

# ***Interactive comment on “The INSIEME seismic network: a research infrastructure for studying induced seismicity in the High AgriValley (southern Italy)” by Tony Alfredo Stabile et al.***

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The aim of this paper is to describe a local seismic network for the observation of induced seismicity at the High Agri Valley in S. Italy. The waveform data that is recorded from the associated stations is open and induced seismicity is an interesting topic with serious implications for the local communities. The paper covers topics such as the installation process and technical characteristics of the associated seismic stations, as well as the site effect characteristics. My main points are (i) the addition of a new figure showing an example of a station's response (amplitude/phase) even though the data-less station files are available in the supplementary material, and (ii) that the discrimi-

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nation of induced events and local earthquakes is being done based on the hypocentre depth only. I think that the paper would benefit from a brief source mechanism study for the discussed (or a sample) seismic events. I have made other minor comments (see below) which have to do mainly with the English language syntax throughout the manuscript. Overall the scientific content is good and useful and I recommend moderate/major revisions of the paper. I suggest the authors to proof read the manuscript very carefully upon submission of the revised manuscript.

REPLY: We would like to thank you for your useful major and minor comments that surely improve the quality and the readability of the paper. Even if we do not completely agree with some few comments, they were important to better clarify some sentences or to provide additional information in the paper. Regarding the main point (i), as requested, we will add in the supplementary material of the revised manuscript a new figure showing a station's response both in amplitude and phase. Regarding the main point (ii) we would like to highlight that the classification of induced events is not based merely on their focal depth but also by evaluating if the event belongs to the cluster already classified as induced from previous studies. Probably this aspect was not evinced in the original manuscript, therefore we will add few sentences in the revised version to better describe how new recorded events are classified as induced. Furthermore, we will provide in the supplementary material some focal mechanisms computed with SeisComp3 for a sample of induced events (both fluid-injection and reservoir-induced events), and we will discuss the results in the text. Finally, we will carefully proof read the revised manuscript. Please, let us know if you need additional clarifications. Following we will provide a point-by-point reply to each minor comment. Each reply is preceded by the word "REPLY":

p.2 - I.2-6 Induced seismicity is commonly accepted to be anthropogenic. I think McGarr(2002) discusses whether different cases are induced or not and in which degree, but in general he accepts induced seismicity as anthropogenic - please rephrase.

REPLY: Probably our sentence was too short and not clear enough. In the frame-

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work of “anthropogenic seismicity” McGarr (2002) provided a specific significance to the adjectives “induced”, “triggered”, and “stimulated”: «As used here, the adjective “induced” describes seismicity resulting from an activity that causes a stress change that is comparable in magnitude to the ambient shear stress acting on a fault to cause slip, whereas “triggered” is used if the stress change is only a small fraction of the ambient level. By “stimulated” we refer generally to seismicity either triggered or induced by human activities». Therefore, using the word induced as synonymous with anthropogenic is in principle technically incorrect. Anyway, nowadays is commonly accepted to interchange the two words for the sake of simplicity. We will rephrase the sentence with the aim to better explain this concept that allows us to use “induced” as well as “anthropogenic” along the whole manuscript.

p.2 - l.19 and the discrimination between natural and induced seismicity. I think this should go to b) from a pure scientific point of view... I don't think this has to do much with social and economic impacts.

REPLY: We prefer to leave it in a) because in our opinion the discrimination between natural and induced seismicity has both strong social and economic implications. Indeed, establishing cause and effect between recorded earthquakes and local energy technologies is an important information for insurance and legal purposes to assess if a damaging earthquake is associated or not to the energy technology in operation nearby the damaged area. As an example, after the occurrence of the M<sub>L</sub>=3.4 induced earthquake in Basilea, several damage claims arose from local residence and the company's liability insurance paid more than \$9 million for damages (e.g., see Grigoli et al., 2017, and references therein). Furthermore, we have to bear in mind that people can tolerate the occurrence of non-damaging natural events but they do not tolerate induced felt events even if any damage does not occur.

p.3 -l.14 remove instead.

REPLY: Ok, thank you.

