Avalanche accidents in back country terrain of the Swiss alps: New investigations of a 30 year database

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Abstract: More than 1000 avalanche incidents involving skiers, snowboarders and mountaineers in the back country terrain of the Swiss Alps have been filed in an electronic database. New results concerning accidents on ski-tours and out of bound-skiing (off-piste) can be presented.

95 % off all avalanche accidents were human triggered. In 60 % of the cases the first person in the slope triggered the avalanche. In 30 % of the accidents ski tracks from the same day of the avalanche were present in the slope, in 10 % older ski tracks were found in the slope. Although the same amount of accidents on ski-tours occurred on descent as on ascent, 50 % more people got caught while ascending. The typical victim is male, between 17 and 30 years old. Fatal avalanches are larger than those where nobody got killed. Analysis of complete burials shows that people are more affected on multiple burials than expected.

On 24 days in the last 30 years 4 or more avalanche accidents happened on a single day. Many accident-days occurred after new snow, strong winds with weak snow pack layers. In 20 % of the days there was neither a significant amount of new snow, nor strong winds, but an increase of temperature. On these days the mean predicted avalanche danger was the lowest.

Keywords: avalanche accident, avalanche incident, avalanche accident statistics, avalanche forecast, avalanche bulletin, avalanche danger degree.

1. Introduction

Over the last years an avalanche data base was developed at the Swiss Federal Institute for Snow and Avalanche Research (SFISAR). This unique data base contains all known naturally triggered avalanches causing damage over 100 years and all human triggered avalanche incidents in back country terrain of the last 30 years. It contains totally round 11'000 datasets.

The statistics presented here draw on the data base of all recreational avalanche accidents from 1970 to 1999. This kind of avalanches includes all avalanche accidents where people on tour or off-piste (e.g. skiers, snowboarders, mountaineers, etc.) got caught. Totally 2649 people were involved (677 died, 1986 survived) in 1057 separate incidents. 95 % of them were human triggered, 5 % naturally. The avalanche accidents were analysed in a first part with a focus on new evaluations. In a second part a comparison of the recreational accidents with snow and weather parameters of observation stations from the SFISAR is presented. The results base on studies of Signorell (2001).

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2. New results of recreational avalanche accidents

2.1 Spatial and temporal distribution

An analysis of the areas in Switzerland where recreational accidents occurred, shows that in the region of Davos much more happened than in all the other larger ski resorts of the country (Signorell, 2001). Whereas the number of fatal incidents in Davos does not show this tendency. This can be explained by the fact that the SFISAR gets to know of nearly all avalanche incidents in the region, whereas from other areas the information of non-fatal avalanches is not always transferred to the institute. Therefore we assume that there is a large estimated number of unknown cases were people got caught, but nobody was badly injured. With the comparison of fatal accidents between Davos and other ski resorts a estimated number of unknown non-fatal cases of about 65 % was estimated. This percentage turned out to be a little higher than the estimation by Tschirky et al. (2000) (somewhat below 50 %).

Since 1970 93 % of all recreational avalanche accidents occur during the winter months November to April (Figure 1), 10 % more than in Canada (Jamieson and Geldsetzer, 1996). 50 % of all accidents happen on a weekend day (Saturday or Sunday). During the week there are no significant differences in the days (Figure 2).

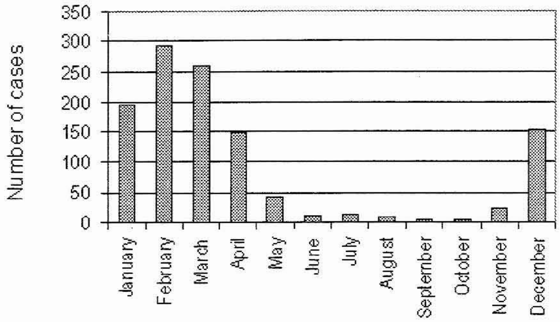
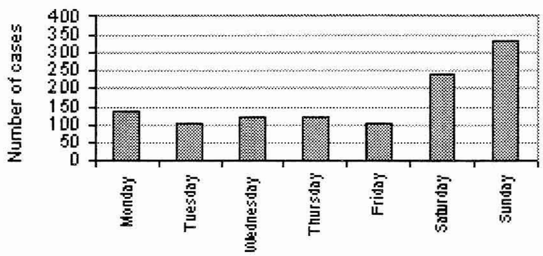


Figure 1: Number of recreational accidents for each month from 1970 to 1999.



