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Preliminary analysis of InSAR data from south-west part of Upper Silesian Coal Basin

Introduction

The Upper Silesian Coal Basin (USCB) is characterised by a complicated geological structure, which is affected by the over 200-year hard coal mining. USCB is one of the world's biggest mining centres. The negative aspect of such a magnitude of exploitation is visible on the surface in the form of surface deformation, subsidence and induced seismicity and it necessitate monitoring the USCB area. With the use of an established geodetic network in the first case, and by means of a seismic network in the second case. The availability of satellite data resulted in the development of novel methods, which can significantly affect the monitoring quality of an endangered area.

Interferometric synthetic aperture radar is powerful tool for mapping the Earth's land, ice and even the sea surface topography. By bouncing signals from a radar satellite off the ground in successive orbits and looking at the differences between the images, interferometric synthetic aperture radar can detect small differences in the distance between its position and the ground as the land surface moves – whether up or down. InSAR shows spatial patterns of deformation and in combination with ground-based monitoring gives unprecedented insight into a wide range of earth science processes (e.g. Zebker, Goldstein 1986; Gabriel et al. 1989; Goldstein et al. 1993; Massonet, Adragna 1993; Weydahl 1996; Rott et al. 1999).

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A digital SAR image can be seen as a mosaic of pixels. Each pixel gives a complex number that carries amplitude and phase information about the microwave field back-scattered by all the scatterers (such as rocks, buildings, vegetation) within the corresponding resolution cell projected on the ground. The amplitude depends on the roughness and typically, exposed rocks and urban areas show strong amplitudes, whereas smooth flat surfaces (like quiet water basins) show low amplitudes. The phase is directly linked to the distance between the observed terrain and the satellite sensor. By calculating the differences in phases (interferogram) between two sets of data, one can determine ground displacements that have occurred in the time between the data acquisitions. Interferogram is measured in radians of phase difference and, due to the cyclic nature of phase, is recorded as repeating fringes which each represent a full 2π cycle. One full 2π cycle corresponds to a change of range of a half a wavelength (for ERS-1/2 and ENVISAT satellites it is about 2,5 cm).

InSAR was proposed for monitoring of hard coal mining influence for the first time by Ostaficzuk (Ostaficzuk 1995). This technique was applied for monitoring of mining subsidence in the Selby Coalfield (United Kingdom) for the first time (Stow, Wright 1997). In Poland InSAR for mining monitoring was applied with success in Upper Silesian Coal Basin (Perski 1998; Perski 1999a; Perski 1999b; Perski, Jura 1999) and Legnica-Głogów Copper Mining District (Krawczyk, Perski 2000; Popiołek et al. 2002; Popiołek 2003; Popiołek et al. 2006).

The Permanent Scatterer Interferometry technique (PSInSAR) is an upgrade of InSAR. This technique was developed to resolve problem of geometrical and temporal decorrelation (Ferretti et al. 2000, Ferretti et al. 2001). Furthermore, by using a large amount of data, atmospheric signal is estimated and corrected for. PSInSAR technique uses coherent radar targets (called Permanent Scatterers or PS) that can be clearly distinguished in all images and do not vary in their properties. In Poland for the first time, PSInSAR technique was used in Upper Silesian Coal Basin by Graniczny (Graniczny et al. 2005; Graniczny 2006) and next it was developed by another researchers (Leśniak, Porzycka 2008a; Leśniak, Porzycka 2008b; Mirek, Mirek 2008).

1. Preliminary processing and data analysis

The interferogram was processed from two SAR images acquired by ENVISAT satellite (tab. 1.1). SAR images were made on March and April 2008, and covered south-west part of USCB. In the first stage of processing, the whole SAR scene was processed (100 km · 100 km).

Typical InSAR processing chain consists of several points, such as (Hanssen 2001): data input, pre-processing, co-registration and resampling, products (computation of complex interferogram and coherence image), phase unwrapping, geocoding. However preliminary processing of selected pair of SAR images excluded phase unwrapping and geocoding. The co-registration step is fundamental in interferogram generation, as it ensures that each ground target contributes to the same (range, azimuth) pixel in both the master and the slave image.

