Ambient noise variations in Sos Enattos

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ET Sardinia Site Characterization
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Outline

- Paper in preparation;
- Instruments used;
- Seasonal noise variations caused by microseisms;
- Ambient noise variations caused by environmental effects (wind);
- Ambient noise variations in the anthropic band;
    - Contribution of two road bridges near Sos Enattos.

The paper

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

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Submitted to TBD

ABSTRACT

The 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 by constraining 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, and over short (seconds long) to long (seasonal) time scales.

➡ The paper draft is in at an advanced stage;

➡ Draft will circulate soon;

➡ Target paper TBD.

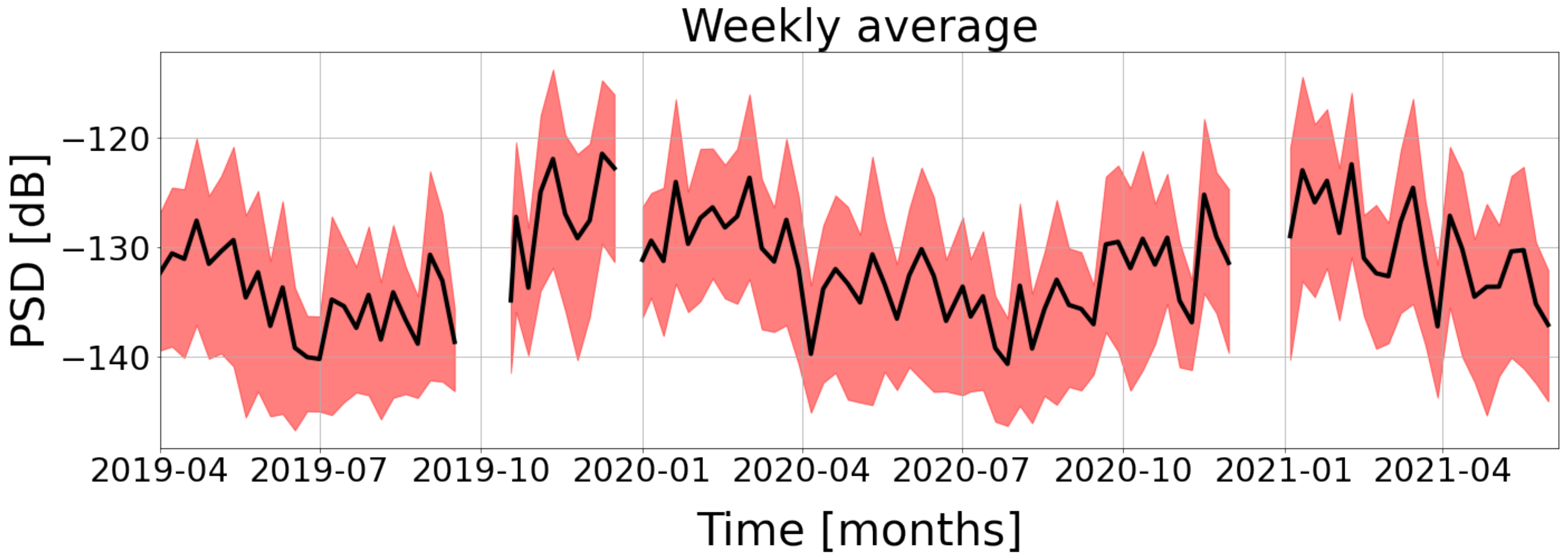
Instruments

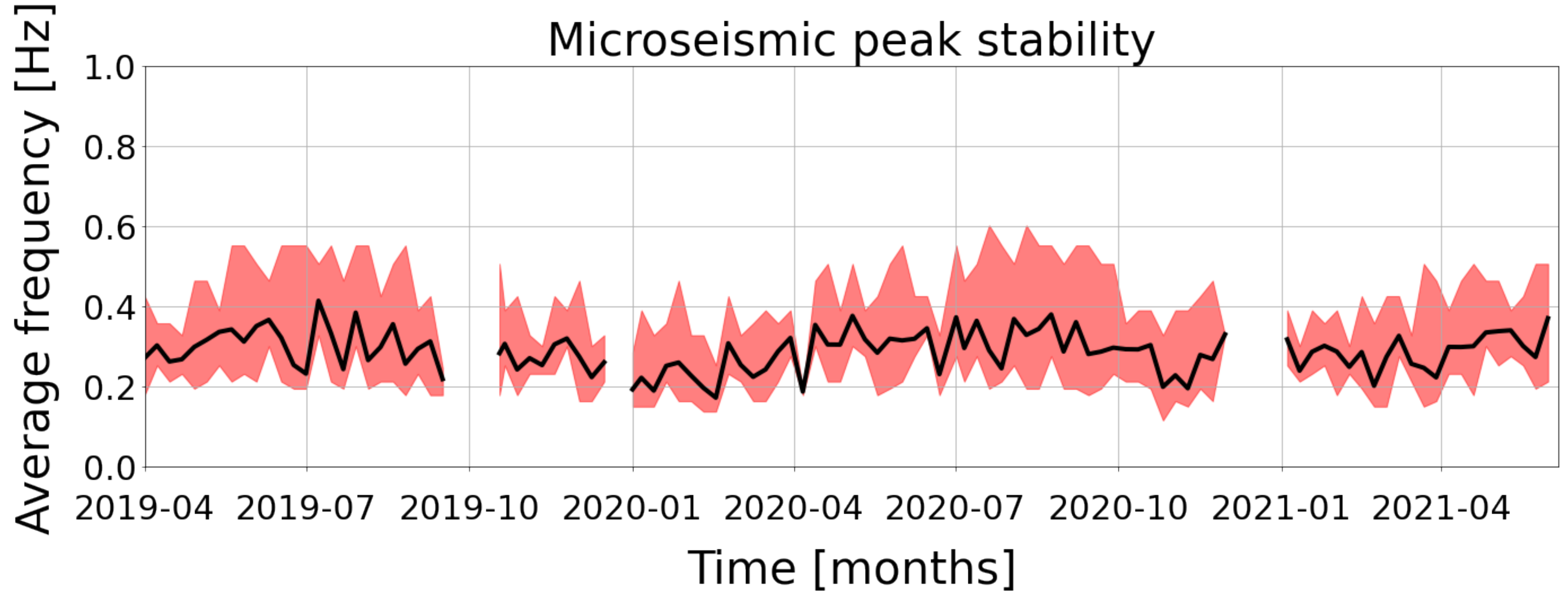
✓ The three seismic stations at Sos Enattos (SOE0, SOE1, SOE2)

✓ The weather station installed at the mine;

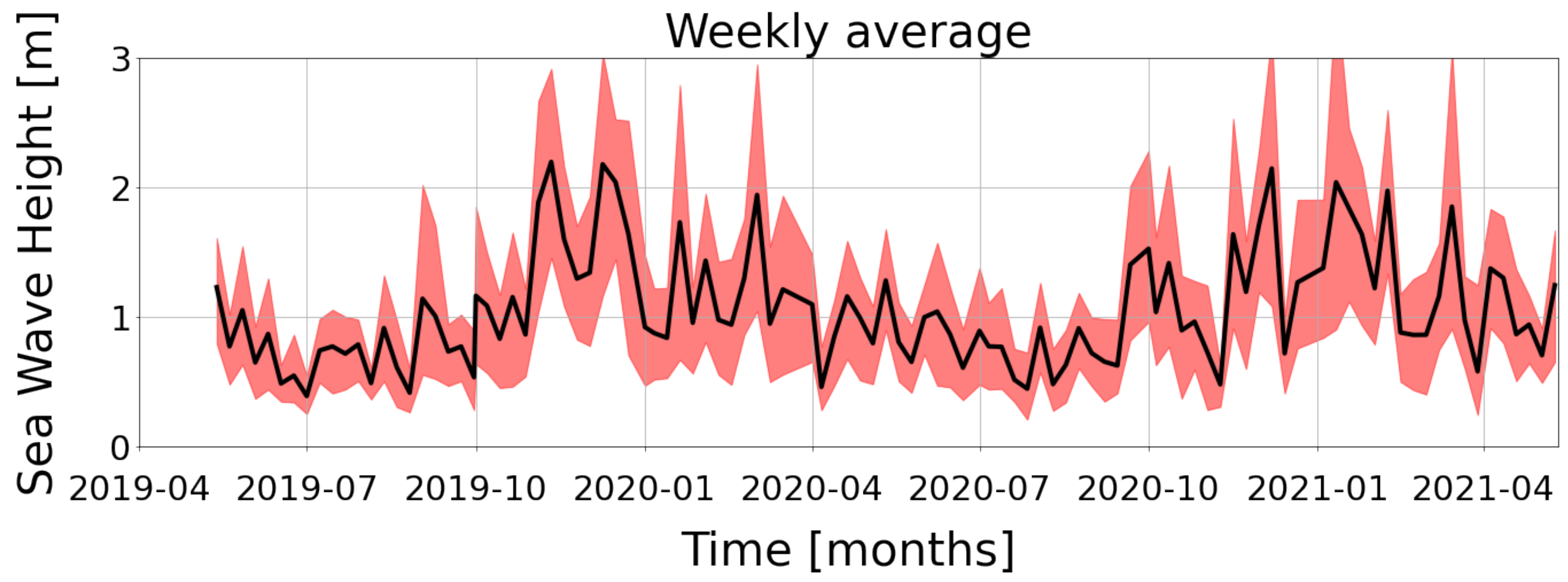
✓ Geophones deployed in November 2021.

