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3D SPATIAL DATA INTEGRATION FOR AVALANCHE RISK MANAGEMENT

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ABSTRACT

The southern part of the Alps is interested by frequent avalanche phenomena. It is very important to provide a suitable method to manage avalanche risk. The usual approach is based on the mapping of the avalanches occurred on the "Carta di Localizzazione Probabile delle Valanghe" (C.L.P.V. Possible Avalanche Location Map). Modern methods are based on statistical approaches or on the evaluation of the morphology and vegetation characteristics. We have chosen to follow the latter approach because in this way we can locate not only the events occurred but also the dangerous areas where no past events have been reported.
Different kinds of data have been integrated in a Geographic Information System to evaluate land morphology and vegetation types. 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 digital terrain model has been created with the 3D algorithm of the Geographic Information System GRASS. A map representing the different 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 digitalised aerial photographs with the help of the DTM and some control points. The orthoimages have been used to test the real location of the boundaries and the extension of the parcels.
The avalanche risk areas have been recognised applying morphologic criteria (slope between 28° and 55° and minimum surface of about 625 m^2, upstream slope change greater than 10°).
An algorithm which uses these morphologic rules has been developed and applied to obtain a map of the "morphologic risk", i.e. areas showing an avalanche probability based only on their geometric features.
The vegetation has been classed in 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. Both maps themselves 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 the one we use to assess the avalanche risk. This map has been verified comparing it to the C.L.P.V..
Three different regions have been recognised:
· real risk areas where our 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.
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. and the potential surface obtained following the described criteria, if divided in three different vegetation classes, highlights the importance of the vegetation coverage in protecting from avalanche risk.
The creation and the use of the 3D model and its integration with digital images and environment data has permitted the elaboration of thematic maps which contain much information suitable for forest and land management.

Key words: digital terrain model, orthophoto, thematic mapping, data integration, avalanche risk management

1 INTRODUCTION

The southern part of the Alps is interested by frequent avalanche phenomena. It is very important to provide a suitable method to manage avalanche risk.
The avalanches represent a real problem because they can endanger inhabited zones or touristic areas and they can improve superficial erosion and solid transport affecting the hydrological characteristics of the alpine valleys.
The usual approach is based on the mapping of the avalanches occurred and reported by local foresters or found in historical documents or identified in aerial photographs on the "Carta di Localizzazione Probabile delle Valanghe" (C.L.P.V. i.e. Possible Avalanche Location Map).
Modern methods are based on statistical approaches or on the evaluation of the morphology and vegetation characteristics. We have chosen to follow the latter approach because in this way we can locate not only

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the events occurred but also the dangerous areas where no past events have been reported.
This could be useful in land management at different scales. Besides, it permits the evaluation of th influence of forest types on the avalanche risk.
This kind of approach can be succesfully developed using instruments like the Geographic Information System to store and elaborate different data.
Different kinds of data (vegetation, aerial photographs, 3D models) have been integrated in a Geographic Information System to evaluate land morphology and vegetation types.
Grass GIS, a freeware Geographic Information System developed by USACERL, has been used.
Val di Pejo, located in the north-western Trentino, an Italian alpine region, has been selected as test area.

Figure 1: location of the Trentino region in Europe.

This valley has been considered particularly suitable for this study because it shows frequent and sometimes huge avalanche phenomena.

2 PURPOSES

The main purpose of this research has been the fully automated creation of an avalanche map for the risk management.
The map must be immediately suitable for the use in planning and decision making.
In developing our model, we have chosen to consider only the morphology and vegetation characteristic. We have preferred not to introduce other factors (like roughness) to make the model simpler and to avoid the use of variables whose value is very difficult to determine. These data are 3D structured and they are very heterogeneous. Therefore, we need a tool that permits us the integration of all the data we can dispose of. That is why we have decided to use Grass GIS to join data and make them suitable to be used in the model. Grass is a freeware Geographic Information System developed especially to be used in environmental application. It runs on several Unix platforms; we use Linux PCs.

3 STUDY AREA

The higher part of Val di Pejo, located in the north-western Trentino (fig. 2), an Italian alpine region, has been selected as test area.

