

OPTIMIZATION OF SATELLITE INSAR TECHNIQUES FOR MONITORING OF SUBSIDENCE IN THE SURROUNDINGS OF KARVINÁ MINE: LAZY PLANT

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ABSTRACT

This paper deals with issues related to convenient monitoring of subsidence due to longtime mining activities of Czech Karviná Mine: Lazy plant, using satellite SAR interferometry (InSAR) techniques. It maintains approaches for optimizations of differential InSAR, especially including available filtering possibilities. It was realized that current SAR satellites were not able to appropriately evaluate deep subsidence as it occurs in Czech mining sites. Other issues are related to the presence of dense vegetation. Data from previous and only available L-band SAR satellite ALOS demonstrates its high potential in this area of interest. However, only a few acquisitions are available of the mining site disallowing usage for purposes of continuous monitoring of subsidence in the area. Processing results of InSAR techniques of the Lazy plant are presented in this paper.

KEYWORDS: SAR Interferometry, mining subsidence, ERS-2, ALOS, non-local mean filtering

INTRODUCTION

Spaceborne Synthetic Aperture Radar (SAR) Interferometry is a technique that currently allows to measure even sub-centimeter terrain changes on nearly any part of the world. Range of radar wavelengths used in spaceborne SAR instruments is approximately between 3 – 30 cm (disregarding missions that are not concerned in a solid terrain monitoring). Because only a difference within reflected fractions of wavelength is computed using interferometry, the technique can reach sensitivity for a terrain change even in a millimetre scale in optimal conditions.

Unfortunately due to such fine sensitivity, the radar phase information is often strongly affected by noise from atmospheric delay or by phase contribution of every scatterer in the radar image resolution cell (e.g. from vegetation). Also monitoring of deep deformations highly exceeding the scale of radar wavelength is problematic. This is the case of subsidence due to longtime mining activity of Lazy plant of Karviná Mine.

AREA OF INTEREST

Karviná Mine: Lazy plant in the Czech part of the Upper-Silesian Coal Basin is one of the largest and deepest mining complexes in the Czech Republic, purposed for extraction of black coal. Mine working is performed by a method of longwall mining with controlled caving (Jiránková, 2010). The mine plant is operating in the depths of approximately 600-800 m under the land surface in the area between Orlová and

Karviná cities. Three layers of black coal seams have a thickness of average 4-5.8 m there. Their projection to the land surface partially overlap – in some areas the exploited material can easily exceed height of 15 m which in current geology (composed mostly of sandstone, claystone and conglomerate rock environment) makes a significant subsidence expectable.

Publication by Jiránková (2010) describes a progress in exploitation of these seams numbered no. 38 (exploited since 1997 till 2003), no. 39 (2003-2005), no. 40 (since 2006) – and their effect on forming of subsidence troughs. One of the most critical sites affected by Lazy plant mining was the area surrounding Lazecká Road. Since October 1998 the road has been continuously measured by levelling (Jiránková and Mučková, 2009) in six-month intervals. In 10 years period of 1999-2009, the levelling detected a subsidence of up to 7.5 meters in the middle of Lazecká Road.

Work of (Mulková, 2007) monitors landscape changes in much wider surroundings affected by activities of the Lazy plant from aerial photography already since 1940s. It was found from aerial images between 1971-1995 that during intensified mining in this period the landscape changed significantly from an inhabited area to a shrubbery, forest, agricultural areas. According to information of this work, 92 houses forming inhabited colonies in Orlová were demolished due to damages caused by subsidence.

In the same thesis a comparison between digital models of ZABAGED (2003) and a DEM made from

contour lines from a national map SM 1:5000 (1951) took place to find height changes in surroundings of Lazy plant between 1951-2003 in a range of 16-30 m of subsidence. Through the years of 1995-2003 the most of the area was recultivated, subsidence effects were insignificant at these places, as observed using aerial images.

METHODOLOGY

Satellite synthetic aperture radar (SAR) has proved its effectivity in remote sensing. The first available continuously monitoring satellite radar onboard of ERS-1 was used since 1991 in plenty of projects involving monitoring of terrain relief changes, for example for monitoring of mining-caused subsidence, using primarily radar phase information for some interferometry processing technique.

