APPLICATION OF SATELLITE RADAR INTERFEROMETRY ON THE AREAS OF UNDERGROUND EXPLOITATION OF COPPER ORE IN LGOM - POLAND

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ABSTRACT:
Satellite Radar Interferometry is a unique method that gives us a possibility to take measurements of a land subsidence on strictly determined huge areas and with precision state the time range. This method uses the phase signal difference between two SAR satellite images (Synthetic Aperture Radar). Until this time this method was successfully tested on underground coal mining areas in the Upper Silesian Coal Region, where it gave us information about land deformations, about its location, range and size. As a result of the research, an interferomtric image of LGOM area was processed. It presents two-month growth of land subsidence over the copper ore exploitation fields. In the following text the benefits from satellite radar interferometry in a field of mining areas protection are presented.

1. INTRODUCTION

During the last few years, we can observe a continuous growth of applications of satellite radar imaging data in different science disciplines. One of them is the research on a land subsidence caused by underground mining exploitation. Satellite radar imaging technology (Perski, 1998) has begun to be applied in this filed in Poland.

Capturing of interferomertic data relies on the process of digital calculation of the phase differences between two satellite radar images (radarograms). As a result of this interferometric processing we receives a new image – the interferogram. This new image makes it possible to take an observation of the height change of the terrain surface. One of the first field where this technology was applied, was an observation of the earth surface movement (Gabriel and others, 1989), caused by earthquakes as well as the movement of tectonic plates. This application proved that the technology is a very useful method to make an observation of vertical ground movement. The first research in Poland was done in 1997 in the Silesian Coal Region (Perski 1998). The research confirmed high credibility of interferometry technology, and its particular usefulness in environmental monitoring and in the observation of dynamic changes of land subsidence caused by underground mining exploitation. In this paper, we have presented the first results of the application of the method in the field LGOM (Legnica - Głogów Copper Region), where underground copper ore exploitation as well as in the Silesian Coal Region has caused movements and deformations of terrain surface.

2. THE AREA OF RESEARCH

In the region of Legnica – Głogów Copper Region (LGOM) there are 7 mining areas, where mining exploitation are being carried out in 3 mines. Total mining areas in LGOM occupy about 400 km^2 of the area surface. In the range of ground movement caused by mining exploitation there are two towns: Lubin, Polkowice and about a dozen villages. To protect the buildings on the town area and mine shafts about 20 protection pillars were established. Mining works, which have been conducted since 1960, have caused arising area of subsidence. This subsidence is mainly generated by underground exploitation and by underground water pumping.

The size of the land subsidence in the LGOM over the areas of intensive exploitation, which have been conducted mainly room and pillar exploitation system with the fall of roof, reaches average values from 2000 to 2600 mm. The value of maximal land subsidence, w_{max} was observed in the mining area „Polkowice II" and reached 3380 mm (Popiołek, 1998). The surveying and theoretical calculations indicate, that an average revealed rate of this type of the land subsidences over the breaking down exploitation does not exceed 1,25 mm/twenty – four hours. And the maximal rate should not exceed 100% of an average value - 2,5 mm/twenty – four hours (Ostrowski & others, 1996).

3. THE METHOD OF MEASUREMENT

The interferogram of LGOM area (Fig.1) has been processed from two SAR (Synthetic Aperture Radar) images acquired by ERS-1 satellite (European Remote-Sensing Satellite) during repeat-pass observations. During data acquisition the SAR antenna generated the electromagnetic pulse that is radiated and propagates to the terrain. A fraction of incident field is reflected back towards antenna where it is gathered by receiving SAR antenna (Henderson, Levis 1997). The received signal, after digital processing is formed into SAR image – the radarogramme. The digital SAR image contains information about the power of bacscattered signal, which is called scene intensity and the phase of the received signal. The intensity of the signal is used for land-use maps generation. The phase of the SAR signal is used then for an interferogram generation i.e. phase-change pattern between repeated SAR observation. This interferometric phase is represented on interferogram by the sets of colours called inteferometric fringes. Repeat-Pass Radar Interferometry is a technique to extract information relative to vertical height changes on the Earth's surface. This is a relatively new method but the result so far demonstrates the potential of its use in the protection of mining areas in Upper Silesia (Perski 1998, Perski, Jura, 1999). For the SAR sensors of ERS-1 and ERS-2 satellites with a wave length 5.6 cm (FAO/ESA 1993) the inteferometric fringe marks a change of 2.8 cm in the amount of ground motion between the two data sets, in the direction towards the satellite. This value corresponds to 2.58 cm of vertical surface change. In mining subsidence, the interpretation of the fringes is different from other cases, e.g. earthquake effects where shifts can be expected subside in all directions. In mining subsidence close to vertical shifts can be assumed (Perski, Jura 1999).

