

POTENTIAL RELEASE AREAS AND RETURN PERIOD OF AVALANCHES: IS THERE A RELATION?

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ABSTRACT: Avalanche hazard zones are usually defined in terms of impact pressures and run-out distances for avalanches with a specific return period (T). Calculating these parameters through avalanche dynamics models requires a range of input parameters including the extent of the release area, which gives, together with the fracture depth, the total avalanche volume.

Today, in Switzerland and Italy release areas for a 30, 100 and 300 year avalanches are assumed to have the same size while fracture depths are varied with T . This paper focuses on the question of whether it is possible to find a reliable relationship between the extent of a release area and the return period.

Following the same approach that is used in Switzerland to determine the fracture depth of avalanches, we analyzed with Gumbel extreme-value statistics the relationship between T and the extent of the release area of previously observed events in specific avalanche paths. This study is based on avalanche databases of the regions of Davos, Switzerland and the Aosta Valley, Italy.

The results show that for 300yr-avalanches the total extent of the potential release area has to be considered. However, for more frequent avalanches, it is often appropriate to specify only a subarea of the total potential release area. This result suggests that avalanche hazard mapping experts could use the proposed procedure as a help to determine the extent of the release area with a given return period. However, such an approach also emphasizes the need to extend avalanche release area databases by adding new regions and by improving the quality of the release area information collected.

KEYWORDS: avalanche hazard maps, release area, return period, extreme-values statistics.

1. INTRODUCTION

Avalanche hazard maps identify areas endangered by avalanches of different intensity.

In Switzerland, hazard mapping began after the catastrophic winter of 1951 when 98 persons were killed by avalanches and more than 1430 buildings were destroyed. The principle is to prohibit the construction of buildings in an endangered area. Since 1984, the Swiss Guidelines for avalanche zoning (BBF and SLF, 1984) have been the reference document within Switzerland to delineate different levels of avalanche danger and

consequent land use planning. The avalanche hazard is a function of the return period (T equal to 300 or 30 years) and of the impact pressure of an avalanche.

In Italy the situation varies from region to region. The Aosta Valley is the first region that introduced a law regulating the land use planning with reference to the avalanche hazard graduation (L.R. 44/94). At present, avalanche hazard zones are defined by the Law 11/98 (L.R. 11/98), which states that the hazard classification must be done with respect to the maximum historical avalanche event and to the impact pressure calculated for a 100yr-avalanche.

In both cases, avalanche hazard maps are created by a combination of different factors. The application of avalanche dynamics models is one of these factors. Avalanche simulations are performed for avalanches with a specific return period according to the law of the considered country.

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In avalanche simulations an important first step is to determine the potential release area, which, together with the fracture depth, determines the total volume of an avalanche. The most useful source of information are historical avalanche events, because they provide data about the extent of the release area, as well as the runout distance, the fracture depth and the avalanche type.

Until now, no rule has existed to define the potential release area of avalanches as a function of a specific return period. The goal of this paper is to develop a procedure that aims to help the expert to define this input for avalanche dynamics models. In particular, we introduce a statistical method to estimate the extent of the release area of avalanches with specific return periods on the basis of historical events.

In this paper we use data from the region of Davos in Switzerland to present two examples of the proposed method. The results of the method are discussed to identify salient points of the use of extreme value statistics in considering potential avalanche release areas.

2. STUDY SITE

The case study presented is for a study area located in the region of Davos in Canton Grisons in Switzerland (Fig. 1). It is a mountain area of about 300 km² with altitudes between about 1500 m and 3200 m a.s.l. The main features of the region are the principal valley with a NE-SW direction and three parallel lateral valleys with a NW-SE direction (Flüelatal, Dischmatal and Sertigtal).

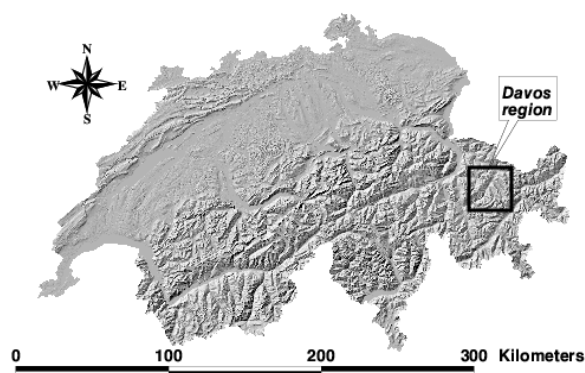


Figure 1. Location of the study site of Davos, Canton Grisons, Switzerland.

