EPOS – European Plate Observing System

# InSAR techniques to determine mining-related deformations using Sentinel-1 data: the case study of Rydułtowy mine in 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**

**Period of realization: 2016 - 2021**
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**Consortium members:**

CYFRONET
GIG
IGiK
UNIVERSITAS RERUM NATURALIUM WRATISLAVIENSIS
WAT
POLSKA GRUPA GÓRNICZA

PROJECT **EPOS - EUROPEAN PLATE OBSERVING SYSTEM** IS CO-FINANCED BY THE EUROPEAN UNION FROM THE FUNDS OF THE EUROPEAN REGIONAL DEVELOPMENT FUND (ERDF)

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# EPOS project

- The project (https://epos-pl.eu/about-project,12,en.html) aims at creating 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 Work package 9 monitoring of the mining and post-mining areas by different remote sensing techniques has been carried out.

# Motivation

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

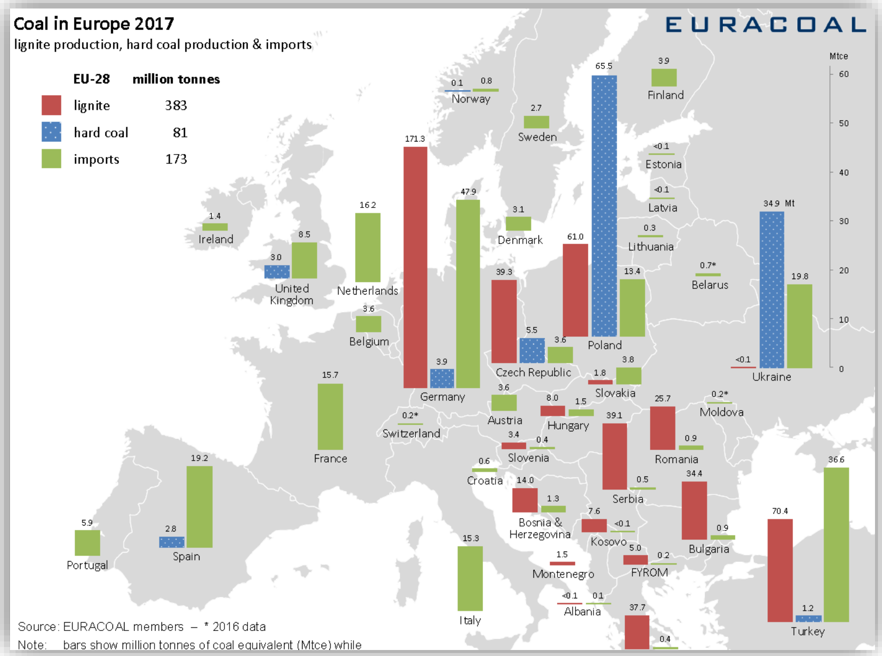

*Figure 1. Coal extraction in Europe*

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# Study area

- Rydułtowy mine is located in southern-western part of Upper Silesian Coal Basin (USCB).
- Rydułtowy mine is the oldest activ mining plant in Upper Silesia (operating since 1792).
- The average daily extraction of coa in the Rydułtowy mine ranges fror 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 thu deformation monitoring over Rydułtowy region is crucial

