SURFACE DEFORMATION MONITORING (GNSS)

Politechnika Śląska

Presenter: Violetta Sokoła-Szewioła,

Authors: Violetta Sokoła-Szewioła, Zbigniew Siejka
Institution: Silesian University of Technology
Country: Poland

Surface deformation monitoring
GNSS

Main objectives:

- establish the relationship between seismic events or surface deformation and the coal mine flooding process,
- select methods and plans for long-term monitoring of post-mining areas to reduce seismic risk during and after coal mine closure.

	Presentation contents
1.	Test site
2.	Monitoring network
3.	Measurements system
4.	Measurements
5	Elaboration of observations
6.	Results
7.	Analysis
8.	Summary and conclusions
9.	Recommendations

POSTMINQUAKE
Induced earthquake and rock mass movements in coal post mining areas: mechanisms, hazard and risk assessment.

The presentation shows the results of Task 6.3 and Deliverable 6.2 entitled „Report on the observed changes of displacements of the mining area in relation to registered seismic activity on 'Kazimierz-Juliusz' mine”

Test site
Kazimierz – Juliusz Mine

The area of currently flooded Kazimierz-Juliusz hard coal mine in Poland.

Location: the eastern part of the Upper Silesian Coal Basin.

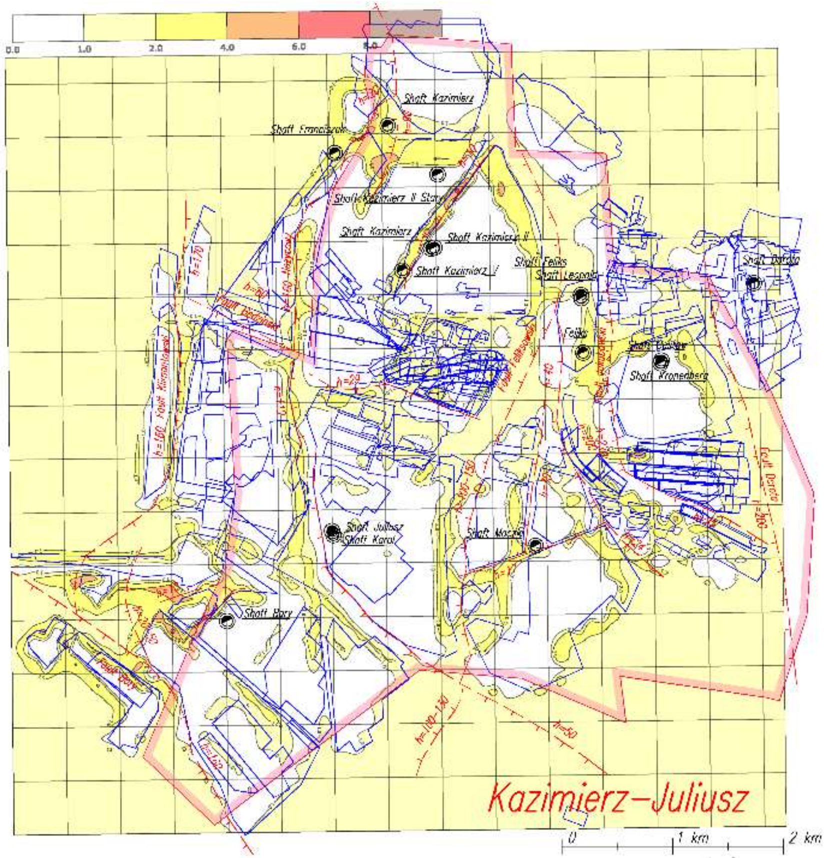
Location of Kazimierz –Juliusz hard coal mine
Backround source: https://www.geoportal.gov.pl

Monitoring network

The design of the spatial observation network.

Taken into account:

- analyses of the deformation-strain (energy) states of the rock mass,
- the completed mining,
- the possibility of stabilizing observation points in the field.

