

Response to Reviewer 2

The authors would first like to thank the reviewer for their comments and suggestions. The authors would like to point out that there is limited to no work that can be compared to the results of this study. The study was meant to highlight the different methods that can be used to analyze the shape of rockfall events using TLS remote sensing data. This is then demonstrated with application to a case study in the White Canyon, British Columbia, Canada.

In terms of the modelling component, the authors agree with the reviewer. In fact, this is planned future work for another paper. If we must include it here, this will require description of the model, input parameters, parametric analysis and output information, as well as discussions of the study output. This would likely be 6 or more additional pages of text and numerous figures, which will put this well over a reasonable length of paper. We would prefer to keep this work as an additional paper.

Abstract

It would help the reader to estimate the importance of the paper if the novel approaches or so far un-answered knowledge gaps that the paper suggests to answer are shortly presented in the abstract.

This will be added in the abstract.

P1 lines 16-17: “a database of close to 5000 rockfalls is presented...” – the authors do not present the database, or any other database which they refer to (50/60 blocks referred to later in the results). Either present the databases in supplemental materials or not state implicitly that you present them.

This will be updated in the abstract.

Introduction

General: What is the importance of 3-D block mapping for rockfall hazard assessment?

The Introduction could benefit from more reference to previous studies which discuss that issue, and perhaps to point out the importance of the 3-D block classification for rockfall hazard estimation worldwide (as opposed to other simplified block shape methodologies, which were proven to be relatively robust so far). At current stage – this link is missing and the importance of the study is not well constrained.

P1 line 25: perhaps add a short description of rockfall triggers.

This will be added for completeness.

P2 lines 5-8: there are more large scale works that can be mentioned as previous works on frequency-magnitude and return periods (e.g. Malamud et al., 2004, Wiczorek and Jäger, 1996).

The suggested publications will be added as references in these lines.

P2 line 28: what do you mean by ‘quickly’ and ‘with substantial detail’? – how quickly? To what extent of detail?

What was meant by “quickly” is that a TLS system is quite portable, is mounted on a tripod and can be deployed as soon as the site is accessed. There is no need to establish a baseline data set as is the case with radar systems, for example. In terms of detail, point clouds captured with TLS systems can have sub-millimeter scale point spacings. These sentences will be altered for clarity and references can be added.

Section 1.1: rockfall shape were previously described in literature and most rockfall hazard programs use some simple geometry shape for falling blocks – providing relatively good results (e.g. Guzzetti et al., 2002) . Please address what was previously used for hazard assessment and what is the novelty that TLS 3-D measurements (or the current study) contribute to rockfall hazard? Please provide references to emphasize the importance / augmentation of TLS rockfall shape determination over previous methodologies simplifications.

STONE (Guzzetti et al., 2002) uses a lumped mass approach to simulate the trajectory of rockfall, such that all of the mass is concentrated in a point. Therefore, the size and shape of the rock being simulated are not considered. More recent work, using rigid body physics (e.g. Sala, 2018) can explicitly capture the interactions of the object’s geometry and the terrain. These simulations, including the ones of Glover (2015), show that the true 3D shape can have an influence on the runout of

the rockfall object. Utilizing TLS, we can capture the exact shape and location of the block detachment location. These cases can then be explicitly incorporated into rockfall simulations for both calibration of the model and development of more representative hazard mapping.

In comparison to previous approaches for rockfall hazard assessment, TLS offers the ability to capture a large section of slope in great detail. Structural kinematic analysis can be completed using the scan data. The work of Lato et al. (2010) demonstrate a workflow to incorporate TLS into rockfall hazard assessment. The TLS scan provides a permanent record of the slope at a given point in time. With multi-temporal data, change detection can provide insight into locations where rockfall activity is impending or has occurred.

It should also be mentioned that in P3 Lines 2 to 4, the authors reference the works of Glover (2015) and Sala (2018) which demonstrate the effects of rockfall shape on the runout distances when using 3D shapes in numerical simulations.

