Terrestrial Laser Scanning for the Montaguto Landslide (Southern Italy)

Domenico Denora, Lia Romano, and Giulia Cecaro

Abstract

The evaluation of the landslide surface movements is often difficult because of the inaccessibility of these impervious areas. For this reason, a powerful tool for monitoring is the laser scanning technology (TLS). The landslide monitoring by TLS is complementary to terrestrial SAR interferometry and traditional monitoring techniques. While SAR interferometry is useful for rapid detection of the displacement velocity of monitored points, laser scanning technology also allows the displacement volume quantification (Schwalbe et al. 2008). These analysis provide important information for planning hazard management actions. Experimental surveys were performed for the Montaguto landslide (Campania, Italy), the greatest of Europe, by means of laser scanner Riegl LPM-321 (Alba et al. 2005), with measurement range up to 6,000 m. Differential volume maps from different surveys were obtained. The complex morphology of the Montaguto landslide, located in the Cervaro river valley, had required a viewshed analysis for the selection of the base station locations. Detailed laser scanner acquisitions were conducted on the tip landslide zone, because of the presence of strategic mobility.

Keywords

Terrestrial laser scanning • TLS • Landslide monitoring • Displacement volume quantification • GPS • Montaguto

Introduction

The landslide of Montaguto is one of the most important landslide in Europe. It is located in South Italy, in Campania Region. The landslide concerns an hillslope on the hydraulic left of Cervaro river – that in this section drains about 135 km^2 – from 956 m s.l.m. to the river bed at 400 m s.l.m. The geological formation are related to the Faeto flysch, the Marne Argillose del 'Toppo Capuana' (clay and clayey blue-grey marls, layered with rare sandy layers; Tortonian) and the Altavilla Unit (Tortonian Middle Pleistocene) (Guadagno 2010).

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The landslide is activated in the upper part by several roto-translational mechanisms and develops into an earth flow, moving along a deep and extending on the whole over a length of 3 km for a variable width of 400 m in the upper and lower parts to 100 m in the medium part (Fig. 1). The movement has involved in the last years a mass of about one milion cubic meters (Cascini and Di Nocera 2009).

Between the tip of the landslide and the Cervaro river there are two important transport infrastructures, that connected Apulia and Campania – the federal road 90 and a strategic railway – which requires a constant monitoring, carried out by the Civil Protection Department by means of SAR interferometry. In this activities, the Apulia Basin Authority (AdBP) has tested the use of modern technologies in topographic data acquisition and modelling, with particular attention to the tip zone.

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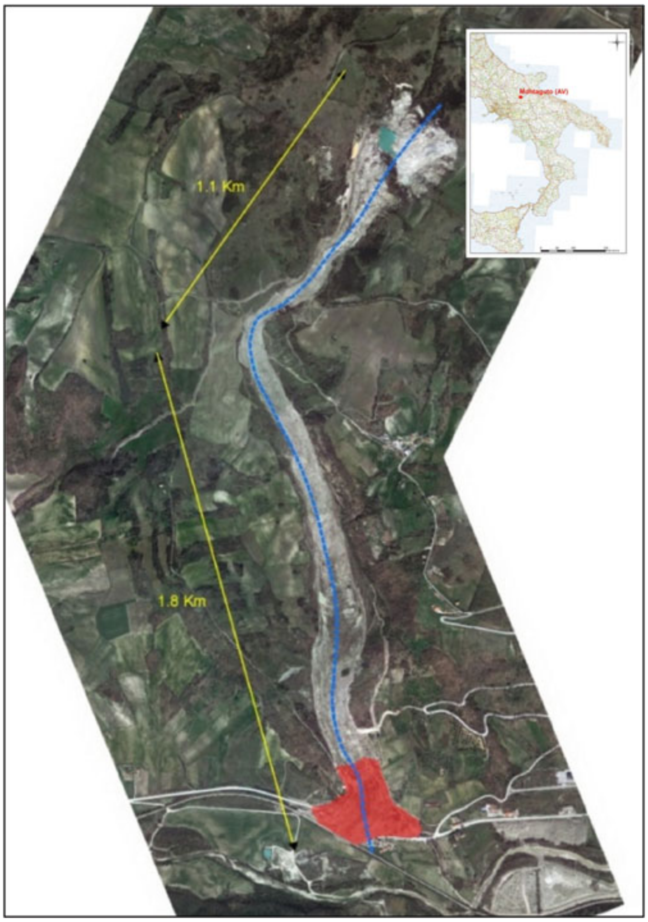

