EPOS – European Plate Observing System

# Subsidence monitoring of coal mining using spaceborne SAR interferometry and Sentinel 1 data, Rydułtowy case study, Poland.

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## POIR.04.02.00-14-A0003/16

Priority IV: **INCREASING THE RESEARCH POTENTIAL**
Action 4.2: **DEVELOPMENT OF MODERN RESEARCH INFRASTRUCTURE OF THE SCIENCE SECTOR**

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**Consortium members:**

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# EPOS project

The project aims:

- the creation of a multilayer, multidisciplinary and interoperable research infrastructure, where data from different measurement networks and technique will be collected, processed, standardized and integrated in uniformed database,
- Two study areas called Multidisciplinary Upper Silesian Episode (MUSE) have been selected in mining and post-mining areas in the USCB to integrate various geodetic measuring techniques as well as seismological, gravimetric and geophysical measurements for observing physical phenomena occurring within rock mass and subsurface zone.
- Within the framework of Workpackage 9 monitoring of the mining and post-mining areas by different remote sensing techniques is carried out

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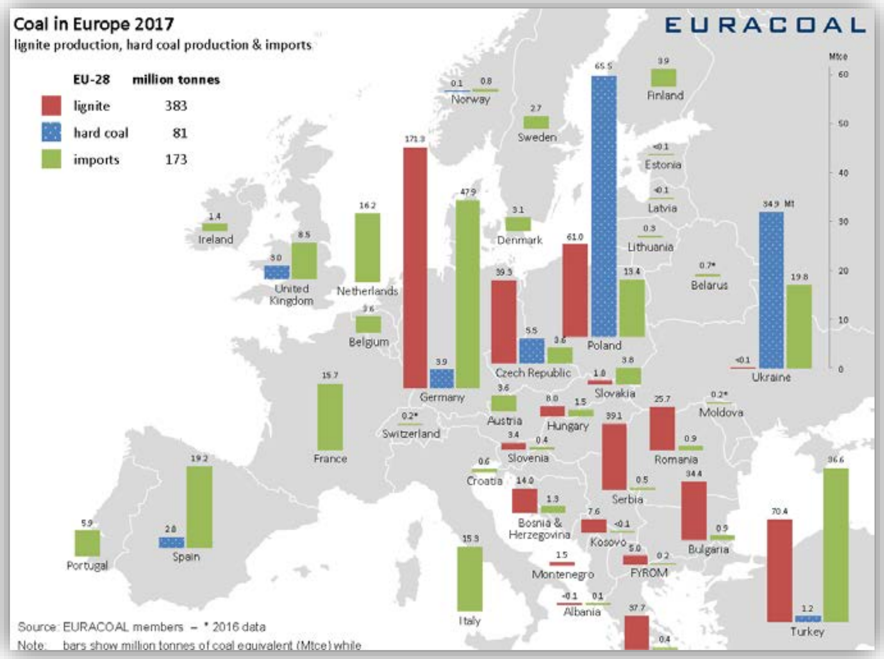
# Motivation

- USCB located in Poland is one of the largest hard coal mining regions in Europe
- the exhaustive underground coal extraction breake the Earth's surface stability and leads to serious terrain subsidence, which can reach meters per year
- mapping ground surface dynamics caused by underground coal extraction is crucial to assess mining –releted geo-hazards and understand the mechanics of the mining subsidence

