Regional methods for snow avalanche prediction: the case of Italian Alps

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ABSTRACT: Regional statistical methods carry considerable bearing on prediction of natural events with low frequency of occurrence, including snow avalanches. These methods trade time variability for spatial distribution and increase sample dimensionality for model estimation, so coping with shortness of usually available data base as compared to the high return periods of the design events. In the Italian alpine range, the *guidelines* set out by AINEVA association inspired to Swiss Procedure Sp endorse hazard mapping based on design avalanches with release depth predicted using the three day snow depth H_{72} with return period up to 100 years. Considerable uncertainty is entailed in such prediction, mainly due to the average length of the observed H_{72} series, of twenty years or so. Here, I adopt the regional approach to provide hazard mapping for a particular avalanche site in Lombardia Region of Italy. Hazard maps are built by: i)Sp based upon regional evaluation of H_{72}, ii) long term simulation of snowfall and avalanche occurrence based upon a previously developed regional approach. I then carry out a comparison with the hazard maps as deduced by the two approaches, and draw some final remarks.

KEYWORDS: avalanche hazard, regional methods, long term simulation, Italian Alps.

1 INTRODUCTION

The Alpine and pre-Alpine area of Lombardia region, in northern Italy, is characterized by relevant tourism during winter and features many ski resort areas. Every year, several avalanches occur therein, and in the period from 1990 to 2000 at least 7200 avalanche events were mapped, with at least 215 casualties (Regione Lombardia, Regional Avalanches Information System, SIRVAL, 2002), thus claiming for reliable avalanche hazard management and land use planning. The current approaches to avalanche hazard mapping include avalanche dynamic modelling coupled with statistical analysis of snow depth at avalanche start (e.g. Bocchiola *et al.*, 2006; Bocchiola and Rosso, 2007a; Bocchiola *et al.*, 2008), also with snow entrainment (Bianchi Janetti *et al.*, 2008). In avalanche hazard mapping exercise according to Sp, the *T*-years return period avalanches at a given site are computed and their run out zone and pressure are evaluated. The snow depth at release is often assumed to coincide with the snow depth precipitation in the three days before the event, or three days snow fall depth, H_{72}. The *Swiss procedure* (hereon *Sp*, *e.g.* Salm *et al.*, 1990), also used as a reference in Italy (*e.g.* Barbolini *et al.*, 2003), provide mapping criteria for dense snow avalanches requiring as an input for each avalanche site the evaluation of the *T*-years value of H_{72} for $T = 30$ and $T = 300$, at least. The statistical estimation of the *T*-years quantiles of H_{72} is carried out by distribution fitting of the single site maximum annual observed values of H_{72}. According to the theory of extreme values to provide reliable estimates of the *T*-years quantiles using empirical distribution fitting, a least number of observations is required, in the order of $n_{obs} = T/2$. For $T = 300$ years, this amounts to about 150 years of sampled data. In the Italian alps, unless for a very few cases, only short series of observed snow depth are available, covering a period of 20 years or so (*e.g.* Bocchiola and Rosso, 2007b). Bocchiola *et al* (2006) have shown that the lack of observed data for distribution fitting of extreme values of H_{72} can be overcome by using the *index value* approach. This implies that values of a hydrological variable that are scaled, *i.e.* divided by an index value have identical frequency distributions across all sites within a given homogenous area, or region (see *e.g.* Bocchiola *et al.*, 2006). Bocchiola *et al.* (2006) and Bocchiola and Rosso (2007b) have shown that the considered region is homogeneous with respect to the distribution of the greatest annual value of H_{72} and of the daily snow fall, thus making suitable the regional approach. Further, Bocchiola *et al.* (2009), have shown how regional methods can be to set up more sophisticated methods for long term simulation of avalanche regime for hazard mapping purposes.

Here, I adopt the regional approach to provide hazard mapping for a particular avalanche site in Lombardia Region of Italy. This is the

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Vallecetta avalanche, endangering the town of Bormio and the roadway on the river Adda valley. Voellmy Salm (henceforth VS) dynamic model is calibrated for the considered site and validated against data from historical avalanche events (see Bocchiola *et al.*, 2009; Bocchiola and Medagliani, 2008). Then hazard maps are built by: i)Sp based upon regional evaluation of H_{72}, ii) long term simulation (henceforth LT) of snowfall and avalanche occurrence (based upon Bocchiola *et al*., 2009)

A comparison is then carried out with the hazard maps as deduced by the two approaches, and some final remarks are drawn.

