San José, Costa Rica, August 16, 2021

Dear Topical Editor,

Below you will find a detailed author response and a list of changes/additions made to the manuscript. This is practically a merge of the responses provided to the referees on the interactive discussion process in which was based our modifications to the manuscript. We are using the comments of the reviewers on the Open Discussion process as a reference and marked in blue the changes or comments that we incorporated or modified. You will also find a Track-changes Manuscript with all changes/additions marked in turquoise.

Dr. Valerio de Rubeis,
(Referee #1)

1. The paper applies the methods of a previous interesting analysis on the perception of seismicity both from an instrumental point of view and from the perception of citizens during the lockdown period due to Covid-19. The analyzed data are in favor of an effective difference in instrumental and human perception between the period during the lockdown and the previous one. Although the analysis is interesting, the method of analysis is extremely simple: in essence it merely shows the difference in average values. There is no in-depth statistical analysis, nor are there any statistical tests to quantitatively support the results.

Thanks for your suggestion. First, we want to emphasize that the goal of our paper is to show and document in a simple and pragmatic way, the significant decrease of seismic noise due to the lockdown measures in Central America, and it is not an in-depth statical analysis of the seismic noise variation for each station. Therefore, we believe that basic observation is provided, showing a clear decrease of down to ~50% of the site noise level of a station for several subsequent weeks during the lockdown. These stations have been recoding data since years, and we document an unprecedented decrease of anthropogenic noise for all most of the stations described, except for Nicaragua, for which we give an explanation. Furthermore, we believe that the displacement values that we provide are already very quantitative, computed with a validated method (Lecocq et al., 2020b), used by many seismologists in dozens of different research papers.

Having clarified that, to complement the analysis and to try to address your comment, we have added a new table to the appendix of the manuscript, as a simple statistically testing for the results, by doing a series of hypothesis tests for cases where there is an observed increase: null hypothesis of “no increase” vs. alternative hypothesis of “increase” (see Table A3 below).

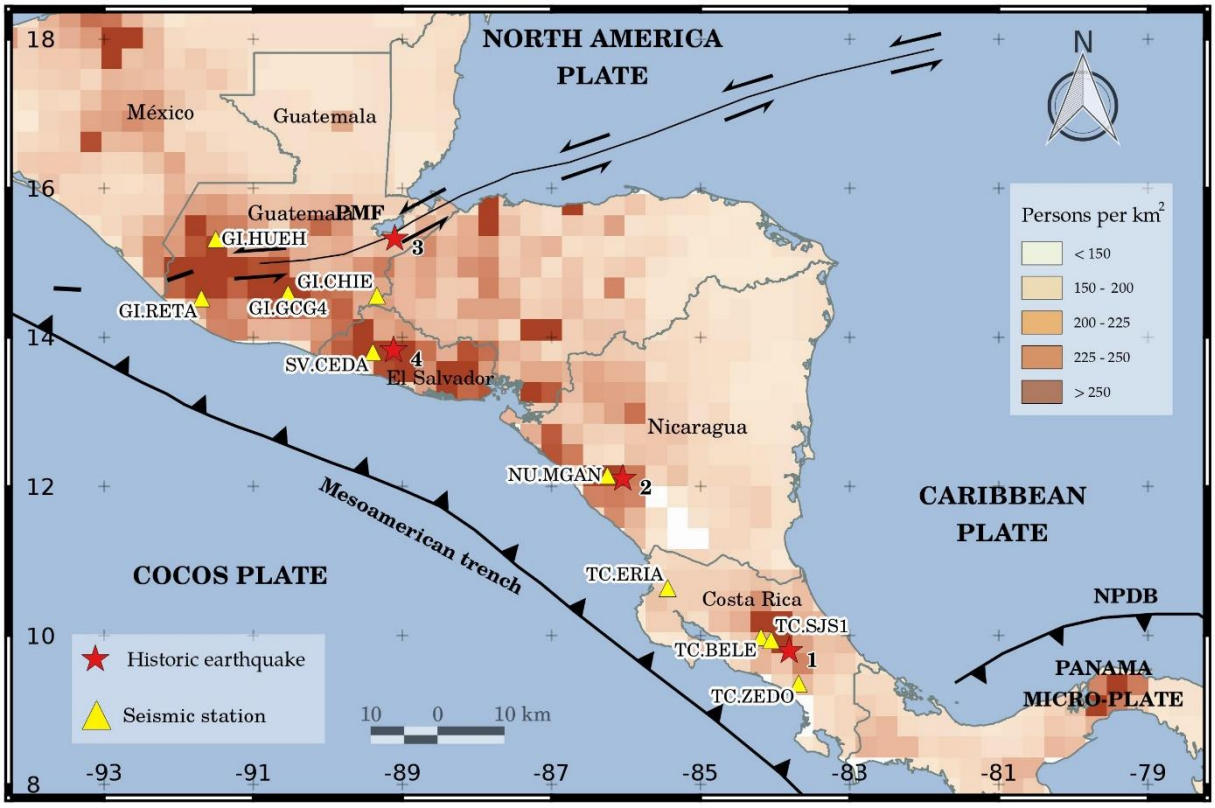
Besides, we added some general text about this exercise and to refer this new table in Section 3.2.

