Avalanche risk management using GRASS GIS

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Abstract

The GRASS system has been used to evaluate avalanche risk. This has been done by combining heterogeneous data. Val di Pejo, located in the north-western Trentino, an Italian alpine region which shows frequent and sometimes huge avalanche phenomena, has been selected as test area.
A morphologic risk has been defined in those areas where the slope is between 28° and 55° for a minimum surface of about 625 m^2 with an upstream slope change greater than 10°.
An algorithm which uses these morphologic rules has been developed and applied using the GRASS MAPCALC feature to obtain a map of the "morphologic risk", i.e. areas showing an avalanche probability based only on their geometric features.
The ability of the vegetation to protect against the avalanche phenomena has been evaluated by recognizing three different coverage types depending on their density, since the latter influences their ability to avoid the creation of a compact and homogeneous snow layer. A map of the vegetation's protection ability has been obtained. vegetation types has been obtained using the information of the Trento's Forest Management Bureau. The boundaries of the vegetation types in the maps used for forest management are generally approximated, so it has been necessary to verify the real extension of the different kinds of vegetation. An orthophoto has been obtained by differential rectification of digitalized aerial photographs using the DTM and some control points in GRASS. The orthoimages have been used to test the real location of the boundaries and the extension of the parcels.
The real ability of the different vegetation classes to offer protection against avalanches has been evaluated comparing the morphologic avalanche risk area with the extension of the events occurred. The ratio between the real surface covered by avalanches on the C.L.P.V. "Carta di Localizzazione Probabile delle Valanghe" (C.L.P.V. Possible Avalanche Location Map) and the potential surface obtained following the described criteria, divided in three different vegetation classes, highlights the importance of the vegetation coverage in protecting from avalanche risk.

1. Introduction

The GRASS GIS has proved a powerful tool for the development of complex models. Such models can adequately describe complex phenomena providing effective hints for land management. In this paper the implementation of a model for the avalanche risk is presented. A risk map is plotted starting from morphology and vegetation of the region. The small number of input variables and their simplicity allow the immediate use of the model for the avalanche risk management. Moreover, this approach gives direct indication of the protection capability against the avalanches

of the different vegetation coverage. It is possible therefore to give suggestions for the forest management plans.
While the usual approach is to identify dangerous areas by mapping the occurred avalanche events, the model hereafter can detect hazardous areas even if no avalanche event has been reported. In this way it is possible to describe the avalanche risk regardless the availability of avalanche screening. Furthermore it is possible to predict different scenarios based on the vegetation evolution over the time.

2. Avalanche risk prediction model

Several factors influence the avalanche slip. Some factors, such as snow height and properties, wind speed and so on, are quickly variable, while other, such as land morphology, change slowly in time. The implemented model involves only stationary variables, preventing from the need of near real time surveys on site.
Two kind of data are used as input: vegetation and morphology description. The joint use of these heterogeneous data is possible for their spatial registration.
The final risk map results from the combination of the morphologic risk map, based solely on the geometric properties of the land, with the map of the protection capability of the vegetation.

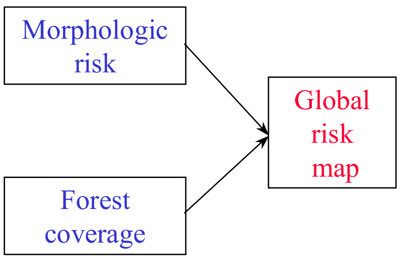

Figure 1 – Main model structure

The morphologic risk map depicts the existence of three essential conditions: slope between 28° and 55°, area where this circumstance is true of at least 625 m² and presence of break lines (Gray D.M., Male D.H., 1981).
Slope can not exceed 55° because no snow amassing would occur and can not be lower than 28° since snow slip would be hardly possible. An area of at least 625 m² is required for noteworthy avalanche phenomena, while break lines over the slip areas denote the presence of convex zones with a slope variation larger than 10°.

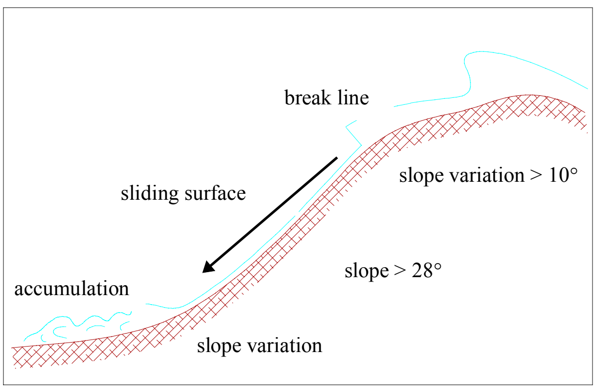

Figure 2: morphological slope properties affecting avalanche risk.

