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Discussions

Avalanche risk in backcountry terrain based on usage frequency and accident data

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Abstract

In Switzerland, the vast majority of avalanche accidents occurs during recreational activities. Risk analysis studies mostly rely on accident statistics without considering exposure (or the elements at risk), i.e. how many and where people are recreating. We compared the accident data (backcountry touring) with reports from two social media mountaineering networks – bergportal.ch and camptocamp.org. On these websites, users reported more than 15 000 backcountry tours during the five winters 2009/2010 to 2013/2014. We noted similar patterns in avalanche accident data and user data like demographics of recreationists, distribution of the day of the week (weekday vs. weekend) or weather conditions (fine vs. poor weather). However, we also found differences such as the avalanche danger conditions on days with activities and accidents, but also the geographic distribution. While backcountry activities are concentrated in proximity to the main population centres in the West and North of the Swiss Alps, a large proportion of the severe avalanche accidents occurred in the inner-alpine, more continental regions with frequently unfavorably snowpack structure. This suggests that even greater emphasis should be put on the type of avalanche problem in avalanche education and avalanche forecasting to increase the safety of backcountry recreationists.

1 Introduction

During the last years, about 95 % of avalanche accidents involving people in Switzerland occurred during winter sports activities in uncontrolled backcountry terrain (Techel and Zweifel, 2013). In 90 % of the cases, a dry snow avalanche was triggered by the recreationists themselves (e.g. Schweizer and Lütschg, 2001; Techel and Zweifel, 2013). About two thirds of the avalanche fatalities happened during backcountry ski touring[1], the remaining mostly while out-of-bounds skiing near ski areas. Harvey (2002) noted that during backcountry touring activities a considerable proportion of accidents

[1] Ski or skiing in this article means either ski, snowboard or snowshoe.

occurred at avalanche danger level 2. This contrasts to out-of-bounds skiing, where most accidents occurred at danger level 3. Combining both activities, the collective risk of damage to people to occur by an avalanche increases (exponentially) from one avalanche danger level to the next (e.g. Munter, 1997; Engler and Mersch, 2001; Harvey, 2002). However, as Harvey has pointed out, the individual risk for backcountry users can only be calculated, if the numbers of people in potential avalanche areas are known.

Grímsdóttir and McClung (2006) calculated the probability of triggering an avalanche for a large heli-ski operation in Western Canada by including usage frequencies of different slopes. The likelihood of triggering an avalanche did depend mostly on snow stability and then on elevation level, time of the winter season and slope aspect, but not slope angle. Questioning the guides further, they noted that terrain shape was considered more relevant than slope angle and aspect. Zweifel and Wäger (2008) showed that the number of users undertaking ski tours in the region of Davos (Switzerland) was only half as high on days with danger level 3 compared to danger level 2, while out-of-bounds skiing frequencies were similar at the two danger levels. Jamieson et al. (2009) used these numbers to recalculate the avalanche risk to be about 1 : 70 000 deaths per skier-day. Based on a survey among mountain guides, Jamieson et al. estimated the odds of triggering an avalanche by a skier to increase by a factor of ten from one danger level to another, but noted also a linear increase with the number of start zones skied regardless of danger level. Pfeifer (2009), using Tyrolean (Austria) accident data, simulated skier frequencies using the variables skiing conditions and weekend (yes/no) and confirmed a risk increase factor of 2 from one danger level to the next and showed that slope aspect reduced the risk by one step (e.g. as both used in Munter, 1997).

During recent decades, considerable efforts were undertaken to provide recreationists with tools to reduce the risk while undertaken winter sport activities in backcountry terrain. At the forefront of these efforts, Munter (1992, 1997) developed the reduction method, a simple tool for backcountry recreationists to check their risk. Based on the predicted avalanche danger, Munter took factors like the slope angle and aspect of slope traveled on, if a slope was frequently skied, group size and distances between group members and assessed their potential to reduce the risk.

The lack of backcountry usage data often limits studies investigating the risk in recreational activities in avalanche terrain or evaluating risk reduction tools. However, usage is a basic factor to assess the risk of these recreationists. In our study, we therefore combined accident data from the Swiss avalanche accident database with backcountry usage data originating from two social-media mountaineering websites, where recreationists share information on mountaineering conditions www.bergportal.ch and www.camptocamp.org. The aims of this study are to:

- compare accident and backcountry ski touring activity patterns;
- detect relevant factors and their combinations for high risk of avalanche accidents;
- investigate regional patterns of usage and avalanche accidents.