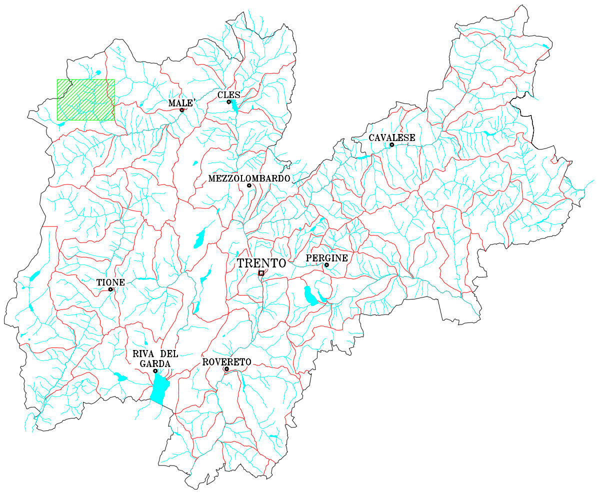

Figure 2: location of the study area, Val di Pejo (upper left rectangle) in Trentino.

This test area has been chosen for the present study 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.
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 METHODS

4.1 Criteria

Avalanches are caused by many different reasons, so it is difficult to understand with absolute certainty how much a single reason could condition the avalanche slip. Among these reasons we can cite the many different kinds of snow, wind and solar ray incidence. Nevertheless, the most important factor is surely slope. According to the bibliography, slope is the most important indicator of the potential risk zones.
Avalanches are connected with the slope and the terrain morphology.

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Avalanches may happen on slopes ranging between 28° and 55°; when the slope is more than 55° the snow slips down without accumulating, while when the slope is less than 28° the snow does not slip down or slips very slowly without any danger (BERGER F. 1995 and MEYER-GRASS M 1985).
A discontinuity of the slope is needed. Convex zones promote breakings in the continuity of the snow blanket, especially when a slope variation of at least 10° is present.

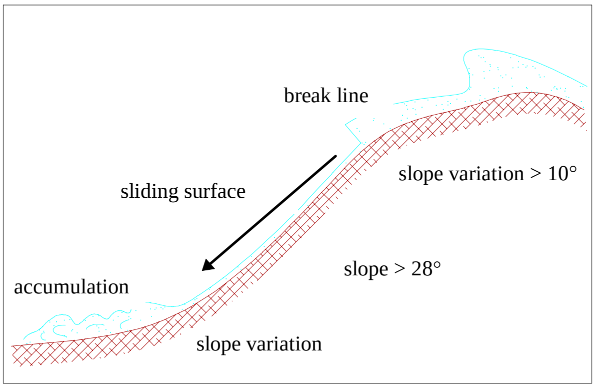

Figure 3: morphological slope properties affecting avalanche risk.

Another important factor is the extension of the area interested by the slope. A minimum extension of the area where the slope satisfies the above conditions is required to have natural avalanches. We have individuated a minimum area of 625 m^2 (BERGER F. 1995 and MEYER-GRASS M 1985).
The avalanche risk areas have been recognised applying the criteria described above:

- slope ranging between 28° and 55°;
- minimum surface of about 625 m^2;
- upstream slope change greater than 10°.

An algorithm which uses the above morphologic rules has been developed and applied to obtain a map of the "morphologic risk", i.e. areas showing an avalanche probability based only on their geometric features.

4.2 Vegetation

A dense vegetation coverage can provide the best defense against avalanches (MEYER-GRASS M 1985).
Vegetation coverage cannot stop avalanches that run through it, having started somewhere else; nevertheless, a dense tree coverage avoids the creation of a compact and homogeneous snow layer and therefore avoids avalanche formation inside the area covered with vegetation (BISCHOFF N. 1987 and MEYER-GRASS M. IMBECK H 1986).

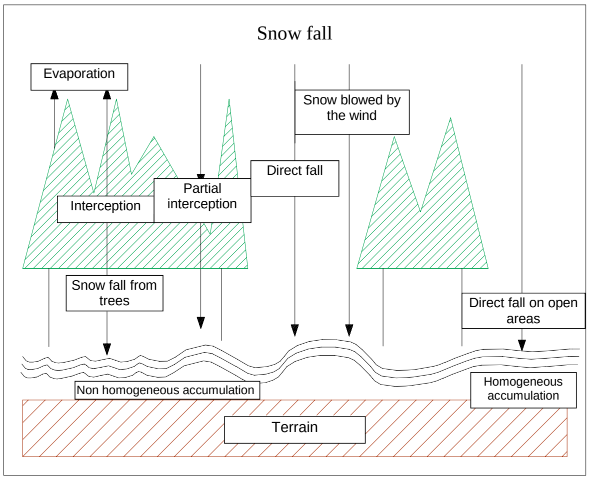

Figure 4: influence of the wood structure on the snow layer accumulation (from MEYER-GRASS M., IMBECK H., 1987, mod.).