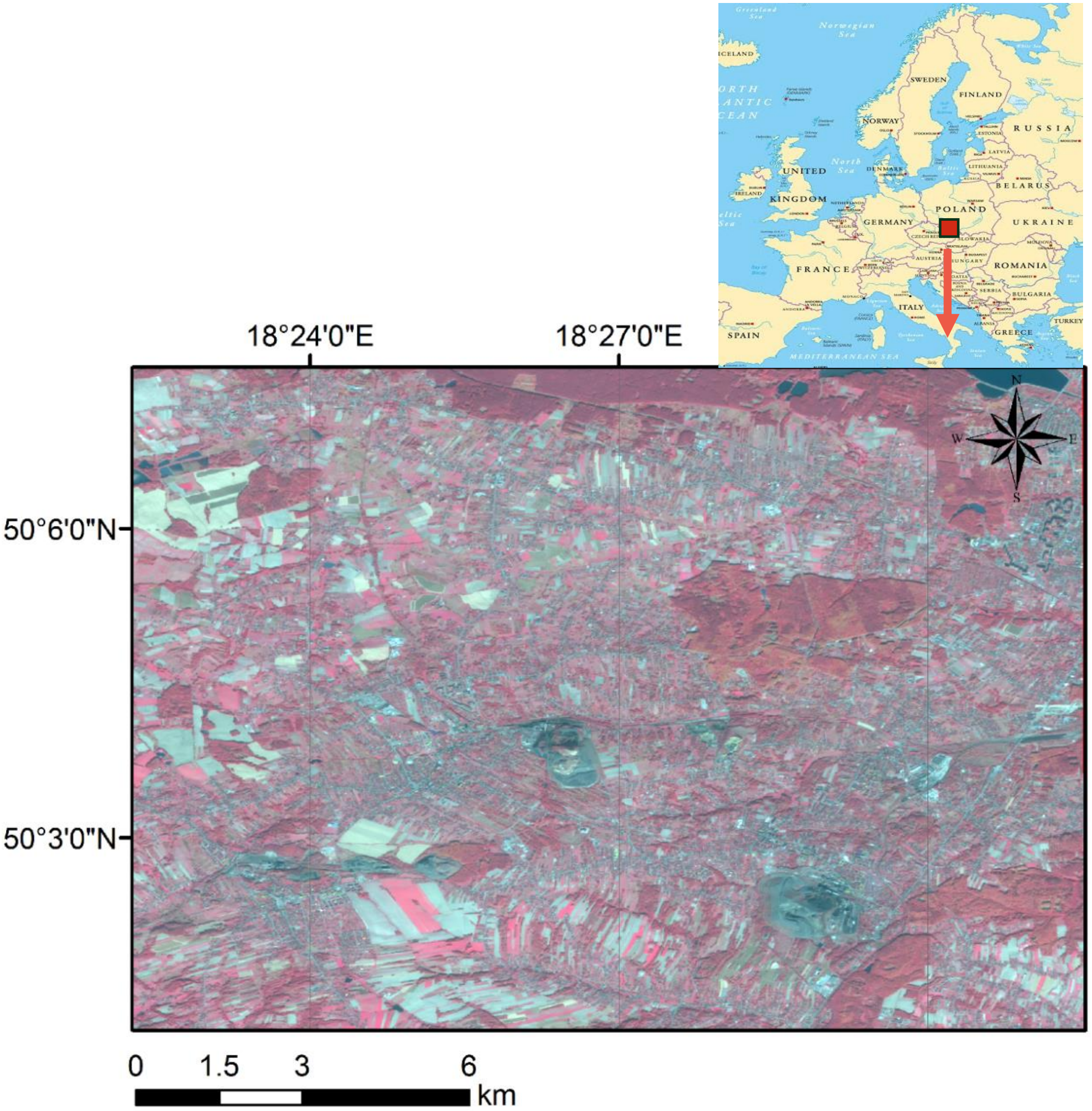

*Figure 2. Location of the study area*

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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 |

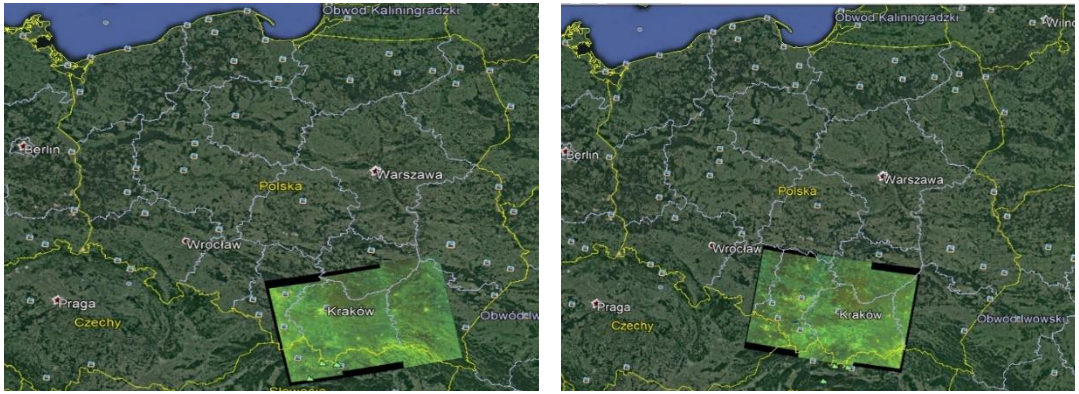

*Figure 3. Footprint of ascending (left) and descending (right) images used in presented study*

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# 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

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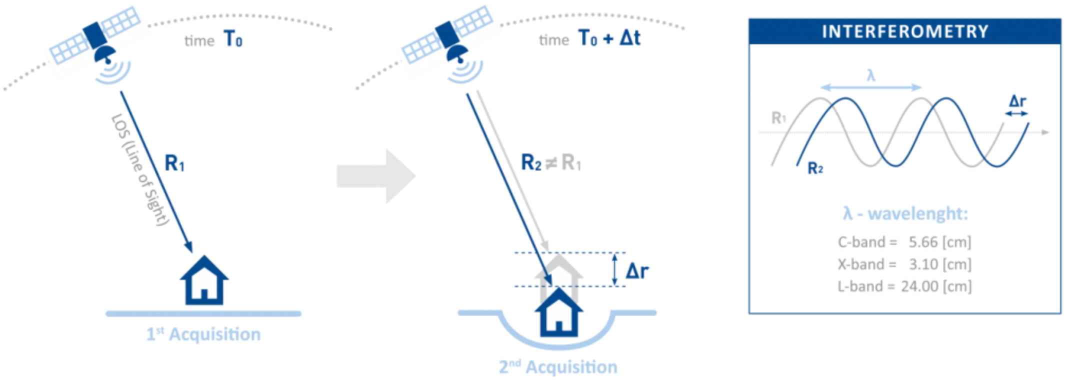
# Concept of DInSAR



