The integration of optical and InSAR data for land subsidence monitoring and its impact on environment of the Upper Silesian Coal Basin

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ABSTRACT: It was demonstrated in many articles that interferometric satellite data (InSAR) from ERS-1/2 SAR sensor give the products from which a Digital Terrain Model can be extracted. A three-pass interferometry (DiffSAR) is a strong and crucial remote sensing technique to monitor of terrain movements like land subsidence. The practical results of InSAR technique application for land subsidence monitoring for the Upper Silesian Coal Basin, a densely urbanised, heavily industrialised area were demonstrated in many papers of second author. Mining subsidence causes damage to buildings and other structures, changes surface drainage patterns and can be associated to deep fracturing of the ground. Knowledge of the spatial distribution of the endangered area may help in landuse planning and compensation strategies. The main aim of the work presented in the paper was to demonstrate the synergism of optical and SAR data for environmental monitoring, precisely for land subsidence monitoring caused by coal mining activity and its impact on environment. The space maps in the form of color compositions were elaborated based on Landsat 5 optical data. To monitor the impact of coal mining activity on environment the maps showing land movements (subsidence) were elaborated from ERS SAR SLC data using Atlantis InSAR Workstation. Next, two remote sensing technologies (interferogram and multitemporal composition from ERS also with multispectral compositions from Landsat) were fused for improvement of the interpretation of land cover in the regions of subsidence. This kind of multisource spacemaps can be useful not only for environmental monitoring "ex post" but also for future urban and regional planning purposes.

1 INTRODUCTION

Since the 19th century the Upper Silesian Coal Basin in Poland is one of the world’s biggest mining centres producing today some 130 million tonnes of coal from 65 underground mines each year. The negative aspect of such a magnitude of exploitation is visible on the surface in form of surface deformation and subsidence. In this case an area of almost 1500 km² is affected (fig. 1). Changes in topography and hydrography damage buildings and other structures in a substantial way. Furthermore, some of the affected areas had to be excluded from urbanisation planning. Nevertheless since 1970 almost 40% of coal mining activity are located under cities and important infrastructures, i.e. in densely urbanised area, of 4000 inhabitants per square km. The effects of mining damages at the surface and the impact on the environment are not sufficiently mapped. Newest developments in remote sensing techniques (InSAR) may now allow mapping and prediction of mine damages more cost-efficient, more accurate and more frequent. The information about the subsidence extracted from interferometry only is not easily readable in the context of spatial localisation and surrounding of damaged terrain without a cartographic support lake maps or satellite images.

2 SUBSIDENCE MEASUREMENTS BY SAR INTERFEROMETRY

2.1 Subsidence due to mining

The area under investigation covers approximately 300 km² (fig. 2) and is affected by heavy mining activities with the exploitation of almost horizontal coal seams and subsequently filling, applying hydraulic technology. Expected subsidence due to roof falling is 70 to 80% in volume of the coal seam thickness, and in case of hydraulic filling is reduced to 15 to 20%. But in any case, a subsidence trough develops (fig. 3). Initial downwarping is slow, not exceeding a few millimetres daily, after 6-8 months it accelerates to 1 cm per day. After the
next 6-12 months the surface movement is fastest and migrates, following the working front of coal exploitation. After 18 months the subsidence rate decreases and becomes neglected (Borecki 1980).

2.2 Repeat-pass interferometry

SAR Interferometry (InSAR) is a technique for extracting information relating to the topography of the Earth’s surface (Zebker, Goldstein 1989). It uses the phase difference between the radar echoes from repeated SAR (Synthetic Aperture Radar) observations of the same area. The result of this operation is presented in the form of an interferogram, where phase differences are presented in the form of “interferometric fringes” (Fig. 4). The first interferometric studies, which were focused on topography retrieval, clearly showed the applicability of InSAR to digital elevation model generation. Differential InSAR (D-InSAR) represents an interesting branch of InSAR, which exploits the phase differences to derive terrain displacements. D-InSAR has already been successfully used in different applications: the monitoring of volcanic activity, earthquakes, glacier dynamics, landslides and urban subsidence (Massonnet, Feigl 1998). In many cases D-InSAR has demonstrated its capability in measuring surface movements of the order of centimetres. Since 1995 D-InSAR has been used to study the impact of underground mining on surface movements at a number of sites, for example in Southern France (Carnec, King, Massonnet, 1995), in the Selby Coalfield in UK (Stow 1996), and in Upper Silesia in Poland (Perski 1998).