Table A3. Summary of observations when comparing the earthquake detections and felt reports from the time before the lockdown (BL) and during lockdown (DL) for Costa Rica and Guatemala (see also Figures 7, 8, 9, 10 and A2). The observations that favor an increase in the hypothesis of lower magnitude earthquakes (LM) are marked.

Observations	**Costa Rica**		**Guatemala**	
	M ≤ 3.5	M > 3.5	M ≤ 3.5	M > 3.5
Number of detected earthquakes	Slightly decrease	No change	Slightly increase (LM)	Increase
Number of picked phases	~20% increase (LM)	Slightly increase	~40% increase (LM)	No change
Number of Felt earthquakes	Increase (LM)	Decrease	No change	Increase
Number of felt earthquakes reports	No change	Increase	-----	
Mc	Slightly increase		Slightly increase	
a-value	Slightly decrease		Increase (LM)	
b-value	Slightly increase (LM)		Slightly increase (LM)	

2. Since these are anthropogenic effects on seismicity detection, there is no in-depth analysis of the anthropic component. For example, the population density map is appreciated, but why not introduce the numerical values of the aforementioned density to normalize the data of the stations?

Regarding to the density map and numerical values to analyze the anthropic component, we have added as a reference a color bar with the density population values to gives a better idea of the amount of geographic distribution of people (Figure 1, below). However, this density values are a coarse approximation, and we think that the normalization of the data through density values would bring bias to the analysis. We believe that it would show the same effect that is already presented. Furthermore, we think that to compare data from the registry of stations in different contexts and with different populations, might minimize the real impact of the decrease in seismic noise observed at each of these sites.



3. To demonstrate the increase in the number of earthquakes detected as a function of magnitude, why not present the b-value graphs before and during the L.D.?

We have followed the referee suggestion and performed the a- and b-value calculation for the seismic data of Costa Rica and Guatemala, for the two time periods, before (BL) and during (DL) lockdown. We also present the Gutenberg-Richter relationship graph for each data set and each period. To calculate these seismic parameters and their uncertainties, we used the classical maximum likelihood technique of Aki (1965) modified by Weichert (1980). This method solves the likelihood function for grouped magnitudes and unequal periods of observation based on the Magnitude of completeness (Mc). To run this methodology, we used the OpenQuake software (GEM, 2020). The Mc was estimated by means of the MAXC method, which corresponds to the maximum point in the non-cumulative graph of the Gutenberg-Richter relationship (e.g. Wiemer and Wyss, 2000; Woessner and Wiemer, 2005). For Costa Rica the Mc was determined on 2.9 BL (Fig. a) and 3.0 DL (Fig. b) and for Guatemala on 3.7 BL (Fig. c) and 3.8 DL (Fig. d). These values seem to show that the impact of the lockdown measures in the detected earthquakes is not big enough to change the Mc.

We present these results in this response letter and as a complement in the Appendix material as Figure A2. Besides, we added some general text about this exercise in Section 3.2. We agree with the reviewer that this test is useful to check the increase in the number of earthquakes detected as a function of magnitude through the productivity rate (a-value) and the relationship

between low and high magnitude earthquakes (b-value). However, the a- and b- values are very sensitive to many aspects, including the instant within the earthquake cycle, magnitude conversions, time span, aftershocks and foreshocks, consistency of the observatory operations, etc, and we won't be able to isolate any change observe to associated with the lockdown.
We want to stress that we have focused our paper only in the documentation of the number of earthquakes detected and the seismic noise levels related to the lockdown measures. The interpretation of this temporal variability of the Gutenberg-Richter parameters and its use to infer earthquake rates and tectonic implications, may require more careful analysis, including a detailed seismic catalog processing and a wider time window, so we feel we cannot address that in the current manuscript without making it too long, and may need the addition of many more calculations and figures to make a good study case.

The new graphs added to address the reviewer suggestion show the Gutenberg-Richter relationship and the a- and b-values for each country, before and during the lockdown measures. As it can be seen in these figures, the b-value is very consistent and there are not significant changes. For Costa Rica, increasing from 0.76 to 0.77, with differences of less than the uncertainty range (+/- 0.02), and for Guatemala, it varies a little more, incrementing from 0.87 to 0.91. This could be explained as an increment in the rate of low magnitude earthquakes compared to high magnitude (i.e., an increment the slope of the Gutenberg-Richter curve). Unlike the b-value, the a-value presents a contrary trend for Costa Rica and Guatemala, but still very similar before and during lockdown. For Costa Rica it shows a slightly decrease from 3.62 to 3.56 and for Guatemala it increases from 4.43 to 4.63. This shows a general increment in the occurrence seismic rate for Guatemala and a decrease for Costa Rica during the lockdown, but again the observed changes are not easy to separate from other origins.

