

INVESTIGATING STRONG MINING-INDUCED GROUND SUBSIDENCE WITH X-BAND SAR INTERFEROMETRY IN UPPER SILESIA IN POLAND

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ABSTRACT

The Upper Silesian Coal Basin is one of the biggest coal basins in Europe located in southern Poland. Underground exploitation of coal deposits causes changes in the rock mass and terrain surface. The mechanical strength of the rocks is reduced and as a consequence surface deformation occur. Deformation after a single wall excavation forms a basin on the ground that can be 0,75 to 2,0 m deep. Hence, several mining works operated at different depths produce a total ground surface displacement of several meters. For this reason, there are many places in USCB urban areas where damages are important. Bytom city is one of such examples, where coal has been exploited since 1902. The city suffers mining subsidence, producing damages to linear structures like roads, railways, gas and water pipelines, electric power lines and buildings. Different methods are used for evaluating hazards caused by deep hard coal mining. These methods include mostly geodetic surveying and GPS measurements. Satellite Synthetic Aperture Radar Interferometry (InSAR) data can successfully complement geodetic measurements providing displacement measurements of wide areas. In this work 30 TerraSAR-X satellite images acquired during the period 05/07/2011 to 21/06/2012 were used. X-band wavelength proved to be very helpful tool for investigating very fast movements, directly connected with underground mining activity. Ground surface displacement data was retrieved from both conventional (DInSAR) and advanced differential interferometry (A-DInSAR), also called permanent scatterers interferometry (PSI). Differential interferograms helped to detect and measure ground surface displacement of the subsidence basins, reaching up to few decimetres in a few months, equivalent to 1-2 meters/year. Completing these measurements, PSI technique provided measures of 14 cm/year maximum, permitting to define the boundaries of the area affected by mining subsidence. As a result, both methods of displacement measurement permitted to estimate the total mining subsidence affecting Bytom city in period 07.2011-06.2012.

INTRODUCTION

The extraction of underground ore material through mining activities is usually associated with major geological, hydrogeological and geochemical impact on the environment. One particular phenomenon that may cause extensive damage to houses and infrastructure is surface deformation. It is therefore necessary to monitor ground movements, in order to detect and prevent potential damages to urban structures and infrastructures.

In Poland Upper Silesian Coal Basin (USCB) is one of the biggest coal basins in Europe. Hard coal underground exploitation has been conducted since the XIX century [1]. Nowadays, there are thirty active hard coal mines, where longwall mining typically operate at depths ranging from a few meters to more than 1000m [2]. Ground surface deformations triggered by underground mining activities reach several meters in USCB [2]. In this work we focus on Bobrek-Centrum mine due to its impact in Bytom urban area (area outline in red in Fig. 1).

Leveling is the most popular subsidence monitoring method used in USCB. The main limitation of field-based monitoring techniques, such as leveling, is the need of frequent field observations in time and in space, which will increase the monitoring cost. This limitation can be overcome by Synthetic Aperture Radar Interferometry (InSAR) [3]. By systematic large-scale coverage, high spatial and temporal resolution, InSAR provide the ability to detect from decimeter to millimeter scale surface deformation. The technique is based on the phase difference measurement between two SAR images. Differential SAR interferometry (DInSAR) removes the topographic phases with an external digital elevation model, in order to measure ground surface displacement. DInSAR main limitation is the radar signal decorrelation in time that will prevent DInSAR from successfully measure ground surface displacement [8]. Decorrelation can be due to atmospheric artifacts, land cover or even the velocity of ground surface displacement. One of the techniques developed to partially overcome these disadvantages is Persistent Scatterers Interferometry (PSI) [4]. By processing a set of interferograms, slow deformation over a long time span is detected on selected pixels called "persistent scatterers" (PS). SqueeSAR algorithm is an evolution of PSI, where a greater amount of PS, or distributed scatterers (DS) are detected, increasing the number of displacement measurements. The details of the techniques can be found in the literature, e.g. for DInSAR processing: [3], for PSI [4] and for SqueeSAR [5]. Several authors have studied applications of InSAR for mining induced surface subsidence monitoring, e.g. [6], [7], [8] and [9]. USCB was the subject of similar studies [10], [11] and [12]. The objective of this paper is to show the result of combining displacement data derived from DInSAR interferograms and SqueeSAR algorithm over Bytom urban area. For this purpose high resolution radar satellite images acquired by TerraSAR-X SAR images were used. The basic characteristics of TSX satellite can be found in [13]. Maximum detectable deformation is constrained by its 3 cm wavelength that permits to detect, at least from a theoretical point of view, up to 1.5 cm between two neighboring pixels of a differential interferogram, which is generated from two TSX satellite SAR images. Similarly, the SqueeSAR maximum theoretical detectable displacement will be 245 mm/yr. Taking into account that underground longwall mining exploitation may produce centimetric to metric subsidence per day, we will assess throughout this work the limits of TSX radar interferometry to monitor fast mining subsidence.

