

Dear Vuk Mandic,

Please submit

1. A detailed response to reviews, including a list of changes or rebuttals as well as an Annotated Manuscript. When you submit your revised paper, you will find the step "Respond to Reviewers." Entering information in the text box on that page is required; you can enter either the complete responses to reviews or a statement that responses are in an uploaded file. The information in the text box will be available to reviewers. In the "Attach Files" step, you can upload the files labeled "Response to Reviews" and "Annotated Manuscript." Both of those files will be available to reviewers. A file uploaded as "Letter to Editor" will be seen only by the editors.
2. A source file (Microsoft Word or LaTeX) of your revised and complete manuscript. The manuscript text must be double spaced, and it must include references, affiliations, figure captions, and tables (if any). It may also contain the figures.
3. Figures. These can be submitted within the source file OR as separate files OR together in a PDF file. Please include the figure number on the figure itself, and use color only in those figures, if any, that should be in color upon publication.
4. A signed and completed copyright/page-charges form (if not already submitted).

If you have an electronic supplement, submit it as described in our guidelines at <http://www.seismosoc.org/publications/esupps>. Deviation from these guidelines could cause a delay in the processing of your paper.

I look forward to hearing from you.

Yours sincerely,

Zhigang Peng, Ph.D.
Editor In Chief
Seismological Research Letters

Reviewers' comments:

AE comment: This manuscript documents a three-dimensional broadband seismic array deployed at the Homestake Mine in South Dakota. The authors provide fundamental information of this experiment so that users can easily use for their own research. Therefore this manuscript would be of great importance for the seismological community. The two reviewers provide constructive comments to improve the manuscript. I have minor comments:

1. L131-L140: sensor installation

This part summarizes the sensor installation very well. I wonder if the authors can provide some photographs showing the sites so that future experiments can follow the Homestake experiment.

2. L148: NMEA

What is NMEA (abbreviation)?

Reply: added explanation of NMEA.

3. L198: two sensor failures

Could you clarify which sensors (stations)?

4. L201: "This was repaired"

When this repair was happened?

Reply: Added a note that the repair was completed in May 2015.

5. L241-L242: "(left)" and "(right)"

Please use (a) and (b) instead of (left) and (right). This would require add "(a)" and "(b)" to Figure 3.

Reply: done

6. Figure 1.

Please add an inset map showing the target area in larger map (ma of US Lower 48 State for example).

7. L552: "black filled triangles" -> "black filled reverse triangles"?

Reply: Done

8. Figures 2 and 3.

Please add "(a)" and "(b)" and update the figure captions.

Reply: Done

9. L575: "Black filled" -> "Yellow filled"?

Reply: Done

10. Figures 5, 6, and 7.

Please add a scale of amplitude so that SRL readers can identify the level of amplitudes.

***** GARY?

Additional editorial comments: this article would fit the new SRL column Data Mine very well. See the article guideline at <https://www.seismosoc.org/publications/srl/srl-data-mine-author-information/>. If the authors are interested in, please make sure to select this article type when submitting the revised version. Please make sure to include the right network code and URL (like <http://ds.iris.edu/mda/X6?timewindow=2014-2016>) in the Data and Resources section.

*****OTHERS?

Reviewer #1: This was a very interesting paper to read. It is quite rare to see an array of this geometry and the authors point out several interesting and important studies that they are embarking on in examining teleseismic, regional, and local data. Indeed, all three data types were shown in the paper and I am personally very excited when the data are released from embargo since some nice wave propagation studies can be made such as source excitation of multimode surface waves from local quarry blasts.

The paper, obviously, was written to announce the experiment by showing some initial results on

noise levels as a function of depth and other zeroth order wave propagation effects.