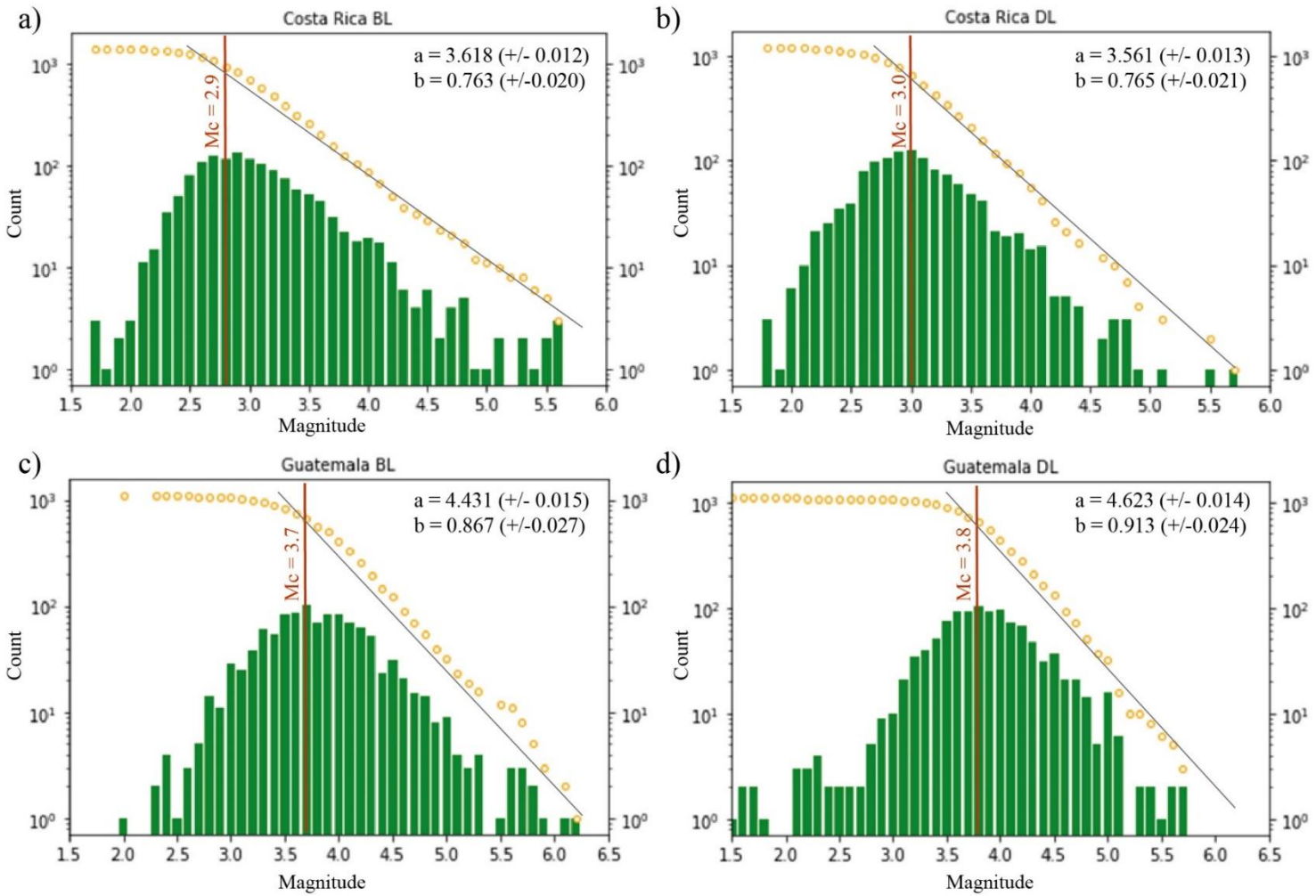


Figure A2. a) Magnitude-frequency distribution for earthquakes in Costa Rica before lockdown. b) Magnitude-frequency distribution for earthquakes in Costa Rica during lockdown. c) Magnitude-frequency distribution for earthquakes in Guatemala before lockdown. d) Magnitude-frequency distribution for earthquakes in Guatemala during lockdown. Green bars represent the incremental (non-cumulative) and yellow circles the cumulative distribution of earthquakes. The grey solid line fits the data points for the cumulative distribution for magnitude above Magnitude of completeness (Mc). Vertical lines indicate the Mc estimated from the maximum curvature (MAXC) method.

4. I believe that the work deserves on the one hand a satisfactory quantitative statistical analysis, on the other hand a reduction of the text which is, in my opinion, too verbose.

To address those aspects, we have improved our results as explained before in points 1 and 3.

5. Minor corrections are highlighted in the attached pdf file.

Thank you for the comments and the detailed revision. We have followed the corrections made according to the observations. All line numbers mentioned in this reply refer to line numbers in the manuscript version of the referee revision, without the track changes.

-Line 25: This kind of verification seems to be very indirect.

It is explained above in point 1, why we conducted the analyses in that way.

