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STUDYING AND MONITORING LARGE LANDSLIDES WITH PERSISTENT SCATTERER DATA

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ABSTRACT

This work is focused on very slow moving landslides and the new generation of Persistent Scatterers PSI (SqueeSAR™ processing, developed by Telerilevamento Europa) that allows to increase the density and the time series quality of interferometric data. The improvement in the time series quality helps also to understand the behaviour of some processes and to have a best comparison with traditional monitoring system and/or rainfall data.

The consequent aim of the research is to evaluate the potential and the limitations of PSI data for large landslide studying and monitoring.

Some large landslides belonging to different geological, geomorphologic and land-use contexts and with different monitoring systems, in Western and Ligurian Alps, Langhe Hills and a portion of Northern Apennines (Oltrepò Pavese), have been analyzed. The study area is covered by 18 years of SAR data, consisting on ERS (1992- 2001) and RADARSAT platform (2003-2010).

The results show that the PSI analysis is useful both on regional and local scale. At regional scale PSI allows to improve landslide inventories. At local scale the PSI joined with other data can help in the understanding landslide features and kinematics.

Key words: *large landslides, Persistent Scatterers, monitoring, SqueeSAR™, DSGSD, GIS*

INTRODUCTION

Large landslides are widespread both in the Alps and in Apennines (Mortara & Sorzana, 1987; Forlati *et alii*, 2001; Ambrosi & Crosta, 2006); the observed movements are generally from extremely slow to slow (Cruden & Varnes, 1996); they are quite regular with some occasional acceleration. Rapid and superficial phenomena are often associated and they result in significant direct and indirect damage. The sudden and paroxysmal collapse of the whole mass may have catastrophic consequences. They are also difficult to characterize in their boundaries and state of activity, to monitor with traditional tools due to their extension (landslides over 0.2 km^2) and low rates of movement, which are close to the detection limit of traditional monitoring equipment.

In the last years the development of Persistent Scatterer Interferometry (PSI) methods, e.g. PSInSAR™ Ferretti *et alii,* 2001), SqueeSAR™ (Ferretti *et alii,* 2011), small baseline subset - SBAS (Berardino *et alii,* 2002), SPN (Arnaud *et alii*, 2003), and coherent pixel techniques - CPT (Blanco-Sànchez, 2008), PSP-DIFSAR (Persistent Scatterers Pairs - Differential InSAR; (Costantini *et alii*, 2000), allowed to help the detection and monitoring of the very slow and extremely slow movements typical of many large landslides (Colesanti & Wasowski, 2006; Farina *et alii,* 2006; Meisina *et alii*, 2006; Herrera *et alii*, 2009; Guzzetti *et alii*, 2009; Lauknes *et alii*, 2010; Yin *et alii*, 2010).

The aims of this study are:

a) to study large landslides and to assess their state of activity through the use of SqueeSAR™ and PSInSAR™ techniques;

b) to analyze the large landslide kinematics through specific case histories in Alps and Apennines with particular focus on spatial and temporal analysis of the movement.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS OF THE STUDY AREA

The study area (about 16000 km^2) is located in NW Italy and it presents very heterogeneous geological and geomorphologic settings (Fig. 1). It is possible to indentify four main sectors:

1. The Alps in the Northern and Western part of Piemonte region represent the sector most affected by large landslides. The alpine valleys after the last glaciations are characterized by an high relief energy with erosion processes, that, joined with tectonic settings, are the causes of widespread presence of Deep Seated Gravitational Slope Deformations DSGSD (Mortara & Sorzana, 1987) and large complex landslides that affect many large portion of the valleys and also some villages and infrastructures (roads, railways). The movement of these landslides is usually slow but sometimes rapid acceleration or collapse may occur (e.g. Grange Orgiera landslide (Arpa Piemonte, 2009)). The areas affected by large landslides are usually also interested by more rapid landslides like rockfalls or debris flows. The large landslides are particularly diffused in the area, where calcschist formation of Penninic nappe outcrops.
The presence of many debris and rock (good scatterers) is favourable for the PSI analysis.
2. The Ligurian Alps correspond to the South-western sectors of the Alps and are characterised by

