# Geomatics application for geological and geomorphological mapping and landslide hazard evaluation: case studies in the Italian NW-Alps

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**Abstract – Theoretical assumptions, research methodologies and results applications of innovative geological and geomorphological mapping for landslide hazard evaluation in the alpine environment are presented in the paper. Case studies from the Italian NW-Alps highlight the role of Geomatics techniques in enhancing the accuracy of multitemporal reconstructions of geomorphic processes and landforms. Aerial and satellite remote sensing stereoscopy, derived DTMs, high resolution hyperspectral images, allow precise slope movements evaluation and detailed thematic mapping. Results are available for supporting hazard studies and disaster management.**

**Keywords:** Geomatics, Alpine environment, Landforms, Geomorphological Processes, Photogrammetry, GIS, Remote Sensing.

## 1. INTRODUCTION

The geomorphology of the Alps results from the overlapping of several modeling processes characterized by different time length and intensity. Sensible landscape changes at various scale occur only when the size of these modeling processes crosses a given threshold. Crossing a threshold of the geomorphic systems often involves activation of impulsive, high energy processes: evaluation of the possible occurrence of natural disaster can be facilitated by innovative technologies supporting geomorphological studies.

The general purpose of the paper is to highlight the theoretical assumption, the research methodologies and the results application of innovative geological and geomorphological mapping for landslide hazard evaluation: some case-studies from the Susa Valley (Italian NW-Alps, Piemonte Region; Fig. 1) are presented, stressing the role of Geomatics techniques in enhancing the accuracy of multitemporal reconstructions of geomorphic processes and landforms.

Two research lines will be shown: the first one includes a wide areas assessment for a general recognition of relief evolution in the internal side of the NW-Alps; the second one is devoted to the time repeated measurements in specific Susa Valley sectors for local slopes movements identification.

Digital Terrain Models (DTM), derived both from high and medium resolution stereo satellite images and aerial ones, have been used for the reconstruction of the glacial dynamics Particularly, the geological-geomorphologic analysis of the Susa Valley and the Rivoli-Avigliana morainic amphitheater has been carried out in this way. Photogrammetric techniques has been used to identify recent deep-seated gravitational dynamics related to large slope instabilities (e.g. Sauze d'Oulx paleo-landslide). Multitemporal comparison of differently dated Digital Elevation Models generated from aerial images has been carried out taking care of planimetric and height accuracy determination.

High resolution hyperspectral images (airborne MIVIS sensor) have been also adopted for thematic purposes, looking for possible correlations between terrain deformations and land covers (e.g. Cassas landslide).

## 2. GEOMORPHOLOGICAL HISTORY AND ENVIRONMENTAL DYNAMICS

The are some "geomorphological" theoretical assumptions for the development of a multitemporal analysis of slope dynamics in the alpine region: we have to deal with the general and local factors controlling the environmental dynamics of the mountain range.

First of all, the alpine landscape has suffered from the exogenous agents action as well as the endogenous ones all during its evolution time. The litho-structural features "statically" condition the evolution of mountain relief, while the tectonic deformations, eventually propagating up to the surface through different mechanisms and rates, offer a "dynamic" conditioning to the evolution at a regional scale, based on the temporal changes of the stress field (Summerfield, 1991). For the landscape analysis, it is important to investigate the relationships between deformational and modeling rates: this force to a deep multitemporal and multispatial analysis. The landforms conservation (and identifiably) is the result of the time past from their formation, the intrinsic "strength" to following modeling processes, the level of environmental dynamics affecting each sector of the alpine range, and the original size of each single landform. Among ancient landforms, only highly conservative ones are shown in the present landscape as relict landforms (e.g.: major Pleistocene terminal moraines).