P4 line20: what is the CN main line?

The CN main line is the primary rail track that is situated at the base of the White Canyon. The wording in this sentence will be altered to improve clarity.

Results

In general – there is not a word mentioned on the size of the mapped rockfalls in the results or in the discussion. It will be better to include these – and also power-law size/volume distributions so the readers from other places can relate your database and its applicability to their own study cases and areas.

Work on the frequency-magnitude relationship has been completed by van Veen et al., (2017) using a subset of the database. The focus of this work was on the shape of the rockfall events, not the frequency-magnitude relationships. The monitoring at the White Canyon study site has not been conducted for long enough time period to generate realistic frequency-magnitude relations for larger volume events, and work is ongoing within the research team on this topic

Section 3.2 – what are the size ranges of the rockfalls in the 160 and the 50 blocks selected?

The volumes range from 1 m^3 up to 130 m^3 as the largest event recorded. This information will be added in the results section.

Discussion

In general – the discussion part is relatively short compared to other sections of the manuscript (e.g. Methods or Results). I believe it should be better balanced, as currently the discussion about the insights obtained from the analysis and their implications for other studies were not sufficiently extracted from the data. This could also be achieved by answering the following suggested issues:

Most of the rockfall objects in the study case were classified as ‘very bladed’ or ‘very elongate’. Please consider discussing the possible source for that – i.e. the local geology and structure of the cliff-face or any other factors.

This is a direct result of the foliation and orientation of the joint sets within the gneiss. As a result, the blocks trend towards the ‘very bladed’ or ‘very elongate’ shapes. Details regarding this will be added in the discussion.

About 30% of the identified ‘feasible for analysis’ rockfalls were included from the suggested methodology (50 out of 160) due to irregular morphology (not to mention ~4800 excluded cases of less than 1 m^3). Consider discussing the amount of ‘good’ identified rockfalls valid for using your suggested methodology and relate to how much you assume it is reliable for application in the real-world.

The greater than 1 m^3 threshold was set based on a criteria in CN’s Rockfall Hazard Rating system (RHRA: Abbott et al., 1998) which focuses on the rockfall events that are greater than 1 m^3 . This will be clarified in the text.

The reviewer’s comment: “amount of ‘good’ identified rockfalls valid for using your suggested methodology and relate to how much you assume it is reliable for application in the real-world”, is not addressed specifically in this paper. This is in part due to the temporal frequency of scanning. It has been shown by a number of authors (e.g. Veen et al. (2017), Williams et al. (2018) and Williams (2017)) that temporal frequency of monitoring has direct implications for the size and shape of the rockfalls that can be detected using remote sensing methods. As longer times elapse between scan intervals, several smaller rockfall events may occur from a location, with the result that the detected shape and volume is larger than would

be the case for any of the single events, The proposed methodologies used in this study will work regardless of the input data and will classify the rockfall shapes accordingly. In more real-world situations, where there is potentially even less data available, large rockfall events could be detected which are in reality a series of smaller coalescing rockfall events. This would then have implications for calculated return period but also the shape. Therefore the concept of “good” is not easily quantified. Ongoing work to characterise rockfall shapes, related to slope geometry and rockfall shapes may yield some future logic about “good”, and to determine which rockfalls, identified from change detection, should be rejected from analysis as they are likely to be the result of coalescence of several events.

The events smaller than 1 m³ were excluded based on the RHRA criteria discussed above. In addition, the authors wanted to use a reasonably manageable subset of the data for a preliminary analysis of the rockfall database in order to demonstrate the methods.

P13 lines 20-24 (Results) + P14 lines 25-27 (Discussion): All suggested automatic methods failed to predict the shape of the single exemplary object (very elongated) with relation to its manual measurements (very bladed). Please consider discussing: (1) the significant contribution or advantage for using the automated methods vs the manual measurements; (2) the significant contribution of the two newly suggested methods in the current study over previously used methods.

