PSInSAR DATA ANALYSIS – AN INSIGHT INTO ACTIVE TECTONICS AND MASS MOVEMENTS IN WEST SLOVENIA

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ABSTRACT

Using relatively new method called PSInSAR (Permanent Scatterer interferometry) technique active tectonics and slope mass movements in the area that spreads over 700 km^2 and lies in the NW part of Slovenia were assessed. The research area forms the eastern flank of the Alpine arch and is tectonically still active. For the analytical purposes 57 images of descending orbit from satellites ERS 1 and ERS 2 were used. The time span of the acquired images was from April 1992 to December 2000. The average signal reflector (PS) density for the area was 23 per km^2. Altogether 16,304 permanent scatters were detected. For the best 10 % (1646 PS), time series of displacements were acquired. The results also show a constant uplift of Alps and they indicate that the uplift is of higher magnitude than it was considered until now. The relative uplift in relation to the reference point in the Alpine foreland ranges up to 3.35 mm per year. Several landslide sites were examined and their movements analysed in relation to triggering factors.

Key words: Permanent Scatterer, InSAR, mass movement, landslides, tectonics, Alps, Slovenia.

INTRODUCTION

Slovenia lays in the eastern flank of Alpine arch and an active tectonics present are main driving forces for mass movements in the region, especially the north-western part of Slovenia. The research area was chosen as the study area due to its neotectonic activity (Poljak et al., 2000; Zupančič et al., 2001; Grenerczy et al., 2005) and due to a number of landslide, rockfall and debris flow occurrences (Komac et al., 2005). The proved active tectonics of the region is a consequence of compression field with approximate tension field σ_1 in N-S direction (Placer, 1998; Grenerczy et. al., 2005; Weber et al., 2006; Rižnar et al., 2007). There are several major active faults (Idrija, Sava and Ravne fault) and an active South Alps thrust (Poljak, 2000). These faults are most probably right displacement faults, at least this can be stated for Ravne fault (Zupančič et al., 2001; Bajc et al., 2001). The area is subdivided into several nappes (Julian nappe, Tolmin nappe, Trnovski nappe; after Placer, 1998). Wider area is classified as of middle seismic activity area (Poljak et al., 2000). During the InSAR data acquisition, between April 1992 and December 2000, a major earthquake occurred in the research area wit magnitude of MW = 5.6 (Bajc et al., 2001; Gosar et al., 2001; Zupančič et al., 2001).

The research area consists mainly of Mesozoic carbonate rocks, some flisch clastites, in the northern part of Paleozoic clastic and carbonate rocks. The net of fluvial and glacial valleys is filled with Quaternary sediments. (Buser, 1987; Jurkovšek, 1987).

Modern satellite radar permanent (also persistent) scatterer interferometric technique (PSInSAR) enables very accurate monitoring of relative vertical displacement velocities of observed surfaces and grounds (Ferretti et al., 2001; Ferretti et al., 2005; Bürgmann et al., 2006; Dixon et al., 2006; Ferretti & Crespa, 2006). Technique is also very useful in geology for monitoring coseismic and aseismic tectonic displacements (Massonnet et al., 1993; Massonnet et al., 1994; Dixon, 1995; Peltzer et al., 1996; Massonnet et al., 1996; Peltzer et al., 1999), slow moving landslides (Ferretti et al; 2001; Colesanti et al., 2003a; Hilley et al., 2004), and swelling of ground or subsidence (Carnec and Delacourt, 2000; Ferretti et al., 2000; Colesanti et al., 2003b; Vasco & Ferretti, 2005).

