DEFORMATION OF THE MARGIN OF SUDETY MOUNTAINS (SOUTHERN POLAND) STUDIED BY PERSISTENT SCATTERERS INTERFEROMETRY

Zbigniew Perski (1), Ramon Hanssen(2), Petar Marinkovic(2)

(1) Faculty of Earth Sciences, University of Silesia,Bedzinska 60, 41-500 Sosnowiec, Poland,
Email: Zbigniew.Perski@us.edu.pl
(2) Delft Institute of Earth Observation and Space Systems; Delft University of Technology
Kluyverweg 1, 2629 HS Delft, The Netherlands,
Emails:R.F.Hanssen@TUDelft.nl, P.Marinkovic@TUDelft.nl

ABSTRACT

The scope of this work was to use the newest achievements in a field of SAR Interferometry to measure recently occurring natural earth surface movements in south-western Poland and near-border areas. The presented work is a part of the GEO-INSAR project which aimed to perform InSAR deformation measurements in recently active areas in Poland. This paper presents the results of PSInSAR study of Wrocław city and Paczków tectonic graben. The analysis of the obtained results and their comparisons with the levelling data and geological information show hifh consistency of the results and reveals that the measured deformations are related mostly to the changes of the ground water level.

1. INTRODUCTION

The GEO-IN-SAR project is focused on application of SAR (Synthetic Aperture Radar) interferometric (InSAR) methods for the study of natural earth surface displacements in Poland. The main idea of the project is to use the newest achievements in a field of SAR interferometry to measure recently occurring earth surface movements on the areas where the evidence of vertical movements have been archived. Three study areas have been selected: Sambia peninsula and Warmia area which was affected by the strong and unexpected earthquake in September 2004, the area of Lower Silesia where the system of recently active faults has been mapped as e.g. Paczkow tectonic graben. The third region is located in Podhale and Tatra Mounatins which is dominated by young alpine tectonics associated with geothermal springs and frequent earthquakes (Fig. 1).

This paper presents the preliminary results of Lower Silesia area where interesting deformations were measured within two areas of Paczkow Graben and Wrocław basin.

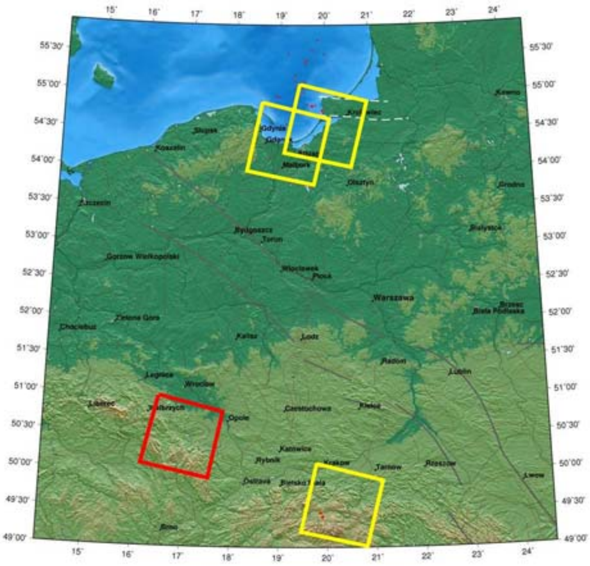

Figure 1. The areas of interest of GEO-IN-SAR project (yellow). Red rectangle denotes the location of Lower Silesia area discussed in this paper

2. SUDETIC MARGINAL FAULT AND NEOTECTONIC ACTIVITY OF LOWER SILESIA

Poland is a country of low seismic risk. However, there are areas where natural surface movement of the amplitude more than some millimetres per year have been archived [1].

