Study of seismic noise reduction due to COVID-19 lockdown

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Abstract: The study focuses on the analysis of the seismic signals recorded by the ALBA station (located in Cerdanyola del Vallès) over three bimonthly periods in 2019, 2020 and 2021. The seismic records of the three years have been compared to check whether the measures to restrict human activity, due to the COVID-19 pandemic in 2020, have led to a decrease in seismic noise in the area. In addition, the noise levels of the station have been characterised and the main sources of seismic noise in the area have been located. To achieve these objectives, the seismic noise variations have been studied and analysed using the PSD spectral power density calculation method.

I. INTRODUCTION

Seismometers are instruments designed to detect vibrations coming from the ground. The origin of these seismic disturbances is either natural (earthquakes, ocean tides…) or anthropogenic (machinery, road traffic…) e.g. **[1]**.

The year 2020 has been marked in our lives by the COVID-19 pandemic. On 11th March 2020, the Director General of the WHO (World Health Organisation) declared the COVID-19 outbreak as a pandemic. From this date onwards, most countries adopted various measures to restrict mobility and imposed social distancing. In Spain, a state of alarm was activated on 15 March until 21 June. This entailed house confinement and the stoppage of non-essential activity. Subsequently, there have been various outbreaks that have forced the adoption of new regional restrictive measures until 2021, such as, regional lockdown and the establishment of a curfew after a certain time at night.

Following these changes in our activity, a worldwide research was conducted on the effect of changes in human behaviour on anthropogenic noise levels at seismic stations during the most acute stage of the pandemic. Lecocq's study **[2]** showed that there was a decrease in seismic noise of up to 50%. In particular, there was a research in the city of Barcelona, where Díaz et al. **[3]** showed that there was also a reduction in the noise level.

The seismic signals from the ALBA seismic station, located near Barcelona, have been used for this research. The conclusion of the aforementioned studies by Lecocq and Díaz has motivated the present work with the aim of: (a) checking whether our study area has been affected by the decrease in anthropogenic noise during the pandemic, (b) identifying the noise levels of ALBA station and (c) locating the main sources that originate seismic noise in the area.

II. ALBA SEISMIC STATION

The ALBA seismic station, owned, deployed and maintained by LEGEF-IEC[1] with the help of ALBA-CELLS, is located inside the scientific premises of the ALBA Synchrotron in an industrial area of Cerdanyola del Vallès (Barcelona) close to the Mediterranean motorway. The geographical coordinates of the scientific complex are 41° 29' 12.38" N and 2° 6' 35.74" E.

The measuring devices used during the years under analysis include a 3 component (Vertical, NS and EW) Miniseismonitor velocity short period sensor (Geospace Technologies®) and a SpiderNano digitizer (Worldsensing©) acquiring at a rate of 250 samples/second, thus obtaining an instrumental flat response from 2 Hz to 125 Hz.

The Miniseismonitor converts ground vibrations into electrical potential differences while SpiderNano digitizes the data, obtaining a time series of samples and stores them in Spider format in a memory card. The data is then extracted, downloaded and uploaded to the LEGEF servers. Finally, the data are converted into standard mseed format **[4]** for further pre-processing.

III. DATA

To achieve the main objective of this work, it would have been ideal to analyse the data over the course of January to June 2020, but as these data are not available because of logistic problems, three periods of several months in the years 2019, 2020 and 2021 were used to characterise the pre-pandemic noise, the pandemic/post-pandemic noise and the post-pandemic recovery stage noise, respectively.

The seismic data obtained correspond to the following periods: 27 March to 23 May 2019, 14 July to 14 September 2020 and 1 March to 19 April 2021. These available data periods are sufficient to measure and establish representative noise levels for each year.

The ALBA seismic Z-component was selected for our study in these periods, because it is less sensitive to transverse vibrations such as those caused by wind.

IV. METHODOLOGY

A. Theory

The background seismic noise of a station's signal is considered as a stochastic phenomenon, so the power spectral density (PSD) is used to study it. The PSD is a function that allows the analysis of the frequency content of a stationary stochastic process, has dimensions of power per Hz and is calculated from the Fourier transform of the square of the signal value **[5][6]**. Its mathematical expression is:

$$P(\omega) = \int p(\tau)\, e^{-i\omega\tau} d\tau \qquad (1)$$

Where $p(\tau) = < f(t)f(t+\tau) >$ is the autocorrelation function, $<>$ is the time average calculation and $f(t)$ is the signal. In our case, the seismic noise.

