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Detection of measurement errors in the time series of coordinates of surface movement monitoring points with the use of satellite navigation systems

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European Commission | Research Fund for Coal & Steel

PostMinQuake RFCS RESEARCH PROJECT

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POSTMINQUAKE

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

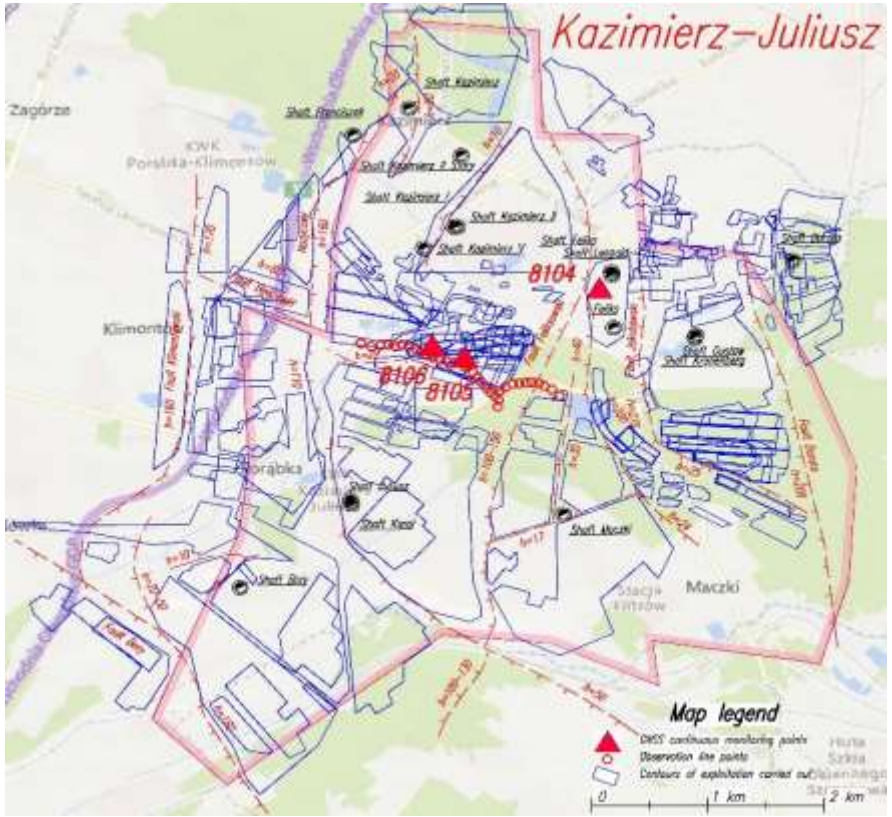
Main objectives of the project :

- establish the relationship between seismic events or surface deformations and the process of mine flooding,
- investigate and choose updated methods and plans for long term monitoring of post mining areas in order to mitigate seismic risk during and after coal

Backround source: https://www.geoportal.gov.pl

Monitoring of surface movements

- Continuous monitoring at single observation points using multi-system GNSS receivers.
- Periodical, control measurements-
  - angular - linear and leveling on stabilized observation points,
  - 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.
Backround source: https://www.geoportal.gov.pl

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The automatic GNSS measurement system

- High-frequency and multi-system satellite observations
- The relative method is 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.

