Reviewer 2

We thank the reviewer for the very careful revision of our paper and the helpful suggestions. In the following, we respond to the author's comments (blue) and explain changes and adaption we propose for the final article. All comments not specifically addressed in the following list will be adapted in the manuscript as suggested.

Title

The actual title of the paper without the term 'occurrence' (see specific comments on terminological approximations) could be used to describe the work done in the paper. However it could be better to highlight the work done on the development of statistical models (meta models) which can predict the protective efficiency of forests against rockfall hazard. The latter result is the innovation in the paper.

We agree that the term "occurrence" can be deleted in the title. The corresponding terms are introduced and explained later in the text. However, we decided not to name the statistical models in the title, although we agree that the "meta models" are a main innovation of the paper.

General comments

Responses to the general comments can be found in the respective specific comments.

Specific comments 1

1. The phrase "occurrence frequency" is not adequate. The author can use frequency instead. In addition to this remark, it would be appreciated to use a consistent terminology related with the frequency of blocks passing through an evaluation line: either frequency or return period.

We use the "occurrence frequency" as description of the frequency that a certain point is reached in dependence of the rock release and its propagation. It is thus defined as the product of the "onset frequency" and the "propagation probability". We tried to clarify that in the text.

Regarding the presentation of the results, we agree that a mixing between the presentation of frequencies and return periods may be confusing. For this reason, we only present yearly frequencies in the results and the graphs.

3. P2, L12: "the propagation probability and thus the occurrence frequency" could be modified in reaching probability.

See comment to 3.1.1.

4. P2, L25, L28 "... the annual exceedance frequency ..." this sentence has to be improved.

We tried to formulate the sentence and the whole paragraph more clearly.

5. P4, L18: What is a 3D vector? RockyFor3D simulate rockfall propagation using a 3D raster map.

This is a slightly unclear formulation. Therefore, we rewrote the sentence.

6. P4, L20,L24: "The elasticity of the surface material". Elasticity cannot be used to describe the response of the surface during a block impact. If a soil is elastic no energy dissipation occurred during the impact. It would be preferable to use "the response of the surface material" instead. P10, L28 "Soil elasticity" should be replaced. For example : capacity of the soil to dissipate energy.

Thank you for this suggestion which we implemented in the text.

7. P5, L30: "aisles" could be replaced by corridors.

After doing additional research, we replaced the term “aisles” by “clearcut strips”, which is apparently the most adapted forestry term.

Specific comments 2

References were added where deemed necessary.

Specific comments 3

1. P4: The first paragraph of the material and methods section is not an introduction. It may be placed in a subsection or restructure according to my last comment.

We placed the first paragraph of section 2 in a separate subsection.

2. P4: The presentation of RockyFor3D can be improved by adding a description of the input raster maps associated to the tree generation. An highlight on the output used for the creation of the statistical models would be appreciated.

A short description of the tree input data is already present. The output used for the statistical models is described in section 2.5.

4. P5, L8: The value chosen for the parameter needs to be added.

We added the value for β.

5. P5, L10-13: Why didn’t you take an interval of block volumes ranging between 0.05 and 5 $m3$. The justification of the interval: 0.05 and 2 $m3$, could be improved. In Stockes 2006, forests are presented as having a protection function for block volume until $5\ m3$ (Berger et al. 2002; Stoffel et al. 2005).

We decided to simulate only block volumes between 0.05 and 2 m^3 because certain references mention a volume of 2 m^3 as limiting volume for the protective function of forests (reference changed in the article in order to avoid confusion). Blocks with volumes between 0.05 and 2 m^3 are most risk relevant as they exhibit high occurrence frequencies.

6. P5, L31: According the element given in the paper, 68 simulation scenarios are identified (2 soiltype * 2 rugosity * 4 forests * 4 horizontal structure + 2 soiltype *

2 rugosity * 1 noForest). The author reach only 49 scenarios.
Did you define 49 scenarios or 68? It would be appreciated, in both cases, to present them clearly in your paper.