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B. Data treatment

The seismic data processing is made up of two different stages: the pre-processing and the processing of the data (the steps followed in both stages are represented in the diagram of Fig. 1).To carry it out, the Python library ObsPy has been used and the free software SeismoRMS **[7]** has been suitably adapted for this work.

The pre-processing of the seismic data in this work only includes the instrumental deconvolution to recover the real movement of the ground. No other corrections or filters were applied since we want to observe the spectrum of the seismic noise as it is. Once the seismic data are expressed in units of velocity, they are converted into seismic acceleration, since in our study the seismic noise signal $f(t)$ is expressed in acceleration (first step from Fig.1).

Subsequently, in the processing (second step in Fig. 1), the PSD of the seismic data is calculated using equation (1). It is calculated in three formats: Cumulative PSD, temporal PSD (also known as spectrogram) and RMS amplitude. The continuous seismic signal is divided into intervals of a given length where the PSD is computed. The cumulative PSD is the probability density function of these PSDs collection **[5]** **[8]** **[9].** The PSD spectrograms are the representation of the computed PSD over time. For the representation of RMS amplitudes, the seismic data are divided into fixed 30 minutes windows with 50% of overlap where the PSD is computed. Then, the root mean square amplitudes of the PSDs of the selected frequency band are calculated. Finally, the acceleration RMS amplitudes are transformed into displacement and the time evolution of the seismic noise values are plotted.

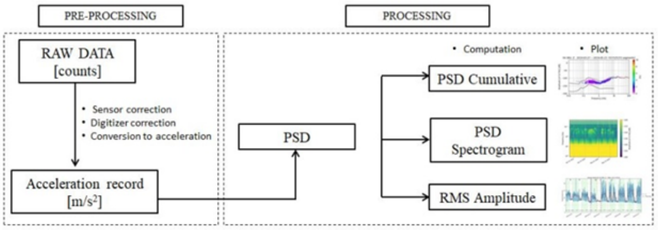

FIG. 1: Diagram of the steps performed in this study to analyse seismic noise and output results.

V. RESULTS

A. Cumulative PSD

Following Lecocq's model and analysing the cumulative PSD spectra for the three studied years two different behaviours are observed within the 4-14 Hz band (Fig. 2). The first one takes place between 4 and 7 Hz where a broad PSD band with two types of behaviors is observed: a higher density of spectra is found in the blue zones (1.5-3 %) compared to the pink zone (less than 1.5 %). The second one occurs from 7 to 14Hz, where the PSD spectra converge in a narrower band with values higher than 4 % and the previous behaviour is no longer perceived.

According to this first observation, 4-7 Hz and 7-14 Hz bands are selected from now in this study to carry out the evaluation of the anthropic noise of Cerdanyola del Vallés (Barcelona Synchrotron Park).

