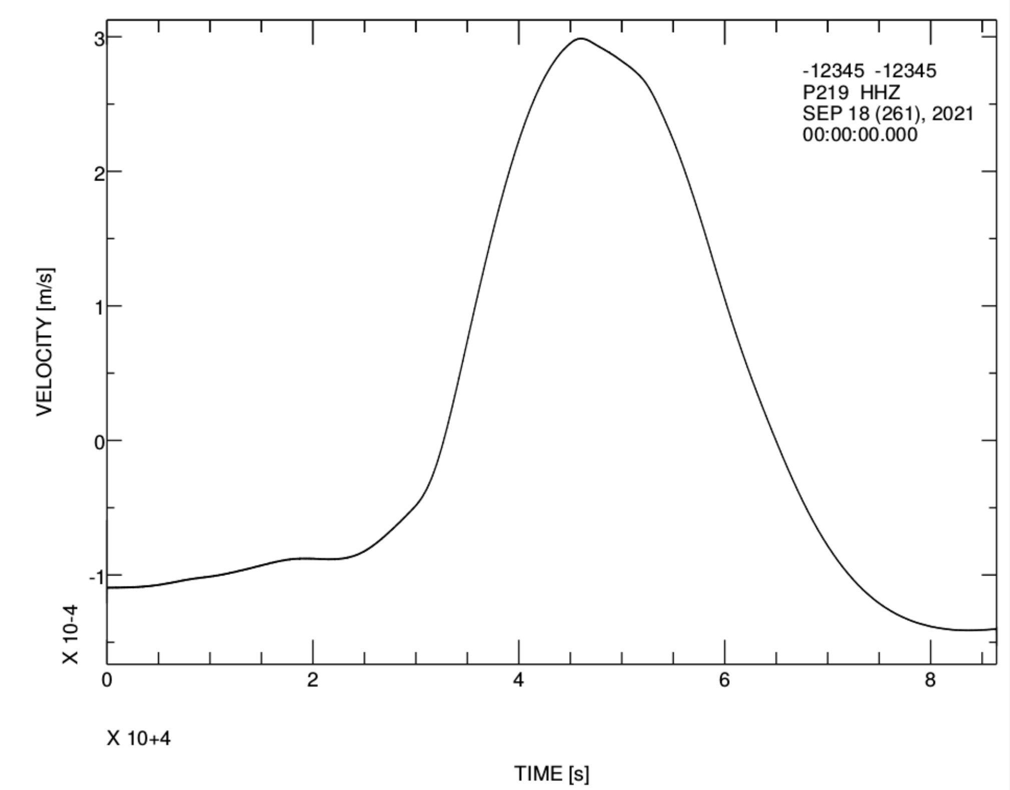


Problem 2: The internal noise of the ADC must be considered as well.





Solution 2 → High-Gain ADC

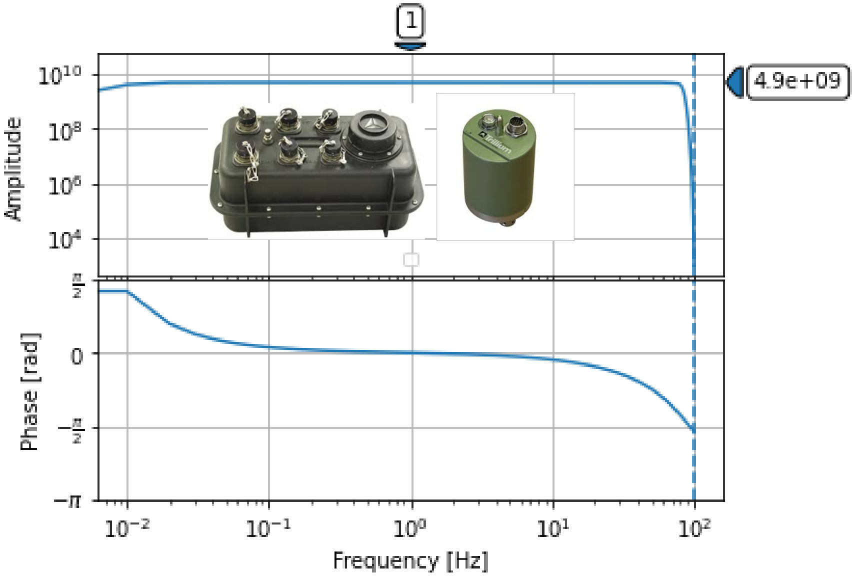
However: Issues with dynamics, due to long-period oscillations related to thermal instabilities.

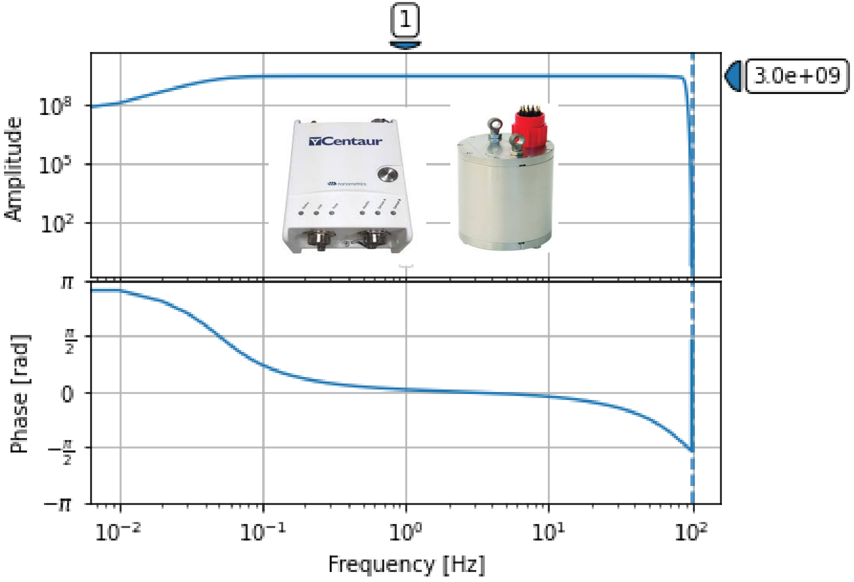
Experiment P1:
Sos Enattos mine
21 Jan 2021 - 3 Feb 2021

Instruments

12 Reftek 130 datalogger
12 Nanometrics Trillium Compact 120s
borrowed from INGV CoReMo

3 Nanometrics Centaur
3 Nanometrics Trillium Compact PH 20s
from UniSS





Huddle test

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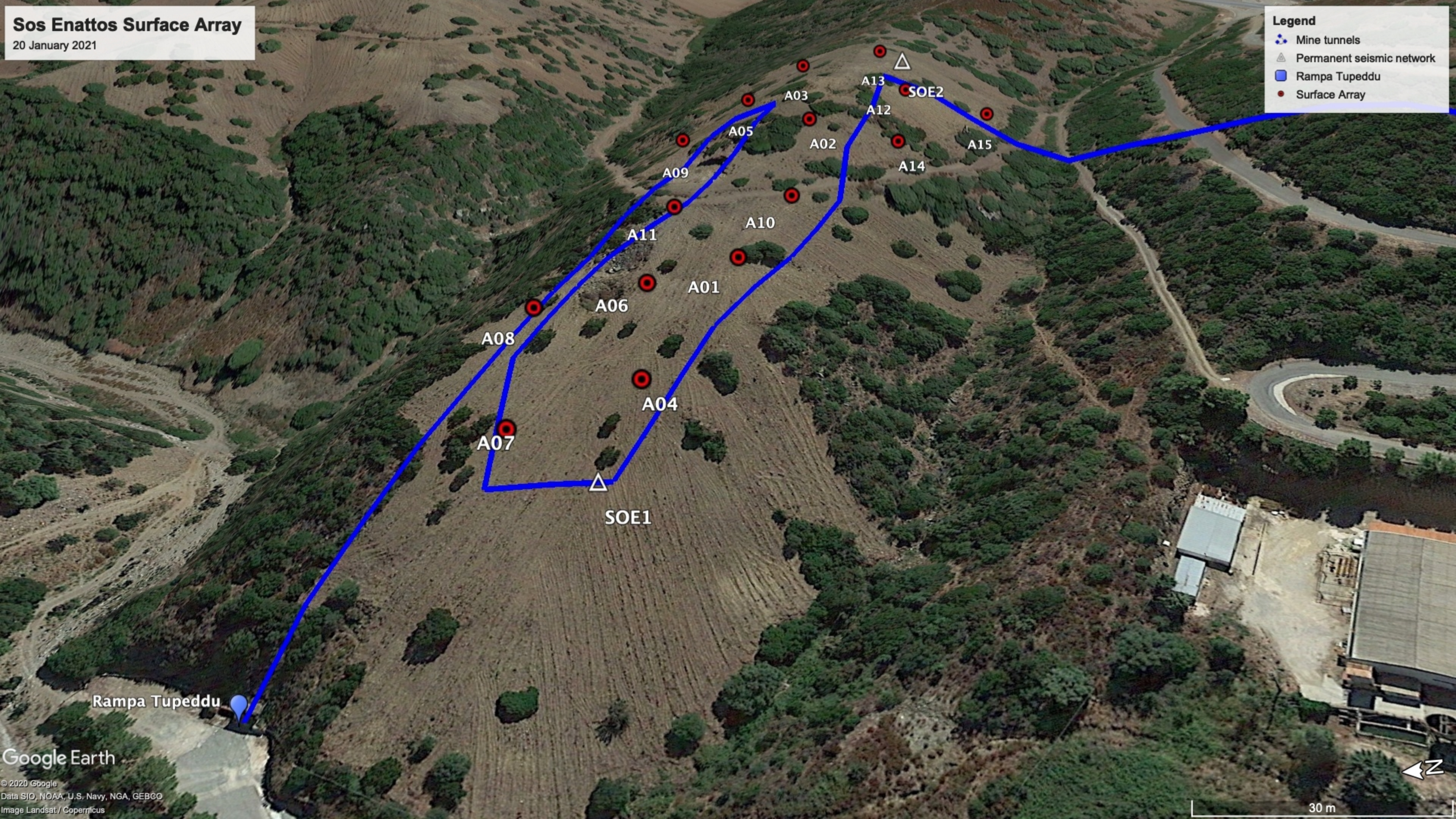
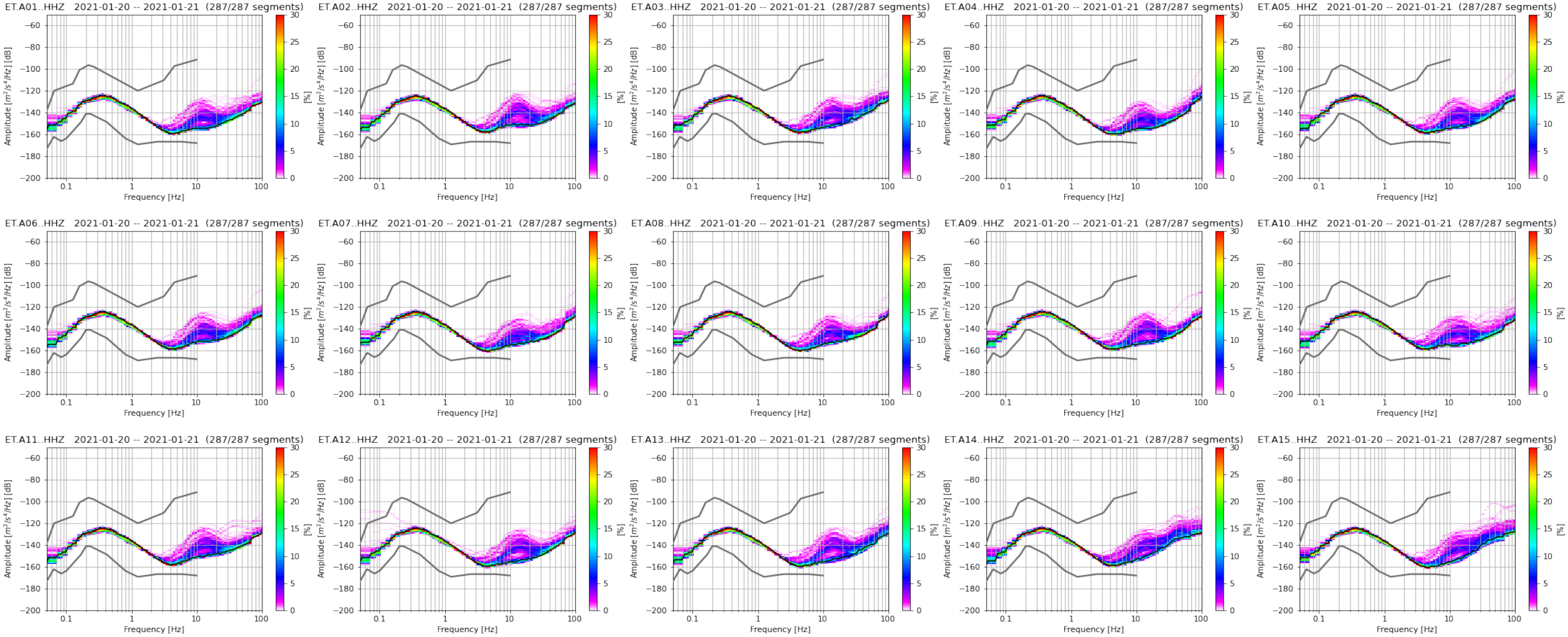


