RadarMon 2008: Subsidence monitoring over a collapsed mine in Berezniki, Russia

H.-P. Hebel, W. Busch, M. Schäfer, D. Walter

Institute for Geotechnical Engineering and Mine Surveying, Clausthal Technical University, Erzstraße 18, D-38678 Clausthal-Zellerfeld, Germany

Abstract

The project "RadarMon 2008" deals with the acquisition and observation of vertical displacements in Berezniki, a city in the region Perm in Russia. Below the city a potash mine has been closed because of a mine accident with an uncontrollable water inrush. Caused by the water inrush a sink hole already occurred on the outskirts. For utilization the results of Differential SAR Interferometry (DINSAR) and Interferometric Point Target Analysis (IPTA) are used. The area is also monitored with ENVISAT data. It is aimed to compare the datasets regarding their resolution, wavelength and iteration rate and to find out the advantages and possible handicaps of TerraSAR-X for the monitoring of vertical displacements.
In addition to the StripMap data, SpotLight mode data shall be analysed. On the one hand it is intended to gain experience with the new data with its higher resolution. On the other hand the possibility of increasing the accuracy, the quality and the reliability shall be investigated for both dInSAR and IPTA analyses in comparison to StripMap data.

1. Introduction

The project deals with the acquisition and observation of vertical displacements in Berezniki, a city in the region Perm in Russia. Under the city a potash mine has been closed in autumn 2006 because of a mine accident with an uncontrollable water inrush. This water inrush is still going on and causes dissolution of the potash, resulting in progressive vertical movements at the earth's surface in the area of interest. Also sink holes have been predicted.

In summer 2007 a first sink hole on the outskirts of Berezniki appeared (see also Figure 1). This sink hole threatened the very important railroad line between Perm and Cherdyn. For this reason the railway line was provisionally relocated until a spaciously alternative route will be completed. In October 2008 the sink hole reached an extent of 423 meters x 310 meters, a deep of about 100 meters and truncated the original railway. The actual distance from the provisional railroad line is merely about 100 meters.

Figure 1: Sink hole at june 3rd 2008 [Busch2008]

Additionally it has been predicted that at the end of the year 2008 the water will reach the area directly under the city. Therefore, to be on the save side, parts of the city have been evacuated and further evacuations will follow.
That's why the people are very interested in a technology for a continuously subsidence monitoring.

The objective of the project is the acquisition and analysis of area-wide vertical displacements with Differential SAR Interferometry (DInSAR) and point wise with Interferometric Point Target Analysis (IPTA) developed by GAMMA Remote Sensing AG, Switzerland. This is already successfully done using ENVISAT ASAR data in the same area. It shall be investigated, in which way the data from TerraSAR-X can help to improve, augment and to complement the results derived by ENVISAT data using DINSAR and IPTA. The results of both satellite systems will be compared. Furthermore the usability of a combination of StripMap or SpotLight mode data and ENVISAT data shall be investigated.
Based on the geographic location the amount of vegetation in the environs of the area of interest is very high and in the winter there is a considerable adverse effect through snowfall and snow. There are both urban and rural areas with fast as well as slow subsidence. The fast subsidence amount to

several centimeters per eleven days, the slow subsidence comes to few millimeters per month (see also Figure 2).

