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.

For the new version of the article we extended the database (for both: Austria and other countries for comparison) up to the winter period 2015/16 using national data in case of Austria and ICAR

data in case of the other countries. Further on we checked the data according to the comments of Techel in the SC1 (Swiss Data: Auszug der Lawinendatenbank des SLF; Italian data: Mauro Valt: Associazione Interregionale Neve e Valanghe, Trento). Additionally, a similar crosscheck was made with the French and the US data (Frederic Jarry: ANENA; Ethan Greene: Colorado Avalanche Information Center).

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

Detailed comments, by section

Abstract

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

We changed to "backcountry and off-piste avalanche fatalities ...", see line 29.

l.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 changed to:

"to the widespread opinion in Austria, that the number....", see line 31

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:

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@Book{,
 author = {Roth E.},
 title = { Lawinen: verstehen -vermeiden-Praxistipps },
 year = {2013},
 pages = {303},
 publisher = {Bergverlag Rother},
 address = {München}
```

Introduction
l. 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 added a citation of the a master thesis from the 1980s in line 45 which addresses this topic:

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@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}
}
```

l. 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)

Please see lines 46-57. But note that e.g.

in case of France the trend functions of Jarry (2011) indicate rather no positive or negative trend (if anything, the lower counts in the mid 1990's).

in case of Italy Valt & Pivot only observed an increase/decrease of the percentage of casualties among backcountry/off-piste skiers.

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

You are right, we skipped this citation!

l. 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.

l. 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 at. (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.

Please, see lines 53-57, 266-67 in the new version of the paper.

Data and methods

l. 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 (which are the lines 113-115 in the new version).

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

l. 117-118 and l. 129-130: I find this very difficult to understand. Did you calculate the trend for each municipality (aggregating the data in terms of location, l. 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 changed this in order to be more clear; see line 133 ff.:

"After aggregating the spatio-temporal data y_st (denoting the observed fatalities at time t and location s) in terms of location, which means summing up over the locations,......"

l. 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).

