Wrocław University of Science and Technology

Detection of surface subsidence using SAR SENTINEL 1A imagery and the short baseline InSAR method – a case study of the Belchatow open pit mine, Central Poland

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Abstract

The work focuses on time series analysis application through the high temporary resolution imagery from the SENTINEL 1A/1B mission. The analysis of surface subsidence in open pit mining area was performed by the selected InSAR approach - small baseline InSAR. This methodology allows for continuous monitoring of the mining area. The study was performed in the 700 km² mining area of the PGE GiEK KWB Belchatow mine in Central Europe (Area Of Interest, AOI). The SAR imageries acquired by the SENTINEL 1A/1B satellite for the 124-descending track in two years period - 10.2015 and 01.2017 have been used in the analysis (64 SAR IW imagery, ca. 12 days sampling rate) . The post-processed satellite LOS (Line of Sight) displacement indicates vertical changes of the surface within the dumping and excavation area. The analyzed AOI shows total subsidence of ca. -500 mm, whereas the excavation area shows a trend of terrain uplift ca. +250 mm during the analyzed periods. The presented processing pathway allows for the early detection of landslides in near real-time. Future work will focus on the accuracy assessment of analyzed data and detection of horizontal displacements of the AOI.

2. Introduction and Area of interest

In the presented work an active and passive remote sensors were used for the monitoring of surface changes. The main aim of this work was to determine the values of pseudo vertical movements as well as land cover changes of the PGE GiEK KWB Bełchatów Open Pit Mine (Central Poland, Europe). The developed methodology was matched to the specifics of a lignite open cast mine, which surface continuously changes within the time. The main concept is based on Sentinel1 and Sentinel2 big data fusion. The research area of this work presents the SBinSAR and Bare Soil Index time series analysis of Copernicus Sentinel imagery and land cover change detection form Sentinel2 for LOS displacement validation.

The analyses were carried out at PGE GiEK KWB Belchatow open pit mine located in Europe, Central Poland. The entire mining area is ~700 km2 (Fig.1). The KWB Bełchatow open-pit mine consists of two excavation areas. These are named as Belchatow (A) and Szczercow open-pit mine (B). The analyzed mining area covers the area of dumping ground (C). The main goal was to separate the anthropological changes and natural changes of the AOI. Components: dumping area, mining terrain, land cover, and bare earth detection were taken into account. The land cover changes and anthropological changes were subtracted from the whole observation to improve the interpretation of the final results in two aspects: macro and micro scale. The macro-scale covers the mining area. The micro/local scale covers the areas which represent a land cover change (LCC) caused by i.a. mining excavators.

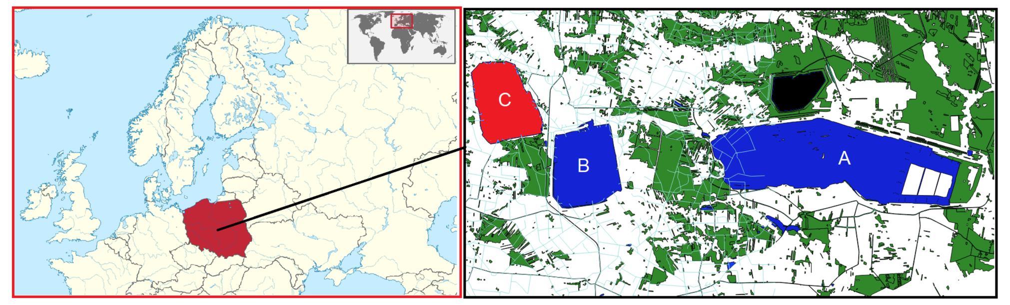

Fig. 1. Area of Interest (AOI) - PGE GiEK KWB Belchatow Open Pit Mine (Central Poland, Europe) [Map.Center(19.245N, 51.2414E, WGS)]. The QR code represents the localization of AOI in the web portal.