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p.3 -l.20 with the highest seismogenic potential... I think this term is described better in terms of energy accumulation ...or motion rate mm/year? The expected maximum acceleration has to do also with local site conditions - maybe rephrase.

REPLY: The expected maximum acceleration referred to average hard ground conditions is the parameter used by the Italian national reference seismic hazard model (Gruppo di Lavoro MPS, 2004); therefore, we use the same parameter. We will clarify the definition by modifying the sentence from "...with an expected maximum acceleration for an exceedance probability of 10%..." to "...with an expected maximum acceleration (referred to average hard ground conditions) for an exceedance probability of 10%...". Furthermore, we will add at p.3 - l.25, the following sentence: "Furthermore, it has been estimated from GPS velocity and strain rate field data (D'Agostino, 2014) that the extensional opening in the axial part of southern Apennines is about 3 mm/yr."

p.4 - l.10 regular azimuthal coverage and distribution as regular as possible. ... I believe the authors mean uniform azimuthal distribution - please clarify and rephrase.

REPLY: Thank you. We will substitute "with a regular azimuthal coverage and distribution as regular as possible" with "with as uniform as possible azimuthal distribution".

p.4 l.15 - 20 - the average distance between stations. I think the same point is repeated twice here, please correct this. Moreover, it is better to give the depth range on the second point where you first discuss the importance of depth and epicentral distance (l.13).

REPLY: The point at l.13 imposes the constraint on the minimum distance of the nearest station to the event whereas the point at l.15 is referred to the minimum distance among stations. Both the constraints are dependent from the event focal depth, so it is better to introduce them together. We will merge the two points (l.13 and l.15) and we clarify the sentence.

p.5 - l.1 remove Afterwards

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REPLY: Ok, thank you.

p.5 - l.3 ...as more constraints as possible... correct to ...as many constraints as possible

REPLY: Thank you. We accept your suggestion.

p.5 - Subsection 2.2 I think the first part of the first paragraph does not read very well in my opinion. Please replace by: Considering that the main target of the INSIEME network is to detect and locate the anthropogenic microseismicity in the HAV ( $MI \leq 2.7$ ), the seismic stations were equipped with triaxial weak-motion broadband sensors: six 0.05-100 Hz and two 0.0083-100 Hz Trillium Compact Posthole (TCPH) seismometers which provide a flat response to ground velocity up to 100 Hz. The data-loggers are Centaur Digital Recorders with a dynamic range of 140 dB. All seismometers and data-loggers are manufactured by Nanometrics Inc. (see Table 1). Continuous acquisition of digital waveforms is provided by the INSIEME network at 250 Hz sampling rate.

REPLY: Thank you very much for your effort. We will replace the sentence according to your comment.

p.5 - l.15 Even though the Nyquist frequency is well beyond the instrument's flat response high end I am wondering what is the phase response especially in the high frequencies from the instruments' sensitivity frequency to 125 Hz. What is the target frequency range in this study? There are a few broadband instruments currently in the IRIS data services showing strange phase responses even close to 1Hz. I believe a figure showing the amplitude and phase response of one station would be a good addition.

REPLY: We will add in the supplements a figure showing the amplitude and phase response of one station. Regarding the target frequency range, our goal is to provide recordings with a range as broad as possible. The high frequency bound allows us to estimate the corner frequency of small events (if we are able to correctly remove

the attenuation); the low frequency bound allows the seismologists to use the data also for other applications (e.g., evaluation of possible site amplification effects at low frequencies, ambient seismic noise tomography, recordings of teleseismic events, etc.).

p.5 - l.22 ...the Winter season (see Figure 2a), then the solar.. start new sentence: ...the winter season (see Figure 2a). The solar...

REPLY: Thank you. We will fix it.

p.5 - l.30 what is this system? please give a brief description.

REPLY: Ok, we will provide a brief description of the system.

p.6 -l.1 is highly deviated over 20 m depth - not very clear, please rephrase

REPLY: Ok, we will rephrase the sentence. We will write that the inclination of the borehole becomes greater than the maximum operational tilt of the sensor.

p.6 - l.3 ...seismometers model, which operates... change to: ...seismometers which operate...

