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ERS InSAR for Detecting Slope Movement in a Periglacial Mountain Environment (Western Valais Alps, Switzerland)

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Abstract

The potential of ERS InSAR for detecting slope motion in a periglacial mountain environment has been tested in the western part of the Swiss Alps. An inventory has been built from the analysis of the InSAR data. It contains a large number of areas that can be possibly attributed to various types of mass movement (glacier, debris-covered glacier, rock glacier, landslide, sagging, gelifluction) occurring with various rates of activity above the tree line. The applied methodology is briefly described and several typical examples of detected slope movement are illustrated.

KEY WORDS: ERS InSAR, slope movement, rock glacier, push-moraine, landslide

1. Introduction

A proactive management of natural hazard related to the creep of mountain permafrost (debris flow, landslides) requires regional overviews (mapping) of slope instabilities to be produced. Available data on slope motion in remote mountain periglacial areas is however often lacking or restricted to a few sites. InSAR (space-borne Synthetic Aperture Radar interferometry) appears to be a potential tool to fill in this gap by providing, at least partially, such large scale overviews on landslide and permafrost creep (rock glacier) activity in high mountain areas. The technique is well established for the mapping of topography changes at mm to cm resolution (Bamler and Hartl 1999, Rosen et al. 2000, Strozzi et al. 2001). Over alpine areas, where dense vegetation is no longer present, observations of mass movements in the satellite line-of-sight direction are feasible during the snow free period between early summer and mid fall in spite of incomplete coverage caused by the very rugged topography (Rott et al. 1999, Kenyi and Kaufmann 2003, Strozzi et al. 2004, Kääb et al. 2005).

With the support of ESA (European Space Agency) in the framework of the SLAM (Service for Landslide Monitoring) project and of the Swiss Federal Office for the Environment (FOEN), the capability of InSAR for detecting and inventorying both location and magnitude of slope instabilities in a mountain periglacial environment was tested in the western part of the Valais Alps (50 x 30 km) with ERS (European Remote Sensing Satellites) SAR data (Delaloye et al. 2005a). The reliability of the results (location of "instable" zones and movement rate) was evaluated by comparison with existing data such as rock glacier inventories (Delaloye and Morand 1997, Lambiel 1999), GPS measurements (e.g. Lambiel and Delaloye 2004, Perruchoud and Delaloye 2007) and air-borne photogrammetry (e.g. Kääb 2005). They were also compared to geomorphic features observed on orthoimages and to new GPS surveys and field observations that were performed. The paper summarizes and illustrates some of the most important aspects and results of the project.

2. InSAR data

A series of 34 interferograms from the ERS-1 and ERS-2 satellites (wavelength of 5.6 cm) was used. Interferograms were computed from SAR images acquired along ascending and descending orbits, dating from 1995 to 2000, and with baselines shorter than 100-150 m. Time lapse ranges between 1 and 1085 days (only multiples of 35 days +/- 1 day, time necessary for the satellites to accomplish an orbit). The topographic reference was determined from an external Digital Elevation Model (DEM) with a spatial resolution of 25 m and an estimated vertical accuracy of 3m. The InSAR products were also computed at 25 m spatial resolution.

Main limitations of InSAR are atmospheric effects, i.e. phase delay caused by changing tropospheric water vapour conditions at the time of the two SAR acquisitions, and signal decorrelation. Over alpine areas, high coherence of ERS interferogram data is regularly obtained during the snow free period between early summer and mid fall above the tree line. The favourable period becomes reduced at higher elevation because of the more frequent occurrence of old or fresh snow. The presence of late-laying snow avalanche deposits may also disturb the SAR signal. Coherent data are also observed for daily time lapse in winter time where the snow surface is cold (see Fig. 3b). Further limitations of InSAR arise from layover and shadowing, that prevent to cover steep rock wall and deep valley, and from the sensitivity of the interferometric phase to the deformation component along the radar look direction (23° from nadir). Therefore, north and south slopes are not favorably illuminated by the ERS SAR, what decreases the capacity for detecting mass movements in these orientations.

3. Procedure for slope movement detection

The procedure applied in this study for the detection and qualification of moving areas comprised five successive steps.

(1) The major obstacle limiting the potential of InSAR is the presence of wet snow which strongly disturbs the radar signal. To prevent any misinterpretation of the SAR interferograms, estimating the (old and fresh) snow conditions at SAR image dates has proved to be a necessary first step. In this study, a rough assessment of the elevation of the snow line depending on aspect was performed on the basis of the daily reports on weather conditions by meteoswiss.