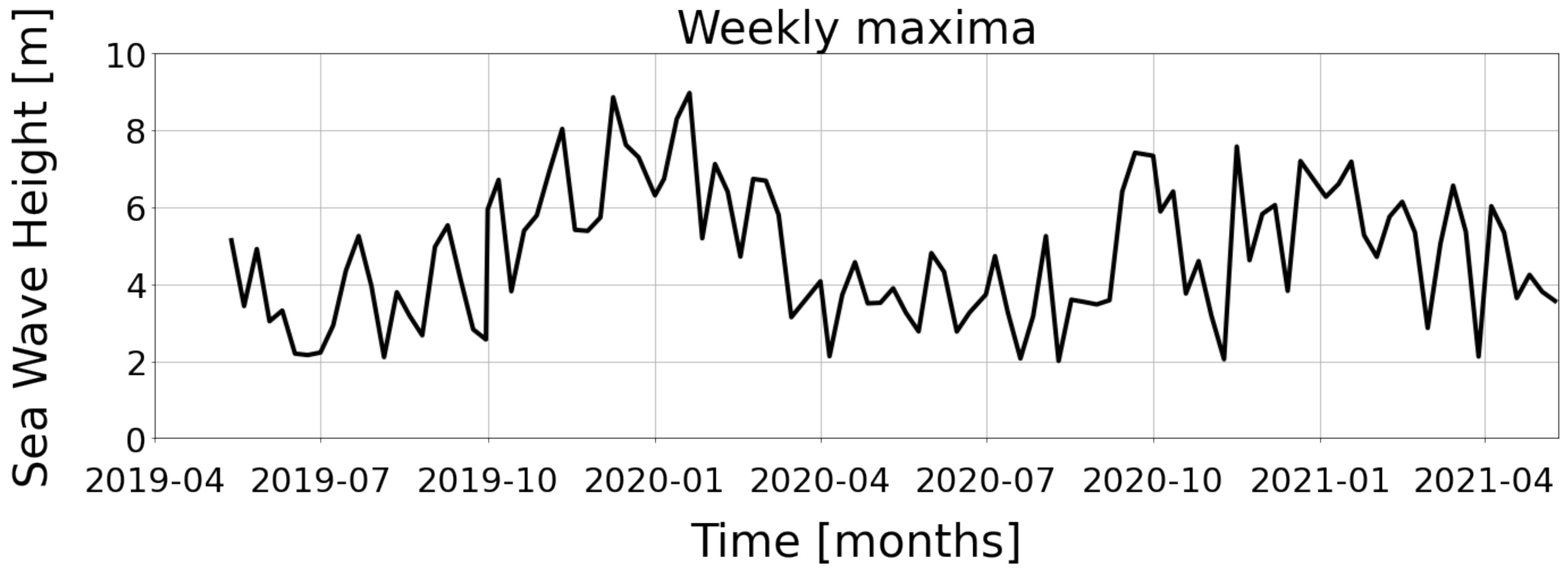
Microseismic seasonal noise variations





- Seismic data from SOE2
- Sea wave data come from copernicus.eu





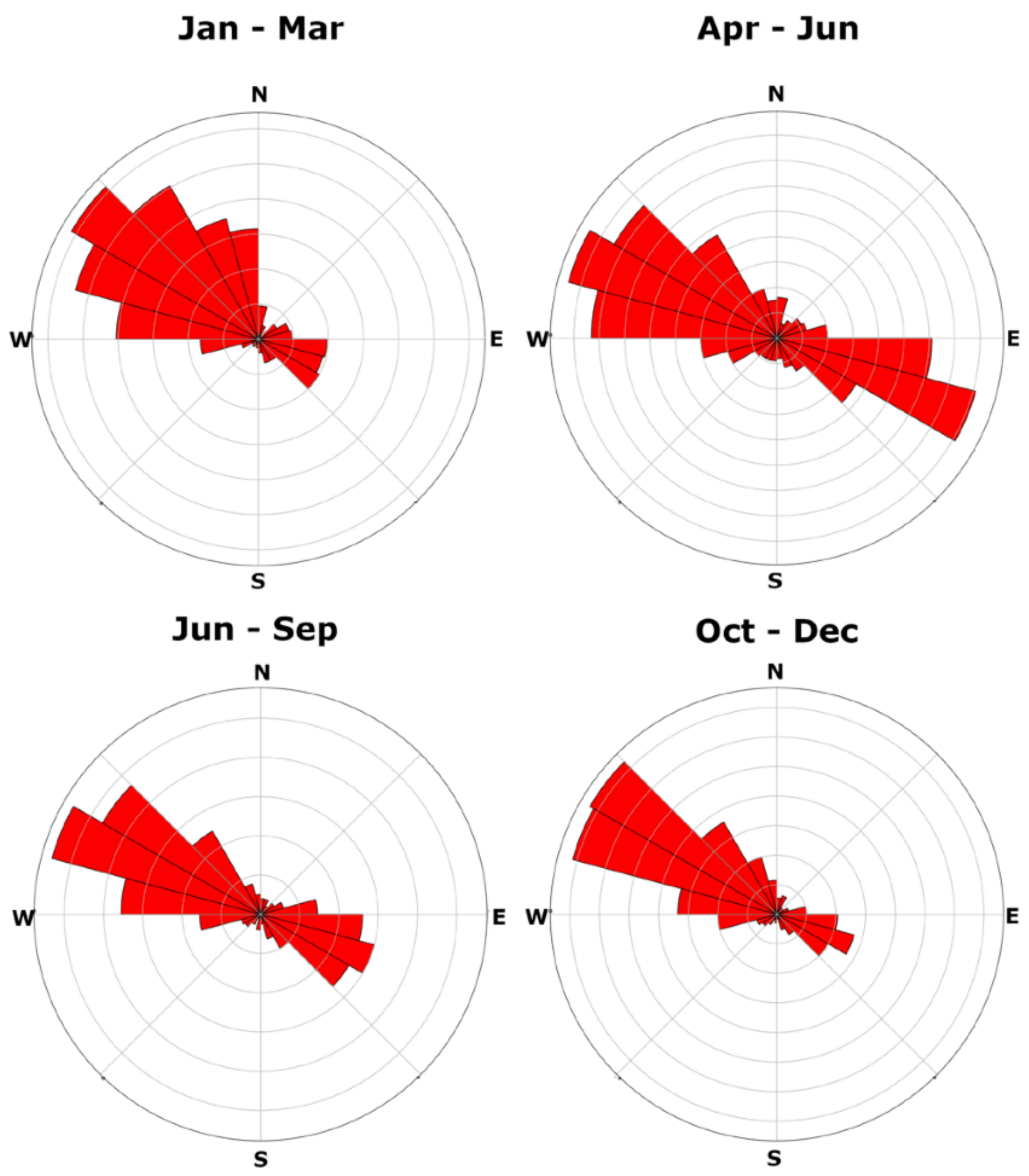
➡ There is a clear relationship between the weekly average noise level and the weekly average sea wave height;

➡ Clear seasonal trend;

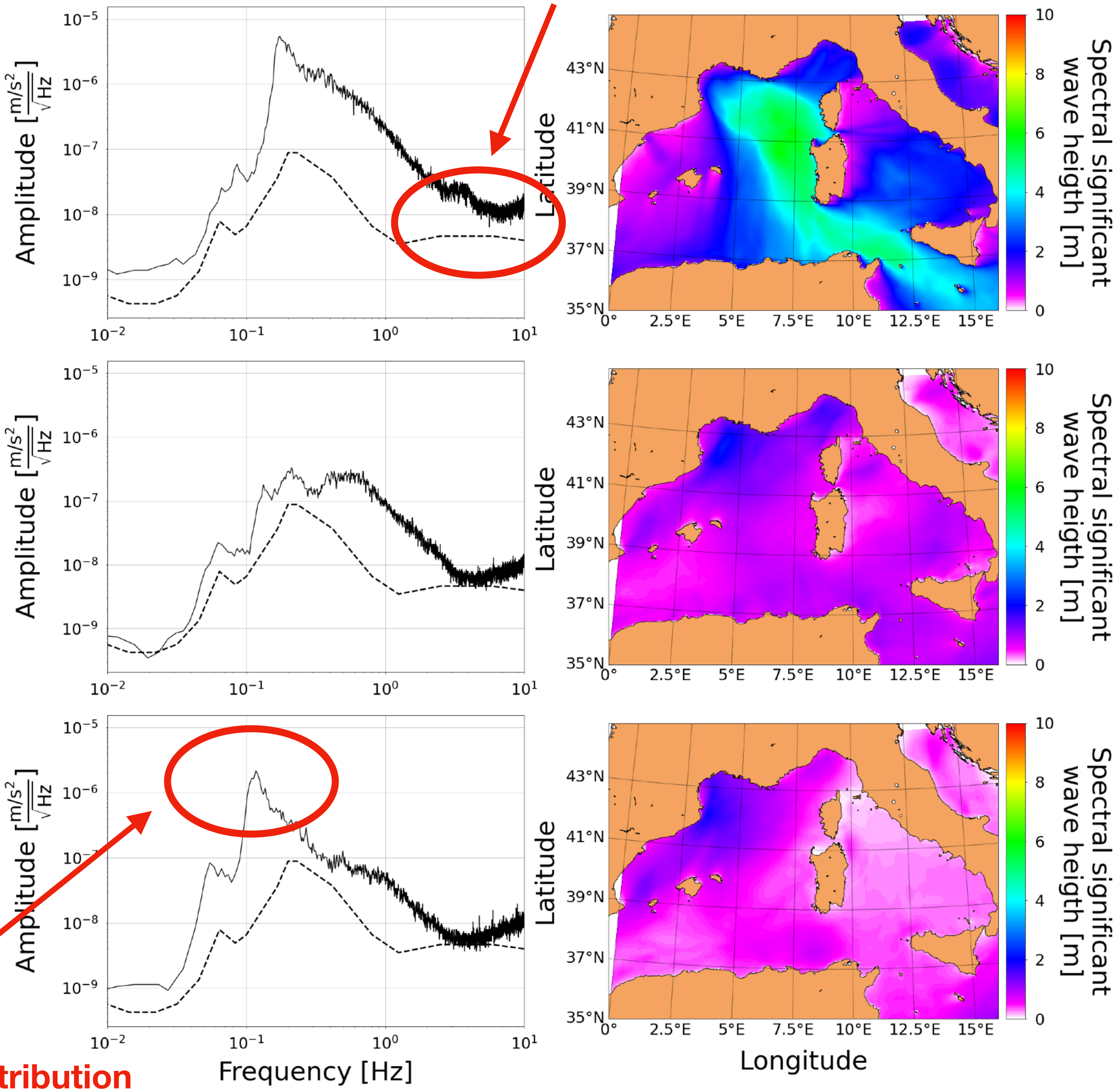
➡ Gaps in the plots are related to periods in which data were not available.

Microseismic seasonal noise variations

- Visual comparison of the spectra against sea wave height helps to understand the relationship with seasonality;
- Main contribution to microseismic noise comes from a region located between Corsica and the Gulf of Lyon.



The tail of the microseisms extends to the anthropic band



This peak is the contribution of an Atlantic storm

Evidence of oceanic storms

- Analysis of the spectra revealed that Mediterranean storms have a frequency peak between 0.17 Hz and 0.22 Hz;
- Atlantic storms have a frequency peak at about 0.12 Hz;

↓

- Oceanic contribution to the overall noise may be hidden by local sea activity (degenerate peak);
- Must look for quiet Mediterranean coincident with Atlantic Storm.