2.3 Importance of appropriate image selection

The area of interest is coarsely shown in the Fig.1. The interferometric pairs were selected from the set available for the second half of 1992 year. We had at our disposal also an image registered by Landsat 5 satellite for this period (august ’92).

Fig.1. Area of interest.

The characteristics of the ERS data used in this work are shown in the table 1.

<table>
<thead>
<tr>
<th>“Master” image</th>
<th>“Slave” image</th>
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<tbody>
<tr>
<td>satellite</td>
<td>orbit</td>
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<tr>
<td>ERS-1</td>
<td>06880</td>
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<tr>
<td>ERS-1</td>
<td>06880</td>
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*The topographic effects have been removed from this interferogram by using DEM computed from ERS SAR tandem mission data

In this project only the couples of ERS SAR data acquired from very close orbits, with perpendicular baselines not exceeding 100 m have been selected. Such selection practically eliminates the effects of the topographic influence, since the height resolution becomes very coarse. These pairs have been further selected according to weather and season condition on the day of acquisition (Perski 1999).

2.4 The interpretation of SAR interferograms

In the case of underground longwall coal mining, the SAR interferogram presents only the terrain surface changes which occur on the active (advancing) slope of a developed subsidence trough. In such a configuration the centre of the fringe – i.e. the area of maximum surface displacement – is located in the middle of the active slope of the subsidence trough and thus indicates the zone of highest rate of surface changes (Perski, Jura, 1999) with respect to the time base between SAR data acquisitions. For the satellites ERS-1 applied in this project this is a 35-day difference or its integer multiplication. Interferometric results on an interferogram from 08.11 to 04.10.1992 show concentric fringes - typical for areas of land subsidence.

Fig.2 Fringes due to land subsidence.

The centre of the fringe indicates the zone of highest-rate mining subsidence. For the example analysed, this rate varies between 2.5 and 12 cm per 35 days.
3 IMAGE PROCESSING

3.1 ERS SAR amplitude image processing.
During interferometric processing of SLC data with Atlantis EARTHView InSAR Workstation the amplitude “master” and “slave” images were generated. In the same chain processing the coherence maps were created and geocoded. The amplitude images were deeply examined and their contrast carefully stretched. The color composition carried out based on three images mentioned in the table 1 shows well urban areas with the building ensembles marked as the strong scatterers. It is very important for land cover studies because on Landsat images the densely urbanized area looks like non vegetated rural areas. It is due to rather low geometric resolution of TM sensor versus building dimensions and comparable spectral characteristics of soils and mineral materials used for building construction.

Two coherence maps are rather poor and only one can be exploited for separation of dense urban area. The second one shows quite clearly only forested and non-forested areas so it is not particularly interested for further analysis.

3.2 Landsat 5 TM data processing
Several channel subsets from TM set were tried for land cover studies. Two subsets seemed to be particularly interested. Channels 435 and 547 displayed as RGB plans. The near and middle infrared channels were rather preferred than visible due to image sharpness and clearness. Two compositions were done: one more “realistic” for the users of space maps with weak knowledge in satellite image interpretation and the second one showing the vegetated areas (like grasslands and crops) in red and orange colors.

3.3 Merging of radar and optical data
The interferogram was deeply analyzed and the areas of strong subsidence were identified and masked. The areas of well marked fringes were then extracted from interferogram and “incrusted into” optical images. Each of two Landsat compositions were split into independent channels RGB and each component was merged with analogue component issued from interferogram. Mutual masking of both types of images permitted to conserve their original palettes. Additionally the transformation RGB-IHS was performed to superpose the well identified on radar multitemporal composition urban areas with false color Landsat composition.

The resulting images are shown respectively in the figures: 3, 4 and 5.

![Fig.3. False color composition.](image1)

![Fig.4. “Realistic” color composition.](image2)

![Fig.5. Radar image merged with false color composition.](image3)
CONCLUSION

The InSAR data can become in future the basic, independent source of information about surface dynamics in Upper Silesian Region. Analysis of interferograms shows that the fringe pattern strongly relates on the position, shape and length of the mining front, the rate of mining advance and technique applied for the roof control and the geological structure of rock mass and the presence of abandoned underground workings. InSAR data brings valuable information about surface dynamics in regional as well as in local scale.

The InSAR data merged with optical images like Landsat or others can produce the spacemaps easy to interpret so easy to use in the practice of land management and environment monitoring.

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