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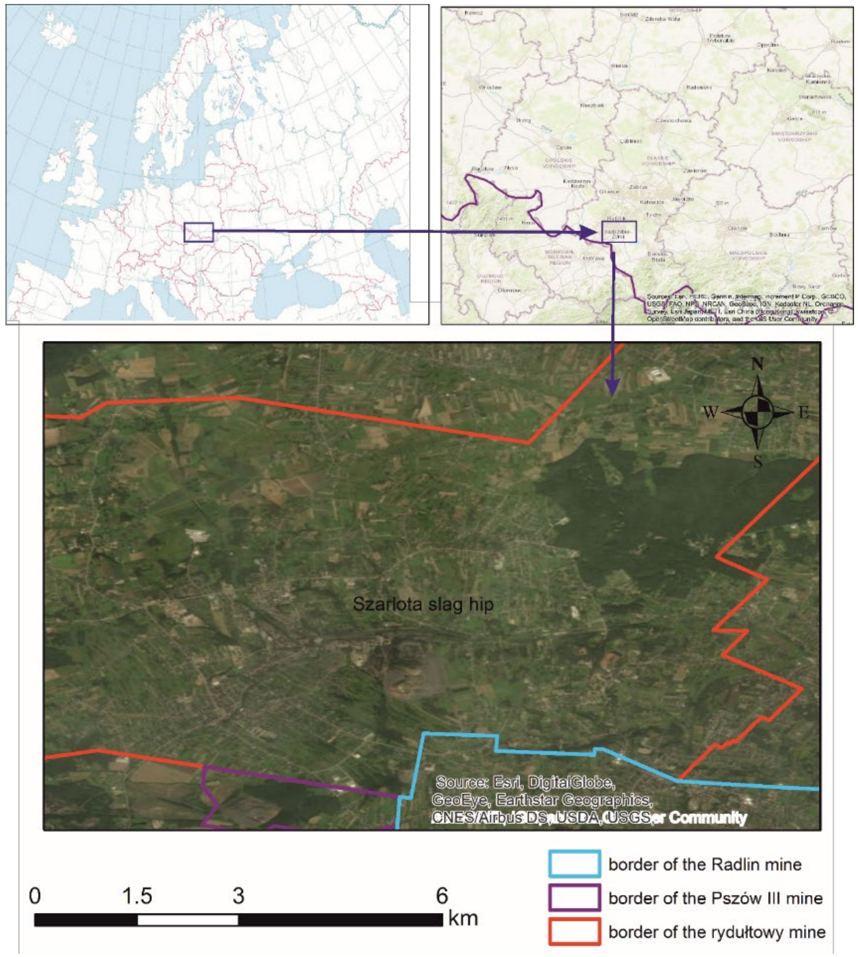
# Study area (MUSE 2)

- Rydułtowy mine is located in southern-western part of Upper Silesian Coal Basin (USCB).
- Rydułtowy mine is the oldest active mining plant in Upper Silesia (operating since 1792).
- The average daily extraction of coal in the Rydułtowy mine ranges from 9,000 - 9,500t /day and in the coming years it is expected to maintain production capacity at a similar level
- Last year, many highly energetic mining shocks were recorded and many buildings were damaged, thus, deformation monitoring over Rydułtowy region is crucial

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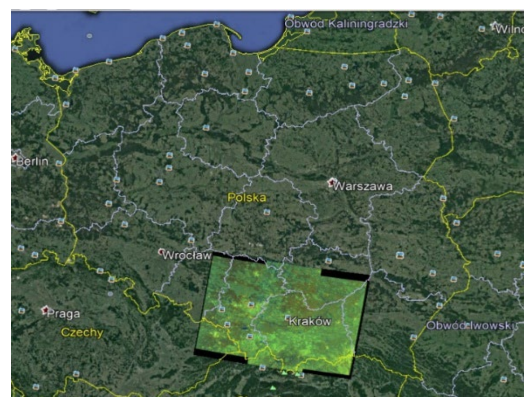
# Data used