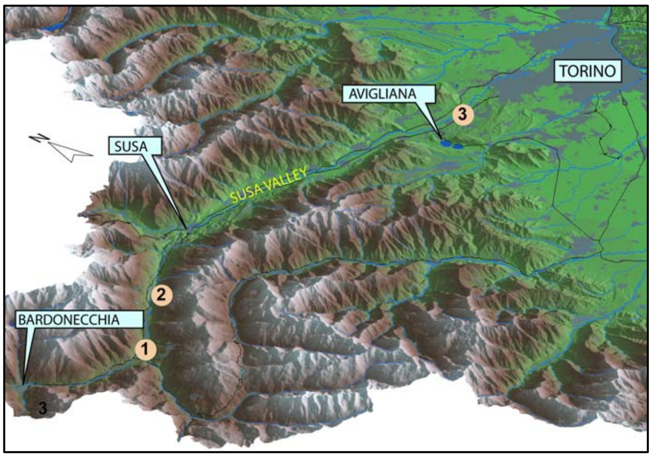


Figure 1. Sketch map of the studied area in the Italian NW-Alps and location of test sites and geomorphological features. (1= Sauze d'Oulx paleo-landslide; 2= Cassas landslide; 3= Rivoli-Avigliana moraine amphitheater).

## 2.1 "Geomorphological stages" and slope instabilities

To trace back the events of the Western Alps geomorphological history, whose overlapping caused slope instability in the present landscape, one have to take in account landforms conservativeness and their original size. It follows that there are different order of "geomorphological stages" in the history of the alpine landscape, below listed starting from the older (and larger).

- The old geodynamics is identifiable only by analyzing trends of drainage networks and migration of major watersheds and local divides, at the scale of the whole mountain range.
- Among the Pleistocene events, basically only the elements connected to high magnitude/long-term glacial processes are identifiable at the scale of the entire valley: among these, the conservativeness decreases backward in time (e.g. terminal moraines; Fig. 2).
- The general characteristics of the post-glacial "stage" are mainly testified by large slope instabilities affecting whole slopes of the valley sides (Figs. 3 and 4).
- The present-day exogenetic dynamics (e.g. mainly fluvial/torrential and landslide/gravitational processes) is well identifiable by small "active" landforms (Fig. 5) due to single short events. A useful scale of analysis is that of micro-scale landforms and single outcrops.

Older "geomorphological stages" affects present-day slope instability phenomena only as heritage conditioning factors. Nevertheless it is important to locate the areas of their possible geomorphic influence and to quantify their role in mass movement activation. Traditional geomorphological mapping at a regional and local scale is a starting point for these researches (Demek & Embleton, 1978).

## 2.2 Geomorphic rates and mass movements

The geomorphological change affect the alpine range at various scale in terms of dimension of area involved and rates of geomorphic processes. So, a preliminary step in the analysis of natural hazards in a sensible environment is to classify geomorphic changes by evaluating rates of related processes.
In the case of the post-glacial stage, geological and geomorphological studies showed that large portions of the mountain relieves along the Alpine chain are affected by deep-seated gravitational slope deformations (Nemcock, 1972). These huge gravitational phenomena can be also defined as "large slope instabilities" because of their large area extension (multi-km$^2$) and their complex geometrical, geomorphological and geomechanical settings (Crosta, 1996). A precise recognition of superficial deformation markers is essential for dimensional evaluation of involved area and movement rates: mean, long-term rates range up to dm/year as along slope displacements (Mortara & Sorzana, 1987) .
Nevertheless, slow- and long-term superficial deformations connected to deep-seated gravitational instabilities can lead to the crossing of a threshold in the slope system. This could involves activation of impulsive, high energy landslides: thus, measurement and monitoring of terrain movements of both wide instable slopes and very localized landslide phenomena are objectively difficult to be faced in a traditional way (field survey, analogical aerial photointerpretation).

# 3. INNOVATIVE APPROACHES

Geomatics techniques as satellite/aerial remote sensing and photogrammetry, GPS surveys and GIS have recently shown how well they can work in context as the Susa Valley area is, in particular, for the definition of its geomorphological setting in a multitemporal and multispatial perspective. Three examples are here shown to validate this statement.
The first one, shows as simple data fusion approach, can be used for scenarios generation and mapping/didactic purposes. Second one explores geometric potentialities of this techniques. The third one presents how well the thematic content of remote sensed images can be exploited to complete the area description ad to lead to a synthetic approach producing, for example, hazard and risk maps.

