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NON-PARAMETRIC APPROXIMATION USED TO ANALYSIS OF PSINSAR^{TM} DATA OF UPPER SILESIAN COAL BASIN, POLAND

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ABSTRACT
In the paper, an attempt to interpret the PSInSAR data for the northern part of the Upper Silesian Coal Basin with the use of kernel approximation is described. The PSInSAR technique is characterised by the Permanent Scatterer points (so-called PS points, Permanent Scatterers), which usually correspond to the objects such as: buildings, industrial and transport infrastructure, and natural components of surface relief (Ferretti et. al., 2000, 2001). The PSInSAR technique allows to monitor ground movements. A non-uniform distribution of the PS points makes the interpretation of PSInSAR data difficult, as well as the fact that one point can assume both positive and negative values. The application of the kernel approximation for the interpretation of the PSInSAR data allowed of more unambiguous interpretation.

KEYWORDS: PSInSAR, non-parametric kernel approximation

INTRODUCTION

The Upper Silesian Coal Basin (USCB) is characterised by a complicated geological structure, which is affected by the over 200-year hard coal mining. The hazards caused by the induced seismicity and ground subsidence are connected with the hard coal mining. The mining induced earth shocks can be divided into two groups (Teper, 1998): the first one constituted by low-energy shocks directly attributed to the mining, and the second one, which is associated with higher-energy phenomenons showing the relation to orogenic structure. The hazards arising from the formation of subsidence and induced seismicity-related troughs necessitate monitoring the USCB area. With the use of an established geodetic network in the first case, and by means of a seismic network in the second case. The availability of satellite data resulted in the development of novel methods, which can significantly affect the monitoring quality of an endangered area. The InSAR satellite interferometry (Perski, 1999) was used for monitoring the USCB. The next development stage of the satellite interferometry is the PSInSAR technique.

The satellite interferometric synthetic aperture radar (InSAR) method is based on the measurement of the phase differences between two SAR images. As a result of calculations an interferogram, i.e. an image of the phase differences of two radar pictures, is obtained. The quality of the obtained interferograms is affected, among other things, by the distance in time between two pictures. The bigger it is, the worse the quality of the interferogram. Therefore, better results can be achieved with the use of the PSInSAR technique when planning a longer monitoring, e.g. of ground subsidence in mining areas or landslides.

PSInSAR (Permanent Scatterer Interferometry) is the technique, which facilitates the detection of conspicuous objects, so-called PS points (Permanent Scatterers) and reduces negative influence of atmospheric conditions while taking pictures (Ferretti et. al., 2000, 2001; Hanssen, 2004; Kampes, 2006) in consequence of the use of a large number of satellite images (over 30). The PS points usually correspond to the objects such as: buildings, industrial and transport infrastructure, and natural components of surface relief (e.g. geological outcrops). The possibility to measure a displacement with millimetre precision is undoubtedly an advantage of the PSInSAR technique. On the other hand, very high precision is also a limitation on this method as the ground deformation should develop relatively slowly – fast displacements exceeding 5-6 cm/year will not be recorded. Another limitation on this method is the required density – at least 3 PS points per km^2, which makes that the method provides very good results, in principle, in heavily urbanised areas, only.

GEOLOGY OF INVESTIGATED AREA

The Upper Silesian Coal Basin constitutes a foreland subsidence basin, which has been formed in the foredeep of the Moravian-Silesian orogenic zone (Bukowy, 1972; Kotas, 1972; Kotas, 1985; Znosko, 1965). The deposits filling this subsidence basin are related to the Variscan coal-bearing formation of the subsidence basin and are composed of two horizons: the older one built from the deposits of Devonian and Lower Carboniferous carbonate association, and Molassian horizon. The Molassian horizon is divided into a lower one – comprising Upper Carboniferous deposits (coal-bearing sequence), and an upper one – built from Lower Permian rocks. The Upper Carboniferous coal-bearing deposits of the USCB are built from clastic and coal deposits while the deposits forming older substratum of the basin are mainly metamorphous and magmatic rocks.

In the coal-bearing sequence, three zones of structural development can be distinguished: a fold tectonics zone, a block tectonics zone, and a fold-block tectonics zone, which extends beyond the basin area (Kotas, 1972).

The fold tectonics zone comprises the western part of the basin fringe. Multiple unsymmetrical folds and troughs are observed within the fold tectonics. The troughs are situated, to a greater or lesser extent, in two parallel belts and usually occur in pairs – facing each other. The major dislocations of this zone are the Michałkowice-Rybnik and Orlova-Boguszowice overthrusts. Moreover, the fold tectonics area is cut by downthrow and downthrow-shift faults.

