

# Interactive comment on “Spatial and temporal analysis of fatal off-piste and backcountry avalanche accidents in Austria with a comparison of results in Switzerland, France, Italy and the United States”

by

Christian Pfeifer et al.

Anonymous Referee #1

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The authors explore trends in the annual number of backcountry avalanche fatalities in Austria and compare these to four other countries. The temporal analysis is carried out applying a generalized additive model. The study evaluates whether linear or non-linear functions describe the annual fatality data best. Additionally, maps showing the spatial distribution of avalanche fatalities by municipality in Austria are presented. These are the novel aspects of the presented work. The topic of the study is within the scope of the journal and will likely be of interest to the journals audience.

General comments

I would like to address two main issues concerning the manuscript: (1) the insufficient discussion of the results and embedding of the study within the context of current research, and (2) the time-period analyzed.

(1) Concerning the first point, potentially relevant studies are mentioned in the detailed comments below.

**(Our point by point reply to the reviewer’s comments in bold)**

**Thank you for the many constructive comments. We will bring up to date the discussion of our results in the context of the relevant literature. See below for more comments and details regarding the suggested references.**

(2) The most recent five years (2011/12 - 2015/16) were not considered in this analysis. However, their inclusion would greatly increase the currency of the analysis. This seems particularly important, as the authors suggest avalanche prevention measures in their study (abstract and lines 282-286). Extending the data-set until 2015/16 would allow a comparison to results shown in recent publications, in which (not significantly) increasing backcountry avalanche fatality numbers were noted during the most recent years (e.g. United States (Birkeland, 2016) and European Alps (Techel et al., 2016)). Therefore, I strongly recommend to include these years, not just for Austria, but also for the other countries.

Detailed comments, by section

**We are going to extend the database at least up to 2015 (having calculated first results in case of Austria). We checked that this is able for both: The Austrian data and the international data. Further on we are checking our data according to the comments of Techel.**

**(Originally, the database of the survey was established in 2011 within the frame of a research seminar at the University of Innsbruck).**

Abstract

I. 29: The study addresses backcountry avalanche fatalities, not avalanche fatalities as written.

**We will change this; thank you for this advice.**

I.

30-31: There are numerous studies which showed that the backcountry and out-of-bounds avalanche fatality numbers are not constant (e.g. France (Jarry, 2011, Fig. 3); Switzerland (Harvey and Zweifel, 2008); United States (Page et al., 1999); Italy (Valt and Pivot, 2013); European Alps, France, Austria, Switzerland, Italy: (Techel et al., 2016)).

**We mean relating to Austrian data. We change to:**

**"to the widespread opinion in Austria, that the number...."**

**Here are some comments (press, World Wide Web, literature) referring to Austria:**

**derStandard 15.1.2012: 25 Lawinentote werden akzeptiert citing Thomas Wiesinger (Universität für Bodenkultur); Lawinenkolloquium 2012 Salzburg:**

**"Je nach Schätzung gibt es in Österreich 350.000 bis 650.000 aktive Skitourengeher. Trotzdem ist die Zahl der Lawinentoten über Jahrzehnte hinweg konstant."**

**Url:**

**<http://derstandard.at/1326502791533/Maengel-bei-Lawinenwarnung-25-Lawinentote-werden-akzeptiert>**

**SpringerMedizin.at 18.1.2016: Schneemenschen unter sich:**

**"20 Menschen sterben in Österreich jeden Winter den Weißen Tod, sie enden jämmerlich begraben unter Schneebrettern. Doch ihre Zahl bleibt konstant, während sich jene der Skitouren- und Variantengeher der Millionengrenze annähert."**

**Url:**

**<http://www.springermedizin.at/schwerpunkt/lebensstil/?full=51211>**

**Further on, the book of Elke Roth**

**Roth 2013: Lawinen: verstehen -vermeiden-Praxistipps. Bergverlag Rother, München p141:**

**"Alle Ursachen zusammen haben dazu geführt, dass die Zahl der Lawinentoten in etwa konstant geblieben und nicht mit der Zahl der exponierten Personen gewachsen ist."**

