Subsidence Monitoring in Northern Bohemia by Method of Permanent Scatterers

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Abstract. North-Bohemian coal basin is a largely unstable area with very old mining sites, which are potentially dangerous for people living there. Mining has been performed for several centuries; deep mines were active in the past (the surface above is not expected to subside any more), and currently open-pit mines are used for exploitation. Most of them are later reclaimed to forests, lakes, agriculture fields etc. Landslides and subsidence occur in these areas and they need to be monitored. In addition to classical levelling methods new methods are being used for detection of possibly dangerous areas. One of them is radar interferometry. It allows for Earth-crust deformation mapping with the use of satellite images, without the necessity of expensive on-site measurements. Its accuracy may even reach several mm/yr in the theoretical case. This method is usable in areas with low amount of vegetation and for objects, which are not expected to change their spectral characteristics during monitoring. This applies to artificial objects (buildings, roads, railways), which are of most interest to public (centres of villages, cultural monuments, communications and industrial areas). A significant limitation of standard InSAR processing is the impact of atmosphere, which shows strong spatial correlation and is uncorrelated in time, whereas target motion is usually correlated in time. Therefore the method of Permanent Scatterers is used in order to deal with this atmospheric effect. To improve the method, corner reflectors are installed in the neighbourhood of the area of interest. That usually is in village centres, next to cultural monuments and water reservoirs and some in industrial areas.

Keywords: InSAR, Permanent Scatterers, Mining, North Bohemia, Subsidence

1 Introduction

Radar interferometry is a method providing a possibility to map ground deformations in an area imaged by a satellite carrying synthetic aperture radar (SAR), without the necessity of expensive on-site measurements. The accuracy of this method may even reach several mm/yr in the theoretical case. However, this method is only usable in areas low amount of vegetation and for object, which are not expected to change their spectral characteristics during monitoring. Generally considered, it can be said that InSAR is suitable for artificial objects, such as building, roads, railways, etc. In addition, it is more important to measure the deformations for these artificial objects, than for forests or agricultural fields.

We use ERS-1/2 scenes of the North-Bohemian area to assess the deformations of high coherent point targets in time in the area of the North-Bohemian coal basin that is a largely unstable area. In addition to many huge open mines, it contains also deep mines; some of them are very old and abandoned and may possess a potential danger for people living in those areas.

2 InSAR Overview

Synthetic aperture radar (SAR) interferometry (InSAR) processes a pair of satellite SAR images, acquired by a satellite carrying SAR that is ERS-1/2, ENVISAT, RADARSAT, JERS-1/2 and others. These scenes are complex-conjugate-multiplied, giving the multiple of their magnitudes and the difference of their phases, which is related to the difference of the distances between the satellite and the reflector in the two scenes. The phase map is called an interferogram. However, before actual postprocessing, the phase given by the flat-Earth and phase given by the DEM must be subtracted from the interferogram, and then the interferogram is considered to contain only the atmospheric signal, deformation signal and noise.

The result of SAR interferometry may be a digital elevation model (DEM) or a map of Earth-crust deformations in the processed area.

The most significant limitation of InSAR is the ambiguity of the phase - the measured phase is always within the ($-\pi$, $+\pi$) interval; however, the multiple of 2π to be added to the measured phase is never known. The step where the phase is converted from the ambiguous interval to the unambiguous real number is called phase unwrapping. Classically, this is performed in 2D array of the interferogram and the criterion is set for the unwrapped interferogram to have as little phase jumps (more than 2π difference between the neighbouring pixels) as possible. However, this criterion is set artificially and the result may be unreliable, especially in low-coherent areas (where the phase value is also considered unreliable).

3 Permanent Scatterer Technique

The atmospheric artefact has strong spatial correlation and is uncorrelated in time. On the other hand, target motion is usually correlated in time and different degrees of spatial correlation depend on the particular displacement rate. The Permanent Scatterer (PS) technique deals with atmospheric effect, which is estimated and removed combining data from long time series.

In processing only scatterers slightly affected by temporal and geometrical decorrelation are selected in order to exploit all available images and approve accuracy. PS (phase stable point wise targets) are detected on basis of a statistical analysis on the amplitude.

