Authors' response to 2nd set of comments by Brian Luckman

We thank Brian Luckman for reviewing the revised manuscript and providing comments to help improve this manuscript. We are pleased that the reviewer recommends publication after minor revisions. We address the second set of comments on the revised version (ms2) below.

Overall comment

I reiterate my general comments from the initial review. *This paper presents snow avalanche histories from 12 avalanche tracks, 3 from each of four regions in the Northern Rocky Mountains of N.W Montana based on tree-ring data from 637 trees. These data are used to define the history and frequency of large magnitude avalanches for individual tracks, sub-regions (mountain ranges) and across a region of ca 3500 km^2. The paper then estimates the efficiency of using various combinations of these chronologies to estimate a regional chronology of high magnitude avalanches in order to guide future sampling strategies for estimating regional avalanche activity. The techniques used are based on prior usage from the literature and, to my knowledge, the attempt to assess the efficiency of developing a regional history is novel*

The authors have addressed many of the issues raised in my earlier review. However, I still maintain that there needs to be some indication of the relative importance of the various inputs (GDs) to the determination of growth disturbances.

Peitzsch et al. Response:

We included a table (Table A3) in Appendix A indicating the proportion of each growth disturbance signal to each growth disturbance class used in this study. This illustrates the relative importance of each signal to the final GD class. We also included a sentence in the Results (line 288) and elaborated on this in the Discussion (lines 476).

Secondly there needs to be a stronger recognition that although significant large avalanches can be identified from the longer tree ring records, any assessment or comparison of recurrence intervals must be based on an adequate sample base i.e. one without significant gaps due to the influence of fire or probable removal of parts of the record by previous avalanche activity. Therefore there should be some assessment of the quality of the record from individual tracks and the discussion of recurrence intervals should be restricted to their "scaled" data set.

Peitzsch et al. Response:

We included further discussion of the "scaled" dataset and included an assessment of the quality of records from individual paths (line 491). Revised to: "The results from examining return intervals during a truncated period from 1967-2017 across all paths illustrate that several of the individual path return interval results should be treated with caution (e.g. JGO, LJC, and LGP). The difference in minimum and maximum return interval values is a function of a decreasing sample size back in time. The minimum return interval values in many of the paths are concentrated during recent periods. This is a limitation of using dendrochronology to estimate return intervals. Comparing avalanche return intervals across individual paths should also be treated with caution given the variable nature of sample availability across paths. This variability across individual paths further provides reason to evaluate the number of paths necessary to create a regional avalanche chronology from tree rings. Most of the paths have a reasonable record over this truncated period and also highlight the importance of strategic sampling in numerous avalanche paths. While dendrochronology underestimates avalanche activity, we show that sampling enough paths across a region provides a reasonable estimate of avalanche activity at this scale."

The authors provided a set of responses to my initial review comments plus a revised manuscript (identified herein as ms2). Attached please find two sets of comments

(i) my comments on several of these responses prior to evaluation of the revised ms (*text in italics is my responses)*
(ii) Comments on the revised manuscript.

PART 1 responses to previous comments

BHL Comment: One of the principal difficulties is the comparison of statistics such as RI values between sites based on records of different length where the RI values are strongly related to survival of older individuals within the avalanche path. Perhaps a comparison based on e.g. the last fifty years would be better to compare differences between tracks. **AU Response:** We subset the period of record for each path from 1967- 2017 and compared RI values. *See Comments on ms2*

Peitzsch et al. Response:

Addressed in comments on ms2.

BHL Comment. There is no specific exploration of the relationship between avalanche activity and climatic factors.
AU Response: Climate and regional avalanche relationships are the topic of a follow-on manuscript using this dataset that is currently undergoing peer-review.
In this regard, it would be interesting to know what proportion of the avalanches are "direct action" i.e. directly triggered by precipitation vs delayed action due to changes in the condition of the snowpack since the former are more directly controlled by (regional) precipitation events

Peitzsch et al. Response:

Noted. Thanks for the suggestion.

Detailed and specific comments:
BHL Comment: 312 More importantly were results from these cores actually used in the analysis.
AU Response: These "cores" were simulated cores as if we indeed cored the sample as opposed to using the full cross section. *This is a misunderstanding. The question was rather were data from the cored trees used in the analysis (not the simulated cores from the cross section examples).*

Peitzsch et al. Response:

Cores were used in the overall analysis. See line 287.

BHL Comment: 334 Table 4 An additional line identifying the sub region should be added to the top of the table.
AU Response: We added the line*. This refers to the new Table 3 and this line was not added*

Peitzsch et al. Response:

We now added the sub-region at the top of Table 3.