As only a proportion of backcountry users report their tour on the internet, this study cannot investigate the absolute avalanche risk. However, we can analyze the relative risk in dependence of different contributing factors. This allows detecting high risk patterns. Thus, safety can be increased by focusing on these lump risk factors in avalanche education and avalanche forecasting.

2 Data

We used a variety of data-sources, always for the period 1 December until 30 April and for the region of the Swiss Alps:

- Activity: backcountry activity has been taken from the condition reports on the two social media mountaineering websites www.bergportal.ch (hereafter bergportal) and www.camptocamp.org (hereafter camptocamp). On these two portals, registered users have the opportunity to describe their backcountry touring and mountaineering activities. Any internet user can view these entries. In this study, we considered only backcountry touring activities, either by ski, snowboard or snowshoe. Both websites provided data for the 5 year period from winter 2009/2010 to winter 2013/2014 (Table 1).

- Accidents: we extracted avalanche accident data from the Swiss avalanche accident database. As the total number of accidents was much smaller than the reported backcountry touring activities in a similar 5 year period, we selected a 10 year period as a more representative and robust data set. To allow comparison of the data-sets activity and accidents, we used only accidents during backcountry touring and excluded off-piste accidents in this analysis (Table 1).
- Weather: we used the modal value per region (described in the Sect. 3.1) of the manual morning weather observations from the SLF observer network (about 15 000 manual observations per winter). Observations were classified using three categories
  - 1 – fine: less than 50 % cloudiness,
  - 2 – fair: if neither category 1 nor 3,
  - 3 – poor: precipitation, storm, poor visibility (fog).
- Avalanche danger: the avalanche danger level was taken from the evening forecast of the Swiss avalanche bulletin – issued at 17:00 LT – and valid for the next day (SLF, 2013).
- Snowpack: we investigated patterns of snow structure and dominant avalanche problems by focusing on data providing information on persistent weak layers. These layers are responsible for a large proportion of the severe avalanche accidents (Schweizer and Lütschg, 2001). We used different data sources to describe regional snow structure, snow stability and the main avalanche problems (Table 2, regions described in Sect. 3.1, Fig. 1). These data-sources are part of the operational network used for avalanche forecasting in Switzerland.

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- Manual snow-profiles observed in potential avalanche slopes facing West, North or East. The profiles are classified by snow-structure (Techel and Pielmeier, 2014). This classification is strongly related to the threshold-sum approach (Schweizer and Jamieson, 2007) and combines information on (1) the depth of the uppermost persistent weakness, (2) the proportion of the snowpack, which is soft, coarse-grained and consists of persistent weak layers and (3) the weakest layer interface. Profiles classified as favorable or very favorable contain very few or no persistent weak layers and/or the weakness is buried deep in the snowpack, while profiles classified as unfavorable or very unfavorable contain persistent weak layers, weak layer boundaries and often a weak snowpack base.
- Rutschblock stability tests (RB; Föhn, 1987; Schweizer, 2002) observed on potential avalanche slopes facing West, North or East. We focused on RB which failed in persistent weak layers defined by the threshold sum approach with low or moderate load (RB score 1–4) or moderate load with whole-block releases (RB score 5, whole block).
- The main avalanche problem (Harvey et al., 2012) describing the avalanche danger as recorded by the specifically trained, professional mountain-guides (mAvalanche network; Suter et al., 2010). We analyzed observations, when the guides estimated a critical situation (danger level ≥ 3 for dry snow avalanches). We defined three categories of avalanche problems (Table 2).

3 Methods

3.1 Regional analysis

Geo-referenced activities (generally summit coordinates), accidents (start zone coordinates) and locations of observations (weather, snowpack) were intersected with the more than 120 forecast-areas used to regionalize the avalanche forecast (Stoffel and Meister, 2004).

We investigated regional patterns by splitting the territory of the Swiss Alps into 15 snow-climatological regions (Fig. 1). The regionalization was based on the snow and avalanche climatology classification by Laternser (2002), but incorporates also an avalanche forecaster's perspective (Harvey and Zweifel, 2008).