**Citation:**

**@Book{,**

**author = {Roth E.},**

**title = { Lawinen: verstehen -vermeiden-Praxistipps },**

year = {2013},  
pages = {303},  
publisher = {Bergverlag Rother},  
address = {München}

Introduction

I. 43-44: specify the "various" reasons which are of special public interest.

- mass media; bad news are good (interesting) news
- see e.g. public interest in the Galtür 1999 disaster (or in the Eiger north face climbing disaster in 1936)
- public interest of protection against natural hazards

But we change to:

"which are of special public interest, see e.g. the Galtür avalanche disaster in 1999."

with a citation of the a master thesis from the 1980s which addresses this topic:

```
@Book{  
  author = {Januskovecz A.},  
  title = { Zeitungsberichterstattung über Naturkatastrophen, Ansätze für die forstliche  
  Öffentlichkeitsarbeit zum Thema Lawinen –Hochwasser –Muren },  
  year = {1989},  
  pages = {112},  
  publisher = {Hochschulschrift: Univ. für Bodenkultur, Dipl.-Arb.},  
  address = {Wien}  
}
```

I. 47-48: additionally to Brugger et al. (2001), more recent publications should be investigated whether this statement is still considered true (see also the before mentioned references concerning the abstract)

**We will do this, see above.**

I. 52: not clear how the citation of Ammann, 2001 is related to the statement by Harvey and Zweifel (2008)

**You are right, we will skip this citation!**

I. 53-55: additionally, in their annual reports the Österreichische Lawinenwarndienste (2016) provide a 20-year overview of the avalanche fatalities in Austria (e.g. Fig. 4, p. 33 in the 2016 report)

**This is just a copy of the idea of the Kuratorium für alpine Sicherheit (Kurasi) which was used in the recent reports of the ÖLWD. This kind of the graphics is a "tradition" of the Kurasi report since the early 1990s. However, we have no problem with adding this citation.**

I. 66-69: there are brief summaries showing long-term trends of Austrian backcountry fatality statistics in the book by Höller (p. 91, 2015) and also in the 2016 report of the Österreichische Lawinenwarndienste (2016) (pages 210 and 211, results based on Techel et al. (2016))

**The citation of Höller is referring to a presentation of mine in Palermo 2013 (based on the data of this paper which has not been published yet in a peer reviewed journal)**

**But, thank you for bringing the highly relevant paper of Techel et al. (2016) to our attention. At the time of writing this was not turned up by searches in the Web of Science. Indeed, there are many parallels between our work and that of Techel. However, there are also important differences in the population considered. Specifically, the group of backcountry and off-piste fatalities in our study is just a subset of avalanche fatalities as analyzed in Techel et al.**

**We, of course, will update the discussion considering the new results of Techel et al.**

Data and methods

I. 105-111: It should be mentioned, when and how the ICAR data was accessed (URL or citation). It is unclear which of the mentioned ICAR fatality categories were used in the analysis.

**Due to personal contact of Mr. Höller with the ICAR. We mentioned the ICAR fatality categories in line 110.**

**And as written above, we will check the ICAR data according the statement of Techel in SC1: "comment on table 1".**

I. 117-118 and I. 129-130: I find this very difficult to understand. Did you calculate the trend for each municipality (aggregating the data in terms of location, I. 117-118) separately and then aggregate it again for the regional analysis? Or did you use the annual fatality numbers (all of Austria) for the trend analysis, and the total number of fatalities for each municipality? Please explain this more clearly.

**The meaning is as follows: Aggregating the spatio-temporal DATABASE in terms of municipalities which means summing up all over Austria resulting in annual fatality numbers (or summing up over the years resulting in data stratified for municipalities).**

**We will change this such as (in order to be more clear):**

**"After aggregating the spatio-temporal database in terms of location (summing up over the municipalities resulting in annual fatality numbers) we propose ...."**

I. 125: You state that in your "opinion" AIC and BIC are better criterion than reporting p-values. You should explain why using AIC and BIC would be more appropriate (advantages, disadvantages). Possibly, you could also give a reference.