*source: www.copernicus.eu*

**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
$\phi_{atm}d(t_B,x,r) - \phi_{atm}d(t_A,x,r)$ represents atmospheric phase component,
$d(t_B,x,r) - d(t_A,x,r)$ represents 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

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## Consecutive DInSAR

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

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

## SBAS (Berardino et al., 2002)

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

- small distances among either the satellite positions or different acquisition times are 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.

*Berardino, P., Fornaro, G., Lanari, R., & Sansosti, E. (2002). A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Transactions on geoscience and remote sensing, 40(11), 2375-2383.*

# Consecutive DInSAR processing

## atmospheric artefacts mitigation by precipitation and relative humidity investigation

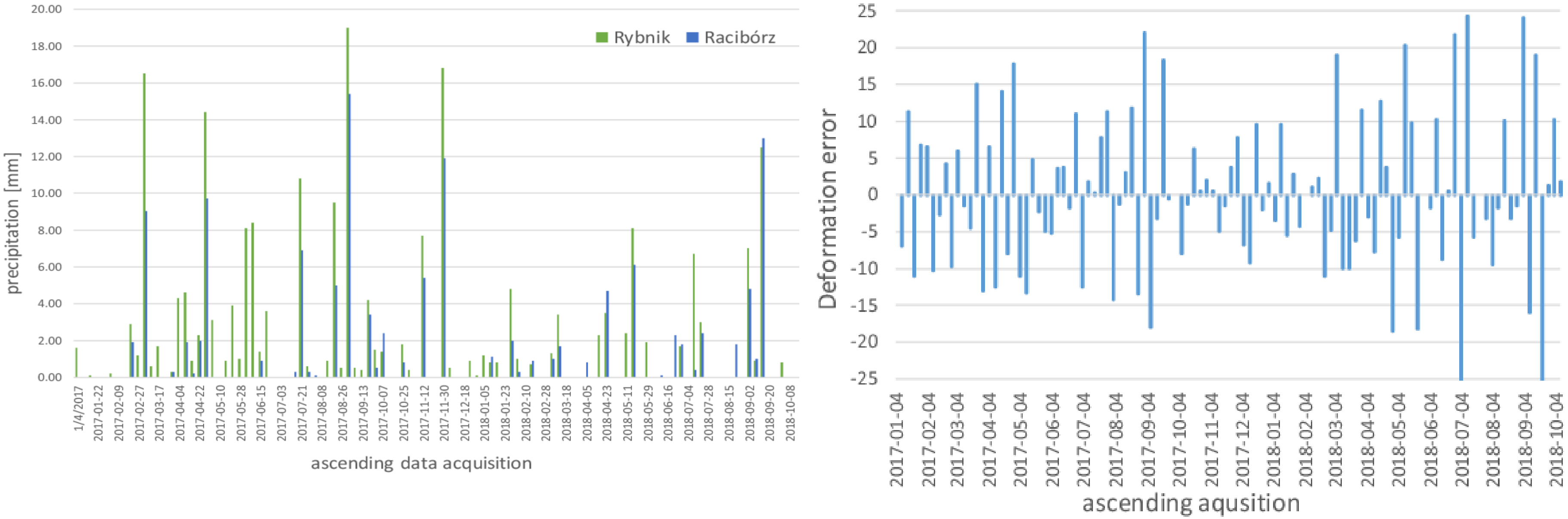

*Figure 4. Precipitation (left) and relative humidity error estimated based on Haward et el., 1997*

*[1] Howard A. Zebker, Paul, A. Rosen, and Scott, Hensley (1997) "Atmospheric effects in interferometric synthetic aperture radar surface deformation and topographic maps." Journal of Geophysical Research: Solid Earth, **102(B4)**, 7547-7563*

**We investigated the interferograms with high precipitation and relative humidity error.
„Bad interferograms" have been removed from further processing**

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**ascending orbit**
**(4.1.2017 -8.10.2018)**

