USAGE OF INSAR TECHNIQUES TO DETECT AND MONITOR TERRAIN SUBSIDENCE DUE TO MINING ACTIVITIES

VYUŽITÍ TECHNIK RADAROVÉ INTERFEROMETRIE PRO DETEKCI A MONITOROVÁNÍ POKLESŮ PŮDY VLIVEM DŮLNÍ ČINNOSTI

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Abstract

Land subsidence is monitored in several ways. Mostly the geodetic technique of geometric levelling is used. Also, the possibility to use the radar interferometry for monitoring has been successfully verified. In the area of Nnorthern Moravia several active mines are located causing in some places a subsidence of more than 1m a year. The existing radar images of this area from the ERS-1, ERS-2 and Envisat satellites, which had been acquired in the period from 1996 to 2008, were processed by 2-pass differential radar interferometry and advanced methods of radar interferometry, and thus subsidence epicentres were indicated and subsidence rates estimated. From the resulting interferograms the evolution and movement of subsidence can be seen, however, when compared to the survey data it is apparent the predicted subsidence rate is heavily underestimated. This is due to the sensitivity of the radar interferometry method to the quality of input data - only a very small number from 128 available images could be properly combined; the reasons are given below. For the advanced methods using the entire time series of shots, not just individual couples, pictures were selected only from a sufficiently short period, during which only a slight movement of subsidence epicentre is assumed over driven mine workings. The attempts to process a longer period of 4 years resulted in the loss of information on the evolution of subsidence in individual points due to their relatively rapid horizontal motion - the subsiding area was detected in this period (1996-2000), but no correct data on the rate of subsidence is available. For the processing the Permanent Scatterers and Small Baseline methods were used, both of them are implemented in the StaMPS program, whose concrete results also exceeded the tested Delft SP Toolbox implementation.

Abstrakt

Poklesy půdy jsou monitorovány několika způsoby. Většinou se využívá geodetické techniky geometrické nivelace. Pro monitoring již byla také úspěšně ověřena možnost využití techniky radarové interferometrie. Na území severní Moravy je umístěno několik aktivních dolů, které na některých místech způsobují poklesy i více než 1m ročně. Existující radarové snímky tohoto území z družic ERS-1, ERS-2 a Envisat, které jsou k dispozici z období 1996-2008, byly zpracovány metodou dvouprůchodové diferenciální radarové interferometrie i pokročilými metodami radarové interferometrie, a byla tak identifikována poklesová epicentra a odhadnuta rychlost klesání. Z výsledných interferogramů je možno pozorovat vývoj a pohyb poklesů, nicméně podle srovnání s geodeticky naměřenými daty je zřejmé, že odhad rychlosti klesání je silně podceněn. To je způsobeno citlivostí metody radarové interferometrie na kvalitu vstupních dat – jen velmi malý počet ze 128 disponibilních snímků bylo možno korektně zkombinovat; důvody jsou uvedeny. Pro pokročilé metody využívající celé časové řady snímků, nikoliv jen jednotlivé páry, byly vybrány jen snímky z dostatečně krátkého období, při kterém se předpokládá jen nepatrný pohyb poklesových epicenter nad raženými důlními díly. Pokusy o zpracování delší doby, 4 let, vyústily ve ztrátu informací o vývoji poklesů v jednotlivých bodech vlivem jejich relativně rychlého horizontálního pohybu – bylo detekováno území klesající v této době (1996-2000), ale bez korektních údajů o rychlosti poklesů. Pro zpracování bylo použito metod Permanent Scatterers a Small Baseline, obě jsou implementovány v programu StaMPS, jehož konkrétní výsledky předčily rovněž testovanou implementaci Delft PS Toolbox.

Key words: radar interferometry, subsidence, mining, Permanent Scatterers, ESA

1 INTRODUCTION

The land subsidence is one of the most common and sometimes dangerous effects of the mining industry having impact on our environment. Even with the most sophisticated mining techniques used, the subsidence still occur and provide damage to buildings, roads and other human structures on the land surface. In the Northern Moravia region in the Czech Republic, there is a huge black coal habitat of an area about 1500 km^2 being extracted since the 18th century. Several mines, built in the region between Ostrava and Karvina cities (OKR) have dramatically changed the landscape character - the invoked land subsidence in this area in the rates of sometimes several meters per year is the cause of damage that often leads to a destruction of many structures, such as the castle in Orlova city, Orlova tramlines and railway, and some other buildings in the Karvina outskirts. For example, the Karvina-Doly church of St. Peter of Alcantara descended for about 35 meters during last 50 years and is standing inclined for almost 7 degrees to the south (while the famous Pisa tower inclines for “only” 3.97 degrees).

Since 2007, only 5 mines are active in the region. Nevertheless, also the surroundings of terminated mines are still unstable and continue to subside, though in much lower speed. The land instabilities can still denote a threat for citizens in the region. This claims a necessity of land subsidence detection and monitoring. For a long period of time, the subsidence has been monitored using geodetical techniques that resulted in maps of subsidence. Unfortunately, this solution is very expensive, spatially limited and sometimes even not very dependable because of the need of very precise levelling measurements.

In the last decades, other usable methods have been developed for detection of land subsidence. The images from satellites with a radar sensor on board are used in the science branch called the radar interferometry. Radar interferometry techniques were successfully used in many situations similar to the one in this region. For example, Dr. Zbigniew Perski [10] has worked for many years on the monitoring of land subsidence due to the mining activities in southern Poland and proved that it is possible to detect subsidence effectively this way, with some limitations, nevertheless. After the fashion of his work, the VSB-Technical University of Ostrava has arranged an ESA project that uses the radar interferometry to detect and monitor the subsidence in Northern Moravia. A quite large dataset of 12 ERS-1, 106 ERS-2 and 10 Envisat images dated from 1996 to 2008 in almost periodic 35 days steps was achieved for this scientific purpose.

2 RADAR INTERFEROMETRY USED FOR MONITORING THE DEFORMATION

The main principle of the synthetic aperture radar interferometry (InSAR) techniques [1] is a creation of so-called differential interferograms from two synthetic aperture radar (SAR, a technology for radar sensing from satellite with a short antenna) images of the exactly same area achieved in a temporal difference that match the probable velocity of subsidence - to be able to detect the land movement during the time between these two acquisitions, in a sub-centimeter accuracy. This subsidence is represented by homocentric circles in the consequent image called fringes. The center of a fringe is a subsidence epicenter and every circle contour formed by the whole colour spectrum in the image (usually from red to blue) figures the terrain movement from the epicentre in the length of a half wavelength in the satellite line-of-sight direction (for ERS satellites with a wavelength ~5.6 cm, one fringe depicts a terrain deformation of 2.8 cm).