-Line 28: Remove "and"

It has been removed

-Line 81: Stations far from towns are important as comparison to evaluate the effects of lockdown reduced noise in towns.

In our analysis we wanted to explore data for stations close to large cities to demonstrate the effects in seismic noise levels in each of the countries selected. We believe the seismic noise levels will more dramatically change in cities, rather than in quiet stations in the country side. For Costa Rica and Guatemala, we also explored some stations in the countryside and near small towns.

-Line 140: Other aspect could be analized from macroseismic data

In our study we wanted to focus our analysis in low-magnitude events, as not large earthquakes occurred during the lockdown.

-Lines 195-201: Why not add further statistical analysis after the simple calculation of average values?

It is explained above in point 1. We have also added a Table and Figures in the Appendix.

-Line 278: is not what?

We missed a word. Thank you very much for the observation. The sentence is: "*Although the difference in the number of P wave arrivals before and during the pandemic* ***is not too much****…*"

Dr. Alan Kafka,
(Referee #2)

General Comments:

This paper describes observations regarding effects of COVID-19 lockdowns (LDs) on seismic noise, number of detected and located earthquakes, and number of felt and reported earthquakes for Central America. I think this documentation is important and I recommend publication after significant revision. Below are some thoughts I have regarding revisions that the authors might consider to improve the paper.

I see two components to this paper:

1. Documentation of a pattern decrease in seismic noise during LDs in Central America. The authors show this effect clearly, and the documentation of this effect is useful for comparison with similar analyses published for other regions, as well as globally. I think this contribution is very good as basic science, and likely also be good for society, as it contributes to improving our understanding of how seismology could be used for tracking pandemics and other human activities. So, I think this component of the paper should be published without much change.

2. The results are somewhat more mixed regarding the extent to which it demonstrates an increase in (a) number of detected and located earthquakes, and in (b) number of felt and reported earthquakes. Although I see some evidence of such increases, that increase looks less dramatic to me than what I might have imagined, given the clear case for decrease in noise. That mix of results makes it hard to interpret and write about this component of the study. I nonetheless think it's important that the authors are documenting this and that these results should be published, but:

    a. I think there could be improvement in how the authors can best interpret and write about these not-so-dramatic and mixed results regarding the question of whether we are actually seeing an increase in the number of detected and located earthquakes, and in the number of felt and reported earthquakes. Under Specific Comments below, I provide a suggestion for how that might be done.

    We thank you again for such constructive comments. We really appreciate the way you have pointed to us the stronger and weaker parts of our study. Your respectful approach as a reviewer is not common in our experience and we are grateful for the opportunity of receiving your careful observations. We have improved some paragraphs, especially in section 3.2, to try to better address the fact that the changes in earthquake detections and felt events are not so dramatic, as you expected.

    b. Another reviewer suggested that the paper needs an in-depth statistical analysis. I agree that there needs to be some statistical analysis of the results, but I don't think that implementing that needs to be complicated. Below, Under Specific Comments, I suggest a way that the results could be statistically tested.

Regarding the statistical analysis, we added a new Table to the Appendix following your suggestions.

c. That other reviewer also suggested presenting b-value graphs as a comparison for assessing whether or not the number of detected earthquakes is increasing. I think that is a good idea, and I think the analysis could be improved by including that, such as: fitting a Gutenberg-Richter relationship line to the data for each region analyzed, projecting that to lower magnitudes, and analyzing the extent to which the observed number of earthquakes matches that expected from the projected G-R relationship.

We have followed your suggestion and performed the a- and b-value calculation for the seismic data of Costa Rica and Guatemala, for the two time periods, before (BL) and during (DL) lockdown. We now present the Gutenberg-Richter relationship for each dataset and each period in the Appendix and below this answer. To calculate these seismic parameters and their uncertainties, we used the classical maximum likelihood technique of Aki (1965) modified by Weichert (1980). This method solves the likelihood function for grouped magnitudes and unequal periods of observation based on the Magnitude of completeness (Mc). To run this methodology, we used the OpenQuake software (GEM, 2020). The Mc was estimated by the MAXC method, which corresponds to the maximum point in the non-cumulative graph of the Gutenberg-Richter relationship (e.g. Wiemer and Wyss, 2000; Woessner and Wiemer, 2005).

For Costa Rica the Mc obtained was 2.9 BL (Fig. a, see below) and 3.0 DL (Fig. b) and for Guatemala on 3.7 BL (Fig. c) and 3.8 DL (Fig. d). As it can be seen these values do not reflect a dramatic impact of the lockdown measures in the Mc, and the variation from BL to DL is not significant enough to make a strong interpretation.