Comparisons with p-values (e.g., from likelihood ratio or Wald tests) always pertain to comparisons of pairs of nested models. When a larger number of models has to be compared this typically leads to (a) many pairwise comparisons, (b) possibly non-nested models, (c) multiplicity of tests. Therefore, in such situations information criteria are often used for model selection rather than significance tests. This is particularly popular in regression analysis (see e.g., Venables & Ripley 2002) and ARIMA modeling for time series (see e.g., Cryer & Chan 2008).

```
@Book{  
  author = {William N. Venables and Brian D. Ripley},  
  title = {Modern Applied Statistics with \proglang{S}},  
  edition = {4th},  
  year = {2002},  
  pages = {495},  
  publisher = {Springer-Verlag},  
  address = {New York}  
}
```

```
@Book{  
  author = {Jonathan D. Cryer and Kung-Sik Chan},  
  title = {Time Series Analysis With Applications in {R}},  
  publisher = {Springer-Verlag},  
  address = {New York},  
  year = {2008}  
}
```

## Results and Discussion

The results section refers to the graphs and tables, but does not present any data. Data is presented mostly in the discussion section.

However, in the result section it is referred to tables and figures at the end of the paper (according to the guidelines). Some journals ask for this kind of manuscript composition we did. But nethertheless, we are open for possible changes.

The results should be discussed in more depth than is currently the case.

We would like, if wished, to extend the discussion adding

- the tables of avalanche counts for municipalities with the most avalanche events in Austria
- the list of avalanche events with highest counts

in the regional part of the paper. We skipped these tables in the current version in order to keep the paper short (instead of tables we tried to use citations, see e.g. line 261).

In any case, there are further points which we would like to address in the discussion, see below.

Trend analysis

The advantage and disadvantage of the proposed statistical approach should be discussed, as this is the main methodological novelty compared to previous publications exploring avalanche fatality statistics. In particular, the following points might be of interest to the reader:

- To what extent do single (or a cluster of) winters with many (or very few) fatalities influence the trend lines shown?

**A good question! One single extreme event (winter) has almost no effect on the nonlinear trend function. In our opinion, the GAM estimator behaves robust (in contrast to the linear model or the running mean of Techel et al. 2016). See e.g. the single extreme winter ( $\geq 40$ ) of “Austria total” in the early 1970s or the single extreme winter of “France total” in the early 1990s.**

There are clusters of winters which do have an influence on the profiles e.g.:

- Austria total (6 larger values) in the mid 1980s - see paper line 186-194
- Switzerland off-piste (5 smaller values) in the early 1990s
- France total (5 smaller values) around 1990; despite the single extreme event mentioned above
- Italy total (5 smaller values) in the mid 1990s.

We will address these points (especially the clusters of “extreme” winters) in the final version. Thank you for this advice.

- In your analysis, you analyze subgroups of the data (e.g. off-piste fatalities only). One of the arguments Techel et al. (2016) considered relevant for combining national fatality statistics was the assumption that single multi-fatality events and/or years with many fatalities potentially could have a large effect on trend statistics.

**We do not think that single multi fatality events have an influence on the GAM estimator; see our comment earlier. Single multi-fatality events in Austria, e.g. Werfenweng 1982 (13 fatalities), Niedensill 2000 (12), Galtür 1999 (9), have an influence on the Markov random field (MRF) estimator (see discussion line 260) but not on the estimated temporal profile of Figure 1.**

Please discuss to what extent this may be relevant, in particular for the trend calculation of the off-piste subgroup, which are characterized by even fewer incidents per year. Please explain whether relatively small accident numbers could be a reason for the sometimes highly fluctuating trend lines (you already briefly comment on this for the Austrian data on lines 193-194).