One thing that was missing, from my point of view, was a semi-quantitative analysis of the potential performance of the 3D and surface 2D array. Figure 1 was a bit too complicated to grasp the 3D geometry. The addition of the tunnels and vertical shafts with colors made it difficult to see station locations in 2 or 3D. Might the authors consider making a 3D perspective plot of station locations? Once the station locations are more clearly seen, it could also be helpful to analyze the beam forming ability of the arrays using simple array design arguments. For example, an array aperture of 1.5km in depth would suggest that 3D vertical slowness estimates could be made for wavelengths of about 0.5km or shorter. For a vertically propagating P wave traveling at ~5km/s, this implies that the 3D extent of the array will be useful for 10 Hz or higher frequency P waves. Somewhat lower frequency S and surface waves would also be amenable to the geometry. I think readers who examine array data would appreciate some discussion like this.

***** NEED TO DISCUSS

One other comment - the introduction lead sentence is a bit too general and obvious. I would suggest a very short discussion of the use of array seismology instead. The sentence starting on line 34 also seems to equate seismic arrays with numbers of broadband instruments, which is a bit misleading. Many of the broadband instruments were deployed in networks, not arrays.

***** VICTOR?

Line 55 on the near-surface weathered layer - It could be argued from a rock mechanics point of view that 1.5km is still in the weathered layer.

***** VICTOR?

Page 13 discussion on detecting seismic events - it seems that the raw data were sent through the detector. How would filtering improve detections of smaller teleseismic, regional or local events?

***** VUK: I don't know what this means – help from Gary/Victor?

The paper is generally clearly written. There are only a few typos and style problems:

Line 135 - arrangement of parenthesis around the Harms reference.

Reply: It is not clear to us what should be changed here, could you please be more specific?

Lines 241-248 should be relegated to the figure caption.

Reply: made changes to accommodate this suggestion.

Line 390 - mention the IRIS array designation (X6, I believe - I looked it up)

Reply: Added designation *****GARY CHECK PLEASE

Chuck Langston

November 13, 2017

Reviewer #2: Comments following the line numbers

[1-2] Title should be "A Three Dimensional Broadband Seismometer Array at the Homestake Mine"

Reply: Done.

[24] Change "... We describe unique opportunities and challenges related to the 3D ..." by "... We describe unique research opportunities related to the 3D ..."

Reply: we added the word "research", but we also kept "challenges" since a part of the purpose of the paper is to document challenges we encountered and overcame in the process of installing this array in underground environment.

[27-28] "... and discusses directions for potential future analysis ...". I suggest to remove this part and concentrate to the results you obtained since potential future analysis is an open program that depends on too many factors. You write a paper and not a project proposal, please, present the network, present the acquisition strategy, the data and their quality, and present the advantages to have broadband 3D array using underground space is largely sufficient for this initial paper.

Reply: We modified the last sentence of the abstract to emphasize the preliminary results and their importance.

[32] "... subsurface ...". Not only subsurface

***** VICTOR?

[40-43] "... The exceptions ... Richardson and Jordan 2002) ...". I suggest that you mention also existing European 3D broadband array, for instance UNDERSEIS at Gran Sasso underground Research Laboratory (Saccorotti et al., 2006) and the 3D array at LSBB Underground Research Laboratory (Gaffet et al., 2009).

Saccorotti G., B. Di Lieto, F. Tronca, C. Fischione, R. Scarpa, and R. Muscente (2006) Performances of the UNDERground SEISmic array for the analysis of seismicity in Central Italy. *Annals Geophys.* 49, 17pp

Gaffet S., J. Wang, M. Yedlin, G. Nolet, D. Brunel, A. Cavaillou, D. Boyer, C. Sudre, and M. Auguste (2009) A 3D Broadband Seismic Array at LSBB. *IRIS Data Services Newsletter* 11, 6pp. <http://ds.iris.edu/ds/newsletter/vol11/no3>

Reply: We now mention these arrays in the introduction, and we added the suggested references.

[44] "... geophones rather than more broadband seismometers ...". This is wrong for UNDERSEIS and LSBB arrays.

