Using SAR Interferometry for Detecting Landslides and Subsidence in the Coal Basin in Northern Bohemia

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Abstract

This article describes the possibilities and applications of active remote sensing. It also considers using SAR interferometry techniques in geotechnical applications in northern Bohemia. First of all, is this problem connected with SAR (Synthetic Aperture Radar). This is the kind of radar that scans Earth surface by receiving and measuring not only delay and amplitude of reflected signal, but also frequency and phase. This helps resolving the problem of resolution in flight direction and it is possible to receive data in resolution about three orders higher. This radar is named coherent radar and it is the basic condition for using the SAR interferometry method. In principle, radar interferometry in digital processing is comparison of corresponding pixels in two images of the same area acquired in a very little different looking angles. Generating the interferogram involves only pixelwise subtraction of the phases of both images. Phase difference is closely connected with difference in distance between Earth surface and the satellite. The advantage of the method is the possibility of very accurate measurements of this phase difference.

The method can be applied for topographic mapping with relative precission of 10 – 15 m, deformation mapping with precission less than 1 cm, another possibility is thematic mapping based on change detection, and last one is measuring the atmospheric influence on satellite movements.

We can see wide use of this method but in practice, obtaining data with such high precision is difficult, because it's very sensitive on many events. For instance a wet surface, snow or vegetation has a significant influence on surface features in longer time periods, and the interferometry method is impossible to use due to decorrelation.

Our project is focused on using of the conventional interferometry for monitoring landslides and ground displacements caused by mining activities in northern Bohemia. We are using data from European satellites ERS 1 and ERS 2 (Earth Resource Satellite). Hence ERS 1 is over we plan to use data from the new biggest remote sensing satellite, ENVISAT. In our whole solution we wanted to use only free software products, but the step named SAR processing is not covered be this kind of service, so we used SAR processor developed in Indian Bombay University. For an intereferometric processing, open-source product DORIS is used. A digital elevation model (DEM) was successfully derived from a tandem pair. This topographic information serves as input into so called three pass interferometry where three scenes are needed. One topographic pair and one differential one, which should already contain deformation. The purpose of our research is to test this method and compare the results with different ground based methods on specified area of the open brown coal mine Chabarovice. Unfortunately, deformation interferogram doesn't show good results in the place. Next step is to improve method using or developing different algorithms, and using data selected with different criteria.

Abstrakt

Tento článek popisuje možnosti a aplikace aktivního dálkového průzkumu. Také se týká použití SAR interferometrie v geotechnických aplikacích v severních Čechách. Především se tento problém týká radaru se syntetickou aperturou (SAR). To je druh radaru, který snímá povrch Země vysíláním a přijímáním radarového signálu – nezpracovává se však jen zpoždění signálu a jeho amplituda, nýbrž též frekvence a fáze. To nám umožní zvýšit rozlišení ve směru letu až o tři řády. Tento radar se nazývá koherentní a koherence je tou základní podmínkou pro možnost aplikace radarové interferometrie na takto získaná data. Radarová interferometrie v podstatě spočívá v porovnání fází dvou snímků stejného území, sejmutých z velmi podobných úhlů pohledu. Tvorba interferogramu obnáší odečtení fáze těchto dvou snímků (pixel po pixelu). Rozdíl fází je úzce spojen s rozdílem vzdáleností mezi Zemí a satelity. Výhodou této metody je možnost velmi přesného měření tohoto rozdílu fází.

Tuto metodu lze užít pro topografické mapování s relativní přesností 10 – 15 m, mapování deformací s přesností nižší než 1 cm, další možností je tematické mapování založené na detekci změn a poslední možností je měření vlivu atmosféry na pohyb družic.

Možnosti užití této metody jsou rozsáhlé, nicméně získání dat takové přesnosti je v praxi obtížné, protože jsou závislá na mnoha faktorech. Například vlhký povrch, sníh či vegetace mají v čase podstatný vliv na vlastnosti povrchu, a interferometrii potom v důsledku dekorelace nelze použít.

