

PERSISTENT SCATTERER SAR INTERFEROMETRY APPLICATIONS ON LANDSLIDES IN CARPATHIANS (SOUTHERN POLAND)

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ABSTRACT

This paper presents preliminary results of the application of Persistent Scatterers Interferometry (PSI) supported with detailed field landslide mapping. The research was focused on the areas located near the towns Rabka Zdroj and Jordanow located in southern-central Poland where detailed landslide mapping campaigns were performed in the summer of 2009. According to the field experience the average spatial density of landslide occurrence in both areas is up to 3 landslides/sq km.

The application of various Synthetic Aperture Radar (SAR) interferometry techniques on the above-mentioned areas was very difficult due to the very rough topography, vegetation and forest cover, and the long season with the snow cover. Following previous successful studies on other rural areas, PSI technique was therefore applied. Field work has been carried out within the frame of a national project launched in 2008 aimed to create a detailed database of all landslides in Poland. The areas where landslide problems are extremely important are the Polish Carpathians. As in previous experiments on a sparse urbanized area we noticed that it is still possible to successfully detect a number of persistent scatterers but, the interpretation of the associated deformation is difficult. However, based on cartographic data collected during the field mapping campaign it is possible to significantly improve analysis and interpretation of PSI results.

KEYWORDS: SAR Interferometry, Persistent Scatterers Interferometry, landslides, Carpathians

1. INTRODUCTION

Two years ago the Polish Ministry of Environment together with Polish Geological Institute initiated the national project named “The Protection System Against the Risk of Geodynamic Phenomena” (SOPO). One of the aims of the project was to create detailed evidence in the form of a digital database of all recently active and inactive landslides and areas of slope instability risks in Poland. The main part of the work is currently carried out by the field mapping in scale of 1: 10 000 in the Carpathians where more than 80 % of the total number of landslides in Poland is located because of the combination of the specific geological, geomorphological and hydrogeological conditions.

Since the SOPO project was launched, the interest on the applications of new remote sensing monitoring techniques became more important. Traditionally, to support the mapping of landslide extent and its internal structure a stereo-pairs of aerial photographs are applied. Recently stereo pairs were replaced by digital ortophotomaps with associated Digital Terrain Models (DTMs) and interpretation is done within Geographic Information System (GIS) environment. Another important goal of SOPO project

besides mapping is to establish a monitoring system on the landslides dangerous to infrastructure. The landslide monitoring systems consist usually on in-situ borehole measurements (inclinometers and piezometers) and on the surface, it consist of a set of geodetic benchmarks measured with GPS and tachymeter.

InSAR has been already recognized as a very effective low-cost technique for landslide deformation detection and monitoring (Colesanti and Wasowski, 2006). The application of various SAR Interferometric (InSAR) techniques like Differential InSAR (DInSAR) (Achache et al., 1995), Persistent Scatterers Interferometry (PSI) (Colesanti and Wasowski, 2006; Hilley et al., 2004), and Small Baseline Subsets (SBAS) (Lanari, 2003) proved their high reliability and usefulness. However, it should be noted that InSAR is an opportunistic technique (Hanssen, 2001) and it is not possible to predict its performance for a specific area and application prior to data processing. There are also several factors degrading the temporal and geometrical correlation of radar signals. In the case of the Carpathian landslides InSAR applications are extremely difficult due to the following environmental factors:

- very rough topography,
- lack of rock outcrops,
- dense vegetation cover (forests in the higher parts of the slopes and meadows and fields in the lower parts)
- bad weather conditions with high precipitation,
- long season with thick snow cover,
- very sparse urbanization concentrated in the valleys and along the roads.

However, PSI has been already successfully applied on rural areas (Ketelaar et al., 2004). This technique utilizes the long time series of the SAR data and allows overriding some of the above-listed limitations.

2. THE STUDY AREA

The current study was focused on two small areas located Rabka Zdroj and Jordanow towns in Beskid Wyspowy and Beskid Wysoki mountains respectively, which are the parts of Outer Carpathians ridge in southern Poland. The area presents typical Carpathian landscape with 700 m height differences (Fig. 1) and slopes ranging 5° to 15°. Some 30 % of the area mainly on the steep slopes and high altitudes is occupied by the forests. About 20 % of the area and most of the 0 to 10° slopes are deforested and used for agriculture. Farms and other buildings are sparse and located along the roads which are usually following the river valleys.