**Because of the smoothness of the GAM estimator, we do not observe fluctuating trend lines (which is the case if we use the running mean, see Techel et al. (2016)), even if the accident numbers are rather small.**

**(Maybe in case of Austrian off-piste data, we assume some uncertainty because of a boundary effect at the end of the temporal profile, see the following:)**

- The 90% confidence intervals shown in the figures is large at the beginning/end of the time-series. This highlights the greater uncertainty of the trend line calculation. Readers not familiar with confidence intervals, might miss this point when looking at the figures. Therefore, I propose to discuss these uncertainties in the text.

**These effects are due to boundary effects which are well known in the analysis of time dependent data. As a result of observing no data on the left at the beginning and no data on the right at the end, the estimates at the beginning and the end are more uncertain.**

**Thank you, we will mention this point in the discussion of the final version.**

- Often, the 90% confidence band is relatively wide, which raises the question whether the reported trends can be interpreted as statistically significant. For instance, the trend line of the Swiss off-piste fatalities drops in the nineties and rises in the 2000's. However, the max of the confidence interval in the 1990's is about as high as the minimum in 2000. Therefore, I wonder if the peak around the year 2000 can be considered statistically significant. I recommend you show which of the trends are statistically significant.

**Our AIC/BIC approach is model selection between the constant, linear, or nonlinear model on the whole. In this paper we did not test significances for subintervals (eg.  $\geq 2000$ ) knowing that the number of cases would be too small. We are only able to give descriptive analysis (more or less by visual inspection): In case of Switzerland off-piste, the nonlinear model is preferable; we notice smaller counts in the early 1990s (please take notice of a cluster with 4 (or 5) small values) and large(r) counts in the early 2000s. See also Techel et al. (2016) with larger number of counts in the early 2000s.**

**Maybe, the extreme estimates in the early 1980s are due to uncertainties because of the boundary effect as described above.**

You show in Table 2 that the non-linear model is preferable for all the European countries (except for Austrian off-piste fatalities). This is a main result of the study. However, I suggest you discuss potential reasons for the Austrian off-piste fatality trend line being linear, when all the other European trend lines are non-linear. The trend line for the Swiss backcountry fatalities (Fig. 3) drops from almost 30 in 1983/84 to approximately 15 in the mid-1990's (Fig. 3). This seems like a very strong decrease and is in contrast to the slight but not significant decrease shown/described for the 1990's (e.g. Fig. 3 in SLF (2016) or in Techel et al. (2016)).

**Good question: It could be some uncertainty at the beginning of the time profile (larger confidence band). Another reason could be that the data of Techel 2016 are different to our data ("uncontrolled terrain").**

**However, we will mention in the final version that the GAM estimates of the early 1980 Swiss-backcountry counts (maybe others too?!) are rather uncertain because of the large confidence band at the beginning – see discussion above.**

On lines 186 to 194 you note a peak in the fatality numbers for Austria in the 1980's, and conclude that higher precipitation during these years might explain this. Looking at off-piste fatalities only, you do not note this peak for Austria. These two statements seem contradictory. It may also be of interest that several authors noted increased numbers of recreational avalanche fatalities in years with less snow (e.g. Luzian, 2000; Valt et al., 2009; Valt and Cianfarra, 2012).

**It is supposed that increased snowfall has an effect on increased avalanche counts (although not fully examined and published, we have some evidence for this in our research, e.g. increased snowfall in the 80's in the "St. Anton" cluster).**

**However, we have no idea (empirical explanation, citations which we could mention in the paper) why there is a peak in the total case and no peak in the off-piste case. We simply observe that increased snowfall in the 1980s has no effect on off-piste avalanche fatalities in Austria. Last but not least, we observe larger counts of off-piste fatalities in the 1980s if we look at the counts of Switzerland, France and Italy.**

**Finally, we note that we will respond to all these points in the final manuscript.**

#### Regional analysis

The regional analysis showed spatial clusters in two regions (Arlberg and Sölden, Fig. 7 and 8). However, an in-depth discussion of potential reasons for these hot-spots is lacking. For instance, visually comparing the clusters shown in Fig. 8 to the size and spatial distribution of ski resorts in Austria (map in Fig. 1 and list of top 20 winter sport municipalities in Fleischhacker (2016)), seems to indicate that these clusters correlate to the spatial distribution of ski resorts in Austria (and hence a greater number of recreationists riding off-piste?). Even though Fuchs et al. (2015) explored the spatial distribution of houses and residents exposed to snow avalanches, the spatial pattern looks again similar to those in Fig.s 7 and 8. with the highest density in the Arlberg and southern Tirol regions.