Náš projekt se zaměřuje na využití konvenční interferometrie pro sledování sesuvů a horizontálních posunů způsobených těžební činností v severních Čechách. Používáme data z družic ERS 1 and ERS 2 (Earth Resource Satellite). Jelikož je ERS 1 již mimo provoz, hodláme též použít snímky z nové, největší družice určené pro dálkový průzkum, jíž je ENVISAT. Při řešení problému jsme původně chtěli použít pouze softwarové produkty, které jsou dostupné zdarma, ale krok nazvaný SAR zpracování žádný takový software nepokrývá. Použili jsme tudíž SAR procesor vyvinutý na Indian Bombay University. Pro interferometrické zpracování používáme open-source software DORIS. V tomto softwaru byl z tandem dvojice úspěšně vytvořen digitální model terénu (DEM). Tato topografická informace je jedním ze vstupů do tzv. three-pass interferometrie, kde se zpracovávají tři scény. Z nich se vytvoří dvě interferometrické dvojice, jedna topografická (neobsahující deformaci) a jedna deformační (obsahující jak topografii, tak deformaci). Cílem našeho výzkumu je tuto metodu vyzkoušet a výsledky porovnat s pozemními metodami v oblasti povrchového dolu Chabařovice. Deformační interferogram však bohužel v tomto místě nevykazuje dobré výsledky. Dalším krokem bude vylepšení metody použitím nebo vývojem jiných algoritmů a opětovný výběr dat s jinými kritérii.

Introduction

The coal basin in nothern Bohemia is not stable with respect to landslides, ground displacements etc. A large part of the area consists of open mines. In some regions, such as Chabařovice, the landslides reach the value of decimeters per year, according to other methods used.

One of the methods for measuring ground displacements is radar interferometry. For interferometry, at least two radar images of the area are needed, forming so-called interferometric pair. Satellite orbits of the two images have to be close to each other and the difference in frequency of the received radar signal must not be large. Also, the way of processing of the images must be similar.

Image radar data are then stored in SLC (single-look complex) format. This kind of data, acquired by a coherent radar, contains two informations: the magnitude (i.e. intensity of signal) and the phase obtained by comparing the transmitted and received signals. ERS-1/2 satellite scene covers an area of about 100 x 100 kms, corresponding to approx. 5600 x 26000 pixels of the complex radar image (resolution is approx. 4 m in the satellite flight (azimuth) direction and 20 to 30 m in the perpendicular direction (range)).

In our project, we are processing five scenes. For data selection, very strict criteria were used. Our aim is to test the limits of the SAR interferometry method in our conditions, not to use interferometry for a concrete application. Hopefully, more data sets will be available later and we will be able to improve present results.

Some theory

The theory of the SAR interferometry method looks quite easy. First, we need to choose two radar images of the same area, considering both spatial and temporal baselines. The spatial baseline cannot be too large because the images would be too diferent in this case because radar reflections depend largely on the incidence angle. For ERS-1/2 satellites, this maximum baseline is approx. 2 kms. For some applications, it can neither be too small. E. g. for DEM (digital elevation model) generation, the perpendicular baseline should be about 100m. On the other hand, for deformation mapping, the smaller the spatial baseline, the better.

An important condition for interferometry is so-called good coherence of ground surface. Coherence is a number describing the ability to reflect the radar signal always with the same phase. If the coherence is bad, the interferometry method doesn't work and the interferogram has no fringes. This phenomenon is also known as decorrelation.

The convential interferometry solves two basic problems: DEM generation (topographic mapping) and ground deformation mapping. In addition, interferometric results can be used for thematic mapping and measuring atmospheric parameters.

For topographic mapping, the temporal baseline should be as small as possible. The interferograms degrade with time. With growing temporal baseline, larger and larger regions get decorrelated. The decorrelation is often caused by vegetation and varying soil moisture.

Ground changes may be detected only if they are „uniform“ in the area of one pixel. In the humid climate, the problem of decorrelation arises for temporal baseline larger than a fraction of a second, due to vegetation. With interferometric methods, in vegetated areas no DEM can be constructed nor an deformation map generated.