Figur 2: Number of recreational accidents for each weekday from 1970 to 1999.

2.2 Total burials

From 2649 caught people in recreational avalanche accidents 698 were completely buried and could not be found due to visible parts. To further development of avalanche transceivers and for rescue teams, statistics with this number of burials are of interest.

Burial depth of all completely buried people are deeper than in investigations of Tschiky (2000), because the presented results in this paper relay on a database containing people who were not found due to visible parts. The median burial depth of all 698 completely buried people is 100 cm. The depth for survival people is 70 cm, the one for dead 120 cm.

Completely buried people (698 cases)		
All (tour: 471; off-piste: 227 cases)	**Dead** (tour: 342; off-piste: 144 cases)	**Survived** (tour: 128; off-piste: 83 cases
100 cm	**120 cm**	**70 cm**

Table 1: Median burial depth of completely buried people found without visible parts. Burial depth for touring and off-piste terrain are the same.

27 % of all avalanche accidents, where people were not found due to visible parts, include multiple burials. For accidents on tours 35 % were multiple burials, for off-piste 16 %. Therefore in two of tree avalanche accidents on tours only one person is totally buried. In casualties point of view, 61 % of all buried people on tours are involved in multiple burials. Approximately ¼ are buried with 4 or more people. In off-piste terrain around 30 % are involved in multiple burials and 4 % are buried with 4 or more people (Table 2 and 3).

	Tours		Off-piste		Total	
Number of burials	Number of Accidents	Number of affected people	Number of Accidents	Number of affected people	Number of Accidents	Number of affected people
1	183	183	156	156	339	339
2	49	98	23	46	72	144
3	22	66	5	15	27	81
4	15	60	0	0	15	60
5	5	25	2	10	7	35
6	4	24	0	0	4	24
7	1	7	0	0	1	7
8	1	8	0	0	1	8
Total	280	471	186	227	466	698

Table 2: Number of accidents and affected people for multiple burials (completely buried people found without visible parts from 1970 to 1999).

	Tours		Off-piste		Total	
Number of burials	Cases %	affected people %	Cases %	affected people %	Cases %	affected people %
1	65.36	38.85	83.87	68.72	72.75	48.57
2	17.50	20.81	12.37	20.26	15.45	20.63
3	7.86	14.01	2.69	6.61	5.79	11.60
4	5.36	12.74	0.00	0.00	3.22	8.60
5	1.79	5.31	1.08	4.41	1.50	5.01
6	1.43	5.10	0.00	0.00	0.86	3.44
7	0.36	1.49	0.00	0.00	0.21	1.00
8	0.36	1.70	0.00	0.00	0.21	1.15
Total	100	100	100	100	100	100

Table 3: Percentage of accidents and affected people for multiple burials (completely buried people found without visible parts from 1970 to 1999).

If people get buried completely by an avalanche the chance is quite high that more than one person is buried.

2.3 Avalanche size of fatal and non-fatal accidents

Between fatal and non-fatal recreational accidents there are significant differences concerning overall length and width of the avalanches (Figure 3 and 4). The smaller the avalanche the bigger is the chance to ski out of it. The probability for lower burial depth is also higher. As described in previous chapter the burial depth for survival people is much lower (70 cm) than in fatal cases (120 cm).

The mean fracture depth is the same for fatal and non-fatal avalanches (Figure 5), namely around 50 cm. This corresponds to the depth at which a person can induce easily a failure in a week layer (Schweizer, 1998). Comparisons between ski tour and off-piste (Schweizer et al., 2000) and also between the different avalanche danger degrees (Harvey, 2002) did neither show any significant differences in the mean fracture depth.