Density and tree characteristics (evergreen, deciduous) are the most important factors which influence vegetation protection ability.
The forest management plan database contains a lot of heterogeneous information about density, species distribution, and vegetation: all this data have to be grouped into a few classes which must be both representative and significant with respect to avalanche protection capacity.
So we have identified three forest coverage classes

- dense evergreen forest (spruce or spruce with larch)
- sparse wood or non evergreen wood (larch)
- bare or covered by grass or sparse vegetation (pasture and bushes)

A map of the vegetation protection ability has been obtained using this classification.

4.3 3D model

Input data were vector isolines which came from the Forest Management Bureau in ARCHINFO *ungenerate* format. They have been translated into GRASS format and accurately examined to find mistakes in the altitude values typed in the database of the isolines. This task has been carried out comparing the isolines with the raster file of the original official 1:10.000 scale cartography of the Trentino region.
After that, and after having eliminated all the blunders, we have transformed the vector height information given by the isolines into a raster digital terrain model with a five-meter pixel-size on the ground.
The file was now ready to be elaborated in a 3D model by GRASS GIS, which fills the spaces among the isolines using a flood fill algorithm.

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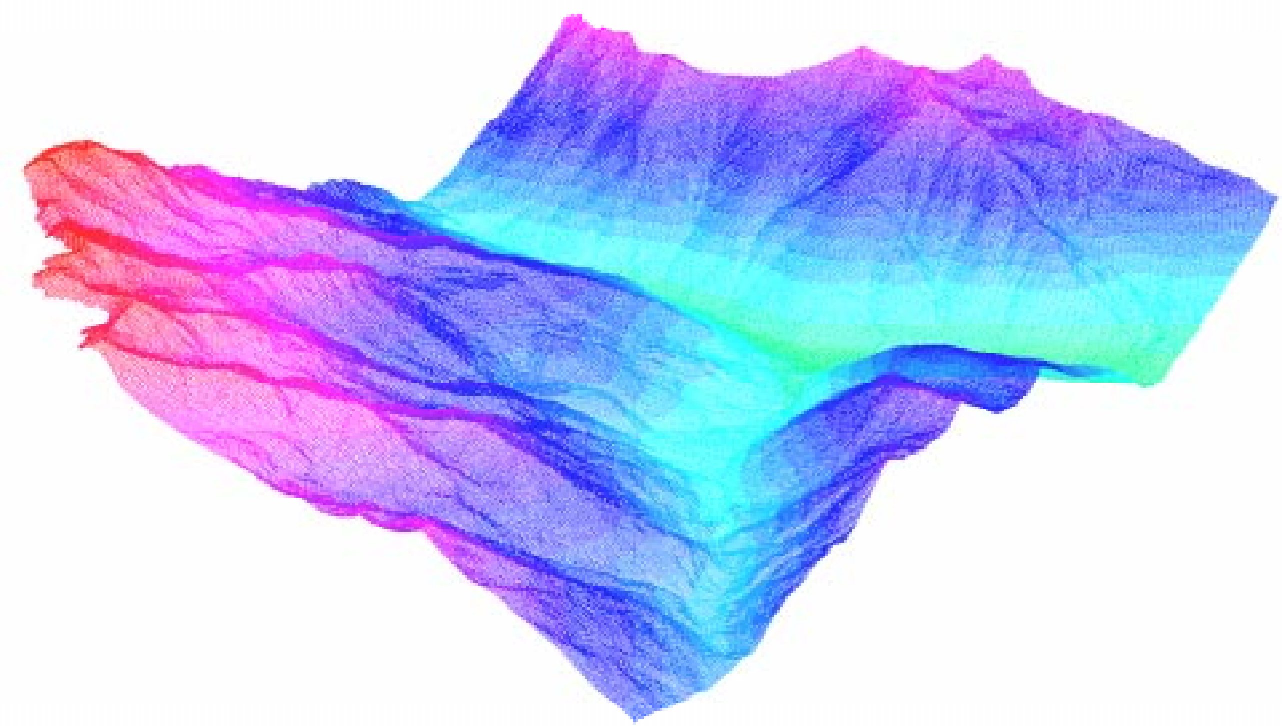

Figure 5: Digital elevation model with 5x5 meters cell resolution.