## 3.1 Geomatics and landforms analysis in the Susa Valley

Geomatics devices and digital data demonstrated to be really suitable for improved analysis and representation of the observed phenomena. They can be easily integrated each other within Geographical Information Systems (GIS) for decision support requirements. In this way field data and remote sensing ones can collaborate to generate synthetic information, to produce effective spatial interpolations of punctual field-recorded data, to build impressive 3D scenarios useful for simulations and advertising.
The moraine amphitheatre of Rivoli-Avigliana (AMRA), sited in the Piemonte Region, is a complex hilly area, characterized by straight parallel morphostructures alternated with curved ones, that separate the lower Susa Valley from the middle Sangone Valley. The origin of these morphostructures dates between 750.000 e 12.000 years ago, and it is related to the pulses of the ancient Susa Valley glacier.
Digital data, as vectorial maps, satellite medium and high resolution images, aerial images permit us to produce, within a GIS environment, thematic maps and 3D visualisations, which are very effective.
3D visualisation of the Rivol-Avigliana terminal moraines, for example, (Fig. 2) allows to look at the area from different points of view; moreover, the morphologic identity of the moraine hills complex is enhanced with respect to others close landforms, supplying a powerful tool for management and didactic purposes.

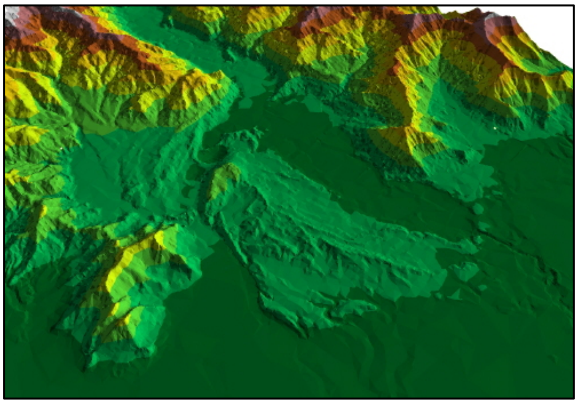

Figure 2. 3D visualization of Rivoli-Avigliana moraine amphitheatre.

### 3.2 Photogrammetry for detection of large slope instabilities activity

In this section is briefly presented a successful case study, carried out in the Upper Susa Valley for the detection of a “paleolandslide” (Carraro et Al., 1979), connected to a wider deep-seated gravitational slope deformation, based on Geomatics and in particular on a photogrammetric approach. Digital photogrammetry allows to measure objects exploiting a 3D stereo model obtained by stereo images orientation. This technique is a very consolidate one in the field of cartography: all maps around the world, nowadays, are generated in this way, using aerial stereo images. Anyway, this same approach is not still so common in the geological applications, that are still often limited to the simple image interpretation.

The goal of the research was to understand if the Sauze d’Oulx (Susa Valley) large slope instability was active. This has been done comparing two multitemporal DEMs (Digital Elevation Model) in a differential way. The area test is currently intensively studied in sight of the 2006 Winter Olympic Games in Turin. The ancient geological view of the area as a great mixed alluvial fan, bordered by glacial deposits, has been abandoned for the interpretation as a large landslide activated in highly deformed rock units after the release of compressive stresses induced by the Susa Valley’s glacier during last glacial maximum.

Two aerial image series have been used: a stereo pair dating 1964 (mean image scale about 1: 30.000); an image block (6 images) dating 2000 (mean scale 1: 13.000). All auxiliary data, related to these blocks (camera interior orientation parameters, reference map) were available to correctly manage the orientation of the stereo models, necessary to proceed to the plotting operations. In this case stereo plotting has been limited to the generation of two DEMs, corresponding respectively to the 1964 and 2000 years.

The two DEMs have been successively compared through a matrix subtraction ($DEM_{2000} - DEM_{1964}$; Fig. 4) using a specific procedure autonomously developed in IDL language (Interactive Data Language). Positive values indicate probable lift-ups, negative values possible subsidences.