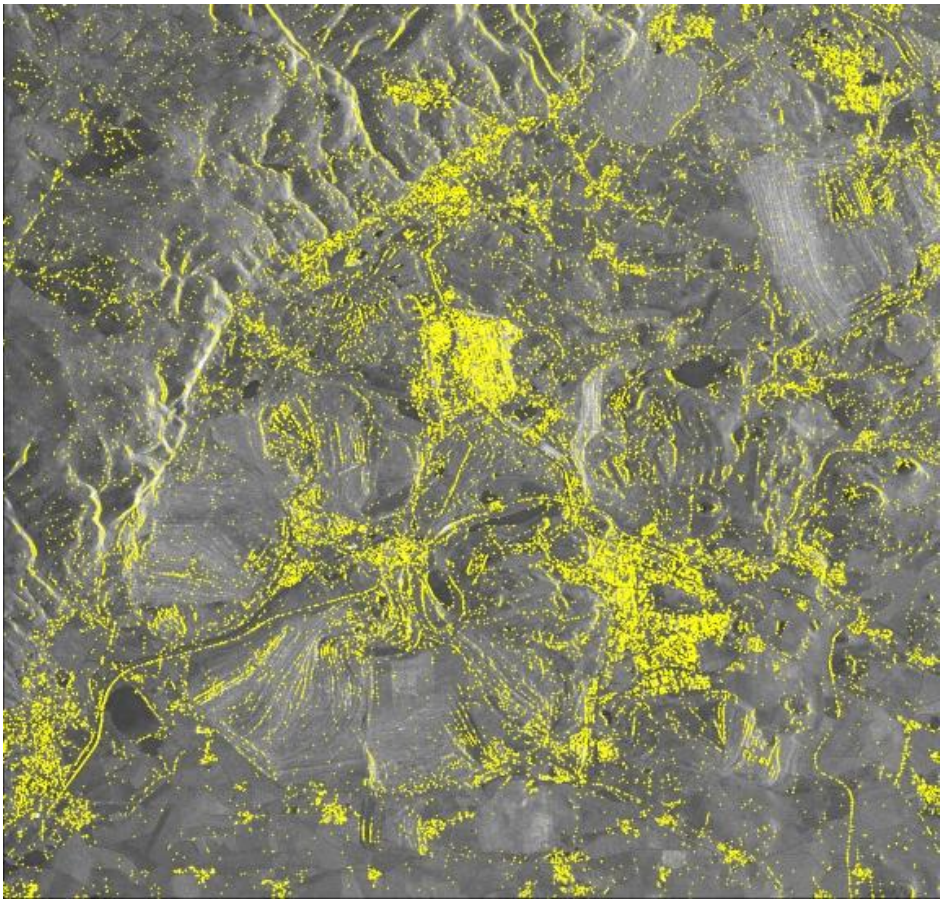

Fig. 1. PS candidates (for Da > 0,7)

First of all, all available images are coregistered to one master image and radiometric correction is performed. The amplitude data are analyzed on a pixel-by-pixel basis, which means that a so-called “amplitude stability index” is computed (according to [1]):

$$D_a = \frac{\sigma_a}{\bar{a}}, \tag{1}$$

where *σa* stands for temporal standard deviation of the amplitude and *a* is temporal mean of the amplitude for a certain pixel. This index provides information about the expected phase stability of each cell and afterwards the identification of “PS Candidates“ is performed by tresholding. The sufficient density of PS is approximately 3-4 PS/km^2 (see [4]).

The phase of each single pixel of interferogram *i* consists of several contributions [1]:

$$\phi_i = \frac{4\pi}{\lambda} r_{Ti} + \alpha_i + n_i + \phi_{topo-res}, \tag{2}$$

where λ is wavelength, α_i stands for atmospheric phase contribution, n_i for decorrelation noise and $\Phi_{topo-res}$ is residual topographic phase contribution (caused by inaccuracies in the reference DEM). The task is to separate all these factors.

The atmospheric contribution is determined from time series of samples and is interpolated all over the image from the value on PSs, which are assumed not to change their characteristics. Then the atmospheric effect is subtracted from the whole interferogram.

