ABSTRACT

Information on landslide displacement from SAR Interferometric Point Target Analysis (IPTA) and sketch maps from aerial photography interpretation are combined for the study of landslides in Ticino, Southern Switzerland. Numerous unstable phenomena are considered in this mountainous region, with an elevation range from approximately 200 m a.s.l. to more than 3000 m a.s.l. The results achieved with IPTA are attractive to complement aerial photographs interpretation for the evaluation of the state of activity of landslides over villages and in sparsely vegetated areas with numerous exposed rocks. On the other hand, over vegetated areas (forests and meadows) IPTA failed to retrieve displacement information.

1. INTRODUCTION

Hazards due to slope instabilities affect about 6% of the Swiss territory covering an area of 41'300 km² [1,2]. In 1991 new executive measures have been adopted to prevent and mitigate natural disasters. According to the federal recommendations, the regional authorities (cantons) are required to establish hazard maps to be incorporated in regional master plans and local development plans. Hazard is defined as the occurrence of potentially damaging natural phenomena within a specific period of time in a given area [1]. Hazard maps are based on two major parameters: intensity and probability (or return period). For simplicity, three levels of intensity and probability are considered (high, medium and low) and the hazard level is classified according to a matrix diagram [2]. The intensity of landslides is given as the rate of displacement: below 2 cm per year (sub-stabilized), 2 to 10 cm per year (slow), and more than 10 cm per year (active). Because landslides are usually non-recurring processes, the return period has here only a relative meaning.

An indispensable prerequisite for hazard identification is the extensive knowledge of past events at a regional scale, i.e. the compilation of a landslide inventory. Landslide mapping is also fundamental to evaluate hazard. Aerial photography interpretation is an essential tool for the detection of landslides in vast alpine areas in support to field identification. For the definitive hazard assessment the evaluation of the state of activity of a landslide is necessary.

In order to correctly attribute a rate of displacement to a landslide, a suitable set of monitoring data is needed. If monitoring data is unavailable, the state of activity is quite difficult to define on the basis of field observations only, especially for relatively slow and continuous movements or large slope instabilities. The identification of differential movements of individual slope sectors is difficult in the absence of buildings and infrastructures that show visible damage. Furthermore, slope movements become evident only after a minimal displacement has occurred and at that moment no monitoring data is usually available for any interpretation of the phenomenon itself. The lack of a displacement history for the landslide can hamper both the interpretation of the process and the forecast of future development. Information on landslide displacement from satellite SAR interferometry in general and from Interferometric Point Target Analysis (IPTA) in particular can be of large importance in these cases [3,4]. IPTA displacements can be integrated with previous landslide inventory maps to reach a more complete and substantiated conclusion about the activity of slope instabilities.

After a short review of data and methods considered in this study, typical results of the combination of IPTA-derived displacements with landslide maps are presented for five sites. When available, geological and geomorphological studies and high resolution ground motion geodetic data are considered to complement information from IPTA and aerial photography interpretation. An outlook to future sensors and methods is summarized in the conclusions.

2. DATA AND METHODS

2.1 SAR Interferometric Point Target Analysis

Repeat-pass Interferometric Synthetic Aperture Radar (InSAR) is a powerful technique for mapping land
surface deformation from space at fine spatial resolution over large areas [5,6]. The application of InSAR is however limited due to temporal and geometric decorrelation and inhomogeneities in the tropospheric path delay. In Interferometric Point Target Analysis (IPTA) differential SAR interferometry is applied only on selected pixels that do exhibit a point-target scattering behavior and are persistent over an extended observation time period [7,8]. Through the use of many SAR scenes, even if separated by large baselines, errors resulting from atmospherich artifacts are reduced and a higher accuracy can be achieved. Over urban areas with numerous man-made structures or in regions where exposed rocks or single infrastructures (e.g. houses, powerline masts) scattered outside the cities and villages are visible, it is possible to estimate the progressive deformation of the terrain at millimeter accuracy [9].

In our study IPTA has been applied to stacks of ERS-1/2 SAR images acquired between 1992 and 2000 excluding winter acquisitions with snow cover. Images from ascending (Track 487) and descending (Track 251) orbits were analyzed for a better spatial coverage. IPTA results consist of linear deformation rates and displacement histories in the satellite line-of-sight direction. Reference points were selected individually for each of the site in areas estimated stable.

