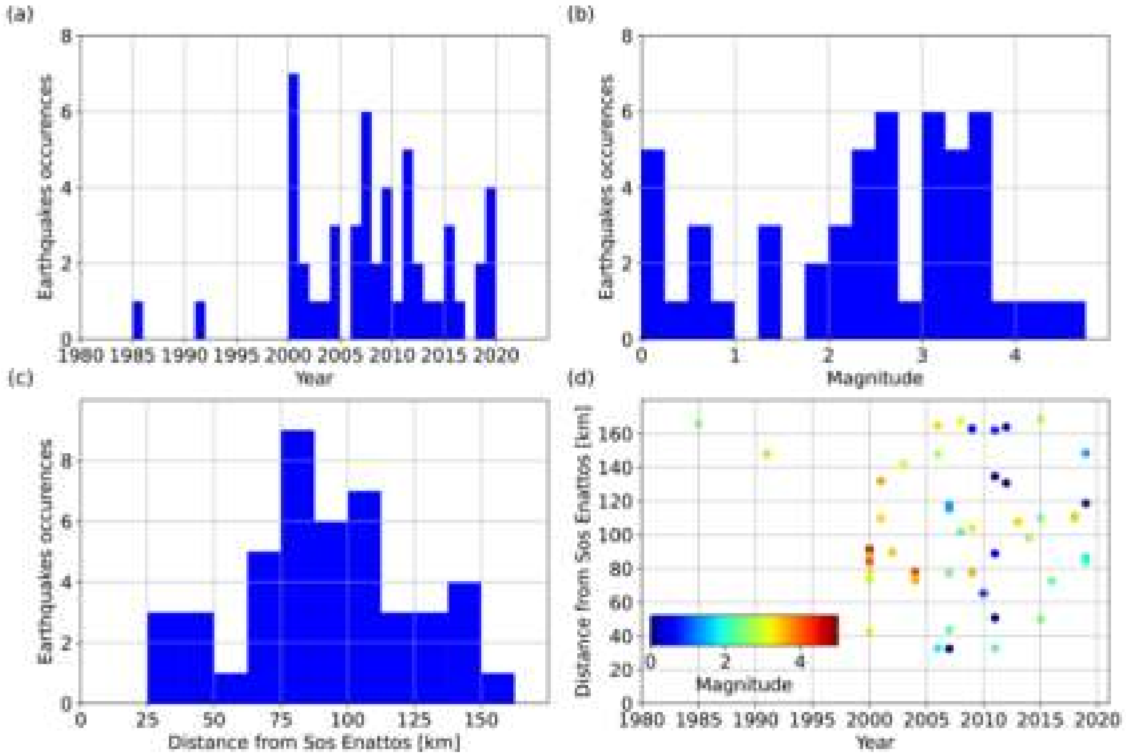
Update on Seismic Noise studies at Sos Enattos

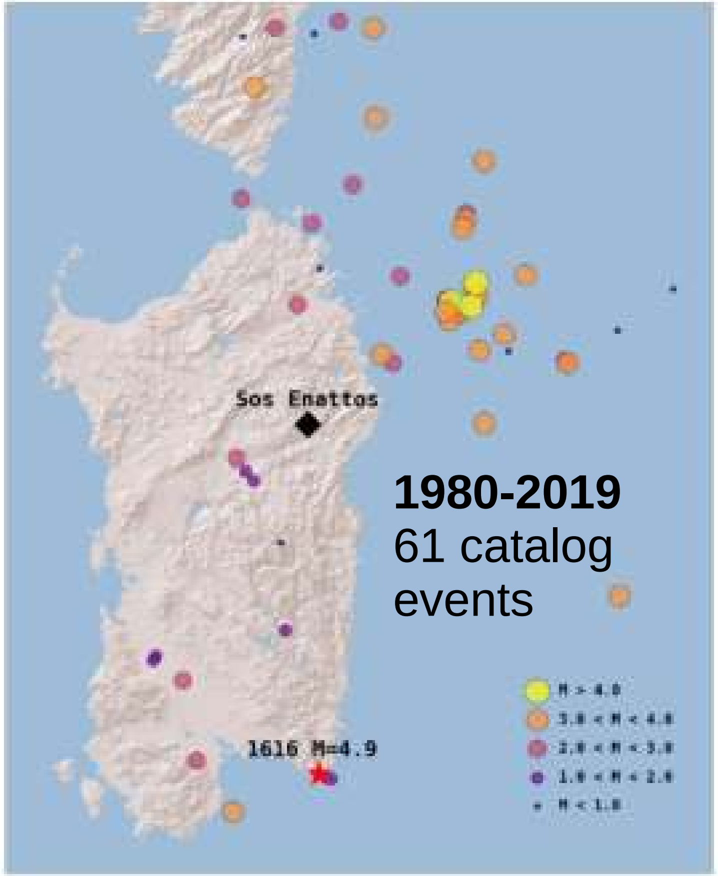
Gilberto Saccorotti, Matteo di Giovanni, Carlo Giunchi, Luca Naticchioni, Marco Olivieri and the ET Sardegna site characterization team

The Sos-Enattos site (NE Sardinia)

Earthquake Activity

cnt.rm.ingv.it



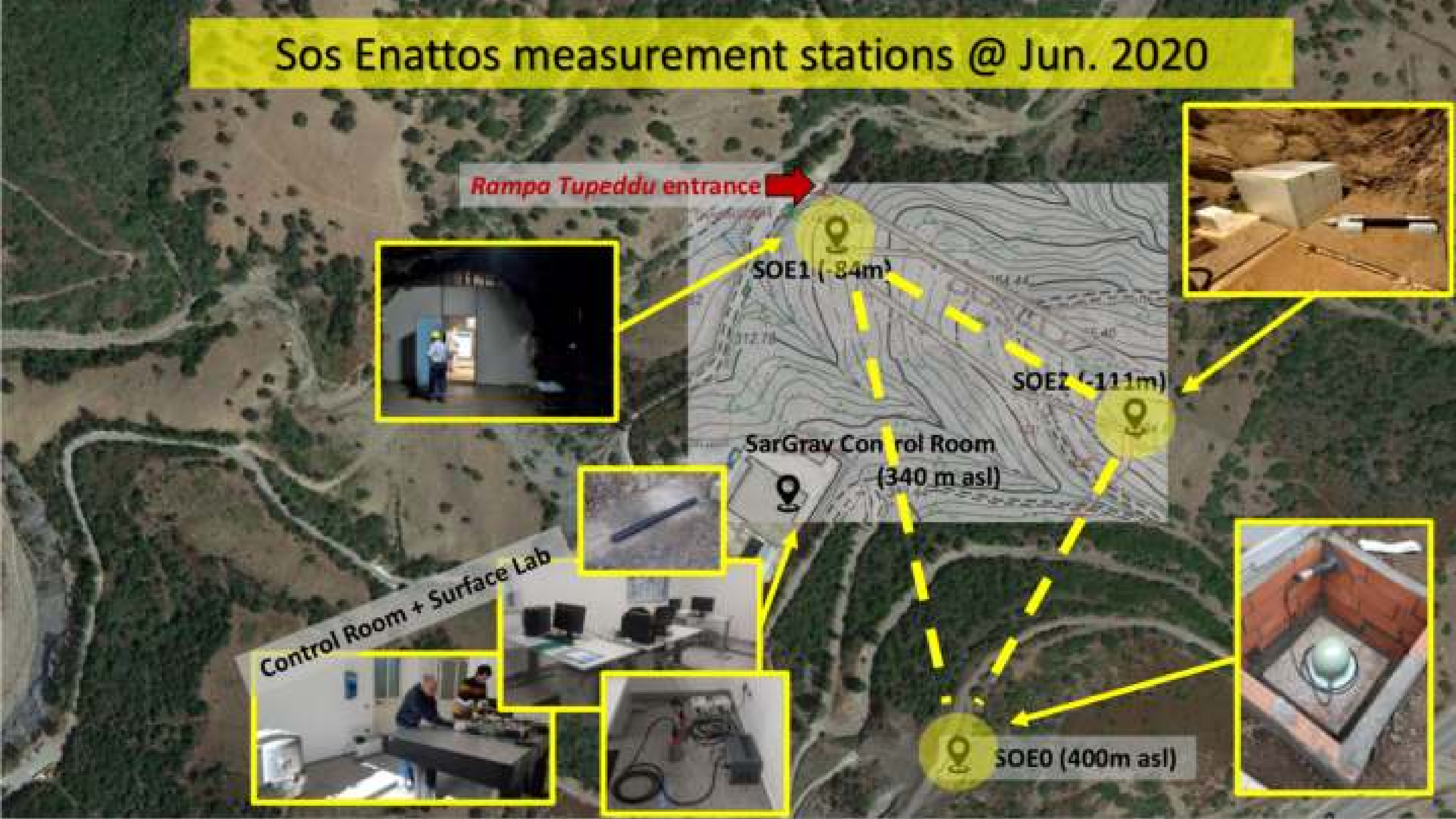


1980-2019
61 catalog events

Average for the rest of Italy: 2000 - 14000 eq / year (M > 2)

Seismic noise assessment at Sos-Enattos

- **First measurements started in 2010;**
- **Long-term site characterisation started in 2012;**
  - Seismometers;
  - Temperature and humidity sensors;
  - Weather station;
- **Site hosts the SAR-GRAV project since 2018;**
- **In March 2019 three new seismometers were installed for new long-term measurements.**