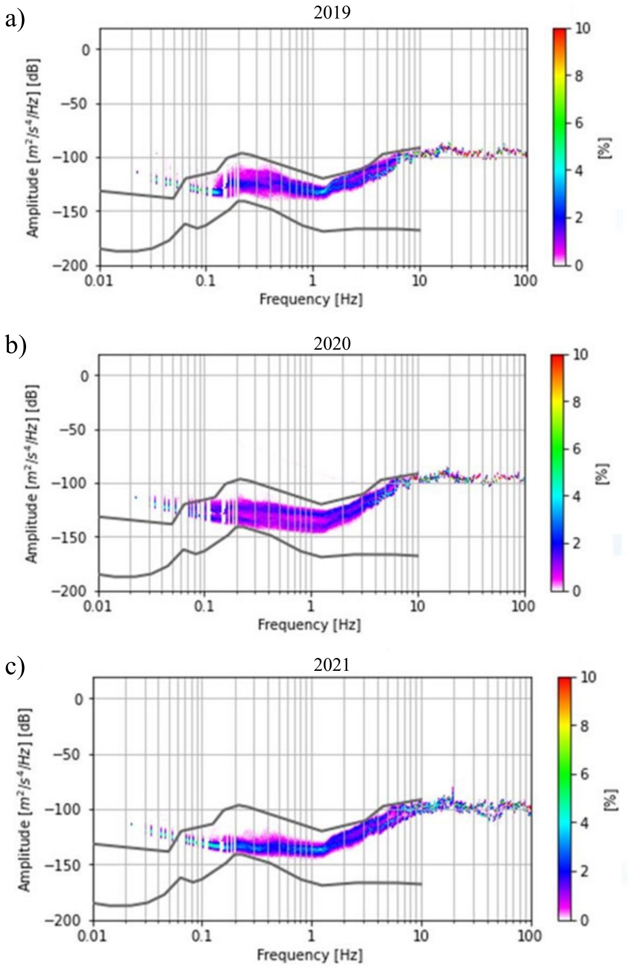

FIG. 2: Cumulative PSD spectra expressed in % for the Z-component data for the different years studied: (a) 2019, (b) 2020 and (c) 2021 period. The grey curves are PSD spectra of the Earth's ambient seismic noise from **[5]**: upper (noisy) and lower (quiet). Data are expressed as dB relative to 1m^2 s^{-4} Hz^{-1}.

B. Spectrograms

The 4-7 Hz and 7-14 Hz bands of the spectrograms in Fig. 3 are characterised by a pattern typical of cultural noise. This pattern is formed by the interleaving of bands of different amplitudes that is repeated every 7 days under normal conditions (weeks from Monday to Sunday with no public holidays on working days). This agrees with the behavior observed in the previous section for the interval 4-7 Hz.

For example, in a normal week (6 to 12 May 2019, marked with a rectangle in Fig. 3a), from Monday to Friday, daytime hours (yellowish hue with mean amplitude of -110 dB) can be clearly distinguished from night time hours (greenish/bluish hue with mean amplitude of -120 dB). However, this distinction is more difficult to observe on Saturday and Sunday. On the other hand, working days (sequence of two stripes of yellowish and greenish hue) can be differentiated from public holidays (days without a significant sequence of stripes). This variability between day/night and workday/holiday can also be perceived at lower frequencies during 2021 (Fig. 3c), whereas in the 7-14 Hz band this variability is no longer perceptible from 9 Hz upwards (except for four consecutive weeks in 2020, Fig. 3b).

In general, at frequencies from 4 to 9 Hz the average amplitude variation between daytime and night-time hours of a working day is about 10 dB. It can also be observed that the amplitude (the seismic noise level) of public holidays is similar to that of weekday nights, but is smaller than that of weekday daytime hours.

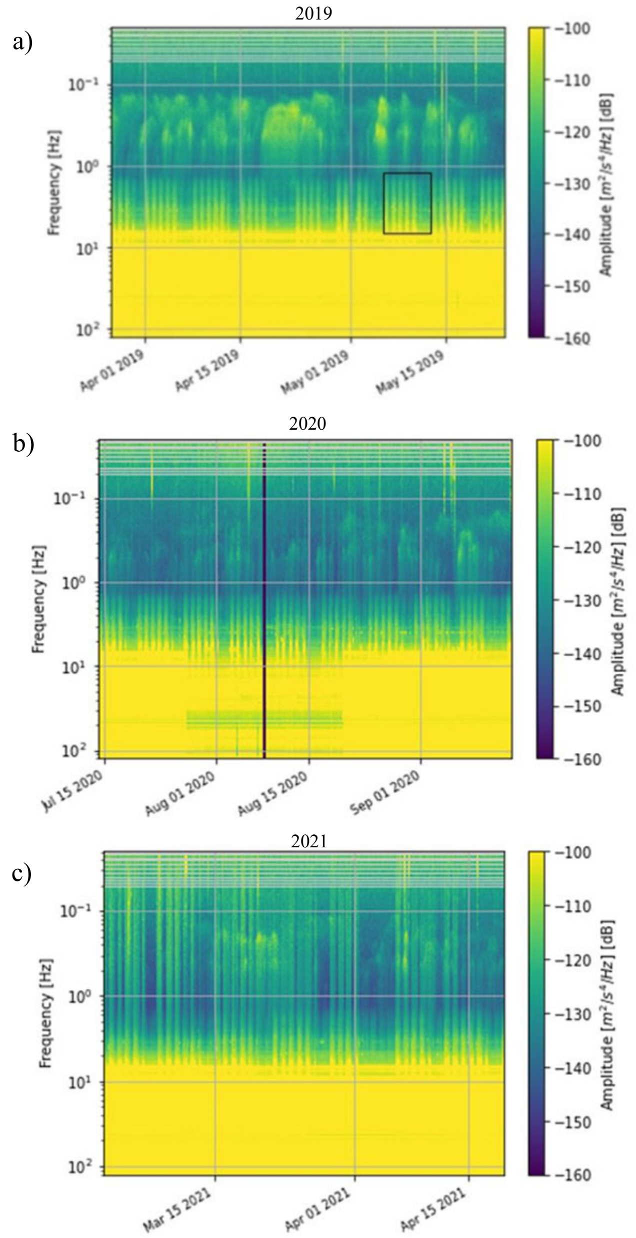

FIG. 3: PSD spectrograms for each 30 minutes with 50 % of overlap of the Z component data for (a) 2019, (b) 2020 and (c) 2021 period. The rectangle marked in Fig. 3a comprises a weekly period. Data are expressed as dB relative to 1m^2 s^{-4} Hz^{-1}.