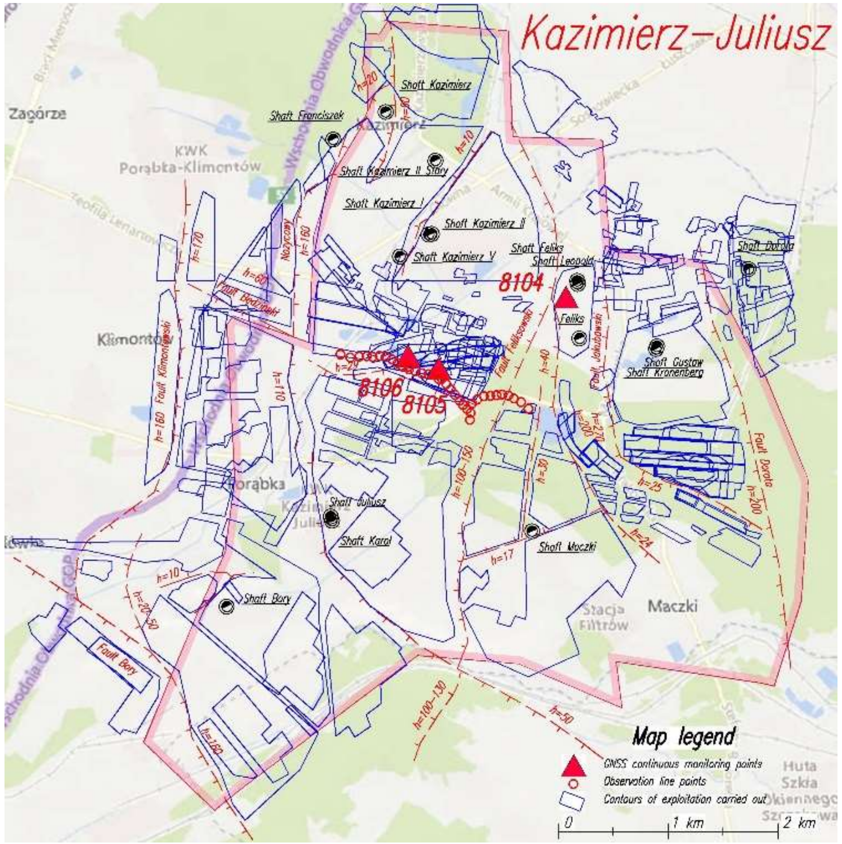


Distribution of the concentration factor of the vertical component of the spatial state stress in the sandstone overlying the seam 510 and the contours of the completed mining (in blue)

Monitoring network

Location of the monitoring points stabilized in the mine area:

- Points: 8104, 8105, 8106: GNSS monitoring stations- continuous monitoring.
- 34 observation points : periodic control measurements (angular - linear and leveling measurements, static GNSS measurements at selected observation points).



Location of monitoring stations and observation line points in the field overlaid with the mine map of the area. Background source: https://www.geoportal.gov.pl

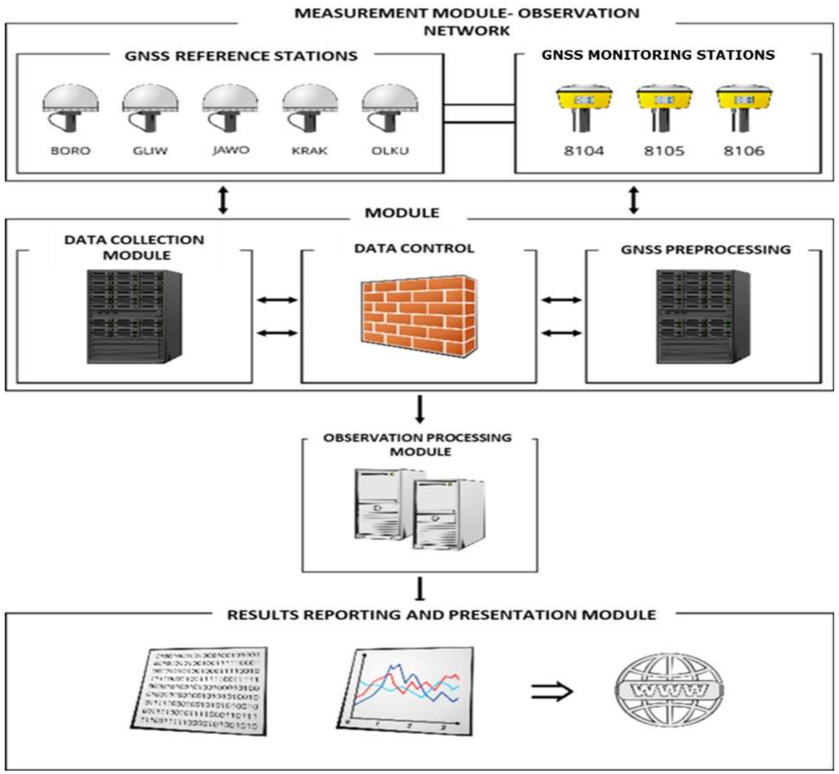
The automatic GNSS measurement system

- high-frequency and multi-system satellite observations,
- the relative method was used to precisely determine the position.