Correct is a total of 48 scenarios: 4 forest types, 4 forest structures and 3 terrain scenarios (rough + soiltype 3, rough + soiltype 4, zero roughness + soiltype 3 > zero roughness was not combined with soiltype 4). We tried to better explain them in the text.

7. P5, 32: Can you give us details about the number of blocks considered for each interval, in particular the interval [1.9-2] $m3$. Could you create a table to indicate the number of blocks for each interval? This point is particularly important to evaluate the robustness of your statistical analysis.

Due to your justified questioning of the statistical robustness of the simulation results for larger volumes, we decided to run new simulations with a higher and more robust number of blocks. We simulated the whole release area (7500 cells) with 50 simulations per block for all block volumes. Based on these simulations, we calculated the propagation probabilities of the blocks (described in section 2.2.) and multiplied them with the onset frequency in order to obtain the occurrence frequencies. We further evaluated the 95-percentile of the maximum energies of all blocks passing an evaluation line (not as the mean of the 95-percentile of all cells).

8. P6 L15-20: It would be preferable to choose either the passing frequency of the block through a line or the return period for all the analysis.

See response “Specific comments 1, 1.”

9. P6, L29: A precise description of the method used to calculate the indicator E95red is required to evaluate the robustness of the method. Calculating E95 using the average of E95 values along an evaluation line (these values being averaged over a hundred simulations) cannot be used as a relevant statistical indicator. In addition using the percentile 0.95 of a distribution is only valid for a high number of blocks passing through a line.
How many blocks are used to calculate E95 for the different evaluation lines (especially for large block volumes)?

See response “Specific comments 3, 7.”

10. P7, L5-13: In this section a complete description of the two main statistical analyses is required. The statistical model are the main results of this work. Thus, a description of the hypothesis associated to each one is requested.
In addition, for the regression tree models, (P7, L10-11) either you have to explain all the method to select the splitting variable and the impurity reduction or you have to remove those two sentences from the article.

11. P7, L23: The presentation of the GLM method is to short, additional information on the method is requested.

We agree that the statistical models are the main results of the study and a special focus should be placed on them. However, since the two applied multivariate models are well-established and well-described in literature, we describe them briefly, however with sufficient literature references for more detail.

Specific comments 4

1. Results of the Wilcoxon rank sum test (methodology section P7 L5) have to be added to the results section.

P-values of the Wilcoxon rank sum test are reported in brackets for the respective variables. In order to keep the result section short and concise, we do not report exact p-values and parameters of the Wilcoxon rank sum tests.

2. Results of the Spearman correlations coefficient (methodology section P7 L5) have to be added to the results section.

The Spearman correlation coefficients were calculated in order to exclude strongly correlated explanatory variables in the multivariate statistical models. This was not clearly described in the article and thus adapted. In order to keep the result section focused, we do not report them in detail.

3. P8, L16: In the legend of Fig 4 and 5, the volumes of the blocks ranging between 0.01 to 2 $m3$ are indicated. A different range is presented in the material and methods section (block volumes ranging between 0.05 to 2 $m3$).

Thank you for this indication. Volumes ranging from 0.05 to 2.0 m^3 were simulated.

4. P8, L19-L25: The results presented in Fig 6 and Fig 7 should be improved. The data on which each curve are fitted could be placed in the background of each figure. In addition, the smoothing techniques used to create the curves (Fig 6 and Fig 7) should be detailed in the material and methods section.

We decided to plot only the fitted curves in order to highlight and summarize the main tendency of the data in a striking way. However, we understand your point and we will re-examine several alternatives for plotting the underlying data.

5. P8, L31: A simplification of the results presented in table 3 could be done to improve its understanding. In addition, each term used in the table has to be defined in the material and methods section. For example: (Intercept), Vol, GLMFreq, GLMInt... In table 4 RTFreq and RTE95 are not defined in the material and methods section.