4. THE RESERACH

In our research we have included mapping data about a mining exploitation, which took place between 1960 and 1994, and topographic maps in the scale 1:10000.

On the basis of chapter 2 where velocity and depth of land subsidence areas in the LGOM area was discussed, we estimate that the first interferometry observation will take two radarograms with time base equal 2 months (60 days).

As a result of the research the subsidence troughs should be observe over the ore exploitation fields, which an average size of a land subsidence is about 75 mm/60days (a maximal land subsidence shouldn't exceed 150 mm/60 days). In this time base the subsidence trough caused by underground pumping shouldn't exceed average 1,5 mm/60 days.

Two ERS SAR images have been selected according to the following criteria:

- dry weather conditions for weather data
- interferometric baseline i.e. - the distance between satellite positions during repeated observations - not exceeds 100m
- time-base 60 days

The weather data analysis for SAR data has been performed and based on field measurements from the Weather Observation Station in Polkowice Dolne.

According to these criteria two SAR SLCI images in descending mode of ERS-1 satellite were selected. Small area of the study allows us to request only SE quarter of full SLCI SAR frame.

Finally, two ERS SAR scenes in SLCI quarter, acquired during phase D (second ice phase) of ERS-1 mission have been selected.

The characteristic of selected data:

Satellite: ERS-1, data type: SAR SLC quarter,				
	ORBIT	DATE	Time-base	B_{perp}
MASTER	12921	10.01.1994	60 days	24 m
SLAVE	13867	11.03.1994		

The Faculty of Earth Sciences of the University of Silesia performed Interferometric processing of selected data in the two-pass mode. The EarthView InSAR Workstation (Atlantis 1997) has been applied for digital data processing. A small value of perpendicular baseline and near flat terrain allows neglecting the topographic effect on interferogram in this phase of the project. However, some phase variation due to topographic is still visible on interferogram, but small scale of this effect allows neglecting it (Fig.1). The first quality check shows that, selected data presents very high coherence, which is very unique for the data of the time base higher than 35 days in Europe (Perski 1999a). In the first processing stage the full quarter has been processed but obtained interferogram shows that the fringes due to subsidence appear only in the northern part. Finally, the area 1587 columns x 1530 rows has been selected for full two-pass InSAR processing.

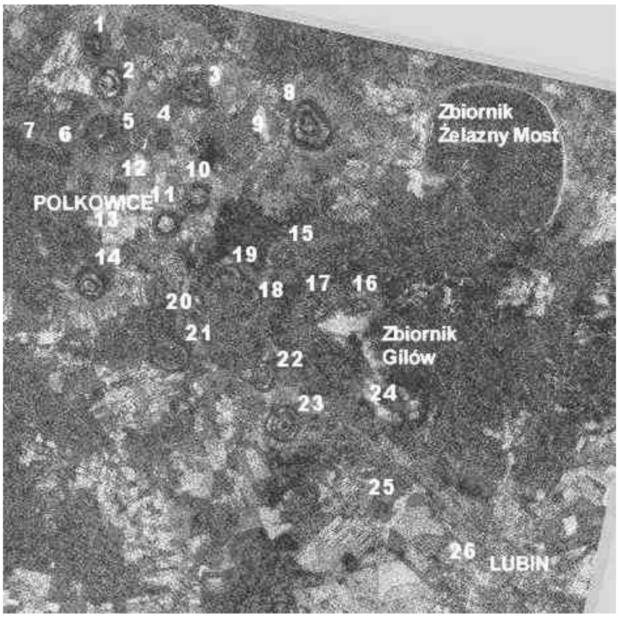


Fig. 1. ERS SAR Interferogram of LGOM area presents configuration of dynamic subsidence trough. The numbers presenting the locations of identified subsidence troughs

