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Solid Earth Discussions

Interactive comment on "Seismic monitoring of urban activity in Barcelona during COVID-19 lockdown" *by* Jordi Diaz et al.

Jordi Diaz et al.

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Please find enclosed our answers ("==>" marks) intercalated with the reviewer's comments. "==>"

The paper "Seismic monitoring of urban activity in Barcelona during COVID-19 lockdown" by Jordi Diaz and co-authors deals with the seismic signature of the lockdown measures as observed by a very dense local seismic network, installed in Barcelona and composed of a fairly wide variety of instruments: broad-band sensors, short-period sensors, accelerometers and Raspberry shake seismometers. The paper is in a very good shape and scientifically sound, it shows very interesting results regarding how the amount of seismic noise reduction, due to the lockdown measures, is strongly site

dependent even in a so dense network and reflects the local human activity variations. In my opinion, the manuscript deserves to be published in Solid-Earth after minor revision.

==> Thanks for these positive comments

MAJOR POINTS

- Section 3.1: it is not clear how you identified the frequency band of interest, that is, the band where the seismic signature of lockdown measures is most evident. It is hard to identify it just by looking at the spectrograms. In addition, each spectrogram shows peculiar features, different from the others.

==> We agree that it is difficult to fix the better bandwidth to detect the effects of human activities is seismic data. However, looking at the spectrograms is, in our opinion, the best option, as it provides a visual way to evaluate the band of interest. Having around 20 stations, we have verified that the frequency band showing large variations is not the same for all the sites. We have produced figures as Fig 4 for different bands and finally choose to use the 2-20 Hz period for all the sites, better than choosing the band with the largest variations for each site. Below 2 Hz, the effects of ocean waves and meteorological factors become important and above 20 Hz the subway activity is relevant for stations located near the tunnels. Restricting the bandwidth (e.g. 4-14 Hz) does not result in significant changes in the interpretation of the data.

- Line 175: how did you calculate such mean value, as well as the power values shown in Table 1? By taking into account the whole time series, or by focusing on weekdays/daytime?

==> The relative variations reported in Table 1 have been calculated using the values obtained during working hours. This is now stated in the manuscript.

- The "Discussion and conclusions" section does not discuss all the findings of the manuscript, but it mainly focuses on the comparison between seismic data and mobility

information. I suggest to rename the section and write another section, truly discussing all the findings of the paper.

==> Attending also the comments of Reviewer #2, we have now divided the section into a section focused on the comparison between seismic results and mobility ("4 Seismic results and mobility patterns") and a Conclusions section, where the findings of our work are reviewed..

MINOR POINTS

- Line 59: What does "CA" indicate? ==> This is the official code for the ICGC seismic network

- Lines 58-72: the sampling rate information is missing for all the instruments. ==> We have now stated the sampling rates used for the different stations (250 sps for the permanent broad-band, 200 sps for the permanent accelerometers, 100 sps for all but one temporary instrument, 50 sps for this last one)

- Line 78-79: please provide further information about the spectral analysis. For instance, did you divide the 30-min-long windows into smaller windows? If so, how long do the smaller windows last? ==> The processing is done using the same parameters as in Lecocq et al 2020, using 30 min windows with a 50% of overlap.

- Line 80: What do you mean when you talk about "spectra dynamic". Sorry, I do not know this term. ==> It refers in fact to the width of the db bins used during the PPSD calculation. This width is selected to be smaller than the default value (0.25 vs 1.0) in order to have more resolution. We have used here a similar phrasing as in the Supporting material document of Lecocq et al 2020.

- Line 95: "(i.e., (Díaz, 2016a)": please remove the double brackets. ==> Done

- Line 108: is "official time" the local time? ==> Yes, we have now used "official local time" to clarify

- Lines 108-109: "the period of high energy period begins earlier": sounds a bit strange... ==> That's absolutely true. We have changed to "the time interval with the highest energy begins earlier."

- Line 126: "Location of the seismic network": actually, the location is not indicated in the table, but rather site descriptions and power amplitude information. ==> We have changed the Table caption to "Site description and differences in power amplitude observed between the different lockdown phases for all the investigated seismic stations" to clarify this point.