Fig. 1 The Montaguto landslide longitudinal extension with the tip zone in *red*

Table 1 RIEGL LPM-321 technical characteristics (Bornaz et al. 2008)

Max measurement range	@ rate 1,000 Hz	@ rate 100 Hz	@ rate 10 Hz
For natural targets, ρ > 80 %	≥1,500 m	≥2,500 m	6,000 m
For natural targets, ρ > 10 %	≥500 m	≥850 m	≥1,500 m
Meas. accuracy	25 mm		
Precision	15 mm		
Laser beam diverg	typ. 0.8 mrad		
Laser wavelength	Near infrared		
Meas. rate	10–1,000 points/s		

The Landslide Analysis

The Surveying Equipment

The instruments used are the Laser Profile Measuring System LPM-321 (Table 1) with a continuous electrical generator for the data acquisition system, the GPS Leica System 1200, and several 10 cm cylindrical and 50 cm flat circular retroreflectors.

Fig. 2 The viewshed analysis for LS1 scan position with a range of 3 km

A viewshed analysis (Fig. 2) based on the digital terrain model had showed the need to locate the acquisition point on the opposite hillslope of the Cervaro valley, in the LS1 scan position, for covering the whole lower part of the landslide. The distance of the landslide surface, which starts on about 1 km from LS1, detects in the LPM-321, having a range up to 6 km and a measurement accuracy of 25 mm, the suitable instrument for this long range 3D profiling, considering moreover that the acquisition range is strictly influenced by the measurement rate, by the reflectivity of materials and by the atmospheric conditions. In particular, the tip of the landslide from LS1 is totally covered by the laser scanner, from the railway to the next 1 km, with about 47 ° horizontal range and 7 ° vertical range. For time optimization, the measurement rate has been set to 100 Hz.

The Leica System 1200 is a geodetic GPS receiver (GPS GLONASS), which allows the communication through RTCM 3.0 transmission protocol to the permanent stations for differential correction data for reducing the systematic errors that decrease the accuracy of GPS positions.

3D Georeferenced Terrestrial Laser Scanning

Since may 2010, when the landslide closed the railway, four measurement campaigns were performed on the tip of the Montaguto landslide (Table 2). A great work to clear the landslide from the railway and the federal road was made, despite the continuous movement of the landslide.

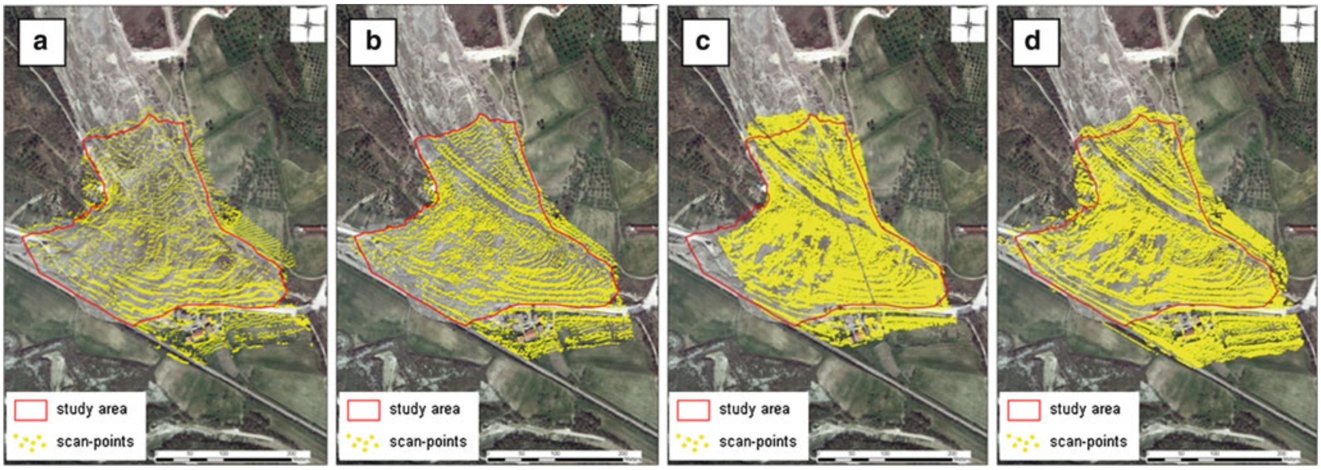

Fig. 3 The point clouds acquired for the four measurement campaigns: (**a**) May 27, 2010 (the landslide invades the railway); (**b**) November 4, 2010 (trench cut for opening the railway, cut-off drain excavation and benching); (**c**) December 1, 2010 (progression of landslide movement on the west side); (**d**) March 31, 2011 (stability conditions)