The Sudetic Marginal Fault (SMF) is one of the longest and and most important faults in south-western Poland [2]. As a morphological border the SMF separates two regions showing differentiated morphology: the Sudetes, represented by mountain ranges broad ridges and deeply dissected uplands of average altitude of 400-800 m a.s.l. near the fault; and the Sudetic Foreland of gently undulated relief (approximately 200-300 m a.s.l.). Despite its morphological distinctness, the evolutionary history of this fault has not been fully recognised yet. It is originated during Variscian orogeny and becomes reactivated during Alpine cycle [3, 4]. The presence of overhanging valleys and rocky steps [3] and fractured clasts in river gravels [5] appear to confirm the recent tectonic mobility along SMF.

Two large artificial water reservoirs on Nysa Kłodzka river are located within the area of Paczków tectonic graben: Otmuchów Lake and Nysa Lake. The reservoirs were located on a tertiary tectonic faults covered by 10-40 m thick quaternary deposits. The precise leveling measurements were carried out within this area since 80-s by Department of geodesy of Wrocław Agriculture Academy. Recently the measurements are continued with GPS equipment within the framework of the international GEOSUD II project [6]. The highest rates of deformations (some mm/year) measured in a framework of that project has been recorded in Paczkow Graben. The benchmark measured in Nysa town measured in 80's show significant lowering [6] and that downward movement was expressed on map of vertical movements in Poland completed by Wyrzykowski [1]. According to more recent measurements the area has a tendency to uplifting [7]. Significant changes of gravity (Δg) were registered between 1997 and 1998 and that changes are interpreted as related to the catastrophic flood in Nysa Kłodzka river valley (July 1997). However, gravity changes between 1993 and 2003 reached significant negative values (-44 μGal to -131 μGal) what also suggests the uplifting [8].

3. METHODS OF THE STUDY

The measurements of natural terrain deformations are from technical viewpoint very difficult, time consuming and expensive. Moreover, for reliable results the measurements must be done repeatedly over many years. Due to that fact and due to a small practical importance such measurements are performed rarely. InSAR is one of the most advanced techniques for the measurements of subtle, very slow movements which are usually announcing the seismic risk.

Natural recent surface movements have not yet been studied with InSAR in Poland. Similar works abroad have been focused on relatively high rate displacements like e.g. rifting activity in Iceland [9] or the development of anticline in Taiwan [10]. In Europe, the most of InSAR deformation studies have been focused on anthropogenic (technogenic) phenomena (e.g. [11]) Very few works have been done on landslides or natural subsidence (e.g. [12], [13]).

Since the beginning, in the early 90s, the InSAR and D-InSAR methods have been used in various research projects. However, despite their high potential, these methods have not reached an operational status yet. The current problems of InSAR are not only related to the SAR sensor itself, but also to the SAR signal interaction with environment: a) The seasonal backscatter variability, which causes the temporal decorrelation; b) The variable weather conditions, especially those related to surface moisture that cause decorrelation; c) The local atmospheric conditions that introduce phase errors; d) The local topography, which affects the accuracy of the D-InSAR measurements.

The recently developed point-wise approaches like Permanent Scatterer technique [14], [15] allows going beyond the current limitations of interferometry. This method and its modifications, so called Persistent Scatterer Techniques (PS) – see e.g. [16, 17] utilizes identification and exploitation of stable natural radar reflectors. The dimensions of the reflectors are usually smaller that the resolution cell and their coherence remain high for large temporal and geometrical baselines. The PS-InSAR technique is expanding now towards decorrelated areas with low PS density and a small deformation signal [18].

The interferometric processing for the study area was performed based on 67 ERS-1/2 SAR images covering almost 8-year period from 04 April 1992 to 11 January 2001. The data acquired from the descending satellite track (Fig. 1) were used. For PSInSAR processing the TUDelft implementation [19] of original Persistent Scatteres algorithm was applied. For D-InSAR part of the processing the Delft Object Oriented Interferometric Software (DORIS) was used [20]. Final analysis of the PSInSAR results requires GIS environment which allows putting all interferometric results and external data into one common reference system. For this purpose open-source GRASS (Geographic Resources Analysis Support System) was applied [21].