- Line 184: "characteristics. (Figures 7e-f)" –> "characteristics (Figures 7e-h)"? ==> Corrected

- Line 234-240: the power level at this station is very very low compared to what is recorded by the other sensors (it is hard to clearly read it, but it seems to be lower than -300 dB). Is it reasonable? Or is there a problem in the instrument? ==> FBR station has a power level around -120 dB, as shown at Figure 7h or in the spectrogram included al Suppl Fig S1

- Line 258-262: this finding is very interesting. However, it is not highlighted in the abstract, neither in the Discussion and conclusions section. ==> As the main focus of this manuscript is the effect of human activities on seismic noise, we will prefer do not to discuss here in detail the relationship with geology. Our plans include writing an independent contribution including HVSR and autocorrelation measurements before and during the COVID-19 lockdown, where this relationship with geology will be developed.

FIGURES

- Figure 1: it would be useful to add in the legend information about the symbols used for the seismic stations. In addition, I suggest to use different symbols (or colors) for short-period and Raspberry Shake sensors (as far as I understand they are both indicated by red dots). The font size of the legend is very small, I suggest to make it bigger.

==> We have increased the size of the geological units legend. As suggested, we have included now a legend presenting the color codes used to show the different types of stations. We have now made discriminated the temporary 1D (Raspberryshake) and 3D instrument using red and orange circles. We have also included some geographic labels (Montjuic, Collserola hills, city center. . .) that may help the reader

- Figure 2: it would be useful to indicate the different phase names in the figure (similar to what has been done in Figures 4 and 5). ==> We have now indicated the lockdown phases in all the panels

- Figure 3: I suggest to increase the font size. In addition, please correct the caption "Data is expressed as dB as dB relative. . ." –> "Data is expressed as dB relative. . ." ==> The Figure has been modified by increasing the font size a 20%. The caption has been corrected

- Figure 4: it is really hard to identify the names of the stations associated with each time series. I suggest to increase the font size of the legend, and to sort the names in the legend into descending noise power order. ==> We have modified the figure following these recommendations

- Figure 6: I suggest to increase the font size of the labels surrounding each plot. ==> Done

- Figure 7: I suggest to increase the font size and to indicate the different phase names in the figure (similar to what has been done in Figures 4 and 5). ==> Done

- Figure 8: I suggest to increase the font size of the labels surrounding each plot. In addition, to make the comparison between seismic noise power and geology easier, I suggest to add another subplot with a schematic map showing the main material distribution, such as Paleozoic, Holocene and Pleistocene materials (a sort of simplified version of Figure 1), as well as the location of the places you cite in the text, as the city center, the industrial factory affecting the station R4B31, Montjuic. ==> We have

increased the font size of the coordinates in the frame. However, we would prefer not to include the geology here, as we think that will make the figure too charged. We have added a comment in the figure caption stating that the reader can refer to Fig 1 to compare with geology. Regarding the location of places cited in the text, we have added them to Fig 1

- Figure 9: "Eastern 2019" –> "Easter 2019". ==> Corrected

- Figure 10: I suggest to increase the font size and to indicate the different phase names in the figure (similar to what has been done in Figures 4 and 5). ==> Done

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Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2020-190, 2020.

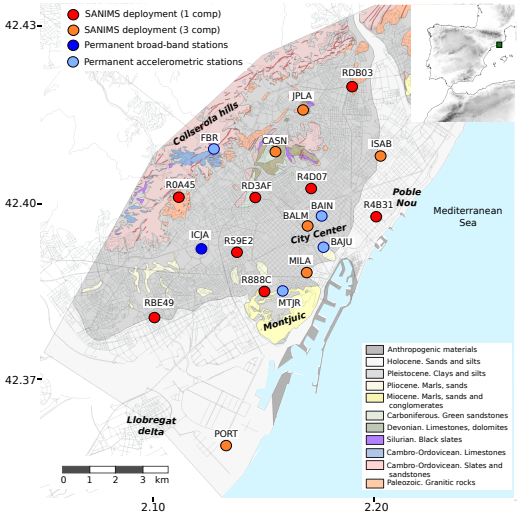

Fig. 1. Location plan of the available seismic stations on the geotechnical map of Barcelona (ICGC). The color code for the different types of instruments used is shown at the top-left corner. Road map from ©

