Summary of long term seismic characterization activities at Sos Enattos

Matteo Di Giovanni

on behalf of the ET Sardinia site characterization team

Matteo Di Giovanni, Carlo Giunchi, Marco Olivieri, Gilberto Saccorotti, Luca Naticchioni, Giacomo Oggiano, Stefano Cuccuru, Massimo Carpinelli, Domenico D'Urso, Davide Rozza, Annalisa Allocca, Luciano Errico, Enrico Calloni, Alessandro Cardini, Aniello Grado, Luciano Di Fiore, Rosario De Rosa, Federico Paoletti, Irene Fiori, Soumen Koley, Tomislav Andric, Maria Tringali, Ettore Majorana, Maria Marsella, Piero Rapagnani, Jan Harms, Michele Punturo, Fulvio Ricci

Workshop on ET site studies and characterization

INFN Istituto Nazionale di Fisica Nucleare

uniss Università degli Studi di Sassari

Sapienza Università di Roma

Istituto Nazionale di Geofisica e Vulcanologia

Università degli Studi di Napoli Federico II

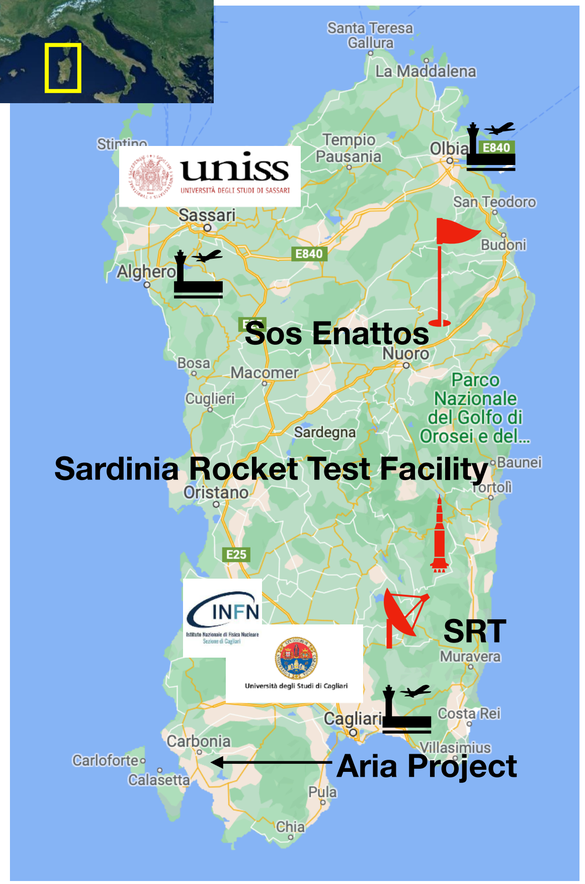
GSSI Gran Sasso Science Institute – School of Advanced Studies – Scuola Universitaria Superiore

Outline

- The Sos Enattos site and its seismic network;
- Summary of the results of the 2-year seismic characterization studies (2019-2021):
  - noise levels;
  - identification of possible noise sources;
  - effect of environmental variables over seismic measurements;
- Conclusions and open questions.

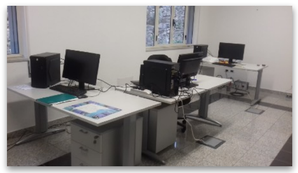
The Sos Enattos site

- Sos Enattos is a former lead and zinc mine active until the late 1990s;
- Today it is still maintained for environmental safety and guided tours and hosts the SargGrav laboratory.



Main well

Former mineral processing unit



SarGrav laboratory

The Sos Enattos site

If the configuration and orientation of ET will be confirmed, the triangle will be north of Sos Enattos with the corners hosted in remote locations.

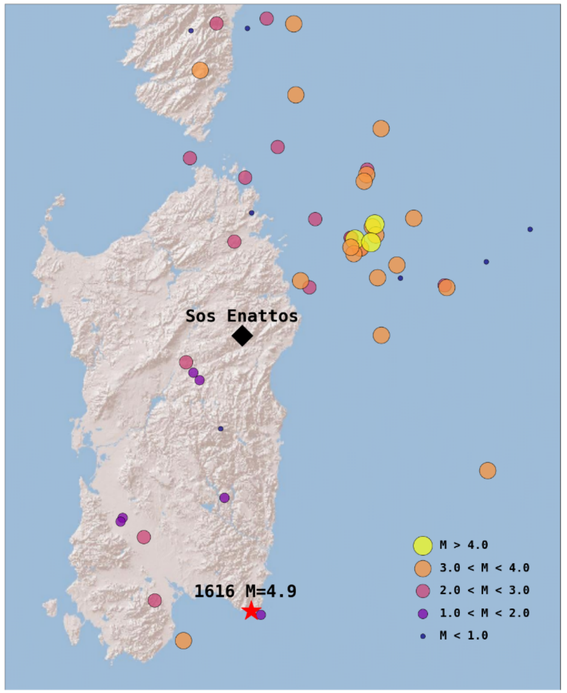
The Onanì corner

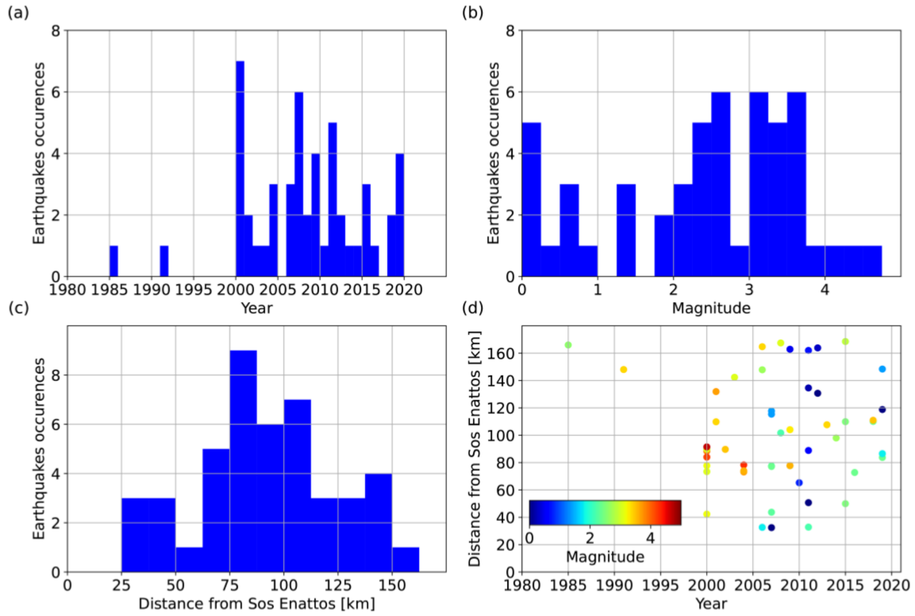
The Bitti corner

The Sos Enattos site

Earthquake occurence rate

- Sardinia has a very low seismic occurrence rate;
- Less than 7 events (M > 2) are recorded each year;
- On continental Italy we record between 2000 and 12000 events (M > 2) per year.

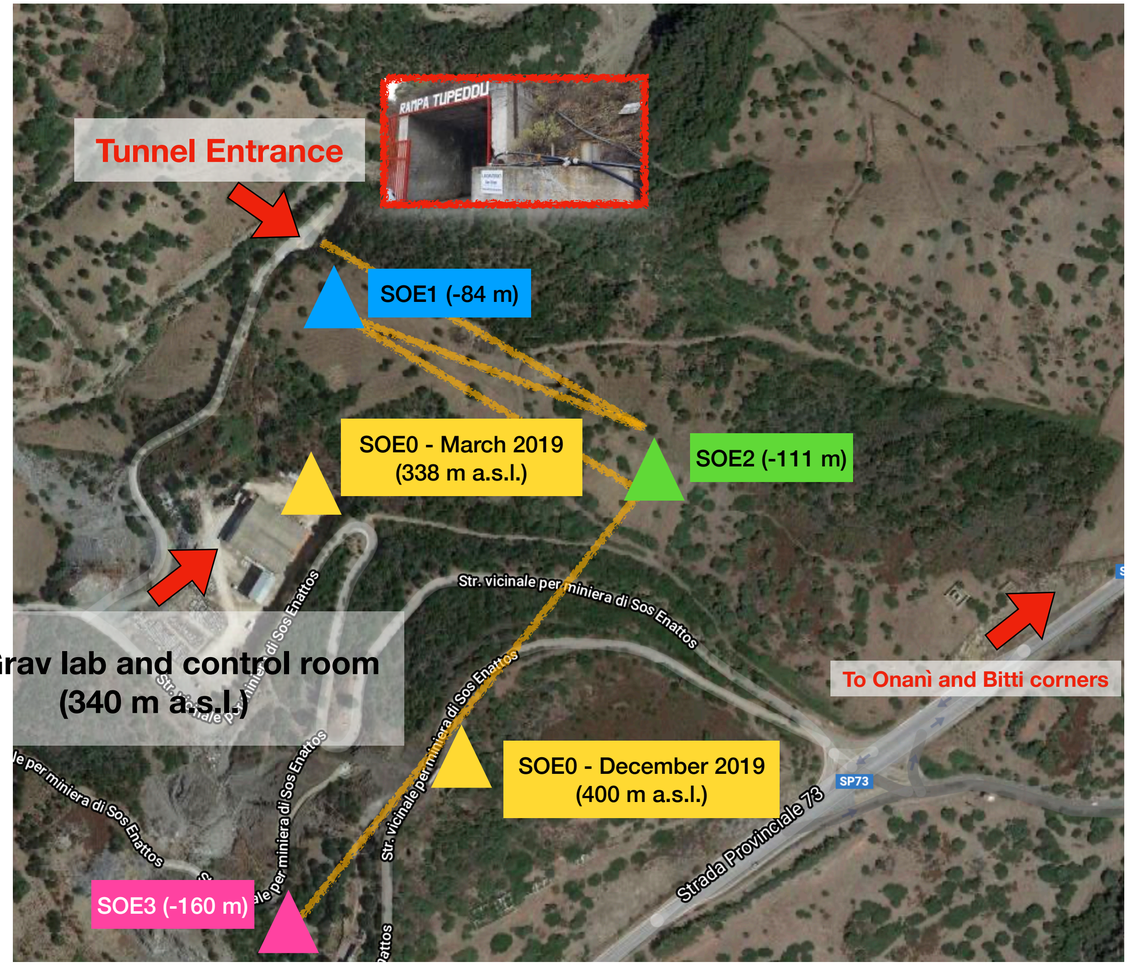




The Sos Enattos seismic network

Permanent seismic stations

- Seismic characterization of Sos Enattos started in 2010 with temporary installations;
- Since 2019, there are 4 permanent seismic stations for long term studies:
  - Surface: SOE0;
  - Underground: SOE1, SOE2, SOE3;
- All permanent seismic stations are provided with broadband seismometers (Trillium 240, 360 and 120 Horizon, Guralp 360);
- Plus weather station, 2 magnetometers, high precision tiltmeter (Archimedes experiment)…



The Sos Enattos seismic network

Permanent seismic stations

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

Jun 2020: walls of SOE2 room rebuilt for better insulation

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

Jun 2021: SOE2 sensor changed

Jul 2021: SOE1 sensor changed

Aug 2020: SOE3 added to the network

March 2019
Start of long term
site characterization

2020

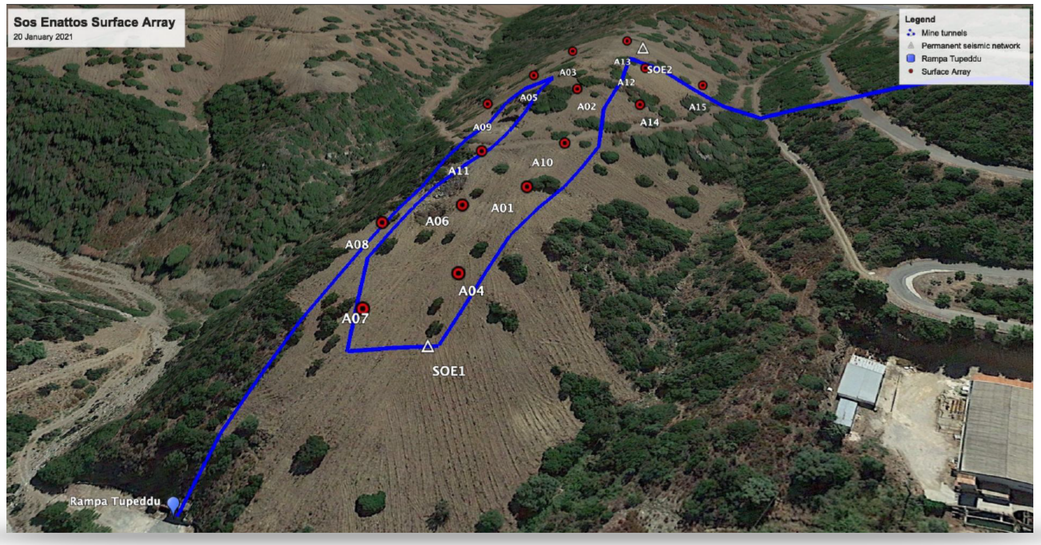
2021

The Sos Enattos seismic network

Surface arrays

November 2020: 3 Trillium 20s installed near SOE0 installed by UNISS-INFN

The details will be discussed in later talks



January 2021: 15 broadband sensors installed on the surface over the tunnels of Sos Enattos by INGV.