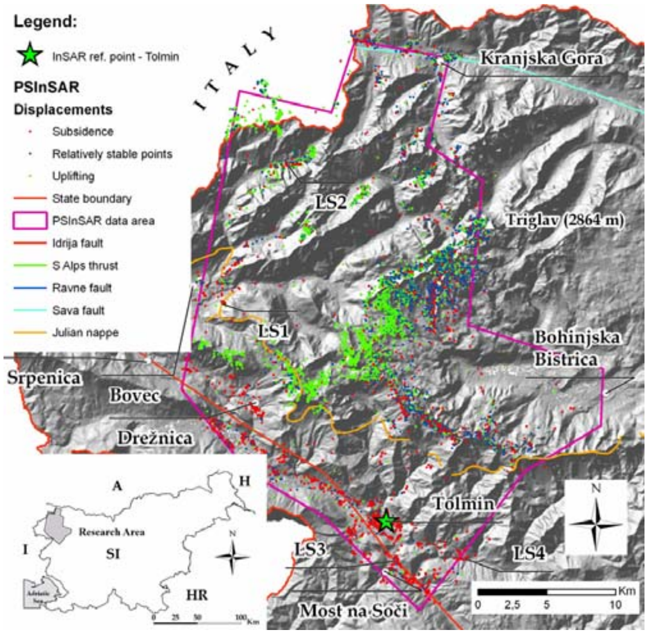

Figure 1.: The research area is located in the NW part of Slovenia, bordering the Italy and covering the south-eastern flank of Alps, the area of Julian Alps. The reference was set in the town of Tolmin represented in the Figure 1 with the star. Landslide sites are marked with LS 1 to LS 4.

RESEARCH AREA AND DATA USED

Using the PSInSAR technique an assessment of tectonic and landslide mass movements was carried out in the research area in NW part of Slovenia, spreading between town Most na Soči (13°46′50′′E, 46°7′41′′N) in the south, town Kranjska Gora (46°29′23′′, 13°47′7′′E) in the north, village Srpenica (13°33′12′′E, 46°16′15′′N) in the west and village Bohinjska Bistrica (46°16′1′′N, 13°57′3′′E) in the east (Figure 1). The area includes the highest areas of Slovenia and roughly half of Triglav National park. The average altitude of the area is 1157 m.a.s.l., while the highest peak reaches 2664 and the lowest 141 m.a.s.l.

To assess the tectonic and landslide mass movements in the research area, geological (Buser, 1987; Jurkovšek, 1987), structural data, digital elevation model (SMA, 2001), landslide occurrences (Komac et al., 2005), seismic (Placer, 1998; Poljak et al., 2000; Bajc et al., 2001; Gosar et al., 2001; Zupančič et al., 2001; Grenerczy et al., 2005; Weber et al., 2006; Živčić, 2006; Rižnar et al., 2007), rainfall (ARSO, 2006) and “geophysical” (Permanent Scatterer InSAR; T.R.E., 2006) data were used. Analyses were focused into assessment of applicability of PSInSAR technique for monitoring the uplifts or subsidence of masses, either as a consequence of endogenic (tectonics) or exogenic (gravitation, climate…) forces.

For the purpose of analyses presented 57 images from the descending orbits of ERS-1 and ERS-2 satellites were used. Images were acquired in the period between April 21st 1992 and December 29th 2000. As the reference image, the image taken on September 26th 1997 was selected (Bianchi & Ferretti, 2006).

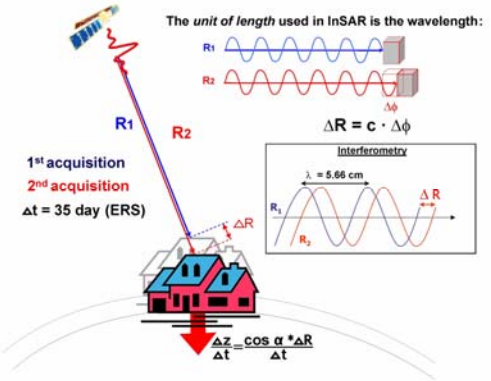

Figure 2.: Basic principles of PSInSAR (Premanent Scatterer Interferometric Side Aperture Radar) functioning (after Ferretti & Crespa, 2006).