After selecting the two images, these images must be coregistered, i.e. one of the images must be resampled onto other for the two to be exactly the same (to the order of approx. 0.1 pixel). The coregistration is usually performed using only magnitude of the images.

After resampling, the phases are subtracted for each pixel in order to make the interferogram. The interferogram now contains following influences:

- flat-earth phase, i.e. the phase difference between the two images changes with different position on the earth; this influence may be easily subtracted using known satellite positions in the acquisition time and the reference body,
- topography, i.e. the phase difference between the two images due to the non-zero height of the imaged area,
- ground displacements, i.e. phase differences due to movements between the two acquisitions,
- atmospheric effects, i.e. phase differences due to refraction and different atmospheric delays (depends on the humidity, ionospere etc.); this influence can be limited by data selection with respect to weather conditions at the time of acquisition,
- orbit errors effects, i.e. phase differences due to incorrect subtraction of the flat-earth phase, originating from imprecise orbits; these make few fringes per scene and can be eliminated

by sophisticated methods.

For DEM creation applications, image pairs with short temporal baseline are optimal, so that there is just a short time for the decorrelation, deformations and atmospheric changes to occure. In addition, the correlation gets worse as the temporal baseline gets longer.

For deformation mapping applications, on the other side, the temporal baseline must be set carefully, in order for the images to be correlated enough and in order for the deformations to occur. Now, the topographic phase difference in the interferogram is an artifact and must be removed. There are two possibilities to make it: to use another interferometric pair (three-pass interferometry: both pairs have common master images to which the other two images are resampled), or to use an external DEM (two-pass interferometry). Both methods have both advantages and disadvantages which will be discussed later.

After generating the interferogram, we need to unwrap it, i.e. convert the complex numbers with phase in the interval of $(-\pi, \pi)$ to real numbers corresponding to the altitude or deformation size. This problem looks quite easy: taking the points of the interferogram one by one and computing the phase difference between the neighboring pixels; and this difference is added to the phase of the neighboring pixel to get the value of the pixel. But in practice, this problem is ambiguous due to two circumstances: the first are too steep slopes causing the phase difference between two adjacent pixels to be larger than π; and the other is the noise, causing the pixel having different phase when computing it's phase using different paths. To distinguish the noisy and non-noisy points, external information is used: coherence images. These images show the „reliability“ of the phase in each point.

The open-source software SNAPHU [3] implementing phase unwrapping takes the magnitude into account; e.g. if the magnitude is larger for a pixel, the presence of layover or foreshortening is considered and the slopes are estimated with respect to it. This software works on a statistical basis and the results are often good.

After an interferogram is unwrapped, it needs to be geocoded. Geocoding could be done only with the orbit information if it would be precise enough; usually the results are unusable and tie points need to be used, both for the horizontal and vertical positionioning.

Let's stress here that the deformation map is not the same as the one obtained from other methods: the radar is only able to measure the distance, the deformations are therefore known only in the range direction. There is no possibility to obtain the deformations perpendicular to this direction. If we process two interferograms, one from ascending flyover and the other from descending, we are able to reliably compute the vertical displacement. But we are never able to compute the displacement in the azimuth direction. Deformations in the flight direction cause decorrelation of the images and the area cannot be often evaluated at all.

Comparison of two-pass and three-pass interferometry

As already suggested, there are two methods to subtract the topography from a deformation interferogram: we can use either another interferogram with the same master image, or an external DEM. We are using a DEM obtained from SRTM (Shuttle Radar Topography Mission), which can be downloaded for free [4]. An important advantage of the three-pass method is the „automatic“ coregistration of the two interferograms; the external DEM (converted to the radar system) is shifted due to the orbit and timing errors and must be coregistered manually which is not so accurate.