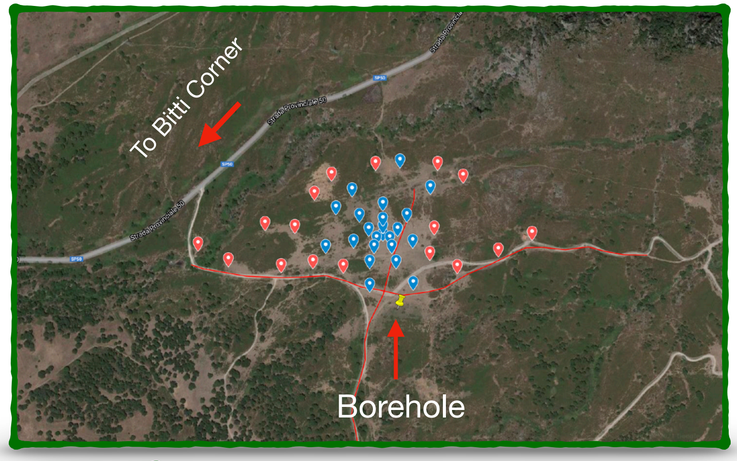
The Sos Enattos seismic network

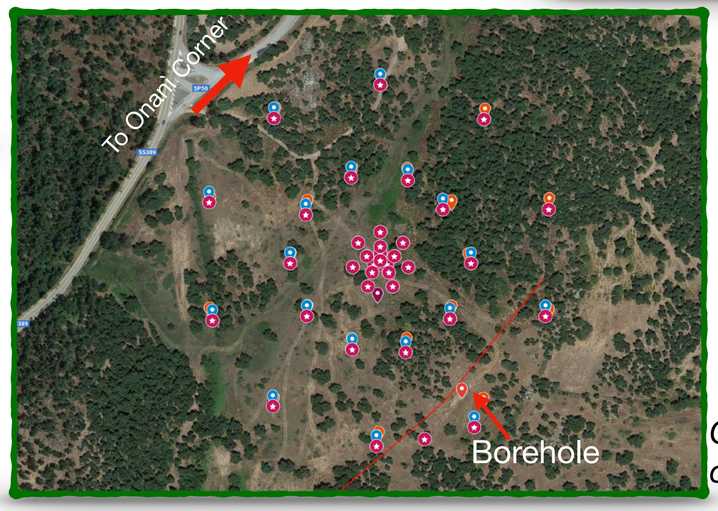
Surface arrays at Bitti and Onanì corners

The details will be discussed in later talks

Deployed by GSSI, INGV and KIT (July - September 2021)

GSSI geophone array at Onanì corner





GSSI geophone array + INGV array at Bitti corner

Sos Enattos characterization studies

First summary of long term seismic characterization studies was published online on *Seismological Research Letters* 1 year ago.

RESEARCH ARTICLE | NOVEMBER 04, 2020

A Seismological Study of the Sos Enattos Area—the Sardinia Candidate Site for the Einstein Telescope

Matteo Di Giovanni; Carlo Giunchi; Gilberto Saccorotti; Andrea Berbellini; Lapo Boschi; Marco Olivieri; Rosario De Rosa; Luca Naticchioni; Giacomo Oggiano; Massimo Carpinelli; Domenico D'Urso; Stefano Cuccuru; Valeria Sipala; Enrico Calloni; Luciano Di Fiore; Aniello Grado; Carlo Migoni; Alessandro Cardini; Federico Paoletti; Irene Fiori; Jan Harms; Ettore Majorana; Piero Rapagnani; Fulvio Ricci; Michele Punturo

Seismological Research Letters (2021) 92 (1): 352–364.

https://doi.org/10.1785/0220200186 **Article history**

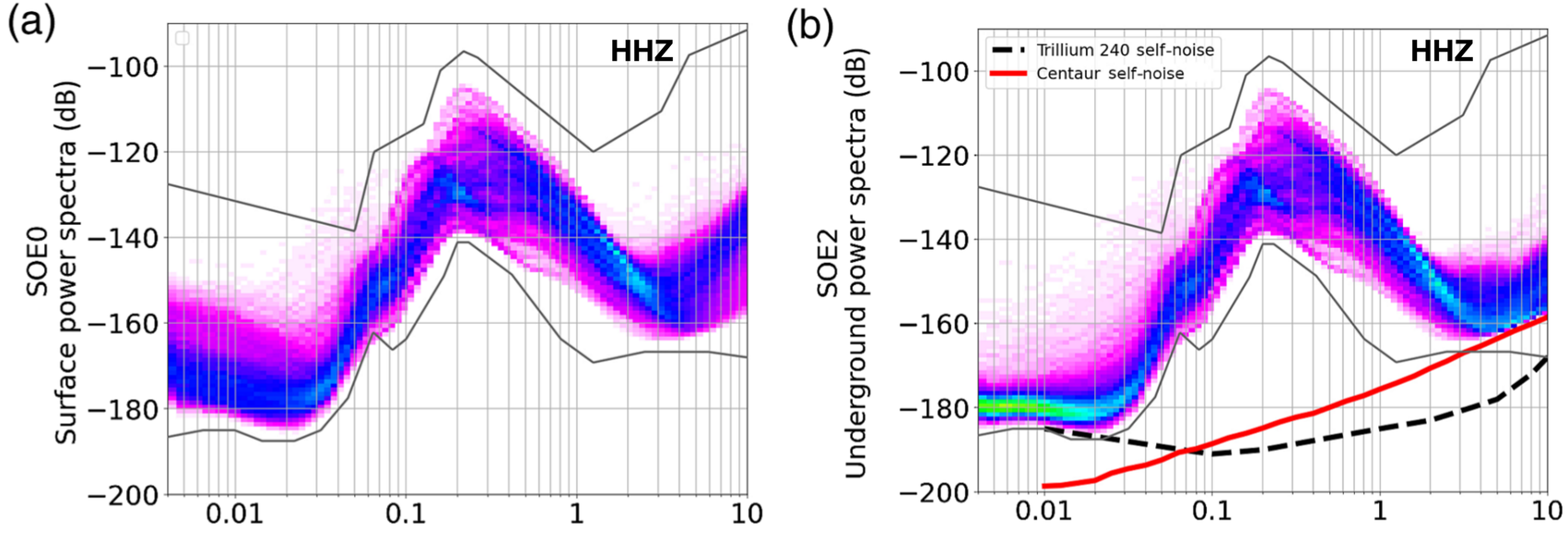
Abstract

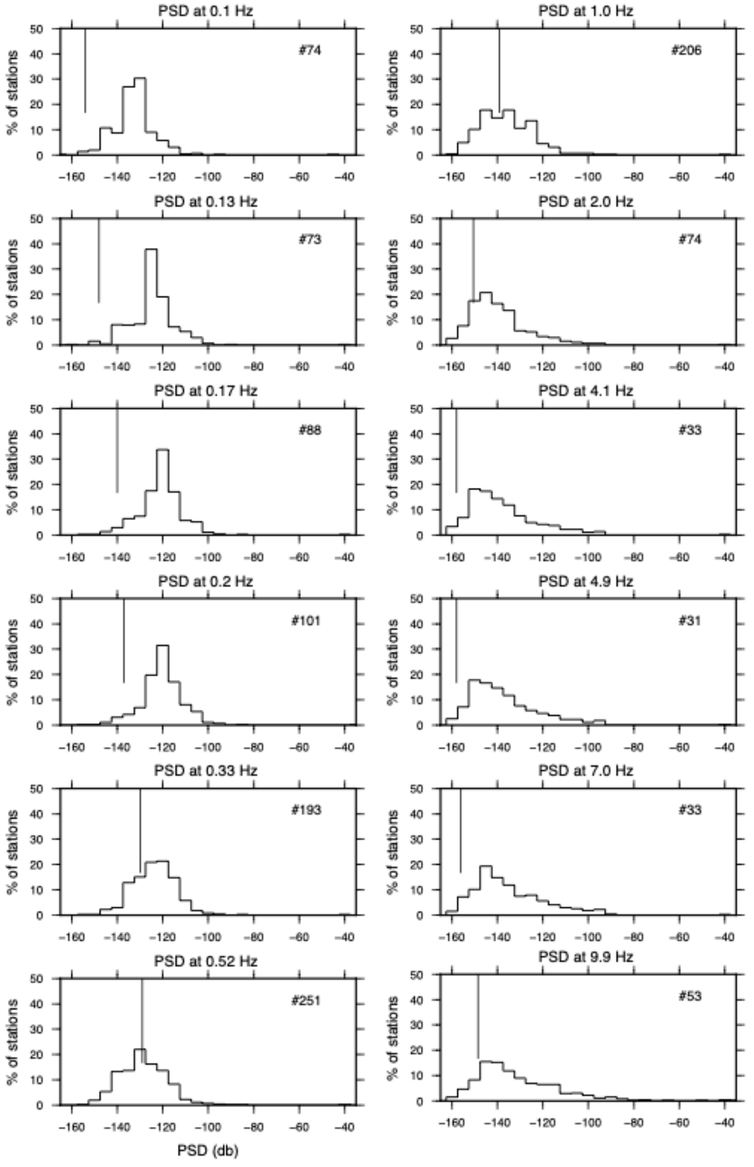
The recent discovery of gravitational waves (GWs) and their potential for cosmic observations prompted the design of the future third-generation GW interferometers, able to extend the observation distance for sources up to the frontier of the Universe. In particular, the European detector Einstein Telescope (ET) has been proposed to reach peak strain sensitivities of about 3×10^{-25} $\mathrm{Hz}^{-1/2}$ in the 100 Hz frequency region and to extend the detection band down to 1 Hz. In the bandwidth [1,10] Hz, the seismic ambient noise is expected to represent the major perturbation to interferometric measurements, and the site that will host the future detectors must fulfill stringent requirements on seismic disturbances. In this article, we conduct a seismological study at the Italian ET candidate site, the dismissed mine of Sos Enattos in Sardinia. In the range between few mHz to hundreds of mHz, out of the detection bandwidth for ET, the seismic noise is compatible with the new low-noise model (Peterson, 1993); in the [0.1,1] Hz bandwidth, we found that seismic noise is correlated with sea wave height in the northwestern Mediterranean Sea. In the [1,10] Hz frequency band, noise is mainly due to anthropic activities; within the mine tunnels ($\simeq 100$ m underground), its spectrum is compliant with the requirements of the ET design. Noise amplitude decay with depth is consistent with a dominance of Rayleigh waves, as suggested by synthetic seismograms calculated for a realistic velocity structure obtained from the inversion of phase- and group-velocity dispersion data from array recording of a mine blasting. Further investigations are planned for a quantitative assessment of the principal noise sources and their spatiotemporal variations.

