

# DINSAR GROUND MOVEMENT MONITORING IN THE RURAL ENVIRONMENT OF AN OPEN PIT MINING AREA

Michael Schäfer<sup>(1)</sup>, Diana Walter<sup>(1)</sup>, Wolfgang Busch<sup>(1)</sup>

<sup>(1)</sup>Clausthal University of Technology, Institute of Geotechnical Engineering and Mine Surveying (IGMC),  
Erzstr. 18, D-38678 Clausthal-Zellerfeld, Germany, Email: [michael.schaefer@tu-clausthal.de](mailto:michael.schaefer@tu-clausthal.de),  
[diana.walter@tu-clausthal.de](mailto:diana.walter@tu-clausthal.de), [wolfgang.busch@tu-clausthal.de](mailto:wolfgang.busch@tu-clausthal.de)

## ABSTRACT

We present intermediary results using conventional differential SAR interferometry (DInSAR) in a lignite open pit mining area in Germany. All available ENVISAT and ERS-2 scenes since 2002 were used. Due to the area of interest's rural character and vegetation zone, temporal decorrelation is a limiting factor for C-band based interferometric analyses. Additionally a network of twelve Corner Reflectors has been installed to investigate possible advantages for the analysis.

Another limiting factor is caused by radar signal delay variations in the earth's atmosphere which can produce an additional phase contribution to the differential phase. This contribution is often highly variable in the spatial domain by ranges up to tens of kilometres, but can also show linear trends. A simple approach for the elimination of these phase contributions is shown.

## 1. INTRODUCTION

The area of interest is situated in south-eastern Germany, south of the city Leipzig (cf. Fig. 1). As a result



Figure 1: Area of interest with active (brown) and decommissioned mining sites (green). The red box shows extent of Fig. 5 & 6. Source: [www.lmbv.de](http://www.lmbv.de)

of extensive lignite mining activities in this area, active and decommissioned mining sites nowadays lie in a spatially close neighbourhood. Within the area of interest two active open pit mines as well as several abandoned mine sites currently under remediation cause a complex ground water situation. The operating company of the active lignite mine sites is the "Mitteldeutsche Braunkohlengesellschaft mbH" (MIBRAG).

Due to the ended dewatering within large parts of the area over decades in conjunction with an active flooding of selected open pit sites, a rising of the groundwater has taken place, resulting in a slight uplift of the topographic surface. On the other hand active mining sites relocate slowly and likewise the dewatering of the ground water moves forward, resulting in ground subsidence.

Therefore a detailed monitoring of ground movements is essential for both the mining and the rehabilitation companies. At the moment ground deformation measurements are conducted by terrestrial levelling every two years. These measurements are much cost and time expensive, and aren't spread equably over the whole area. Hence, the aim of this research project was to investigate if differential SAR interferometry (DInSAR) would be applicable for the supplementation (and perhaps partial substitution) of the terrestrial measurements.

## 2. CORNER REFLECTORS

A total of twelve Corner Reflectors (CR) have been developed and built by the Institute of Geotechnical Engineering and Mine Surveying (IGMC) and were installed in the area of interest in August 2005 (see Fig. 2). These Reflectors were built out of aluminium perforated plates using an optimum pentagonal plate design primarily described by [1].

This particular CR design was preferred because it offers a lighter construction with 33% smaller plates while giving the same intensity response (RADAR cross section, RCS) as an ordinary CR with triangular plates. In other words the design allows to build CR with bigger RCS using the same metal plates. Additionally the pentagonal CR possess less interaction with waves reflected by the ground surface in front of the CR.



*Figure 2: Pentagonal Corner Reflector in the surrounding of an open pit mine*

The Corner Reflectors are used as control points for geocoding of the SAR data and for the comparison with reference deformation measurements derived from terrestrial levelling. The CR will also act as homologous points in a future Persistent Scatterer analysis of a larger stack of SAR data. Till now (April 2007) a total number of 15 scenes with CR could be acquired which should be enough for a first evaluation.

### 3. AVAILABLE SAR AND REFERENCE DATA

Methods of conventional differential SAR interferometry (DInSAR) were applied on a set of all available ENVISAT ASAR and ERS-2 SAR scenes since 2002. This is because almost all of the reference data were only available for this time span.

