MONITORING MINING INDUCED GROUND-MOVEMENTS USING SAR INTERFEROMETRIC TECHNIQUES

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ABSTRACT

This paper introduces the project EOMD Mining. High-level objectives of the project included the definition and implementation of a marketable integrated service for the mining market which includes satellite SAR based land surface deformation monitoring as a key element and to achieve market awareness and acceptance for this EO based integrated service. After a short introduction of the service offer the main focus of this paper is on the presentation and evaluation of the pre-commercial projects conducted as par of the EOMD Mining project.

1 INTRODUCTION

The scope of the project "EOMD Mining: EO Services Market Development for the Mining Sector", an Earth Observation Market Development (EOMD) activity within the framework of the ESA EOEP Market Development Element, was to develop marketable land surface deformation monitoring services with SAR interferometric techniques being a key element. In the targeted mining and oil&gas market there exists a significant demand for deformation information for reasons including legal obligations, safety, and environmental monitoring. Existing non-EO techniques are rather expensive so that we identified a significant market potential for the EO based technique provided that a better awareness and acceptance can be achieved. Important blockages identified included the difficulty in accessing the customers and in achieving their acceptance for the service. The approach followed was to strongly involve an established market player and to integrate the EO based information with non-EO elements. DMT GmbH is a nationally and internationally established service company in mining business with a portfolio covering a wide range of mining related questions and tasks.

A modular service approach was selected to manage the combination of the broad portfolio of service elements which are considered with the end-to-end service integration offered. A case specific service consists typically of non-EO elements, EO-based elements, integration procedures, and customization elements. Optical EO based elements are contributed by MfB Geoconsulting, Switzerland (http://www.mfb-geo.com) For more details on the service structure and the elements covered it is referred to [1]. For more details on the interferometric point target analysis (IPTA) and DINSAR techniques used it is referred to [2, 3]

To achieve market awareness and acceptance a number of pre-commercial projects (PCPs) with strong user involvement were conducted. Several partners from the mining and oil&gas sector with varying monitoring requirements participated to the PCPs. In the following results of the PCPs are presented and its utility discussed.

2 LAND MOTION MONITORING SERVICES

2.1 LMBV – Flooding of an open cast mine

The requirements of *Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH, Germany* (LMBV) were to close a temporal gap in the ground-based monitoring and the determination of surface movements due to flooding of an open-cast mine after the end of the excavation. The IPTA analysis, conducted to close a temporal gap in the monitoring with leveling, confirmed low deformation rates for the settlements located a few kilometers from the open pit mine (Figure 1) and confirmed the applicability and utility of the technique. Flooding was just started but will last for many years, so that there is a need to continue monitoring activities over decades. Furthermore, using DINSAR, indications of localized faster deformations were identified at the slopes of the open-pit mine.

The expectations of LMBV were fully met. Potential follow on services include continued monitoring services during the ongoing flooding of the open cast and similar monitoring activities for other mines.

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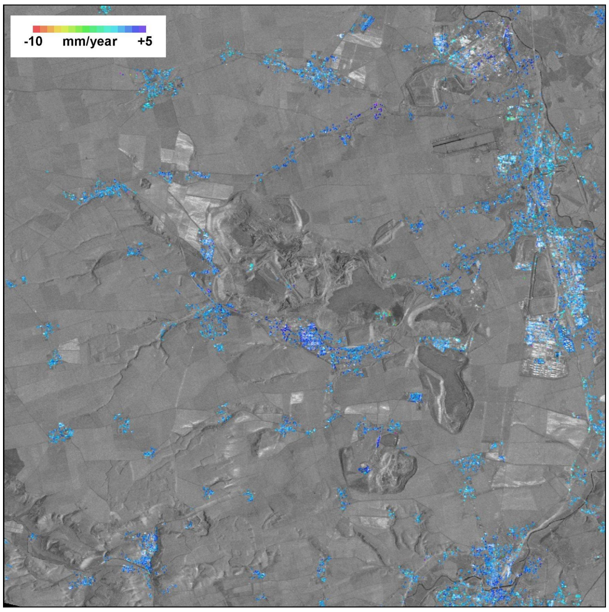

Figure 1 Geiseltal open cast mine. Linear subsidence rate from IPTA for 1992-2002 derived from ERS SAR data stack.