The authors participated in detailed landslide mapping campaigns performed in the summer of 2009 (Fig. 1). According to the SOPO mapping results the average spatial density of landslide occurrence in the study area is up to 3 landslides/sq km.

3. METHODS APPLIED

The measurements of landslide deformations are from the technical viewpoint very difficult, time consuming and expensive. Moreover, for the reliable results the measurements must be done repeatedly over many years. Due to that fact such measurements are performed rarely and only in hazardous situations. InSAR is one of the most advanced techniques for the measurements of subtle, very slow movements.

Point-wise approaches like the permanent scatterers technique (Ferretti et al., 2000; Ferretti et al., 2001) allows going beyond the current limitations of interferometry. This method and its modifications, the so called Persistent Scatterers techniques (PSI, see e.g. (Crosetto et al., 2002; Hooper et al., 2004) utilizes the identification and the exploitation of stable natural radar reflectors. The dimensions of the reflectors are usually smaller than the resolution cell and their coherence remain high for large temporal and geometrical baselines. The PSI technique is expanding now towards the decorrelated areas with low PS

density and a small deformation signal (Ketelaar et al., 2004).

The terrain surface displacement associated with landsliding is fully three dimensional. It should be noted that the InSAR and PSI techniques are capable only to measure path differences in one direction, which is the Line of Sight (LoS) direction. Therefore, having only one projection of the three-dimensional displacement to the radar LoS, it is not possible to retrieve the full displacement vector. To properly reconstruct the displacement into e.g. horizontal and vertical components the InSAR measurements must be taken from two directions (ascending and descending interferograms). For the third component, assumptions or the measurements taken by other techniques are necessary. Unfortunately within this study only data acquired from one direction (the descending satellite pass) were available. Therefore, within this study only LoS deformation is considered since no ground truth data are available.

The results of PSI must be very carefully analyzed. The main uncertainties associated with PSI method are related to the proper phase unwrapping. In most cases phase unwrapping errors are associated with low density networks of PS candidates and too long arcs. For non-linear deformations the phase component associated with the deformation signal might be mixed with atmospheric component.

4. DATA PROCESSING

The interferometric processing for the study area was performed based on 50 ERS-1/2 SAR images covering more than 8 years period from 18 June 1992 to 17 December 2000. The data acquired from the descending satellite track (Fig. 1) were used. For PSI processing the TUDelft implementation (Leijen et al., 2005) of the original Persistent Scatterers algorithm was applied. For DInSAR part of the processing the Delft Object Oriented Interferometric Software (DORIS) was used (Kampes et al., 2003).

To minimize the effect of topography on the interferograms, which is significant within the study area, the DTED level 2 DEM with a post spacing of one arc second (~30 meters) was applied (<http://www.vterrain.org/Elevation/dted.html>).

Coregistration of the image pairs was performed applying the optimization of window distribution based on SAR amplitude and the optimization of the computation of coregistration polynomial. The mentioned method ensures correct coregistration even on areas lacking of urbanisation and was successfully applied by (Perski et al., 2008).

During the processing of all available images it was found that only a small number of PS could be obtained. Unfortunately PS points were located in the densely urbanised areas of Jordanow and Rabka towns. To increase the number of PS, different processing strategies were tested. Finally, the best

results were obtained with only 29 SAR images. The ERS-1 images acquired before 1995 and all the scenes containing snow cover were excluded. Snow cover existence and the meteorological parameters were checked with the daily meteorological bulletins issued by the Institute of Meteorology and Water Management. Thick and wet snow cover change indeed scatterer characteristics of the underlying ground. This operation it is a common procedure used mainly for a standard InSAR processing. In most cases PS are not sensible to atmospheric conditions but thick snow cover may simply mask many of them.

For the integration of the interferometric data within a GIS system the interferograms and the PS points must be geocoded. To convert the data from the slant-range geometry into a cartographic coordinate system the acquisition timing, its geometry and the terrain topography must be known. Usually a DTM is used for this purpose. For the study areas the photogrammetric DTM of one meter resolution was applied. That type of DTM is a product available together with digital aerial orthophotomaps provided by the regional (provincial) cartographic office in Krakow. The applied DTM allows precisely geocode standard interferograms (up to 0.5 pixels). The only problem appears for precise location of PS points. The proper PS geolocation depends whether the point is located on the terrain or at the top of a building. Since the DEM represents the terrain surface (buildings and other structure were filtered out) it may introduce an error of a few meters in the case of a typical building height of 10 m.

