ANALYSIS OF TREND CHANGES OF GROUND DEFORMATIONS IN THE SELECTED MINING AREAS IN DABROWSKI COAL BASIN (SOUTH POLAND)

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Motivation of the analysis

In presentation the **small, long-term ground deformations** were analyzed for the area of **Dabrowski Coal Basin** located in south Poland.

Vertical ground deformations in Poland were measured in several measuring companies using standard method (**leveling**). For particular point the annual rates of deformations does not change in time.

Satellite remote sensing has given possibilities to analyze vertical ground deformations of some areas with higher precision to investigate the deviations from linear trends of the vertical ground deformations. The **PSInSAR** method was used to determine the value of small, long-term ground deformations.

Wyrzykowski T. 1987 *Nowe wyznaczenie współczesnych pionowych ruchów powierzchni skorupy ziemskiej na obszarze Polski*. Prace Instytutu Geodezji i Kartografii Tom XXXIV, Zeszyt 1 (78)
The **PSInSAR** (**Permanent Scatterers Interferometry Synthetic Aperture Radar**) method is used in order to determine the values of small, long-term ground deformations for stable (coherent) radar targets called **PS points** (**Permanent Scatterers**). In this method PS points are identified using a large set of radar images taken over the same area in different times.

In the standard algorithm of PSInSAR technique only those PS points are identified for which the ground deformations have approximately the linear trend in time.
The ground deformations values determined by the PSInSAR method depend on many local factors that act on individual stable scatterers.

The approximation of ground deformations using linear model (as is done in a standard PSInSAR algorithm) leads to loss of some information - A. On the other hand the over-interpretation may take into account the irrelevant factors - B.

**Ground deformations approximation**

A) Under-interpretation  
B) Over-Interpretation  
C) Trade-off  

(Gehlot et al., 2005)

Gehlot S., Verbree E., Hanssen R. F. Dissemination of PSInSAR results for improved interpretation and analysis.
Developed algorithm

For the purpose of analysis the algorithm that detects the **deformations trend changes in time** was developed. It allows to approximate the values of ground deformations measured for individual PS point using two lines - C.

For each PS point for which the deformation trend changes the **approximate time and category** of this trend change were recorded.

**Categories of trend changes:**

I – increase of subsidence velocity \( \uparrow V_0 \)

II – decrease of subsidence velocity \( \downarrow V_0 \)

III – increase of ground lifting velocity \( \uparrow V_p \)

IV – decrease of ground lifting velocity \( \downarrow V_p \)

The example of the II category of the trend changes. High rate of subsidence turns to smaller one (in the moment in red circle). \( \downarrow V_0 \)
Developed algorithm

- The algorithm was developed in R environment – useful for advanced statistical analysis.
- Designed algorithm allows to perform the analysis, even for very large PSInSAR data sets.

- Developed algorithm allows to detect for each PS points only one (the most significant) trend change.
- If for particular PS point the difference in slopes of the fitted model is smaller than 20° the deformations are finally approximated using only one line.
- For each fitted model it was tested whether it satisfies the assumptions of linear regression.
- For each model the coefficient of determination R2 and the regression standard error RSE were calculated.
The temporal analysis of ground deformations were performed for selected mining areas of Dabrowski Coal Basin (South Poland).

For studied region:

• **6105 PS points** were identified;

• **for each PS point 79** values of relative ground deformations were determined for time period between **1992** and **2003**

• **complicated geological structure** is characteristic for the basin (a lot of faults)

• **only „Kazimierz-Juliusz”** is an active coal mine nowadays (other were liquidate between years 1995 and 2000)
Performed research revealed that for 41% PS points located in the Dabrowski Coal Basin the ground deformations trend changes occurred in the six time periods. The numbers of the points in particular categories are presented in table and images.
The aim of the next step of presented work was to study the **spatial distribution of PS points for which the trend changes were detected** in successive time intervals.

For each analysed time interval the maps of relative density of PS points for which the trend changes occurred were prepared (separately for category I and II).