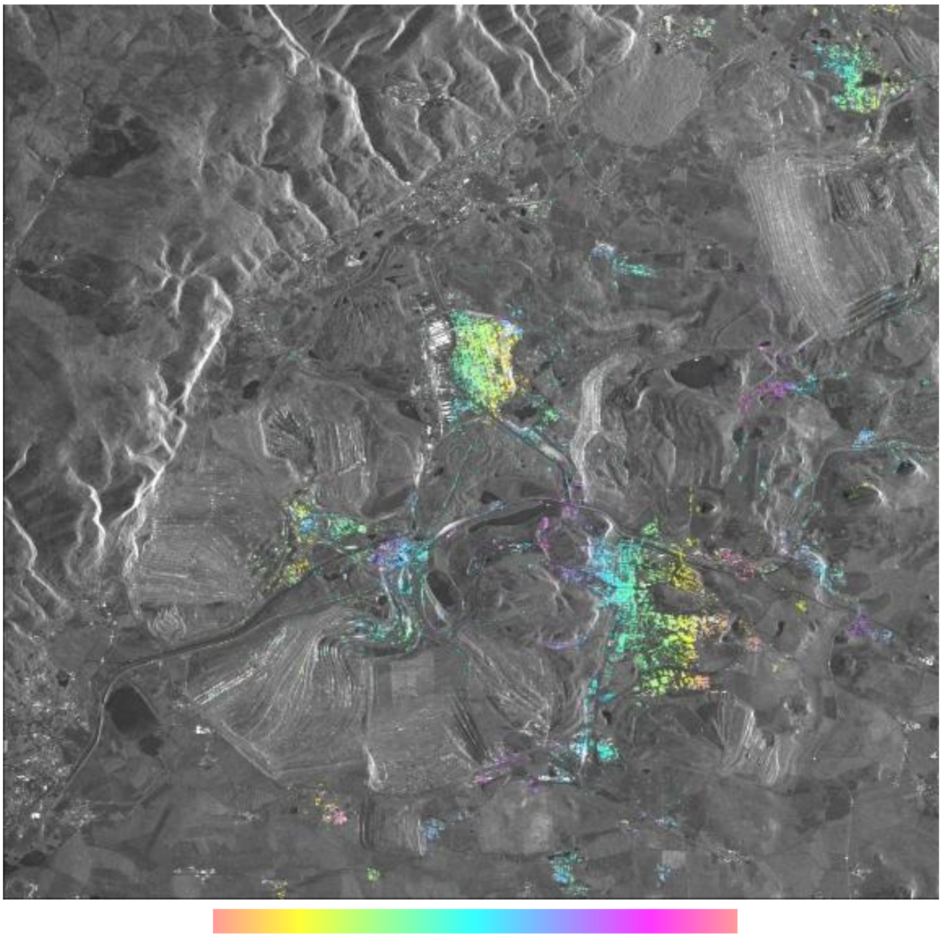

Fig. 2. Atmospheric phase (time baseline of 106 days) – value cycle of 2π

4 Data Sets

We focus on the North-Bohemian brown coal basin where mining has been performed for several centuries, using different mining methods. In past, lots of deep mines were opened - however, these areas are expected not to subside any more. Currently, most coal is being mined using open-pit mines, which are then mostly reclaimed to forests, lakes, agricultural fields etc.

For processing data acquired by ERS-1 and ERS-2 satellites during 1992-2002 are used. In this analysis 31 data sets from this period were used (track 122, frame 2583).

5 Processing

Gamma software is used for interferometric processing. A special module IPTA (Interferometric Point Target Analysis) handles the specific analyses concerning permanent scatterers.

Series of 31 differential interferograms were created using one common master image. These were used in phase regression analysis to select the best reference point with low height correction. A reference point in the centre of area was selected (this area is known not to subside). Subsequently, unwrapping was performed, resulting in set of residual phases, which could be searched for unwrapping errors. The erroneous images were temporarily excluded from processing and regression analysis was performed for the second time without them. Here, the residuals represented atmospheric phase, which was spatially filtered and subtracted. In Figure 2 an image of atmospheric phase is depicted for time baseline of 106 days.

Linear deformation was determined for all of the interferograms after subtracting atmospheric phase (see Figure 3). The deformation can be evaluated only within smaller regions since the areas are far from each other. There are also many points, which were excluded from further processing due to their high noise value. Only urban areas were processed through all quality checks.