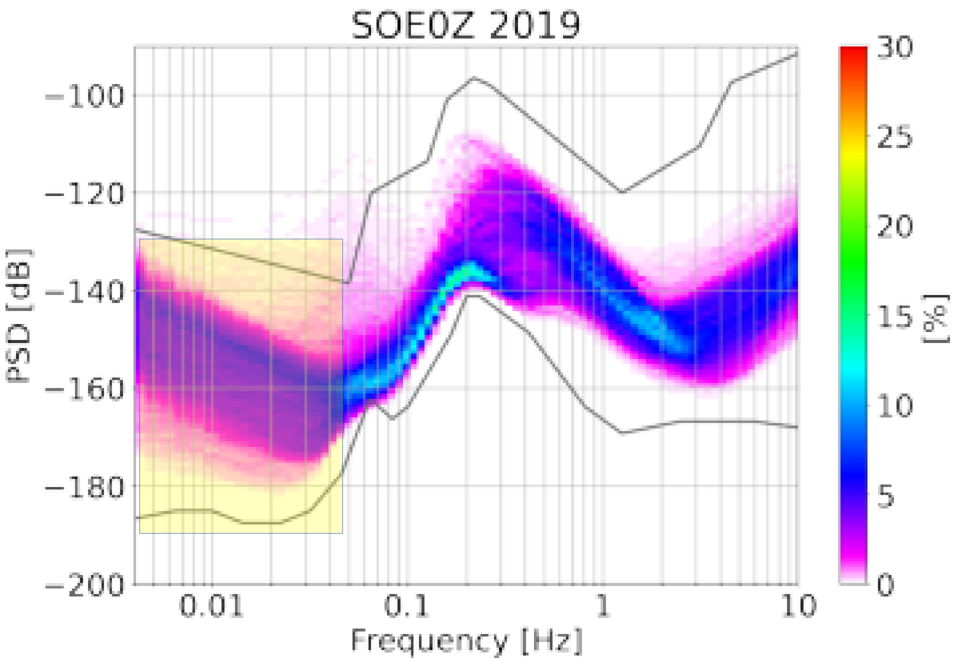


Sos Enattos measurement stations @ Jun. 2020
Rampa Tupeddu entrance
SOE1 (-84m)
SOE2 (-111m)
SarGrav Control Room
(340 m asl)
Control Room + Surface Lab
SOE0 (400m asl)

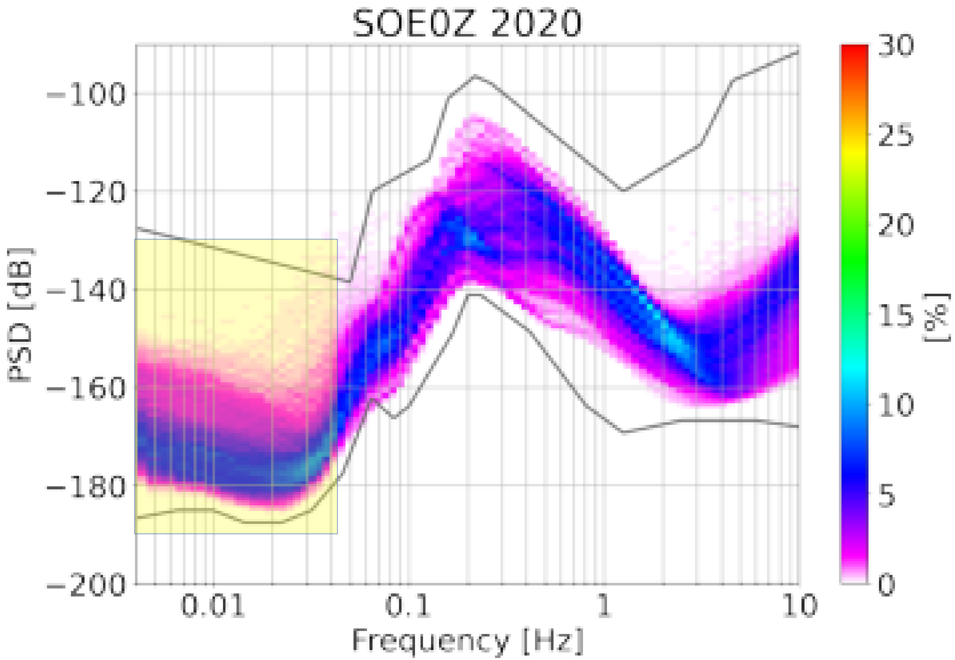
INSTRUMENTS

- **March 2019**
  - SOE0: Guralp 360
  - SOE1/SOE2: Trillium 240
- **December 2019**
  - SOE0/1/2: Trillium 240
  - SOE0 also got a new installation
  - SOE2 now in Italian seismological network as IV.SENA

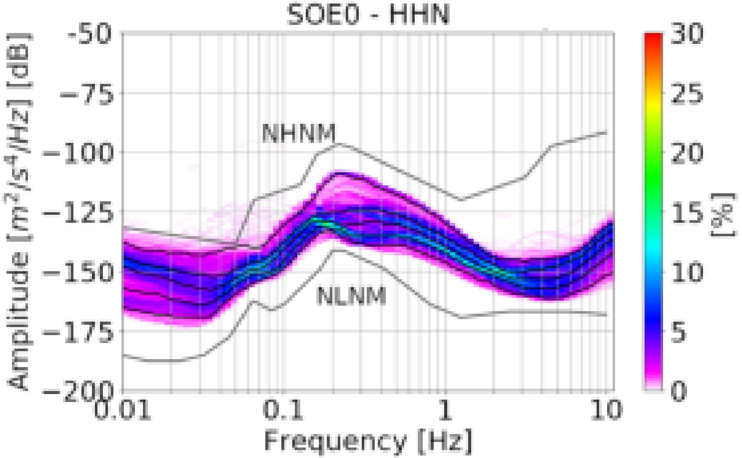
Surface seismometer: the importance of instrument & siting

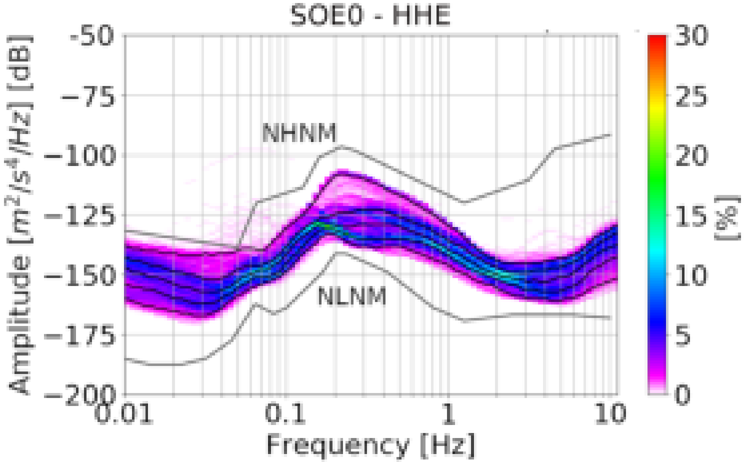


Guralp 120s
Shack Installation

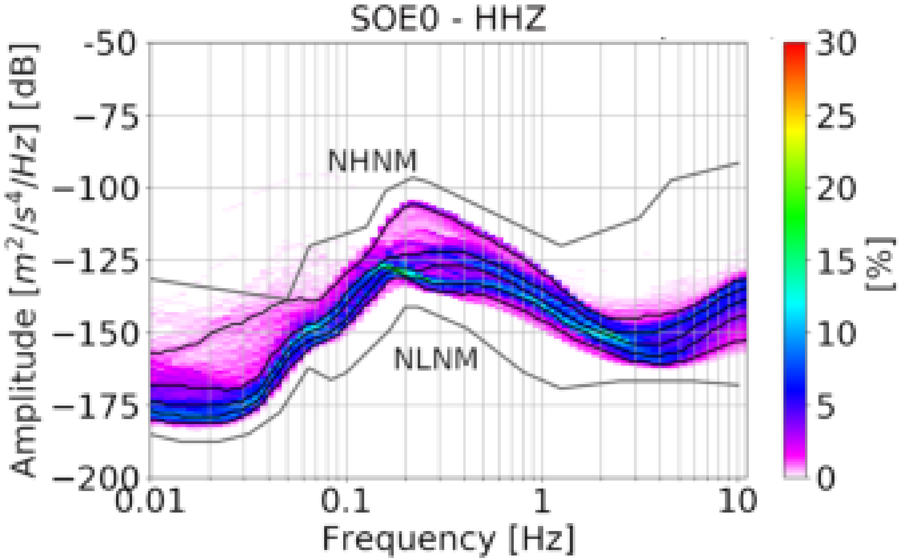


Trillium 240s
Vault Installation



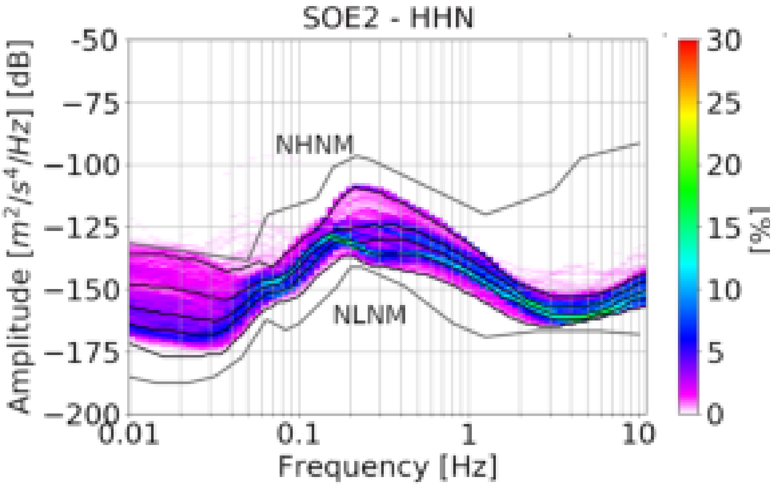


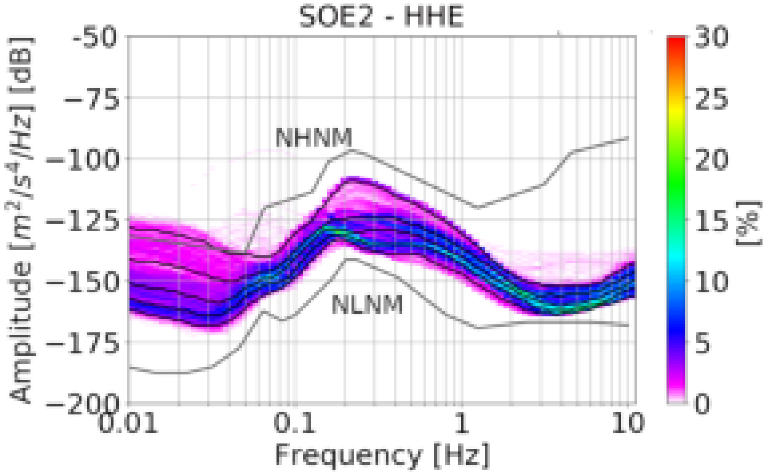
2020 data (01/01/2020 - 18/02/2020)