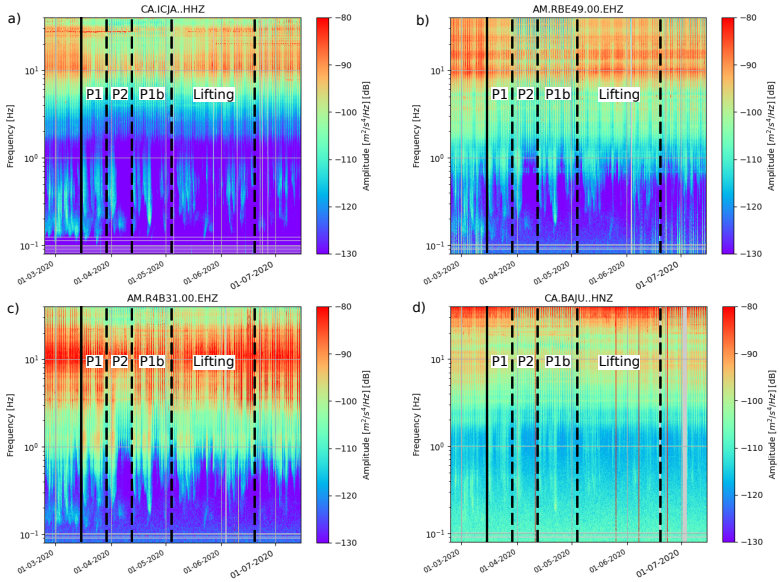

Fig. 2. Spectrograms for period from February 24 to July 14, 2020 corresponding to the ICJA, RBE49, R4B31 and BAJU sites. The solid lines mark the beginning of the lockdown period and the dashed lines show th

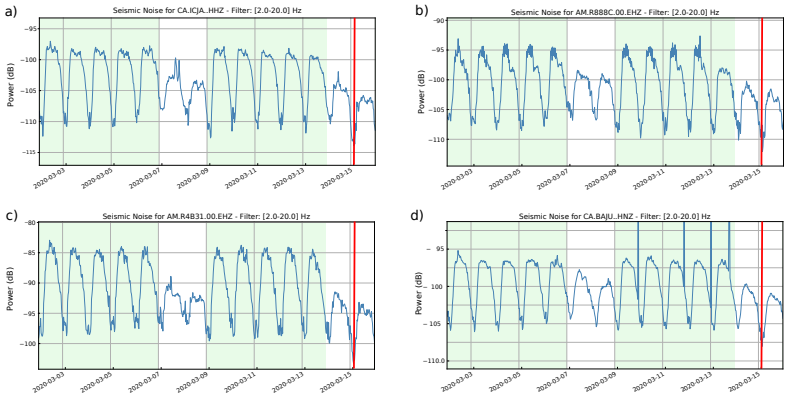

Fig. 3. Trends in power acceleration variation in the 2-20 Hz band prior to lockdown at the ICJA (broad-band), R888C, R4B31 (short period stations installed in high schools) and BAJU (accelerometer located do

