Review of "Large-scale risk assessment on snow avalanche hazard in alpine regions" by Ortner et al.

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Overview

This paper by Ortner and co-authors describes a new approach for assessing the long-term risk from avalanches to buildings in an entire valley, region or country using a series of existing models. Following the well-established definition of risk = hazard x exposure x vulnerability, the authors use RAMMS::LSHIM to first define probable release areas for three different avalanche scenarios (1/30 yrs, 1/100 yrs, and 1/300 yrs) and then simulate the resulting avalanches to express the hazard in term of impact pressures. They then combine this information with a detailed building layer and building type specific damage functions to estimate the risk in terms of expected annual monetary impact for each building (CHF/yr) and the aggregated average annual monetary impact for the entire study area. The authors also conduct an uncertainty and sensitivity analysis to strengthen their confidence in their approach and explore the impact of uncertainties of individual variables.

The present study is a natural progression of the recent work of the author team, and it explores an important topic that is of broad interest to the NHESS readership because even though the study focuses on avalanches, the model approach is applicable to natural hazard more generally. The presented approach is well thought out and grounded in the existing literature. Overall, I really like the research and the manuscript, but I see two main areas where the manuscript can be improved.

First, the writing is somewhat dense and a bit convoluted at times, which make it difficult for the reader to follow all the details. In addition, tables and figures could be used more strategically, and improving their quality would further strengthen the clarity of the paper. My second main comment is that the discussion is currently very limited almost exclusively focusing on limitations. I believe that expanding the discussion section to better highlight general insight from the study, the strength of the presented model in comparison to existing approaches, the practical implications, and opportunities for future research would make it much stronger. I believe that addressing these two challenges would improve the quality of the manuscript considerably and make it a more accessible and impactful paper. My comments are organized into these two themes.

I hope you find my comments constructive and useful for the revision of you paper.

Pascal Haegeli
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Manuscript structure, writing and clarity

Major comments

General

- This manuscript uses a lot of abbreviations, and not all of them are properly introduced when you use them for the first time. Please be kind to your reader and make it easier for them to find the definition of the various abbreviations. Furthermore, once you have introduced an abbreviation, use it consistently. Also see my comment on Fig. 1 as a potential way for presenting all abbreviations in a central place. I also recommend to only introduce abbreviations when you really need them. Some of them (e.g., GEV-MLE, GUM) might not be necessary since you only use them once or twice in the paper.

Introduction

- Line 35: Since the risk definition employed in this paper is broadly used in natural hazards, it would be useful to include a more general reference before you discuss the implementation of the concept in Switzerland.
- Line 45: In my opinion, it would be better to include the description of the overall approach taken in this study (incl. Fig. 1) at the beginning of the methods section and not in the introduction. Instead, the introduction should include a brief overview of the existing approaches that highlights the research need before the objective of this study is defined.
- Line 59: It might be useful to either properly introduce the study area right here or have a dedicated section to do that at the beginning of the methods section. Right now, the description of the study area is somewhat buried in the hazard section, which already describes a specific component of your model. I also recommend that you have a dedicated figure that shows the details the study area without combining it with another aspect of the model. This will help readers unfamiliar with the local geography understand the context of the study area better.
- Fig. 1: While this figure is visually pleasing, it could be made more informative by including a more detailed flowchart that shows how the different datasets and model components work together. This figure could also be used to introduce all variables with their abbreviations. See earlier comment on abbreviations.

Methods

- The presentation of the different topics in the hazard section seems a bit convoluted and not follow a linear story line. For example, you already talk about the different scenarios on L100 before you introduce them on L131. You also talk about potential release zones of difference sizes on L114+ before you properly introduce them on L124. I recommend that you reorganize this entire section and present the information in a more linear and logical way. The suggested expansion of Fig. 1 could be part of making this part of your manuscript easier to understand.
- Line 101: It is unclear to me how the forest model is improved and extended with the shrub forest and ground roughness layers. Please explain in more detail.
- Fig. 2: This is the only figure that displays a specific component of the model in detail. In my opinion, this figures in not necessary as this information can be found in Bebi et al. (2021), and