Since April 2005 all possible ENVISAT ASAR scenes in configuration “descending swath 2” had been programmed. Till now (April 2007) a total number of 21 scenes should have been acquired. Two scenes were not acquired (April 13<sup>th</sup>, 2006 because of a late frame start and December 14<sup>th</sup>, 2006 because of high solar activity). One other scene (September 15<sup>th</sup>, 2006) was affected by a temporal modification of the ASAR antenna radiation pattern and therefore slightly degraded [2]. This scene could be processed, but was not usable for DInSAR. For these reasons only 18 out of 21 acquisitions (86%) are usable.

Previous April 2005 only six ENVISAT ASAR scenes have been acquired in this configuration in the area of interest. For this reason also ERS-2 SAR scenes have been ordered for this time span. These scenes were acquired in the satellites “gyro-less mode” (gyroscope-free positioning) after a failure of the spacecraft in 2001 [3]. These scenes have only very restricted use for DInSAR due to much different doppler centroid frequencies and cannot be combined with ENVISAT scenes in the most cases. For a future Persistent Scatterer analysis also

ERS-1 and ERS-2 scenes before 2002 are planned to be used to get a better time series.

For the comparison and validation of satellite derived results with other measurements, reference data were collected, which were made available by MIBRAG mbH. This data consist of height data like photogrammetric height models (TINs), terrestrial levelling data over several years, aerial photos, and topographic maps.

### 4. DATA PROCESSING AND CORRECTION FOR UNWANTED PHASE CONTRIBUTIONS

Currently the processing is restrained to DInSAR processing using software by Gamma Remote Sensing. The SAR data were processed from raw data (ASAR level 0 product) to single look complex (SLC) data. Further processing steps contain precise multiple co-registration of SAR images and afterwards generation of differential interferograms using a mosaic of height data by MIBRAG and SRTM-C data. Use of a Persistent Scatterer approach (Gamma’s IPTA module) is planned for the near future.

Main problems for automated interferometric analyses of ground deformations are phase offsets especially due to small orbit errors and variability of the refractive index of the atmosphere. These contributions can show a linear trend, but often they are highly variable in the spatial domain by ranges of hundreds of metres to tens of kilometres. Especially they are caused by atmospheric path delays such as changes in the water vapour amount, clouds or rainfall [4].

The phase contributions by slight orbit errors can be highly reduced by using highly precise state vectors processed by TU Delft Institute for Earth-oriented Space Research (DEOS). These orbits are based on both DORIS data and satellite laser ranging.

For atmospheric phase contributions a simple software tool has been developed in programming language IDL. This software computes an average phase value within a circle shaped moving window with a diameter of roughly 10 km. The contribution of each pixel value in the circle is weighted from the centre of the circle to its perimeter. For the big filter size one goal was the optimization of the computing speed which is now less than 15 minutes for one whole ASAR scene.

The result from the averaging process is then subtracted from the original phase values of the interferogram. In such corrected interferograms the colour cyan seems to appear dominant, showing the areas of no deformation (phase value zero). Fig. 3 visualizes an example of this phase correction procedure showing the original phase values (a), corresponding correction image (b) and corrected phase image (c) of a subset of an ASAR scene.

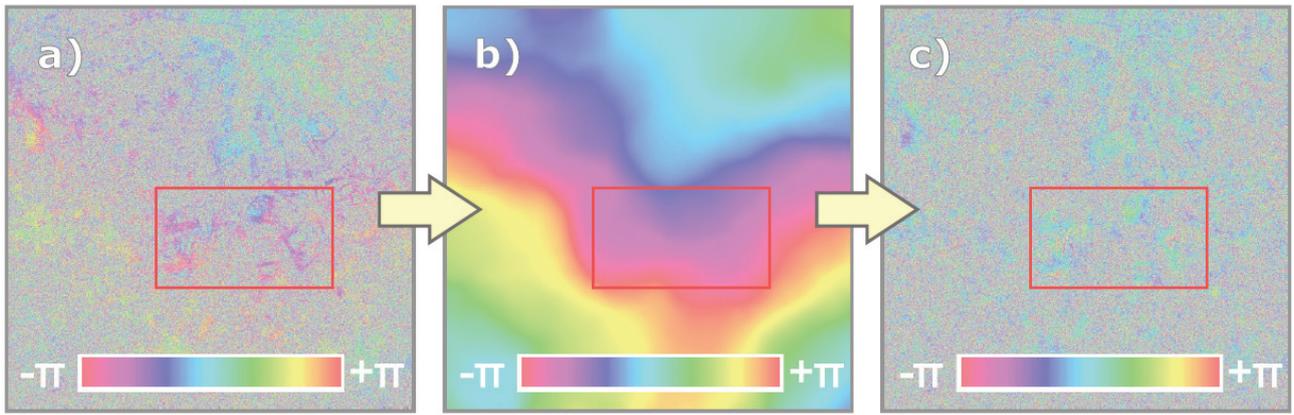


Figure 3: The result of the computation (b) is subtracted from the original phase (a), resulting in the corrected phase image (c) in which colour cyan (phase values of zero) stands for areas of no deformation. All images are approx.  $45 \times 45 \text{ km}^2$  in size, the red box shows extent of Fig. 5 & 6.