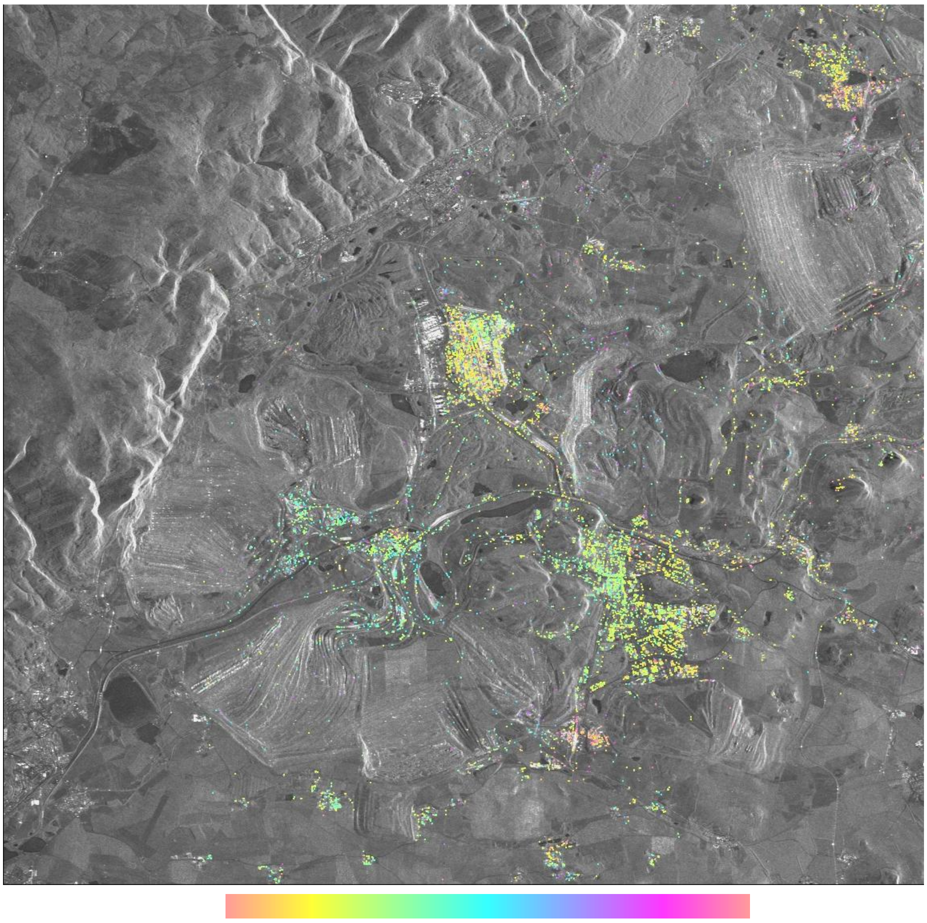

Fig. 3. Linear deformation (temporal baseline 106 days) – one colour cycle stands for 0,02 m (-0,01;0,01)

6 Corner Reflectors

For better results and to achieve information, which can be compared with classic geodetic methods (such as levelling), corner reflectors are installed in the neighbourhood of the interest area in cooperation with Czech Coal Services (mining company active in Northern-Bohemia).

The corner reflectors are mounted on concrete foundations and are adjustable according to the flight specifications of the satellites (in vertical and horizontal directions). There are also levelling points set up in their closest neighbourhood (it the concrete foundations).

Fig. 4. Corner reflector

Eleven corner reflectors were mounted in November 2008 in the area of North-Bohemian Brown Coal Basin. Since then 8 images taken by ERS-2 were used for first testing processing. The parameters of acquired images are in Table 1.

Tab. 1. Parameters of acquired images (track 394, frame 2583)

Orbit	Date	Doppler fr. [Hz]	Perp. baseline [m]
71390	2008 12 15	356.296	-1381
71891	2009 01 19	-239.412	-946
72392	2009 02 23	230.173	-1504
72893	2009 03 30	-620.303	-655
73394	2009 05 04	67.493	158
73895	2009 06 08	178.126	483
74396	2009 07 13	747.704	-2
75398	2009 09 21	71.543	448

The first processing shows that the area is usually very low-coherent, on average 0,20 (see Table 2 and Figure 5). The large extent of perpendicular baseline values (almost 2 km) is also a slight disadvantage for processing (causing geometric decorrelation). Eight processed pictures are very small amount to create enough differential interferograms, which enter the processing to estimate the atmospheric signal reliably.

The uncertainty in processing is also caused by the absence of precise orbits of the ERS-2 satellite (they were not yet available).

Tab. 2.