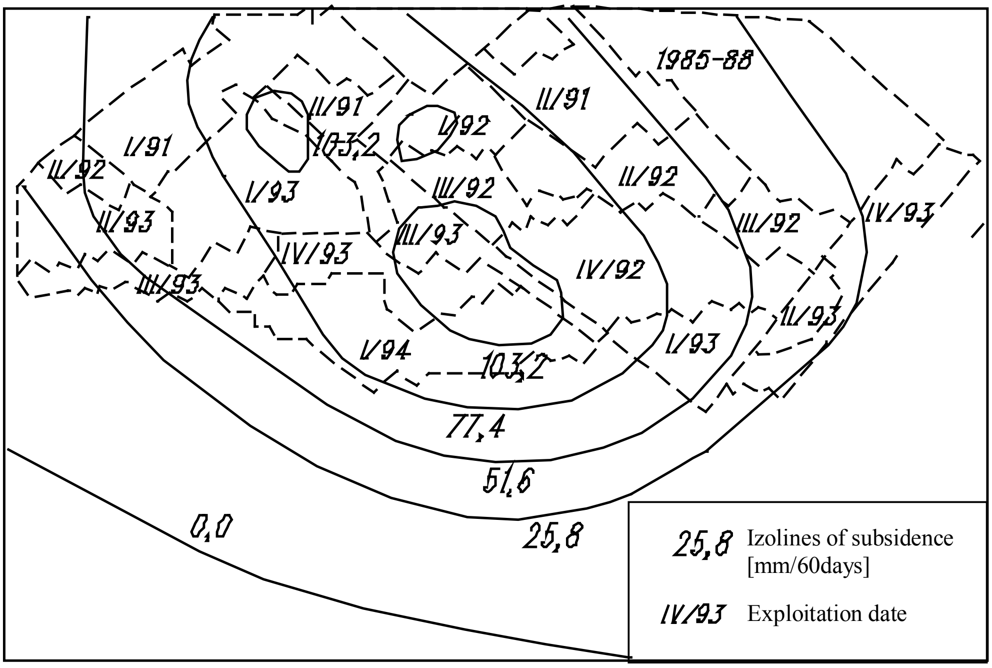
Obtained interferogram and radarograms have been then imported into the Information System of Mining Areas (Popiołek 1993, Piwowarski & Krawczyk, 1999) for further data processing and interpretation. The main problem at this stage of the project was a high error in co-registration of InSAR data with topographic and mining data stored in local coordinate system. These different data sets are also characterized by different pixel size: 20x20m for InSAR data and 5x5 m for raster topographic data. Further selection of additional control points and application of higher order of transformation allows to co-register data with 30m of error.

5. RELATIONSHIPS BETWEEN INTERFEROMETRIC OBSERVATION AND LEADED MINING EXPLOITATIONS

As a result of interferogram analysis 26 dynamical slopes of subsidence troughs have been located. After fitting the interferogram to the coordinate system "Pieszkowice", a correlation analysis of an appearance of subsidence troughs with the exploitations of excavation areas was made. As a consequence of analysis fixed, that the centres of 24 subsidence troughs occurs at the limits of exploitation, which was leaded in IV quarter of 1993 and I quarter of 1994. Remaining two small land subsidence were observed in the neighbourhood of abandoned workings. At the Mining Area „OG Sieroszowice I" 4 dynamical land subsidences number: 1, 2, 5, 7 (Fig. 1) was observed. None of this land subsidences exceed 70 mm/60days. Generally, in the researched period the subsidence included approximately 342,8 ha.

On the area "OG Polkowice II" 6 subsidence troughs number: 6, 13, 14, 20, 21, 22 and 12 were observed (Fig.1 and 2). On this mining area, the deepest dynamical subsidence trough is the subsidence trough number 21. It has reached subsidence about 110 mm during 60 days. At the figure number 2, the discussed subsidence trough, shape and also location of exploitation of excavation areas is presented.

Fig. 2. The subsidence trough number 21



As the subsidence trough number 21 as all-remaining subsidence troughs were directly interpreted as the results of exploitation at the turn of 1993 years (Fig.2). One relatively shallow subsidence trough number 12 (Fig.3) can not be simply interpreted with a current exploitation. This subsidence trough formed over the area of exploitation in the years 1976 – 1982 (Fig. 3). An explanation could probably give the information, that in 1994 in the close neighbourhood of abandoned workings the new panelling of the seam was executed, which prepared the reactivation of abandoned exploitation from 1995 to 1998. It allows us to formulate a hypothesis about the connection of an appearance of the discussed land subsidence with the preparation of a seam to exploitation.