In the region of Davos a large database of about 5000 avalanche events over the last 50 years is available (Fig. 2). There are three defined areas where avalanches are observed by ski-patrols of the existing four ski-resorts and reported to the Swiss Federal Institute for Snow and Avalanche Research. They observe large avalanches causing damage or arriving at the valley bottom as well as smaller avalanches in the neighborhood of the ski pistes. The database is also supplemented by avalanche observations from back-country skiers and by avalanche security personnel of the community of Davos. For the analysis performed in this research, natural avalanches of any types and dimension are relevant.

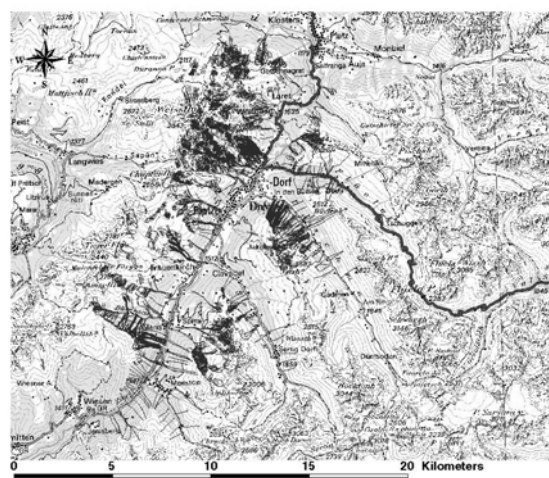


Figure 2. Avalanche database of Davos: the black lines represent the natural avalanches recorded in the last 50 years. Source: SLF.

Every winter, the avalanches that occurred in this region are recorded in a winter report (SLF, 1949-2003), with annotations describing each particular event. Moreover, all the avalanches recorded in these winter reports have been digitized in a GIS to create a digital database. The relevant information for the analysis performed in this study are the avalanche outline, the triggering (spontaneous or artificially triggered) and the width of the avalanche. For this study, natural avalanches are of the most importance; 3297 natural avalanches are recorded in the Davos database (65 % of the total recorded avalanches).

Unfortunately, precise information does not exist for all of the avalanches recorded. As a consequence, the quality of the database is not

homogeneous, because avalanches that occurred in areas far from villages or ski resorts or avalanches that happened at night or in a stormy period may not have been recorded or have been recorded with limited detail.

Unfortunately, there is no possibility to derive a measure of the quality of the recording of every avalanche, because the data cannot anymore be compared with the corresponding historical avalanche events. Due to these uncertainties, in this paper we begin the application of the new proposed methodology considering only two avalanche paths in the region of Davos, where the quality of the avalanche data is known to be very good.

2.1 Brämabüel avalanche path

The avalanche path of Brämabüel is situated at the beginning of the Dischma valley in the region of Davos. It is a steep constant slope, always greater than 30° , from an altitude of 2300 m a.s.l. down to the valley bottom at 1560 m a.s.l., where the inclination becomes gentler. It has a N-NE aspect. On the northern side of Brämabüel, avalanches are frequent. They can break loose from different release areas and run down the slope taking as path one of the four channels through the forest.

The avalanche track considered in this case study is shown in Figure 3.

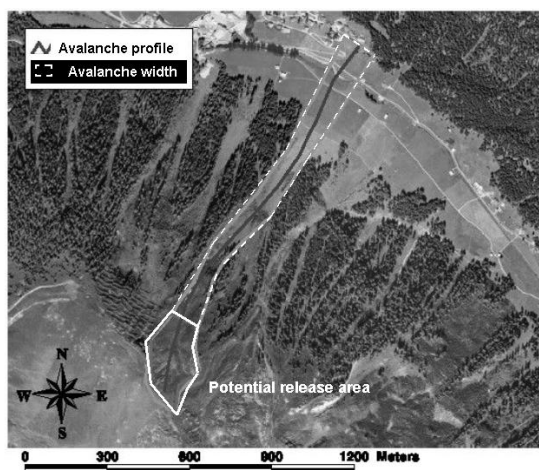


Figure 3. Brämabüel avalanche track: the black line and the white dashed outline indicate the avalanche track, the white polygon represents the potential release area.

