GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN

ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

Seismic ambient noise studies in Sardinia for the Einstein

MATTEO DI GIOVANNI ON BEHALF OF THE SARDINIA SITE CHARACTERIZATION TEAM

GWADW 2023

Outline

- Introduction;
- The Sardinia site and its instrument network;
- Potential ambient noise sources;
- Summary of long term ambient noise studies (2019 - 2023);
  - noise levels;
  - ambient noise variations by natural sources;
  - ambient noise variations by anthropogenic sources;
- Conclusions and open questions.

Introduction

The paper **Temporal variations of the ambient seismic field at the Sardinia candidate site of the Einstein Telescope** (**DOI** 10.1093/gji/ggad178) has finally been accepted for publication on Geophysical Journal international on 20/04/2023.

This paper completes, for now, the set of publications devoted to the ambient noise characterization of the Sardinia candidate site:

- Naticchioni et al. (2014) **DOI** 10.1088/0264-9381/31/10/105016
- Naticchioni et al. (2020) **DOI** 10.1088/1742-6596/1468/1/012242
- Di Giovanni et al. (2021) **DOI** 10.1785/0220200186
- Allocca et al. (2021) **DOI** 10.1140/epjp/s13360-021-01450-8

JOURNAL ARTICLE ACCEPTED MANUSCRIPT

Temporal variations of the ambient seismic field at the Sardinia candidate site of the Einstein Telescope

M Di Giovanni, S Koley ✉, J X Ensing, T Andric, J Harms, D D'Urso, L Naticchioni, R De Rosa, C Giunchi, A Allocca ... Show more

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Summary

Einstein Telescope (ET) is a proposed underground infrastructure in Europe to host future generations of gravitational-wave (GW) detectors. One of its design goals is to extend the observation band of terrestrial GW detectors from currently about 20 Hz down to 3 Hz. The coupling of a detector to its environment becomes stronger at lower frequencies, which makes it important to carefully analyze environmental disturbances at ET candidate sites. Seismic disturbances pose the greatest challenge since there are several important mechanisms for seismic vibrations to produce noise in ET, e.g., through gravitational coupling, stray light, or through harmful constraints on the design of ET's control system. In this paper, we present an analysis of the time-variant properties of the seismic field at the Sardinia candidate site of ET connected to anthropogenic as well as natural phenomena. We find that temporal variations of source distributions and of the noise spectra generally follow predictable trends in the form of diurnal, weekly, or seasonal cycles. Specific seismic sources were identified such as road bridges, which produce observable disturbances underground. This information can be used to adapt a detector's seismic isolation and control system.

Keywords: Einstein Telescope, Gravitational waves, Time series analysis, Seismic noise, Seismic instruments

Issue Section: Research Paper

The Sardinia site

- Sos Enattos is a former lead and zinc mine active from the Roman age until the late 1990s;
- Today it is not abandoned and is still maintained for environmental safety and guided tours and hosts the SarGrav laboratory and the Archimedes experiment;

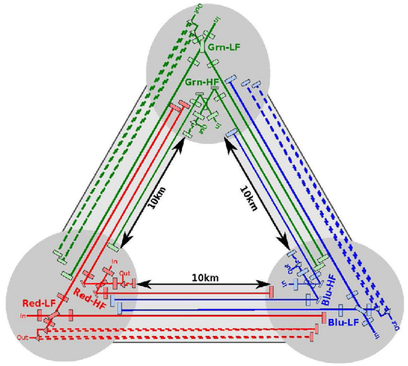
Main well

Former mineral processing unit

SarGrav laboratory

Introduction

- Properties of seismic noise are influenced by local activities (natural and anthropogenic);
- Investigation of noise sources of human origin is particularly important for future decisions about exclusion zones;
- Gather useful information to adapt the detector seismic isolation and control system.



The proposed ET Triangle foresees three nested interferometers. Being all at the same location, ambient noise plays a crucial role in the correction operation of the detector.

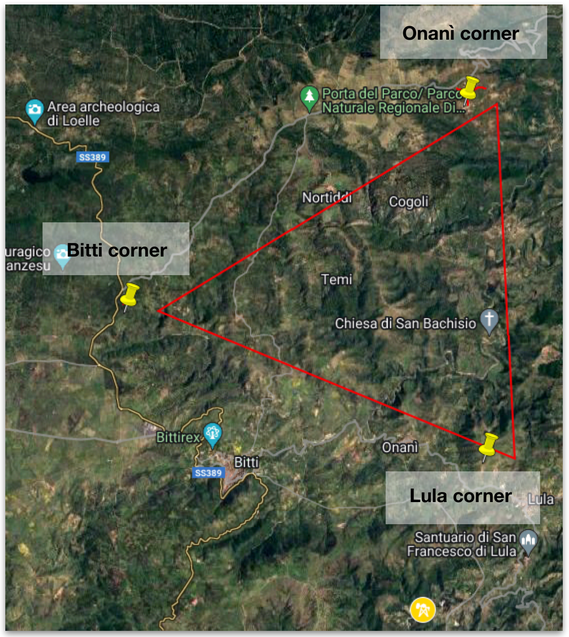
Proposed ET triangle orientation at the Sardinia Site.

The Sardinia site

According to the current proposed orientation for the ET Triangle, the sites to host the actual vertices of the interferometer have also been identified

The Onanì corner

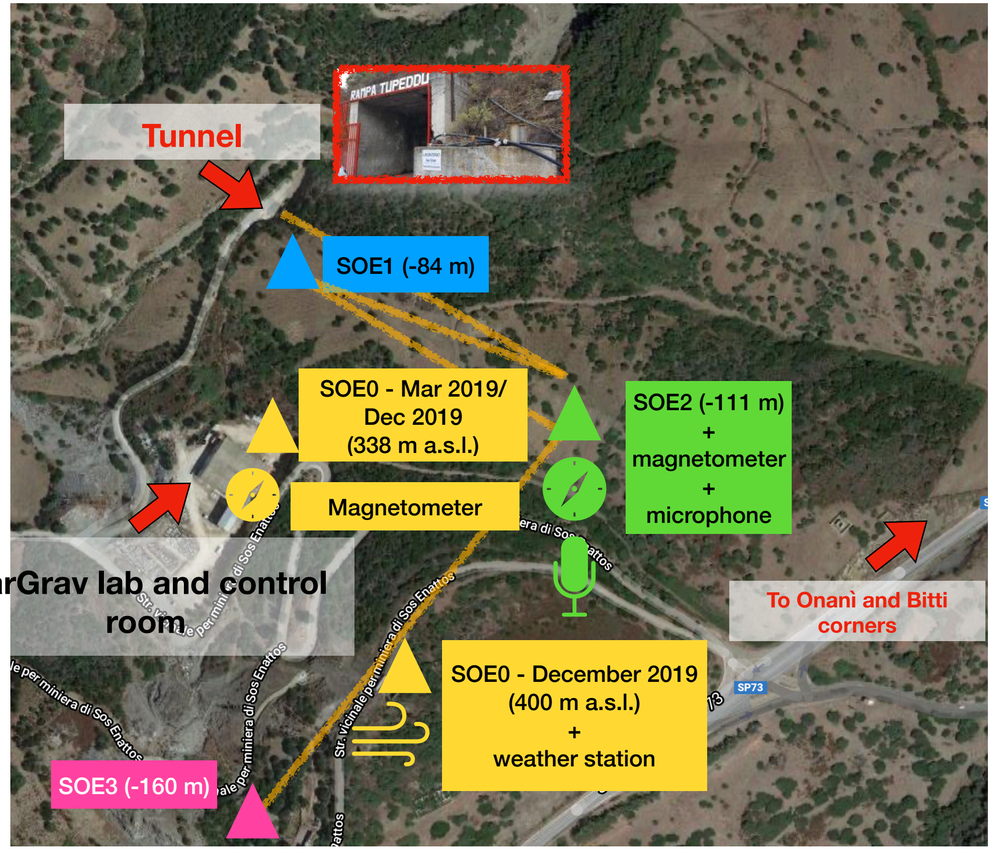
The Bitti corner



Permanent Instrument Network

Since 2019, in Sos Enattos there are:

- 4 permanent seismic stations for long term studies:
  - Surface: SOE0;
  - Underground: SOE1, SOE2, SOE3;
- 1 weather station;
- 1 microphone (SOE2)
- 2 magnetometers;
  - Surface: control room;
  - Underground: SOE2;
- All permanent seismic stations are provided with broadband seismometers (Trillium 240, 360 and 120 Horizon, Guralp 360);



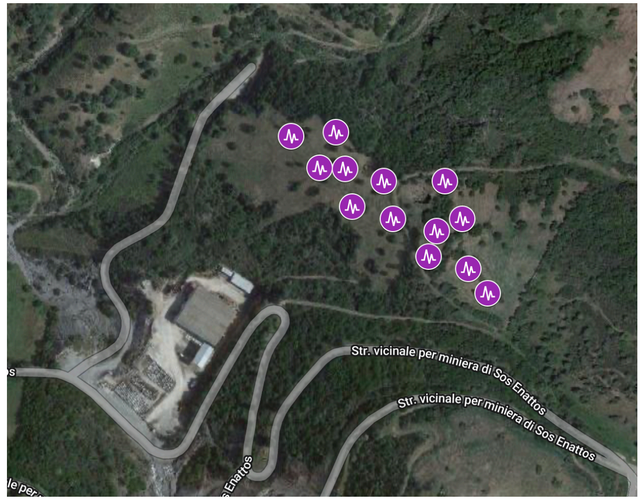
Permanent Instrument Network

In 2021, more permanent sensors have been installed at 2 of the proposed vertices (P2/3):

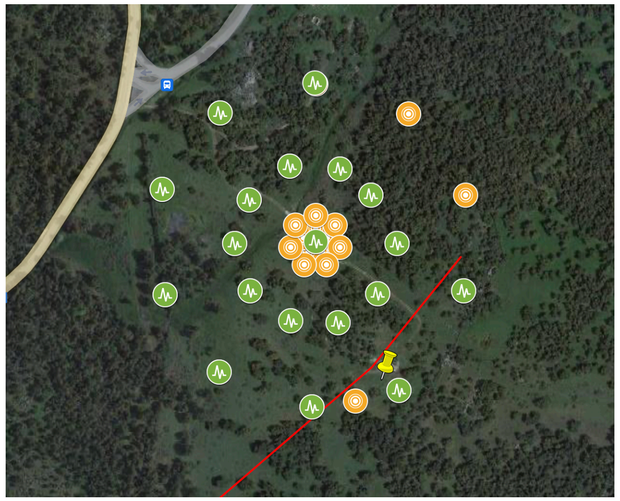
- 2 broadband seismometers on surface;
- 2 broadband seismometers in borehole;
- 1 magnetometer at P2

In the near future, more sensors will be installed also at P1.

