Large-scale risk assessment on snow avalanche hazard in alpine regions

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Review:

1. Overview

The paper by Ortner et al. describes a framework for spatially evaluating risk on a regional/country wide scale. The framework encompasses probability of release combined with hazard assessment, exposure and vulnerability using the risk assessment platform CLIMADA. The hazard part is evaluated using RAMMS:LSHIM with geometrically computed probable release areas for three different prototypical avalanches (1/30 yr, 1/100 yr and 1/300 yr return periods). This allows the authors to express the hazard in terms of approximated impact pressures. Further techniques are used to classify forested areas and adjust the simulation parameters accordingly. The exposure is evaluated using an identification process for building type in order to spatially represent monetary assets. Specific damage functions are then used to estimate the vulnerability of the buildings and the annual monetary impact estimated (using the software EconoMe) for each building. Alongside this, the aggregated annual monetary impact is calculated for the full evaluated area at a regional scale. Further to this, uncertainty and sensitivity analyses were conducted to assess the variability in input parameters.

The study presented explores an interesting topic with far reaching use cases. I believe the work to be of interest to NHESS readers. The study has a clear purpose and combines established techniques in recent literature for a novel framework for quantitative avalanche risk assessment. Due to this I believe the manuscript will be well suited for publication pending major revisions which the authors should address. These revisions fall into two major categories:

1) Technical detail:

There are a few areas of the text where further explanation is required. Specific examples are listed below in the detailed comments section. Due to the nature of the approach combining several established methodologies it is understandable that full explanation of each of the methods is not completely contained in the manuscript and is appropriately linked to citations, however, I feel in some cases it would be beneficial for the reader to get a bit more insight into the methods used so the paper can stand alone.

2) Structure and writing:

There are a lot of examples of typography errors and I feel there are a couple of sections where the structure could be adapted to have established the key concepts/methods prior to the section. The authors should revise the manuscript taking care to catch mistakes and organize the structure to better relay the scientific message of the paper.

Following up on these comments the authors should address, I have provided some more detailed explanation expanding on the examples where I have spotted some technical issues. I hope that the following comments are useful for the revision of your paper.

2. Detailed comments

2.1 General

- Throughout the manuscript there are a variety of typography errors that should be addressed. These fall into the following categories:
  - Figures referenced out of order - the current order goes figure 1, 5, 3, 2 .... If appropriate figures should be placed in a strategic order such that the reader isn't required to jump around the paper too much as the contents are discussed in the text.
  - Typos.
  - Some citations in text are wrong type - *e.g.* lacking parenthesis.
  - Some more care needed with sentence structure - wrong use of commas, missing words.
  - Structure issues *e.g.* forest section refers to a lot of definitions that haven't been introduced yet and are not linked in the text - *e.g.* could say "as expanded upon in section ..." - or adjust the structure of the paper such that the forest section comes after the required definitions - for example - the definition of three avalanche scenarios.
  - Excessive abbreviations / acronyms - not all are needed - and inconsistent formatting and use within text - for example - some are not uniformly applied from figure title to the figure caption. Most are all uppercase but some are lower case - most are introduced more than once and then not used - or the definition repeated - or the same definition applied to two different variables (see *e.g.* Line 221). This is distracting to the reader rather than helpful! I recommend using a consistent heuristic for usage throughout and consider carefully in which cases encoding terms in a abbreviation is beneficial.
  - Units should not be in italics - see *e.g.* m^3 vs m^3.
  - Some references in bibliography are missing information and are not of uniform style.

2.2 Introduction

- Line 24: Apparent missing word in sentence "In winter 2019, for example, exceptional snowfall events [occurred?] which caused high damages".
- Equations (1) and (2) - although give a clearer explanation for the risk formulation used - are lacking in descriptive detail. For example f_{imp} is undefined in the text at the equations and not further referenced. It may also be clearer to the reader if the syntax f_{impact} is used. Risk is repeatedly referred to as a product of hazard, exposure and vulnerability, however, equations suggest this is not the case - rather - it is a function of hazard, exposure vulnerability and probability of consequence. Probability of consequence is also undefined in the text and needs further explanation.
- Line 41: introduces the idea of vulnerability under the IPCC definition with "economic, material or environmental consequences". The paper then utilizes this concept for vulnerability, however, appears to neglect the environmental consequence and focuses on economic and material consequences. While I think this choice does not affect the scientific contribution of this paper it could be expressed clearer if environmental consequences are intended to be included/neglected and why in the risk framework.
- Line 55: sentence unclear - extra comma?
- Figure 1: abbreviations in input key are undefined. Perhaps expand in the caption or link to text.