**descending orbit**
**1.1.2017 -4.11.2018**

**Consecutive DInSAR results**

**SBAS results**

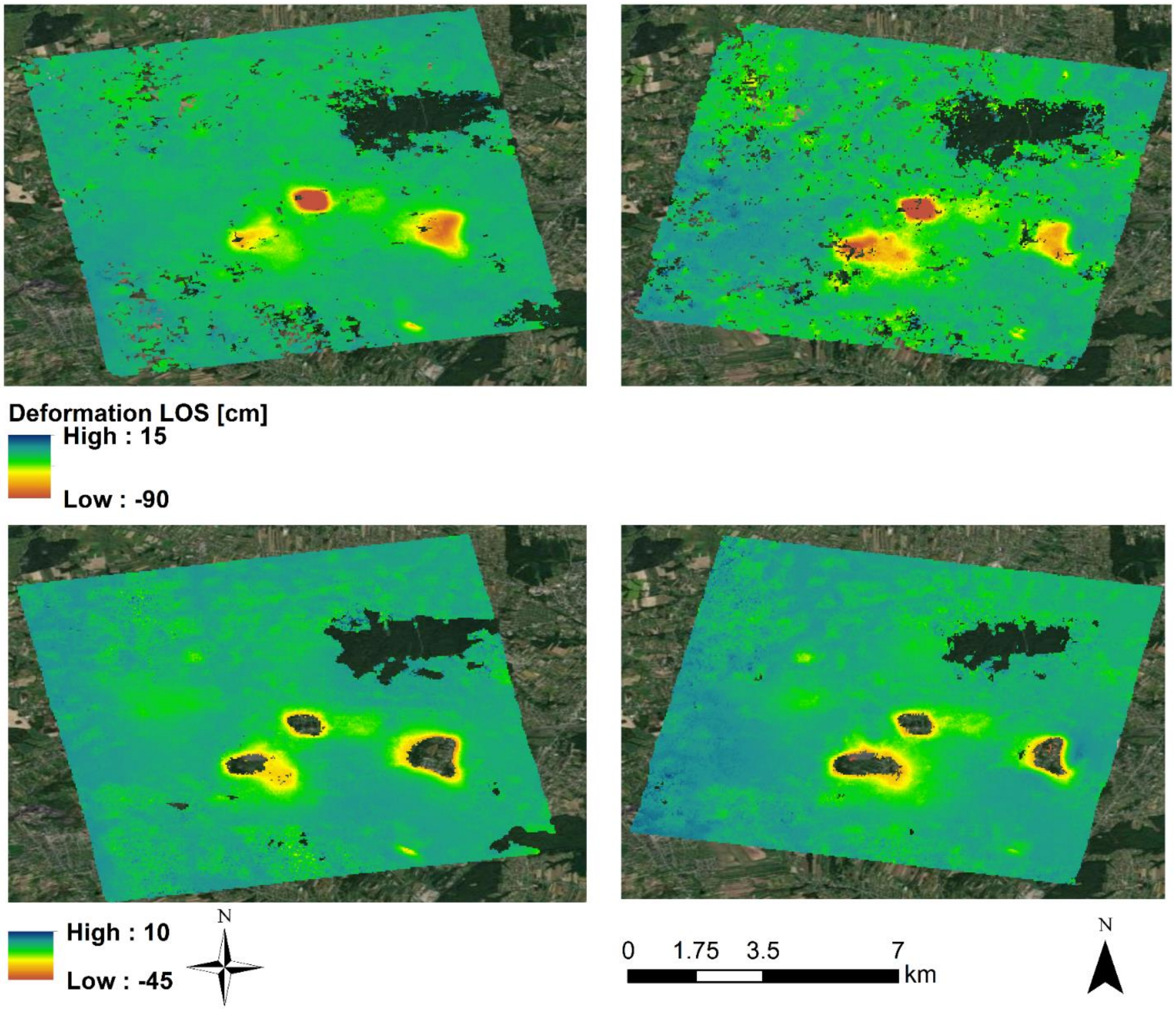

*Figure 5. LOS deformations*

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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,*

$d_n \approx 0$

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

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

## Integration technique using kriging based method

- SBAS results as „atmospherics-free” results have been used for the whole study area
- Consective DInSAR results applied only in „emphty holes”
- Cross validation applied to assess the model accuracy of the prediction
- Expotential function was used for Kriging integration (Fig. 6)
- RMSE between predicted and measured values for vertical and horizontal displacements were 5mm and 8mm, respectively