2 CASE STUDY AREA

The case study area (Fig. 1) covers the mountainous area of the Lombardia region, in the central Alpine and pre-Alpine area. There, 40 snow depth measurement stations are present, mainly adopted for avalanche warning purposes, property of the Interregional Association for Snow and Avalanches (AINEVA, 33 stations), located at the Snow and Meteorological Center of Lombardia Region in Bormio city (see Fig. 1b) and of the Regional Agency for the Protection of the Environment (ARPA) of the Lombardia region (7 Stations), located in Sondrio city (see Figure 1b). The altitude of the stations ranges from the 660 m asl of the CUC station to the 2675 m asl of LCA station. The reader is referred to Bocchiola *et al.* (2006) and Bocchiola and Rosso (2007) for detailed description of the data base.

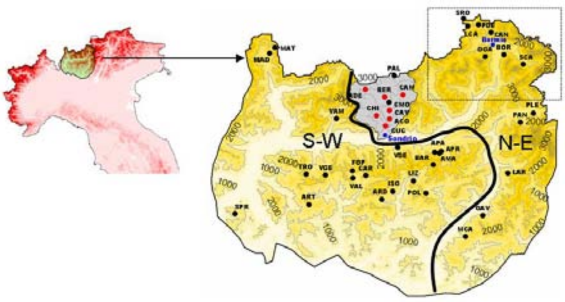

Figure 1. Case study area. Dark dots are ARPA stations, light dots are AINEVA stations. The dark area is Val Malenco. The black line divides the subregions S-W and N-E for index value assessment.

The available avalanche data base for regional avalanche occurrence evaluation (Fig. 1b) cover the eastern part of Valtellina Valley. Six historical avalanche sites were investigated, for a number of 69 observed avalanche events (see for full description, Bocchiola and Medagliani, 2007; Bocchiola *et al.*, 2009). Avalanche data for these events were retrieved mainly into the data base of the Rangers of Sondrio City (Corpo Forestale dello Stato, CFS) and also into the archives of the Italian Association for Snow and Avalanche (AINEVA).

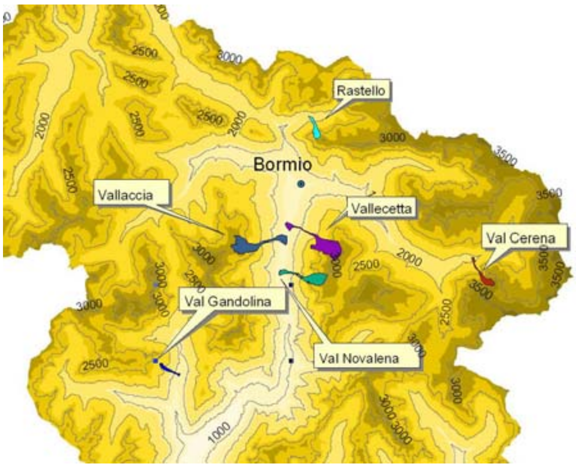

Figure 2. Investigated avalanche sites for regional long term simulation, historical end marks.

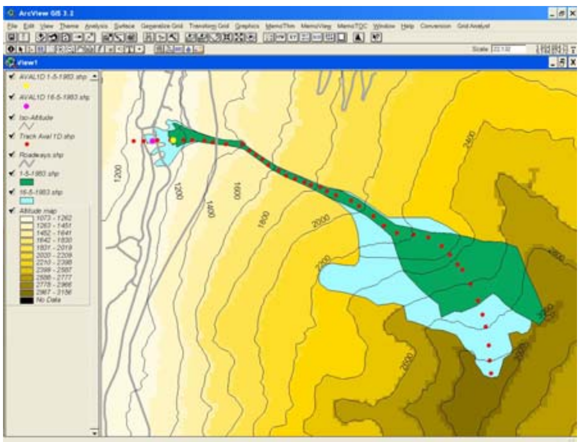

Figure 3. Vallecetta avalanche site. Mapped release and runout of the two largest observed events on 1th and 16th of May 1983. Red dots show the profile chosen for dynamic simulation.

The Vallecetta mountain (Figure 3) is situated in the village of Valdisotto, south of Bormio city. The release area of the avalanche is in a wide amphitheatre placed above 2400 m. asl. The narrow Vallecetta channel starts at about 2100 m. asl. Channel slope ranges from about 40° in the initial part, to about 30° in the final. At about 1300 m asl, the channel spreads into a vast, more gently sloping alluvial fan and the avalanche track bends towards left, taking west direction and reaching the deposition zone. More than twenty avalanche events of increasing magnitude occurred at this avalanche site ever since 1886, when the first recorded event is reported. Two events of considerable magnitude occurred in May 1983. On May 1th, the avalanche reached the alluvial fan and stopped at

1174 m asl and the deposited snow blanket paved the way for a second avalanche, occurring on May 16th, reaching the Adda river (longest path ever) and occupying the state road SS 38 in the valley below for 500 meters, also causing one casualty. For hazard mapping of dense snow avalanches, of interest here, two main tools are necessary. The first is an estimation of H_{72} at release, while the second is a numerical model, allowing dynamic simulation of a flowing avalanche, which is shown to be reliable by comparison against some observed avalanche events. While I used AVAL1D® in past simulations, and while I developed, together with other scientists a distributed mass centre model, already successfully tested for the Vallecetta site (see Bocchiola and Rosso, 2007a; Arena Lo Riggio *et al.*, 2009), I use here VS model, because it was calibrated for the whole sample of avalanches within the area and its friction parameter μ can be explicitly estimated as a function of H_{72} here (see Bocchiola and Medagliani, 2007), Also VS model is quick enough that it can be used coupled with the long term avalanche occurrence simulation model, developed in Bocchiola *et al*., 2009.

