Integration of dendrochronology and GIS techniques to study avalanche phenomena

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Riassunto
Il lavoro illustra i risultati di una ricerca, volta ad integrare le potenzialità di impiego di tecniche GIS e di dendrocronologia applicata per lo studio di zone potenzialmente esposte al rischio di valanghe in Trentino. Con il GIS GRASS, utilizzando i dati morfologici e vegetazionali, si sono realizzate carte del rischio potenziale che sono state confrontate con le Carte di Localizzazione Probabile delle Valanghe (CLPV) che forniscono informazioni sulle aree interessate dagli eventi in passato ma che possono essere incomplete e non forniscono l'estensione delle valanghe per ciascuna annata. Si è perciò fatto ricorso alla dendrocronologia per ricostruire le serie storiche degli eventi, mappare i limiti raggiunti dalle valanghe nei vari anni, georefenziando le piante con GPS, e verificare la rispondenza delle CLPV all'estensione del fenomeno.

Abstract
The results of a research evaluating avalanche risk with the aid of GIS and dendrochronological techniques in Trentino, are presented. GRASS GIS has been used to obtain an avalanche risk map based on morphological and vegetation features which has been compared with CLPV (possible avalanche location map). It is generally very difficult to obtain information regarding avalanche tracks because of incomplete historical data. Dendrochronological techniques have been used to analyse cores taken from trees (GPS positioned) growing within the avalanche tracks. The analysis of several features recorded in tree rings and the investigation of the vegetation in avalanche paths have proven to be effective to deduce information about past occurrences. Integrating dendrochronological and GIS techniques it is possible to reconstruct historical data, to map old avalanche paths in each year and to correct CLPV.

1. Introduction

The present work is part of a research project sponsored by Provincia Autonoma di Trento and has been carried out at the Department of Environmental and Civil Engineering, University of Trento in collaboration with Swiss Federal Research Institute WSL of Birmensdorf, Switzerland.
The purpose of this research is to study the integration of GIS and dendrochronological techniques, and in particular the objectives are:
- to map potential morphologic risk and to relate it to the vegetation maps to produce global risk maps;

- to compare these maps with CLPV "Carta di Localizzazione Probabile delle Valanghe" (Possible Avalanche Location Map) to evaluate and highlight the protective influence of the different vegetation coverage;
- to reconstruct avalanche events chronologies to complete lacking historical records;
- to reconstruct, by means of dendrochronological indicators, the extent of avalanche events in each year;
- to verify CLPV with the dendrochronological data based maps;
- to obtain useful data for the development and refining of mathematical models actually in an experimental phase at the Department of Environmental and Civil Engineering of Trento.

This research is driven by the consideration that the present knowledge about avalanche phenomena is not always sufficient to protect the inhabited areas and the infrastructure of anthropic activity in the mountain areas. There exists an always growing problem of land overuse especially for tourist purposes on one side, and there is an increasing withdrawal of traditional human activities on the other. These problems underline the importance of a correct evaluation of avalanche risk both for landscape management and planning purposes as for correct project of avalanche control structures.

An ecologically oriented planning and a correct land management are undoubtedly the most effective instruments to avoid disasters as in 1999 (SLF, 2000), an year characterized by many and huge avalanche phenomena.

2. Avalanche risk maps

By combining heterogeneous data, the Open Source GIS GRASS has been used to evaluate avalanche risk. Some avalanche tracks located in Val di Pejo, north-western Trentino (an Italian alpine region which shows frequent and sometimes huge avalanche phenomena) have been selected as test areas. In particular an avalanche track (Val dei Spini) menaces Cogolo, a village in the valley. In 1901 a huge avalanche phenomena destroyed some houses and passed near the centre of Cogolo. The people of the valley “forgot” the past events and recently built new houses in the old and now undetectable 1901 avalanche path.

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° (Berger, 1995; Tabarelli, 1996; Ciolli et al., 1998; Comunello, 2000;).