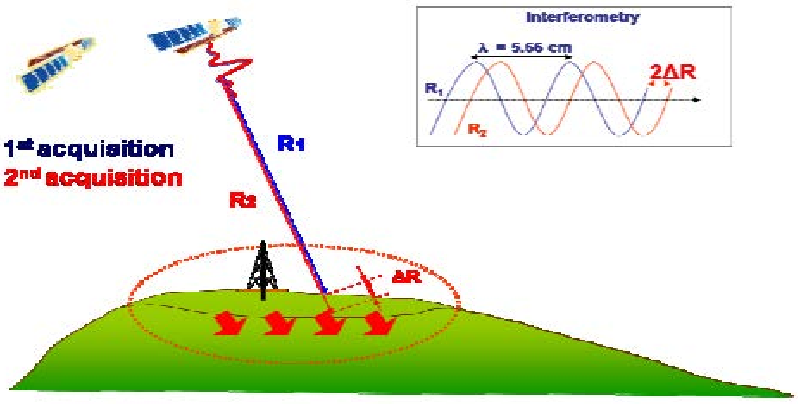
| Parameters | Description | |
|---|---|---|
| Product type | Sentinel1 SLC IW | Sentinel1 SLC IW |
| Track number | 175 | 124 |
| Mean incidence angle on the study area (degree) | 38.11 | 35.56 |
| Azimuth angle (degree) | 81.77 | -77.70 |
| Orbit mode | ascending | descending |
| Time span | 4/01/2017 - 8/10/2018 | 1/01/2017- 4/11/2018 |
| Number of images | 106 | 112 |

# Methodology

1. SAR processing (DInSAR and SBAS approach) asc&desc orbit
2. Mutual authentication of the results
3. LOS deformation decomposition (DInSAR&SBAS results)
4. Results integration using kriging
5. Internal evaluation
6. External evaluation

# Interferometry concept




Deformation ΔR

$$\delta\phi_j(x,r) = \phi(t_B,x,r) - \phi(t_A,x,r) \approx \frac{4\pi}{\lambda}[d(t_B,x,r) - d(t_A,x,r)] + \frac{4\pi}{\lambda}\frac{B_\perp \Delta z}{R\sin\theta} + [\phi_{atm}d(t_B,x,r) - \phi_{atm}d(t_A,x,r)] + \text{noise}$$

Topographic error

Atmospheric artefacts

$\phi(t_B,x,r)$ and $\phi(t_A,x,r)$ are the phases that corresponds to times $t_A$ and $t_B$ and
$\Delta z$ corresponds to topographic error
$\phi_{atm}d(t_B,x,r) - \phi_{atm}d(t_A,x,r)$ reference as atmospheric phase component,
$d(t_B,x,r) - d(t_A,x,r)$ reference as deformation phase components
$B_\perp$is a perpendicular baseline between two acquisitions,
**R** - range distance,$\theta$ - incidence angle, $\lambda$ is a sensor wavelength
$\Delta_{n_j}$ represents noise and decorrelation effect

## Consecutive DInSAR

$$\delta\phi_j(x,r) = \frac{4\pi}{\lambda}\Delta R + \alpha + \varepsilon + \text{noise}$$

($\alpha + \varepsilon + \text{noise}$): ignored

- is based on calculation of differential interferograms of adjacent SAR acquisitions and accumulated with each other and provide completed time series interferometric results (e.g.,$\varphi_{1\text{-}2}$, $\varphi_{2\text{-}3}$ , $\varphi_{3\text{-}4}$,… $\varphi_{n\text{-}1,n}$)
- atmospheric influences are not removed
- no deformation model needed

## SBAS

$$\delta\phi_j(x,r) = \frac{4\pi}{\lambda}\Delta R + \alpha + \varepsilon + \text{noise}$$

($\Delta R + \alpha + \varepsilon + \text{noise}$): modelled

- small distances among either the satellite positions or different acquisition times, is introduced to reduce the geometric and temporal decorrelation.
- atmospheric components are modeled and removed
- defomation components are also estimated according to the predefined deformation model