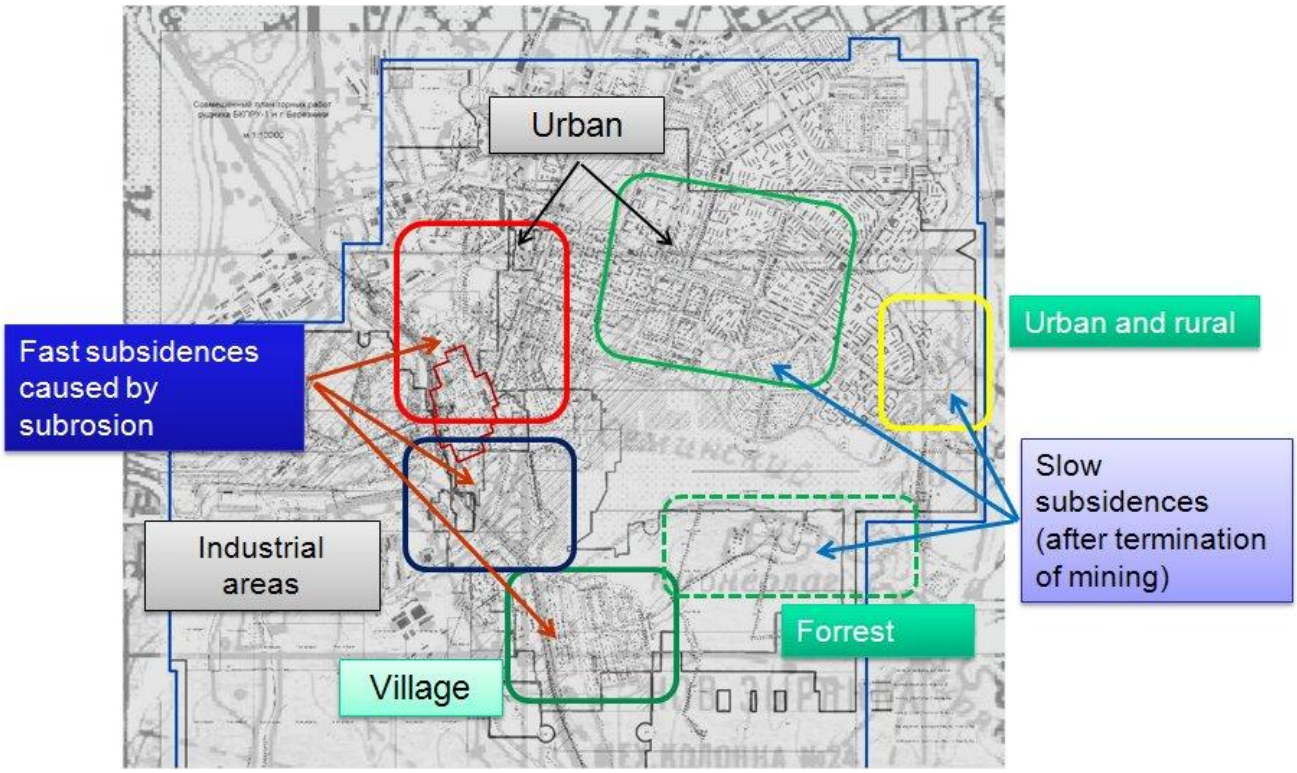

Figure 2: Areas with different subsidence and land use [Busch2008]

2. Data

Since May 2008 StripMap mode data has been programmed and ordered for Berezniki (strip_009R) with an incident angle between 34° and 37°. Except of the scene at September 30th caused by technical problems all scenes could be delivered successfully and were used for investigation.

Additionally all scenes in SpotLight mode has been ordered for the interval from May to October. Unfortunately the GAMMA software is not able to handle data in SpotLight mode. So it wasn't possible until now to use this data for analysis.

The Deutsche Zentrum für Luft- und Raumfahrt (DLR) provided both StripMap data and SpotLIght data as single-look complex (SLC) data. StripMap data have a pixel spacing of 1.59 meters in slant-range and 1.90 meters in azimuth, SpotLight data 1.59 meters in slant-range and 1.28 meters in azimuth.

Also a digital elevation model (DEM) is used calculated from SRTM X-band data with a ground spacing of 1 second.

3. Differential SAR interferogram analysis (DINSAR)

First all scenes are co-registered to the May 14th scene and an average intensity image (Figure 3) is calculated. At one point the DEM is also co-registered to the average intensity image.

Figure 3: Average intensity image of a part of Berezniki and the sink hole

Afterwards the differential interferograms are calculated and linear phase trends are subtracted (see Figure 4).