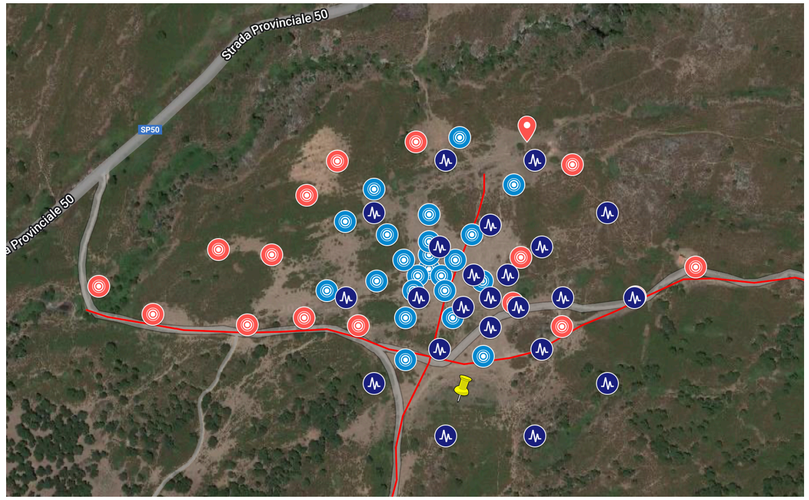
Temporary Deployments



Sos Enattos - Broadband array (January 2021)

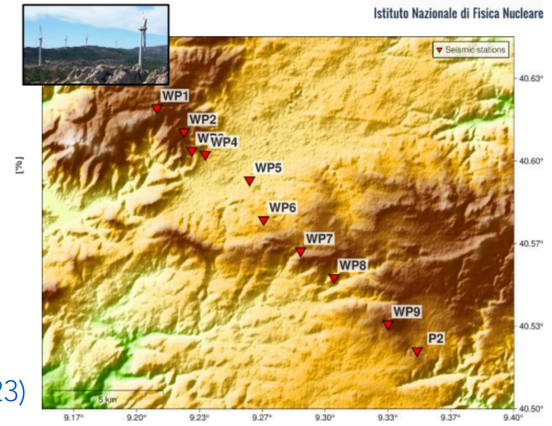


P2 broadband array + geophones (September 2021)



P3 broadband array + geophones (July & Oct 2021)

Aimed at characterization of the corners for seismic noise properties and NN purposes (correlation analysis).

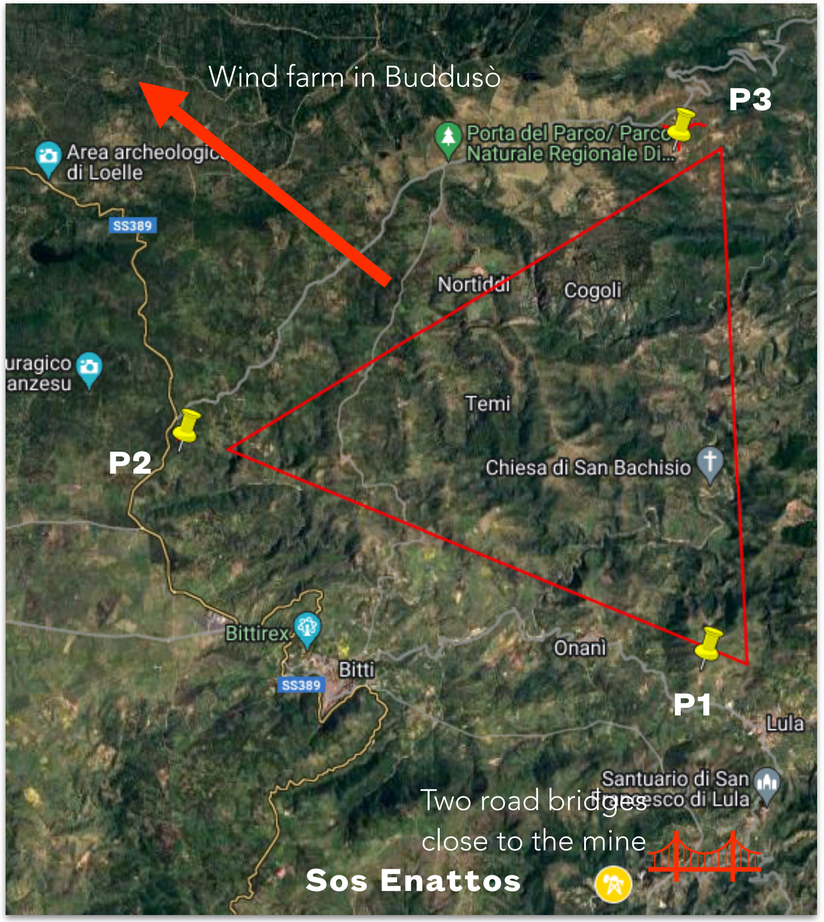


Broadband array (early 2023)

Potential noise sources

We identified some potential noise sources, both of natural and anthropic origin. Some of them have been clearly identified and characterized. Other are still being investigated to assess their contribution to the overall background noise in Sos Enattos.

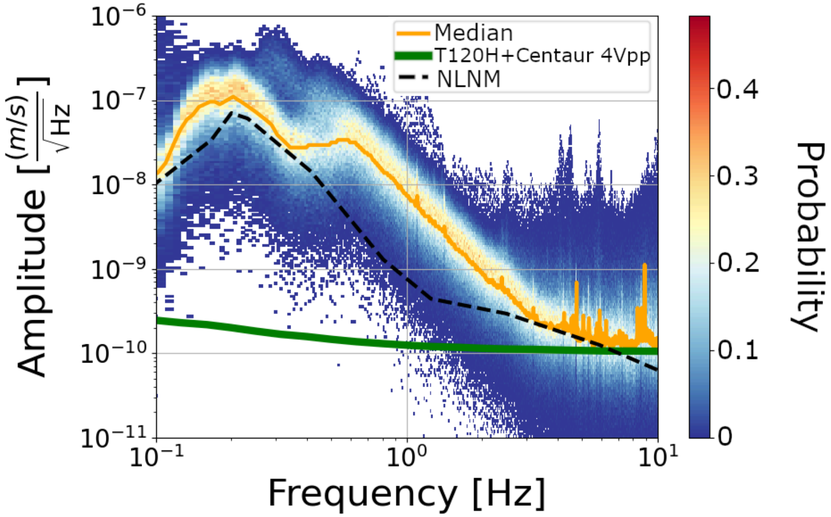
- Natural:
  - microseisms;
  - wind;
- Anthropic:
  - day/night cycle from human activities (mainly farming activities);
  - two road bridges in the neighborhood of the mine;
  - wind farms;
  - no other relevant infrastructures in the area.

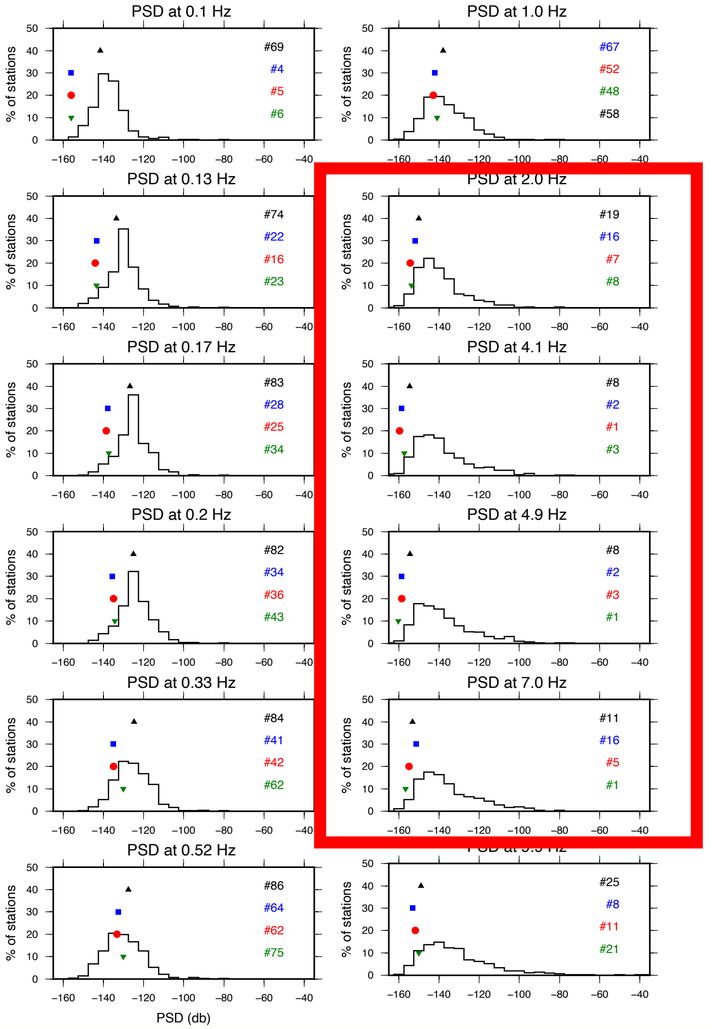


Noise levels

DOI 10.1093/gji/ggad178

- Noise level in Sardinia are very low and hit the self noise of the seismometers;
- The seismic stations have an excellent raking when compared against other quiet seismic stations all around the world;
- For more details see Naticchioni et al. (2014, 2020) and Di Giovanni et al. (2021, 2023)