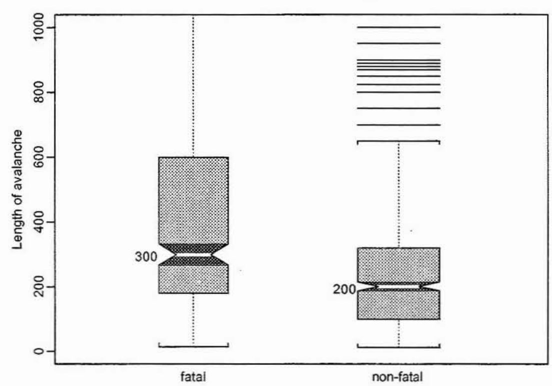


Figure 3: Overall avalanche length of fatal and non-fatal recreational accidents from 1970 to 1999.

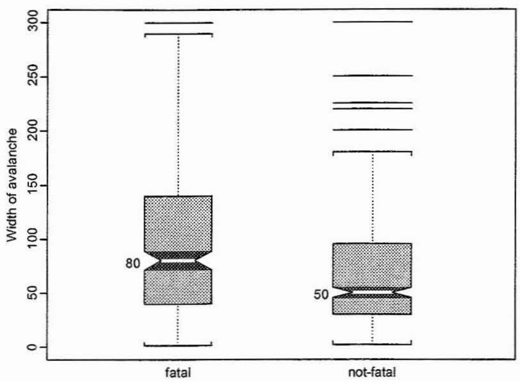


Figure 4: Avalanche width of fatal and non-fatal recreational accidents from 1970 to 1999.

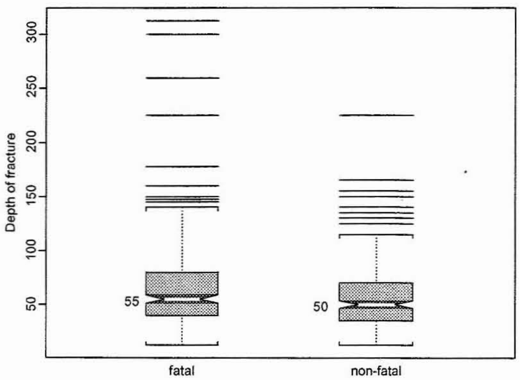


Figure 5: Mean fracture depth of fatal and non-fatal recreational accidents from 1970 to 1999.

2.4 Triggering

2/3 of all recreational avalanche accidents in Switzerland get triggered on tours, 1/3 off-piste. In 60 % of the cases the avalanche slope had no visible traces before the accident and the avalanche got triggered by the first person skiing the slope. In 30 % the slope was skied already on the same day of the accident. Only 1 % of all accidents occurred while ascending in an existing track (Figure 6).

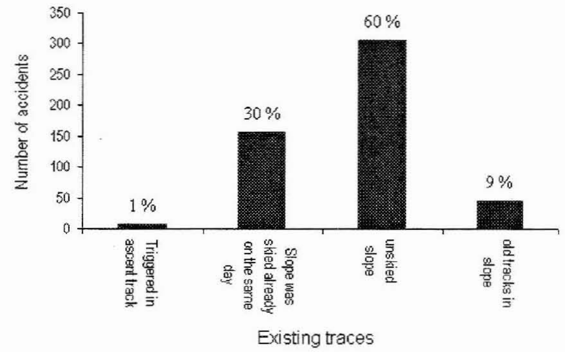


Figure 6: Existing traces in an avalanche slope before the accident. Total number of cases with according data: 517.

On ski tours the amount of accidents which occurred on descents is slightly higher than on ascents. But the number of caught people and the number of fatalities is clearly lower (Figure 7 + 8). 50% more people get caught while ascending. Avalanche accidents with several fatalities happen very often while ascending.

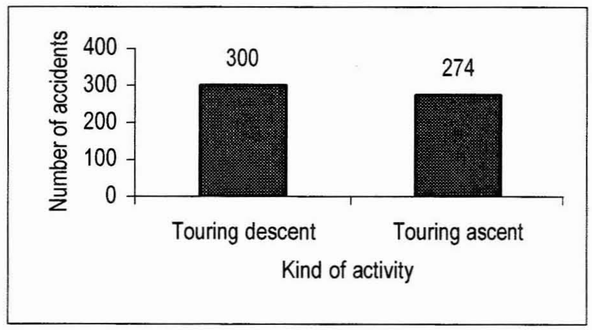


Figure 7: Number of accidents on ski tours on descents and ascents. Total number of cases with according data: 574.