Sos Enattos Surface Array
20 January 2021
Legend
Mine tunnels
Permanent seismic network
Rampa Tupeddu
Surface Array
A03
A13
SOE2
A12
A05
A02
A15
A14
A09
A10
A11
A01
A06
A08
A04
A07
SOE1
Rampa Tupeddu
Google Earth
© 2020 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
30 m

Power spectral densities



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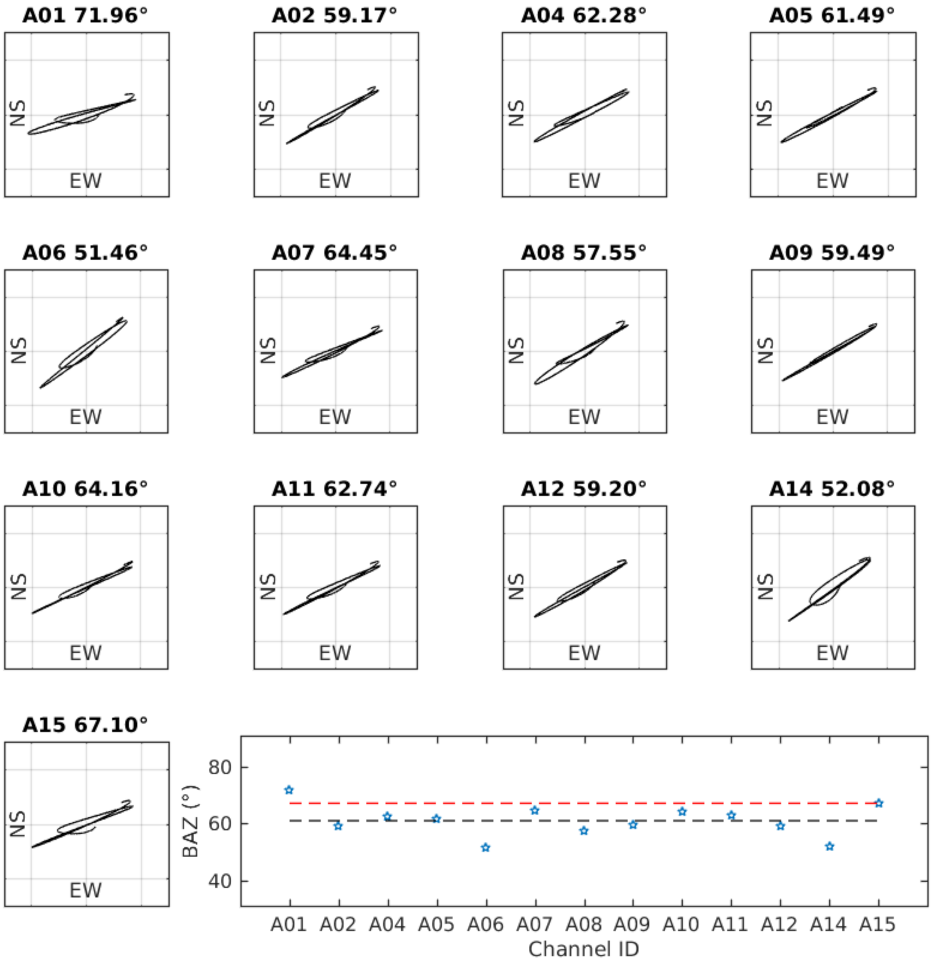
Polarity Check



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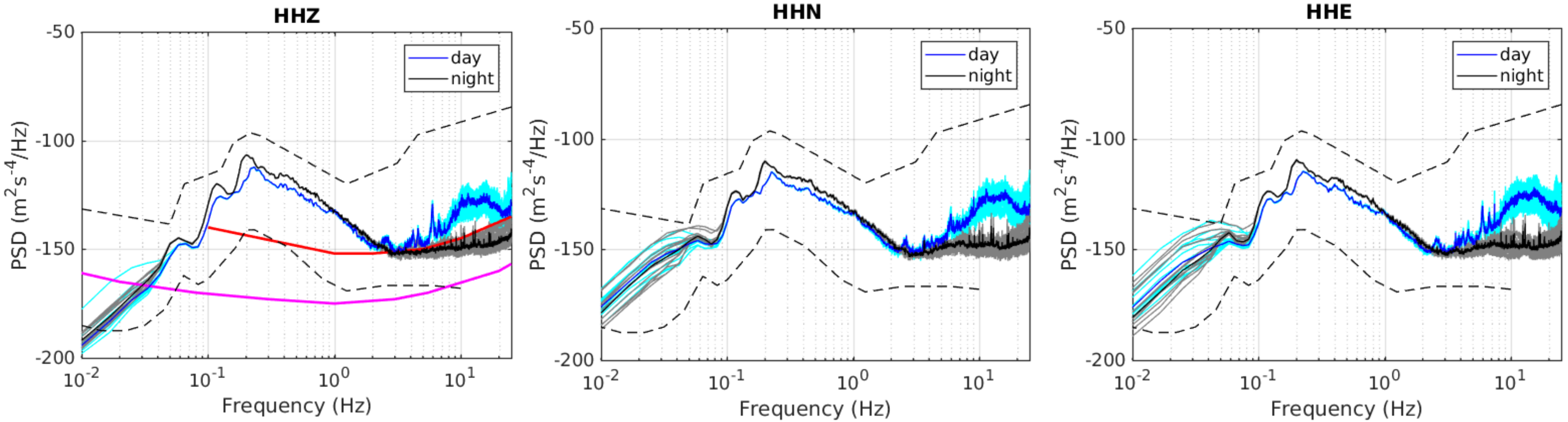
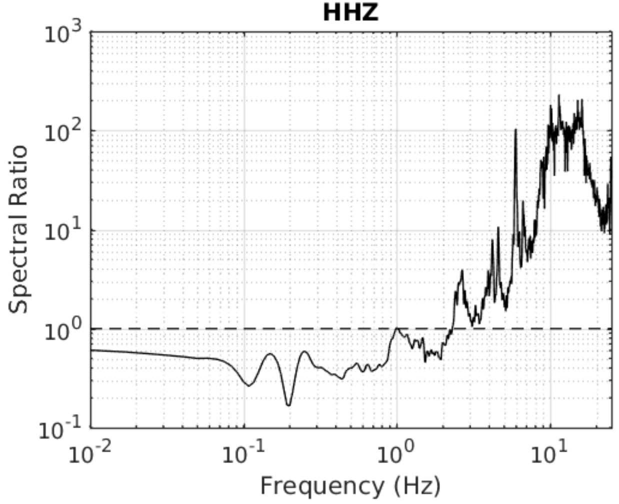
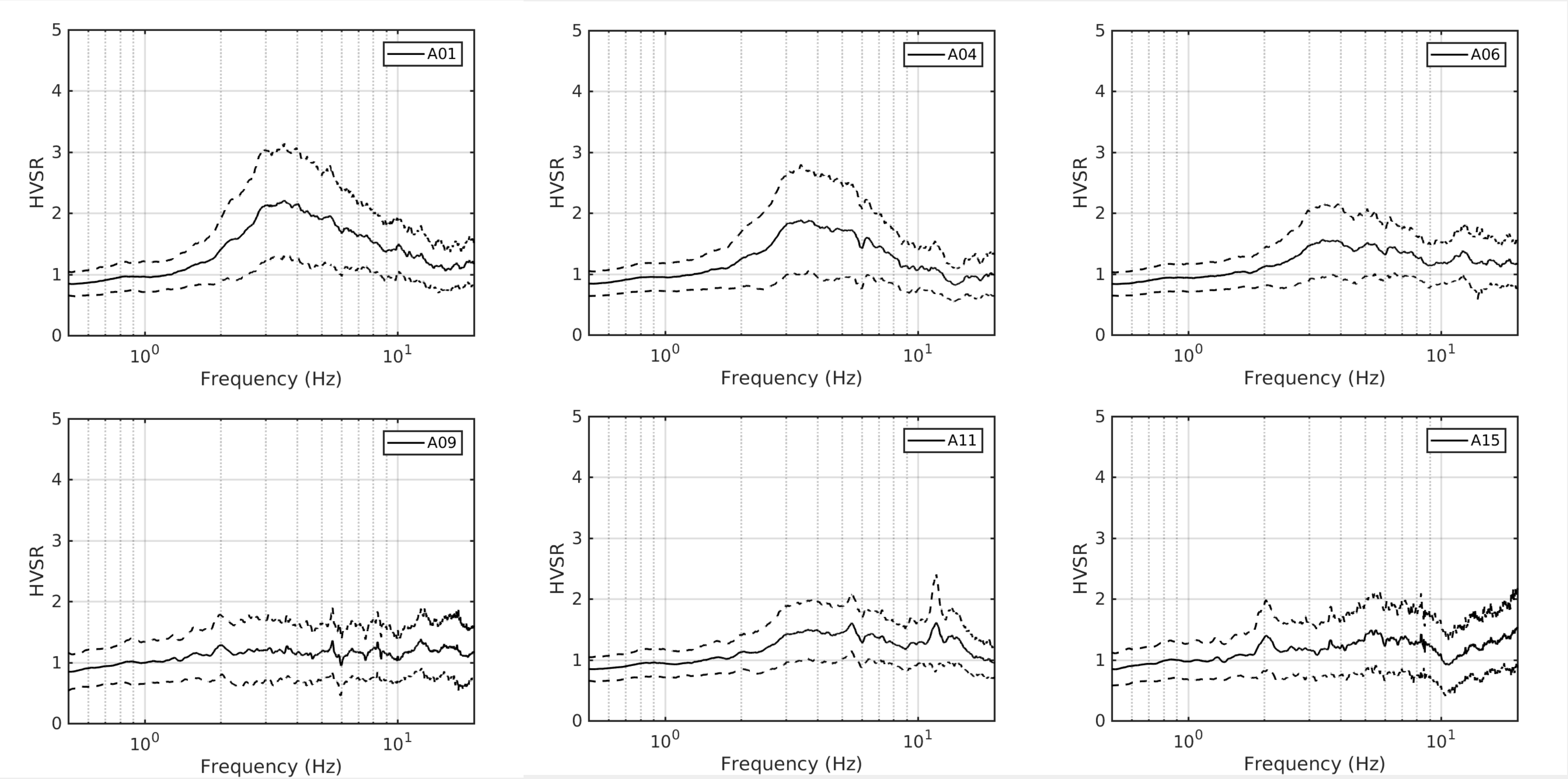


Day – Night Spectral Ratios

provide clues about the most characteristic frequency band of anthropogenic noise. Power increases by about 2 orders of magnitude (factor 10 in amplitude) over the 2-10 Hz frequency band.



