

# Reviews and Replies of manuscript “Retrieval of body waves with seismic interferometry of vehicle traffic: A case study from upstate New York, USA.” by Diego A. Quiros and Larry D. Brown

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## **REVIEW ROUND 1**

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### **Reviewer 1**

#### **Main Evaluation**

This study investigates the retrieval of body waves using a linear array along a highway. As the authors note, this has been demonstrated in previous studies. They test various processing approaches and qualitatively assess which methods are most effective for retrieving body waves. The retrieved signals are compared with active seismic data, showing consistency with known regional geological features.

The manuscript is well-written and generally clear. The comparison of processing techniques is valuable and highlights the potential of traffic-generated seismic signals. However, the evaluation is primarily qualitative. To strengthen the conclusions, I recommend incorporating a quantitative assessment of processing performance (e.g., metrics such as SNR, coherence, or other similarity measures). This would provide a more robust basis for identifying the most effective method.

Furthermore, the manuscript would benefit from a deeper explanation of why certain processing techniques perform better than others. This could include modeling, referencing similar studies, or ray tracing to validate the interpretation.

Figures should also be revised for consistency in font size and clarity, which would significantly enhance the presentation.

One important question that remains unaddressed is why the retrieved body waves are not used for imaging or inversion. Given that the authors show these signals are coherent and match active source arrivals, it would be helpful to discuss the potential (or limitations) of using them for shallow subsurface imaging, velocity model updates, or structural interpretation.

#### **Suggested References**

*The authors might consider complementing their literature review on traffic-generated sources for seismic interferometry. I list below some of the relevant papers.*

- M Rezaeifar, F Lavoué, G Maggio, Y Xu, C J Bean, L Pinzon-Rincon, S Lebedev, F Brenguier, Imaging shallow structures using interferometry of seismic body waves generated by train traffic, *Geophysical Journal International*, Volume 233, Issue 2, May 2023, Pages 964–977, <https://doi.org/10.1093/gji/ggac507>
- Sheng, Y. (2023). Seismic stereometry: an alternative two-station algorithm to seismic interferometry for analysing car-generated seismic signals. *Geophysical Journal International*, 235(1), 853-861.

- Meng, H., Ben-Zion, Y., & Johnson, C. W. (2021). Analysis of seismic signals generated by vehicle traffic with application to derivation of subsurface Q-values. *Seismological Society of America*, 92(4), 2354–2363. <https://doi.org/10.1785/0220200457>
- Laura Pinzon-Rincon, François Lavoué, Aurélien Mordret, Pierre Boué, Florent Brenguier, Philippe Dales, Yehuda Ben-Zion, Frank Vernon, Christopher J. Bean, Daniel Hollis; Humming Trains in Seismology: An Opportune Source for Probing the Shallow Crust. *Seismological Research Letters* 2021; 92 (2A): 623–635. doi: <https://doi.org/10.1785/0220200248>
- Ayala-Garcia D, Curtis A, Branicki M. Seismic Interferometry from Correlated Noise Sources. *Remote Sensing*. 2021; 13(14):2703. <https://doi.org/10.3390/rs13142703>
- Philippe Dales, Laura Pinzon-Rincon, Florent Brenguier, Pierre Boué, Nick Arndt, John McBride, François Lavoué, Christopher J. Bean, Sophie Beaupretre, Rosemary Fayjaloun, Gerrit Olivier; Virtual Sources of Body Waves from Noise Correlations in a Mineral Exploration Context. *Seismological Research Letters* 2020; 91 (4): 2278–2286. doi: <https://doi.org/10.1785/0220200023>
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## Technical Comments

- **L45:** Why focus on station 17? Is the spectral behavior similar across other stations?
- **L119:** 7 days correspond to 168 hours, not 172 hours.
- **L154:** The spectral characteristics described have been observed in other studies—please cite relevant literature.
- **L162:** Consider adding a figure showing amplitude consistency from hour to hour to support the decision to omit temporal normalization.
- **L165–171:** The description of the processing workflow could be clarified. Consider using bullet points or organizing by processing case (e.g., with or without filtering, whitening, etc.).
- **L195:** Why does this result in increased coherency for both the fast and slow arrivals described earlier? Results can be compared with other studies.
- **L207–208:** "A slight improvement" may understate the result—consider quantifying the improvement to increase precision.
- **L211–223:** Discuss differences in spectral characteristics or PSD between stations. Could data quality, rather than just proximity to the highway, explain the variations?
- **L226:** Specify which processing method was used to generate the common-offset stack virtual gather.
- **L255–260:** Consider adding a ray tracing analysis to support the discussion of the waves retrieved.