REPLY: Thank you. We will fix it.

p.6 - l.15 remove Afterwards

REPLY: Ok, thank you.

p.6 -l.27 was only 70 m distance from the borehole sensor... change to: was only 70 m away from the borehole sensor...

REPLY: Thank you. We accept your suggestion.

p.6 - l. 28 ...and acquired simultaneously with station INS1 from 2016-10-12 to 2017-01-24 I think the authors mean that these stations were in operation during the same period of time - please rephrase

REPLY: Yes, you are right. We will rephrase the sentence.

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p.6 -I.30 please provide a numerical description of your calculations

REPLY: Ok, we will provide a numerical description of our calculation.

p.7 -I.4 see similar comment at p.6 - I.28

REPLY: Ok. We will rephrase the sentence.

p.7 - I. 5-6 teleseisms - please change to: teleseismic events

REPLY: The word “teleseism” is correct. Anyway, we will write “teleseismic event” along the whole text.

p.7 -I.21 Nanometric Centaur digital recorder... correct to: The Nanometrics Centaur digital recorder..

REPLY: Ok. Thank you.

p.7 - I.25 ..that prevent the internet connection - please rephrase

REPLY: We will substitute “problems that prevent the internet connection” with “problems causing the interruption of the internet connection”

p.7 -I.26 disconnects for few seconds.. for a few seconds

REPLY: Ok. Thank you.

p.8 - section 2.3 (last paragraph) use collect instead of gather Why some events cannot be located? please explain briefly

REPLY: We will substitute “gathered” with “collected”. Some small events can be only detected because we do not have enough P- and S-wave pickings for locating them. As an example, if we have an event recorded by only one or two stations the event is not locatable.

p. 9 I. 22 ..compared to each other

REPLY: We will fix it.

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p.9 l. 22-23 ..the noise level is more regular at 50 m depth - what does regular noise level mean? please rephrase

REPLY: Ok. We will rephrase the sentence. With “regular noise” we would like to explain that during time the noise does not change so much.

p.10 l.8 ..when both the stations - remove "the", remove "respective"

REPLY: We will fix it.

p.10 l.32-33 ..In that way, we guaranteed... please rephrase

REPLY: We will substitute the sentence “In that way, we guaranteed that the highest number of stations had recorded the selected data.” with “Indeed, the greater the earthquake is the greater is the number of recording stations.”

p.11 - l.1 why is date time seismic noise is being used? please explain

REPLY: We are not sure if we rightly understood this question. Do you mean "why did you specify the date of the seismic noise recordings"? If so, we decided to specify it in order to allow the reproducibility of the analyses. Otherwise, if you mean "day" instead of "date", we decided to show the results obtained by one of the ambient noise data streams that we selected for the analyses. Indeed, we carried out the analyses by using different noise data streams (night time data, day time data, very noisy day data, low noisy day data, etc.), obtaining consistent results. Attached Figure 1 shows an example of results related to INS1 station by using data characterized by low level of noise (left panel) and high level of noise (right panel). Black and red lines in Figure 1 indicate the results obtained using day time and night time noise data streams, respectively. The dashed lines identify the  $\pm$  one standard deviation.

p.11 eq. 2 should be HVSR =

REPLY: Yes, thank you.

p.11 - l.28 ..that the most.. remove "the"

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REPLY: Ok. We will remove “the”.

p.11 - l.32 did the authors calculate NS and EW HVSRs separately to investigate any directivity and azimuthal effects? If yes, were they found negligible?

REPLY: We thank you for this comment. Yes, we already separately computed the HVSR taking into account only the NS and the EW component. As an example, we show in attached Figure 2 the comparison between the retrieved HVSR curves obtained using the NS and EW component, respectively, of reservoir data recordings at INS5 seismic station. Indeed, INS5 site is the one characterized by an amplification at about 3 Hz, as shown in figure 8 of the manuscript. As shown in Figure 2, we do not observe any azimuthal or directivity effects. Actually, the retrieved HVSR curves are very similar. As shown in the manuscript, the results do not depend from the earthquake category selection (IIE, RIE and LE).

p.12 -l.11 competent rocks - Is there a better term to describe this?

