Monitoring of mining induced surface deformation

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Abstract
The main objective of the project "Monitoring of mining induced surface deformation" (ALOS-RA-94) is to evaluate multi-temporal PALSAR data for land surface deformation monitoring, using interferometric techniques. Differential interferometry using PALSAR data over several mining sites in Germany, Poland and Czech Republic, as well as over alpine landslides in Switzerland and Italy was used to assess the potential of L-band repeat-pass DINSAR for these applications. In general the PALSAR data obtained were well suited. The data were found of good quality and well suited, with generally short baselines (< 1.5km), well overlapping range and azimuth reflectivity spectra, and a systematic acquisition of data following the strategic observation plan. Acquisitions acquired in single polarization mode as well as dual polarization acquisitions were used. Of particular interest was the relatively good potential found even for vegetated surfaces and for deformation fields with high spatial deformation gradients. Pairs with 46 days intervals permitted to retrieve the deformation above active coal mining with subsidence rates as high as 30cm/month. Similarly, fast moving landslides could be identified in single differential interferograms. For many of the test sites chosen results from C-band interferometry, mainly based on ERS and ENVISAT data, were available for comparison. As compared to C-band interferometry the applicability is clearly enhanced in the case of vegetated surfaces and for deformation fields with high spatial deformation gradients.

Keywords: ALOS PALSAR, SAR interferometry, land motion, mining, landslides.

1. INTRODUCTION

In the mining sector there exists a significant demand for deformation information for legal obligation, safety, and environmental reasons. Existing non-EO techniques as leveling and GPS are operationally used. In spite of this there is a high interest in potential complementary or alternative techniques. In spite of advanced SAR interferometric processing techniques and numerous very convincing results, there remain limitations to the utility which can be summarized as "partial unavailability of the EO based information". The most important reasons include information gaps for low coherence areas (C-band long-term coherence is low for most vegetated areas) and the difficulty to resolve high phase gradients. Examples showed [1], that we were not able to correctly retrieve the deformation rates for localized mining induced subsidence cones with subsidence values larger than 10*cm* for the observation period, when using C-band SAR. Rapid localized subsidence during underground coal excavation results in the requirement that deformation gradients as high as 30*cm /month/km* need to be resolved. Furthermore, adequate SAR data are required, which is restricted by the satellite return cycle (e.g. 35 day for ERS and ASAR) and requirements such as "short enough baseline", or "sufficiently overlapping Doppler spectra".

In the past mainly C-band SAR sensors were available. Thanks to ALOS PALSAR there is now again an L-band SAR in orbit. One important focus of our ALOS RA project work is to demonstrate the high potential of PALSAR interferometry for the monitoring of land surface motion.

2. SAR DATASET AND PROCESSING

The PALSAR dataset analyzed consisted of PALSAR Fine Beam Single (FBS) and Fine Beam Double (FBD) data sets over mining sites in Germany, Poland, and the Czech Republic, as well as over alpine sites in Switzerland and Italy.

All the available scenes were processed to SLC and then co-registered to the same slant-range geometry. For the processing of single interferometric PALSAR data pairs a two-pass differential SAR interferometry [2] approach was applied, using the SRTM 3" DEM as height reference. As a special processing optimized for the fast deformation rates as expected in the case of active mining and landslides we separated the localized deformation signal and the large scale error terms (large scale atmospheric distortion and baseline related phase errors), based on their different spatial resolutions. The methodology used in the case of mixed FBS and FBD pairs is described in more detail in [3].

What we present in this paper are intermediate results. Phase unwrapping, the inclusion of additional data sets, validation and interpretation activities just started.

3. RESULTS

3.1. Hamm, Germany

PALSAR data over the Ruhr area are being used to evaluate the potential to monitor surface deformation above active coal mining. This is particularly important as large information gaps remain when using the currently available C-band sensors due to too high phase gradients preventing reliable unwrapping of the differential interferometric phases. PALSAR differential interferograms (see Figures 1 and 2) generated show that an almost complete spatial coverage with deformation information is achieved for 46 day intervals. In spite of the very significant deformation over this time span immediately following the coal excavation of sometimes > 30cm in one month it looks feasible to unwrap the differential interferograms to obtain quantitative information on this deformation. In any case the locations of the fast deformations can reliably be detected. For periods of 3 or 4 46 day intervals the coherence is still high enough so that most areas of high deformation can reliably be identified. Nevertheless, increased noise over forest and for some agricultural areas and the high phase gradients resulting from the strong deformations may prevent in some cases a reliable unwrapping and quantitative subsidence estimation.