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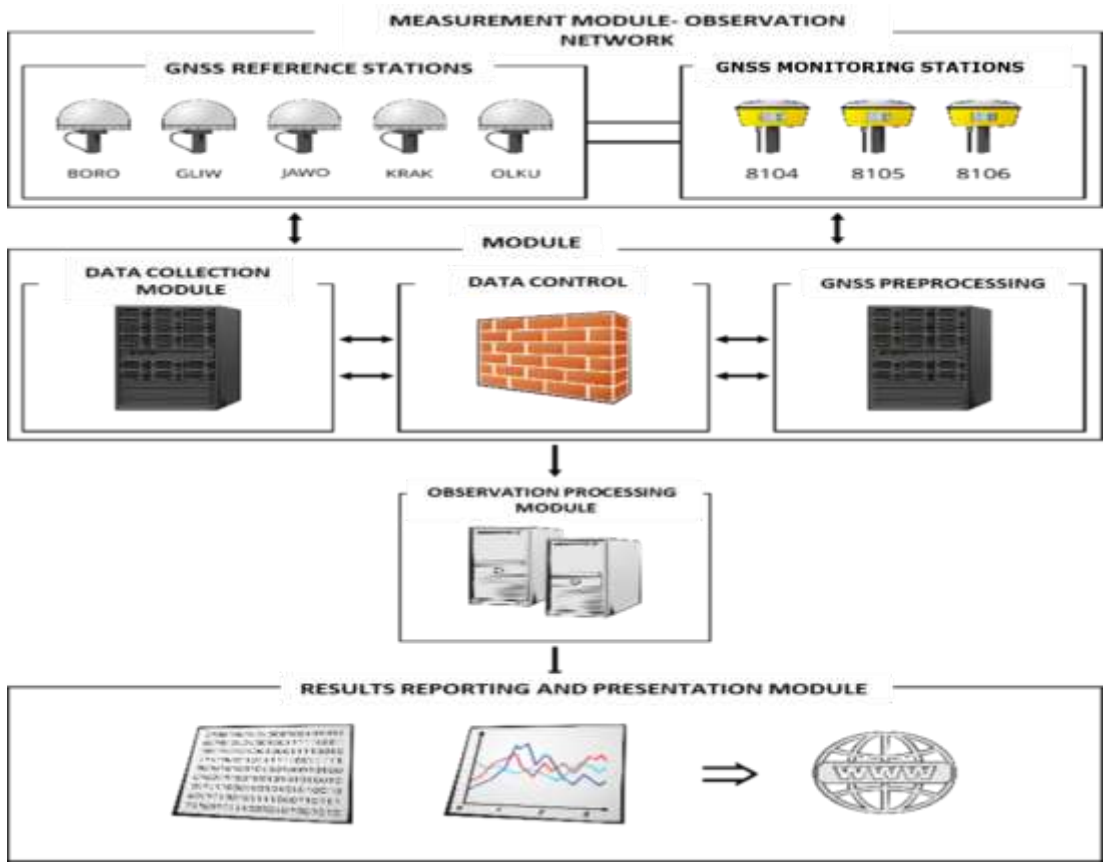
The Trimble 4D Control software.

