

Author's response for "Seismic noise variability as an indicator of urban mobility during COVID-19 pandemic in Santiago Metropolitan Region, Chile"

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Firstly, we would like to thank the reviewers for their fruitful comments and suggestions that they made to improve our work. We agree with most of them and worked on it to make clear our study.

Most of the point-by-point response presented here was included in the interactive comments (Reply on RC1 and Reply on RC2). However, we sort some of them according to the track changes of our manuscript.

All line numbers added in this reply refer to line numbers in the updated clean manuscript.

1 Reviewer 1

1. Regarding the Re timeseries, description and calculations

We complemented section 2.3 properly describing the Re indicator (L90), as well as a brief description of how ICOVID Chile (2020) estimate this parameter:

"The Re indicator is defined as the actual average number of secondary cases generated by a primary case during the epidemic outbreak (Caicedo-Ochoa et al., 2020; Tariq et al., 2021), their estimation is helpful to the assessment of public policies, to estimate population immunity, to monitor near real-time changes in transmission of the viruses over time, among others (Gostic et al., 2020). To control an epidemic outbreak, the Re indicator needs to be reduced below one (Riley et al., 2003). Herein, we used the estimation provided by ICOVID Chile (2020) who described the function Re depending on the proportion of susceptible individuals to be infected, a transmission coefficient and the infectious life expectancy. In other words, the Re accounts for the coefficient between the new infections and the recovery rates plus mortality rates (Contreras et al., 2020). ICOVID Chile (2020) used the method proposed by Cori et al. (2013) to monitor Re in real-time, modelling the transmission like a Poisson process calculated on the basis of the last seven days. We considered only the Re median and 95% credible interval estimated for the urban area in the MR, according to the data given by the Health Service of Santiago City."

New references:

Contreras S, Villavicencio HA, Medina-Ortiz D, Saavedra CP and Olivera-Nappa Á (2020) Real-Time Estimation of Rt for Supporting Public-Health Policies Against COVID-19. *Front. Public Health* 8:556689. doi: 10.3389/fpubh.2020.556689

Gostic, K. M., McGough, L., Baskerville, E. B., Abbott, S., Joshi, K., Tedijanto, C., ... & Cobey, S. (2020). Practical considerations for measuring the effective reproductive number, R t. *PLoS computational biology*, 16(12), e1008409.

Tariq, A., Undurraga, E. A., Laborde, C. C., Vogt-Geisse, K., Luo, R., Rothenberg, R., & Chowell, G. (2021). Transmission dynamics and control of COVID-19 in Chile, March-October, 2020. *PLoS neglected tropical diseases*, 15(1), e0009070.

2. Figure A4. What is 100%?

We clarify this adding a brief sentence in the caption of Figure A4.

"The ASN amplitudes and Apple mobility data are normalised by a baseline value of the 13 January 2020."

3. Lines 108-112 are results, not methods.

We moved this paragraph to the new subsection 3.1 (L110).

4. **Was lockdown 2 ever lifted? What are phases 2 and 3?**

We added the next line in the Introduction section (L21):

“During this first period, the main public health policy addresses the isolation and social distance, including the closure of schools, universities and other educational centres (16 March), national night-time curfew (23 March), and the lockdown of communes. From 19 July 2020, the Chilean government implemented the step-by-step programme, which considers a gradual open of each commune by five phases, based on the monitoring of epidemiological and health system indicators (see Table A1; Tariq et al., 2021).”

Besides, we include the new Table A2, which remarks the days in which the different cities analysed move from lockdown to phases.

5. **You report a “strong correlation” (line 167) between Re and ASN at station MT14**

We agree with your comment, we consider more a matching pattern than a “strong correlation”. We replace “strong correlation” by “matching pattern” statement in the manuscript (L151).

6. **The link between Re and ASN is stronger before ‘phase 2’ than after it. Is there any reason for this? Might there be some ASN generating activities which are not linked to changes in Re?**

Regarding this point, we added the next sentence in the section “Discussions” (L216)

“Although the ASN amplitudes increased due to Phase 2 and Phase 3 of deconfinement in eastern MR, the Re parameter was not linked, indicating better management of the epidemic outbreak with the broad-scale social distancing interventions implemented in MR (Tariq et al, 2021).”