We present these results in this response letter and as a complement in the Appendix material as Figure A2. Besides, we added some text about this exercise in Section 3.2. We agree with the reviewer that this test is useful to check the the number of earthquakes detected as a function of magnitude (a-value) and the relationship between low and high magnitude earthquakes (b-value). Also, we believe it may be very interesting to interpret the meaning of the temporal variation, as this might express the effects of the lockdown measures. However, the variation we observe is very small, so that we believe we cannot make a strong interpretation regarding the consequences of lower seismic noise with the magnitude of completeness or the number of earthquakes detected. We also have to say that the a- and b- value could be affected by many aspects, including the different moments within the earthquake cycle, among other related to the seismic network itself. The interpretation of this temporal variability of the Gutenberg-Richter parameters and its use to infer earthquake rates, asses the fitting of the plots, and tectonic implications, may require more careful analysis, including a detailed seismic catalog processing and a wider time window, so we believe we cannot address that in the current manuscript without making it too long, and may need the addition of many more calculations and figures to make a good study case.

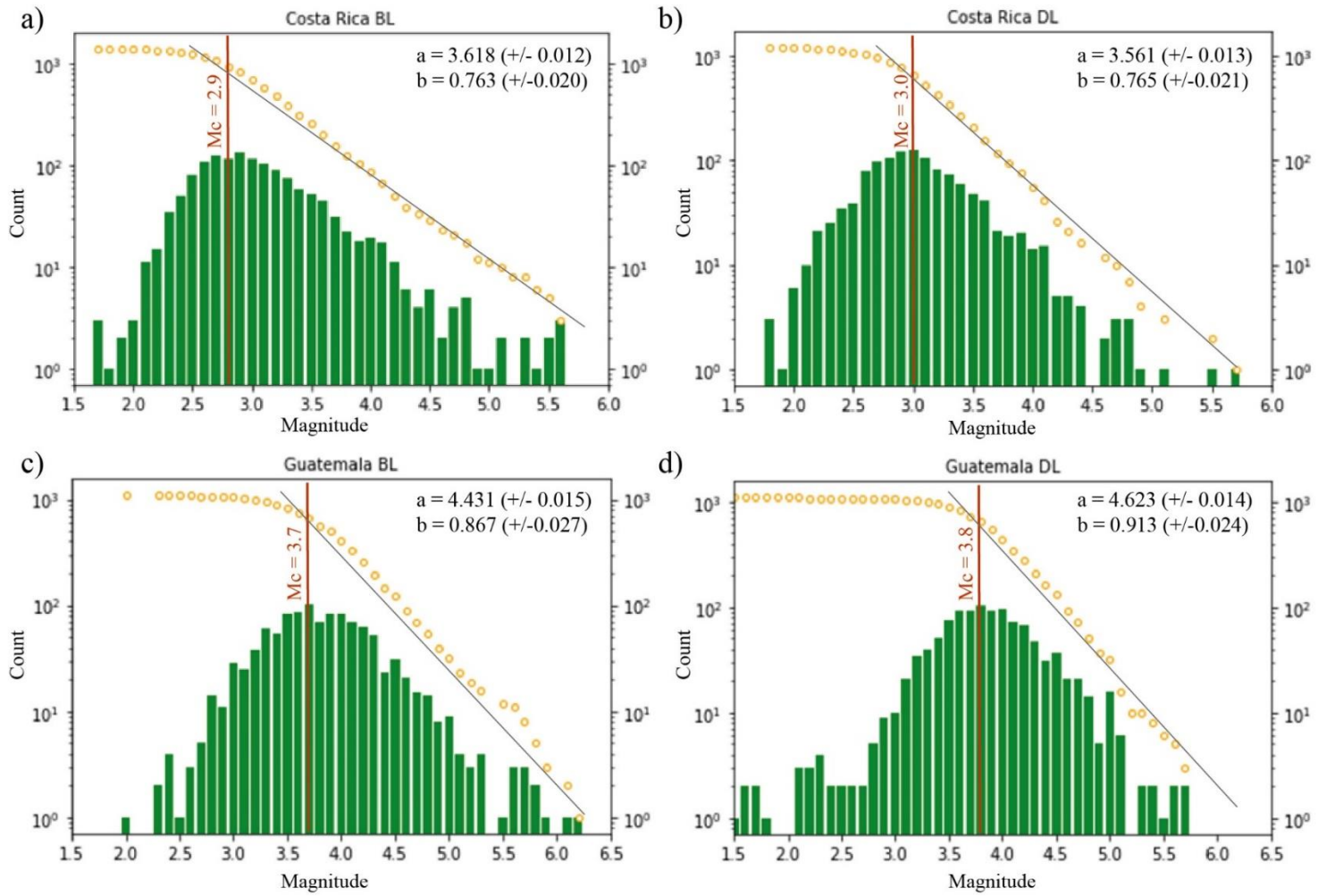


Figure A2. a) Magnitude-frequency distribution for earthquakes in Costa Rica before lockdown. b) Magnitude-frequency distribution for earthquakes in Costa Rica during lockdown. c) Magnitude-frequency distribution for earthquakes in Guatemala before lockdown. d) Magnitude-frequency distribution for earthquakes in Guatemala during lockdown. Green bars represent the incremental (non-cumulative) and yellow circles the cumulative distribution of earthquakes. The grey solid line fits the data points for the cumulative distribution for magnitude above Magnitude of completeness (Mc). Vertical lines indicate the Mc estimated from the maximum curvature (MAXC) method.