(2) A combined visualization of valid interferograms with various time lags (1 day, 1-2 months, 1-3 years) was applied over smaller areas (about 5 x 5 km) in order to detect the polygons potentially related to slope instabilities. This systematic method permitted to identify not only the location and spatial extent of unstable zones but also the magnitude order of the displacement velocities in the radar line-of-sight (three categories were defined, namely cm/day, cm/month, cm/year). The identification and delimitation of the polygons was subjective and obviously might differ depending on user.

(3) The detected polygons were then compared to the geomorphic landforms with the help of topographic maps and orthophotos. This step permitted on the one hand to evaluate the reliability of the detected InSAR signal and,

on the other hand, to attribute a possible/probable cause to the slope movement.

(4) Where available, the comparison of the InSAR data with "terrestrial" slope motion measurements was performed. This analysis also permitted to evaluate the reliability of the InSAR technique.

(5) A few additional field observations (geomorphic mapping and GPS survey) were performed locally to precise or to confirm the InSAR results.

Steps (3) to (5) have shown an encouraging and often excellent fitting of both the magnitude order and spatial pattern of slope movements between the signals detected on interferograms and the field data.

More than 600 polygons were thus identified as ERS InSAR detected slope instabilities within the tested area above the tree line (about 2000-2200 m a.s.l.) (Fig. 1). The inventory was not an exhaustive list of all the slope instabilities in the area, but an inventory of all polygons showing any kind of signal on ERS SAR interferograms that can be interpreted as a possible slope movement. It was also possible to define typical ERS InSAR signatures depending on the activity and/or type of the geomorphic landform (glaciers, debris-covered glaciers, push-moraines, rock glaciers and landslides with various rate of activity, gelifluction areas). Three examples are illustrated hereafter.

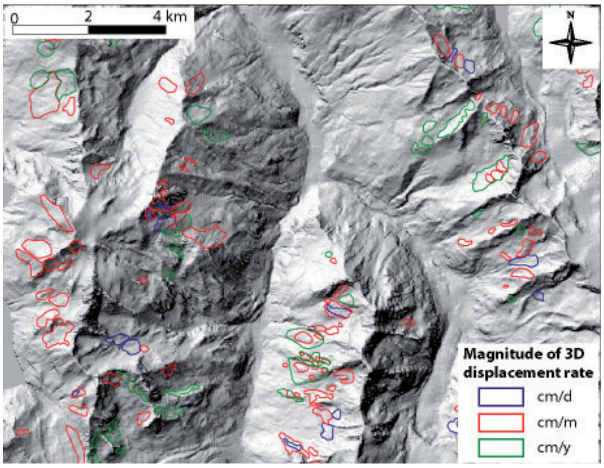

Figure 1: Extract of the "ERS InSAR detected slope movement" inventory in the Valais Alps (upper Val d'Hérens, 46°07' N, 7°30' E).

4. Push-moraine and debris-covered glacier

The first case illustrates the typical ERS InSAR signals detected on many historical forefields of alpine cirque glaciers located in the belt of discontinuous permafrost for both 1-day and 35-days time lapses in summer time (Fig. 2a-2b). The Penna area (Val d'Entremont, 47°56'30 N, 7°13'00 E) comprises a debris-covered glacier (La Trouye Glacier) surrounding by an impressive edifice of push-moraines (Fig. 2c), that are, according to Haeberli (1979), glacio-tectonically deformed frozen sediments. The spatial pattern of alpine push-moraine systems mostly dates back to the advance of the glacier during the Little Ice Age (LIA). In many cases, the former frozen materials were pushed up to lateral slopes. Movements that are currently susceptible to occur in such landforms may be the back-creeping of still frozen sediments towards the glacier talweg and/or the surface subsidence due to melting of massive ice at depth (in some cases melting of buried glacier ice) (Reynard et al. 2003, Delaloye 2004). At Penna, most of the whole complex of push-moraines is distinguishable on a 35-days lag SAR interferogram in front of the debris-covered glacier (Fig. 2b). The later is already well delimited at a daily time lapse in summer (Fig. 2a) with a decorrelated signal that can be caused by the exposure of the melting ice itself (thinner debris coverage), by the rapid settlement of the glacier surface and/or by a significant glacier motion.