Horizontal-to-**V**ertical **S**pectral **R**atios



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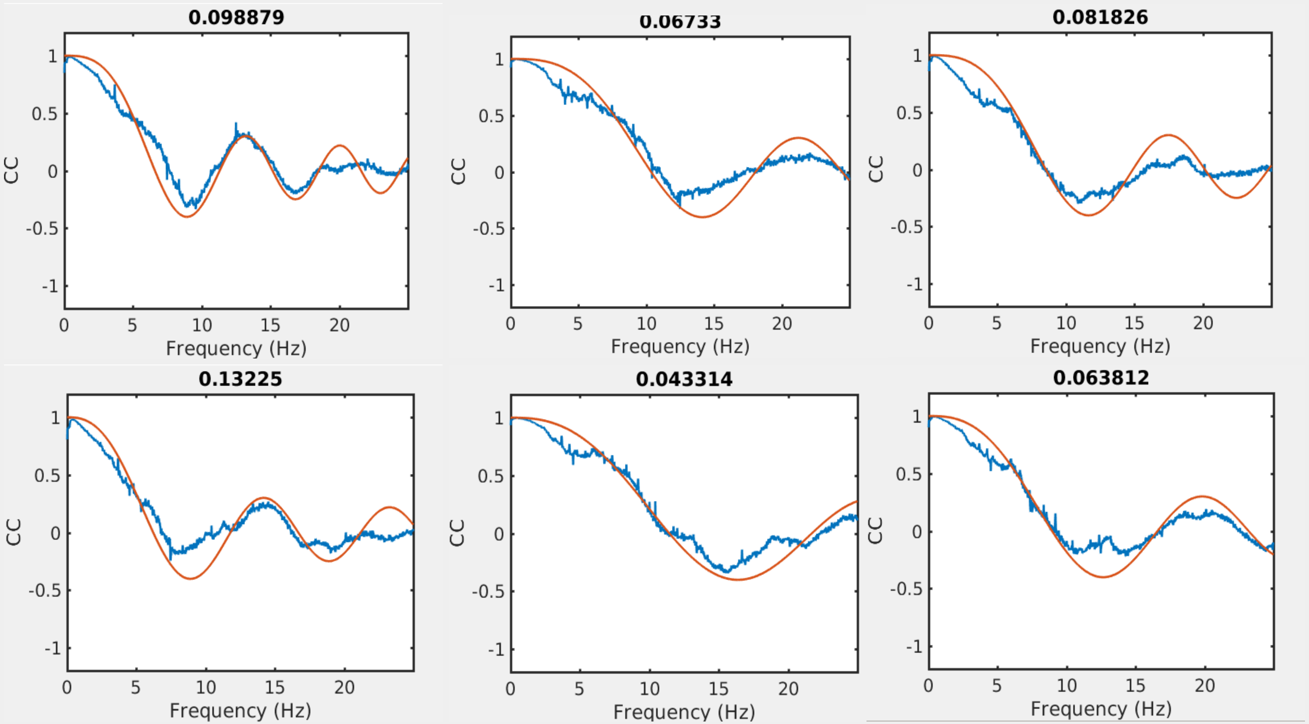
SPatial **A**uto**C**orrelation - 1

Under the hypothesis that the noise wavefield is **stochastic** and **stationary in time and space**, the relationship between azimuthally-averaged spatial autocorrelation and phase velocity is (Aki, 1957):

$$\bar{\rho}(r, \omega_0) = J_0 \left[\frac{\omega_0}{c(\omega_0)} r \right]$$

SPAC is calculated at all the independent station pairs over the DC-25Hz frequency band. The dispersion relationship of Rayleigh waves c(f) can then be derived in a variety of manners (non-linear fit by assuming a dispersion functional, from the 0-xings, linearized inversions, etc etc).

SPatial **A**uto**C**orrelation - 2



Dispersion curves for individual CCs.

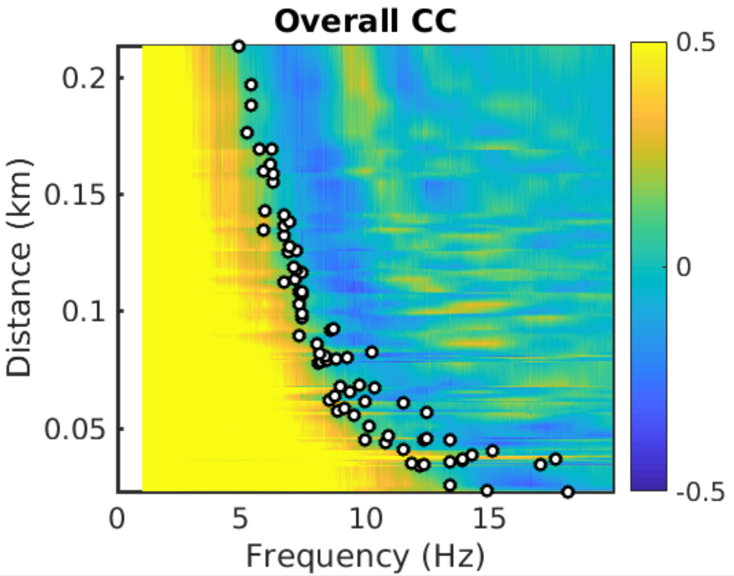
Red lines are the Bessel fits assuming dispersion follows a power law in the form:

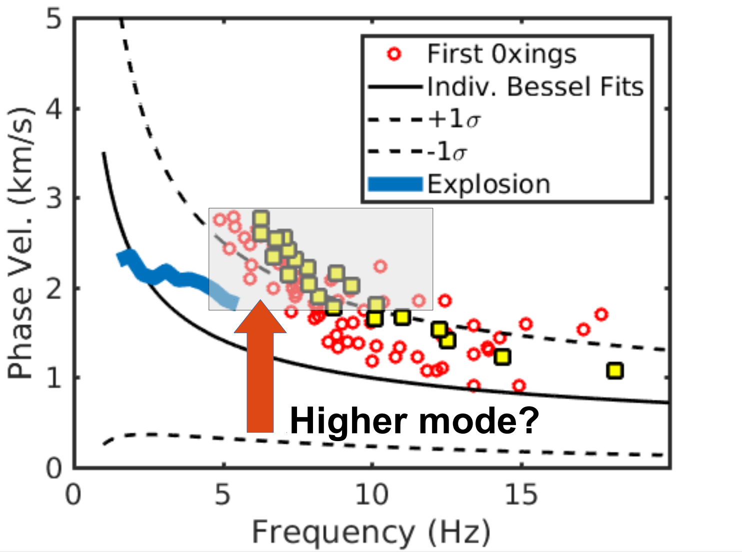
$c(f)=A\,f^{-b}$

SPatial **A**uto**C**orrelation - 3

The ρ(f,r) function.

Here c(f) is derived by the first 0-xing of the correlation curves, with and without averaging ρ(f,r) over consecutive r +/-dr intervals.





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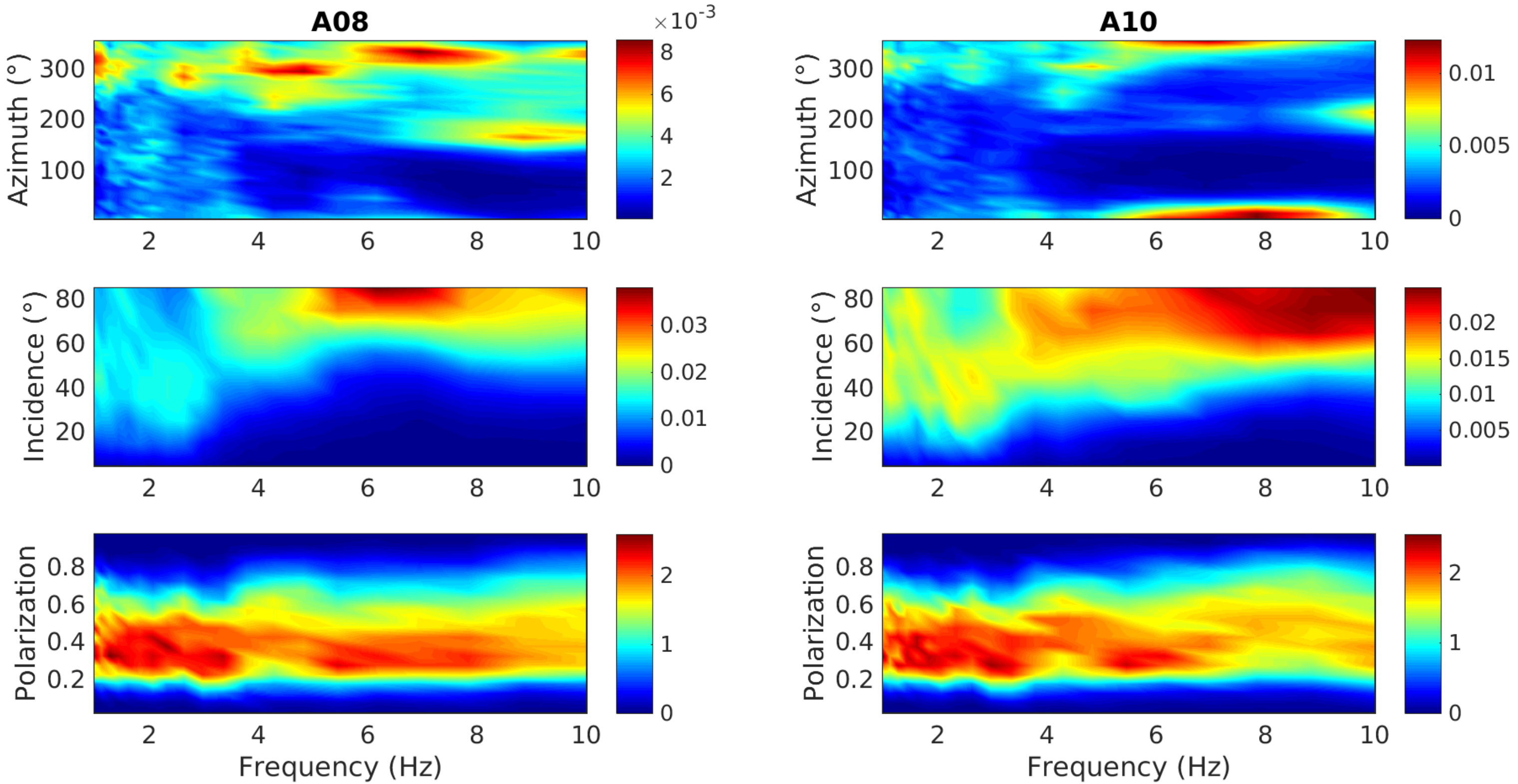
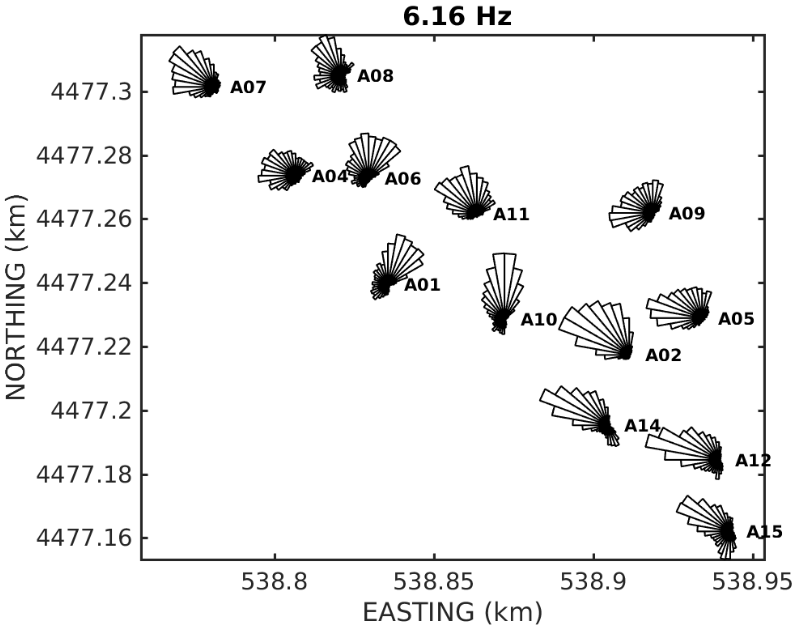
Polarization analysis (from eigenstructure of 3C covariance matrix, for subsequent narrow frequency intervals)