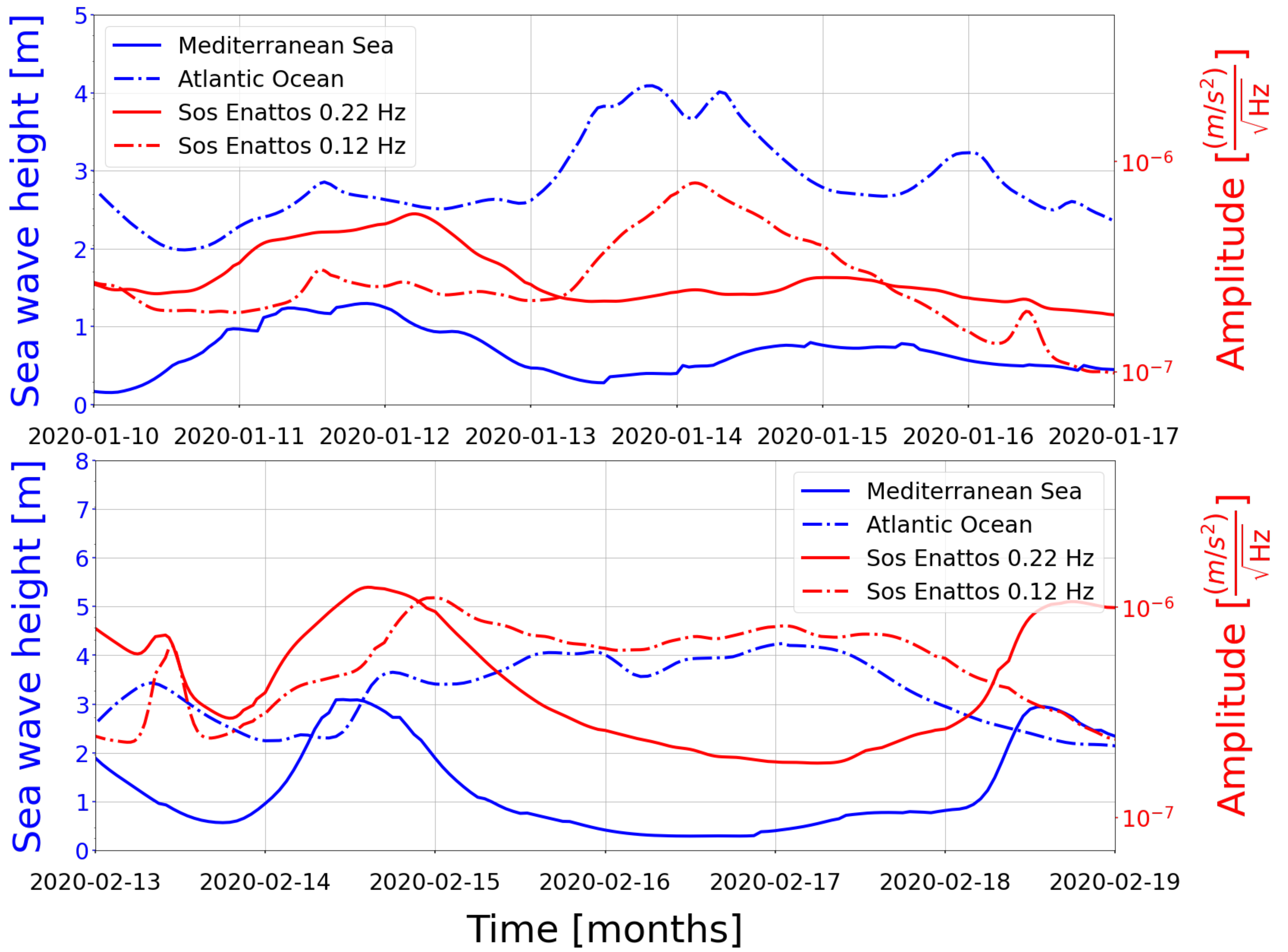
Evidence of oceanic storms

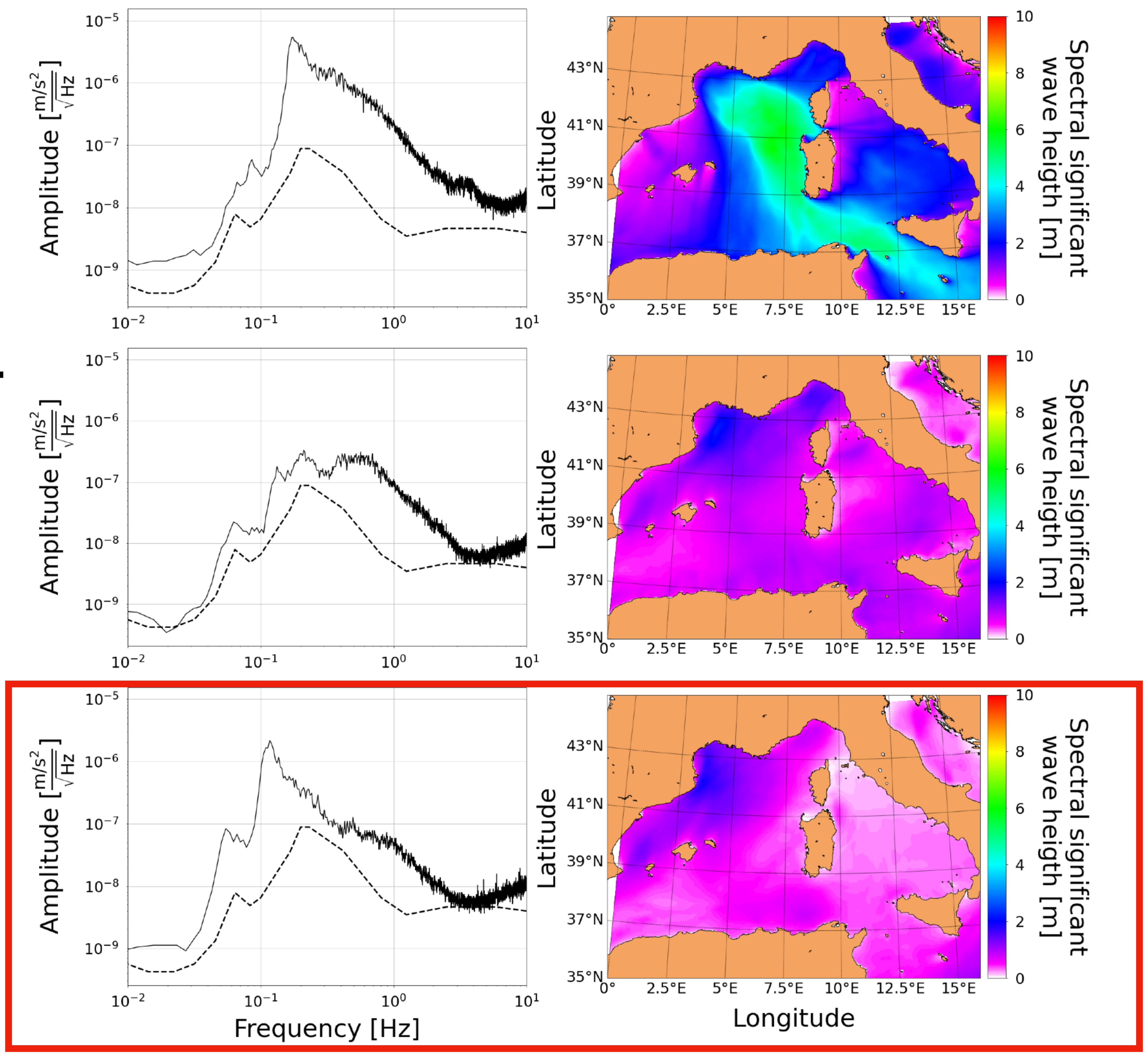
- Analysis of the time-series makes more clear the contribution of the oceanic noise at different frequency bands;

- Since the direction is the same of local microseisms, using a simple polarization analysis makes difficult to disentangle the two contributions.