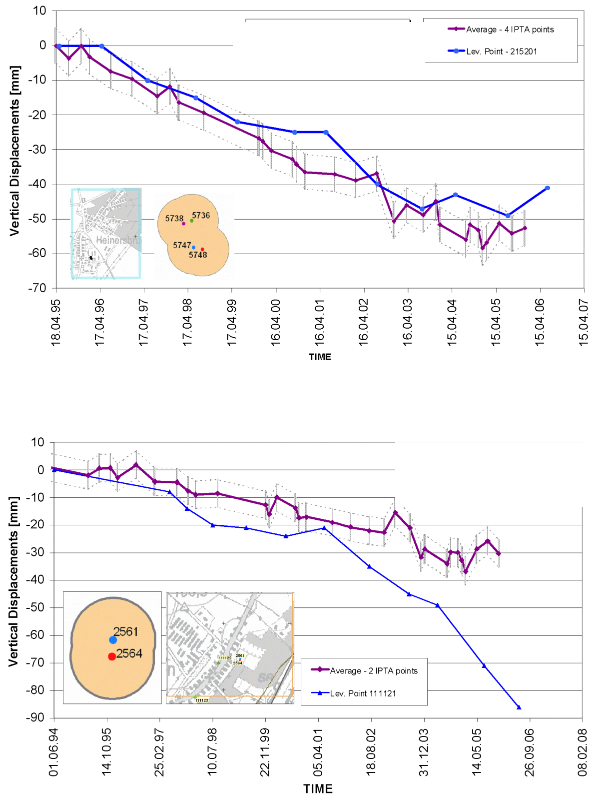

Figure 2 Validation of IPTA times series with leveling data. The upper image (a) shows a comparison where the two methods show good correspondence, the lower image (b) shows and example of a significant deviation.

2.2 DSK – Pre-excavation assessment of natural surface movements

Deutsche Steinkohle AG (DSK) is responsible for the operation of under-ground hard coal mining in Germany with excavations ongoing in the Ruhr and Saarland areas. DSK was already involved in previous activities concerning the use of SAR interferometric techniques for mining related surface movement monitoring [4]. The main requirement of the service provided to DSK in the PCP of the EOMD Mining project was the identification of surface movements prior to the start of the excavation in order to separate future mining induced surface movements from movements not related to the mining. The IPTA analysis of ERS and ASAR data covering the time before the start of the excavation showed only very minimal movements. In particular, no distinct seasonal correlation with available information on ground water levels, river gauges, and precipitation, could be found. Reasons included that relatively few ERS and ASAR acquisitions exist for the period for which ground water level and river gauges measurements were available. Unfortunately no in-situ surface movement measurements were available. Furthermore, there was no clear expectation concerning the level of the potential surface movements caused by ground water level variations.

Considering that the expected correlation between surface movements and ground water levels could not be confirmed DSK was not fully satisfied with the result. At present a follow on interferometry project is pursued for another area of interest of DSK in cooperation between DSK, TU Clausthal, DMT, and GAMMA.

2.3 Vattenfall – Monitoring of surface movements for open-pit mining

Vattenfall Europe Mining AG (Vattenfall) operates open cast lignite mines in Germany. The requirement of Vattenfall in the related PCP was to get surface movement information in the vicinity of the open pit. Subsidence in the vicinity of the open pit is expected from the mining induced reduction of the water table level. ERS and ASAR data acquired between 1992 and 2005 were selected. The IPTA processing resulted in average deformation rates and point-wise deformation histories. The IPTA result derived from ERS and ASAR data nicely shows the main spatial pattern of the movements. This result and specific time series were validated using corresponding leveling data (Figure 2).

The overall deformation pattern was well retrieved from the SAR data. Nevertheless, for a number of locations where significant non-linearities in the temporal behavior occurred the non-linearity was not correctly monitored (see example in Figure 2b). For this reason and even more important because of the missing acceptance of the interferometric method by the mining authorities Vattenfall does not include the interferometric method in their current monitoring strategy. They are open to reconsider this decision if progress is made concerning the reliability of the method and the acceptance by the mining authorities. As Vattenfall is spending every year a very significant budget on in-situ monitoring activities any reduction of the overall monitoring costs (e.g. by partially substituting leveling campaigns by interferometry) would be highly welcome.