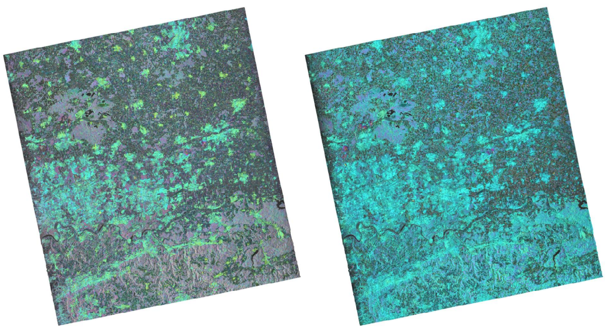


Figure 1. Georeferenced PALSAR differential interferograms (approx. 100km x 100km) over Hamm site, 20070125_20070612, Δt=138days, $B_\perp$=1391m (left) and 20070612_20070728, Δt=46days, $B_\perp$=-1593m (right).

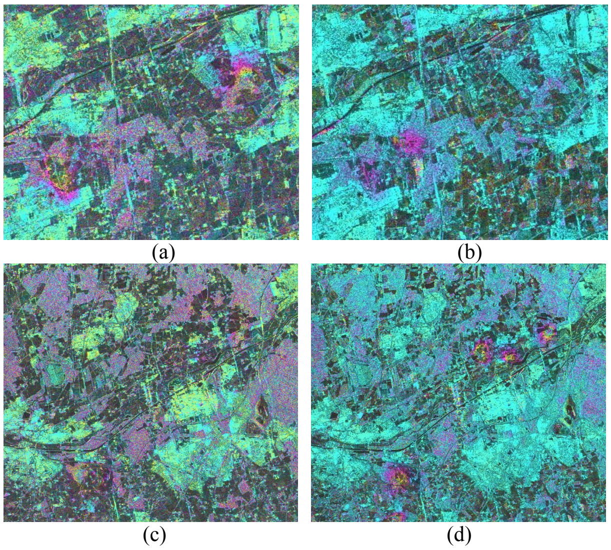


Figure 2. Sections of differential interferograms showing the areas above active coal mining; (a,c) 20070125_20070612, Δt=138days, $B_\perp$=1391m and (b,d) 20070612_20070728, Δt=46days, $B_\perp$=-1593m.

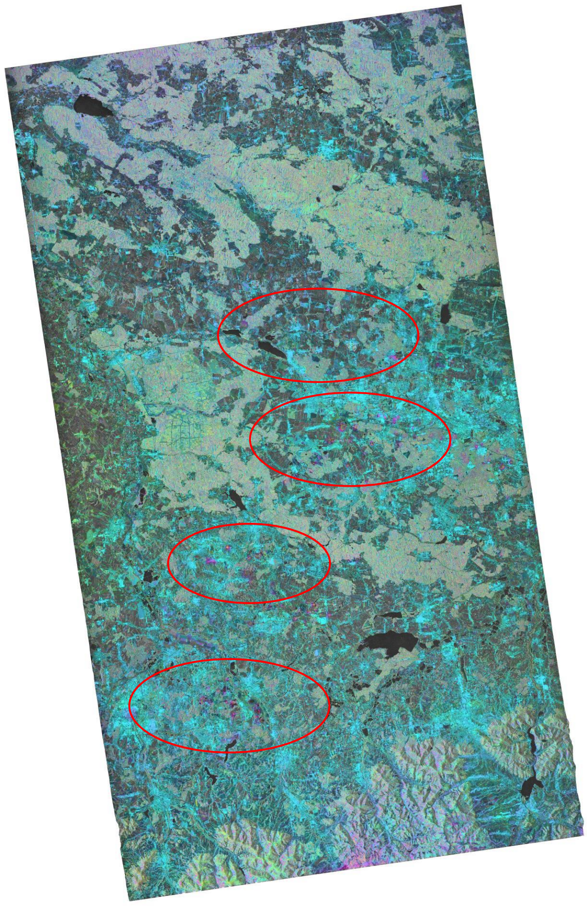


Figure 3. Georeferenced PALSAR differential interferograms (approx. 100km x 200km) over Silesian Basin (Poland, Czech Republic), 20070710_20070825, Δt=46days, $B_\perp$=235m. Red ellipses indicate areas with many active coal mines.