Sos Enattos characterization studies

Spectra

Acceleration spectra



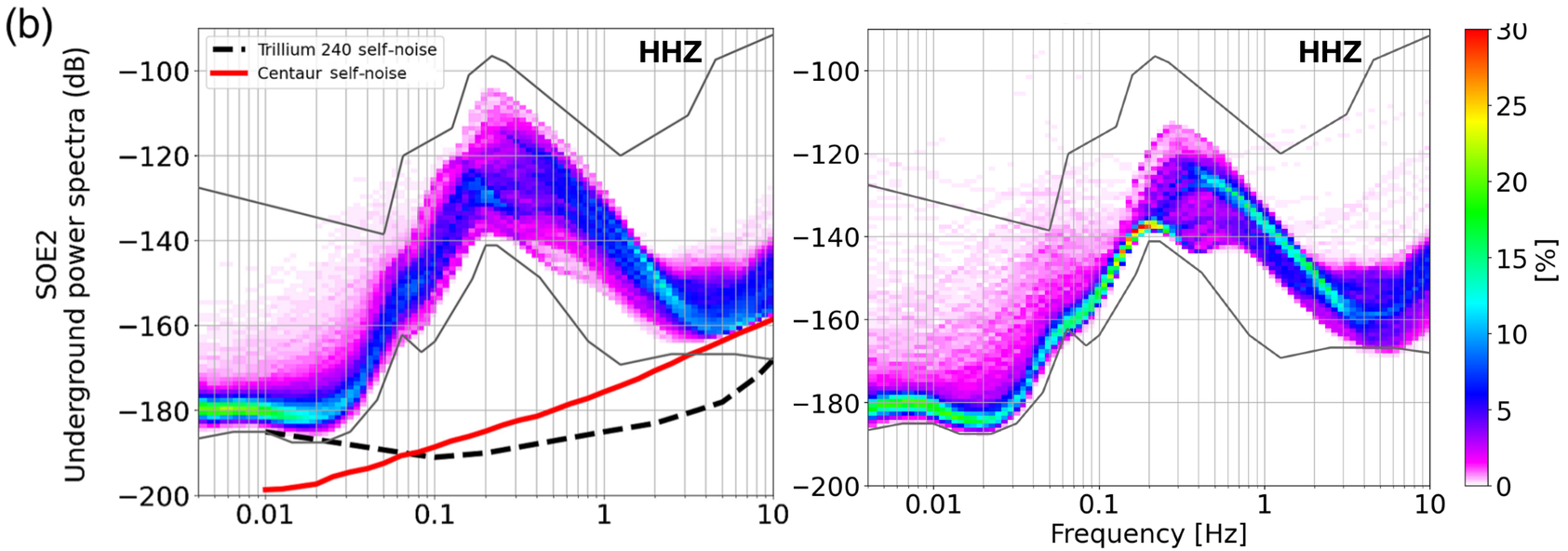


- Extremely low noise conditions in the 2 Hz - 10 Hz band;
- Underground, seismic noise hits the noise floor of the DAQ;
- SOE2 had low-gain settings to be compliant to the national earthquake monitoring program.

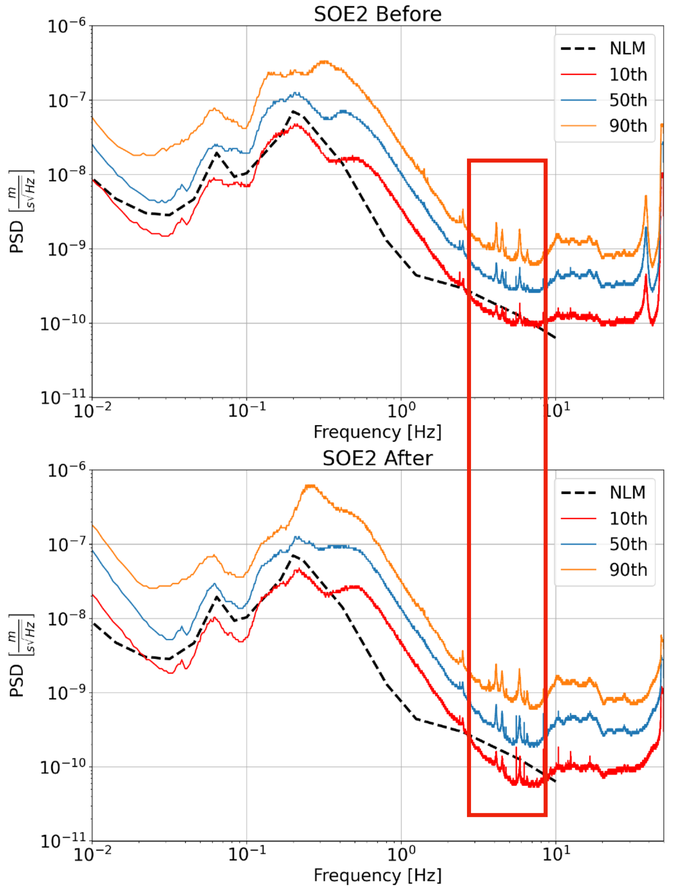
Sos Enattos characterization studies

Spectra

Acceleration spectra



Velocity spectra



Improvement in the 3 Hz - 9 Hz bucket
(1 week before and 1 week after gain change)

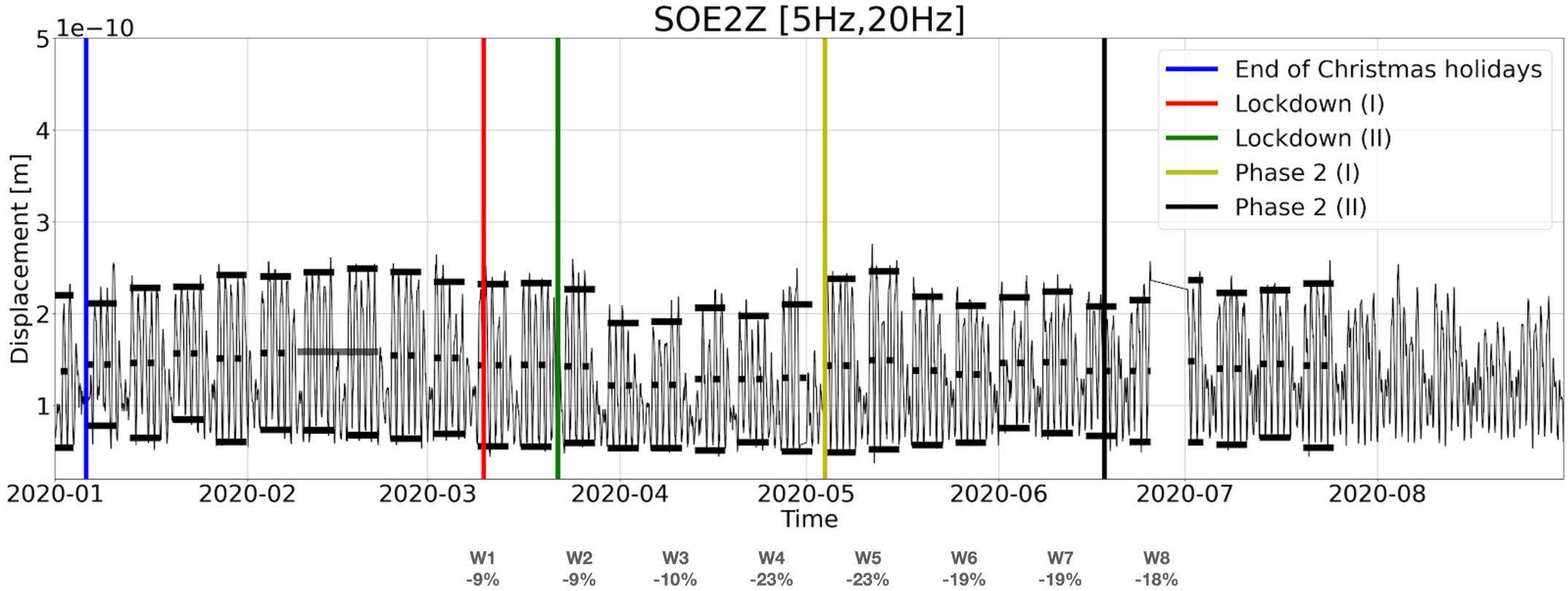
Changes in the gain settings (Jun. 2021) improved data quality at SOE2.

The same can be seen also at SOE1 after the gain was changed in June 2020.

Sos Enattos characterization studies

Estimating human contribution to ambient noise

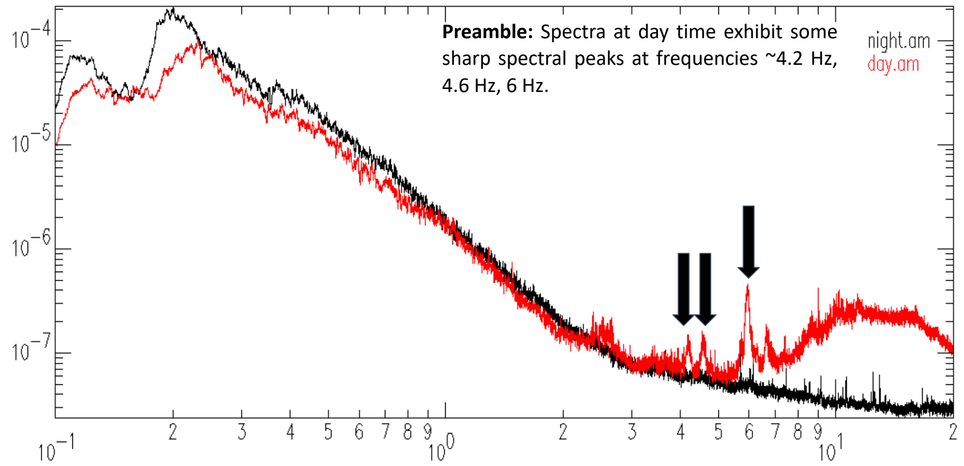
Procedure proposed by Piccinini et al. (2020)

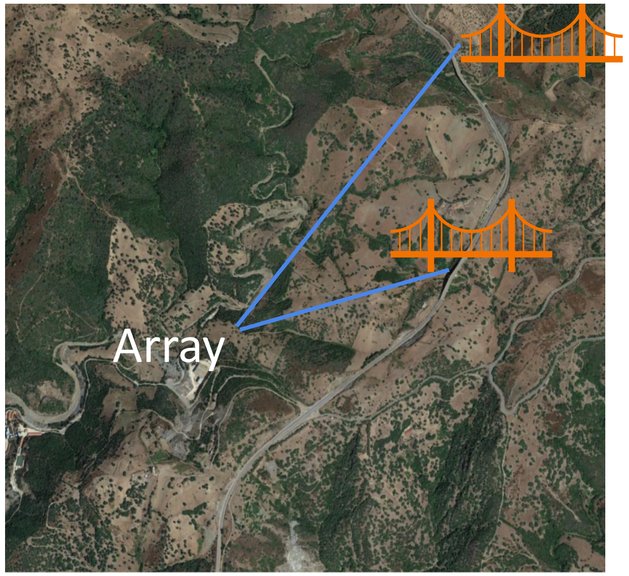


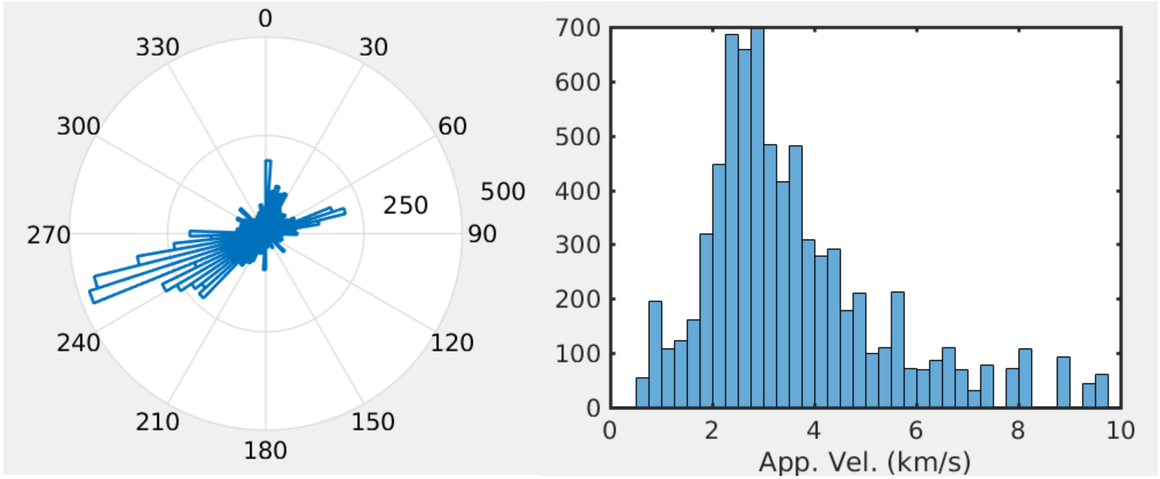
Ambient noise drop consistent with other studies concerning the effects of lock downs all over Europe on ambient seismic noise (Poli et al., 2020; Lecocq et al., 2020; Piccinini et al., 2020).