From the east side, the fold tectonics zone borders the block tectonics zone, which covers the major part of the basin. The block tectonics zone is characterised by almost flat-laying deposits of the coal-bearing formation. The largest part of the block tectonics zone is occupied by the main trough. From the north side, the main trough is adjacent to the Main Syncline. Numerous faults occurring in this part of the basin are in the main downthrow and downthrow-shift. Besides, the dislocations with the features of typical shift faults were found, too. The Kłodnica, Książ, Bełk and Jawiszowice faults are counted among the biggest faults of that area.

The fold-block tectonics zone extends over the northern and north-eastern parts of the basin. The zone is characterised by the occurrence of the approximately NW-SE striking folding units (brachy-synclines and brachyanticlines) and the NW-SE striking faults, copying the course of the basin border and axes of the folding units. The Krzeszowice and Wojkowice-Będzin fault systems are counted among the biggest dislocations of this tectonics zone.

NON-PARAMETRIC KERNEL APPROXIMATION OF VERTICAL VELOCITY FIELD OF LAND SURFACE

The data obtained with the use of the PSInSAR technique covering the north-eastern part of the Upper Silesian Coal Basin with a surface area of approx. 1210 km^2 were used in this work (Fig. 1). The radar pictures were taken by the ERS-1, ERS-2 and ENVISAT satellites and cover a period of time of 1992 to 2003.

The presentation of the analysis results of vertical movements of the Earth surface by the PSInSAR method may significantly affect the interpretation of the results. As a result of the analysis, the velocities of the vertical movements at points non-uniformly distributed over the given area are obtained, in spite of the fact that the SAR pictures are taken on a regular grid. The reason for this is that the objects situated within the given pixel area have the ability to scatter radar waves. An additional interpretation problem is the fact that the pixels with a positive velocity (uplift) are found in the immediate vicinity of the pixels with a negative velocity (subsidence). In Figure 2, there is an enlarged part of the area where black points with negative velocities and white points with positive velocities are visible.

The result analysis was carried out using a non-parametric kernel approximation. It is an universal tool that enables the fit of the curve to a set of data without assuming any mathematical model. The most frequently used estimator is the Nadaraya-Watson estimator (1) (Nadaraya, 1964):

$$\hat{f}(x) = \frac{\sum_{i=1}^{n} v_i K\left(\frac{x - X_i}{h}\right)}{\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right)} \tag{1}$$

In equation (1), *K(x)* is the kernel function, which in most cases is the Gaussian probability density function. For a one-dimension case, it assumes the form (2)

$$K(x) = \frac{1}{\sqrt{2\pi}} e^{\frac{-x^2}{2}} \tag{2}$$

Apart form the afore-mentioned Nadaraya-Watson estimator, other estimators for the regression function have been developed, too, e.g. Priestley-Chao or Gasser-Müller estimators (Gasser and Müller, 1979; Gasser and Müller, 1984; Priestley and Chao, 1972) discussed in a more detailed manner in (Jones et al., 1994).

In the case of the analysis of surface data, the two-dimensional Gaussian kernel (3) and estimator (4) are used.

$$K(x, y) = \frac{1}{2\pi} e^{\frac{-\left(x^2 + y^2\right)}{2}} \tag{3}$$

$$\hat{f}(x, y) = \frac{\sum_{i=1}^{n} v_i K\left(\frac{x - X_i}{h_x}, \frac{y - Y_i}{h_y}\right)}{\sum_{i=1}^{n} K\left(\frac{x - X_i}{h_x}, \frac{y - Y_i}{h_y}\right)} \tag{4}$$

