Monitoring of deformations in North-Bohemian coal basin by Permanent Scatterer technique

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Abstrakt. Severočeská hnědouhelná pánev je velmi nestabilní oblast, kde se nachází mnoho starých těžebních oblastí, které mohou být nebezpečné pro lidi žijící v jejich okolí. Těžba probíhá už několik staletí; v oblasti se nacházejí již nepoužívané hlubinné doly (povrch nad nimi je považován za stabilní) a v současnosti aktivní povrchové doly. Většina z nich je po ukončení těžby rekultivována na lesy, vodní plochy, zemědělskou plochu atd. Dochází zde k sesuvům a poklesům půdy a tyto jevy je třeba sledovat. Kromě klasických metod se k sledování nebezpečných oblastí využívají i technologie nové. Jednou z nich je radarová interferometrie. Umožňuje mapování deformací zemského povrchu použitím satelitních snímků bez nutnosti drahého a časově náročného místního měření. Přesnost této metody může dosahovat až řádově milimetry za rok. Užití této technologie je vhodné zejména pro oblasti s menším výskytem vegetace a pro umělé objekty (budovy, silnice, železnice), u kterých se předpokládají neměnné odrazivé vlastností v čase. Zároveň jsou tyto objekty v centru zájmu veřejnosti, protože se to týká zejména budov v obcích, kulturních památek, komunikací a průmyslových areálů. Největším omezením klasického interferometrického zpracování radarových snímků je vliv atmosféry, který vykazuje silnou prostorovou korelaci, ale naopak je nekorelovaná v čase, zatímco pohyb odražečů je většinou korelovaný v čase. Proto je použita metoda trvalých odražečů, aby se odstranil negativní vliv atmosféry na měření. Aby byly výsledky kvalitnější, jsou v oblasti pánve instalovány koutové odražeče, které slouží jako umělé trvalé odražeče pro místa nejvyššího zájmu. Těmi jsou zejména centra obcí, kulturní památky, vodní díla a některé průmyslové areály.

Klíčová slova: InSAR, trvalé odražeče, těžba, severní Čechy, poklesy

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 no 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 (PS) 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 with no vegetation and for object, which are not expected to change 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 approximately 100 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. This area 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, which 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).

2.1 Stack processing

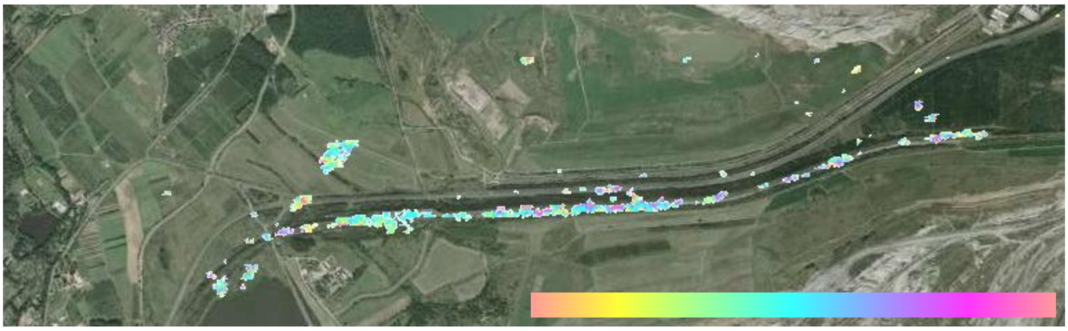
The method used is stack processing. It involves processing of several interferograms with a common master, with respect to which the deformations are related. In order to achieve a larger number of interferograms, the slave scenes are resampled in order to correspond exactly (i.e. with subpixel accuracy) to the master. Then, any of these resampled scenes can be used as a master for creating other interferograms, although the baseline parameters etc. do not change by resampling.

2.2 Previous method

Until now a simpler method was used for processing. As many interferograms as possible were generated from the available data. Then, after the topography was subtracted and the interferograms were spatially filtered and unwrapped, the most coherent points were selected from the interferograms and then the most coherent interferograms were selected, which enter further processing (about 100). In some interferograms there were not pixels coherent enough, so that the whole scene was excluded from postprocessing. The processing itself is time and memory requiring and thus only areas of special interest were processed.

