Satellite and Terrestrial Radar Interferometry for the Measurement of Slope Deformation

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Synergistic use of satellite and terrestrial radar interferometry was considered for the measurement of slope deformation in the Mattervalley (Canton of Valais, Switzerland). Highest rates of movement of more than 1 cm/day were measured only with terrestrial radar interferometry, because of the large time interval between satellite SAR observations. Summer TerraSAR-X and Cosmo-SkyMed interferograms as well as terrestrial radar interferometry campaigns repeated with a time interval of a few days were jointly considered for the study of landslides moving at rates of dm/year. Persistent scatterer interferometric analyses conducted with ERS-1/2, ENVISAT, Radarsat-2, TerraSAR-X and Cosmo-SkyMed images were finally used to detect the slowest moving landslides, with rates of movement below a few cm/yr in the line-of-sight direction.

Keywords: Satellite SAR interferometry, terrestrial radar interferometry, landslides, rock glaciers.

1. Study Area

The Mattervalley in the Swiss Alps is going up from the bottom of the Rhonevalley to the famous station of Zermatt. In this valley there are numerous unstable slopes which can cause damage to inhabited areas, touristic installations, roads and railways. Many landslides, rockslides, and rockfalls are active and the annual costs for mitigation and countermeasures are high. Due to the difficulties in the detection of the active, slow or dormant portions of the landslides, the use of a radar interferometric approach can positively impact the current practices used by the local authorities to plan and implement the hazard mitigation activities. In this contribution we present investigations performed along the orographic right side of the Mattervalley at altitudes ranging from about 1'200 m to more than 4'000 m a.s.l. , where considerable parts of the slopes are without any vegetation or dominated by scarce patches of alpine grass. The test area encompasses numerous active rockglaciers with deformation rates ranging between 0.1 and 2.0 m/yr (Strozzi et al. 2004). The velocity of rock glaciers has risen significantly since the 1980s over the whole alpine range in response to a significant permafrost warming (Roer et al. 2008). Recently, destabilized (or “surging”) rockglaciers showing morphological indices of landslide-like mass wasting have been reported from several regions, including Grosse Grabe, Breithorn, Dirru and principally Grabengufer in the Mattervalley (Figure 1). Also particularly significant in the Mattervalley site is a large deep seated gravitational slope deformation on the upper Breithorn west face. Debris originating either from the weathering of the bedrock or from various gravitational processes are covering the bedrock in many places.

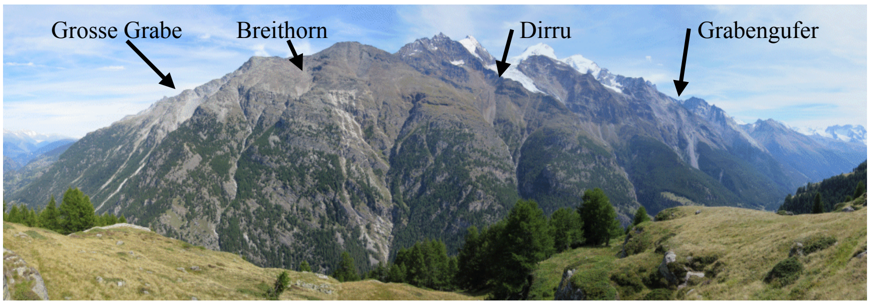

Figure 1. Right side of the Mattervalley from the terrestrial radar position on September 2, 2010 with indication of the most active rock glaciers. The Breithorn landslide is located just on the left (i.e. north) of the Breithorn rockglacier.

2. Methods

2.1 Satellite SAR Interferometry

Satellite Synthetic Aperture Radar Interferometric (InSAR) is a powerful technique for mapping land surface deformation from space at fine spatial resolution over large areas, which was successfully applied in alpine areas for the mapping and monitoring of rockglaciers (Strozzi et al. 2004) and landslides (Strozzi et al. 2013). The application of InSAR is limited by temporal and geometric decorrelation and inhomogeneities in the tropospheric path delay. In Persistent Scatterer Interferometry (PSI) 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 (Wegmüller et al., 2003) in order to estimate over urban areas and rocks the progressive deformation of the terrain at millimetre accuracy. In mountainous regions the number of persistent scatterers is limited by the sparse urbanization, the large forest cover, and areas of shadow and layover. A significant improvement was possible in recent years with the use of SAR sensors characterized by a higher spatial resolution and a shorter revisiting time. We performed a PSI processing using stacks of ERS-1/2, ENVISAT, TerraSAR-X, Cosmo-SkyMed and Radarsat-2 SAR data acquired between 1995 and 2012. In addition, differential interferograms were computed for a large number of image pairs, including Cosmo-SkyMed pairs with 4 days time interval.