Let's recognize two-pass differential interferometry (DInSAR) as a technique combining phase information from two radar acquisitions taken from spatially close position but from different time/satellite pass, that after subtraction of phase induced from land topography (simulating using an external DEM, for example SRTM model) has the ability to show terrain deformations within the period between acquisitions, in the magnitude of half of radar wavelength – that is, in the sensitivity for terrain deformations within 2.8 cm for ERS-1.

Let's recognize also other SAR Interferometry techniques that use a larger set of radar acquisitions, i.e. a family of multitemporal SAR interferometry (MT-InSAR) techniques, for example Persistent Scatterers (PS) technique or Small Baselines (SB) techniques. Usage of larger dataset in special processing approaches has the unique ability to evaluate subsiding/uplifting objects or generally radar scatterers in the precision often better than 1 millimetre, and to model and filter out unwanted phase contributions from for example an atmosphere.

Both PS and SB techniques were implemented in StaMPS processing software (Hooper, 2008) and used in the scope of this project for processing datasets of ERS-1, ERS-2 and Envisat over the Lazy plant surrounding, together with DInSAR only processing of ALOS Palsar data using an open-source Doris software (Kampes et al., 2003). Presented results are based on results from (Lazecký, 2011) dissertation thesis.

Results were compared to levelling data performed since 1998 within 40 levelling points selected in a line with a distance of 50 meters of Lazecká Road. Levelling parameters are set to achieve a measurement precision of first millimetres within the levelling line.

VISUAL OPTIMIZATIONS OF DINSAR RESULTS

In most cases the interferometric phase should be filtered to increase an interpretation ability. Such a filtered interferogram can be used for visualisation

purposes but it loses its precise phase measurements that could be otherwise used for an MT-InSAR processing.

Figure 1 shows examples of three different types of phase filtration over a sample area of 1.7 km² nearby the area of interest where a local deformation of about 6 cm in the subsidence trough center was detected. The differential interferogram has been created from two ERS-2 acquisitions from dates of 23rd February 1998 and 30th March 1998. The area is covered by vegetation that decorrelates the interferogram.

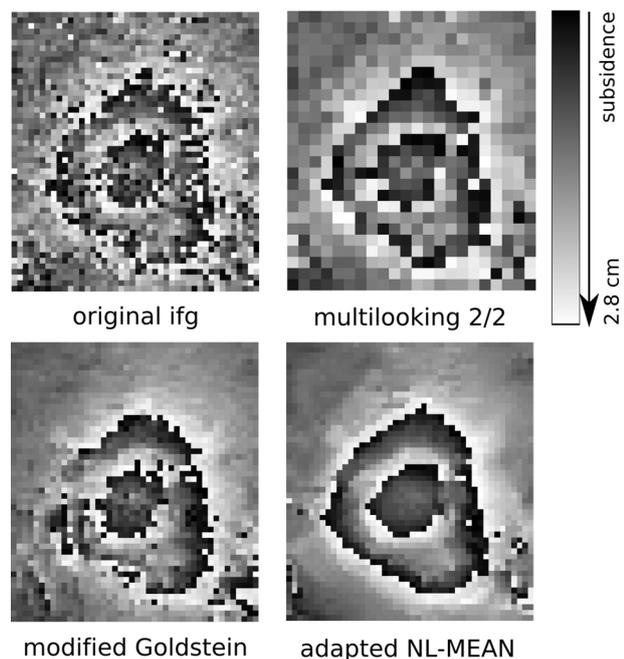


Fig. 1 Examples of techniques for phase filtering of differential interferogram.

In most cases a simple multilooking gives a sufficiently better overview at the expense of a resolution decrease. In this case, the area of interest is affected by decorrelation strongly, an advanced filtering technique is needed.

A Goldstein filtering method modified by (Baran et al., 2003) uses a coherence image for weighting a reliability of phase measurements. Low coherent areas (decorrelating pixels) are smoothed.

A non-local mean filtering method (NL-MEAN) is a special algorithm proposed by (Deledalle et al., 2010) that tries to reconstruct the phase affected by noise for homogeneous areas (using the intensity image of interferogram).