BHL Comment: 337 JGO is a function of the early record but why LJB? LJB and LJC are 26, LGA is 25 and shed 7 is 28?
AU Response: We don't really follow this comment. What are the values you reference for LJB, LJC, LGP (LGA [sic]) and S7? Those values aren't the RI for any of those paths.
Values are the difference between the max and min values in old Table 4 JGO is 68

Peitzsch et al. Response:

Thanks for clarifying. We addressed this issue with more explanation in the discussion of the "scaled" RIs for the individual paths (line 491)

BHL Comment: 338-40 surely the similarities and differences between tracks reflect the length and nature of the avalanche record in each track? Differences/ similarity in return intervals are partially dependant on the length of record.

AU Response: As we demonstrated to your comment in the beginning of the review, "scaling" the period of record makes a difference in only the two paths that we already discuss as being different in terms of RI values. Here is the response to that original comment: We subset the period of record for each path from 1967- 2017 and compared RI values. Nine paths exhibit no change in RI values when compared to the full record and one path RI values decreased by 4 years. We observed larger changes in the other two paths; JGO path where only one avalanche year was recorded (down from 5) and the median RI in LJC changed from 22.5 years to 35 years. We previously discussed JGO and LJC and the variable RIs of each of those paths in the Discussion. This exercise highlights that discussion that these two paths were indeed slightly different than the others. We added the above text (ca. 348-351) to illustrate that we examined the most recent 50 years to "scale" the return periods to account for loss of older trees.

The lack of change between the original and "scaled data" is largely because of the similarity of records between the two data sets as most sites only have records for the period after 1967. It does not address the gaps in several records.

Peitzsch et al. Response:

We chose to scale the data to this time period precisely because of this. This allows a comparison with the greatest number of responses. The gaps are indeed due to other factors which we now address in the discussion in the updated version of the manuscript. See responses below and above (and line numbers) to specific comments in the new manuscript on this topic of RIs.

BHL Comment: 405-6 These trends are mainly an effect of the increased sampling of avalanche years

AU Response: Yes, these trends are likely a function of increasing samples through time which is why we mention them, but don't hang our hat on the trend results. The RAAI is simply another way to view a regional chronology using techniques from previous literature to allow for comparison.

The point here is that the trend has nothing to do with trends in avalanche activity but is mainly due to the increased availability of sites and sampling over time and should therefore be deleted (lines 420-424 in the 2nd ms)

Peitzsch et al. Response:

We deleted the reference to the trends in the Results as well as the Methods and Discussion.

BHL Comment: 435 up into the bottom? English? Is the bottom the end or center of the track?

AU **Response:** Revised sentence to read "However, at several sites we also collected samples into the bottom of the track (S10.7, Shed 7, and 1163) rather than just the runout zone." (lines 447-448). The bottom is the end of the track just above the runout zone.

451-2 (ms2) Still not clear to me. How is the end (bottom) of the track different from the runout zone? From the context it would appear that the bottom here refers to the middle of the track upvalley (i.e. having smaller avalanches) of the runout zone

Peitzsch et al. Response:

We revised this sentence for clarity:
"At several sites we collected samples at the upper extent of the runout zones (S10.7, Shed 7, and 1163)." (line 444)

BHL Comment: 451-2 how frequent is tree removal? What % of GDs are termination of growth vs other indicators of avalanche damage?
AU Response: We don't really know the frequency of tree removal. It depends on the impact pressure of any given avalanche and this isn't something we can tease out from our data. It is not possible to determine the real % of GDs due to termination of growth because we can't assume the tree was killed by an avalanche for all of our dead and downed samples.
This could be tested by comparison of outer ring dates with known dates of avalanches (based on other evidence) in the track. Tree mortality could be caused by insects, storm damage, etc. and a subsequent avalanche could then transport the tree. However, if we assume that all sampled trees were removed by an avalanche (a rather large assumption), then we can take the number of cross sections (614) divided by the number of GD (2134). This provides a rough estimate under this assumption. 614/2134 × 100 = 29% of GDs are termination of growth. *This is not clear. You clearly identified some outer dates as termination of growth by avalanches and not others. So what criteria were used if you scored termination of growth as a GD.?*

Peitzsch et al. Response:
We included termination of growth due to avalanches based on the historical/observational record as is classified as a C_1 response. This is also included in the new Table A3 as "Termination of Growth". Some of the samples even have earlywood when the avalanche occurred in the late winter or early spring. However, when we have termination of growth that does not coincide with a known avalanche year from the observational record we cannot assume it was killed by an avalanche. So the proportion included in Table A3 is when termination of growth coincides with a known (observed) avalanche.