These three conditions locate the areas where avalanche risk is real if it is not balanced by other factors, i.e. there exists a “morphologic” avalanche risk.
The presence of vegetation is not able to stop avalanches once they have started. Nevertheless vegetation coverage, mainly depending on vegetation density, is able to prevent snow slip and avalanche occurrence by avoiding the creation of a compact and homogeneous snow layer. All the available information about vegetation has been processed to form three vegetation classes with respect to the protection capability against avalanche. The most important vegetation characteristics for the protection against avalanche are density and tree type (evergreen or deciduous). Therefore vegetation coverage has been split into three classes:

- dense evergreen forest (spruce or spruce with larch);
- sparse wood or deciduous dense wood (larch);
- bare or covered by grass or sparse vegetation (pasture or bushes).

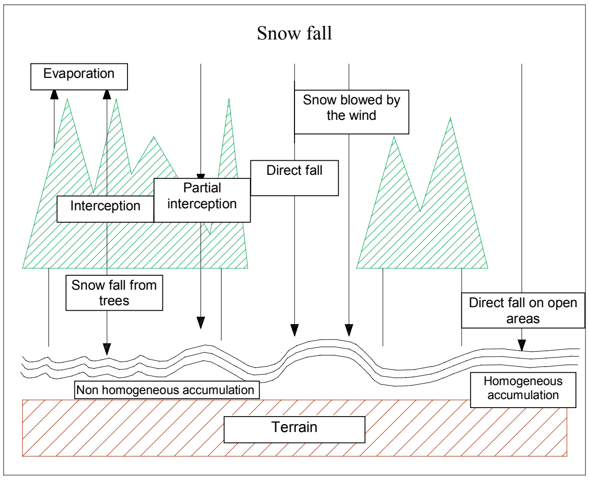

Figure 4 - Influence of the wood structure on the snow layer accumulation (from MEYER-GRASS M., IMBECK H., 1987, mod.).

3. Study area

The higher part of Val di Pejo, located in the north-western Trentino (fig. 5), an Italian alpine region, has been selected as test area.

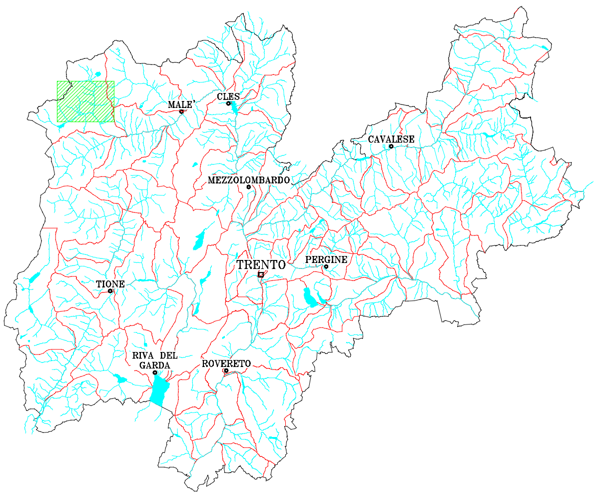

Figure 5 - Location of the study area, Val di Pejo (upper left rectangle) in Trentino.

This test area has been chosen for the presence of frequent and sometimes huge avalanche phenomena. Besides, we can provide all data about vegetation and occurred avalanche phenomena characteristics.
The valley is covered by spruce and larch forests whose density can be determined by forest management plans which are carried out with a particular accuracy in the Trentino region. Spruce is more present at lower altitudes, while larch is more present at higher altitudes, and it reaches the zone of the tree development limit.

Figure 6 – 3D view of the orthophoto overlaid to the DTM of the study area.

The valley is surrounded by a wide mountain chain and the highest mountains reaches 3700 m..
Trentino has an old tradition of forest management, because both forest wood products and landscape conservation for tourism play an important role in the economy of the region. Therefore, accurate data on many forest aspects are available.

4. Data availability and formats

Accurate datasets covering the test area are available, describing both the morphology and the vegetation.
A digital terrain model (DTM) is available from Provincia Autonoma di Trento (PAT) with 10 or 40 meters resolution. However the digital terrain models has been re-estimated from isolines to gain a 5 meters resolution. Input data consist of vector isolines from the Forest Management Bureau (PAT) in ARCHINFO UNGENERATE format. They have been imported into GRASS vector format and accurately checked against the official 1:10.000 scale cartography of the Trentino region to spot the presence of wrong height values for the isolines. Vector data have been rasterised with a five-meter pixel resolution on the ground. Afterwards a DTM has been generated by the *r.surf.contour* GRASS module. The resulting 5 meters resolution DTM has been checked against the official 10 meters resolution DTM to detect blunders.
Data about the vegetation are available from the Forest Management Bureau (PAT) in ARCHINFO UNGENERATE format. They mainly consist of the Forest Management Plan (Piano di Assestamento Forestale) which, among other data, carries the (vector) areas with homogenous vegetation (Particellare Forestale). These areas have been ranked in three forest coverage classes depending on their density and tree type (see paragraph 2).