Reply: Our wording in the introduction is now consistent with this comment. We note however, that UNDERSEIS uses short-period seismometers, operating above 1 Hz.

[55-57] "... measurements at depth could be advantageous is that Earth structure is most heterogeneous in the highly weathered near-surface layers ...". I suggest this modification "... measurements at depth could be advantageous since the weathered near-surface layers highly complicates the initial heterogeneity of the medium properties ..." The medium is heterogeneous everywhere, not mostly at the surface, notably at Homestake.

Reply: We have made this change.

[60] "... it is not known precisely how severe the effect is ...". Too strong assertion, you cannot say that like that in a so general way.

Reply: We have modified the wording to "it is often challenging to estimate the magnitude of this effect"

[70-72] "... To fully explore the scientific potential of this field, more sensitive detectors are being designed such as the Einstein Telescope [Punturo 2010] and the Cosmic Explorer [Abbott 2017] ...". You should add the MIGA initiative for gravitational wave underground measurement [Canuel et al., 2016].

Canuel B., S. Pelisson, L. Amand, A. Bertoldi, E. Cormier, B. Fang, S. Gaffet, R. Geiger, J. Harms, D. Holleville, A. Landragin, G. Lefèvre, J. Lhermite, N. Mielec, M. Prevedelli, I. Riou,

and P Bouyer (2016) MIGA: combining laser and matter wave interferometry for mass distribution monitoring and advanced geodesy. Proc. of SPIE 9900, Quantum Optics 990008. doi: 0.1117/12.2228825

Reply: We added this reference.

[76] "... quantify this suppression factor and its depth dependence ...". Attenuation with depth" should be more suitable than "suppression.

Reply: We made this change.

[90] "... Homestake Mine an ideal location ...". Highly relevant would be more suitable than ideal.

Reply: We replaced "ideal" with "well-suited".

[101] "... The locations of stations ...". Use sensors instead of stations. What about the orientation of the horizontal components.

Reply: We respectfully disagree, and prefer to use the term "station". This is because at each location we did not just install the seismic sensor – rather we installed a substantial amount of equipment needed to acquire, digitize, and transmit data over the network, synchronize the time with the GPS signal, and provide power to all electronics components. Consequently, each location really hosted a full "station" and not just the seismic sensor. The horizontal components of the sensor were oriented using the Octans, as described in paragraph 3 of the "Seismometer Array" section.

[119-120] "... In several cases, we had to extend existing power and network cables to support the stations ...". Useless.

Reply: We agree, this sentence was removed.

[122-125] "... Stations were usually placed in alcoves or blind alleys to minimize the effects of the air drifts, although several stations were installed in enlarged areas within the main drifts of the mine. In most cases, we found there were complex tradeoffs between cost of installation and distance from active operations ...". Some images and a short caption would better illustrate the installation than a long sentence in order to visualize the underground environment and the seismometer confinements.

Reply: Please see our reply to the AE comment #1.

[132] "... gyrocompass from the IRIS-PASSCAL ...". What is the precision of the orientation finally obtained.

Reply: We added a comment that the final precision was about 1 degree. *****DO OTHERS AGREE?

[136] "... Quanterra ...". Replace with Quanterra.

Reply: Quanterra is the correct spelling of the digitizer's name. No change made.

[142-158] "... In addition ... was negligible ...". Too technical paragraph, should be suppressed or replaced by a scheme describing the network topology should complete this description. Please, add also the sampling rate of data.

Reply: We agree with the reviewer that this paragraph is rather technical. However, this was intentional: synchronizing the underground stations was arguably the most unique and challenging technical aspect of the deployment. We developed and implemented a new solution capable of transmitting signals over large distances (kilometers), based on a custom-made optical distribution system on which we iterated with a manufacturer. We expect this solution will be of relevance to future underground deployments, and so we provide the technical information needed for replicating our setup.

We added the sample rate (100 Hz) in the preceding paragraph, when Q330 is first introduced.