Storm Brendan

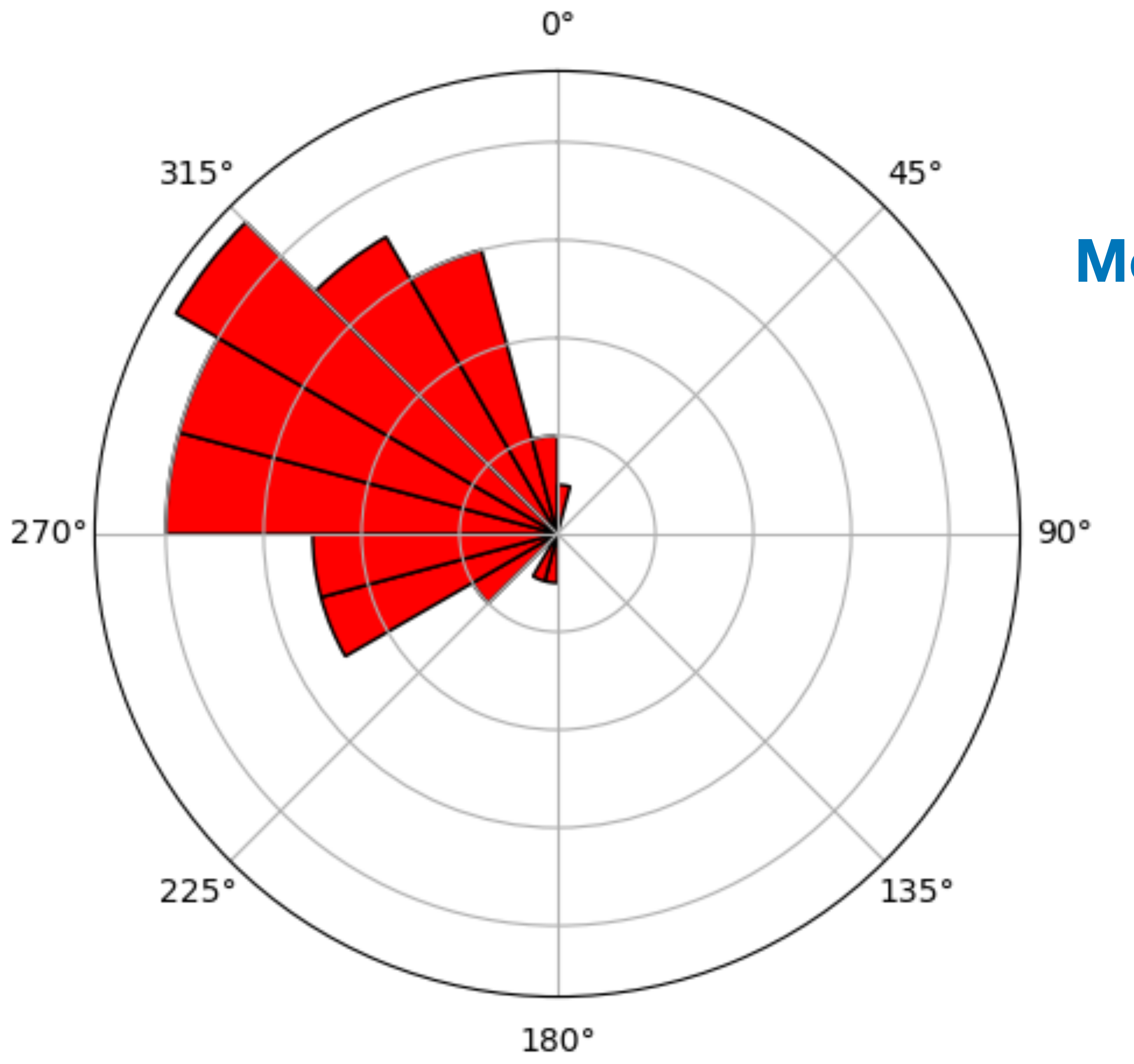
Storm Dennis



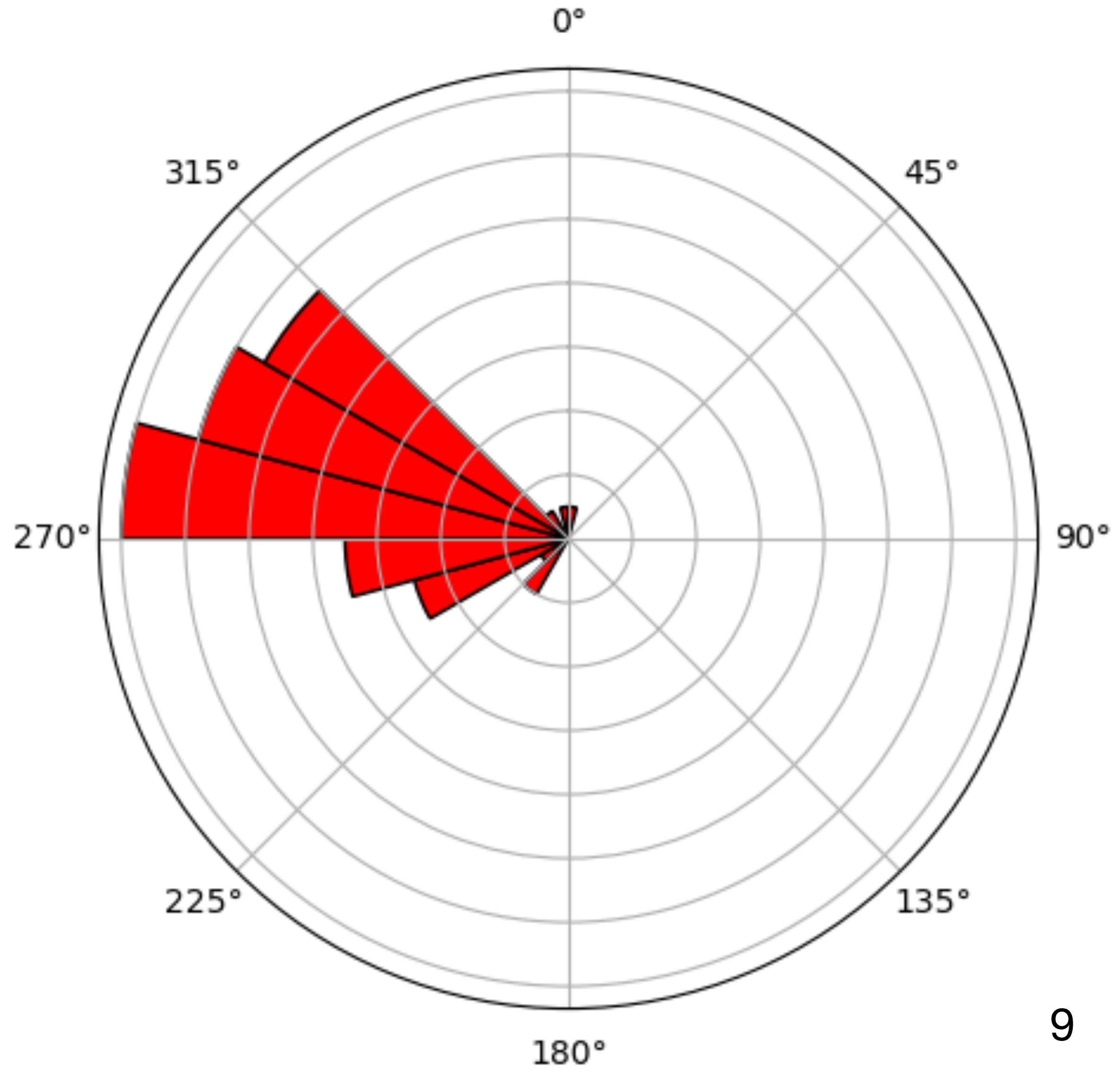


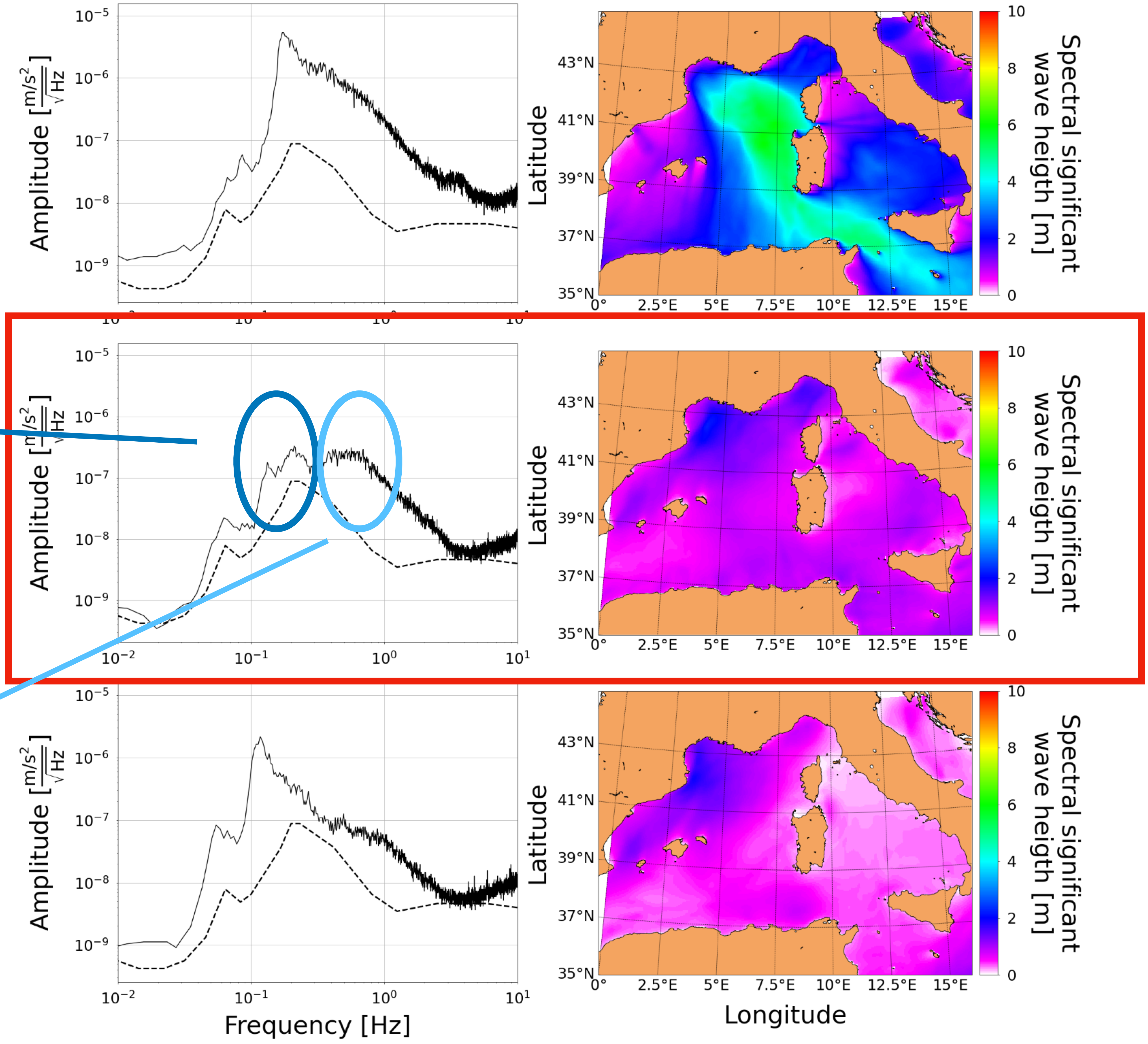
A comment that is not in the paper

- When two peaks appear in the spectra, calculating polarization separately gives similar results.



More contribution from oceanic sources?





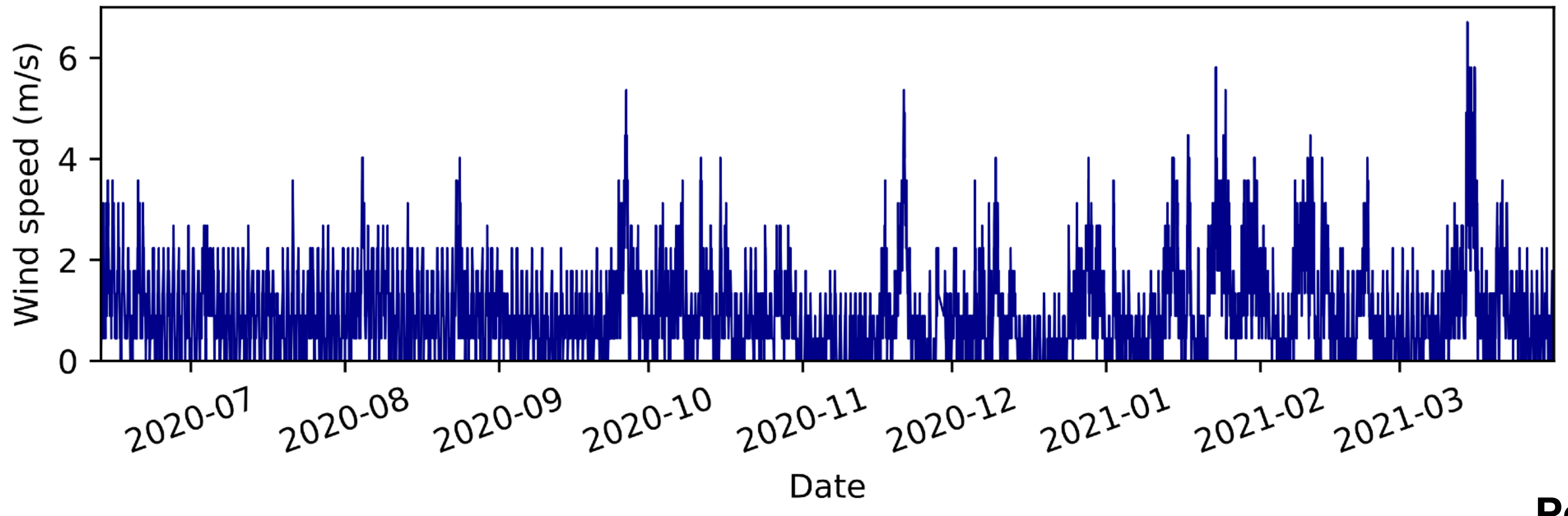
Wind noise studies

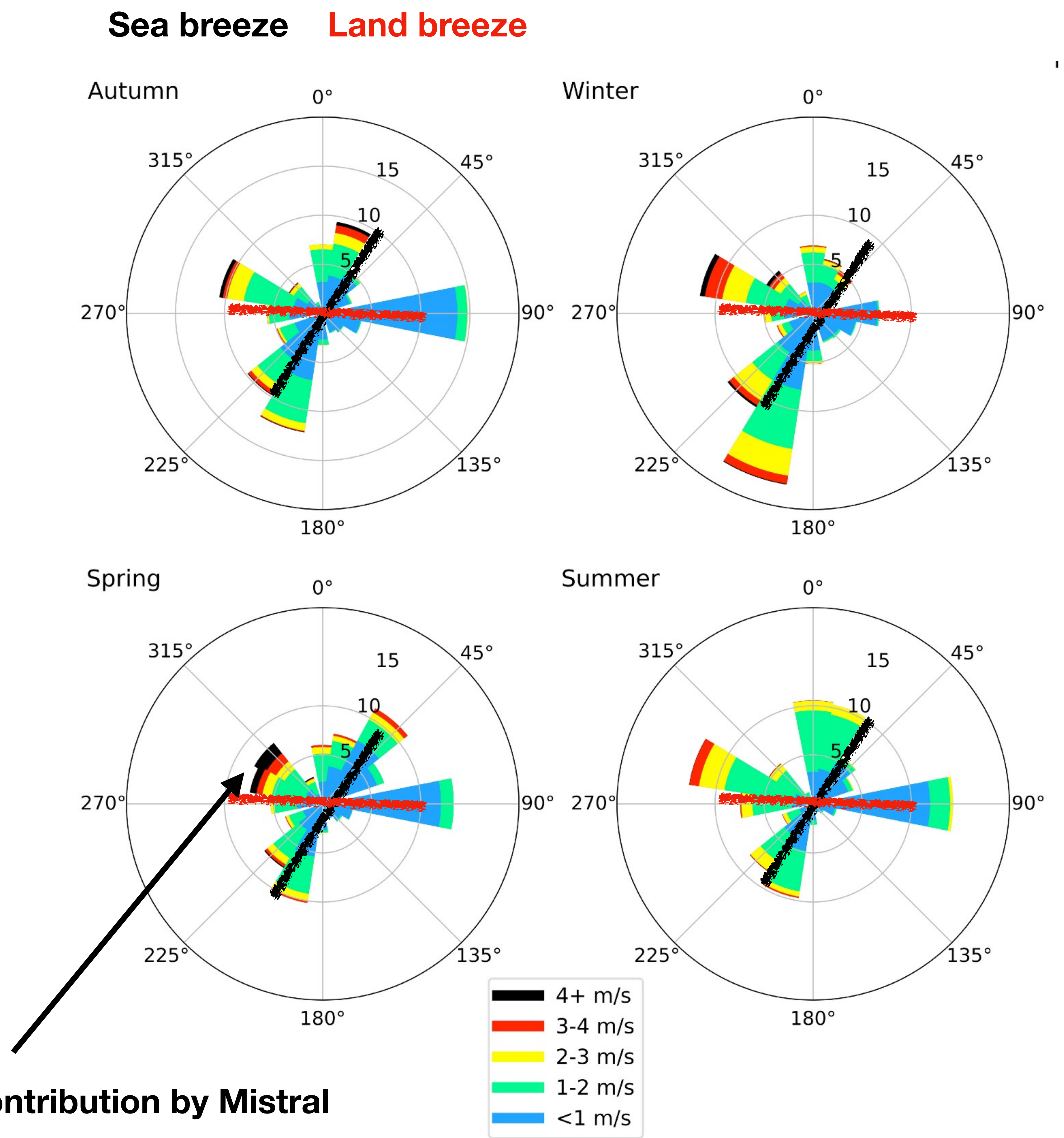
- Wind can cause an excess of seismic noise between 1Hz and 60 Hz;
  - shaking of tall structures and trees;
  - doors slamming;
  - Buildings shacking.
- Sardinia can be windy (like July 2021…);
- Which is the effect on ambient noise variation?

Wind noise studies

Wind speed data from June 2020 until March 2021

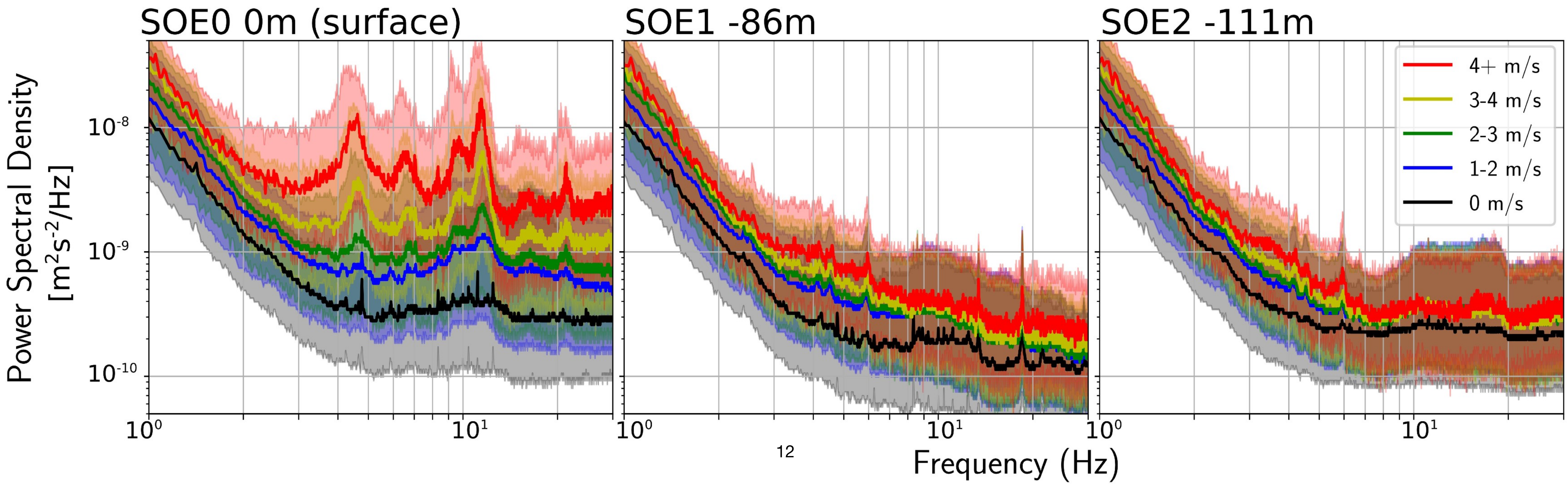
- Overall average wind speed is 1 m/s;
- Clear day/night cycle;
- Day breezes are be caused by the temperature gradient between the hot surface of the ground and the cooler surface of the sea.





Effects of wind on noise levels

- Spectra calculated over one minute following the wind speed measurement (every 30 min);
- Spectra divided into bins according to the wind speed;
- Clear effect of wind over the surface noise levels;
- Effect of wind underground is negligible;
- No correlation between wind direction and noise levels.