TABLE 1.1

The characteristic of data used for interferometric processing

TABELA 1.1

Zestawienie analizowanej pary zdjęć

Satellite	MASTER		SLAVE		Baseline [m]	Perpendicular baseline [m]	Temporal separation
	orbit	date	orbit	date			
ENVISAT	31531	2008.03.11	32032	2008.04.15	422	366	35 days

Where co-registration is poor or the maximum baseline is exceeded the pixel phase will become incoherent – the phase becomes essentially random from pixel to pixel rather than varying smoothly, and the area appears noisy. Co-registration is usually separated in two steps: coarse and fine co-registration. Additionally, external DEMs (Digital Elevation Model) were used in co registration of selected pair of SAR images to increase precision.

Next step in processing chain is resampling and interpolation. The interferometric combination of the two complex images requires evaluation of the complex values in one of the two at the pixel positions of the other. Resampling can be regarded as consisting of two subsequent steps: reconstruction of the continuous signal from its sampled version by convolution with an interpolation kernel, and sampling of the reconstructed signal at the new sampling locations.

One of the most important step in processing chain is interferogram formation. A complex interferogram is constructed by a pointwise complex multiplication of corresponding pixels in both datasets (1.1):

$$y_1 y_2^* = |y_1| \exp(j\psi_1) |y_2| \exp(-j\psi_2) = |y_1||y_2| \exp(j(\psi_1 - \psi_2)) \tag{1.1}$$

where:

y_1, y_2 – complex values of corresponding pixels,
ψ_1, ψ_2 – phase,
j – amplitude.

Analysis was started from estimation of coherence. Coherence is a measure for local interferogram quality and it provides valuable information about the scatterer (Bamler, Hartl 1998). There are two main factors which determine image coherence, firstly the perpendicular baseline (Bperp) separation of the image acquisition (a critical baseline is about 1100 m) and secondly changes in ground scattering characteristic between image acquisition (changes in vegetation, freezing, thawing or human activities such as ploughing). Several sources of coherence decorrelation can be distinguished, such as (Hanssen 2001): baseline or geometric decorrelation – caused by the difference in the incidence angle between the two acquisitions, system noise – caused by the characteristics of the system (e.g. antenna characteristics), temporal decorrelation – caused by too long time distance between the two acquisitions, processing induced decorrelation – caused by chosen algorithms (e.g. for co registration and interpolation).

Analysis of coherence demonstrated high value (fig. 1.1), which is connected with short time period and short perpendicular baseline of selected images, as well as highly urbanized area. The coherence value ranges from 0 (the interfeormetric phase is just noise) to 1 (complete absence of phase noise). Figure 1.1 illustrates coherence map, where high coherence value is represented as a white colour and lack of coherence – as a black colour.

Fig. 1.1. Coherence map

Rys. 1.1. Wartość koherencji

In the presented work, external SRTM DEMs (Shuttle Radar Topography Mission Digital Elevation Models) were used for interferogram generation to reduce the errors in data processing and remove topographic phase.

The interpretation of interferometric data shows distinctive concentric fringe features. The centre of the fringe is an area of maximum of surface downwarp caused by coal mining (Stow 1997; Perski 1999). Figure 1.2 shows excerpt of example interferogram. There is interferogram computed for whole SAR scene on the left side and scale up excerpt of interferogram of Knurów area on the right side. In the area of Knurów two subsidence troughs were located. Both of them consist of two interferometric fringes, correspond with 5 cm subsidence per 35 days.