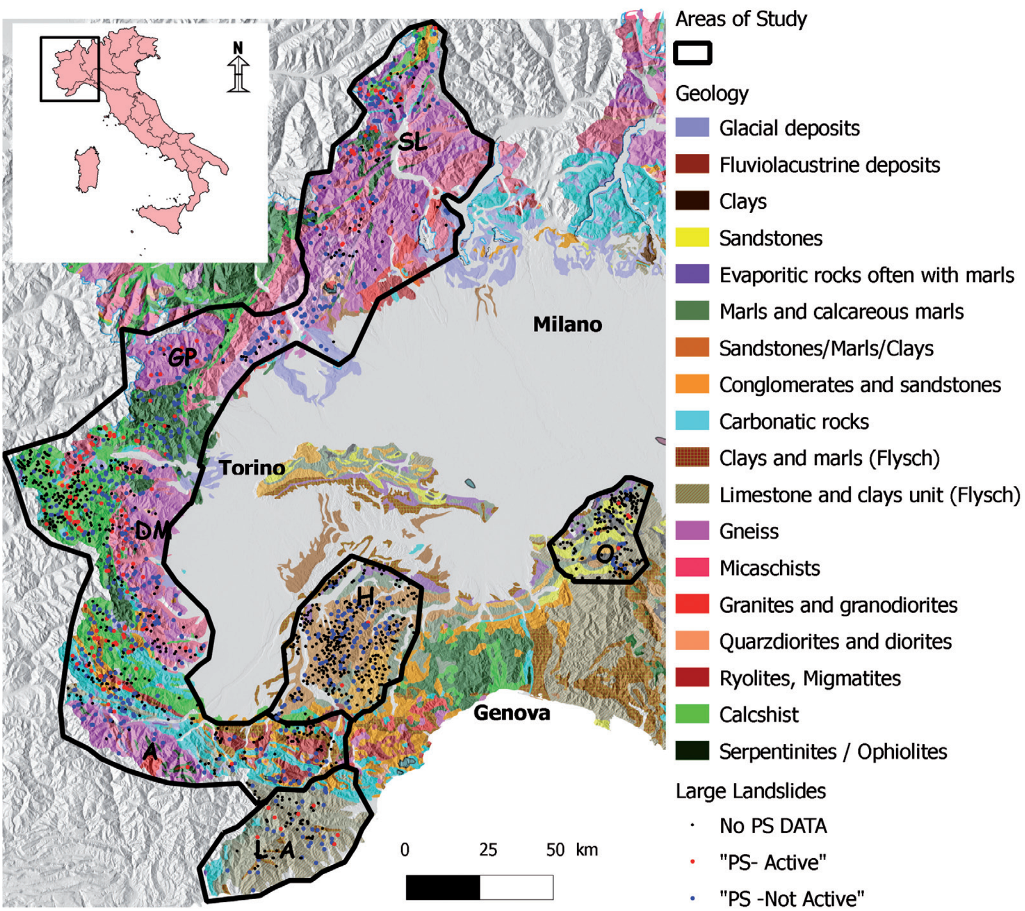

Fig. 1 - Geological settings of the study areas. A = Argentera Massif; DM = Dora Maira; GP=Gran Paradiso Massif, SL= Sesia-Lanzo zone, L.A = Ligurian Alps, H = Langhe Hill, O = Oltrepo Pavese/Northern Apennines

the presence of flysch and limestone formations. The area presents a fluvial-modelled landscape. Even if the DSGSD are not very diffused there are many large complex landslides. The vegetation coverage is wide, however some villages are settled over slow landslides that present a gentler slope with a high PS density (PS generally correspond to buildings).

3. The Langhe hills: the area is located in Central and Southern part of Piedmont and it is characterised by monocline tertiary formations of marl, sandstone and shale and it is mainly affected by translational rock-block slides on gentle slopes (10° - 20°) with dip slope stratifications. The area affected by planar slide is usually covered by cultivated fields or vineyards and the PS data density is typically low. Moreover, these landslides present a rapid movement triggered by strong rainfall events (Luino, 1999) and with PSI techniques is possible to detect residual or pre-failure movement.
4. The Oltrepò Pavese corresponds to the NW Apennines and it is characterised by the presence of flysch and shale. Mainly complex landslides (roto-translational slides and slow flows) affect the slopes. The area is mainly covered by vegetation, vineyards or cultivated fields, however many villages were built within landslide areas, so PSI could detect movements even if for only a small number of large landslides.

The landslide monitoring system net presents a quite good distribution especially in Piedmont, where about 300 landslides are monitored, meanwhile in Ligurian Alps and in the Oltrepo Pavese only few sites are monitored.

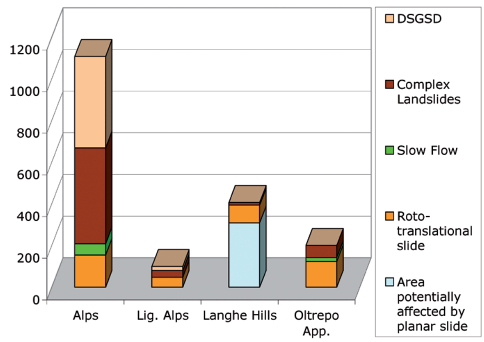

Fig. 2 - Distribution and typology of large landsides in the study area

In this research we have analyzed the very (less than 1.6 m/yr) and extremely slow (less than 16 mm/yr) large landslides using Cruden & Varnes (1996) velocity classification. About 1820 large landslides were identified in the study area. Slow flows, deep seated gravitational slope deformations (DSGSD), roto-translational slides and complex landslides (Fig. 2), which represent the slope movements most suitable for PSI techniques, were selected.

THE PSI DATASET

The landslides were analyzed with PSI data elaborated mainly with SqueeSAR™ technique using images of RADARSAT (2003 - 2009) and of ERS 1-2 (1992 -2000) satellites for the Oltrepo Pavese.

The SqueeSAR™ technique (Ferretti *et alii*, 2011) extracts movement information not only from traditional persistent scatterers (PS) like buildings, anthropic structure or rocks but also from distributed scatterers (DS) like sparse vegetated areas or debris covered areas. This allowed having a high density of SAR data in the Alpine area covered by huge debris (e.g. Fig 2). The time series of SqueeSAR™ are elaborated with a non-linear algorithm (polynomial trends). The time series can follow acceleration and slowing of a scatterer. This allows to better observing the kinematic of landslides related to seasonal cycles or extreme rainfall events.

ERS and ENVISAT data processed with PSInSAR™ technique were also used in order to extend the time span of the movement history from 1992.