2.2 Aerial photography interpretation

The interpretation of optical images is commonly applied in support of landslide inventories. Based on aerial photography interpretation complemented by field surveys and historical records, landslide inventory maps were produced for a number of catchments in Ticino (Southern Swiss Alps). The aerial photographs (© Swisstopo) are available at 1:20’000 scale and were taken in the last 50 years. Using stereoscopic images landslides were distinguished by typology, depth and activity. The high resolution of aerial photographs has allowed to recognize the geomorphological features associated by mass movements, such as scarps, counterscarps, trenches, debris flows, debris fans and rockfalls.

For the combined use of IPTA and aerial photography interpretation, the average displacement rates of point targets in the satellite line-of-sight direction are plotted on the sketch maps with geomorphological features. Landslides are classified as rotational and translational slides (dark grey), complex slides and rockfalls (medium grey), sackungen (bright grey) and diffuse shallow slides (crossed grey). Swiss topographic maps at scale 1:25’000 (grid size of 1 km) are used as image background.

3. RESULTS

3.1 Cimadera (Val Colla)

The Cimadera rotational slide, located in Val Colla about 20 km northeast of Lugano, covers an area of 0.5 km² and is placed between Prato Bello (1205 m a.s.l.) and the Valle delle Spine river. A series of north-trending scarps and counterscarps extend east and south of Cimadera. The counterscarps are 10 to 50 m long, have a few meters of relief and delimit small graben-like structures. The main scarp has a high geomorphological evidence and shows a topographic concave shape. Evidence of present activity is the hummocky topographic surface that affects the accumulation area between Cimadera and Le Spine.

IPTA results (Fig. 1) confirm the present activity of the Cimadera landslide, which is also in agreement with available geodetic data. The average displacement rate is on the order of 5 mm/year to the north of the landslide. The few points in the south of Cimadera indicate a lower velocity. For the smaller landslides east and west of Cimadera there is no information from IPTA because of vegetation cover. In general the quality of IPTA information in the entire Val Colla, derived from images of both ascending and descending orbits for a spatial extent of about 40 km², has been found to be dependent on the exposition of the slope subject motion with respect to the satellite line-of-sight direction.

3.2 Pregassona – Cureggia

A large sackung covers an area of about 5 km² on the east flank of Mt. Boglia (1516 m a.s.l.), a few km northeast of Lugano. The evolution of this instability is controlled by the northeast trending Lugano Line, which extends along the middle part of the slope and is marked by mylonites and cataclasites. In the upper part of the slope a series of scarps are parallel to Lugano Line. Geological evidences suggest that the rock mass have moved towards east with more than one hundred meters of displacement. The lower half part of the slope, below 800 m, has a strongly convex profile resulting from large rotational landslides that overlap one another at different levels. These large landslides are known to be postglacial in age because of glacial deposits located in the lower part of the slope and are cut by scarps. Superficial instabilities such as rockfalls, debris flows and some shallow landslides suggest a recent state of activity.

The state of activity of some large landslides in the lower part of the slope, where urban areas and rocks are present, has been established by IPTA. As shown in Fig. 2 for the southern part of the sackung, a few points with
an average displacement rate of 2 to 8 mm/year indicate sub-stabilized landslides. The village of Cureggia, on the other hand, is to a large extent stable.

3.3 Mezzovico – Sigirino (Valle del Vedeggio)

In the Vedeggio valley north of Lugano the western flank of Mt. Gradicioli is involved in a large slope instability. Above the villages of Mezzovico and Sigirino the landslide scarps are located in the upper part of the slope (above 1200 m a.s.l.), the toe corresponds to the bed of the Valle Cusella river. The presence of this landslide is marked also by the slope geometry, which is characterized by longitudinal and transverse convexity. Many scarps facing northeast are located in the lower part of the slope where the valley bottom is moved towards northeast. This fact suggests recent movements of this landslide, which has been confirmed by IPTA (Fig. 3). Here, ERS-1/2 SAR data of ascending orbit, characterized by a smaller number of acquisitions, were successfully analyzed to characterize the sub-stabilized landslide with information arising mainly from rocks and scattered houses.