## Figures

- **Figure 1:** Improve clarity by reorganizing or adding a third panel (e.g., a zoomed-out map of the U.S. or region).
  - a. Add a larger-scale reference for readers unfamiliar with Ithaca.
  - b. A zoom-in could help clarify array geometry.
  - **Figure 3:** Increase font size in the caption.
  - **Figure 5:** Explain why only the positive lag is shown.
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## **Reviewer 2**

Dear Editor, Dear Authors,

Thank you for assigning me this review. The manuscript by Quiros and Brown presents an interesting application of seismic interferometry to vehicle traffic data. The authors successfully extract high-quality body and surface waves from passive recordings, and their results are convincingly validated through comparison with active-source data. This is a very interesting and well-executed study that offers valuable practical insights into ambient-noise imaging.

Major Comment:

My main suggestion is to encourage the authors to further capitalize on the great dataset and analysis they present. Specifically, I recommend considering the addition of imaging results using the retrieved VSGs as input (using preferred method of choice, like CMP imaging, S-wave velocity profile from dispersion curve etc). This would significantly elevate the impact of the study by demonstrating a practical output: such as a velocity model or structural interpretation derived from the interferometric processing.

Minor Comments:

- Line 91: Please remove the second bracket.
- Figure 1a: Improve the map by adding a clear legend and/or directional arrow. Currently, the symbols for towns and the survey site are very similar and can be confusing.
- Figure 1b: Clarify the figure by clearly distinguishing the locations specific to the passive and active surveys.
- Figure 2: Consider using arrows to indicate dipping arrivals associated with vehicle traffic along Route 13.
- Citation: Please consider replacing the conference abstract citation (Chamarczuk et al., 2018) with the related peer-reviewed article:  
Chamarczuk, M., Malinowski, M., Draganov, D., Koivisto, E., Heinonen, S., & Röttsä, S. (2022). Reflection imaging of complex geology in a crystalline environment using virtual-source seismology: case study from the Kylylahti polymetallic mine, Finland. *Solid Earth*, 13, 705–723. <https://doi.org/10.5194/se-13-705-2022>
- Road name: Please unify the naming convention for the road—either "Rt 13" or "NY 13"—throughout the manuscript and Figure 1b.
- Figure 3: I appreciate the inclusion of the spectrogram in Figure 4. For completeness and improved interpretability, I suggest also adding spectrograms alongside the time-domain records in Figure 3. This would help the reader distinguish signal types in the frequency domain, observe variations between day and night, and compare vehicular traffic noise to

other ambient sources.

- Line 149:

"The speed shown in Figure 4a–c was obtained by measuring the slope on each data gather before extracting the trace for station 17."

Please clarify whether the estimated speeds correspond to the actual speed of the passing vehicles or represent apparent velocities of wave arrivals. Additionally, I would be interested to know if you observed any variation in frequency content or signal energy depending on the weight or type of the passing vehicles.

Overall, I think this manuscript is an novel and significant contribution, which will be of interest to redears of Seismica. I believe addressing the comments above would further strengthen the clarity and impact of this work.

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*The REPLIES by the authors start 2 pages further down, below the final comments by both reviewers (next page).*

## **REVIEW ROUND 2**

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### **Reviewer 1**

The revisions address the previous comments adequately, improving the clarity and quality of the manuscript. The responses resolve the earlier concerns in comprehensive way. I particularly appreciate the detailed description of the different approaches for body-waves retrieval, which can be very useful for the community. I look forward to seeing future studies where body-waves can be retrieved and then used for imaging purposes.

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### **Reviewer 2**

#### **Final Review**

I would like to thank the authors for carefully considering the comments and for providing detailed responses. The revisions have substantially improved the manuscript, both in clarity and technical depth. The text has been modified to add clearer explanations of the processing steps and the resulting observations. A new paragraph has been included discussing the signal-to-noise ratio of cross-correlation and cross-coherence, which strengthens the methodological transparency. The figures have been modified and improved according to the suggestions of Reviewer 1 and me. In addition, the authors provided a thoughtful clarification regarding imaging: while reflection imaging was of interest, they explained that no clear reflections were observed in the interferometric gathers, and therefore a CMP 2D profile was not pursued. I believe that this is an appropriate and scientifically sound justification.