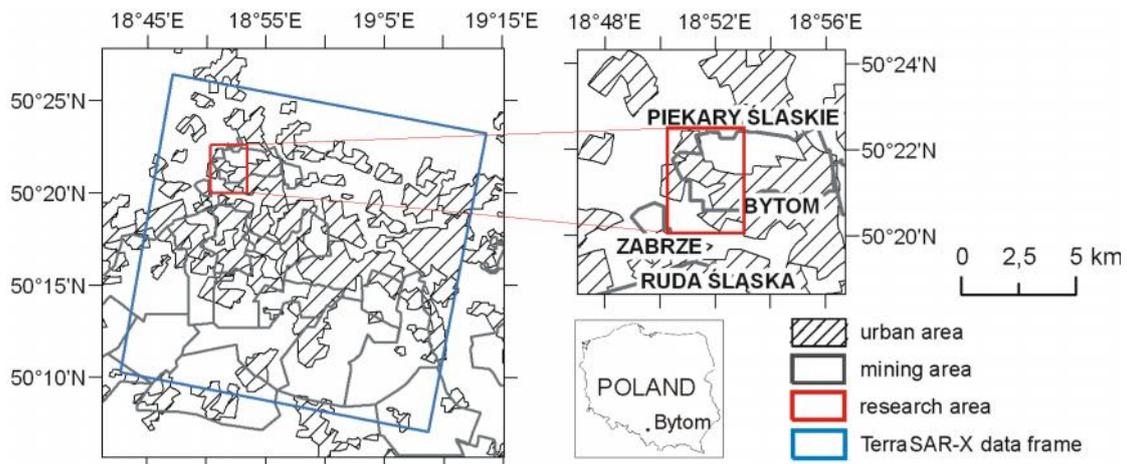


Fig. 1 Geographical location of the study area.

RESULTS

SAR data and DInSAR processing

Conventional DInSAR and SqueeSAR techniques were used to process 30 descending high resolution SAR satellite TerraSAR-X scenes acquired in strip map mode between the 5th July 2012

and the 21st June 2012. The study area, about 500 sq km, includes Tarnowskie Gory (NW), Dabrowa Gornicza (NE), Zabrze (SW) and Sosnowiec (SE) cities. A single master image from 1st October 2011 was selected for coregistration, generating 28 interferograms with perpendicular baseline smaller than 285 m and 11 days temporal baselines. The same dataset was process with SqueeSAR resulting in 1,7 Mln of PS for the whole dataframe, measuring velocities between -338 and 68 mm/yr. A ramp oriented south to north was removed from the PSI dataset through a multiple regression analysis using the least squares method. This work will focus on a subset of the whole dataset on Bytom area consisting of 28297 PS over 18 sq km. Fig. 2 a-d presents four out of twenty eight interferograms over Bytom area, where several deformation signals or subsidence basins are evident (black lines). However, the phase noise effect, most probably due to the very fast movement, is evident in the central part of subsidence basins. According to SqueeSAR results measured total displacement varies between +22 and -131 mm (Fig. 2e). In this figure it is evident that the absence of measurements in the central part of the subsidence troughs is due to the fast mining subsidence.