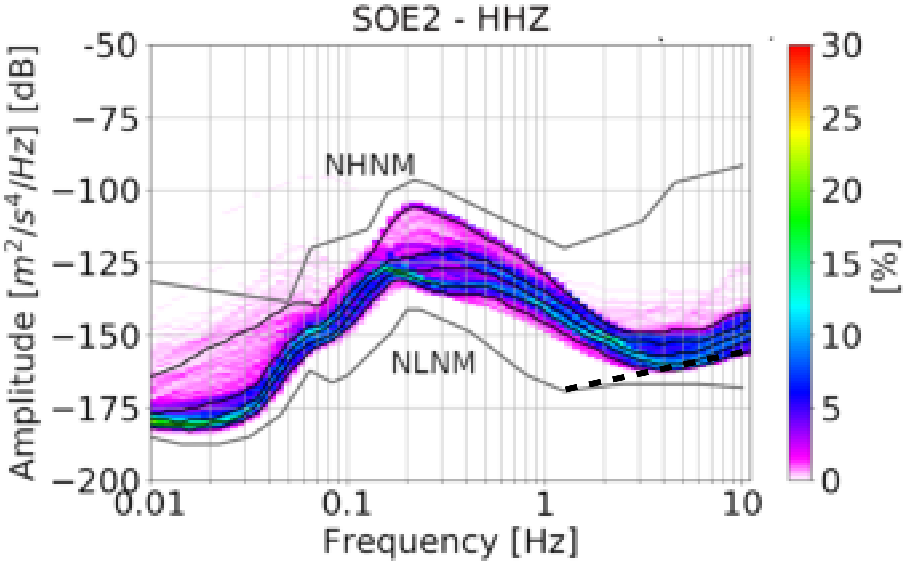


Surface seismometer
Trillium 240
0m – 338m a.s.l.

<u>2020 data</u> (01/01/2020 - 18/02/2020)







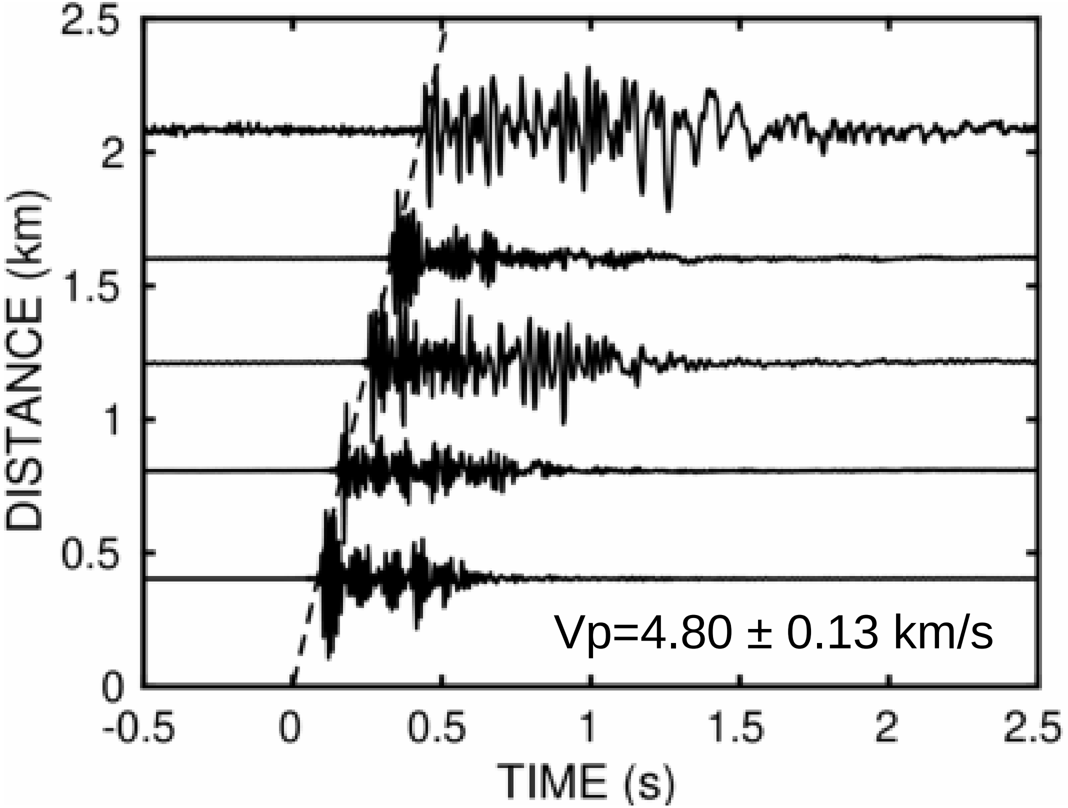
Second underground seismometer
-111m – 227m a.s.l.

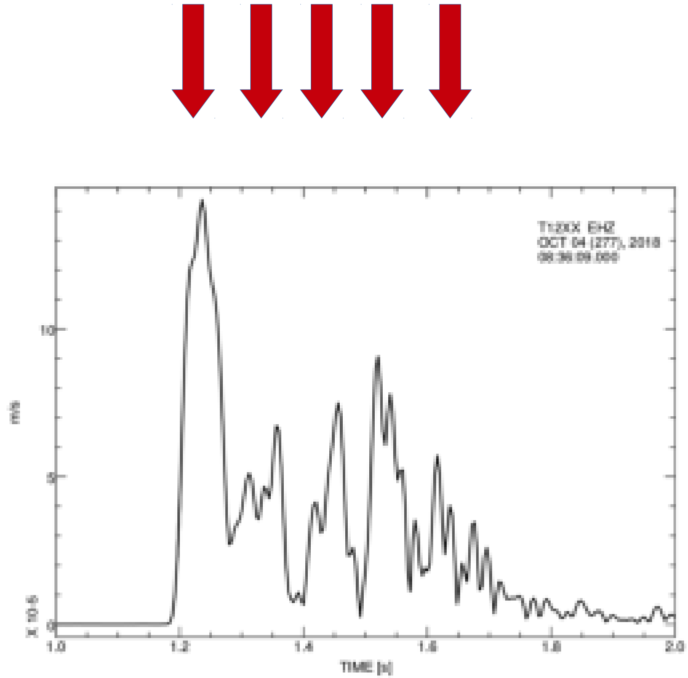
Recording of a mine blast
Oct 4, 2018

- 25 kg, 5 blasts (gallery enlargement for ARCHIMEDES experiment)

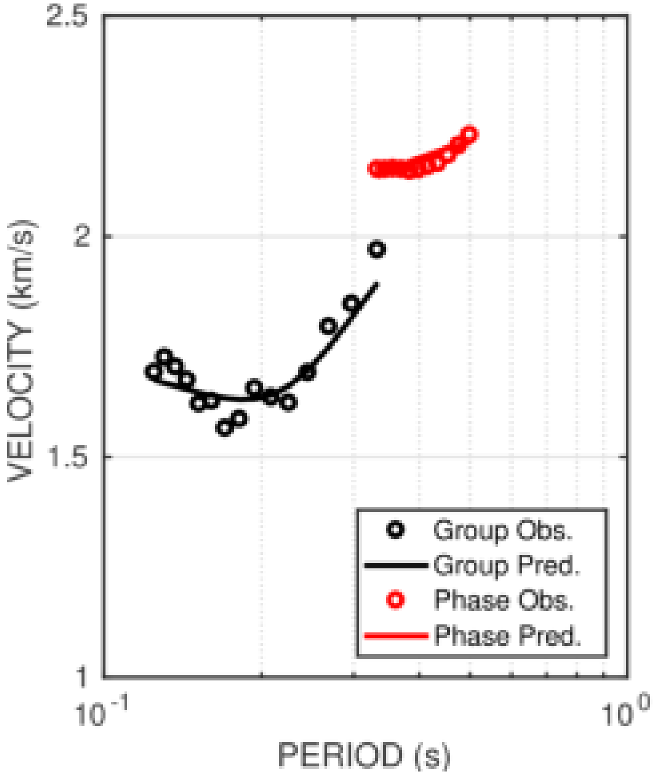
- 5 short-period stations, 500m spacing

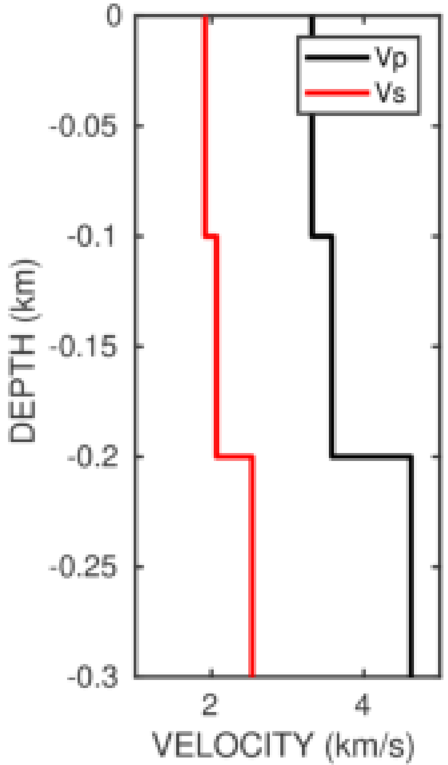
Recording of a mine blast
Oct 4, 2018





Shallow S-wave velocity structure from inversion of the dispersion curves of blast-generated Rayleigh waves