In addition, the resolution of the SRTM DEM is only 3 arc sec, i.e. about 100 m. Due to the topographic radar effects (shadows, layover, foreshortening) there are some „blank spots“ in the radarcoded DEM – some originating from the SRTM acquisitions, some originating during the radarcoding procedure. After radarcoding, the DEM must be interpolated. On the other hand, the topographic interferogram has the same resolution as the deformation interferogram and has no „blank spots“.

But all interferograms are sometimes decorrelated due to vegetation and other effects and therefore this area cannot be analyzed (this area is usually decorrelated in the deformation interferogram too). In addition, the topographic interferogram usually contains also the orbit errors and atmospheric influence and therefore can be „sloped“. When using this interferogram for removing the topographic influence from the deformation interferogram, these errors transfer to the differential interferogram and make the „deformation spots“ more difficult to identify.

A solution may be to adjust the observations to a plane and subtract this plane; another, more sophisticated solution may be found in [5]. These methods were not implemented yet.

Coregistration

Before generating the interferogram, both images must be precisely coregistered (i.e. a point in one image must correspond to the same point in the other image). This is done by resampling but before that, coregistration parameters must be computed. This is performed by computing correlation between regions in each image; the shifts in each region are then approximated by a polynomial function and the slave image is resampled.

This step is very trickybecause due to decorrelation, many corresponding may be lost, together with coregistration accuracy. This error is then directly propagated into the interferogram.

Coefficients of the polynomial function depend on the images coregistered; they are different when coregistrating different cutouts of the image.

Results

In this section, we will show some interferograms of the northern Bohemia. Due to the limited space here, the images are undersampled; for full resolution images (and also current state of the project), see [2].

In our project, deformation interferogram was processed from images acquired on March 8, 1999, and December 28, 1998, and the topographic interferogram was generated from images acquired on March 8, 1999, and March 7, 1999. One of the images is acquired by ERS-1 and the other by ERS-2: at that time the satellites were in so-called tandem mode, one following the other after approx. 24 hours.