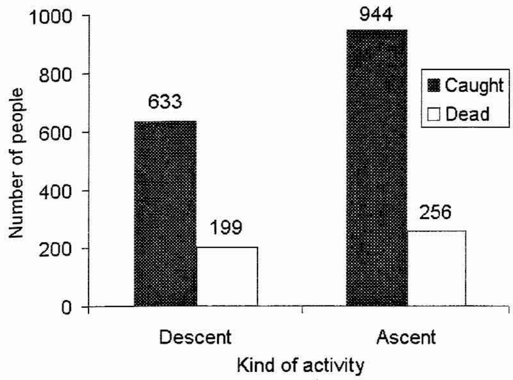


Figure 8: Number of caught and dead people on ascents and descents. Number of people with according data: caught: 1577; dead: 455.

2.5 Damage to people

Mostly males between 17 and 30 years are involved in avalanche accidents (Figure 9). In 30 % of the cases the size of the group causing the accident consists of 2 people, to 16 % of 3 people and to after all 12 % of loners. 80 % of completely buried loners died in the avalanche. For all completely buried people this part is 50 % (Tschirky et al.,2000). Therefore the chance to survive in an avalanche is significantly lower for loners, if totally buried.

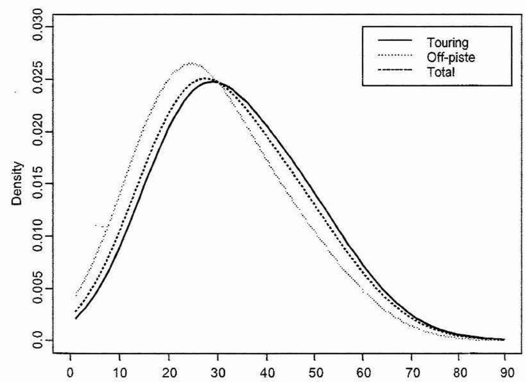


Figure 9: Age of caught people in recreational avalanche accidents on tours and off-piste. Total number of people considered: 1500.

3. Comparison of avalanche days with snow and weather parameters

The avalanche warning service of the SFISAR is based on an avalanche and snow observer network covering the whole Swiss alpine area. About 80 human observers who measure following snow and weather parameters which were used for comparison in this study:

Snow parameters:
- New snow (HN; cm)
- Total snow depth (HS; cm)
- Temperature of snow (TS; °C)

Weather parameters:
- Wind velocity (kts)
- Air temperature (TA; °C)

Days with four or more recreational avalanche accidents (24 days with totally 128 accidents) were defined as avalanche days and were compared with observation stations. Therefore for each accident site the measured data of the nearest observer was considered in the analysis. For the statistical evaluation the snow and weather data were transformed to following nine parameters which were used for a cluster analysis:

- Sum of new snow 7 days back (sum HN)
- Sum of new snow 3 days back (3d HN)
- Sum of new snow of the first 4 days out of 7 (4d HN)
- Percentage of total snow depth to long time mean (% HS)
- Air temperature difference from accident day to day before (TA diff 6/7)
- Snow temperature difference from accident day to day before (TS diff 6/7)
- Sum of wind velocities 7 days back (sum wind; one measurement per day)
- Sum of wind velocities 3 days back (3d wind); one measurement per day
- Sum of wind velocities of the first 4 days out of 7 (4d wind); one measurement per day.

The percentage of total snow depth to the long time mean (% HS) is an indicator for a brief evaluation of the quality of the snow cover (e.g. a low percentage indicates unusually little amount of snow and therefore a higher probability for snow metamorphism and formation of depth hoar).

For each avalanche day the mean of the nine parameters above of each accident was calculated. With a cluster analysis (k-means method) 5 clusters could be evaluated with similar avalanche days concerning the nine parameters. In Figure 10 to 13 the distribution of the relevant parameters for avalanche formation (new snow, temperature, relative total snow depth and wind) is displayed for each cluster.