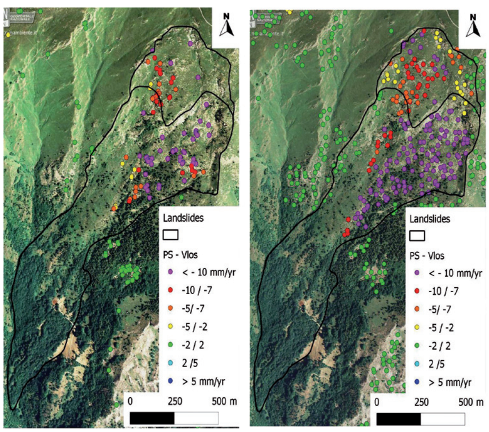

Fig. 3 - PSInSAR data from ERS (1992-2000) (left) and SqueeSAR™ data from Radarsat (2003-2009) (right) density over a landslide in Western Alps

ANALYSIS AT REGIONAL SCALE

In the study area the PSI data were compared with the italian national landslide inventory (IFFI, ISPRA, 2008), in order to check how many large landslides have useful SAR data.

Only the landslides with a certain number of PS/DS (at least 3) and with a density greater than 30 PS/km^2 were selected. These values were chosen on the basis of empirical experience, there is not a fixed rule, but generally the more SAR data is dense and distributed the more reliable the results became. We considered also the landslides that have an "anomalous area" interpreted as landslides. The anomalous areas (Meisina *et alii*, 2008) are clusters of PS/DS that show significant movements.

It is possible to see (Fig. 4) that in the Alps about the 60% of large landslides are suitable for PSI analysis while in the Ligurian Alps the percentage decreases to 48%. In the Langhe Hills and Apennine areas the percentage of landslides suitable for PSI analysis is considerably lower (about 20%).

In order to discriminate moving/non-moving phenomena as well as the state of activity of large landslides we applied the threshold of +/-2 mm/yr measured along the LOS (Vlos) (Meisina *et alii*, 2008) and related to the precision technique. The active landslides represent the 30% of PSI suitable landslides in Alps and Apennines, the 20% in the Ligurian Alps and the 5% in the Langhe hills (Tab. 1). If we applied the threshold of -5 mm/yr of velocity projected along the slope (Vslope) proposed by Cigna *et alii* (2012) the results are quite similar: the landslides with movements range from 30% (of PSI suitable) in the Oltrepo Pavese to 3% of Langhe Hills.

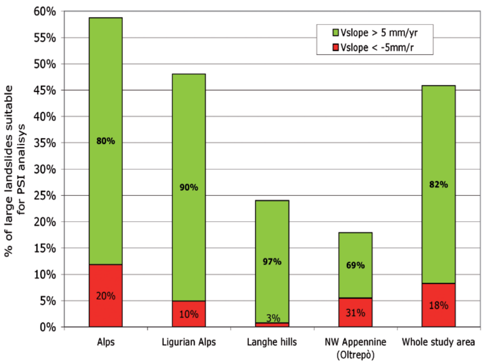

Fig. 4 - Percentage of large landslides suitable for PSI analysis in the different areas of study. The number inside the bars is the percentage of active and not-active landslides using the 5 mm/yr Vslope threshold

It is also interesting to consider the percentage of landslides with movement in the Alpine area classified for lithology (Tab. 2): calc-schist formations present a high percentage of "active" landslides (45%), however carbonate rocks and serpentine have about 20 - 25% of landslides with movement. This is quite in agreement with literature (Forlati *et alii*, 1995): the landslides involving lithology with a ductile behaviour (calc-schist) are characterized by slow continuous deformations with gentle slope morphology compared with landslides on brittle-behaviour lithology (limestone or serpentine). By observing the spatial distributions of landslides activity it is possible to see the areas with high concentration of active large landslides: the Ligurian-Piedmont domain between Maira and Susa Valley, the area near Simplon Pass and the area near Gran Paradiso massif (Fig. 1).

The analysis of the type of PS/DS shows that in the Alpine area the scatterers are mostly represented by debris, or rock. The analysis made for each single lithology (Tab. 3) shows that the areas covered by calch-schist formation present a great number of building targets. This can be explained with the gentle slopes associated to this lithology that allowed the development of some villages (e.g. Sauze D'Oulx, Susa Valley) over large DSGSD. In the Langhe hills and Oltrepo Pavese the majority of PS/DS are buildings or anthropic structures.

	Percentage of active large landslides	
Sector	Active Vslope (-5 mm/yr)	Active Vlos (+/-2 mm/yr)
Alps	20%	31%
Ligurian Alps	13%	21%
Langhe hills	3%	5%
NW Apennines	31%	28%

Tab. 1 - Active large landslides with different thresholds

Lithology	Percentage of landslides with PSI movement
Calc-schist	44%
Gneiss	28%
Carbonatic Rocks	23%
Serpentine rocks	22%
Flysch Formations	6%

Tab . 2 - Percentage of active landslides versus lithology for the Alps

It is important to remind that the landslides state of activity assessed at regional scale is only indicative due to the well known limitations of PSI techniques. Detailed geomorphological and historical analyses for each landslide are necessary in order to confirm the state of activity and to update the landslide inventory.

ANALYSIS AT LOCAL SCALE

At local scale it was possible to make further analysis on PS data. In particular we analyze time series, the distribution of the movement related with geomorphology and the components of the velocity.

The large landslides with significant movement and with good monitoring data are mostly concentrated in the Alps.