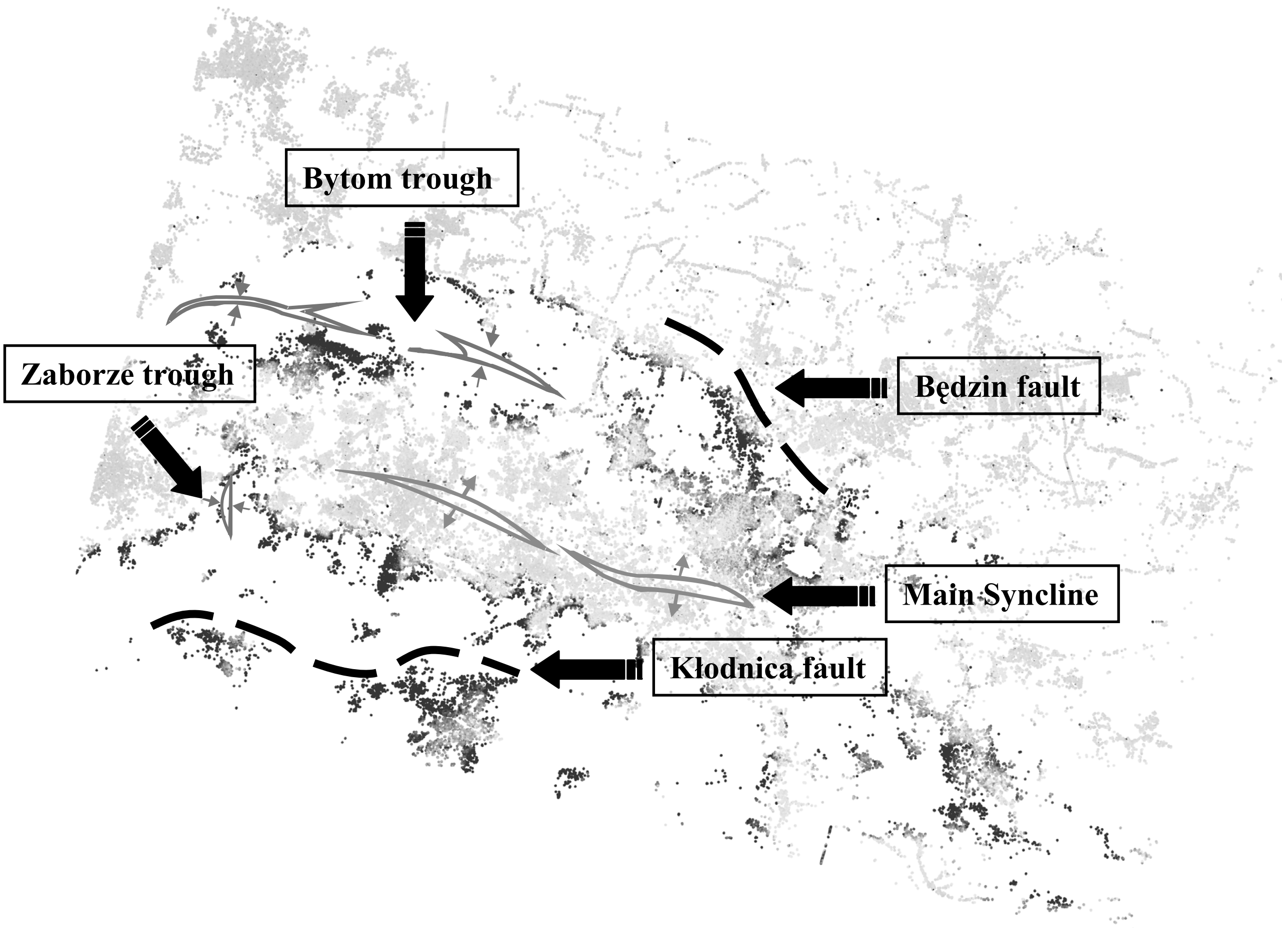

Fig. 1 PS points assigned as gray and black dots, and main geology structures of investigated area (according to Graniczny et al., 2006, 2008).

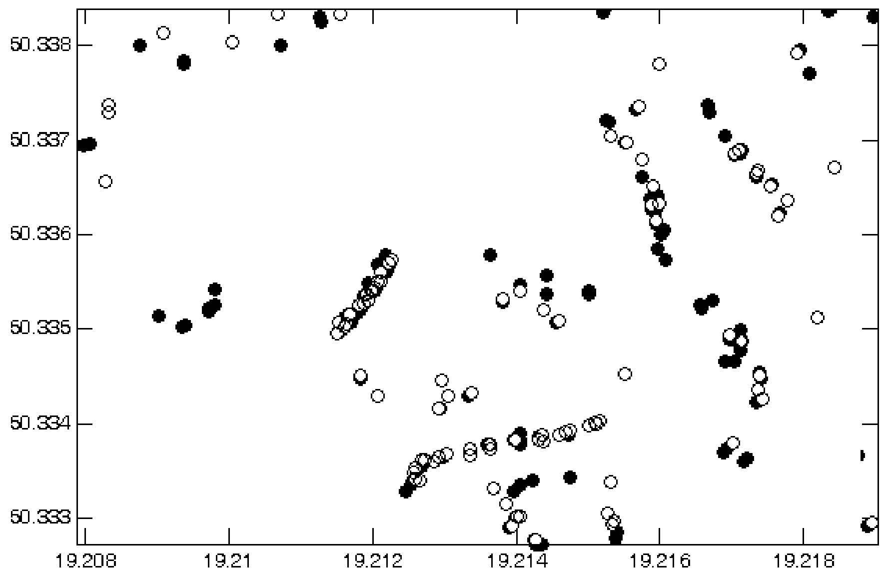

Fig. 2 PSInSAR subsidence velocity points. Black points - negative velocities; white points - positive velocities.