The authors provided thorough and respectful replies to both the first reviewer's comments and my own. Each concern has been addressed either through revisions in the text, additional discussion, or a clear justification where further analysis was not feasible. The manuscript is now well-structured, with improved explanations that will benefit the readership.

Based on the corrections introduced and the detailed responses to both reviewers, I am satisfied that all major issues have been addressed. I recommend this manuscript for publication. Congratulations to the authors on this valuable contribution.

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## *Response to Reviewers*

### **Main Evaluation**

This study investigates the retrieval of body waves using a linear array along a highway. As the authors note, this has been demonstrated in previous studies. They test various processing approaches and qualitatively assess which methods are most effective for retrieving body waves. The retrieved signals are compared with active seismic data, showing consistency with known regional geological features.

The manuscript is well-written and generally clear. The comparison of processing techniques is valuable and highlights the potential of traffic-generated seismic signals. However, the evaluation is primarily qualitative. To strengthen the conclusions, I recommend incorporating a quantitative assessment of processing performance (e.g., metrics such as SNR, coherence, or other similarity measures). This would provide a more robust basis for identifying the most effective method.

Furthermore, the manuscript would benefit from a deeper explanation of why certain processing techniques perform better than others. This could include modeling, referencing similar studies, or ray tracing to validate the interpretation.

Figures should also be revised for consistency in font size and clarity, which would significantly enhance the presentation.

One important question that remains unaddressed is why the retrieved body waves are not used for imaging or inversion. Given that the authors show these signals are coherent and match active source arrivals, it would be helpful to discuss the potential (or limitations) of using them for shallow subsurface imaging, velocity model updates, or structural interpretation.

*R/ Thank you for the comments and taking the time to review the manuscript. We have considered most suggestions. The text has been modified to add clearer explanations about the processing and results, included a paragraph on the SNR of cross-correlation and cross-coherence, and modified the figures as suggested. In terms of imaging, I am interested in reflection imaging, unfortunately, I could not observe clear reflections in the interferometric gathers, so there is little use in trying to generate a CMP 2D profile.*

*As you say, we could potentially generate a shallow tomographic model from the first arrivals. We have attempted to generate one, however the cyclic behavior of the first breaks derived from SI makes it quite difficult to accurately pick them, in addition to quantifying uncertainty of the picks. As a result, we don't feel confident enough in the result as to include it in the manuscript. We will keep working on it and if we are confident in the result we will try to publish it at a later stage. Nonetheless, we feel it is important to mention that even if we were confident in the model, without velocity information from standard sources (e.g., similar scale refraction survey to the SI survey) to compare with, it is difficult to provide any sense of accuracy. Making any analysis*

*generated from any SI velocity model difficult to interpret (e.g., ray tracing, modeling, etc) as we would have little information about how the error propagates through those analyses.*

## **Suggested References**

*The authors might consider complementing their literature review on traffic-generated sources for seismic interferometry. I list below some of the relevant papers.*

- M Rezaeifar, F Lavoué, G Maggio, Y Xu, C J Bean, L Pinzon-Rincon, S Lebedev, F Brenguier, Imaging shallow structures using interferometry of seismic body waves generated by train traffic, *Geophysical Journal International*, Volume 233, Issue 2, May 2023, Pages 964–977, <https://doi.org/10.1093/gji/ggac507>
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*R/ Thank you for the suggestions, I have added references that are relevant to vehicular (trucks and cars) traffic but excluded those related to trains as they are very different noise sources.*

## **Technical Comments**

- **L45:** Why focus on station 17? Is the spectral behavior similar across other stations?

*R/ Thank you, the spectral characteristics are basically the same across stations, station 17 was chosen as an example but any other station would have shown very similar spectral plots. I have corrected the text to reflect this.*

- **L119:** 7 days correspond to 168 hours, not 172 hours.

*R/ Thank you, corrected to 172 hours (i.e., 7.16 days)*

- **L154:** The spectral characteristics described have been observed in other studies—please cite relevant literature.

*R/ Thank you, referenced Meng et al., 2021; Riahi & Gerstoft, 2015 as suggested.*

- **L162:** Consider adding a figure showing amplitude consistency from hour to hour to support the decision to omit temporal normalization.