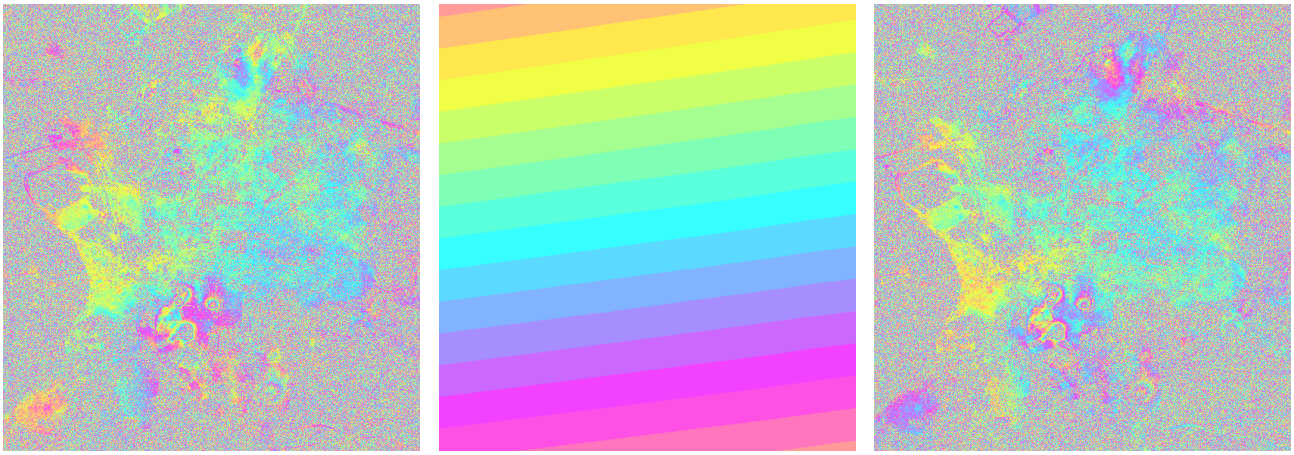

Figure 4: Left: Original interferogram, Middle: Linear phase trend, Right: Interferogram after remove of the linear trend

For simplification and advancement of the phase unwrapping the interferograms are filtered spectrally. Finally the vertical displacements are calculated out of the unwrapped interferograms.

Caused by the brisance in the area of interest an important focus is to extrapolate vertical displacements out of any new scene fast, contemporarily and within a few days. To make this possibly the workflow had to become automated to a great part. Through this automation some compromises must be found. The interferograms have to be “well”. The coherence between the used scenes of the interferogram has thereby a wide influence. A short time interval of the interferogram is at that absolutely necessary. Therefore, and caused by the very fast small-scaled subsidence, a time interval of 11 days is chosen for building interferograms if it was possibly.

Another effect to corrupt the quality of interferograms is a large perpendicular baseline. Unfortunately the perpendicular baselines between two sequential scenes increased since the middle of the year as seen in Figure 5.

To determine vertical displacements for longer time intervals than 11 days, the results of the interferogram analysis are added up. This is possible caused by the fact that for the investigation interferingly effects like atmosphere eliminate itself. Only the effects of the first and last used scenes persist present.

Based on the added up vertical displacements both isokatabases (see exemplarily Figure 7) and vertical displacement profiles (compare Figure 6) are generated.