2.2 Altein avalanche path

The avalanche path of Altein is situated about 10 km south of Davos. It is a slope of constant inclination (mean slope angle 32°) from an altitude of 2200 m a.s.l. down to the valley bottom at 1420 m a.s.l., with an E-SE aspect. On the eastern side of the Altein ridge, avalanches are frequent. They can break loose from different release areas and run down the slope taking as paths one of the three channels through the forest.

The avalanche track considered in this study is the most northern channel shown in Figure 4.

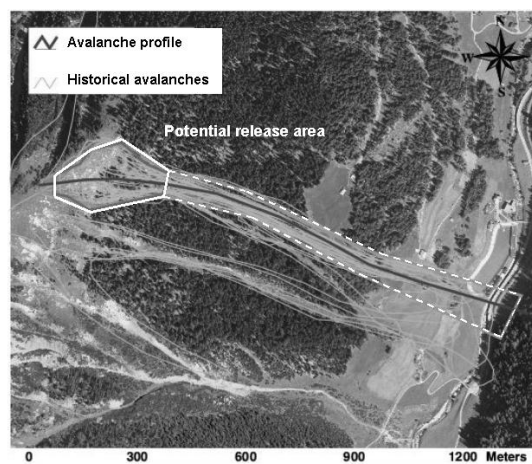


Figure 4. Altein avalanche track: the black line and the white dashed outline indicate the avalanche track, the white polygon represents the potential release area, the thin grey lines are the historical avalanches (1949 – 2003).

3. METHODS

The goal of this work is to examine the possible relationship between the extent of avalanche release areas and the return period of an avalanche for a particular path through the use of extreme value statistics.

The method can be summarized as follows:

- 1) Maximum potential release areas for all paths in the database are defined through the application of an automatic procedure, developed in a GIS, which is based on rules related to topographical parameters of the terrain, such as slope angle, aspect and curvature for example (Maggioni and Gruber, 2003 and Maggioni, 2005). This

procedure helps the expert in the definition of the potential release area (PRA) of an avalanche, where only limited historical data are available.

- 2) The outline of historical avalanches stored in the database is intersected with the total release area to derive the extent of the release area for each historical avalanche as a proportion of the PRA.
- 3) A list of the proportions of PRA released for every historical avalanche is created. This list is then filtered to retain only the largest event per year.
- 4) Using the list, the return period T for proportions of the PRA can be calculated, and an appropriate Gumbel curve generated (Reiss and Thomas, 1997). The method to generate this curve is similar to that used in Switzerland to elaborate the snow data to determine the fracture depth of an avalanche with a specific return period (Figure 5) (Salm et al., 1990).

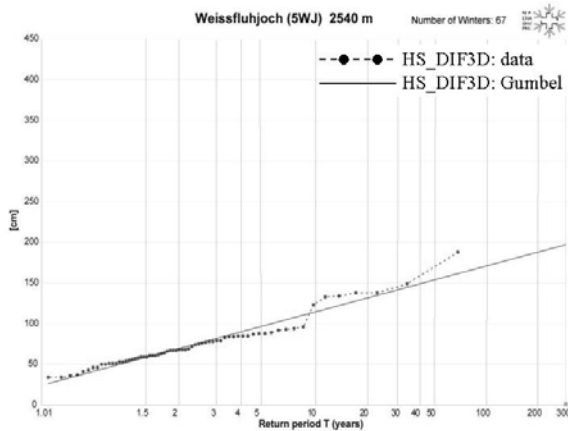


Figure 5. Gumbel statistic for the data of the snow measurement site Weissfluhjoch: maximum difference of the snow height over three days (HS_DIF3D) versus the return period (T). Source: SLF Database.

4. RESULTS AND DISCUSSION

Curves are shown for the two slopes described earlier – that is the Brämabüel and Altein avalanche paths.

For the Brämabüel avalanche path, Gumbel statistics are applied to the maximum values of the release area for the 20 recorded avalanche events and result in the fit shown in Figure 6. The graph relates the extent of the

release area, in percentage of the total PRA, to the return period T .

From the fitted curve, the release area becomes equal to 100 % of the total PRA for avalanches with a return period of 28 years. This finding supports the commonly used assumption that for an extreme event (return period equal to 300yr) the total extent of the PRA has to be taken as input for the avalanche simulations. In this case, a 30yr-avalanche also has a release area already equal to 100 % of the PRA. We will see in our second example, that this is not always true.