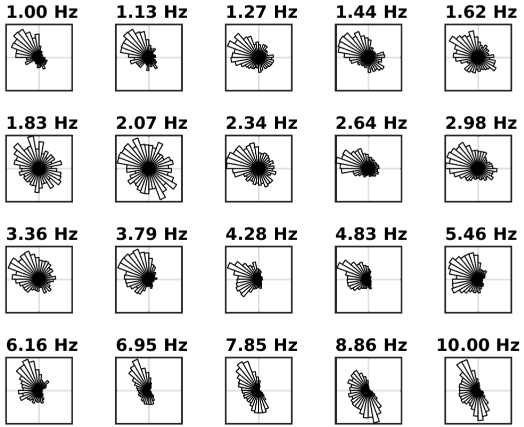


Polarization analysis

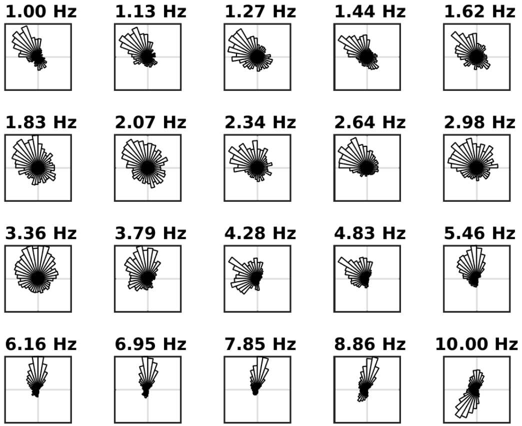


Polarization depends markedly on space and frequency → Topographic effects?

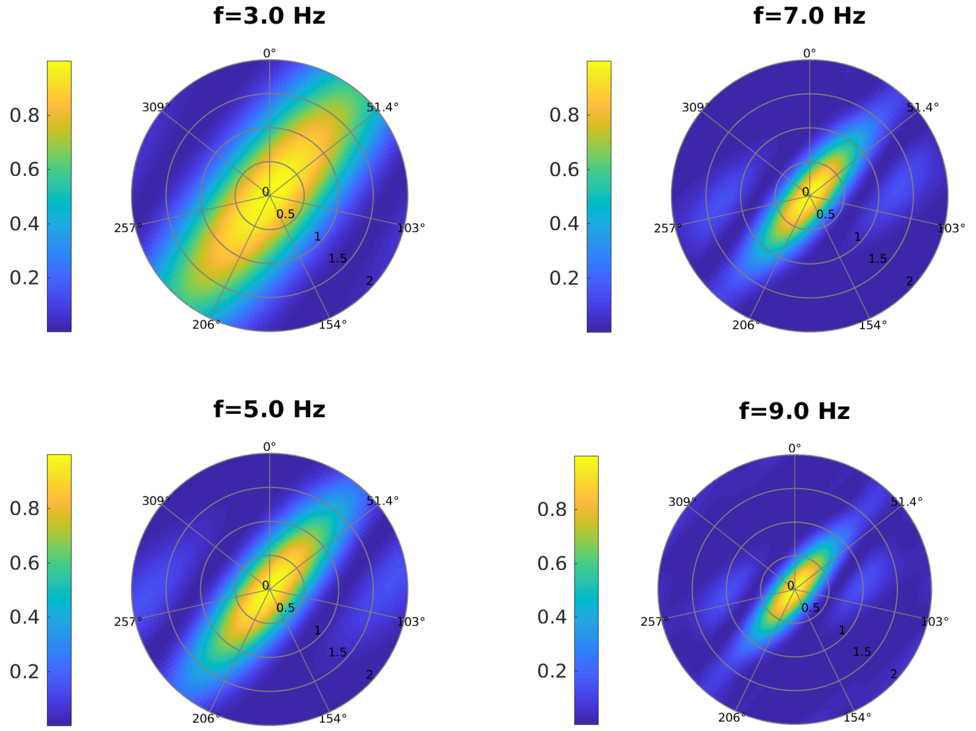
A8



A10



Frequency-Slowness Analysis

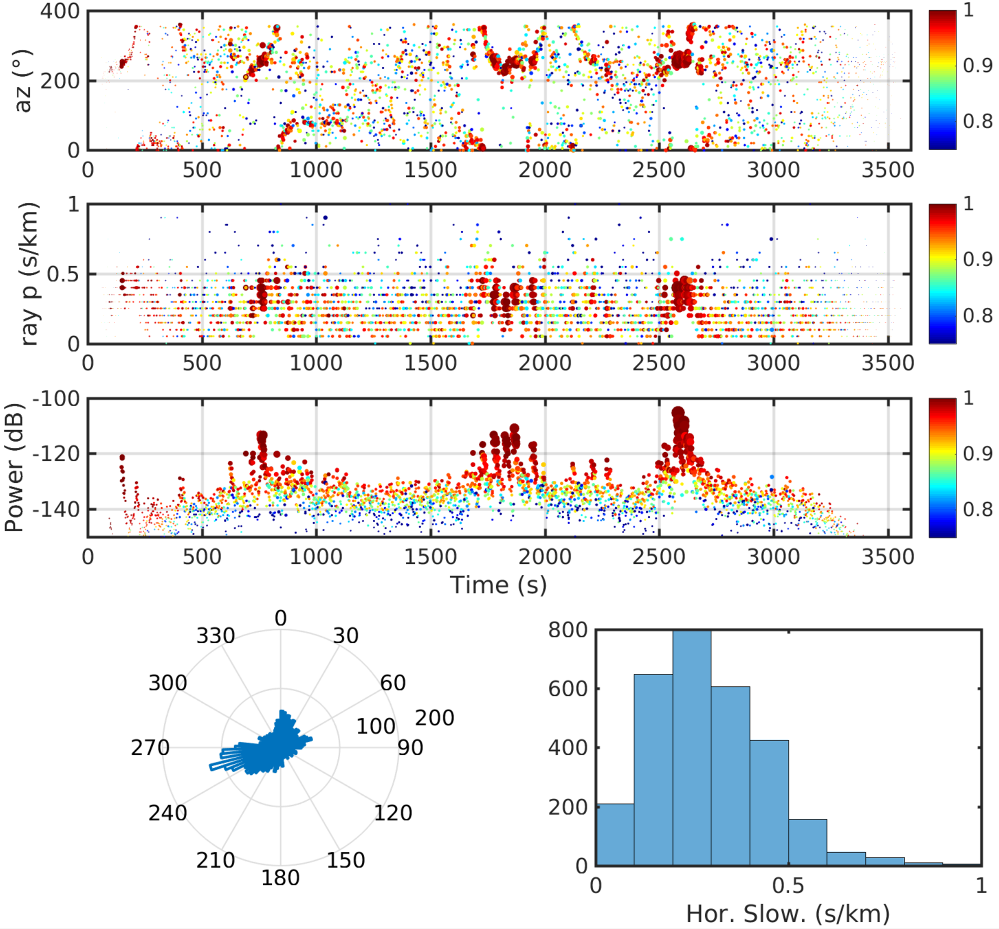


Deterministic approach: assume the wavefield is composed by plane waves propagating with given azimuth and apparent velocity. **Array Response Functions** serve to evaluate possible aliasing effects due to spatial down-sampling