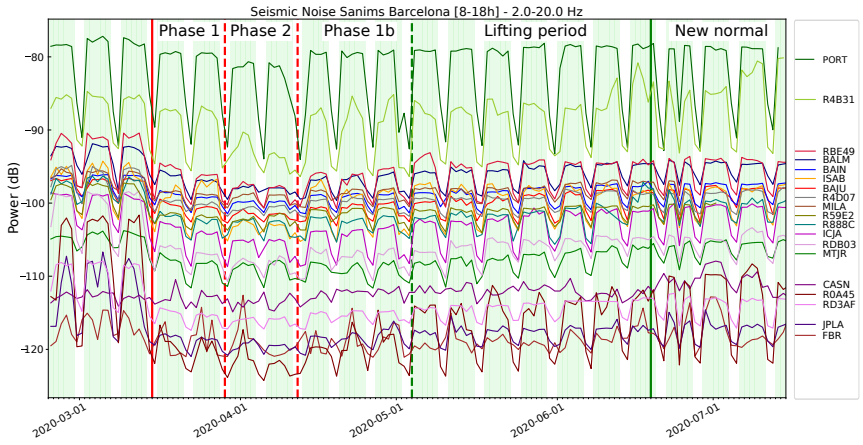

Fig. 4. Variation of the power of the seismic acceleration in the 2-20 Hz band for all the investigated sites, expressed in dB. The colored lines show the daily average during business hours. The vertical bar

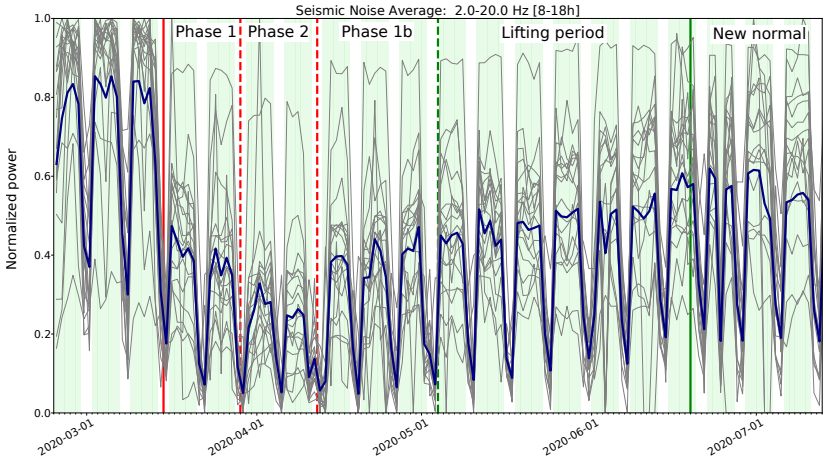

Fig. 5. Normalized power in the 2-20 Hz band during working hours for all the stations (gray lines) and the corresponding mean profile (blue line). Bars as in Figure 4.

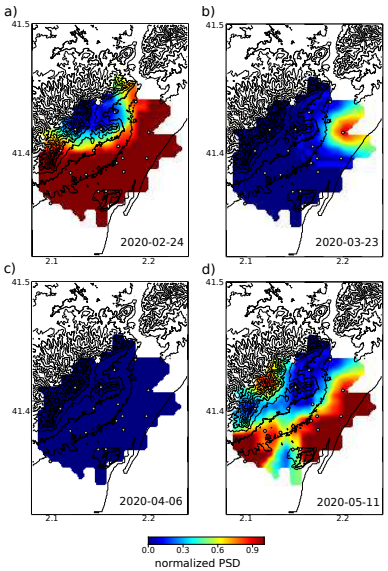

Fig. 6. Daily maps representing the normalized power in the 2-20 Hz band during working hours. Each image corresponds to a Monday. (Supplementary figure S2 shows all the daily snapshots). a) Pre-lockdown peri

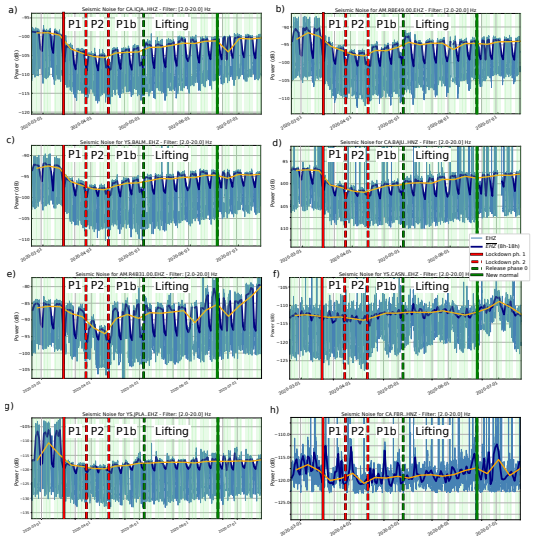

Fig. 7. Variations of the PSD of the seismic acceleration in the 2-20 Hz band for representative stations. a-d) sites that follow the general trend. e-h) sites with particular characteristics (see text). Ligh