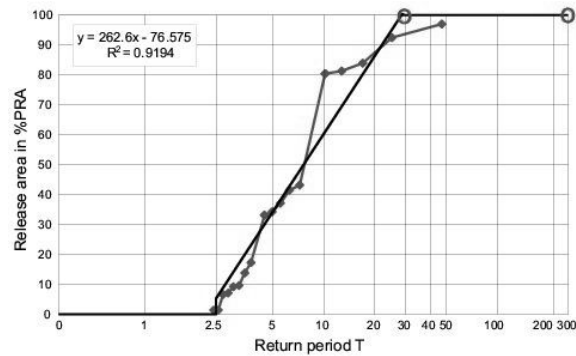


Figure 6. Brämabüel avalanche path: Gumbel statistics for the release area plotted against the return period. See text for explanations.

For the Altein avalanche path, the data of the release areas of 14 historical avalanches are elaborated with Gumbel statistics and result in the fit shown in Figure 7.

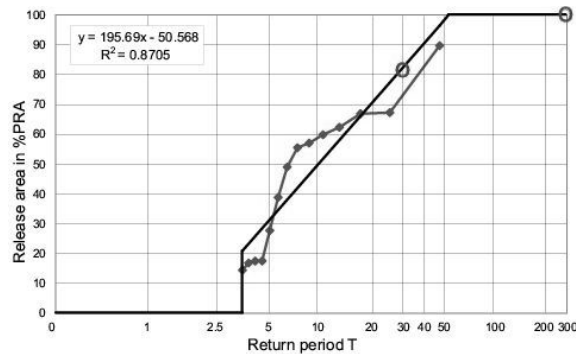


Figure 7. Altein avalanche path: Gumbel statistics for the release area plotted against the return period. See text for explanations.

In this case, the release area becomes equal to 100 % of the PRA for avalanches with a return period greater than 50 years, and for a 30yr-avalanche it is equal to 83 % of the total

area. Therefore, in this case an expert could use for simulation of a 30yr-avalanche an input value for the release area that is lower than the commonly used one in Switzerland (equal to the total extent of the PRA).

Analyzing both cases there are several important features for the Gumbel statistics:

- There exists a minimum value for the return period. This is related to how many historical avalanches were reported in the recording period.
- The maximum value of the PRA was not reached by any historical avalanches. This might suggest that the maximum event did not happen within the recording period.
- The steepness of the fitted curve gives an idea of how rapidly the extent of the release area changes for greater return periods.

In the present paper, only two avalanche paths are examined, therefore it is clear that many more cases must be studied to try to determine a rule, which could then be applied by experts for determining the extent of release areas of avalanches with specific return periods. It is also clear that good historical data for the release area is of great importance, because Gumbel statistics are based on these input data.

5. CONCLUSIONS AND FURTHER WORK

The goal of this paper was to suggest a method to determine the extent of the release area for avalanches with specific return periods.

For avalanche paths where historical data exist, Gumbel statistics on the release area of these past avalanche events can be used to find a relationship between these two variables, which might help avalanche experts to choose the value of the release area for the simulations of avalanches with return periods of 30, 100 and 300 years.

Gumbel statistics provides information about the extent of the release area (as a percentage of the total PRA) of an avalanche with a specific return period. Figure 8 gives fictitious examples of the possible results of Gumbel statistics applied in case of different PRAs. For PRAb, as for the PRA at Brämabüel (see Fig. 6), the release area of a 30yr-avalanche covers already the total extent of the PRA. In case of PRAa, the 100 % of the PRA is reached by an avalanche with $T = 90$ years and the extent of the release area for a 30yr-avalanche is equal to the 77 % of the PRA. PRAb is an example of a potential release area

with only 5 avalanches within the 49 years of the recording period, thus it is not possible to have information about avalanches with a return period smaller than 10 years. For both PRAa and PRAb, as well as for Bramabüel, the release area of a 300yr-avalanches covers the total extent of the PRA, while for PRAc these avalanches have a release area equal to the 90 % of the PRA.

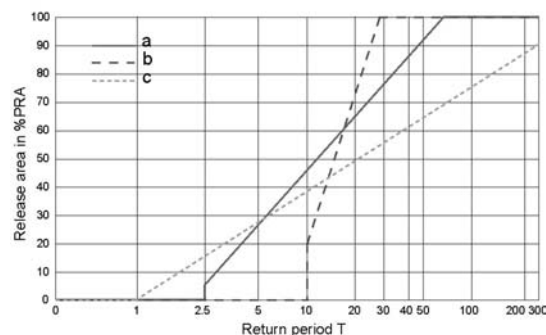


Figure 8. Fictitious examples of possible results of the Gumbel statistics applied on the data of release areas of past avalanche events within three different PRAs.