3.2. Poland and Czech Republic coal mining areas

Two-frame strips of PALSAR data over the Silesian Basin covering major coal mining areas in Poland and the Czech Republic are being used in the frame of the ESA GSE Project Terrafirma to monitor mining induced surface deformation. The deformations observed and the considerations concerning feasibility and potential are identical to those for Hamm, Germany. The surface subsidence induced by the many active coal mines in the Polish Rybnik and the Czech Ostrava mining areas can be reliably identified in the georeferenced differential interferograms (Figure 3).

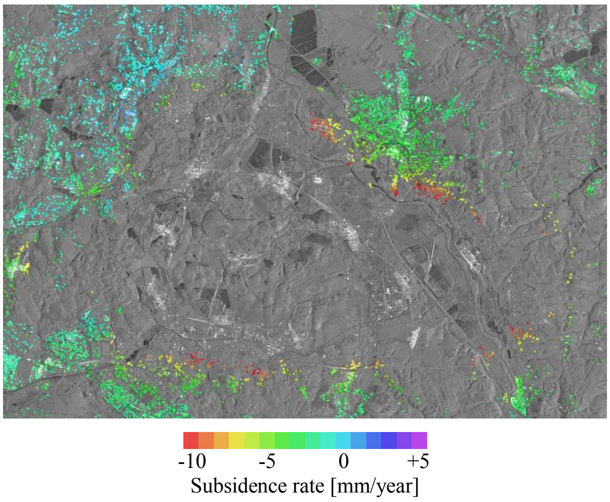


Figure 4. Section of georeferenced average subsidence rate for 1992-2006 derived from ERS and ENVISAT data over Rybnik-Ostrava using persistent scatterer interferometry. For gray areas no deformation rates were retrieved.

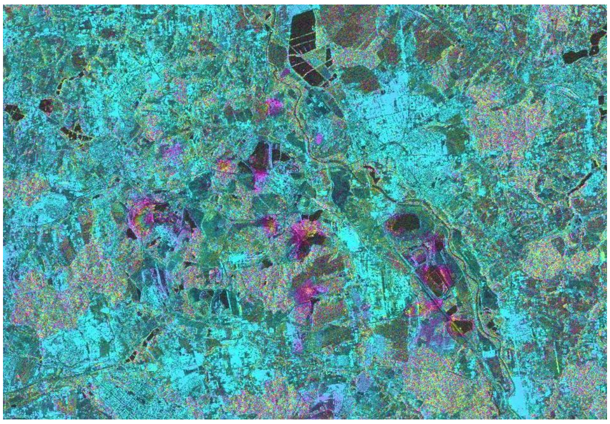
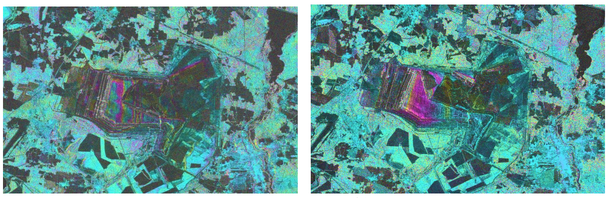


Figure 5. Extract of georeferenced PALSAR differential interferogram for same area as deformation map shown in Figure 4, 20070710_20070825, Δt=46days, $B_\perp$=235m. One color cycle corresponds to 11.7cm displacement along the line-of-sight direction.

For a relatively small section of this area the result of an ERS based Persistent Scatterer Interferometry (PSI) analysis (Figure 4) is compared to the PALSAR differential interferogram (Figure 5). While the C-band result indicates low deformation rates and histories at mm precision there remains a huge information gap in the most strongly moving area. The L-band result from PALSAR nicely complements this in that it provides information on the faster moving areas.