C. Temporal evolution of seismic noise displacement

The results of the RMS displacement amplitudes for each year are included in detail in this section together with Fig. 4.

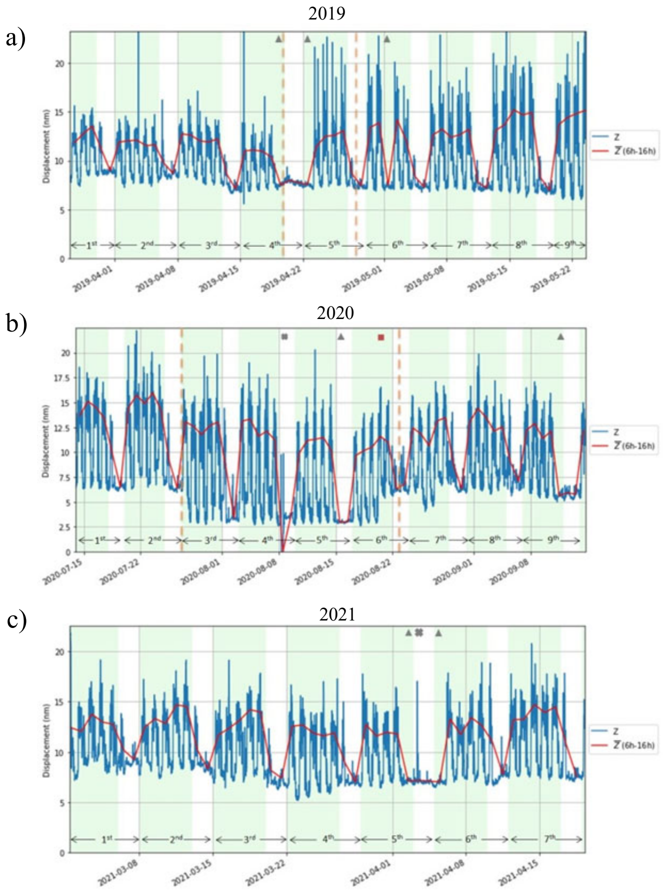

FIG. 4: Variations of the seismic noise displacement of the Z component of the ALBA station for the 4-7 Hz frequency band during the period: (a) 2019, (b) 2020 and (c) 2021. The weeks are numbered. Blue line: displacement value averaged every 30 minutes. Red line: daily average of the shift of working hours (6h-16h UTC). Green background: working days (Monday to Friday). White background: weekend. Triangles: public holidays. Crosses: anomalous peaks. Period marked with orange dashed lines: (a) days on which a tempest crossed over and (b) ALBA Synchrotron holidays. Square: specific day mentioned in the text.

C.1 2019 period

To describe in more detail the differences and similarities of behaviour between the weeks of the 2019 period considered, we have constructed Fig. 4a which shows the temporal evolution of the displacement of the seismic noise between 4 and 7Hz. The periodic pattern of five oscillations corresponding to the first five working days of the week (from Monday to Friday) should be highlighted. However, there are three weeks (the fourth, fifth and sixth) that do not follow this behaviour because 19 April, 22 April and 1st May are national holidays (days marked with a triangle at the top of Fig. 4a and Fig. A1a) resulting in only 4 oscillations per week. On these three days, the decrease in anthropogenic noise is strongly noticeable compared to the rest of the working days. Their average displacement during working hours (6h to 16h) is approximately 8 nm.

On weekends, a decrease in the seismic noise displacement is observed from midday on Saturday, and the lowest noise levels are reached in the afternoon and remain low the whole following day, Sunday. The weekly variations of the seismic noise displacement observed in Fig. 4a are explained in detail in section IA of the Appendix.