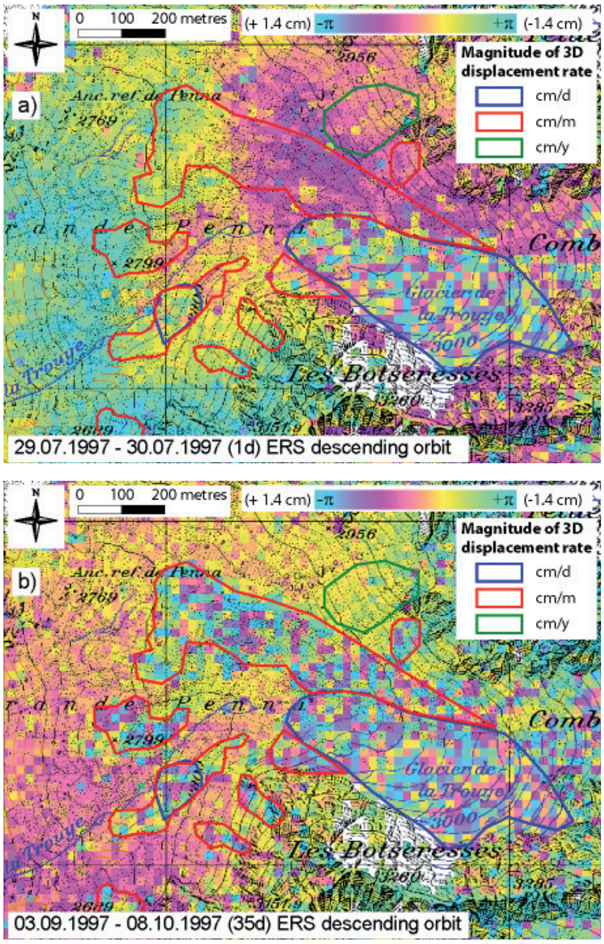

Figure 2a-b: Daily and monthly ERS InSAR signal on push-moraines and debris-covered glacier at Penna. Orthoimage by swisstopo.

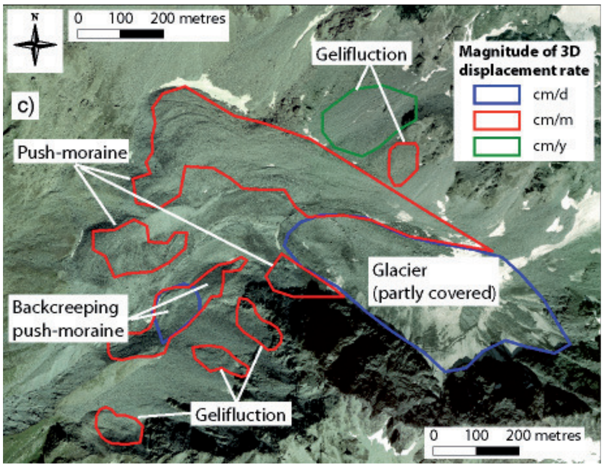

Figure 2c: Daily and monthly ERS InSAR signal on push-moraines and debris-covered glacier at Penna. Orthoimage by swisstopo.

5. Active and "surging" rock glaciers

The velocity range of active rock glaciers is large. For most active features, an obvious signal is detectable at monthly interval (see Fig. 4b). For the most active, a low signal may be already detected at 1-day interval in summer and decorrelation is widespread over the landform at monthly interval. For the slowest, any signal can be difficult to be evidenced at monthly time lapse but becomes evident, sometimes decorrelated at yearly interval.

A peculiar case is the so-called "surging" rock glacier, that is a (part of) rock glacier moving very fast and showing crevasses and/or collapse features (Delaloye et al. 2005b). The Petit-Vélan rock glacier (45°55' N, 7°14' E) is such a surging rock glacier whose 200 m long terminal section is collapsing (Fig. 3a). The superficial velocity has been measured by GPS in summer 2005 up to 7 m/a (Delaloye et al. 2005a). Its dramatic rate of activity was first discovered by InSAR : obvious signals were observed at daily interval both in winter and summer 1997 (Fig. 3b-3c). The GPS data has confirmed that the magnitude order of the collapsing rock glacier movement is to much large for any coherent detection on 35-days ERS interferograms (Fig. 3a, up to more than 40 cm of horizontal displacement in 35 days), but fits with the detection range of 1-day interferograms.