1. Motivation

The classical way of geodetic measurements is based on a fixed reference geodetic frame around the mining area. Classical measurements allow determining absolute coordinates of measurement of each previously stabilized control point. In this approach, we can calculate differentia changes and velocities (Wajs, 2018a).

In this work, we analyzed images from active remote sensing Sentinel 1A and 1B satellites. Another part of the research was the development of images from remote sensing passive sensors Sentinel 2A and 2B named as MSI (Multispectral Imagery). The idea of antrophogenical change detection and SAR subsidences of natural origin was presented on (Fig.2).

Due to the fact, that in the analyzed AOI there is an active production process connected with anthropogenic human activity, the monitoring of the mining area is a big challenge. The aim of this work was to get the answer:

Question 1: What the SAR signal is reflected from?

Question 2: Do the antrophogenical changes (caused by the mining excavation process) have an impact on observed LOS displacements?

The last question was divided into two aspects:

In macro-scale (for analyzed mining area boundary)

In the local scale (testing area – dumping site in the western part of AOI) and what is the noise of the final reflected subregions?

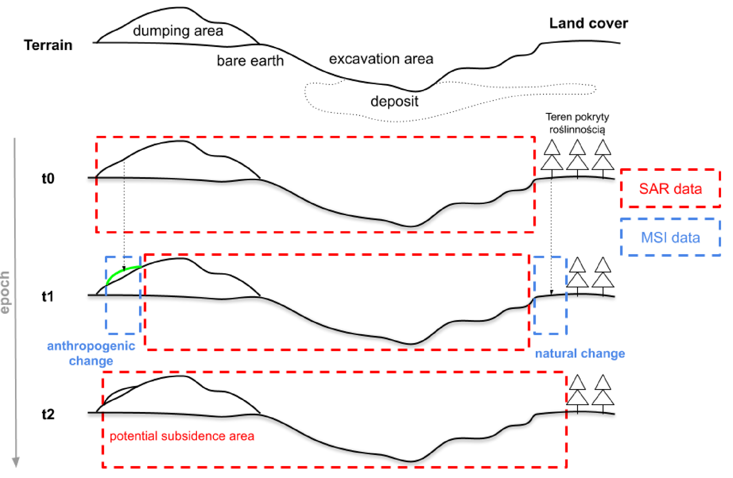

Fig. 2. Optical anrophogenical change detection and SAR subsidences of natural origin.

3. Methodology 1

The main goal of the research was to process the time series of Sentinel-1A/1B SAR data. The Small Baseline InSAR approach was chosen for data processing (Berardino et all., 2002; Ferretti et all., 2007). We tried to answer Question 1 which was connected to reflectance. For this purpose, the results of InSAR (SBAS) processing were integrated with passive remote sensing data. In this work, the DInSAR with small (short) baselines time series methodology was used. The high temporal resolution of Sentinel 1A/1B satellites combined with precise orbits ephemerides allowed us to use time series analysis with an additional constraint (Fig. 3). The first stage of Sentinel 1 was to acquire data in a single 1A platform. Science 04.2016 we took into consideration Sentinel 1B and this increased the frequency of SAR sampling of AOI (Fig. 4). The final results present the cumulative subsidence in the analyzed period of time. The analyzed pixels are parametrized by coherence and represent LOS changes of DS scatters. Processing of the spectral index of areas not covered by vegetation (bare soil index estimation; BSI) resulted in the construction of a mask identifying regions strongly reflecting SAR signals (Fig 7.) The methodology was: subtraction of the potential unwanted scatters such as objects with high noise to signal ratio (Fig 5, 6). It can be observed by post-processing BSI at Sentinel 2A/2B passive imagery. The BSI combines blue, red, near-infrared (NIR), and short wave infrared (SWIR) bands to capture soil variations (Li, S. and Chen, 2014). These bands are used in a normalized manner, with the SWIR and red bands being used to quantify the soil mineral composition, while the blue and NIR bands are used to enhance the presence of vegetation. Fig 5 shows the Corine 2018 land cover of analyzed mining area with visualization of class – forest. These regions may represent high noise to signal the C band ratio. Figure 6 shows the hierarchical exploitation process of brown coal excavation which may cause additional decorrelation of the SAR signal.