Within the scope of this project, the NL-MEAN filter was partially adapted to enable its application at a differential interferogram. The original filter was designed to combine and process original acquisitions from two satellite passes. Such filtered interferogram, however, is not applicable for further DInSAR processing. The filter was (with the author's approval)

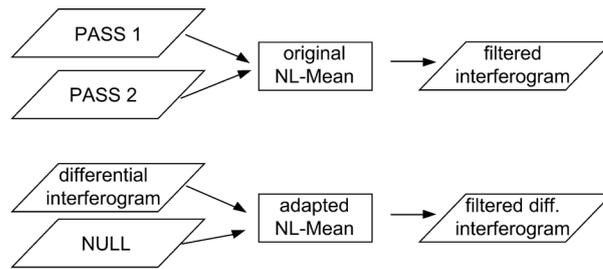


Fig. 2 Scheme describing adaptation of NL-MEAN filtering method for purposes of DInSAR processing.

adapted to allow a differential interferogram to be put as an input file as described by Figure 2.

It is recommendable to perform phase unwrapping in decorrelating areas after a satisfying phase filtering. Even that signs of local deformations will be obviously lost when using such aggressive filtering as the NL-MEAN (it can totally override noisy area by an intensity weighted mean replacement), still the shape, extent and general depth of subsidence trough will remain in the final DInSAR result.

SUBSIDENCE EVALUATION FROM DINSAR

In the case of Lazy plant area of interest, the NL-MEAN filtering was applied on ERS and Envisat interferograms. Aggressive filtering options were set to diminish strong decorrelation effects of vegetation in the area. The radar beam is reflected from any object of comparable size to the radar wavelength. Both ERS and Envisat satellites use carrier wavelength of around 5.6 cm. As can be seen from the situation map in Figure 3, the observed area around measured Lazecká Road is covered by vegetation, including deciduous forests. Only strong filtering of ERS/Envisat interferograms could discover borders of subsidence troughs in several interferograms.

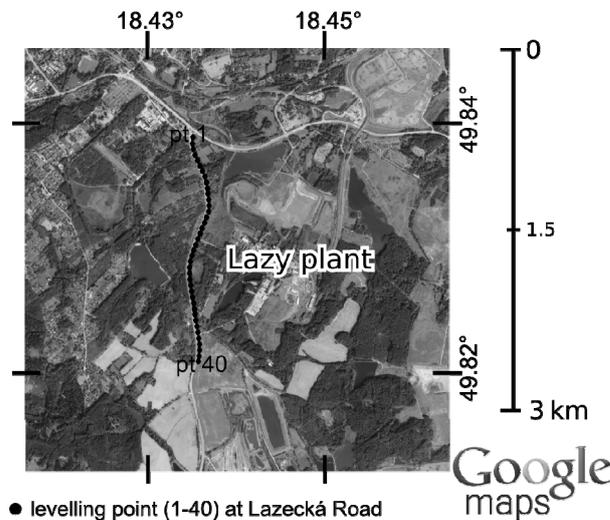


Fig. 3 Situation map of Lazy plant surroundings with Lazecká Road marked by levelling point symbols.

Selected interferograms are shown in Figure 4. The spatio-temporal development of subsidence troughs is visible from these interferograms in different times. ERS-2 and Envisat interferograms have temporal baseline of 35 days while ALOS interferogram from 2008 shows deformations within 46 days. All of the interferograms were created from acquisitions taken at optimal dates during winter and early spring time when the vegetation activity was low. Snow cover was probably minimal during time of the acquisitions – yet could cause the decorrelation phenomena that led to the needs of filtering. After the filtering some interferometric fringes wouldn't appear – it is not possible to evaluate reliably the rate of subsidence from such interferograms. Extents of subsidence troughs can be interpreted.

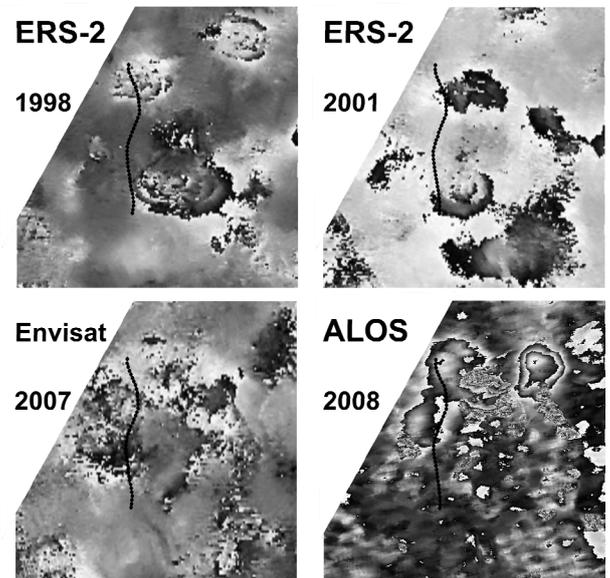


Fig. 4 Selected differential interferograms detecting subsidence troughs in the Lazecká Road (dotted polyline) surroundings.

