Investigation for mining-induced deformation in Upper Silesia Coal Basin with multi-GNSS in Near Real-Time

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epos pl

1. Introduction

The most exposed region in Poland on the effects of deformations is the area of Upper Silesia Coal Basin (USCB) - one of the largest coal mining zone in Europe. The exploitation of the deposits has been carried out there for the last 200 years (Fig.1).

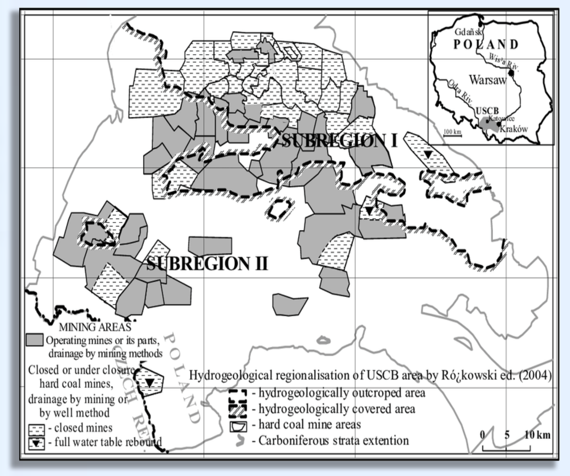

Fig.1 Location of coal mines in the Upper Silesian Coal Basin
Source: Bukowski P. et al.. (2007). Use of void space in abandoned mines in the Upper Silesian Coal Basin (Poland)

In order to conduct deformation research in this area, eight high-frequency GNSS receivers have been purchased within the EPOS-PL project established in two research polygons, called Multidisciplinary Upper Silesian Episodes (MUSE).

The current mining works cause terrain subsidence of the most populated area in Poland. Our interest is focused on the area of Rydultowy mine where the predicted deformation zone caused by the extraction in this mine is limited to 30 km² and the results from one GNSS station (RES1) can be discussed. The station is set on the roof of historic mine building, which is out of coal exploitation.

The main purpose of this paper is the investigation for coal mining-induced deformation with multi-GNSS in Near Real-Time (NRT) system. As a reference to the GNSS NRT results we used natural persistent scatterers (PS) in advanced InSAR technique.

2. Ultra – fast NRT system

One of the tasks in EPOS-PL project was to create a service for continuous monitoring of GNSS stations in Near Real-Time (NRT) processing in areas affected by mining exploitation. The NRT service was carried out with a ultra-fast 15-minutes interval of GNSS parameter estimation. The service based on GPS and GLONASS navigation systems data was adapted in Bernese GNSS Software v. 5.2 using Double-Differences method. The below scheme (Fig. 2) presents the external data sources included for each epoch of NRT EPOS-PL estimation process.

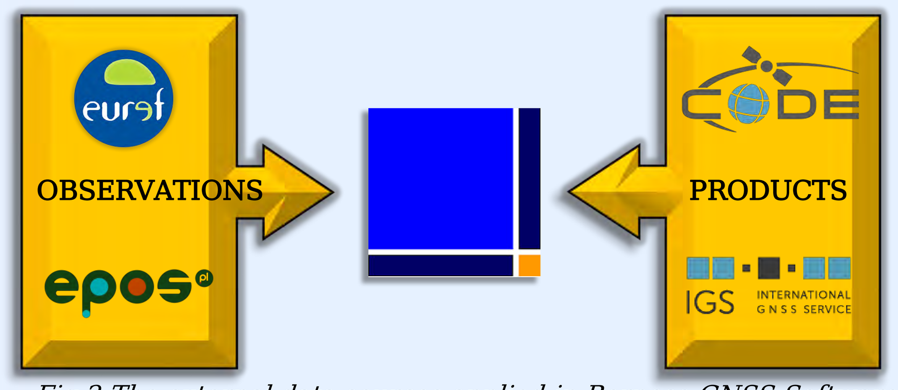

Fig.2 The external data sources applied in Bernese GNSS Software

The data from 34 GNSS stations, situated on territory of Poland and neighbourhood countries, are included to NRT system. Five from eight GNSS EPOS-PL stations are located on the USCB area (MUSE polygons) (Fig.3). Three remaining stations have a control function and they are located on areas not exposed to subsidence. The ITRF2014 reference frame is introduced using the 26 stations belonging to the IGS and EPN networks.