Sos Enattos characterization studies

Other possible human noise sources (credits: G. Saccorotti)







Propagation azimuths directed WSW (i.e., main sources located ENE of the array)

Further analysis of the time evolution of the azimuth suggests that it is compatible with a vehicle traveling at 60 km/h southward along road SP73.

Sos Enattos characterization studies

Other possible human noise sources

We deployed 2 geophones at each bridge plus 1 next to SOE0.

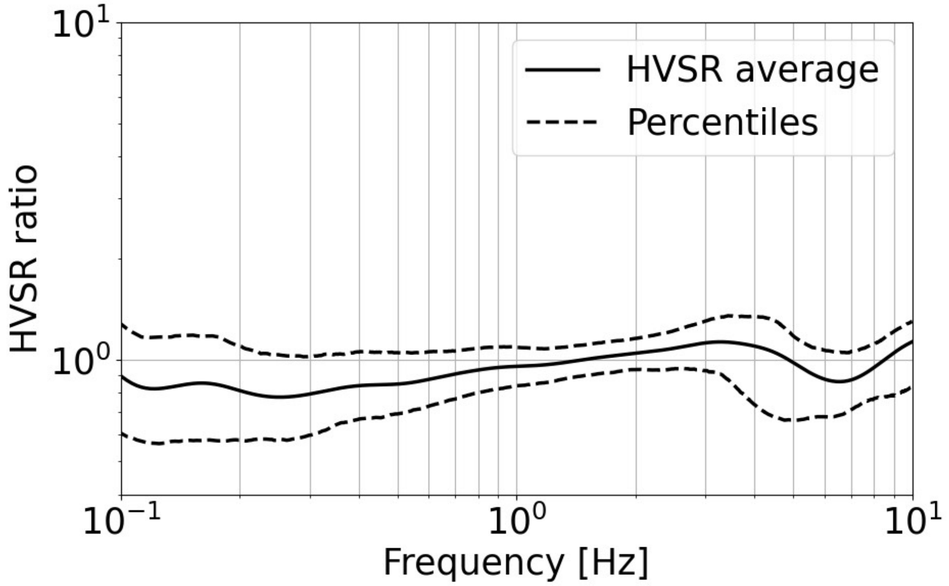
Sos Enattos characterization studies

H/V Ratio

$$H/V = \frac{\sqrt{H_E \times H_N}}{H_Z}$$

H_E, H_N, H_Z = 3 component spectra

H/V Ratio is a rapid tool for understanding the presence and the properties of underground layers. E.g. peaks in the H/V Ratio mark the impedance contrast between a soft layer and underlying bedrock.



$$f_c = \frac{V_s}{4h}$$

$$V_s = [2.0; 2.7] km/s$$

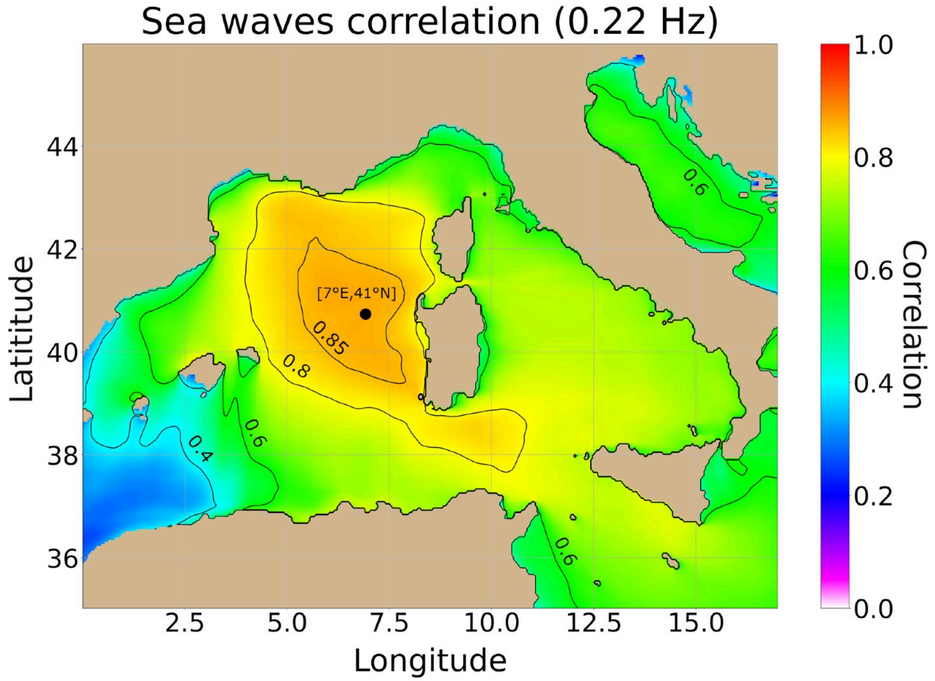
Given the measured S-wave velocity in Sos Enattos and the shape of the H/V ratio, we infer that the soil is uniform up to [2.500;3000] m underground.

This is consistent with what we know about the Geology of Sardinia (general lack of soft surface layers).

Sos Enattos characterization studies

Seismic noise and weather conditions

Between [0.1; 1] Hz the shape of the spectra are influenced by sea wave noise.



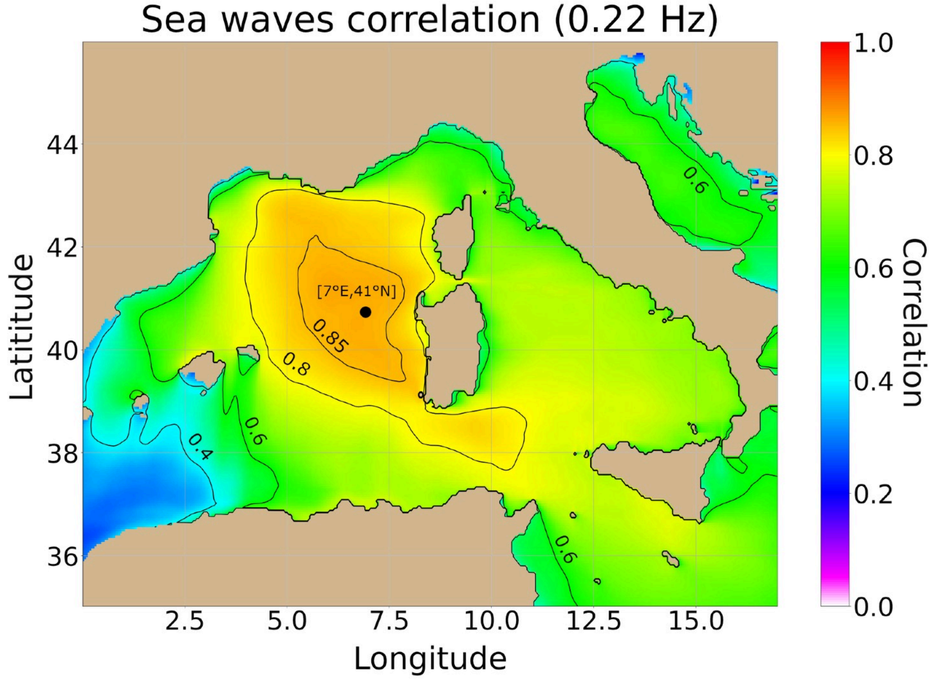
- Ambient noise in Sos Enattos is strongly correlated with sea wave height from the western Mediterranean;
- This result is in agreement with Chevrot et al. [2007] that identify that region as the main source of microseisms in the Mediterranean sea.

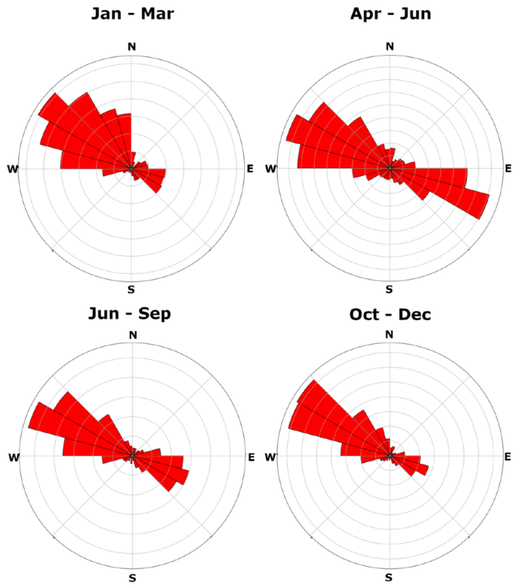
On some occasions it is also possible to correlate microseismic noise in Sos Enattos with storms in the Atlantic Ocean.

Sos Enattos characterization studies

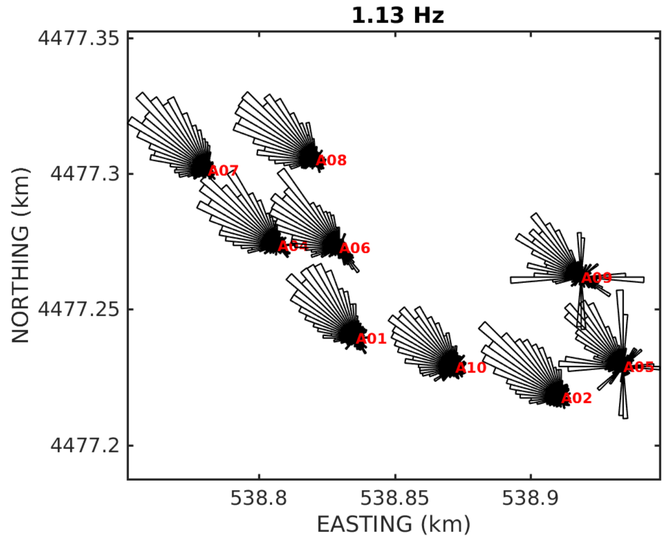
Seismic noise and weather conditions

Main location of sea wave noise is also confirmed by analysis of the direction of microseisms



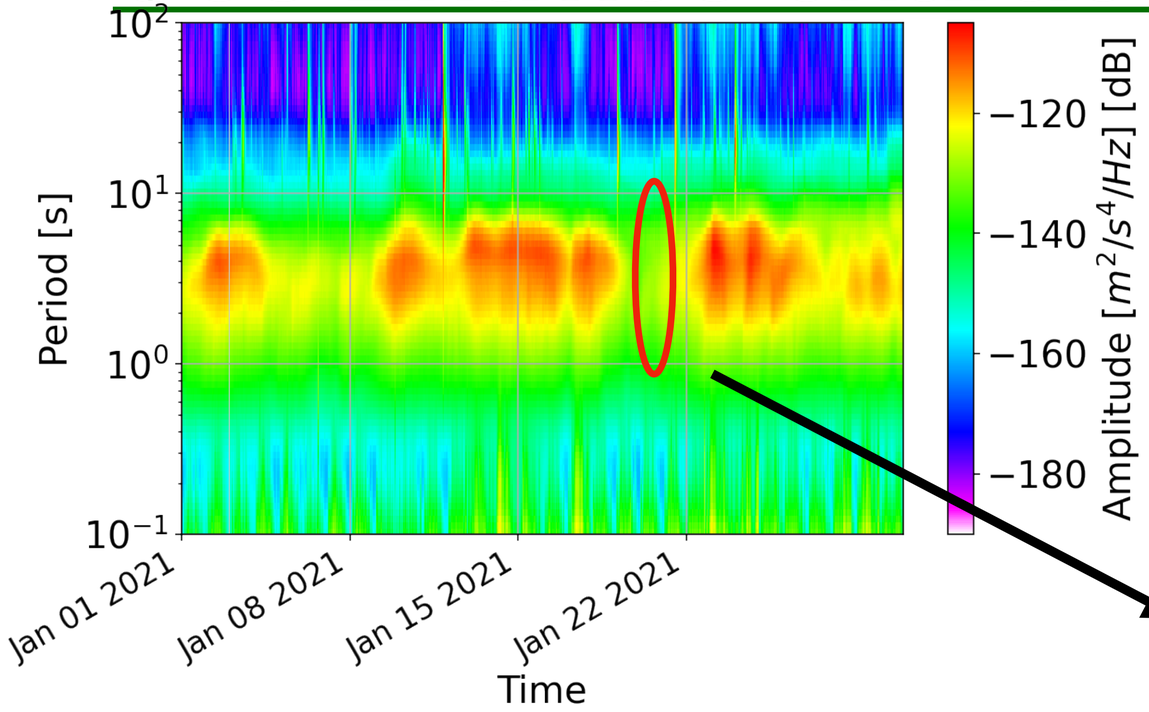


Long time-period analysis of microseisms direction by M. Di Giovanni using the method of Tanimoto et al. [2009]