To allow comparing between interferograms created from data of different wavelengths, the ALOS interferogram phase values were recomputed (and wrapped to dimensions of $-\pi;\pi$) to the scale of ERS/Envisat using a simple formula:

$$\theta_{\text{ALOS,ERS}} = \theta_{\text{ALOS}} \cdot \lambda_{\text{ALOS}} / \lambda_{\text{ERS}} \quad (1)$$

λ ... radar carrier wavelength

θ ... interferogram phase

Using Equation 1, the phase difference in ALOS interferogram is recomputed by a ratio of ALOS/ERS radar carrier wavelengths. After phase-rewrapping, the result is a simulation of ERS interferogram from the phase difference detected by ALOS, useful for comparison between wrapped interferograms of both sensors.

ALOS interferogram shows clear high coherent areas. This is due to its longer wavelength that has the ability of better penetration through the vegetation cover – and also due to higher resolution that is ~10 m against the ERS/Envisat resolution of ~25 m. It is possible to observe the extent of a landslide covered by the deciduous forest on the west side of the Lazecká Road. This landslide is observable in the terrain from strongly bended tree trunks.

It is possible to compute the corresponding rate of subsidence from ALOS interferogram (i.e. to perform an operation of phase unwrapping) since the phase information is not spoiled by significant noise. Such extracted information from phase values corresponding to deformation of Lazecká Road in the ALOS Palsar line of sight (i.e. 34° from nadir, looking to the East) was compared to levelling line measurements.

While the ALOS Palsar interferogram was composed from acquisition of 27-01-2008 and 13-03-2008, the closest dates of available levelling measurements were at 13-10-2007 and 24-05-2008. Data from these dates were linearly interpolated to approximately correspond to the dates of ALOS data and skewed using simple Pythagorean calculations to correspond to the ALOS line of sight. Both were referenced to the same location (reference levelling point no. 26).

It should be noted that this attempt involves many sources of errors. Unfortunately no better combination of ALOS data exists that would fit better to the levelling dates. Moreover, the ALOS satellite has ended its activity in 2011 disallowing rearrangement of future levelling missions. Even that ALOS acquisitions have relatively high resolution, the phase values will be influenced by radar reflection from all scatterers within 10x10 m resolution cell while positions of the levelling points are clearly known. The attempt of comparison with levelling is depicted in Figure 5.

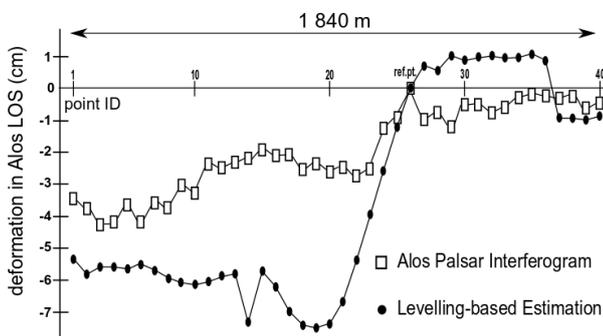


Fig. 5 Comparison between unwrapped ALOS Palsar interferogram and corresponding recomputed levelling measurements of Lazecká Road levelling line.

RESULT FROM MULTITEMPORAL INSAR MONITORING

Surroundings of Lazy plant are covered mostly by natural areas as a forest, meadows, agricultural land or water reservoirs. Due to a low number of stable reflecting objects (such as buildings) and due to fact that there are subsidence often exceeding detection limits for Envisat radar, this processing copes with errors.

An attempt to evaluate a progress of subsidence according to interferometric estimations of these points is shown together with a result from Envisat data processing of period February 2007-September 2010 using StaMPS SB method in the Lazy plant area in Figure 6. Some of SB points were detected also directly on the Lazecká Road. From the comparison with existing levelling measurement, however, a strong underestimation of subsidence is noticeable - the subsidence is too high to be properly evaluated using Envisat radar.