REPLY: We will substitute “at that depth a sharp lithological change between less and more competent rocks.” with “at that depth a sharp lithological change from alluvial deposits to Gorgoglione Formation.”

p.12 - l.18 ..located in the 1-D velocity model by Improta et al. (2017) by adopting Hypo71.. change to ..using the 1-D velocity model by Improta et al. (2017) and Hypo71..

REPLY: Thank you. We accept your suggestion.

p.12 -l.20 To this purpose, and particularly to better locate.. change to In order to better locate local events outside the...

REPLY: Thank you for your suggestion. We will fix it.

p.12 - l.20 what is the distance between stations of the virtual network? Maybe a new figure showing the distribution of the "virtual network" and the INSIEME network

together could be shown at the supplementary material.

REPLY: Thank you for your idea. We will update the supplemental file “INSIEME-network.kmz” by adding the locations of all the public and private seismic stations that can be used for the “virtual network”. By clicking on each station one can interactively read additional details.

p.12 -l.33 ..related to an earthquake occurred on 2018-01-29.. I think the authors mean that this is an induced event. Maybe it would have been more appropriate not to use the term earthquake and simply refer to it as an induced seismic event, similar to the line above (l.32) ..from preliminary event location..

REPLY: We will fix it. Anyway, induced seismic events in the High Agri Valley are (micro)earthquakes.

p.13 -l.11 similar as in my previous comment (replace earthquake with event)

REPLY: We will fix it.

p.13 - paragraph 2. The authors discriminate the induced events from local earthquakes using the depth as their main criterion. Did the authors attempt to determine the focal mechanisms of any of these events, by means of first motion polarities and/or amplitude ratios for example? Is there a high signal-to-noise ratio on the INSIEME stations and the virtual seismic network recordings to do so? please add an example, if not please justify your answer.

REPLY: We provided a detailed answer to these questions in the first reply to your comments. We will add some examples of focal mechanisms in the supplementary material. Indeed, in some cases we have enough first motion polarities.

p.13 l-32 replace Dziewonsky with Dziewonski.

REPLY: Thank you for pointing out the typewriting error.

p.14 - l.5 ..we have decided to do not uninstall the network.. change to ..we have

decided not to uninstall the network..

REPLY: Thank you. We accept your suggestion.

p.14 - l.11 the begin of data.. change to ..the beginning of data..

REPLY: We will fix it.

p.14 - l.11 very attractive area.. attractive in which manner? maybe change to very interesting area

REPLY: You're right. We will fix it.

p.14 - l.15 ..consisting in.. change to consisting of..

REPLY: You're right. We will fix it.

p.14 -l.16 and two 120s-100Hz Trillium Compact Posthole sensors,

REPLY: We will fix it.

p.14 l.18-19 ..started to have troubles.. please rephrase (e.g. presented an intermittent fault)

REPLY: Ok. Thank you for your suggestion.

p.14 - l.24-25 ..with negligible site amplification..

REPLY: We will fix it.

Fig. 1 I am not sure if the last sentence in the caption is necessary, maybe move it to the Acknowledgements.

REPLY: This was required by the journal policy during the validation of the initial submission.

Fig.5 caption: Below each actual... I think the authors could rephrase the caption beyond that point. It is not very clear to me.

REPLY: The sentences “Below each actual PPSD there is visualized the data basis for the PPSD. The top row shows data fed into the PPSD: green patches represent available data, red patches (not in this case) represent eventual gaps in streams. The bottom row in blue shows the single PSD measurements that go into the histogram.” are taken from the PPSD webpage describing how to read the figure ([https://docs.obspy.org/tutorial/code\\_snippets/probabilistic\\_power\\_spectral\\_density.html](https://docs.obspy.org/tutorial/code_snippets/probabilistic_power_spectral_density.html)). Anyway, we will simplify such description in the revised manuscript.

Fig.8 caption: The solid coloured lines...

REPLY: We will fix the error.