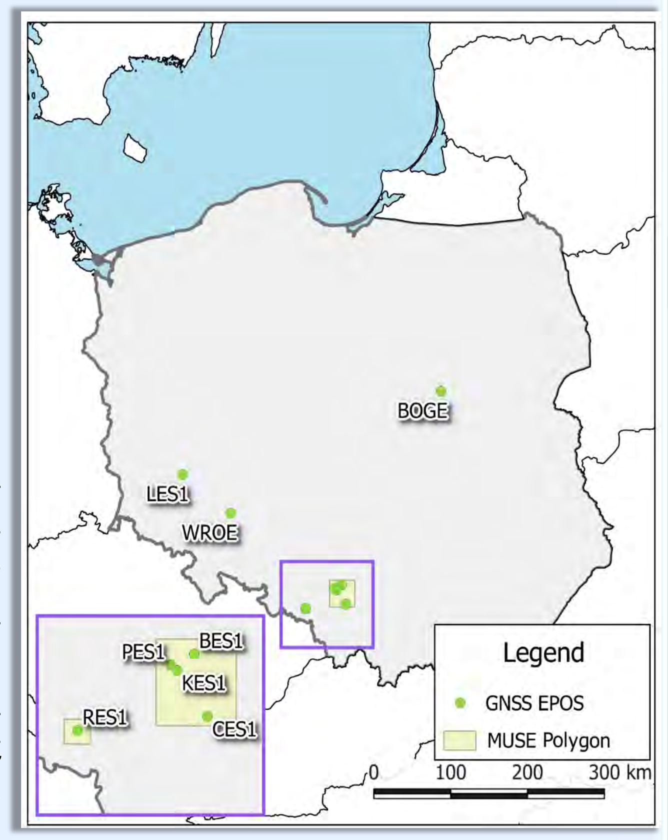

Fig.3 Locations of GNSS stations included to NRT processing only EPOS-PL stations

3. InSAR data

In presented study, we applied classical PSInSAR technique developed to employ the natural persistent scatterers (PS) which sizes are smaller than the resolution cell of SAR image (Tab.1). Using this technique, it is possible to achieve sub-meter precision of DEM formation and a deformation precision of a few millimeters.

Tab. 1 SAR data specifications for the study area

Parameter	Value
Sensor	Sentinel 1A+1B
Orbit direction	Descending
Product type	SLC IW
Track number	51
Num. of acquisitions	30
First acquisition	01/08/2018
Last acquisition	29/01/2019
Mean incidence angle	44.04o
Azimuth angle	-78.97o
Polarization	VV
DEM	SRTM

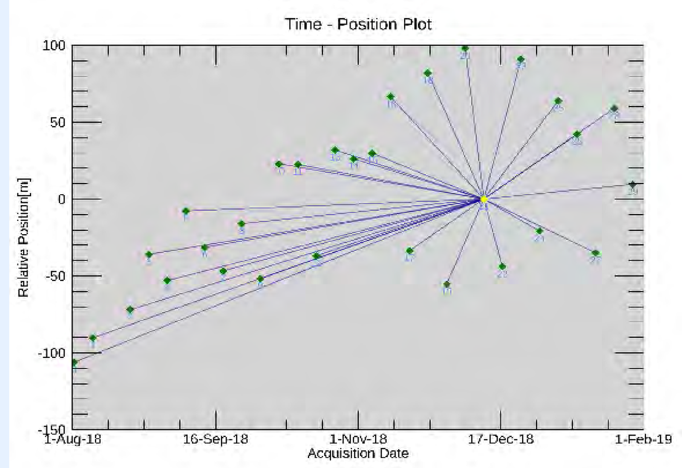

Fig. 4 Baseline configuration between InSAR images

Therefore, this approach has considerable advantage that PS points are not affected by baseline decorrelation (Fig.4). The RES1 GNSS station is located at southern part of one of the subsidence basins, however the specificity of the SAR technique makes it impossible to detect displacements in the north-south directions (Fig.5).