3.2 Statistical methods

For each activity-report and avalanche accident we used the modal value of the weather conditions (climate region) and the avalanche hazard forecast (issued for the forecast-area).

We compared the data-sets activity and accidents between each other, but also to the base rate of weekdays, weather conditions and forecasted avalanche hazard. The base rate was used to standardize the observed frequencies of activities and accidents. Frequency data is shown in contingency tables. We applied the χ^2 test to the contingency tables to compare the distributions between the data sets (Crawley, 2007).

Many of the parameters are of ordinal nature (for instance route difficulty, avalanche danger). For the purpose of our analysis, we assumed equal intervals between levels.

The non-parametric Mann–Whitney test (Crawley, 2007) was used to compare two populations. Monotonic relationships were tested using the Spearman rank order correlation (Crawley, 2007). Results were considered significantly different when the level of significance was ≤ 0.05 and marginally significant if ≤ 0.1.

4 Results and discussion

4.1 Description and representativeness of data

The available basic demographics of users posting reports and avalanche victims were similar, with a large proportion being male and between 30 and 50 years old (Table 3), and corresponded also to a survey concerning the SLF avalanche forecast (Winkler and Techel, 2014). While the age distribution was similar to a sport demographic survey of the Swiss population (Lamprecht et al., 2014), the proportion of female persons reporting activities or being involved in accidents was considerably lower. The proportion of French and Italian speaking users (camptocamp (= French and Italian) 33 %) was comparable to the Swiss population (32 %), the survey by Winkler and Techel (2014) (32 %) and Lamprecht et al. (2014) (36 %). Differences between users and accident victims concerned group size with more single recreationists posting reports. Among other considerations, Zweifel et al. (2014) and Harvey et al. (2012) surmise that single skiers (1) have a greater desire to communicate their activity to the community, (2) are more risk-conscious and (3) have a lower impact on the snowpack resulting in a lower proportion of accidents. While we do not know the number of tours undertaken each winter in our data-sets (accidents and activities), we suspect that condition reports are posted mostly by experienced users, which would be similar to the study by Zweifel et al. (2012, 25 tours per winter, unpublished data, survey respondents also from bergportal and camptocamp) and Winkler and Techel (2014, 22 per winter, unpublished data). These numbers are considerably higher than Lamprecht et al. (2014, 10 per winter). Also, about 20 % of the active users frequenting bergportal had a higher level of avalanche training (mountain guide, tour guide etc.). Thus, we consider experienced, single and male backcountry users to be overrepresented in the activities data compared to the Swiss mean, but to be reasonably representative for a comparison with the accident data.

The true number of recreationists undertaking backcountry ski-tours in the Swiss Alps is unknown and number estimations are difficult. Based on Swiss data (Zweifel and Wäger, 2008), Jamieson et al. (2009) calculated a death risk of 1 : 70 000 deaths per skier-day. With an average of 14 to 15 avalanche fatalities in the backcountry per year (excluding off-piste), this would result in about one million backcountry tour days per winter in the Swiss Alps. Lamprecht et al. (2008, 2014) showed strongly increasing numbers of people practicing back-country touring (2008: 2.3 % and 2014: 3.9 % of the Swiss population between 15 and 74 years; about 10 ski, snowboard or snowshoe tours per winter) resulting in approximately 1.5 to 2.5 million tour days per winter by the Swiss population. Thus, we estimated that the reported activities represent less than 1 % of the backcountry ski touring activity.

748 accidents involving 1321 people occurred during the investigated time period. Of these, 300 were severe accidents (at least one person was injured, fully buried or died) and of those 103 were fatal accidents (at least one person died). The reporting frequency of severe avalanche accidents is very high and also more formalized than for relatively harmless accidents. The reporting frequency of relatively harmless accidents is not the same throughout Switzerland (e.g. about 20 % higher in the region surrounding Davos than elsewhere; Techel and Zweifel, 2013). To avoid this regional bias, we limited the regional analysis (Sect. 4.3) to the data-set of severe accidents.

4.2 Univariate analysis of factors

- *Seasonal and weekday distribution*: the seasonal distribution for activities and accidents was similar with the highest numbers during the months January, February and March. Activities and accidents were much more frequent on weekend-days than weekdays (ratio on a weekend-day vs. a weekday 3.3 to 1 and 2.6 to 1, respectively, Table 4).