Fig. 9 caption: replace earthquake with event Fig. 10 caption: ..from top to the bottom,

REPLY: Ok. We will fix it.

As a general rule when the authors refer to the number of objects (e.g., stations) which is less than ten, please write this as a word. If this number is higher than ten, you can write it as a number.

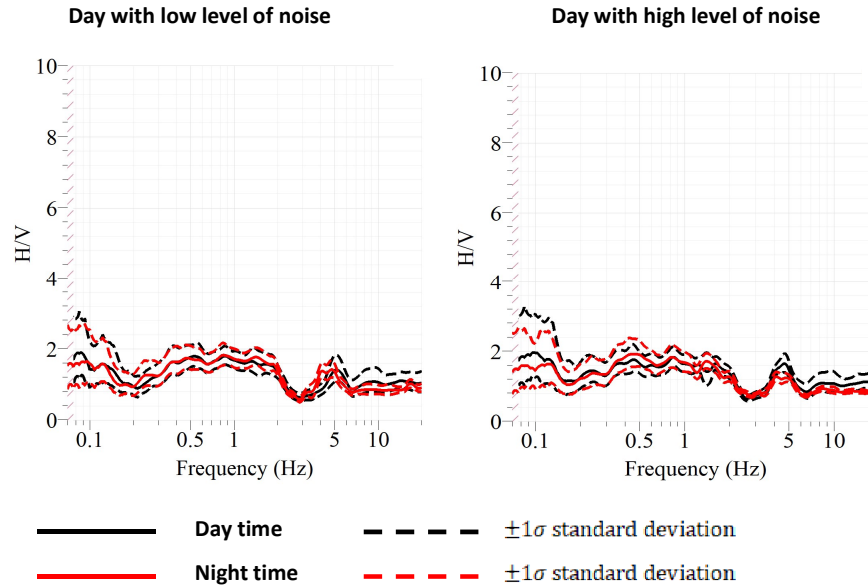
REPLY: Thank you for your suggestion. We will write along the whole manuscript the number as a word if it is less than ten.

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# INS1

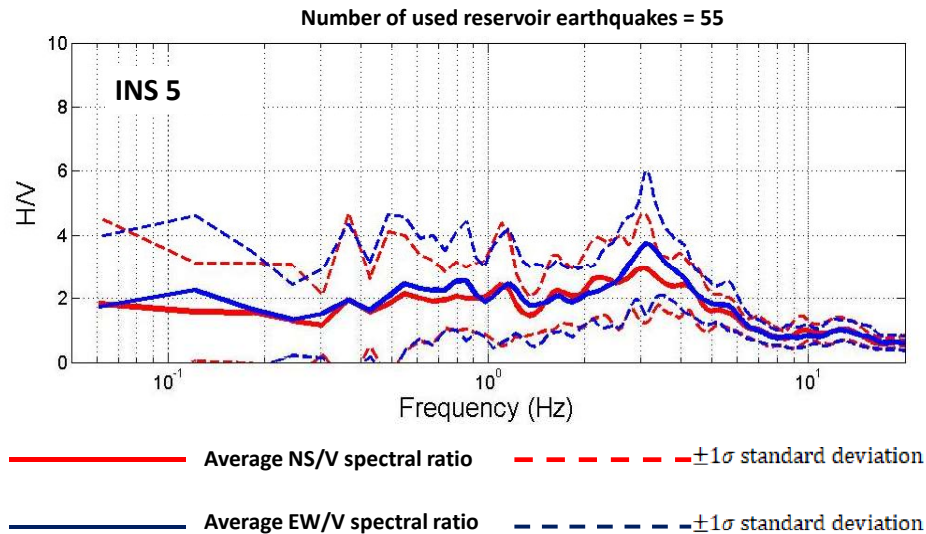


**Fig. 1.** HVNSR curves obtained for INS1 station by using data characterized by low level of noise (left panel) and high level of noise (right panel).

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**Fig. 2.** Average HVSR curves retrieved by analyzing the recordings at station INS5 of the reservoir induced events: red and blue lines indicate the HVSR obtained for the NS and the EW component, respectively.

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