If going a little deeper, in comparison with the passive satellite sensors that can only achieve the amount of light energy sent (reflected) from the Earth sensed in some wavelength spectrum, the radar scanner is able to send a microwave signal to the Earth surface and get more information describing the wave reflection back to the satellite. The characteristics of the sent radar wave are well known. It is possible to achieve not only the delay and power of the returned signal, but also a change in the wave phase. Using interferometry, after subtraction of the measured wave phase from two radar acquisitions of the same place with some time delay, it can be interpreted (after series of processing steps subtracting all the phase contributions due to the land topography, Earth curvature, atmospheric delay if possible, orbital errors) as a relative change of the investigated point in the satellite line of sight. If this phase change value, in radians, is successfully converted to the vertical height value in metric units according to the used wavelength, it can result in the land subsidence rate computation. However, this step called the phase unwrapping is not trivial not even for ideal results without any unneeded contributions (noise), because only a modulo of the phase is known, not the number of cycles the wave has done on its way between the surface and satellite. For a high subsidence rate the situation is more complicated because of the phase jumps when the land movement exceeds a half of the carrier wavelength in the line of satellite sight. This makes difficulties especially for the application of advanced techniques that use the unwrapped phase of separated points from many images - the unwrapping errors are gathering to make the resulting subsidence rate value pointless (that happened also in this case, where the subsidence rate is sometimes more then 1 m per year).

By the advanced InSAR techniques, the Persistent Scatterers (PS) processing and Small Baselines Subset (SBAS) technique are meant. Both of them can describe the subsiding trend in a longer time period using a stack with many more images. Their principle is to find stably reflecting objects that can be spotted at a pixel or subpixel level in each interferogram of the created set of interferograms. After selecting these points, their phase values are again filtered for unneeded contributions including atmospheric errors (that can be modeled only using a larger stack of interferograms) and then used to form a subsiding trend in the whole time duration of the dataset. This way it is possible to improve the sensitivity of deformation detection as these methods can unveil subsidence of even several mm per a time period. Unfortunately, it seems to be too sensitive to achieve a real trend in the case of a very fast subsidence due to the ambiguous phase unwrapping solution, as mentioned before.

In the PS technique, one image with the most optimal configuration in the whole dataset, regarding time differences, satellite position and look angle, is selected as a master image. All the other images denoted as "slaves" are used to form interferograms with this common master image. The principle of SBAS is slightly different - it searches for optimal combinations of all the radar acquisitions considering as small temporal, geometrical and "Doppler centroid" (that represent the look angle) satellite baselines as possible. So in this case there are combinations with different master images which imply the need of precise resampling of the interferograms to the exactly same position. If this is achieved, the results might be far better than from the PS processing, because by forming interferograms only between images separated by a short time interval and with a small difference in satellite look and squint angle, the decorrelation (different phase contribution of a scatterer that is caused by a relative scatterer movement or changes of the mentioned angles) of the dominant scatterer phase is minimized. Anyway, still a spectral filtering of range and azimuth sensing directions (azimuth is a direction of movement of the satellite that is scanning the Earth surface perpendicularly in the range direction) must be included to reduce the decorrelation effect even more.

The advantages of the radar interferometry are its cost effectiveness and very precise measurement of land deformation (in the areas with a good radar scattering characteristics, it is theoretically possible to detect even mm sized land movement). On the other hand, the method has its weaknesses – it is very dependable on the quality of the image acquisitions – on the atmospheric conditions during scanning, geometrical characteristics of the scanned land (e.g. orientation of hill slopes and the direction of subsidence itself), seasonal characteristics etc. [4]

3 DIFFERENTIAL INTERFEROMETRY PROCESSING

From all the available data, all possible combinations (except for combining ERS and Envisat satellites together) were used to create differential interferograms using the Doris InSAR processor [7]. For the topography phase removal, the SRTM3 data were used. Different approaches were undertaken to filter out the noisy areas that prevented to acquire the terrain deformation induced phase values. From the whole huge dataset of 128 radar images, only about 20 generated interferograms can predicate the present subsidence in the OKR area by visual interpretation. Unfortunately, most of the images contain a large amount of disturbing signals. First of all, the area is widely covered by vegetation that causes a loss of phase coherence – and also, in the area surrounded by mountains gathering the rain clouds and with strong industrial activities that have an influence on the air quality, the phase is often affected by atmospheric artifacts the radar wave passes through. From the set of successfully produced interferograms it is possible to make several conclusions for choosing proper data:

- from May to August, it is almost not possible to achieve a good interferogram because the vegetation changes the radar wave phase mostly in this season (it is reflected by the leaves, grass etc. that change their position every moment inducing the phase change)
- more than 105 days temporal baseline causes a decorrelation. The phase information isn't lost at all, but mostly because of phase jumps due to a fast subsidence in the area the phase fringes are not detectable.
- due to very large differences in Doppler centroid frequency of the ERS-2 data after 2001, even after a proper azimuth filtering, the results aren't operable

The advantage of the visual interferograms interpretation is the possibility to observe the horizontal movement of the subsiding area in time. Because the cause of subsidence is the long-wall mining, the subsiding centers are following its routes, so do the interferogram fringes. In the advanced multi temporal radar interferometry (MT-InSAR) techniques that are based on the detection and analysis of identical pixels in all the images in the dataset, the subsidence rate represents much smaller significance of the subsiding danger than it is in reality – just due to the long-wall mining induced subsidence movement. During the period 1997-2001, some subsidence epicenters changed their positions at a distance even more than 500 m, as inspected by visual distance measurements.

Several critical places were depicted using DInSAR. In Orlova city, not only subsidence between the Lazy Mine and Doubrava Mine was detected, but also other places in the city were subsiding – the areal of the closed Zofie pit and the Orlova Vyhoda area. Some subsidence were detected in Havirov city (one of them even near the city center), probably caused by the Dukla Mine and in Karvina nearby its several mines (Gabriela, Barbora, CSA Mine and others), and other places. The biggest subsidence detected was in Stonava, under the Dul Krivy Mine catchpit and near the Darkov Mine, CSM Mine, CSM2 Mine, their catchpits and dumps in the Stonava and Karvina-Darkov area. These subsiding places are figured as fringes in an interferogram of period 23.2.1998-30.3.1998 in Figure 1. Also, to compare several resulting interferograms from different dates, check Figure 11.