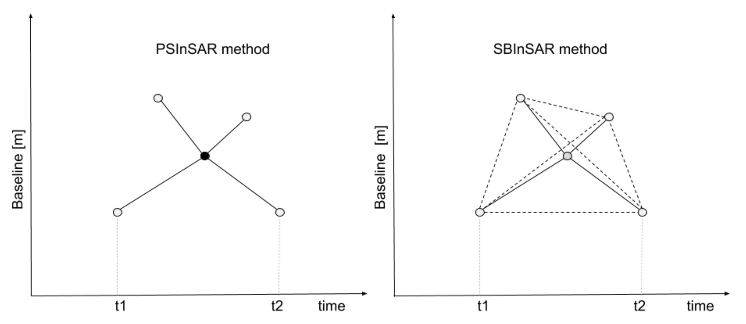

Fig. 3. Persistent Scatterer InSAR vs. Small Baseline InSAR.

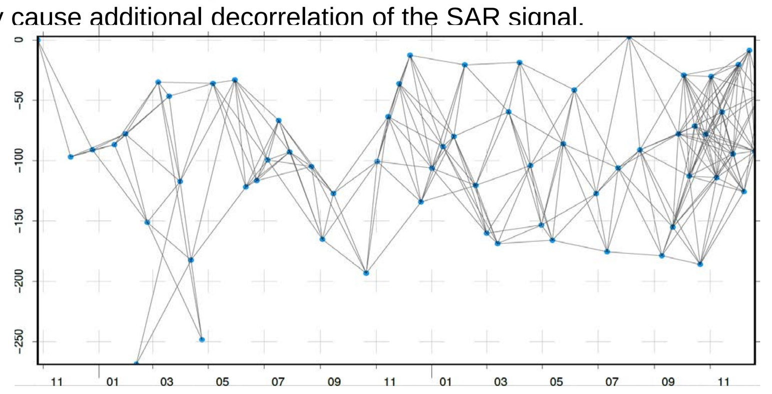

Fig. 4. Baseline plot for analyzed time series years: 10.2014 to 1.2017 (64 SAR IW imagery, ca. 12 days sampling rate).

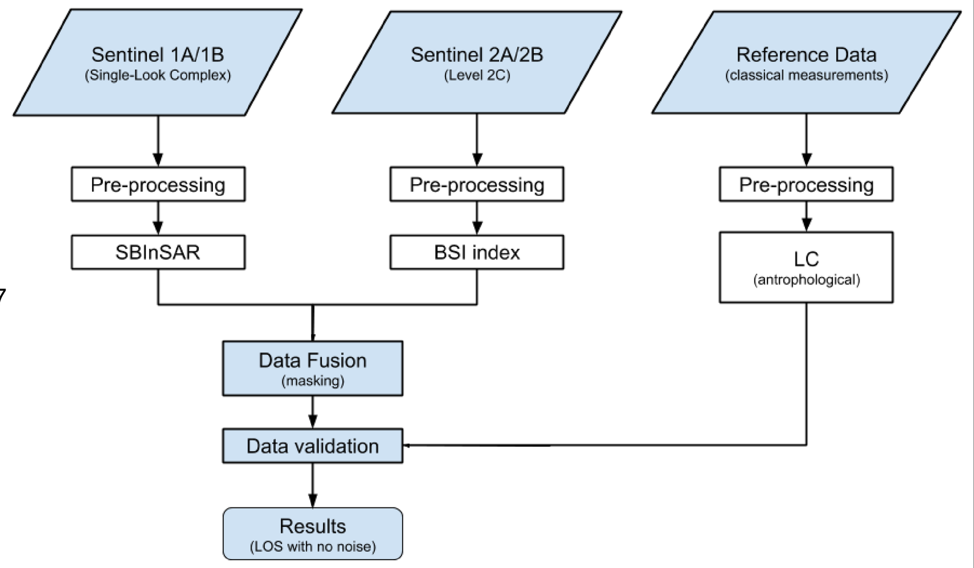

Fig.7. Flowchart of the developed BSI methodology.