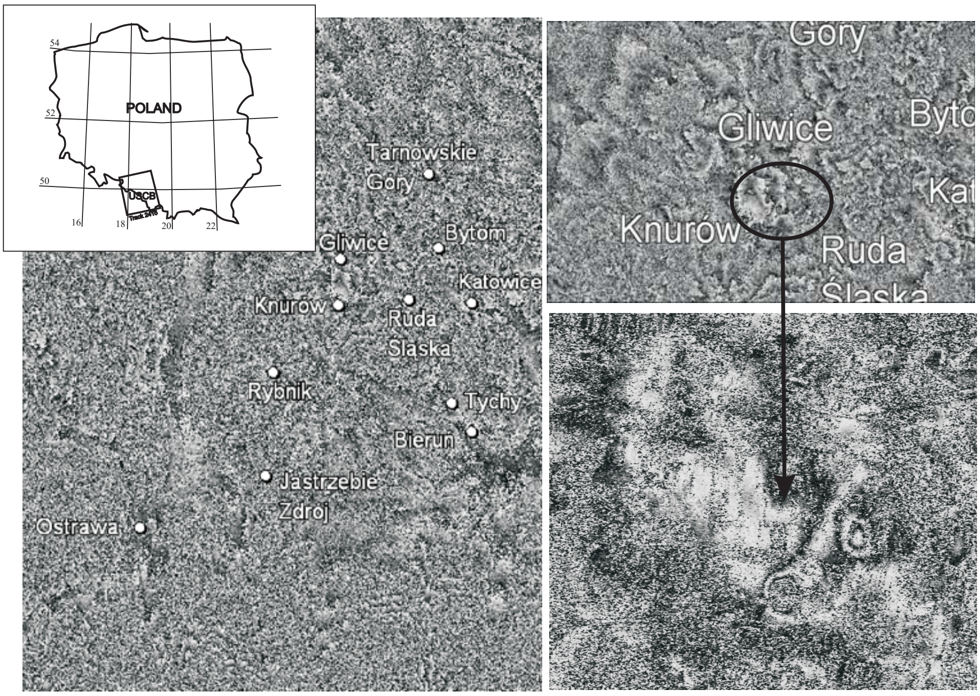

Fig. 1.2. Differential interferogram 2008.03.11–2008.04.15 (explanation in text)

Rys. 1.2. Interferogram uzyskany z pary zdjęć 2008.03.11 i 2008.04.15 (opis w tekście)

Conclusions

After preliminary full-scene (100km x 100km) SAR processing it was clearly visible that selected pair of SAR images was suitable for interferogram generation:

- analysis of coherence demonstrated high value;
- the interferometric phase image shows areas where subsidence troughs are clearly visible;
- for example in the area of Knurów two subsidence troughs were located – subsidence patterns show 2 cycles of deformation, corresponding with 5 cm subsidence per 35 days;
- high value of coherence and concentric fringe features are good indicators to limit processing to areas of subsidence troughs and to compare them with areas of mining activity.

External DEMs were used both to increase precision in co registration of selected pair of SAR images and to reduce the errors in data processing and remove topographic phase during interferogram formation.

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REFERENCES

Bamler R., Hartl P., 1998 – Synthetic Aperture Radar Interferometry. Inverse Problems, vol. 14, 1–54.

Ferretti A., Prati C., Rocca F., 2000 – Nonlinear Subsidence Rate Estimation Using Permanent Scatterers in Differential SAR Interferometry. IEEE Transactions on Geoscience and Remote Sensing 38 (5), 2202–2212.

Ferretti A., Prati C., Rocca F., 2001 – Permanent Scatterers in SAR Interferometry. IEEE Transactions on Geoscience and Remote Sensing 39 (1), 8–20.

Gabriel A.K., Goldstein R.M., Zebker H.A., 1989 – Mapping small elevation changes over large areas: differential radar interferometry. Journal of Geophysical Research, 94(B7), 9183–9191.

Goldstein R.M., Engelhardt H., Kamp B., Frolich R.M., 1993 – Satellite radar interfermetry for monitoring ice sheet motion: Application to Antarctic ice stream. Science, 262, 1525–1530.

Graniczny M., Kowalski Z., Jureczka J., Czarnogórska M., 2005 – TerraFirma Project – Monitoring of subsidence of Northeastern part of Upper Silesian Coal Basin. Sp. Papers Polish Geological Institute, 20, 59–63.

Graniczny M., 2006 – Wykorzystanie technologii PSInSAR dla obserwacji przemieszczeń powierzchni terenu na przykładzie Górnego Śląska. Materiały Sympozjum Warsztaty Górnicze 2006.