In relation to the temporal evolution of the displacement of the seismic noise between 7 and 14 Hz in the 2019 period (Fig. A1a) the decrease in the daytime noise with respect to the rest of the days occurs during Easter (from 19 to 22 April), on 1st May and on Sundays. It should also be noted that the variation of the average noise displacement between day and night is about 2-3 nm, i.e. it is smaller compared to that of the 4-7 Hz band, according to what was observed in Fig. 2. Also note the occurrence of anomalous peaks on 3 and 15 April (peaks also perceived in the 4-7 Hz band) and the first four days of the fifth week. All the days mentioned are marked with a cross in Fig. A1a.

In summary, in the 4-7 Hz band, the average amplitude of the oscillations of the entire 2019 seismic dataset has its minimum at about 7 nm and its maximum at about 15 nm. On the other hand, in the 7-14 Hz band (Fig. A1a) the oscillation amplitude is seen to be in the range of 9 nm to 12 nm.

C.2 2020 period

Fig. 4b shows the time evolution of the displacement of the seismic noise between 4 and 7 Hz for the 2020 period considered. During this two-month period, the difference in behaviour between day/night and working day/weekend can also be appreciated. In addition, it is important to highlight the strong reduction of anthropogenic noise that occurs approximately during four consecutive weeks: the last week of July and the first three weeks of August.

In general, it should be noted that Sundays are generally quieter than Saturdays and that the average noise level during the hours 6h-16h UTC on Sundays is similar to that of weekday evenings. On the other hand, Saturday 15 August and Friday 11 September are public holidays in the working calendar (marked with a triangle in Fig. 4b and Fig. A1b). On this weekend and on this long weekend, the mean seismic noise displacement during 6h-16h UTC reaches the lowest value with respect to the previous weekends of the same month. The weekly variations of the seismic noise displacement observed in Fig. 4b are explained in detail in section IB of the Appendix.

In relation to the temporal evolution of the displacement of seismic noise vibrations between 7 and 14Hz for the 2020 period (Fig. A1b), it is observed that the amplitude variation between day and night is between 3 and 4 nm, i.e. it is lower with respect to that of the 4 to 7 Hz frequencies, as seen Fig. 2. Also, a reduction of the anthropogenic noise by 5 nm can be perceived from 27 July onwards and its increase from 20 August onwards (marked with a red square in Fig. A1b). The seventh week is a week of transition towards the recovery of the oscillatory behaviour of the first two weeks. This behaviour is reached in the eighth and ninth weeks. In contrast, the recovery of the noise level is not observed at frequencies from 4 to 7Hz.

Finally, Fig. 4b shows that the average maximum amplitude of the displacement for the months of 2020, without considering the four consecutive weeks of the generalised seismic noise fall, is 15 nm and the minimum amplitude is 6 nm. On the other hand, in the frequency band 7-14Hz (Fig. A1b) the oscillation amplitude is in the range of 9 nm to 12 nm.

C.3 2021 period

The 2021 period is analysed in Fig. 4c where the temporal evolution of the displacement of seismic noise between 4 and 7 Hz is represented. The two different behaviours between day/night and working day/weekend mentioned in the previous periods are repeated. In addition, from 15 March onwards the nights are quieter than in the previous weeks. The minimum seismic displacement is on average about 1 nm lower than in previous weeks.

On the other hand, the reduction in diurnal anthropogenic noise that occurs during the Easter holidays (between 2 and 5 April marked with a triangle at the top of Fig. 4c and Fig. A1c) is noteworthy. The mean seismic noise displacement during the 6h-16h UTC of those days is 7 nm. The noise level of these two holidays, moreover, coincides with that of the previous weekday nights. The weekly variations of the seismic noise displacement observed in Fig. 4a are explained in detail in section IA of the Appendix.

Regarding the temporal evolution of the seismic noise displacement between 7 and 14 Hz for the period of 2021 (Fig. A1c), it is worth noting the progressive decrease of the average seismic noise level during the 6-16 h UTC until reaching its minimum of 10 nm during Easter and the subsequent seismic noise recovery during the following two weeks. In addition, the noise difference between day and night is small (approximately 2-2.5 nm).

Finally, during the period 2021, it is observed that the minimum and maximum average amplitude of the oscillations of the 4-7 Hz frequency band is 7 nm and 15 nm respectively. The oscillations in the 7-14 Hz band are between 10 and 13 nm.

VI. DISCUSSION

Firstly, from the graphs of the time evolution of the seismic noise displacement between 4-7 Hz (Fig. 4a, 4b, 4c) a significant variation between day and night is shown. Therefore, it is confirmed that the blue side zones (1.5-3 % values) seen in the cumulative PSD spectra (Fig. 2) between 4 and 7 Hz are due to the noise variability between day and night.