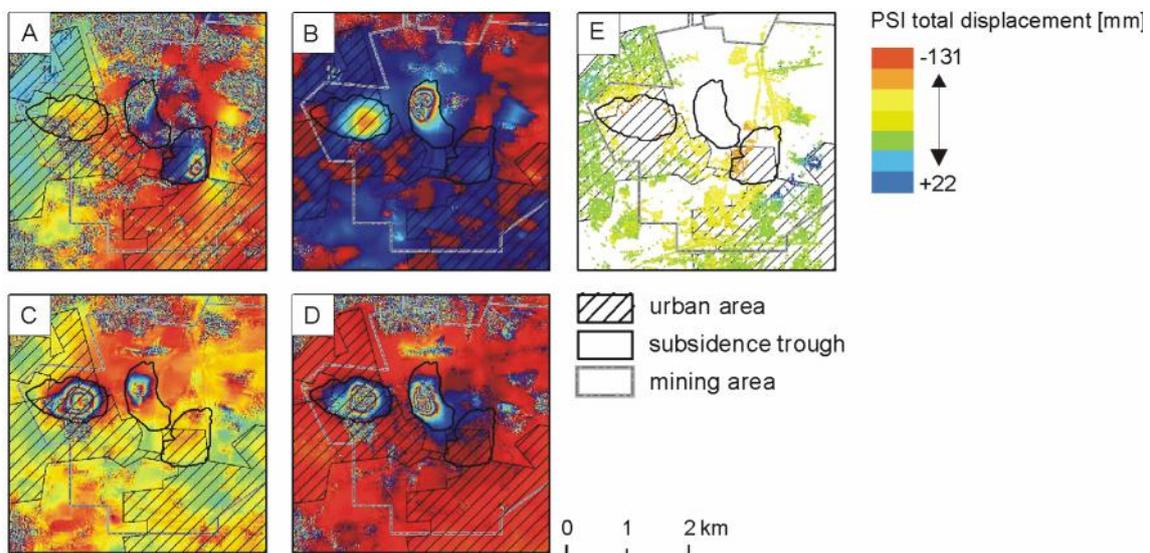


Fig. 2 Dataset used for the analysis. A-D. Examples of four out of twenty eight differential infetrferograms. The start and end dates of the interferograms: A. 18.08.2011-29.08.2011, B. 14.11.2011-25.11.2011, C. 17.12.2011-28.12.2011, D. 05.04.2012-16.04.2012. E. Values of total displacement of PSI points displayed in a colour scale, where red-yellow colours refer to subsidence, green stability and blue uplift. Three black polygons are borders of indentified subsidence troughs.

Subsidence activity maps

Subsidence activity maps were obtained through the integration of differential interferograms and SqueeSAR displacement measurements. Differential interferograms were analysed to compute displacements based on interferometric fringes count (Fig. 3). In some of the interferograms up to 5 fringes were visible, which is equivalent to 6 cm of deformation in 11 days (200 cm/yr). In order to calculate total mining subsidence, estimated displacements on every interferogram were added (Fig. 4b). The results suggest that for the longwall mining activity, surface deformation reached a maximum of 54 cm in the subsidence basin during the period 07.2011-06.2012.