Image 1	Image 2	Coherence	Image 1	Image 2	Coherence	Image 1	Image 2	Coherence
70889	71390	0.22	71390	73895	0.24	72392	74396	0.16
70889	71891	0.19	71390	74396	0.18	72392	75398	0.25
70889	72392	0.23	71390	75398	0.23	72893	73394	0.14
70889	72893	0.15	71891	72392	0.22	72893	73895	0.12
70889	73394	0.20	71891	72893	0.14	72893	74396	0.24

Image 1	Image 2	Coherence	Image 1	Image 2	Coherence	Image 1	Image 2	Coherence
70889	73895	0.23	71891	73394	0.22	72893	75398	0.13
70889	74396	0.18	71891	73895	0.21	73394	73895	0.26
70889	75398	0.23	71891	74396	0.13	73394	74396	0.12
71390	71891	0.18	71891	75398	0.21	73394	75398	0.23
71390	72392	0.29	72392	72893	0.14	73895	74396	0.15
71390	72893	0.16	72392	73394	0.24	73895	75398	0.23
71390	73394	0.21	72392	73895	0.25	74396	75398	0.14

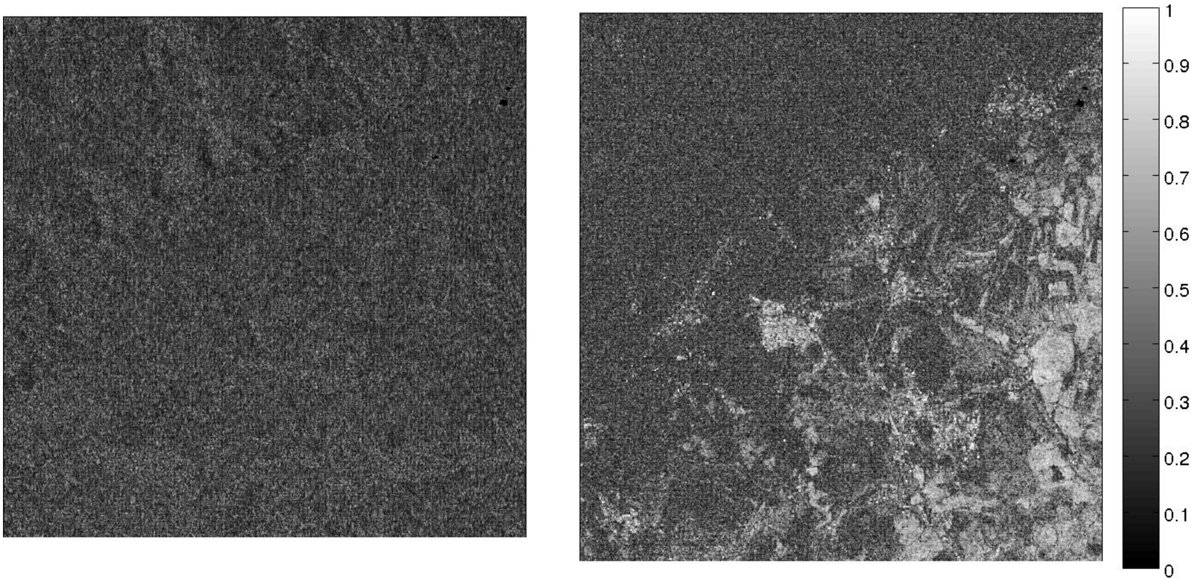

Fig. 5. Average coherence of entire images for pairs: 71891-75398 (Jan 2009 – Sep 2009) – 0.18 and 71390-72392 (Dec 2008 – Feb 2009) – 0.29 (maximal coherence)

7 Conclusions and future prospects

In this area the results are hard to interpret because the density of points is quite low. However, using this method allows for atmosphere estimation, which was not possible earlier. There are many ways to process the data, which should be used in the future (estimating non-linear deformation, processing interferograms without a special master image).

The processing is time requiring (tens of steps must be performed with parameters selected very carefully). When the process is set up successfully, bash processing will be performed.

For proper atmosphere and topographic residual estimation more images is required. Also a new DEM (created by Aster mission) will be used – it is expected to give better results than SRTM DEM used previously.

Images from other tracks will be processed as well.

It must be stressed that it is the first time this method is used in the Czech Republic and it is very good that even commercial bodies are interested in its results and possibilities and are willing to support the development of PS method.

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Reference

[1] Ferretti, A. et al., Monitoring of landslides and tectonic motions with the Permanent Scatterers Technique. Engineering Geology 68 (2002), 3-14.

[2] Hanssen, R. F. Radar Interferometry: Data Interpretation and Error Analysis. Kluwer Academic Publishers, Dordrecht, 2001.

[3] Hlaváčová, I., Knechtlová, B. Deformation monitoring by means of SAR Interferometry in the North-Bohemian area. ISPRS Congress Beijing 2008, Proceedings of Commission VII. Beijing, 2008.

[4] Kampes, B. M. Radar Interferometry: Persistent Scatterer Technique. Springer, Dordrecht, 2006.