The system consists of four basic modules:

- a measurement module,
- a module for collecting, controlling and pre-processing observations,
- a module for processing and developing observations ,
- a module for reporting and presenting results.

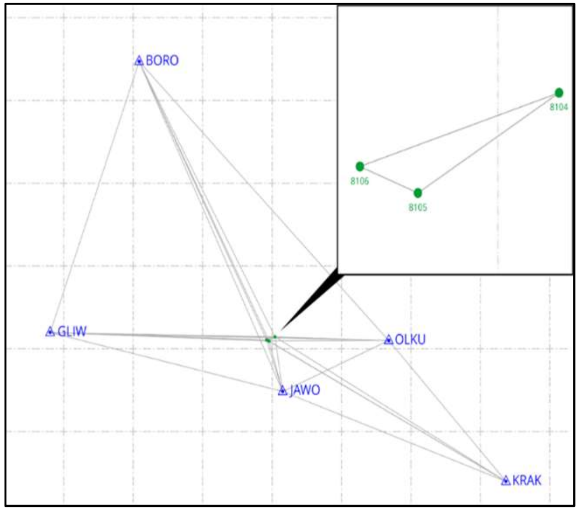
The Trimble 4D Control software.



Block diagram of the construction of an automatic measurement system and the development of GNSS observations in the Kazimierz-Juliusz mine- - developed in the project - details in (Sokoła & Siejka,2022- https://postminquake.eu/)

Measurements

A measurement module - the total GNSS continuous monitoring network
- three monitoring stations (80104, 8105, 8106),
- 5 reference stations, which were reference points for monitoring stations.



Sketch of the GNSS monitoring network at the Kazimierz-Juliusz site

Equipment of the each monitoring station:
- TRIMBLE NETR9s receivers
- Antena Zephyr 3 Rover.
- The Moxa communication module (GSM).
- APC BX500CI UPS emergency power supply module.
- Industrial camera for visualisation and monitoring GNSS antenna.


GNSS antenna and a camera installed on monitoring stations

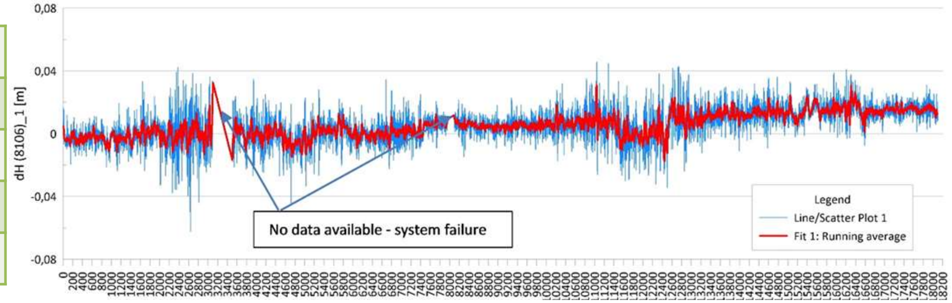

Equipment of the monitoring station at point 8106

Elaboration of observations

1. Observations - saved as one-hour observation files - in the receivers' internal memory
2. Communication modules - files sent to the server
3. Raw observation data converted to RINEX 3.03 format
4. Generate navigation files for all observed GNSS satellites necessary to estimate station coordinates
5. The development of GNSS observations in the post-processing mode -the relative positioning method
6. The changes in horizontal increments in the N and E directions and H changes - obtained
7. Elaboration of results for different computational strategies- method elaborated in the PostMinQuake project (details: Siejka& Sokoła, 2022- https://postminquake.eu/)
8. Displacements changes prepared for analysis.