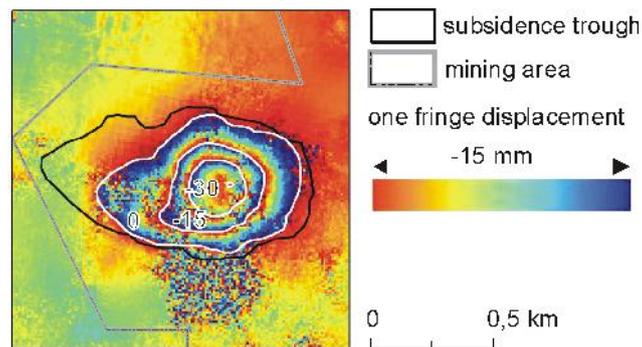


Fig. 3 Miechowice area on the interferogram from 17.12.2011-28.12.2011. An example of manual digitalization of subsequent fringes (white lines).

SqueeSAR displacement results were analysed to define residual mining subsidence influence area, i.e. the boundary between slow motion and stable areas. For this purpose over 28 thousand of PS points were interpolated, resulting on a continuous 50 m raster with cumulated subsidence values below 13 cm during the observation period (Fig. 4a). The combination of both generated results, permitted to map slow and faster movements together (Fig. 4c). In this map green colour depicts stable area, blue depict small uplift and yellow-orange-red colour depict subsidence. A large region around the subsidence troughs is affected by a residual subsidence 5 mm and 5 cm per year (yellow). A greater subsidence up to 13 cm is defined on the boundaries of the subsidence basins, reaching up to 54 cm in the central part. The positive displacement or uplift shown in the south-west could be related to rise of groundwater level after abandonment of underground mining activity. It should be noted that formation of subsidence troughs induced by underground excavation works assumes the largest vertical deformation in the middle of the basin, being gradually reduced towards the borders.

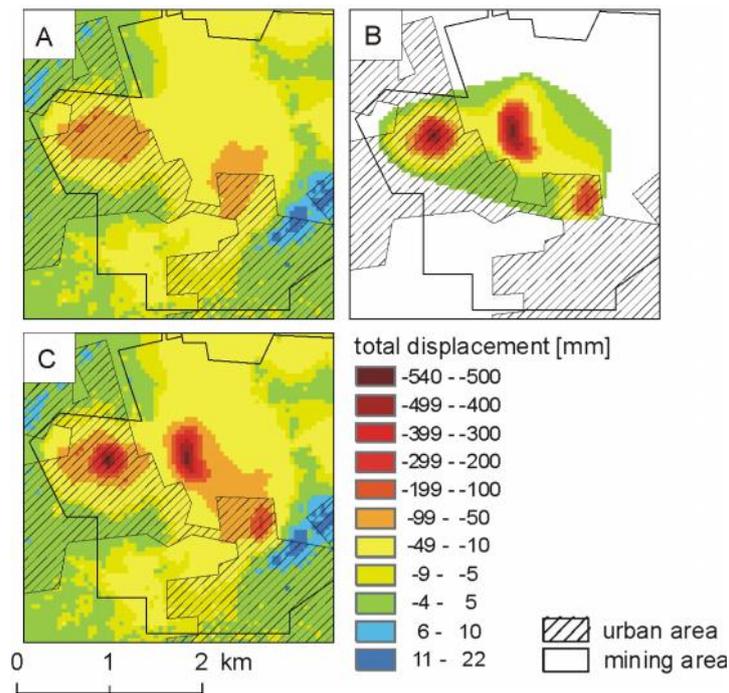


Fig. 4 Resulting total displacement maps with 50m pixel resolution. A. Interpolation of PSI points. B. Summed total displacement identified on the differential interferograms. C. Interpolation of both kind of information: PSI and interferograms.

CONCLUSIONS

Results obtained in this study show that the combination of DInSAR displacement measurements derived from conventional DInSAR and SqueeSAR exploitation of high resolution TerraSAR-X satellite images, can significantly improve the monitoring of mining subsidence areas affected by fast displacement patterns. The final result benefits from TerraSAR-X short revisit cycle and high resolution, permitting to successfully measure up to 54 cm/yr, as well as residual subsidence and uplift occurring in the surroundings of subsidence basin. Further studies should consider improving geostatistical processing and combination with ground truth data.

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