The model can be used simply to display raster maps in 3D views or as a base to compute different kind of morphological parameters, such as slope, surface orientation and so on, of the interested area.
Once we have obtained the 3D model we have been able automatically compute morphologic risk simply applying the criteria we have individuated.

4.4 Orthophoto

A map representing the different vegetation types has been obtained using the information of the Trento Forest Management Bureau. The problem we have to face to make our data more representative of the reality (especially to evaluate the influence of the different kinds of vegetation) is that the boundaries of the vegetation types in the maps used for forest management are generally approximated. In fact, the boundaries of forest compartments are defined following natural morphology as if the vegetation distribution inside the compartment was perfectly homogeneous, while the vegetation can vary especially near the boundaries. For this reason it has been necessary to verify the real extension of the different kinds of vegetation.
We have disposed of recent aerial photographs in which it has been possible to individuate the vegetation boundaries with a higher accuracy, but we have needed a tool that permitting us to superimpose the images to the maps used in forest management, providing an easy way to determine the variations of the boundaries of the homogeneous areas and, where possible, the variation of the vegetation types.

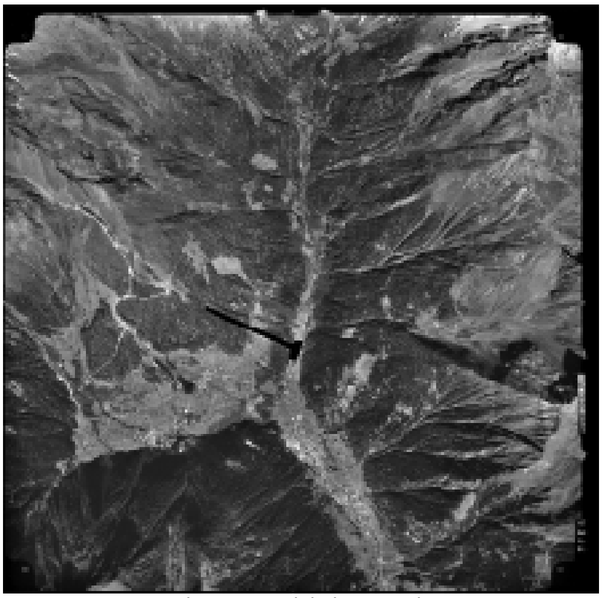

Figure 6: aerial photograph

This could have been done by producing orthophotos using the available aerial imagery and the morphologic information coming from the digital terrain model. The georeferenced orthoimages can be directly superimposed to all the available cartography and to all the thematic maps we have created
We dispose of aerial photographs that have been scanned at 400 dpi. The images, in TIFF format, were imported in GRASS. The software enables the marking of fiducial points on the Tiff image and computes the transformation using the elevation model of the DTM.

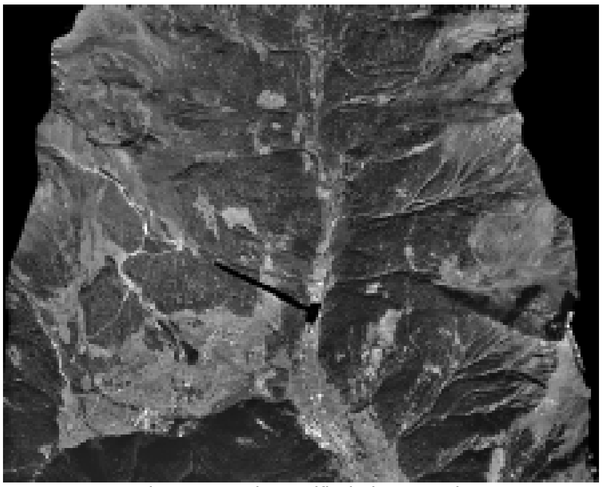
Figure 6: Orthorectified photograph

Some ortho-photos have been obtained by differential rectification of digitalised aerial photographs with the help of the DTM and some control points.
The orthoimages have been used to test the real location of the boundaries and the extension of the forest compartment.