Likewise, during the three years of study it has been possible to distinguish the different behaviour between day and night, and between working days and public holidays. It has also been seen that anthropogenic noise decreases considerably during holidays and working nights due to the decrease in vehicle traffic and the decrease or cessation of industrial activity in the area where the seismic station is located.

On the other hand, additional studies of some anomalous peaks show that anthropogenic noise may be contaminated by natural noise. For example, in the seismic records of 3 April 2019 and 3 April 2021 we observe three earthquakes (consulted in the ICGC[2] catalogue) originated in Alt Urgell. The first one in 2019 reaches a magnitude of 4.4 on the Richter scale, whereas the two of 2021 have a magnitude in the Richter scale of 3.1 and 2.8, respectively. In addition, the lack of seismic data also causes the false appearance of unwanted peaks due to the computation method used. This is

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the case of the lower peak on 15 April 2019 and 8 August 2020, which corresponds to a gap of data in the station.

In 2019, an increase of the baseline of 1nm is observed during the days of Easter and the following week with respect to the first four days of the fourth week (Figs. 4a and A1a). To explain this increase, the temporal evolution of the mean wind speed and the mean atmospheric pressure during four consecutive weeks (from 8 April to 6 May) has been studied. Meteorological data from the Sant Cugat del Vallès and Fabra Observatory stations, respectively (obtained from the Catalan Meteorological Service website[3]) were used. It has been seen that the increase in seismic noise during this week is not correlated with the periodic behaviour of the wind. However, it has been observed that from 20 to 27 April (period marked with orange dashed lines in Fig. 4a and A1a) a squall crossed the area, reaching a minimum pressure of 996 hPa on 23 April. Low pressures are indicative of bad weather (they are associated with thunderstorms) and contribute to increased seismic noise in the area. Therefore, one of the causes of the increase in seismic noise might be bad weather.

In 2020 we have seen a generalised drop of 3 nm (in 4-7 Hz band) and 5 nm (in 7-14 Hz band) in the seismic noise displacement occurring from 27 July onwards. This drop is mainly correlated with the ALBA Synchrotron's operational schedule (provided by the facility itself), as it coincides with the start date of the facility's holidays (holiday period marked with orange dashed lines in Figs. 4b and A1b). This includes the total shutdown of the machinery, including the water- and air-cooling systems. The latter are not shut down in Easter of the other periods analysed (2019, 2021 periods) or during site maintenance days (Monday of each week), which explains why there is not such a marked reduction in noise during these days. Therefore, the cooling systems are the main source of seismic noise from all ALBA machinery.

Subsequently, the increase of 3 nm (in 4-7 Hz band) and 5 nm (in 7-14 Hz band) in the seismic noise displacement observed on 20 August is not in line with the date of the end of the ALBA holidays (22 August). However, it coincides with the information provided by the centre on the commissioning of instrumentation, machinery, and cooling systems, which is carried out progressively, without adjusting to the holiday schedule. The value of this increase is the same as that of the decrease on 27 July. Therefore, the ALBA contribution to anthropogenic seismic noise in the area is 3nm at frequencies 4 to 7 Hz and 5 nm at frequencies 7 to 14 Hz. The impact of ALBA machinery and cooling systems is greater at higher frequencies.

In the periods of activity of the ALBA, the seismic noise levels of the ALBA station in the 4-7 Hz frequency band have been found to oscillate between 7 and 15 nm during 2019 and between 6 and 15 nm during 2020. Likewise, in the 7-14 Hz frequency band the oscillation is in the range of 9 nm to 12 nm in both years. The analysis of these values does not show changes in anthropogenic noise in the area. Therefore, with the analysed data there is no evidence that the pandemic has affected the area in terms of seismic noise.

During the studied months of 2021, mobility restrictions such as curfew and regional lockdown due to COVID-19 outbreaks were in force, in contrast to the studied period of 2020. In this case, the seismic noise levels of the ALBA station in the 4-7 Hz frequency band range between 7 and 15 nm and in the 7-14 Hz band between 10 and 13 nm. The values in the former frequency band coincide with those obtained in 2019. In the 7-14 Hz band there is only a 1 nm increase in noise levels compared to the 2019 and 2020 period. Therefore, the curfew restriction and country lockdown have not affected the level of anthropogenic seismic noise in the area.