2.4 RWE-WWE – Monitoring of surface movements above underground gas caverns

RWE WWE Netzservice GmbH (RWE) uses underground caverns for the storage of natural gas. Changing gas pressure in the caverns causes ground movements (uplift and subsidence) above the caverns. The requirement of RWE for the PCP was to evaluate the potential of SAR interferometric techniques to monitor movements above underground caverns used for gas storage. In spite of the vegetated surface ground movement monitoring with IPTA was feasibly for many of the caverns; this probably because of the cavern infrastructures acting as persistent scatterers. For other caverns artificial reflectors would be needed to get reliable information from the SAR data.

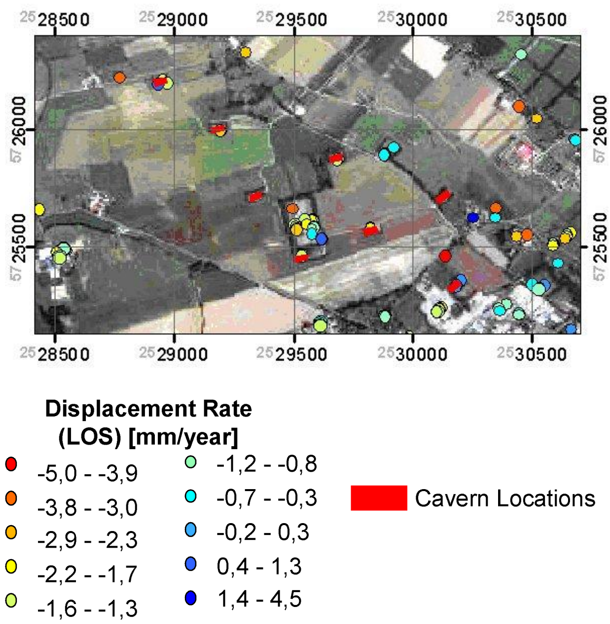

Figure 3 IPTA based average deformation rates for gas cavern site.

RWE was not fully satisfied with the result, though, due to overall insufficient point densities and the relative high noise on the individual observation. Furthermore, the area of interest is relatively small which results in relatively high costs of the IPTA method as compared to conventional techniques.

2.5 Akzo Nobel – Monitoring of surface movements for solution mining site

Akzo Nobel Base Chemicals bv (Akzo Nobel) operates solution mining sites. One part of the subsidence management system applied by Akzo Nobel at Hengelo brine field is the modeling of subsidence using latest information about the mining process in the underground. In addition direct measurements of the ground deformations are required. The requirement for the PCP was to monitor the deformation using IPTA. Given the rural nature of much of the brine field area it was clear that no complete coverage could be expected. Nevertheless, the site also includes areas of undergoing and future industrial and urban development – and these areas where the main interest in the PCP. ERS data were used to monitor the ground movements between 1995 and 2000 and ASAR data for the period 2004-2005. Indeed useful information could be provided for the main area of interest, with increasing subsidence rates towards the brine field (Figure 4). The IPTA result corresponded well to available leveling data (Figure 5)

Akzo Nobel was very satisfied with the result and concluded that this technique can considered as a suitable element of their subsidence management system.

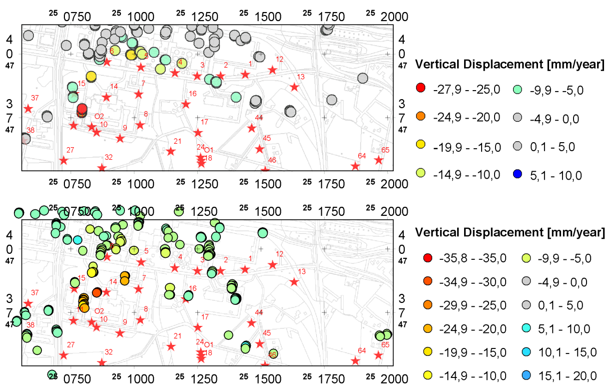

Figure 4 IPTA based average deformation rates 1995-2000 from ERS data (top) and 2004-2005 from ASAR data (bottom). Brinewell locations are indicated by red stars.

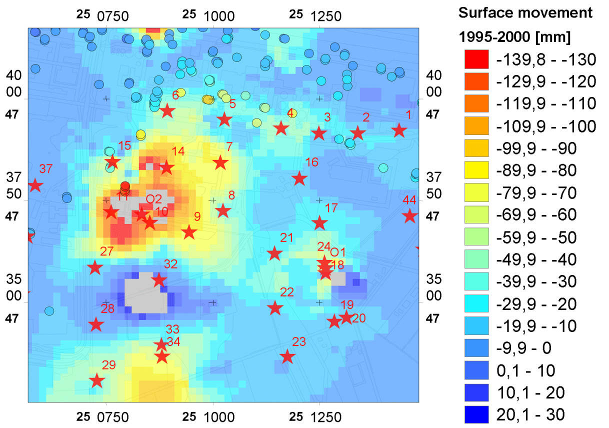

Figure 5 Comparison of IPTA based vertical surface movements 1995-2000 from ERS data (colors in circles) with information from leveling (background color, spatially interpolated). Brinewell locations are indicated by red stars. The same color is used for both data sets displaced.