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@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}
}
```

Please, see citation at line 144.

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, the result section refers 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.

In the new version, at least, we added the tables as described above. Further on, we extended the discussion in the "temporal" and the "regional" part considerably.

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 for this data (in contrast to the linear model or the running mean of Techel et al. 2016). See e.g. the single extreme winter (>=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 (214-219 new version)**
- **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 addressed these points (especially the clusters of "extreme" winters) in the final version, see lines 268-276. 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 mentioned this point in the discussion of the final version, e.g. see lines 268-276.

- 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. >=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.

***please note, that in case of Swiss off-piste fatalities the BIC values based on the new (extended) data almost indicate that the constant model is appropriate.**

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 lines 268-276 of the new version and the 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.

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, see lines, 339-346.

In general, I would consider it benefitial 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 add a map visualizing the municipal Alpine terrain (>=1500m) 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 Austria (instead of the federal states Vorarlberg, Tyrol and Salzburg as proposed). 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. See lines 195-198.

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.

We skipped the lines 262-264 and we added the citation of Spencer and Ashley, see line 340 in the new version. Looking at the proceeding paper of Logan and Witmer I am not shure about the validity of the statement above.

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

Conclusion

l. 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, see lines 331 ff. of the new version. 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, see the grid lines in the new version.

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. This would facilitate the comparison between the different time-series.

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.

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.

→ As a result of further discussion between the authors of the article we changed the color scheme to: dark red-light yellow

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 the just represent where in Austria popular ski and free ride resorts are, but have no meaning if the chance is actual higher to have an avalanche accident in this 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 skiers/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 (now lines 363-ff).

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.

Thank you for this advice, see e.g. lines 372-374. But, if we e.g. compare the temporal profile of winter overnight stays in Tirol since 1986 with those of the avalanche fatalities the congruence is rather weak. It would be of some interest if there is a congruity in case of the off-piste fatality centers Sölden and St. Anton? But so far we have only data for these municipalities beginning at 2000.

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).

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.

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Abstract

In this article we analyzed spatial and temporal patterns of fatal Austrian avalanche accidents caused by backcountry and off-piste skiers and snowboarders within the winter periods 1967/68–2015/16. The data were based on reports of the Austrian Board for Alpine Safety and reports of the information services of the federal states.

Using the date and the location of the recorded avalanche accidents we were able to carry out spatial and temporal analyses applying generalized additive models and Markov random field models.

As the result of the trend analysis we noticed an increasing trend of backcountry and off-piste avalanche fatalities within the winter periods from 1967/68 to 2015/16 (although slightly decreasing in recent years), which is in contradiction to the widespread opinion in Austria that the number of fatalities is constant over time. Additionally, we compared Austrian results with results of Switzerland, France, Italy and the United States based on data from the International Commission of Alpine Rescue (ICAR). As the result of the spatial analysis we noticed two hotspots of avalanche fatalities ('Arlberg-Silvretta' and 'Sölden').

