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Planning with snow avalanche risk: when the *Carte de localisation probable des avalanches* becomes old-fashioned

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Introduction

Alpine communities have since ever lived with snow avalanche risk: local people has known where to build in safe locations and where to pay attention to when travelling under snow avalanche conditions. Since the last four decades, the demand of spaces for structures and facilities to increase winter tourism capacity has enormously speeded up, thus forcing a closer cohabitation between man and snow avalanches. This is the reason why local communities have started to search for appropriate methods to identify areas more susceptible than others to snow avalanche occurrence.

The most popular method developed, and still widely used, at least within some of the alpine regions, is represented by the "*Carte de localisation probable des avalanches*" (map of snow avalanche probable locations) where avalanche tracks are traced after interpretation of aerial photographs, direct field survey and interviews of snow avalanche eye-witnesses. The scale of that map is usually 1:25.000. The photographs usually capture the study area during times of the year when the ground is free of snow, and during summer time the filed survey is undertaken. The observer tries to identify areas (mainly the middle and the run-out parts of the track) where the signs of avalanche activity are clear due to vegetation destruction, but he can not correctly draw the boundaries of release areas, usually lying in places free of vegetation. In this way, release areas tend to be overestimated, since the observer is likely to put himself on the safe side, including in what he considers to be "release area" also areas which, in reality, may be not. As an example, the areas estimated by the observer as probable release areas are usually represented by the whole funnel-shaped concavity forming the upper part of a gully where the snow avalanche is canalised. It is true that those concavities appear to act as homogeneous containers for potentially sliding snow, but it is also known, by experience, that not all the snow contained in a concavity is released at once. Most of the times, only parts of those concavities are prone to avalanching. It should be clear how hard it can be to distinguish, during the summer time, which part of a topographical concavity is more susceptible than another to avalanching, when no snow accumulation pattern is visible!

The map drawn by the expert after photo-interpretation and fieldwork is then validated using snow avalanche eye-witnesses. But what is the degree of precision that human memory (usually the witnesses are very old men) can have and, more than that, how high is the chance for a human being to be right there to look at the exact point where the avalanche has been released?

It is evident that the degree of subjectivity of the map is rather high and that there is no real validation of it during winter time. Moreover, the costs of production are also high, mainly due to the time needed for fieldwork. Another weak point is that the map "photographs" a static situation: maps of snow avalanche probable locations are already 20-year old in certain parts of the Alpine chain, therefore what has happened during the last 20 years is neglected.

On the other hand, where absolutely no data on past snow avalanche occurrence is available, the map represents the only tool to assess the snow avalanche susceptibility of a certain territory.

If at least some of the most hazardous snow avalanches that occurred in the past within a certain territory were available (almost all inhabited Alpine areas are covered by the provincial snow avalanche registers, at least in Italy), a different approach should be chosen for a more objective susceptibility assessment, specially nowadays that spatial data analysis, together with GIS functionalities, allows to reach results in a quicker and more precise way.

The methodology presented in this abstract goes towards the direction indicated by the latter approach: it is based on the analysis of the statistical relationship between past snow avalanche release areas (those recorded in Provincial snow avalanche registers) and causal factors of snow avalanche occurrence which could be represented by maps. The result is a susceptibility map which shows the areas with the highest probabilities to be part of future snow avalanche release areas, it is validated and its pattern compared with the one shown by the map of snow avalanche probable locations of the same area. The study area chosen for this experiment is the Alta Val Badia (Italian Dolomites). The susceptibility pattern produced through this methodology appears to fit well with that of the map of snow avalanche probable locations, spotting also potentially susceptible areas which are skipped by the classic methodology. The fieldwork is totally avoided and the digital maps needed for the assessment are easily acquirable or derivable, thus reducing the costs to the minimum.

1 The GIS-based statistical way

The methodology proposed has already been presented, in its mathematical and operative bases, in three papers which the reader can refer to for a deeper insight...........(Ghinoi, 2004; Ghinoi and Chung, 2004; Ghinoi et al., 2002). Here the focus will be on the type of data needed for running the susceptibility assessment, the way to acquire it and to handle it, the output obtainable and its comparison with the map of snow avalanche probable location.