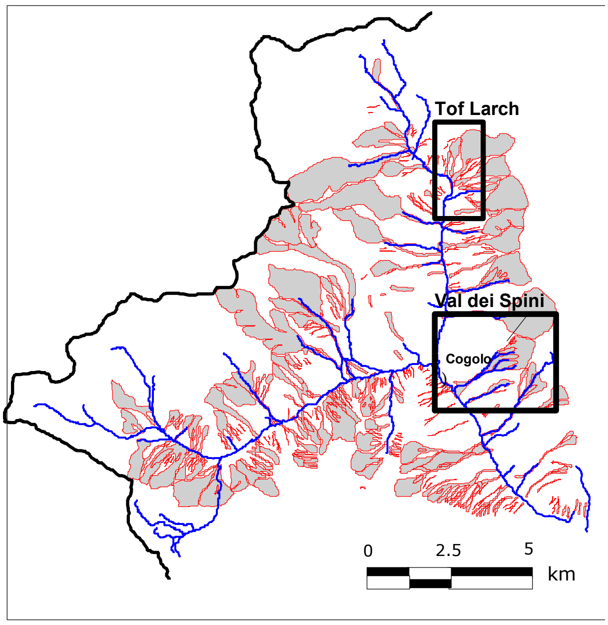

Figure 1- Location of study areas in Val di Pejo.

By means of the GRASS Mapcalc feature, 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 high avalanche probability based only on their geometric features.
The ability of the vegetation to protect against the avalanche phenomena has been evaluated by recognizing different coverage types depending on species and density, since the latter influences their ability to avoid the creation of a compact and homogeneous snow layer (Ciolli et al., 1998; Cherubini et al., 2000). A map of the vegetation's protection ability has been obtained. Vegetation types have 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 and correct 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" (Possible Avalanche Location Map) and the potential surface obtained following the described criteria, divided in different vegetation classes, highlights the importance of the vegetation coverage in protecting from avalanche risk (Ciolli et al., 1998). The risk map obtained with GRASS picks out more risk areas than avalanche paths in C.L.P.V.; this fact depends both on how C.L.P.V. are traced and on vegetation protection ability.

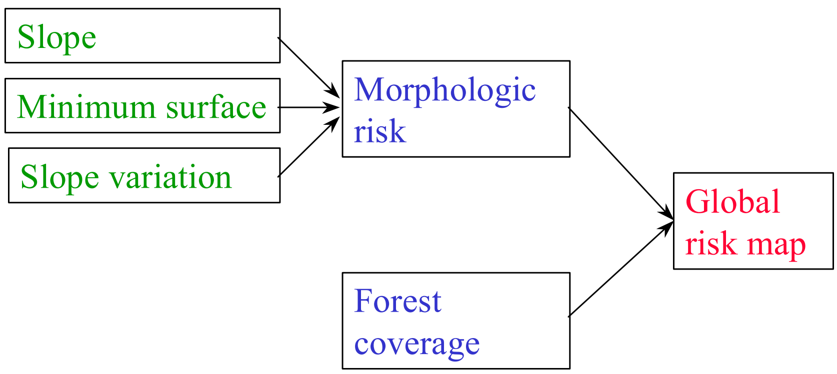

Figure 2 - Global risk map building scheme.

The maps obtained in this way are also useful to identify the break lines on the avalanche paths and to understand the track features. Moreover, by mean of GRASS GIS it is possible to trace the paths of the snow inside an avalanche track and this can be useful to understand avalanche dynamic and select interesting dendrochronological sites (Comunello, 2000). A significant lack of official information comes from historical data. Only last thirty years events are registered in an avalanche cadastre, some huge older events are reported and sometimes approximately mapped; even if an event is registered, the real extension of the avalanche on its path in each year is not available. All these information are indispensable to develop reliable dynamic avalanche models. A deeper knowledge is particularly important to control avalanches and avoid destruction where avalanche phenomena may involve villages or towns.
An avalanche track has been monitored for four years to register information about snow movement, snow height, avalanche real extension per year and so on (Scotton, 1999). This will be

surely useful in the future, but how many missing information of the past decades can be provided? Dendrochronology may give a helpful hand.

3. Dendrochronology and avalanches

Dendrochronology is a science that has gained a significative reliability between applied sciences and can be used in several different applications.