Because of the increasing trend and the rather 'narrow' regional distribution of the fatalities consequences on prevention of avalanche accidents were highly recommended.

Keywords: Snow, Avalanches, Accidents

1 Introduction

In the Alps, backcountry skiing has become very popular in the last 50 years. Unfortunately, there are a lot of fatal accidents due to snow avalanches caused by skiers and/or snowboarders. They are of special public interest (Januskovecz, 1989).

In Austria, about 25–30 fatalities caused by snow avalanches are expected every year (Neuhold, 2012; Höller, 2009). Furthermore, it is reported that in Alpine countries (such as Austria) the number of fatalities is more or less constant over the time (Brugger et al., 2001; Valt & Pivot 2013; Roth, 2013) and that there is some sort of seasonality in the data in terms of higher frequencies of accidents within a distance of 5 or 6 years (Höller, 2009; Tschirky et al., 2000). Harvey and Zweifel (2008) even denote that fatalities are decreasing over time in Switzerland. In a most recent paper Techel et al. (2016) investigated avalanche fatalities in the European Alps (in addition to Switzerland–Austria–Slovenia) over time stratified for controlled and uncontrolled terrain, concluding that in the case of uncontrolled terrain the trend seems to be constant over time from the 1980s up to now.

Usually trend information for Austrian avalanche fatalities is given in the annual reports of the Austrian Board for Alpine Safety (Kuratorium für alpine Sicherheit, 2016). Considering these profiles, we notice higher frequencies of fatalities in the 1980s. However, the highest frequency in winter 1998/99 is due to avalanche fatalities in villages (Galtür, Ischgl), also affecting buildings. This is because the statistics in the reports do not distinguish between fatal avalanches in buildings, on roads, outdoors without skiing, fatalities due to skiing on slopes and backcountry skiing.

In this paper our focus is on accidents caused by backcountry (using no ascent support) and off-piste ('leaving the ski resort in order to travel in areas that were not controlled for avalanches', see (Silverton et al., 2009)) skiers or snowboarders. Until now there has not been an investigation for this special group of avalanche incidents in Austria keeping in mind that accidents due to off-piste and backcountry skiing are by far the most common way to be involved in avalanche accidents.

Our task in this paper is to carry out a spatial and temporal analysis, identifying (potentially nonlinear) trends over time and regional patterns. In the case of trend analysis, we compare Austrian results with results of Switzerland, France, Italy and the United States.

2 Materials and methods

2.1 Data

For our study we built a data base of fatal avalanche accidents recording the

1. date,
2. municipal area where the accident took place,
3. federal state of the municipality,
4. number of persons involved,
5. number of fatalities,
6. type of activity (on/off-piste, backcountry skiing, etc.)

of fatal accident events in Austria within the winter periods 1980/81–2015/16, which are available from the annual reports of the Austrian Board for Alpine Safety (Kuratorium für alpine Sicherheit, 2016) and the annual reports of the information services of the federal states (Amt der Tiroler Landesregierung, 2009). In order to check the reliability of the accident data, we made a cross-check between those reported in the two sources. Looking at winter season 1986/87 we figured out that the reports were incomplete. However, we were able to fill this gap using records of the BFW (Austrian Research Centre for Forests, Institute for Natural Hazards, Innsbruck), e.g. see (Schaffhauser et al., 1988).

For the period 1967/68–1979/80 we used aggregated information published in the annual reports of the Austrian Board for Alpine Safety (Kuratorium für alpine Sicherheit, 2016). Starting from 1977/78 we were able to distinguish between backcountry and off-piste fatalities. Finally, further annual reports of the BFW were helpful in order to resolve classification problems of avalanche events.

Keeping in mind aspects of data quality, it seems to be that avalanche information back to the period 1967/68 is reliable for our purposes. In general information relating to fatal avalanches seems to be much more reliable than information relating only to avalanches with injured or uninjured persons. Most notably, in the case of fatal avalanches we do not expect that there are records missing.

In order to compare Austrian results with international results we use data from the International Commission of Alpine Rescue (ICAR) which was kindly made available for us by the ICAR.