PERMANENT SCATTERER INSAR

Radar interferometry is a technique that has been successfully applied in different fields. The Earth's topography can be observed with interferometry by using two approaches, with either one or two passes (overflights). In the first approach emission and reception antennas are placed on the same platform (airplane or satellite), while in the second approach, which is usually used in satellite acquisition, the same or identical platform overflies the same area with a time lag from slightly shifted orbits (Oštir, 2000; Oštir, 2006). Permanent scatterer interferomety (PSInSAR) is relatively new technique that enables very accurate monitoring of relative vertical displacement velocities of observed surfaces and grounds in the line-of-sight of the satellite signal. In the case of ERS satellites the declination of radar signal from vertical is 23°. InSAR data have limitations such as changes in the reflection of objects or areas, atmospheric influences (decorrelation), and signal disturbances. A statistical minimization of these disturbances can be achieved by using radar data over a longer period and by determining coherent radar targets – permanent scatterers. This technique is named Permanent Scatter Interferometric Synthetic Aperture Radar or PSInSAR (Ferretti & Crespa, 2006). Figure 2 shows the basic principles of InSAR permanent scatterer functioning.

Satellites (ERS-1 in ERS-2) providing images that are the main source for PSInSAR have an orbit cycle of 35 days. Displacements (Δz) in the line of sight, which are during this time smaller than the half of the wavelength used (5.66 cm), can be registered on the basis of wave difference ($\Delta \phi$) of the backscattered signal. The best results are expected to be achieved in the urban areas, in the areas with little or no vegetation and in areas of rock outcrops. The technique is useful for detecting and monitoring of vertical displacements of the surface, but caution is necessary when analysing PS data, since the horizontal movements can blur or intensify actual vertical displacements.

Based on the preliminary data analyses and geological prospect for the reference point (stable or a "zero" displacement point), the location near the town of Tolmin was chosen. The location of the reference point is 46°11´3.44´´N, 13°44´45.12´´E and its overall coherence is 0.84. The average density of permanent scatterers is $23/km^2$, and the minimum density required for analysis is $15/km^2$. Average displacements in the line-of-sight (LOS) were determined for the whole population of targets. Altogether 16304 permanent scatterers with coherence, higher than 0.5 were detected. For the most reliable 10 % of the population (1646 PS with a coherence higher than 0.74) the displacement data of all 57 acquisitions were calculated (temporal measurements). For these targets, time series of displacements from 1992 to 1994 and again from 1995 to 2000 were derived. All displacements, referred to in this text, are relative and as such related to the status of reference point in town Tolmin. Although the reference point is considered as stable there are no absolute stable points in the area (cf. Rižnar et al., 2007), and the awareness of this relativity is crucial for comprehension of results. Negative velocities do not necessarily represent the subsidence, but possibly only its slower uplift according to reference point.

RESULTS AND DISCUSSION

Tectonic uplifting

To assess the tectonically driven mass movements in the research area the PS data were analysed. Considering only of the best 10 % pf PS (n = 1646) the maximum velocities towards the satellite in the line-of-sight range up to 6.65 mm/year and maximum velocities away from the satellite range up to (-)3.30 mm/year. Relative vertical components of velocities are 6.12 and (-)3.06 mm/year respectively.

Table A represents the uplifting velocities for the PS with temporal measurements (n = 91) situated in the area of Julian Alps (Julian nappe). The region has already been confirmed to uplift (Rižnar et al., 2005, 2007). The estimation of relative vertical velocities of 91 PS was based on the average uplifting velocity for each PS criteria. The most conservative approach that encompasses all uplifting PS (n = 91) shows that on average Julian Alps uplift for a millimetre annually. Considering only the most extreme PS with uplifting velocities over 2.43 mm/year (upper 2.5 % of population; n = 5) the estimation of average vertical uplift of Julian Alps is 3.35 mm/year in relation to reference point. The velocity is unexpectedly high hence the possibility of data error should not be neglected. This dilemma will be solved in future research.

Table A.: Average daily or annual displacements (D) for a) PS with uplift velocity above 2.43 mm/y and b) PS with uplift velocity above 0.0 mm/y.