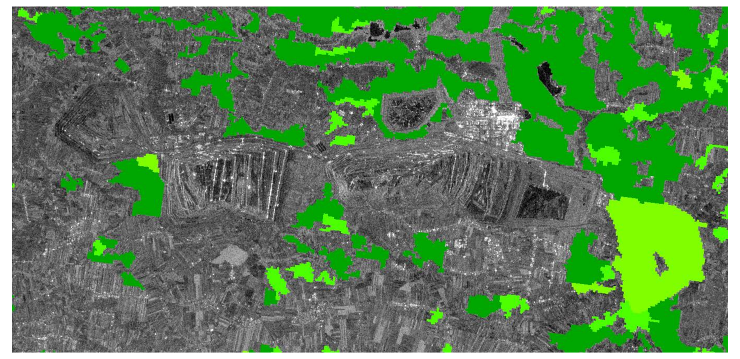

Fig. 5. Visualization of Corine LC 2018– Forests in the analysed mining area.

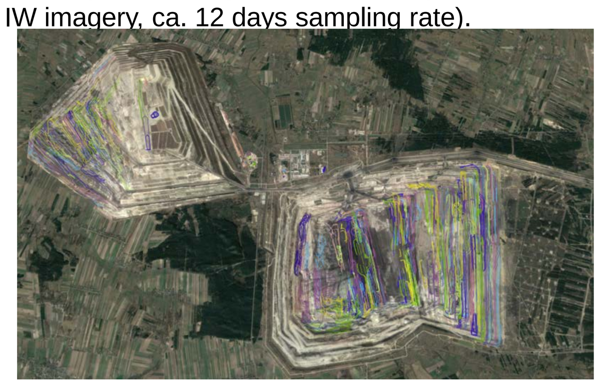

Fig. 6. Visualization of hierarchical excavation work on B and C part of AOI.

4. Methodology

Analyzing the problem connected with the detection of anthropogenic changes caused by the excavation process on the macro scale. The Sentinel-2 multispectral imagery was used as an independent source of data to determine the land cover changes in the mining area (Wajs, 218b). The regions of changes in the scale of the mining area (full AOI) proceeded from initial date (10_2015) and end of an analyzed period of time (01.2017). In this approach developed in GEE (Google Eart Engine) processor we produce a simpy model of change developed by image differencing. The results presented in Fig 5. shows that the excavation process in open pit hole B was conducted by excavators in the east direction. The final results of the SAR imagery processing allow determining the continuous changes in this region. The hypothesis is as follows: the hierarchical excavation process ca. 30 m in depth and system Sentinel 1A/1B acquisition of single track ca. 6 days allows to detect continuous pseudo vertical uplifts in LOS direction.

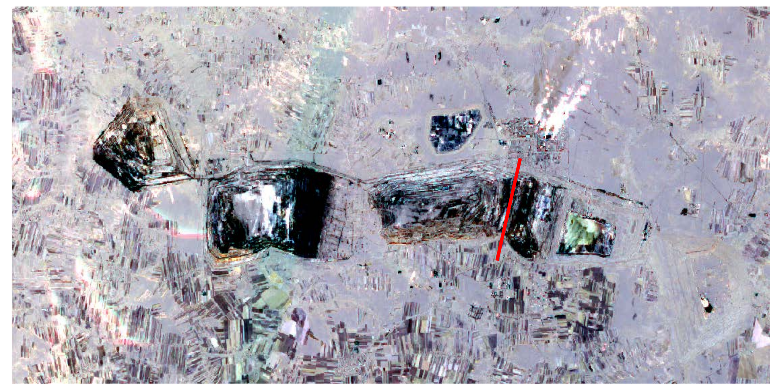

Fig.8. Map of differences Sentinel 2A 10_2015 to 1.2017 with attached red profile line.