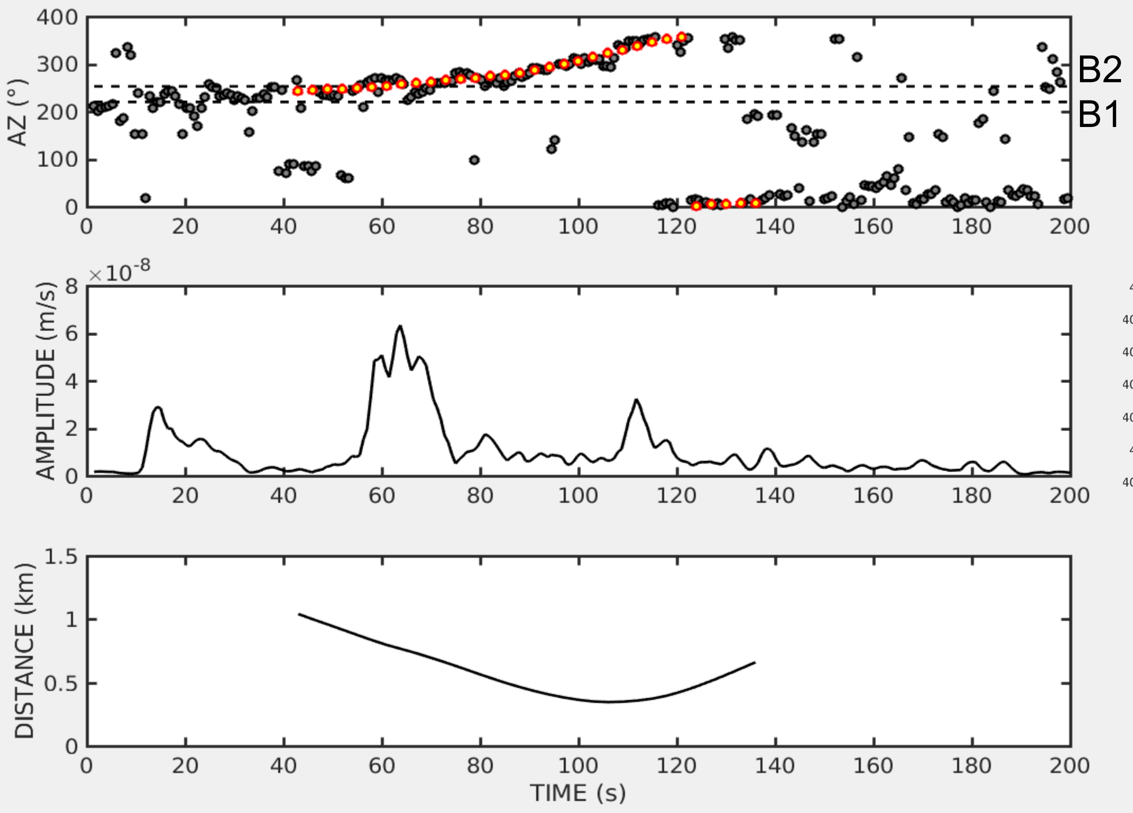
FK-Analysis (Capon's High-Res)

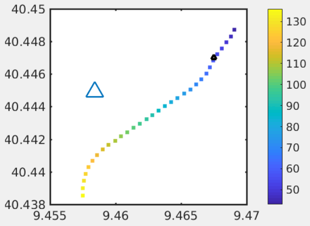
@ f = 4.5 Hz, Propagation azimuths directed WSW (i.e., main sources located ENE of the array). High velocities (> 2.5 km/s).

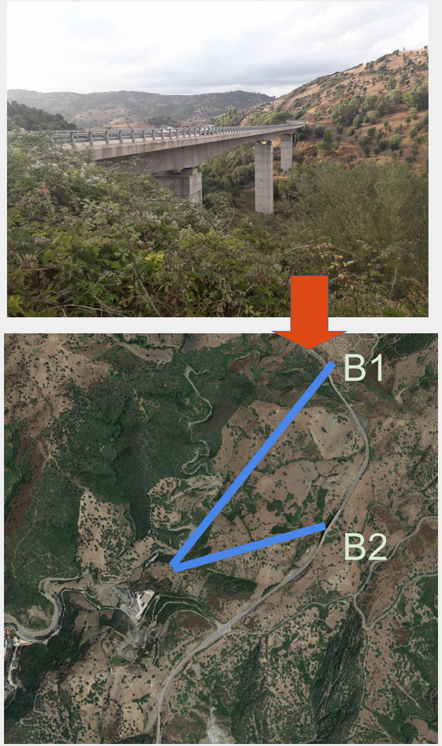
Largest-amplitude arrivals exhibit time-varying DOA, suggestive of a moving source.



Vehicle Tracking



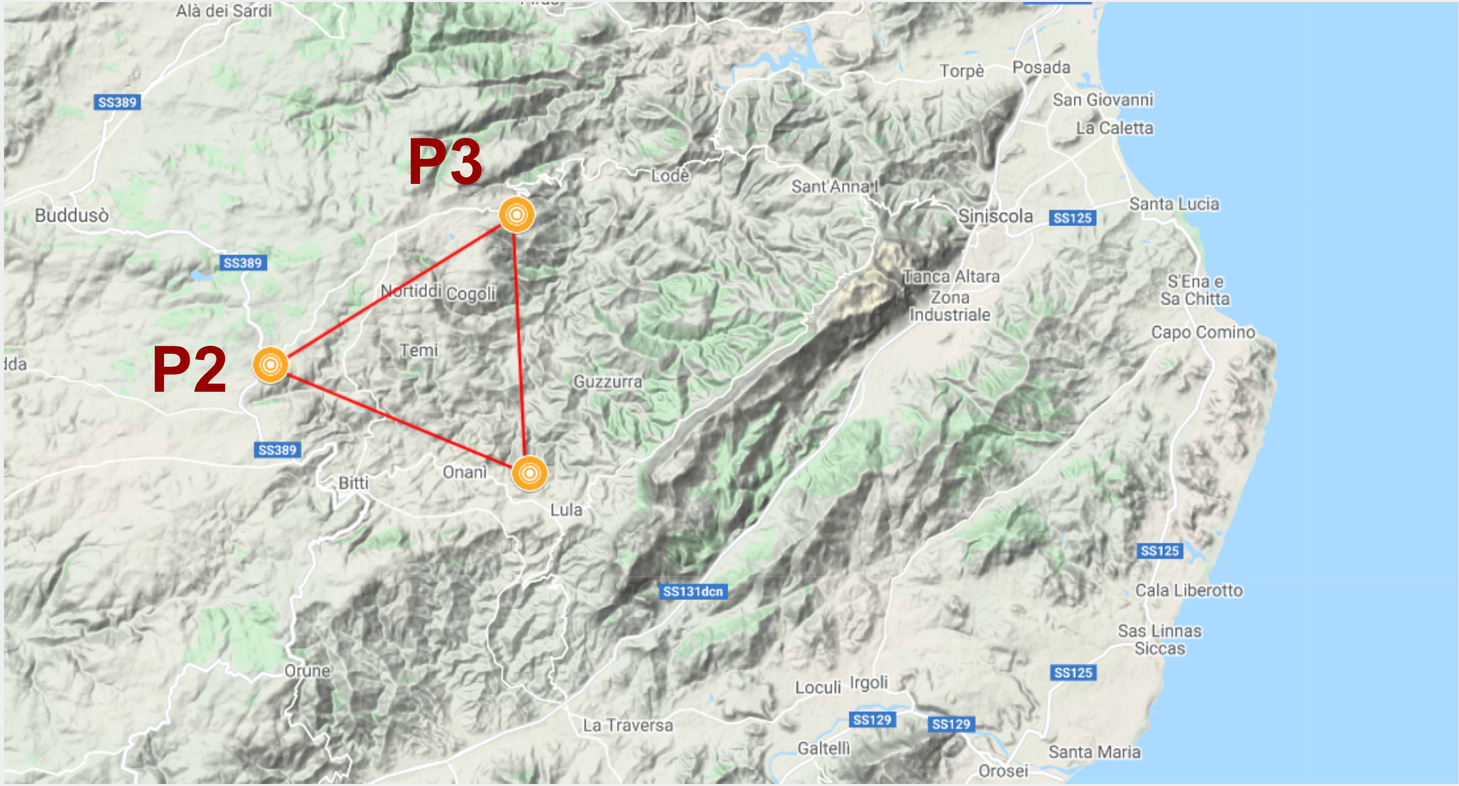




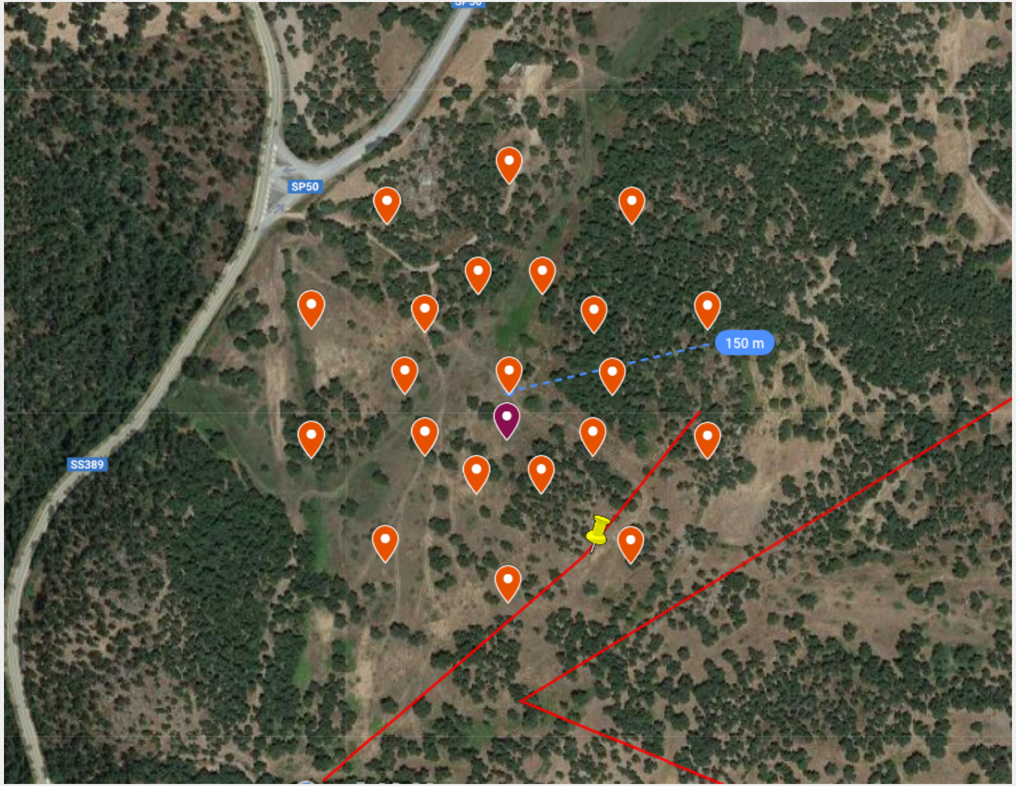
Time evolution of azimuth compatible with a vehicle traveling at 60 km/h southward along SP73.