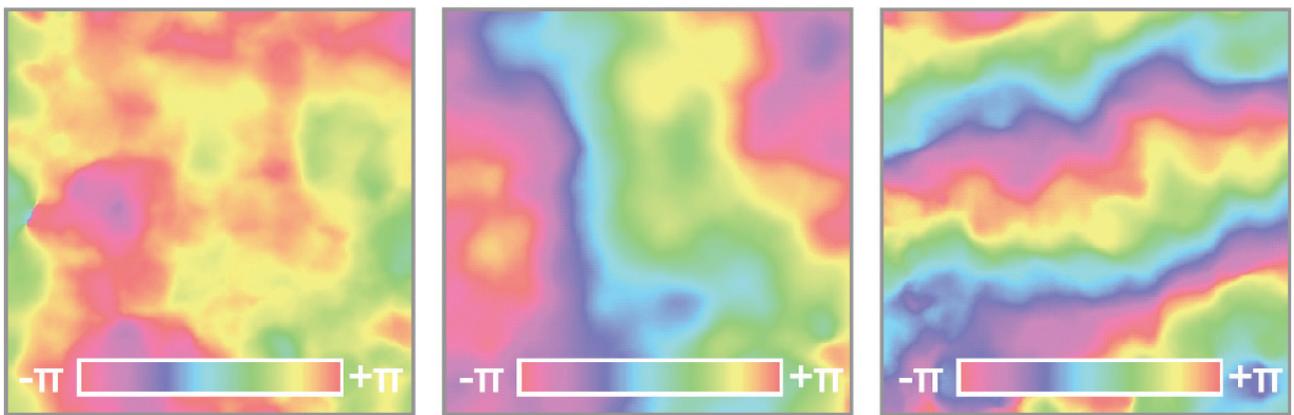


Figure 4: Examples of phase correction images for three different interferograms. All images are  $100 \times 100 \text{ km}^2$  in size (whole ENVISAT ASAR scenes).

The correction images (Fig. 3 b and Fig. 4) possess high analogy with atmospheric phenomenon. But additionally also residual orbit trends can occur in the correction images. For the comparison with real weather data, some of the correction images have been visually compared with Meteosat MSG images by EUMETSAT. This comparison is difficult and rather subjective because the correction images always show the superposition of the two atmospheric conditions at the times of acquisition of the individual SAR scenes used for computation of the interferogram.

The biggest advantage of the correction approach is that the corrected phase images allow direct comparison and combination of different interferograms. Without correction, the need for the visual interpretation of the DInSAR results by an experienced user is much higher.

One residual problem is that spatially large areas of deformation (extent over 10 km), which could appear in the area due to ground water extraction, can't be distinguished from atmospheric effects at the moment. This could be solved by stacking of interferograms in future.

## 5. PRELIMINARY RESULTS

The area of interest shows quite good interferometric coherence in respect of vegetation conditions in Central Europe, particularly in the range of open pit mines and their surroundings (cf. Fig. 5).

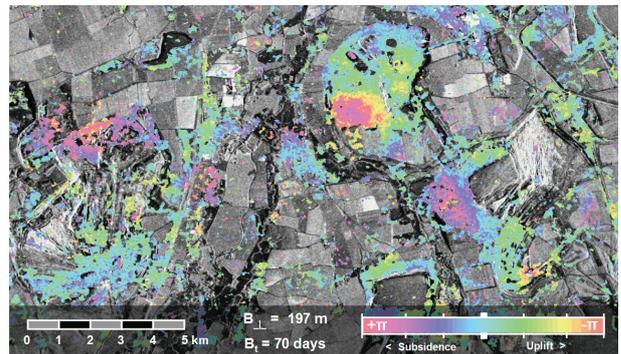


Figure 5: Interferogram (corrected as described in chapter 4) with temporal baseline of 70 days, perpendicular baseline of 197 m, masked for regions with coherence greater 0.35% (one colour cycle corresponds a vertical surface displacement of approx. 3.0 cm)

Of course coherence is lost if any mining activities have been performed in the open pit areas. However many surfaces used for agriculture and forestry most times show no coherence, except of few interferograms in the winter months when no agriculture was performed.