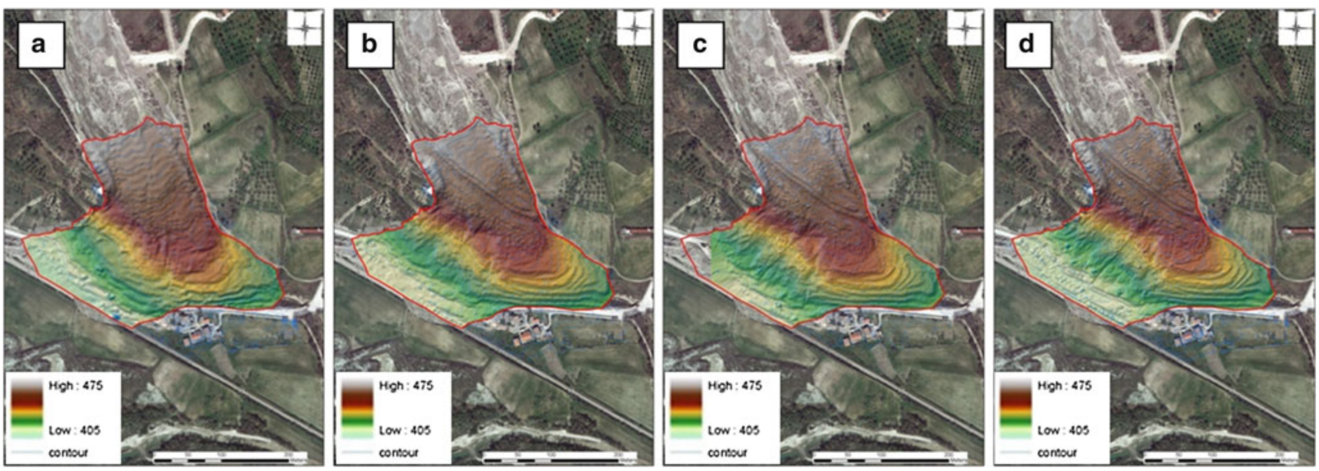

Fig. 4 The digital model terrain of the landslide tip related to previous scan acquisition

Table 2 Technical parameters of scan acquisitions

Date	T (°C)	Press (mbar)	RH (%)	N. points	Resolution (m)
05-27-10	22.0	1,020	49.1	28,796	1
11-4-10	14.7	1,000	88.4	13,460	1
12-1-10	6.4	921	77	20,777	0.4
03-31-11	13	1,016	60	189,302	0.35

For controlling the landslide, a cut-off drain was excavated in the upper part of the tip for intercepting subsurface ground-water flowing down in the main body of the landslide and a stable benching system was realized.

The laser scanning was managed by the software 'Riprofile', which allows the scan setting, the georeferencing of the point cloud acquired (Fig. 3), the post-processing of data and the export to ASCII format for GIS applications.

In particular, the scan was georeferenced in WGS84-ETRF89 projection UTM zone 33 N, placing at least four reflector-tiepoints, which coordinates were identified by the GPS receiver in RTK mode with differential correction data provided by the Grottaminarda (AV) permanent station of the smartNET ITALPOS national network. The ellipsoidical heights were processed by using Verto 3 K software (IGMI) for the geoidal heights calculation, based on the standard geoid 'ITALGEO2005', characterized by an average deviation of ±0.04 m referred to the geometric levelling lines. About the altitude values, an appropriate data table of IGMI was analyzed taking into account the differences between the national geoid and the GRS80 ellipsoid (in the ETRS89 system), in order to convert the ellipsoid records WGS84 (ETRS89) in geoidal data, based on national altimetric networks. The roto-translation matrix was calculated for obtaining georeferenced scan acquisitions.