Hanssen R., 2001 – Radar Interferometry. Data Interpretation and Error Analysis. Kluwer Academic Publishers.

Krawczyk A., Perski Z., 2000 – Application of satellite radar interferometry on the areas of udeground exploitation of copper ore in LGOM – Poland. First International Congress of the International Society for Mine Surveying, vol. 2, 209–218.

Leśniak A., Porzycka S., 2008a – Environment monitoring using satellite radar interferometry technique (PSInSAR). Polish Journal of Environmental Studies, vol. 17, no. 3A, 382–387.

Leśniak A., Porzycka S., 2008b – Kompleksowa interpretacja pomiarów satelitarnych i naziemnych w ocenie zagrożeń na terenach górniczych i pogórniczych. Gospodarka Surowcami Mineralnymi t. 24, z. 2/3, 147––159.

Massonet D., Adragna F., 1993 – A full-scale validation of Radar Interferometry with ERS-1: the Landers earthquake. Earth Observation Quarterly, 41.

Mirek K., Mirek J., 2008 – Zastosowanie jądrowej aproksymacji w procesie interpretacji danych PSInSAR z północnej części GZW. Komputerowe Wspomaganie Badań Naukowych, T. 15, Prace Wrocławskiego Towarzystwa. Seria B, nr 214, 141–146.

Ostaficzuk S., 1995 – Interferometry and its possibile application in geology. FORGES Remote Sensing Group Meeting. Warsaw 16–18.10.1995.

Perski Z., 1998 – The test of applicability of land subsidence monitoring by InSAR ERS-1 and ERS-2 in the coal mine damaged region (Upper Silesia). International Archives of Photogrammetry and Remote Sensing, vol. XXII part 7, 555–558.

Perski Z., 1999a – Zakres interpretowalności osiadań terenu za pomocą satelitarnej interferometrii radarowej (InSAR). Archiwum Fotogrametrii, Kartografii i Teledetekcji vol. 9, 191–199.

Perski Z., 1999b – Osiadania terenu GZW pod wpływem eksploatacji podziemnej określane za pomocą satelitarnej interferometrii radarowej (InSAR). Przegląd Geologiczny, vol. 47, nr 2, 171–174.

Perski Z., Jura D., 1999 – ERS SAR Interferometry for Land Subsidence Detection in Coal Mining Areas. Earth Observation Quartery 63, 25–29.

Popiołek E., 2003 – Możliwości wykorzystania nowoczesnych metod monitorowania terenu górniczego w LGOM. Mat. Symp. Warsztaty 2003, 127–142.

Popiołek E., Hejmanowski R., Krawczyk A., Perski Z., 2002 – Application of Satellite Radar Interferometry to the examination of the areas of mining exploitation. Surface Mining Braunkhole & Other Minerals, vol. 54 no. 1, 74–82.

Popiołek E., Marcak H., Krawczyk A., 2006 – Możliwości wykorzystania satelitarnej interferometrii radarowej InSAR w monitorowaniu zagrożeń górniczych. Mat. Symp. Warsztaty 2006, 339–352.

Rott H., Schechl B., Siegel A., Grasemann B., 1999 – Monitoring very slow slope movements by means of SAR Interferometry: A case study from a mass waste above a reservoir in the Ötztal Alps, Austria. Geophysical Research Letters, 26(11), 1629–1632.

S t o w R.J., W r i g h t P., 1997 – Mining Subsidence Land Surveying by SAR Interferometry. 3rd ERS Symposium, Florence.

W e y d a h l D.J., 1996 – Flood Monitoring in Norway Using ERS-1 SAR Images. Geoscience and Remote Sensing Symposium IGARSS'96.

Z e b k e r H.A., G o l d s t e i n R.M., 1986 – Topographic Mapping From Interferometric Synthetic Aperture Radar Observations. Journal of Geophysical Research, 91(B5), 4993–4999.