The graphs we presented show of the Gutenberg-Richter relationship plots and the a- and b-values for each country, before and during lockdown measures. As it can be seen in these figures, the b value is very consistent and there are not significant changes. For Costa Rica, it changes from 0.76 to 0.77, with differences of less than the uncertainty range (+/- 0.02), and for Guatemala, it varies from 0.87 to 0.91. This could be explained as an increment in the rate of low magnitude earthquakes compared to the intermediate and high magnitude (i.e., an increment the slope of the Gutenberg-Richter curve). Unlike the b-value, the a-value presents a contrary trend for Costa Rica and Guatemala, but still very similar before and during lockdown. In Costa Rica it goes from 3.62 to 3.56 and in Guatemala it changes from 4.43 to 4.63. This may imply an increment in the seismicity for Guatemala and a slight decrease for Costa Rica during the lockdown. Again, we believe that it is difficult to separate the different facts that affect the a- and b- value for such a short period of time for the catalog of each country.

Specific Comments:

I had a difficult time trying to follow what was the overall pattern of the extent to which we are actually seeing an increase in the number of detected, located, felt, reported earthquakes for before LD vs during LD. I think this could be helped by adding a table or figure something like the one shown below, that tries to capture the overall pattern of which observations in Figures 7 and 9 show increase versus decrease, versus remains the same, for before vs during LD, and for high versus low magnitude ranges. The authors might be able to find a better way to do this than the way I've done it here, and I might have made some misinterpretations of my specific entries in this table that the authors could correct. But I do think that adding something along these lines would strengthen the interpretation. This type of framework might provide a way of statistically testing the results by doing a series of hypothesis tests for cases where there is an observed increase: null hypothesis of "no increase" vs. alternative hypothesis of "increase."

Thanks for your comment and the idea. We added a new Table A3 as a summary of Figures 7, 8, 9 and 10 on the Appendix section to make clearer and easier to follow the observations, according to your example. We choose to add this Table in the Appendix. Besides, we have added some general text about this exercise and to refer this new Table through Section 3.2. In this Table we have made the exercise to show the observations in favor of both, higher and lower magnitude increase, but in the Appendix of the manuscript we have decided to show only the evidence that support our main hypothesis of lower magnitude (LM) increase.

Rather than presenting the results as a positive finding, i.e., discovery of increase during LD, I think this contribution might be more valuable if the storyline was from a more skeptical perspective, i.e., about how the results are mixed and how, although there is some evidence of increase, there is also a storyline about how that increase is not very dramatic and not easy to untangle from other effects, such as random coincidence.

We have modified the text, especially in section 3.2, to incorporate your comment.

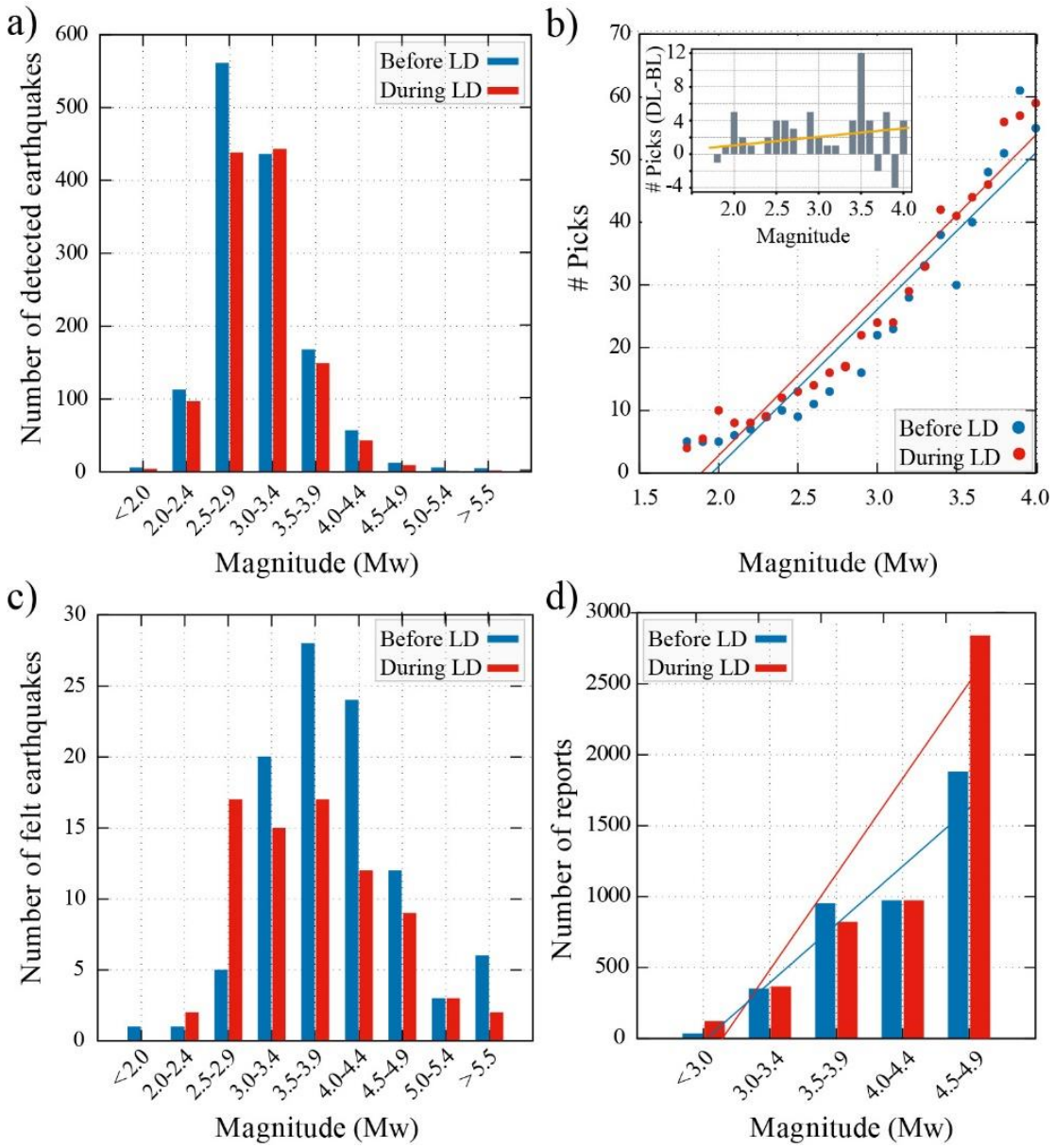
Table A3. Summary of observations when comparing the earthquake detections and felt reports from the time before the lockdown (BL) and during lockdown (DL) for Costa Rica and Guatemala (see also Figures 7, 8, 9, 10 and A2). The observations that favor the hypothesis of an increase in lower magnitude earthquakes (LM) and an increase in higher magnitude earthquake (HM) are marked.