7. **The paper already mentioned other work in other countries, but I would appreciate a brief paragraph which let me know if the links between ASN and other observables are comparable to**

We included a brief paragraph in L35:

“Previous works in other countries compare the temporal variability between ASN and other observables such as mobility data from cell phone displacements in northern Italy (Poli et al., 2020), Río de Janeiro, Brazil (Dias et al., 2020), Sicily, Italy (Canatta et al., 2021), Auckland, New Zealand (van Wijk et al., 2021), Barcelona, Spain (Díaz et al., 2020), and Querétaro, México (De Plaen et al., 2020). In addition, Xiao et al. (2020) reported cultural noise changes in China, as well as Guenaga et al. (2021) distinguished significant ASN reductions in academic institutions across the United States.”

8. **The first sentence (line 34-35) would benefit from a reference from the scientific policy literature.**

We added the next reference (L19):

Walker, P. G., Whittaker, C., Watson, O. J., Baguelin, M., Winskill, P., Hamlet, A., ... & Ghani, A. C. (2020). The impact of COVID-19 and strategies for mitigation and suppression in low-and middle-income countries. *Science*, 369(6502), 413-422.

9. **Line 40 – km2 → km2**

This has been changed. (L28)

10. **Line 46 – anthropic → anthropogenic (we’re making the noise).**

This has been changed. (L31)

11. **Line 92 – to better understand the effects of the chosen corner frequency?**

This has been changed. (L74)

12. **Lines 108-110 – be clearer about the time windows over which the ‘gradual’ reduction happens, and when the changes cease.**

We modified the paragraph and moved to another section (L110) since we described results instead of methods:

“3.1 Lockdown, curfew and ASN amplitudes

We analysed the seismic effect caused by the first lockdown in Santiago City using the 24-h clock plots in station MT18 (Figure 4a, 4b). Although we observed a gradual reduction in ASN amplitudes on weekdays due to

the day-cares, schools and universities near the station closed (16 March), we also notice a strong reduction on weekends, especially between 11h and 19h local time. Figure A1b shows the area close to MT18 in which we can distinguish the hippodrome "Club Hípico de Santiago" and the O'Higgins Park. The highest ASN amplitudes observed on Saturday before Lockdown 1 (Figure 4a) is explained by the activities of the hippodrome on Saturdays (and some Thursdays during January-February). The hippodrome closed on 21 March 2021, which is in agreement with the decrease in the ASN amplitudes observed after Lockdown 1 (Figure 4b).

We also distinguish the lockdown effect in the hourly grid representation (Figure 4c). The large ASN amplitudes observed during holidays are associated with near activities in both hippodrome and O'Higgins Park, which only persist on weekends during March. After the implementation of Lockdown 1, the ASN amplitudes drop, especially on weekends. Moreover, we observed a systematic behaviour of lower ASN amplitudes between 22h and 5h local time due to the overnight curfew implemented at the same hours, imposed from Lockdown 1 and remain during the full time-window studied."

13. **Line 124 – “Related to mobility data, we analysed” → “the mobility data we analysed is”**

This has been changed. (L101)

14. **Line 125 – What actually is. Mobility data**

We modified the sentence (L101):

“The mobility data we analysed is provided by Apple mobile-phone locations in Santiago City, which corresponds to the percentage of change in the public’s walking and driving in relation to a baseline value from 13 January (Apple, 2020).”

15. **Line 128 – could you explain what a mobility card is?**

We complemented the information in the paragraph (L104):

“They account for the total number of validations using the public transportation card in the MR. This mobility card is the only system to make transactions in public transport.”

16. **Line 167 – different to what? (a range of different responses?)**

We modified the sentence (L150) by:

“and the area implemented a diversity of public policies for mitigating the effects of the pandemic”.

17. **Line 194 – might benefit from a reference to oceanic seismic noise for the interested reader?**

We added the next reference about oceanic seismic noise (L175):

Cessaro, R. K. (1994). Sources of primary and secondary microseisms. *Bulletin of the Seismological Society of America*, 84(1), 142-148.

Ardhuin, F., Stutzmann, E., Schimmel, M., & Mangeney, A. (2011). Ocean wave sources of seismic noise. *Journal of Geophysical Research: Oceans*, 116(C9).