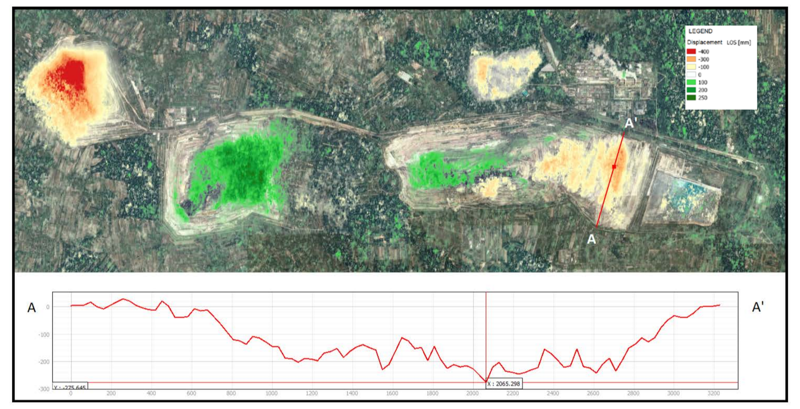

Fig.9. Summary LOS displacements profile plot of Sentinel 2A 10_2015 to 1.2017.

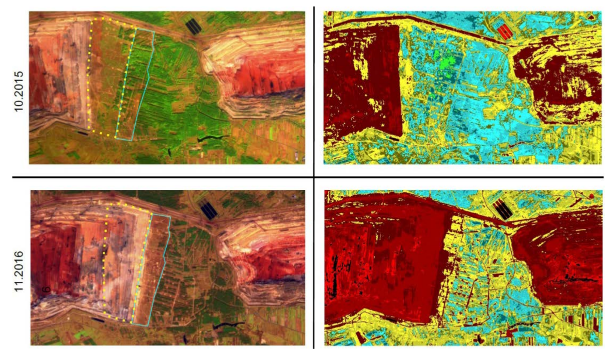

Fig.10. Change detection of exploitation foreground based on post-classification comparison Sentinel 2A/B 10.2015 to 11.2016 imagery.

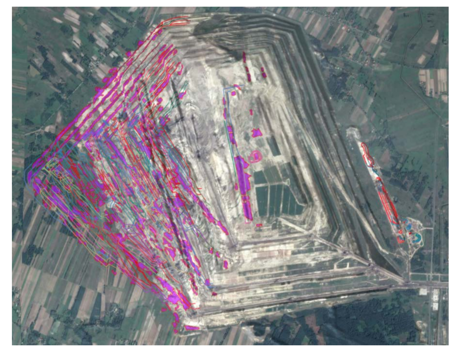

Fig.11. Change detection of dumping area C, based on algorithm 2D-Otsu (scene of Sentinel 2A/B 10.2015 to 11.2016).

5. Results of macro scale analysis

The BSI-SBAS approach allows detecting the mean trend of surface changes in the study area. Application of the Sentinel 1 and 2 satellite missions in this methodology allows for continuous monitoring of the open cast mine area in 6-day intervals. An attempt to examine the internal quality control of the estimated subsidence was also undertaken. The final result was a map of cumulative uplifted and subsided areas for a 2-year long period as well as mean velocity of the pseudo-vertical changes in the Line Of Sight (LOS) direction (Figs. 12, 14).

The obtained results show that the LOS measurement noise does not exceed ±50 mm for unfavorable regions with a vegetation cover (Fig. 15). Existing uplifts are visible inside the excavation area (central part of AOI) and subsidences are present on the dumping area (western part of AOI) and in the internal dumping area (central part of AOI; Fig.12, 14).