[170] "... oriented with the Octans instrument ...". Why did not you used the same gyrocompass for all?

Reply: The installation of surface and underground stations could not be done at the same time, due to the surface weather conditions in South Dakota at the time when Octans was available to us. Specifically, at the time when we had access to the Octans, we did not have access to surface stations. Hence, surface stations were oriented in the standard GPS-based way.

[170-172] "... We insulated the sensor vault with a layer of foam and burial with as much of a soil cover as possible. We had the common problem of rain washing some cover away that we restored when the instruments were serviced ...". What is the efficiency of the insulation compared to shallow buried broadband seismometers?

***** GARY?

[193] "... rotating shift schedule ...". What do you mean?

Reply: We established a rotation among our group members, where each member would cover a week at a time during which they would monitor the diagnostic information. The idea was that if a sensor fails, we would observe this within a day and could react quickly to rectify the problem. We added "among our group members" to this sentence to clarify how this rotation was set up.

[195-197] "... near 100% for every site except DEAD, which had power problems in the winter of 2015-2016 and also had a corrupted E-channel response ...". Is it really necessary to take time to describe this dead station? You already mentioned it at line #167.

Reply: This station was operational for most of the observing period (we added a note to clarify this), and the data it acquired is included in the IRIS dataset. We therefore feel it is important to include this brief description as it might be relevant for future users of Homestake data. The DEAD station is indeed mentioned earlier in the text, but only to note that it was installed differently from other surface stations. Hence, this is the only place in the text where we mention the partial failure of this station.

***** WAS THE E CHANNEL CORRUPTION LIMITED TO THE WINTER 2015-2016?

[208] "... geologically stable ...". What do you mean? I suggest you add a geological map surrounding the Homestake facility and seismic array area.

***** not sure what to respond here, should we delete these two words?

[217] "... heterogeneity ...". And also free surface conversion of waves.

Reply: we added this comment.

[224] "... (ASD) ...". The use of acceleration RMS or db(acceleration) RMS would suit better, especially since you mentioned astrophysical application for which perturbation of gravity, hence acceleration, must be quantified.

***** This is a good point, should we switch plots?

[227] "... east-west ...". Something wrong, the North channel is indicated in the figure 2. Moreover why do you not present also the vertical spectra?

Reply: Indeed, this was an error, we corrected this to read "north-south". The vertical spectra follow similar patterns, so we feel that including them would not contribute significantly to the results of this analysis.

***** DO OTHERS AGREE? SHOULD WE ADD VERTICAL SPECTRA?

[238-239] "... This is due to differences in the local environment in terms of thermal insulation and proximity to human activity ...". This point should be better demonstrated or at least discussed in term of insulation (i.e. variation of temperature or differences in seismometer thermal confinement) and also in term of local site effect characterization (shallow subsurface geological properties, topography, surrounding geological and topographic heterogeneities ...).

Reply: We have modified this sentence to read "This is due to differences in the local environment of surface stations and in their proximity to human activity: while YATES and ROSS were near the two shafts of the mine (and therefore subject to constant activity), ORO was far from human activity. Similarly while ORO was located in a valley and shielded by nearby topography, RRDG was located at the top of a bare hill and subject to strong winds."

[244] "... from 400-second ...". Why do you change the spectral analysis protocol from 900 s window length to 400 s? Cf line #226.

***** CHECK WITH PAT, IS THIS AN ERROR IN THE PAPER?

[245] "... of the seismic noise at each station ...". Please be a little more explicit, for instance do you reject the windows with seismic events.

***** CHECK WITH PAT

[246] "... the black curves represent the 95% ...". This information is redundant, being also in the figure caption.

Reply: We have addressed this in the context of a comment from Referee 1 above.

[257-258] "... We also observe a considerable difference between the vertical channel and the horizontal channels at low frequencies ...". There is no evidence for that since you do not show the vertical component neither both horizontal components.