Due to the presence vegetation placed in the borders of the landslide, the data was firstly cleaned by filtering techniques in RISCANPRO software for obtaining a bare

Table 3 Volume analysis of reprofiling works related to three different observation periods

Period	Volume (m^3)	
	Accumulation	Emptying
May 2010	5,8076.48	3,7383.09
November 2010		
November 2010	5,3903.99	21,245.05
December 2010		
December 2010	6,445.93	169,109.92
March 2011		

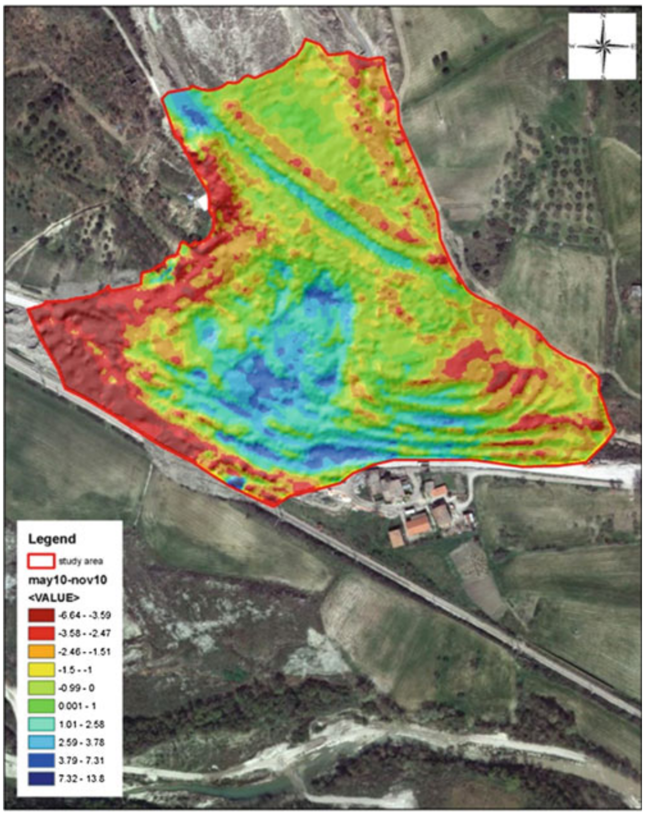

Fig. 5 Volumetric analysis from May to November 2010

ground surface. Then the scan points were interpolated by ordinary kriging method for generating DTM (Fig. 4) (Scaioni et al. 2004).

Volumetric Analysis

Since the landslide movement was in progress and works for cleaning the railway and defining stable profile were executed during the months of observation, it's not possible to quantify the slide down materials or the removal one by volumetric analysis at the landslide tip. The comparison between the terrain surfaces of different dates defines just reprofiling of landslide for anthropic or natural causes (Table 3).