3.3. Cottbus, Germany open-pit lignite mining

In the area of Cottbus, Germany, there are several open-pit lignite mines in operation. The differential interferograms in Figure 6 show significant phase values in the area of the open pit mining. The pinkish phase to the right of the current position of the open pit indicates compaction of the material after transporting it from one side of the open pit to the other side. This signal is present in both images shown, moving to the West with the progress of the excavation. Caution is needed in the interpretation of the strong phase gradient observed near the image center of Figure 6a. This phase is most likely not indicating deformation but relates to topography. During the SRTM mission the open pit was likely at this location so that the terrain SRTM DEM used in the differential interferometric processing was outdated due to the shift of the open pit. The fact that this topographic phase is much stronger for the longer baseline pair in Figure 6a than for the short baseline pair in Figure 6b supports this hypothesis.



(a) 20060611_20060727, Δt=46days, $B_\perp$=-2145m

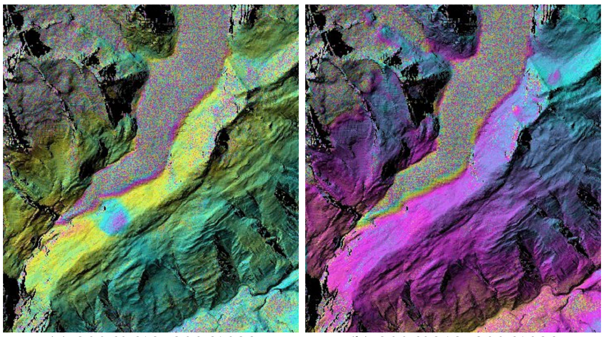
(b) 20070621_20070806, Δt=46days, $B_\perp$=255m

Figure 6. Georeferenced PALSAR differential interferograms over an open-pit lignite mine near Cottbus Germany.

3.4. Swiss alps

In Alpine areas we used PALSAR data for the identification and monitoring of landslides. Figures 7 shows two PALSAR differential interferograms in the area of the Grosse Aletsch glacier in Wallis (Switzerland) ALOS PALSAR. The line-of-sight direction is from east-southeast (descending orbit), the incidence angle is about 38 degrees, and the image width is 9 km. As background image a shaded relief of the DEM is used.

The retreat of the Grosse Aletsch glacier in Wallis (Switzerland) resulted in the formation of a rockslide. The displacement in the slant-range direction in about three years between 1993 and 1996 previously determined with JERS-1 DINSAR was about 12 cm (i.e. one phase cycle in three years). The newer ALOS PALSAR data in the summer of 2006 indicate now a significant increase of the displacement rate in the slant-range direction to about 8 cm in 138 days. Also visible in the ALOS PALSAR interferogram of 13th September to 29th October 2006 are signals related to the displacement of active rock glaciers. In the other interferogram phase decorrelation is observed at high altitudes because of the presence of snow in mid June 2006. The phase signals visible in the ALOS PALSAR interferograms at the border of the Aletsch glacier relate to the reduction of the glacier height since the DEM generation as a consequence of the rapid retreat of the glacier in the last years. The use of an aged DEM for topographic phase removal lead to these uncompensated effects.



(a) 20060613_20061029, Δt=138days, $B_\perp$=-862m

(b) 20060913_20061029, Δt=46days, $B_\perp$=368m

Figure 7. Georeferenced PALSAR differential interferograms over the Aletsch Glacier, Switzerland.

4. CONCLUSIONS

PALSAR L-band interferometry was applied over several mining and landslide sites. The applicability of the technique was found to be very good. Baselines and Doppler Centroids of the data selected always permitted to generate high quality differential interferograms. As compared to C-band interferometry the applicability is significantly improved in the case of vegetated areas and for high deformation gradients. For 46 day and 92 day intervals the interferometric phase was found to be interpretable even for forested areas. Fast mining deformation and landslide motion could be retrieved using PALSAR data. This information on faster movements complements the C-band interferometry based information which is limited to lower deformation rates with significant information gaps above underground coal mining. For slow deformation rates the accuracy achieved using C-band is high because of the use of multi-interferogram techniques (stacking or persistent scatterer interferometry). As the atmospheric errors are comparable at L-band we expect to achieve similar accuracies as at C-band if similar data stacks are becoming available. To build such stacks it is relevant the PALSAR FBS and FBD data can be interferometrically combined, which could also be confirmed with the examples shown.

The results shown will now be further analyzed and where possible also be validated.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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