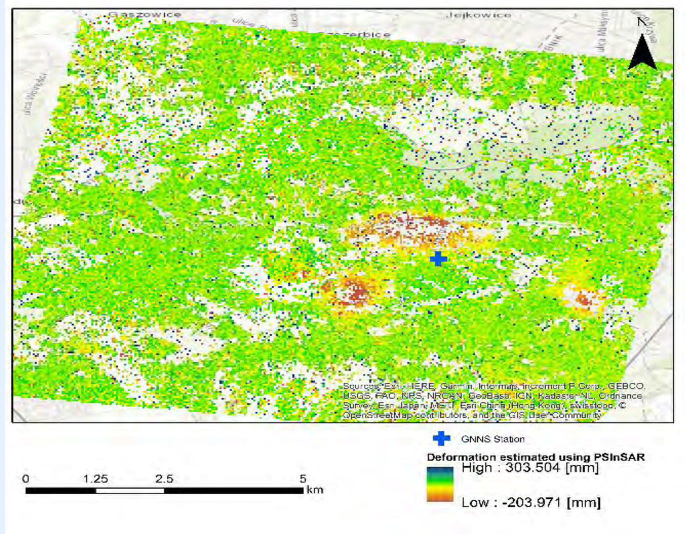

Fig. 5 Deformation estimated using PSInSAR approach (time span 1.08.2018 -29.01.2019)

4. Results

The GNSS velocity determination was based on a four month observation period covered by the time span from 5th of December 2018 up to 4th of March 2019. The annual displacement velocities for RES1 station in the North (N), East (E), Up (U) directions have been determined as 8.3, 1.4, -4.5 cm/year, respectively.

To limit the influence of outliers on the final results the M-estimation method was used (Fig. 6).

The results for the PSInSAR processing have been estimated since 1st of August 2018 to 29th of January 2019. Due to the temporal decorrelation, some information within the center of subsidence basins is missing. Nevertheless, the RES1 station is located at the border of one of the subsidence basins, where the deformation velocity was able to capture using PSInSAR approach (Fig. 5).

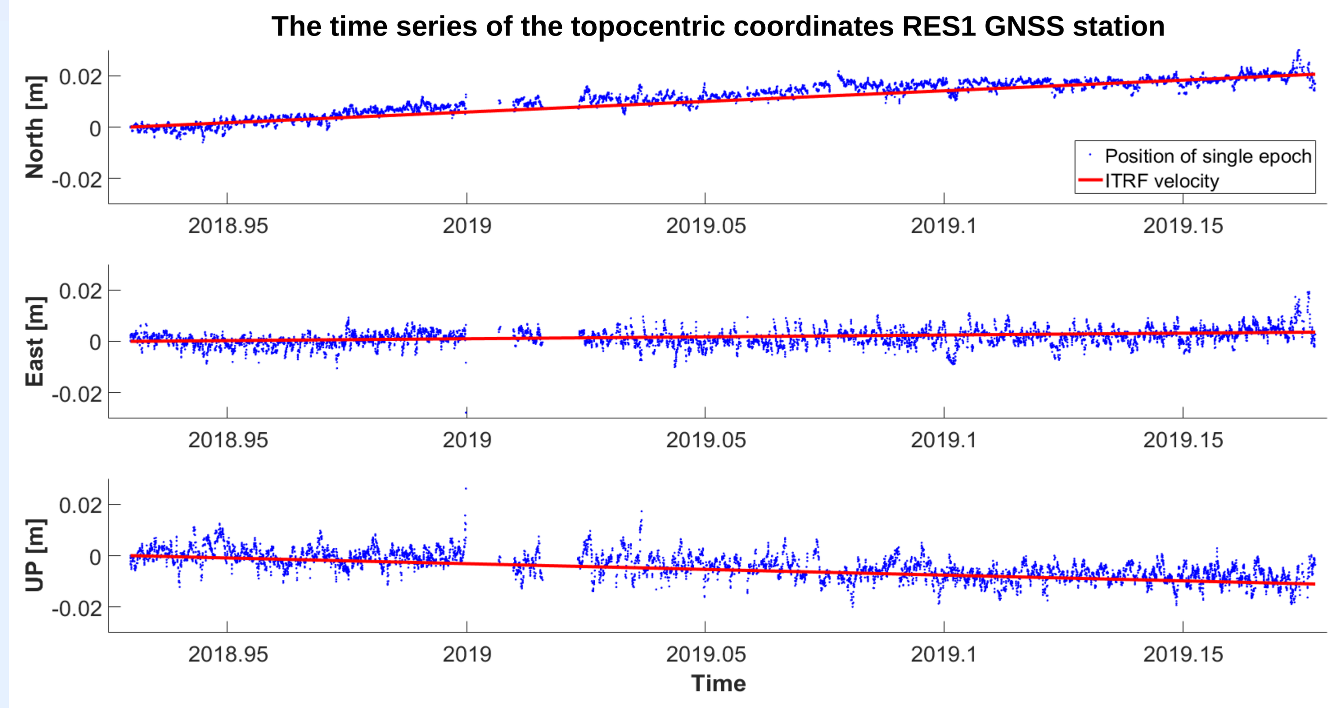

Fig. 6 The estimated topocentric positions and velocities in ITRF2014 reference frame