VII. CONCLUSION

The use of the PSD calculation method and its subsequent representation through cumulative PDS spectra, spectrograms and graphs of the time evolution of the seismic noise displacement has allowed us to study the behaviour of seismic noise in the area to conclude:

- During our study periods throughout 2019, 2020 and 2021 no reduction in anthropogenic seismic noise has been detected in the area due to social behaviour.
- The overall seismic noise levels of the ALBA station are between 7 and 15 nm for the 4-7 Hz frequency band and between 9 and 12 nm for the 7-14 Hz band.
- The main sources of seismic noise in the area are industrial activity, road traffic, and the machinery and cooling systems of the ALBA synchrotron, that produce mostly higher frequency vibrations. No occasional natural phenomena contribute to the increase of seismic noise.

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[1] J. Díaz, On the origin of the signals observed across the seismic spectrum, Earth-Science Rev. 161 (2016) 224-232. https://doi.org/10.1016/j.earscirev.2016.07.006.

[2] T. Lecocq, S.P. Hicks, K. Van Noten, et al (76 authors), Global quieting of high-frequency seismic noise due to COVID-19 pandemic lockdown measures, Science (80-369). (2020) 1338-1343. https://doi.org/10.1126/science.abd2438.

[3] J. Diaz, M. Ruiz, J.-A. Jara, Seismic monitoring of urban activity in Barcelona during the COVID-19 lockdown, Solid Earth. 12 (2021) 725-739. https://doi.org/10.5194/se-12-725-2021.

[4] T. Ahern, R. Casey, D. Barnes, R. Bensor, T. Knight, SEED Reference Manual, (2009). http://www.fdsn.org/seed_manual/SEEDManual_V2.4.pdfversion 2.4.

[5] D.E. McNamara and R.I. Boaz, Seismic Noise Analysis System Using Power Spectral Density Probability Density Functions: A Stand-Alone Software Package, U.S. Geol. Surv. (2006).

[6] M. Tapia and E. Suriñach, Informe sobre una comparativa del soroll de les estacions sísmiques del Monestir de Poblet (POBL) i del Túnel del Cadí (CADI) amb altres estacions sísmiques, Inst. Geològic Catalunya. (2010).

[7] T. Lecocq, F. Massin, C. Satriano, M. Vanstone, T. Megies, SeismoRMS - A simple python/jupyter notebook package for studying seismic noise changes, (2020). https://doi.org/10.5281/ZENODO.3820046.

[8] D.E. McNamara, Ambient Noise Levels in the Continental United States, Bull. Seismol. Soc. Am. 94 (2004) 1517-1527. https://doi.org/10.1785/012003001.

[9] E. Bormann, P. and Wielandt, Chapter 4 from New Manual of Seismological Observatory Practice (NMSOP-2), GFZ Ger. Res. Cent. Geosci. (2012). https://doi.org/10.2312/GFZ.NMSOP-2.

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[3] https://www.meteo.cat/observacions/xema/dades

APPENDIX. ANALYSIS OF THE NOISE VARIATION FOR THE FREQUENCY BANDS 4-7 Hz AND 7-14 Hz

I. 4-7 Hz BAND ANALYSIS

This Appendix section explains in detail the seismic noise displacement variations shown in Fig. 4 for the 4-7 Hz frequency band for the three analysed periods: 2019, 2020 and 2021.

A. 2019 period

Fig. 4a shows that the first three weeks have an average seismic displacement ranging between a maximum of 14 nm and a minimum of 8 nm. On the other hand, the average noise level during general working hours (6h-16h UTC) on weekdays is around 12 nm. In the fourth week between 19 and 22 April a reduction of the daytime noise is observed, reaching 8 nm, whereas in the fifth week the baseline remains at 8 nm (1 nm higher compared to the first days of the fourth week) and the maximum amplitude of the seismic displacement increases 1 nm on average compared to the values of the first three weeks.

From the sixth week onwards, the baseline is at 7 nm, although the amplitude of the working day oscillations increases extremely. The average maximum noise displacement of these four weeks reaches a level around 17 nm, i.e. 3 nm higher than in the first three weeks. The average noise level of the last two weeks during the active hours of weekdays is about 15 nm (3 nm higher than the first weeks).

B. 2020 Period

Fig. 4b shows that the seismic noise displacement during the first two weeks has an average maximum amplitude level of 17.5 nm and a minimum of 6 nm. In addition, the average noise level during the active hours of the working days is about 15nm.

From the third week to the middle of the sixth week (27 July to 19 August, inclusive) a reduction in the anthropogenic noise is observed. The average minimum seismic noise displacement of these four weeks stabilises at 3 nm and the maximum at 12.5 nm.