PRELIMINARY ANALYSIS OF INSAR DATA FROM SOUTH-WEST PART OF UPPER SILESIAN COAL BASIN

K e y w o r d s

InSAR, Upper Silesian Coal Basin, subsidence

A b s t r a c t

In recent years, the usage of Synthetic Aperture Radar Interferometry technique became more and more popular and it is used in many scientific field: for creating digital elevation models (DEMs), monitoring of deformation, glacier and ice motion etc. The paper presents preliminary analysis of satellite interferometry data from south-west part of Upper Silesian Coal Basin (USCB). USCB is characterised by a complicated geological structure, which is affected by the over 200-year hard coal mining. USCB is one of the world's biggest mining centres. The negative aspect of such a magnitude of exploitation is visible on the surface in the form of surface deformation, subsidence and induced seismicity and it necessitate monitoring the USCB area. With the use of an established geodetic network in the first case, and by means of a seismic network in the second case. The availability of satellite data resulted in the development of novel methods, which can significantly affect the monitoring quality of an endangered area.

Authors used pair of satellite images for interferometric processing, made in March and April 2008. In the first stage of processing, the whole SAR scene was processed (100km x 100km). External DEMs were used both to increase precision in co registration of selected pair of SAR images and to reduce the errors in data processing and remove topographic phase during interferogram formation. Analysis of coherence demonstrated high value, which is connected with short time period and short perpendicular baseline of selected images, as well as highly urbanized area. The interpretation of interferometric data shows distinctive concentric fringe features. The centre of the fringe is an area of maximum of surface downwarp caused by coal mining. In the area of Knurów two subsidence troughs were located. Both of them consist of two interferometric fringes, correspond with 5 cm subsidence per 35 days.

WSTĘPNA ANALIZA DANYCH SATELITARNEJ INTERFEROMETRII RADAROWEJ Z POŁUDNIOWO-ZACHODNIEJ CZĘŚCI GÓRNOŚLĄSKIEGO ZAGŁĘBIA WĘGLOWEGO

S ł o w a k l u c z o w e

InSAR, GZW, osiadanie

S t r e s z c z e n i e

Satelitarna interferometria radarowa staje się coraz bardziej popularną techniką wykorzystywaną w różnych dziedzinach: od tworzenia numerycznych modeli powierzchni terenu (DEM) poprzez monitorowanie osuwisk, lodowców, osiadania terenu aż po badanie zjawisk przyrodniczych i wegetacji roślin. Niniejszy artykuł przedstawia wstępne wyniki analizy interferogramów utworzonych z radarowych zdjęć satelitarnych, obejmujących południowo-zachodnią część Górnośląskiego Zagłębia Węglowego (GZW). GZW charakteryzuje się skomplikowaną budową geologiczną, na którą dodatkowo nakładają się wpływy ponad 200 lat eksploatacji węgla

kamiennego. Z eksploatacją węgla kamiennego wiążą się zagrożenia spowodowane sejsmicznością indukowaną oraz osiadaniem terenu. Obszar GZW jest silnie zurbanizowany, w związku z czym zagrożenia wynikające z powstawania niecek osiadań oraz sejsmiczności indukowanej wymuszają monitorowanie rejonów związanych z eksploatacją węgla kamiennego, poprzez rozwijanie sieci geodezyjnej lub sejsmologicznej. Dostęp do danych satelitarnych spowodował rozwój nowych metod, które pozwalają na objęcie monitoringiem znacznego obszaru.

Do przetwarzania wykorzystano parę zdjęć wykonanych w marcu i kwietniu 2008 roku. Zdjęcia charakteryzują się niedużą odległością bazową i czasową. Przetwarzanie zostało wykonane dla całej sceny (100 km · 100 km). Koherencja uzyskana z przetworzonych obrazów wykazuje wysokie wartości. Niewątpliwie jest to związane z niewielką odległością czasową i bazową przetwarzanych zdjęć oraz silnie zurbanizowanym terenem. Na uzyskanych interferogramach widoczne są koncentryczne, eliptyczne prążki interferencyjne, które wskazują na tworzenie się niecek osiadania na badanym obszarze. W okolicy Knurowa widoczne są dwa eliptyczne obszary wskazujące na osiadanie powstałe na skutek eksploatacji węgla kamiennego. Obszary osiadanie składają się z około 2 prążków, co wskazuje na osiadanie rzędu około 5 cm na 35 dni.