The observed surface deformation rates are very small, in majority of cases less than 5 mm between two acquisitions (35 days). Often the observed areas which did show subsidence in the previous interferogram show uplift in the subsequent interferogram and vice versa. These little uplifts and subsidences are most likely for seasonal reasons or different soil moisture states. Nevertheless the causes for the motions aren't fully understood yet and have to be investigated.

For the comparison with reference data, which were typically measured every two years, it is indispensable to discover long-term surface deformations. This comparison is a difficult task which we want to improve and automate in the future. Results concerning this topic will be presented later. Fig. 6 shows some example charts obtained directly from differential interferograms by hand, trying to summarize up to nine interferogram combinations to one long-term deformation investigation over a total time span of two years.

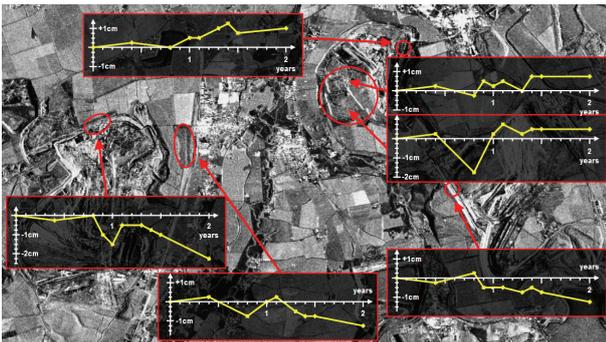


Figure 6: Six example deformation charts for selected regions (red circles)

Please note that the charts were selected for regions with the biggest observed ground motions in the surrounding of the open pit mines. Many other regions in the area show much less motion. But even considering this fact the charts show only motions in the order of around  $\pm 1$  cm over two years.

## 6. CONCLUSIONS

The area of interest shows very little ground motions. These motions derived from DInSAR methods were difficult to separate from weather effects at the two acquisition times which can show similar spatial characteristics. An approach for the correction of such unwanted phase contributions by spatial filtering has been developed; problems are still remaining with the separa-

tion of large area deformations which could possibly appear in the area. At the moment solutions for these problems exist for point based persistent scatterer interferometry analyses, but not for DInSAR analyses.

Another big problem is due to the very big baselines between the ENVISAT acquisitions. Often the perpendicular baseline ( $B_p$ ) amounts to several hundreds of metres; up to 1494 m have been observed in this research project. A maximum  $B_p$  of 300-400 m would be appreciated for C-band data to achieve a good interferometric geometry and hence good interferometric coherence. Combinations with  $B_p$  of more than 600 m only very seldom gave any useful results. For these reasons only few of the possible interferometric combinations between the acquisitions are usable for DInSAR. The selection of these combinations is important to achieve the best possible time series of interferograms for the investigation of a long time enduring motion.

For satellite life time reasons the number of orbit manoeuvres have to be limited for the finite amount of fuel on board of ENVISAT. But considering the designated EO market development the actual acquisition strategy should perhaps be reconsidered, at least in terms of differential interferometry. Considering in addition the failed acquisitions mentioned in chapter 3, currently it is not possible to ensure a commercial client the measurement of ground motions for a given time span. Therefore future SAR satellites to be used for interferometry should achieve at least a narrower orbit dead-band, depending on the used radar wavelength.

## 7. ACKNOWLEDGEMENT

This research project is financed by the budget of the German Federal Ministry of Economics and Technology (BMWi) via the "Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e.V." (AiF).

The used SAR data was partially provided by the European Space Agency through Category 1 proposal 3085.

## 8. REFERENCES

1. SARABANDI, K., CHIU, T.C. (1996): Optimum Corner Reflectors Design. – Proc. IEEE National Radar Conf., Ann Arbor, Michigan.
2. ESA (2005): ASAR Product Quality Disclaimer. – [http://envisat.esa.int/dataproducts/availability/disclaimers/PQD\\_0081\\_ASA\\_all.pdf](http://envisat.esa.int/dataproducts/availability/disclaimers/PQD_0081_ASA_all.pdf)
3. MIRANDA, N., ROSICH, B., SANTELLA, C., GRION, M. (2004): Review of the impact of ERS-2 piloting modes on the SAR doppler stability. – Proc. Envisat & ERS Symp., ESA SP-572, Salzburg.
4. Hanssen, H., Zebker, H., Klees, R., Barlag, S. (1998): On the use of meteorological observations in SAR interferometry. – Proc. IGARSS 1998, Seattle.