4. RESULTS AND INTERPRETATION

Recently two crops were processed within Lower Silesia SAR scene. The processing for the area of Wroclaw town and surroundings has been designed as a "blind" PSInSAR experiment. The initial idea was to test SAR data quality against PSInSAR method over the densely urbanised area where many PS points were expected. The following processing of Paczków area was also performed in a "blind" mode since it was not clear how many scatterers will be detected and whether will be possible to detect any deformation.

4.1. Wrocław area

As the input for the PSInSAR processing 64 interferograms were used. During PSInSAR processing linear model of deformation was assumed. For the most of the points with high coherence the resulted relative linear velocities are varying between -3 and +3 mm/year. The points showing a relative uplift are located in south-western part of the city whereas subsiding points are scattered almost randomly with higher concentration near the Odra river (Fig. 2). It should be noted that the observed "upward movement" is relative to the reference point located in the northern part of the processed crop and highlights only relative differences of velocities within spatial and temporal framework of PS processing. However, the comparison with results of vertical movements of levelling benchmarks between 1968 and 1998 [22] reveal high correlation. Both datasets show upward movement in the south-western part of the city. According to [7] the reason of the uplift is related to ground water level changes. In the south-western part of Wrocław water withdrawal was carried out for industrial purposes. Due to changes in economy and technology and also due to collapse of heavy industry in Wrocław the groundwater use was significantly decreased after 1990 year.

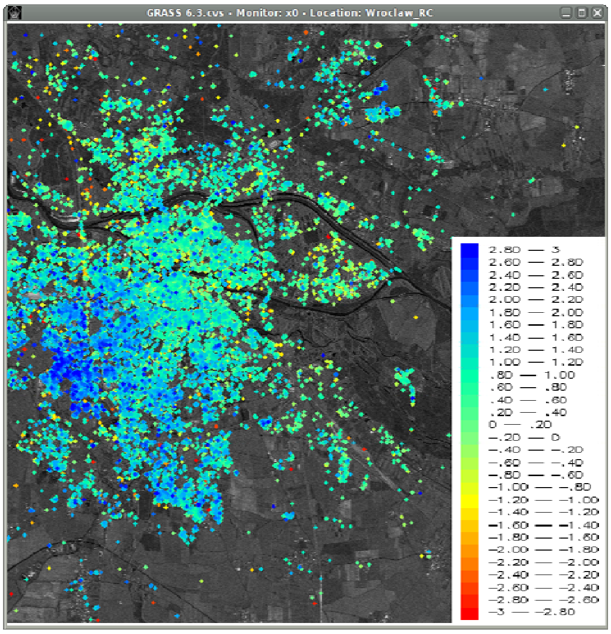

Figure 2. The PSInSAR results of Wrocław area. The relative velocities are varying between -5 and 5 mm/yr.. The crop size is approx 18 x 18 km

4.2. Paczków area

Due to very sparse urbanisation and presence of agriculture and large areas occupied by water the problem of coregistering of the SAR images has been noted. The problem was solved by application of the coregistration with optimization of window distribution based on amplitude and optimization of the computation of coregistration polynomial. As the input for PSInSAR processing also 64 interferograms were used. The results show the appearance of the clusters of PS points associated with towns: Nysa, Paczkow and surrounding villages. The connection between those two main clusters is made trough sparse PS points located around water reservoirs and on dams. As in case of Wrocław area the linear model was applied for PSInSAR processing. The obtained linear velocities are ranged between -5 and +5 mm/year for the majority of highly coherent points (Fig. 3). The most interesting feature is the cluster of PS points located within Nysa town. The Nysa town with 47 thousands of inhabitants occupies the area of 27 km^2 which allows to obtain high PS density (> 100 PS/km^2) with reference point located in the north-western part of the city. The densely urbanised centre of the town show relative upward deformation of 5 mm/year. Accordingly, the most of the surroundings of Nysa Lake and Paczków town reveal subsidence of some of 2 mm/year. Those areas might be considered as "stable". The relative uplift of Nysa town is very consistent and showing zones of gradual decrease of deformation towards to the limits of the urbanised area. The high consistency of the first results convinced us to process the slightly larger crop of the same dataset. Obtained results of that second PSInSAR processing shows the same pattern. As it was described in section two the upward movement of Nysa town has been already reported by [8] and [7] based on levelling and gravity data. However the origin of that deformation is not clear. The most probable explanation is the groundwater level rise due to changes in industrial technology and economy of the region. The role of active faults mapped in that area is still not confirmed.