The Piemonte Region (Alps and Langhe hills) has a widespread monitoring system of landslides so it is possible to compare the capacity of PSI techniques versus the other type of monitoring instruments. In the alpine area PS/DS can monitor a larger number of landslides (59%) than traditional monitoring system (9%), while in the Langhe hills the landslides monitored are almost the same: 19% with traditional monitoring systems and 24% with PSI data. The landsides with both PS and traditional monitoring systems are only 7%-8% of total.

Sector	PS on buildings
Alps:	4%
Gneiss	*5%*
Serpentine	*2%*
Calc-schist	*7%*
Limestone	*2%*
Langhe Hills	40%

Tab. 3 - Percentage of PS/DS on buildings with RADARSAT SqueeSAR™ data

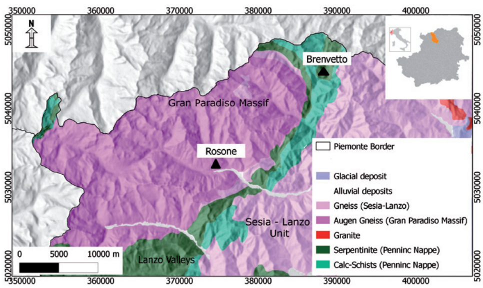

Fig. 5 - Geological settings of Rosone and Brenvetto landslides

Three case histories will be described in this work. In two cases (Brenvetto and Rosone) PS/DS data can be compared with other monitoring instruments while in the Alpe Baranca DSGSD PS/DS are the only monitoring system available.

BRENVETTO LANDSLIDE

The landslide of Brenvetto is located in Soana stream basin at the east boundary of Gran Paradiso massif. The landslide is geologically located in the Pennine Nappe, between Sesia-Lanzo zone and Gran Paradiso internal massif (Fig. 5). It is characterized by calc-schist and serpentine formation bedrock. The area is covered also by moraine quaternary deposits (Carraro *et alii*, 1995). The main element at risk is the road that connects the high Soana Valley with Orco valley and then the Torino plain.

The upper sector of the slope is affected by large DSGSD that does not show any particular evidence of movement except in the central part of the deformation, where a complex landslide was detected (Fig. 6). The complex landslide shows clear evidences of movement like trenches, scarps, a strongly fractured

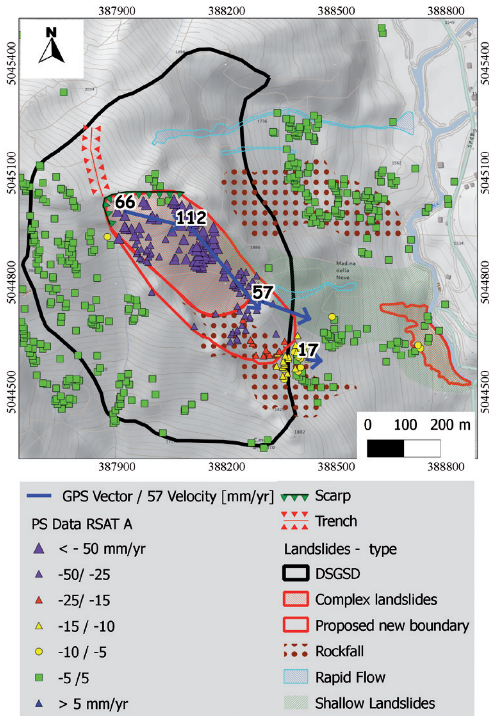

Fig. 6 - Brenvetto Landslides. GPS data (2004-2011) and SqueeSAR™ data (2003-2009)

rock-mass and many debris flows derived from rock fall and rock mass disaggregation.

In the lower sector of the slope widespread shallow landslides, debris flows can be noticed and at the toe of the slope erosion of Soana stream contributes to the general instability (Fig. 6). The landslide is monitored by ARPA Piemonte with 5 GPS at manual reading since 2004. The measurements made once at year showed a rate of movement that is up to 110 mm/yr in the central sector of the complex landslide. The SqueeSAR™ data derived from RADARSAT (2003-2009) ascending geometry show a very good numbers (>20) and spatial distribution of PS/DS on complex landslide. The rate and the spatial distribution of movement registered by PS/DS is almost the same of GPS measurements.

The ERS PSInSAR™ data (1992-2000) present a low density of PS and they were not considered for the analysis.

The direction of the movement (from ESE to SE) is quite parallel with LOS ascending direction and about the 80% of the movement can be detected. It is not possible to resolve the north/south component of the movement due to the few descending data available. The PS/DS data suggested potential enlargement of the complex landslide boundaries to include also some downslope sectors and to update the state of activity: now the landslide is classified as active. The time series of PS and GPS (Fig. 7) data show a linear and constant trend of deformation that seems not influenced by rainfall or snow melting. However a small acceleration of the movement was detected by GPS, and also by some PS in 2008/2009. This can be related to the rainy period started in May 2008. Due to the high velocity registered it is possible that some errors related to phase unwrapping (movement greater than λ/4 between two consecutive acquisitions) should be occurred

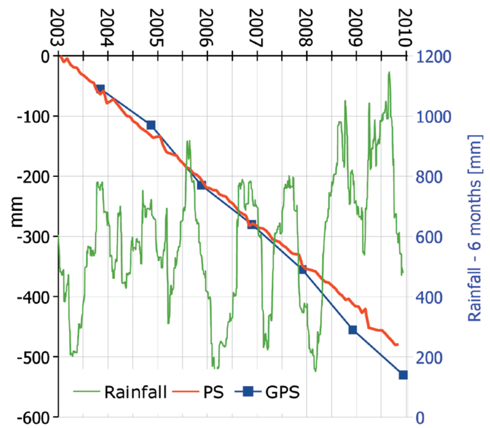

Fig. 7 - Brenvetto Landslide PS (RADARSAT ascending data) and GPS time series compared with 6 months cumulated rainfall

ROSONE LANDSLIDES

The Rosone landslide is located in the NW Italian Alps in the Orco Valley and it is classified as DSGSD.