Largest signal amplitude is NOT associated when the vehicle is closest to the array, but when it traverses bridge B2

The Autumn Experiments: corners P2 and P3



Experiment @ P2 [18 Sept. 2021 - 27 Sept. 2021]



The plan: 21 stations, 2 circles with radius 75 and 150m

Experiment @ P2: Trans-National Instrumentation

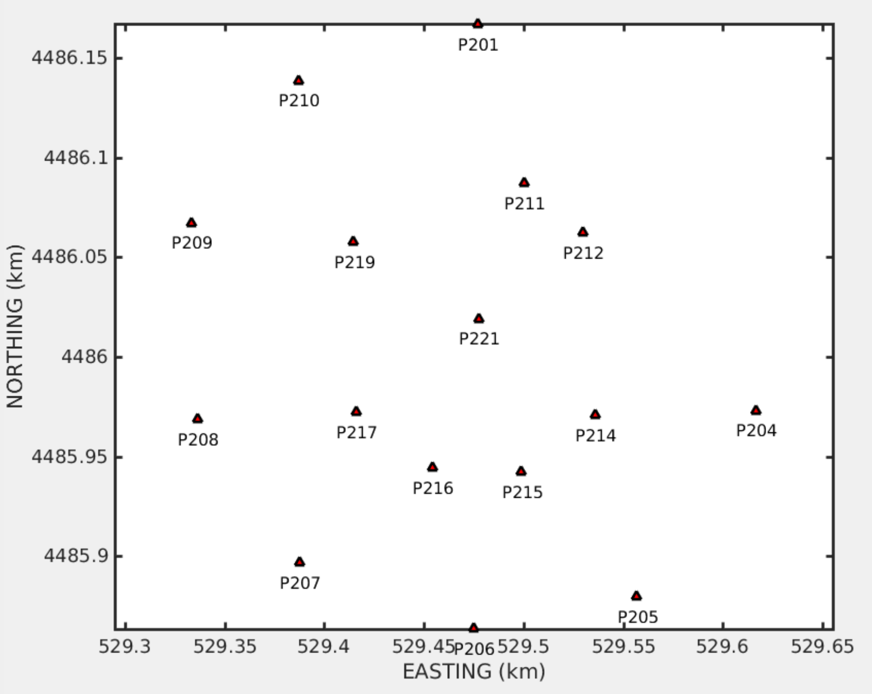
12 Digos CUBE + Nanometrics Trillium Compact 120s on loan from **INGV** CoReMo and **Univ. Liverpool**

7 Nanometrics Centaur + Nanometrics Trillium Compact PH 20s from **UniSS**

1 Nanometrics Centaur + Nanometrics Trillium 240 from **AstroCent**

1 Nanometrics Centaur + Nanometrics Trillium 240 from **UNICA**

Experiment @ P2: effective configuration



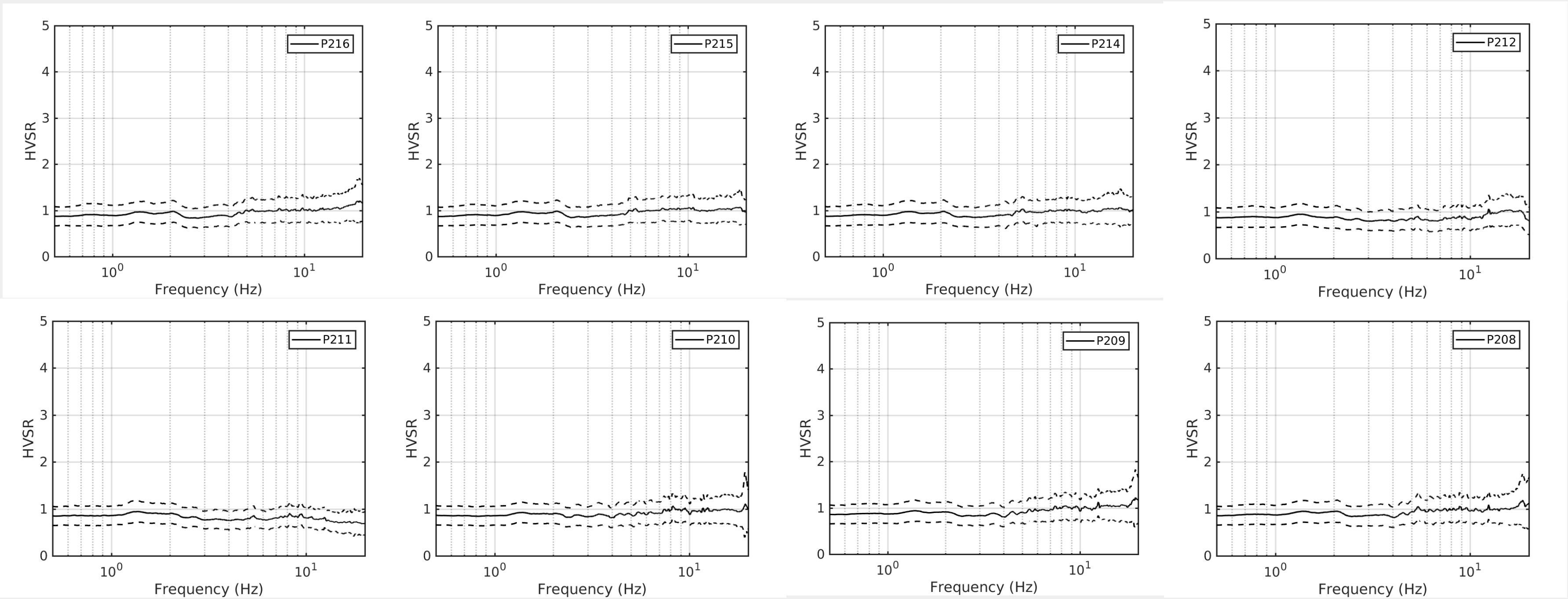
The actual configuration had to account for 5 casualties in the seismometer team.

Experiment @ P2: HVSR

B1

Complete lack of local effects => subsurface materials are homogeneous and stiff

B2



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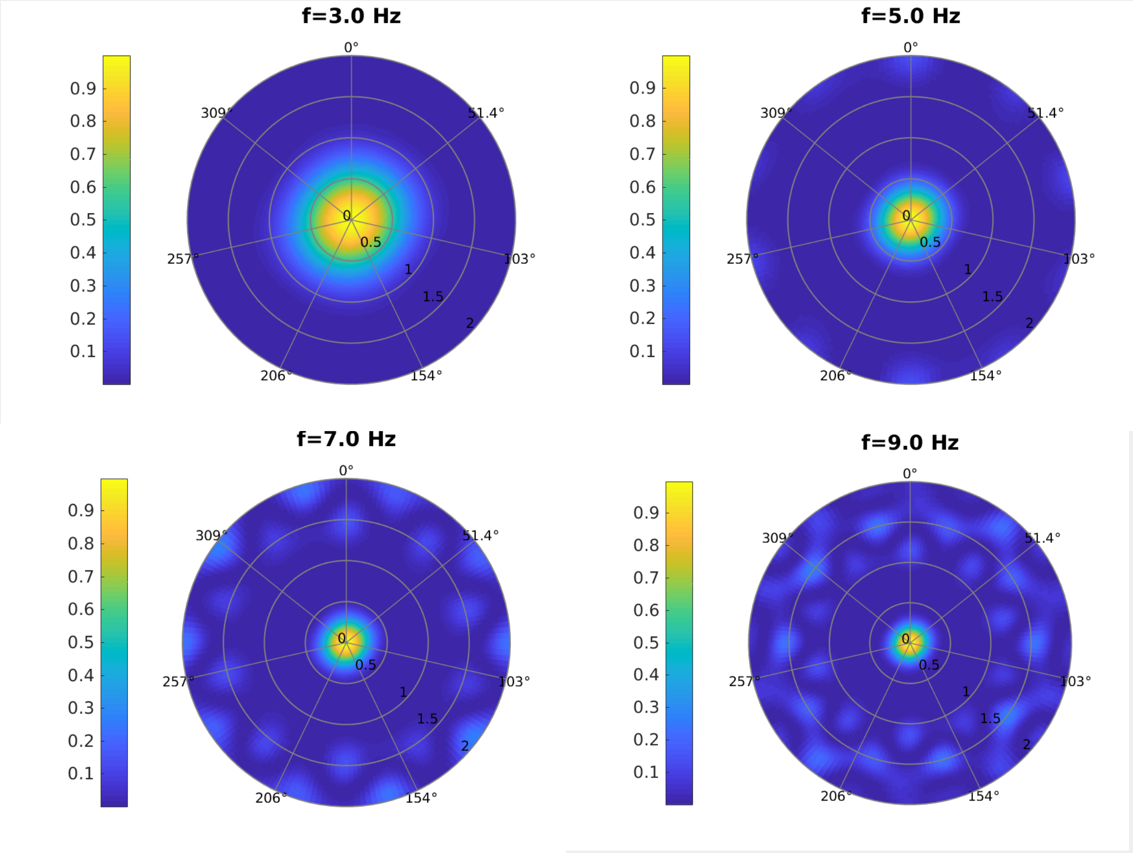
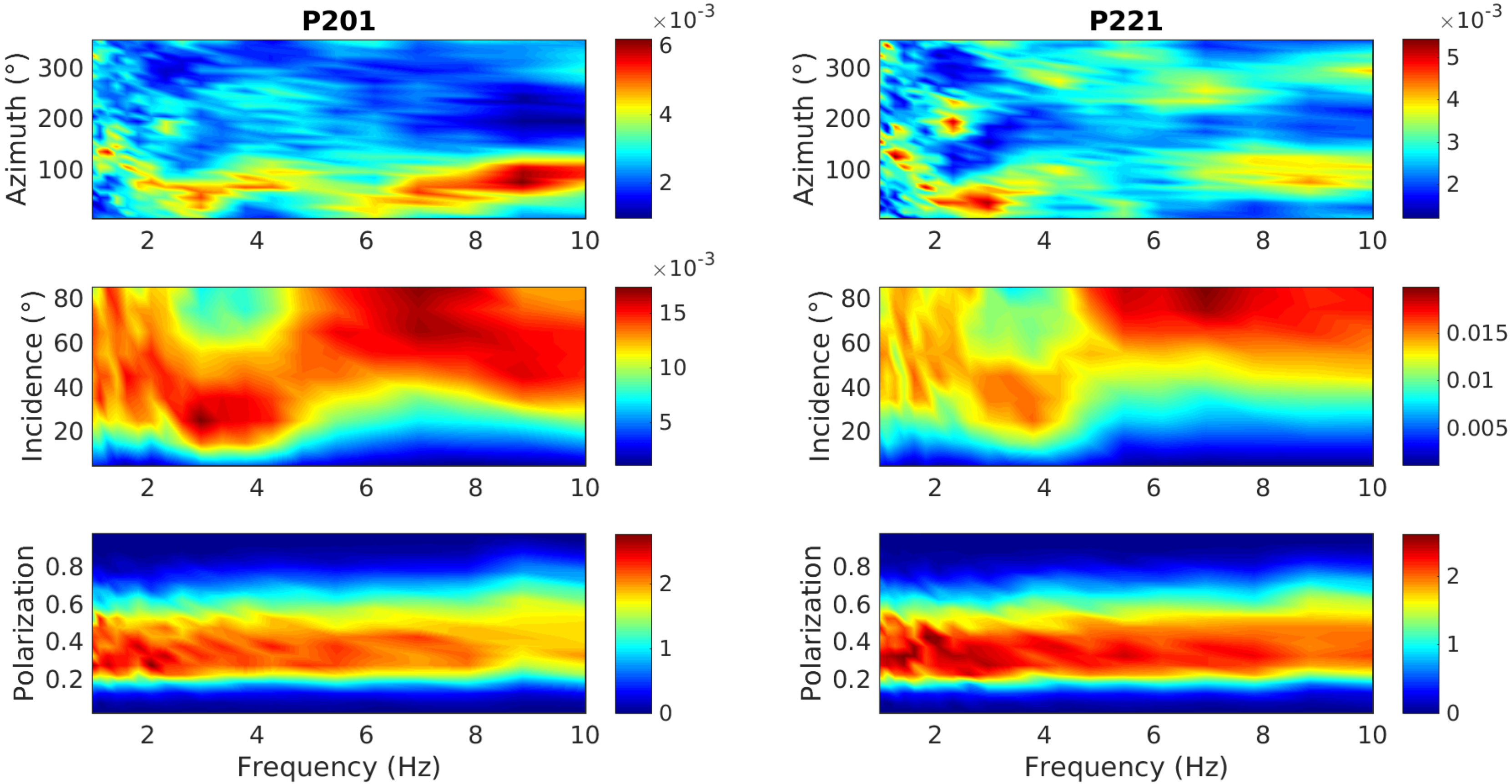
Experiment @ P2: Array Response Functions

Weak Peaks due to spatial aliasing appear at frequencies >= 7 Hz.