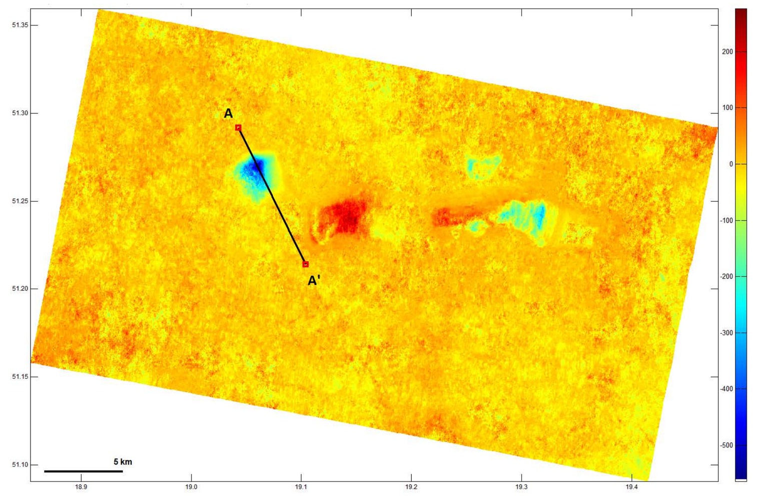

Fig. 12. Small Baseline InSAR cumulative map of subsidence of the mining area. The profile of subsidence A-A' is shown in Fig. 15 (a).

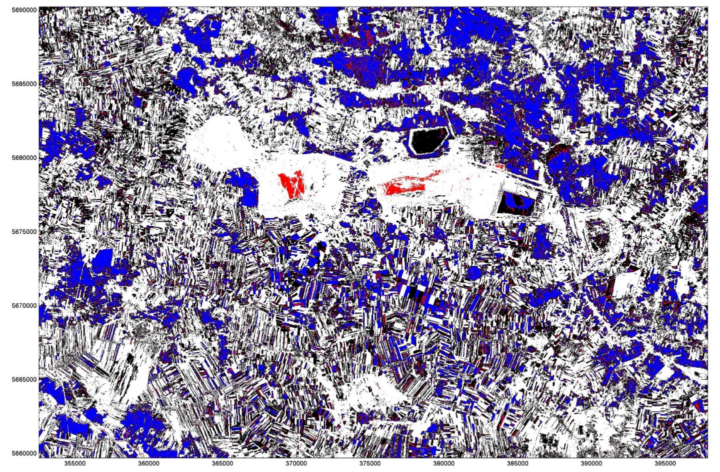

Fig. 13. Proceed final bare soil index BSI mask from Sentinel 2A/2B.

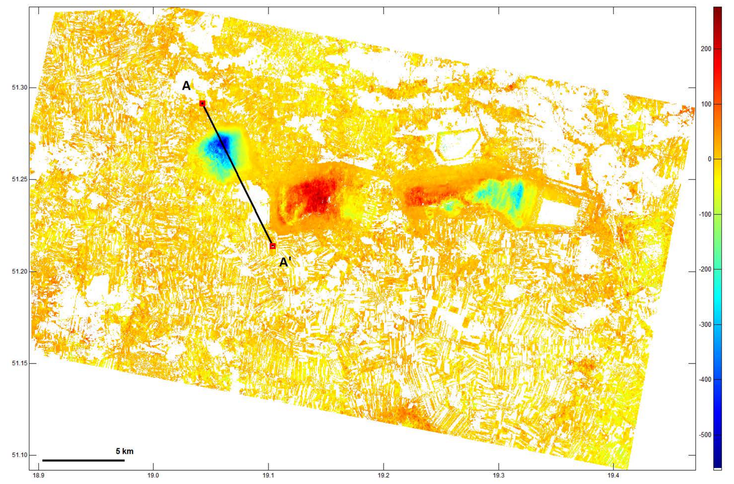

Fig. 14. BSI-SBAS cumulative map of subsidence of the mining area. The profile of subsidence A-A' is shown in Fig. 15 (b).