The landslide affects the penstock of the near hydroelectric central and in case of collapse may create a dam in the Orco river and an interruption of the road that connects the upper part of the valley with the plain. For these reasons the landslide was well studied by many authors (Forlati *et alii*, 2001; Pisani, 2010; Ramasco *et alii*, 1989) that provide to asses the geomorphological, hydrogeological and mechanical settings and they try to model the possible evolution.

The Orco Valley is located in the central part of the Gran Paradiso Massif. This complex belongs to the Upper Pennine Units (Pennine Nappe System) and it consists of a composite crystalline basement and a Permo-Liassic cover (Fig. 5).

Rosone landslide is modelled on the Augen Gneiss Complex. The geological-structural configuration of the studied area is relatively simple: granite and augen gneiss crop out.

The rock mass is characterized by several alpine

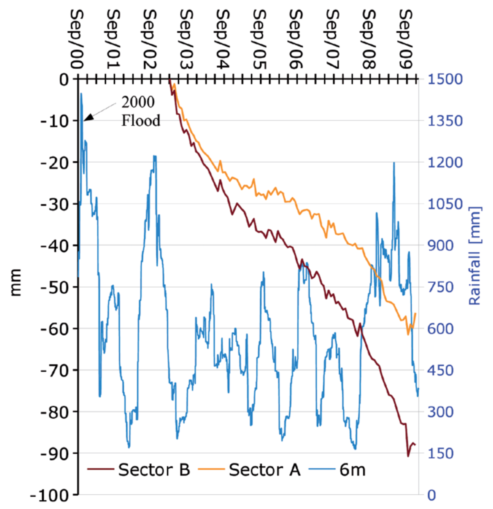

Fig. 8 - Rosone Landslide. PS Time series (2003-2009 RADARSAT descending data) of the sectors A and B compared with 6 months (6m) cumulated rainfall (2000-2009)

ductile deformation phases. The main schistosity is affected by the periclinal orientation of the massif, which, in this area, displays an average dip direction of about 150°, with 35° dip (Regione Piemonte, 1996). The brittle structural attitude is defined by three main discontinuity systems: a KS system parallel to main schistosity (SR) and two sub-vertical lineaments corresponding to E-W and N-S striking normal fault conjugate system.

The landslide of Rosone is located on a slope affected by large DSGSD but only the sector of Rosone/Bertodasco has high deformation and instability. The western sector of DSGSD (Ronchi village) presents less evidence of deformations and the movement is more related to shallow debris and colluvium instability.

Considering the most active part of the DSGSD, the Bertodasco area, the geomorphological and the structural analysis joined with monitoring data allowed to detect three main sectors with different rock mass evolution and movement (Fig. 9).

Sector A. It corresponds to the upper part of slope. This is the less weathered rock mass, however many trenches and scarps can be detected. The movement is generally weak and sliding surface is between 30 and 75 m.

Sector B. It is in the central part of deformations. The rock mass is rather weathered with completely disarticulated rock block, scarps and the presence of many debris. The sliding surface can be identified 46 m depth.

Sector C. It is in the bottom part of the slope and it is the most weathered sector, the rock mass is completely disarticulated. The depth of sliding surface is 39 m. This sector is also affected by rock fall and debris flow. In the 1953 a strong reactivation of the movement caused severe damages to Bertodasco village and the inhabitants were evacuated.

The landslide monitoring started in the sixties and now a wide system of monitoring data is installed: inclinometers, extensometers, GPS, optical measurements and from 1922 also from SAR data (Tab. 4). On this site ERS 1-2 data (1992-2001) elaborated with PSInSAR techniques and RADARSAT data (2003-2009) elaborated with SqueeSAR™ are available.

The PSI analysis it is possible only in the sectors A and B where a good density of data is available especially with RADARSAT data. The sector C has a wide forest coverage and too fast movement and

Landslide sectors	Velocity mm/yr			
	GPS	Optical	Inclin.	PSI Vlos
A	12	5	< 10	4 - 10
B	20	15	10 - 30	8 - 15
C	45 - 130	38 - 43	n/a	n/a
Period	2001-2011	2001-2011	1991-2008	2003-2009