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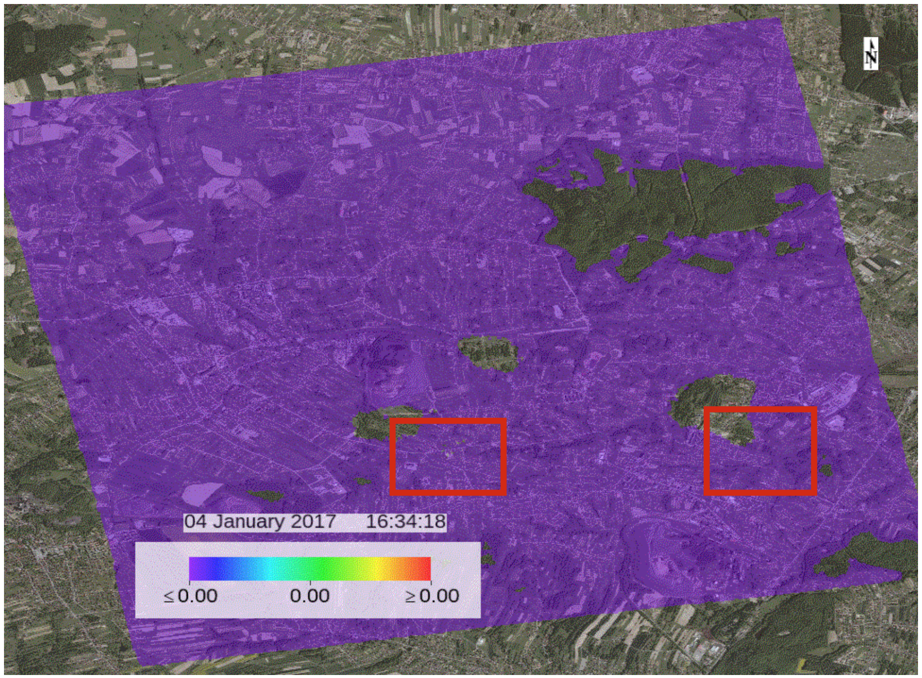
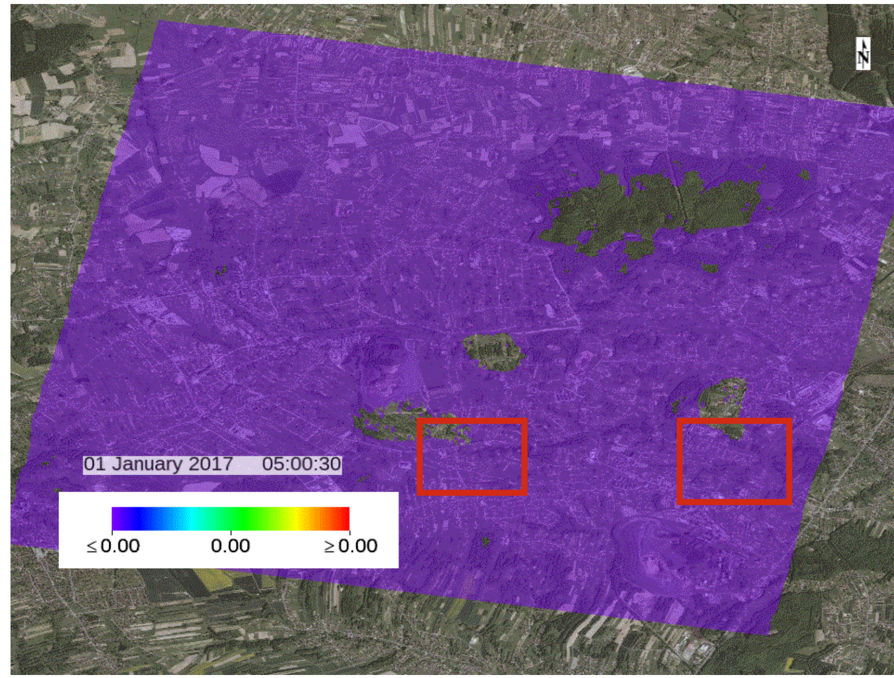
## SBAS results