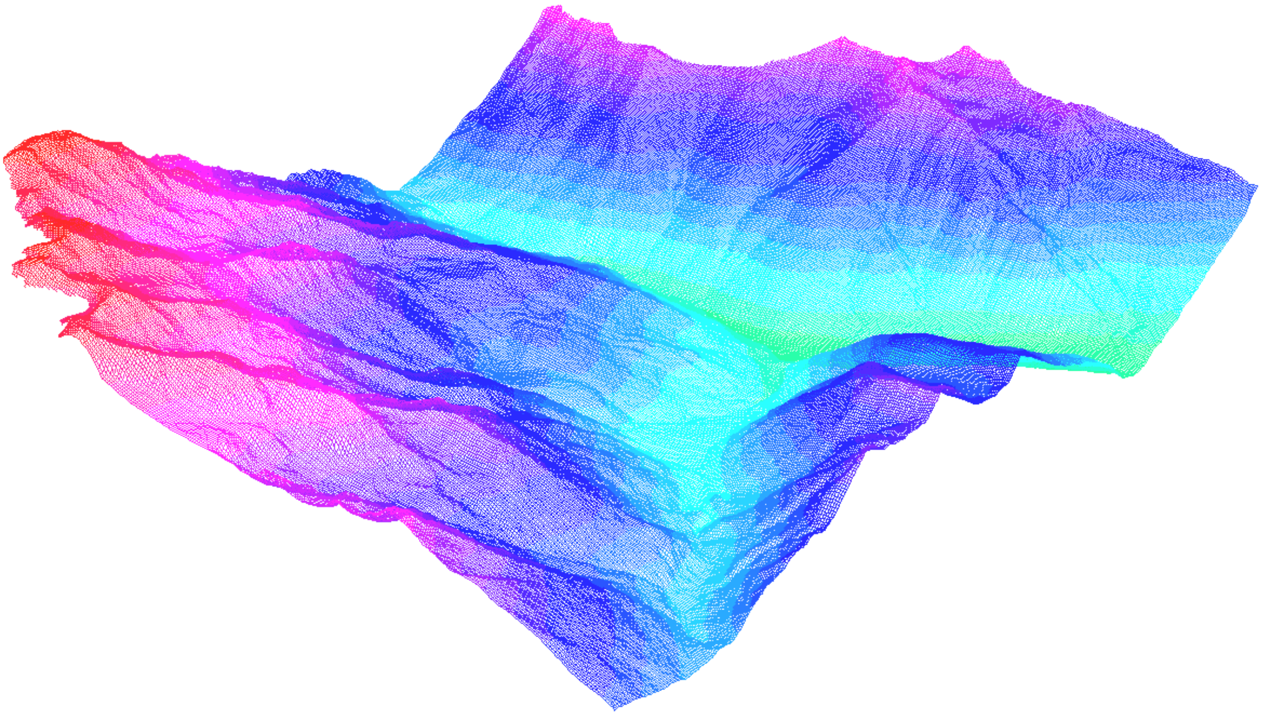

Figure 7 - Digital elevation model with 5x5 meters cell resolution.

Aerial images in analogical format are available. They have been digitized with 800 dpi resolution and othophotos have been produced by using the *i.ortho.photo* GRASS module.
The report of the avalanches occurred in the past is available from PAT in the C.L.P.V. "Carta di Localizzazione Probabile delle Valanghe" (Possible Avalanche Location Map) in ARCHINFO E00 format.

5. The morphologic risk map

Morphologic risk map describes the avalanche risk using only geometric features of the terrain.
Starting from the 5 meters resolution DTM the slope and aspect maps have been computed with the *r.slope.aspect* GRASS module.

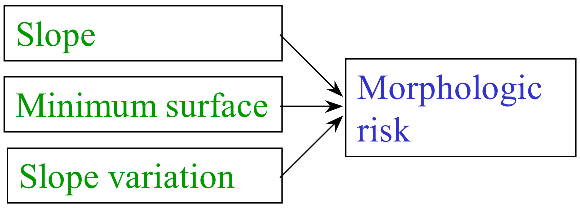

Figure 8 – Morphologic risk map building scheme.

The selection of the cells with slope between 28° and 55° is carried out using the *r.mapcalc* GRASS module with the formula *pejo.slope28_55=pejo.slope>=28&&pejo.slope<=55* , which creates a new binary map from the slope map *pejo.slope*, containing 1 where the slope value satisfies the criteria and 0 elsewhere. A slightly modified formula would create a map preserving the original slope values: *pejo.slope28_55b=if(pejo.slope>=28&&pejo.slope<=55, pejo.slope)*.
The extraction of the areas of at least 625 m^2 where the slope condition is satisfied is again performed using the *r.mapcalc* module using the formula in appendix A. The area of 625 m^2 results

from the fact that the resolution of the slope and all the derived maps is 5 m, therefore uniform areas of 5x5 cells (i.e. 25x25 meters) are selected.
Break lines are detected by selecting the cell with a slope variation larger than 10°. Once more *r.mapcalc* is involved; the formula given in appendix A is applied to the slope map.