The final analysis of the geocoded PSI data requires a GIS environment which allows combining all the interferometric results and external data into one common reference system. For this purpose the open-source GRASS (Geographic Resources Analysis Support System) was applied (GRASS-Development-Team, 2006).

5. RESULTS AND INTERPRETATION

Finally 3648 PS points, which present good quality, were obtained (Fig. 2). Most of the PS are related to the man-made structures; therefore points are distributed along main valleys where all the settlements are concentrated.

Most of the points report linear deformation within a fraction of near 1 mm/year therefore presents stable areas with no movement. However within our study area there were individual points or small clusters of PS with a higher magnitude of the linear movement. Detailed analysis of their deformations in time and their locations were performed following the field verification. It could be stated that in most cases the high rate of deformation is related to landslide deformations. Some examples are presented in Figure 3 and discussed below.

5.1. EXAMPLE A

Persistent Scatterers (PS) in the village of Osielec exhibit a small cluster of the points related to the buildings near the Osielec-Jordanow road. The road is frequently damaged by the landslides on the distance of few kilometres. There are large rotational rock-type landslides developed on the contact between the Osielec sandstones and different types of shells being reactivated during wet seasons. The buildings and the road are located in the middle part of the slope with no clear evidence of landslide. However, the existence of the landslides in the neighbourhood and some evidences of the surface mass-movements suggest high landslide hazard and may indicate new landslide development. The basement of one building is damaged. A 2.6 mm linear deformation rate of the PS located on that specific building was recorded.

5.2. EXAMPLE B

This area is also located along the Osielec-Jordanow road. In this area the road cut is located very closely to the active landslide scarp. The road and its cuts and scarps were repaired and reinforced in 2008 after the damages caused by the active landslide. The PS points are located on the road scarp and on the buildings above. The analysed PS is located on the road cut and it reveals a linear velocity of deformation of 3.8 mm/year. Since the ERS-1/2 data series cover the period until the end of 2000 PS records the early stage of deformation responsible for the damage before the reparation works.

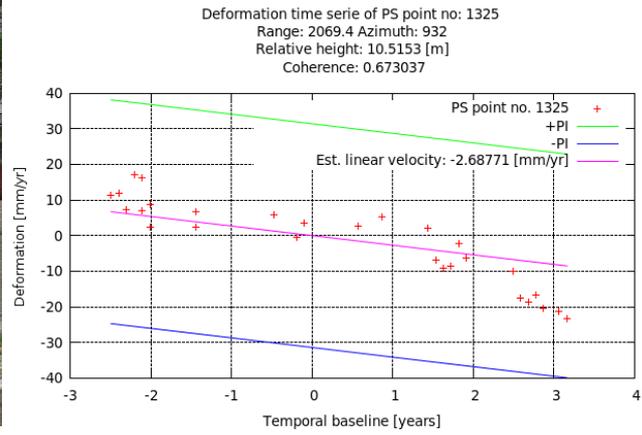
5.3. EXAMPLE C

It is located in Rabka city where the active landslide is located on the northern slope of the local river valley. It is a densely urbanised residential district. The entire area is used for housing and gardens and do not present therefore a natural surface. In such an environment it is very difficult to classify an active landslide because no fresh damages are visible. In addition all small damages and ground deformations are usually quickly repaired by inhabitants. The PS's obtained within this area with linear deformation of 3.5 mm/year confirm the existence of a suspected landslide hazard.

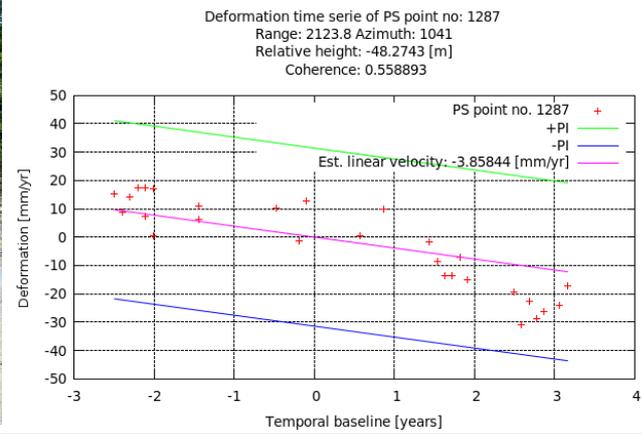
6. CONCLUSIONS AND FUTURE WORK

The presented preliminary results of the detailed PS dataset analysis show that PS results, even on very problematic areas may present reliable information. Careful PS processing of ERS data results in high PS data quality, however it also decreases the total number of PS points detected. Detailed analysis of landslide deformation using PS data in Carpathians is possible, however very difficult. Further studies will focus on the following issues:

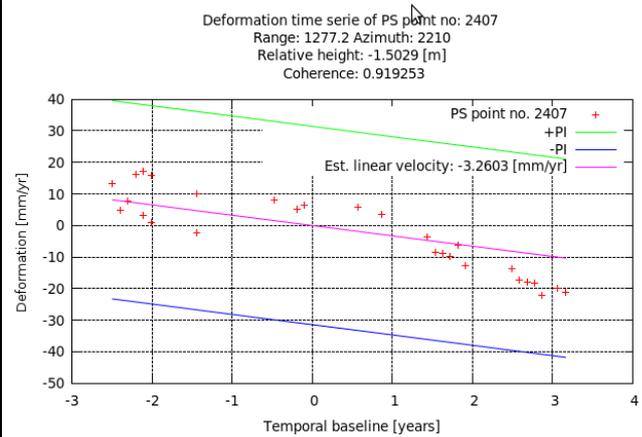
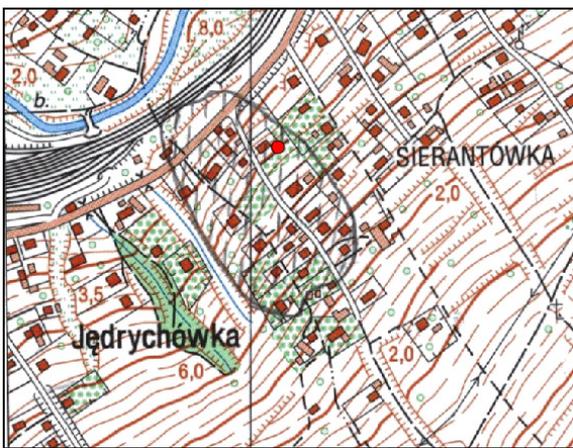
1. Application of external information for the PS data processing. The application of ASL (airborne



EXAMPLE A



EXAMPLE B



EXAMPLE C

Fig. 3 Examples of interpretation and verification of PS time series. For more explanations see the text.

laser scanning) and terrestrial laser scanning are planned in the following months. Detailed DEM will be used to support SAR data coregistration and will help to estimate PS height.

2. Field verification of detected PS points and detailed interpretation of deformation origin.
3. Application of different InSAR approaches like SBAS (Lanari, 2003) and StaMPS (Hooper et al., 2004) towards the detection of more scatterers in vegetated areas.

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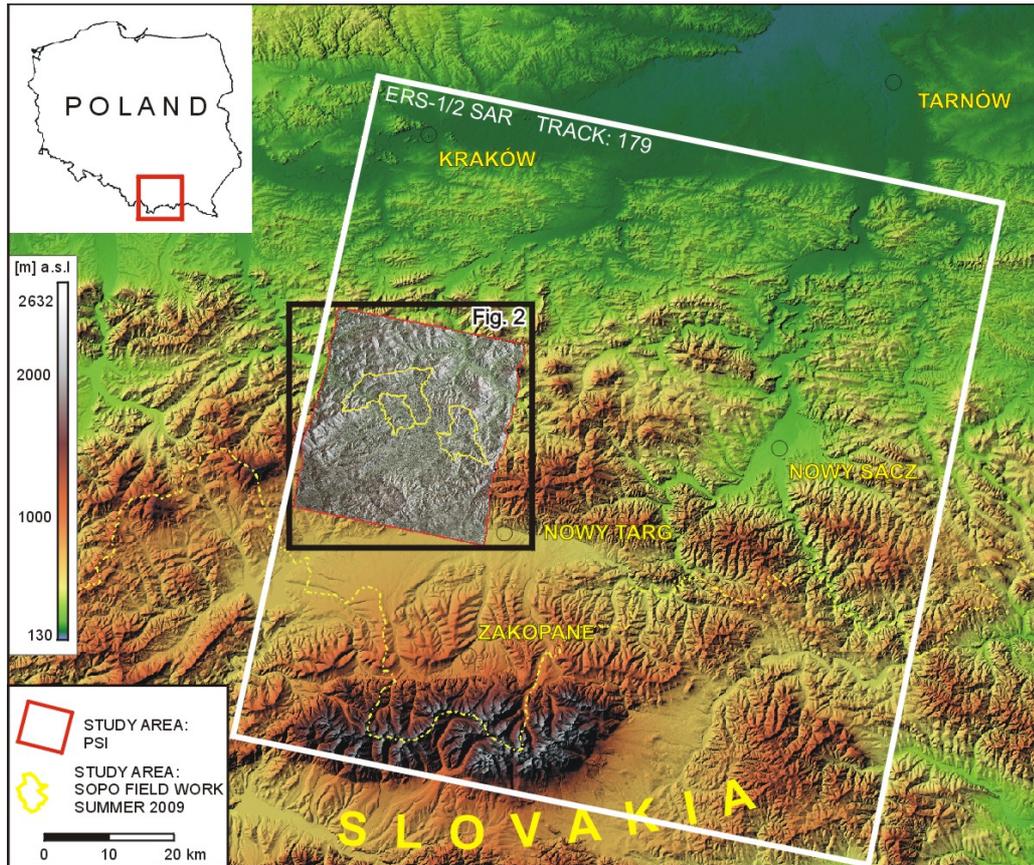