- the extension of the model with the shrub forest and ground roughness layers should be described better in the text.
- Line 149: It is unclear to me how exactly the elevation and incline corrections are applied to the probable release areas. Is a single correction factor derived and applied for each entire probable release area or is it done differently?
- Line 185+: This section on the exposure data is extremely convoluted and difficult to follow. One issue is the different datasets, and the repeated references to them. It might be easier for the reader if you describe the three (?) main dataset first before you get into the details of their use. This will reduce the number of required references. In my opinion, much of the relevant derived building information is actually contained in Table 2 and it is not necessary to repeat this information in the text again. So, the text and table should be more complementary.
- Fig. 6: It is unclear to me why the layout of this map figure is very different from the previous figures. I think it would make it easier for the reader the related the content of the different figures to each other if the layout of all the figures with maps were consistent. Furthermore, the purple dots in Panel b are really hard to see. A similar main-panel-and-three-side-panels layout as Fig. 3 and 5 might allow you to zoom into two additional areas of interest (e.g., the SE and SW facing slopes E of Altdorf), which could support the later discussion of the results.
- Line 221+: The definitions of these terms are difficult to understand? Since you are assuming PAA to be 100% for all avalanche pressures and MDR = MDD, I think this could be simplified considerably. It is also unclear to me why the charts show all three variables when only one is used.
- Line 229: It seem to me that CLIMADA should be explained at the beginning of the methods section when you give a general overview of the modelling approach (see earlier comment). Describing these details here is odd since you already referred to CLIMADA when you explained the impact functions.
- Line 247+: This paragraph on uncertainty and sensitivities seems unnecessary as the following section discuss the topics in more detail. Hence this information should be integrated into the subsequent sections. This will make the overall description more concise.
- Fig 8: This figure does not seem to provide useful information beyond what is described in the text. I recommend deleting this figure.
- Table 3: This table does not seem necessary as it does not provide any information beyond what is explained and easily understandable in the text.
- Line 285: A little bit more detail on the Sobol index S1 would help the reader to properly understand what insight it can provide.

Results

- Line 291+ and Fig. 9: I think the information presented in Fig 9 is interesting, but you need to describe it in more detail in the text. I also wonder whether the figure would benefit from having the same layout as the previous map figures. It is necessary to show the results from all four scenarios or are the spatial patterns actually quite similar? If possible, the figure could be made more impactful by only showing one scenario, and have three subpanels that zoom in to special areas of interest in the same layout as the previous map figures. The same figures for the other scenarios could be included in an appendix or supplementary material.

- Line 291+ and Fig. 9: The labels of local towns also need to be improved as your description that the hot spots are located on the slopes of the main Reuss valley near Wassen, Gurtnellen, and in the side valley near Meien will not make any sense to readers unfamiliar with the detailed geography of the Reuss Valley. See earlier comment about a map that just shows the study area.
- Line 301: The description of how the combined average damages are calculated belongs into the methods section and not the results.
- Fig 10: This figure is very useful for providing the reader with a sense of the results of the uncertainty analysis, but I think it could be even more insightful if the axis were the same in all panels. This would give the reader a better sense of the locations and spread of these curves, which would further support the discussion on the observed pattern. Since you are presenting the data in bars, it might be easier to have your y-axis in counts or proportions and not as a density. This relates to another comment on the description of counts on L333.
- Fig 11: It is unclear to me why both panels are necessary for this figure. If I understand the presented information correctly, both panels present the same information, in the left panel with the mean and the 5th and 95th percentiles, and in the right panel with the median, the quartiles, the whiskers, and the mean. In my opinion, the left panel is completely sufficient to present the information. The information presented in Fig. 10 could potentially be presented in the same format (mean and percentiles), which would lead to more consistency in the information presentation.
- Sections 3.2 and 3.3: The way I understand these two sections, they both use the results of the uncertainty analysis to provide additional insight into the calculated values for the annual impact severity (Section 3.2) and the aggregated average annual impact (Section 3.3). While the section titles currently focus on the presentation format (uncertainty ranges and damage frequency curves), both of these formats can be applied to either impact measures, and there is considerable overlap between them (e.g., the spread presented in Fig. 11 are uncertainty ranges). Hence it might make sense to reorganize this section and present the results of uncertainty analysis more generally with respect to the two different impact measures.

Discussion
- See more detailed comment on discussion below.
- Line 431: Your discussion of "all geometrically possible release areas" is unclear to me. Please explain this in more detail.
- Line 453: The fact that you consider buildings as point objects seems to be an important piece of information that should be mentioned in the methods section. Please move that sentence into the method section.

Conclusion
- Line 480: You mention that your approach could also be applied to other natural hazards. To make this point more strongly, I think it would be useful to illustrate it with one or two potential examples. This will be how non-avalanche NHESS readers will connect to your study.

Minor technical comments

General
- At the beginning of the manuscript, the references to figures and tables are a bit challenging because it is out of order (Fig. 1 on L44, Fig. 5 on L84, Fig. 3 on L86, Fig. 2 on L96). This is

confusing and forces the reader to flip back and forth through the manuscript. Please present figures in the proper order. Also see my comment about a dedicated figure for presenting the study area, which might address this issue.

- There are many in-text citations that are not properly formatted. Some of them are missing parentheses while others have too many.
- Many sentences start with 'In order to'. This can be simplified to just 'To'.