Tab . 4 - Velocity registered by the different monitoring system

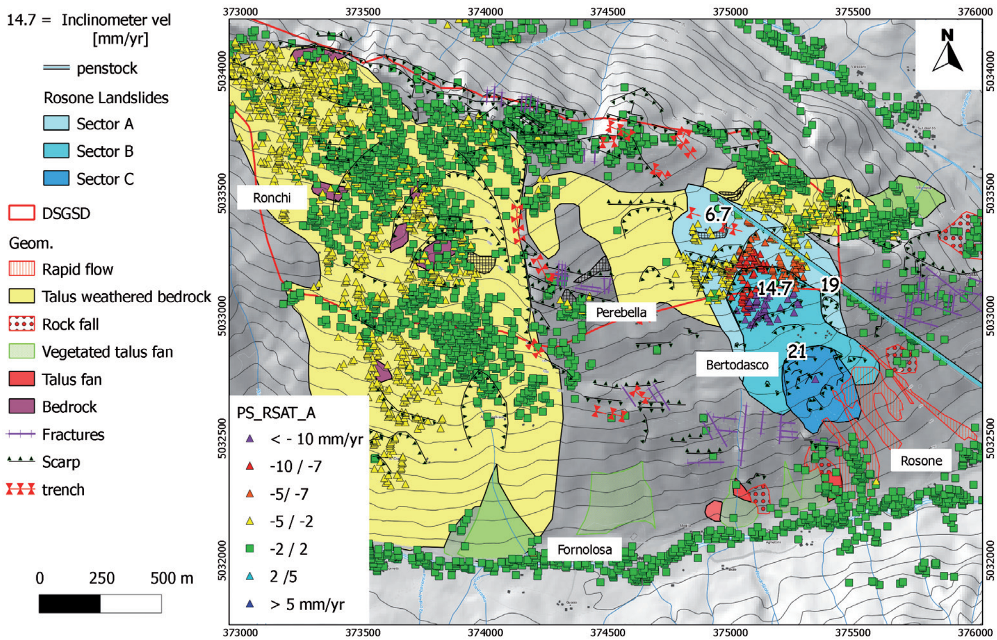

Fig . 9 - Rosone geomorphological map and PS data (SqueeSAR™, RADARSAT Ascending) only 1 PS is present.

- The sector A presents weak movements (5 mm/yr) in the eastern part and moderate movements (up to 10 mm/yr) in the western part that affect the penstock. The movements progressively increase from upslope to downslope.

- The sector B is characterized by moderate movements from 10 to 20 mm/yr. It is possible to see that a scarp borders a sub-sector with major movement.

- The sector C does not have significant PS data due to the vegetation coverage and the high movements that probably cause unwrapping problems. However, the only PS in the sector C recorded a velocity of 25 mm/yr. The GPS and optical measurements show a velocity from 45 up to 130 mm/yr.

The time series of PS RADARSAT data (Fig. 8) show a small decrease of the movement in 2005-2007, probably related to a drier period. The movement can be considered as constant and linear. Other monitoring systems show some acceleration after October 2000 flood especially in the sector "C" but no PS data are available for this period.

The ERS data (1992-2001) present a very low density of data especially for ascending geometry, however the few PS on the landslide confirm the same rate of velocity of RADARSAT.

The projection of the velocity of PS data was made on the mean dip direction schistosity of the rock mass and from the results of GPS measurements. The direction of the movement is between SE and SSE (150°-170°). With this parameters ascending geometries can detected about the 60 % of real movement.

The combination of ascending and descending geometries allowed to resolve the vertical and E-W component of the movement. The results (up to 6 mm/yr toward East, and 10 mm/yr to down) are in a very good agreement with the other monitoring instruments .

Finally on the C sector of the Bertodasco landslide some corner reflectors will be installed in the next future. Thanks to these artificial scatterers the satellite Cosmo-SkyMed will acquire SAR data for civil protection application.

ALPE BARANCA DSGSD

The Alpe Baranca DSGSD is located in the upper Mastallone stream basin near the village of Fobello. The PS/DS data is the only monitoring system available on this landslide.

Excepted an alpine hut there are no anthropic elements at risk however the landslide is interesting because after October 2000 flood a large fracture appeared in the upper part of the slope as evidence of a great acceleration of the movement of the whole mass.

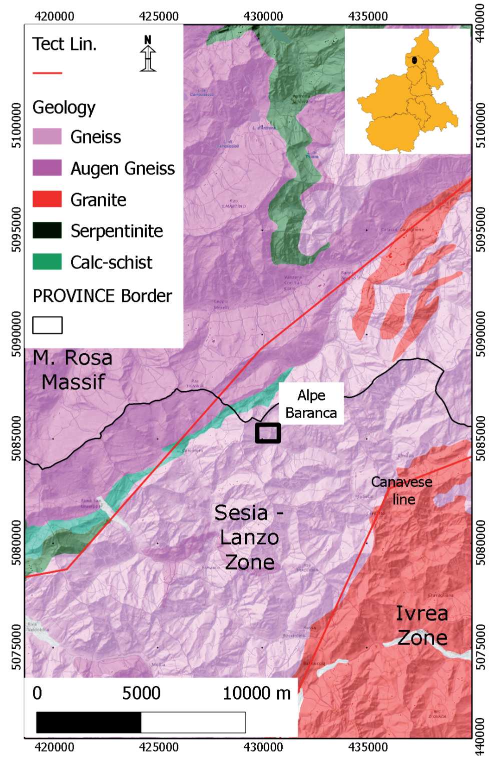

Fig. 10 - Alpe Baranca geological settings

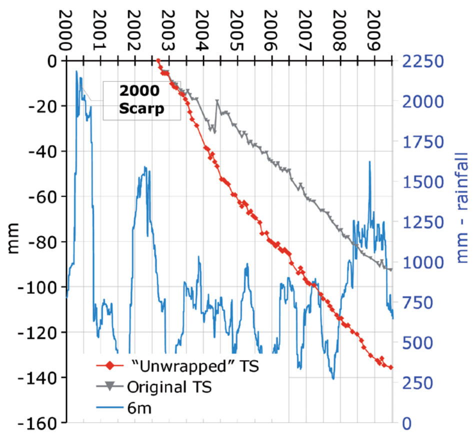

Fig. 11 - Alpe Baranca DSGSD: original and "unwrapped" Time series (2003-2009) compared with and 6 months cumulated rainfall (2000-2009). Note the high peak of rainfall occurred in winter 2000-2001

This area is geologically located inside the Sesia-Lanzo zone, with bedrock of diorite-kinzigite and mica-schist. The main tectonic lineament are oriented SW-NE (Fig. 10).