**Thank you for this interesting congruity, we will add these citations for discussion in the final version.**

In general, I would consider it beneficial if you could include other relevant parameters in the spatial analysis. For instance, the spatial clusters of off-piste fatalities could be compared to the distribution and size of the ski areas in the municipalities in Austria (e.g. the data behind the map in Fleischhacker (2016)), while calculating the density of fatalities per surface area above a critical elevation might show if these clusters are related to Alpine topography (e.g. in a Swiss study Techel et al. (2015) considered the elevation range where more than 95% of the recreational accidents occurred).

**We propose to add a map visualizing the municipal Alpine terrain ( $\geq 1500\text{m}$ ) with additional information (points) of the 50 largest municipalities relating to overnight stays in the winter**



**season 2016. We are able to calculate this using an Austrian digital elevation model and the information of overnight stays from the federal states Vorarlberg, Tyrol and Salzburg. As a result of this we are able to compare the maps in the discussion (which I prefer from an epidemiologic point of view instead of calculating the density of fatalities).**

In the methods section (lines 143-147) you describe the use of Markov random fields to identify the regional hot spots. In the results section and Fig. 7 and 8, it remains unclear how this method was used and what results were obtained. Please highlight what results were gained using this method.

**Spatial estimates were calculated with the MRF model and the colorings of the maps are based on these estimates. The spatial estimates were only used for the coloring in order to explore regional clusters with visual inspection. We will be more precise in the final version.**

On lines 262-264 you state that you cannot compare spatial patterns to other countries due to lack of information. However, at least for some countries or regions, spatial patterns have been explored and explanations for clusters were given. Relevant publications might include Spencer and Ashley (2010, for the western United States), Logan and Witmer (2012, for Colorado) or Techel et al. (2015, for Switzerland). While Spencer and Ashley argued that these clusters are the areas with the highest concentration of winter sport activities, Logan and Witmer showed that most accidents occurred in areas which are highly accessible (closeness to roads). Techel et al. concluded that a higher risk to be involved in a backcountry avalanche accident was also correlated to regions with a more frequent shallow snowpack and persistent weak layers. These were not always the regions with the highest number of fatalities.

**We will take this into account in the discussion of the final paper; thank you for this advice.**

**However, some issues (shallow snowpack and persistent weak layer) are topic of our research proposal which we submitted a view weeks ago.**

## Conclusion

I. 287-297: It is indeed difficult to verify the influence of increased numbers of recreational activity in winter backcountry. The study by Fleischhacker (2016) might provide a suitable reference indicating trends observed in Austrian winter sport regions. A recent study by Winkler (2016, in German) or Winkler et al. (2016, in English) has explored the trends in the number of winter backcountry users in Switzerland during the last two decades. Potentially, this study may be of interest when discussing backcountry usage trends.

**We will take this into consideration for discussion. However, one very important part of our submitted research project (spatio-temporal model) is to get reliable information on the number backcountry and off-piste skiers in general.**

Figures

Fig. 1 and 2:

The caption should mention that a 90%-confidence interval is shown. Grid lines would be helpful.

**Thank you for this advice.**

Fig. 3 to 6:

The x-axis labeling of the right plot (off-piste) is difficult to read. Maybe leave some space between the plots.

**We did this in order to gain space for the plots, we tried some versions (among them with space between the plots) and decided for the current version. But, we are able to put the axis labels of the second plot to the right side (which is a good solution if we add grid lines).**

The caption should mention that a 90%-confidence interval is shown. Grid lines would be helpful.

**Thank you for this advice, we will add grid lines.**

All these figures, and possibly also the Austrian data for the years 1983/84 until 2010/11 could be presented in a panel plot with the same axis-limits for all countries.