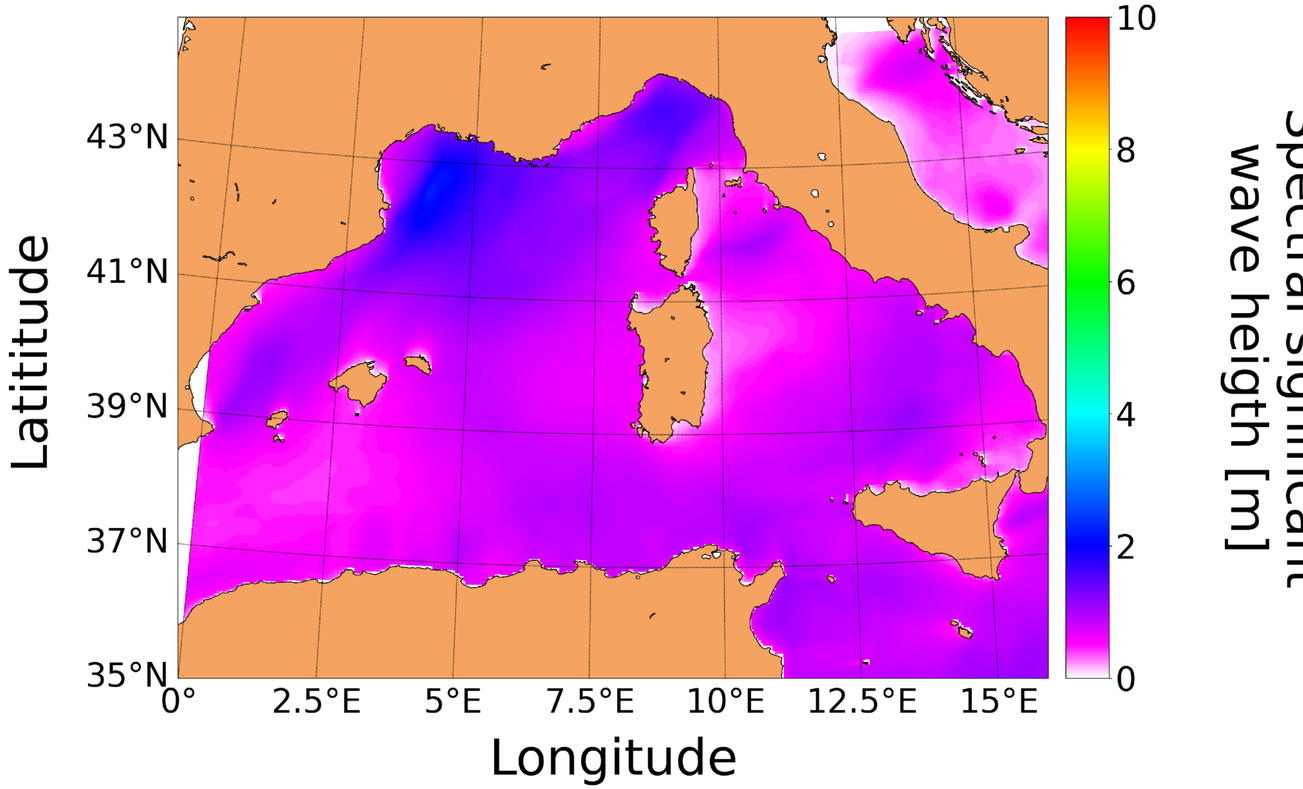


Analysis of the January 2021 array data by G. Saccorotti.

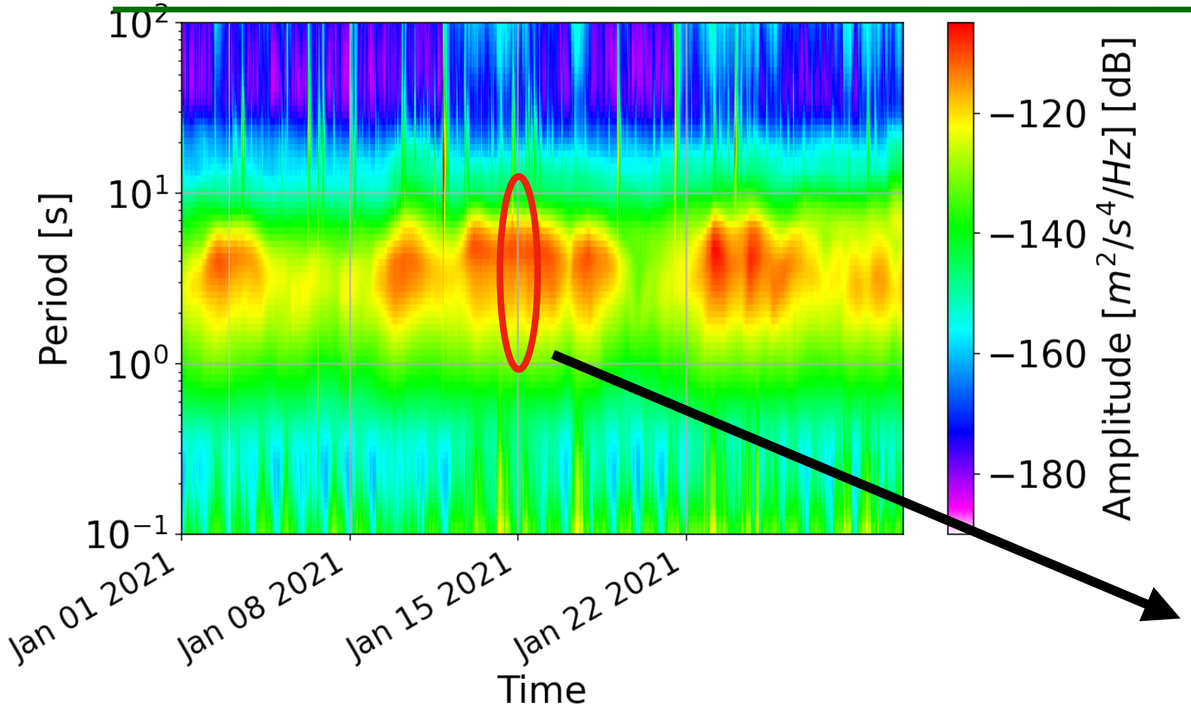
Sos Enattos characterization studies



Sea activity can also be easily inferred from the spectrograms.



Sos Enattos characterization studies



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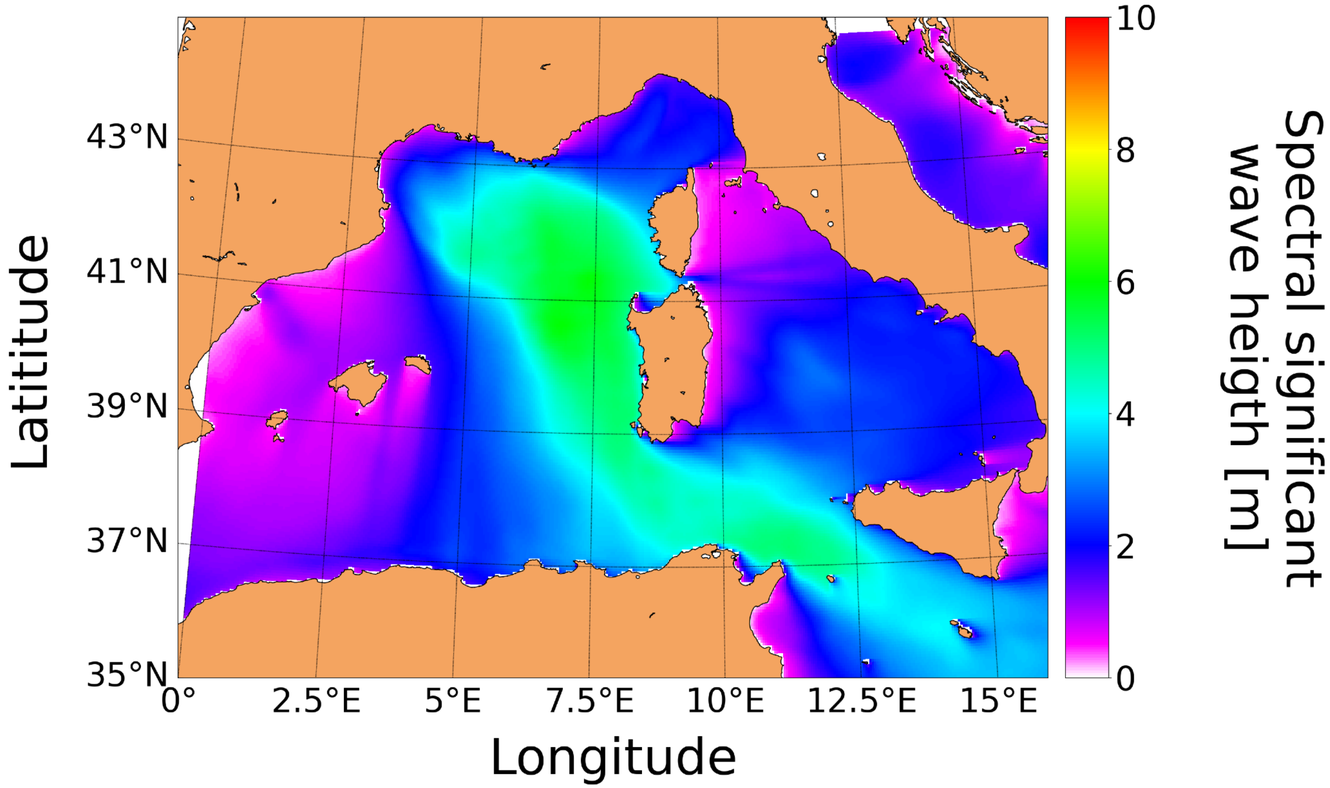
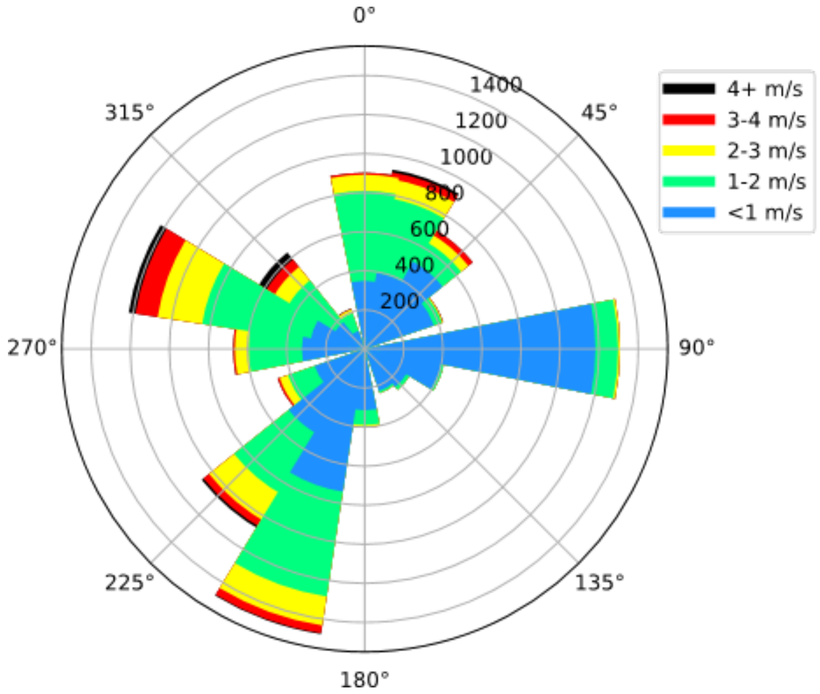