*R/ Thank you, Figure 3 has been modified. Normalization is now done by the peak value of both records for easier comparison. The text now mentions clearly that the night record shown (Fig 3a) is the hour record with the lowest volume of vehicle traffic in the dataset while the day record shows peak volumes of vehicle traffic. The average amplitude spectrum for each hour-long record is shown in Fig 3b & 3d, these effectively represent the lower and upper amplitude limits, respectively of the dataset, showing that both are within the same order of magnitude. Although most of the dataset amp. Spc. is closer to Fig 3d, meaning is difficult to observe quiet periods such as Fig 3a.*

- **L165–171:** The description of the processing workflow could be clarified. Consider using bullet points or organizing by processing case (e.g., with or without filtering, whitening, etc.).

*R/ Thank you, I have read the processing explanation a few times, and I don't see any issues with it, it's not particularly complicated, I made some very minor edits, but I rather not include bullet points or flow chart diagrams.*



- **L195:** Why does this result in increased coherency for both the fast and slow arrivals described earlier? Results can be compared with other studies.

*R/ Thank you, because the smallest data time window used (10 s windows) still allows for surface waves to propagate through the array, if one were trying to remove surface waves (slow arrivals) then I would imagine using a data time window of 1 s would increase the coherency of the fast arrivals and reduce the coherency of slow arrivals, although this is computationally intensive. Now if you are trying to remove the fast arrivals one could use data time windows smaller in size that the time it takes for those arrivals to propagate through the array (e.g. 0.25 s)*

- **L207–208:** "A slight improvement" may understate the result—consider quantifying the improvement to increase precision.

*R/ Thank you, SNR has been calculated for the two preferred cases, cross-correlation and cross-coherence, quantifying the improvement as commented.*

- **L211–223:** Discuss differences in spectral characteristics or PSD between stations. Could data quality, rather than just proximity to the highway, explain the variations?

*R/ Thank you, there are no differences in the frequency content of station 5, 10, and all the others. The geometry as one would expect has an obvious effect, because for stations 1-13 the sources are not in-line most of the time (not stationary phase positions), and what we end up obtaining in the SI are spurious arrivals with apparent velocities. I have commented on this a bit more.*

- **L226:** Specify which processing method was used to generate the common-offset stack virtual gather.

*R/ Thank you, how the c-o stack is generated is already specified in the text, clearly specifying bin size, and I have added the specifics about the normalization used as well.*

- **L255–260:** Consider adding a ray tracing analysis to support the discussion of the waves retrieved.

*R/ Thank you, I think this is unnecessary, and difficult to achieve given that there is no reliable 2D velocity model as commented on in the beginning. Potentially one could do this if a velocity model was available from another source (e.g., multichannel refraction tomography) to accurately ray trace and have ground truth. But as we mentioned earlier, we had trouble generating a 2D model from the interferometry results due to the difficulty in selecting first breaks, and to then ray trace from that model would just be propagating uncertainty.*

## Figures

- **Figure 1:** Improve clarity by reorganizing or adding a third panel (e.g., a zoomed-out map of the U.S. or region).
- a. Add a larger-scale reference for readers unfamiliar with Ithaca.

*R/ Thank you, added a globe for reference*

- b. A zoom-in could help clarify array geometry.

*R/ Thank you, I think is fairly clear already, but I have modified the map to have larger zoom.*

- **Figure 3:** Increase font size in the caption.

*R/ Thank you, all figure captions have the same font size, smaller than the text, I'll leave it and can be fixed during copyediting.*

- **Figure 5:** Explain why only the positive lag is shown.

*R/ Thank you, no particular reason, mostly to save space like other authors do as well, one can see negative lags in the Cross-correlation vs Cross-coherence figure.*

*Thank you again for taking the time to review the manuscript, your comments are very appreciated.*

*Best*

*Diego Q.*

Dear Editor, Dear Authors,

Thank you for assigning me this review. The manuscript by Quiros and Brown presents an interesting application of seismic interferometry to vehicle traffic data. The authors successfully extract high-quality body and surface waves from passive recordings, and their results are convincingly validated through comparison with active-source data. This is a very interesting and well-executed study that offers valuable practical insights into ambient-noise imaging.

