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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Infrasound array criteria for automatic detection and front velocity estimation of snow avalanches: towards a real-time early-warning system" *by* E. Marchetti et al.

E. Marchetti et al.

emanuele.marchetti@unifi.it

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Reply to the interactive comment by an anonymous reviewer (nhessd-3-C1499-2015) on "infrasound array criteria for automatic detection and front velocity estimation of snow avalanches: towards a real-time early-warning system" by Marchetti et al.

Comment: This paper presents results of an experiment investigating the use of infrasound for automatic detection of avalanches and for estimating avalanche velocity. The results are mainly based on data measured in the Grosstal avalanche path, Austria dur-

ing one winter. The topic is highly relevant for avalanche risk management and fits to the scope of NHESS. However, the paper needs a major revision regarding the content, the structure and the language before publication. The experimental setup, the data and the applied method need to be explained clearer in order to attract readers interest, who are not very familiar with this topic. I also think that much more experiments and data are necessary to confirm statements made in the paper. Reply: The comments of the present reviewer partly overlap with the comments provided by Emma Surinach. In both cases we tried to address all the comments and this led to a reorganisation of the manuscript, which allowed us to: 1) provide a better description of the experimental setup and processing method; 2) present data better; 3) provide a better discussion on presented results. We agree with the reviewer that more data will be required, in order to validate and expand the method and this is the direction our research activity is going to. However, the presented results are extremely promising, and from the point of view of array processing, which is one our main aim of research activity, the presented procedure and results are extremely robust. We understand however that this aspect might not be so clear to readers who are not very familiar with this topic and for this reason we improved this topic. At the same time however, a detailed description of the procedure is beyond the scope of the manuscript.

Comment: 2.1 Abstract. In the first part the authors claim that their method overcomes existing limits of infrasound for detection of avalanches. Since results are based on data of only one winter at one site, authors should be careful. Furthermore, the authors write in the final sentence that their results indicate that infrasound is suited for a robust remote detection of avalanches. I suggest to reformulate the abstract in the sense that this paper is an additional contribution in this field. I recommend to replace the term avalanche forecasting by avalanche detection. Reply: The abstract was corrected following the comments of the reviewer. Considering the term "forecasting" it is now used in a different way following the comments of E. Surinach.

Comment: 2.2 Section 1 'Introduction'. In the first part of the introduction I would also

include recent work on radar e.g. by N. Vriend et al. Reply: This was done in the text and was suggested also by E. Surinach.

Comment: 2.3 Section 2 'The Grosstal avalanche'. The experimental setup and the method is described very roughly, especially for readers who are not fully familiar with radar and infrasound measurements. I recommend to add a sketch of the setup and a brief description of the method including the concept of back-azimuth and apparent velocity (see description on p. 2715, eq. 1). Reply: Following the comments of the reviewer a sketch of the set-up is included in figure 1 and linked to the explanation of the array processing procedure described in the text. Furthermore this has been presented in more detail. See the new Figure1 below.

Comment: It becomes not clear in the beginning of section 2 what your dataset is consisting of. It seems at this point that you have data only from one single avalanche (which is clarified later in the paper). I recommend to briefly describe the whole dataset and which data you used. Reply: Following the comment of the reviewer, this point is clarified in the text both in the introduction and at the beginning of section 3 (former section 2, being the manuscript reorganized according to the comments of E. Surinach).

Comment: Why not analyze data of all three events, which is done later in the paper? Reply: The 3 events are extracted automatically from the whole dataset applying threshold values derived from the Dec. 23rd , 2012 event. For this reason they need to be presented later in the text while section 3 focuses on the Dec. 23rd 2012 event.

Comment: From Fig. 1 (referred in section 2.2) it becomes not clear which avalanche paths could be measured (detected) by the device. Reply: An infrasound array is able to measure and detect infrasound over 360 degrees, so theoretically from any avalanche path around the array. Distance and topography then prevent detections from a given path or sector, but inferring the spatial sensitivity of an array requires specific analysis which is behind the scope of the present paper. This aspect has been

briefly clarified in the text.