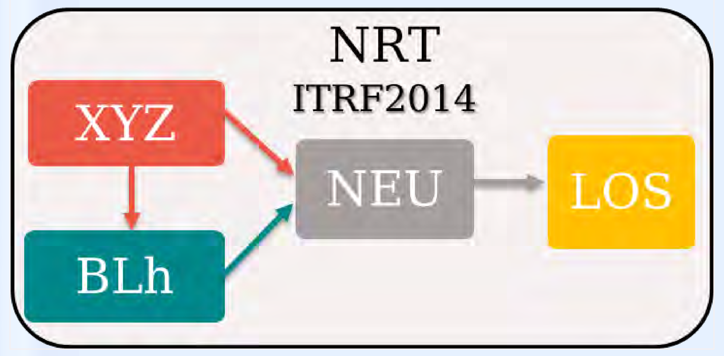

Fig. 7 The conversion scheme of the GNSS data set results

In order to compare the deformation value from both techniques, it was necessary to convert the NEU GNSS values into a displacement towards the SAR satellite along the line-of-sight (LOS) (Fig. 7, 8). To accomplish this task, the following relation was used (1):

$$Z_{los} = [sin(\theta_{inc})sin(\alpha) - sin(\theta_{inc})cos(\alpha)\ cos(\theta_{inc})] \begin{bmatrix} N \\ E \\ U \end{bmatrix} \quad (1)$$

where Z_{los} = the deformation in direction of line-of-sight
θ_{inc} = the radar incidence angle
α = the azimuth angle of Sentinel-1 flight
N, E, U = the station position in the local topocentric reference frame

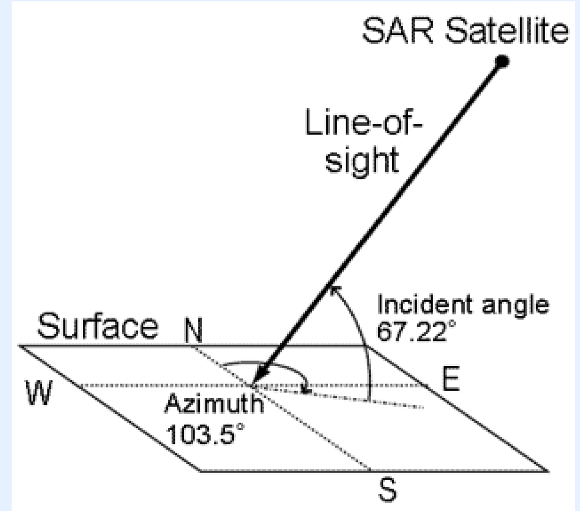

Fig. 8 The relation between SAR image and topocentric NEU coordinates

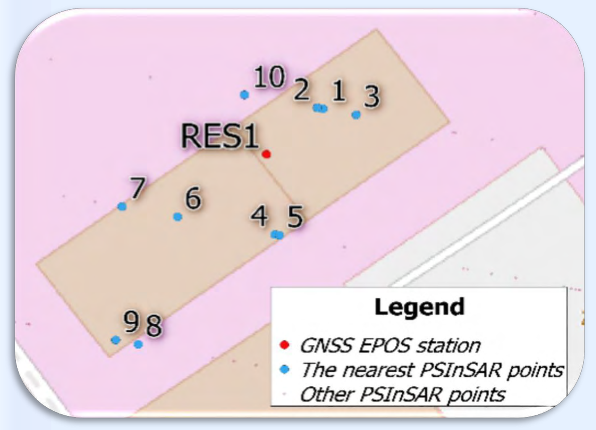

Fig. 9 The location of the 10 nearest PSInSAR points with respect to the RES1 station

The proposed GNSS processing approach shows stable solution in the areas of intensive mining exploitation. The results are validated by a comparison with PSInSAR results. For that purpose, ten the nearest to the RES1 GNSS station PS points were selected. Eight of the points are located on the building, while the other two are situated outside the contour of the building (Fig. 9). Overlapping periods of observations performed by GNSS and PSInSAR measurements were extracted for the period from 5th of December 2018 to 21st of January 2019. The M-estimation approach was used to determine the parameters of the deformation velocity towards LOS direction for each method.

