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 US

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ABSTRACT: In this article we analyze 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 are based on reports of the Austrian Board for Alpine Safety and reports of the information services of the federal states. Additionally, we compare Austrian results with results of Switzerland, France, Italy and the United States based on data from the International Commission of Alpine Rescue (ICAR).

Because of the increasing trend and the rather 'narrow' regional distribution of the fatalities consequences on prevention of avalanche accidents are 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. 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)).

In this paper our focus is on accidents caused by backcountry (using no ascent support) and off-piste skiers or snowboarders and the task of the 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 (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. 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 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

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without ski/snowboard, on road, buildings, snowmobile, other).

In case of the international data (Switzerland: Frank Techel, 'Auszug aus der Lawinenschadensdatenbank des SLF' (SLF (2016)); 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.

2.2. Statistical methods

After aggregating the spatio-temporal data in terms of location (resulting in disaggregated data in terms of time), we propose the following model for capturing the trend over time:

$$\log(\mu_{\mathbf{t}}) = f(t) + x_t \tag{1}$$

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. Lower AIC- and BIC-values, however, indicate significantly better fits when comparing the different models. After aggregating the spatio-temporal data y_{st} in terms of time (resulting in disaggregated data in terms of location), 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:

$$\log(\mu_{\mathbf{s}}) = Z\beta_s \tag{2}$$

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:

$$\beta_s|\beta_{-s} \sim N\{\frac{1}{n_s}\sum_{r\sim s}\beta_r, \frac{\tau^2}{n_s}\} \tag{3}$$

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` (RCoreTeam (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 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 AND DISCUSSION

3.1. Temporal analysis with an international overview

If we look at the trend function of Austria in total (temporal estimated function of avalanche fatatilties within the winter periods 1967/68 – 2015/16 with a 90% confidence band of the estimate in 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

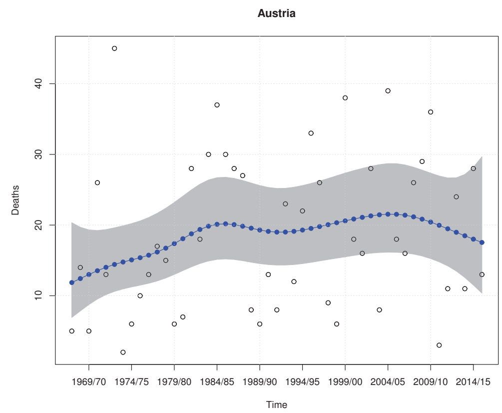

Figure 1: Observed (○) and estimated (•) annual total avalanche fatalities (off-piste and backcountry) with 90% confidence band (grey) in Austria within 1967/68–2015/16.

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 (2003),Abegg (1996)) could give some evidence for this pattern.

Looking at the off-piste trend function starting from the winter season 1977/78 (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 slightly decreasing from the mid 2000s on. Lower AIC- and BIC-values (due to lack of space not reported here, see Pfeifer et al. (2018)) indicate that the nonlinear model is preferable to the constant or linear model – although in case of 'Austria off-piste'

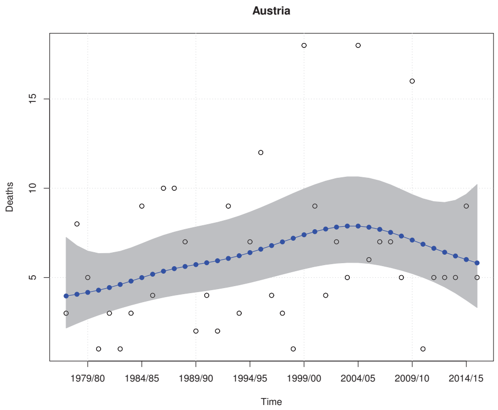

Figure 2: Observed (∘) and estimated (•) annual off-piste avalanche fatalities with 90% confidence band (grey) in Austria within 1977/78–2015/16.

the BIC-value indicates that the linear model seems to be preferable.

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 the total fatality profile of the summing-up of CHE, FRA and ITA within the winter periods 1983/84 – 2015/16 in Figure 3 result in:

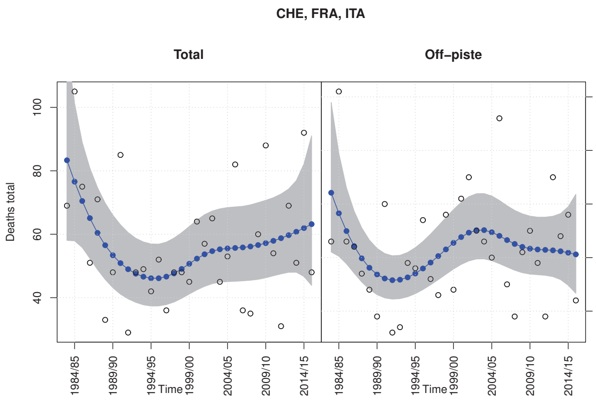

Figure 3: Observed (∘) and estimated (•) annual avalanche fatalities (off-piste and backcountry, i.e. total, on the left and off-piste on the right) with 90% confidence bands (grey) in CHE, FRA and ITA (summing-up) within 1983/84–2015/16.

1. high frequencies in the 1980s,
2. low counts in the 1990s,
3. increasing trend beginning in 2000

which in turn is rather similar to the results of Austria. However, if we consider the results of the United States in Figure 4 (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.