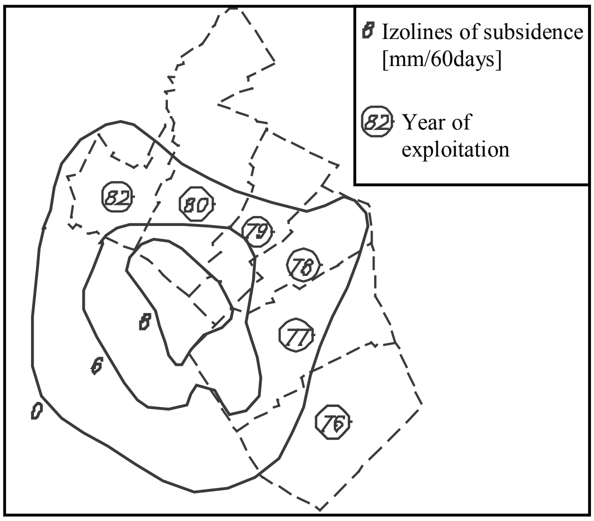


Fig. 3. The subsidence trough number 12

On the Mining Area "OG Rudna I" 9 subsidence troughs were observed. For the sake of leading the exploitation by Mine O/ZG "Rudna" in the town protecting pillar of Polkowice the rate of subsidence increment within the pillar's area was compared with the subsidence on the remaining areas around. During interferometric measurements the exploitation at the pillar was leading, which caused a rise of 2 dynamical slopes of the subsidence troughs numbers 10 and 11 (Fig. 1, 4). The average subsidence of these subsidence troughs amounted to 25 mm/60days. All remaining subsidence troughs on the area „OGRudna I", which rise directly is interpreted as a result of exploitation from 1993/94 years, reached an average subsidence over 50 mm/60days. Below, at the figure number 4 the subsidence trough number 10 is shown.

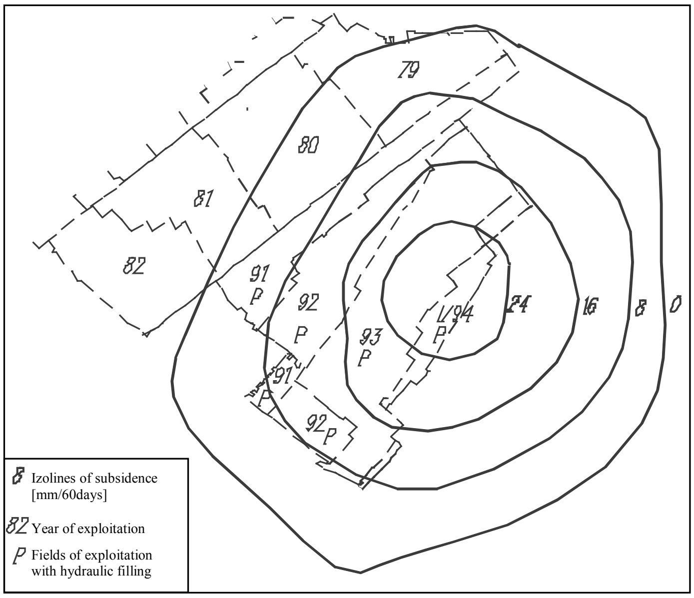


Fig 4. The subsidence trough number 10

Besides, on the discussing area between the shafts R-VII and R-IX the largest in the regard of the area, the single subsidence trough number 8 was observed. It includes its range approximately 199 ha.

On the Mining Area ”Lubin”, the appearance of 6 dynamical slopes of the subsidence troughs numbers 16, 23, 24, 25 and 26 was observed (Fig.1). Only the subsidence trough number 26 appeared on the limit between Mining Areas ”Lubin I” and ”Małomice I”. Other observed on the interferogram subsidence troughs was formed within the limit of Mining Area „Lubin I”. The deepest registered subsidence trough is the subsidence trough number 23, which during 60 days reached the depth of about 110 mm.

On the Mining Area ”Rudna II” and ”Radwanice Wschód” at the first quarter of 1994 none subsidence troughs were observed.

6. THE DETAIL CONCLUSIONS FROM THE REALISED RESEARCH CARRIED OUT ON LGOM

1. The discussed measurement method of the land subsidences can be classified as non-geodetic measurement technique of permanent terrain deformations caused by the underground mining exploitation.
2. The fitting of the interferograms to existing mining maps of terrain surface, which are realized in the scale of 1:10.000 and bigger one is very difficult to perform - more useful for this aim are maps in the scale of 1:25.000 and smaller ones.
3. For the interpretation of the all area LGOM presently enough is getting 1/4 of the frame of ERS SAR image. In a case of undertaking in the future an exploitation in northern part of the Mining Area „OG Sieroszowice I” and the east part of Mining Area „OG Małomice I” would be necessary getting whole frame of the ERS SAR image.