A dendrochronological approach in avalanche areas has been already tried in some scientific researches carried out in Canada, Italy, Switzerland and USA and the results can be here briefly resumed:

- it is possible to develop avalanche events chronologies even if official data are not available (Potter, 1969; Rayback, 1998; Nagel, 2000; Comunello, 2000; Borter, 2000);
- it is possible to highlight dendroecological indicators and evaluate their reliability (Carrara, 1979; Johnson et al., 1985; Keller Singh, 1995; Cherubini et al., 2000);
- anomalies in tree rings features or sequences are more frequent in avalanching years and useful information can be provided by plants at the end of the track (Keller Singh, 1995).

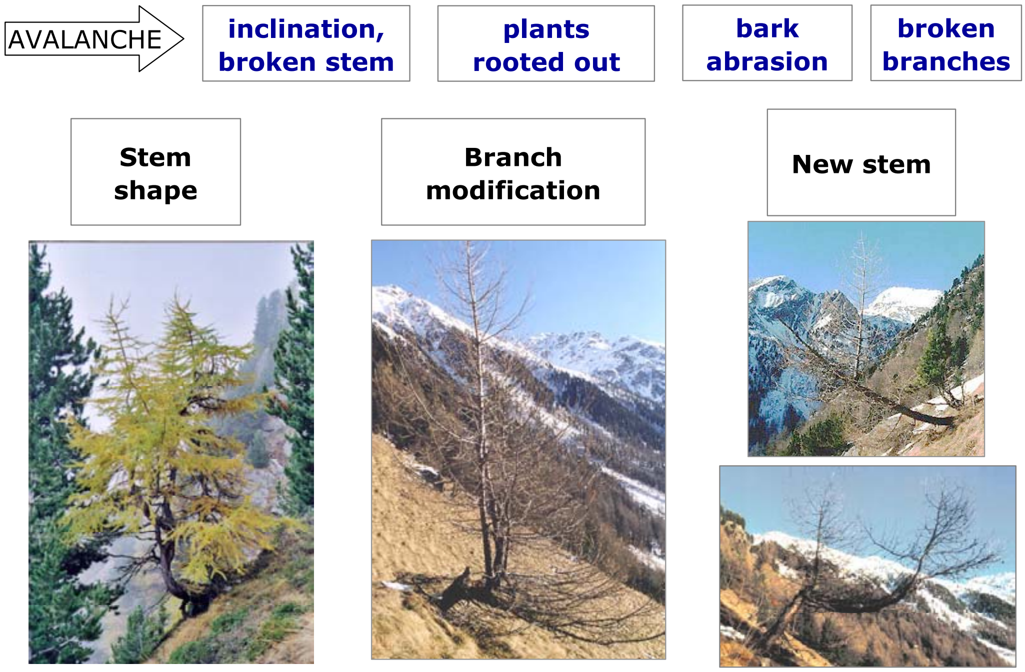

Figure 3 - Visible signs of an avalanche on plants features.

The anomalies to look for in ring sequences are scars, micro-rings, sequences of extra large or extra micro-rings, compression wood, traumatic resin ducts and/or the tree death date. Combining tree ring anomalies with an accurate observation of the vegetation shape, the presence of newly formed stems and other macroscopic vegetation features, it is possible to draw the picture of the events.

The major objectives of dendrochronological techniques in this research were to reconstruct lacking avalanche event chronologies in some avalanche tracks and to obtain dendrochronological data to enter in a GIS to map the spatial extent of prior avalanche events. Cores and cross-sections preparation, microscope analysis and dendroecological data elaboration, have been carried out in the Federal Research Institute WSL of Birmensdorf (CH); GIS data elaboration has been carried out in the Laboratory of Ecology of Trento University.

The reconstruction of event chronologies must be compared with the available historical records to test and verify the reliability of the method.

This has been done comparing the available thirty years chronology with the results of dendrochronological analysis.