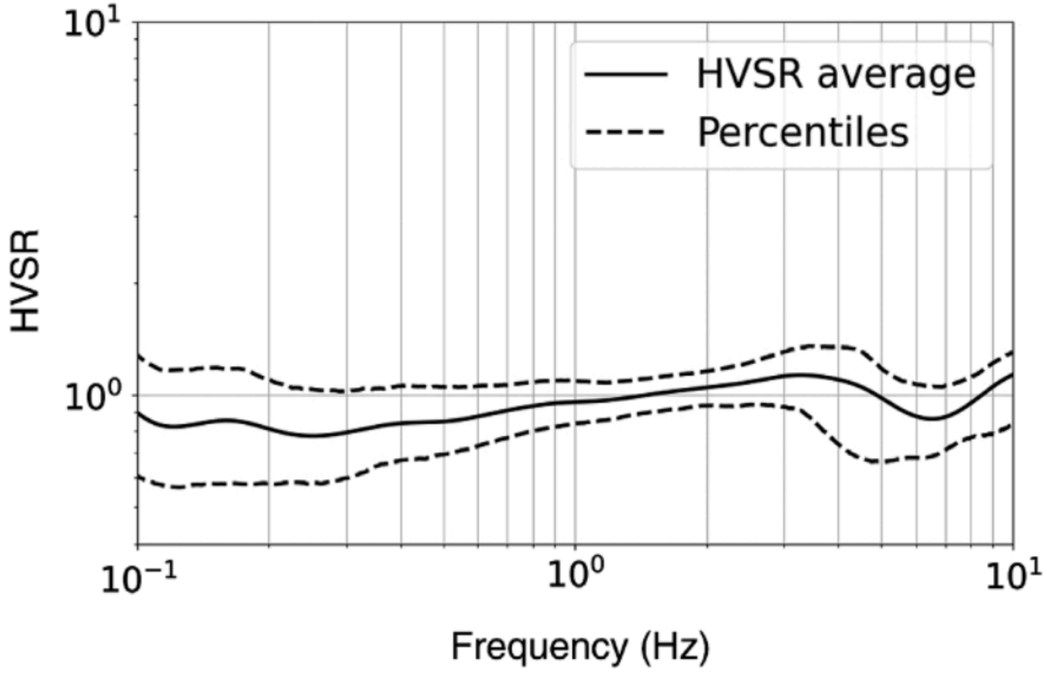


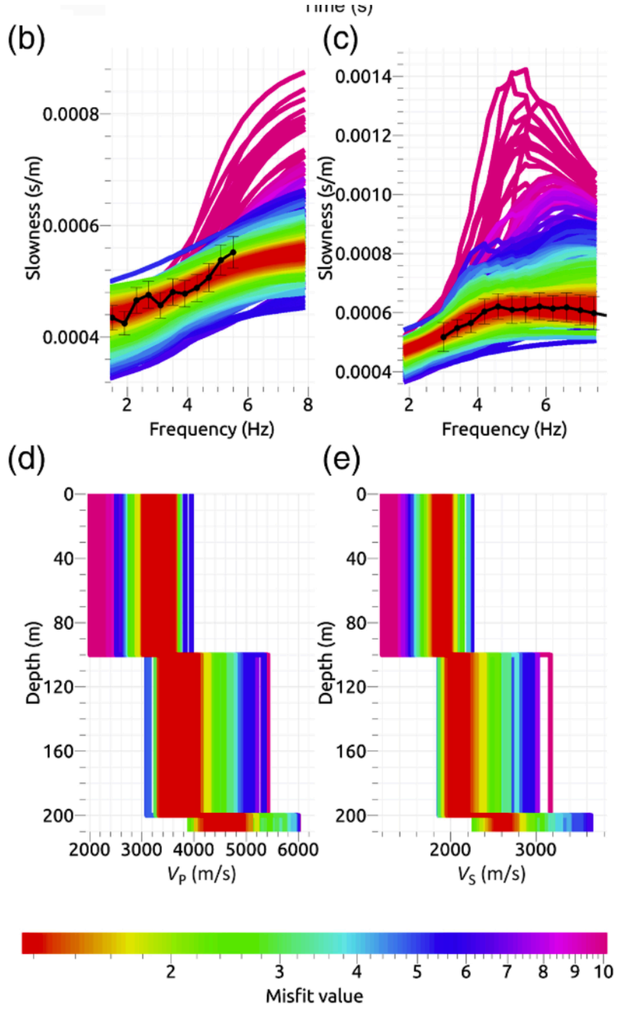
Seismic velocities

DOI 10.1785/0220200186

- Discontinuities in the composition of the underground layers may show up as resonances in the Horizontal-to-vertical spectra ratio;
- No peaks observed in Sos Enattos, using estimates of seismic velocities we get uniform soil up to 3 km underground

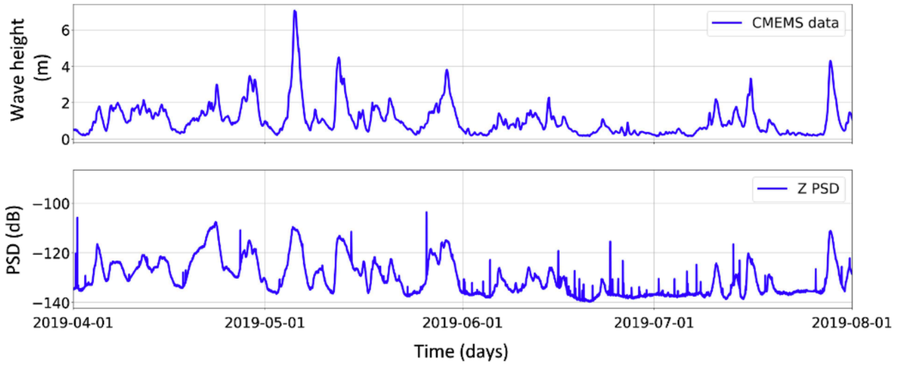
Same results at the vertexes





Ambient noise (natural sources)

- Using correlation and polarization analysis, we identified the region of the Mediterranean Sea that contributes the most to the generation of microseisms;
- The identified region is in agreement with previous seismological studies of the Mediterranean basin [Chevrot et al. 2007];



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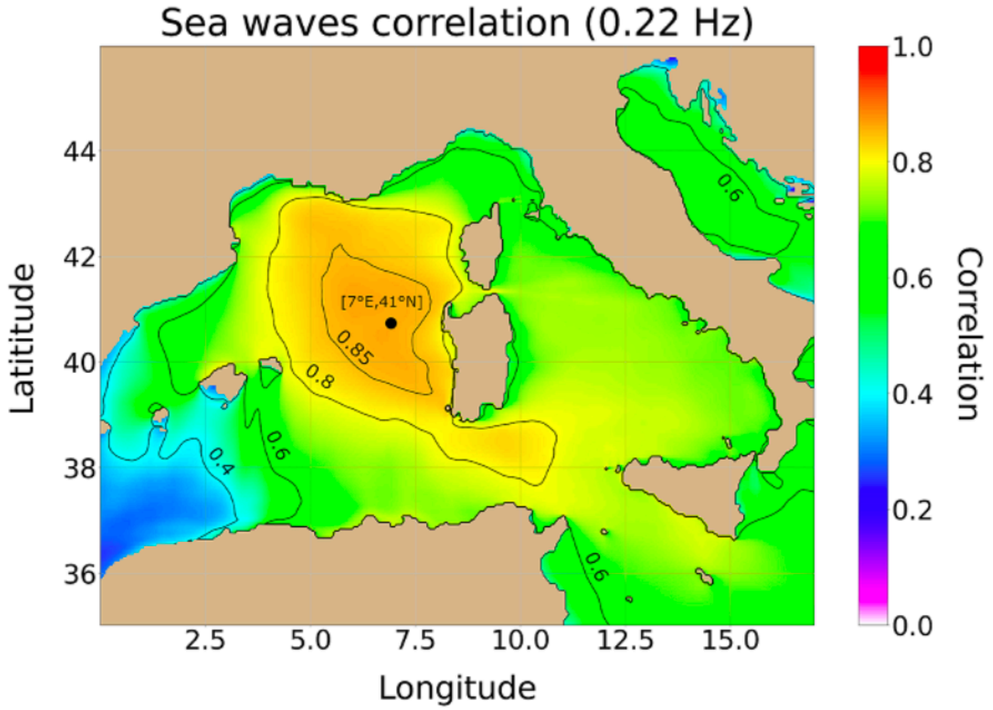