The exemplary object used for the analysis represents one of the more complicated geometries used in the analysis. This was done purposefully to highlight that in these cases where there is deviation in the shape classification depending on the methods used. The authors will add an additional object that is less geometrically complex to demonstrate a case where all the methods align in the shape classification.

Do you consider any scaling factor or effect on your results and conclusions? It appears that most of the discussed rockfalls in the manuscript are of very small size (up to 1-2 cubic meters) compared to other slopes and areas in the world reported in literature (up to tens and even hundreds of cubic meters at places). Please consider discussing the size of the blocks in the database (volume-frequency power laws) and its implications for larger scale blocks and volumes.

This database has been collected between a select period of time and we have seen volumes ranging between 1 and 130 m³. We have not been monitoring long enough to see the larger volume events.

There are also a number of recent studies that have demonstrated the influences of temporal frequency of monitoring. van Veen et al. (2017), Williams et al. (2018) and Williams (2017) highlight these considerations where depending on the time-frame analyzed, large rockfall events are actually multiple smaller coalescing events.

P14 lines 19-24: Consider discussing the superiority of your suggested methodology (if such exists) – how much computation time / effort do these new models require – versus how better is the accuracy they obtain and how significant it is for more successful rockfall hazard estimation? Which one of them would you recommend for use (at least in your case study – and if you can – try to recommend for other readers).

Considering the definition given by Sneed and Folk (1958) of how to measure shape, the RFCYLIN approach is most closely aligned. The RFCYLIN approach, however, is the most computationally demanding in comparison to the other methods. The RFSHAPZ approach was generated to deal with cases where the surface of the rockfall being analyzed is quite rough and is an attempt at averaging the dimension being calculated.

The bounding box approach should absolutely not be used in any case. All results will be biased towards the cubic end of the Sneed and Folk diagram. If a bounding box type of approach is going to be implemented, it is necessary to implement the adjusted approach. In addition, the adjusted bounding box approach is one of the simpler methods to implement in comparison to the RFCYLIN and RFSHAPZ approaches.

The authors will elaborate more and provide recommendations on implementing the different methods.

Conclusion

Please try to confine the conclusion to insights from the current study only (for example – first paragraph in P15 lines 17-21 cites conclusions from previous studies.)

These sentences will be altered to improve clarity.

Please consider actively stating your opinion by suggesting a priority for block shape methodologies: which is most adequate for most cases and which is the less adequate. Try to list them by priority or robustness of success potential to predict real-world rock block shape.

This can be added following the last comment in the discussion section. The authors can include a table or list to rank the different methods. Some additional comments about these points have been given above, as well.

Figures

Figure 2: Please consider a better World location map for readers outside Canada / N America.

Figure 6: Please refer in the figure caption to the relevant studies which presented the different models shown in the plot.

The appropriate references can be added to the figure caption.

Figure 9: As the main results presented in this study – please consider putting more effort in presenting the data more vividly in this plot. There is a lot of white space and very little data presented.

The decision to present the data in this form was deliberate. It was done purposefully to illustrate spatially the difference in using each of the methods to calculate the dimensions and as a result, the classified shape.

The abbreviations at bottom legend are never referred to in the text or figures. Especially the ones of ‘RFSHAPZ_???’ should be at least detailed once in the text or figure. Please add the ‘Cubic, Platy, elongated...’ the corners of the plots for clarity.

The appropriate abbreviations can be added to the figure caption.

Figures 10-11: the abbreviations at right-hand legend are never referred to in the text or figures.

The descriptions of each of the abbreviations can be included in the figure captions for both Figures 10 and 11.

Figure 12: please indicate the location of each of the plots (A, B) on Figure 3 of the study area. What are the sizes or size range of the rockfalls indicated here? It is not mentioned in the text or figures. How do these sizes relate to the declared identification threshold detailed in the Methods?

The locations of each of the objects used in the analysis can be noted by using a different coloured dot.