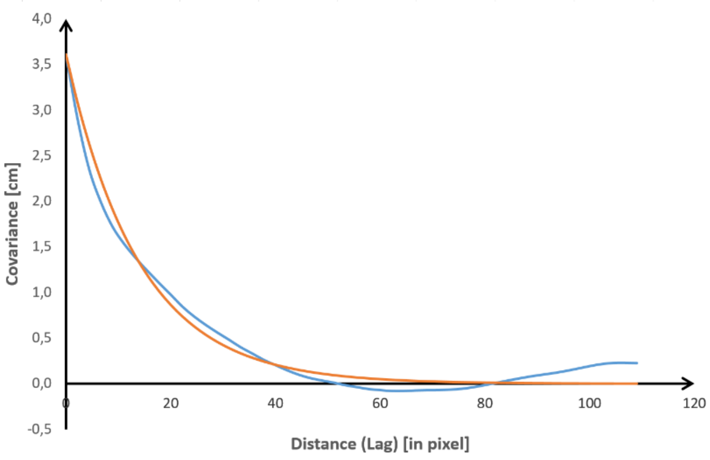

*Figure 6. Empirical autocovariance function for Δd residual deformations (blue) and the corresponding exponential model*

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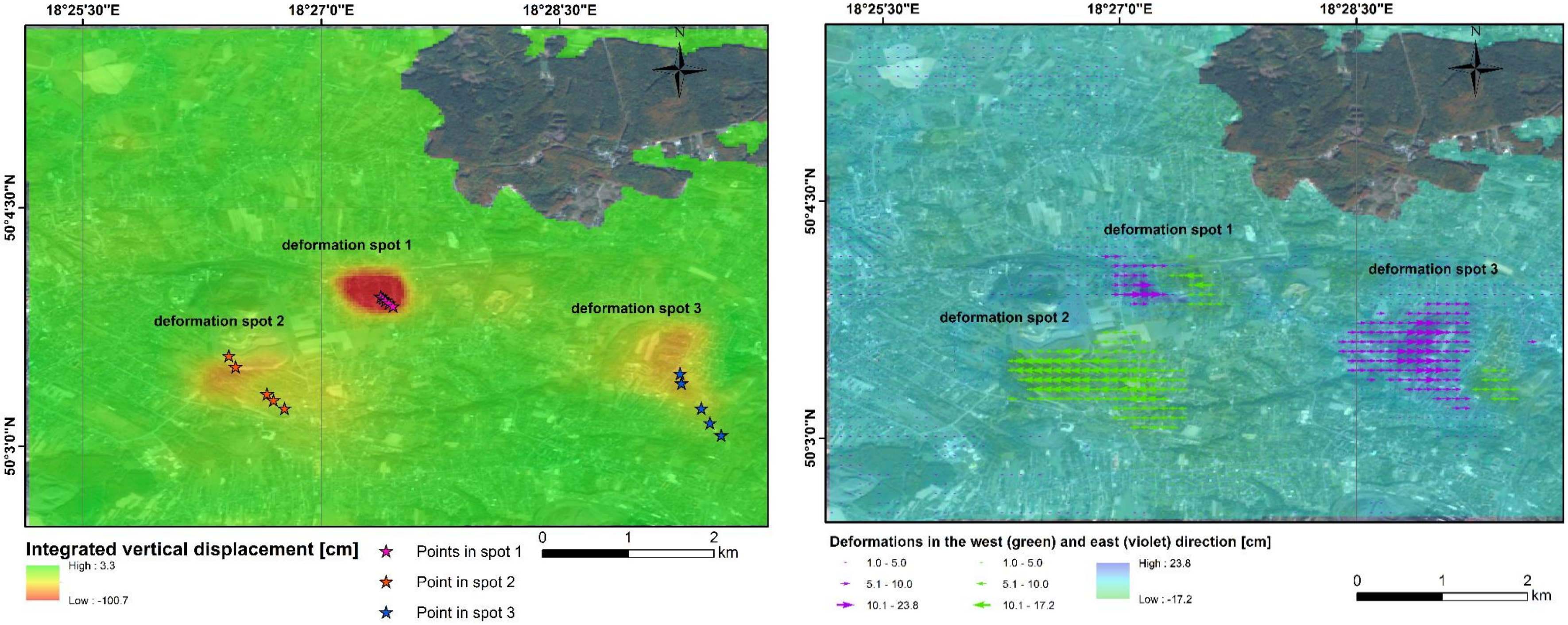
# Results
# Vertical and east-west deformation components



$d_u$ $d_e$

*Figure 7. Vertical (left) and east-west (right) deformation components estimated for the time span of 4.1.2017 -8.10.2018*

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# Results comparision between SBAS and DInSAR