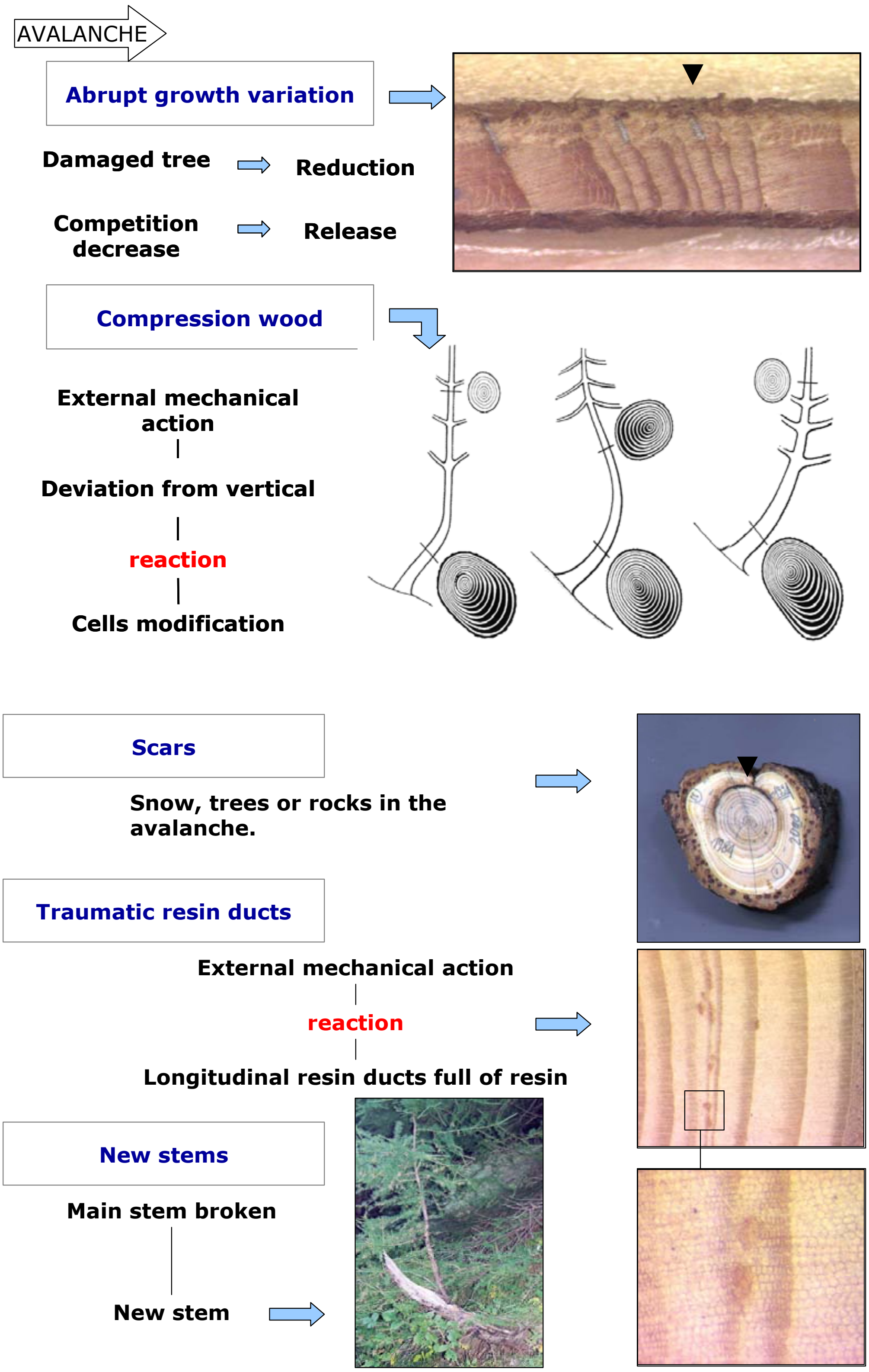

Figure 4 - Dendrochronological indicators (the picture of compression wood from Schweingrüber, 1996).

All the dendrochronological indicators have been used to date avalanche events but some of them have been selected as the most indicative.

By means of skeleton plotting, ring-width variations and anomalies from each sample are graphically represented and used to match the ring patterns of individual trees with those or other stems sampled.