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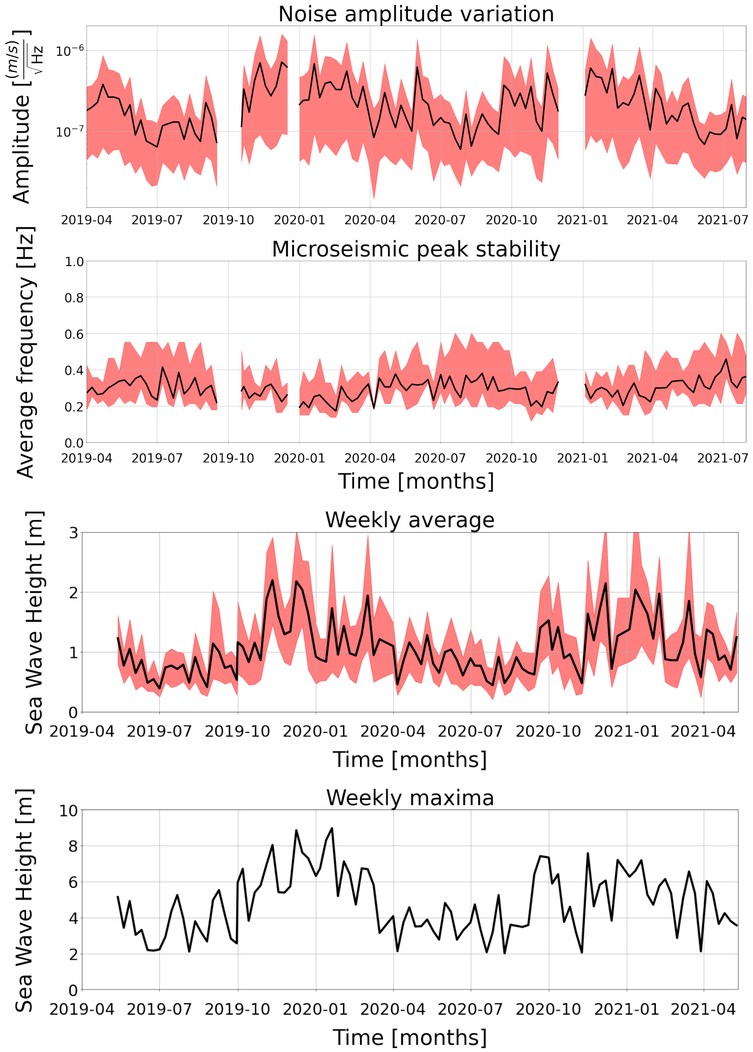
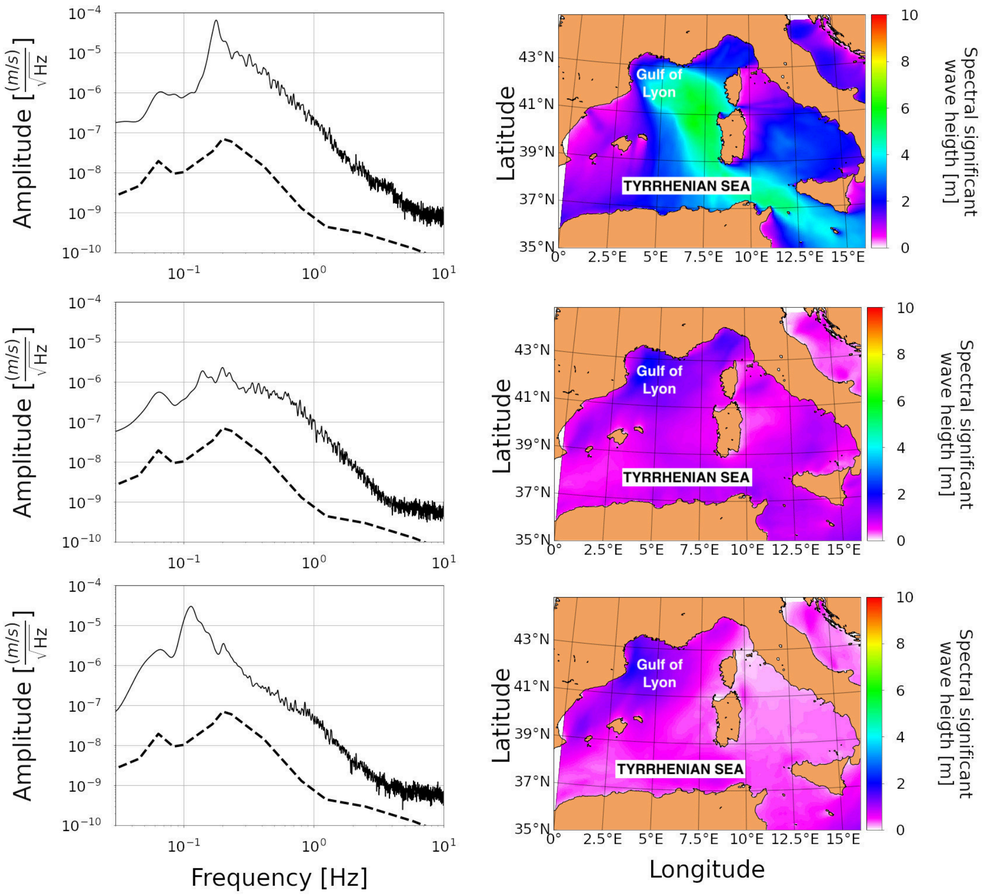
Ambient noise variations (natural sources)





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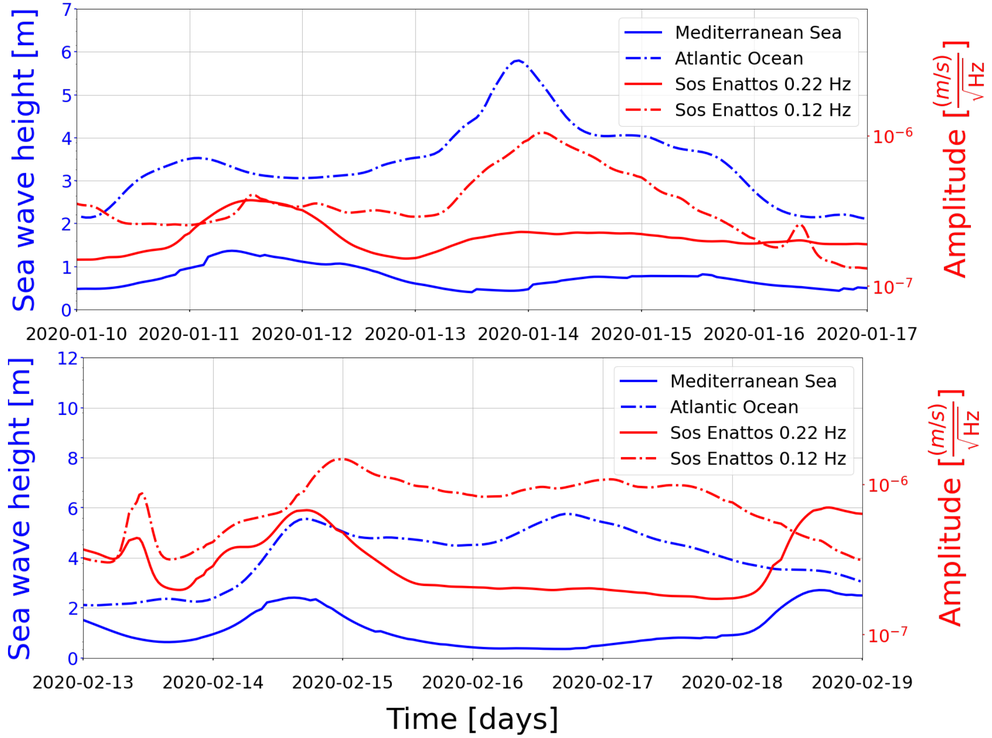
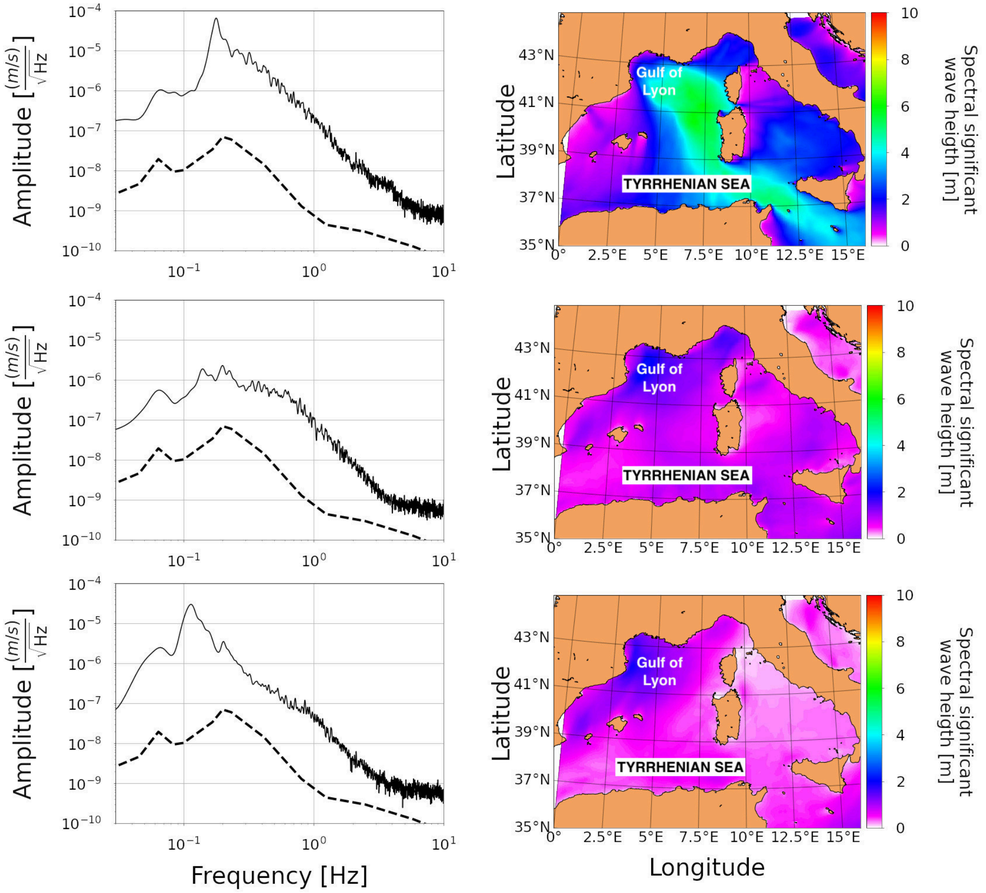
Ambient noise variations (natural sources)





