Exploring the relationship between avalanche hazard and large-scale terrain choices at a helicopter skiing operation – Insight from run list ratings

Response to Anonymous Referee #3

Reto Sterchi, Pascal Haegeli
July 6, 2019

We would like to thank the reviewer for taking the time to read our manuscript in detail and provide constructive feedback. The following sections describe our response to the comments raised by the referee and outline the changes we made to the manuscript to address these concerns.

1 Title

Review (Reviewer #1 made a related comment)
[…] Consider "Exploring the relationship between avalanche hazard conditions and run-list terrain choices at a helicopter skiing operation". A little shorter and the phrase "large-scale terrain choices" is ambiguous. […]

Response to the review and changes made to the manuscript
Thank you for this comment. Reviewer #1 had similar concerns about the term ”large-scale”. We think the proposed modification is an excellent suggestion that makes the title clearer.

Adapted title: “*Exploring the relationship between avalanche hazard conditions and run-list terrain choices at a helicopter skiing operation”*

2 Reference: Walcher et al.

Review (Reviewer #1 made a related comment)
[…] Page 1 Line 24-25: Please check if there is a more recent reference. Walcher et al. (under review) or Walcher (Master thesis) perhaps would be more appropriate […]

Response to the review and changes made to the manuscript
Thank you for highlighting this. The paper is in press and should have a DOI shortly.

Walcher, M., Haegeli, P., and Fuchs, S.: Risk of death and major injury from natural winter hazards in mechanized backcountry skiing in Canada, Wild. Environ. Med., in press.

3 Introduction: Additional methods of controlling avalanche hazard

Review
[…] Page 1 Line 27 - 29: Consider mentioning that operations use direct control of avalanche hazard through the use of explosives and strategic control of future avalanche hazard through "run maintenance" skier traffic. […]

Response to the review and changes made to the manuscript
Thank you for pointing this out. We agree with the reviewer that it is worth mentioning that depending on the operational practices, the use of explosives or the strategic control of the snowpack through skier

traffic is common. To address the reviewer's comment, we made the following changes (highlighted in green):

Page 1, Line 27ff
[…] Operations manage this risk by continuously assessing the local avalanche hazard conditions and carefully choosing appropriate terrain and travel procedures to limit their exposure to avalanche hazard and keep the residual risk at an acceptable level while still providing a high-quality skiing experience. Some operations may use explosives to directly control avalanche hazard or purposely ski individual ski runs to control future avalanche hazard by modifying the local snowpack (often referred to as "run maintenance"). […]

4 Introduction: Hazard forecast only for first couple runs

Review
[…] Page 2 Line 3-5: General comment for reference, most mechanized guiding teams will produce the avalanche hazard forecast for the first run or two of the day rather than for the full day. i.e. "what is the avalanche hazard as we head out the door?". This hazard evaluation is then updated as new information is obtained throughout the day. […]

Response to the review and changes made to the manuscript
Thank you for commenting that this sentence needs clarification. We fully agree with the comment of the reviewer and are proposing the following changes (highlighted in green) to better highlight the evolutionary character of the hazard assessment and run selection.

Page 2, Line 3ff
[…] The daily process starts with a morning meeting where the guiding team assesses the current hazard conditions and produces a first large-scale avalanche hazard forecast across the entire tenure based on the previous day's experiences and the observed overnight changes. This initial hazard assessment is the foundation for the day's "run list", which represents the first terrain elimination filter. In this step, the guiding team goes through their inventory of predefined ski runs and collectively decides for each run whether it is open or closed for skiing with guests under the expected avalanche hazard conditions. It is important to note that depending on the nature of the operation, the scale of ski runs can range from tightly defined ski lines to areas the size of a medium ski resort. However, regardless of their size, the nature of ski run is consistent enough that they represent meaningful decision units at this stage of the risk management process. The large-scale, consensus-based run list that emerges from the morning meeting sets the stage for the skiing program of the day. Over the course of a skiing day, the avalanche hazard assessment is refined and adapted in response to direct field observations and runs that are skied are chosen from the run list accordingly. […]

5 Introduction: Description of hazard assessment

Review (Reviewer #2 made a related comment)
[…] Page 2 Line 3 - 5: Consider adding brief details about 'avalanche problems' as these are more impactful on the run list than the avalanche hazard rating. […]

Response to the review and changes made to the manuscript
We intentionally speak of avalanche hazard in general here in the introduction while we go into the details of how avalanche hazard is characterized with avalanche problems and an avalanche rating in the

methods section where we describe our data set. We did not make changes to the manuscript in response to this comment. However, please note that we revised the description of the avalanche problems included in our data set in response to Reviewer #2 (comment 1, manuscript page 4, lines 21ff).