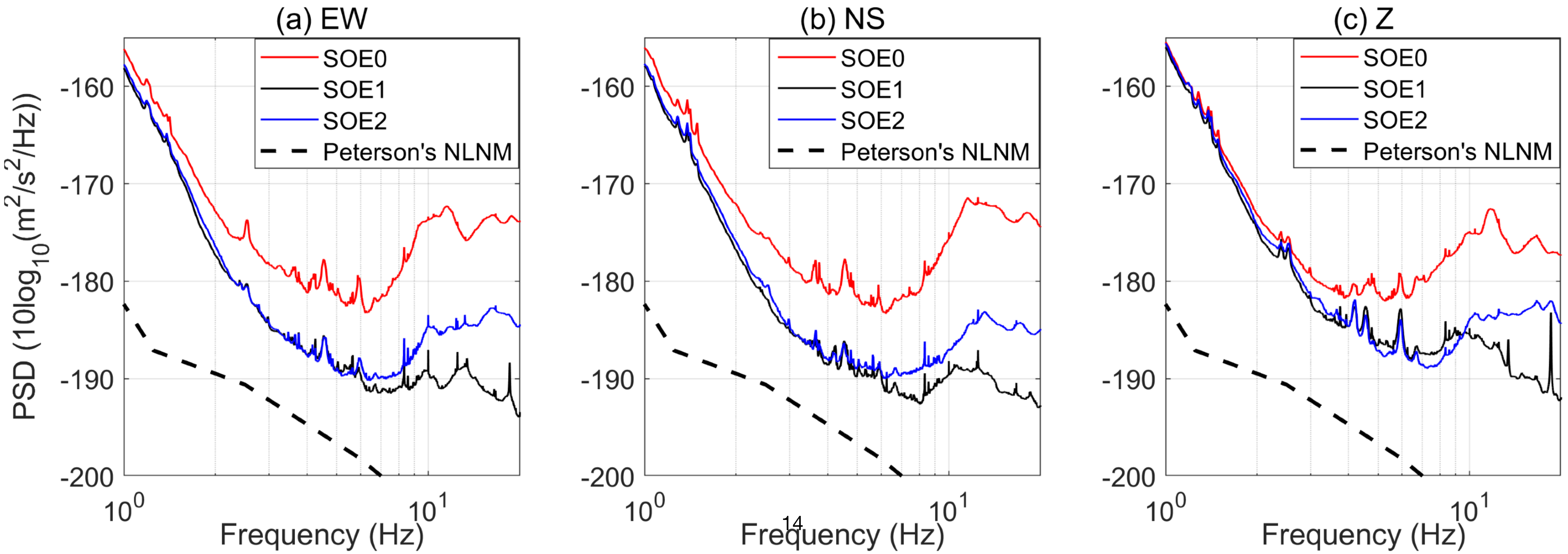
Temporal variations of anthropogenic noise

- Typical transition to anthropogenic is observed for frequencies greater than 1 Hz (Bonenefoy & Claudet 2006);

- The characteristics hard-rock geology at Sos-Enattos points to transition to anthropogenic noise at relatively higher frequencies of 5 Hz (Seo, 1997);

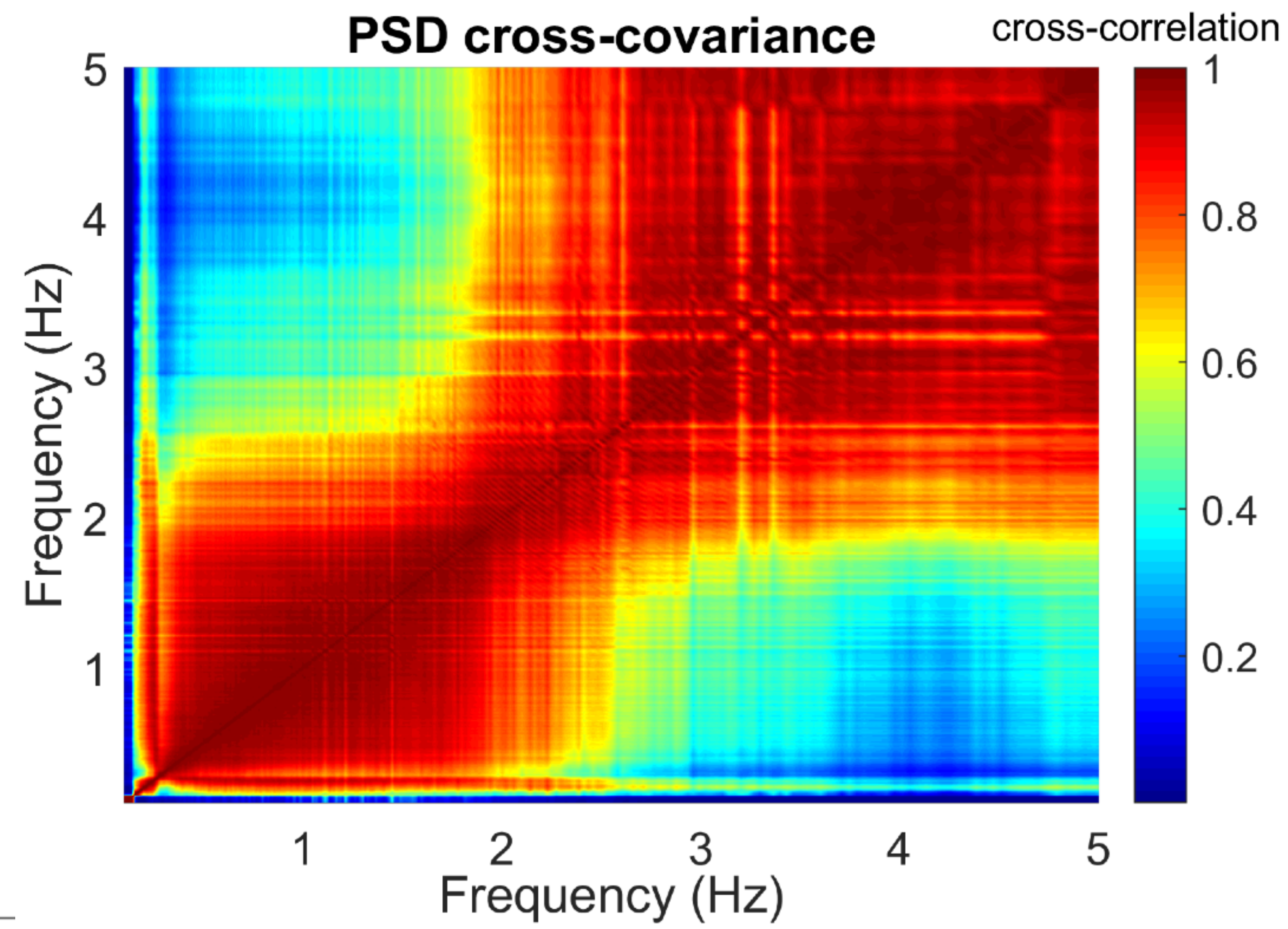
Temporal variations of anthropogenic noise

- A significant increase in seismic noise PSD is observed for frequencies above 5 Hz;
- The trough in the seismic-noise PSD between 1 and 5 Hz is only characterized by some spectral peaks due to stationary local sources of noise as discussed later;
- Similar transition-band observed underground with about a 5-10 dB reduction in PSD when compared to the surface;

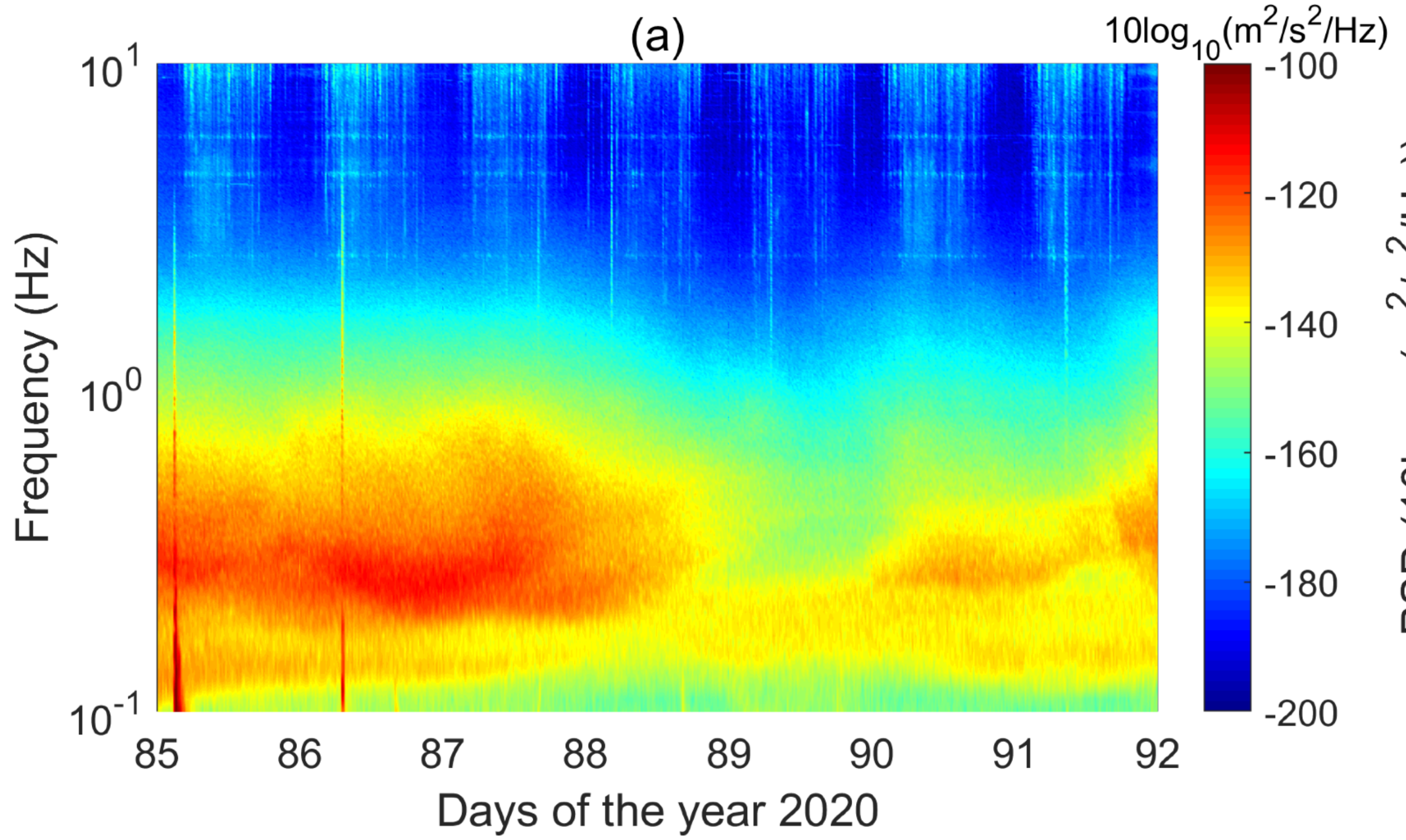


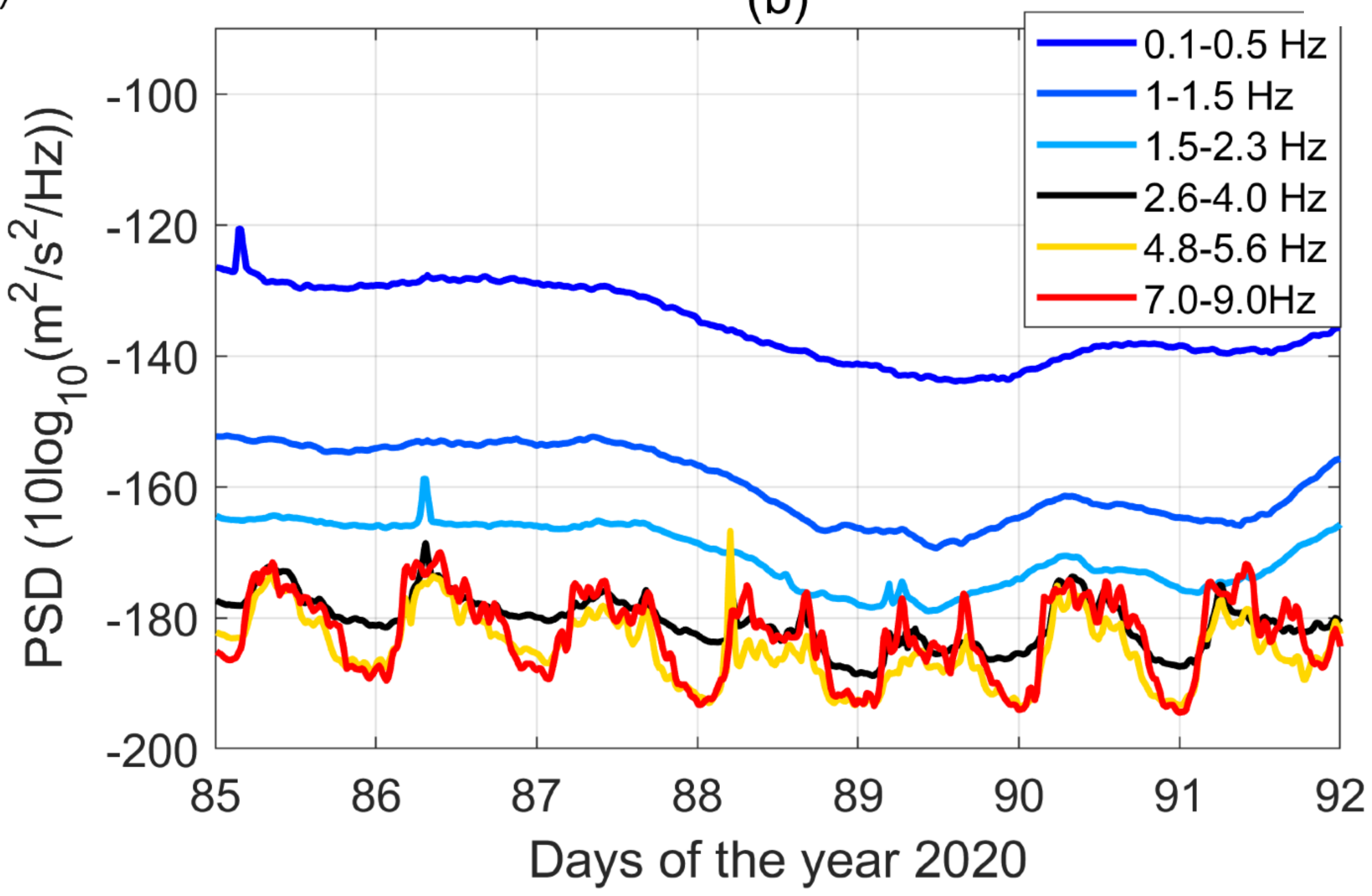
Temporal variations of anthropogenic noise