The data are annual count data of fatal avalanche events ('Statistique d'accidents d'avalanche') based on 21 countries within the periods 1983/84–2015/16 which are categorized by the type of fatalities (backcountry skiing or snowboarding, off-piste, on-piste, alpinist without ski/snowboard, on road, buildings, snowmobile, other).

In case of the international data (Switzerland: Frank Techel, 'Auszug aus der Lawinenschadensdatenbank des SLF' (SLF 2017); Italy: Mauro Valt, Associazione Interregionale Neve e Valanghe, Trento; France: Frederic Jarry, ANENA; United States: Ethan Greene, Colorado Avalanche Information Center) a crosscheck was carried out.

For looking at the regional distribution of avalanche fatalities we built small area maps based on Austrian municipalities. For this purpose we use polygon boundaries of the small-scaled areas provided by the 'Bundesamt für Eich- und Vermessungswesen' (BEV) in a shapefile. In order to get a regional overview of the alpine terrain ($\geq$ 1500m above sea level) for discussion, we use digital elevation model (DEM) data from the BEV at an 250m resolution. Further on, we use data of overnight stays in the winter season 2015/16 at community level provided by the 'Statistik Austria' as an additional approach for discussion (https://www.statistik.gv.at/web_de/statistiken/wirtschaft/tourismus/beherbergung/ankuenfte_naechtigungen/index.html).

2.2 Statistical methods

After aggregating the spatio-temporal data y_{st} (denoting the observed fatalities at time t and location s) in terms of location, which means summing up over the locations, $\sum_s y_{st}$, we propose the following model for capturing the trend over time:

$$\log(\mu_{\mathbf{t}}) = f(t) + x_t \tag{2.1}$$

where $\mu_{\mathbf{t}}$ denotes the expectation of the Poisson distributed number of annual avalanche fatalities over time t (in our case: winter periods). The logarithms of these values are modelled as the sum of potentially nonlinear trend function $f(t)$ and a stationary remainder x_t. We use the Aikake information criterion (AIC) and the Bayesian information criterion (BIC) in order to compare the constant, linear and nonlinear model (which is in our opinion the better choice than reporting pairwise comparisons of p-values for potentially non-parametric trend functions, see e.g. Venables & Ripley, 2002). To account for potential serial correlation and periodic variation in the remainder, we consider autoregressive moving-average (ARMA) effects.

After aggregating the spatio-temporal data y_{st} in terms of time, which means summing up over the time, $\sum_t y_{st}$, we propose a Markov random field approach modelling the expected number of avalanche fatalities $\mu_{\mathbf{s}}$ (s, $s \in \{1, \ldots, S\}$, denoting the region which are municipalities in our case) as follows:

$$\log(\mu_{\mathbf{s}}) = Z\beta_s \tag{2.2}$$

where the $S \times S$ design matrix Z depends on the specific form of the spatial layout. The coefficients β_s are conditionally Gaussian distributed (Markov random fields) according to:

$$\beta_s|\beta_{-s} \sim N\{\frac{1}{n_s}\sum_{r\sim s}\beta_r, \frac{\tau^2}{n_s}\} \tag{2.3}$$

where β_{-s} denotes the vector of parameters without its sth component, n_s is equal to the number of neighboring regions with reference to region s, $s \sim r$ indexes all units adjacent to region s and τ^2 denotes a (unknown) variance parameter.

For fitting these models we use the `R` package `mgcv` (R Development Core Team, 2012; Wood, 2006) which applies the smoothing spline approach for fitting generalized additive models (GAM).

Further on, for looking at the regional distribution of avalanche fatalities (and subsequently at the regional distribution of alpine terrain and overnight stays) we build small area maps based on Austrian municipalities using the geographic information system (GIS) `ArcMap`. We, of course, use Markov random field estimates as described above which helps us to identify regional hot spots of avalanche fatalities.

3 Results

3.1 Temporal results

In the following, we give the plots of temporal estimated functions of avalanche fatalities at first plotting the function for Austria in total within the winter periods 1967/68–2015/16 (see Figure 1). Additionally, we plot the trend function of exclusively off-piste fatalities starting from the winter season 1977/78 (see Figure 2). Further on, we calculate 90% confidence bands of the estimated functions in both cases as shown in the plots.