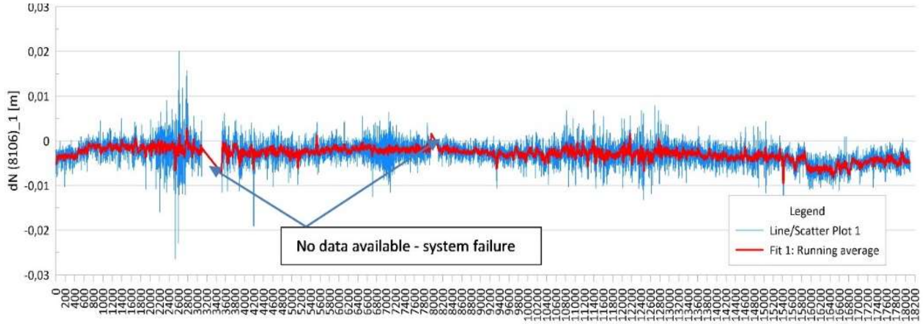
Results of GNSS observations

Point No.	dH		
	MIN [m]	MAX [m]	σ [m]
8104	– 0,0668	+0,0560	0,0069
8105	– 0,0641	+0,0633	0,0070
8106	– 0,0624	+0,0456	0,0072



Time series of changes of height H at point 8106 in one-hour solutions

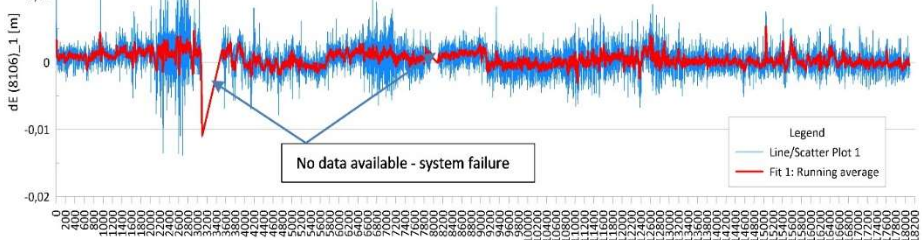
Point No.	dN		
	MIN [m]	MAX [m]	σ [m]
8104	-0.0238	+0.0236	0,0019
8105	- 0.0212	+ 0.0239	0,0019
8106	- 0.0265	+ 0.0201	0,0020



Time series of changes of the northing coordinate dN at point 8106 in one-hour solutions

Point No.	dE		
	MIN [m]	MAX [m]	σ [m]
8104	-0.0282	+0.0232	0,0016
8105	- 0.0227	+ 0.0169	0,0016
8106	- 0.0138	+0.0136	0,0017

σ- average standard deviation

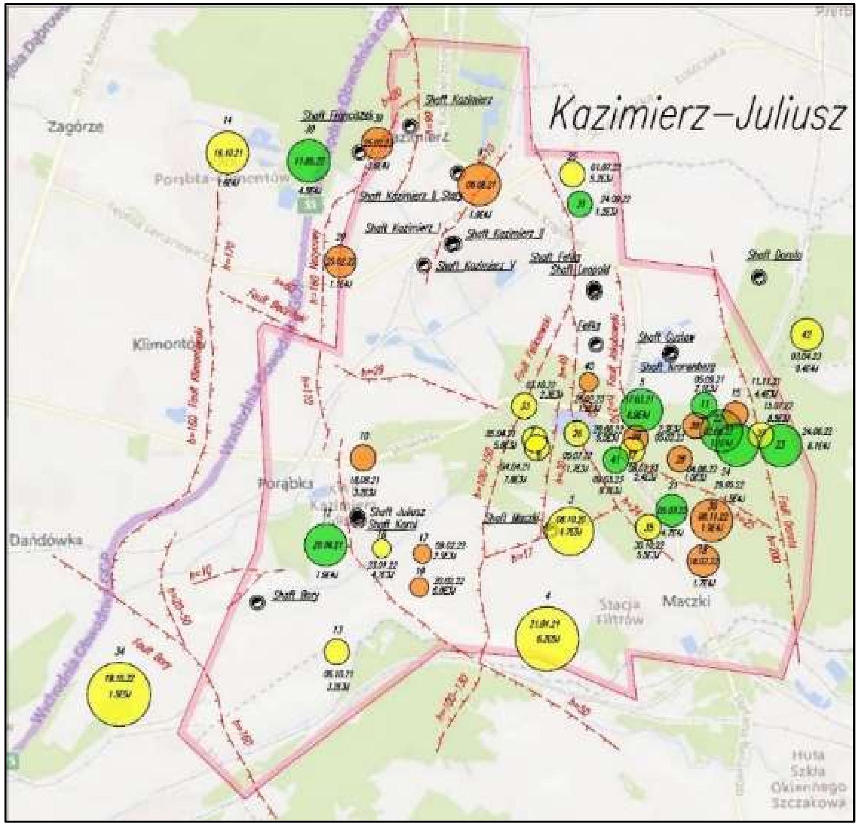


Time series of changes of the easting coordinate dE at point 8106 in one-hour solutions