6 Introduction: General wording of run list codes

Review

[…] Page 2 Line 7: Please change "...open or closed for skiing with guests..." to "...open or closed for guiding with guests...". Note, disregard this if the specific operation (Northern Escape) uses the stated nomenclature. […]

Response to the review and changes made to the manuscript

Thanks you for pointing out this inconsistency in the description of the codes in the methods section. To address the reviewer's comment, we made the following changes (highlighted in green):

[…] In this step, the guiding team goes through their inventory of predefined ski runs and collectively decides for each run whether it is open or closed for guiding with guests under the expected avalanche hazard conditions. […]

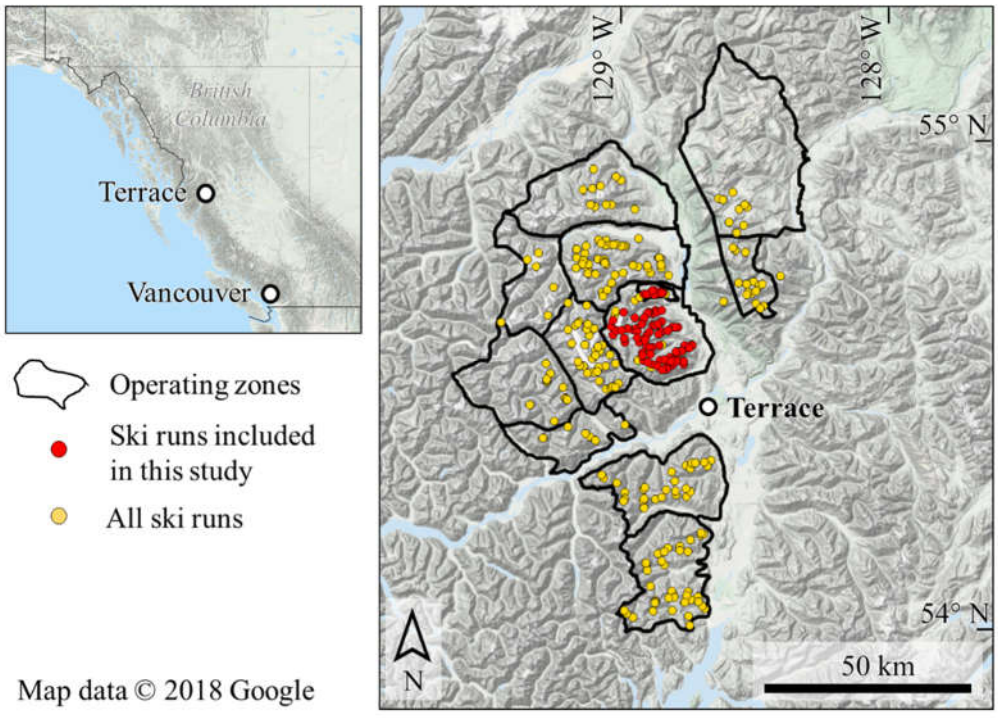
7 Figure 1: North arrow and coordinates

Review

[…] Page 3 Figure 1: Please add direction indication (i.e. north arrow) and coordinates. […]

Response to the review and changes made to the manuscript

Thank you for pointing out this cartographic flaw. To address the reviewer's comment, we changed the figure accordingly.



8 Data set: Use of yellow coding of runs

Review

[…] Page 4 Line 1 - 8: Does NEH use yellow coding of runs that can be opened in the field after a specific condition has been confirmed? If so, could you comment on how this might affect the results of the study? […]

Response to the review and changes made to the manuscript

Northern Escape does not use yellow codes to indicate that runs could be opened in the field conditional on specific conditions observed. No changes were made to the manuscript.