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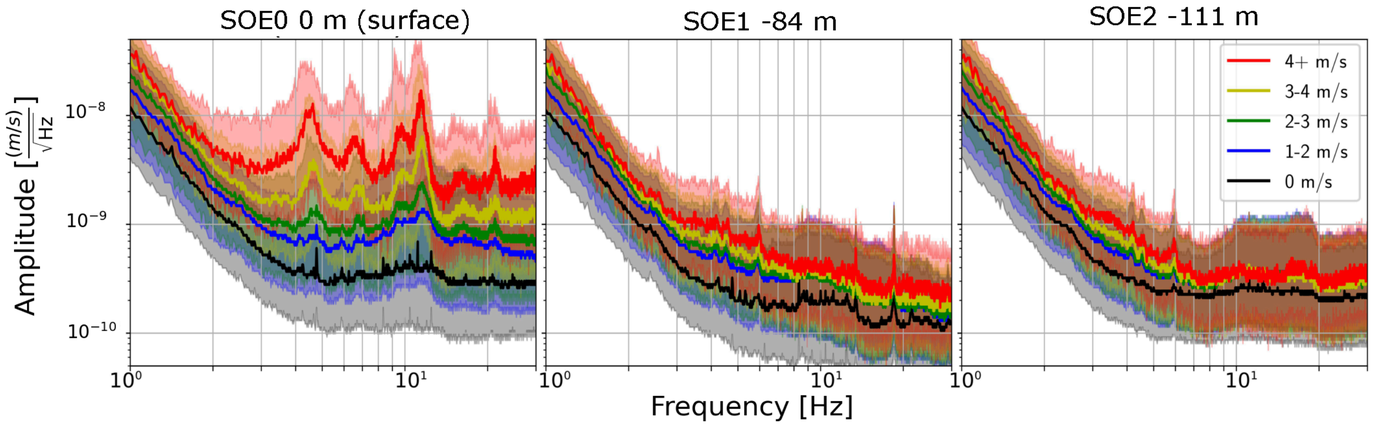
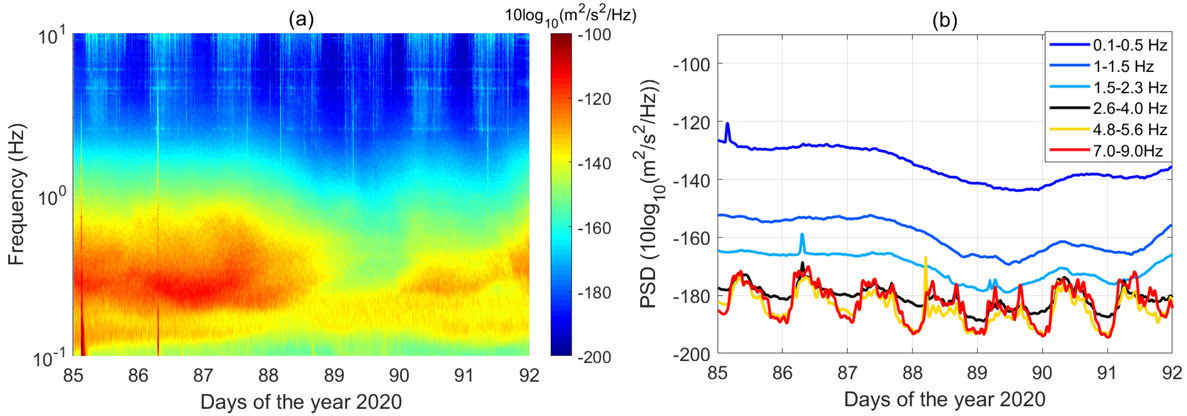
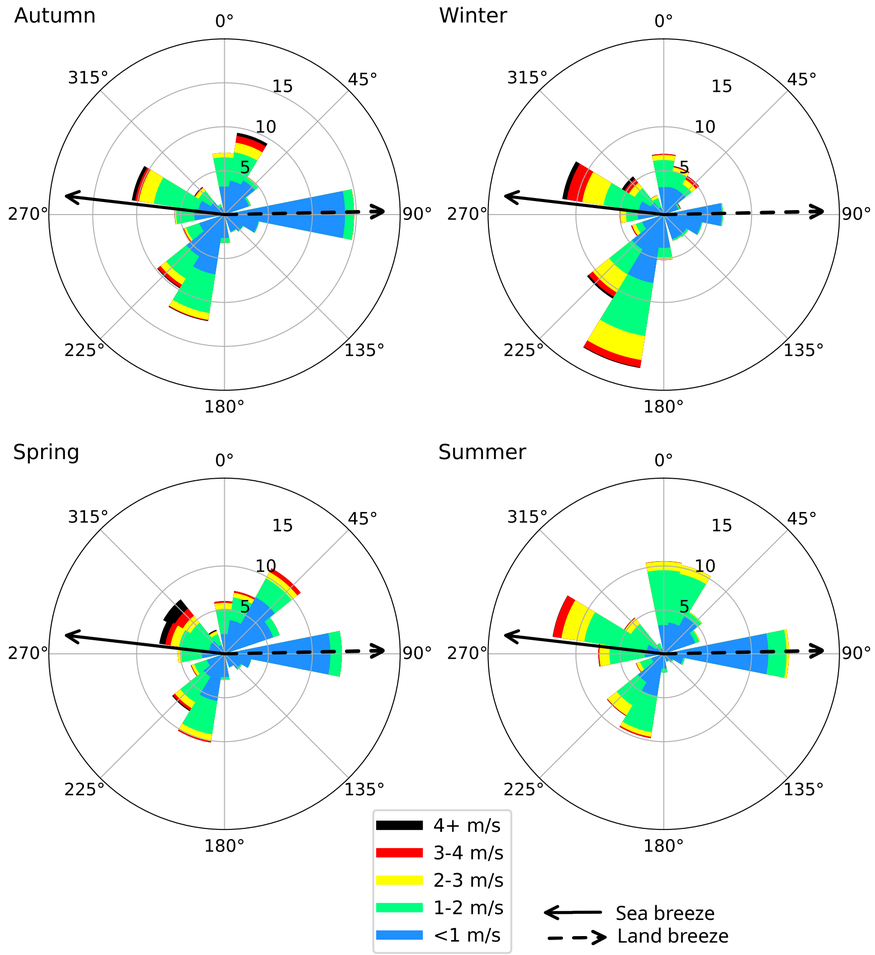
Ambient noise variations (natural sources)