2.2 Terrestrial Radar Interferometry

A terrestrial radar interferometer compliments satellite SAR data in time and space, allowing the measurement of additional displacement vectors and velocity classes. The GAMMA Portable Radar Interferometer (GPRI) can operate over distances up to about 10 km with resolutions of 0.95m in range and of 6.8m in azimuth at 1km range. The measurement accuracy is less than 1mm at 1km and is dependent on variability of the atmospheric water vapour. Scans of even more than 180° size can be taken in less than one minute to allow for near real-time monitoring (Werner et al. 2012). On the other hand, the GPRI is also suited to measure slower movements by coming back to the same site after days, weeks or months. GPRI measurements were performed from a position on the opposite side of the valley during six campaigns: 01-03.09.2010, 11-12.10.2010, 10-12.08.2011, 16-17.08.2011, 23-24.08.2011, and 30-31.08.2011. The distance to the target was considerably large, from about 3 to more than 6 km, with significant atmospheric artifacts. In order to study the effect of the large distance to the objects, two campaigns of the Grabengufer rockglacier were also performed on 20-21.07.2010 and 10.08.2011 from a distance of about 1 km. Interferograms of every campaign with a time interval between subsequent acquisitions on the order of 10' to 30' were processed in series and cumulative displacement maps of the fastest moving objects were computed for the six dates. In addition, displacement maps of the slower moving objects were computed using a few images of every campaign.

3. Results

The highest rates of movement were measured with the GPRI for the Grabengufer rockglacier, with values larger than 10 cm/day in 2010 and on the order of 10 cm/day in 2011 (Figure 2). This is in agreement with measurements performed with other surveying techniques like GPS and tachometers over this rockglacier which has shown since the beginning of 2009 a landslide-like mass wasting phenomenon. The comparison with the Grabengufer rockglacier measurements from a distance of about 1 km on 20 July 2010 shows the degradation of the azimuth resolution of the terrestrial radar system at 6 km distance, but nevertheless similar rates of movement. The same displacement map represented with a different color scale (Figure 2) highlights the movement of the three other active rockglaciers of our test area, i.e. Grosse Grabe, Breithorn and Dirru. General rates of movements of these rockglaciers at the front were larger than 1 cm/day. Also visible in these images is the movement of the Hobärg glacier.

The activity of these very rapidly moving rockglaciers cannot be detected from satellite SAR interferometry, because interferograms with short perpendicular baselines from Cosmo-SkyMed (Figure 3), TerraSAR-X, Radarsat-2, ENVISAT ASAR and JERS-1 present all very important signal decorrelation after the 4, 11, 24, 35 and 44 days repeat intervals of these SAR sensors operating at X-, C- and L-band, respectively. On the other hand, with all these satellites other slower moving landslides can be well discriminated.

In order to quantitatively study the movement of the slower landslides, PSI analyses were conducted with the summer TerraSAR-X images of 2009 and 2011. All points detected with these two separate analyses were plotted on the same image (Figure 4) and compared with the ground-based radar interferogram computed with images of August 10 and 16, 2011 (Figure 5). In both the ground-based and the satellite-based results the signals of the Breithorn landslide to the north of the Breithorn rockglacier and of the landslide just to the north of the Grabengufer rockglacier are very well visible. Other smaller signals scattered along the test site and consistently observed in the two cases can be appreciated as well. In spite of the very different viewing geometries the rate and the shape of the detected signals is very similar from ground and satellite. PSI analyses conducted with all ERS-1/2, ENVISAT (Figure 6), Radarsat-2 and TerraSAR-X images might be finally used to detect the slowest moving landslides, where rates of movement are below a few cm/yr in the line-of-sight direction. All the areas with significantly faster movements appear in these analyses without information, similarly to vegetated regions and slopes affected by layover and shadow.