4. Observed 24 dynamical slopes of the subsidence troughs, which rised is directly connected with leading exploitation of the last quarter of 1993 and the first quarter of 1994.
5. The all observed subsidence troughs are suitable for further interpretation. For the sake of land cultivation, especially because of woodlands, the subsidence troughs characterizes a different level of difficulty of its interpretation.
6. The observed subsidence troughs over the exploitation area, where is used fall of roof system, during 2 month reached a maximal value of approximately 110 mm/60days (1,83 mm/twenty – four hours) and didn't exceed an anticipated maximal value 2,5 mm/twenty – four hours.

7. GENERAL CONCLUSIONS

The research induced the authors to the realization the consideration concerning the wider aspect of the satellite interferometry using to the protection of the mining areas. It is possible to pay attention to some benefits and limitations of using presented method of the research. However, before proceeding with the discussion, it is necessary to bring into consideration three particularly fundamental qualities of this method:

1. **The measurement independence –** both the mining industry and the local communities situated on the mining areas could use this method for gaining the information about the area of appearance of land subsidence, its range and size,
2. **The price of a measurement -** in case of satellite images - the cost of the purchase of two radarograms at present is approximately 8 thousands zł and on the basis of periodical agreement the price falls from 20% to 40%,
3. **The frequency of measure -** radarograms particular region of terrestrial globe is possible to be acquire at the moment in 35-day period.

In practice we can assume that the application of this method may brings the following profits:

1. as it was proved it is possible to use this method for monitoring the exploitation in town protecting pillars,
2. it is very easy to create - using the interferogram - contour maps of subsidence during researched period of time and a continuity of gaining information could considerably raise an accuracy in map making of an accomplished exploitation,
3. a possibility of receiving relatively high (in comparison with the yearly cycles or two years') of frequency cheap performed measurements is especially attractive, what makes leading a monitoring of land subsidences growth possible.

Naturally, taking the steps in order to permanent application of this method for the research of land subsidences one should pay attention to some conditions of the discussed method. Certainly, the first period of the research must be spent on the interpretation of the area and periods of the best method application. Besides, some relationship to the satellite technology exist:

1. the preservation of a permanent base - the satellite positions while the following measurements of the same area should be identically, in reality in spite of the best among existing the systems of the satellites orbit protecting ESA, the appearing orbit deviations orbit are many times to large for interferometry,

2. data acquisition must be ordered early, because SAR device doesn't work in permanent,
3. the ESA decisions concerning a continuation of satellite radar observations of the program,
4. a accidental loss/failure of the satellite,

The following quality of discussed method is a dependence of executing measurements from the conditions of executing image:

1. the general weather conditions have very important influence on the interferogram quality, the atmosphere phenomenons like: a snow cover, all types of the precipitation, make the processing of a reliable interferogram very difficult,
2. for the sake of a wave length the woods covers effectively the possibility of terrain penetration by used the radio waves, moreover, an intensive vegetation within a period of spring unbeneficially influences an interferogram quality (Perski 1999a).

The last factor, which has been discussed before, is a low precision of a horizontal measurements. So it is rather difficult to do the correct fitting of received interferograms images into a local coordinate system.

Analysing the above limitations one should also remember, that 10 years have already passed since the first European civil satellite ERS-1- which is destined for doing the satellite radar images – was set off. Trough this period of time the radar images and an interferometrical images have found series of applications, among other things for the crust of the earth movements monitoring, the volcano activity observation, a structure of terrain model, the argicultural cultivations monitoring and the nature observations. Such a wide scale of radarogram applications was the reason for undertaking the decision by ESA over the further continuation of the radar observations of our terrestrial globe program. In 1995 the second satellite of the same type, which is called ERS-2, was set off. In 1999 the satellite ERS-1 finished it's mission. At the moment a successor of the satellite ERS-2, the satellite Envisat-1 is being prepared. The outlook of a continuation of radarometrical observations creates premises to assumption the working aim to the eliminations existing limitations of this method. For example, a possible application of ground radarometrical reflectors (where the coordinate system is known) during of the radarogram acquisition could let for a considerable correction of interferogram fitting quality into the selected coordinate system. The order of satellite images shortly before its acquisition gives an assurance of the weather conditions and the nature conditions (vegetation, snow cover).

As it has been mentioned above the possibilities of using of the described technology have not been used up yet and the existing results show numerous possibilities of practical application of interferometry in the mining areas protection in LGOM.

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