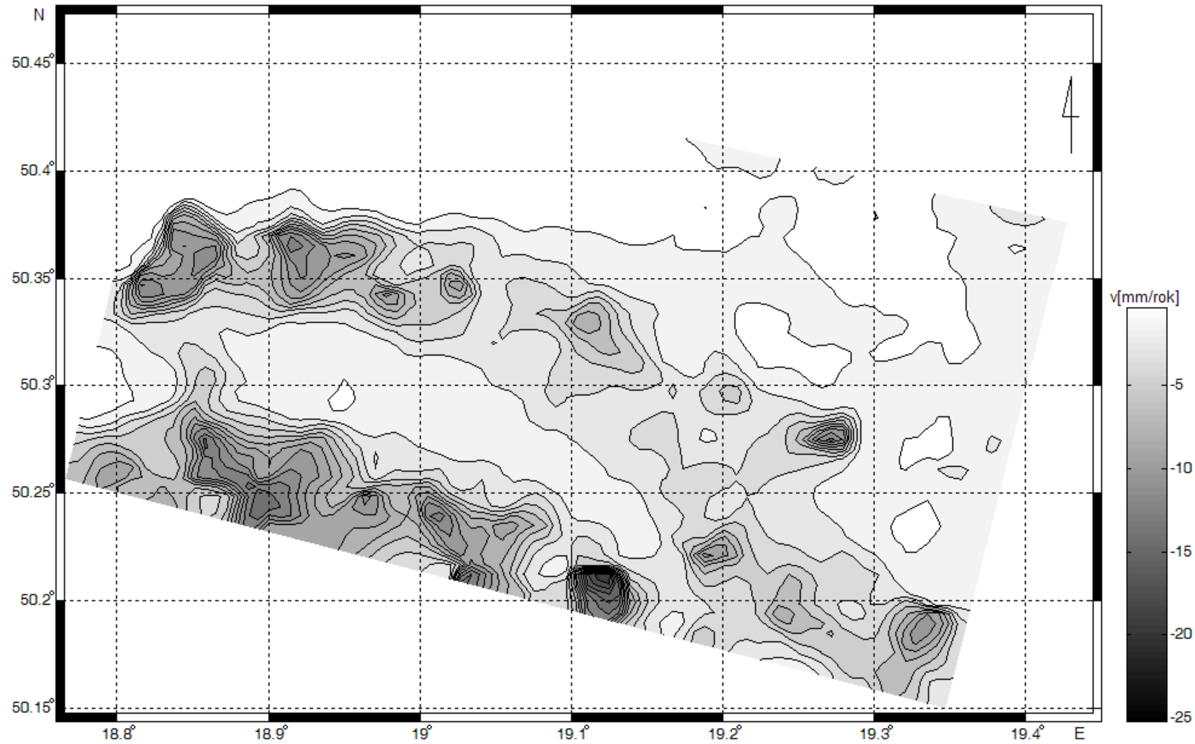

Fig. 3 A subsidence velocity map.

The parametera h_x and h_y appearing in the above equations is the smoothing parameter, sometimes called 'window width'. Upon this parameter, the degree of smoothness of the approximating function depends. The bigger the value of the smoothing parameter, the smoother the function. This parameters was automatically fitted using the cross-validation method.

A subsidence velocity map (Fig. 3) has been prepared using the non-parametric kernel approximation.

While analysing the map obtained, one can notice that the distribution of the PS points, which copy the strike of the main geological structures of the USCB is characteristic. The biggest subsidence can be seen on the Kłodnica fault and at the Bytom trough. The subsidence values on the Kłodnica fault vary from –10 to -15 mm/year. The subsidence values for the Bytom trough are from –5 to –15 mm/year, the largest subsidence values being concentrated in the eastern part in the form troughs. The Main Syncline, another big structure of the USCB, separating the Kłodnica fault and the Bytom trough, is characterised by a high stability. A slight subsidence rate of the order of –3 to –5 mm/year can also be observed on the Będzin fault and at the Zaborska trough.

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