- *Weather conditions*: activities and accidents were much more frequent during fine weather, rather than on days with poor weather conditions (Table 4, $p < 0.01$). On the other hand, activities and accidents had a similar distribution. Taking into account the base rate for weather conditions, activities and accidents were much more frequent on fine weather days than poor weather days (ratio 2.5 to 1 and 1.8 to 1, respectively). Although the difference between activities and accidents was not significant, the lower ratio for accidents compared to activities hints at a higher accident risk in poor weather conditions.

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- *Avalanche danger*: danger level 2 was the most frequently forecasted danger level (Table 4). Most activities as well as most accidents occurred at this level. Danger level 4 was issued very seldom and comparably less activities and accidents (winter recreationists) were recorded on these days. The frequency of activities and accidents differed significantly at the different danger levels ($p < 0.01$). Standardizing activities and accidents by the danger level base rate, we see that relatively more people ventured into the backcountry on days with lower predicted avalanche danger levels (levels 1 and 2), compared to accidents, which were more frequent on days with danger level ≥ 3.

  Based on the above data, the increase in the odds of an accident to occur while backcountry touring is much more pronounced between danger levels 1 and 2 (factor 5) than from 2 to 3 and 3 to 4 (factor 2). These risk increase factors are, with the exception of danger level 1, where our data-set contained significantly less accidents than activities, comparable to Munter (1997); Harvey (2002); Harvey and Zweifel (2008); Pfeifer (2009, factor 2 to 3 one danger level to next), but much lower than the factor 10 estimated by Jamieson et al. (2009) for triggering an avalanche.

- *Terrain*: generally, summits with higher elevation and tours with greater difficulty were the goal on days with fine weather and a lower avalanche danger. The proportion of aborted trips (mean 8 %) increased significantly ($p < 10^{-10}$) with an increase in avalanche danger (level 1: 4 %, level 2: 8 %, level 3: 10 %, level 4: 27 %), a decrease in weather (fine weather 6 %, poor weather 13 %) and an increase in route difficulty. The proportion of aborted trips did not depend on gender, avalanche education (mountain or tour guide, other users) or group size. There was no difference in route difficulty with different group sizes.

  34 % of undertaken routes were graded harder than WS (“wenig schwierig” = “little challenging”) with minor differences between the two web-portals (bergportal 34 %, camptocamp 32 %). The proportion of routes with grades harder than grade

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WS decreased markedly with increasing avalanche danger (level 1: 53 %, level 2: 38 %, level 3: 17 %). In 84 % of the accidents the maximum slope angle was greater than 35° (measured within the outline of an avalanche).

4.3 Regional analysis

4.3.1 Activities and accidents

The two social media mountaineering websites showed differing but complementing geographical patterns, which are closely linked to the Swiss language regions. Bergportal-activities, almost exclusively written in German, were mostly in the northern and to a lesser extent in the eastern part of the Swiss Alps. Camptocamp-reports, mostly written in French and Italian, were primarily from the western and to a lesser extent from the southern part of the Swiss Alps. The climate regions (as shown in Fig. 1), where users recreate mostly (modal value), and the regional frequency of all activities showed no significant differences. This implies that the influence of frequent users (e.g. the 10 % of the users with the highest number of reports contributed to 53 % of all activity reports) is relatively minor when aggregating the data in the 15 larger regions. The only study we are aware of describing where backcountry users recreate mostly is the survey concerning the Swiss avalanche forecast (Winkler and Techel, 2014). The spatial distribution (our data and data by Winkler and Techel, 2014) showed a strong correlation, although the activity reports are somewhat more frequent in northern and western than southern and eastern regions (Fig. 2a).

Figure 2b shows the cumulative activity for the two web-portals for each of the Alpine forecast-areas and the 15 larger climate regions (compare Fig. 1). The greatest densities of activities were logged in the N2, N5 and VS1 regions, while the Obersimmental forecast area by itself contributed to 6 % of the activity reports.