9 Data set: Avalanche size classification

Review

[…] Page 5 Line 4: Delete "for a given path". Avalanche size classification relative to the path size is the US relative scale size definitions and the Canadian size definitions are referenced […]

Response to the review and changes made to the manuscript

We agree with the comment and deleted “for a given path”.

Page 5, line 3ff:

[…] Destructive size is assessed according to the Canadian avalanche size classification (Canadian Avalanche Association, 2014) on a scale ranging from 1.0 (relatively harmless for people) to 5.0 (largest snow avalanche known ~~for a given path~~, which 5 could destroy a village or a large forest area of approximately 40 hectares). […]

10 Data set: Description of avalanche hazard levels

Review

[…] Page 5 Line 8 - 10: Consider deleting the sentence "While this hazard ... ". This is not directly relevant to the study and can be discovered through the references. […]

Response to the review and changes made to the manuscript

We agree with the reviewer that this specification can be omitted from the description of the hazard rating applied by NEH. We made the following changes to the manuscript (additions and deletions highlighted in green and red respectively) to address this comment.

Page 5, line 7-10:

[…] The hazard assessments for each elevation band are concluded by summarizing the overall hazard level that emerges from the combined avalanche problems with a single hazard rating on an ordinal scale from 1 (least hazardous) to 5 (most hazardous; Canadian Avalanche Association, *2015).~~While this hazard scale is derived from the North American Public Avalanche Danger Scale (Statham et al., 2010), it is distinctly different as it does not include the common signal words (i.e., Low, Moderate, Considerable, High, and Extreme) or travel advice.~~ […]*

New reference for the hazard rating:

Canadian Avalanche Association: Avalanche Hazard Rating Scale. InfoEx Advisory Committee. Available at http://infoexhelp.avalancheassociation.ca/wiki/Hazard_rating_definition_table (last access: 3 July 2019), 2015.

11 Data set: Description of terrain classification

Review

[…] Page 5 Line 12 - 28: Please consider deleting these lines and re-wording. The background information on avalanche terrain classification, while interesting, is not very relevant. In my opinion, it would be more beneficial to focus on the methods used in this study to encode the runs and the benefits of these methods. The Wakefield et al., 2018; and Sterchi and Haegeli, 2019; studies are appropriate to describe and to describe how they were applied here in this study. […]

Response to the review and changes made to the manuscript

A similar comment was made by Reviewer #2. We substantially shortened and changed the text of lines 11-30 as following.

Page 5, line 11ff

[…] To identify meaningful patterns between avalanche hazard and terrain choices numerically, it is critical to encode the nature of the available ski runs in a concise, but insightful way. To comprehensively capture of complex nature of entire ski runs into our model in a way that reflects how professional guides perceive them, we used the approach introduced by Sterchi and Haegeli (2019), which groups the ski runs into operation-specific terrain classes based on multi-seasonal patterns in run list ratings (i.e., revealed terrain preferences). In comparison to existing terrain classification systems with small numbers of universal terrain classes (e.g., ATES; Statham et al., 2006; Campbell and Gould, 2013), Sterchi and Haegeli's approach identifies high-resolution, operation-specific ski run hierarchies based on multi-seasonal patterns in run list ratings (i.e., revealed terrain preferences). Sterchi and Haegeli first identified groups of ski runs by clustering similarly coded ski runs over the course of several winter seasons. Subsequently, they arranged the identified groups into a hierarchy that ranges from runs that are almost always open to runs that are only open when conditions are favourable. To better understand the nature of the revealed ski run classes, the authors had a senior lead guide at each participating operation provide a comprehensive but structured description of their ski runs with respect to access, type of terrain, skiing experience, operational role, hazard potential, and guide-ability. Since this ski run classification is based on past operational risk management decisions, it reflects the local terrain expertise and avalanche risk management practices in the context of the available terrain and local snow and avalanche climate conditions (Sterchi and Haegeli, 2019). Thus, this approach represents a more meaningful characterization of ski run classes to analyze professional terrain choices in mechanized skiing operations. […]

12 Data set: Terrain descriptors

Review

[…] Page 6 Line 19 - 20: Please re-word or delete "or non-glaciated or glaciated alpine". […]

Response to the review and changes made to the manuscript

We simplified this sentence (changes highlighted in red):

Page 6, Line 19f:

[…] Most of the skiing is through open slopes at tree line, open canopy snow forest below tree line, ~~or~~ non-glaciated or glaciated alpine. […]

13 Figure 2: Size and caption

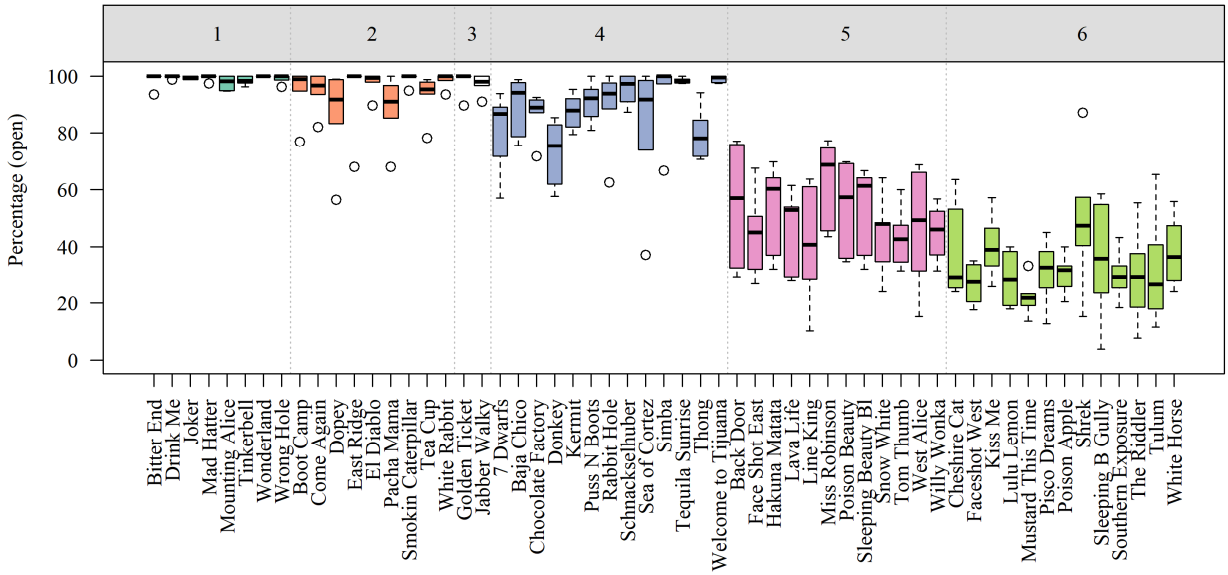
Review

[…] Page 6 Figure 2: Increase the size of the Figure with the aim to increase the font size. It is difficult to read the run labels. […]

[…] Page 6 Figure 2 caption: Change the word "average" to "boxplots" or something similar that describes what data are shown. […]

Response to the review and changes made to the manuscript

A similar comment was made by Reviewer #2. In response we increased the size of this figure to enhance readability. We also changed the caption of the figure (changes highlighted in green).



Caption:

Figure 2: Boxplot of average seasonal percentages of run code 'open' for the 57 ski runs during the six seasons 2012/13 to 2017/18 with the six identified classes of similarly managed ski runs (Sterchi & Haegeli, 2019). Due to the small group size and their outlier characteristics, the two runs of Class 3 were not included in the present analysis.

14 Data set: Table with terrain characteristics

Review

[…] Page 6 Line 18 to Page 7 Line 14: Consider using a table to describe the characteristics of the 6 classes of runs. Consider example photographs of the terrain from each code as these would greatly enrich the understanding of the terrain types. […]

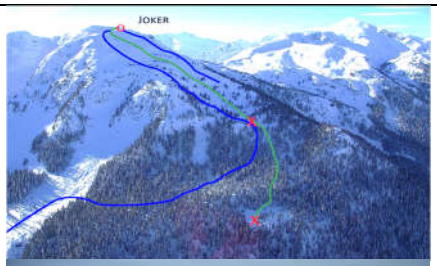
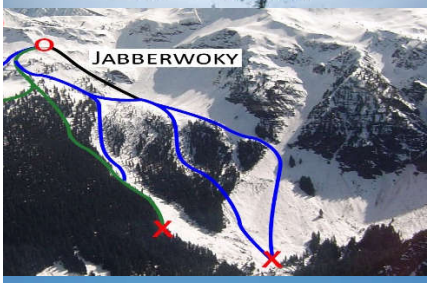
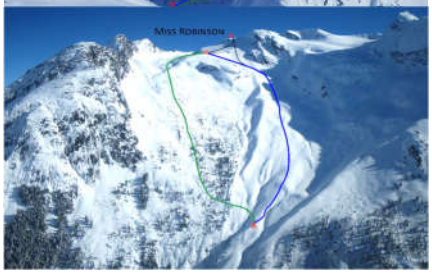
Response to the review and changes made to the manuscript