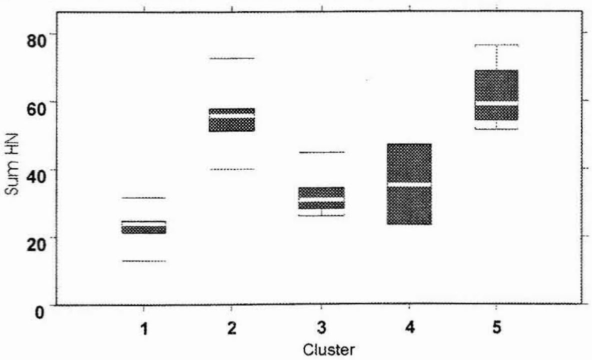


Figure 10: Distribution of sum of new snow 7 days back for each cluster (sum HN).

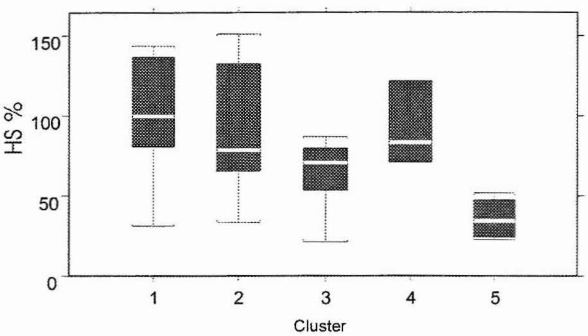


Figure 11: Distribution of percentage of total snow depth to long time mean (% HS).

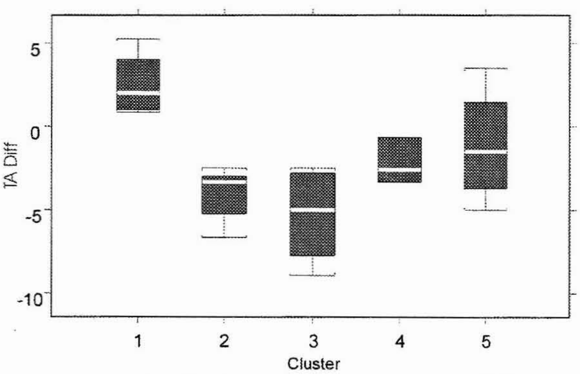


Figure 12: Distribution of air temperature difference from accident day to day before (TA diff 6/7).

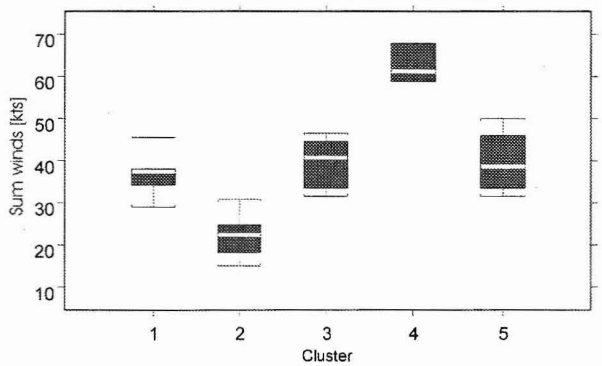


Figure 13: Distribution of Sum of wind velocities 7 days back (sum wind).

The following temperatures referring to 2000 m above see level occurred in the morning for each cluster:

- Cluster 1: -6 °C
- Cluster 2: -12 °C
- Cluster 3: -10 °C
- Cluster 4: -9 °C
- Cluster 5: -10 °C

The resulting 5 clusters can be described as following:

- **Cluster 1: Temperature rise and sparse new snow**
  23 Accidents spread over 4 days were put into this cluster. The mean 3d HN was only 10 cm. It's the only group with a rise of air and snow temperature on the accident day. In 2 cases the predicted avalanche danger degree was "low".

- **Cluster 2: Lots of new snow (specially 3d HN) and cold temperatures**
  25 accidents spread over 5 days were put into cluster 2. The largest amount of new snow fell during the 3 days before the accident (on an average of 36 cm). The temperatures were cold (all mean temperatures below –10 °C at 2000 m above see level).