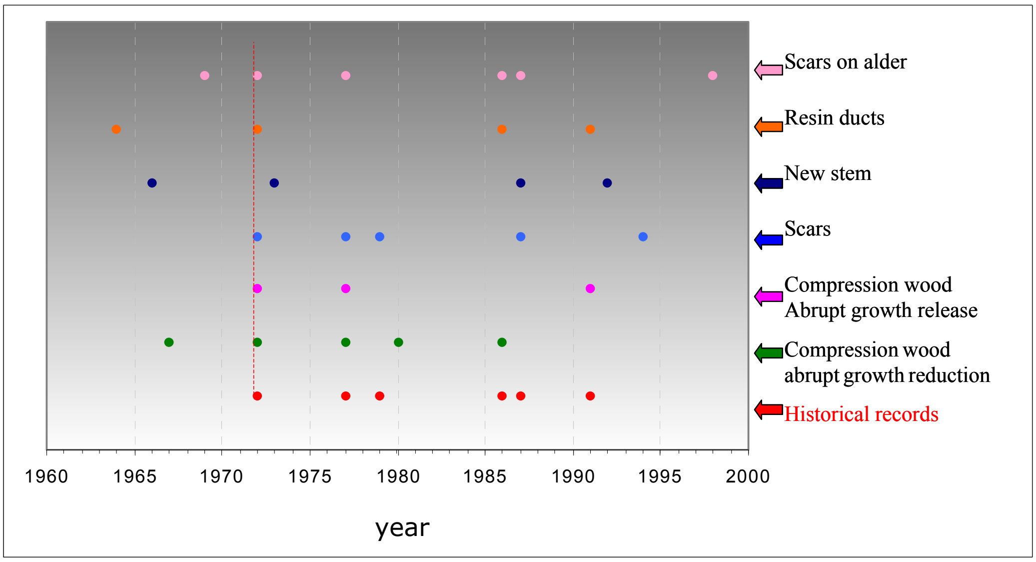

Figure 5 - Historical data compared with dendrochronological evidences in sample trees (years 1970-2000).

Two master chronologies have been created; the first, obtained with avalanche track samples has been used to cross-date them, and the second, made with undisturbed areas samples, has been used to filter out climatic effects.

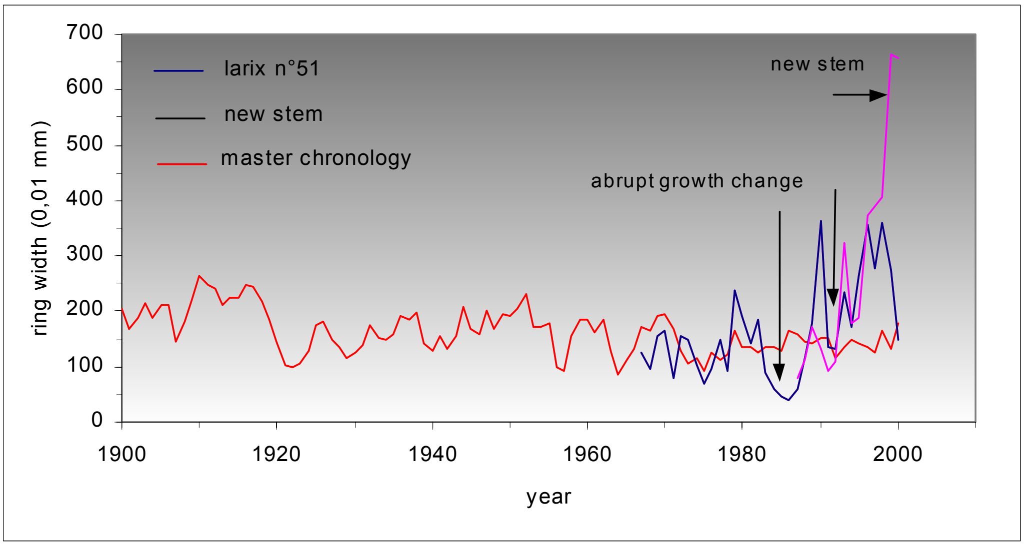

Figure 6 - Example of comparison of master chronology with one Larch (number 51) and its new stem chronologies.