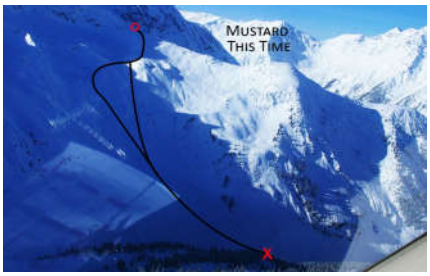
We believe that providing photos of typical runs for each group add value to the presentation of the terrain characteristics and we added the following table to the manuscript:

Page 6, line 10:

[…] Table 1 provides an overview of the general character of the NEH ski runs included in this study. […]

Caption for Table 1: Photos of typical ski runs included in this study. All photos reproduced with permission of NEH.

Class	Number of runs	Typical ski runs	
Class 1	8		
Class 2	9		
Class 3	3		
Class 4	13		
Class 5	12		

Class 6	13		

15 Data set: Descriptor “life-changing”

Review

[…] Page 7 Line 9: Consider re-wording "Life-changing". […]

Response to the review and changes made to the manuscript

The description of the terrain classes is based on the study by Sterchi and Haegeli (2019). They used a survey that was developed in collaboration with senior lead guides to characterize and describe different terrain types. Since the descriptor “life-changing” originates form this survey, we did not make any changes to this manuscript.

16 Data set: Number of avalanche problems

Review

[…] Page 8 Line 27: Page 4 Line 15 details that the CMAH uses nine avalanche problems. It appears as though you removed glide-slab problem from the analysis, which seems appropriate, however could you provide the rational for this? […]

Response to the review and changes made to the manuscript

Thank you for commenting in this inconsistency. Since NEH does not specify glide slab avalanches, we only have eight avalanche problems in our dataset. We propose the following amendments for the manuscript (highlighted in green):

Page 4, Line 15ff

[…] Overall, Statham et al. (2018) and describe nine[1] distinct types of avalanches problems (Dry loose avalanche problem, Wet loose avalanche problem, Storm slab avalanche problem, Wind slab avalanche problem, Persistent slab avalanche problem, Deep persistent slab avalanche problem, Wet slab avalanche problem, Glide avalanche problem, and Cornice avalanche problem) that differ in their development, avalanche activity patterns, how they are best recognized and assessed in the field, and what risk management strategies are most effective for managing them. […]

Footnote 1: Please note that NEH only uses eight types of avalanche problems as they do not specify Glide avalanches problems.

17 Data set: Avalanche problem likelihood

Review

[…] Page 8 Line 31 -32: The CMAH specifies "unlikely" as the lowest likelihood term, how were avalanche problems assessed lower than "unlikely"? […]

Response to the review and changes made to the manuscript

Thank you for highlighting this issue. We realize that our description of the avalanche problem cases that were not included in the analysis was not clear in the original version of the manuscript. We considered cases were both the maximum and the typical likelihood of avalanches were both considered to be "unlikely" to be outliers and excluded them from the analysis. We changed the manuscript in the following way:

[…] Because of the small number of cases, we also excluded avalanche problems where both typical and maximum likelihood were assessed ~~lower than~~ as "unlikely". […]

18 Data set: Exclusion of data point based on avalanche size

Review

[…] Page 8 Line 29 - 31: This sentence is not entirely accurate. Size 1 avalanches are "relatively harmless to people", whereas Size 1.5 avalanches are not specifically defined and are somewhere between Size 1 "relatively harmless to people" and Size 2 "could injure, bury or kill a person". Further, the analysis would likely be more insightful with avalanche problems assessed with Size 1.5 avalanches included. The avalanche problem "Loose Dry" is often associated with smaller more predictable avalanching and often isn't assigned avalanche sizes larger than 1.5. Saying that, better insights into the "Loose Dry" avalanche problem will not substantially alter the results of the paper, so I leave it to the authors to decide whether to change the analysis. […]

Response to the review and changes made to the manuscript

We rerun the analysis as suggested and revised the content of the results section accordingly. The model calculations are robust, and all parameter estimates only differed in the sub-decimal range.