Comment: In section 2.2 you describe results in detail; however, methods for signal processing need to be explained better. Reply: A detailed description of array processing procedure is behind the scope of the present paper and the paper Ulivieri et al., 2011 (CRST) which discuss the topic in great detail is referenced often in the text. Adding the sketch of the array and corresponding array information (back-azimuth, ray, wave-front) as requested by the reviewer in a previous comment, allowed also clarifying this topic.

Comment: In line 6 on p. 2716 you write ": : : are consistent with the Grosstal avalanche path". I can't see this in Fig. 3 and in the other figures presented up to this point. Line 13 to 19 might fit better in the discussion section than here. Reply: This section is quite hard to understand for people who are not famialiar with apparent velocity and array processing. We clarified the text to make understanding easier to the reader.

Comment: Section 3 is difficult to understand without a broader explanation of the method. For example, in line 23 on p. 2716 you mention the term "peak pressure" and in line 19 on p. 2717 "array analysis" which remains unclear. Reply: Again, the array processing procedure has been clarified in the text and benefits in the revised manuscript from a dedicated figure (Figure 1c). The term peak pressure means maximum pressure, and this was changed in the text.

Comment: In the section "Comparison : : :" on p. 2718 you provide some basic explanations on how infrasound data have to be analyzed and interpreted. Shouldn't this information be better provided at the beginning (maybe in a method section before section 2; this would also address my comments above)? Reply: The manuscript has been reorganised significantly, a much broader discussion of the processing procedure is presented in section 2, before data are presented. In the section 3.1 (Comparison of infrasound and radar observation. . ..) we present and discuss a processing which is di-

rectly related to the topic discussed here and is not directly related to array processing. For this reason we prefer to keep this discussion at this stage in the manuscript.

Comment: I suggest to rewrite the explanation of Fig. 6. I cannot see the good matching of the results as described. In my opinion you cannot draw the conclusion that velocity of an avalanche front can be derived from infrasound data based on the dataset and results presented here. May be you can move some sentences from this paragraph to the discussion section and comparing your results with those of other authors instead of simple citing it. Do you have explanations for the pulsing avalanche velocity derived from infrasound (see also Fig. 5)? Reply: We disagree with the reviewer on this point. In the text we clearly state that "infrasound derived velocity appears to match the general trend of radar measurement". We believe indeed that the figure 6 is a good example on how an estimate of the front velocity can be obtained with infrasound array observations. Even radar provide a velocity which is an integration of all reflecting surfaces in a given range gate and is thus not necessarily true. From our point of view, reaching a match in terms of order of magnitude is already a success, especially considering that this can be applied to multiple paths around the array while radar focus only on a single path. Concerning the pulses of velocity derived from infrasound (Fig. 5) these might depend from the topography (and the relation of position in the path and back-azimuth), from the azimuthal resolution of the array (<1° as stated in the text) and from the fact that infrasound array analysis allows identifying the back-azimuth and apparent velocity of the most energetic source, while different parts of the avalanche flow can radiate infrasound at the same time.

Comment: In the first paragraph you make the firm statement that velocity can be derived from infrasound data. Please consider above comments also in this context. Reply: The answer to the comment above holds here.

Comment: I think you cannot speak of a "robust automatic identification" based on the presented results (p. 2720, line 24). Reply: We are quite confident that using back-azimuth and apparent velocity is the best way to identify infrasound produced by a

moving source such an avalanche. This topic is discussed in detail in section 4. Based on these parameters we extract from the dataset of a whole winter season, only infrasonic signals which are likely to be radiated from sources moving downhill. Different sources, such as airplanes, explosions, microbaroms are excluded. Figures 9 and 10 are in our opinion a clear example of that. We believe that what is missing is the direct observation and validation in the field and in our knowledge this is a general problem in avalanche research. We believe however, that in its revised form the manuscript is much clearer, thanks to the comment of both reviewer, and this point is highlighted better.

Comment: For this section, I recommend you make clear for which area the results you are presenting are valid. You describe the back-azimuth range (1st paragraph on p. 2721), which seems to me very specific for a site. Reply: This aspect of array analysis and sensitivity is addressed in the revised manuscript (Section 2.2).