For reasons of comparison Table 1 gives the frequencies of backcountry, off-piste and total fatalities of Austria and the Austrian neighboring countries Italy and Switzerland within the winter periods 1983/84–2015/16. Additionally the off-piste percentages are reported. Furthermore, we report the results of fatalities in France, which turns out to be the country with the highest counts of fatalities in Europe, and the results of the United States, which is probably the most important country outside of Europe in terms of avalanche fatalities. For this purpose, however, we use ICAR data as described above.

For further international comparison we consider estimated functions of off-piste and backcountry avalanche fatalities (and off-piste fatalities detached) of Switzerland, France, Italy and the United States in Figures 3–6.

Finally, the Aikake information criterion (AIC) and the Bayesian information criterion (BIC) of the constant (no trend effect), linear and nonlinear models are reported for model comparison – see Table 2. Lower AIC- and BIC-values, however, indicate significantly better fits when comparing the different models.

3.2 Regional results

Figures 7 and 8 show the regional distribution of fatal avalanche events (Figure 7 in total and Figure 8 off-piste only) using colored maps based on small areas, which are the Austrian municipalities in our case. The coloring, however, is based on Markov random field estimates of avalanche fatalities as described in the previous Section; the number corresponding with each spatial unit in the plot is equal to the original count.

In addition to Figures 7–8, Table 3 gives a list of those municipalities with the most avalanche fatalities in Austria. Further on, we list those avalanche events in Austria with the highest counts of fatalities in Table 4 which turns out to be useful for the discussion section.

Finally, Figure 9 shows the distribution of Alpine terrain ($\geq 1500m$ above sea level) and the distribution of the overnight stays in the winter season 2016 at municipal level (restricted to the 130 municipalities with more than 100,000 overnight stays in Austria) which allows us to discuss possible reasons for the observed distribution of avalanche fatalities in Figure 7 and Figure 8.

4 Discussion

4.1 Temporal analysis with an international overview

If we look at the trend function of Austria in total (see Figure 1) we notice an increasing trend having its maximum at winter period 2005/06 (1969/70: approx. 12, 2005/06 approx. 22). In recent years we, however, notice that the number of annual fatalities is slightly decreasing.

Additionally we take notice of a peak in the 1980s ranging between 1981/82 and 1987/88. But keeping in mind that increased snowfall has an essential effect on the number of accidents (Harvey, 2008; Harvey et al., 2012; Höller, 2012), increased solid precipitation in the 1980s during wintertime (Laternser & Schneebeli, 2003; Abegg, 1996) could give some evidence for this pattern.

Looking at the off-piste trend function (see Figure 2), we notice an increasing (linear) trend without any peak in the 1980s. As in the 'total' case, the off-piste fatalities are sightly decreasing from the mid 2000s on.

Lower AIC- and BIC-values (see Table 2) indicate that the nonlinear model is preferable to the constant or linear model – although in case of 'Austria off-piste' the BIC-value indicates that the linear model seems to be preferable.

Considering ARMA effects, we did not find any substantial serial correlation or any sort of periodicity in the remainder x_t. Further on, we notice that there is a lot of variation of the observed counts around estimated function(s).

Comparing Austrian fatal backcountry and off-piste counts within 1983/84 – 2015/16 with results of counts in Switzerland, France, Italy and the United States (see Table 1) we notice, led by France (787 fatalities in total, 23.85 fatalities per year), the second largest number of total avalanche fatalities (680, 20.61) in Austria. Having a focus on backcountry fatalities only, Austria is leading (458, 13.88) followed by France (433,13.12) and Switzerland (395, 11.97). In Austria a share of 32.65% of total fatalities are due to off-piste accidents (largest value France: 44.98%; smallest: United States 29.23%).

Comparisons with total fatality profiles of France, Switzerland and Italy result in:

1. high frequencies in the 1980s,
2. low counts in the 1990s,
3. increasing trend beginning in 2000
4. to some extent decreasing in recent years,

which in turn is rather similar to the results of Austria.

However, if we consider the results of the United States in Figure 6 (284 total fatalities, 8.61 fatalities per year) we note a positive almost linear trend without any peaks in the 1980s. The AIC- and BIC-values indicate that, with the exception of the United States (linear model), nonlinear models are preferable (whereas the BIC-values of France almost indicate that there is no effect at all in case of France).

If we compare the off-piste trends of the countries we notice quite different shapes to those of Austria (positive trend without peak in the 1980s):