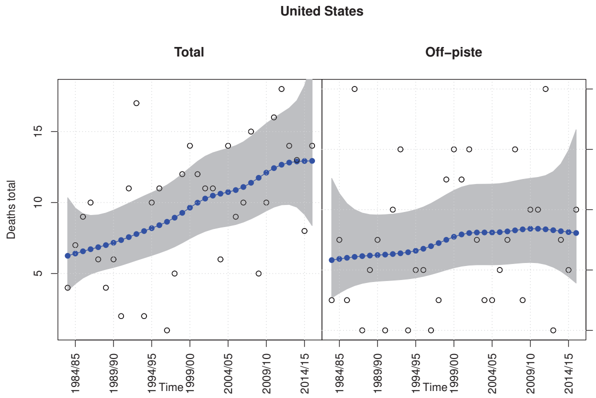

Figure 4: Observed (∘) and estimated (•) annual avalanche fatalities (off-piste and backcountry, i.e. total, on the left and off-piste on the right) with 90% confidence bands (grey) in the United States within 1983/84–2015/16.

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. CHE, FRA, ITA: similar to the total case, but decreasing in recent years.
2. 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 which is in contradiction to linear functions in the literature for avalanche data, see e.g. (Tschirky et al. (2000),Harvey and Zweifel (2008),Spencer and Ashley (2011),Page et al. (1999)). In this context, we observe a significant decrease of number of avalanche accidents with more than 1 fatality, see Figure 5 and AIC/BIC values of the constant, linear and nonlinear model suggesting that the linear model is preferable.

3.2. Regional analysis

In Figure 6 we explore the regional or spatial distribution of avalanche fatalities in Austria within the years 1981–2016. Here the total area of Austria is

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%
Sum	1608	48.73	936	28.36	2544	77.09	36.79%
USA	201	6.09	83	2.52	284	8.61	29.23%

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

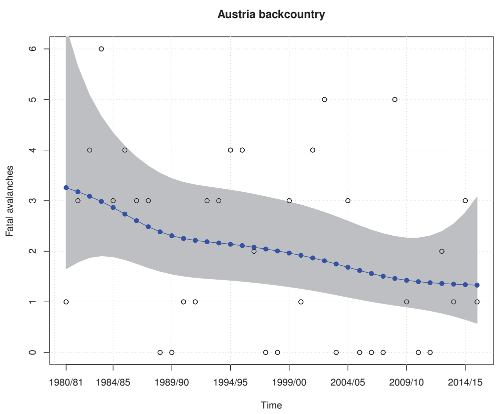

Figure 5: Observed (○) and estimated (•) annual backcountry avalanches (more than 1 fatality) with 90% confidence band (grey) in Austria within 1980/81–2015/16.

divided into small areas, equal to the areas of the Austrian municipalities (211 municipalities with at least one reported fatality). The coloring 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. The municipalities with highest numbers are ‘Sölden’ (50) and ‘St. Anton a. Arlberg’ (31). 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.

4. 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 6: ‘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

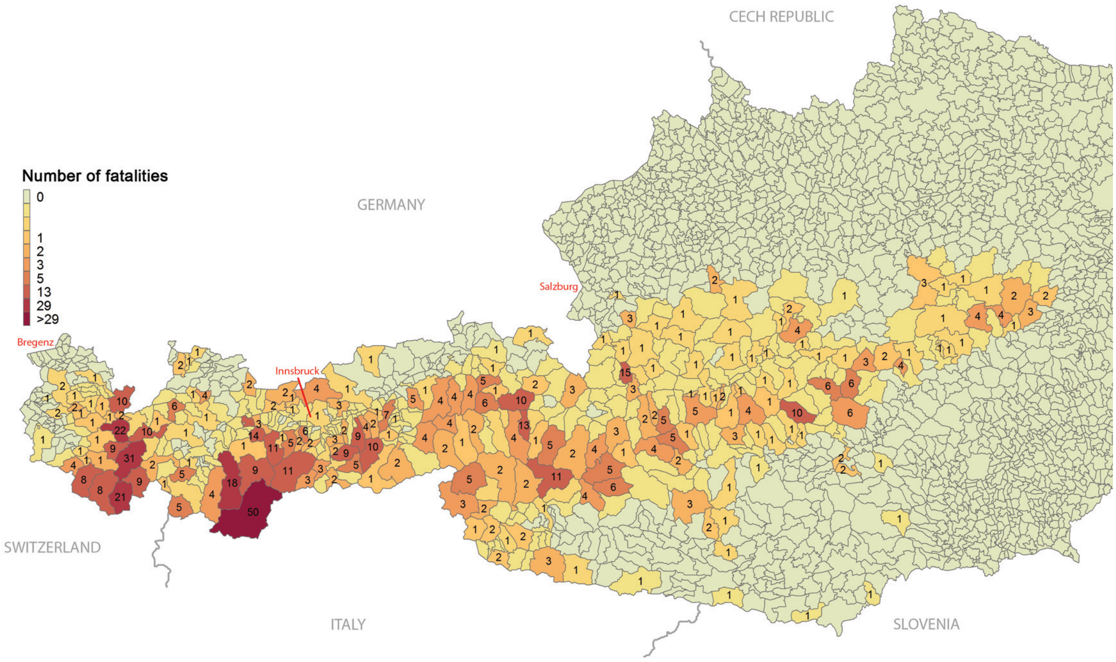

Figure 6: Regional distribution of avalanche fatalities (off-piste and backcountry) in Austria within 1980/81–2015/16.

done in order to prevent the large number of off-piste (freerider) fatalities in St. Anton-Lech-Ischgl and Sölden. Additionally, we observe decreasing numbers of fatal backcountry avalanches with more than 1 fatality, see Figure 5, which could be the effect of more awareness of danger in the last 30 years.

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.

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 in a spatio-temporal model. For this purpose, further and more precise data are necessary.

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