- **Cluster 3: relatively weak snow cover, moderate amount of new snow and winds, cold temperatures.**
  45 accidents spread over 7 days were put into this cluster. As in cluster 5 the percentage of total snow depth is also low and indicates a bad stratigraphy in the snow cover.

- **Cluster 4: Strong winds**
  On 3 days 17 accidents occurred in this cluster. The most characteristic parameter in this cluster are the strong winds which caused dangerous wind drifted snow.

- **Cluster 5: catastrophe cluster**
  18 accidents spread over 4 days were put into this cluster. The largest amount of new snow was measured and the winds were medium. The mean snow cover is indicated to be the weakest of all clusters. In this cluster many relevant factors for avalanche formation were given.

From 1970 to 1999 "only" on 24 days more than 3 recreational accidents happened in Switzerland. The weather and snow situations before the accidents were not extraordinary on these days but other circumstances matched to achieve an avalanche day. For example on most of these days the weather was beautifully sunny and they often fell on Sundays or holidays (12 of 24 days were Sundays). On such days many people are skiing in back country terrain and therefore the potential for a damage to people increases. On most avalanche days the danger degree "considerable" was predicted by the Swiss avalanche warning service. On the 1. January 1997 (cluster 1) two accidents occurred at danger degree "low" and two more at level "moderate". Except for the temperatures all other snow and weather parameter were rather positive (Sum HN = 13 cm; 3d sum HN = 8 cm; % HS = 136 % (the snow pack was also judged as good by the forecasters); 3d wind = 9 knots). The temperatures on this day rose by about 8 °. On the day before –12 °C was measured at 2000 m, on the accident day –4 °C. The only indicator for an increase of the avalanche danger was the temperature rise, which is one of the most difficult parameter for a forecaster and practitioner to estimate what the consequences are.

4. *Conclusion*

Fatal avalanches are significant larger than non fatal accidents. But the mean fracture depth is the same for all accidents and corresponds to the ideal depth to induce a failure in a weak layer.

Although the stress induced in the snow cover is larger on descents than on ascents, most people on tours get caught while ascending. The reason is, that ascending people often walk quite close to each other and therefore more than one person is situated in a dangerous zone. Furthermore on ascents you are slower to react and try to get out of the avalanche. The fact that nearly 40 % of recreational accidents occur in slopes with existing tracks in it shows, that reliance on existent tracks is not the best advise. However it has to be taken into consideration that from many accidents there is no information about the existence of traces in the slope before the accident happened. In existing ascending tracks hardly any accidents happen. The chance of totally buried people to be involved in multiple burials is higher than expected (61 % for tours and 31 % for off-piste)

The combination of avalanche forming parameters with sunny weather and holidays results often in an avalanche day. Mostly a reasonable amount of new snow (30-60 cm in 7 days) was required for an avalanche day. But in 20 % of the days there was neither a significant amount of new snow, nor strong winds, but an increase of temperature.

5. *References*

Harvey, S. 2002. Skifahrerlawinen und Lawinen-bulletin: Ein Vergleich. Die Alpen 4/2002. Schweizer Alpen Club (SAC).

Jamieson, J. B. and Geldsetzer, T. 1996. Avalanche accidents in Canada – Vol. 4: 1984-1996. Canadian Avalanche Association, Revelstock BC, Canada

Schweizer, J. 1998. Contribution on the role of deficit zones or imperfections in dry snow slab avalanche release. Proceedings International Snow Science Workshop, Sunriver Oregon, USA, 1998.

Schweizer, J. and Lütschg, M. 2000. Characteristics of human triggered avalanches. Proceedings International Snow Science Workshop, Blue Sky MT, USA, 1-6 October 2000.

Signorell, C. 2001. Skifahrerlawinenunfälle in den Schweizer Alpen. Eine Auswertung der letzten 30 Jahre. Diplomarbeit Eidg. Institut für Schnee- und Lawinenforschung, SLF, Davos.

Tschirky, F., Brabec, B. and Kern, M. 2000. Avalanche rescue systems in Switzerland: experience and limitations. Proceedings International Snow Science Workshop, Blue Sky MT, USA, 1-6 October 2000.