Page 8, Line 29ff

[…] Since avalanches of Size 1.0 ~~to 1.5~~ are considered relatively harmless to people (McClung and Schaerer, 2006), we only included avalanche problems in our analysis that were characterized with a maximum destructive size of at least Size 1.5. Because of the small number of cases, we also excluded avalanche problems where both typical and maximum likelihood were assessed ~~lower than~~ as "unlikely". […]

19 Figure 4: Readability, axis label and caption

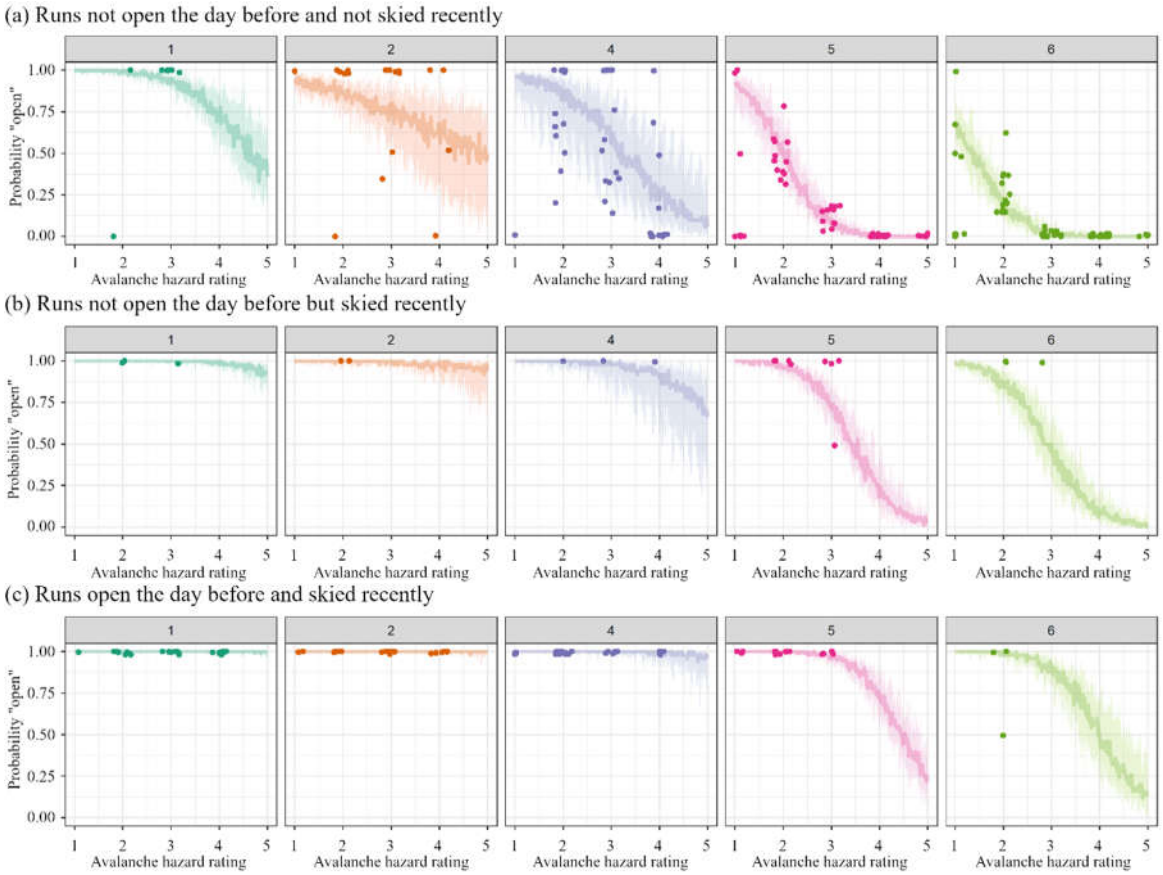
Review

[…] Page 12 Figure 4: Label the X-axis and increase font size for the axes.