On 20 August (marked with a red square in Fig. 4b) the baseline rises to 6 nm. From this point onwards, the average night-time noise of the first two weeks is recovered.

In the seventh, eighth and ninth weeks, which are the last week of August and the first two weeks of September, the maximum amplitude of the seismic noise displacement reaches 16 nm on average (i.e. 1.5 nm lower than in the first two weeks).

C. 2021 Period

Fig. 4c shows that the seismic noise displacement oscillations the first two weeks have an average minimum amplitude of the order of 8 nm whereas the average maximum is of the order of 15 nm in the first week and of 16 nm in the second week. During the third week the noise baseline decreases to a value of 7nm and the maximum amplitude of the oscillations reaches an average of 15 nm. In general, from 22 March to 1st April inclusive, the average maximum seismic noise displacement is 14 nm and the average noise level during the active hours of the working days is 12 nm.

During the Easter holidays, the lowest diurnal seismic noise of the whole period is observed, although on April 3rd (marked with a cross in Fig. 4c) we find an anomalous peak. In the sixth and seventh weeks the amplitude of the seismic noise displacement increases, reaching an average of 15 nm and 17 nm, respectively.

II. 7-14 Hz BAND ANALYSIS

This Appendix section describes the seismic noise displacement variations shown in Fig. A1 for the 7-14 Hz frequency band for the three studied periods: 2019, 2020 and 2021.

The results of analysing the seismic noise displacement variations of the 7-14Hz band for the three studied periods are similar to those obtained in the case of the 4-7Hz band. The main difference is the amplitude range between night and day hours, maximum and minimum values, that is smaller compared to that of the 4-7 Hz band whereas in the range between 4-7Hz the oscillation varies about 7-8nm between the minimum and maximum values, in the range of 7-14Hz it varies only about 2-3nm (Fig A1).

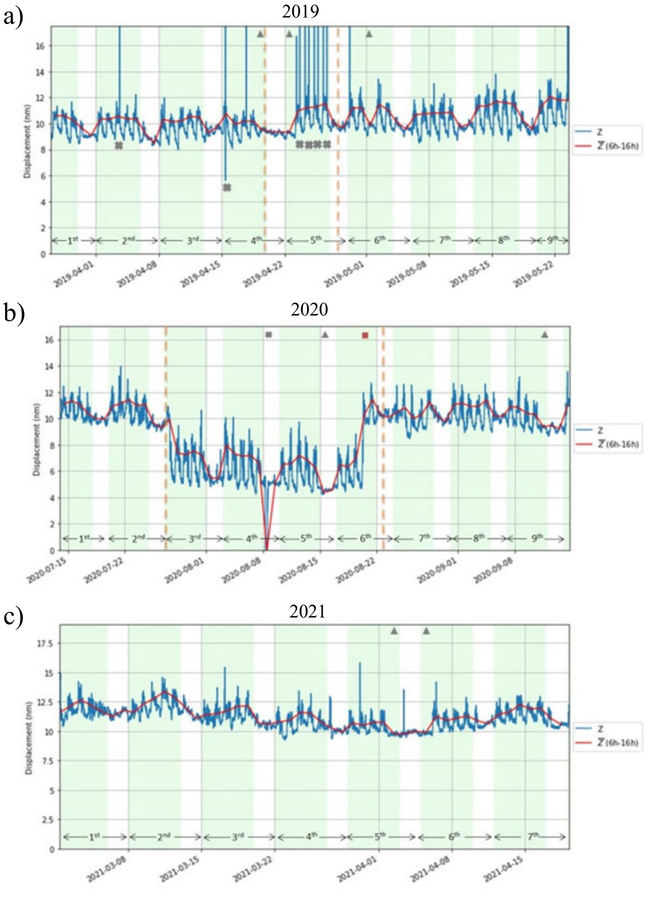

FIG. A1: Variations of the seismic noise displacement of the Z component of the ALBA station for the 7-14 Hz frequency band during the period: (a) 2019, (b) 2020 and (c) 2021. The weeks are numbered. Blue line: displacement value every 30 minutes. Red line: daily average of the shift of working hours (6h-16h UTC). Green background: working days (Monday to Friday). White background: weekend. Triangles: public holidays. Crosses: anomalous peaks. Period marked with orange dashed lines: (a) days on which a squall crossed over and (b) ALBA Synchrotron holidays. Square: specific day mentioned in the text.