### ascending orbit



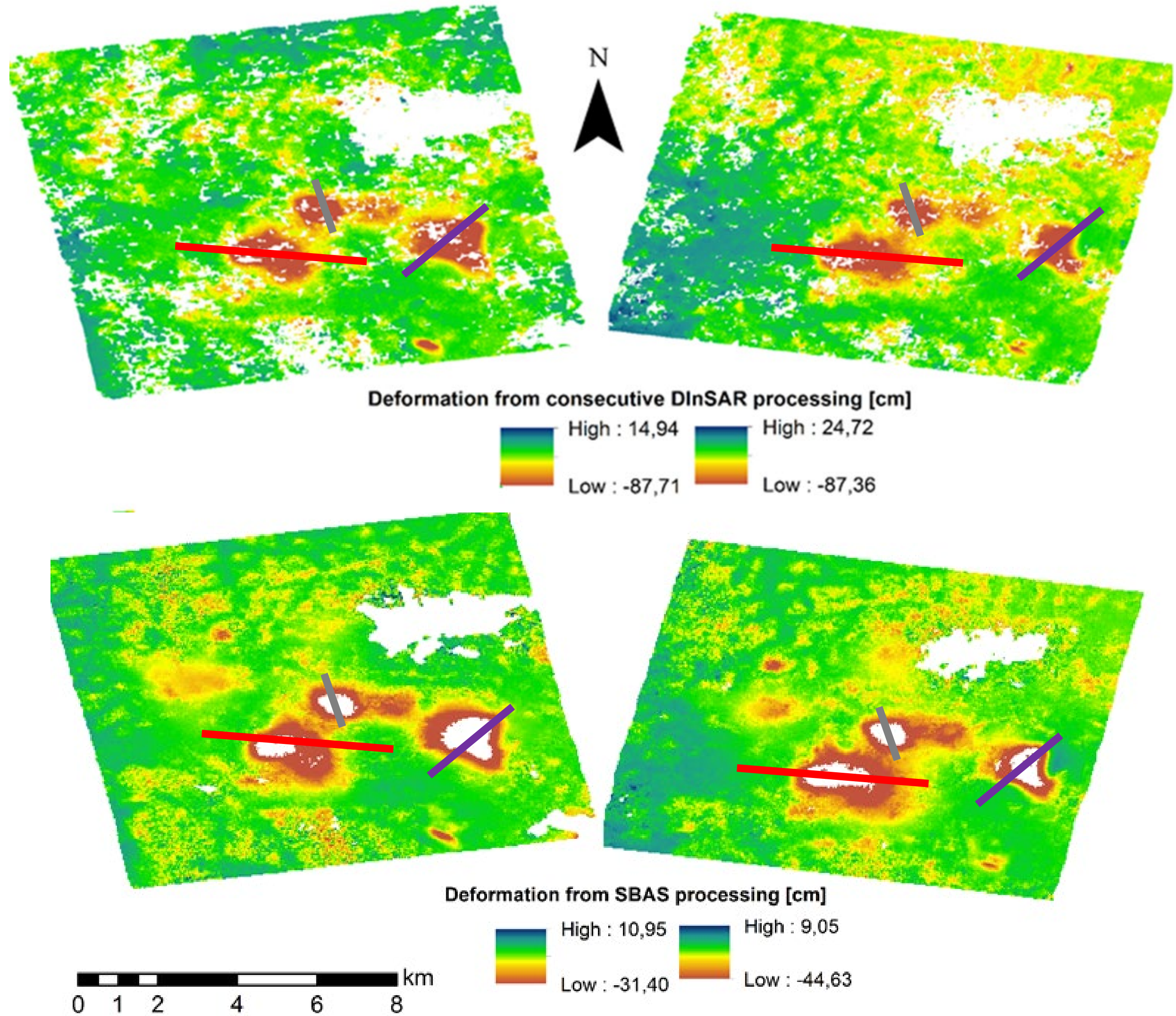

### descending orbit



**ascending orbit (4.1.2017 -8.10.2018)** | **descending orbit 1.1.2017 -4.11.2018**

**Consecutive