You are right that certain abbreviations are not introduced in the material and methods and the table caption, respectively. We corrected this. The presented parameters of the GLM (e.g. Z-value), however, correspond to the standard representation of the results of a GLM and thus, we omit to explain them in more detail.

6. P8, L21: Where are the results illustrating the influence of the forest structure? The only results presented are simulation scenarios with random or no forest (Fig4 and Fig5).

We decided to show results of two different forest types and no forest in fig. 4 and 5 as we do not want to overload the figure. The influence of the forest structure is reported in the text and can be seen in fig. 9 (intensity-frequency curves) as well as the statistical models.

7. P9, L1: Why, for the level 8 of the RTFreq model (Fig 8), a volume < 1.1 $m3$ has a smaller Nrpred value than a volume > 1.1 $m3$, and why, for the level 11 of the RTFreq model (Fig 8), a volume < 1.2 $m3$ has a higher Nrpred value than a volume < 1.2 $m3$? Could you explain the difference?

There was a mistake in the initial graph at level 8: There is a smaller Nrp_{red} value for volume > 1.1 m^3 than for volumes < 1.1 m^3. Level 11, however, is correct: Nrp_{red} is smaller for volumes > 1.2 m^3 than for volumes < 1.2 m^3. In case of volumes > 1.2 m3, Nrp_{red} is smaller for confiers (conif 100%) than deciduous forests (conif 10%).

9. P9, L30: Which data were used to build the Fig 9?

Description of figure will be corrected according to “Specific comments 3, 5.”

Specific comments 5

4. P10, L22-32: This paragraph is currently a description of your results. A comparison between your results and other one from the literature would improve significantly the discussion. Here is a list of recent papers working on similar subjects:

We thank for the interesting literature suggestions and integrated part of them in our discussion. However, we did not substantially change the mentioned paragraph as we do not only describe the results but also highlight and summarize their significance. A discussion and comparison with other literature follow in the next paragraph(s).

Other comments

2. P3, L17-20: This two sentences should be located in the material and methods section. In the introduction, it would be appreciated to have a short paragraph describing the different rockfall models that can be found in the literature and highlight the few one that take into account the protection effect of the forest.

We made reference to Volkwein et al. 2011 who summarize and describe in detail a wide variety of existing rockfall models.

4. P4, L5: A justification for the choice of a concave profile with slope angle varying between 20 to 40° needs to be added.

We chose a concave profile as this corresponds to typical and probably most frequent slope geometries of rockfall slopes. In order to test the influence of the slope profile on the results, we validated the statistical models with results of simulations on linear slopes with slope angles of 32°, 35°, 38° and 40°.

5. P4, L6: Why do you add random slope angle variation to your profile? Adding this angle variation comes in conflict with the "controlled conditions" you are looking for P4, L4.

6. P4, L10: Why do you add a road into your slope profile? Adding a road does not appear to be necessary for the analysis done in the paper. Its influence is never presented in the result section nor in the discussion and conclusion section.

We randomly varied the slope angle of each cell aiming at more realistic conditions. We agree, however, that this is slightly contradictory to the “controlled conditions”. For this reason, we decided to run the new simulations without slope angle variation and we also omitted the road in the new slope as it is indeed not necessary for the presented analysis.

8. P7, L16: Why do you choose to calculate cbA using a slope width of 100 m? Did you test other widths and analyse their influence on this indicator?

The slope width of 100 m is used to normalize the cumulative basal area for a given runout distance. As such, it does not make any difference whether we use 1, 10 or 100 m.

9. P8: Can you give a ranking of the influence of the different parameters for the 4 statistical models?

The p-values of the parameters and the position in the regression tree can be regarded as ranking. This, however, has to be interpreted carefully, since the multivariate models reflect interactions of the parameters and a ranking does not necessarily make sense.