3.4 Lavertezzo (Val Verzasca)

A huge sackung covers an area of about 3 km$^2$ on the southern flank of Föpia Mount, northeast of Lavertezzo in Val Verzasca. A series of northeast trending scarps and counterscarps characterize the ridge between 1000 and 1400 m a.s.l. Evidence of past activity of this large deformation is given by the presence of numerous slumps, complex slides and debris fans at the toe of the slope, that collectively cover an area of more than 0.5 km$^2$. Three large rotational rockslides affect the lower half part of the slope below 1200 m a.s.l. The toe of these phenomena coincides with the valley bottom.

The Revoira rotational rockslide (Fig. 4), with an area of about 1 km$^2$, is the largest instability that affects the entire sackung. This landslide is located in northern flank of the sackung where the slope shows a transversal convex profile. IPTA analysis evidences the current activity of this instability with average displacement rates of 3 to 6 mm/year. The location of the IPTA points and their average annual displacement rates are in good agreement with the mapped morphologic evidences. A correlation between the displacement of one of the fastest moving points (Fig. 5) and precipitation rates (Fig. 6.) shows the response of the slope to the November 1993 and November 2000 rain storms with an increase in the average velocity.

The average displacement rate of the landslide located in southern flank of the sackung is very low, on the order of 1 to 3 mm/year. For a comprehensive analysis of the sackung with ERS SAR data, however, it has to be considered that the lower part of the Verzasca valley is masked by layover.

3.5 Campello – Molare (Val Leventina)

The northern flank of the Leventina valley above Faido is affected by a deep-seated slope movement. With an area of more than 20 km$^2$ this sackung is the largest of the five reported in this paper. In the upper part of the slope numerous scarps, counterscarps and grabens are present. Most of these morphostructures are 50 to 150 m long and have a few meters of displacement. The lower half of the slope has a strongly convex profile resulting from numerous large rotational and translational slides. A deep ravine delimits the western part of the sackung close to the village of Osco. In Fig. 7, however, we present only the eastern part of the sackung, where two large landslides in correspondence of the villages Molare and Campello are present. The evidence of the current activity of these landslides is the presence of numerous scarps which cut glacial deposits and shows displacements up to 50 m.

The IPTA average displacement rates are in good agreement with the mapped landslides. In particular, relatively large displacement rates of 4 to 6 mm/year are observed in Campello and Molare. An even larger velocity of 5 to 12 mm/year is recorded to the east of Campello. Because these values are along the satellite line-of-sight direction, the actual motion is certainly above 2 cm/year in this part of the landslide. On the other hand, a very slow motion of about 1 to 3 mm/year is observed between the two landslides of Campello and Molare and in Calpiogna. At the bottom of the valley no motion is observed. Also the eastern upper part do not show displacement, whereas on the western upper part a motion of 2 to 5 mm/year is recorded for a large number rocks. For many of the points with a significant motion a correlation with the November 1993 rain storm event has been detected. High resolution ground motion geodetic data available for a tenth of points in the eastern part of the sackung [10] confirm overall displacements of more than 5 mm/year with larger values around Campello.
Figure 1. Cimadera (Val Colla).

Figure 2. Pregassona – Cureggia.

Figure 3. Mezzovico – Sigirino (Valle del Vedeggio).

Figure 4. Lavertezzo (Val Verzasca).

Figure 5. Time series for a point target at the Lavertezzo rockslide (Val Verzasca). Mean rate is -6 mm/year.

Figure 6. Monthly precipitation in mm at Frasco (Val Verzasca).
5. CONCLUSIONS

Results achieved with IPTA are attractive to complement aerial photographs interpretation for the evaluation of the state of activity of landslides over villages and in sparsely vegetated areas with numerous exposed rocks. On the other hand, over vegetated areas (forests and meadows) IPTA is unsuccessful to retrieve displacement information. Because displacement from InSAR is recorded along the satellite line-of-sight direction, IPTA cannot be directly used for the determination of the intensity of landslides in hazard mapping. In general, the actual displacement rate is larger than that recorded with InSAR.

For current and future ITPA investigations, ENVISAT and RADARSAT SAR acquisitions over the Swiss territory are available. Over alpine areas characterized by sparse vegetation, where snow cover limits the availability of a large number of SAR acquisitions, conventional InSAR was successfully applied to estimate the motion of rock glaciers and other periglacial phenomena [11,12]. For vegetated areas and relatively rapid landslides L-band InSAR (JERS-1 SAR and ALOS PALSAR) has been found to be an efficient solution [13].

6. ACKNOWLEDGMENTS

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7. REFERENCES

Figure 7. Campello – Molare (Val Leventina).