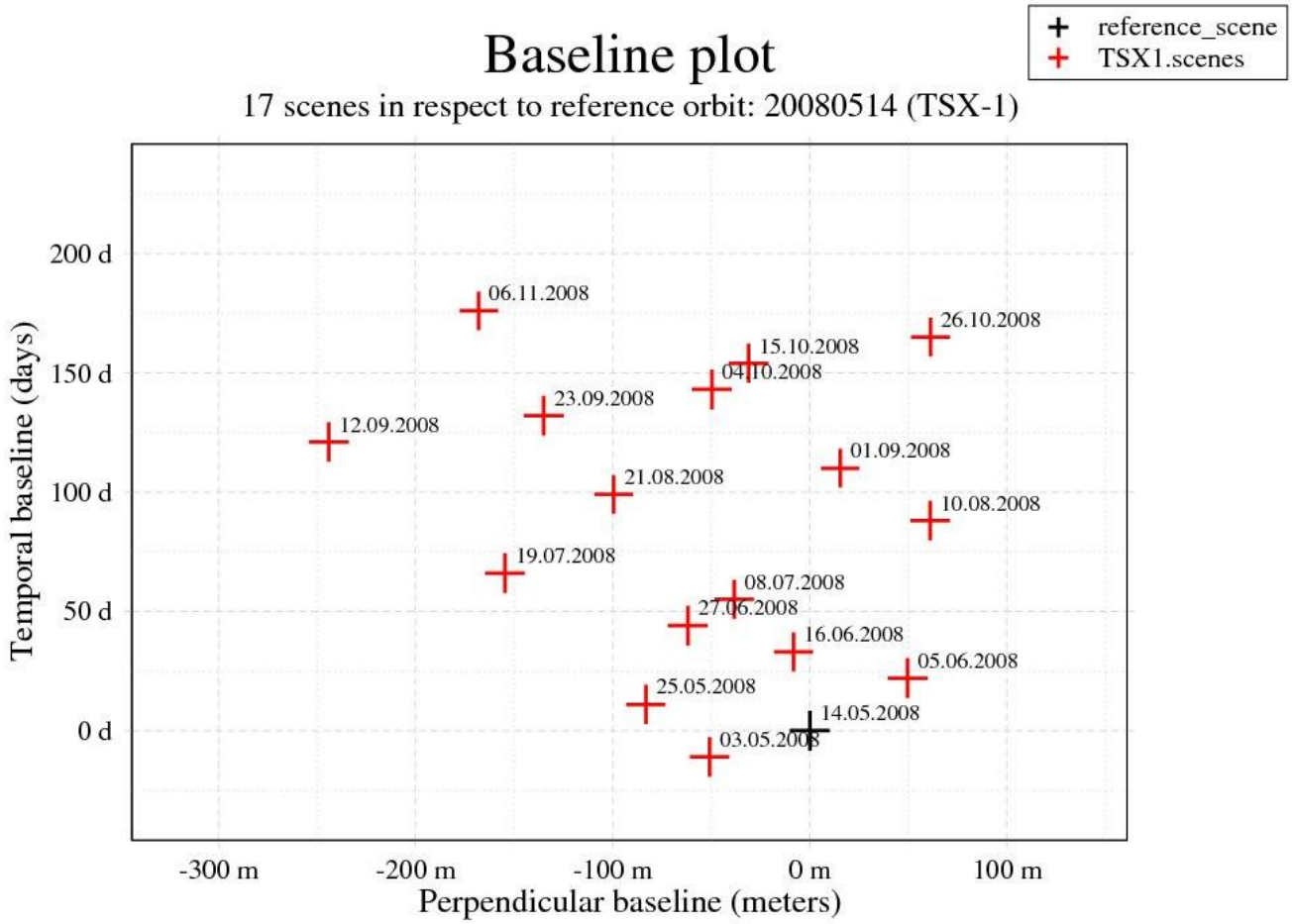

Figure 5: Baseline plot of all delivered scenes

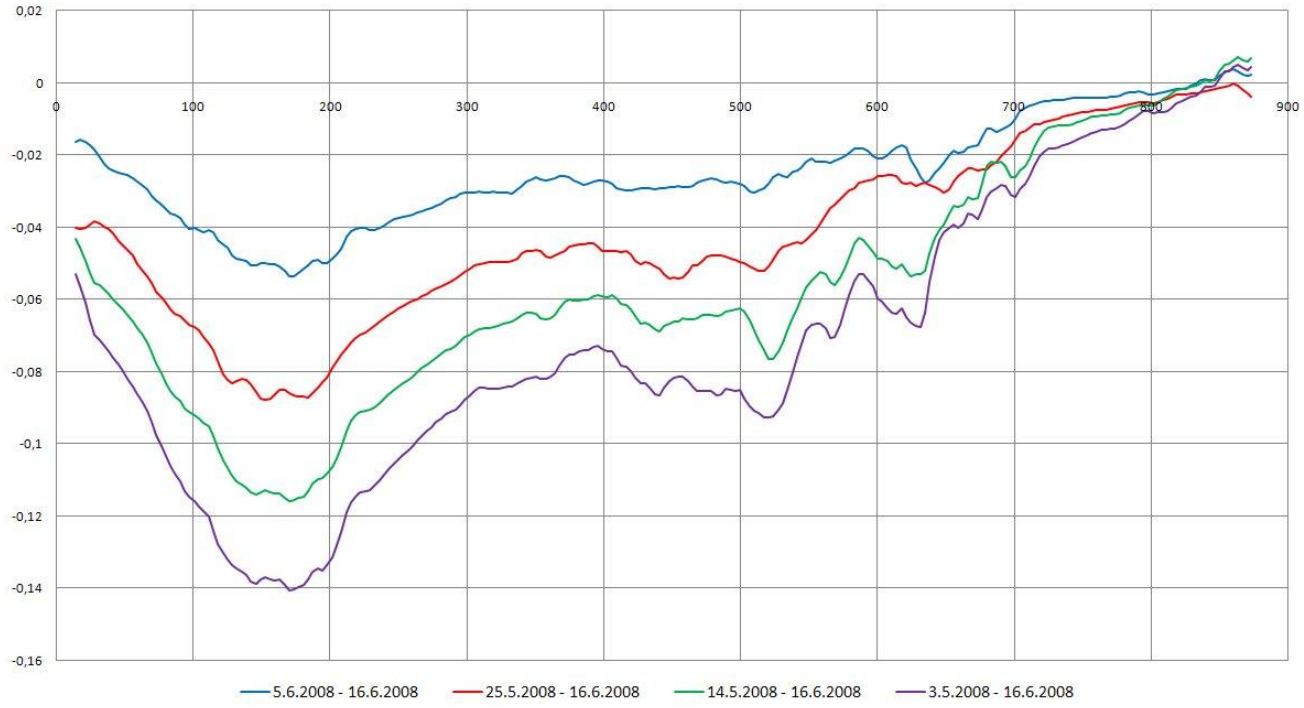

Figure 6: Subsidence of different time intervals along a profile line
x-axes: Subsidence in meters, y-axes: distance in meters along the profile line