18. **Line 280 – which network code is appropriate? And is there a doi for the seismic network which could be cited here.**

Corrected, we added a new sentence in the “Data availability” section with the appropriate reference (L258):

Universidad De Chile. (2013). Red Sismologica Nacional. International Federation of Digital Seismograph Networks. <https://doi.org/10.7914/SN/C1>

19. **Line 322 – is there a volume + page range for Caicedo-Ochoa et al?**

Yes, and it was corrected

20. **Line 331 – doi or link missing for Cuadrado et al**

Corrected

21. **Line 367 – add the rest of the author list? Not sure what SE editorial policy is.**

Corrected

22. **Line 415 – square → squares**

This has been changed. (Figure 1 caption)

23. **Line 428 – you have an otherwise un-defined term in the key (H*Z). I assume it's because you've got two different components used at this location, but it's not explained anywhere. Consider re-labelling/explaining.**

We explained the H*Z key in the Figure 3 caption:

“Key legend H*Z can be applied for broadband (HHZ) and strong-motion (HNZ) seismic data.”

24. **Line 435 – the icons for the school closures, and lockdowns 1 2 are really hard to distinguish between. Maybe color more of the icons?**

We modified Figure 4 and increase the colour size of the icons representing school closures and lockdowns.

25. **Is the after-lockdown 1 clock plot (b) for this whole time window, or just until the end of lockdown 1? Please clarify**

We added the dates in the Figure 4 caption:

“(a) before Lockdown 1 (period 23 Jan. 2020 – 25 Mar. 2020) and (b) after Lockdown 1 (period 26 Mar. 2020 – 10 Aug 2020)”

26. **Line 446 – not sure what ratio means here?**

We modified the sentence to avoid misleading. Now, in the Figure 5 caption we wrote:

“the near 2 km distance from stations”

27. **Lines 76, 78 + others + 471 – localized (or localised) → located**

This has been changed, and some of them were changed by “placed”

28. **Line 24-25 – “Finally, we suggest to consider monitoring in real time the changes in ASN amplitudes to be included in the public policies” think about changing to something like “Finally, we suggest that real-time monitoring of changes in ASN amplitudes should be considered as part of public health monitoring”.**

This has been changed in L14:

“Finally, we suggest that real-time changes in ASN amplitudes should be considered as part of public health policy in further protocols in Santiago as well as other high-density cities of the world, as has been useful during the recent pandemic.”

2 Reviewer 2

1. **Abstract: Please, consider to mention in the abstract the results with other stations in Chile (section 3.3)**

We added a brief sentence about other stations in Chile (L9):

“The same results are observed in other cities such as Iquique, La Serena, and Concepción.”

2. **Line 24: real time to real-time**

This has been changed. (L14)

3. **Line 25: high density to High-density**

This has been changed. (L16)

4. **Line 35: risk of the spreading of the virus to risk of the virus spreading.**

This has been changed. (L19)

5. **Line 65: Please, consider to include large and long-scale events in big cities. I believe that this is important to stress.**

This has been changed. (L49)

6. **Line 76: Please, provide further information on the conditions where those five stations are installed. Any special treatment because they are inside the city?**

To give more information in our manuscript, we added the next sentence (L58):

“Further information about geophysical characterization and soil conditions where stations were deployed can be found in Leyton et al., (2018a) and Leyton et al., (2018b).”

7. **Line 83: For all stations we processed to For all stations, we processed**

This has been changed. (L67)

8. **Line 103-104: The median day-time amplitudes between 5h and 22h local time obtained from the seismometer and the accelerometer exhibits similar trends and behaviour to “The median day-time amplitudes between 5h and 22h local time obtained from the seismometer and the accelerometer exhibit similar trends and behaviour”.**

This has been changed. (L81)

9. **Line 105: Please, provide an explanation of why Saturday is the noisier day of the week, according to 4a. Is it due to the of people in the park? But Sunday is equivalent to Friday. Some explanation is in line 214. Just call attention to that.**

We added the new sub-section 3.1 on Results, where we answer your question

“3.1 Lockdown, curfew and ASN amplitudes

We analysed the seismic effect caused by the first lockdown in Santiago City using the 24-h clock plots in station MT18 (Figure 4a, 4b). Although we observed a gradual reduction in ASN amplitudes on weekdays due to the day-cares, schools and universities near the station closed (16 March), we also notice a strong reduction on weekends, especially between 11h and 19h local time. Figure A1b shows the area close to MT18 in which we can distinguish the hippodrome “Club Hípico de Santiago” and the O’Higgins Park. The highest ASN amplitudes observed on Saturday before Lockdown 1 (Figure 4a) is explained by the activities of the hippodrome on Saturdays (and some Thursdays during January-February). The hippodrome closed on 21 March 2021, which is in agreement to the decrease in the ASN amplitudes observed after Lockdown 1 (Figure 4b).

