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Interactive comment on "Single-block rockfall dynamics inferred from seismic signal analysis" *by* Clément Hibert et al.

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(We invite the readers to look at the version of this response uploaded as supplement for a better readability)

Response to Referee 1 (Major Points) :

Dear Maxime Farin,

We are very grateful for the reviews and comments you provided on our paper entitled "Single-block rockfall dynamics inferred from seismic signal analysis." We provided below answers to each of the major points raised. Several comments are repeated in the review. We responded to these repeated comments the first time they appear in the review and then refer to these answers when needed. The comments on specific

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lines will be address in our final response. The answer to a comment is given after repeating the comment.

The authors.

Review by M. Farin

General comments :

MF: The paper is globally clear to read and the successive sections follow naturally each others. I ïňĄnd personally that it is interesting to have new data of seismic signals generated by block impacts and be able to evaluate the dynamics of the block in parallel in order to better understand the link between the two on the ïňĄeld. The authors took care to evaluate the dynamics of the block with a good precision, with an uncertainty less than 1 m sˆ-1 for block speeds varying from 6 m sˆ-1 to 17 m sˆ-1. When we compare seismic parameters to dynamic parameters, it is important to evaluate the absolute seismic parameters at the source because they strongly depend on the distance between the source and the instrument and on the frequency. Care has also been taken in evaluating absolute seismic parameters in this paper. Therefore I think the presented data are of good quality. However, I think that the paper needs a major revision before being considered for publication because it contains major confusions and misinterpretations of the data. My main concern in is the fact that the authors say several times in the paper that they show a scaling (or proportionality) between the seismic amplitude and the momentum of the block while they are showing a linear relationship. There is a important confusion here because a scaling (or proportionality) is a relation Y = a X while a linear relationship (as showed in this paper) is Y = aX+b, with b a nonzero constant. This has a different implication for the interpretation of the data. The paper should be rewritten with this point in mind. This confusion is particularly problematic when the authors are comparing the parameter mVzˆ(13/5) derived by Farin et al. (2015) to the radiated seismic energy Es. They are testing a law Es = a mVzˆ(13/5) + b and claim that the ïňĄt of this law with their data is better than it was in the paper of Farin et al. (2015). However, the analytical scaling law established in Farin et al. (2015) and tested with their rockfall experiments was Es = a mVzˆ(13/5) (with b=0): this is a different law. In the present paper, the parameter b is not 0 and it is several orders of magnitude larger than the parameter a. The ïňĄt Es = a mVzˆ(13/5) (with b=0) should be tested instead. Moreover, since the parameter b does not exist in the analytical model, I do not know if this parameter has a physical meaning, even though it has the dimension of an energy. Also, an analytical expression of the proportionality coefïňĄcient a is given in Farin et al. (2015). The exact law and empirical law (with the exact and empirical value of a) could be compared to the seismic energy Es.

AC: Our first intention was to process the data for single rockfalls and seek for the best relationships as it was done in other studies on large landslides or rockfalls (e.g. Deparis et al., 2008, Hibert et al., 2017). In those studies, the best correlations were found using linear relationships, which naturally led us to use the same approach for this study. We agree, in the light of the comments made by the referees and the editor, that proportionality laws have to be tested too, and the confusion between linear and proportional relationships lifted.

To address this comment we computed proportional laws for each pair of quantities chosen. We modified table 2 to show these results. The new Table 2 is reproduced below. For the sake of clarity, we also decided to remove the coefficients computed in the logarithm space, as we discuss and use only the relationships computed in the linear space in the rest of the paper. We will also modify figure 4 to show the data in the linear space, and add the regression lines associated with proportional relationships. Table 1 : New table 2 – Coefficients of the regression lines for proportional and linear relationships.

As shown by this new table, the regression of our data by proportional laws yields slightly worst fits (lower R2 values), but with α coefficients very close to the one returned by linear regression. The coefficients β in the linear regressions are close to zero (even if order of magnitude larger than coefficients α). This might explain why the coefficient α and R2 returned by the proportional relationships are very close to the one observed for the linear ones. The slightly better fit achieved by linear regressions might come from the accommodation of the uncertainties on the values of the tested parameters, which are inherent to the processing of real data.