Introduction

- Line 21+: You seem to use the term alpine in different ways. For clarity, I recommend using 'mountainous regions' instead of 'alpine landscapes' and 'counties situated in the European Alps' instead of 'alpine countries'.
- Line 24: It is a bit odd that you start the description of the serious winter seasons with the winter 2018/19, but only describe it with a single sentence. If the 2017/18 winter is more insightful, I would start with that winter instead.
- Line 49: At this point, it is not clear why the equation for severity is written in two different ways, and there is no supportive explanation in the text. Why it is done like this becomes clear later in the manuscript, but it is unclear here. Hence, this detail might not be necessary here.
- Line 57: Why limit yourself to adaptation measures? It might be better to talk about avalanche risk management in general, since it includes both mitigation and adaptation.

Methods

- Line 127: Is it necessary to refer to scenarios in this sentence before they are properly introduced in the next section?
- Line 134: "The definition of the scenarios is operationalized…" or "… is implemented …" might be a better wording than "… correspond …".
- Line 145: The use of the abbreviation GUM seems unnecessary.
- Line 150: Do you mean "existing studies" instead of "further studies"?
- Table 1: Use the same terminology to describe the 3-day snow depth increase in the caption as in the text. It helps the reader if you use consistent terminology. Also, the square brackets in the scenario column are not necessary.
- Line 164: Why does the subheading say RAMMS::AVALANCHE and not RAMMS::LSHIM?
- Line 183: "Subsidization" is not a very common word. "… to assist in their decisions on government subsidies." might flow easier.
- Line 210: The last sentence in this paragraph is not necessary since you explain the impact function in detail in the next section.
- Table 2: Is the EconoMe ID relevant information for the reader of this paper? I think this column could probably be deleted.
- Line 240+: Why are the abbreviations for these terms lower case? This is different from most other abbreviations. See earlier comment on abbreviations.
- Line 270: In this context, "less important" is a better term than "subordinate".

Results

- Table 4: Wouldn't it make more sense to have the return period in the second column or integrated into the first column because it is how the scenarios were defined?

- Line 319: This reference to Fig. 9a seems unnecessary. Potentially this is a mistake and should refer to Fig. 10a instead.
- Line 321: I think that adding "The NON-AGGREGATED average annual values …" to this sentence would improve clarity.
- Line 326: I do not completely understand the last sentence of this paragraph. Please clarify.
- Line 329: A reference to Fig. 10b is missing.
- Line 333: The value 3.5e-7 is a density and not a count. See other comment on changing the y-axis in Fig. 10 to counts or proportions.
- Line 338: For consistency, I think it would be better not to change the units for annual impact. Hence, it should be CHF 0.73 million and not 734.06 kCHF.
- Line 338: In scientific writing, the term "significant" should only be used in the context of statistical significance. Use the terms "considerable" or "substantial" instead.
- Line 344: The last sentence of the paragraph is not necessary.
- Line 349: The first sentence of this paragraph is not necessary because you explained this already. See earlier comment on including the description of the calculation of the combined impact in the methods section.
- Line 357: I don't think this reference to Table 4 is necessary. The scenarios are well established by now.
- Line 375: There is no need for this first sentence as this information is described in the method section already.

Discussion

- Line 409: It does not seem necessary to describe the derivation of the fracture depth and avalanche scenarios again. This is described in the methods section already.
- Line 420: It is best to avoid shortened forms in scientific writing (e.g., can't, isn't, etc.).
- Line 436: I believe that "avalanche area" should be "avalanche release area" or even "potential release area". Please use consistent terminology throughout the manuscript.
- Line 449: I believe it should say "structural weak points" or "structural weaknesses" but not "structural weakness points".
- Line 470: I do not understand what you mean with "… out of their focus…".

Discussion

Your discussion section is currently almost exclusively a description of the potential limitations of your modelling approach. At the end, you provide a discussion of previous studies carried out in this field (L465-476), but it is rather brief and superficial. At the same time, some of the sections included in the result section seem to have more of a discussion character. Examples include the description of the spatial patterns that emerge from the analysis of the expected annual impact for individual objects (i.e., Fig. 9) and the discussion of the decreasing average annual impact with increasing return periods.

I think the discussion section could potentially be strengthen considerably by expanding it and reorganizing the material in the following fashion:

1) Move the discussion-like paragraphs from the results section into the discussion and combine them into a subsection that discusses the generalizable insight from the analysis beyond the study-site specific results.
2) Expand the comparison with existing research in this area to better highlight the strengths of your approach (some of this is currently included in the conclusion section) and how it expands on the previously existing methods.
3) Finish with a slightly tighter discussion of the limitations that highlight future research opportunities.

I think a structure like this would considerably strengthen the discussion section and the scientific contribution of your paper.