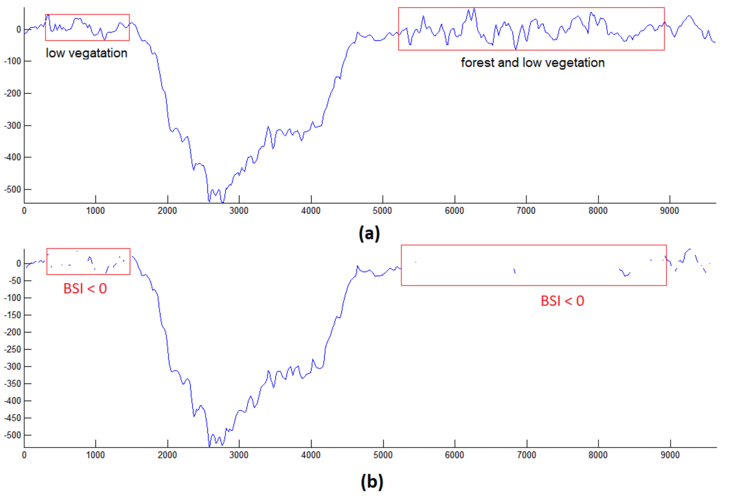

Fig. 15. The profile of subsidence A-A 'presents the plot of cumulative land subsidence of the total analyzed period of time.

6. Results of micro scale analysis

The results of the micro-scale analysis were presented in figure 16. For this kind of analyze we select a one month period of time which was connected with w work of a single spreader machine in dumping area C (AOI). The results show that the Sentinel 11/1B used in this work with a data sampling period= 6 days allows us to detect in this case subsidence ca. 80mm with the small noise off +- 10mm (red boxes on figure 17). The final results of the SBAS time series analysis of the dumping area were shown in fig. 16. We assume that the observed subsidence in dumping area C is connected with the natural process of ground compaction and the maximal value of ground compaction reaches -500 mm. We can observe that the direction of the maximal value of subsidence falls and moves into the direction of the storage process.

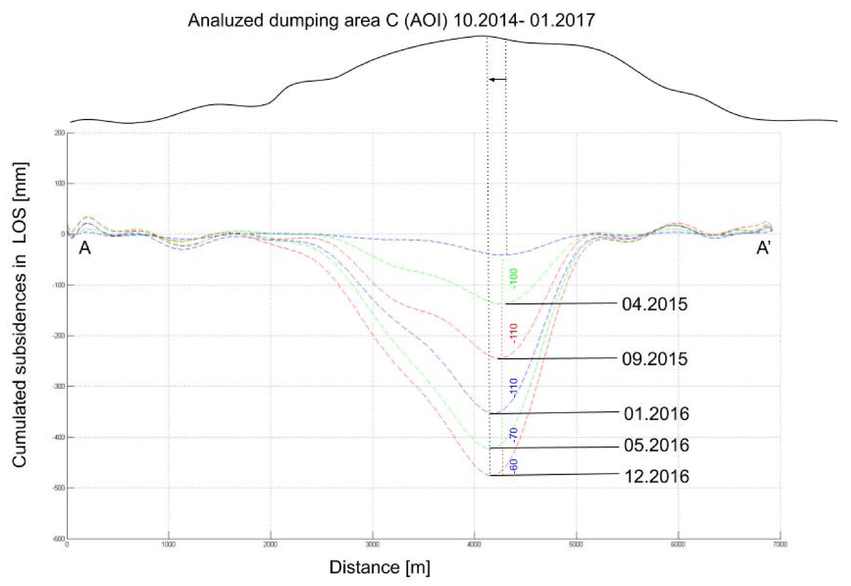

Fig. 16. The plot of cumulative LOS displacements on AOI dumping area C in analyzed period of time.