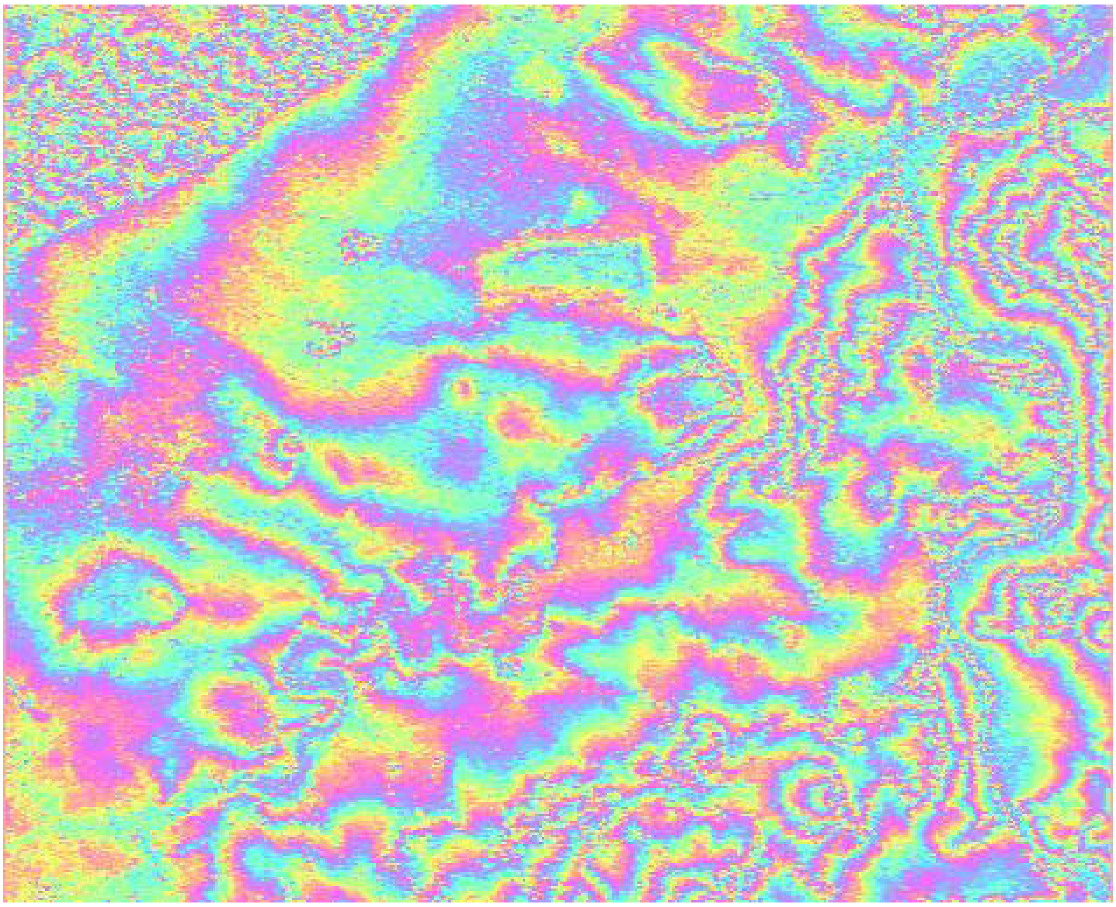


Figure 1: topographic interferogram of the area of interest (tandem interferogram)