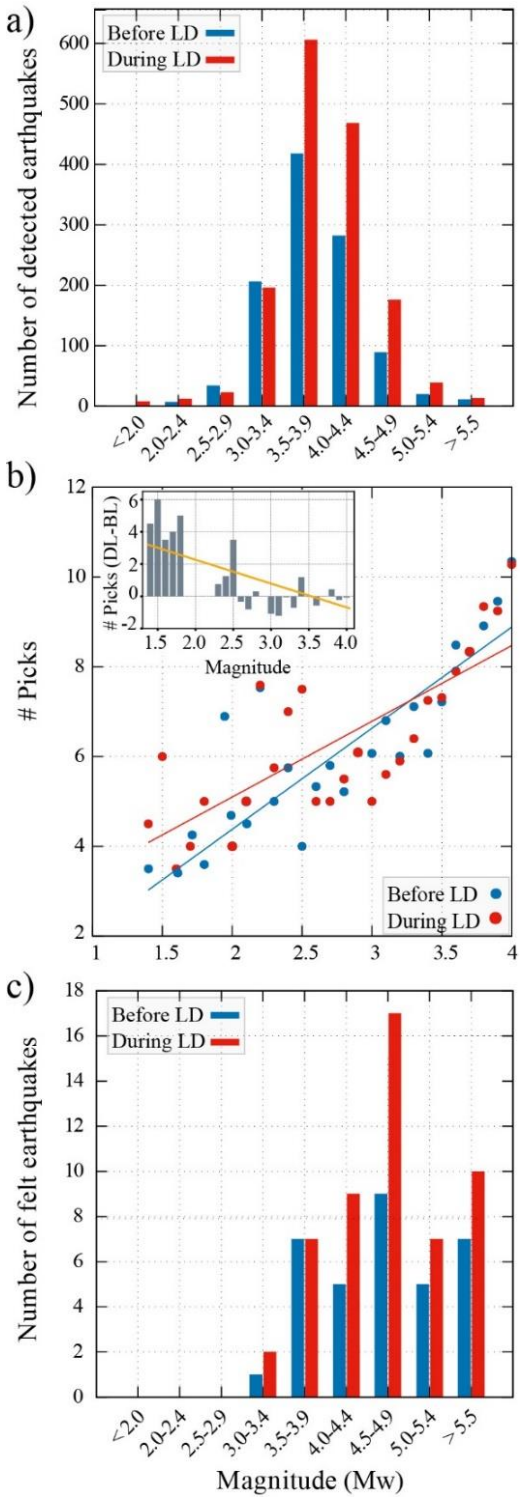
Observations	**Costa Rica**		**Guatemala**	
	M ≤ 3.5	M > 3.5	M ≤ 3.5	M > 3.5
Number of detected earthquakes	Slightly decrease	No change	Slightly increase (LM)	Increase (HM)
Number of picked phases	~20% increase (LM)	Slightly increase (HM)	~40% increase (LM)	No change
Number of Felt earthquakes	Increase (LM)	Decrease	No change	Increase (HM)
Number of felt earthquakes reports	No change	Increase (HM)	-----	
Mc	Slightly increase		Slightly increase	
a-value	Slightly decrease		Increase (LM and HM)	
b-value	Slightly increase (LM)		Slightly increase (LM)	

Technical Corrections:

Figures 7b and 9b: I think that, in addition to showing the scatter plots, it would also be useful to show plots of differences between the number of picks for before vs during LD as a function of magnitude bins. This might be a good way to illustrate how often the number of picks is higher versus lower for before vs during LD.