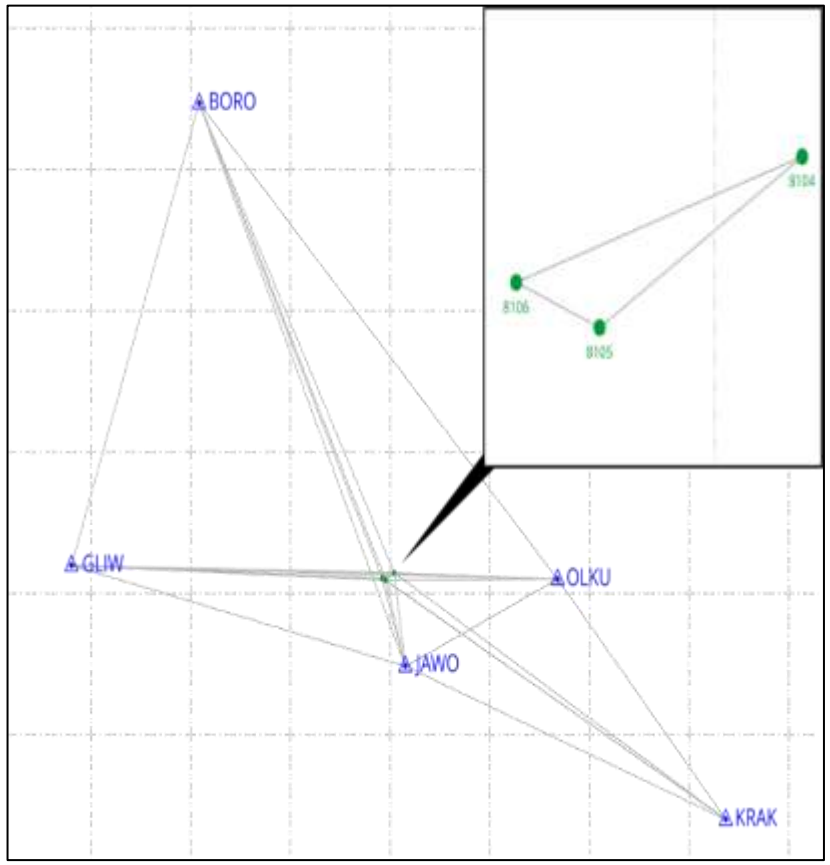


Block diagram of the construction of an automatic measurement system and the development of GNSS observations in the Kazimierz-Juliusz mine

A measurement module

two types of measuring stations:

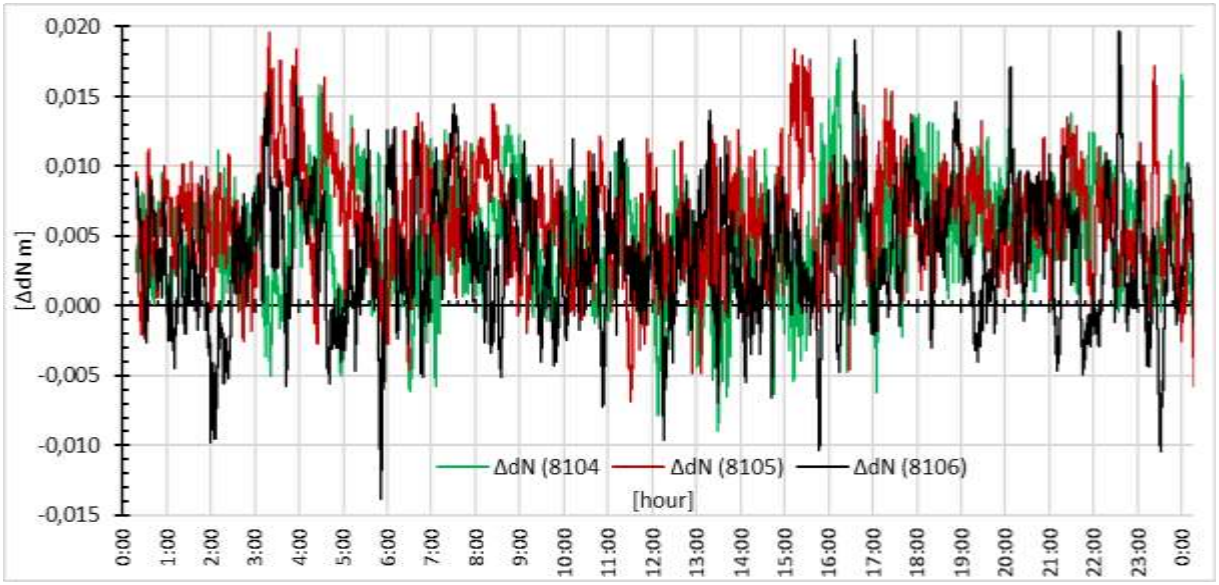
- three monitoring stations (80104, 8105, 8106),
- 5 reference stations, which are reference points for monitoring stations.



Sketch of the GNSS monitoring network at the Kazimierz-Juliusz facility.

Research material

- The high-frequency GNSS observations observed with a time resolution of 1 Hz were used as research material.
- 9 series of observations made on 3 control points covering the time period of 24h were used (February 20, 2022 from 00:19:01 to February 21, 2022 to 00:19:000.)
- At each point, 86,400 observations were recorded, which were summarized into time series showing the differences in 3D coordinates for individual components: north, east and altitude (ΔdN, ΔdE, ΔdH).