Major Comment:

My main suggestion is to encourage the authors to further capitalize on the great dataset and analysis they present. Specifically, I recommend considering the addition of imaging results using the retrieved VSGs as input (using preferred method of choice, like CMP imaging, S-wave velocity profile from dispersion curve etc). This would significantly elevate the impact of the study by demonstrating a practical output: such as a velocity model or structural interpretation derived from the interferometric processing.

*R/ Thank you for the comments. One of the original goals of the study was to produce a 2D reflection profile (CMP imaging) but since no clear reflections are present in the dataset is difficult to justify any further processing.*

*On the other hand S-wave velocity inversion could be done, however as the title of the manuscript suggest we are interested in body waves as this has been quite difficult to observe and only a handful of vehicular (cars and trucks) traffic studies have shown convincing body wave retrievals. Surface waves and therefore S-wave models are ubiquitous in the literature, and really of less interest to us. Another reason why we didn't pursue surface wave dispersion and S-wave inversion is that if one pays close attention to the retrieved surface waves one can see that there is very little dispersion, which would result from a fairly homogeneous velocity structure (relatively thick shale layers), which is not surprising for this region.*

Minor Comments:

- Line 91: Please remove the second bracket.

*R/ Thank you, I have removed it.*

- Figure 1a: Improve the map by adding a clear legend and/or directional arrow. Currently, the symbols for towns and the survey site are very similar and can be confusing.

*R/ Thank you, I have added a global map and slightly zoomed in for the local map.*

- Figure 1b: Clarify the figure by clearly distinguishing the locations specific to the passive and active surveys.

*R/ Thank you, I think the zoomed map helps to clarify this but also the legend in the array map should make it obvious.*

- Figure 2: Consider using arrows to indicate dipping arrivals associated with vehicle traffic along Route 13.

*R/ Thank you, we rather not because the record is full of traffic passing by, and although many are large amplitude signals likely semi-trucks or “lorries” a lot of the record contains vehicles like passenger cars which are slightly smaller amplitude, and if we use an arrow to indicate every event I’ll need too many. I have added to the caption “The largest amplitude dipping events likely correspond to semi-trucks (lorries) traveling through the array while the smaller amplitude dipping events correspond to passenger vehicles.”*

- Citation: Please consider replacing the conference abstract citation (Chamarczuk et al., 2018) with the related peer-reviewed article:

Chamarczuk, M., Malinowski, M., Draganov, D., Koivisto, E., Heinonen, S., & Rötä, S. (2022). Reflection imaging of complex geology in a crystalline environment using virtual-source seismology: case study from the Kylylahti polymetallic mine, Finland. *Solid Earth*, 13, 705–723. <https://doi.org/10.5194/se-13-705-2022>

*R/ Thank you, I have made the modification in the text and the reference list.*

- Road name: Please unify the naming convention for the road—either "Rt 13" or "NY 13"—throughout the manuscript and Figure 1b.

*R/ Thank you, I have change the Rt 13 to NY 13 and also route 13 to NY 13 for consistency*

- Figure 3: I appreciate the inclusion of the spectrogram in Figure 4. For completeness and improved interpretability, I suggest also adding spectrograms alongside the time-domain records in Figure 3. This would help the reader distinguish signal types in the frequency domain, observe variations between day and night, and compare vehicular traffic noise to other ambient sources.

*R/ Thank you, I went ahead and included an amplitude spectra average for both records in figure 3, I think a spectrogram for every trace is overkill and difficult to display, and trying to display an average spectrogram for all the traces would provide no useful information as arrivals are a function of time and space and spectral properties of different traces would interfere if they were summed.*

• Line 149:

"The speed shown in Figure 4a–c was obtained by measuring the slope on each data gather before extracting the trace for station 17."

Please clarify whether the estimated speeds correspond to the actual speed of the passing vehicles or represent apparent velocities of wave arrivals. Additionally, I would be interested to know if you observed any variation in frequency content or signal energy depending on the weight or type of the passing vehicles.

*R/ Thank you, I have clarified that the speed mentioned is the speed of actual vehicles and not that of wave arrivals, as the values shown 20 m/s would be way too slow for apparent velocities of elastic waves propagating between stations.*

Overall, I think this manuscript is an novel and significant contribution, which will be of interest to redears of Seismica. I believe addressing the comments above would further strengthen the clarity and impact of this work.

Best regards,  
Reviewer

*Thank you again for taking the time to review the manuscript, your comments are very appreciated.*

*Best*

*Diego Q.*