DInSAR results**

**SBAS results**




- profile 1
- profile 2
- profile 3

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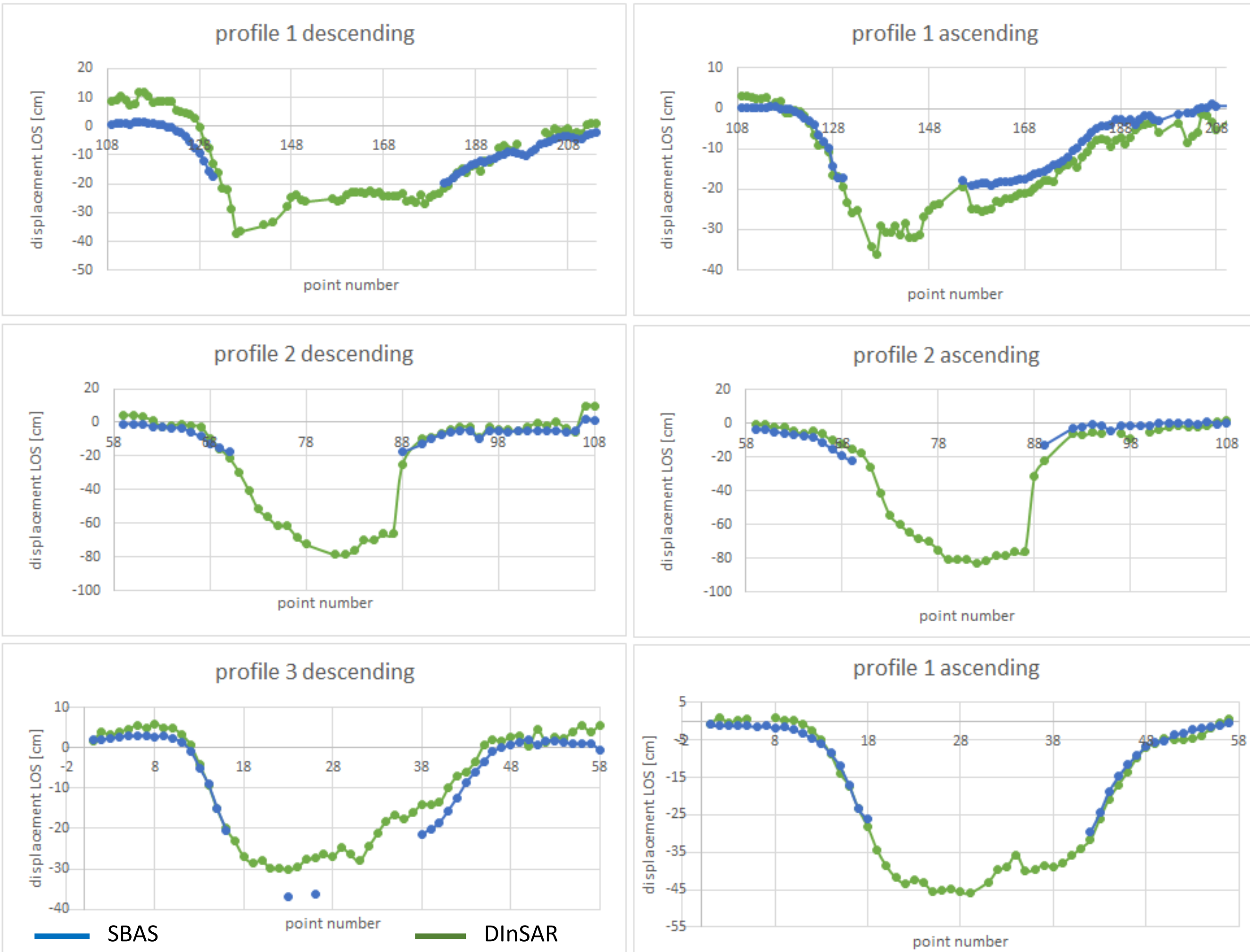
# Mutual authentication