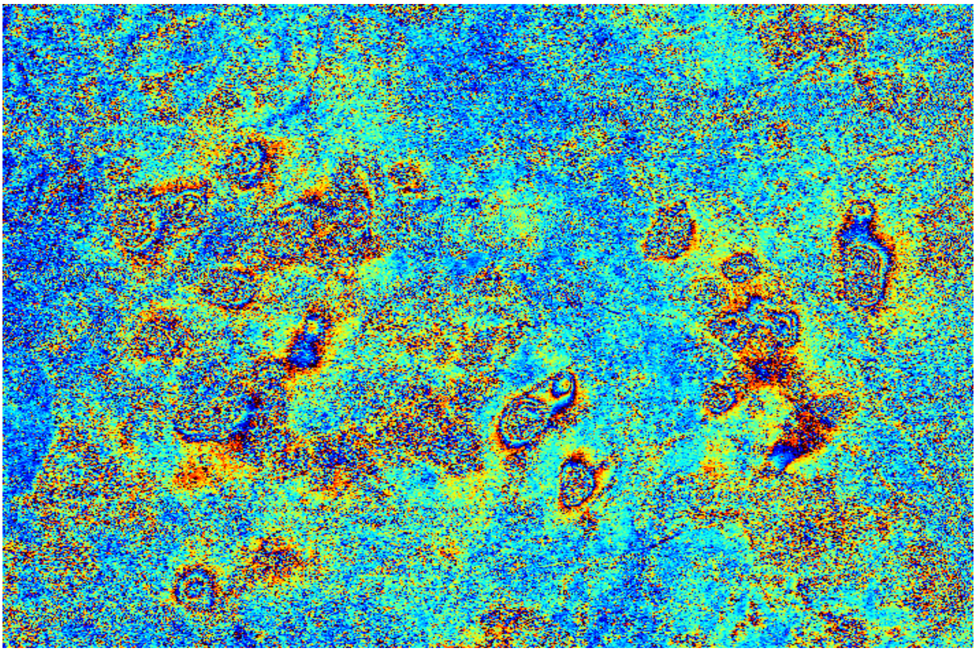


Fig. 1 – Differential interferogram of OKR area, ERS-2, 23.2.1998+30.3.1998

4 MULTITEMPORAL INSAR PROCESSING

In Multitemporal InSAR processing (MT-InSAR), a larger set of data is used to form interferograms and detect the subsiding trend for a subset of highly correlated stable points that are recognizable in all the images. Two instruments were used for this kind of processing. The TU Delft

Permanent Scatterers (PS) implementation as the Delft PS Toolbox (DePSI) [8] and the Standford University implementation of PS and small baselines (SB) techniques – the StaMPS [6]. There are many differences between the Delft PS approach, the StaMPS software and other PS processing implementations from other authors. The major difference between the DePSI and StaMPS PS processing implementations is the manner of PS detection. The DePSI uses a temporal model of interferograms, searching for pixels that are not radically changing their phase in time, while the StaMPS method picks up the PS points based primarily on their spatial phase stability. Both DePSI and StaMPS use the Doris software for the generation of differential interferograms.

The PS method searches for pixels with dominant scatterer objects that ensure stable phase measurements of the PS pixel (containing also minor contributions of more scattering objects) affected only a little by decorrelation in time. The so-called decorrelation is an unwanted effect of a different sum of the scatterer contributions due to their relative movement in time or a change in the satellite look or squint angle of the images used for interferometry [11]. On the other hand, the phase values of elements without a dominant scatterer are getting decorrelated and are not usable in the PS processing. But, to reduce the effect of decorrelation and therefore to use also pixels without a dominant scatterer, the causes of decorrelation can be avoided by forming interferograms only between images separated by a short time interval and with as smallest perpendicular and Doppler centroid baselines as possible. Also, a spectral filtering of interferograms in range and azimuth directions helps to reduce the decorrelation effect (but as this causes a coarsening of the resolution, the single scatterer phase is getting mixed with surrounding pixels disabling the stability advantage of dominant scatterers). The method of achieving this set of slowly-decorrelating filtered phase (SDFP) pixels [6] is called a small baselines (SB) processing.

4.1 Data selection

First of all, a high-quality dataset has to be provided in terms of as lowest perpendicular and Doppler centroid baselines as possible between one image (a master) and the rest of the radar images in the set (titled as slaves). In this case, 4 different datasets were chosen for the PS processing. Unfortunately, after exhausting all the possibilities to improve bad processing results of this data, only one dataset was accepted as rationally usable.

The chosen data consist of 21 ERS-2 images, with a time line from 1999 until 2001. As a master, the image identified by its orbital number 24396 was chosen, as it is in the middle of the whole time series (dated 20th December 1999) and for the perpendicular baselines between all the images in the set this is the optimal image. Only in one case the perpendicular baseline tends to the critical limit of 1100 m for ERS satellites, but the created interferogram still contains correct phase values, anyway. And also, for the PS processing, the effect of a high perpendicular baseline on the point-wise interferometry is not so extensive – even not its difference between more interferograms in a stack, because the PS points usually reflect strongly regardless of a satellite viewing angle [9]. The disadvantages of such a chosen master image are quite high Doppler centroid baselines that are getting near the critical value of 700 Hz, and also possibly induced problems due to the winter time of the master image (that reduces a vegetation inherence, but on the other hand, the present snow can evoke a different scattering of PS points). For the perpendicular baselines towards the master image and the Doppler centroid frequency characteristics of the chosen dataset, see the Figure 2.