Original time series (ΔdN) of changes in the northern component for points 8104, 8105, 8106.

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Research methodology

- For the original time series, the discontinuity of the measurement epochs of coordinate changes in the time series was identified (methods visual and numerical) - no data discontinuities in the time series were found.
- A visual analysis of the original time series in the charts was performed. On this basis, the occurrence of certain cycles of periodic fluctuations in the analyzed measurements was found.
- Basic descriptive statistics were determined.

Summary of the basic descriptive statistics of the original time series of changes in the coordinate components.

statistics	ΔdN [m]			ΔdE [m]			ΔdH [m]		
	8104	8105	8106	8104	8105	8106	8104	8105	8106
MIN	-0.0090	-0.0068	-0.0138	-0.0165	-0.0098	-0.0149	-0.0270	-0.0253	-0.0297
MAX	0.0178	0.0195	0.0197	0.0026	0.0094	0.0083	0.0248	0.0250	0.0411
R	0.0268	0.0264	0.0335	0.0191	0.0191	0.0232	0.0517	0.0503	0.0708
AV	0.0048	0.0061	0.0036	-0.0056	0.0005	-0.0030	-0.0002	-0.0009	0.0034
ME	0.0049	0.0061	0.0035	-0.0056	0.0004	-0.0025	-0.0001	-0.0007	0.0031
SD	0.0037	0.0038	0.0045	0.0027	0.0031	0.0039	0.0077	0.0075	0.0091

It has been shown that the daily solutions from individual stations for certain time periods are characterized by high differentiation and the occurrence of outliers in time series.

- The filtration of the obtained observational data, the aim of which was, among others, the reduction of certain outliers in time.
- In order to eliminate outliers, the 3 sigma rule was used.
- The observations that did not fall within the limit of 3 standard deviations from the mean were eliminated from the analyzed time series.
- Temporarily replaced with a special no data code.
- No data codes were replaced with the simple arithmetic mean based on n = 10 observations preceding no data.

Summary of outliers for individual time series

Number of observations	ΔdN [m]			ΔdE [m]			ΔdH [m]		
	8104	8105	8106	8104	8105	8106	8104	8105	8106
All	86400	86400	86400	86400	86400	86400	86400	86400	86400
removed	519	438	610	488	151	18	228	140	686
[%] removed	0.60 [%]	0.51 [%]	0.71 [%]	0.56 [%]	0.17 [%]	0.02 [%]	0.26 [%]	0.16[%]	0.79[%]

The number of outliers ranged from 0.02% to 0.79%

- In the next stage of the study, a moving average, calculated from an odd number of adjacent elements in the series was used as a method of time series equalization.

Summary of basic descriptive statistics of aligned time series, changes in coordinate components

statistics	ΔdN [m]			ΔdE [m]			ΔdH [m]		
	8104	8105	8106	8104	8105	8106	8104	8105	8106
MIN	-0.0061	-0.0051	-0.0094	-0.0135	-0.0086	-0.0147	-0.0230	-0.0234	-0.0226
MAX	0.0158	0.0173	0.0166	0.0024	0.0094	0.0083	0.0226	0.0215	0.0295
R	0.0218	0.0224	0.0260	0.0159	0.0180	0.0230	0.0456	0.0449	0.0522
AV	0.0048	0.0061	0.0036	-0.0056	0.0005	-0.0030	-0.0002	-0.0009	0.0034
ME	0.0049	0.0061	0.0035	-0.0056	0.0004	-0.0025	-0.0001	-0.0007	0.0031
SD	0.0037	0.0038	0.0044	0.0027	0.0031	0.0039	0.0077	0.0075	0.0090

Conclusions

- The applied approach to the time series equalization allows for the elimination of random fluctuations as well as periodic fluctuations from the series.
- The applied methodology allowed for an improvement of about 22% in the precision of determination of observation time series by removing outliers and equalizing the series.
- This approach, used in the process of developing the results of observations carried out as part of the research project in question, allows the smoothing of the time s[illegible]out interfering with its internal nature and structure.

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