Comment: On page 2721 and Fig. 7 you show the whole dataset from December 2012 – March 2013 and the filter for the Grosstal events. I suggest to rethink the structure of the paper in the respect that you could also put this evaluation at the beginning and going from there to a specific analysis of the event on the 23rd December event. Reply: In our manuscript we define the thresholds for automatic event extraction based on the Dec 23rd, 2012, event and eventually extract the other events (one detected also by the radar). Changing the structure of the manuscript, as suggested by the reviewer, would prevent this approach. In our opinion it is necessary to start from a specific event and then preform the broader analysis.

Comment: I also recommend to highlight the three described events in Fig. 7. Reply: Figure 7 is probably not the best figure to highlight the events, because infrasonic pressure produced by the snow avalanches is very small compared to other sources, such as explosions. We could highlight the three events in Fig. 9.

Comment: Why don't you analyze the events on 10, 11 and 28 December in details

and compare results with the event on 23rd December? Reply: The comparison of the three events is expanded in the revised version of the manuscript, following the comment of both reviewers.

Comment: In the last paragraph on p. 2723 you mention 'Hoherzug avalanche'. Please indicate this location (see also comments above on description of investigation site). Reply: The name Hoherzug was removed from the text. We detect signals with back-azimuth being consistent both with avalanched on the northern and southern flack.

Comment: 2.6 Discussions and conclusions. In this section I miss a critical in-depth discussion of your results with other results presented in cited papers. What is your novel contribution? As mentioned above, I'm very doubtful that your results can be generalized in the way you describe. You also mention this by writing ". . . a systematic field validation should be still required (I would say: . . . is still required). May be you can also compare with those of other density (dense) currents, as mentioned on line 27 on p. 2723. Your argumentation in this respect is not very consistent throughout the paper. Sometimes you make firm statements, sometimes you're more vague. You can greatly improve the value of your paper if you would present more data and compare them with existing results (as far as available). Reply: We are aware that more data would improve our study and this is the direction our research activity is going to. However, results achieved already are extremely satisfactory and publication would be of benefit for infrasound avalanche investigation in general. In the revised version of the manuscript, a comparison with other works on automatic avalanche infrasound detection is presented, also following the comments of E. Surinach.

Comment: âĂć p. 2710, line 23: : : : with the forecast models : : : > : : : with forecast models : : : Reply: corrected.

Comment: âĂć p. 2711, line 4: : : :measurements of snow avalanches (or of a snow avalanche) Reply: corrected.

Comment: âĂć p. 2711, line 15: Do these observations all refer to Bedard et al.?

Otherwise please provide a reference. Reply: Here Bedard is referenced as being among the first authors dealing with infrasound. A full reference list is provided few lines below.

Comment: âĂć p. 2711, line 21: : : : along a single avalanche path : : : Reply: corrected.

Comment: âĂć p. 2712, line 23: : : : Snow avalanches are typically : : : Reply: corrected.

Comment: âĂć p. 2715, line 24: please check the sentence. The last paragraph on p. 2715 is unclear. Please rewrite it. Reply: rephrased.

Comment: âĂć p. 2717, line 20: : : : multiple sources is recorded : : : > : : : multiple sources are recorded : : : Reply: corrected.

Comment: âĂć p. 2717, line 23: valley bottom Reply: corrected.

Comment: âĂć p. 2718, line 9: : : : front velocity of a snow avalanche or : : : of snow avalanches Reply: corrected.

Comment: âĂć p. 2719, line 19: one or several Grosstal avalanches ? Therefore, velocity or velocities? (same line) Reply: corrected.

Comment: âĂć p. 2719, line 20-21: Infrasound signal? derived from front velocity : : : Reply: corrected.

Comment: âĂć p. 2720, line 26: I assume you do not mean only Grosstal avalanche with 'Ischgl'? If yes, please specify the investigated area. Add also years, i.e. December 2012 - March 2013 : : : Reply: corrected.

Comment: âĂć p. 2722, line 21: is it really 240 - 20 _N? Reply: Yes. Several signal start to be detected with a back-azimuth < 360° and back-azimuth migrates as the front moves downhill to values >360°N (>0°N).