Severe avalanche accidents (Fig. 2c) occurred seldom in the Prealps region (N1), in some parts of Valais and Grisons (VS5, GR2) and in the southern region (S1). In contrast, severe accidents were much more frequent in southern Valais (VS1, VS3,

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VS4), the central areas (N5) and large parts of Grisons (GR), with particularly high numbers in the forecast-areas Val Entremont-Val Ferret (6 % of all severe accidents). A larger number of activities generally correlated with larger number of severe accidents (Fig. 2c, forecast-areas $p < 10^{-5}$, snow-climatological regions $p = 0.05$). Thus, the regional pattern of severe accidents can at least in part be explained by the number of people recreating in backcountry terrain.

If we look at the ratio of accidents to activities for each region, some regional patterns show (Fig. 2d):

- many of the regions in Valais (VS1–VS4) as well as in Grisons (GR1, GR3, GR4) had a high ratio of accidents compared to activities

- the regions in the north (N1–N3, N5) and in the south (S1) had a low ratio accidents to activities.

4.3.2 Terrain, avalanche and snowpack patterns

Figure 3 shows the regional patterns of summit elevation (Fig. 3a), route difficulty (Fig. 3b), forecasted days with danger level ≥ 3 (Fig. 3c) and the proportion of reported activities on days with danger level ≥ 3 (Fig. 3d). We considered the first two to be indicators of the typical winter sport backcountry terrain, the forecasted danger level to represent typical regional snow stability patterns and finally, the danger level on days with activities, provided clues at risk behavior.

The mean summit elevation (Fig. 3a) of the undertaken routes corresponded closely to the Alpine topography: the lowest elevations in the Prealps (N1), the highest elevations in the areas along the main alpine ridge and in Valais.

Route difficulty (Fig. 3b) showed a heterogeneous picture: While the large proportion of relatively easy routes seemed plausible for the Prealps (N1), it was somewhat surprising for the inner-alpine regions in Valais and Grisons (VS3, GR2, GR3). Although only marginally significant ($p = 0.06$), regions with more challenging routes corresponded to regions with greater activity. We suspect (1) that portal users report more often difficult tours than easy tours and (2) that familiarity with a touring region leads to more challenging ski tours over time. If we apply this for instance to the Grisons regions (GR), which are not the "home" recreational area for many bergportal and camptocamp users, the higher proportion of relatively easy routes could be explained.

The forecasted danger level (Fig. 3c) was lowest in the Prealps (N1) and the southern region (S1), while many of the other regions had a rather similar proportion of days with danger level ≥ 3. This pattern correlated positively with the accidents ($p = 0.04$), the summit elevations ($p = 0.02$), but also with the number of activities ($p < 0.001$). However, the forecasted danger level on days with reported activities (Fig. 3d) showed the comparably lower activity on days with critical conditions (compare to Fig. 3c, but also Table 4). Also, a strong negative correlation to the summit elevation indicated that users preferred lower elevation tours on days with critical conditions. This is particularly true for the Prealps (N1), the only region where users ventured relatively more often on days with critical avalanche conditions. As shown by Harvey and Zweifel (2008) and confirmed here, the avalanche danger level on days with activities cannot explain the regional patterns of accident numbers or the ratio accidents to activities.

The touring season (based on the activity reports) was considerably shorter in the Prealps (N1) than the other regions. The high alpine Valais region showed the activity peak latest in the season (VS4, late March).

The regional patterns of the three snowpack parameters focusing on persistent weaknesses were similar and a relatively clear regional pattern showed (Fig. 4):

- The old snow or persistent weak layer problem was most pronounced in Grisons (GR1-GR4), and in the central Valais (VS3).
- Persistent weaknesses were of much less relevance in the central northern and central southern parts of the Swiss Alps (S1, N3, N5).
- Despite analyzing a multi-annual data-set insufficient snowpack data was available for the Prealps region N1.

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The results are plausible, as the more continental, inner-alpine regions in Valais and Grisons are those frequently described in the avalanche forecast with a thinner, but unfavorable snowpack structure.

At first glance, the regions with unfavorable snowpack structure were also those with a higher proportion of accidents and a higher ratio of accidents to activities (compare to Fig. 2c and d). However, the correlation between the different variables and the ratio of accidents to activities (Fig. 2d) was generally poor. A significant correlation was noted only for the Rutschblock variable ($p = 0.03$), which combines information on snow structure and snow stability, while the sum of the ranks of the three variables combined (Fig. 4d) was only marginally significant ($p = 0.06$).