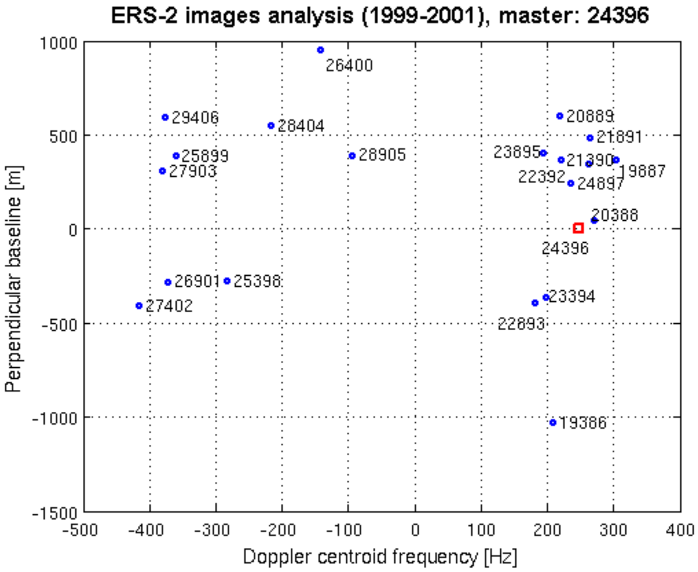


Fig. 2 - Image analysis of the ERS-2 dataset used for the PS processing. Master image position with the orbital number 24396 is marked with a red square.

Depicted reasons for choosing this set of images to be used in the PS processing: compared to the whole set of the ERS-1 and ERS-2 images that are available in the project, it is quite impossible to achieve good results using the ERS-2 data since the ERS-2 gyroscopes failure from 13th January 2001. As since this date the ERS-2 satellite have been piloting using only one active gyroscope of the original number of three, its course is not so stable anymore, which impacts on too unsteady sensing view angle characterized by the Doppler centroid frequency number (see the Fig. 3). The maximal Doppler centroid baseline (f_{DC}) still applicable for the PS processing is assumed to be about 700 Hz (optimal value is f_{DC}<500 Hz), but the difference in the newer ERS-2 data achieve even more than 10000 Hz.

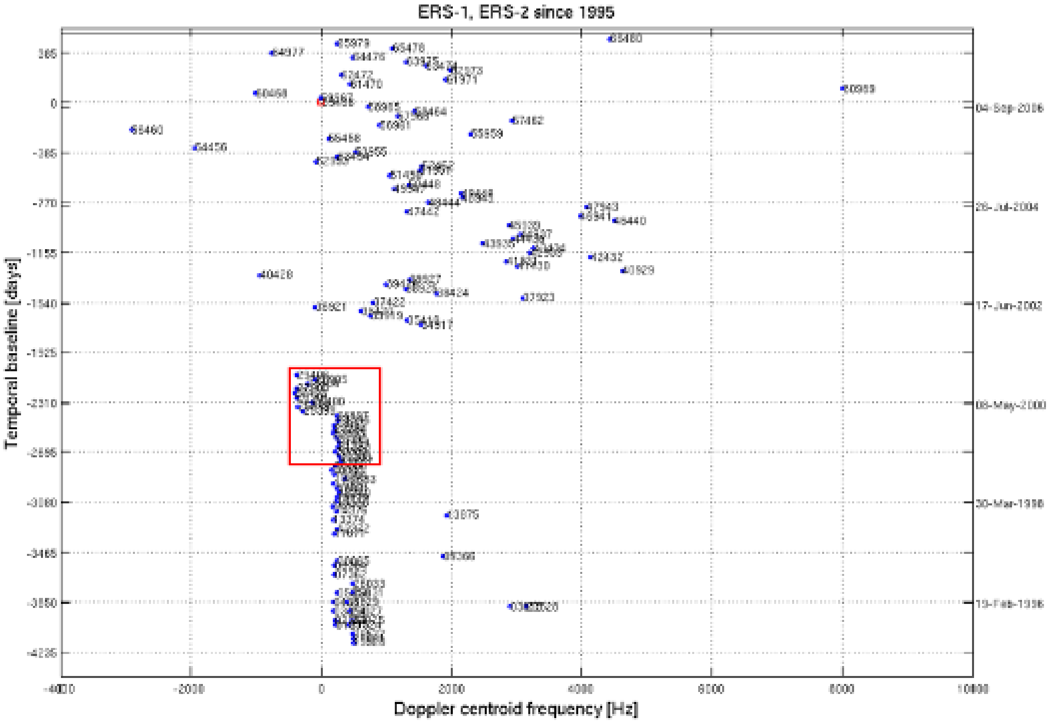


Fig. 3 - Doppler centroid image analysis of the whole available ERS-1, ERS-2 dataset. The red square selection signifies the images used for the PS processing

From the ERS images analysis it seems that the dataset from the 1995-2001 period is usable for the PS processing – but the practical attempts denied this opinion. Due to the single master usage during the whole time period in the area of a fast subsidence and a large vegetation cover, the most of interferograms of a high temporal difference remained decorrelated, so the selected first order PS points didn't form a sufficient network for certain deformation estimation. Also, the subsidence is slowly moving through the area, as mentioned before, so it is possible to detect the point-wise subsidence only for a shorter time period. So, the most up-to-date available data, regarding the described limitations, were chosen and applied by DePSI and also by StaMPS software to be able to compare the results of both of these instruments. The minimal count of interferograms to process with a PS method is in question – the original Permanent Scatterers technique uses the minimal number of 25 interferograms [2], but in practice, also about 18 interferograms should fully suffice for the use in Delft PS Toolbox/StaMPS. So, in the selected set, 21 images were chosen to form 20 interferograms.

4.2 Delft PS Toolbox approach

At the TU Delft, a group of radar specialists have created its implementation of the PS technique. It uses a Doris interferometry processing software in combination with several advanced Matlab scripts to create a stack of interferograms containing only phase contributions of a terrain deformation, atmosphere disturbance and, of course, some unavoidable noise. From these interferograms, only coherent points with a strong and consistent reflection in time, the Persistent Scatterers [3], are chosen by an amplitude dispersion analysis (searching for points with the lowest amplitude dispersion in all the interferograms). All of these first order PS points, called PS Candidates (PSC), form an initial spatial network that, if the PS candidates are distributed evenly over the whole scene (as it is displayed in Figure 4, a left plot), can be used to estimate the orbit errors and atmospheric phase screens (APS) over the scene. In fact, the model of these error influences on the detected phase value is one of the most important features of the PS technique, it reduces the errors of subsidence detection significantly - as a phase contributions, only the terrain induced phase change will remain. Of course, this modeling is not trivial and a fully doubtless result cannot be obtained.

After a quality testing, a second order PS points are selected relatively to the first order network as its densification. Finally, after a spatial unwrapping of the phase values and a phase filtering, a deformation model is created and the resulting image of points representing the values of a subsidence rate in the precision of a mm/year can become a garnish of this article – see the Figure 5.