4.5 Checking criteria

To check the correspondence between our model and the reality we have chosen the "Carta di Localizzazione Probabile delle Valanghe" (C.L.P.V. i.e. Possible Avalanche Location Map) which is based on the mapping of the avalanches occurred and reported by local foresters, found in historical documents or identified in aerial photographs.

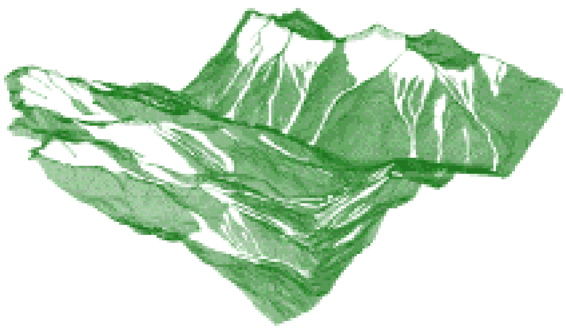
Figure 7: C.L.P.V. ovelayed on the DTM model

A hierarchy of risk maps has been configured and achieved, from that using the single criterion to the one which combines all of them.
The whole hierarchy of the avalanche risk maps, in particular the vegetation protection ability map and the morphological risk map, has been checked against the C.L.P.V. to spot all the areas where our model has failed, to locate an occurred avalanche phenomena.
By comparing the differences between the C.L.P.V. and the morphological risk map on one side, and the differences between the C.L.P.V. and the map which takes into account both vegetational and morphological parameters (global risk map) on the other side, it has been possible to evaluate the importance of the vegetation protection capacity.

5 MAPS

The vegetation has been classed in 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 protection ability has been obtained.
A map of the morphological risk has been obtained following the described criteria.

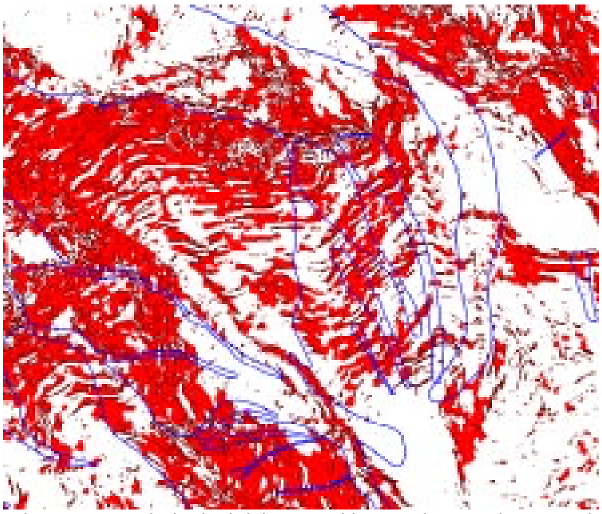
Figure 8: morphological risk map with superimposed occurred avalanche areas (detail).

Both 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 the one we use 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.
Three different regions have been recognised in this map (Global risk map):

- real risk areas where our 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.

6 RESULTS

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

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significant to use them. At the informatic level an effort to obtain homogeneus data formats is also required.
The realization of a 3D model allows the transformation of aerial photographs into orthophotos and the computation of complex algorithms to individuate risk areas. The overlaying of a vegetation map with an orthophoto allows the correction of the vegetation types boundaries.
The superimposition of a morphologic risk map and a vegetation protection map allows the location of different risk areas.
Overlaying the map with morphological characteristics with the C.L.P.V. should have confirmed that all the reported avalanches have been included in the risk areas individuated by our automatic algorithm. We have found a perfect overlapping between them (figure 9); in fact, it is possible to find the risk areas located by our algorithm where there are the break lines of the avalanches in the C.L.P.V.. The algorithm has indeed locate all the existing avalanches and some other risk areas where the phenomenon has not been reported.
Adding the vegetation information it is possible to select the presence of different vegetation types as the discriminant factor affecting the occuring of avalanche phenomena in potential risk zones: it is therefore possible to evaluate the different vegetation type capacity of protection against avalanches.

