Response to reviewer comments on "Assessing the effect of lithological setting, block characteristic and slope topography on the runout length of rockfalls in the Alps and on the La Réunion island"

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Response to Anonymous Referee #3 (RC3)

We thank the anonymous referee #3 (RC3) for the constructive comments and detailed feedback. We greatly appreciate the suggested revisions which will improve the quality of our revised manuscript. In the following the original comments of the reviewer #3 are listed in blue and replied by us point-by-point in black.

The paper presents detailed analysis of rockfall deposits mapped using point cloud datasets captured at four sites with differing lithology. The analysis explores how the properties of rock shape and volume along with terrain roughness and morphology influence runout distance. The findings are discussed and contrasted with previous works on the topic. Differences are identified in the runout character according to lithological setting. A number of analysis methods fail to link the measured metrics with the potential rockfall runout process controlling them and perhaps could be enhanced by applying alternative metrics of rock shape and volume. Inconsistencies in terms applied to descriptions of rock shape lead to some confusions in understanding the findings regarding the influence of rock volume and shape on rockfall runout.

Reply: In the methods section (l.143) we have dealt with the description as well as the calculation of the block shape. We are aware that this can only be an approximation of both the block shape and the block size. When revising the manuscript, we will take care to use more consistent naming with regard to the block form. We decided to perform a more detailed analysis of a sample of selected blocks based on point-cloud data. This is expected to reveal the degree to which the metrics based on three axes represent the actual block shape and volume. Moreover, also in light of other reviewers' comments, we will conduct additional analyses on roughness (based on the original high-resolution point clouds) as a surface property (I) reflecting granulometry also smaller than the measured blocks and (II) influencing the runout length of rockfall particles along their calculated runout paths.

The following observations and questions arise:

Review Comment 1:

1) The differences in lithology between the study sites make this study of interest for rockfall. However, the fragmentation of rock during rockfall and the lithological control on preconditioning down slope fragmentation is poorly treated in this work. It would be interesting to consider the rock-mass properties of each of the rock walls. How do the site specific failure mechanisms, discontinuities and rock strength influence the distribution of rock fragments across the talus cone? Investigating this theme would be possible with the detail of data presented in this work, and have the potential to enhance the observations made in sections 4.1 and 4.2.

Reply: The aim of our analysis was not to analyse the fragmentation of the blocks during an event. We cannot do this with our data. Likewise, we cannot analyse the influence of lithology on fragmentation with our data because

structural data are not available at all sites. We can only measure the deposited blocks and put them into context with the respective lithology, as we have done. The intention of our analysis was not the analysis of different failure mechanisms, discontinuities and rock strength, but how the lithology influences the deposition on the talus cone. Even though we are of course aware that lithology also controls these factors. In the revision of the manuscript, we will make an effort to collect values from the literature for our study areas and different lithology (rock mass, strength) and add them to Table 1 (l102). The distribution of particles (of different sizes) on the talus cone will be analysed additionally by deriving the surface roughness from the high-resolution TLS point clouds. As roughness bears a relation to grain sizes (interesting specifically at sizes smaller than those we measured manually), we are confident to get a more complete idea of the depositional patterns.

Review Comment 2:

2) The use of rock axis ratios as a shape classification is an obvious choice given the volume of available data. Moreover, the geometric axis ratio has a bearing on the inertial axes of the rocks and its ability to maintain momentum during run out. The rock volume and shape are therefore coupled in their influence on runout behaviour. The analysis could benefit from coupling rock volume and shape.

Reply: The coupling of block size and block shape is mathematically difficult. While a multivariate regression of runout length on block shape AND volume failed, the identification of the most extreme block shapes (q10, q90, see Figure 7, l330) provided a clear indication that block shapes moderate the influence of volume (=>gravitational sorting). Regarding the mechanisms through which e.g. block shape may moderate runout length, we pledge to explain these more thoroughly in order to arrive at a more plausible interpretation of the findings.

General comments to the text

1. Introduction

Review Comment 3 – L34 to L38

The text introduces preconditioning and preparatory factors as well as triggering events. A clear distinction between preconditioning and triggering rockfalls for the examples of each that are given would be useful.

Reply: For La Réunion, it can be assumed that the rockfalls taking place there are mainly triggered by preconditioning factors such as the lithology, but also by the high seismic activity as trigger. For Gampenalm, Zwieselbach valley, and Dreitorspitze it cannot be determined exactly, but thawing of mountain permafrost can be excluded due to the altitude and exposure. Unfortunately, we do not have temperature and precipitation data.