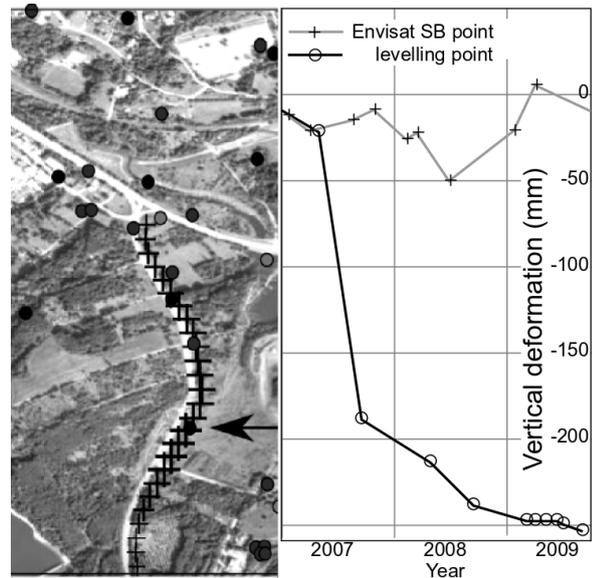


Fig. 6 Result of MT-InSAR processing of Envisat data ranging 2007-2010, with a levelling comparison showing strongly underestimated values of subsidence.

According to Hanssen (2001), with a subsidence of a rate higher than 1.3 cm/35 days/25 m resolution cell for ERS/Envisat (corresponding to a phase change of $\lambda/4$), the subsidence rate estimations will be affected by phase unwrapping jumps that have to be modeled computationally. The real deformation velocity would be most probably wrongly estimated.

In reality even much smaller deformation can be unwrapped properly from noise-free data. The most reliable phase change for unwrapping should be 0.6 rad according to (Colesanti et al., 2003), i.e. 0.27 cm/35 days between neighboring PS points for ERS/Envisat (in the line of sight). Both assumption

don't fit with the expectable subsidence easily exceeding 1 m/year in the Lazy plant surroundings.

Still the MT-InSAR processing can be optimized using appropriate processing parameters. Flexible algorithms of StaMPS can be set to search for deformations of relatively larger extents (a radius of 500 m or larger), including oversampled data files will also significantly increase number of selected pixels due to reasons stated in (Lazecký, 2011). Filtering of dataset from snow-covered acquisitions is recommended.

CONCLUSIONS

Data from ERS or Envisat radar are available in the shortest temporal baseline of 35 days, spatial resolution of cca 25 m and wavelength 5.66 cm. With such configuration its images have a potential to evaluate deformations of up to 54 cm/year within a range of 100 m, in optimal (theoretical) conditions according to Hanssen (2001).

Due to difficult conditions in investigated area (decorrelating factors such as vegetation cover, atmospheric humidity changes, non-optimal satellite orbit configuration, in combination with a deep local subsidence), interferograms from ERS/Envisat data were considered inappropriate - they can be used only to detect terrain deformations without proper quantitative evaluation of such deformations that occur in the area of interest. For example they may be used for appropriate evaluation of extent of subsidence troughs. Other situation can happen when investigating subsidence of a smaller rate in densely urbanized areas which wasn't this case.

Advantages of using ALOS Palsar data were demonstrated - its radiation of 23.6 cm wavelength is able to penetrate better through vegetation and with its higher spatial resolution it would have a potential to evaluate movements on the surface in the range of theoretically up to 468 cm/year within a range of 100 m, again in the optimal conditions (assuming acquisitions every 46 days in fine-resolution mode). Unfortunately only a few acquisitions exist of the area of interest, significantly lowering the proposed detection ability. ALOS satellite as the only available L-band SAR satellite has ended its activity in 2011, its successor is not deployed to the space sector yet.

Also other near-future planned satellite SAR missions seem to provide better opportunities for monitoring of areas with similar characteristics as Karviná Mine: Lazy plant. In combination with appropriate processing techniques, these satellites will have a strong potential to be practically used for monitoring of subsidence and other terrain deformation issues related to problematic areas affected by mining activities.

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