4. Discussion

Satellite SAR interferometry is recognised to be a mature and well consolidated technology for the mapping and monitoring of land deformation. Although progress in the processing algorithms are always taking place, the performance of this technology mainly depends on other factors, like availability of satellite SAR data, temporal interval of the SAR acquisitions, carrier frequency and spatial resolution of the SAR image, land cover (particularly presence of vegetation and snow cover), topography and availability of a good digital elevation model, and spatial dimension and rate of movement of the phenomenon under analysis. In order to provide locally much higher flexibility than the satellites with respect to the area measured and the time intervals considered and highly precise displacement information in near real time, Terrestrial Radar Interferometry (TRI) can be employed.

Slope deformation maps from satellite and terrestrial radar interferometry will be considered for the compilation of an inventory of landslides with indication of the state of activity in the Mattervalley. The identification of ground motion from radar interferometry will be complemented by geomorphological information from photo-interpretation. While the analysis of aerial photographs allows us to recognize many phenomena of instability and to define their limits, radar interferometry allow us to characterize the class of intensity of the landslides with a deformation time-series extended over 20 years (Cigna et al. 2012, Strozzi et al. 2013).

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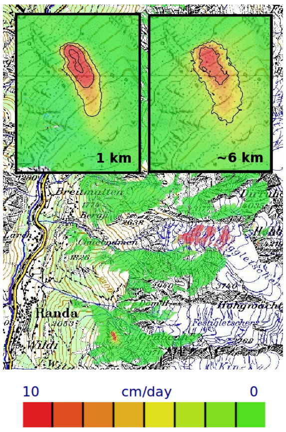

Figure 2. GPRI displacement map from 1 to 3 September 2010.

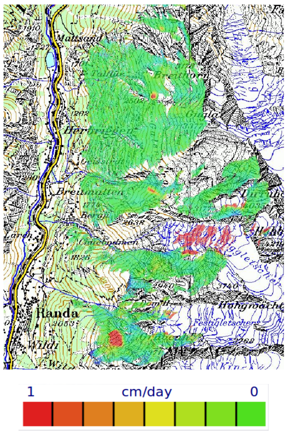

Figure 3. Same as Figure 2 but with a different color scale.

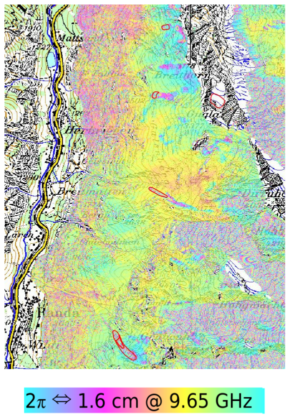

Figure 4. Cosmo-SkyMed interferogram from 23 to 27 September 2011.

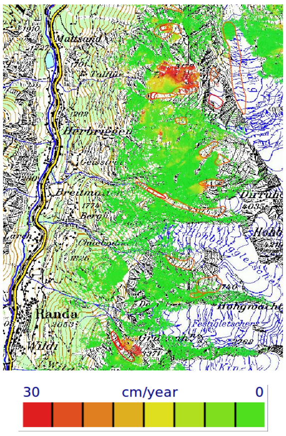

Figure 5. Mean displacement from TerraSAR-X PSI using summer data of 2009 and 2011.

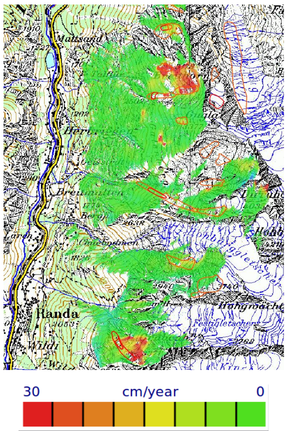

Figure 6. Displacement map from GPRI acquisitions 10-16 August 2011.

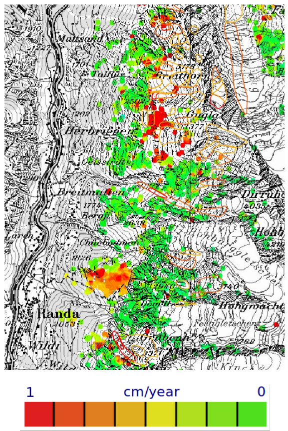

Figure 7. Mean displacement from ENVISAT PSI. Image size is 5 km x 10 km.

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