For those who are not familiar with the spatial data analysis methodology developed by Chung & Fabbri.................(Chung and Fabbri, 1993; Chung and Fabbri, 1999; Chung and Fabbri, 2001), a few lines will be devoted to explain the statistical concept which constitutes the base of the model.

2 Base maps

Almost all Alpine provinces have their own snow avalanche register where several pieces of information are recorded about snow avalanche events occurred in the past. Some provinces have already put that information in digital format, thus speeding up the acquisition time. This is the case of the Autonomous Province of Bolzano where the tracks of past avalanche events are recorded as polygons in ArcView's shape files. Each polygon track has its information collected in a paper folder: the most important data needed are the height, extent and width of each track's release area, thus the track polygons should be split in two portions and just the upper part, corresponding to the release area, should be taken . If polygons of snow avalanche tracks are not available in digital format, the biggest effort will be drawing their release area from scratch on a digital contour-line map after it is georeferenced. Ideal will be then to randomly identify all release areas with numbers from 1 to n.

Maps representing the spatial distribution of some of the most important causal factors of snow avalanche occurrence should then be acquired or built. Those factors, by literature and direct experience, are: 1. slope inclination, 2. vegetation type and type of surficial deposits, 3. shape of the slope (concave, convex slopes), 4. distance from ridges (accounting for snow drift contribution). The ones just listed are not all causal factors, but just those that can be considered “fixed” in time, thus influencing the susceptibility parameter.

Slope inclination is a map that can be easily derived from a Digital Elevation Model (D.E.M.). D.E.M.s are becoming a widely used base map for any kind of spatial analysis, therefore their existence and acquisition should be possible for several portions of the Alpine chain. If not, classic contour-lines are anyhow available and their digitalisation will not involve too much time and effort for producing a good quality D.E.M. The one used for this study has a pixel size of 20x20 meters, already sufficient for the type of analysis to be performed.

The map showing the shape of the slope is also easily and quickly derivable from a D.E.M. and it represents concave and convex portions of all slopes within the study area. Concave slopes can receive high amount of snow both by precipitation and drift, while convex slopes may concentrate tension stresses within the snow pack thus initiating snow pack failures.

The distance from ridges is again derivable from a D.E.M. firstly by extrapolating lines with high curvatures and then creating buffers with constant width around them. By literature it is know how snow drift accumulates on the lee side of mountain crests, at particular distances from them, increasing the weight of snow and therefore decreasing the snow pack stability.

If not already drawn on digital maps, vegetation types and surficial deposits can be digitised directly on top of aerial ortho-photographs. Vegetation and surficial deposits can play an important role in snow pack stability, sometimes increasing it and sometimes decreasing it, therefore their spatial distribution should be carefully described.

Aspect and elevation are also important causal factors, although their input could add more bias than benefit to the overall statistic. At the scale of an Alpine municipality elevation will not change so much the intensity of snow precipitation, while aspect could add a bias if the valley sides are representative of just a few slope orientations.

So far it is evident how most of the working time would be spent in digitising contour lines and vegetation types when that information was not already available; the rest of the working time, devoted to the construction of derived maps from the D.E.M., will take just a few minutes.

2.1 Statistical analysis

It is important to remember that snow avalanche susceptibility is determined by the combined action of the causal factors listed beforehand, not just by each of them separately. For this reason the statistical analysis is performed using all causal factors which, it is important to remember, should be independent from one another.

The statistical algorithm to be used can be chosen among several ones available in literature. Anyhow, apart from the peculiar structure of each algorithm, the main characteristic at the base of all of them is the following one: each class forming a certain causal factor (i.e., the class "dense forest" from the causal factor "vegetation type") will get a probability value to be part of a set of past release areas and a probability value not to be part of the same set of release areas. The comparison between the two values (no matter how it is done) will give a measure of the relevance each class has towards snow avalanche occurrence. The real difference between the algorithms lies in the way all probability values of all classes from all causal factors are calculated for each pixel of the study area; the choice of one algorithm among all should be left to the analyst's sensitivity and experience. Even better, the analyst should try and use different algorithms and compare them for the best one to use.

