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Interactive comment on "Brief communication: Remotely piloted aircraft systems for rapid emergency response: road exposure to rockfall in Villanova di Accumoli (Central Italy)" *by* Michele Santangelo et al.

Michele Santangelo et al.

michele.santangelo@irpi.cnr.it

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This document contains a point-to-point answer to the comments of reviewer #2. Reviewer comments (RC) are reported. Responses (AR) follow each RC. Quotations from the manuscript are between inverted commas.

ANSWERS TO REVIEWER 2

RC: This work describes how Remotely Piloted Aircraft Systems can be used for the analysis of rockfall hazard, mainly through the reconstruction of a DTM to use for rockfall propagation analysis. The technical details about data acquisition and processing to get the DTM are described as well as the propagation analysis using the program STONE, and the use of the results for assessing the exposure of the roadway to potential rockfalls. The case study presents interest as far as the processing of the RPAS to get the DTM. Propagation analysis using an already developed software in itself is more trivial, however the weight here is mostly given to the interpretation of the results for the design of protection measures and hazard assessment for the specific case-study.

AR: We would like to thank the reviewer for this positive comment. We think that the description of the use of RPAS can be a good example for the use of these systems in rockfall related emergency conditions.

RC: In my opinion, there are some issues which require further clarification and/or refinement. I see the following major issues. In the way that the topic is introduced, even from the title, there is a strong focus on the use of RPAS for the emergency response, which is thought to last some hours or few days after an event. However, it not clear how this work provides additional information for improving the emergency management, compared to common pre-disaster or post- disaster exposure assessment. In practical terms, for such an event, 15 days of road closure needed for the analysis is substantial time, especially if no alternative roads exist.

AR: As stated in a comment response, "Working day of one person" is a unit of measure to indicate the overall working load. As evident by the number of authors of this paper, the work was carried out by a multi-disciplinary team. The overall time to carry out the procedure did not exceed 4 working days. We acknowledge that this number is interesting for a reader, and thank the reviewer for pointing out that this is a missing piece of information. Therefore, the text was slightly modified to include this information. At page 10, line29-30 of the annotated pdf a sentence has been rephrased and now reads: "The entire procedure was carried out in 4 working days (estimated in about 15 working days of one person)". The same concept has been repeated in the conclusions, which read: “The complete photogrammetry-based procedure described in the paper was carried out in four working days by a multidisciplinary team, which correspond to a total of 15 working days of one person at an overall cost of 23,000 euros.”

RC: There is no mention about the rockfall magnitude and its effect on the run out analysis. If validation of the terrain parameters was made just for the co-seismic rockfall volumes, it is not clear how the road can be affected by larger post-seismic events.

AR: If by “rockfall magnitude” the reviewer refers to the overall volume of the detached mass, it has been mentioned and estimated. On the effect of the magnitude on the runout analyses, as stated in a reply in the annotated pdf, the reviewer is right, the volume and magnitude are crucial for the evaluation of rockfall risk. In such cases, however, detailed structural information is needed, which was not possible to obtain in this case, due to emergency response time restrictions. Furthermore, detailed structural survey are not possible (too risky) during a seismic sequence. Furthermore, STONE does not take into account rockfall volumes, but is based on a lumped mass assumption. Anyway, as stated at page 5 line 24, we estimate the overall potential unstable rock mass in the range 30-50 cubic meters. About calibration, we carried out a tuning of the parameters based on the literature, on field and remote sensing observations, and on our experience in order to obtain the most reasonable results, which of course did consist in reproducing at least the location of the boulders that reached the road. Unfortunately, in the field, it was not possible to ascertain the actual maximum extent of past historical events, because the slope downhill of the road was used to deposit quarry waste material. As evident from figure 3A, the trajectories simulated by STONE get much farther than the farthest boulders found in the field. Finally, regarding possible larger events, it can be considered that STONE took them into account (i) by assigning initial velocity values that exceed up to one order of magnitude the peak ground velocity measured during the entire six-months seismic sequence (ii) by simulating trajectories from 1,938 source cells, which could produce rockfalls of volumes far larger than the rock mass considered as unstable in the field.

RC: A process is presented in order to improve a DTM in the vegetated areas, where elevation points are missing, which is based on the integration of GNSS-RTK data points. Still the density of those points is not sufficient to provide a good DTM, as seen in Figure 2. The smoothening still seems unrealistic. Some further analysis is required to provide the order of magnitude of the errors of the DTM, and in what extent it can affect the trajectories and the rockfall run-out results, so as to justify its use for risk management.

AR: The reviewer is right, the number of points is quite exiguous compared to a desired target resolution of 1 point per square meter, or comparable, which would be similar to what obtained outside the vegetated areas. In a comment in the annotated pdf, the reviewer suggests to carry out a sensitivity analysis, which was done and implemented in the model to account for the topographic uncertainty and evaluate the effects on the modelled trajectories. Figure 3 was modified to present and explain the analysis performed, and text also was added in sections 3.4 and 4 to properly comment and explain what has been done. Finally, we want to stress that, unfortunately, due to the limitations of acting during a severe seismic sequence, of using a GNSS equipment under the trees in a remote area it was impossible to collect more data points and in a more accurate way without exposing people to severe risk. The added text (end of §3.4) reads: “We have prepared 100 different DTMs modifying the elevation values of the 73 GNSS RTK points by adding delta values to the original elevation data. Delta values were obtained randomly sampling from a Gaussian distribution that reproduces the error values declared by the instrumentation (μ=0, σ=0.25). Each set of modified elevation points was interpolated following the approach described before. The set of 100 DTMs was used to evaluate the spatial distribution of rockfall trajectories considering the topographic uncertainty.” and (§4, before the mark [Figure 3]): “Finally, at the pixel scale, we computed the coefficient of variation (CV=σ/μ) of the number of trajectories computed in the 100 simulations. CV is a measure of the variability of a sample normalized by the average value of the distribution. The distribution of the CV values shows a standard deviation of 0.17 and a mean of 0.20, which indicates that the model can be considered stable despite the errors introduced by the GNSS RTK topographic measurements."

RC: Run-out model results require further validation. As commented in the text, most deposited blocks in Figure 3B seem to be on cells where just 1 trajectory was found out of the more than hundred total trajectories. There has to be some further justification on the credibility of the results, so as to be able to support post disaster decision taking.

AR: The reviewer is right. We maintain that the work to take into account the topographic uncertainty has also contributed to make the model more robust. Runout results are now based on 100 different simulations where the DEM was each time (slightly) different in the vegetated area. Figure 3 shows that the boulders do not stop in areas predicted as 1 by the model, but in areas predicted in the (modal) range of 5 to 10 trajectories. Field and geomorphological observation confirm that the most affected area is the portion of the slope uphill the slope break closest to the source areas, which corresponds to the wooded area for S1 and an area downhill the road for S2.

RC: Figures 1 and 3 could be larger, and sometime legends are not illegible.

AR: The reviewer is right. Figures were amended to improve readability.

Attached is an annotated pdf where the comments of the two reviewers were merged and responded point-to-point. Reviewer comments are color coded.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-177/nhess-2018-177-AC2-supplement.pdf

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