Comment: âĂć p. 2723, line 2: consistent > consistence Reply: corrected.

Comment: âĂć Fig. 1: Other areas which are considered in the paper ('Hoherzug avalanche') should be indicated here. Reply: The name Hoherzug was removed from the text to avoid confusion.

Comment: âĂć Fig. 2: Fig. (b) could be rotated so that it matches Fig. (c); avoid double words, may be you like to replace the second identifies with 'denotes'? Reply: text was corrected. Rotation of Fig 2B is not so easy, being the figure a raster..

Comment: âĂć Fig. 3: Did you record one or several avalanches in 23rd December 2012? (snow avalanches in plural). Reply: Figure 3 shows one single avalanche. The figure caption was corrected.

Comment: âĂć Fig. 6: I cannot detect the grey bars (except the one with 'no radar data'). Reply: corrected.

Comment: âĂć Fig. 7: I suggest to indicate the events on 10th, 11th and 23rd December mentioned in the text. Reply: As discussed already above, including events in this graph is not helpful, being the excess pressure of the events extremely small compared to other signals shown in the whole detection plot.

Comment: âĂć Fig. 8: Wouldn't it be helpful to integrate derived avalanche velocity in all three graphs (below apparent velocity) ? Reply: It is possible to integrate the derived avalanche velocity. It our opinion it in however not improving the figure which describes infrasound wave parameters.

Comment: âĂć Fig. 9: I would mention from where you got the number of events during the winter season 2012-2013 (Fig. c). Reply: Unfortunately no systematic field observation of events is available in the area. The number of events is directly derived from infrasound detections (according to threshold based mostly on infrasound wave-parameters).

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 3, 2709, 2015.

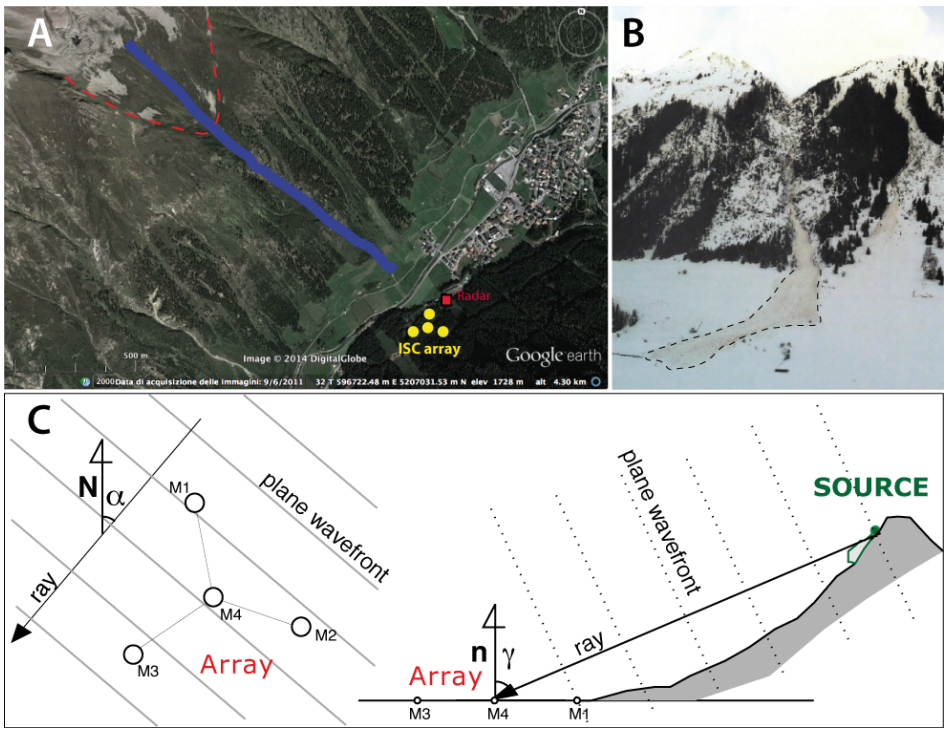
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Fig. 1.