- The noise-floor in the transitional band between 1- 5 Hz is influenced by both the secondary-microseism as well as local storms and wind activity.
- A similar trend in the temporal variation of the noise PSD can be observed up to 2.5 Hz, implying the impact of the secondary microseism in the anthropogenic band
- A strict day-night variation is observed for frequencies greater than 5 Hz

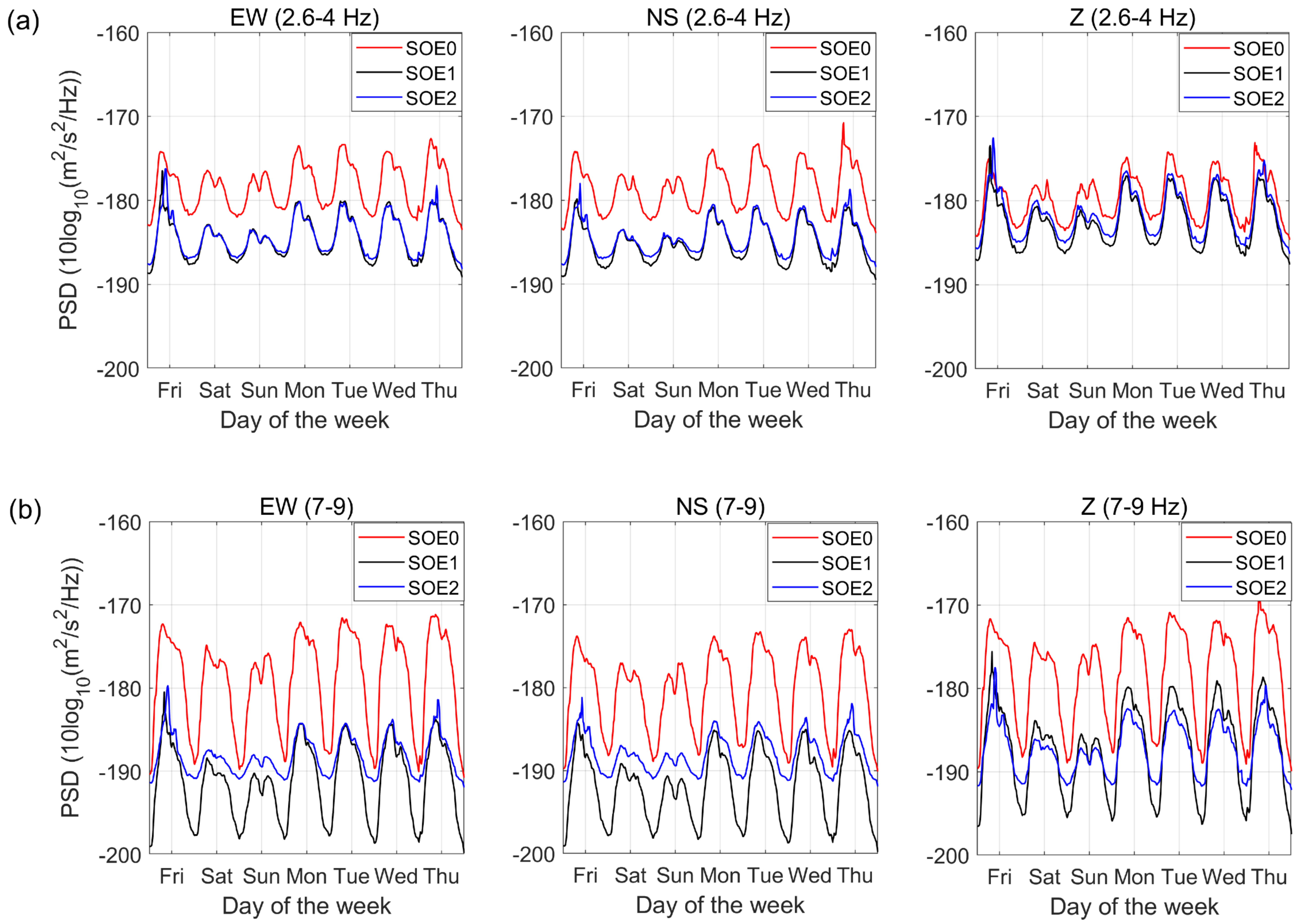


Frequency domain cross-covariance matrix of the temporal variation of seismic noise showing significant correlation between the microseismic noise and the anthropogenic band up to frequencies of 2.5 Hz.





Day-night variations



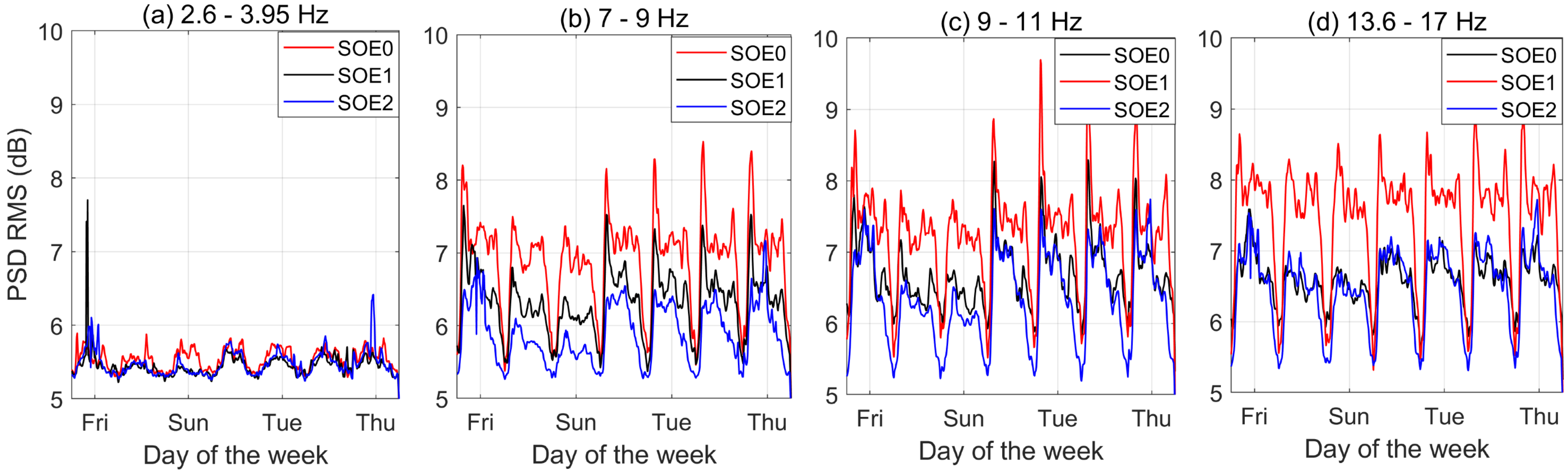
Day-night changes: variation of about 5 dB is observed on weekdays in the frequency band. 2.5-4 Hz and it increases to about 15 dB for the frequency band 7-9 Hz.

- As we move to frequencies > 5 Hz, the minimum seismic noise-floor is observed for SOE1 (other stations could be instrument noise limited);
- Maximum diurnal variation is observed for surface station, SOE0 and minimum for SOE2;
- The vertical component data for all stations show a slightly greater day-night variation when compared to the EW and the NS components;
- Weekends also show lesser day-night variation as compared to weekdays

Noise stationarity

Temporal variation of the rms of the seismic noise shows an increased stationarity of the observed noise during night and steady increase in non-stationarity with increasing frequency.

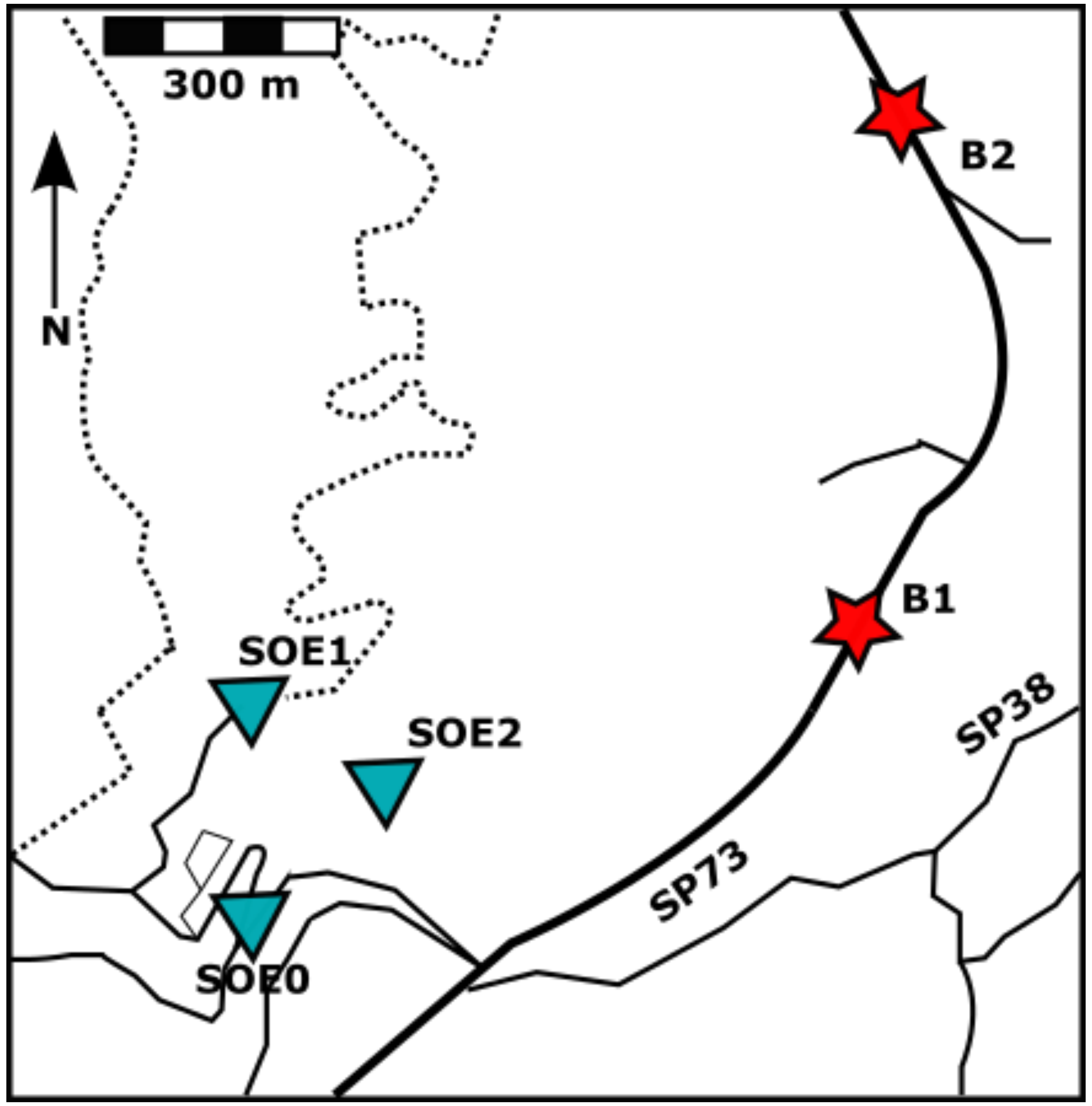
- The frequency band 2.6 - 3.95 Hz shows little diurnal variation in rms and implies that there is only a small change in stationarity between day and night;
  - ➡ *This is expected, since the low-frequency noise tends to be dominated by far-away seismic sources and characterized by a stationary phase;*
- For higher frequencies, the rms during the day increases to about 8 dB for the surface station. The rms during the night is observed to be about 5 dB, implying that the noise measured at night is more stationary than that measured during the day.



Bridge noise

There are two road bridges located 1 km and 1.5 km away from SOE0, respectively.