Combining snowpack (Fig. 4d) and elevation information (sum of their ranks, Fig. 3a) lead to a significant correlation to the ratio of accidents to activities (Fig. 2d, $p < 0.01$). This implies that regions with unfavorable snowpack structure and higher summit elevations (avalanche danger generally increases with elevation) were also the regions with more severe accidents. The snowpack rank sum correlated negatively to the route difficulty ($p = 0.03$). An explanation might be that backcountry users adjusted their travel behavior to the relatively unfavorable snowpack conditions in these regions and selected less steep terrain. However, looking at the accident numbers in these regions, the adjustment in route difficulty was not sufficient.

Analyzing the geographical distribution on an even larger scale shows that Valais (VS1–VS5) and Grisons (GR1–GR4) had very similar ratios of accidents to surface area and to number of activities. This value was generally twice as high as for the regions in the north (N1–N5) or the South (S1). Interestingly, the Valais and Grisons regions are also those, where users estimate the forecasted avalanche danger level as being more often too low rather than in the other regions (Winkler and Techel, 2014).

5 Conclusions

We investigated a large multi-annual dataset of backcountry touring activities and compared these to backcountry touring avalanche accidents. For a first time, we used activities posted on social media mountaineering websites to analyze winter sport backcountry patterns. Although active users posting reports were mostly male and likely more experienced than the Swiss average backcountry recreationist, a plausible demographic, temporal and spatial distribution showed. To our knowledge, this is also the first study showing regional patterns of backcountry activity and comparing these with the regional avalanche accident patterns.

Free time and weather conditions are the most important factors defining the number of backcountry recreationists (hence highest on weekends and during holiday periods with fine weather). Large numbers of backcountry recreationists explain to some extent higher numbers of avalanche accidents (by day and by region). While the number of backcountry touring accidents at the two danger levels 2 and 3 was rather similar, there were considerably less activities reported on days with danger level 3. Although seasonal and annual variability exists, the central Valais and the Grisons regions have frequently an unfavorable snowpack structure. We found this to explain the high ratio of severe avalanche accidents in these areas. While we noted that backcountry ski touring recreationists already seem to exercise extra caution when heading to the more continental climate regions, more caution is required. This is particularly necessary if an old snow problem with pronounced weak layers exists. Thus, avalanche forecasters are recommended to describe clearly the regions with an old snow problem (persistent deep weak layer) and to provide the user with precise and understandable information on the type of avalanche problem. Up-to-date information about regional snowpack structure patterns is a pre-requisite for this. The user, on the other hand, requires the knowledge to interpret and adjust his travel behavior depending not only on the danger degree but also on the avalanche problem, especially if it is an old snow problem. In addition, looking at the patterns of backcountry usage, avalanche-warning services

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should make an increased effort to reach recreationists prior to fine weather weekends and holidays to increase the awareness of the current avalanche danger and avalanche problem.

Future research should attempt to verify the backcountry user numbers and their regional distribution at different locations (similar to the study conducted in South Tyrol; Procter et al., 2013) allowing a more accurate estimation of backcountry usage. Further, as proposed by Hendrikx and Johnson (2013), considerable improvements for an improved avalanche risk calculation for backcountry users should incorporate the exact route undertaken by recreationists, but also a regionally verified avalanche danger and avalanche problem.

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Table 1. Backcountry activity and accidents – data overview.

Parameter	Bergportal[a] N = 10479 reports by 1476 users	Camptocamp[b] N = 5107 reports by 736 users	Accidents backcountry touring[c] N = 748 with 1321 people caught	
Date	(100 %)	(100 %)	Date	(100 %)
Summit	elevation [m] (100 %)	elevation [m] (100 %)	Start zone	elevation (89 %)
	coordinates (100 %)	coordinates (100 %)		coordinates (100 %)
Tour	route difficulty (68 %)[d]	route difficulty (93 %)[e]		max. slope angle (46 %)
	reached summit (100 %)			
User	avalanche education (100 %)[f]		Victims[g]	age (26 %)
				gender (35 %)
				nationality (31 %)
				burial type (93 %)
				consequence (98 %)
Group	group size (98 %)		Group	group size (82 %)

[a] Five winter 2009/2010–2013/2014.
[b] Five winter 2009/2010–2013/2014.
[c] Ten winter 2003/2004–2012/2013.
[d] SAC backcountry ski-touring scale (SAC, 2012).
[e] Global ski difficulty (Camptocamp, 2014a).
[f] Self-declaration of users.
[g] All persons being caught in an avalanche, not just avalanche fatalities.