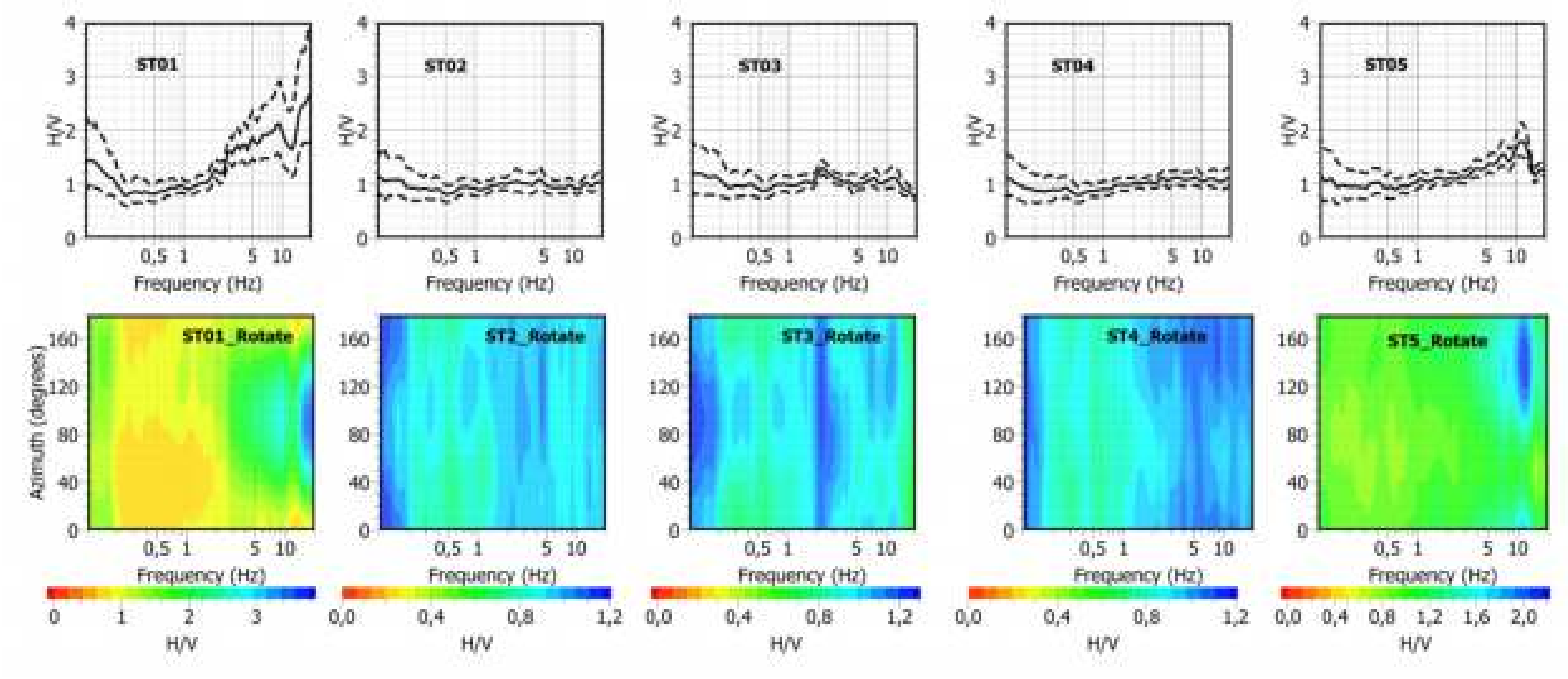




Group velocity:
(1) BP Gaussian filtering
(2) Hilbert Transform (envelopes)
(3) Peak recognition

Phase velocity:
(1) BP filtering
(2) Time delays from xcorr

Noise before the blast: HVSR

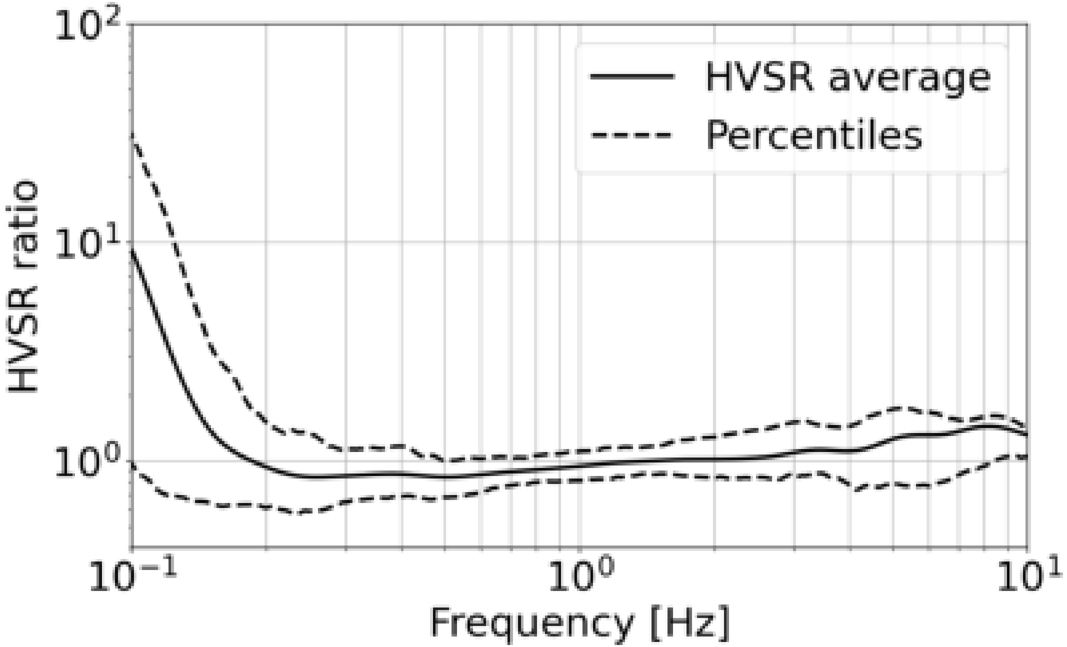


HVSR = **H**orizontal-to-**V**ertical **S**pectral **R**atio

HVSR Peaks are due to resonance effects (impedance contrast)

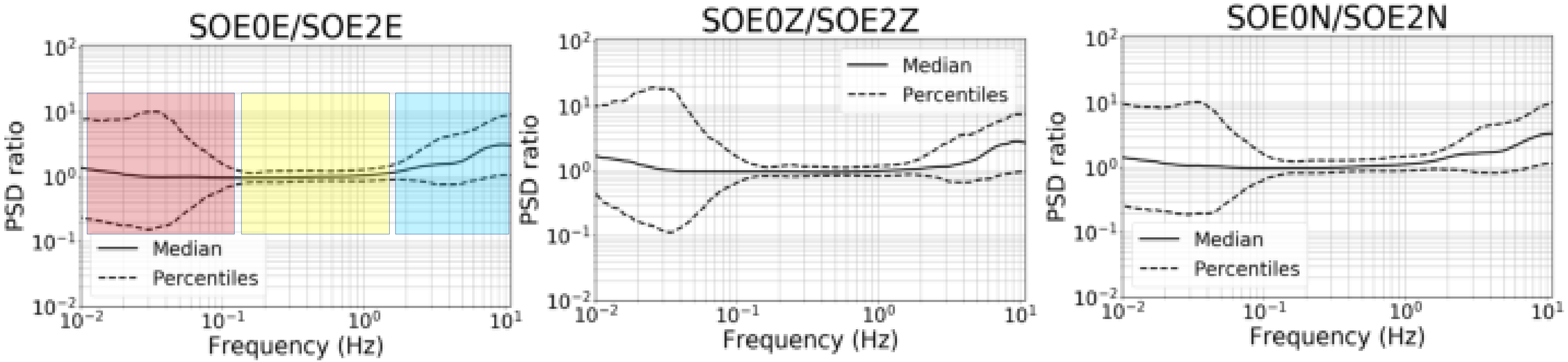
HVSR Peaks are significant when > 2 → **lack of amplification**

HVSR @ SOE0



No HVSR peaks down to f ~ 0.2 Hz. Using fc = Vs / 4h, with Vs in the [2000,2500] m/s range, we infer the lacking of significant impedance contrasts down to depths of about 2500 − 3000 m below the surface.