The unwrapping errors are then estimated iteratively from the neighbouring points (the unwrapping errors are assumed to change slowly in the space). Then, adjustment is performed, modeling that each interferogram is a difference of two scenes. The aim of the adjustment was to estimate the phases of the scene, which could be directly computed into deformations. However, due to a number of measurements excluded during the check process, it happened that a scene was totally excluded, making it impossible to compute the deformation for the particular scene for the point.

The results of this method were the deformation maps for the analyzed areas at different acquisition times (see picture 1). It is displaying deformation of all processed points. The results were highly dependant on coherence of the interest area and it gave only disconnected areas and points with determined subsidence value. The biggest limitation was that the temporal deformation development was largely influenced by atmospheric delay and it was impossible to interpret the results in a straight way.



Pic. 1. Results of previous methods (color scale from –150 mm to 150 mm)

This was the impulse to use a method, which would deal with atmospheric effect, and thus the Permanent Scatteres technique.

3 Permanent Scatterer technique

The atmospheric artifact 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. In the Permanent Scatterer (PS) technique deals with atmospheric effect, which is estimated and removed combining data from long time series.

In processing only scatteres 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.
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 [3]):

$$D_a = \frac{\sigma_a}{\bar{a}}, \qquad (1)$$

where σ_a 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 [1]).

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

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

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.

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 1996-2000 are used.

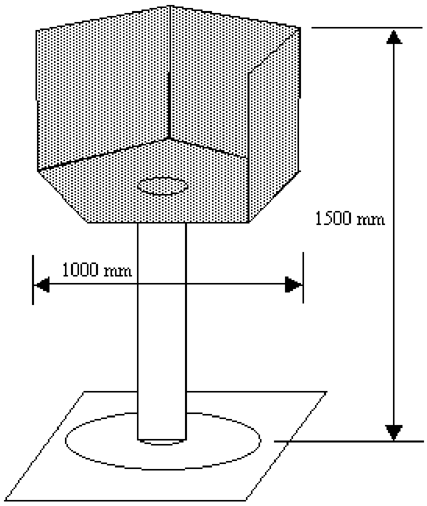
5 Corner reflectors

For better results and to achieve information, which can be compared with classic geodetic methods (such as leveling), corner reflectors are installed in the neighbourhood of the interest area in cooperation with MUS (mining company active in Northern-Bohemia). Figure 1 shows their placement according to type of surface it is mounted on.

Fig. 1. Corner reflectors installed

Type	Amount	Placement
Village center	2	Vysoká Pec, Horní Jiřetín
Cultural monuments	1	Castle Jezeří
Water reservoir	1	Jezeří
Industrial area	7	

The corner reflectors mounted on concrete foundations and are adjustable according to the flight specifications of the satellites (in vertical and horizontal directions). There are also leveling points set up in their closest neighbourhood (it the concrete foundations). A sketch of a corner reflector is depicted in picture 2.



Pic. 2. Corner reflector

6 Conclusions

There are no numeric results yet, but it seems to be a promising method to give better results, which would be easier to interpret. A great advantage is the fact that the atmospheric factor is determined during the processing. It is also the first time in the Czech Republic that the method is used. Another fact to be emphasized is the cooperation with the mining company as well as the municipalities and other subjects, who are interested in the results.

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Reference

1. Ferretti, A. et al. Monitoring of landslides and tectonic motions with the Permanent Scatterers Technique. *Engineering Geology, Volume 68, Issues 1-2, Pages 3-14*. ISSN 0013-7952

2. Hanssen, R. F. *Radar Interferometry: Data Interpretation and Error Analysis*. Kluwer Academic Publishers, Dordrecht, 2001. ISBN 978-0792369455.

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. ISSN 1682-1750.

4. Kampes, B. M. *Radar Interferometry: Persistent Scatterer Technique*. Springer, Dordrecht, 2006. ISBN 978-1-4020-4576-9.