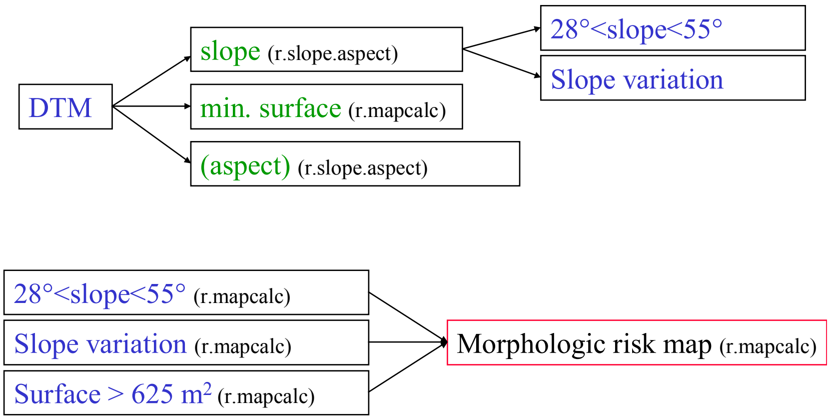

Figure 9 – Maps hierarchy and GRASS modules involved for the morphologic risk detection.

Finally the morphological risk map (fig. 10) is created by combining the minimum surface requirement with the presence of break lines: the *r.mapcalc* is used with the formula *pejo.morphologic_risk=if(pejo.break_lines==2||pejo.supmin==3,1)*. As a result a binary map where nonzero values indicate morphological avalanche risk is created.

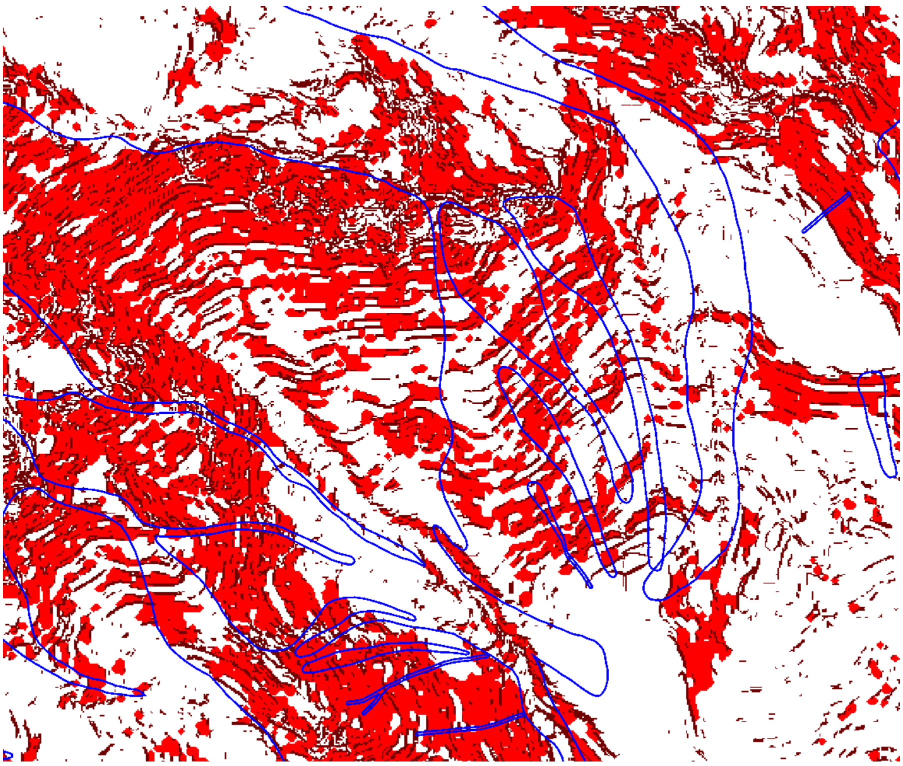

Figure 10 - Morphological risk map with superimposed occurred avalanche areas (detail). Break lines are visible as small dark area.

6. Vegetation map

A map describing the vegetation capability of protection against avalanches has been created by clustering the forest compartments using vegetation density and type. The extraction of these two features from the vegetation database generates two maps which have been reclassified using the *r.reclass* GRASS module. The final vegetation map results from the combination of these two maps using the *r.mapcalc* module.