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## LOS deformation decomposition

$$d_r = \boldsymbol{d_u}\cos(\theta_{inc}) - \sin(\theta_{inc})[\boldsymbol{d_n}\cos\left(\alpha_h - \frac{3\pi}{2}\right) + \boldsymbol{d_e}\sin\left(\alpha_h - \frac{3\pi}{2}\right)]$$

$d_r$ - *slant-range component in the LOS direction,*

$d_u, d_n, d_e$ - *up ,north, east component of displacement vector,*

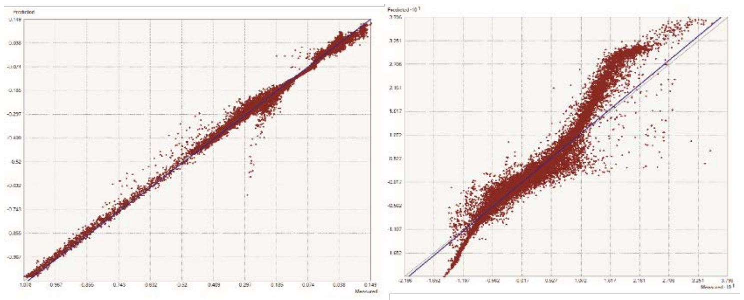
$\alpha_h$ - *heading (azimuth),*

$\alpha_h - \frac{3\pi}{2}$ - *angle to the azimuth look direction,* $\theta_{inc}$ - *incidence angle*

$d_n \approx 0$

## Technique integration using kriging based method

- SBAS results as „atmospherics-free" results have been used for the whole study area
- Consective DInSAR results applied only in „empthy holes"
- Cross validation applied to assess the model accuracy of the prediction
- RMSE between predicted and measured values for vertical and horizontal displacements were 5mm and 8mm, respectively



Predicted vs. measured valueas for vertical (on the left) and horizontal component (on the right)

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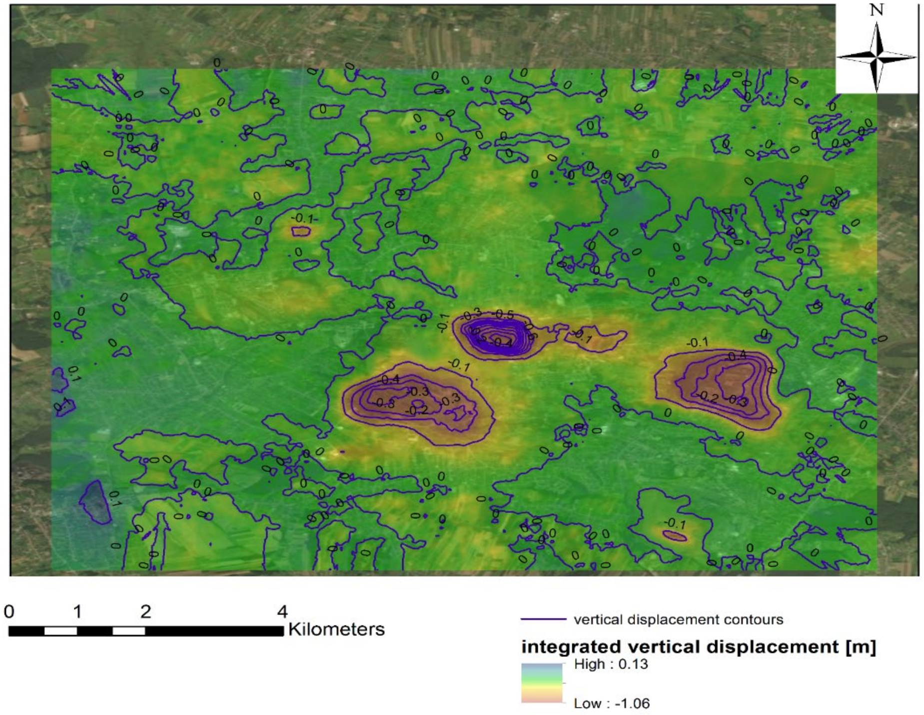
# Vertical and east-west deformation components