The values of PS points density were determined using **two-dimensional kernel density estimator (KDE)**.

<table>
<thead>
<tr>
<th>Point of estimation:</th>
<th>( s = (u_0, v_0) )</th>
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</thead>
<tbody>
<tr>
<td>Estimator of two-dimensional density:</td>
<td>( \hat{f}(u_0, v_0) = \frac{1}{Nb_u b_v} \sum_{i=1}^{N} \left{ K\left( \frac{u_0 - u_i}{b_u} \right) K\left( \frac{v_0 - v_i}{b_v} \right) \right} )</td>
</tr>
<tr>
<td>Kernel function:</td>
<td>( K\left( \frac{u - u_i}{b} \right) = \frac{1}{\sqrt{2\pi b}} \exp\left[ -\frac{1}{2} \left( \frac{u - u_i}{b} \right)^2 \right] )</td>
</tr>
<tr>
<td>Bandwidth of estimation:</td>
<td>( b = 0.9 \min(s, \frac{IQR}{1.34}) N^{-\frac{1}{5}} )</td>
</tr>
</tbody>
</table>
The relative density of PS points for which the trend changes occurred

XII.1993 – XI.1994

XI.1994 – XII.1995
The relative density of PS points for which the trend changes occurred

III.1999 – IV.2000
The analysis of ground deformations trend changes for „Grodziec” coal mine

The more detailed analysis of ground deformations trend changes were performed for „Grodziec” coal mine that is located in the NW part of Dabrowski Coal Basin.

The most important information related with „Grodziec” coal mine:

• It covers approximately 22.4 km².
• The coal exploitation has been carried on since 1901.
• The last ton of coal was exploited in this mine in 1998.
• Within its mining area the 535 PS points were identified.
Within mining area there are two large faults: Grodziecki and Wojkownicko -Bedzinski which divide the mining area into four exploitation tectonic blocks: A, B, C and D.

In the studied period of time the exploitation was carried on in the B part.
The performed analysis revealed that for 45.3% of PS points located within mining area of „Grodziec” coal mine the ground deformations trend changes occurred in studied period of time.

Most of ground deformations trend changes (about 56.8%) occurred during the last analysed period of time (between III.1999 and IV. 2000).
Obtained results for „Grodziec” coal mine

For mining area of „Grodziec” coal mine the most characteristic were ground deformations trend changes that indicate increase and decrease of subsidence velocity.

Number of PS points for which ground deformations trend changes were detected for particular periods of time separately for each of four categories.
The relative density of PS points for which the trend changes occurred (for „Grodziec” mining area)

In order to study the spatial distribution of PS points for which the trend changes were detected in successive time intervals for each analysed time interval the maps of relative density of PS points for which the trend changes occurred were prepared (separately for category I and II). The values of PS points density were determined using two-dimensional kernel density estimator (KDE).

Mining area of „Grodziec” coal mine with the values of relative density of PS points for which the increases of subsidence velocity (category I) were detected for the time period between XI.1994 and XII.1995
The relative density of PS points for which the trend changes occurred (for „Grodziec” mining area)

Mining area of „Grodziec” coal mine with the values of relative density of PS points for which the decreases of subsidence velocity (category II) were detected for the time period between II.1998 and III.1999.

The last tone of coal was exploited in December 1998!

Mining area of „Grodziec” coal mine with the values of relative density of PS points for which the decreases of subsidence velocity (category II) were detected for the time period between III.1999 and IV.2000.
The presented results of analysis of ground deformation trend changes for seven coal mines form Dabrowski Coal Basin revealed the correlation between temporal changes of values of ground deformations and location of main faults (Bedzinski fault).

More detailed analysis of ground deformations trend changes performed for mining area of „Grodziec” coal reveal further regularity correlated with the history of coal exploitation.

Proposed spatio-temporal analysis PSInSAR data may help to assess the impact of coal exploitation on the values of small, long-period ground deformations that occur in the mining and postmining areas.
Thank you