The paper will be modified by taking into account these new results, however this will not impact the main conclusions of our work, which are: (i) Linear/proportional relationships exist between the maximum amplitude and the momentum, and between the seismic, the kinetic and the potential energies, and (ii) we can retrieve rockfalls properties directly from the seismic signals generated at impacts.

MF: - An interesting question when we study the seismic signal generated by rockfall is to establish their energy budget, i.e. determine the amount of kinetic energy or potential energy lost that is radiated in the form of elastic waves. In other words, I think the authors should compute the value of the ratios Es/Ek and Es/Ep (or maybe also Es/(Ek+Ep)). These ratios should be less than 1 and the rest of the kinetic and/or potential energy lost is dissipated in plastic deformation (irreversible deformation) of the ground or in viscoelastic processes (heat). These ratios can then be compared with that computed for larger rockfalls in the crater of the Piton de la Fournaise, La Reunion Island (Hibert et al. 2012) or with that obtained in other studies (e.g. Deparis et al. 2008). Thus we could see if the energy budget for one single impactor is different than for a rockfall constituted of several blocks. These ratios are proportionality relations between seismic and dynamic parameters.

AC: Those ratios are directly given by the relationships we found (see table above). We will add a comment in the discussion on these values, which are slightly lower than the one computed at Piton de la Fournaise or Soufrière Hills volcano (10-6 vs. 10-5 – 10-3). We suspect that the nature of the substrate (black-marls, i.e. soft sediments) can be the cause of these lower ratios.

MF: - In a nutshell, I think that proportionality relationships Y=aX between seismic and dynamic parameters would have much more interesting implications for interpretations of the seismic signals generated by rockfalls than linear relationships Y=aX+b. Besides, no confusion should be made between the two kinds of relationship. A linear relationship may better ïňĄt the data of this paper than a proportionality law X = a Y but in this case, both ïňĄts (X = aY+b and X = aY) should be shown and a physical interpretation of parameter b should be given.

AC: see comment above.

MF: - An other problem I see is when the authors want to retrieve the mass and the speed of the blocks from the seismic signal. Two seismic variables are used: the absolute seismic amplitude and the radiated seismic energy. However, I do not think these two variables are independent of each others. I would not be surprised if the radiated seismic energy is proportional to the squared absolute amplitude. In this case, the mass and the speed could be expressed as functions of the radiated seismic energy alone. The problem is that I don't think it is possible to retrieve two independent dynamic parameters from only one seismic variable.

AC: We do not correlate the absolute seismic amplitude to the momentum but to the maximum of the amplitude envelope. This is an important distinction as the peak amplitude might not be correlated to the seismic energy (integral of the envelope). For example, a long –duration seismic signal with no clear peak amplitude might have the same seismic energy as an impulsive, high–amplitude, short–duration seismic signal. As shown by the figure below with our data, these quantities are not dependant in our case.

MF: An advantage of the present study compared with the previous ones (e.g. Farin et al. (2015)) is that the authors have access to higher frequencies up to 500 Hz, with respect to 50 Hz before. Therefore, they potentially have access to all the frequencies emitted during the impacts, contrary to the previous study. Thus an interesting seismic parameter to evaluate would be the mean frequency of the seismic signal.

the analytical model of impact of Hertz shows that the mean frequency is inversely proportional to the mass m of the block. It would be interesting to test this scaling. The mean frequency of the signal is independent of the radiated seismic energy so if empirical scaling laws are established between these two parameters and the mass and the speed of the block, the laws can be inverted to retrieve the masses and the speeds. Farin et al. (2015) established two analytical scaling laws relating the mass and the speed of the block to the radiated seismic energy and the mean frequency of the signal, i.e. equations (29) and (30) of their paper. I would be curious to see if these equations can provide reasonable values of the masses m and the speeds Vz of the blocks with the present experiments.

AC: Regarding an approach based on the frequency content, there are two limitations. The first one is that the seismometer located down-slope has a Nyquist frequency of 50 Hz. Hence, we had to restrict our study to the 1-50 Hz frequency band, as most of the times we need this station to compute the attenuation parameters and thus the amplitude and the energy at the source. Second, because we are lacking a good propagation model, we cannot reconstruct the Green's function of the medium between the location of each impact and the stations. Without these Green's functions, it is impossible to extract the frequency content of the source. This prevents any analysis of the frequency content of the seismic signal of each impact, as we cannot decipherer source effect from propagation effect. As clearly shown by Figure 2b, the major control on the frequency content of seismic signal recorded at each impact is related to its distance to the station. Therefore it makes no sense to compute the average frequency, as it is predominantly controlled by the medium and not the source.