After combination is accomplished, each pixel of the study area will receive a value that represents its degree of susceptibility towards snow avalanche occurrence. This sentence already highlights two main differences between maps of snow avalanche probable location and the map built with this method: 1. a value (in numbers) representing the degree of susceptibility renders the method objective; 2. the fact that each pixel of the study area gets a value implies a complete coverage of the territory, no area being left out of assessment.

The next step within the statistical analysis is represented by the validation of the susceptibility pattern so far outlined. Validation is crucial to understand how successful the susceptibility pattern is likely to be for the prediction of new snow avalanche release areas, even in places where no avalanche has ever occurred. Validation can be accomplished overlying the susceptibility pattern on a set of release areas which have not been used for the susceptibility calculation (a sort of test set whose number of areas can be varied according to the analyst's needs). The higher the number of test release areas covered by pixels with the highest susceptibility values, the higher are the chances for the susceptibility pattern to localise future snow avalanche release areas (i.e., if it worked fine for the past, it should work fine also for the future).

Validation is another point in favour of this method, when compared to the map of snow avalanche probable location: the latter, in fact, has no real way to be validated before printing it besides the verification in the filed of new occurrences, but this would take several winter seasons of observations to be completed.

Results for the Alta Val Badia

The susceptibility assessment done for the Alta Val Badia is actually wider than just Alta Val Badia, covering also the adjacent valley of Valgardena for a total 230km^2 territory extent. The susceptibility pattern shows the pixels with the highest susceptibility values to be part of future snow avalanche release areas. When overlapped on the map of snow avalanche probable location of the same area (actually to cover the entire area four maps of snow avalanche probable location are needed) it can be noticed what follows: 1. 90% of the areas assessed as susceptible by the map of snow avalanche probable location contain pixels with the highest susceptibility values identified by the model; 2. frequently, even small-size areas assessed as susceptible by the map of snow avalanche probable location contain pixels with the highest susceptibility values identified by the model; 3. 10% of the areas assessed as susceptible by the map of snow avalanche probable location do not contain pixels with the highest susceptibility values identified by the model; 4. some pixels with the highest susceptibility values lie also in areas not identified by the map of snow avalanche probable location.

Points 1 reveals the capability of the statistical method to objectively estimate what is usually assessed in a quite subjective way; point 2 reveals what degree of precision the statistical method can reach; point 3 may reveal a weakness point in one of the two methods; point 4 may reveal a more complete assessment-coverage for the statistical method.

Discussion

This abstract has tried to describe the improvement that the statistical method tested in Alta Val Badia could bring to the assessment of snow avalanche susceptibility for an Alpine area when compared to the usual *carte de localisation probable des avalanches*. The greatest improvement is the complete absence of any fieldwork: this could greatly reduce the amount of time and finances needed for the development of the susceptibility map. In case base maps were already available in digital format, the laboratory time could be even reduced to the minimum. Validation is another great improvement: it gives an estimate of how good the susceptibility assessment can be in terms of capability to identify future snow avalanche release areas: this is done in a totally objective way while in maps of snow avalanche probable location this is completely up to the surveyor's sensitivity. The last important improvement is the possibility to update the map whenever new avalanches will occur: this could change the susceptibility values of the pixels or confirm the old ones, in the latter case increasing the performance of the map. The updates of the map (seasonal updates) could be easily published through web-GIS servers, thus increasing the usage capacity of it.

Obviously, a statistical approach as the one presented here can only be accomplished if a snow avalanche register of the area exists. This is a quite common situation in the Alpine regions. On the other hand, if a snow avalanche register does not exist for the area to be assessed, it could be sufficient to use a register from an adjacent area, although the climatic and physical characteristic of the two areas should be very similar.

The performance of this statistical method and its potential applicability indirectly increase the importance of constant and precise observations of snow avalanche activity during all winter seasons: specially release area locations and extent should be recorded within local avalanche registers. Only this record allows to keep trace of the avalanche activity during the proper time period (winter, not summer as it is the case of the *carte de localisation probable des avalanches*) and to prepare a good base map for the statistical susceptibility analysis.

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