PS, where	Δh (mm)	D (mm/d)	D (mm/y)
a) D > 2.43 mm/y (n = 5)	29.16	0.0092	3.35
b) D > 0.0 mm/y (n = 91)	8.21	0.0026	0.94

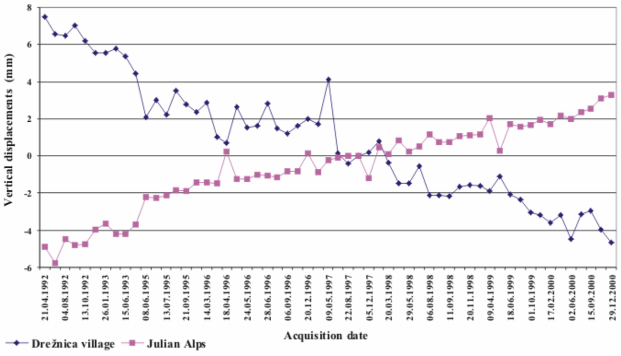

Figure 3.: Comparison of average relative vertical component displacements of 58 PS in the Drežnica village and average relative vertical component displacements of all uplifting PS situated in the Julian nappe (n = 91; PS with average displacement velocity above 0.0 mm/year), shown in blue and red respectively. All displacements are given in mm and represent the vertical component.

Figure 3 represents a comparison of average vertical component displacements of 58 PS in Drežnica village, situated on near the Ravne fault and Julian nappe contact, and average relative vertical component displacements of all uplifting PS situated in the Julian nappe (n = 91; PS with average displacement velocity above 0.0 mm/year). The village Drežnica "subsides" with velocity of 1.4 mm/year. The extraordinary displacements can be observed between 28th February and 9th May 1997. The similar but less obvious displacement in an opposite direction occurs in Julian Alps. A detailed analysis of seismic activity in the limited area around Drežnica indicates that several earthquakes occurred in the fall 1996 - spring 1997 period (29th Nov. 1996 (ML = 1.6) and 15th Feb. 1997 (ML = 2.3) (Živčić, 2006), which have caused described displacements. In the period between 15th March and 18th April 1996 synchronic but again opposite orientated displacements occurred. Similar but reverse phenomenon occurs between 9th April and 14th May 1996. When comparing displacements to seismic data (Živčić, 2006) the mentioned displacements can be related to coseismic surface movements. The cause for intensive displacements in April 1996 is unknown. It could be the consequence of a systematic error, or it could be connected to energy accumulation prior to the Friuli 13th April 1996 earthquake and post earthquake tremors three days later (ML = 4) (Živčić, 2006).

Coseismic surface displacements as a consequence of the Easter earthquake on 12th April 1998

During the PSInSAR monitoring of a major earthquake with magnitude of MW = 5.6 occured almost in the centre of the research area (Gosar et al., 2001; Zupančič et al., 2001; Bajc et al., 2001). The Figure 4 above shows locations of PS that have been affected by the 1998 Easter earthquake. The time displacements are shown below in the Figure 4 where only the displacement time span from January to September 1998, covering several moths before and after the 1998 Easter earthquake are shown. The surface displacements related to the earthquake are well seen, first a subsidence of an average 8.4 mm occurred somewhere between two to ten week after the earthquake, followed by an uplift of an average 12.3 mm. The time lag of displacements could be the consequence of post-earthquake surface "equilibration" or a consequence of systematic error of data during their processing, but the possibility of later is of almost negligible.

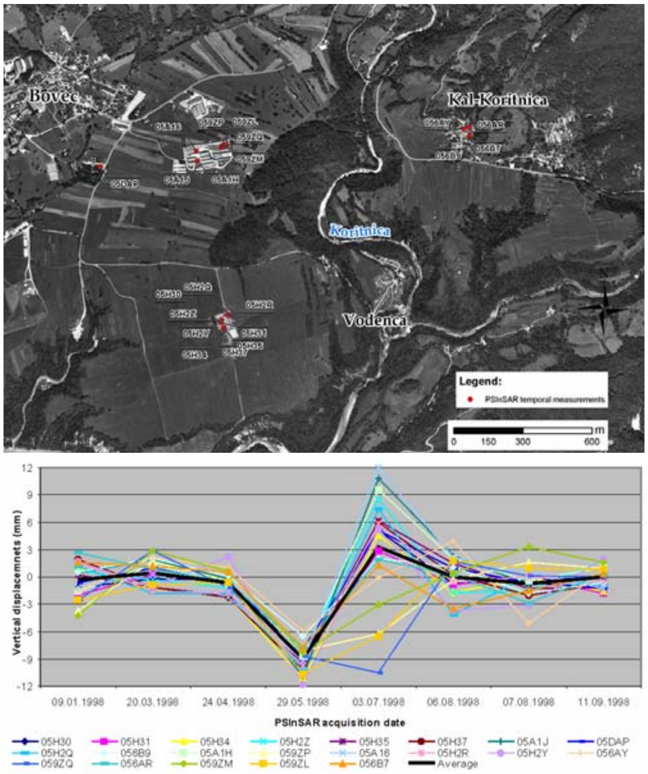

Figure 4.: Above – East part of Bovec basin area where relative vertical component displacements have been measured. Red points represent PS for which temporal displacements are show below. Below – Relative vertical component