Review Comment 4 – L39

“Due . . . importance”, of what?

Reply: We wanted to express that due to past settlement development in mountain regions, the affected infrastructure can be partly affected by rockfall events that take place. We will rephrase this sentence in the revision of the manuscript.

Review Comment 5 – L61-L63

please clarify the use of proximal in this sentence, proximal to the source or deposits?

Reply: By "proximal" we mean the lower slope area where the blocks are deposited. This refers to the distance to the detachment area.

2. Study sites

Review Comment 6 – L97 & L 98

Please clarify the use of “untreated” with regards the rock mass description.

Reply: We will delete "untreated" in this context and refer only to "thick banked", as was done in the relevant lines (l97f).

Review Comment 7

Table 1 could benefit from details of the rock mass properties and strength.

Reply: We will search for the information on rock mass properties and strength for the study sites in the literature and add it to Table 1.

3. Materials and Methods

Review Comment 8 – L122

consider replacing “Both . . .” with “Each scanner works . . ..

Reply: We will follow the reviewer’s comment.

Review Comment 9 – L124

clarity on the importance of coloured point clouds to the methodology would be useful.

Reply: We will deepen the topic of colouring point clouds and describe it in more detail.

Review Comment 10

Section 3.2 the method applied to obtain rock volume using the three principal geometric axes a b & c give the volume of a cuboid. To what extent does this method over estimate rock volume in this study?

Reply: We are aware that we probably overestimate the volumes of the blocks by our calculation. However, we note that we use the same approach for all areas, which in our view makes a comparison between the areas permissible. With our data, however, we are able to randomly quantify this overestimation. For each of the study sites, we will determine the volume in detail for a representative sample of ten blocks using the point cloud (with Riscan Pro) in order to be able to provide an estimate of the overestimation of the volumes.

Review Comment 11 – L152

The applied rock shape indicator bundles the platy and elongate rock shapes into the same indicator, please discuss this choice in more detail.

Reply: We will add more detailed information about the chosen method especially the block shape when revising the manuscript.

Review Comment 12 – L154

The axis ratio of 1 in which axes are the same length is referred to as a round shape. How does the applied shape classification account for the roundness of the rock? Could an axis ratio of 1 be described as “equant”? Please consider applying equant throughout the text. How do larger rocks with flat sides but axis ratio of 1 runout in comparison to a rounded rock?

Reply: We argue that the axial ratio does not precisely represent roundness. Where it approaches a value of 1, the block is thought to be a cuboid, whether for increasing axial ratio blocks become more irregular shaped (Here we refer to Glover et al., 2015.). Large blocks with flat sides and an axial ratio of 1: the corresponding blocks do not have flat sides, but their axes are almost the same length. In the revision of the manuscript, we will make sure to use a uniform naming of the block shape in the methods section as well as in the results and the conclusion in order to avoid misunderstandings.

Review Comment 13 – L168

"rock fall" please replace with rockfall.

Reply: We will follow the reviewer's comment.

4. Results and Discussion

Review Comment 14 – L190

please consider deleting "dispersion also".

Reply: We will follow the reviewer's comment.

Review Comment 15 – L193

please consider "clearly shown" in replacement of "well visible".

Reply: We will follow the reviewer's comment.

Review Comment 16 – L241

To what extent can this be attributed to fragmentation of rock during runout?

Reply: It is not impossible that fragmentation may occur during the fall. However, we cannot determine it with exact probability. For the corresponding study sites, we have to assume that the processes are continuous and not a single major event. In the revision, however, we will emphasise and explain that there is an uncertainty.

Review Comment 17 – L300

repetitive use of adverb "clearly" "obviously".

Reply: We will rephrase that in the revision.

5. Conclusions

Review Comment 18 – L345

the term sphericity is newly introduced in the conclusions, it is not clear how sphericity was measured in the methods. Is rounded or equant shape meant?

Reply: Sphericity or roundness are the wrong terms for the method used. This is our mistake. A measured block with an axial ratio of 1 is thought to be a cuboid. For this reason, it is possible to refer to equant. We will also take care to remain consistent in the manuscript with the naming of the terms while the revision. This also refers to your comments regarding line 152, line 154 and your introduction.