1. Italy: similar to shape as seen in case of total counts.
2. Switzerland: difference to total trend function, peak of off-piste trend around year 2000.
3. France: decrease of off-piste counts in recent years.
4. United States: almost no increase; because of the lowest AIC-value, the constant model turns out to be the best one.

Such as in the 'total' case above, lower AIC- and BIC-values indicate that, with the exception of the United States (constant model), nonlinear models are best-performing. Usually trend information is given as a linear function in the literature for avalanche data, see e.g. (Tschirky et al., 2000; Harvey & Zweifel, 2008; Spencer & Ashley, 2011; Page et al., 1999). Our investigations - see AIC- and BIC-values in Table 2 - showed that (with the exception of the US-data) linear models are not appropriate – see also the results of (Techel et al, 2016) and (SLF, 2016) in the recent research.

At the beginning and the end of the longitudinal profiles we observe larger confidence bands indicating less precice estimates due to missing data in their neighbourhoods. As a result of this extreme estimates at the beginning of the temporal profiles could be less reliable (e.g. in case of Switzerland 'total', if we compare the results with those of SLF, 2016)

The temporal profiles could also be seen as an indicator for low/high freqency temporal clusters, which are: Austia total (6 larger values) in the mid 1980s; Switzerland off-piste, France and Italy total (5 smaller values for each) in the early and mid 1990s.

4.2 Regional analysis

In Figure 7 we explore the regional or spatial distribution of avalanche fatalities in Austria within the years 1981–2016. Here the total area of Austria is divided into small areas, equal to the areas of the Austrian municipalities (211 municipalities with at least one reported fatality). Looking at Table 3, we notice that the municipalities with highest numbers are 'Sölden' and 'St. Anton a. Arlberg' Around the municipalities 'St. Anton a. Arlberg' and 'Sölden' in the western part of the Austrian federal state Tyrol we observe 2 clusters or hot spots of increased fatalities:

The first cluster (CL1), centered around the regions Arlberg and Silvretta, is including the municipalities St. Anton a. Arlberg (number of avalanche fatalities: 31), Kaisers (10), Klösterle (9), Lech (22) in Arlberg, and the municipalities St. Gallenkirch (8), Gaschurn (8), Galtür (21), Ischgl (9) in Silvretta.

The second cluster (CL2), located in the southern part of Ötztal, Kühtai and Stubai, is including the municipalities Sölden (50), St. Leonhard i. Pitztal (18), Längenfeld (9) in the Ötztal Alps, and the municipalities St. Sigmund i. Sellrain (11), Silz (14), Sellrain (5), Neustift i. Stubaital (11) in Kühtai-Stubai.

Further on, we observe some smaller spots in the federal states:

– Tyrol (Tuxer Alpen): Navis (9), Wattenberg (9), Schmirn (5), Tux (10)

– Salzburg (Saalbach): Saalbach-Hinterglemm (10), Niedernsill (13)

– Styria (Triebener Tauern – Seckauer Tauern): Gaal (6), Wald am Schoberpaß (6), Hohentauern (6).

Finally we notice some single areas with increased frequency such as:

Mittelberg Vorarlberg (10), Heiligenblut Carinthia (11), Werfenweng Salzburg (15), Pusterwald Styria (10). Some single areas with increased frequencies, e.g. Werfenweng (15) and Niedernsill (13), are due to disastrous single avalanche events, see e.g. Table 4.

Figure 8 plots the distribution of the off-piste fatalities (without back-country fatalities; 77 municipalities with at least one reported off-piste fatality). As a conclusion we notice 2 hot spots of off-piste fatalities which are: 'St. Anton a. Arlberg' - 'Lech' - 'Ischgl' (Arlberg, Ischgl) and 'Sölden' (southern part of Ötztal).

Furthermore, there are some single spots or small clusters such as: Tux Tyrol (5), Jochberg Tyrol (5) , Saalbach-Hinterglemm Salzburg (6), Niedernsill Salzburg (12).

If we compare Figure 7 and Figure 8 (or if we have a look at Table 3) we notice centres of off-piste avalanche fatalities in CL1 such as Lech (20 off-piste fatalities out of 22 total, 90.91% off-piste), St. Anton a. Arberg (26 out of 31 total, 83.87%) and Ischgl (9 out of 9 total, 100%) while the accidents of Galtür (0% off-piste), St. Gallenkirch (2 out of 8 total) and Gaschurn (0% off-piste) are mainly due to backcountry skiers.

Looking at CL2, the fatal accidents of our interest are mainly caused by backcountry skiers except Sölden which off-piste rate is about 50% (25 out of 50 total, $\geq$ 31.24% in case of Austria).