Page 12 Figure 4 caption: Add details that the x-axis represents the relevant avalanche hazard rating. […]

Response to the review and changes made to the manuscript

Thank you for pointing out those graphical flaws. We adapted both the figure and the caption accordingly.



[…] Figure 4: Probabilities of ski runs being open for Storm slab avalanche problems shown for increasing hazard levels with (a) a scenario where ski runs were neither open previously nor skied recently, (b) a scenario where runs were not open the day before but recently skied, and (c) a scenario where runs were open the day before and recently skied. The visualizations include probability intervals of 50% and 95% for each ski run class as a whole based on 50 draws from the posterior distribution. Average daily percentages of open runs per ski run class are plotted as points where observations for this scenario exist in the dataset. […]

20 Figure 5: Observation for run “Shrek”

Review

[…] Page 18 Line 23 - 30: Inspecting Figure 5 for the run "Shrek", I do not observe the negative random intercept: it appears to be non-significant and slightly positive. It does appear to show significant positive OR for Deep Persistent Slabs and Persistent Slabs. Please explain. […]

Response to the review and changes made to the manuscript

Thanks you for pointing out this inconsistency. This was a leftover from a previous draft that we forgot to adjust. We deleted the corresponding part of the results description accordingly.

21 Figure 5: Graphical representation of results

Review

[…] Page 18 Figure 5: -Please increase font sizes as this figure is nearly unreadable. - Change the x-axis

for "Relevant Avalanche Hazard Rating" to match the other formats. - Overall, I might challenge the authors to consider if there would be another graphical format that might convey the key points of this Figure more clearly and concisely. - One of the fascinating results from this plot is the increased variance in OR between avalanche problems, for example the OR for each run under Deep Persistent Slabs and Persistent Slabs show much higher variance compared to the more predictable avalanche problems like Storm Slabs / Dry Loose / Wet Loose. The Relevant Hazard Rating also shows higher relative variance in ORs. - A very insightful set of results that are likely available with this dataset and analysis would be the relative difference of run coding probabilities between avalanche problems with increasing levels of avalanche hazard ratings. i.e., Produce Figure 4 graphs for grouped avalanche problems (Storm and Wind and Loose Dry, Persistent and Deep Persistent, Wet Slab and Wet) or each individual problem, and remove the recency of skiing on the run classification. […]

Response to the review and changes made to the manuscript

Thank you for pointing out this issue and the input into the variance of the by-run random effects for different avalanche problem types. We believe that this angle provides some valuable insight into our results and we therefore made the following changes to the manuscript:

- Presenting the random effects in a new table that shows their variance and lists ski runs with significant random effects as a foundation for the discussion in section "Random effects on run level (currently 3.4). We believe this presentation makes the results more insightful and we omit Figure 5.
- Discussing the overall insight from this with an additional subsection before discussing the effects of run code of the previous day and recent skiing on a run

Table 5: Variance in by-run random effects expressed with the standard deviation per parameter. In addition, ski runs with significant positive or negative random effects are listed. The number in brackets indicate the ski run class.

		Ski runs with significant random effects	
Parameter	***SD***	***Positive random effect***	***Negative random effect***
Intercept	*0.63*	*Poison Beauty (5)*	*Donkey (4), Line King (5)*
Relevant hazard rating	*1.12*	*East Ridge (2), Back Door (5)*	*Pacha Mama (2), Tea Cup (2)*
Deep persistent slab	*0.47*	*Shrek (6)*	*Sea of Cortez (4)*
Persistent slab	*0.23*	*Back Door (5)*	-
Storm slab	*0.06*	-	-
Wind slab	*0.06*	-	-
Cornice	*0.05*	-	-
Loose wet avalanche	*0.12*	-	-
Loose dry avalanche	*0.17*	-	-
Wet slab	*0.31*	-	-

3.3. Overall insight into the effect of avalanche hazard

Together, the main effects, interaction effects by ski run class and by-run random effects provide comprehensive insight into the overall effect of avalanche hazard (i.e., rating and avalanche problem

presence) on run list choices. While a significant main effect indicates that there is a consistent general response to changes in hazard across the entire run list, significant interaction effects mean that specific ski run groups respond differently from the overall pattern described by the main effect. Finally, significant by-run random effects show that individual runs substantially deviate from the general and/or ski run group specific response pattern.