This underlies that an implementation of a frequency-based approach for the quantification of rockfall properties from the seismic signal they generate would be difficult in an operational context. The new approach we propose in this study does not require a thorough characterization of the medium, and we show that we can determine rockfalls properties simply from the seismic signal temporal features. We will add a paragraph in the discussion about this point.

MF: - Maybe the absolute seismic amplitude and the radiated seismic energy are independent of each others. In that case it should be shown somewhere. Besides, if the mean frequency of the signal is not inversely proportional to the mass of the block, it would be interesting to show it. That would mean that Hertz's model does not apply on the ïňAeld.

AC: see comment above

Please also note the supplement to this comment:
http://www.earth-surf-dynam-discuss.net/esurf-2016-64/esurf-2016-64-AC1-supplement.pdf

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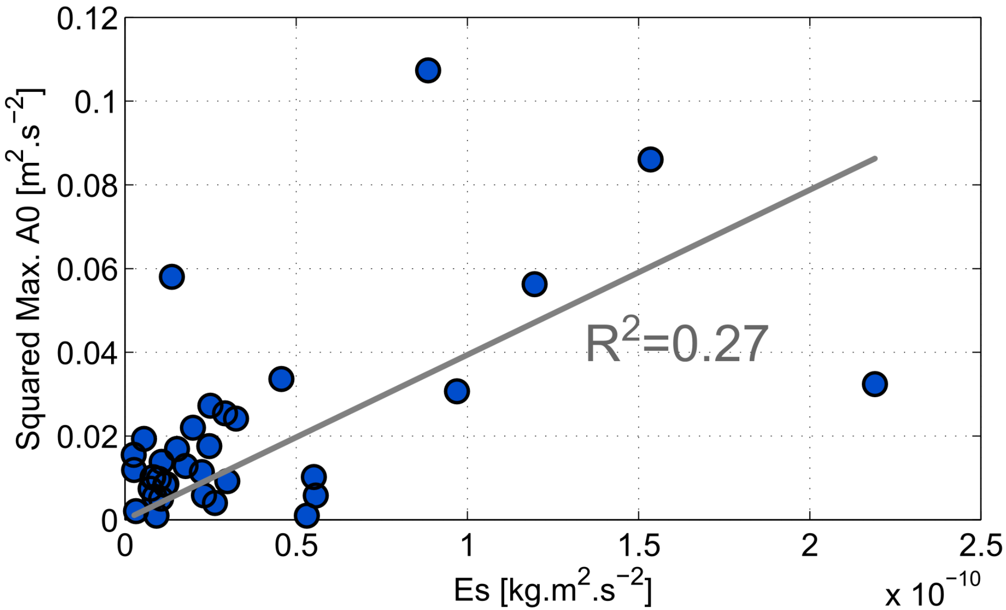

Fig. 1. Squared maximum amplitude A0 as a function of the energy of the seismic signal generated at each impact

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	Proportional			linear		
Parameters (X, Y)	α	β	R^2	α	β	R^2
$A0_{max} = \alpha p + \beta$	$2.35\,10^{-9}$	0	0.63	$2.26\,10^{-9}$	$2.50\,10^{-7}$	0.64
$E_s = \alpha E_p + \beta$	$-4.40\,10^{-6}$	0	0.61	$-5.04\,10^{-6}$	-0.01	0.61
$E_s = \alpha E_k + \beta$	$2.59\,10^{-6}$	0	0.59	$3.09\,10^{-6}$	-0.01	0.64
$E_s = \alpha m + \beta$	$1.48\,10^{-4}$	0	0.23	$2.85\,10^{-4}$	-0.03	0.31
$E_s = \alpha m V_z^{13/5} + \beta$	$4.86\,10^{-7}$	0	0.62	$5.85\,10^{-7}$	-0.01	0.63
$E_s = \alpha m V_z^{0.5} + \beta$	$5.24\,10^{-5}$	0	0.33	$1.07\,10^{-4}$	-0.04	0.47

Fig. 2. New table 2 – Coefficients of the regression lines for proportional and linear relationships.

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