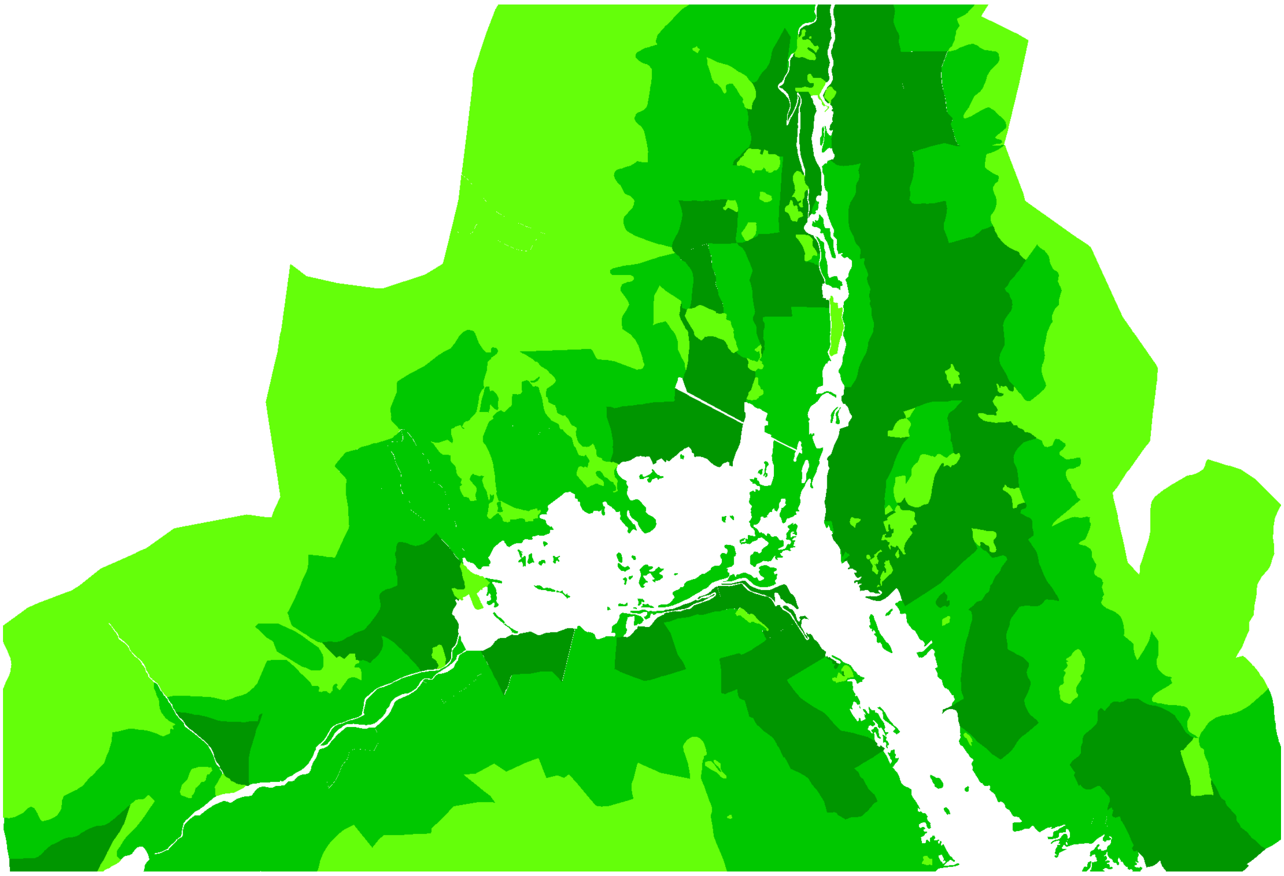

Figure 11 – Vegetation map, the three classes are, from dark gray to lighter: dense evergreen wood spruce or spruce with larch, sparse wood or non-evergreen wood (larch), grass and sparse bushes areas (pasture and Alnus viridis).

7. Orthophoto

Orthophotos have been realized to refine the boundaries of the vegetation types. This has been done because the forest compartments boundaries are approximate, following the natural morphology, and they change in time, therefore the must be checked. The *i.ortho.photo* GRASS module has been used to rectify aerial images digitized at 800 dpi, in TIFF format.

8. Global avalanche risk map

Both morphologic risk and vegetation protection ability maps can be useful to depict the risk situation but a dramatic improvement of the precise location of the risk areas is obtained by combining the two maps.
The resulting map is used to assess the avalanche risk. This map permits the identification of different regions, each one characterized by a different degree of risk. In fact, the assessment of the risk comes from a combination of morphological risk and vegetation protection ability.