BHL Comment: 538 What is an avalanche cycle chronology?
AU Response: Including the word cycle shows that, at the regional scale, we are able to capture major avalanche cycles (widespread avalanche event) through time. We added "(widespread avalanche event)" to line 558. *Cycles is the wrong word*

Peitzsch et al. Response:
We removed the word cycle and replaced with "year". See comment below in new ms.

PART 2 Comments on the revised paper (line numbers as per

ms2) Line comment
151 within the previous

Response:
Revised. (line 150)

156 also depends on the available length of record in the trees sampled.

Response:
Added " This also depends on the available length of record within a given avalanche path." (line 156)

185 verified dating against?

Response:
Added "dating" to read: "We assessed cross-dating calendar-year accuracy of each sample

and statistically verified dating against measured samples...” (line 185)

205 Classification of GDs. The response to my earlier comment on the need for information about the number and types of GDs was as follows “The GD class incorporates type in a systematic way for avalanche identification. Simply using type places imbalanced emphasis on certain types and not the cumulative signature of other types”. However, although GDs as defined do summarise the quality of evidence in an individual year I maintain that it is important for the reader to understand what proportion of the GDs in classes 4 and 5 were based primarily on scars vis-a-vis other criteria. The selection of sites for cross sections suggests that scars were of primary importance in obtaining evidence of past avalanche events.

Response:

See response above where we include this table in Appendix A, the Results (line 288) and elaborate in the Discussion. (lines 476)

236 scars or injuries = GDs? The text still does not indicate the approximate nature of these GD values i.e. how many of the GD>3 were based on primarily on scars, reaction wood, TRDs, etc or alternatively the combination of several lines of evidence for the same year. This is important for readers to ascertain the relative significance of the principal lines of evidence on which these chronologies are based.

Response:

See response above where we include this table in Appendix A, the Results (line 288) and elaborate in the Discussion. (lines 476)

242-3 “We use these RI derived after filtering events for confidence as the intervals throughout the study” .clarify? = “We use these RI values determined after filtering events throughout the study”

Response:

Revised to: “We use these RI values determined after filtering events throughout the study.” (line 242)

274-9 the results of this analysis are discussed later (line 420, see below) where my comment is that they have little or no value for discussion of changes in avalanche activity. Therefore this text should be removed.

420-4 The point here is that the trend has nothing to do with trends in avalanche activity but is mainly due to the increased availability of sites and sampling over time and should therefore be deleted.

Response:

To both comments: see response above. We removed this text throughout the manuscript.

298 The accepted abbreviation for *P. engelmannii* is PCEN not PIEN (PI=pinus). See also Fig 3 caption and label lowest axis Fig 3

Response:

Thanks for catching that. We revised both to PCEN.

306 Betul =betula?

Response:

Thanks for catching that as well. We revised to BETULA in axis and caption.

Section 3.1. I remain to be convinced of this analysis. You should at least provide both sets of summary data.

Response:

We included summary data in new Table A4. We also want to emphasize that we are not suggesting that one must use only cross sections. We added this to the Discussion "We do not discount any studies that use cores for reconstructing avalanche chronologies and understand there are sampling limitations from environmental and policy perspectives in different regions as well as financial and processing constraints. However, we are suggesting that if the ability to collect cross sections exists, then it is advantageous to collect them."
(line 439)

323-4 invert order of sentence "...no clear pattern of similarly identified years from paths….. "

Response:

Revised to "There was no clear pattern of similarly identified years from paths physically closer in proximity to each other." (line 317)

326 weighted?

Response:

Revised to "When we applied the W_{it} process step, the number of identified avalanche years did not change for any individual avalanche path compared to application of the double threshold method alone." (line 319)

Table 3 (old Table 4) a line identifying the sub regions was not added.
This table clearly indicates the strong differences in the reconstructed avalanche histories from these tracks. The only sites that would appear to have a relatively comparable record are the three Red Meadow sites. The others rarely overlap or have unique characteristics (e.g. shed 10-7).

Response:

Added sub-regions heading to Table 3.
We revised the discussion to reflect this (line 491). We also maintain the comparisons as evidence to the overall objective in the study, which is to evaluate the notion of "regional" avalanche chronology from tree rings.

Track LGP has only 3 avalanches. In the table max and min RI are 30 and 8 not 27 and 3 -- and how can one have a median of 8 and mean of 12.67 from two data points?

Response:

When revising this table we mistakenly left out 1974 in LGP. We added that to Table 3.

343 these sub regions not identified in Table 3

Response:

Added sub-regions heading to Table 3.

345 GTSR is the most similar sub region? But in table 3 WF region has medians of 3, 5 and 8, GTSR has medians of 8, 14 and 28.5.