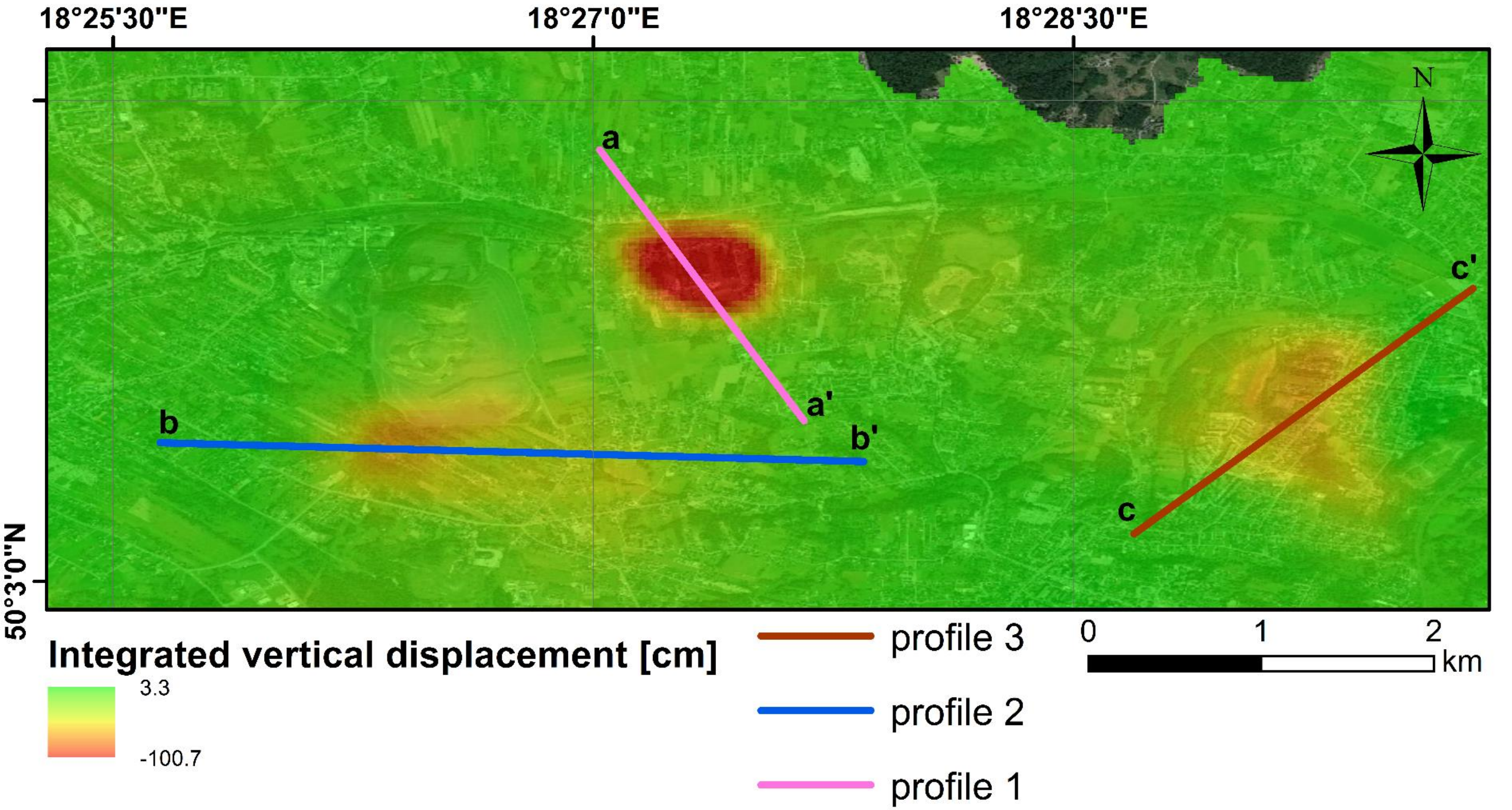

*Figure 8. Subsidence along with profiles for which DInSAR and SBAS LOS deformation has been extracted*

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# Results comparision between SBAS and DInSAR