Time span: 4.1.2017 -8.10.2018

$d_u$ $d_e$

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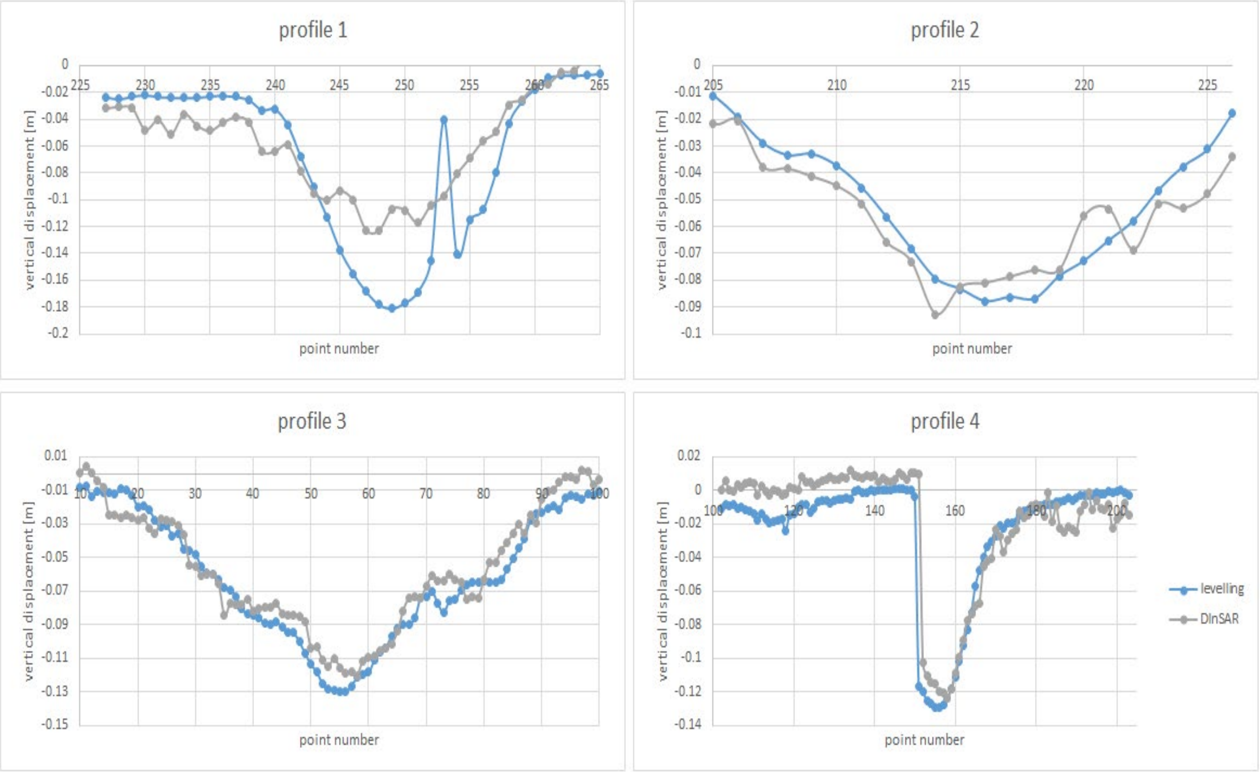
# External evaluation of consecutive DInSAR deformations



## Conclusions

- For the epicentre of the subsidence basins, SBAS approach failed in displacement estimation due to the temporal decorrelation or diverse deformation models which does not fit to the predefine ones. The maximum displacement which have been detected using this technique was around -44cm (LOS) for the time span 1.1.2017-8.10.2018.
- DInSAR measurements allow to identify areas with a maximum cumulative vertical subsidence reaching 1.05cm (vertical component) for the time span 1.1.2017-8.10.2018.
- The integration of both results delivered form Sentinel-1 data using diverse interferometric techniques provide more comprehensive understanding of mining–related subsidence over the study area and permits to fully utilize Sentinel-1 data for subsidence monitoring.

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# Thank you for your attention

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