Sos Enattos characterization studies

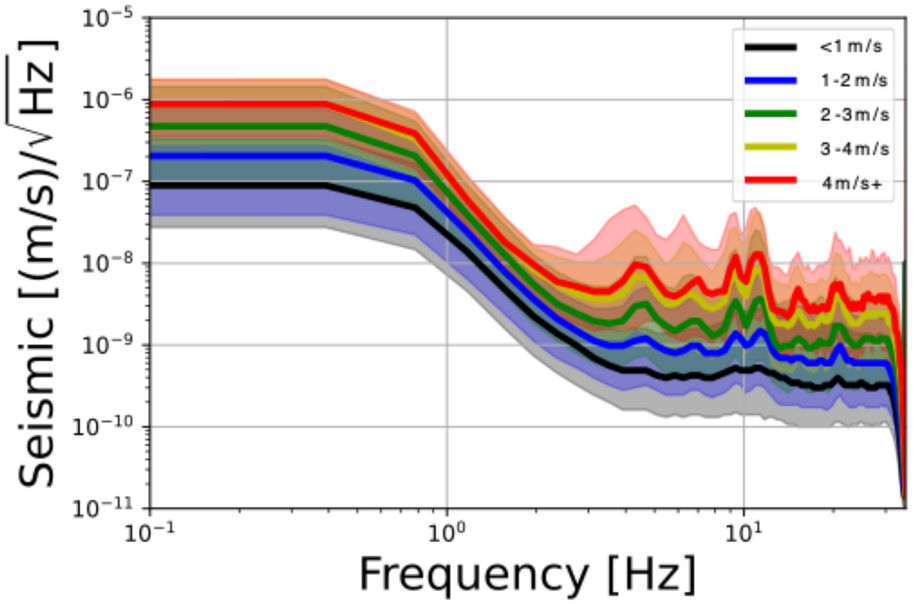
Seismic noise and weather conditions

See talk by J. Ensing

Monitoring the effect of wind on seismic data recordings.



Wind speeds and directions recorded between June 2020 and March 2021



Effect of wind speed over seismic spectra at SOE0

Conclusions

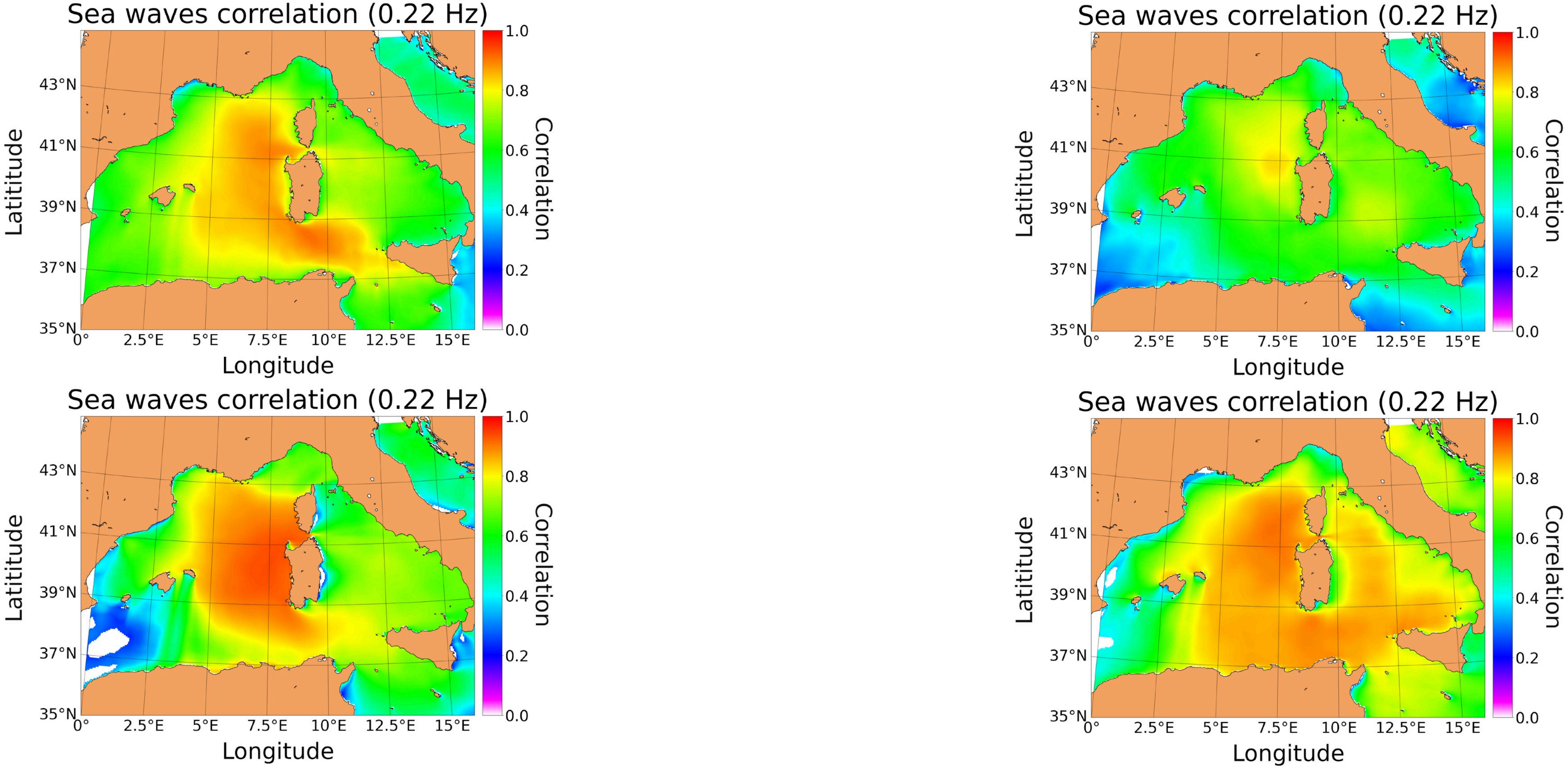
- The effort to provide accurate characterization for the Sardinia candidate site is ongoing and constantly growing;
- In 2021 characterization of the proposed Sardinia ET corners successfully started;
- Preliminary results are promising for Sos Enattos:
  - Site very quiet between 2 Hz and 10 Hz;
  - Improvement of data quality further supports this conclusion;
- H/V ratio confirms the lack of shallow surface layers;
- Consistent results from two independent microseisms direction studies;
- A thorough study of human contribution to ambient seismic noise in Sos Enattos will complete the site characterization.

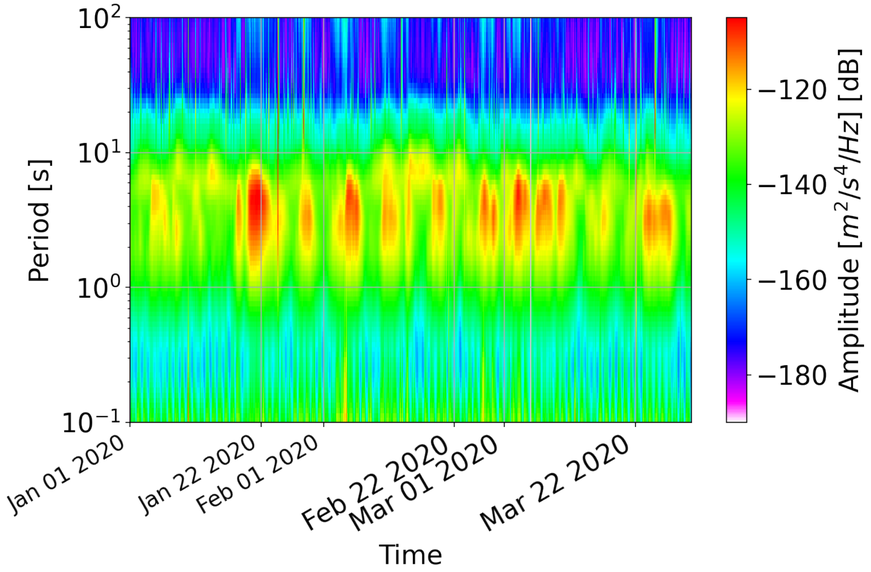
Thank you!

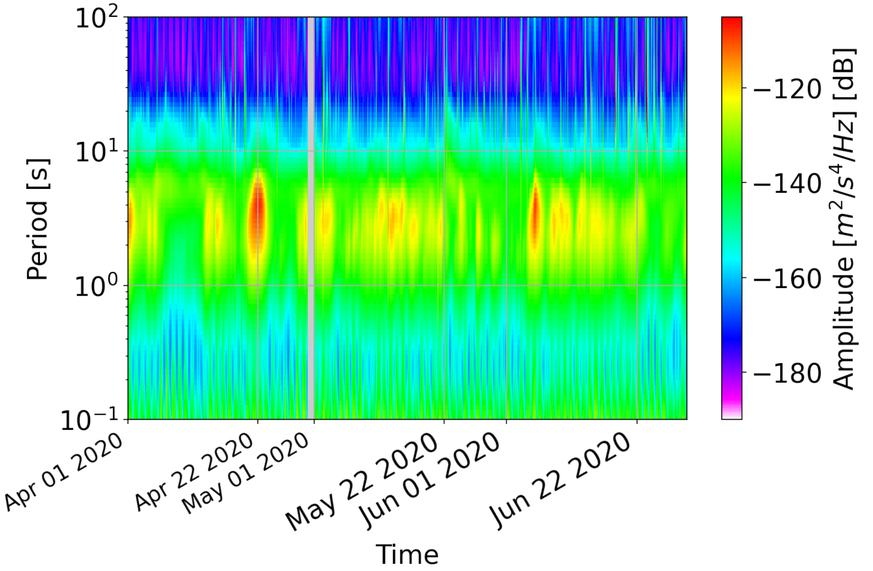
The Sardinia site characterization team

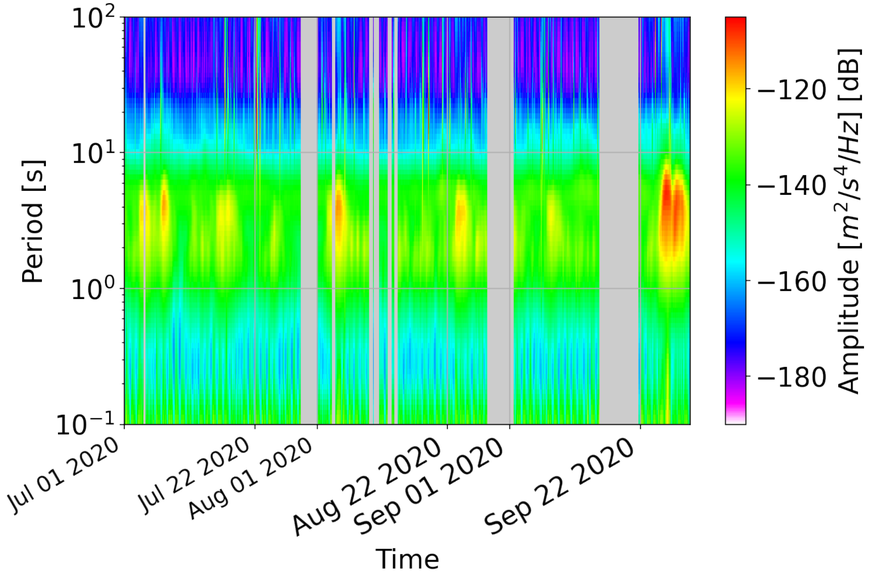
Matteo Di Giovanni, Carlo Giunchi, Marco Olivieri, Gilberto Saccorotti, Luca Naticchioni, Giacomo Oggiano, Stefano Cuccuru, Massimo Carpinelli, Domenico D'Urso, Davide Rozza, Annalisa Allocca, Luciano Errico, Enrico Calloni, Alessandro Cardini, Aniello Grado, Luciano Di Fiore, Rosario De Rosa, Federico Paoletti, Irene Fiori, Soumen Koley, Tomislav Andric, Maria Tringali, Ettore Majorana, Maria Marsella, Piero Rapagnani, Jan Harms, Michele Punturo, Fulvio Ricci