The DSGSD is located on a slope with SW orientation from 2300 to 1600 m a.s.l.

The deformation presents three main sectors (Maffeo & Zanottelli, 2008):

- The upper sector with a steep slope is characterized by weak weathered bedrock but with great evidence of deformations like double ridge and counter slope areas affected by rockfall. The PS/DS data do not show any particular movement in this sector.
- The central sector is the area where bedrock is mostly disarticulated with many scarps, counter slope, bulged profiles and many debris deriving from rockfall. After the 2000 flood this entire sector moved of some meters and at the edge of upper sector a large scarp appeared in 2001 spring after snow melting (Fig. 12). The scarp shows a displacement up to 6 m in the central part.

The ERS data (1992-2000) (pre-failure) identified a movement from -5 up to -15 mm/yr measured along descending LOS. The RADARSAT data during the period 2003-2009 (post-failure) measured the same rate of velocity (average Vlos -13 mm/yr). The analysis of time series allowed also to discover a phase unwrapping problems in 2004 caused by a gap of some images. With the correction of this unwrapping problem the average Vlos can be estimated to -20 mm/yr.

Considering an average slope of 34° and a slope orientation of 205°N azimuth the average velocity projected along the slope is about -50 mm/yr for the period 2003-2009.

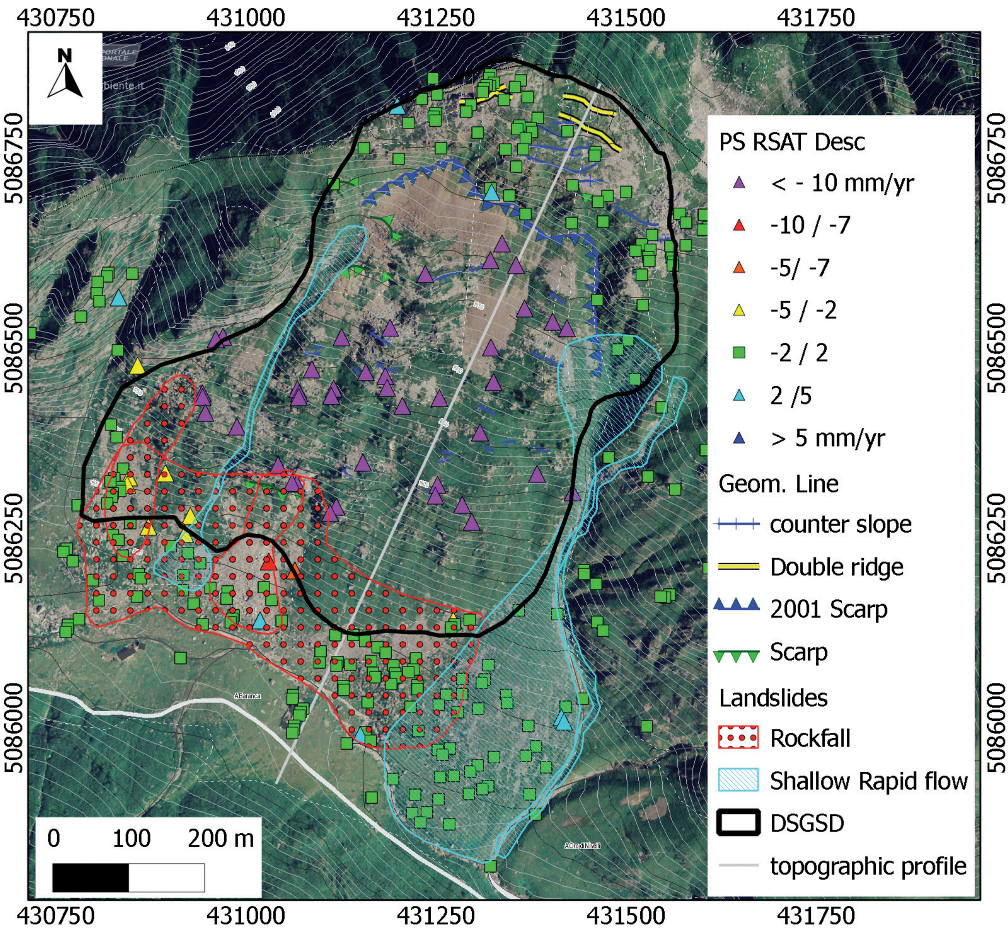

Fig. 12 - Alpe Baranca DSGSD. Main Geomorphological elements and RADARSAT descending data

By combining ascending and descending geometries it was possible to extract East-West and vertical component of the velocity. The vertical component presents greater values than E-W component (up to 10 toward West), the North-South component cannot be calculated but is probably greater than E-W due to SSW slope orientation.

The analysis of time series do not show any particular trend and the movement can be considered linear (Fig. 11). It is possible to appreciate however that in the first years of measurements (2003-2005) the velocity had higher values (-25/-27 mm/yr, along LOS) then slowed to -16/-18 mm/yr. This trend is compatible with deceleration after the events of 2000-2001.