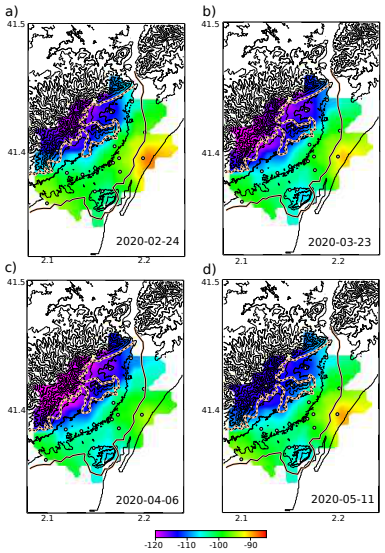

Fig. 8. Daily maps representing the real power values in the 2-20 Hz band during working hours. Each image corresponds to a Monday. (Supplementary figure S4 shows all the daily snapshots). a) Pre-lockdown per

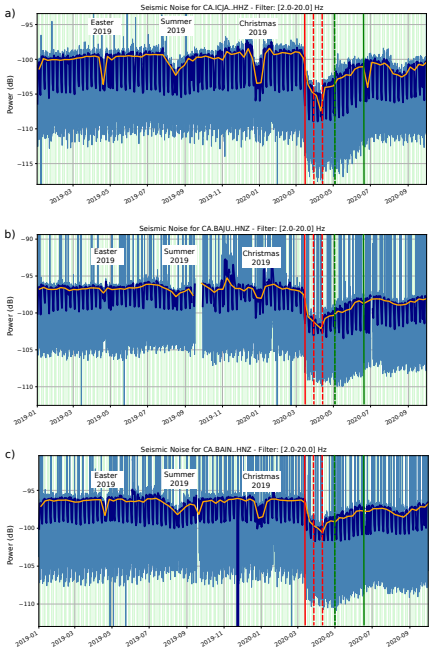

Fig. 9. Long term (1/1/2019 – 30/9/2020) PSD of the seismic accelerations in the 2-20 Hz band. a) ICJA broad-band seismometer. b) BAJU accelerometer. c) BAIN accelerometer. Color code as in Figure 7.

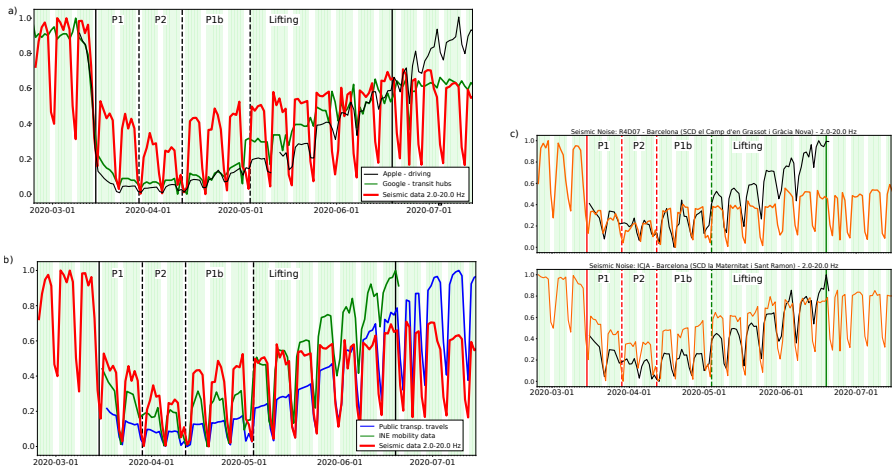

Fig. 10. Mobility data from different sources compared to seismic data. a) Normalized mean seismic power during business hours (9:00 – 19:00) vs. mobility data from Apple and Google. b) Normalized mean seismic