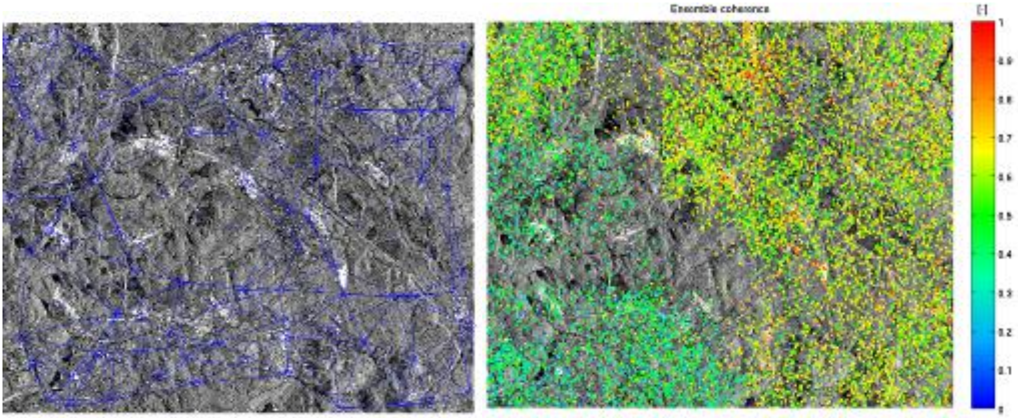


Fig. 4 - DePSI processing of the OKR area – first order PSC network (left), PS points ensemble coherence (right)

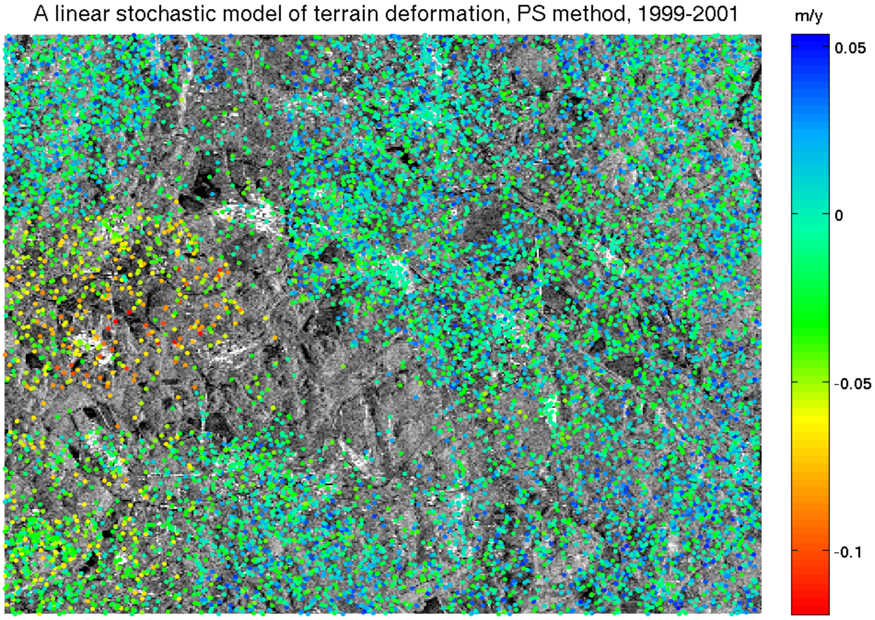


Fig. 5 - Map of subsidence in the OKR area using Delft PS Toolbox

The Figure 5 shows a concrete application of Delft PS Toolbox in the area of OKR, Northern Moravia. Checking the values of topography estimation that more or less fits the real topography in the area, the phase unwrapping process seems to have estimated also the subsidence rate properly, at least for highly coherent PS points. But, according to the PS ensemble coherence plot (Figure 4, right) the subsidence rate values on the western part of the figure don't seem reliable. In fact, there is really a fast subsiding area in the western part, as the results show. But this area is not as large as the DePSI depicted. On the other hand, a high subsidence rate in the middle part of the figure is expected – the DePSI result doesn't show any extreme in this area. After removal of all the points with an ensemble coherence value < 0.5, the resulting image in Figure 6 shows a very random-like character of the PS point’s distribution. Therefore, this result cannot be regarded trustfully. Anyway, the resulting PS were used for a comparison with the StaMPS processing, see later on.