- In January 2021, the INGV array deployed on top of the mine tunnel found the evidence of their contribution to the overall background noise.
- In November 2021 we deployed 5 geophones to support this evidence.
    - one per each pylon of each bridge (total = 4);
    - one at SOE0.



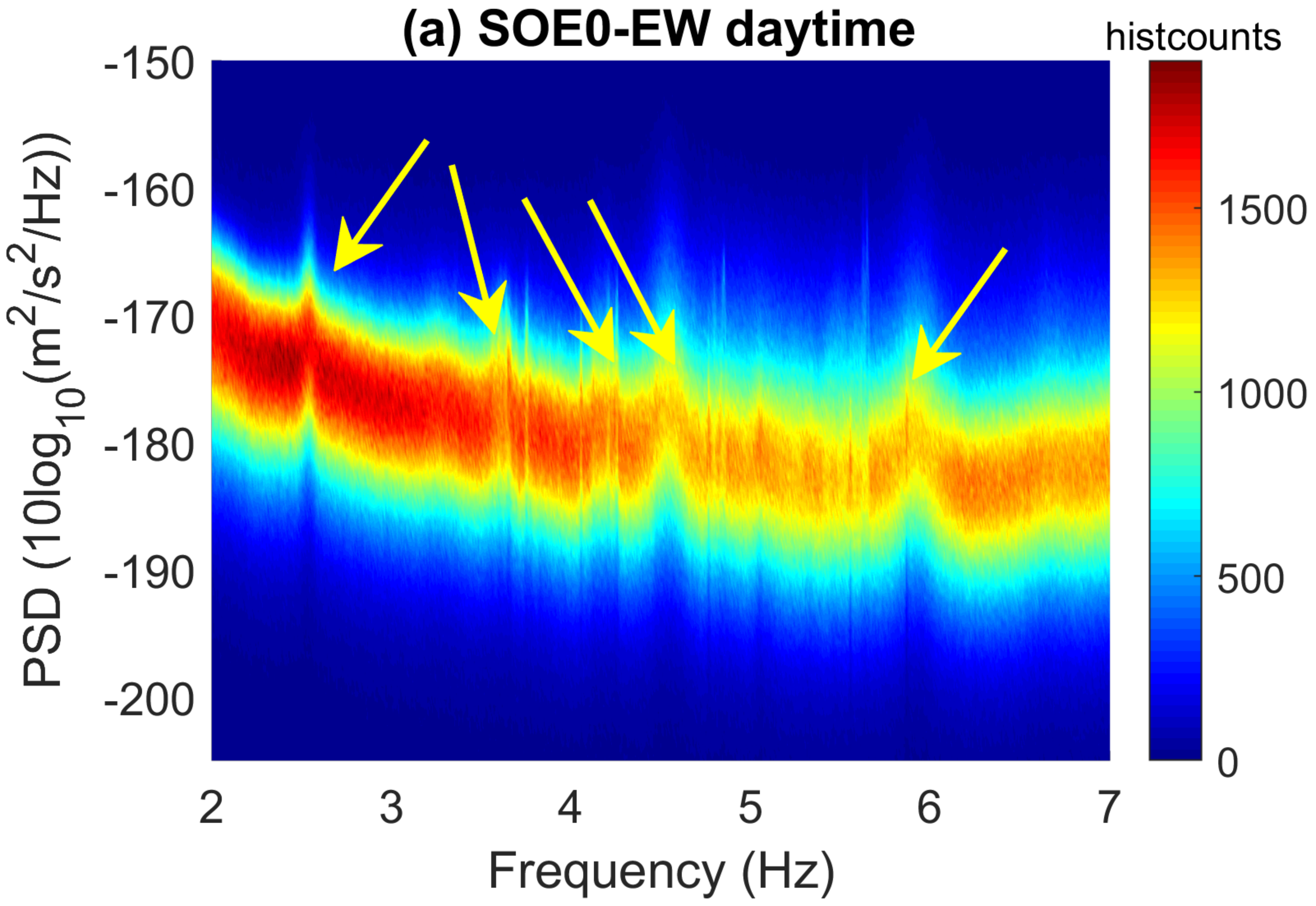
Bridge noise

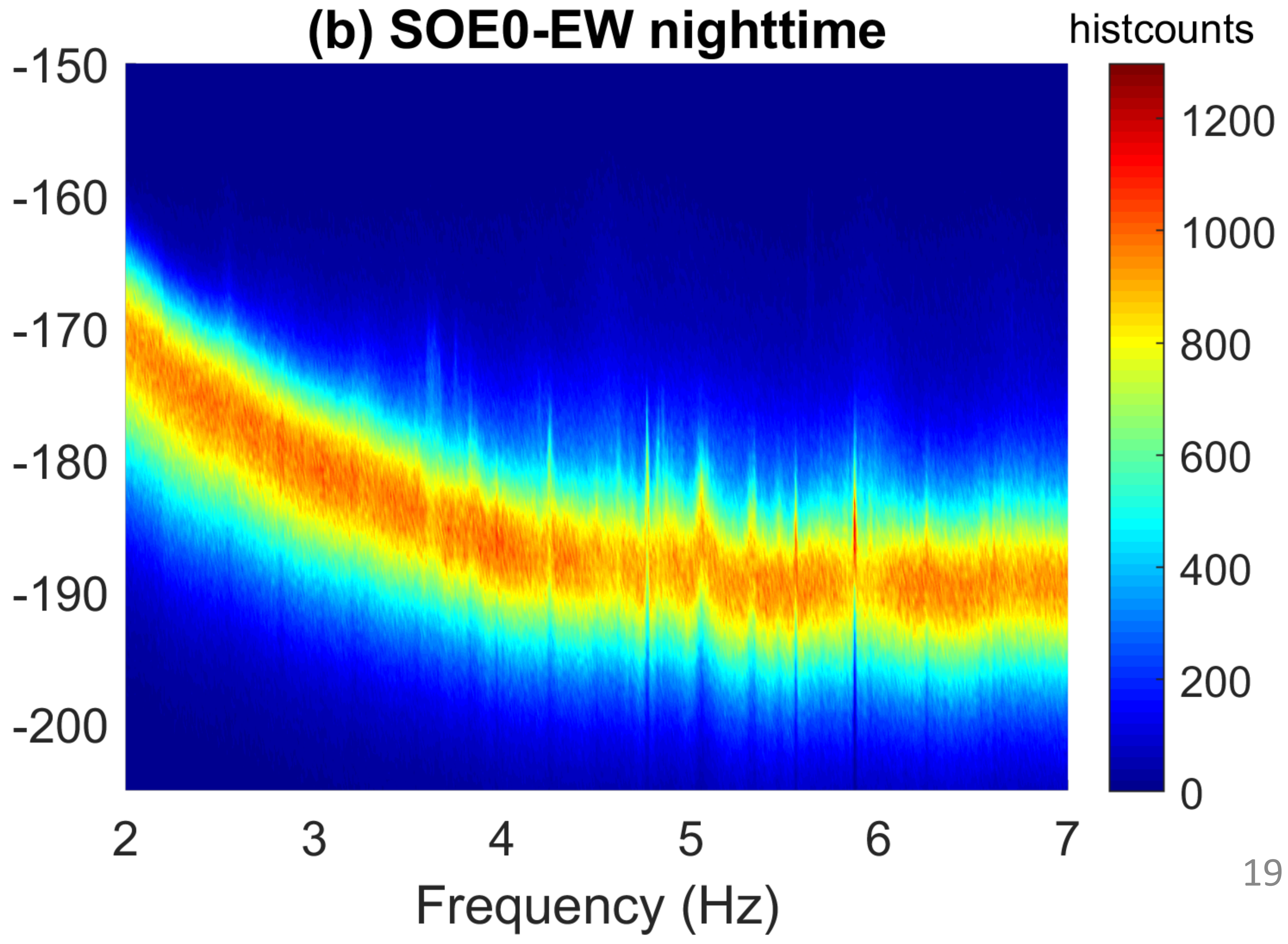
Besides broadband noise, noise peaks centered at 2.54, 4.16, 4.55, 5.92, 6.7 Hz can be attributed to road-bridges near the site.

➡ These peaks exhibit day-night variation and have a greater SNR at the underground stations;

➡ Other peaks centered at 16.4 Hz and 19 Hz are observed only in the Z and the N-S components;

➡ Additionally, a peak centered at 18.5 Hz is observed in the E-W component.

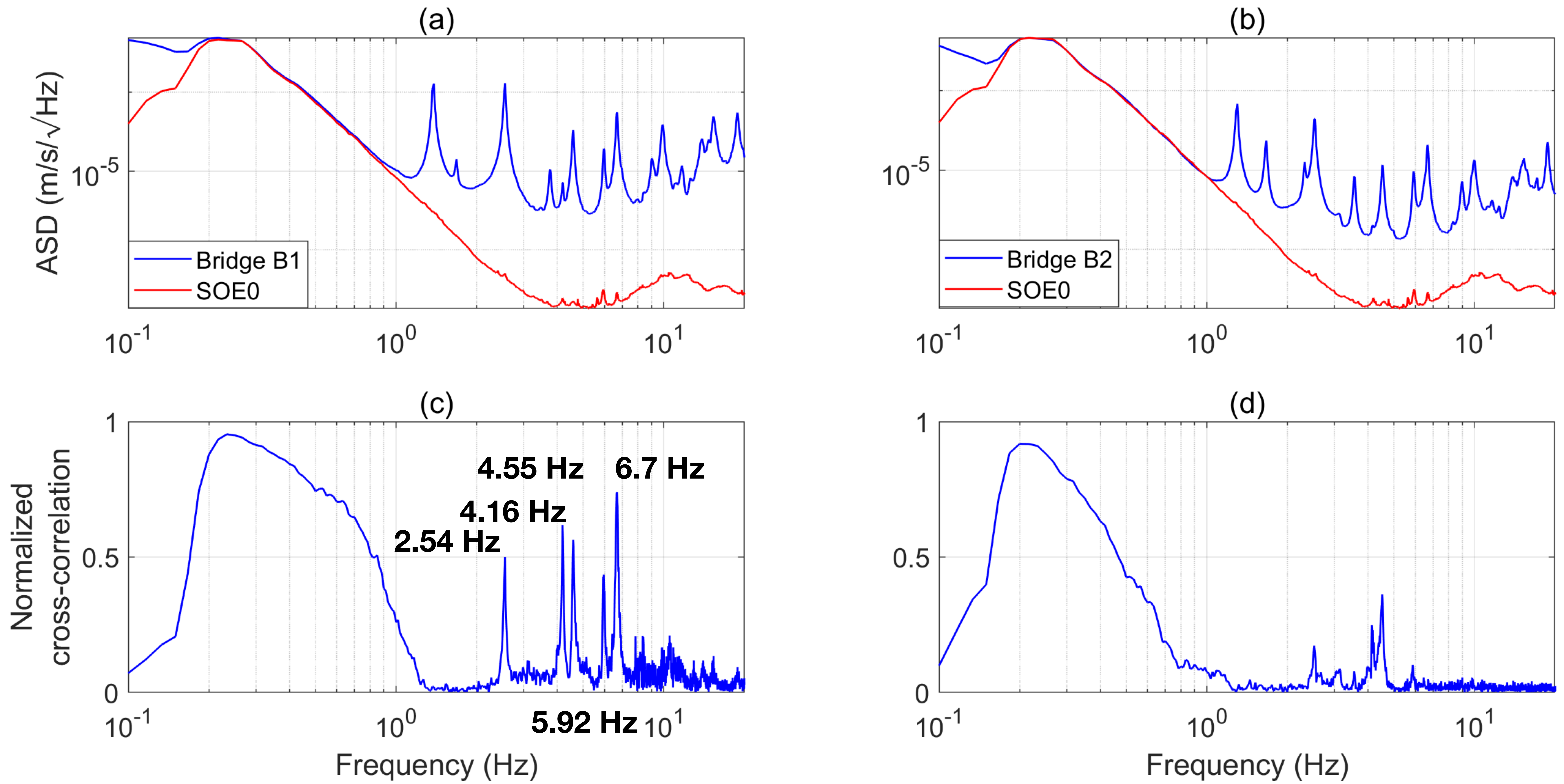




Bridge noise

Several peaks that are observed beneath the bridges are also observed at SOE0, however these peaks are attenuated by over two orders of magnitude.