2.3 Methods

- Line 84: Fig 5 referenced out of order.
- Line 91: Sentence 1 of section 2.1.1 currently doesn't make sense - how does "surface roughness" influence the snowpack structure? I believe a different meaning was intended here. Further to this the concept of surface roughness should be expanded upon here - do you mean of the basal topography or of the snowpack

itself? Also which "transition" is unclear - do you mean the transition to decelerating material - or a specific transition in the topography?

- Figure 2: Typo for "treeheight". VHM introduced twice - once as treeheight and once as vegetation height - are these equivalent or does vegetation height also include shrubforest? This should be clarified. Avalanche disposition is also not well explained as to how it is included as a percentage value. This also needs to the be clarified.

- Line 114: Extreme and frequent scenarios not introduced yet - text should link forward to section 2.1.3 or consider restructuring.

- Line 114: Text should also be more clear on definitions and forest inclusion for all eight potential scenarios *e.g.* frequent / extreme - tiny small medium and large and should not leave it ambiguous to the reader.

- Line 141: Typo "statistic"

- Line 153: Function for ψ stated is incorrect - see Salm, Burkard & Gubler (1990) - which states it as

$$f(\alpha) = \frac{0.219}{\sin(\alpha) - 0.202\cos(\alpha)}. \tag{2.1}$$

  It should be checked that the correct form is applied in the ArcGIS code also. The function for the fracture depth d_0 is then $d_0 = d_0^* f(\alpha)$, which should be further explained.

- Line 170: An overview of the how RAMMS:LSHIM differs from RAMMS:AVALANCHE should be included in this section.

- Line 195: And overview of the EconoMe methodology should be explained.

- Table 2: Typo in caption - swisstopo repeated.

- Line 221: mean degree of damage = to mean percentage of damage?

- Line 223: What is the conceptual difference between mean damage degree and mean damage ratio at a certain pressure?

- Figure 7: General question on the piecewise-step form of the impact functions - do we really expect a 29 kPa avalanche to give 40% impact but 31 kPa to give 80%? I guess my question lies in the idea that while the piecewise plot gives the context for the three prototypical avalanche scenarios wouldn't a smooth function be more realistic where the impact is interpolated between the three key thresholds?

- Line 229: Citation missing parenthesis. Happens several times in this section and section 2.4.2.

2.4 Results

- Line 313: Typo "at this locations".

- Table 4: Should explain how the combined scenario is calculated.

- Figure 9: Black dot at Altdorf label leads to confusion - is this a 10^7 CHF building? If so then aggregated value estimates don't make sense - if not the symbol should be removed. In panel (a) the label also covers points, which should be corrected.

- As a general point about figure 9 - the 1/30 yr expected annual impact seems pessimistic - it would be interesting to see how this compares to actual spending in this area, say from insurance records / payouts or knowing which buildings have been damaged in the last 30 yrs - 50 yrs.

- Figure 10: Typo - "one eight-thousand randomly pulled samples" - doesn't make sense. Also missing units for impact range.

- Line 363: missing CHF?

2.5 Discussion

- Line 453: "We consider buildings as point objects ..." - how does this connect with the mapping - do you consider the building as the point at center of the building area/extent? Can this play a role with larger buildings say large barns or warehouses in the studied regions?

- Line 468: "small scale of hazard process" - this is a bit ambiguous. Please clarify the scale intended.

- Line 473: "night light assessments" is not a common term, please clarify.

2.6 Conclusion

- Line 482: "previously unknown threats"...- clarification needed.

Bibliography

Salm, B, Burkard, André & Gubler, H U 1990 Berechnung von fliesslawinen. Eine Anleitung fuer praktiker mit beispielen. *Tech. Rep.*. Eidg.\ Institut\ für Schnee- und Lawinenforschung, CH–7260 Davos-Weissfluhjoch, publication Title: Mitteilungen des Eidgenössischen Instituts für Schnee und Lawinenforschung Volume: 47.