- The third sector is located at the toe of the slope and it is probably not affected by DSGSD. In this sector we have the presence of talus cone and debris deriving from rockfall. A large fan deriving from rapid flow accumulation is located in the SE sector of the slope. If the velocity and the slope profile are compared (Fig. 13) a quite good match between geomorphology and velocity detected by SAR data can be appreciated.

CONCLUSION

The analysis of large (> 0.2 km^2) slow moving landslides (DSGSD, complex slides, slow flow and roto-traslational slides) with PSI data showed good results, considering the traditional limitations of PSI technique, both on regional and local scale.

- At regional scale, PSI data allowed to study and post-monitoring a wide number of large landslides, particularly in the Alps where the new processing techniques like SqueeSAR allow a high density of targets in the area covered by talus and debris. In this area more than 50 % of large landslides have useful PS/DS data. The other monitoring systems allow to cover only the 9 % of landslides. It is important to remark however that traditional monitoring system is installed on the most interesting and dangerous landslides, while PSI monitoring depends on natural settings. On the other sectors (Langhe and Oltrepo Hills) the percentage of landslides that can be studied and post-monitored with PSI data is sensible less; however the analysis is useful because the scatterers are represented by buildings that are usually built directly on landslides.

As far concerning the state of activity of large landslides, it is possible to observe that in calc-schist formations of the Pennine Nappe of Western Alps there is larger percentage of active landslides compared to other brittle lithologies. This result confirms

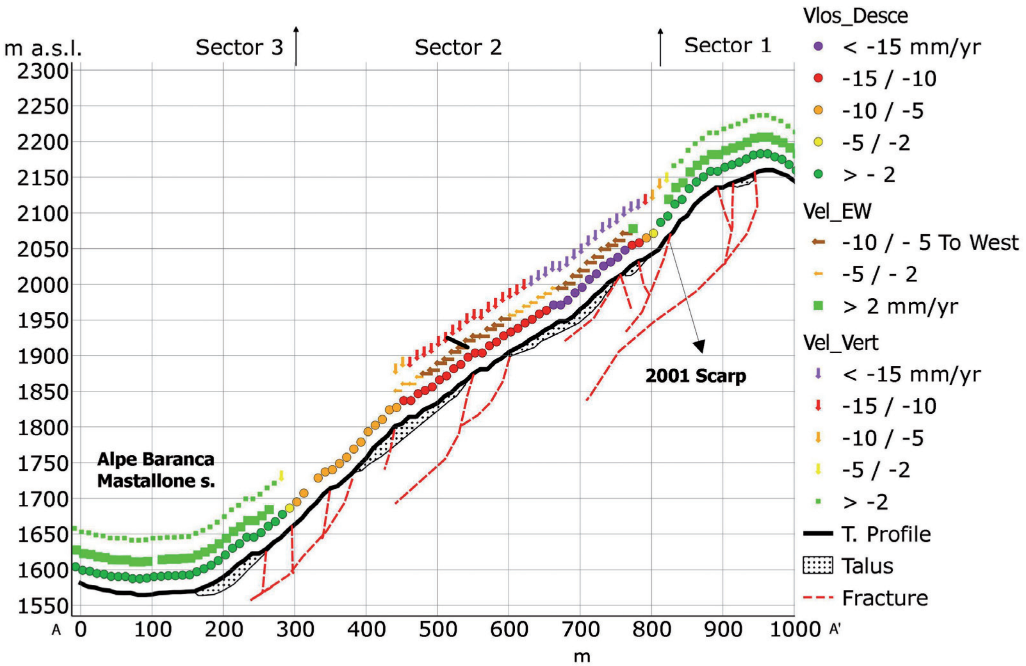

Fig. 13 - Alpe Baranca DSGSD: Topographic profile from Maffeo & Zanotelli (2008) compared with Vlos descending, East-West and Vertical velocity of RADARSAT descending data (2003-2009)

literature study on DSGSD (Forlati *et alii*, 1995) based on geomorphological approach.

- At local scale the PSI data were useful to increase the knowledge about landslide kinematics and to integrate information coming from other monitoring systems.

The Brenvetto landslide, in the Soana Valley, is an example of good integration of PSI and GPS data; both spatial and temporal distributions of the movement (time series) agree and well match the geomorphological evidence.

The Rosone Landslides is one of the most studied landslides in western Alps, due to catastrophic consequence of a collapse that may affect the penstock. In this case the PSI data confirm the already dense and heterogeneous monitoring system network. Due to the benefits in density and for the easiness in data acquisition and storage over large areas, it was decided to integrate and largely replace the old monitoring system with a regular PSI analysis (every year) in order to follow the evolution of the phenomenon for civil protection purposes.

Generally the monitoring data showed that the DSGSD affecting a slope are generally without movement, while the large landslides, which are related to the main DSGSD, are active and potentially dangerous.

On the opposite for the Alpe Baranca DSGSD the role of PSI coupled with geomorphological analysis was fundamental because it was the only available monitoring system. ERS (1992-2000) and RADARSAT (2003-2009) data measured a strong acceleration (some meters) after October 2000 flood and a fracture appeared in the upper part of the slope. PS time series confirm the movement of this sector before and after the paroxysm event but with rate of movement constant and relatively low. This can be an evidence that a good PS coverage allows to detect landslides characterized by extreme slow movement that sometime can have potentially hazardous acceleration when extreme trigger factors occur.

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