The position of each cored plant has been registered with a GPS receiver and the data have been entered in GRASS GIS to map the avalanche path per each year. Integrating the dendrochronological information and GPS data it is possible to map each avalanche year event.

4. Concluding remarks

Dendrochronology has proved to be a very reliable and effective technique to reconstruct avalanche occurred event chronologies in the study areas.

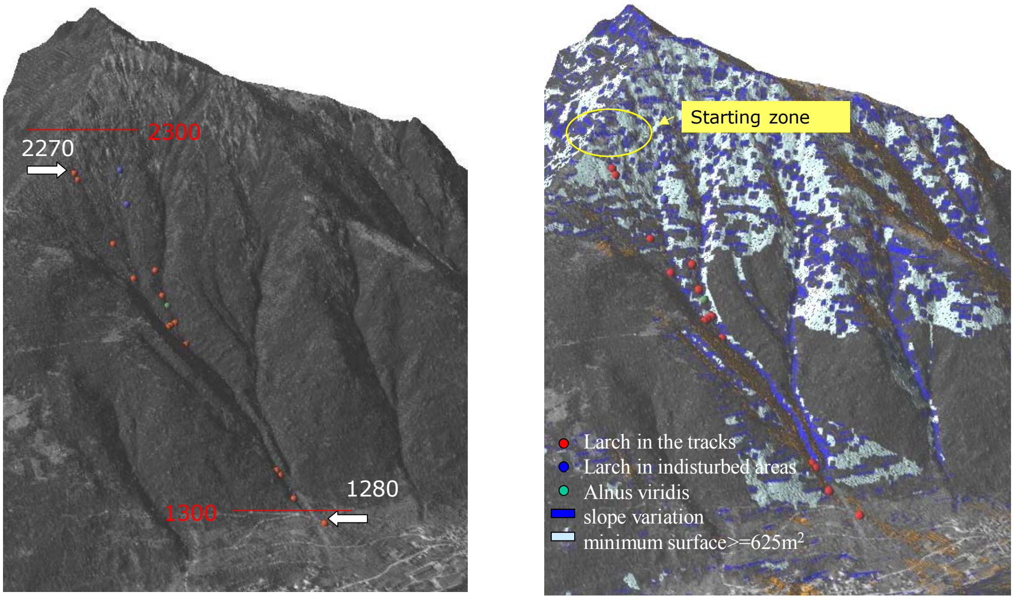

Figure 7 - Reconstruction of 1991 avalanche extent by mean of dendroecological evidences (left) Starting area of avalanche individuated with GRASS GIS (right).

The dendrochronological samples analysis has allowed the individuation of the most reliable indicators of past avalanche passages, that is, new stems and compression wood in association with abrupt growth release. In this research all the available dendrochronological indicators have been taken in account and the results obtained from each single indicator have been integrated to filter out as much as possible climatic effects and other possible noises.

In our opinion, it could be very interesting to extend the research to other different alpine regions; the same scientific protocol in collecting and analyzing data should be used. In this way, the existence of a possible connection between climate change and the intensification of avalanche phenomena could be investigated. This is an undoubtedly very delicate and disputable matter; in any case is a very actual and stimulating subject.

By combining dendrochronology and GIS it is possible to reconstruct the extent of prior avalanche events per each year (figures 7 and 8). The comparison of the registered events with dendrochronological data seems to confirm the high reliability of the method; the results must be critically interpreted since avalanche phenomena are so complex.