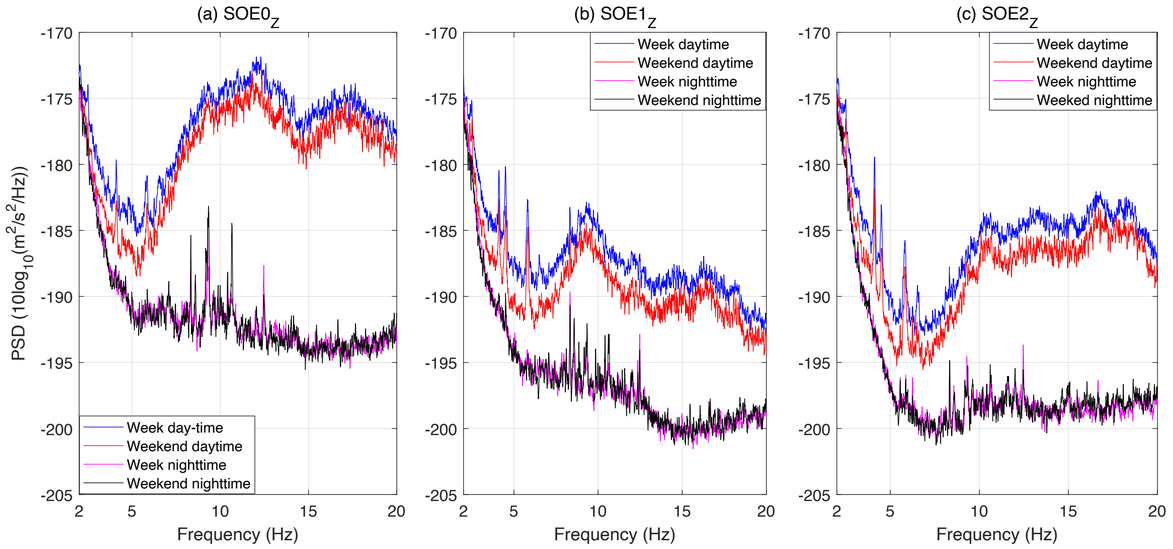
Wind effects



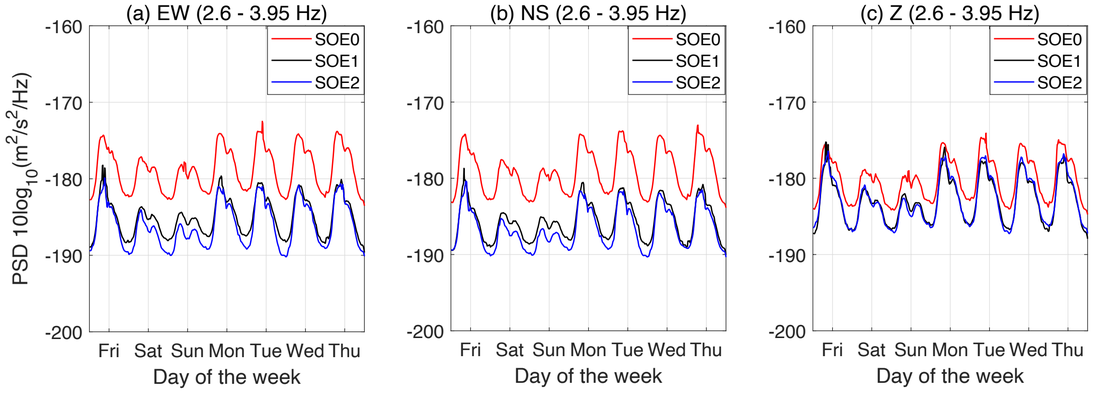
Natural to anthropogenic transition



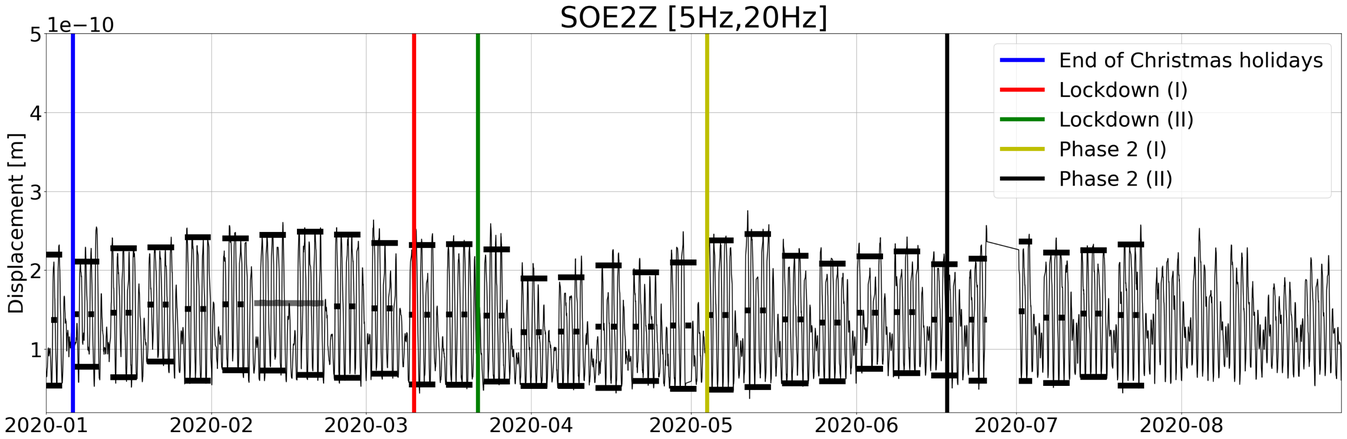
Ambient noise variations (anthropic sources)



Day/night - weekdays/weekend variations

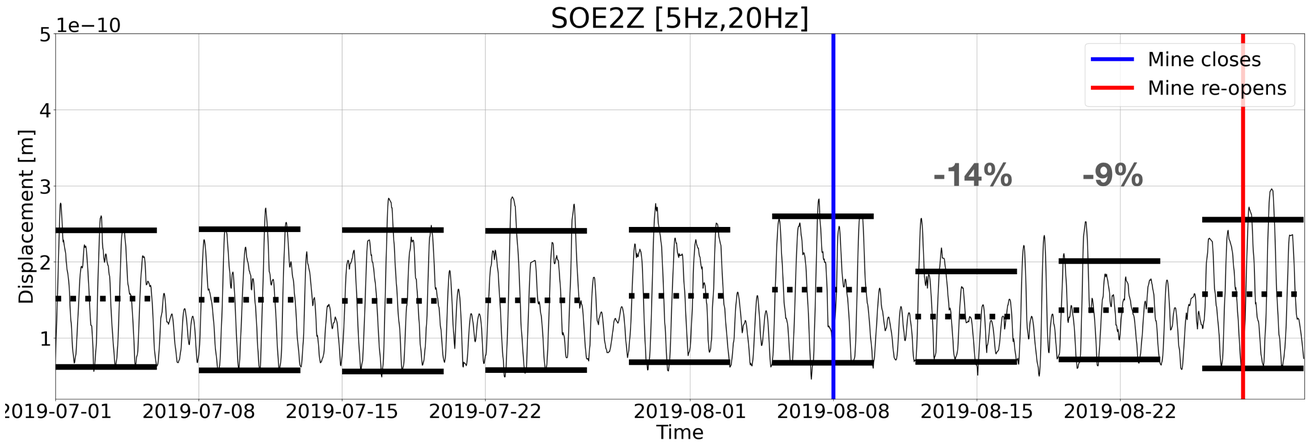


Ambient noise variations (anthropic sources)



Noise level variation during the 2020 COVID lockdown

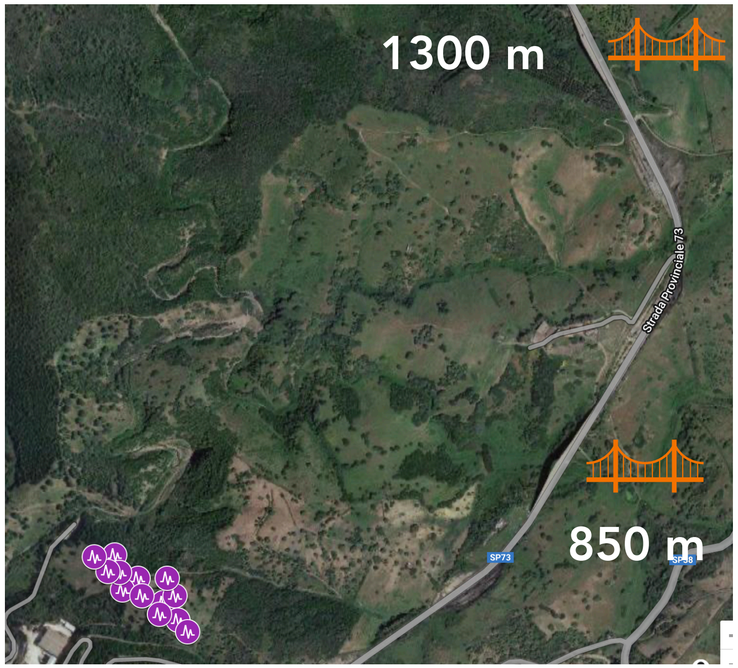
25% less anthropic noise during last week of lockdown with respect the the weeks before the lockdown.

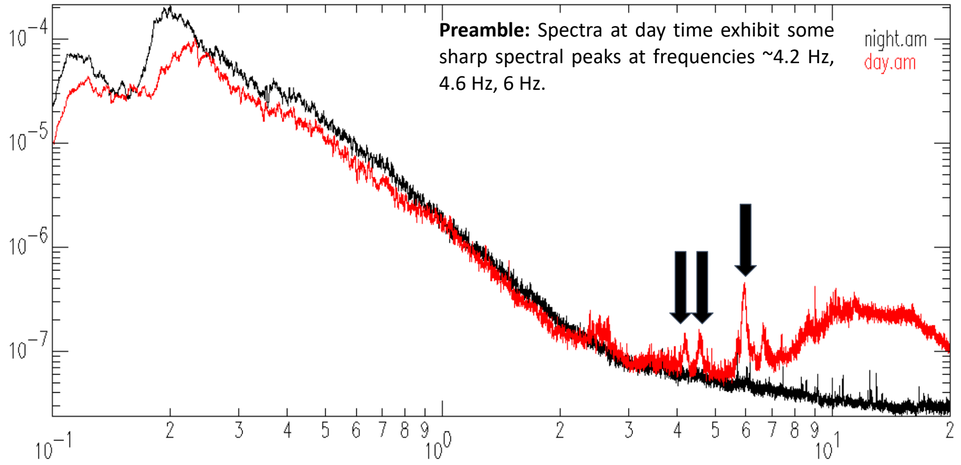


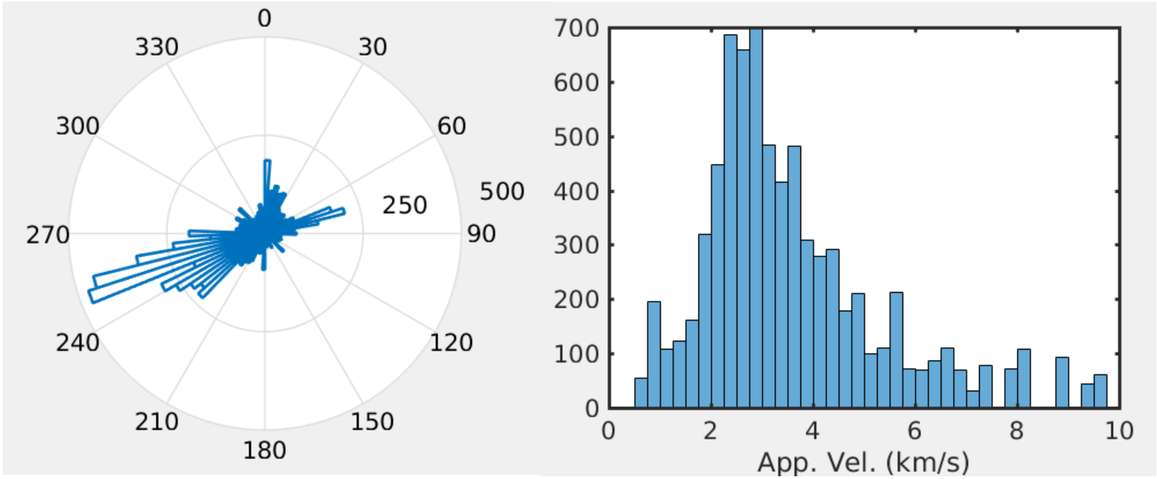
Noise level variation during the 2019 summer holidays

Identification of a noise source in Sos Enattos

- At the beginning of 2021, the deployment of a seismic array by INGV at Sos Enattos, revealed the presence of spectral peaks that seemed compatible with the presence of two road bridges nearby;