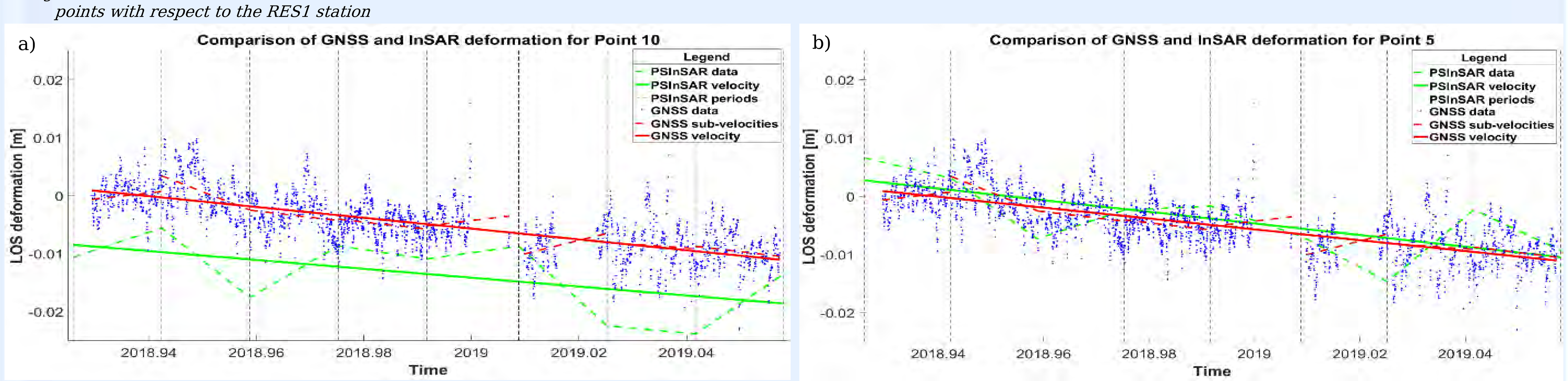

Fig. 10 The comparison between GNSS and PSInSAR deformation for point 10 (a) and point 5 (b)

The results characterized by grater shift of velocities were obtained to point 10 (Fig. 10a), which is located outside the building contour. The shift reaches up to 1 cm, while the velocities are -9.3 cm/year for RES1 station and -7.7 cm/year for point 10. The average standard deviation is -4 mm/year and -7 mm/year respectively.

The most similar results for both techniques are found for point 5 (Fig. 10b), which is situated on the edge of building. For this data time series, the shift is close to 0 cm/year and the velocities reach up -10.0 cm/year for point 5. The average standard deviation 5 mm/year.

The RES1 GNSS station is located in the border of the subsidence basin. Point 10 is located closer to the epicenter of the subsidence basins. Moreover, another reason for this could be, the geometry of the Sentinel sensors. Namely, slant range geometry and near polar orbit constellation, which is insensitive to detect North-South displacement component.

5. Conclusions

Deformations caused by mining industry are a significant problem, especially in areas characterized by high population density. Continuous monitoring over the effects of mining expansion is possible using many measurement techniques, among which are GNSS precise positioning and SAR technology.

The NRT processing enables constant monitoring of the stations location, while PSInSAR technique offers a 6 day exact repeat cycle. However, the integrated use of GNSS and SAR measurements enables to extend the concept of safety monitoring in spatiotemporal mode.

Thanks to the comparison of GNSS and PSInSAR results, this paper proved the effectiveness of both techniques for subsidence monitoring. The GNSS measurements are capable to detect displacements in all directions while the SAR technique makes it impossible to detect displacements in the north-south directions. The conversion of GNSS displacements in North East, Up directions allows to compare with InSAR deformations by the line of sight to the satellite.

From another point of view, PSInSAR provide bigger spatial coverage in comparison to single point of GNSS station. Therefore, both methods should be jointly applied in order to capture comprehensive information about the deformation pattern.

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