We also distinguish the lockdown effect in the hourly grid representation (Figure 4c). The large ASN amplitudes observed during holidays are associated with near activities in both hippodrome and O’Higgins Park, which only persist on weekends during March. After the implementation of Lockdown 1, the ASN amplitudes drop, especially on weekends. Moreover, we observed a systematic behaviour of lower ASN amplitudes between 22h and 5h local time due to the overnight curfew implemented at the same hours, imposed from Lockdown

1 and remain during the full time-window studied.”

10. **Line 106: Please write the date of the Lockdown, beginning and end?**

We added Table A2 with the dates when Lockdown and other phases started and ended in the different cities where stations are located.

11. **Line 110: Is it possible to indicate the park in figure 1?**

This has been changed. We added the park location in Figure 1, and in the new Figure A1b.

12. **Line 111: Sorry if I misunderstood the sentence but how does a curfew between 22 h and 5 h reduce amplitudes between 5 h and 22 h?**

We re-wrote this sentence (L121):

“Moreover, we observed a systematic behaviour of lower ASN amplitudes between 22h and 5h local time due to the overnight curfew implemented at the same hours, imposed from Lockdown 1 and remain during the full time-window studied”

13. **Line 116: Website of the Ministry.**

Corrected (L88):

“Our study integrates epidemiological data available in the website of the Chilean Ministry of Science”

14. **Line 118: Please, provide further explanation of the Re. What does it mean and how is it measured?**

We complete section 2.3 in which we qualitatively describe the Re indicator, as well as how ICOVID Chile (2020) measured (L88):

“One of the primary indicators of the spreading of viruses and contagion dynamics is the estimation of the effective reproductive number (hereafter Re) from confirmed positive cases of COVID-19 since the date of the beginning of symptoms. The Re indicator is defined as the actual average number of secondary cases generated by a primary case during the epidemic outbreak (Caicedo-Ochoa et al., 2020; Tariq et al., 2021), their estimation is helpful to the assessment of public policies, to estimate population immunity, to monitor near real-time changes in transmission of the viruses over time, among others (Gostic et al., 2020). To control an epidemic outbreak, the Re indicator needs to be reduced below one (Riley et al., 2003). Herein, we used the estimation provided by ICOVID Chile (2020) who described the function Re depending on the proportion of susceptible individuals to be infected, a transmission coefficient and the infectious life expectancy. In other words, the Re accounts for the coefficient between the new infections and the recovery rates plus mortality rates (Contreras et al., 2020). ICOVID Chile (2020) used the method proposed by Cori et al. (2013) to monitor Re in real-time, modelling the transmission like a Poisson process calculated on the basis of the last seven days. We considered only the Re median and 95% credible interval estimated for the urban area in the MR, according to the data given by the Health Service of Santiago City.”

15. **Line 124: How is the Apple data measured? Change in relation to what?**

We modified the sentence (L101) by:

“The mobility data we analysed is provided by Apple mobile-phone locations in Santiago City, which corresponds to the percentage of change in the public’s walking and driving in relation to a baseline value from 13 January (Apple, 2020)”

16. **Line 130: Could you plot the airport location in figure 1?**

This has been changed. We added the airport location in Figure 1, and in the new Figure A1c.

17. **Line 145: Just call the attention of the reader that the average amplitude is different for each station. Like MT18 is 15 nm and MT16 is 1.5 nm?**

We added the next sentence (L140):

“Concerning the ASN amplitude variability, we observed that the quieter stations in the urban area of MR correspond to MT05, MT14, MT16 and MT03, stations that are located over hills, unlike the MT18 and MT15 stations which are deployed in the valley. Despite the ASN present an average amplitude difference between

each station, the temporal variations can be observed within Santiago City”

18. **Line 159: Just to make it easier for the reader, please provide the information about the approximate distance between urban and rural stations.**

We added the next sentence (L146):

“Notice that the rural stations analysed are deployed within the MR at a distance of about 15 km to 60 km from the stations installed in urban areas (see Figure A1).”

19. **Line 169: This peak is not so clear in the for the MT18. Some explanation for that? By eye, I believe the MT18 and Re correlation is worst, am I right? Same for Apple’s data**

We added a new paragraph to the Discussion section (L220):

”The matching pattern between the mobility data, the Re indicator and the high-frequency ASN amplitudes is well established for the station MT14 located in Las Condes. Nonetheless, this did not occur with other stations in urban areas such as MT18 placed in Santiago downtown. This observation can be further explained due to the heterogeneity in policy effectiveness against the COVID-19 spread in MR. Bennett (2021) showed that social distancing, quarantines and testing availability are affected by geographical and socioeconomic factors, in which the lockdowns have been more effective in high-income zones (such as Las Condes) rather than lower-income zones (such as the other station analysed in the MR urban area). Furthermore, the people living in high-income zones can reduce their mobility by around 60% while people in low-income zones only reduce their mobility by around 20% during lockdown (Carranza et al., 2020).”