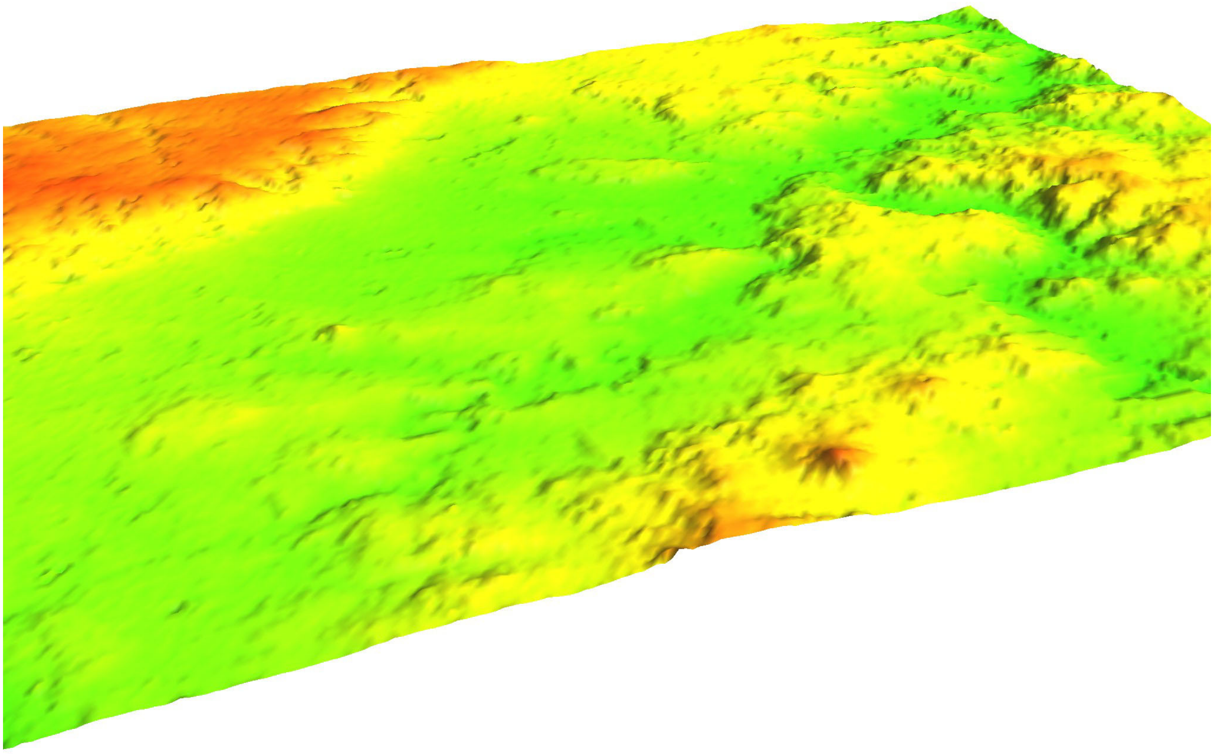


Figure 2: visualisation of the DEM generated from interferogram in figure 1

Figure 1 shows the topographic interferogram of the area of interest which is the mine near to Chabařovice (near to Ústí n. L.), the temporal baseline is only 24 hours here. An orientation point in this image can be the Labe river on the right. The DEM shown in figure 2 is generated from this inteferogram.

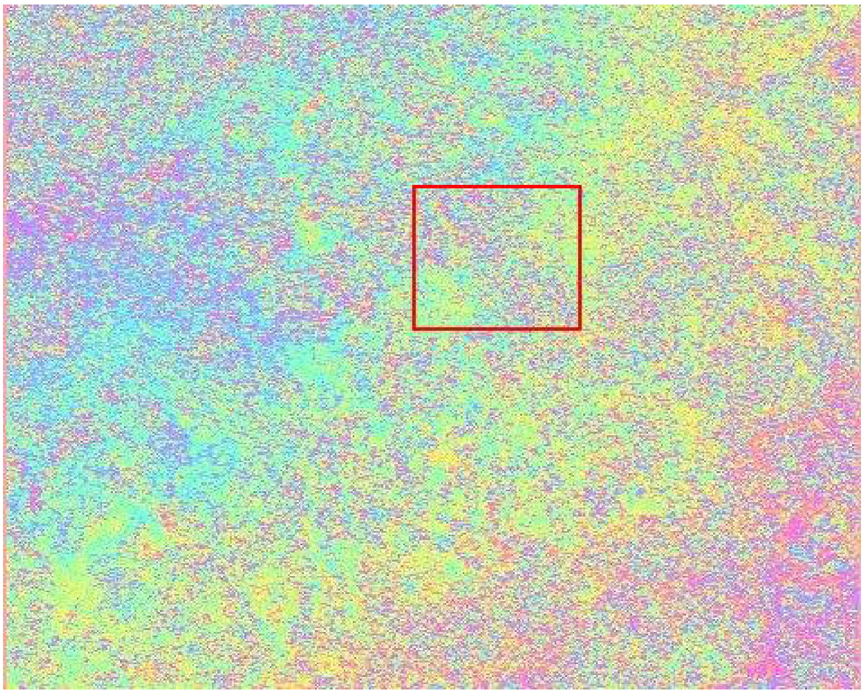


Figure 3: deformation interferogram of the area of interest (three-pass)