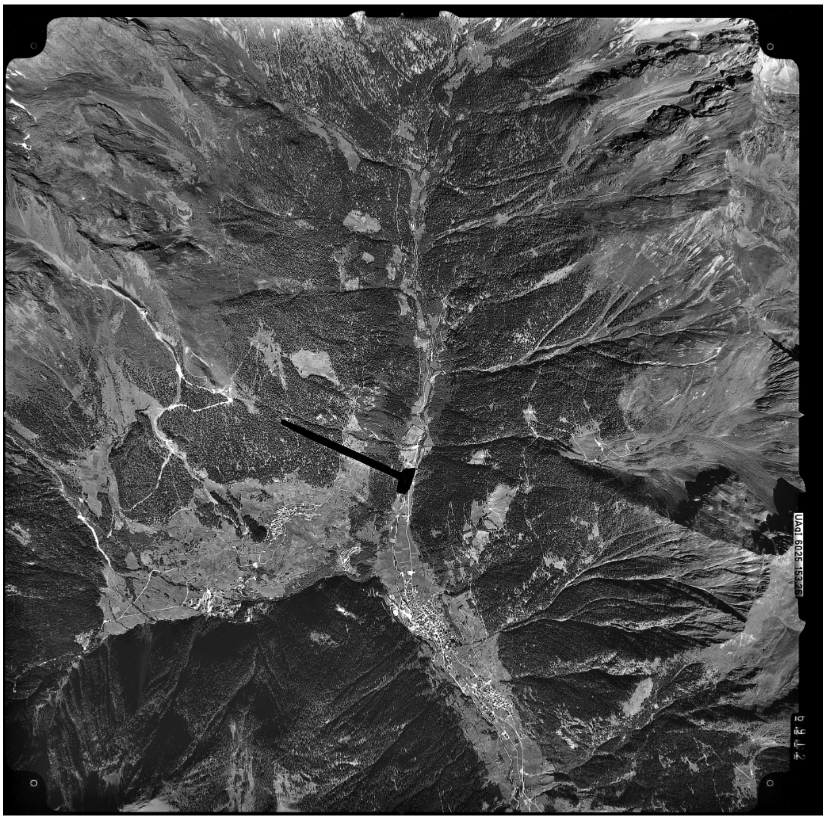

Figure 12 - Aerial image

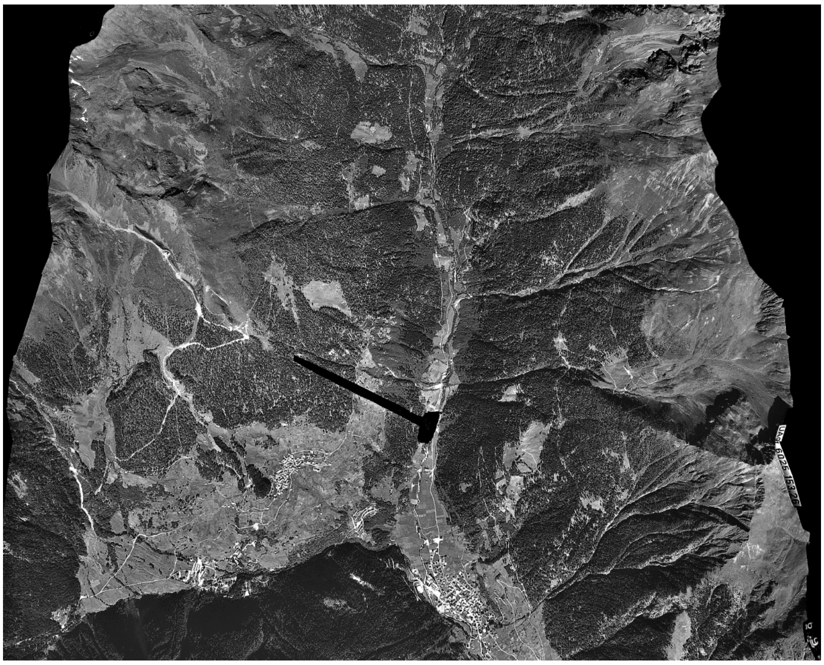

Figure 13 - Orthorectified image

Three different regions have been recognized in this map (Global risk map):

- real risk areas where the global risk map locates high avalanche probability and the phenomenon has been reported;
- areas where the protection ability of the vegetation coverage balances the morphologic risk;
- areas where no avalanches have been reported but the vegetation cannot face the morphologic risk.

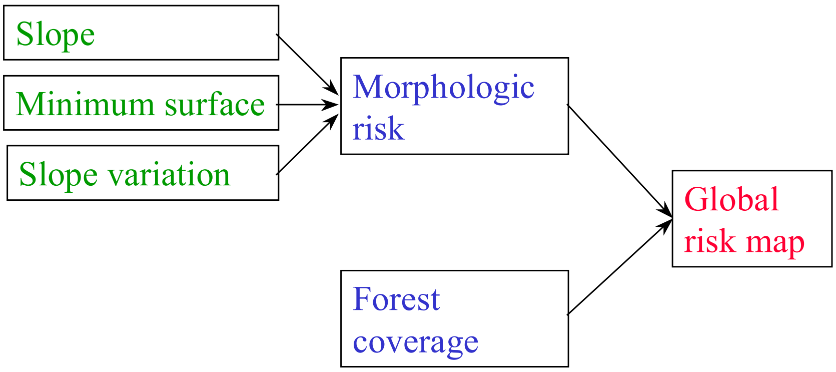

Figure 14 – Global risk map building scheme.

The superimposition of a morphologic risk map and a vegetation protection map allows the location of different risk areas. Overlaying the morphological risk map with the C.L.P.V. has confirmed that all the reported avalanches have been included in the risk areas individuated by the automatic algorithm. In fact, it is possible to find the morphologic risk areas located where the break lines of the avalanches in the C.L.P.V. are. The morphologic risk map has indeed found all the existing avalanches and some other risk areas where the phenomenon has not been reported yet.