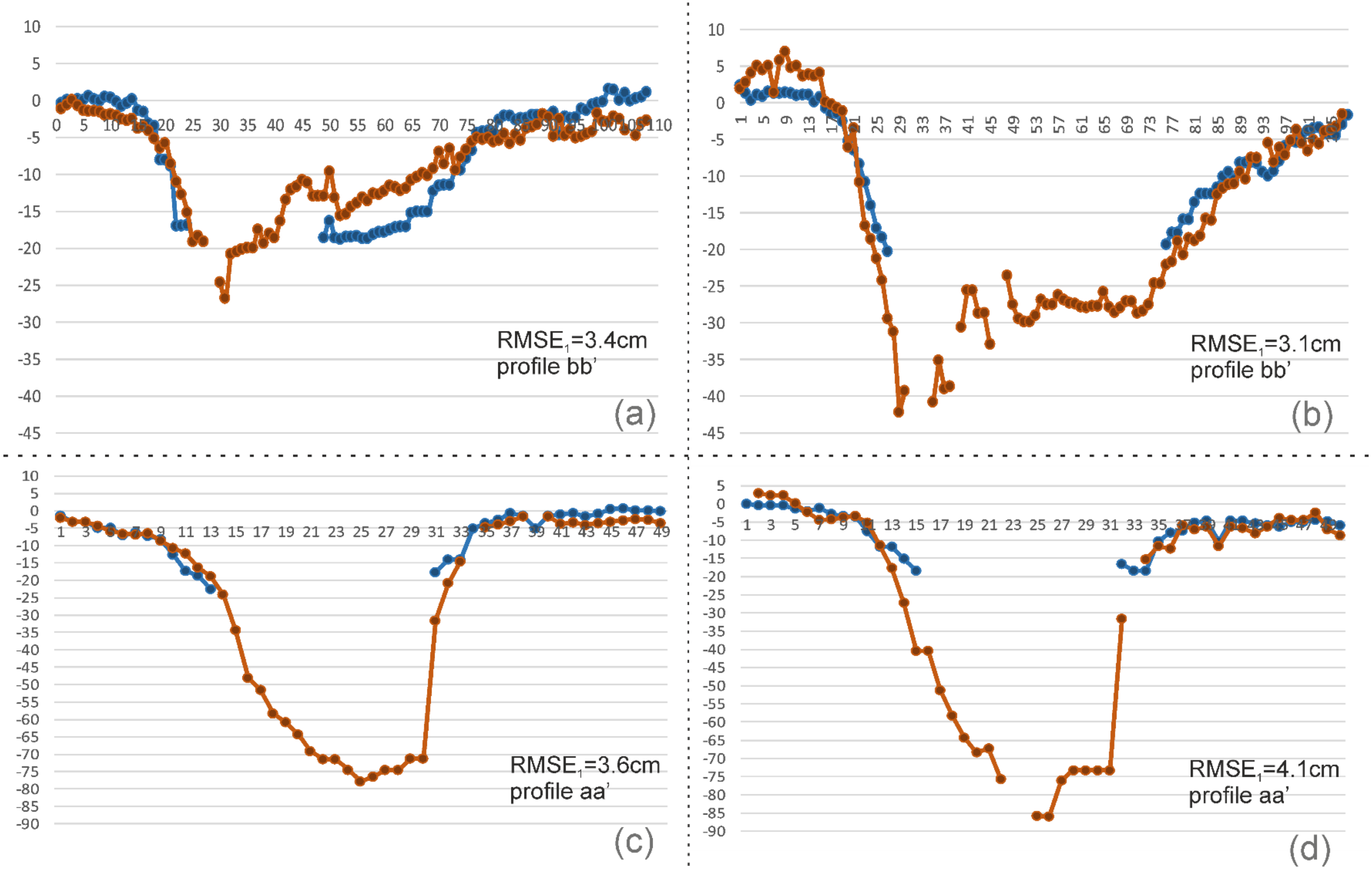

*Figure 9. LOS defromation for ascending (a,c) and descending (b,d) orbit extracted for aa' and bb' profiles*

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# Vertical time series deformation