Analysis

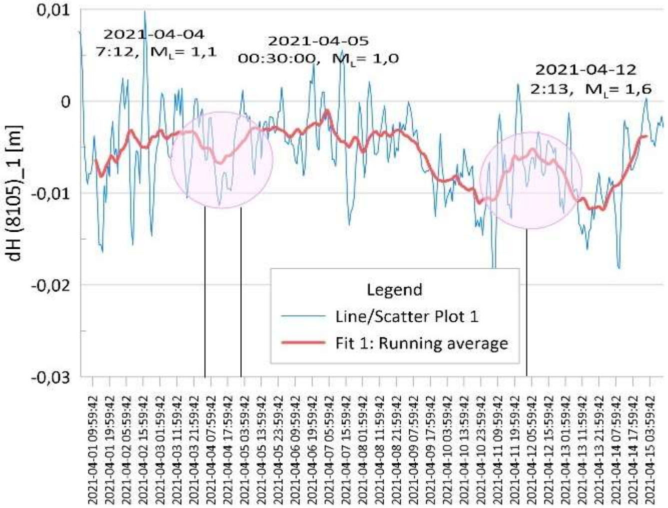
Analysis of the results of GNSS continuous monitoring measurements in relation to post-mining earthquakes:

- I - analysis in relation to the time distribution of registered post-mining earthquakes.
- II - analysis with respect to the periods of occurrence of the post-mining earthquakes identified in the stage I in a time window of about 2 weeks.
- III - analysis of high-frequency changes in the results of GNSS observations over the period of a 24 hours covering the moment of occurrence of post-mining earthquake (Real Time solutions - time resolution of 1 Hz).

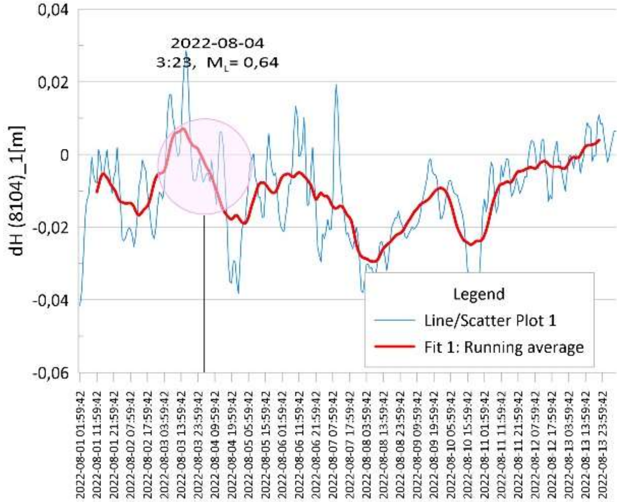


Distribution of epicenters of the analyzed post-mining earthquakes.

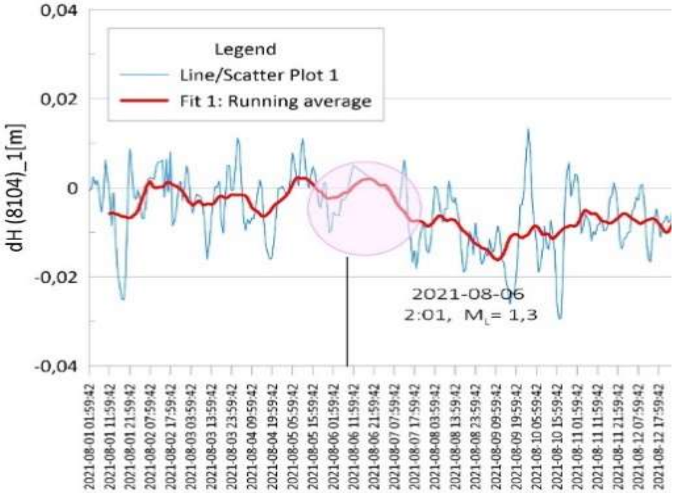
Analysis, cont.