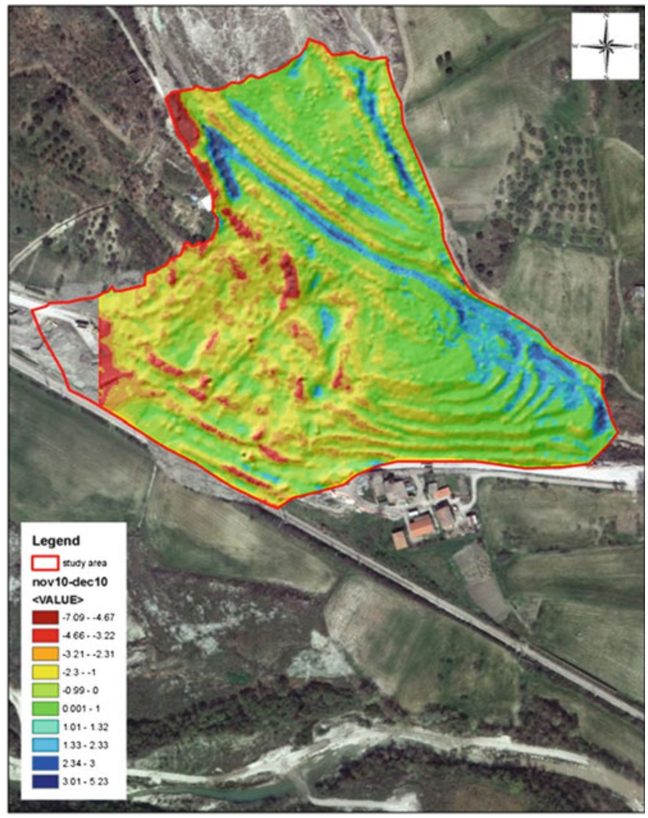

Fig. 6 Volumetric analysis from November to December 2010

Every comparison is obtained subtracting terrain elevation of the newer scan from terrain elevation of the older scan. Consequently the negative values represent material accumulation (red colors), while the positive ones represent emptying (blue colors). Anyway the range of value from -1 to $+1$ m is considered a no-change condition (green colors), according to the scan resolution. The hillshade effect is related to the newest digital terrain model (Guarnieri et al. 2009).

During the period from May to November 2010, works for restoring the traffic on the transport infrastructures have been realized. On the west side of landslide there's a wide emptying area that attested the reprofiling works for cleaning the federal road and the railway from the landslide material, while on the east side the benching has been reshaped. In the upper zone of the tip the cut-off drain is visible (Fig. 5). From November to December 2010, there are not substantial differences of the landslide surfaces, showing a general stable condition, although the west side continues to show landslide movement with material accumulation at the tip. On the east side there's an excavation caused by sediment transport of the drain flows (Fig. 6). In March 2011 it's clear the stop of the landslide movement in the previous months that has allowed to reprofile the hillslope for a stable setting with excavations even over 10 m (Fig. 7).