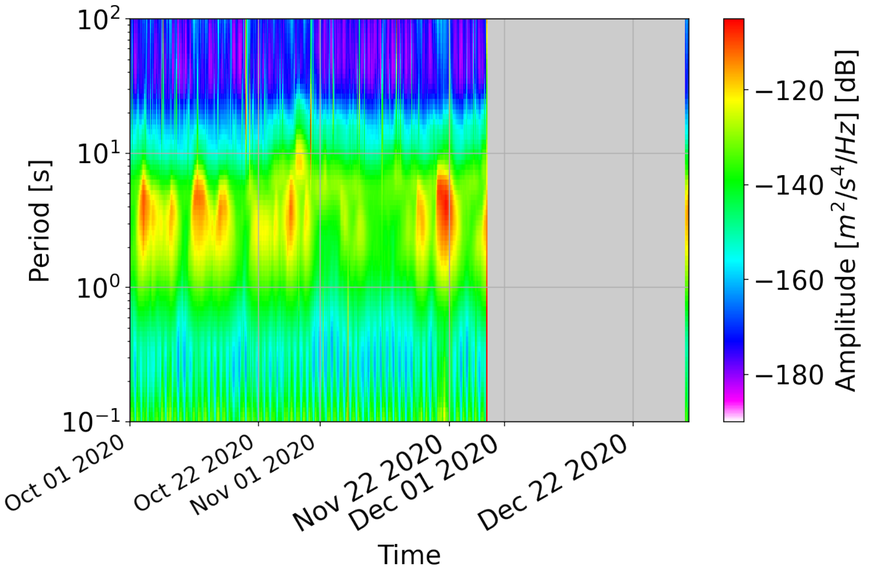
Backup slides

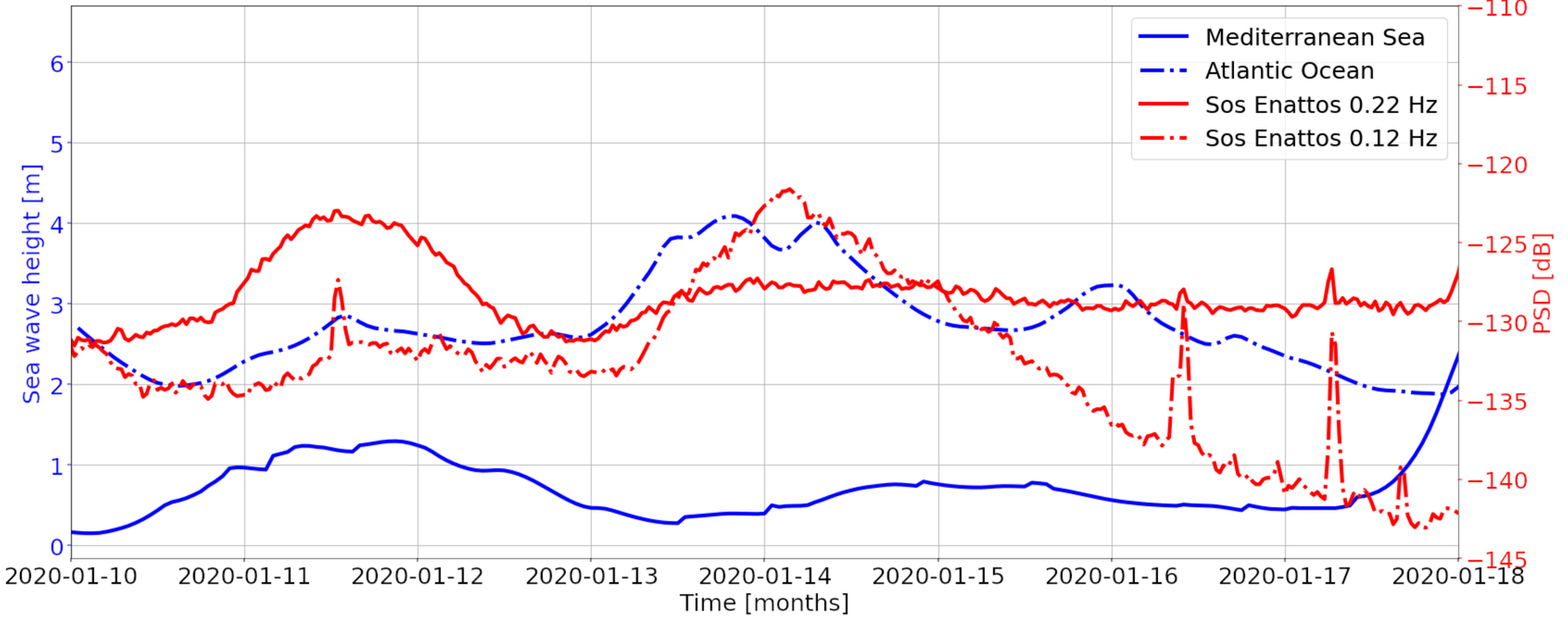

Sea waves correlation (0.22 Hz)
Latititude
43°N
41°N
39°N
37°N
35°N
0°
2.5°E
5°E
7.5°E
10°E
12.5°E
15°E
Longitude
Correlation
1.0
0.8
0.6
0.4
0.2
0.0
Sea waves correlation (0.22 Hz)
Latititude
Longitude
Correlation
Sea waves correlation (0.22 Hz)
Latititude
Longitude
Correlation
Sea waves correlation (0.22 Hz)
Latititude
Longitude
Correlation

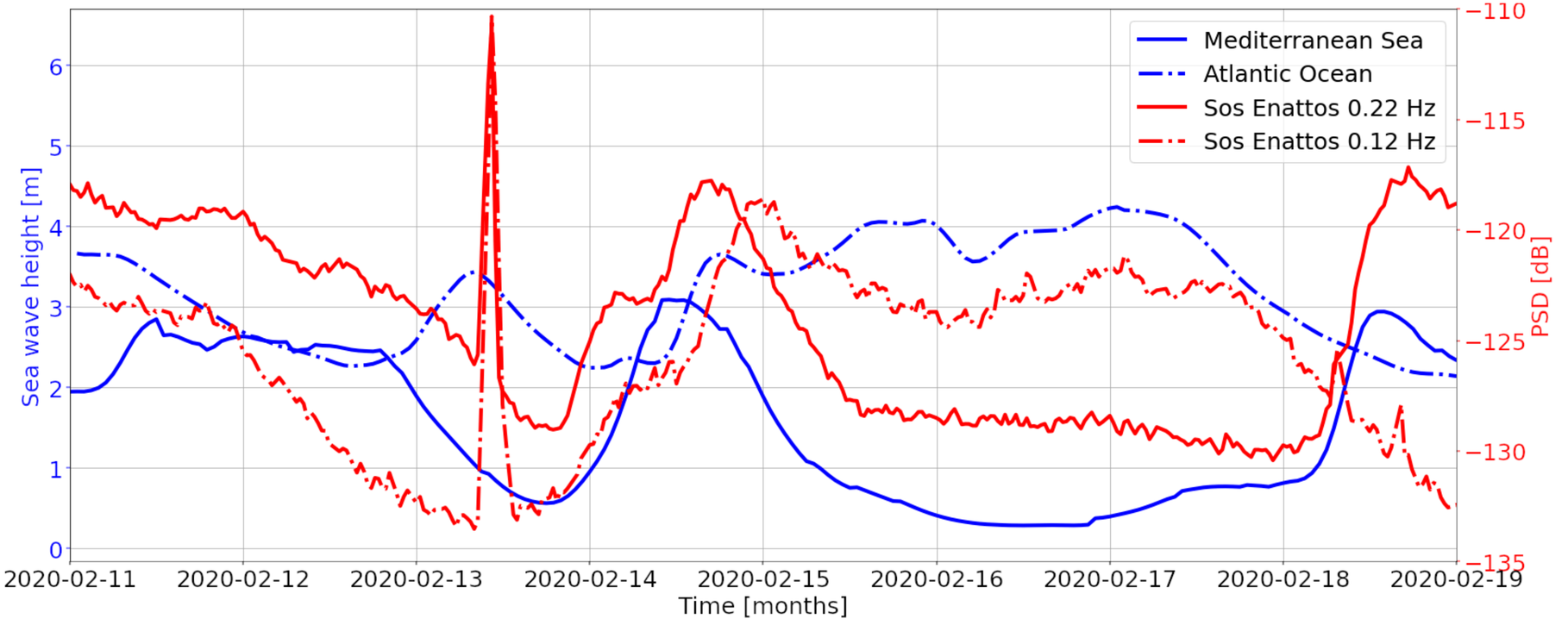

Period [s]
10^2
10^1
10^0
10^{-1}
Jan 01 2020
Jan 22 2020
Feb 01 2020
Feb 22 2020
Mar 01 2020
Mar 22 2020
Time
Amplitude [$m^2/s^4/Hz$] [dB]
−120
−140
−160
−180


Period [s]
10^2
10^1
10^0
10^{-1}
Apr 01 2020
Apr 22 2020
May 01 2020
May 22 2020
Jun 01 2020
Jun 22 2020
Time
Amplitude [$m^2/s^4/Hz$] [dB]
−120
−140
−160
−180

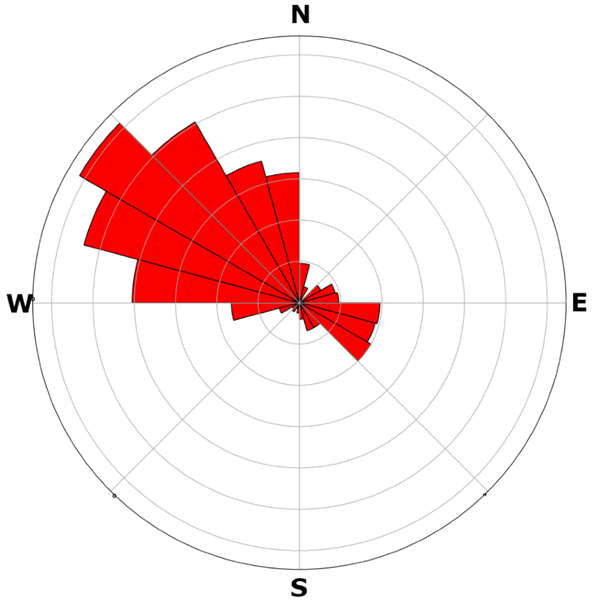

Period [s]
10^2
10^1
10^0
10^{-1}
Jul 01 2020
Jul 22 2020
Aug 01 2020
Aug 22 2020
Sep 01 2020
Sep 22 2020
Time
Amplitude [$m^2/s^4/Hz$] [dB]
−120
−140
−160
−180


Period [s]
10^2
10^1
10^0
10^{-1}
Oct 01 2020
Oct 22 2020
Nov 01 2020
Nov 22 2020
Dec 01 2020
Dec 22 2020
Time
Amplitude [$m^2/s^4/Hz$] [dB]
−120
−140
−160
−180

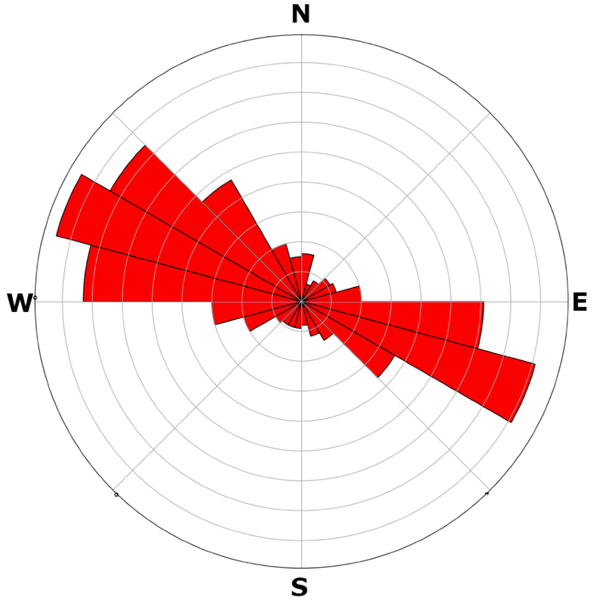

Mediterranean Sea
Atlantic Ocean
Sos Enattos 0.22 Hz
Sos Enattos 0.12 Hz
Sea wave height [m]
PSD [dB]
Time [months]
2020-01-10
2020-01-11
2020-01-12
2020-01-13
2020-01-14
2020-01-15
2020-01-16
2020-01-17
2020-01-18