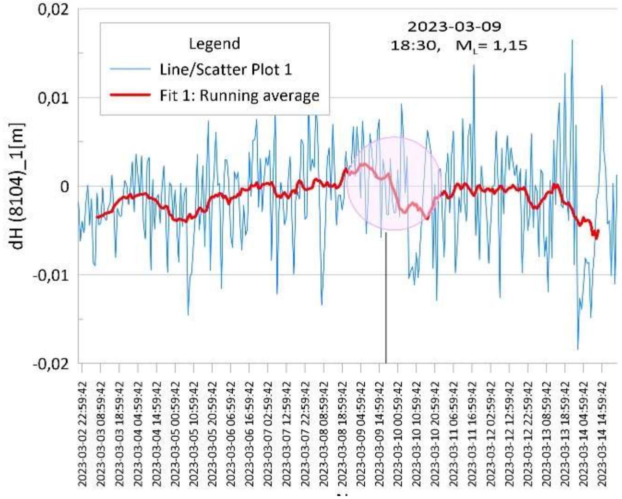
Time series of the changes in the dH coordinate in the time interval related to the occurrence of a seismic events on April 4, 2021, April 5, 2021, and April 12, 2021, at point 8105



Time series of the changes in the dH coordinate in the time interval related to the occurrence of a seismic event on August 4, 2022, at point 8104



Time series of the changes in the dH coordinate in the time interval related to the occurrence of a seismic event on August 6, 2021, at point 8104



Time series of the changes in the dH coordinate in the time interval related to the occurrence of a seismic event on March 9, 2023, at point 8104

Summary and conclusions

- During the period of continuous GNSS monitoring, horizontal and vertical displacements of the observed points were found. For changes in vertical displacements, subsidence and uplift were observed.
- During the observation period, subsidence and uplift were found. In the first period of the study, generally subsidence was observed, with periodic uplifts, and then a long-term trend of gradual uplifting of the area was observed, especially in the area of points located in the area of previous intensive mining.
- The results of continuous monitoring of the area of Kazimierz-Juliusz mine using GNSS technology showed that the occurrence of post-mining earthquake in the study area did not affect the occurrence of significant displacement values that would pose a threat to surface facilities and technical infrastructure.

Summary and conclusions, cont.

- The occurrence of regularities in the course of changes in displacements of points in the periods associated with the occurrence of post-mining earthquakes (58% of the analyzed events) were determined. Characteristic changes were observed in the course of displacement changes before and after the post-mining earthquake.
- It was found that the analysis of the dynamics of changes in surface displacement, under conditions of post-mining seismicity, is most favorably carried out on the basis of observations of vertical displacement.
- The occurrence of the three periods in the course of vertical displacements in the time periods associated with the occurrence of post-mining earthquakes was determined: uplift, an increased increase in subsidence, a stabilization of vertical displacement changes, a slow increase in subsidence and/or an increase in uplift). It was found that the observed patterns can be used to assess the potential possibility of a post-mining earthquake.

Recommendations

- Include continuous surface deformation monitoring system based on high-frequency satellite observations from multiple GNSS, using as many satellites as possible, that allows precise determination of 3D displacements.
- The use of automated systems for monitoring surface deformation, based on differential GNSS are recommended; this allows deformation monitoring and identification of their anomalous changes, which may be precursor or result of post-mining seismicity.
- Out of many various measurement techniques and computational strategies of satellite navigation systems, adopt solutions accounting for techniques for developing observations, which will allow obtaining the maximum amount of information on the movement of the monitored point.
- It is advisable to develop the same, continuous observations on different monitored points using different computational strategies: post-processing and real-time computation, which enable a quick assessment on the level of land surface changes generated by specific seismic phenomena, thus facilitating the impact and damage assessment.
- Analyses of the course of displacement changes, based on solutions obtained from the development of observations in post-processing with a time resolutions of 1 h are useful to identify increased, short-duration vertical (uplifts) velocities that may be an indicator of post-mining earthquakes. It is advantageous to carry out additional analyses based on RT solutions with a time resolution of 1Hz, for a time interval that includes the period of the 24 hours in which the post-mining earthquake occurred.
- Use continuous GNSS monitoring when possible, specifically in areas of surface deformation exceeding the accuracy of InSAR.

Thank you

Violetta Sokoła-Szewioła
Silesian University of Technology
https://www.polsl.pl/
violetta.sokola-szewiola@polsl.pl

ACKNOWLEDGMENTS
“The project leading to this application has received funding from the Research Fund for Coal and Steel under grant agreement No 899192”.

Co-financing in Poland by Ministry of Science and Higher Education: "Scientific work published within the framework of an international project co-funded by the program of the Ministry of Science and Higher Education entitled "PMW" in 2020- 2023; contract No. 5124/FBWiS/2020/2”

Politechnika Śląska