***** THIS MAY BE ADDRESSED IF WE ADD VERTICAL SPECTRA?

[257-264] "... We also observe ... down to tidal frequencies ...". You describe things that cannot be verified since the frequency band below 0.01 Hz is not shown in the figures. Please suppress or change the figures.

***** GARY? HOW DO OTHERS FEEL ABOUT THIS?

[258-261] "... At 0.01 Hz and below, the vertical channels on both stations have almost an order of magnitude lower noise than the horizontals, due to tilt noise that increases with period on horizontal components [Wielandt, 2002] ...". You describe things that cannot be verified since the frequency band below 0.01 Hz is not shown in the figures.

Reply: please see the previous comment.

[266-270] "... The low noise ... future contributions ...". The idea is correct but should not be delivered here. A paper should show results and not explain the research that could be done in the future, please suppress.

Reply: We respectfully disagree with the referee. We believe it is appropriate and useful to indicate possible future research directions that go beyond the scope of the current paper. One of the purposes of this paper is to indicate the scientific potential of the data acquired by this array, and the cited paragraph is important in this regard.

*****DO OTHERS AGREE?

[275] "... of 24 ultra-quiet sites ...". Quiet and ultra-quiet. Perhaps you should suppress this term that cannot be generalized to the whole sensors of the array neither to the whole frequency band nor to all the components of the sensors.

Reply: We removed the word "ultra".

[279-282] "... We solved this issue, and reduced the false detection rate to near zero, by running the detection algorithm only on the three outer surface sites (DEAD, TPK, and SHL), one of the quietest underground sites (D4850), and the 8 regional stations ...". Concerning the calculation of spectra presented above, did you use this methodology to select the noise windows without any teleseismic, regional or local event inside? Finally DEAD is operational or not? The use of this station is not consistent with the comment in line #195.

***** GARY?

[285-289] "... A large number ... in the 4000s subarray ...". This point is useless in this paper since you expect to analyse them in a future work. Moreover you make effort to select the best events excluding by choice the local events, thus you cannot discuss about local event here. There is a contradiction in the presentation, even if local events are really interesting to study too.

***** VUK: DON'T UNDERSTAND THIS... OTHERS?

*****GARY TO ADDRESS THE FOLLOWING:

[293-294] "... Of the 431 epicenters, 359 are in the local area shown in Fig. 4b and 72 are at regional to teleseismic distances shown in Fig. 4a ...". You should define what is far, regional or local in term of epicentre distance or in term of waveform coherency or any other clear classification.

[298] "... 359 local events ...". Local and/or regional events.

[299] "... River Basin in eastern Wyoming ...". How far is it from Homestake? Give the epicentre distance.

[299] "... All have similar waveforms ...". Not really. Moreover, If events have similar waveforms they should be at regional or teleseismic distances, not local. Please clarify the class of events.

[300] "... surface waves like the event shown in Figure 5 ...". This event do not exhibit really similar waveform across the whole 24 stations array but a coherency appears depending on depth like you mention in the next §. Please clarify.

[305] "... for two representative events ...". Describe shortly these events? Why are they representative and of what? I think you should show these events in Fig. 5 instead of the local one.

[308-310] "...Note that we treated the 300 and 800 stations as part of the 'Surface' subarray, grouped the 1700 station with the five 2000-level stations in the 2000s subarray, and grouped the 4100 and 4850 stations in the 4000s subarray ...". This precision should be defined earlier in the denomination given in Fig. 1.

***** THE ABOVE SHOULD BE ADDRESSED BY GARY?

[344] "CONCLUSIONS AND FUTURE DIRECTIONS". If you include FUTURE DIRECTIONS, this manuscript becomes a scientific report rather than a scientific paper. You should concentrate the conclusion to the main results shown in the previous paragraphs otherwise you deliver idea and scientific strategy of your team concerning the analysis of Homestake seismic data provided by the 3D array. Again you write a scientific paper, not a report and not a proposal.