We agree with your suggestion, and we have added a new version of Figures 7b and 9b, in which we now show differences between the number of picks for before vs during LD as a function of magnitude bins. The new figures look like the following below.


a)
Number of detected earthquakes
Before LD
During LD
<2.0
2.0-2.4
2.5-2.9
3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
5.0-5.4
>5.5
Magnitude (Mw)
b)
Picks
Picks (DL-BL)
Magnitude
Before LD
During LD
Magnitude (Mw)
c)
Number of felt earthquakes
Before LD
During LD
Magnitude (Mw)
d)
Number of reports
Before LD
During LD
<3.0
3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
Magnitude (Mw)



Additional comments and suggested revisions are in the attached PDF annotated manuscript.

Thank you for the comments and the detailed revision. We have followed the grammar and writing corrections through the manuscript. Here we explain how we address some of the comments/observations. All line numbers mentioned in this reply refer to line numbers in the manuscript of the referee revision (i.e. without the track changes).

-Line 17: "*spectral and amplitude analyses***" Amplitude analyses maybe not necessary? Spectral analysis includes amplitude analysis?**

This has been changed to just: "*spectral analyses*"

-Line 29: Better word for "*louder*"

This word has been changed to: "*rowdier*"

-Lines 58-59: Not sure what this means. Can you clarify?

We rewrote this sentence as follow: *"Seismometers in urban settings optimize the spatial coverage of seismic networks at these areas, and warn of local geological hazards, for example site effects related to the amplification of seismic waves (Ashenden et al., 2011)."*

-Line 69: Better word for "differentiation"

This word has been changed to: "*delimitation*"

-Lines 122-123: Better wording for "This allows to obtain"

We have decided merge this sentence with the previous, and just delete the transition "This allows". The sentence was rewried as follow: "*Finally, an analysis of the percentage change in the high-frequency seismic displacement RMS was performed to obtain a median amplitude value for the whole period during the major restrictive measures".*

-Lines 150-151: Can you include these questions (translated into English) in an appendix?

We have followed this suggestion and was included a Table A2, with the questions of the RSN module "*Lo Sentiste*". The new Table look like the following below.

Table A2. Questions on the RSN module *"¿Lo Sentiste?"* (Linkimer and Arroyo, 2020).

Number	Question
1	Did you feel it?
2	What were you doing?
3	Where were you?
4	Did others nearby feel it?
5	How would you describe the shaking?
6	How did you react?
7	Was it difficult to stand and/or walk?
8	Did light objects move or fall from the shelves?
9	Did pictures on walls move or get knocked askew?
10	Did the furniture fall, overturn or fall?
11	Was there any damage to the buildings?
12	Additional comments on effects in nature, such as landslides, cracks in the ground, among others?

-Line 163: Clarify "*mass events prohibition*"
This has been changed to: "*massive public events prohibition (concerts, soccer games, etc.)*"

-Lines 166-167: Better wording for "*These measures have suffered flexibilization and/or hardening…"*
This has been changed to: "*These measures have been softened or hardened…".*

-Line 257: Clarify "*a less exposed station site"*
This has been changed to: "*a station site building more confined and less exposed to population and environment dynamics*"

-Line 278: Something missing here?

We missed a word. Thank you very much for the observation. The sentence is: "*Although the difference in the number of P wave arrivals before and during the pandemic* ***is not too much****…*"

-Line 278-279: *"the values are consistently higher during the pandemic, especially for the lower magnitudes (≤ Mw 3.5)".* **By how much? Looks like about 10%.**

Thank you very much for the observation. We have estimated the percentage of difference by each bin of magnitude, and then we obtained the average of that difference by earthquakes with M ≤ 4.0. The average of increase is ~20%, and we have updated the sentence as follow: *"the values are consistently higher* ***(on average ~20%)*** *during the pandemic, especially for the lower magnitudes (≤ Mw 3.5)".*

-Line 279-280: *"This suggests that the decrease in HFSAND-RMS during lockdown may have had a direct positive effect on the earthquake detection capability of the RSN".* **Seems worth noting that the difference is not a lot, suggesting that the rather significant measures to lower the human activity, didn't have a very big effect on earthquake detection.**

We have incorporated a new sentence after this in agreement with your comment: "*However, the difference before and during lockdown is not a lot, suggesting that its effect is not big and strong enough to assert an improvement in the earthquake detection capacity of the RSN*".

Finally, we have added a line in the Acknowledgments Section to thank both reviewers for their suggestions.

Best Regards,

The authors