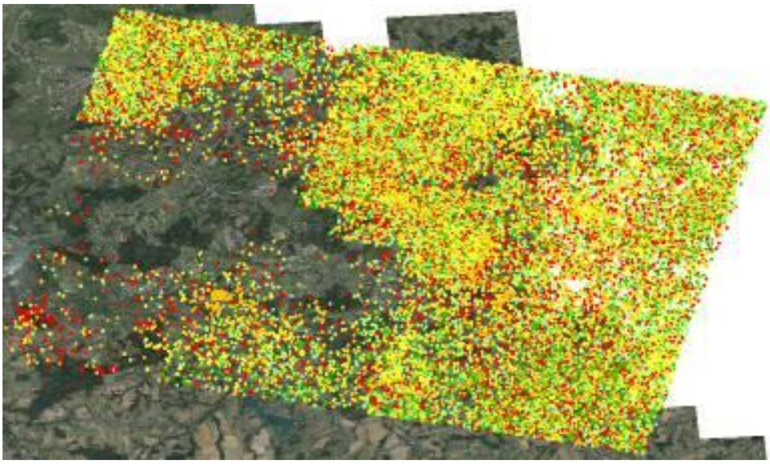


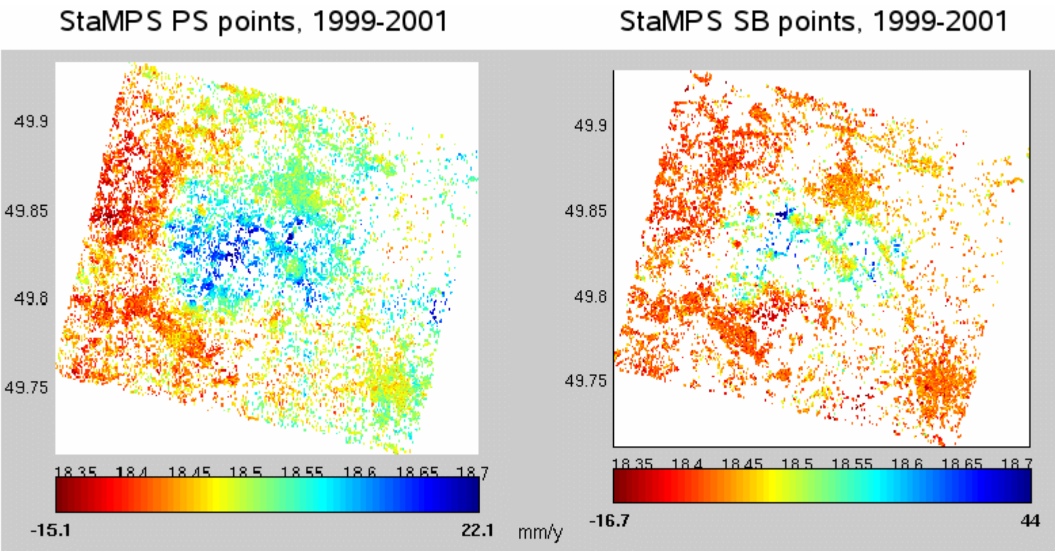
Fig. 6 – DePSI results after low ensemble coherence PS points removal. The colour scale is from red (-45 mm/year) via yellow to green (0 mm/year)

4.3 StaMPS approach

Both PS and SB processing techniques were implemented in the StaMPS software, enabling their combinations to maximize the usability of the source dataset for the multitemporal InSAR, improving the spatial sampling of the resulting points and increasing its signal-to-noise ratio. The combining process is not trivial due to the different resolution of resulting pixels of both methods – for detailed explanation see [6]. The StaMPS has been used successfully to process the ERS-2 data from 1996-2001, focusing on the 1999-2001 subset to prevent a loss of coherence due to long temporal baselines in the PS processing. The 1996-2001 dataset could be therefore processed successfully only by the SB technique, for the resulting image see Figure 10.

4.4 MT-InSAR processing methods comparison

The results of the PS processing by StaMPS of the 1999-2001 ERS-2 data of an area overlapping the scene used by DePSI, are combined with their analysis by the SB method. Usually the sets of selected PS and SDFP points overlap allowing a strong improvement of the terrain deformation estimation in these identical points, if put together by a right procedure. The principle of this join is explained in [6] – it consists of reestimation of a coherence magnitude for the PS pixels (that characterizes their decorrelation noise), mean phase value weighting of the identical points and other steps to presume that the phase can be unwrapped as correctly as possible. In this concrete usage, 25308 PS points were selected of average subsiding velocity of -15 to +22 mm/year (meaning that the largest subsidence value is assumed to be 22 mm during one year, relatively to the point used as a reference – and 37 mm/year as the difference between the extreme points). After SB processing, 45846 SDFP were selected in the range from 16 to 44 mm/year. After their combination and recomputation of unwrapped phase values, 55752 points were selected of LOS subsidence velocities ranging from 18 to 42 mm/year. Both PS and SB points depict the most subsiding area in the Stonava surroundings, see Figure 7 for their comparison and Figure 10 (left picture) for the final result.


StaMPS PS points, 1999-2001

StaMPS SB points, 1999-2001

Fig. 7 – Pixel-wise analysis of the OKR area by the PS and SB methods, using StaMPS

The resulting dataset of the complete StaMPS analysis is used in comparison with the levelling data and the DePSI method in Figure 8 (Stonava city). The graphs can be interpreted in several ways, due to the uncertainty of the real subsidence values:

graph of pixels nearby the measurement point with IDs:

1195 – the trend seems to fit the in-situ levelling measurements – the DePSI result shows a higher subsidence rate – this is possible, as it represents another object than the measurement point. StaMPS underestimates the real subsidence.

1198 – values of two pixels of the StaMPS processing were weighted and in comparison with the DePSI point that is quite nearby, the difference is too large. None of the values can be regarded as true, because the levelling point also doesn't seem to be veritable (first it was subsiding in 1999, then an improbable uplift occurs). Anyway, note that the difference is detected in the order of millimeters, in limits of reachable levelling precision.

1204 – the difference is too big in this area, even that the represented objects are different

1216 – this extremely fast subsidence couldn't be matched by any of the methods, maybe due to the phase unwrapping underestimation. The case of the DePSI point is disputable due to its low ensemble coherence value (0.236).