2000 1964

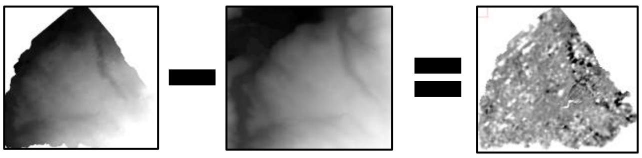

Figure 3. Matrix difference between DEMs ($DEM_{2000} - DEM_{1964}$).

In order to identify just the meaningful vertical movements a precautionary threshold, derived considering both residuals obtained during block bundle adjustments and relation with mean image scale, has been applied equal to +/- 4m.

The obtained results (elevation differences map) have to be considered qualitative. According to the quite low accuracy obtained in the determination of the spatial coordinates of the measured objects in the stereo models, it would be not really safe to consider completely reliable such analysis in a strictly measurements way. In the future this procedure could be applied for active slope monitoring foreseeing automated data collection procedures from satellite stereopairs (Cosmo/Skymed Pleiades, Eros A1, Ikonos). Anyway these results have been successively confirmed by different measurements made both in situ and through satellite SAR interferometric techniques. All of them have shown a vertical evolution comparable to the results of this particular study.

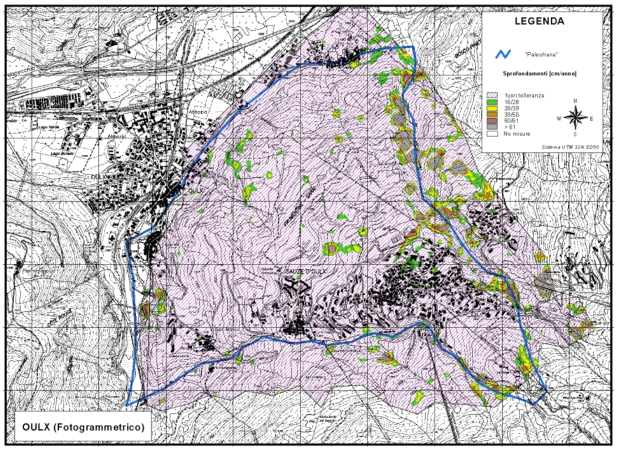


Figure 4. Subsidences Map of Sauze d’Oulx “Paleolandslide”

### 3.3 Recent landslides phenomena and geothematic zonation

The present-day slope dynamics of the middle Susa Valley is also characterized by recent and active landslides of smaller area extent with respect to the above mentioned large slope instabilities. The case studies of Cassas landslide is briefly presented here, as an experience dealing with the thematic mapping supported by digital remote sensing data. High resolution hyperspectral images (airborne MIVIS sensor) have been adopted for thematic purposes looking for possible correlations between terrain deformations and land covers.

LARA-CNR (Aerial Laboratory for Environmental Researches) has elaborated the MIVIS Airborne system (Multi-spectral Infrared Visible Imaging Spectrometer). This sensor allows the recording of 102 spectral bands ranging from the visible to the thermal infrared bands. In these past years, the geological field has developed numerous advantageous applications with this remarkable spectral resolution (Boccardo et al., 2003).

The presented test has been carried out on a MIVIS image recorded flying across Susa Valley and including the Cassas’s landslide. When dealing with territorial applications it’s always important to correctly approach the scale mapping problem. This means that ground object positioning must be coherent for all the used data (often coming from different sources and reference map systems). Such problem can be easily solved with geocoded data such as ancillary and cartographic ones. Not so easy is to face the problem of MIVIS data geocoding maintaining the ground position accurate within an acceptable tolerance range (depending on the nominal scale of the base map it will be adopted). Thus MIVIS image geocoding is a delicate step to go through; further complexities come from the whiskbroom MIVIS sensor model which introduces many deformations to take care of. Scene geometry has to be corrected. Usual methodology based on simple polynomial approach cannot model such geometry especially in a mountain region as the study area is. An orthoprojection has to be done to make MIVIS data suitable for subsequent data integrations (Figure 5a). The area of the Cassas’s landslide (historical event 1957 a.D.) is located on the right slope of the valley above the Serre la Voute Gorge, originated by the occurrence of the Testa del Mottas landslide (historical event 1728 a.D.) and the Serre la Voute deep-seated gravitational deformation (historical events 1957, 1728 a.D.). These instability phenomena dammed the valley bottom originating lacustrine deposits (prehistorical datations on buried subfossil woods: 8380 ± 95 BP; 9525 ± 85 BP). The Cassas landslide develops from a secondary watershed ridge, highest point approximately 1900 m, to the valley bottom, approximately elevation 1000 m.; it is orientated NE-SW. Total area of the landslide is approximately 500.000 square meters.