Mediterranean Sea
Atlantic Ocean
Sos Enattos 0.22 Hz
Sos Enattos 0.12 Hz
Sea wave height [m]
PSD [dB]
Time [months]
2020-02-11
2020-02-12
2020-02-13
2020-02-14
2020-02-15
2020-02-16
2020-02-17
2020-02-18
2020-02-19

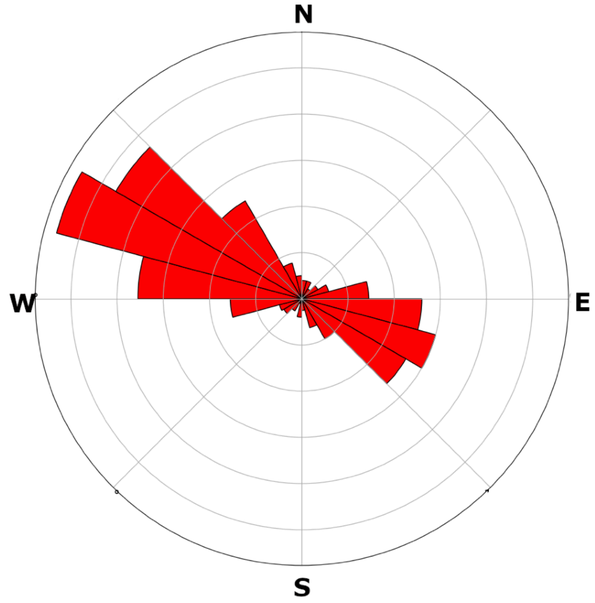
Jan - Mar



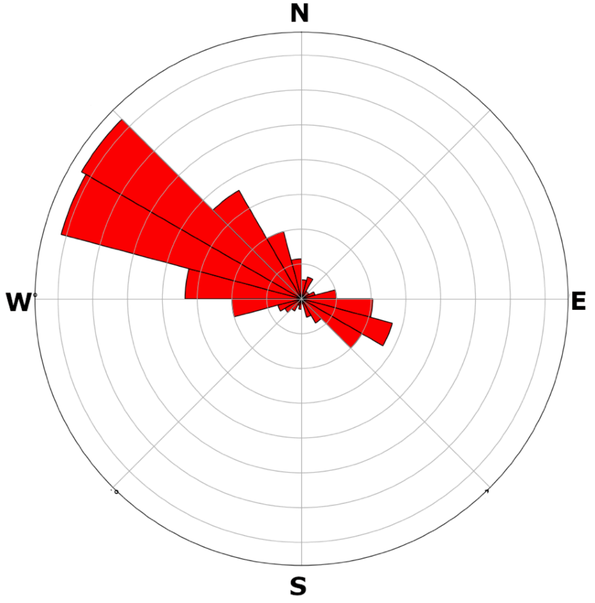
Apr - Jun



Jun - Sep

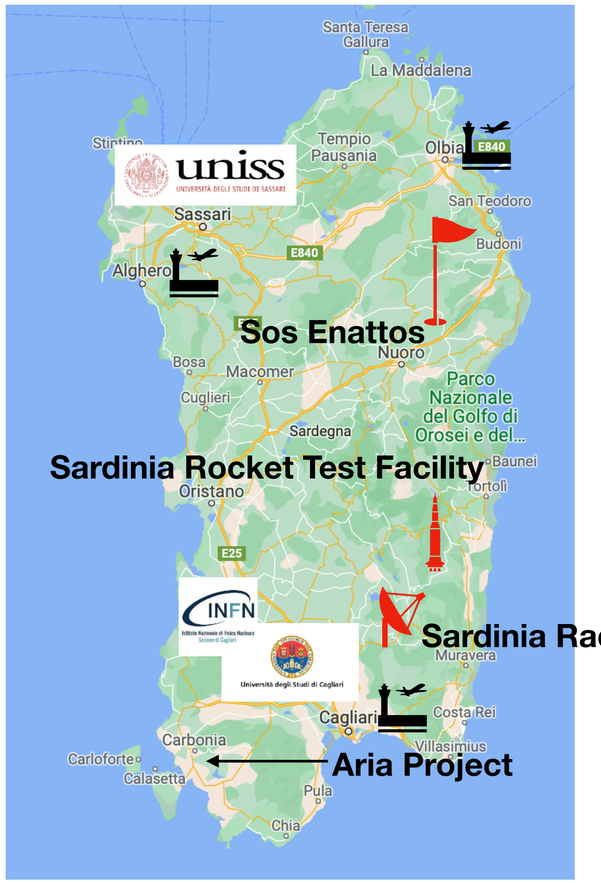


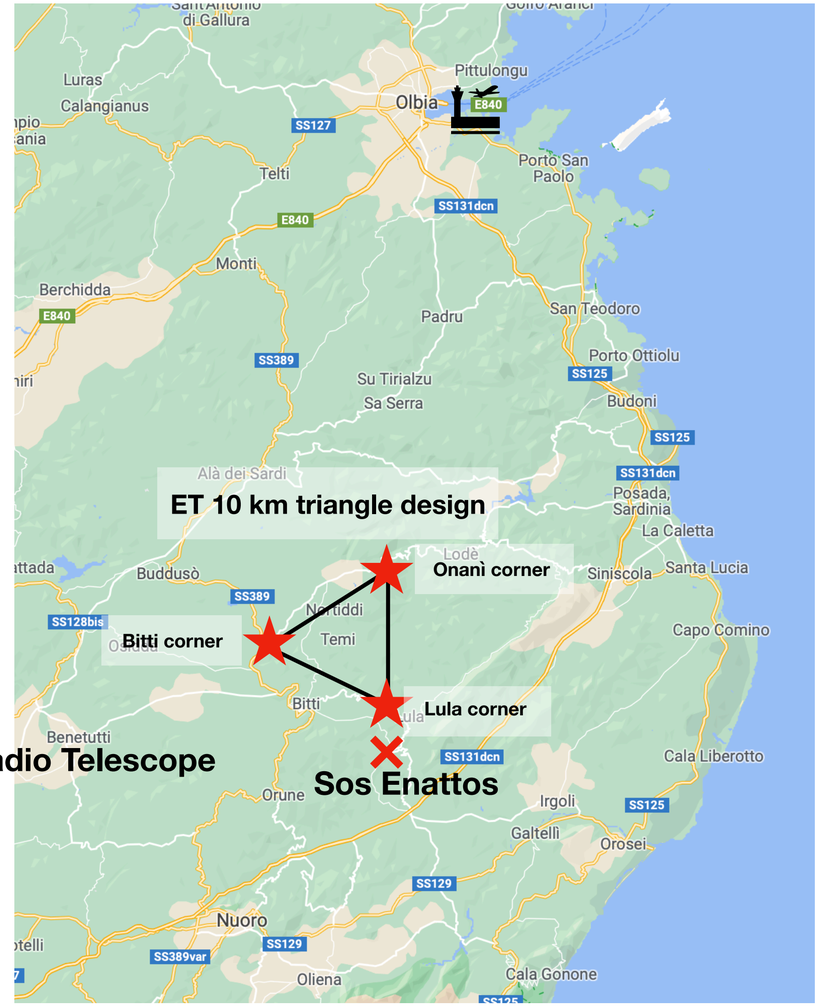
Oct - Dec



The Sos Enattos Site

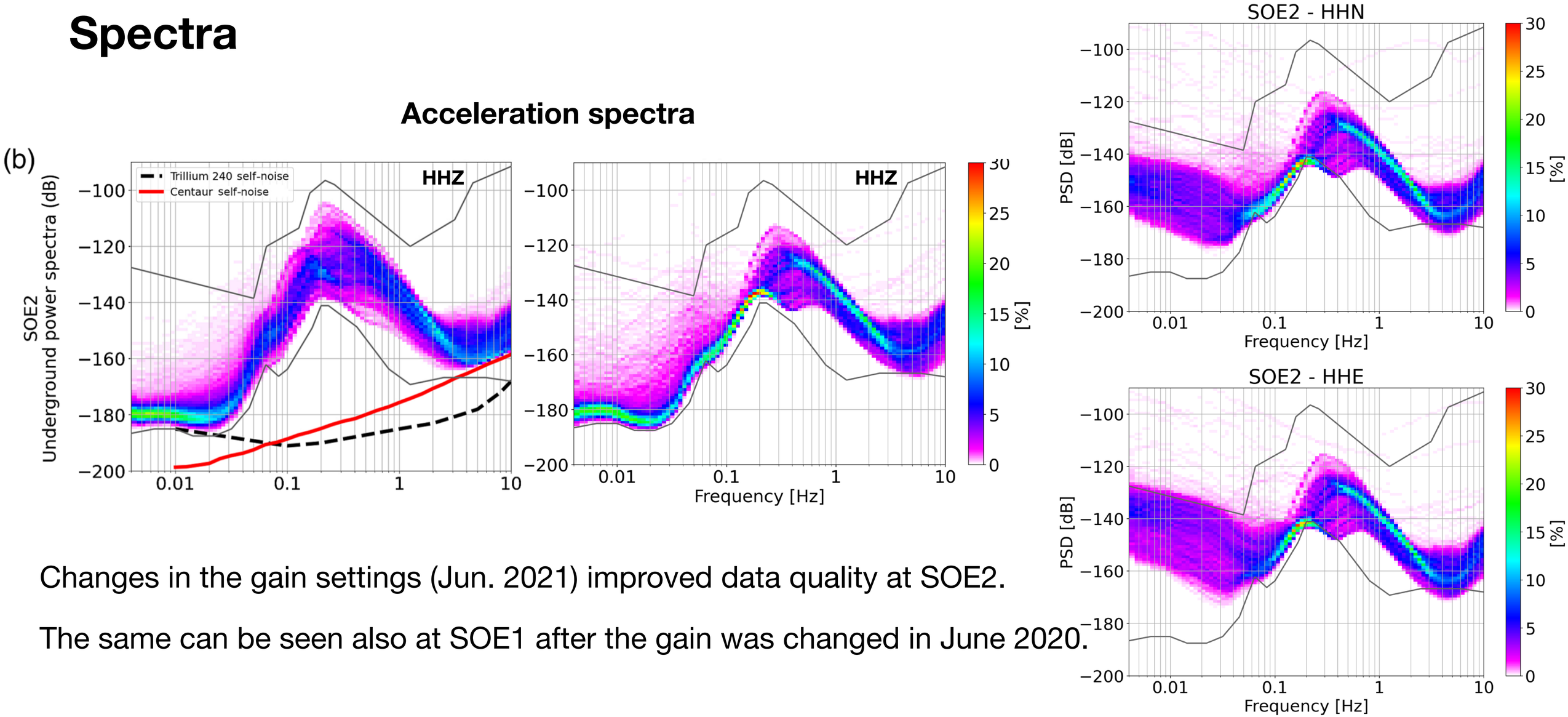
- Sos Enattos is a former lead and zinc mine active until the late 1990s;
- Today it is still maintained for environmental safety and guided tours.





Sos Enattos characterization studies

Spectra



Changes in the gain settings (Jun. 2021) improved data quality at SOE2.

The same can be seen also at SOE1 after the gain was changed in June 2020.

The Sos Enattos Seismic network

Permanent seismic stations

All stations are constantly maintained and upgraded to improve data quality:

- SOE0 sensor changed and moved to another location (Dec. 2019);
- SOE1 sensor, data logger and gain settings changed (Jun. 2020);
- SOE3 installed (Aug. 2020);
- SOE2 sensor changed (Jun. 2021);
- SOE1 sensor changed (Jul. 2021).

SOE1 (March 2019)

SOE0 (Dec 2019)

SOE2