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Table 2. Snowpack data – overview.

Snowpack data	Classes	*N*
snow structure (snow profiles)	(1) very poor/poor (2) intermediate (3) good/very good	7540
rutschblock stability tests (in combination with snow structure of failure plane)	(1) failure in persistent weak layer (3) other failures or no failure	4270
avalanche problem (danger level ≥ 3 for dry-snow conditions)	(1) old-snow problem only (2) mix of old snow and new/wind-drifted snow problem (3) new/wind-drifted snow problem only	1648

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Table 3. Demographic summary statistics.

Data	Accidents Swiss accident database	Bergportal Bergportal (2014)	Bergportal/ camptocamp Respondents in Zweifel et al. (2012)	SLF avalanche bulletin Winkler and Techel (2014)	Demographic sport survey Lamprecht et al. (2014)
male	81 %	80 %	88 %	83 %	46 %
age (median)	43	60 % 30–50 years old	43	41	48

Table 4. Frequency distributions for the day of week, weather and avalanche danger level.

	Day of week		Weather			Avalanche danger level			
	Weekday	Weekend	Fine	Fair	Poor	1	2	3	4
base rate	71 %	29 %	57 %	21 %	22 %	16 %	48 %	33 %	2 %
activities	43 %	57 %	80 %	8 %	12 %	17 %	55 %	28 %	0.2 %
accidents	48 %	52 %	70 %	15 %	15 %	2.7 %	49 %	47 %	0.6 %

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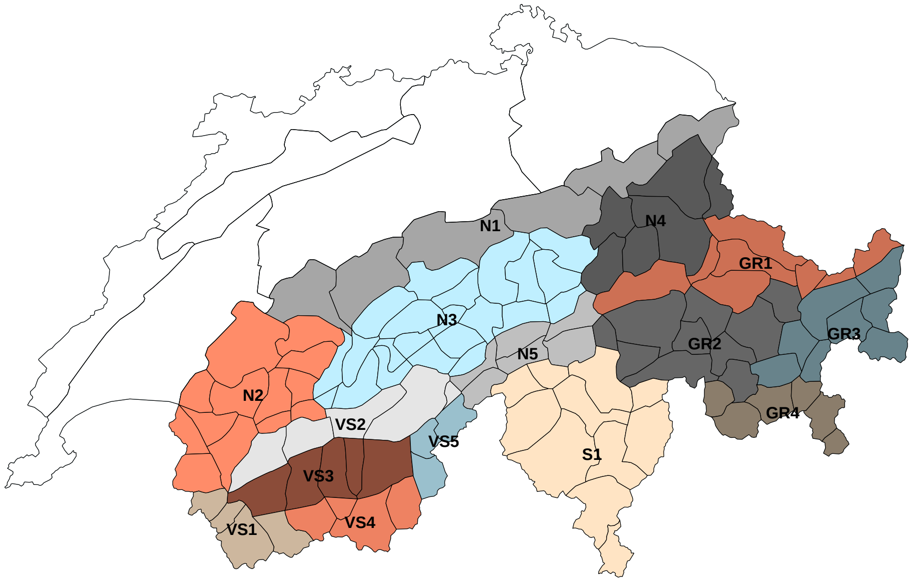

Figure 1. Map of Switzerland showing the forecast-areas used to regionalize the avalanche bulletin (smaller polygons) and the 15 regions (colored and with names) used for analysis in this paper.