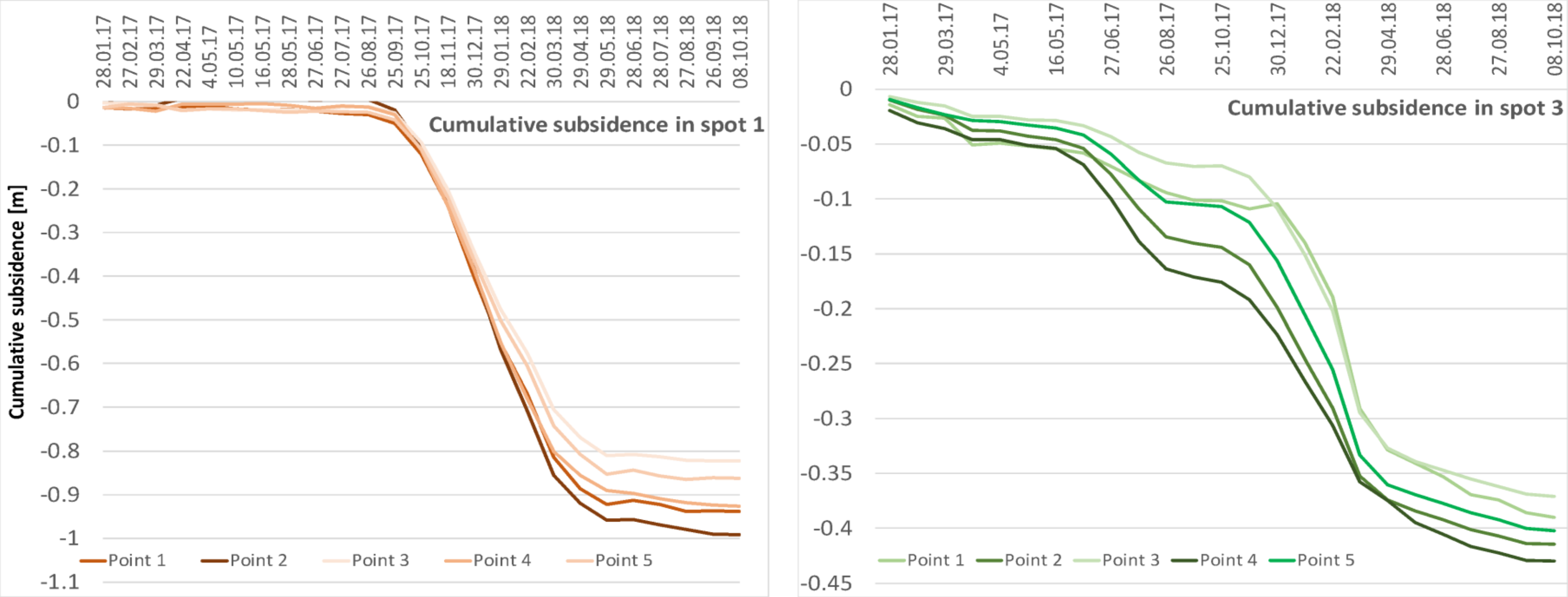

*Figure 10 Time series deformation estracted for the maximal detected deformation for spot n.1 and spot no.2 (for point location please refer to figure 7)*

**Explanation for SBAS failure in deformation estimation:**
**Fast big gradient of the deformation → lost of coherence**

# Conclusions

- For the epicentre of the subsidence basins, SBAS approach failed in displacement estimation due to the temporal decorrelation or due to the fact that deformation models do 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 allowed to identify areas with the maximum cumulative vertical subsidence reaching 1.05cm (wertował component) for the time span 1.1.2017-8.10.2018.
- The integration of both results delivered from Sentinel-1 data using diverse interferometric techniques provides 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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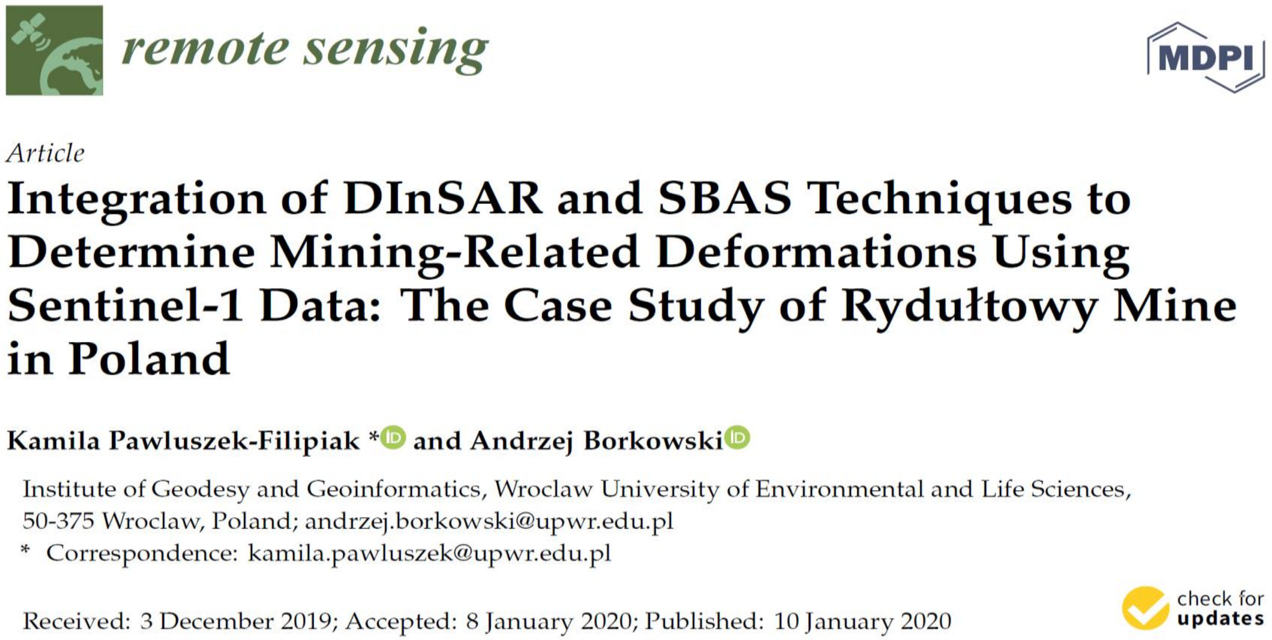
**Further information can be found here in Pawluszek-Filipiak&Borkowski, 2020 ([https://doi.org/10.3390/rs12020242](https://doi.org/10.3390/rs12020242))**



remote sensing

MDPI

*Article*

# Integration of DInSAR and SBAS Techniques to Determine Mining-Related Deformations Using Sentinel-1 Data: The Case Study of Rydułtowy Mine in Poland

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