displacements of PS situated in the east part of Bovec basin according to reference point. All displacements are given in mm and are projected to the vertical axis.

Slope mass movements

Slope mass movements in the research area, detected with the PSInSAR, are more related to tectonic activity than to other triggering factors (i.e. rainfall, human activity…). A general overlook of the research area indicates that majority of the “subsiding” PS indicate their connection to scree deposits and gravitational processes related to them. Analyses of average displacements have been conducted on several sites, Jablenca (6 PS), Koritnica (2 PS), Modrej (6 PS), and Ilovica (1 PS), marked as sites LS1, LS2, LS3, and LS4 respectively in Figure 1. From the movements of observed sites, trends of environs have been deducted to eliminate aseismic displacements in the surrounding areas. Displacement results have been compared to rainfall and seismic data to assess the causes of displacements. In case of Jablenca landslide it can be concluded that displacements are more governed by seismic activity than by rainfall, while for Koritnica and Ilovica sites the rainfall seems to be the main triggering factor, in case of later with a delay of one to two months, most probably due to its geological setting (shale with sandstone and limestone). In case of Modrej movements are most probably a combination of several factors, since neither seismic activity or rainfall are evidently related to displacements. Figure 5 represents the comparison of landslide displacements with monthly rainfall cumulative values.

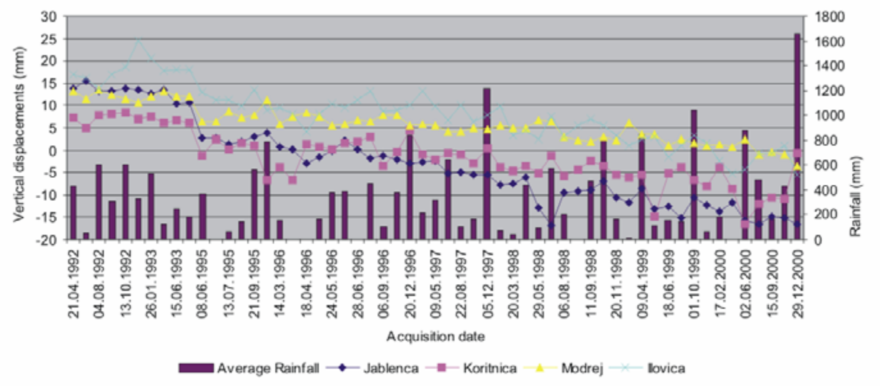

Figure 5.: Vertical displacements (mm) related to mass movements on four sites, Jablenca (LS 1), Koritnica (LS 2), Modrej (LS 3), and Ilovica (LS 4). Monthly rainfall cumulative values are represented with bars.

CONCLUSIONS

In case of uplifting the reasons are more or less clear, it is the consequence of active tectonics and those extreme ones are probably the result of locally limited conditions. On the contrary, the “subsidence” or moving downwards is more of a complex character. It is probably the combination of simultaneous influence of tectonics and gravitation. Most extreme movements are most probably indications of gravitational mass movements – landslides.

Julian Alps are uplifting but estimates from PS measurements differ very much from earlier research. Considering the most conservative approach it is roughly the same (1 mm/y), but considering the fastest uplifting PS, Alps are uplifting with velocities up to 3.35 mm/y. These values have to be interpreted very carefully, since the horizontal displacements can blur real vertical displacements noticeably.

To a certain degree mass displacements in form of landslides can be monitored, although same problems as with tectonic activity exist.

Further investigations would have to be upgraded with ground measurements and with InSAR data from ascending orbits to cover the south-facing slopes where majority of landslides in the area occur. Also more precise geological assessment of individual PS would have to be conducted.

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