20. **Line 175: I am sorry, I believe the is a problematic sentence: Is there any confirmation by the government that Lockdown 2 was responsible for the mitigation?**

We modified the sentence by (L158):

“After Lockdown 2, in mid-July, the Chilean government proposed the step-by-step programme to mitigate the propagation of SARS-CoV-2 virus towards a gradual re-opening and increase mobility in different counties as a public health policy (see Table A1).”

21. **Line 176: Please, explain the five phases. Just a short sentence is enough.**

We added the new Table A1 that includes more information explaining the step-by-step programme with the five phases

In addition, we added the next line in the Introduction section (L21):

“During this first period, the main public health policy addresses the isolation and social distance, including the closure of schools, universities and other educational centres (16 March), national night-time curfew (23 March), and the lockdown of communes. From 19 July 2020, the Chilean government implemented the step-by-step programme, which considers a gradual open of each commune by five phases, based on the monitoring of epidemiological and health system indicators (see Table A1; Tariq et al. (2021)).”

22. **Line 188: Please, make reference that the reader can see where those cities are located in Chile looking at Fig 1.**

We added the mention to the Figure 1 (L167):

“High-frequency ASN changes were also recorded in other cities along Chile (Figure 1).”

23. **Line 195: CCSP shows an average of 30 nm “noisier” the MT18. some explanation?**

We added the next sentence to explain the ASN amplitude observed (L177):

“The ASN amplitudes in Concepción are at least 30 nm noisier than Santiago (MT18), which could be explained by their location on residential areas, but also the different soil conditions where the stations were installed”

24. **Line 197: MG01 shows a strange pattern. Like a strong decrease in January.**

We added the next paragraph (L181):

“Nevertheless, this station shows a strange pattern before Lockdown. The first one corresponds to a high drop in mid-December until the first days of January associated with holidays festivities (Christmas and New Year

Day). The second pattern observed is the temporal variability that could be associated with the activity of the airfield near the site where the station is operating. Unfortunately, we do not have access to the aeroplane activity in those weeks to support our assumption.”

25. **Line 231: transmission of virus to transmission of the virus**

This has been changed. (L208)

26. **Line 272: implemented in other high density cities to implemented in other high-density cities**

This has been changed. (L255)

27. **Line 272: Please, cite some examples where we can find those networks and the impact of their study not just in the mobility but as a tool to teach seismology to school students and the society like Barcelona for example. <https://doi.org/10.3389/feart.2020.00009>**

We added the next sentence to the Conclusions section (L252):

“These seismometers are typically used for the management of seismological networks in urban areas; however, recent studies show the potential opportunity to use them as a tool to teach seismology to school students (e.g., Subedi et al., 2020) and increase the interest of society toward Earth Sciences (e.g., Diaz et al., 2020).”

28. **Figure 1: I would recommend decreasing the coastline thickness, it is blending with the stations**

This has been changed in Figure 1 caption.

29. **Figure 3: Difference between the blue and white background.**

We added the next sentence in Figure 3 caption:

”The grey and white background correspond to weekdays and weekends, respectively.”

3 Additional changes

1. (L45) the Chilean seismic network operated by the National Seismological Centre (hereafter CSN; Centro Sismológico Nacional; Barrientos (2018))
2. (L198) an overnight curfew
3. (L208) Other authors also suggest that small-area lockdowns and reductions in mobility can reduce the transmission of the virus but their impact was smaller than the early closures of schools, universities and other educational centres
4. (L212) The removal of lockdown protocols after 1 May to reopening the economy resulted in a new wave of infections and an exponential increase in the number of positive COVID-19 cases.
5. Figure 7: We changed the size of the figure and we modified the labels for the times of public restrictions implemented (School closures, LD1, end LD1, etc.)
6. Figure A1: We added a close view to the civinity of MT18 and MT05 stations.
7. Figure A4: We changed the size of the figure and we modified the labels for the times of public restrictions implemented (School closures, LD1, end LD1, etc.)
8. Figure A5: We changed the size of the figure and we modified the labels for the times of public restrictions implemented (School closures, LD1, end LD1, etc.)

On behalf of the authors,

Javier Ojeda