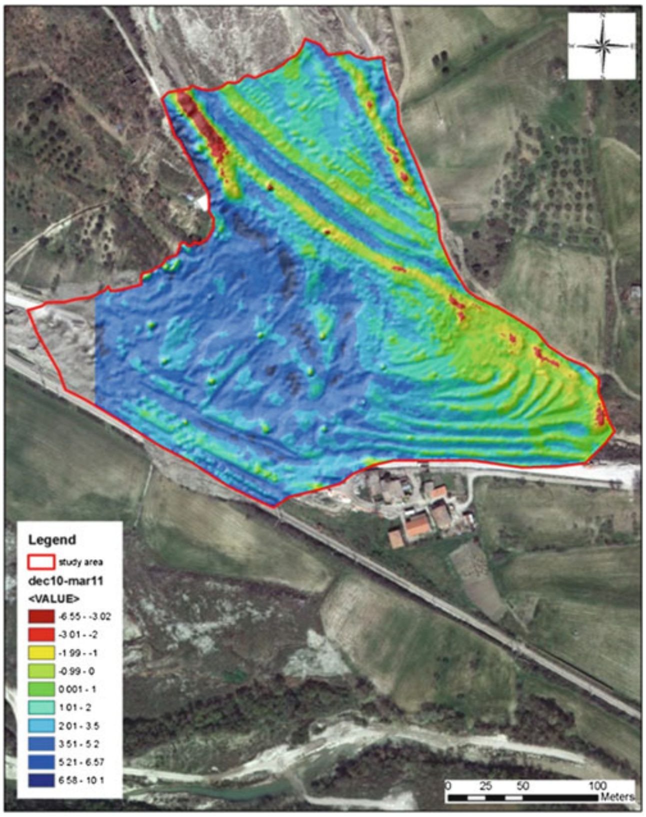

Fig. 7 Volumetric analysis from December 2010 to March 2011

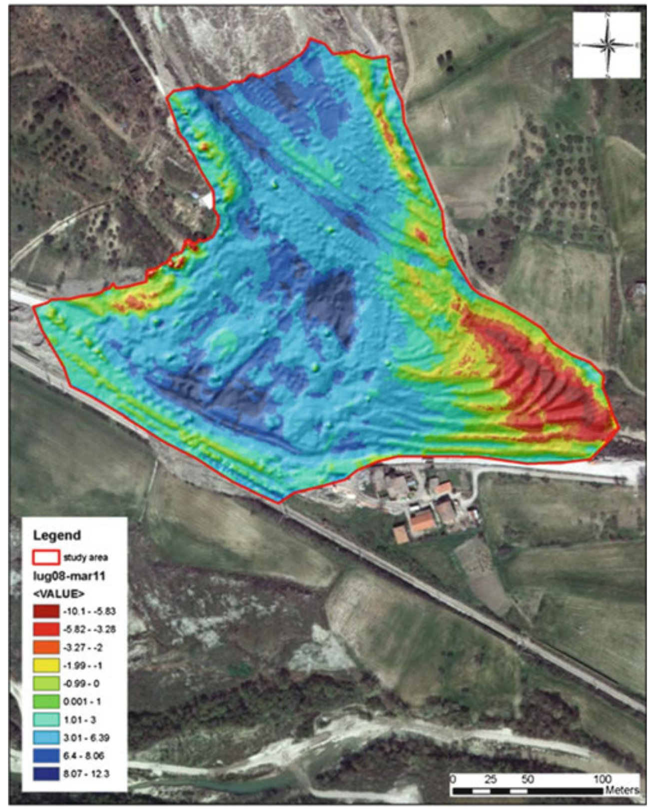

Fig. 8 Volumetric analysis from July 2008 to March 2011

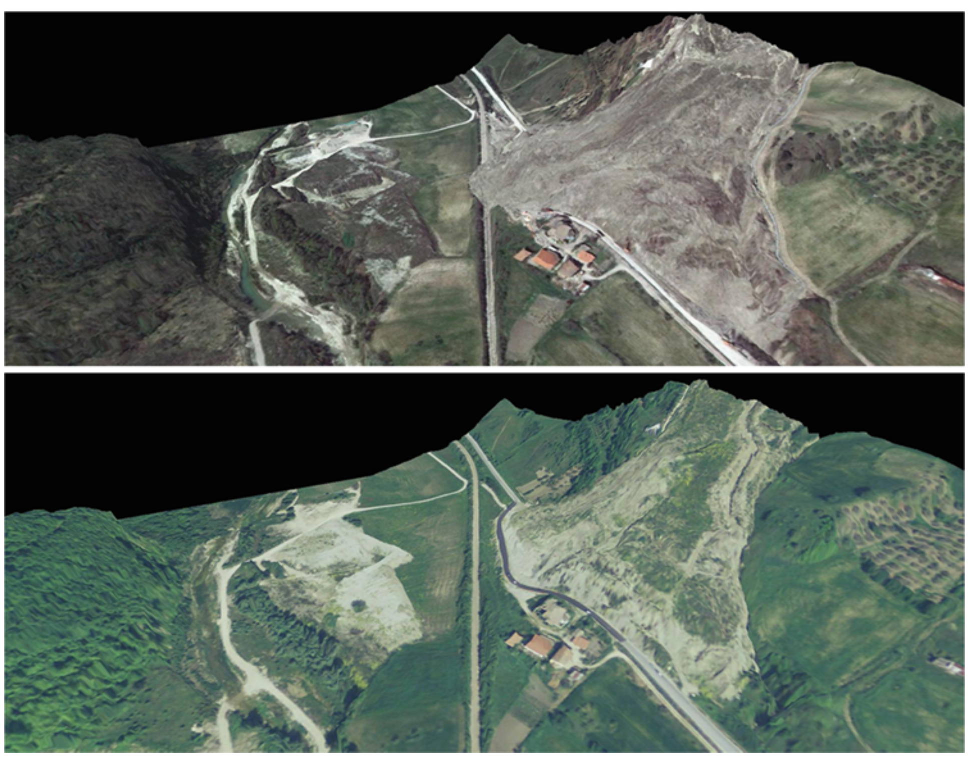

Fig. 9 3D Representation of the landslide tip in the Cervaro valley. May 2010 (*up*) and March 2011 (*down*)

Conclusion

At last, comparing the newest scan with the surface derived from the airborne laser scanning of July 2008, it's possible to mark the settlement works for reducing the slope. While on the east side the benching has given to the surface a stable assessment, the landslide movement has flowed on the west side, causing the need of continuous materials removal works. The open-cut for railway and federal road in the lower part of the tip and for draining the water in the upper part are clearly evident (Fig. 8).

The applications previously showed demonstrate the potentialities of the terrestrial laser scanner technologies for landslide monitoring. The instrument allows the high resolution DTM generation and related contour lines, the survey of impervious area.

The results of the analysis are strictly consistent with the information given by then Civil Protection Department. Moreover the combination of this technologies with SAR interferometry could provide an excellent monitoring system, that not only detects the landslide movements, but also shows where these are placed, useful in this case for transport infrastructures security (Fig. 9).

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