Spectral ratios surface / underground

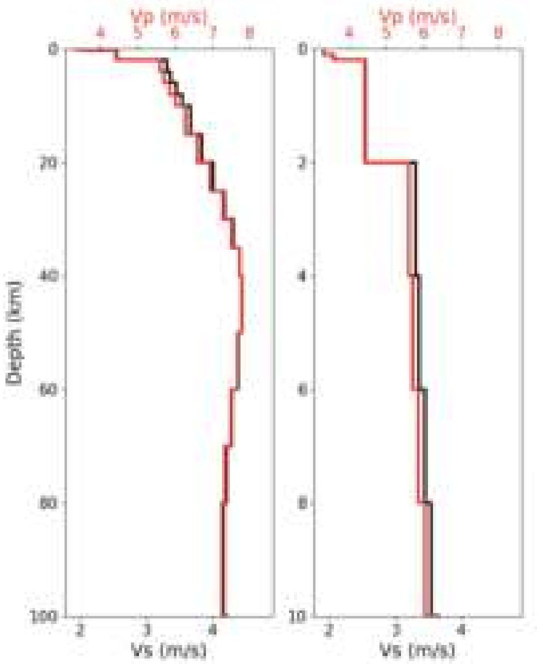


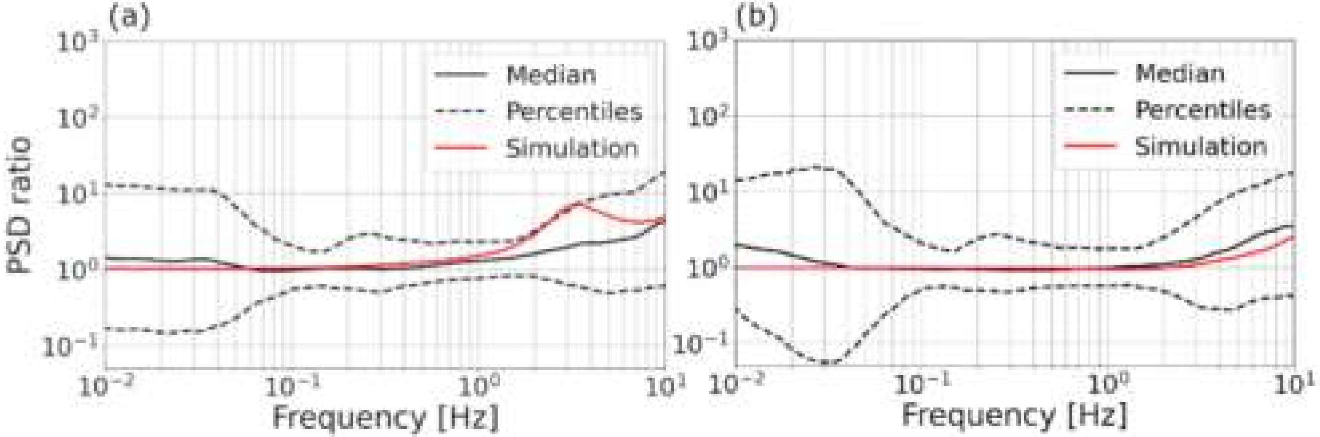
[0.01 - 0.1] Hz → R ~ 1, as expected. The **large variance** can be explained in terms of (a) P/T influence on the surface sensor, and (b) bad-conditioning of the spectral division (response of the underground sensor close to the instrument's self noise).

[0.1 - 2] Hz → R ~ 1.

[2 – 10] Hz → R > 1, **large variance → not only surface sources.**

Interpreting spectral ratios from simulation of Rayleigh wave propagation in layered media



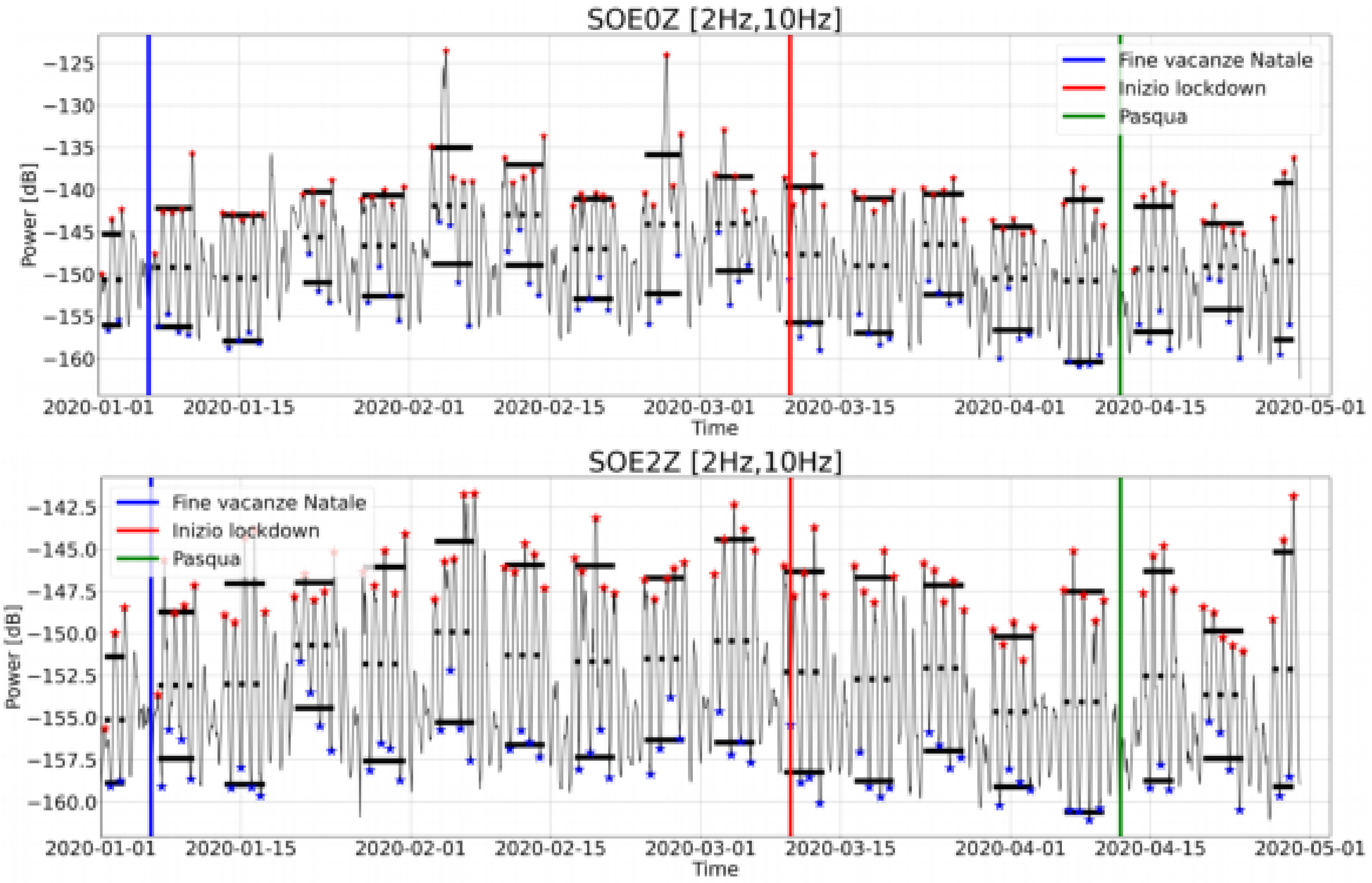


Spectral amplitude ratios surface/depth are consistent with what expected for Rayleigh waves propagating in a simplified, 1D Earth model derived from integration of regional (Magrini et al., 2020) and local (this work) data.

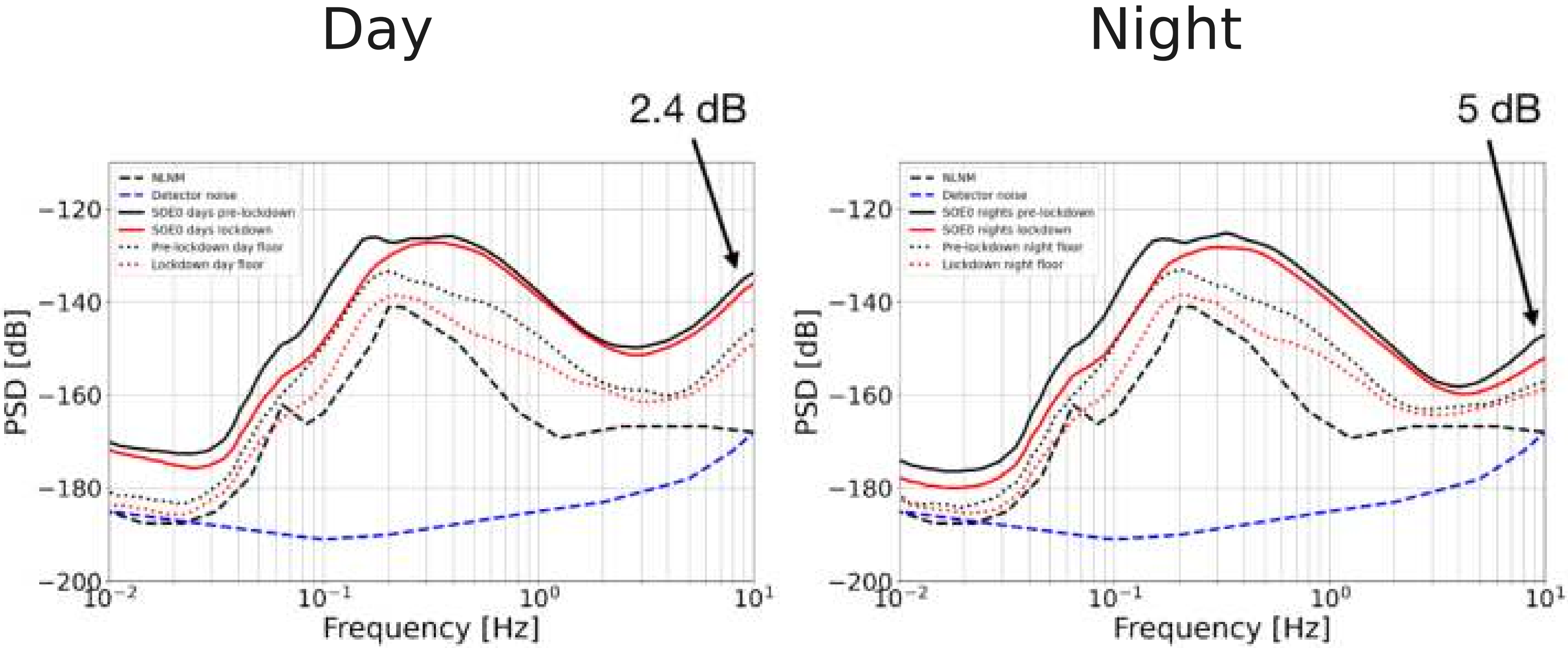
Magrini F., Diaferia G., Fadel I., Cammarano F., van der Meijde M. and Boschi L. (2020). 3-D shear wave velocity model of the lithosphere below the Sardinia-Corsica continental block based on Rayleigh-wave phase velocities, Geophys. J. Int. 220:2119-2130.