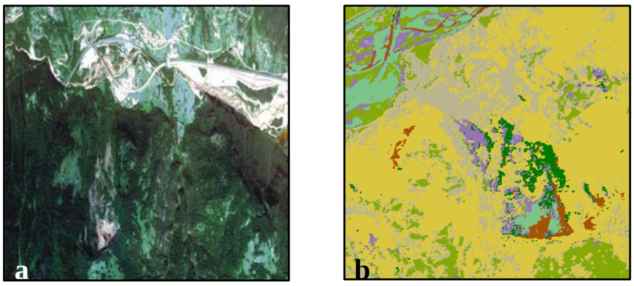


Figure 5. a) Real Color Mivis image of Cassas Landslide before orthoprojection. b) Mivis classified image after orthoprojection.

Images analysis of the Cassas Landslide through the true-color RGB visualization evidences the orientation and development of the Cassas's landslide shear planes and its areal limits. The distinction between the wooded area and the debris-covered area appears very simple also for simple image supervised classifiers (Figure 5b).

One of the most used syntheses is the False Colors one. In this case it has been obtained associating band 18 to the Red, 10 to the Green and 3 to the Blue. In this image it's possible to appreciate the red and blue tonalities, generally the first refers to forests and prairie zones. On the other hand the blue represents the naked ground where the debris covered areas (Cassas's landslide deposits and Dora Riparia's sediments) and the rock emerging portions are founded (along the watershed). In particular it's possible to notice that with false colours the landslide area is very easy to identify with respect to forests and prairies.

The possibility to compose images with numerous portions of the electromagnetic spectrum allows a very accurate preliminary analysis of the landslide phenomena, as well as the possibility to directly place the geomorphologic features on the reference cartography (ortoprojected images). MIVIS Images are a good starting point for landslide phenomena analysis. From a radiometric point of view it's interesting to compose additive synthesis within medium and near infrared regions in order to analyze the covers and other geomorphological features. It's also very important for elaborating measures and tracing the features directly on the orthorectified image. Note how the orthprojection corrects the strong distortion of the landslide itself, allowing to re-shape correctly the landslide area.

## 4. CONCLUSIONS

The presented case studies showed the role of Geomatics techniques in enhancing the accuracy of multitemporal reconstructions of geomorphic processes and landforms connected to present-day landslide activity. Aerial and satellite remote sensing stereoscopy, derived DTMs, high resolution hyperspectral images, allowed precise landform recognition, slope movements evaluation and detailed thematic mapping along the Susa Valley, one of the major valley system of the Italian Western Alps. From the geomorphological point of view, the whole middle and upper Susa Valley resulted affected by deep seated gravitational deformations. Some of them induced present day impulsive, high energy phenomena (e.g. Cassas landslide); some others (Sauze d'Oulx large slope instability) doesn't have superficial evidences of particular hazard. Nevertheless it has been interesting to monitor the slow but constant movements in time, due to compressive and stretching forces that have interested the ancient phenomenon, the "paleo-landslide". Geomatics really improved terrain analysis. Different techniques and data can be used for different purposes, but great attention has to be paid to positioning accuracy. In the Sauze d'Oulx case study, the metric stereo approach resulted effective for determinant measurements. It's worth to point out that measurements accuracy can be determined as well as the measure itself, to guarantee the user to not badly interpret the results he obtains. In the Cassas case study, even if the information related to the spectral content of the used images resulted as the main impact factor in such analysis, has to be underlined how important is the geometric correction of the image for the correct interpretation of the phenomenon. This is a typical problem for aerial images in mountainous region, where relief displacement produces strong deformations of the observed shapes. As a conclusion, interpretations resulted available for supporting hazard studies and disaster management in a alpine area of intense human activity.

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