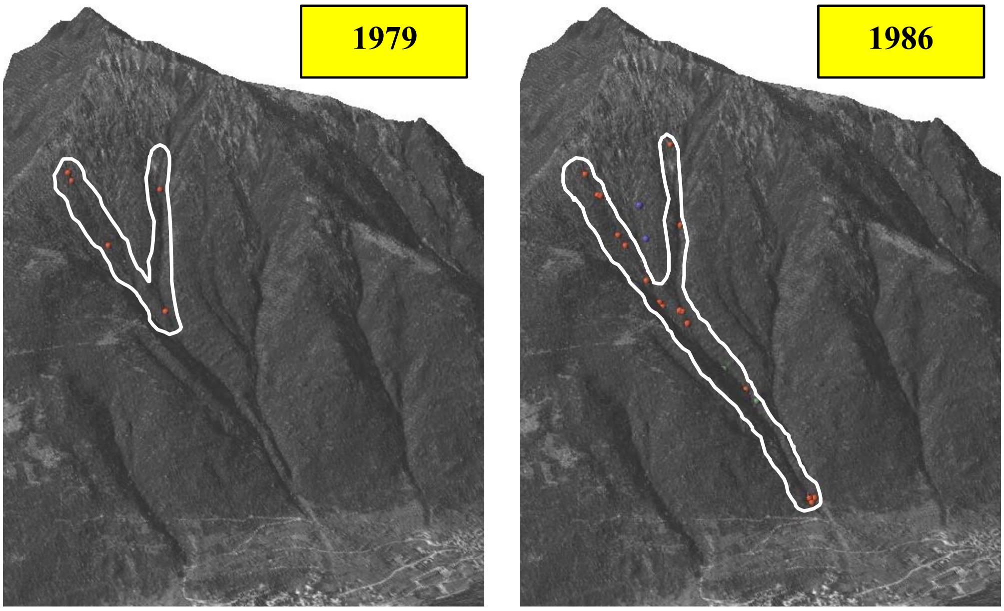

Figure 8 - Extent of 1979 and 1986 avalanches obtained with dendroecological evidences.

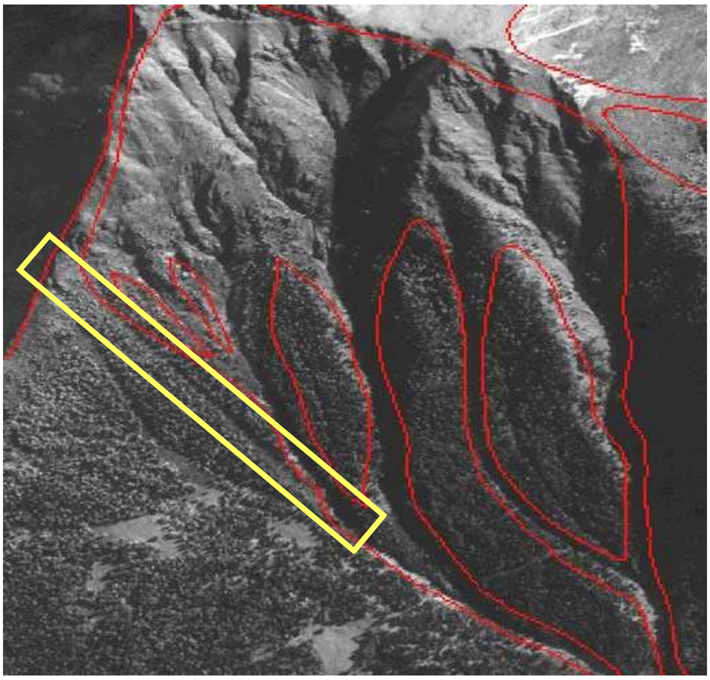

Figure 9 - CLPV (in red) can be corrected with dendrochronological analysis results. In yellow one study area in which dendrochronology has shown the presence of avalanches while the same area is not present in CLPV.

Moreover, this method can pick out the lacks in CLPV (Bezzi et al., 2001), making possible to improve and complete this kind of maps which are usually employed in land management and avalanche control structures (figure 9).
By combining dendrochronology and GIS it is also possible to reconstruct old and now undetectable avalanche paths which may return active in the future (Comunello et al., 2001).
The field work has permitted to highlight the existence of some areas of the avalanche track which can be defined as more "sensitive" to avalanche passage. These places, where dendrochronological

indicators are more often found, could become permanent sample areas. The data coming from those areas may be combined with snow height and volume measures to deepen the analysis of avalanche dynamic (Bezzi et al., 2001).
In conclusion the first results of the research seem very encouraging.
The integration of GIS and dendrochronological techniques show very interesting development perspectives not only in the avalanche risk analysis, but also in other research fields such as debris flow.

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