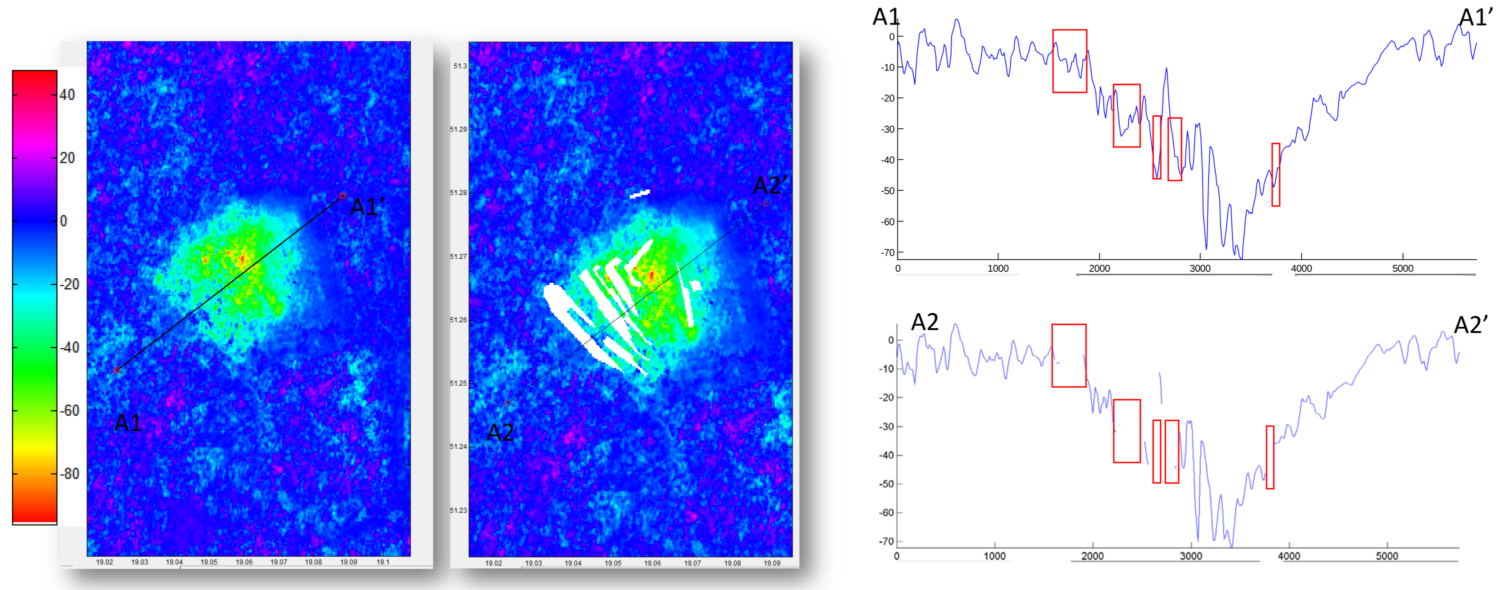

Fig. 17. An example of a spreader machine working on the dumping area C. The profile A1-A1' (left) the final SBAS results of cumulative ground subsidence and (right) image with profile A2-A2'.

7. Conclusions

The developed model provides information on the surface changes with a smaller accuracy than the available classical geodetic surveying techniques. However, the advantage of this study was a high time resolution of the final results and coverage of the entire mining area (700 km²). The obtained maps of surface changes based on remote sensing data may constitute models for operational purposes. The results of the study are not interpreted by the author in terms of geology and geomechanics but represent a signal of the event. The study supplies information on a local scale and enables pointing out the general trends taking place in the entire mining area. At the same time, the result of the BSI-SBAS study allows for indicating areas, for which measurements with classical geodetic techniques would be advisable.

Literature

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