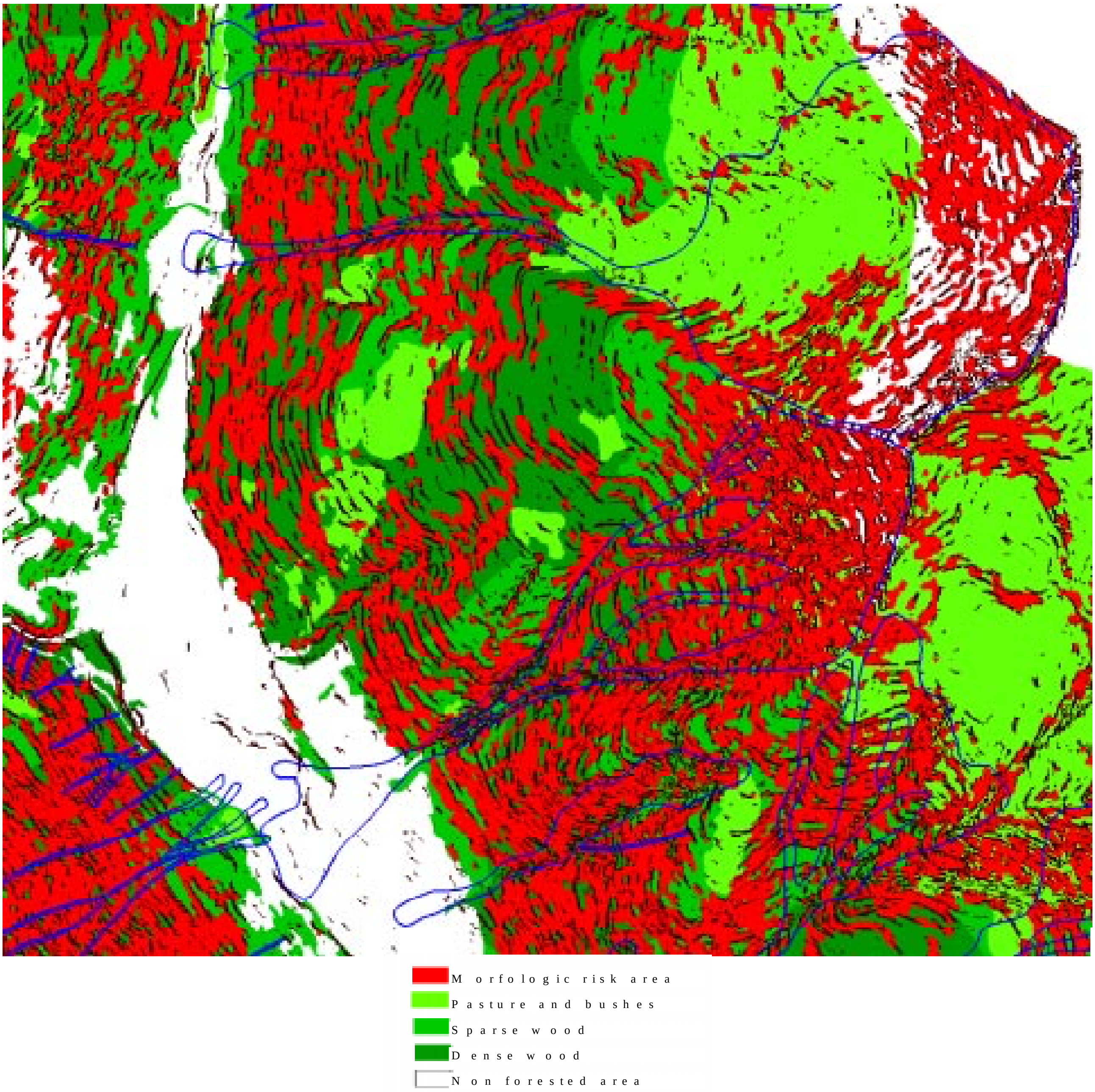

Figure 9: global risk map with superimposed occurred avalanche areas (detail).

Due to this analysis we have been able to evaluate the real ability of the different vegetation classes to protect against avalanches. We have compared the morphologic avalanche risk area with the extension of

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the events occurred (see 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 is really interested by avalanche phenomena.
This parameter highlights the importance of the vegetation coverage in protecting from the avalanche risk (see table 1).

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.

Dense evergreen wood is 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.
Data integration has been essential to reach this result.

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