2.6 KISR – Monitoring of surface movements for oil fields

The objective of the KISR PCP was to map subsidence above major oil fields in Kuwait and in particular to confirm the applicability of the technique. For an IPTA processing the data availability was insufficient. New ASAR scenes needed to be programmed and differential interferometry (DINSAR) was applied. Coherence levels were found sufficient for much of the area, permitting phase unwrapping. Stacking techniques were applied to reduce the errors from strong atmospheric path delay heterogeneities. No actual validation data were available but the observed deformations look consistent with geological information (Figure 6).

The main objective to check whether SAR data are suitable for deformation mapping in Kuwait could be achieved. Given the relatively low cost of the technique to map large areas the technique may further be considered in this area.

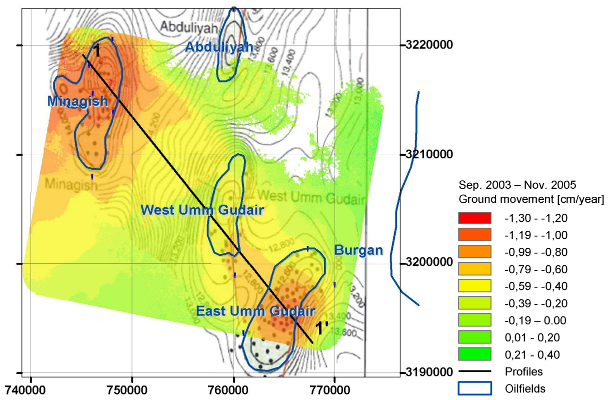

Figure 6 Ground deformation over oil fields in Kuwait derived from ASAR data using DINSAR stacking.

2.7 MIBRAG – Monitoring of active and abandoned lignite mining sites

The area under investigation south of Leipzig includes active and abandoned open-pit lignite mining sites in a spatially close neighbourhood. Within this area the Mitteldeutsche Braunkohlengesellschaft mbH (MIBRAG) operates several mines. A detailed monitoring of the topographic surface is necessary, especially in those areas where initial uplifts have been measured. In their related project TU Clausthal uses differential SAR interferometry (DINSAR) to monitor movements of the topographic surface. A special focus of the project is on the use of corner reflectors to support the interferometric approach. For more details on this project it is referred to [5].

3. DISCUSSION AND CONCLUSIONS

An important element of the EOMD Mining project was to develop marketable land surface deformation monitoring services with SAR interferometric techniques being a key element. The service offer was established. Some progress in the SAR interferometric techniques used could be realized during the project, inluding ERS-ASAR integration, and a separation of the point height and deformation estimation which reduces the dimension of the regression analysis conducted permitting to expand the applicability to higher deformation rates. Progress was also made what concerns the characterization of the quality of the products. Nevertheless, to make further progress in the quality assessment and communication is still requrired.

The high interest and engagement of the users involved as well as the other dissemination activities undertaken allowed us to make much progress in the awareness of SAR data based deformation monitoring. It also helped that a relatively large number of PCPs was conducted covering a wide range of different application cases.

The acceptance achieved for the SAR interferometric techniques, differs strongly between users. Open questions and potential limitations of the technique were critially address and discussed. For many users the curently still missing official acceptance by mining authorities is a major blockage to consider at present the technique as part of their monitoring strategy. Acknowledging this problem steps to advance the certification of the SAR interferometric technique were undertaken. The related activities with the German mining authorities will probably still take at least 2 years. On the positive side it can be stated that the acceptance is already good with some users. The possibility to retrieve deformation information for periods in the past was very positively received in cases where no in-situ measurements were available for an area and time period of interest.

In a small extension the project will be continued to extend the service offer to the novel SAR sensors onboard ALOS (L-band SAR PALSAR) and TerraSAR-X (X-band SAR). In addition, efforts towards the acceptance of Mining authorities will be continued. The project also resulted in a number of further related activities of some of the involved parties.

4. ACKNOWLEDGEMENT

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