Reply: as noted above, we respectfully disagree with the referee's view. In general we believe that scientific papers should include discussions of possible shortcomings of the presented work as well as possible ways to improve or expand on the presented results in future studies. This is particularly important in papers of the kind presented here, whose one purpose (among others) is to present the readers with the existence of the unique data-set acquired by the Homestake array, and indicate the data's scientific potential that could be pursued potentially by other researchers.

*****DO OTHERS AGREE WITH THIS?

[351] "... due to teleseismic events ...". Remove due.

Reply: Done.

[351-352] "... and due to active excitation ...". Remove due

Reply: Done.

[352] "... to active excitation experiments performed at the surface and underground ...". You do not describe these experiments. Which one? To do what? Please suppress.

Reply: We added a note "that will be described in a separate publication". Our goal here is not to present the active excitation experiments (this is a paper in itself), but we want to inform the reader that such experiments were performed, in case they are interested in such data.

*****DO OTHERS AGREE?

[357-359] "... Several such studies are already underway, and here we briefly describe some of these possibilities, which will be subjects of future publications ...". Unnecessary.

Reply: Please see our reply to the referee's comment on the line [344].

[362] "... estimate the directionality and modal content of the seismic noise ...". You do not show such characterization, please suppress.

Reply: We do not claim to have made this characterization, it is a possible future study of interest that we highlight. Please see our reply to the referee's comment on the line [344].

[365-366] "... hence avoiding common assumptions about the dominance of fundamental-mode surface waves ...". No evidence or result in this paper allows you to write this conclusion.

Reply: we have removed the quoted text.

[366-368] "... Combined with other radiometer-based techniques used in other areas of physics [Thrane et al. 2009], such estimates would directly contribute to the design of future underground gravitational-wave detectors ...". What is the question addressed in this paper that is related with this part of the conclusion?

Reply: Again, this is not a conclusion, it is a possible future study of interest that we highlight. Please see our reply to the referee's comment on the line [344].

[378-380] "... comparison of P-wave particle motions within the array may yield unique data on P-wave anisotropy. The rocks at Homestake are predominately highly foliated phyllites and schist ...". Not shown in this manuscript, please suppress. Moreover, such a geological description depicts a strongly heterogeneous underground medium, even far from the weathered subsurface. This consideration requires to clarify the sentence line #56 with something near what I suggested at this line.

***** GARY OR VICTOR?

[references] Please order correctly the references. For report like the ones of Pariseau et al., indicate the number of pages; for long list of authors like Abbott et al., please specify the number of co-authors or the name of the collaboration.

Reply: We have corrected references as suggested by the referee.

[Figure 1] You should define here the terminology 2000s and 4000s subarrays used later in the text. DEAD station is finally operational or not (Cf. line #195).

Reply: Since the terminology 2000s and 4000s subarrays is only used in a part of the paper, we find it clearer to define it where it is used, rather than in the schematic whose purpose is different: to define the array and its relation with the surrounding topography. Also, please see our reply to the comment on the line [195] regarding the DEAD station.

[Figure 2] Should be represented in acceleration RMS or dB of acceleration RMS to fit standard representation of noise.

Reply: please see our reply to the referee's comment on the line [224].

[Figure 3] idem

Reply: please see our reply to the referee's comment on the line [224].

[Figure 4] The scales presented are global and regional. Perhaps you should add a 4c picture with local scale only. Show where the Wyoming event is and the events studied in Figs. 6 and 7.

***** GARY?

[Figure 5] The data shown should be replaced by the data set of the 2 events analysed in Figs 6 and 7.

*****GARY? OTHERS?

[Figure 6] Give also the date and epicentre distance and depth of the Alaskan event. [590-591] "... P (event depth is 120 km and angular distance on the sphere is 33°) ..." this information should be set just after Alaskan earthquake line #586. Event should be depicted in Figure 4.

*****GARY?

[Figure 7] Give the date, distance and depth of the explosion. Event should be depicted in Figure 4.

*****GARY?