The effects of the lock-down

- 2 months pre lockdown: 1 Jan - 25 Feb
- 3 months during lockdown: 10 March - 3 May
- Day: 6 – 17
- Night: 20 – 4
- Z component

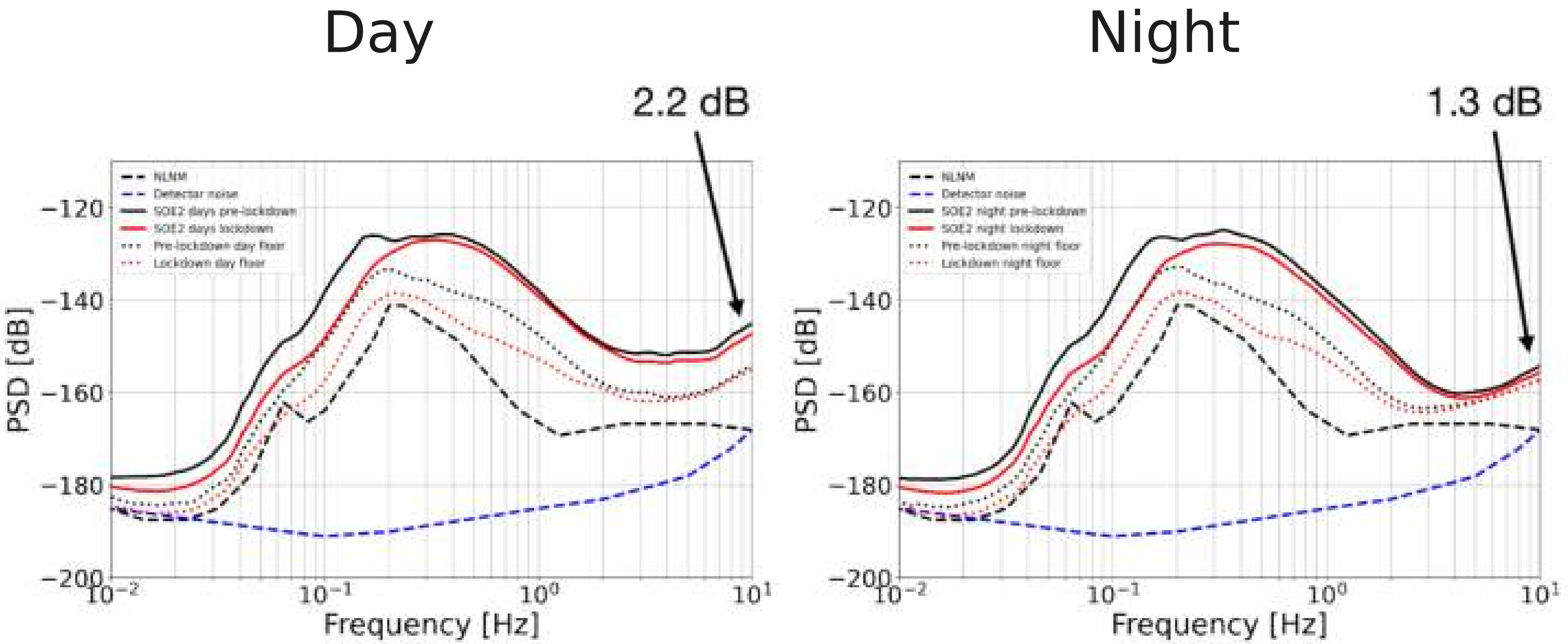

SOE0Z [2Hz,10Hz]
Fine vacanze Natale
Inizio lockdown
Pasqua
Power [dB]
Time
SOE2Z [2Hz,10Hz]
Fine vacanze Natale
Inizio lockdown
Pasqua
Power [dB]
Time

SOE0Z



Day
2.4 dB
NLNM
Detector noise
SOE0 days pre-lockdown
SOE0 days lockdown
Pre-lockdown day floor
Lockdown day floor
PSD [dB]
Frequency [Hz]
Night
5 dB
NLNM
Detector noise
SOE0 nights pre-lockdown
SOE0 nights lockdown
Pre-lockdown night floor
Lockdown night floor
PSD [dB]
Frequency [Hz]

SOE2Z


Day
Night
2.2 dB
1.3 dB
NLNM
Detector noise
SOE2 days pre-lockdown
SOE2 days lockdown
Pre-lockdown day floor
Lockdown day floor
SOE2 night pre-lockdown
SOE2 night lockdown
Pre-lockdown night floor
Lockdown night floor
PSD [dB]
Frequency [Hz]
−120
−140
−160
−180
−200
10^{-2}
10^{-1}
10^{0}
10^{1}

SOE0 reference:

- weeks 9-10
- spectral power average -144 dB

Settimana	Variazione percentuale
11	-2.3%
12	-3.4%
13	-1.7%
14	-4.3%
15	-4.5%
16	-3.6%
17	-3.4%
18	-3%

SOE2 reference:

- weeks 9-10
- spectral power average -151 dB

Settimana	Variazione percentuale
11	-0.9%
12	-1.2%
13	-0.8%
14	-2.4%
15	-2.1%
16	-1.1%
17	-1.2%
18	-0.8%

Glitches

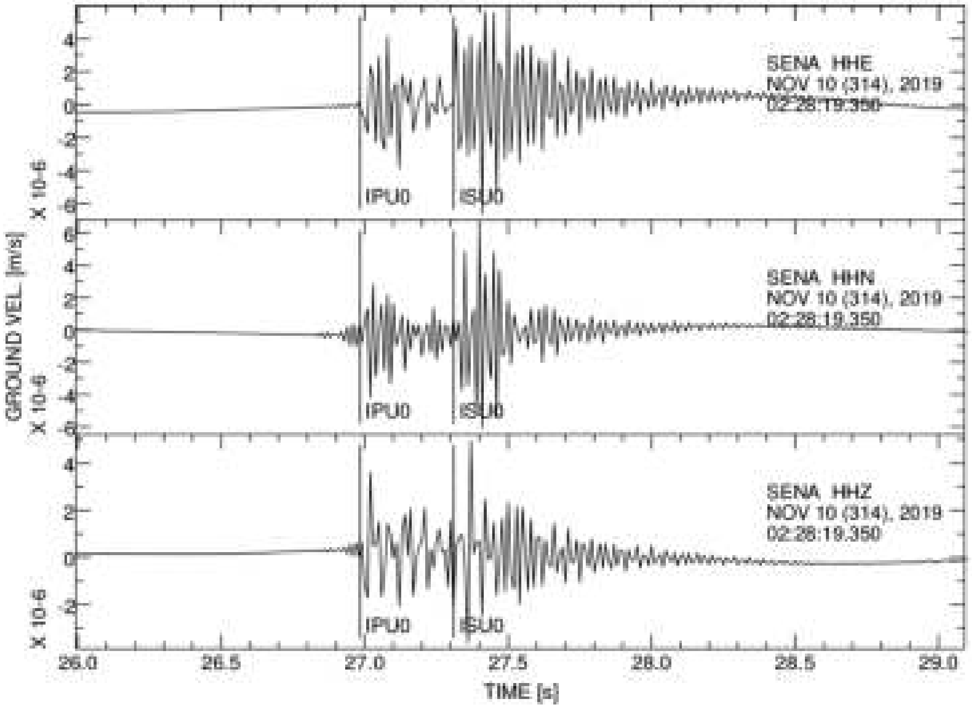
In a companion work, R. de Rosa and E. Calloni are accounting for two measures of goodness:

1. Glitches: a 1-minute events having rms higher than 10 db with respect to the noise floor around the period of time in which the glitch appears.

2. Comparison of the noise rms calculated over subsequent, 1 minute-long time windows with a **Maximun Allowed rms Noise** (MAN), defined as 12 times the rms of the NLNM in the bandwidth 2-10 Hz.

We're performing an in-depth analysis of point (1) above, in order to shed light into the nature of transient signals.