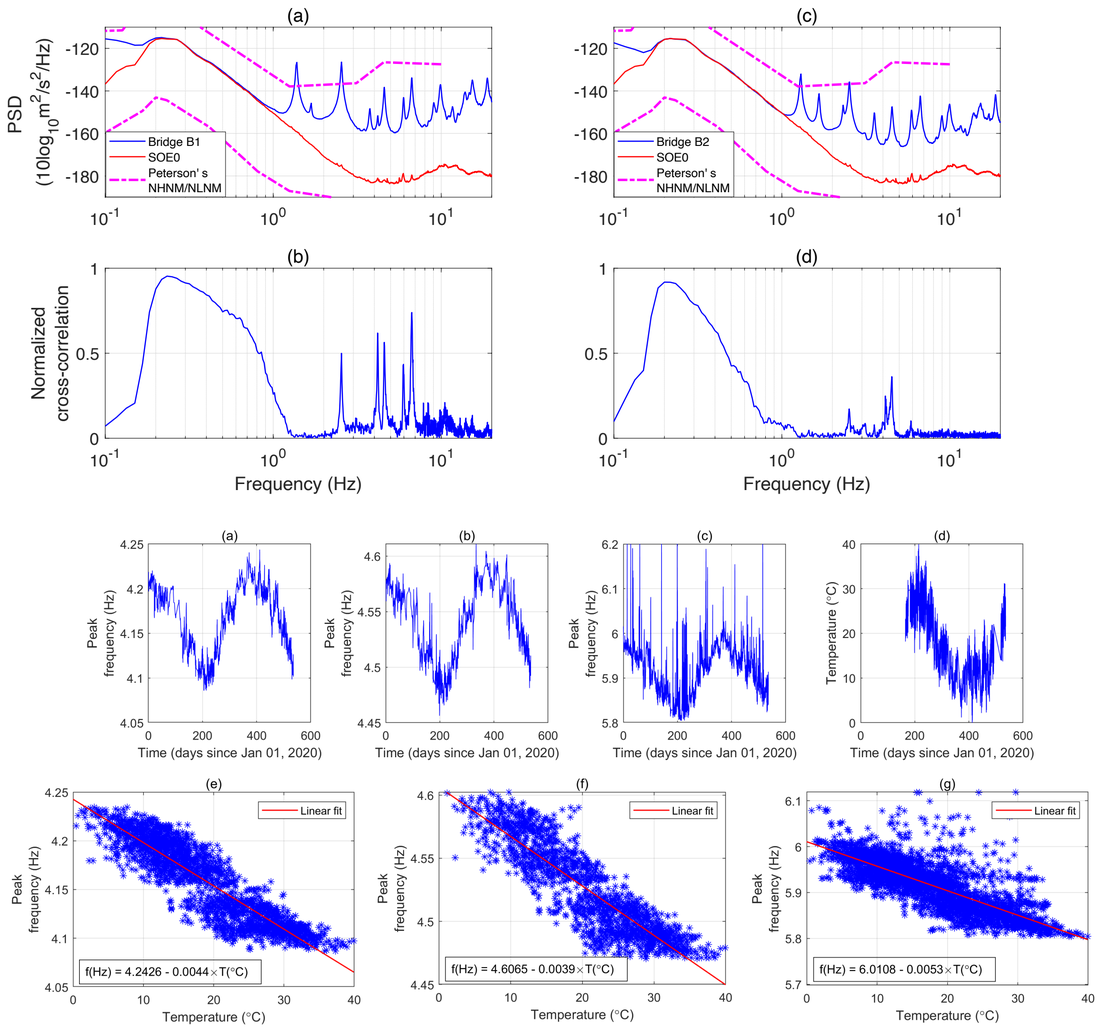


Identification of a noise source in Sos Enattos

- At the end of 2021, GSSI deployed 5 geophones for five days to confirm the origin of those peaks.

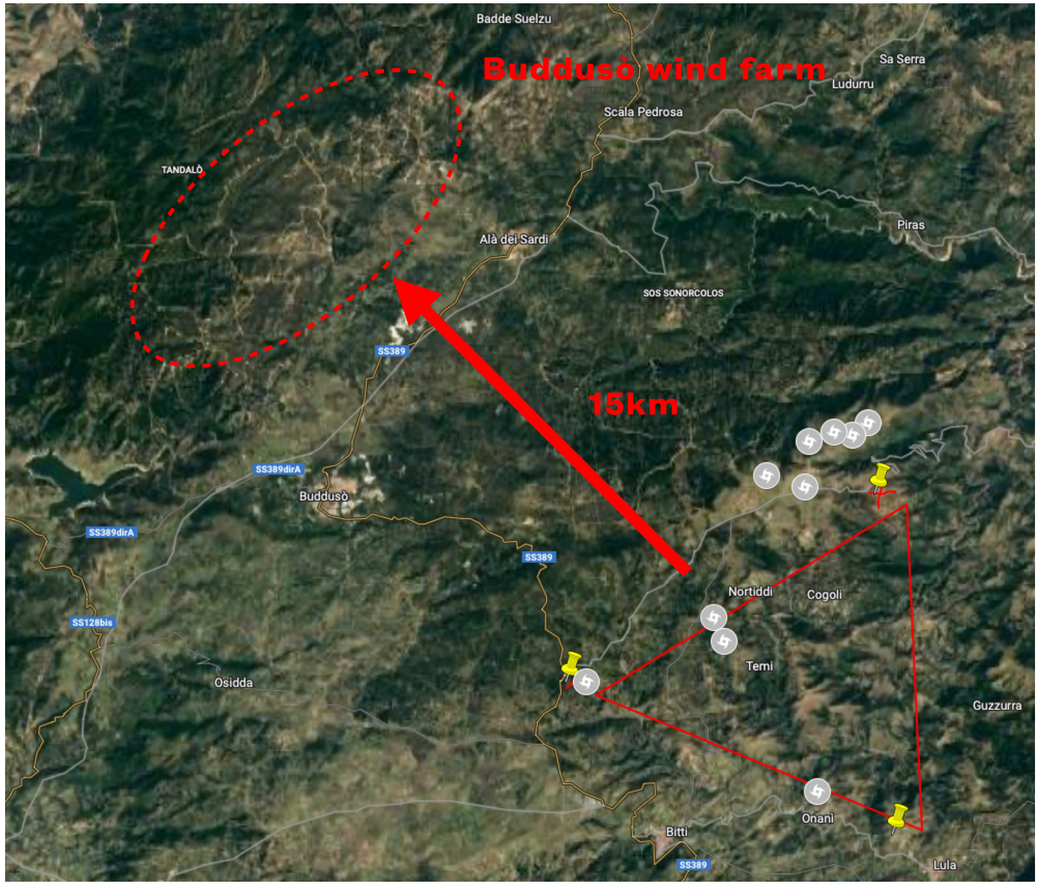
Identification of a noise source in Sos Enattos

- Spectral correlation confirmed the origin of those peaks;
- The distance of the bridges from the site is no more than 1.5 km;
- Those peaks also have a seasonal frequency drift with different rates;
- This may be caused by temperature variations that change the vibrational properties of the structures;
- Engineers observe drift to lower frequencies as the temperature increases and vice-versa as the temperature decreases;



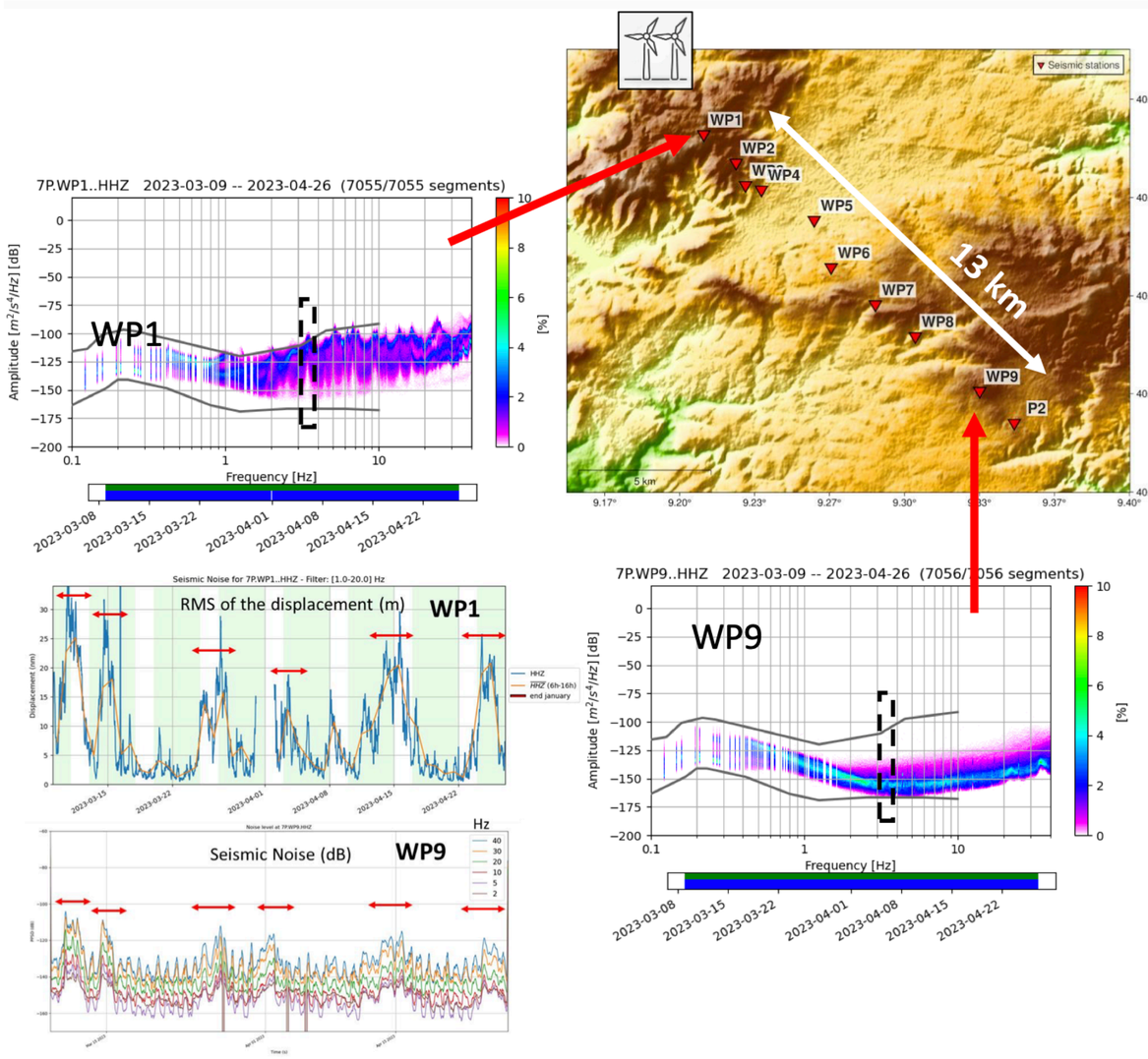
Wind turbines

- Some small wind turbines are located in the area close to P2 and P3;
- According to *Westwood et al. 2015*, noise from small low-power turbines exhibits a significant attenuation already at 200m;
- At the moment, the our attention is devoted to the Buddusò wind park, 15 km away;
- According to studies for the Virgo site (Saccorotti et al. 2011), big wind parks can produce peaks at less than 2.5 Hz and visible up to 10 km.