Response:

We revised to read "The avalanche paths within the WF sub-region had the most similar return intervals of any of the sub-regions." (line 339)

353 probably because these paths have a reasonable record over this interval

whereas 54-3, JGO and LJC are demonstratively different.
Response:
Added text to the Discussion (line 491).

352-7 The similarity between results from the "truncated" and complete records is because the records in the "truncated" and complete records are basically similar when the unusual sites are deleted.
Response:
Added "If we removed 54-3, JGO and LJC for this comparison, the records from the subset period of record are similar to the complete records for the other paths in the study." (line 349)

Table 6 column 3; 24+1=27? Column 6;22+11=34? (included+ excluded = total)
Response:
To clarify we added this to Table 6 caption:
"'# not in regional' refers to avalanche years identified in that particular combination of paths but not identified in the regional record."

403 LGP has the next greatest sample size? Trees sampled or events? LGP only has 3 avalanche events in Table 3?
Response:
Sample size.
"...(the other path with the greatest size of sampled trees)..." (line 397)

427 so scars are identified as such?
Response:
Changed to "When we examined avalanche paths that exhibited at least one GD during avalanche years identified in the regional chronologies (i.e. no thresholds used), the *POD* is generally greater." (line 415)

436 not surprising as these are the most similar and consistent records.
Response:
Added this to the Discussion: "The WF sub-region captured the regional chronology most consistently because of the similar and consistent records within the sub-region." (line 596)

450 collection from areas?
Response:
Revised to "We targeted sample collection in the runout zones..." (line 443)

468-9 10-50% is a large range. Some data should be provided to support this comment or it should be deleted.
Response:
We deleted this as the historical record is incomplete which is the reason the range is large.

490 It is not clear whether the difference is between (i) the Reardon results (not given) and those for path S10.7 in this paper or (ii) between path S10.7 and other tracks in this paper.
Response:

Revised to “This is likely the root of the difference for S10.7 and the other paths in this study and...” (line 485)

499 The problem here is that these large RI values reflect the irregular preservation of evidence for large avalanches. One is sampling a truncated distribution with gaps in the evidence due to removal by intervening avalanche or fire events and, in a single track, these cannot be differentiated from gaps in avalanche activity. Therefore it is not possible to distinguish whether these large RI values are real or an artefact of the preservation of data. Consequently the subsequent discussion of possible causes for the lack of large magnitude avalanches in the JGO track are invalid because of the limited sampling of sites east of the divide.
The real problem seems to be that, in order to provide relatively secure estimates of recurrence intervals of large avalanches one needs an appropriate sample base without obvious temporal gaps. As one goes back in time this becomes increasingly difficult. Therefore there needs to be explicit evaluation of the records in some of these sites and the results from sites with limited sample depth should be treated with caution.
Response:
Removed discussion of potential climatic reasons for JGO and revised to:
“JGO contains the maximum return interval for any path in the study, and the return intervals are significantly different than numerous other paths. A lack of recording data after one large avalanche event could easily skew this value. To understand if this value is accurate, we would have to sample adjacent tracks to determine if the return intervals are similar or not. An appropriate sample base without large temporal gaps is necessary to fully provide an accurate estimate of return intervals within a single avalanche path. While the sample size is sufficient for this individual path, the results should be treated with caution due to the temporal gaps. In other words, the large return interval values may reflect the irregular preservation of evidence for large avalanches as opposed to an accurate estimate of return intervals. Therefore, we cannot fully explain the large maximum return interval for this path.” (line 502)

515 quantitative data to support this?
Response:
See line 343 and Figure A1.

525-6 and also local avalanche/ stand/ fire history.
Response:
“The differences between individual avalanche paths as well as sub-regions are likely due to localized terrain and weather/climate factors and the interaction of the two (Chesley-Preston, 2010) as well as local avalanche, forest stand, and fire history.” (line 530)

530-1 it is also important to establish the relative importance of avalanche triggers (i.e. direct vs delayed action avalanches) when establishing relationships with climatic controls.
Response:
Yes. The relationship between direct action avalanches and spatial extent across a region vs. delayed action avalanches within avalanche paths across a region in the context of climatic controls is an important question for future work.

586 use of cycle (see earlier comment on ms1) replace cycle with year
Response:
Changed to “year” (line 593).

602 OK see earlier comment on line 420

Response:
See response above. Removed this from manuscript.

Table A3 Modify 2nd column heading and reduce width of table to two columns –
Response:
Modified 2nd column and centered text which is the reason it looked like 3 columns.

Figure A1 Statistical significance of the values? Caption should indicate source data are in Table 1.
Response:
Added to caption of Figure A1: "Statistical significance is $p < 0.05$. See source data in Table 1."