Fig. 1 Location of the study area. Shaded relief topography processed from DTED Level2 DTM (courtesy of Ministry of National Defence Poland).

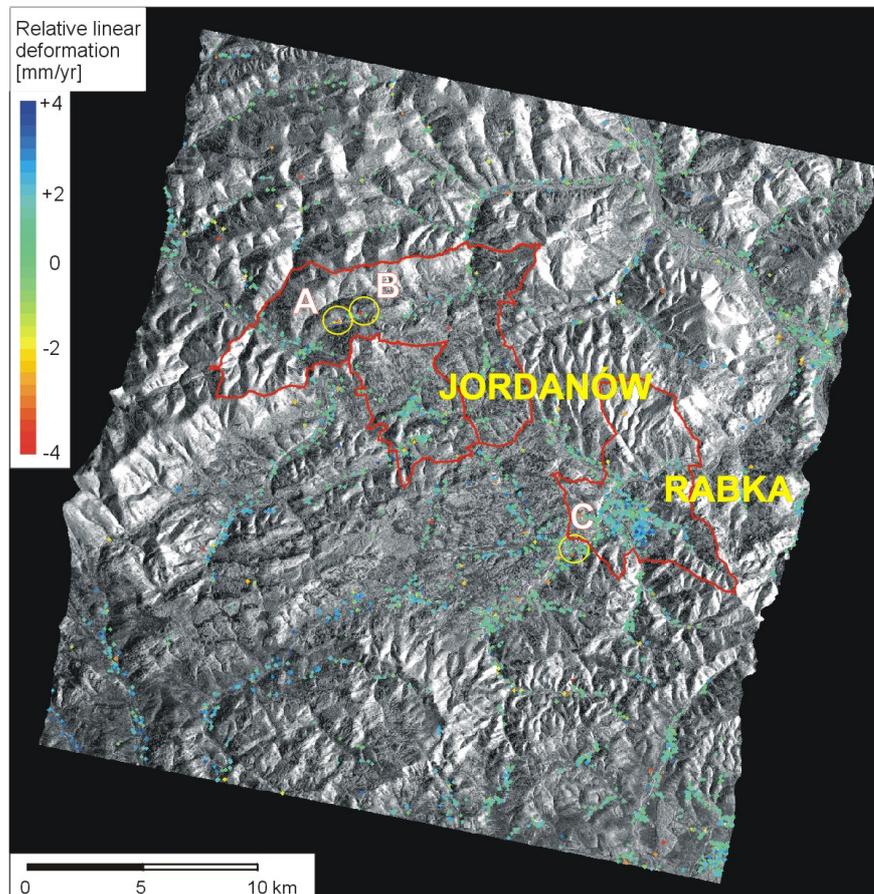


Fig. 2 PSI dataset of the study area with locations of individual examples discussed below. Background: averaged SAR amplitude (multi-image reflectivity map). Red lines present the extents of SOPO field mapping performed by University of Silesia Team in summer of 2009.