**We have some concerns about that because of readability. However, it is possible to “pile up” the plots with the same x-axis (omitting multiple labels) in order to save space.**

This would facilitate the comparison between the different time-series. Fig. 7 and 8: The color choice is difficult to read for colorblind readers. I suggest using any of the color schemes proposed e.g. by Brewer (1994); Neuwirth (2014); Zeileis et al. (2009). Because most readers will be unfamiliar with the Austrian Alps, a map showing the mountainous areas relevant for avalanching - for instance the surface area above 1500 m - would be helpful for comparison.

**The colors indicate:**

**- Green: no danger**

**- Red: danger**

**But, we are open for other color schemes when generating the maps with the new data.**

**Please take note of our proposal of map #3 above.**

Anonymous Referee #2

Received and published: 20 March 2017

For clarification: I was asked to do this review about 3 months after the first reviewer finished his/her review. RC1 is very detailed, and I strongly agree with reviewer 1, so I will just add some comments that I find worth to add: The authors explore trends in the annual number of backcountry avalanche fatalities in Austria and compare these to four other countries. 2 types of studies were executed. While the temporal analysis has some new findings and seems interesting for publication (when the concerns of reviewer 1 are addressed) the regional, spatial analysis is in my opinion not acceptable for publication (I would just skip that part).

As reviewer 1 already mentioned, the spatial analysis lacks of correlation to actual skier/snowboarder frequency data, the maps (figure 7 and 8) are misleading in the current form, as they just represent where in Austria popular ski and free ride resorts are, but have no meaning if the chance is actually higher to have an avalanche accident in these particular regions (what the authors claim).

**Please, also take notice that reviewer #1 referred to some citations with spatial results (without any explaining variables).**

If we just look at the 2 hot spots found (Arlberg and southern Ötztal) snow pack conditions are very different. While in Sölden, for example, an inneralpine snow pack allows for rather dangerous avalanche conditions (shallow cold high altitude snow packs), the Arlberg has often completely different snow pack conditions (warm, heavy snow fall at the border of the Alps with lower altitude).

**Do you have a citation for this (relating to different snowpack conditions considering the Arlberg or Sölden)? It would be of some interest for us; as stated above, this is part of our research planned in the future.**

At the Arlberg the huge amount of skiers going off-piste and back country skiing rather explain the frequency of avalanche accidents. I am completely aware that skier/snowboarder frequency data is difficult to get in a meaningful way (reviewer 1 had some good ideas). I could also suggest using data of ski-tickets sold per day (available from the ski resorts) or statistics of guest-nights (overnight statistics available at the Austrian chamber for tourism) but I think it will be still very difficult to create a meaningful map, so as mentioned I would skip the regional analysis.

**We appreciate that reviewer #2 considers the temporal analysis to be an interesting (in his opinion the only interesting) part of our contribution. However, we feel that there are still interesting insights from the spatial analysis that are worth to be discussed in this publication. As already pointed out in the reply to the reviewer #1, we have tried to improve the spatial analysis, i.e. specifically (a) adding 2 tables for regional discussion, (b) generating map #3 as described above.**

**We think that the spatial analysis is meaningful in terms of prevention if we consider the narrow regional distribution of the fatalities, see conclusion line 281.**

In the temporal analysis I would add at least in the discussion that the number of skiers/snowboarders or winter tourists increased in the period investigated (for

example in Tirol winter guests increased from 1986 being 2.922.842 to 2016 being 5.819.984 <https://www.tirol.gv.at/statistik-budget/statistik/tourismus/>) or use alternative statistics. That fact needs to be discussed in more detail (as reviewer 1 already mentioned) as clearly a boom in back country skiing and off-piste skiing has happened in the last decades. So even if you see a slightly increasing trend of fatalities in Austria it is definitely not an increasing trend when we account for skier/snowboarder frequency.

**We will take this (using overnight stays of the federal state Tyrol) into account for the final version of the paper. Thank you for this advice.**

**However, we think that the size of tourist resorts is misleading in case of backcountry skiers (which are more or less native if we consider for example backcountry skiers around Innsbruck).**