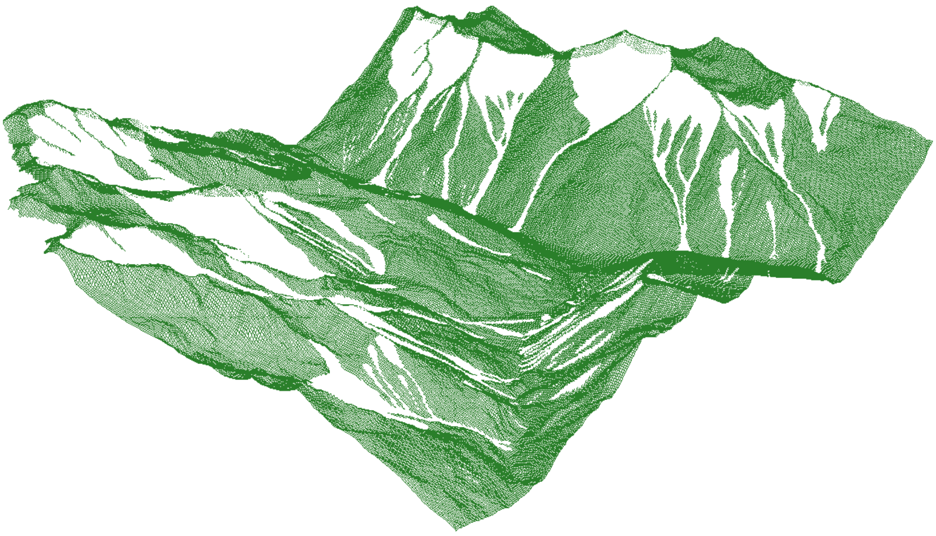

Figure 16 - C.L.P.V. overlaid on the DTM model

Adding the vegetation information it is possible to select the presence of different vegetation types as the discriminating factor affecting the occurrence of avalanche phenomena in potential risk zones: it is therefore possible to evaluate the different vegetation type capacity of protection against avalanches.
This analysis allows the evaluation of the real ability of the different vegetation classes to protect against avalanches. The morphologic avalanche risk area has been compared to the extension of the occurred events, see the table below where the ratio between the real surface interested by avalanches on the C.L.P.V. and the potential surface obtained following the described criteria divided in three different vegetation classes is shown.
The value indicates which part of the potential risk area in a specific vegetation class has been actually interested by avalanche phenomena.