Figure 9 (distribution of alpine terrain and overnight stays in the winter season 2015/16) tries to give some idea in order to explain the spatial distribution of avalanche fatalities of Figure 7 and Figure 8. Obviously, the percentage of alpine terrain at municipal level coincides with the number of fatalities. However, there are alpine areas with less number of fatalities than in those in the western part of Tyrol, see e.g. East Tyrol. The majority of fatalities are restricted to 2 clusters, which is more or less only a small part of the terrain of our interest.

Looking at the overnight stays in Figure 9, we notice that the largest counts of overnight stays coincide with the largest counts of in total and off-piste fatalities (Sölden, St. Anton a. Arlberg, Lech), but there are winter tourist regions with less number of avalanche fatalities, see e.g. the Tauern region or the northeastern part of Tyrol. In the case of total number of fatalities, overnight stays are partly misleading because they e.g. do not take into account the considerable number of native backcountry skiers around Innsbruck.

This is more or less in agreement with considering the size of Austrian ski resorts, see (Fleischhacker, 2016), instead of overnight stays (Spencer and Ashley (2011) stated that areas with higher winter sports activity are those with higher number of avalanche fatalities).

Finally, if we consider the spatial patterns of buildings exposed to snow avalanches in Austria (Fuchs et al., 2015) we could find some remarkable congruences (looking at CL1 and CL2) if we compare them with avalanche fatalities at municipal level.

5 Conclusion

As the result of the trend analysis we notice an increasing trend (although decreasing in recent years) of off-piste and backcountry avalanche fatalities within the winter periods from 1967/68 to 2015/16. This clearly contradicts the widespread opinion that the number of fatalities is constant over time.

Comparing results of off-piste and backcountry avalanche fatalities in Austria with other relevant countries we notice the second highest number of off-piste and backcountry fatalities in Austria and the largest number of backcountry fatalities in Austria. We notice similar estimated functions if we compare Austrian results with results of the relevant European countries. However, the off-piste trend function of Austria is quite different to those of the other relevant European countries (but similar to those of the United States).

As the result of the regional analysis we notice two hot spots of avalanche fatalities in Figure 7: 'St. Anton a. Arlberg (29)' (Arlberg-Silvretta) and 'Sölden (43)' (southern part of Ötztal, Stubai-Kühtai).

Because of the increasing trend (although decreasing in recent years) and the rather 'narrow' regional distribution of the fatalities, consequences on prevention of avalanche accidents are highly recommended, e.g. starting a 'campaign against avalanche accidents' in the centers of the clusters St. Anton and Sölden. This should especially be done in order to prevent the large number of off-piste (freerider) fatalities in St. Anton-Lech-Ischgl and Sölden.

Unfortunately, we are not able to verify the influence of increased number of backcountry and off-piste skiers over time because there is no valid information about frequencies of backcountry and off-piste skiers in general. However, we find some evidence that increased winter overnight stays (which could be seen as an evidence for increased winter sports activity) has an effect on higher number avalanche fatalities, see Figure 9.

Finally, we do not hesitate to mention that further research is needed, e.g. to explore the influence of new fallen snow, temperature, etc. on the number of fatalities. For this purpose, further and more precise data are necessary.

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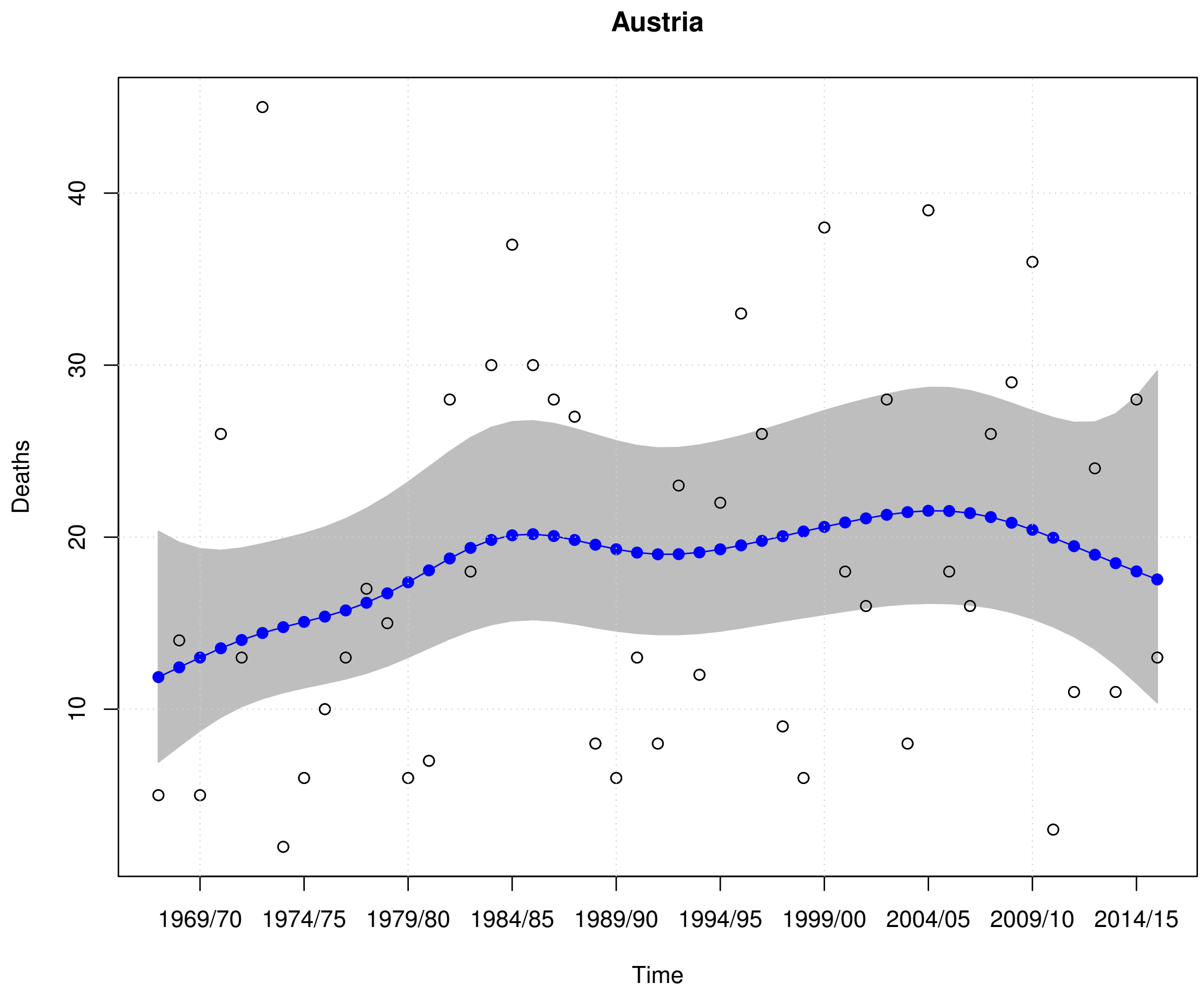

Figure 1: Observed (○) and estimated (•) annual total avalanche fatalities (off-piste and backcountry) with 90% confidence band (grey) in Austria within 1967/68–2015/16.

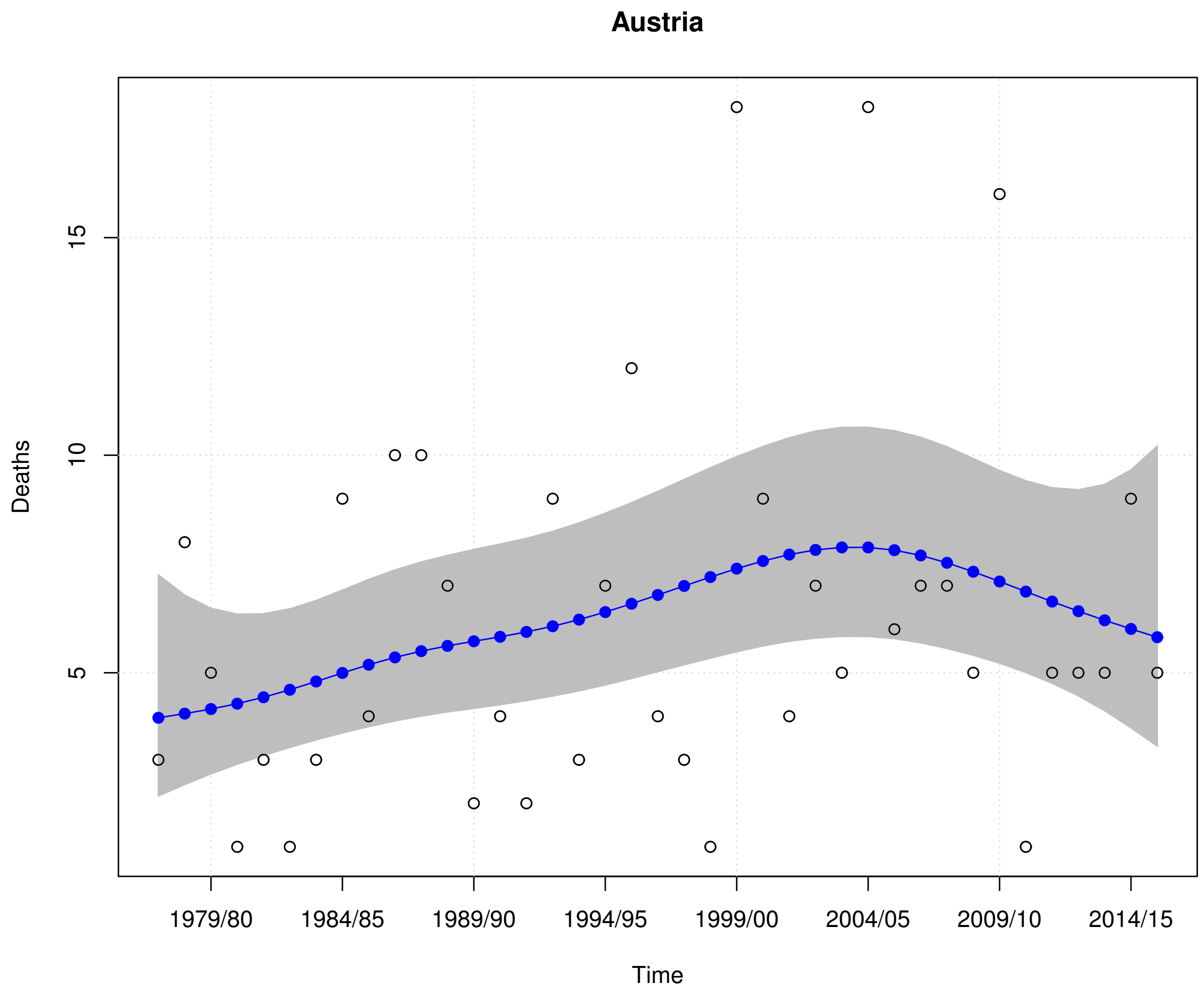

Figure 2: Observed (○) and estimated (●) annual off-piste avalanche fatalities with 90% confidence band (grey) in Austria within 1977/78–2015/16.

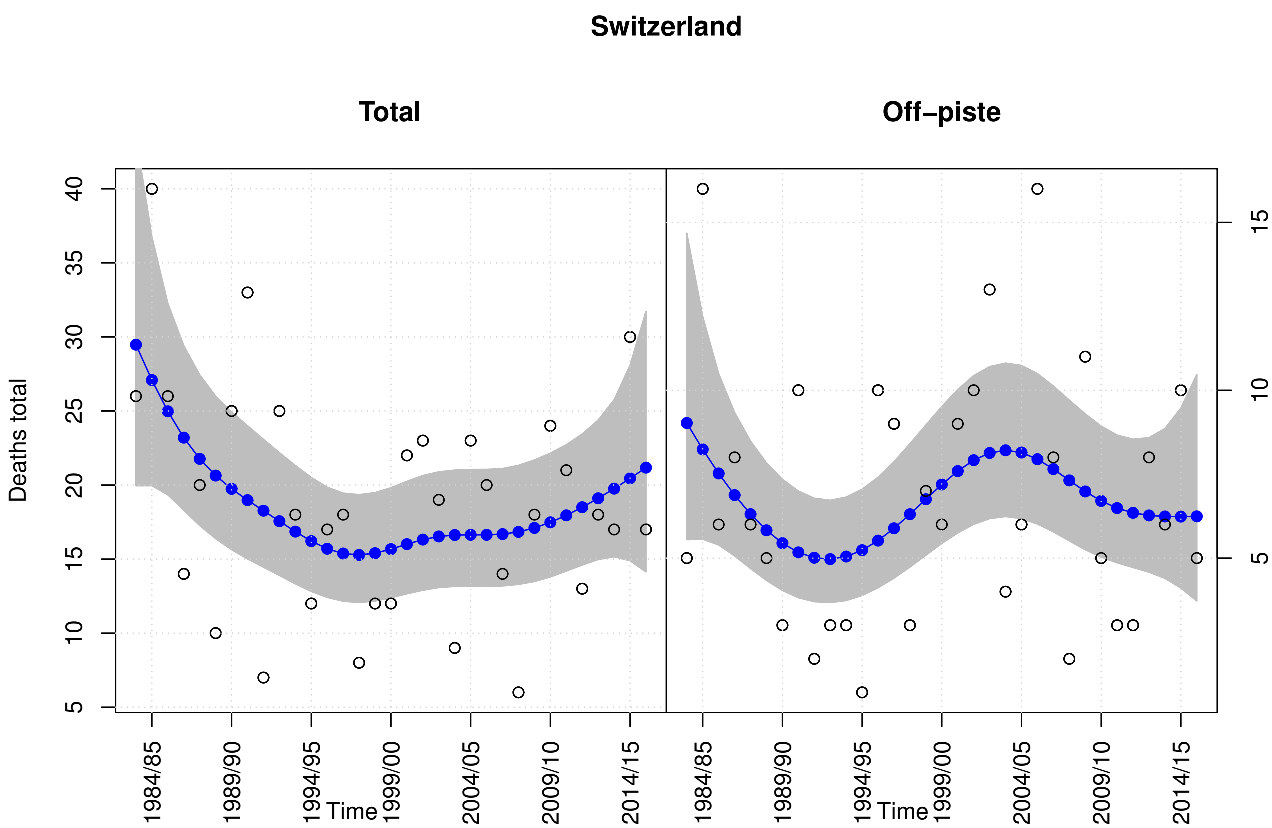

Figure 3: Observed (○) and estimated (•) annual avalanche fatalities (off-piste and backcountry, i.e. total, on the left and off-piste on the right) with 90% confidence bands (grey) in Switzerland within 1983/84–2015/16.

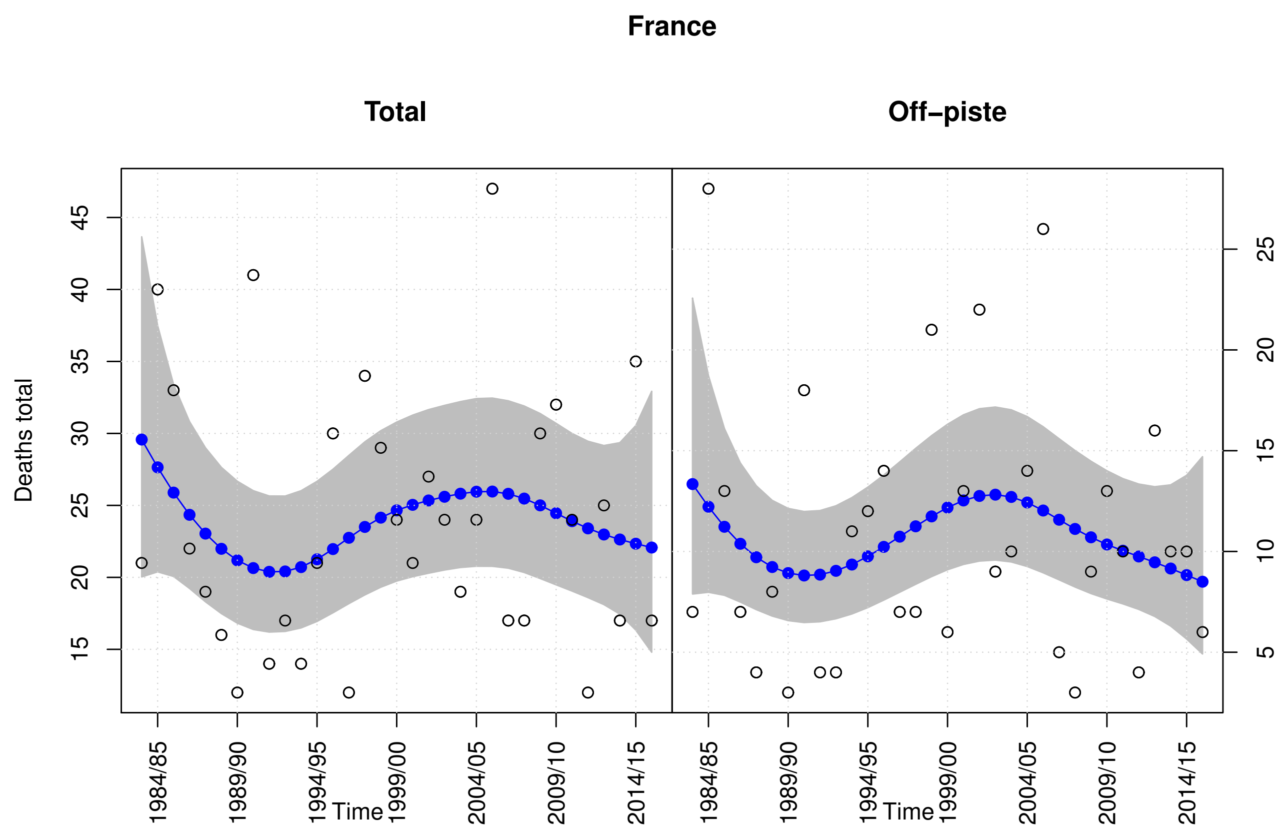

Figure 4: Observed (○) and estimated (●) annual avalanche fatalities (off-piste and backcountry, i.e. total, on the left and off-piste on the right) with 90% confidence bands (grey) in France within 1983/84–2015/16.

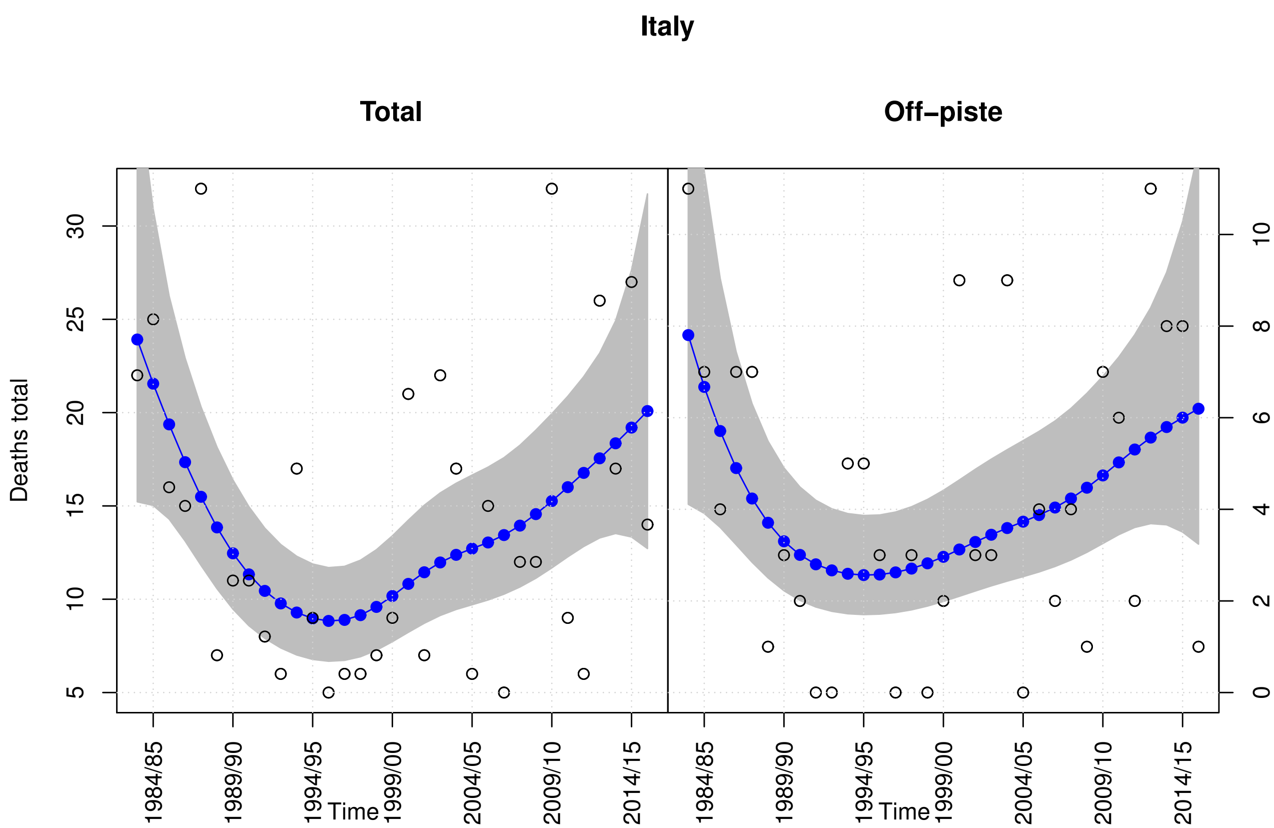

Figure 5: Observed (○) and estimated (•) annual avalanche fatalities (off-piste and backcountry, i.e. total, on the left and off-piste on the right) with 90% confidence bands (grey) in Italy within 1983/84–2015/16.