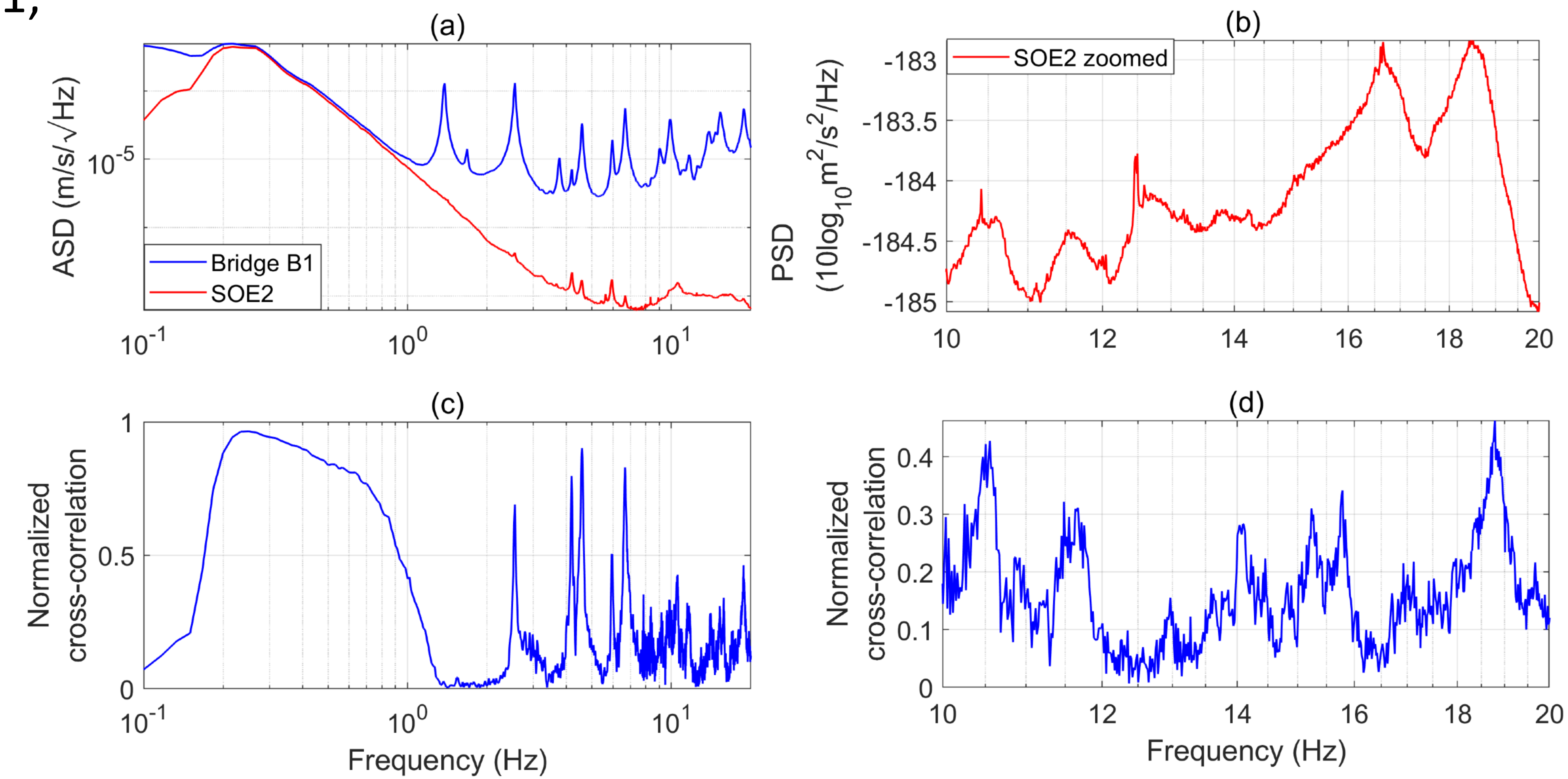
Bridge 1 **Bridge 2**



Bridge noise

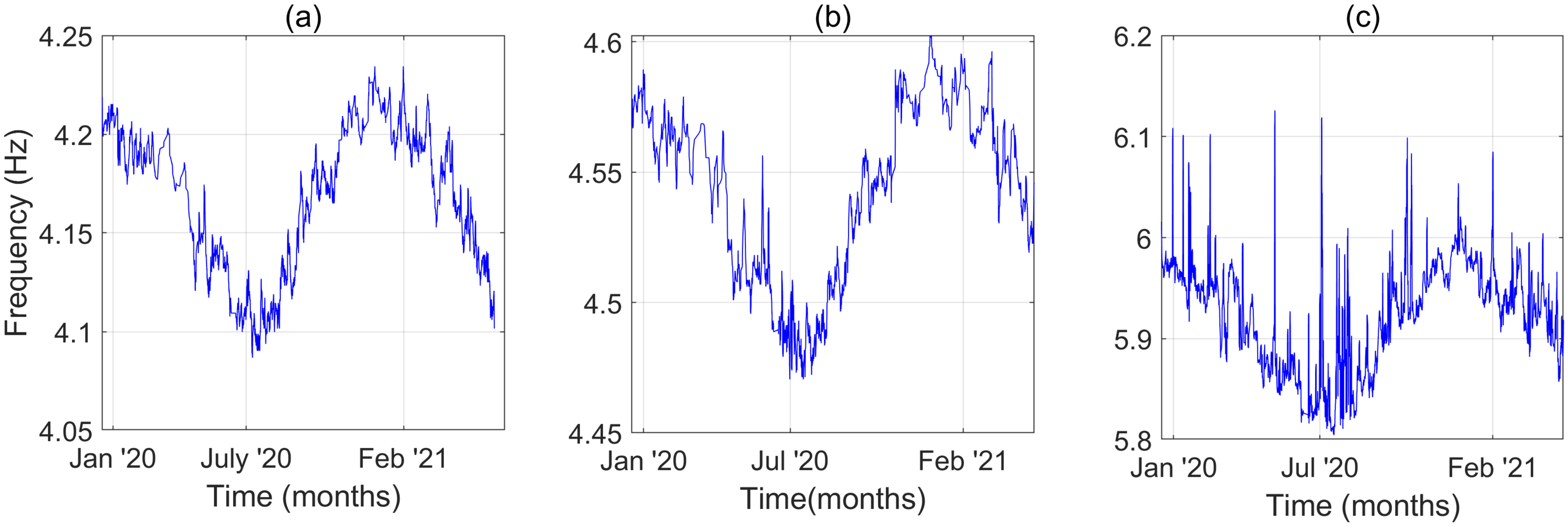
- Besides the peaks stated in the last slide, significant correlations with bridge B1 are observed for the peaks at 10.5 Hz, 11.5 Hz, and 18.5 Hz;

- Similar to the observations for SOE0, SOE2 shows a weaker correlation with bridge B2 compared to bridge B1;



Bridge noise

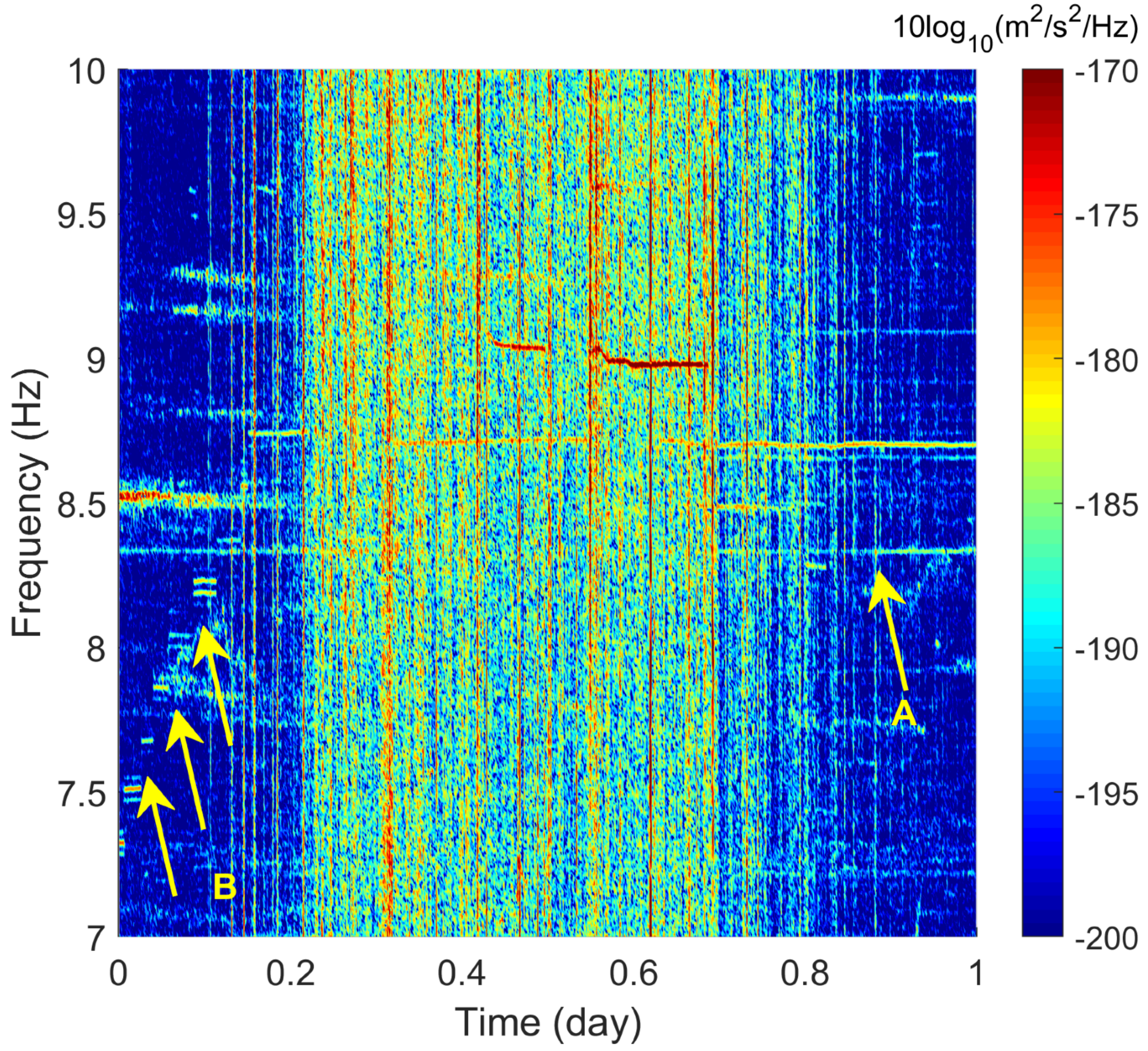
- On tracking the peak frequency over a year, we observed that these peaks show a drift in their peak frequency.
- The drift is correlated with seasonal changes with a higher peak frequency observed during winter and the vice-versa during summer.
- It is worth noting that the rate at which each of these noise peaks drift in frequency is not the same



(a) Drift in frequency of the 4.2 Hz noise peak observed at SOE2. (b) Same as (a), but corresponds to the 4.5 Hz noise peak. (c) Same as (a), but corresponds to the noise peak at 5.9 Hz. Time evolution of the peak frequency of these noise peaks show a seasonal pattern.

High frequency transients

- Besides the bridge noise peaks, several peaks are observed in each of the three stations and with a stronger SNR at night;
- While most these peaks are transients, some peaks at 8.33 (arrow A in figure), 12.5, 16.67 and 18.5 Hz are observed for about 40-50% of the time in the data;
- While the first three peaks are observed in all the three stations, the 18.5 Hz peak is only observed in SOE1;
- The noise peaks at 8.33, 12.5, and 16.67 Hz are somewhat generic;
- In the time domain, these appear as sinusoidal-type seismic waves originating from rotating machinery;
- As observed in previous studies by Kar & Mohanty 2006 and Coward et al., 2005, these frequencies correspond to the rotation frequency of electric motors and cooling fans at the site;
- For example, a twelve-pole engine has a rotation frequency of 8.33 Hz (500 rpm), an eight-pole motor has a rotation frequency of 12.5 Hz (750 rpm), and a six-pole motor has a rotation frequency of 16.67 Hz (1000 rpm);
- Future array studies should also be aimed at understanding the wave-type and the polarization of these noise sources.



Periodogram of seismic noise observed at station SOE1 for a period of a day and zoomed in the frequency band 7-10 Hz. The 8.33 Hz noise peak originating from a twelve-pole motor at the site is labeled as "A" in the figure. Other noise peaks that exhibit jumps in peak-frequency and amplitude are labeled as "B".

Conclusions

- Microseismic noise in Sos Enattos has a seasonal trend with a variation of up to 20 dB between winter and summer;
- Directionality studies of microseisms confirm that they mostly come from the N-W direction;
- In bad weather conditions or rough seas, the tail of microseisms extends beyond 1 Hz;
- Occasionally, sea wave noise from the Atlantic Ocean can show up in Sos Enattos as well;
- Environmental noise caused by wind shows up as an excess of seismic noise on surface;
- Between 1 Hz and 5 Hz there is a transition zone between microseismic noise and anthropogenic noise;
- Maximum day-night variation of seismic noise is observed on surface;
- At increasing frequencies, the stationarity of seismic noise decreases;
- Some noise peaks observed at the mine are clearly associated to the two bridges nearby.
- Evidence was found that other peaks may be associated to machinery.