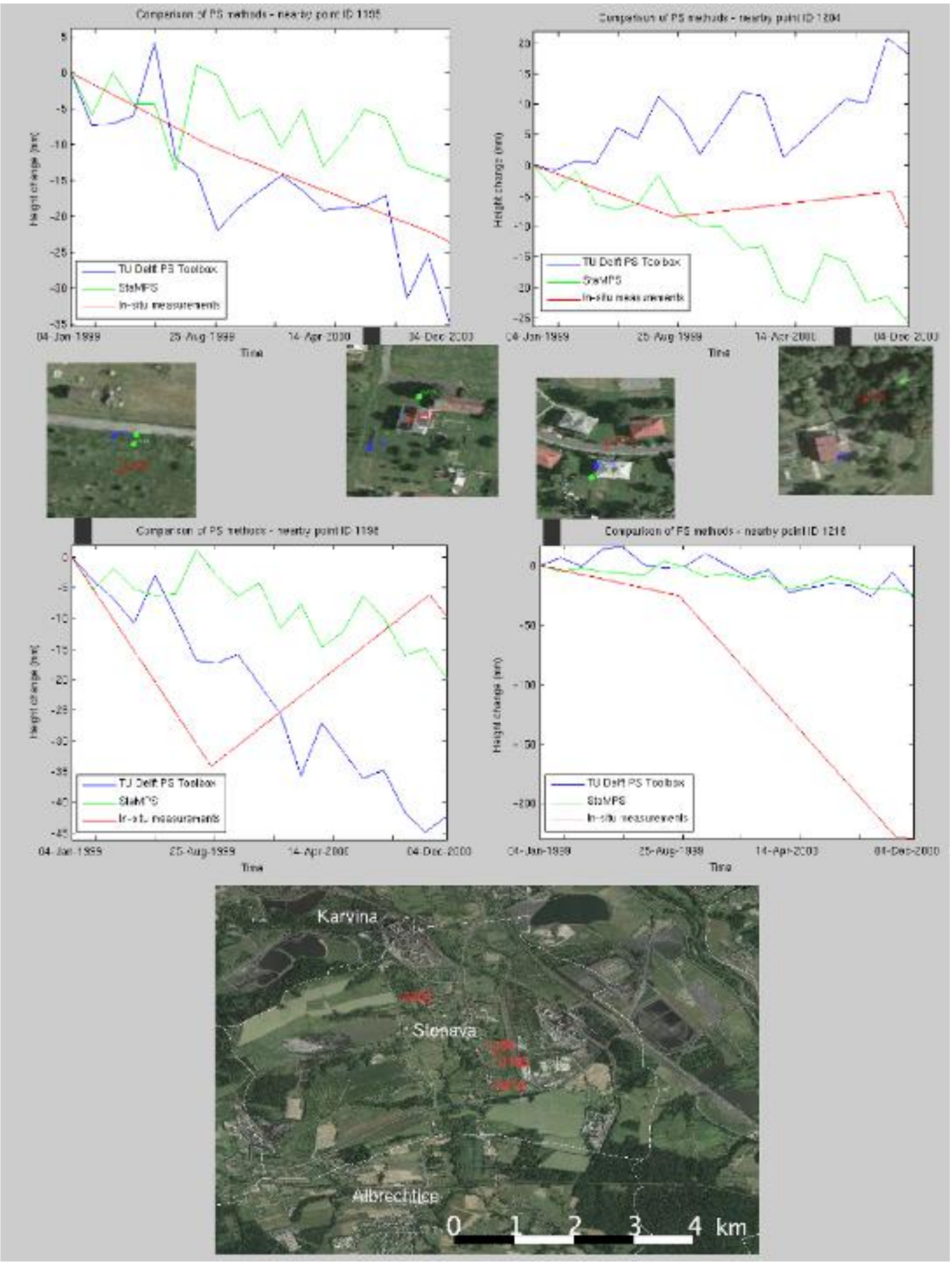


Fig. 8 - levelling and MT-InSAR measurements comparison – period 1999-2001

4.5 Other processing

Several attempts to use another datasets were made. The datasets of ERS-1 and ERS-2 images of the 1996-2000 period were chosen carefully regarded as the optimal combinations due to a relatively small perpendicular and Doppler baselines difference between the images. But, the decorrelation mostly due to long temporal baselines and the presence of a strong noise in several interferograms used in the PS processing caused a depreciation of PS results of this longer time period analysis. Only the StaMPS SB method has succeeded to find some points with reasonable characteristics due to the baselines minimizing and the possibility to filter the noise in data. However, the results were not appropriate to the levelling measurements and the subsidence rate was strongly underestimated by the StaMPS SB results, as shown in the case of one of the points situated nearby the levelling point in Figure 9 – the left graph. Anyway, the critical subsidence areas are depicted correctly – at least corresponding to the smaller dataset that was investigated as the most probable model of subsidence in the area - see their comparison in Figure 10.

For the set of ERS-2 images dated 2002-2006, their characteristics varied too much to be successfully processed (see the Figure 3). An attempt was done using only the SB processing; only 2947 SDFP points were selected in the scene resulting in too low rate of subsidence without the detection of the most subsiding area in Stonava city as the previous applications found it. Despite this, the SDFP pixels were analyzed for comparison with the levelling data revealing that the pixels time series really show no trend and resemble a noise behavior (see the Figure 9 – right graph). Also this failure will be investigated in the future work.