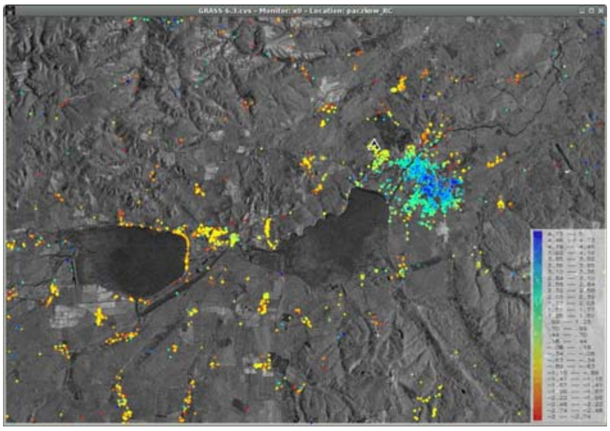

Figure 3. The PSInSAR results of Paczków area. The relative velocities are varying between -5 to 5 mm/yr. The crop size is approx 58 x 17.5 km

5. CONCLUSIONS AND FUTURE WORK

The preliminary PSInSAR processing on SAR data from Lower Silesia area does not allowed to clearly detecting any recent tectonic movement. However, the „blind" experiments over relatively small areas proved high reliability of PSInSAR results. Obtained results show that the deformation signal detected within urban areas is very sensitive to the ground water level changes.

The further works will focus on the selection of larger and more representative crops, the alternative processing with different master scene for cross-validation of the results and the removal of periodic signal related to seasonal groundwater level change and tests with other than linear model. The cross-validation with other point wise InSAR techniques (e.g. StaMPS, SBAS) is also planned.

6. ACKNOWLEDGEMENT

ERS-1 and ERS-2 SAR data used in this work are the courtesy of ESA project C1P.3915. The research was funded by Polish Ministry of Scientific Research (grant no. T12E04329). The authors wish also to acknowledge dr. Janusz Badura from Polish Geological Institute and dr. Piotr Grzempowski from Institute of Geodesy And Geoinformatics, Wroclaw University of Environmental and Life Sciences for providing us geological and leveling data for the study area.