The comparison of several terrestrial and aerial photographs dating back to 1988 shows that the "surge" began between 1989 and 1995: the rock glacier terminal section was still intact in autumn 1988, but large crevasses already occurred in 1995 (Delaloye et al. 2005b). The scarce at the top of the collapsing part is well observable on the orthoimage in 1999 (Fig. 3a). In 2005, the front of the rock glacier was laying at least 20-30 m downward of its position in 1995. In compensation, a strong subsidence has occurred in the upper surging part, lowering the surface of about 5 to more than 10 m.

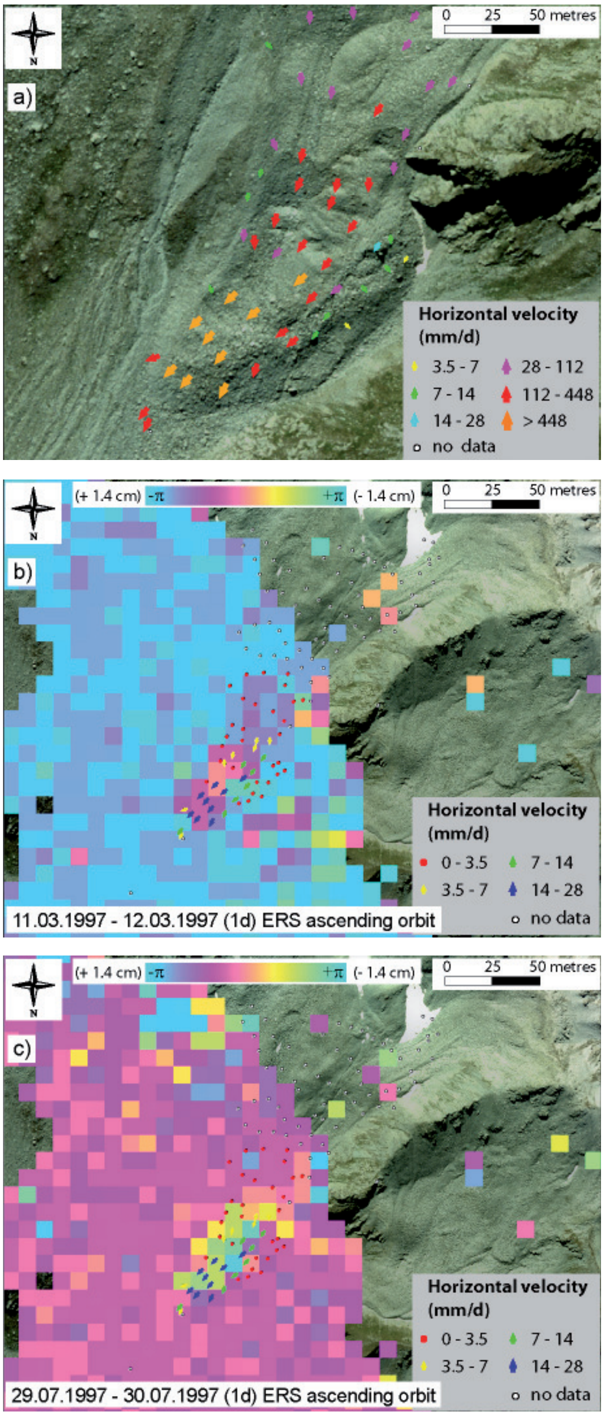

Figure 3a-c: The "surging" Petit-Vélan rock glacier : GPS data (summer 2005) and daily ERS SAR interferograms in winter and summer time. Orthoimage by swisstopo.

6. Landslides

Superficial landslides and deep-seated saggings are slope movements that are not related to glacier or permafrost occurrences. They are nevertheless frequent in the alpine periglacial zone and can be detected by ERS InSAR with various rate of activity. A good illustration is provided by the wide and steep south-western flank of Bec-des-Rosses (46°04' N, 7°17' E) dominating the village of Lourtier (Bagnes Valley). It comprises several active landslides that have been evidenced by InSAR. A large sagging (BaR-201) (Fig. 4c) is well observed at monthly time lapse (Fig. 4a), what reveals a subsidence rate of about 10 cm/y. Several other slower saggings or landslides can be detected on a 1-year interferogram (Fig. 4b). Most landslides correspond to the starting zone of frequent debris flows (BORLE, in prep.) that are crossing the village in a deep channel and reach the valley floor partially damming the main river.