The results of our analysis reveal that the run list ratings respond to the different aspects of avalanche hazard in different ways. The response to the hazard rating is characterized by a significant main effect (Table 1), significant interaction effects for some of the ski run classes (Table 2), and large variations in the by-run random effects with some of them being significant (Table 5). This means the observed general effect is superimposed with ski run group and ski run specific responses. The different avalanche problem types influence the run list ratings as follows. For Wet slab avalanche problems, only the main effect is significant (Table 1) indicating that all ski run classes respond to this avalanche problem the same way (Table 2). For Deep persistent avalanche problems and Persistent avalanche problems only certain ski run classes respond (i.e., no main effect, but ski run class specific interactions, Table 2), but certain individual ski runs significantly deviate from the overall class pattern with more variation in the by-run random effects (Table 5). For Loose wet avalanche problems, our model shows a non-significant main effect, some significant interactions effects for the different ski run classes and non-significant by-run random effects without any significant variability among runs. Finally, our model indicates no effect at all for Storm slab, Wind slabs, Cornices and Loose dry avalanche problems. This means that the response of the run list to these avalanche problem types is fully captured by the effect of the avalanche hazard rating.

Overall, the observed patterns in run list responses seem to be consistent with the existing understanding of different avalanche problems and the complexity of their management (Haegeli, Atkins and Klassen, 2010; Wagner and Hardesty, 2014). While the response to the simpler Storm slab, Wind slab, or Loose dry avalanche problems is fully captured by response to the hazard rating alone, the more complex Wet slab, Persistent slab and Deep persistent slab avalanche problems require more nuanced, avalanche problem specific terrain choices.

References:

Haegeli, P., Atkins, R., and Klassen, K.: Decision making in avalanche terrain - a field book for winter backcountry users. Canadian Avalanche Centre, Revelstoke, BC, Canada, 2010.

Wagner, W. and Hardesty, D: Travel advice for the avalanche problems: A public forecasting tool. In: Proceedings of the International Snow Science Workshop, Banff, AB, Canada, 2014.

22 Technical corrections

Review

[…] Page 3 Figure 1 caption: Delete "Geographical". It is obvious that it is a map.

Response to the review and changes made to the manuscript

We deleted “Geographical” from the sentence.

Review

[…] Page 4 Line 5: Change "(i.e., the run is safe to ski with guests)" to "(i.e., the run is available to guide with guests)".

Response to the review and changes made to the manuscript

This is a valuable comment and we changed the sentence accordingly.

Review

[…] Page 4 Line 15: Delete reference"(Statham et al., 2018)". The CMAH has already been referenced.

Response to the review and changes made to the manuscript

This is a valid comment and we changed the sentence accordingly.

Review

[…] Page 5 Line 21: Reword "at the runs scale".[…]

Response to the review and changes made to the manuscript

Thanks you for pointing this out. We changed the sentence to “at the run scale”.

Review

[…] Page 5 Line 33: Add "(2019)" after Haegeli. […]

Response to the review and changes made to the manuscript

Thank you for pointing this out. We changed the reference accordingly.

[…] Sterchi and Haegeli (2019) first identified groups of ski runs by clustering similarly coded ski runs over the course of several winter seasons. […]

Review

[…] Page 6 Line 1: Change "are" to "were" […]

Response to the review and changes made to the manuscript

Thank you for pointing this out. We changed the sentence accordingly.

Review

[…] Page 6 Line 6: Delete "(Sterchi and Haegeli, 2019)". The study has already been referenced. […]

Response to the review and changes made to the manuscript

We believe the reference should stay to be fully clear to what the description is referring.

Review

[…] Page 6 Figure 2 caption: Please confirm whether the Sterchi and Haegeli study is under review or has been published 2019, then update the manuscript accordingly. […]

Response to the review and changes made to the manuscript

Thank you for pointing this inconsistency out. The sentence will included "(Sterchi and Haegeli, 2019)" as the correct reference.

Review

[…] Page 16 Line 12: Typo: "the" should be "they". […]

Response to the review and changes made to the manuscript

Thank you for pointing this out. We changed the sentence accordingly.