Origin of the glitches - I

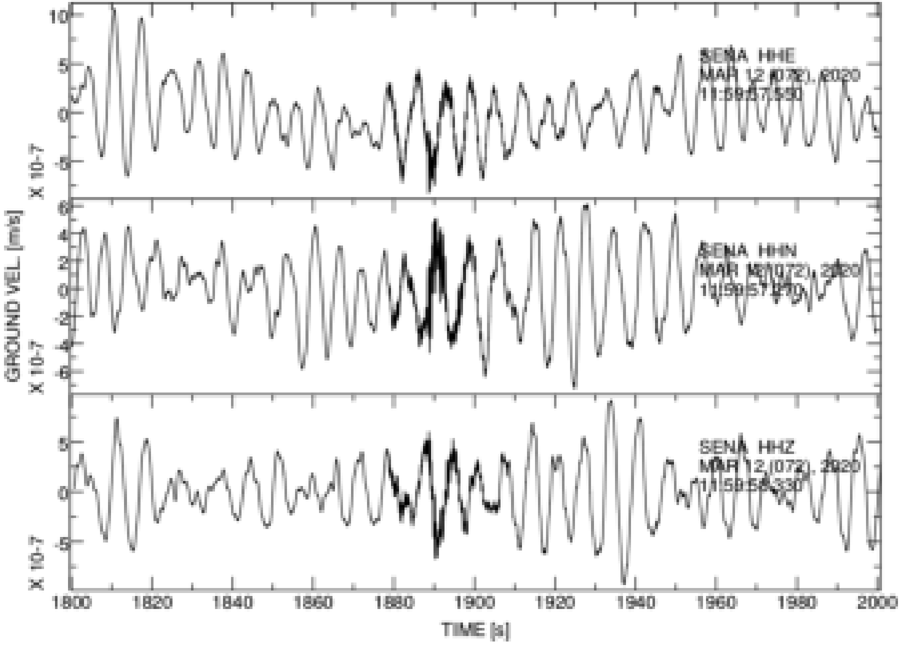


Ts-Tp ~ 0.3s → D = 2.1 km

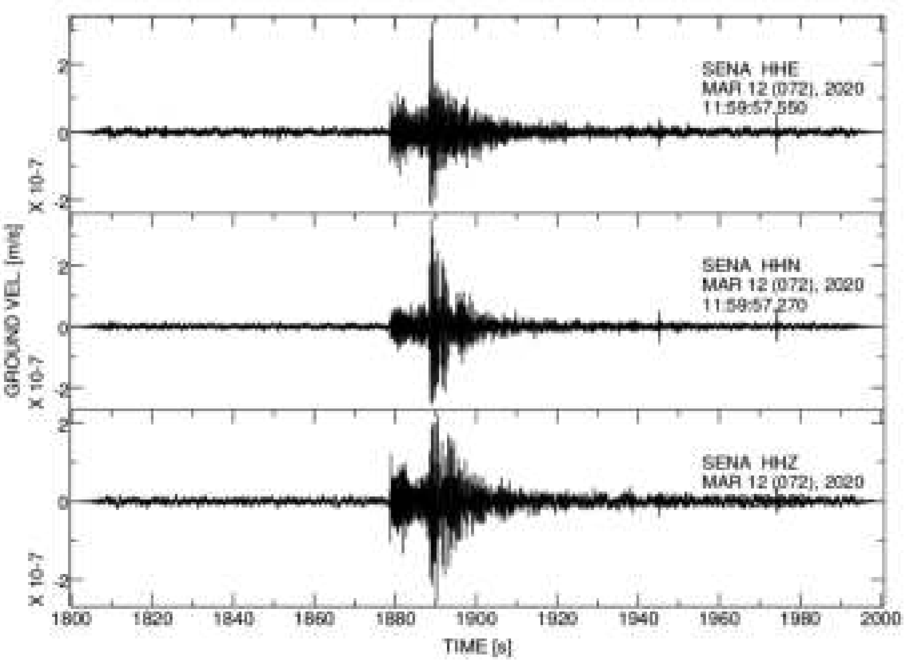
M_L ~ - 0.13

Origin of the glitches - II

Original

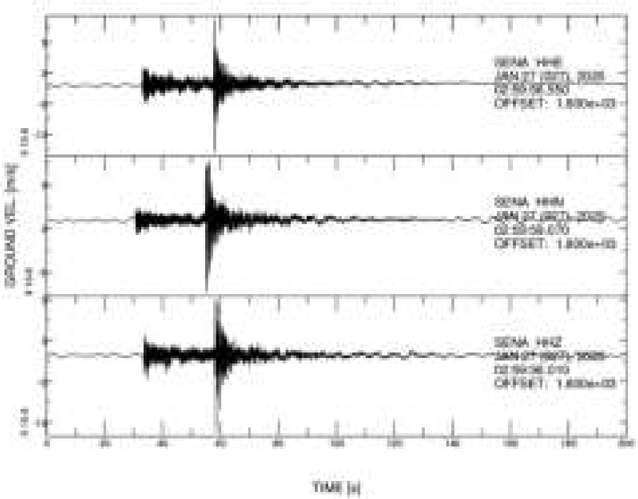


HP 2 Hz



Ts-Tp ~ 9.5s → D = 67 km **M_L ~ 1.2**

Origin of the glitches - III

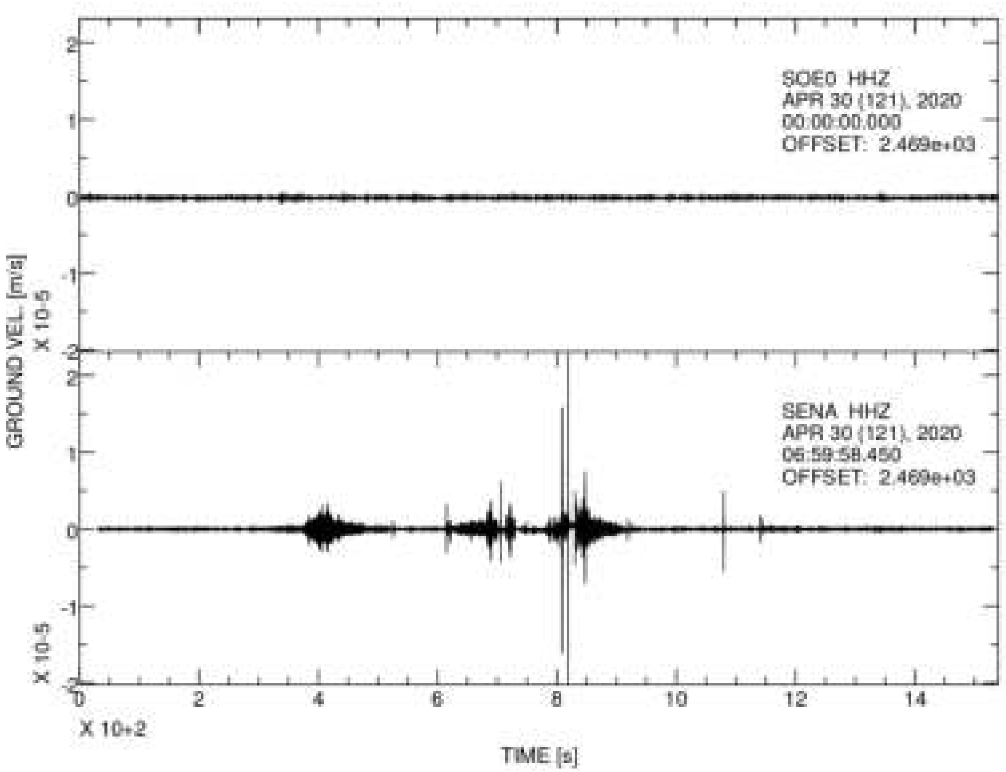


Cronologia delle localizzazioni calcolate

Tipo	Magnitudo	Tempo origine (UTC)	Latitudine	Longitudine	Profondità (km)	Ora pubblicazione (UTC)	Autore	ID Localizzazione
Rev 1000 ★	**ML 3.4 ★**	**2020-01-27 03:29:54**	**42.15**	**7.54**	**24**	**2020-01-27 17:47:06**	**Bollettino Sismico Italiano INGV**	**75909811**
Rev 100	ML 3.6	2020-01-27 03:29:55	42.19	7.52	21	2020-01-27 03:46:44	Sala Sismica INGV-Roma	75903231

★ Localizzazione e magnitudo preferite finora.

Origin of the glitches - IV



Surface Station SOE0

Underground Station SOE2 [SENA]

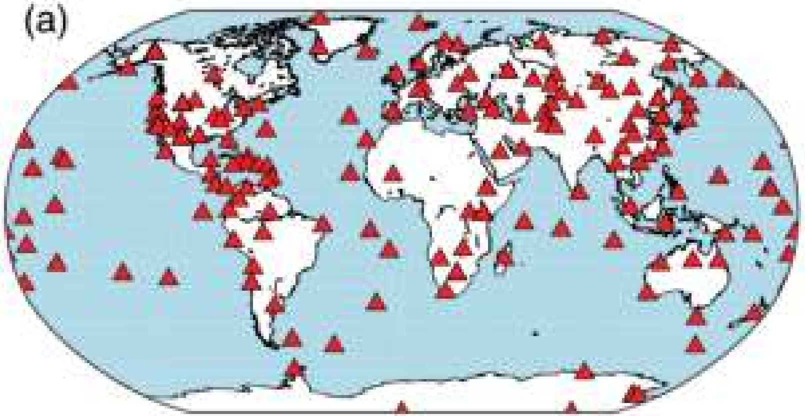
Local noise within the mine due human activity

A final remark on the NLNM as a reference term.