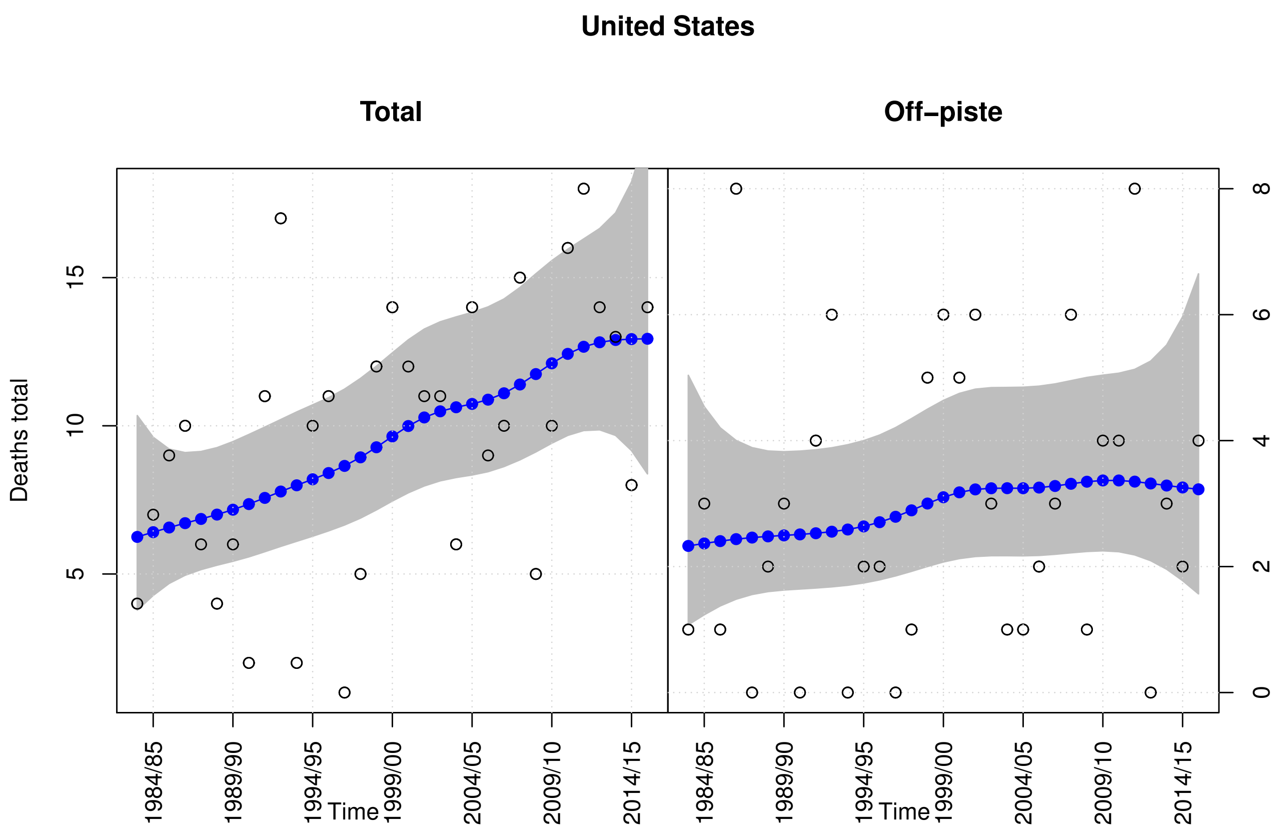

Figure 6: Observed (○) and estimated (●) annual avalanche fatalities (off-piste and backcountry, i.e. total, on the left and off-piste on the right) with 90% confidence bands (grey) in the United States within 1983/84–

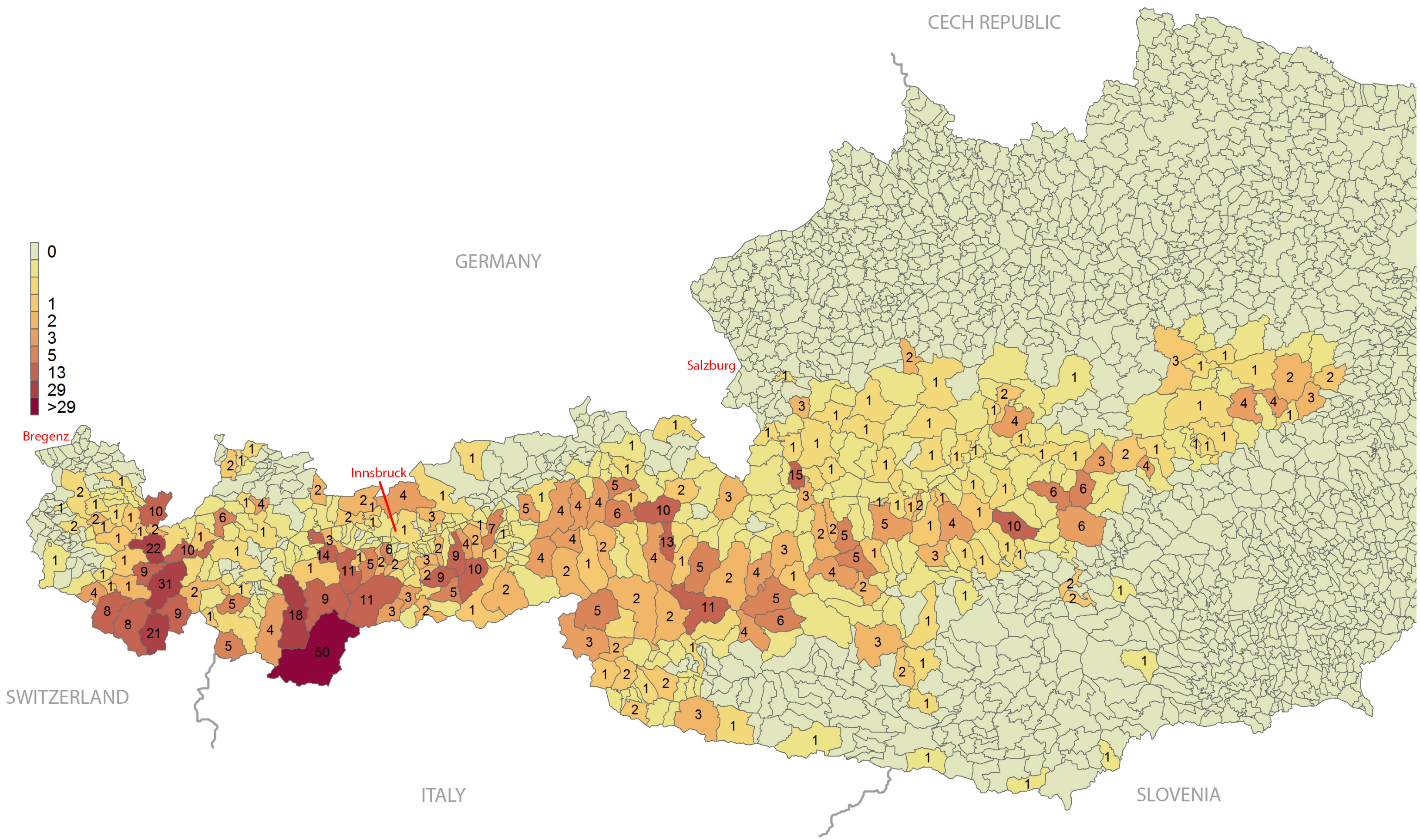

Figure 7: Regional distribution of avalanche fatalities (off-piste and backcountry) in Austria within 1980/81–2015/16.

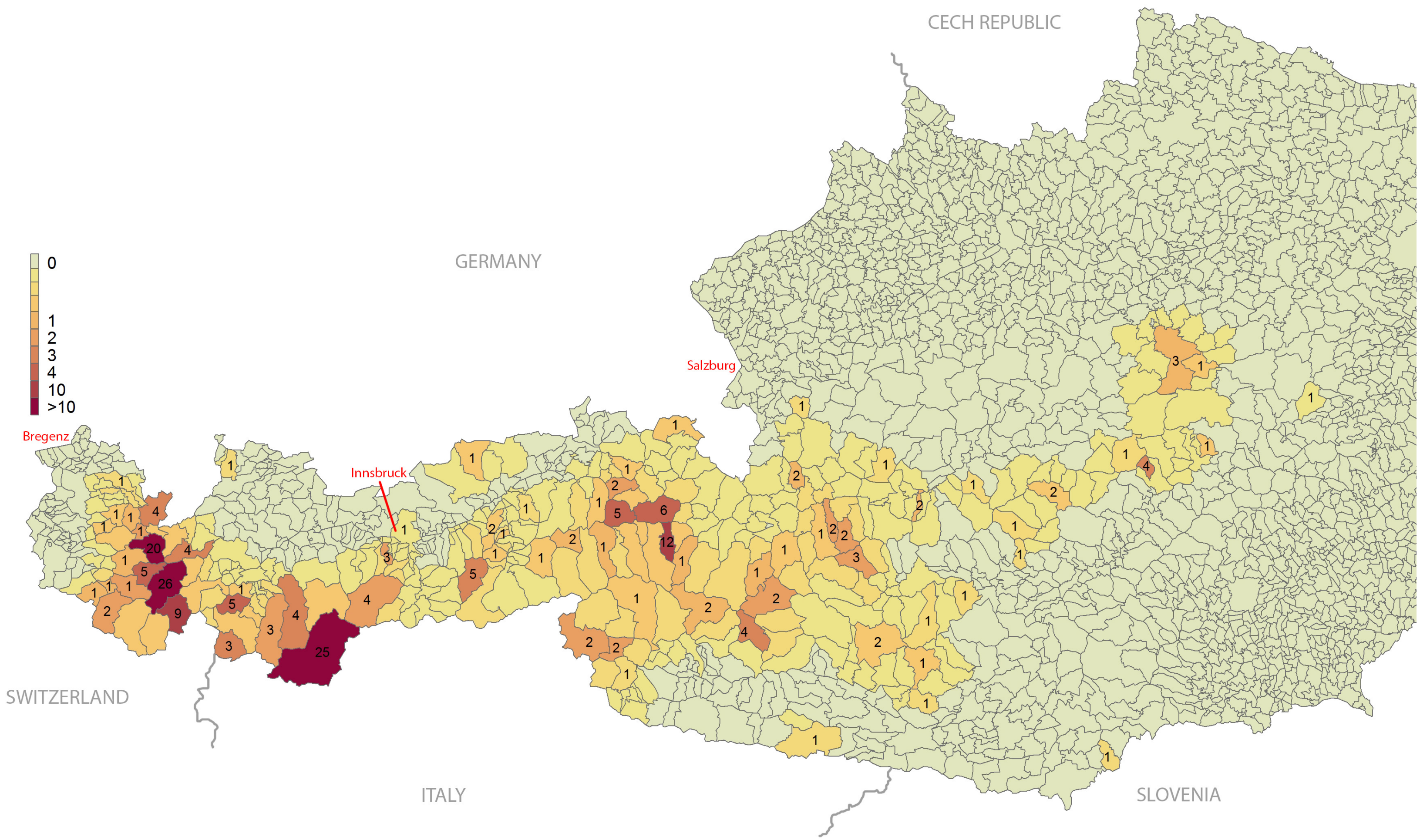

Figure 8: Regional distribution of avalanche fatalities (off-piste) in Austria within 1980/81–2015/16.

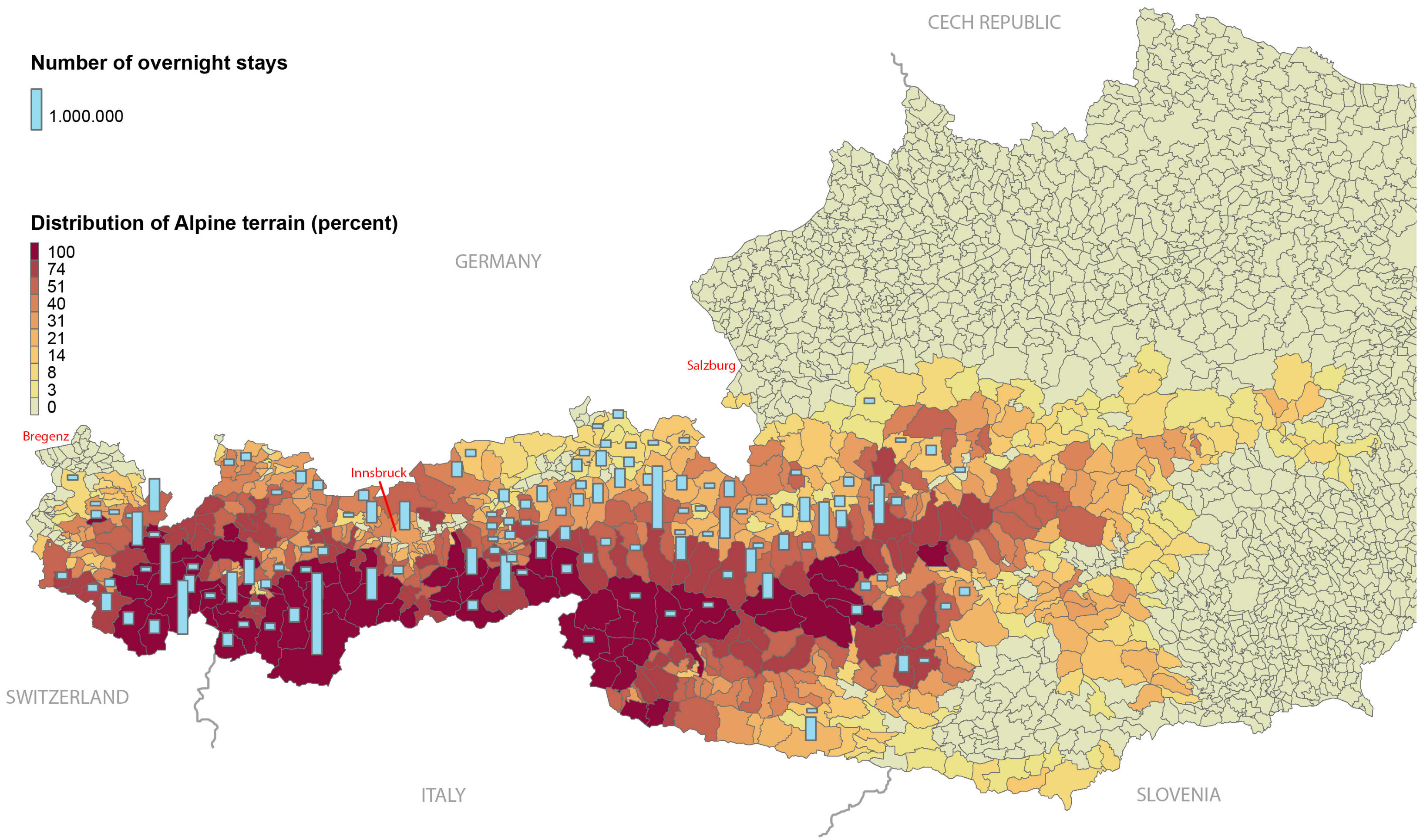

Figure 9: Distribution of Alpine terrain ($\geq 1500m$ above sea level) and number of overnight stays in the winter season 2016 at community level.

Country	Backcountry		Off-piste		Total		
	number	per year	number	per year	number	per year	% off-piste
Austria	458	13.88	222	6.73	680	20.61	32.65%
Switzerland	395	11.97	222	6.73	617	18.70	35.98%
France	433	13.12	354	10.73	787	23.85	44.98%
Italy	322	9.76	138	4.18	460	13.94	30.00%
USA	201	6.09	83	2.52	284	8.61	29.23%
sum	1785	54.09	1033	31.30	2818	85.39	36.66%

Table 1: Number of avalanche fatalities and annual average (off-piste, back-country and total) of 5 countries within the winter periods 1983/84–2015/16.

		Total			Off-piste		
		const	linear	nonlin.	const	linear	nonlin.
Austria	AIC	550.87	543.14	530.3	241.35	238.17	236.46
	BIC	552.76	546.93	539.46	243.02	241.5	243.03
Switzerland	AIC	256.47	254.29	242.79	189.9	191.87	186.79
	BIC	257.96	257.29	250.1	191.4	194.87	192.83
France	AIC	268.9	270.9	267.74	251.2	253.09	245.7
	BIC	270.39	273.89	275.39	252.7	256.08	252.28
Italy	AIC	285.01	286.78	250.69	189.79	191.62	175.23
	BIC	286.5	289.77	257.59	191.29	194.61	180.78
United States	AIC	188.64	182.43	186.33	147.45	148.92	151.33
	BIC	190.13	185.42	192.65	148.95	151.92	156.4

Table 2: AIC and BIC of the constant, linear and nonlinear trend model considering data of Austria total and off-piste (Figure 1, Figure 2), Switzerland total and off-piste (Figure 3), France total and off-piste (Figure 4), Italy total and off-piste (Figure 5) and United States total and off-piste (Figure 6).

Communitiy	Backcountry	Off-piste	Total
Sölden	25	25	50
St. Anton am Arlberg	5	26	31
Lech	2	20	22
Galtür	21	0	21
St. Leonhard im Pitztal	14	4	18
Werfenweng	13	2	15
Silz	14	0	14
Niedernsill	1	12	13
Neustift im Stubaital	7	4	11
Heiligenblut am Großglockner	9	2	11
St. Sigmund im Sellrain	11	0	11
Tux	5	5	10
Kaisers	6	4	10
Mittelberg	6	4	10
Saalbach-Hinterglemm	4	6	10
Pusterwald	9	1	10
Klösterle	4	5	9
Navis	9	0	9
Ischgl	0	9	9
Längenfeld	9	0	9
Wattenberg	9	0	9
Gaschurn	8	0	8
St. Gallenkirch	6	2	8
Fügenberg	5	2	7
Jochberg	1	5	6
Axams	3	3	6
Gaal	6	0	6
Häselgehr	6	0	6
Wald am Schoberpaß	6	0	6
Hohentauern	4	2	6
Mallnitz	6	0	6
Prägraten am Großvenediger	5	0	5
Tweng	2	3	5
Nauders	2	3	5
Kitzbühel	3	2	5
Serfaus	0	5	5
Sellrain	5	0	5
Schmirn	5	0	5
Fusch an der Großglocknerstraße	5	0	5
Alpbach	4	1	5
Bad Gastein	3	2	5
Rohrmoos-Untertal	5	0	5
Untertauern	3	2	5

Table 3: Number of avalanche fatalities (off-piste, backcountry and total) in Austria within 1980/81–2015/16 stratified for communities with more than 4 fatalities in the observation period.

Date	Location	Municip.	Fatalities
1982-01-31	Werfenweng	Werfenweng	13
2000-03-28	Schmiedinger Kogel	Niedernsill	12
1999-12-28	Jamtalhütte - Gde. Galtür	Galtür	9
1987-04-05	Idalpe	Ischgl	6
1988-03-28	Jamtal	Galtür	6
2009-05-02	Schalfkogel	Sölden	6
2016-02-06	Wattener Lizum	Wattenberg	5
1985-03-21	Sonntagkarzinken, Schladm. Tauern	Rohrmoos-Untertal	4
1988-02-14	Hühnereggen, Stubaier Alpen	Sellrain	4
1993-04-12	Querkogeljoch, Ötztaler Alpen	Sölden	4
1997-02-18	Luxnacher Sattel	Häselgehr	4
2005-01-22	Rendl	St. Anton a. Arlberg	4
1981-03-01	Hohe Veitsch	Mürzsteg	3
1984-02-19	Hoher Gleirsch, Karwendelgebirge	Scharnitz	3
1985-05-04	Speikogel, Kitzbüheler Alpen	Westendorf	3
1986-01-08	Kühkarkopf, Hohe Tauern	Fusch a. d. Großglocknerstr.	3
1986-04-01	Tschambreuspitze, Silvretta	Gaschurn	3
1986-04-07	Windachscharte, Stubaier Alpen	Sölden	3
1986-12-21	Lattenberg Triebener Tauern	Wald a. Schoberpaß	3
1987-01-06	Fluchtalpe, Kleines Walsertal	Mittelberg	3
1987-04-18	Scharkogel	Uttendorf	3
1991-12-21	Scharnitzfeld, Wölzer Tauern	Pusterwald	3
1995-01-03	Schöngraben/Törli	St. Anton a. Arlberg	3
1995-02-11	Scheibenspitze	Navis	3
1996-03-09	Frommerkogel, Tennengebirge	Hüttau	3
1996-04-03	Murkarspitze, Gde. Längenfeld	Längenfeld	3
2000-03-16	Wasserradkopf	Heiligenblut	3
2000-11-19	Roßkarschneid	Sölden	3
2003-01-30	Scharnitzalm, Scharnitzfeld	Pusterwald	3
2004-12-20	Mohnenfluh	Lech	3
2005-02-22	Sulzkogel	Silz	3
2005-03-05	Rotschrofenspitze	Kaisers	3
2013-01-18	Mittagskofel, Karnische Alpen	Lesachtal	3

Table 4: List of avalanche events (off-piste or backcountry) in Austria within 1980/81–2015/16 with more than 2 fatalities in each event.