3 AVALANCHE HAZARD ZONING

3.1 Sp approach using regional snow depths

I here estimate $H_{72}(T)$ at avalanche release altitude using the regional approach as explained *e.g.* in Bocchiola and Rosso (2007a), Bianchi Janetti *et al.* (2008) and then use it to feed VS model as calibrated for the area (see Bocchiola and Medagliani, 2007). According to Italian guidelines (e.g. Barbolini *et al*., 2003), I here use T= (30,100) for avalanche hazard zone calculations, contrarily to Sp, enforcing use of T=(30,300).

3.2 Long term simulation

I here use LT of daily snowfall and avalanche occurrence based upon regional concepts, as explained in Bocchiola *et al.*(2009), again coupled with VS approach, to evaluate daily occurrence, runout and velocity of avalanche events, so being able to calculate the necessary statistics for the return periods necessary for hazard zoning.

4 RESULTS

In Figure 4, I report the results of hazard mapping procedure. The LT approach provides in fact consistent results against the Sp (i.e. included within the 5% confidence limits, see for their calculation, *e.g.* Bianchi Janetti *et al.*, 2008), and, in this case, would lead to slightly less conservative zoning.

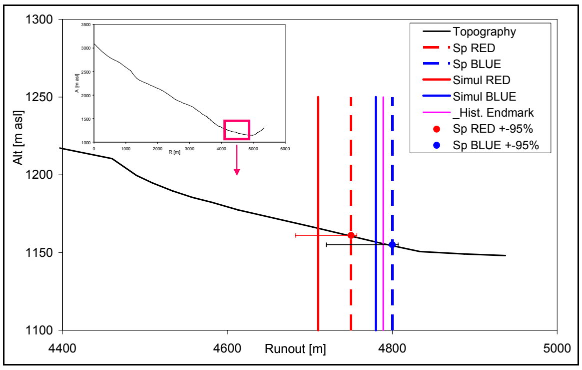

Figure 4. Avalanche hazard zoning, Sp against LT.

In Figure 5, it is shown estimated return period of the whole range of Vallecetta avalanche runout using LT, plotted against historical data (data reported fully in Bocchiola *et al.*, 2009), also of interest in avalanche hazard mapping procedure.

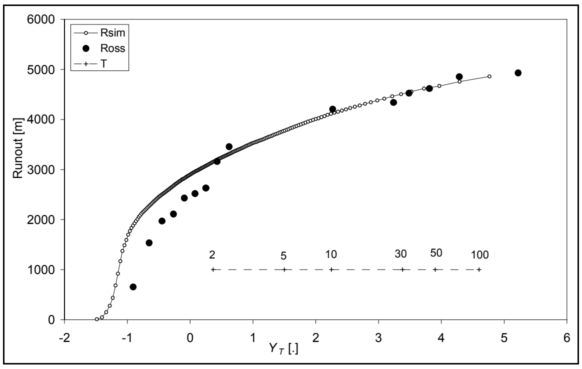

Figure 5. Return period of avalanche runout simulated using LT, against empirical plotting position from historical data.

5 CONCLUSIONS

Use of regional methods results into considerable gain of information for avalanche hazard exercise. I showed already elsewhere that use of regionally estimated values of $H_{72}(T)$ results into less uncertain zoning according to *Sp* approach. Here, I showed that use of a regionally setup method for long term simulation of avalanche occurrence, coupled with a dynamic VS model, allows increase sample of dimensionality for model estimation, and results into proper hazard zoning, *i.e.* one that is consistent with Sp. While definition of the “actual” value of the blue and red zone is clearly speculative, the proposed LT methods allows several numerical repetition of the process, so providing more robust statistical assessment, together with quantified uncertainty.

In the mean while LT feeds back a considerable amount of information, including expected return period of avalanche runout distance, avalanche volume at release, and at deposition (Bocchiola *et al.*, 2009).
In the future, I plan to couple LT approach with a more sophisticated model, maybe with entrainment (e.g. RAMMS®, as in Bianchi Janetti et *al.*, 2008), to obtain more complete simulation of avalanche dynamics at a daily scale. This may be used for more refined hazard zoning as required by well informed land use planning, but also for conjectures about avalanche ecological and morphological effect, also under pending climate change.

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