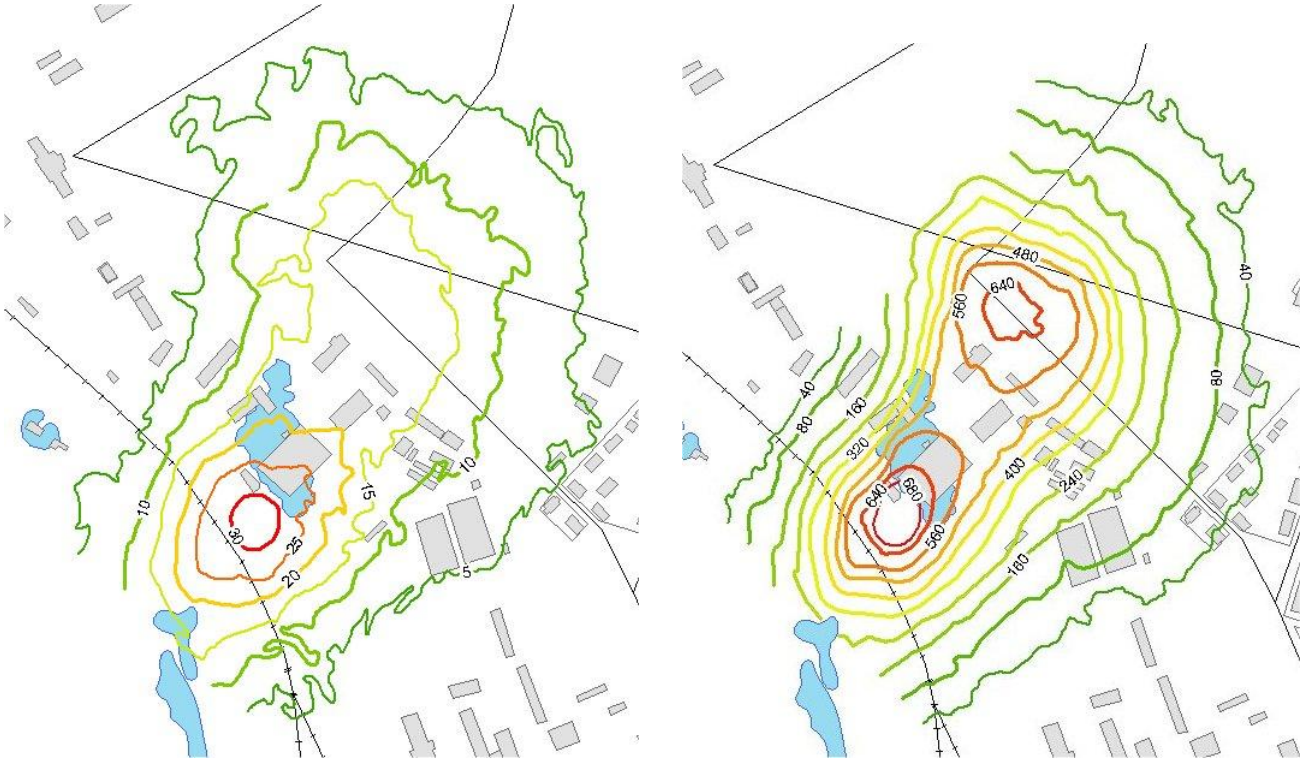

Figure 7: Isokatabases, information in millimeter,
Left: Time interval: May 14th – May 25th, right: Time interval: May 14th – October 26th

This method leads to very good results for urban and rural areas with fast subsidence (compare Figure 2). But for areas with slow subsidence it wasn't feasibly to get plausible results until now. In a next step it shall be tested whether a larger time series or a longer time interval will conduct to to results for the areas with slow subsidence. Expectedly areas with a high vegetation amount feature only noise in the interferograms by which an analysis could not be performed.

4. Persistent scatterer interferometry (PSI)

The PSI analysis is a method to interpret differences between radar scenes through time without the need of a spatial phase unwrapping. Thus it is possible to get subsidence information about areas with commonly low coherence by DINSAR analysis. This analysis is done using the Interferometric Point Target Analysis of GAMMA Remote Sensing AG, Switzerland.

This method uses a combination of linear regression analyses and filtering to calculate the displacements. As a result actually deformations with a high non-linear part can't be analysed. But this problem shall be eliminated by a new ansatz. GAMMA works in the moment at a method which uses a "multi-reference stack that includes pairs with shorter time intervals" [Wegmüller2008].