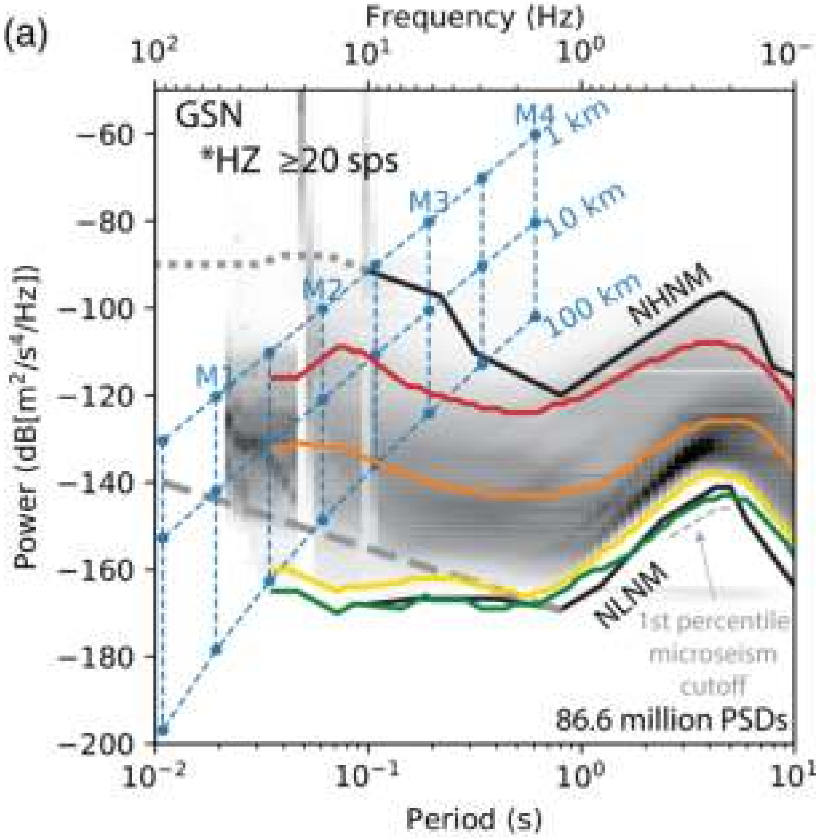
Establishing High-Frequency Noise Baselines to 100 Hz Based on Millions of Power Spectra from IRIS MUSTANG

Emily Wolin*[1,2] and Daniel E. McNamara[3]

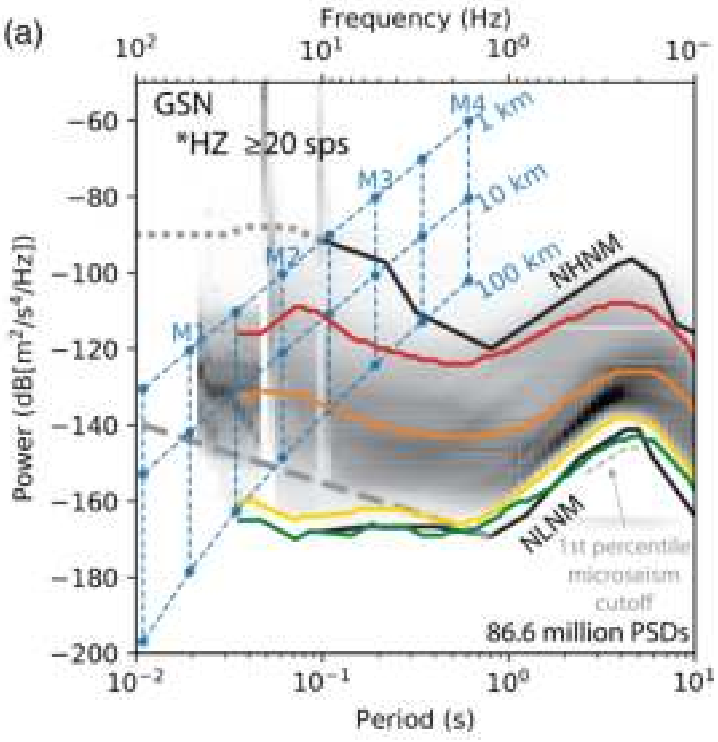
BSSA, 110 - February 2020



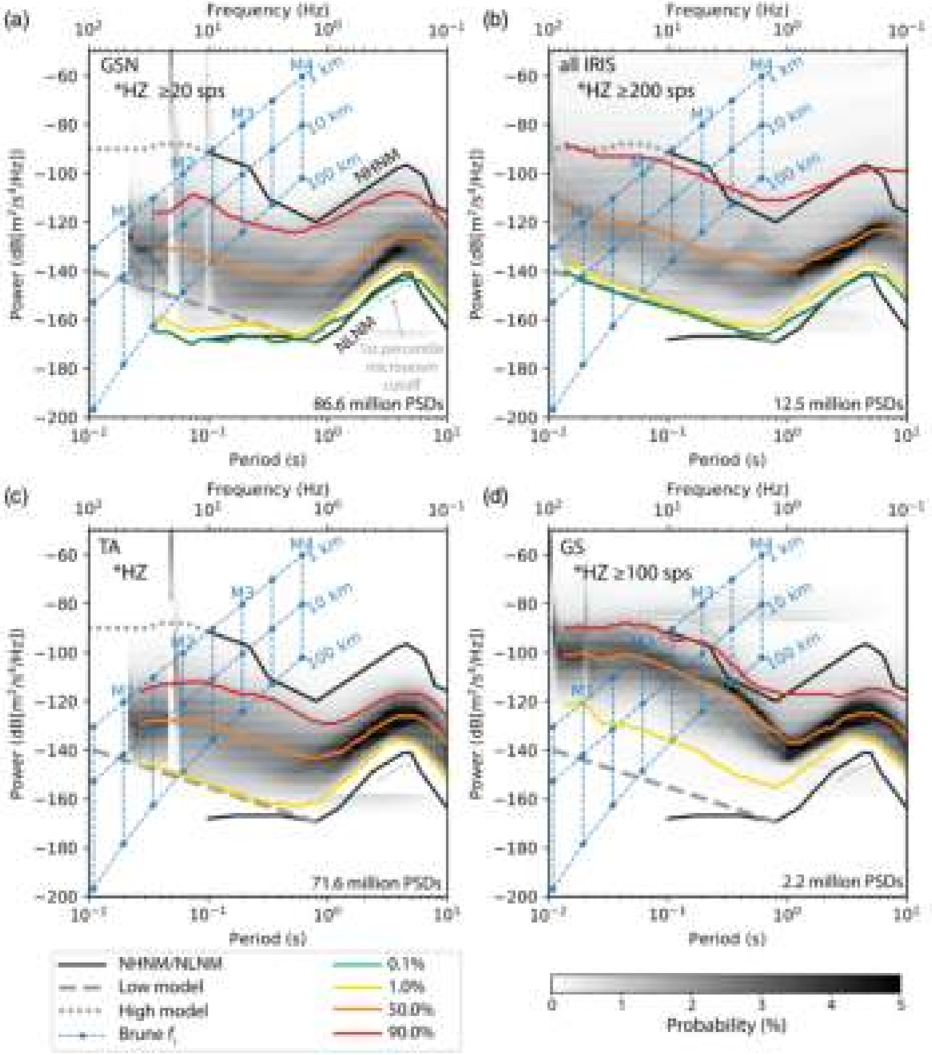
Peterson’s NLNM: 0.1% percentile from GSN



[…] In doing so, Peterson noted that the NLNM above 2 Hz was drawn based on what he considered to be a clearly inadequate number of spectra […] Twenty-five years and millions of PSDs later, the shape of the NLNM in the frequency band between 2 and 10 Hz appears to require no revision.



Most GSN stations never attain noise levels within a few decibels of the NLNM in the 2–10 Hz band, and instead the low-noise floor is defined by a handful of stations that are consistently extremely quiet. [e.g., Borehole sensors at IU.QSPA near the South Pole ….]



The analysis of ALL publicly-available data from both permanent and transportable instruments with sampling rate >= 200Hz reveals a new NLNM which, at 10 Hz, is **more than 10dB higher than Peterson’s NLNM**.

This new trend likely results also from digitizers noise (due to low-gain settings for earthquake studies)

SUMMARY - I

<u>DEPLOYMENTS</u>:

- Long-term, single-station deployment (2012-2014)
- Three-station deployment (March 2019, ongoing)
- A fourth underground station will be deployed soon (as soon as it will be allowed by COVID-19…)

<u>RESULTS</u>:

- At depth ~110 m: factor ~10 attenuation for F < 0.07 Hz and F > 1 Hz;
- Tough geological materials even at the surface (Vp > 4000 m/s, Vs > 2000 m/s)
- No stratigraphic site effects
- Close to NLNM over the 2-5 Hz frequency band
- Microseism band (0.1-1 Hz): Strong influence of wave climate in the Thyrrenian Sea (see *Naticchioni et al., 2014*)

SUMMARY - II

- The measured noise amplitude must be considered as an upper bound, since anthropogenic activities at the mine are still ongoing;

- **For the (crucial) 2-10 Hz frequency band:**
    - Digitizers' performance must be assessed carefully;
    - Spectral ratios with the surface stations < 1 indicate the existence of within-mine disturbances, likely due to human operations;
    - The same is confirmed by the detailed analysis of glitches.

FUTURE WORK

- Further investigation on glitches: their classification, clustering, detection using ML techniques;

- Noise correlation analyses at the present tri-partite array;

- A full characterization of the noise wavefield in terms of its kinetic (direction of arrival, apparent velocity) and polarization properties. → short-duration surveys with surface arrays of seismometers.

- Derivation of shallow S-wave velocity profiles from Rayleigh wave dispersion functions derived from Noise Correlation.

Thank you for listening