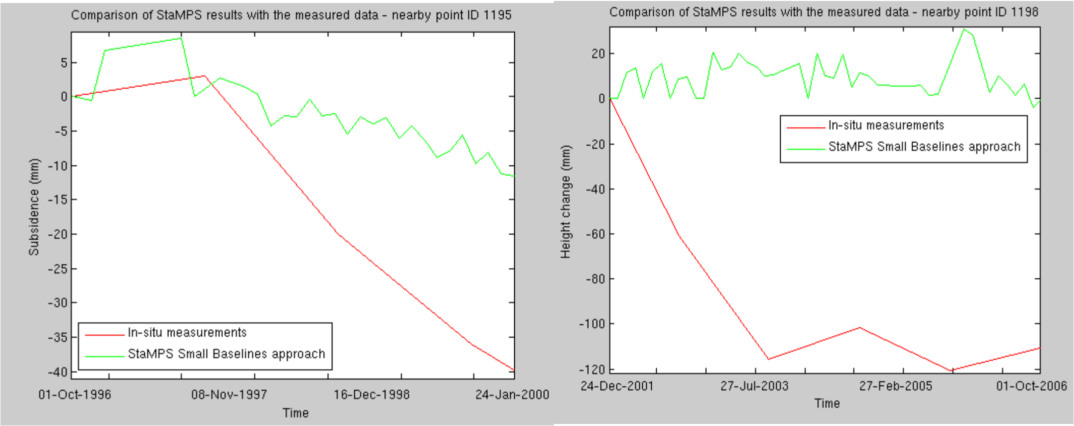


Fig. 9 – Processing the larger dataset using the SB method in StaMPS

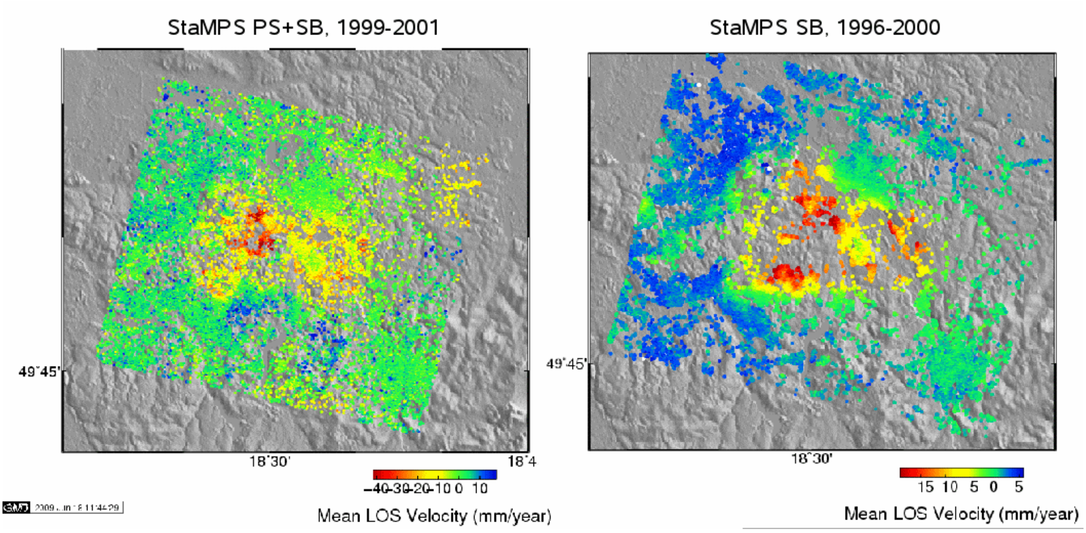


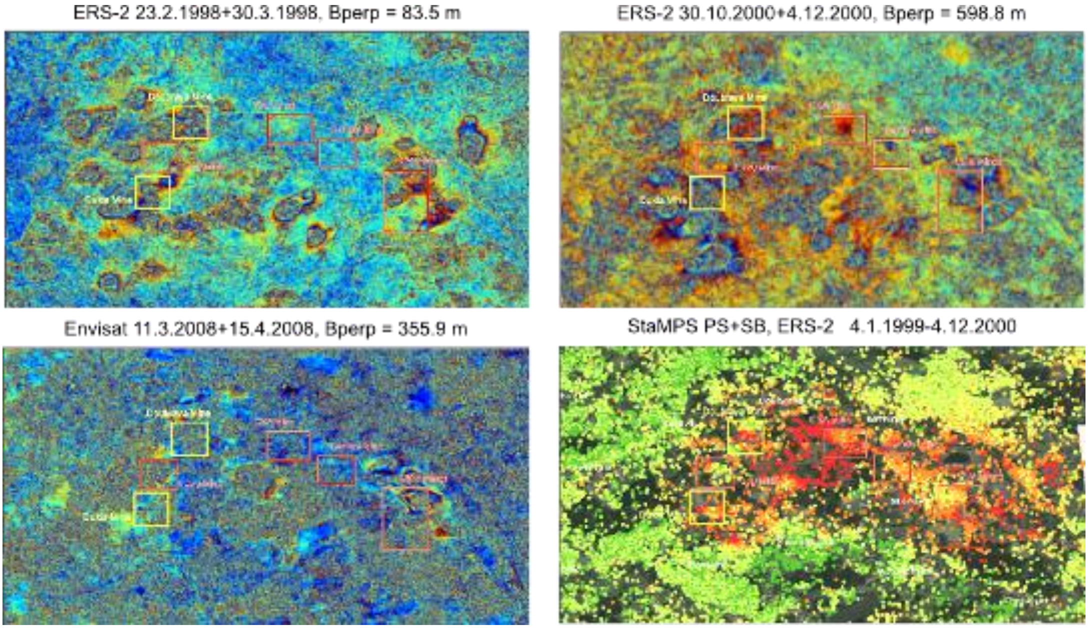
Fig. 10 – Results of the StaMPS processing of different datasets

5 CONCLUSIONS

The InSAR processing of the mining area proves that it is possible to detect the land deformation from the satellite radar acquisitions. The MT-InSAR techniques are useful for a coarse estimation of the subsidence rates, but in the actual processing the results were too underestimated, therefore it is recommended to use these methods only to detect the subsiding areas, eventually the subsidence epicenters.

For a better view on the subsiding activity of the OKR area, Figure 11 visualizes the interferograms from different years. The fourth image is a result of the StaMPS processing (with the colour spectrum of the same range as depicted in Figure 10 – left image). In the 1999-2001 period all of the mines marked by the coloured square were active. Nowadays, since 2007, only the mines marked with red colour are still working – therefore in the newest interferogram, the subsidence is detected only in their surroundings. The subsidence in the places where there is no active mine is caused by the dumps or catchpits of the mines – or, by the post-mining effect where some ex-mines are situated. The subsidence impacts will be investigated in the future work to complete the interferograms interpretation (for example the detected subsidence in the Havirov city center from the year 1998).

The project will also continue fine-tuning the existing results and with more attempts to apply the PS and SB methods in another data subsets to achieve a more complete model of subsidence evolution in the area.



ERS-2 23.2.1998+30.3.1998, Bperp = 83.5 m

ERS-2 30.10.2000+4.12.2000, Bperp = 598.8 m

Envisat 11.3.2008+15.4.2008, Bperp = 355.9 m

StaMPS PS+SB, ERS-2 4.1.1999-4.12.2000

Fig. 11 - InSAR processing results of the OKR area – marked areas localize active (red squares) mines (from left to right: Lazy Mine, CSA Mine, Darkov Mine, CSM+CSM2 Mines) and mines closed in 2007 (from bottom to up: Dukla Mine, Doubrava Mine)

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RESUMÉ

Technologie zvaná radarová interferometrie se již několik let využívá především k detekci změn na zemském povrchu. Použitelnost v prostředí důlních vlivů, které mají svá specifika (především v tom, že se místa poklesů nad razícími chodbami pohybují ve směru ražení), byla ověřena v několika projektech, jedním z nich je i detekce poklesů v důlním prostředí v polském Slezsku, tedy v prostředí ve všech směrech velice blízkém severní Moravě.

Doly severní Moravy způsobují rychlé poklesy půdy, které jsou dlouhodobě mapovány geodeticky. Pokus využít radarovou interferometrii jako náhradu či doplněk nivelačních měření skončil částečným zdarem – klesající místa lze identifikovat, zhruba je možno také odhadnout rychlost jejich poklesů. K tomu byly využity jak základní metody radarové interferometrie, využívající rozdíl fázových informací dvou snímků z radarového snímače na palubě satelitu ERS-1, ERS-2 či Envisat, tak i pokročilé metody, tzv. vícečasové, které umožňují efektivně zpracovat více těchto snímků naráz a odhadnout poklesovou rychlost v jednotlivých vhodných pixelech. Bohužel po porovnání s geodetickými měřeními byly zjištěny až příliš velké rozdíly v těchto odhadech, a tudíž není možno ohodnotit tyto metody jako zcela korektní, nelze je použít jako plnohodnotnou náhradu za geodetická měření.

Byly identifikovány problémy při zpracování. Fázová informace je mimořádně citlivá, je tedy nutné mít co nejkvalitnější data. Z celkového počtu 128 radarových snímků bylo možno vytvořit jen několik interpretovatelných interferogramů, díky principům metod vícečasového zpracování pak bylo možno použít i více zašumělá data. Protože však tyto metody hodnotí poklesy pouze bodově a ty jsou v poddolovávaném prostředí nestálé, je možné takto zpracovat jen data z poměrně krátkého období.

Projekt sledující možnosti uplatnění radarové interferometrie pro detekci a monitorování poklesů důlními vlivy bude dále se zpracováváním pokračovat.