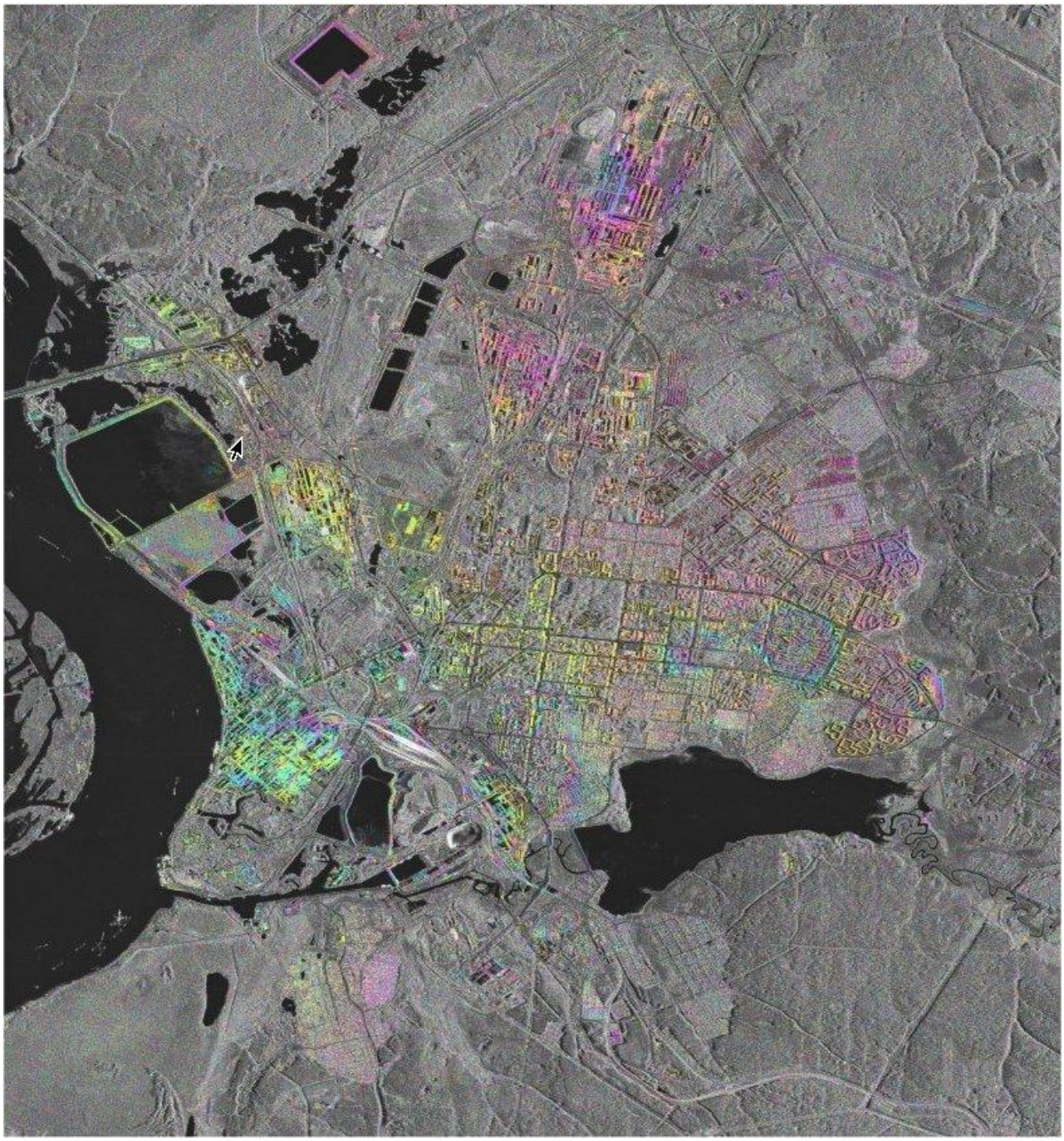

Figure 8: Point interferogram for the interval may 14th to October 4th

Figure 8 shows exemplarily the point interferogram for the time interval may 14th to October 4th. Based on the point interferograms the analysis is done. After the elimination of the atmospheric phase-parts and separating non-linear deformation from noise finally the deformation rate and displacement of every single point can be calculated. Actually no final results are given. The analysis is still going on.

5. Conclusions and Outlook

The up to now accumulated experiences have shown that a quick current analysis of the TerraSAR-X data is possible for areas with high displacement rates by DINSAR method. For areas with small vertical displacement rates continuing investigations must be still undertaken also for clearly larger periods. Another problem still to be examined is the influence of the clearly different ground resolutions of height model and TerraSAR-X data. On this occasion, high expectations are put in the TanDEM-X mission in 2009 to be able to derive then high-resolution surface models.

The PSI evaluation has appeared as an extremely time-consuming and topically not yet absolutely satisfactory method. However, on this occasion, even other investigations must occur, because, on the one hand, the data stack with just once 17 scenes is very small. On the other hand just a new analysis method was developed by GAMMA Remote Sensing AG, Switzerland, which permits a definitely better detection of non-linear movements.

An also very being tight subject will be the influence of snow for the analysis with DINSAR and PSI method for scenes taken during the winter months. The actual scene from November 6th is the first delivered scene with which a snowy covering of few centimetres exists. This could be analysed mainly successfully with the DINSAR method. Nevertheless not all areas of the city could be evaluated as usual. Whether the problems appeared by the investigation are to be led back to the influence of snow, the big perpendicular baseline of over 250 meters or a combination of both is still examined topically.

6. References

[Busch2008] W. Busch, "Radarinterferometrische Erfassung von Bodenbewegungen im Gebiet Berezniki (Perm, Russland)", In: Meier, G.; Sroka, A.; u.a. (Hrsg.): 8. Altbergbaukolloquium, 6.-8. November 2008, TU Clausthal, VGE Verlag GmbH, Essen, pp. 14 – 25

[Wegmüller2008] U. Wegmüller, D. Walter, V. Spreckels, C. Werner, "Evaluation of TerraSAR-X DINSAR and IPTA for ground-motion monitoring", in 3rd TerraSAR-X Science Team Meeting, DLR Oberpfaffenhofen, Germany, Nov 25-26 2008

7. Acknowledgment

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