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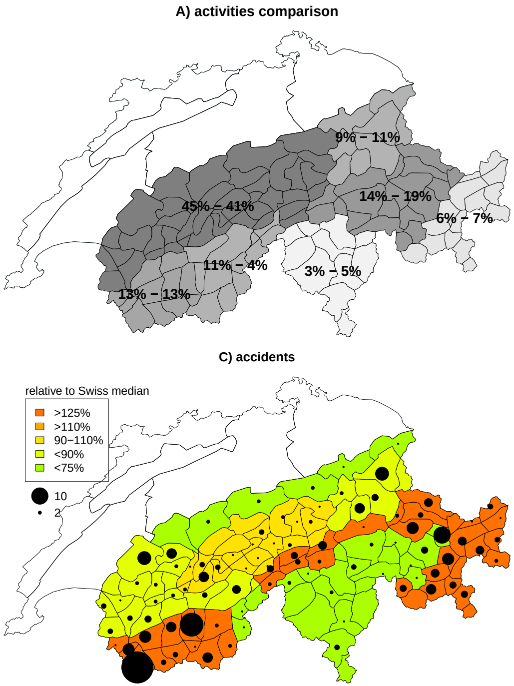

Figure 2. (a) Comparison of the modal value of the region for each user (activities, first value) and the main recreational region for seven regions in Switzerland (second value; survey by Winkler and Techel, 2014); **(b)** distribution of activities; **(c)** severe avalanche accidents and **(d)** ratio of accidents to activities. The size of the circles corresponds to the number of activities and accidents for each avalanche bulletin forecast area. The background color shows the deviation from the Swiss median of the activities or accidents (scaled to surface area, number per square kilometer) for the 15 regions (Fig. 1). Note that Winkler and Techel (Fig. 2a) used different regions than shown in **(b)**–**(d)** and used in this analysis.

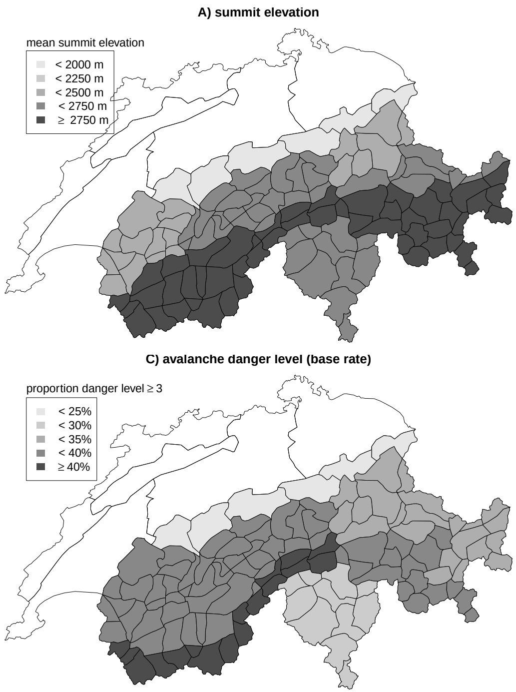

Figure 3. Mean summit elevation **(a)**, proportion of routes graded harder than WS-"little challenging" **(b)**, proportion of forecasted avalanche danger level ≥ 3 **(c)** and proportion of reported activities on days with danger level ≥ 3 **(d)**.

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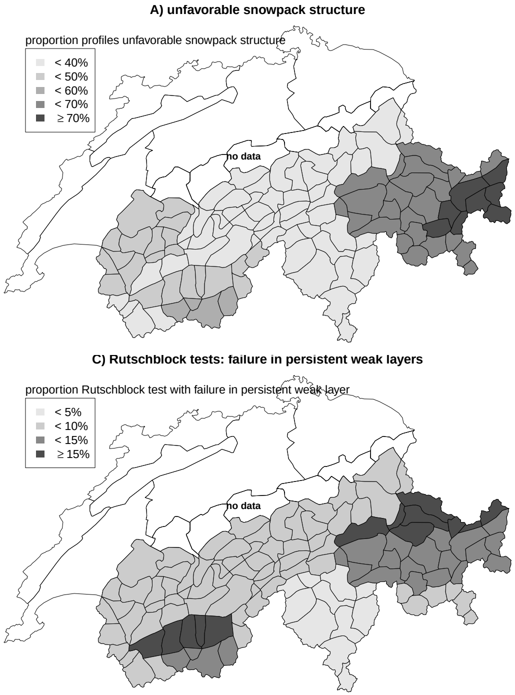

Figure 4. Snowpack structure (**a**, proportion of profiles with unfavorable or very unfavorable snowpack structure), main avalanche problem (**b**, proportion of days with old snow problem and old snow problem combined with new snow problem on days with danger level 3 (or higher)), Rutschblock test results (**c**, proportion of tests which failed in persistent weak layers) and rank sum of the three snowpack parameters **(d)**. No data was available for the Prealps region N1.

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