By analyzing Gumbel statistics performed for many more PRAs it will be interesting to see if the hypothesis that avalanches with $T = 300$ years have a release area equal to the total extent of the PRA is correct. Moreover, it will be possible to give recommendations about the extent of the release area of avalanches with $T = 30$ years for the avalanche hazard mapping procedure.

In the future, our proposal is to work also on the avalanche database of the Aosta Valley in the North-West of Italy (Fig. 9).

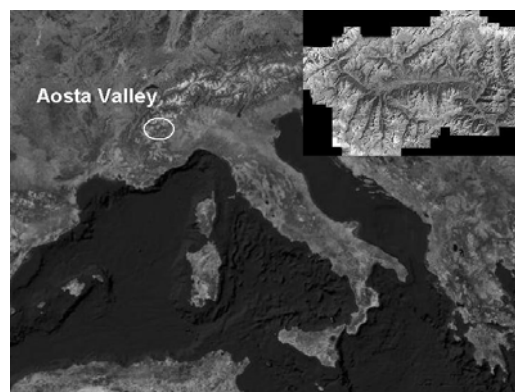


Figure 9. Location of the study site of Aosta Valley in the North-Western Alps, Italy.

The region is 3263 km² with an altitude varying between the 4808 m Mont Blanc and 350 m, with a territory at an altitude above 1200 m for the 85%, where, related to the climatologic conditions of the area, avalanches can occur. Historical avalanche events are recorded in a database composed of numerous forms and photos, organized into 19 sub-areas. In total, ca. 1200 avalanche paths have been identified in the Aosta Valley.

A good existing product is a digitized database (Fig. 10) where however, until now, only the extent of the maximum event for every avalanche path is represented. The problem resulting from such a database is that not all the avalanche events are digitized, while for the study we want to perform this characteristic is necessary, being a research based on avalanche dimension and frequency. The idea is to find some test sites in the region where starting an accurate recording of all the avalanche events in order to obtain a good database usable for testing the proposed procedure.



Figure 10. Digitized avalanche database of the Aosta Valley: black lines represent the 1200 avalanche paths and grey lines the river net. Source: Ufficio Neve e Valanghe of Aosta Valley.

Besides testing the procedure on more numerous avalanche paths, a field of future work is the combination of the Gumbel statistics with a *similarity matching procedure* (Maggioni, 2005) in order to estimate the extent of the release area for avalanches with specific return periods that occur in avalanche path where no historical data are available.

6. AKNOWLEDGEMENTS

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7. REFERENCES

- BBF and SLF, 1984. Richtlinien zur Berücksichtigung der Lawinengefahr bei raumwirksamen Tätigkeiten. Technical report, Eidgenössisches Drucksachen- und Materialzentrale: Bundesamt für Forstwesen; Eidgenössisches Institut für Schnee- und Lawinenforschung.
- Legge Regionale 44/94, 1994. Bollettino Ufficiale Regionale della Regione Autonoma Valle d'Aosta, Italia.
- Legge Regionale 11/98, 1994. Bollettino Ufficiale Regionale della Regione Autonoma Valle d'Aosta, Italia.
- Maggioni, M. and Gruber, U. 2003. The influence of topographic parameters on avalanche release dimension and frequency. *Cold Regions Science and Technology*, 37, 407 - 419
- Maggioni, M., 2005. Avalanche Release Area and Their Influence on Uncertainty in Avalanche Hazard Mapping, PhD Thesis at University of Zürich, Geography Department.
- Reiss, R.-D. and Thomas, M., 1997. *Statistical Analysis of Extreme Values*. Birkhäuser Verlag.
- Salm, B., Burkard, A. and Gubler, H., 1990. Berechnung von Fließlawinen: eine Anleitung für Praktiker mit Beispielen. Mitteilung 47, Eidg. Institut für Schnee- und Lawinenforschung.
- SLF, 1949-2003. *Schnee und Lawinen in den Schweizer Alpen, Winter 1949-2003*. Winterbericht, Eidg. Institut für Schnee- und Lawinenforschung.