7. REFERENCES

1. Wyrzykowski, T., Map of the Recent Vertical Movements of the Surface of the Earth Crust on the Territory of Poland. 1985, Institute of Geodesy and Cartography: Warsaw.
2. Zuchiewicz, W., J. Badura, and M. Jarosiński, *Neotectonics of Poland: An overview of active faulting.* Studia Quaternaria, 2007. **24**: p. 5-20.
3. Badura, J., et al., *Morphotectonic Properties of the Sudetic Marginal Fault, SW Poland.* Acta Montana, 2003. **Series A**(24): p. 21-49.
4. Badura, J., B. Przybylski, and W. Zuchiewicz, *Cainozoic Evolution of Lower Silesia, SW Poland: A New Interpretation in the Light of Sub-Cainozoic and Sub-Quaternary Topography.* Acta Geodyn. Geomater., 2004. **1**(3): p. 7-29.
5. Badura, J., et al., *Terraces of Nysa Kłodzka river and small-scale tectonic structures close to the Sudetic Marginal Fault (Bardo Mts.).* Przegląd Geologiczny, 2007. **55**: p. 228-235.
6. Cacoń, S. *Recent earth crust movements in the Sudety Mts. - GEOSUD project*. in *The 10-th FIG International Symposium on Deformation Measurements*. 2001. 19-22.03, Orange, California, USA.
7. Kowalczyk, K., *New Model of the Vertical Crustal Movements in the Area of Poland.* Geodesy and Cartography, 2006. **32**(4): p. 83-87.
8. Cacoń, S., S. Dyjor, and B. Kontny. *The recent movements of earth crust surface in Sudety and their foreland*. in *IV Conference on Neotectonics of Poland: Active Faults of Central Europe*. 2005. Srebrna Góra 26-28.09: Polsh Academy of Science.
9. J\'onsson, S., *Modeling of Volcano and Earthquake Deformation from Satellite Radar Interferometric Observations*. 2002, Stanford University. p. 164 pp.
10. Fruneau, B., et al., *Uplift of Tainan Tableland (SW Taiwan) revealed by SAR interferometry* Geophysical Research Letters, 2001. **28**(16): p. 3071-3074.
11. Perski, Z. and D. Jura, *ERS SAR Interferometry for the Land Subsidence Detection in Coal Mining Areas.* Earth Observation Quartery, 1999. **63**: p. 25-29.
12. Colesanti, C. and J. Wasowski, *Investigating landslides with space-borne Synthetic Aperture Radar (SAR) interferometry.* Engineering Geology, 2006. **88**: p. 173-199.
13. Strozzi, T., et al., *JERS SAR interferometry for land subsidence monitoring.* IEEE Transactions on Geoscience and Remote Sensing, 2003. **41**(7): p. 1702- 1708.
14. Ferretti, A., C. Prati, and F. Rocca, *Permanent Scatterers in SAR Interferometry.* IEEE Transactions on Geoscience and Remote Sensing, 2001. **39**(1): p. 8-20.
15. Ferretti, A., C. Prati, and F. Rocca, *Nonlinear Subsidence Rate Estimation using Permanent Scatterers in Differential SAR Interferometry.* IEEE Transactions on Geoscience and Remote Sensing, 2000. **38**(5): p. 2202-2212.
16. Crosetto, M., et al., *Subsidence monitoring using SAR interferometry: Reduction of the atmospheric effects using stochastic filtering.* Geophysical Research Letters, 2002. **29**(9): p. xxx.
17. Hooper, A., et al., *A new method for measuring deformation on volcanoes and other non-urban areas using InSAR persistent scatterers.* Geophysical Research Letters, 2004. **31**: p. L23611, doi:10.1029/2004GL021737.
18. Ketelaar, G., P. Marinkovic, and R. Hanssen. *Validation of point scatterer phase statistics in multi-pass InSAR*. in *ENVISAT & ERS Symposium, Salzburg, Austria, 6-10 September, 2004*. 2004.
19. Leijen, F.J.v., et al. *Persistent Scatterer Interferometry: Precision, Reliability and Integration*. in *ISPRS Workshop, High-Resolution Earth Imaging for Geospatial Information, Hannover, Germany, 17-20 May 2005*. 2005.
20. Kampes, B.M., R.F. Hanssen, and Z. Perski. *Radar Interferometry with Public Domain Tools*. in *Third International Workshop on ERS SAR Interferometry, `FRINGE03', Frascati, Italy, 1-5 Dec 2003*. 2003.
21. GRASS-Development-Team, *Geographic Resources Analysis Support System (GRASS) Software.* . ITC-irst, Trento, Italy. http://grass.itc.it 2006.
22. Grzempowski, P. and S. Cacoń, *The cause analysis of benchmark movements in the city of Wrocław.* Reports on Geodesy, 2005. **74**(3): p. 271-281.