Wind turbines

- Recent deployment of a seismic array between the wind park and P2 issued the first results;
- Main peak at 3 Hz + harmonics
- At P2, that peak is still visibile but highly attenuated;
- Characterization of this noise source is ongoing;



Plots credits: Carlo Giunchi

Conclusions

- The Sardinia site is the object of a thorough site characterization campaign (see also other presentation of this session);
- Noise levels generally very low in the frequency band of interest for ET;
- Seismic ambient noise studies revealed which are the dominant noise sources at the site;
- Up to now, besides the day night cycle of normal human activities, the only clear source of noise of anthropic origin at the site are the two bridges at Sos Enattos;
- Studies to asses the contribution of the wind turbines are still underway.

BACK-UP

Permanent Instrument Network

March 2019 Start of long term site characterization

Dec. 2019: SOE0 sensor changed and moved to new location

2020

Jun 2020: walls of SOE2 room rebuilt for better insulation

Jul 2020: SOE1 sensor, data logger and gain settings updated

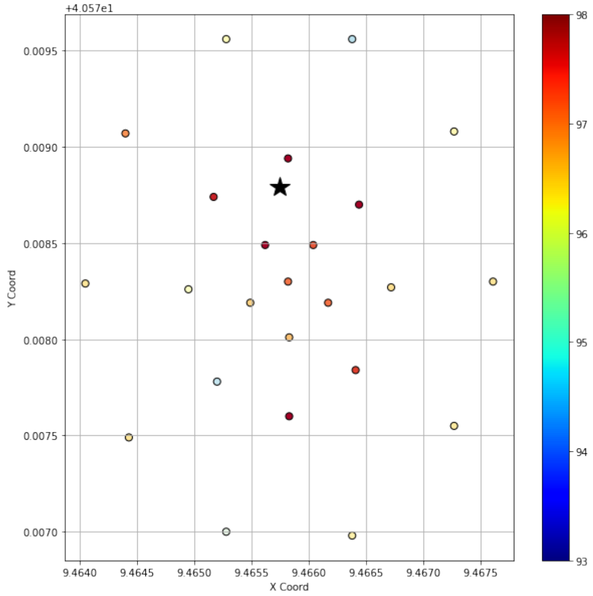
Aug 2020: SOE3 added to the network

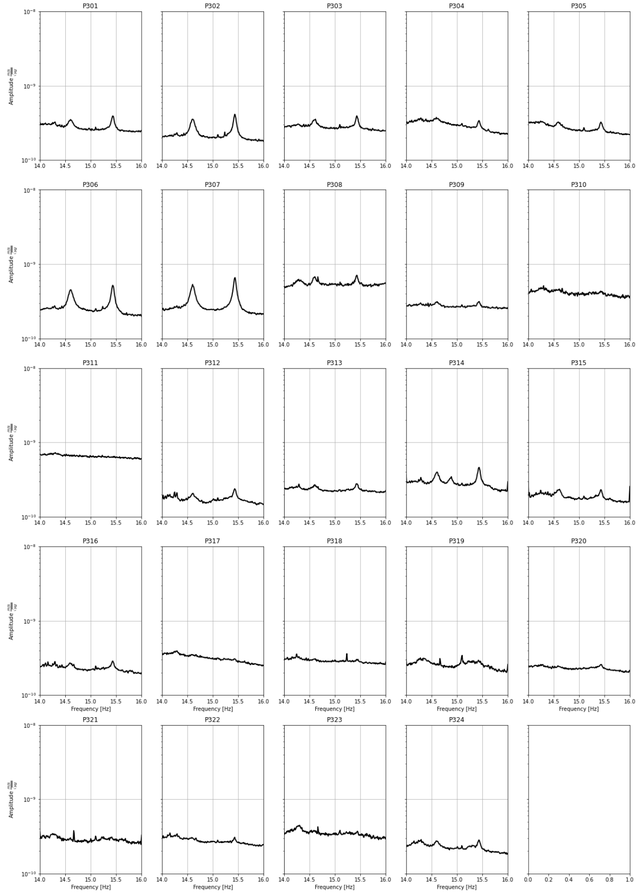
2021

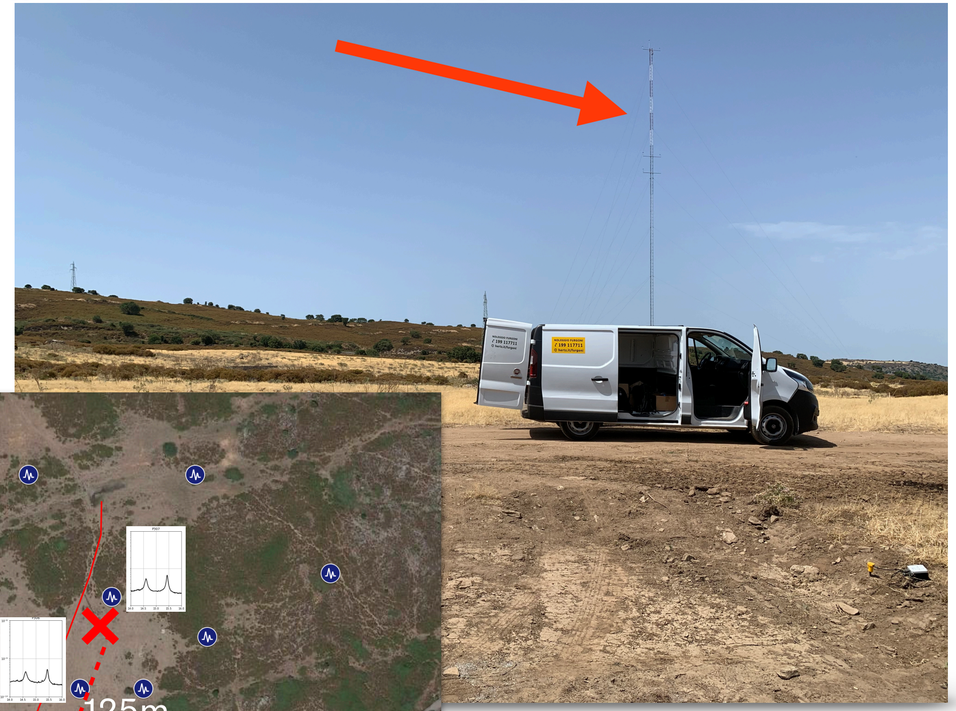
Jun 2021: SOE2 sensor changed

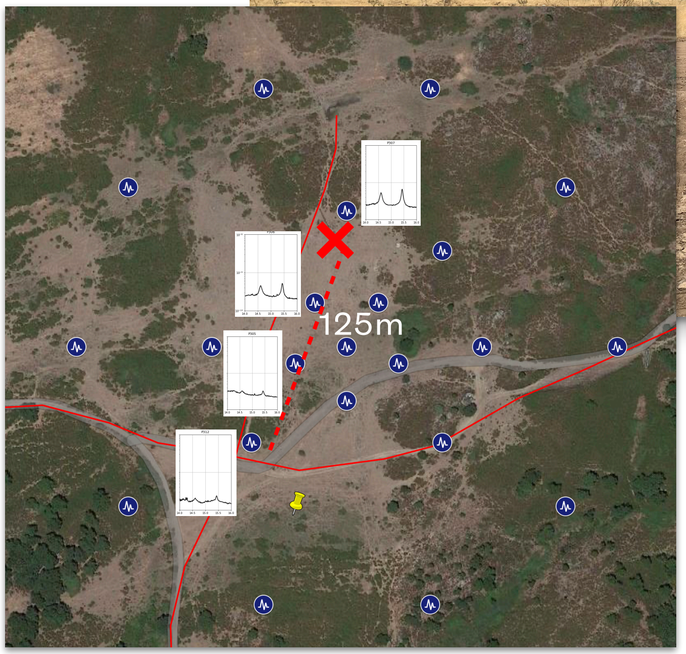
Jul 2021: SOE1 sensor changed

Identification of a noise source at P3

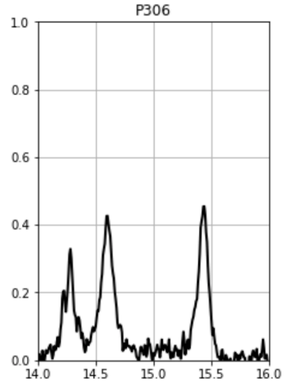


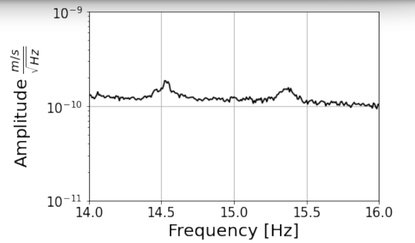






Right - spectral cross correlation between the two seismometers closest to the tower (about 20m each)





Up - Spectra from a geophone deployed in July 2021, about 15m away from the tower