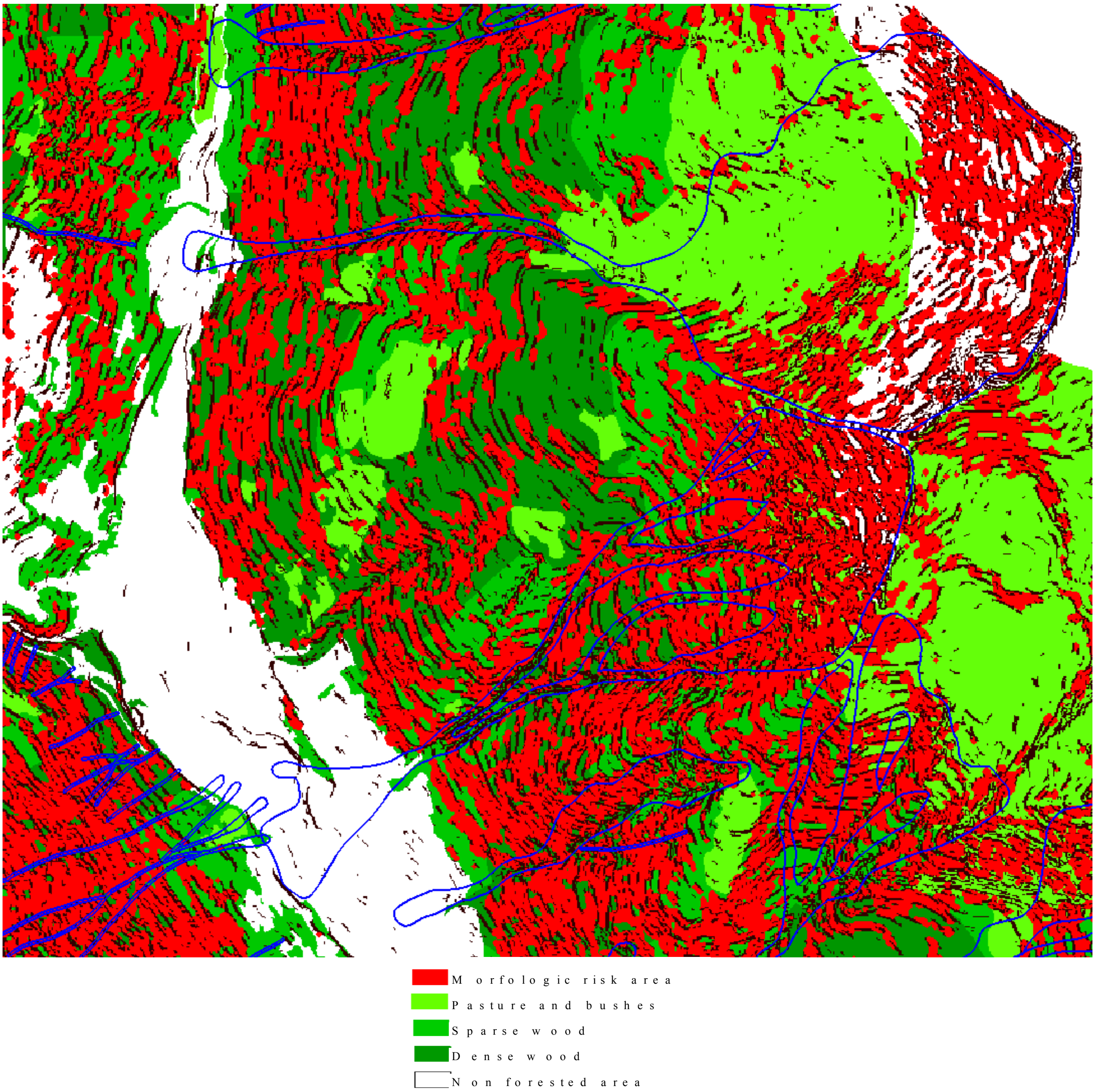

Figure 17 - Global risk map with superimposed occurred avalanche areas (detail).

This parameter highlights the importance of the vegetation coverage in protecting from the avalanche risk.

Ratio	dense evergreen wood spruce or spruce with larch	sparse wood or non-evergreen wood (larch)	grass and sparse bushes areas (pasture and Alnus viridis)
$\frac{S_{avalanches}}{S_{potential}}$	0.096	0.148	0.453

Table 1- Vegetation protection ability.

Less than 10% of the areas covered by dense evergreen wood spruce or spruce with larch which show morphologic risk has been actually struck by avalanches. As expected, this percentage rises to

15% for areas covered by sparse wood or non-evergreen wood (larch), reaching 45% for areas covered by grass and sparse bushes areas (pasture and Alnus viridis).
Dense evergreen wood offers the best protection; sparse wood protects more than expected from the bibliography (BISCHOFF N., 1987 and MEYER-GRASS M., 1985), while grass and sparse bushes provide the minimum protection.
The map of global risk is already suitable to be used in forest and landscape management, and the method to obtain it, once the data have been collected and integrated, is now coded and maybe reproduced.

9. Conclusions

The integration of different data in different formats is essential to build a good base for environmental analysis and planning. In our case, many data about forests and avalanches are available but it is necessary to find a way to relate one kind of data to the other and to transform the raw information into something significant. At the informatics' level an effort to obtain homogeneous data formats is also required.
GRASS has proved a good tool for the realization of a rather complex model performing several simple steps, particularly for its good performance in processing raster data. The ability of doing complex map algebra by writing simple formulas using the *r.mapcalc* GRASS module has played a crucial role in this application.
The model is under refinement for both the morphologic part and the vegetation description. New algorithms are being developed for a better detection of break lines and their selection with reference to their position with respect to homogenous area (only break lines on the top of homogeneous area with slope between 28° and 55° should be selected). A better vegetation description is in preparation, both for boundary accuracy and particles clustering.
These improvements should take more precision, and therefore the possibility of more accuracy in the land planning, to the model.

Appendix A

The following formula is used to extract regions of 5x5 cells with uniform value from the *pejo.slope28_55* map using *r.mapcalc* :

pejo.supmin=if(pejo.slope28_55==1&&pejo.slope28_55[-2,-2]==1&&pejo.slope28_55[2,-1] ==1&&pejo.slope28_55[-2,0]==1&&pejo.slope28_55[-2,1]==1&&pejo.slope28_55[-2,2] ==1&&pejo.slope28_55[-1,-2]==1&&pejo.slope28_55[-1,-1]==1&&pejo.slope28_55[-1,0] ==1&&pejo.slope28_55[-1,1]==1&&pejo.slope28_55[-1,2]==1&&pejo.slope28_55[0,-2] ==1&&pejo.slope28_55[0,-1]==1&&pejo.slope28_55[0,1]==1&&pejo.slope28_55[0,2] ==1&&pejo.slope28_55[1,-2]==1&&pejo.slope28_55[1,-1]==1&&pejo.slope28_55[1,0] ==1&&pejo.slope28_55[1,1] ==1&&pejo.slope28_55[1,2] ==1&&pejo.slope28_55[2,-2] ==1&&pejo.slope28_55[2,-1]==1&&pejo.slope28_55[2,0]==1&&pejo.slope28_55[2,1] ==1&&pejo.slope28_55[2,2]==1,3).

The value 3 is assigned to the cells satisfying the criteria.

Break lines are detected by applying the following formula with *r.mapcalc* to the slope map:

pejo.break_lines=if(pejo.slope-pejo.slope[-1,-1]>=10||pejo.slope-pejo.slope[-1,0]>= 10||pejo.slope-pejo.slope[-1,1]>=10||pejo.slope-pejo.slope[0,-1]>=10||pejo.slope-pejo.slope[0,1]>= 10||pejo.slope-pejo.slope[1,-1]>=10||pejo.slope-pejo.slope[1,0]>=10||pejo.slope-pejo.slope[1,1] >=10,2).

The value 2 is assigned to the cells with slope variation greater or equal to 10° with respect to the 9 surrounding cells.

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