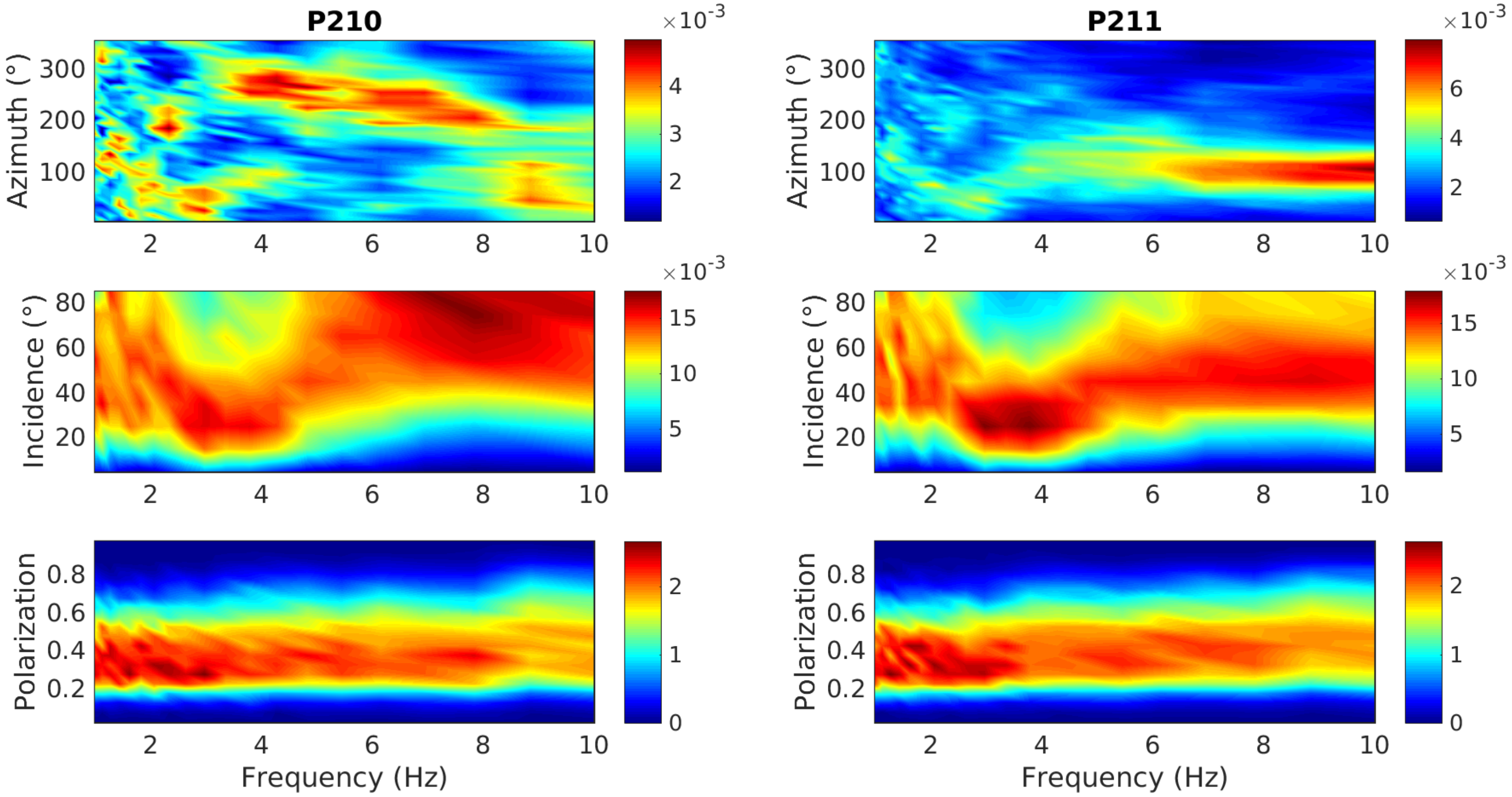


B2

Experiment @ P2: Polarization

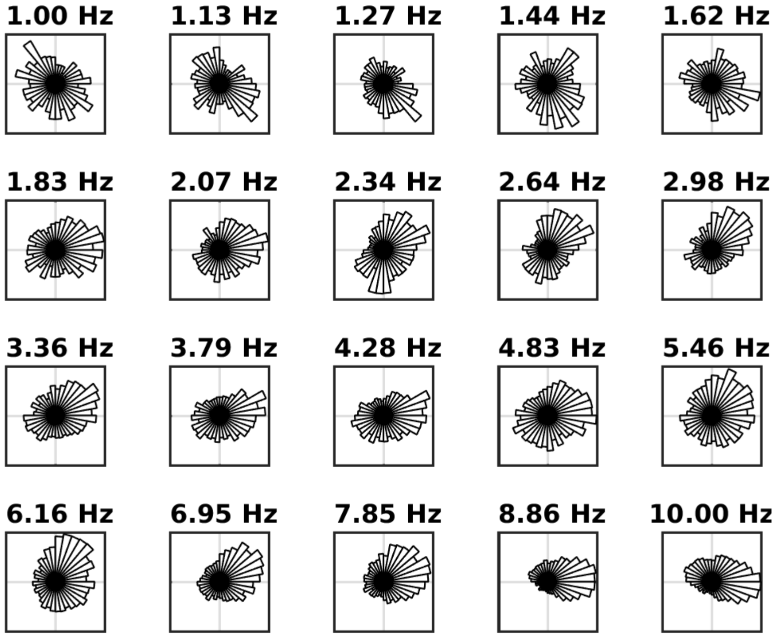


Experiment @ P2: Polarization

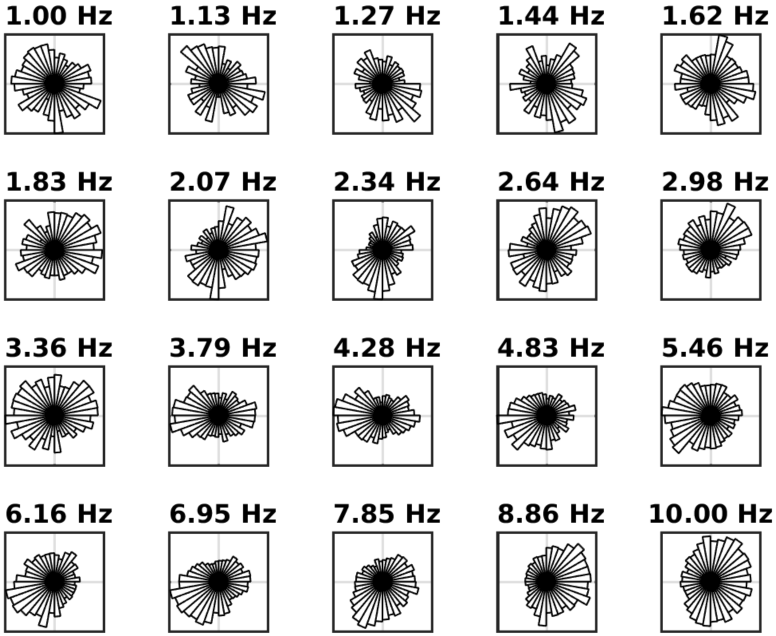


Experiment @ P2: Polarization vs Frequency

P201

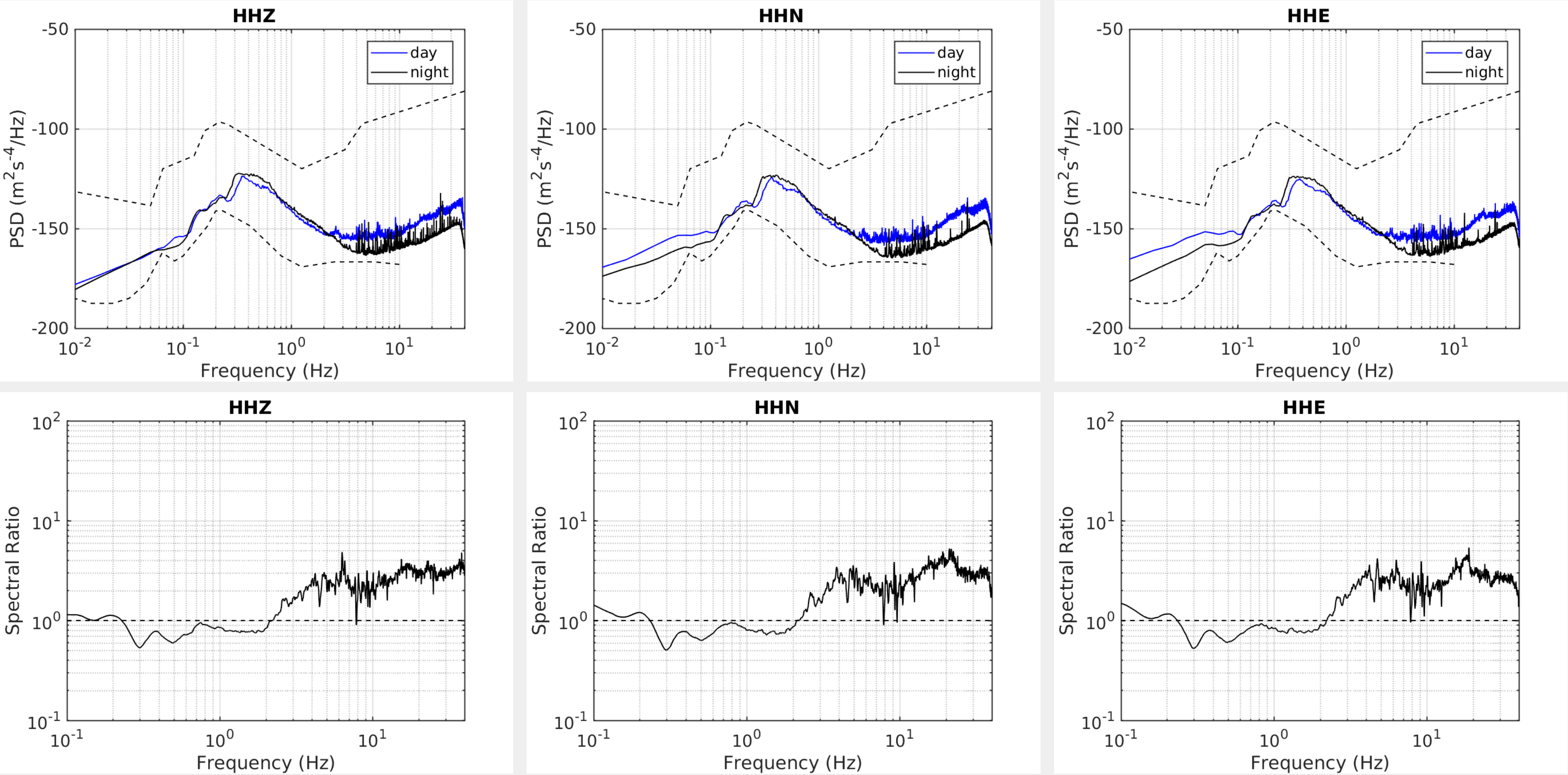


P210



Day-Night Spectral Ratios

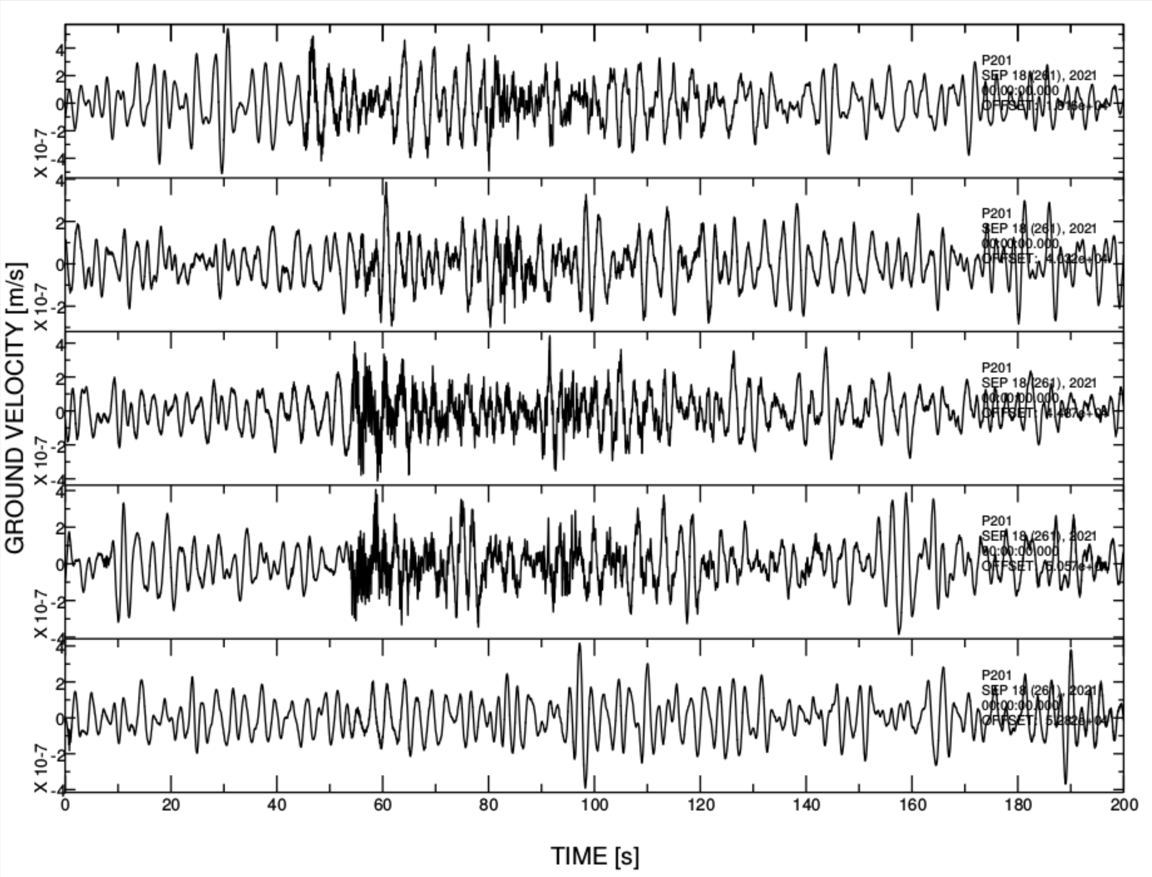
B1



Sample recordings

B1

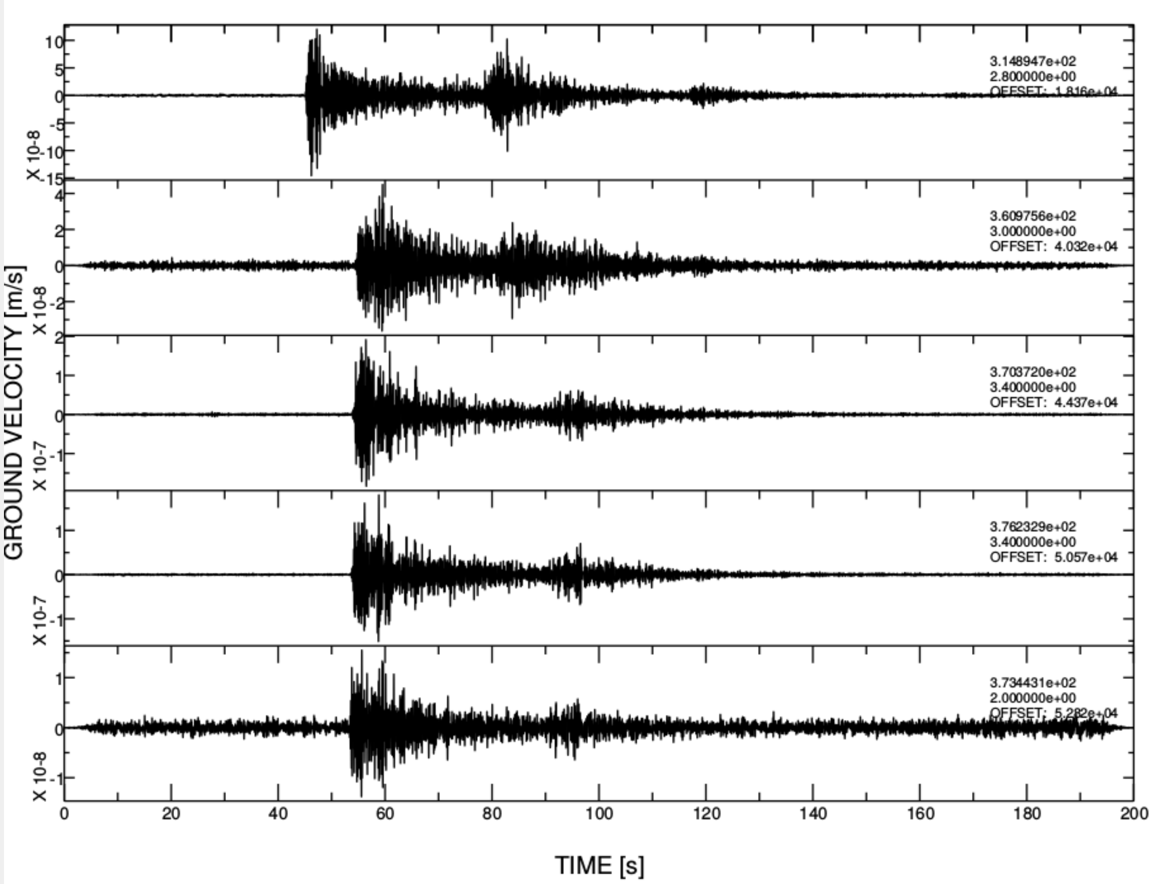
B2



Sample recordings, High-Pass

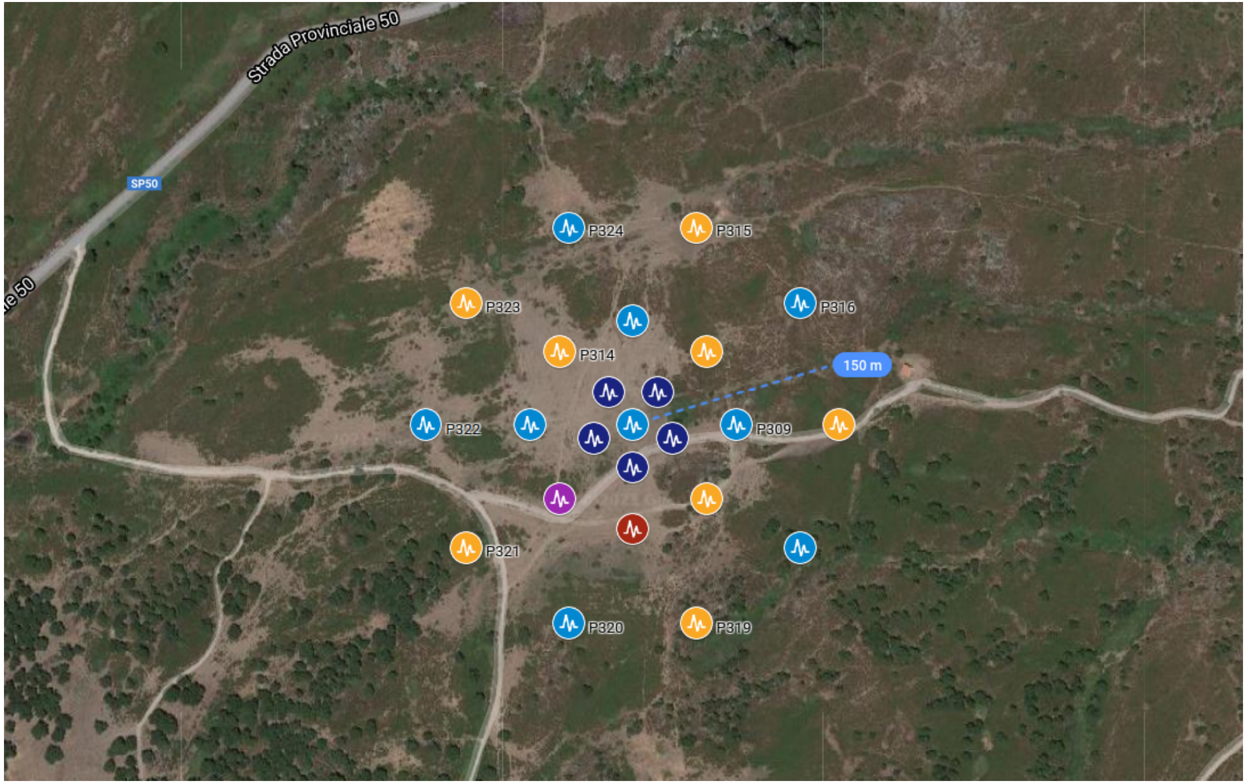
B1

B2




The main source of noise

Experiment @ P3 [2 Oct. 2021 - 12 Oct. 2021]



Experiment @ P3

Experiment @ P3: Instruments

Nanometrics Centaur + Nanometrics Trillium Compact PH 20s from **UniSS**

Digos CUBE + Nanometrics Trillium Compact 120s on loan from INGV CoReMo and Univ. Liverpool.

Digos CUBE + Le3D short period on loan from DIAS (Dublin, IE)

Nanometrics Centaur + Nanometrics Trillium 240 from **AstroCent**

Nanometrics Centaur + Nanometrics Trillium 240 from **UNICA**

Conclusions

Sos Enattos (P1):

- Anthropogenic contributions peak in between 10 Hz and 20 Hz;
- Narrow spectral peaks @ ~ 4-5 Hz
- Prominent direction of propagation WSW
- SPAC and FK analysis yield consistent results: velocities in the 1500-2500 m/s range over the 5-15 Hz frequency band
- time evolution of directional properties compatible with vehicle traffic along SP73;
- main source of energy at f~ 4.5 Hz likely associated with oscillation of 2 bridges
- Polarization is markedly site-dependent → topographic effects ? Need to sample the seismic wavefield over distances shorter than the characteristic wavelength of morphological irregularities;

The very next steps

- Extend SPAC and FK analyses to horizontal components
- Extend to the whole recording period and other arrays
- Extend to other frequency bands
- Harmonize w/ extended temporal analyses

Pending Questions

- Are noise-based methods well suited for subsurface imaging ?

Thank you for listening