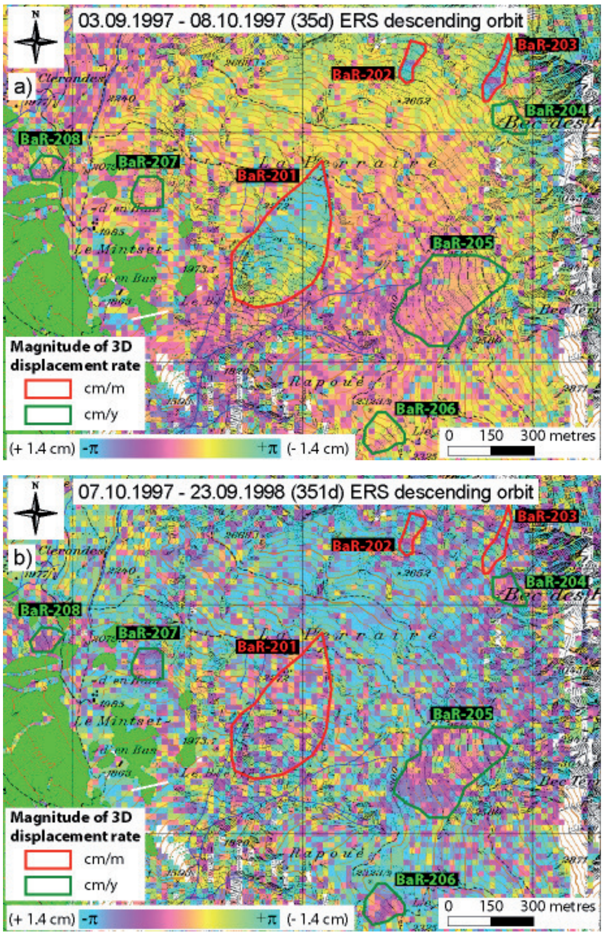

Figure 4a-b: Sagging, landslide and active rock glacier detection at Bec-des-Rosses on monthly and yearly ERS SAR interferograms. Orthoimage by swisstopo.

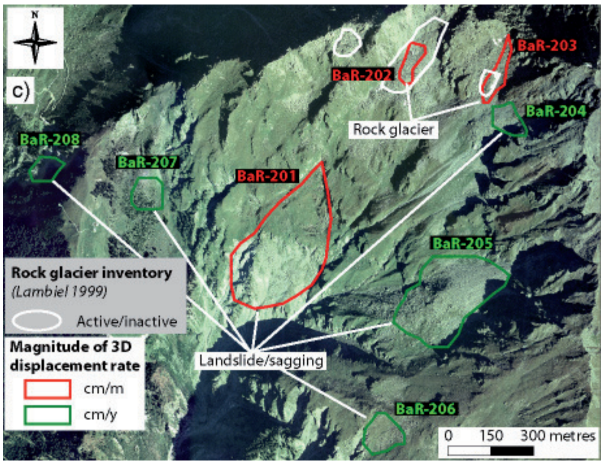

Figure 4c: Sagging, landslide and active rock glacier detection at Bec-des-Rosses on monthly and yearly ERS SAR interferograms. Orthoimage by swisstopo.

7. Conclusions and perspectives

The resulting inventory of ERS InSAR-detected instabilities can be seen as a preliminary tool compiled at regional scale which can be useful for further investigations to be carried out (if required) at local scale. It appears to be an attractive perspective both for early natural hazard management and process understanding of slope movement in permafrost areas.

As mentioned earlier, the inventory of slope motion resulting from an ERS InSAR analysis is not exhaustive : in particular, steep rock walls and unfavourable northern and southern oriented slopes are not or only partially illuminated by ERS InSAR. Moreover, the detection of surface motion does not provide information on the deepness of the mass movement. The type of movement is thus sometimes difficult to evaluate, what requires some additional field geomorphic observation to be carried out. The topography of the test region, mainly consisting of north-south directed valleys has proved to be optimal for an application of the ERS InSAR technique. It is certain that another configuration of the valley system can strongly limit its potential.

Data used in this study is however already about 10 year old and more recent data would be appreciated. The European Environmental Satellite ENVISAT, launched in 2003, operates similarly to ERS. We can thus expect with these new SAR data, the possibility to update the inventory of slope movement in a near future.

ERS SAR data courtesy of C1P.2338 (© ESA, processing GAMMA). DHM25 © 2003 swisstopo.

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