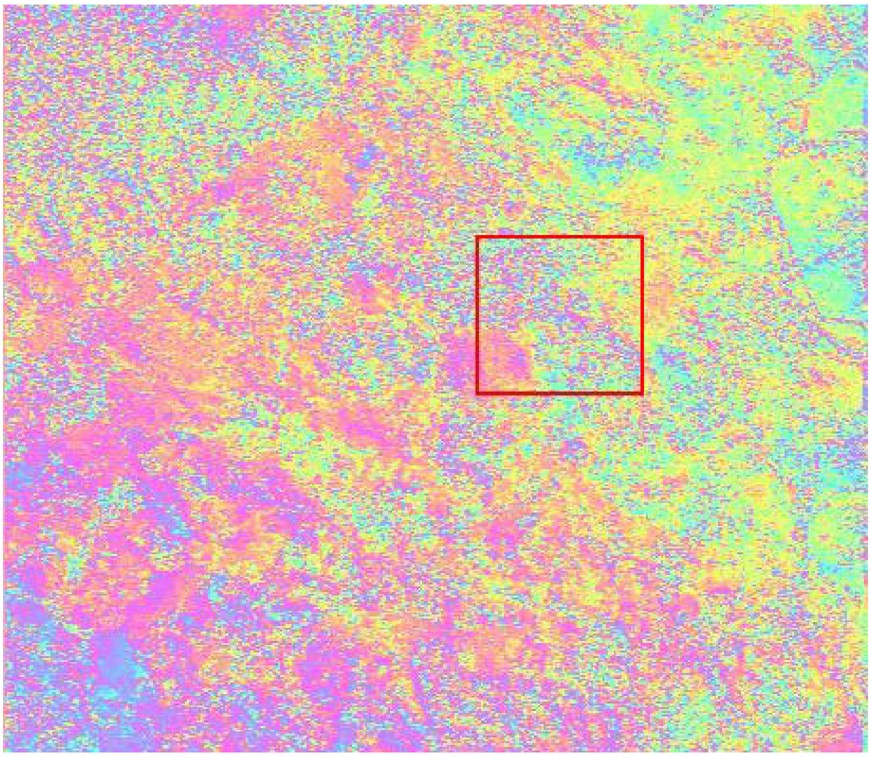


Figure 4: deformation interferogram of the area of interest (two-pass)

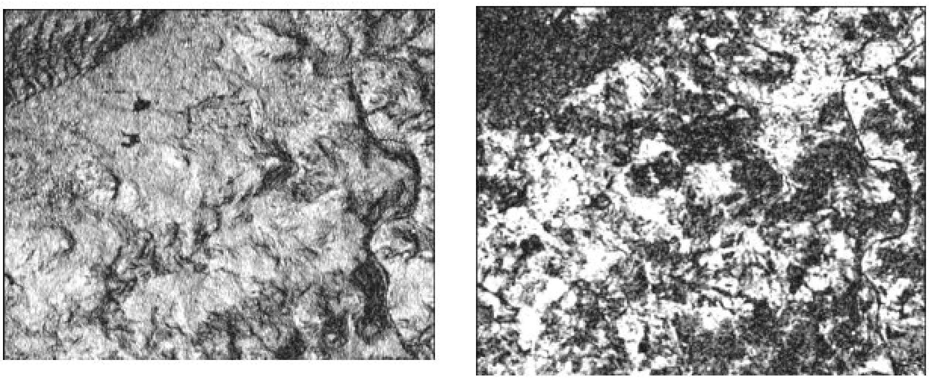
The deformation interferograms in figures 3 and 4 show the deformations in the area of interest: for the three-pass methods, the differences occured between December 28, 1998 and March 7, 1999; for the two-pass methods, the differences occured between December 28, 1998 and February 2000 (when SRTM images were acquired). Three-pass method means using the topographic information obtained from the topographic interferogram, two-pass method means using an external DEM to subtract the topographic influence.

Unfortunately, almost the entire area of interest (pointed out in the images) is decorrelated in the deformation interferograms (although it is not decorrelated in the topographic interferogram): this can be caused by vegetation (although there was winter), soil moisture change, „nonuniform“ landslides, or by landslides in the azimuth direction. The decorrelation can be also seen in the coherence images in figure 5, white color means good correlation, black means decorrelation.

As to comparison of the two-pass and three-pass methods, there are differences in the images: more different-colored spots can be seen in the two-pass interferogram. This can be caused by not-so-accurate coregistration of the interferogram and the external DEM, SRTM DEM errors or by a longer temporal baseline (longer time for the deformations to occur). It is very difficult to distinguish the deformation from other influences, which are DEM errors, atmospheric changes and coherence loss. With such a small data set we cannot recover such an information. But, considering coherence image and local topography, we can find areas suspicious of deformation. These are pointed out in the images.

After recovering the suspicious spots, we need to estimate the deformation size. Unfortunately, using these images, it would be very imprecise without removing the long-wavelength errors - orbit errors and atmospheric influence.

On the other hand, the two-pass interferogram is more „sloped“ in comparison to the three-pass interferogram: this phenomenon is caused by the fact that the orbit errors of the two image pairs (topographic and deformation) compensate each other a bit. The three-pass interferogram is „sloped“ just a little.



A B

Figure 5: Coherence of topographic (A) and deformation interferogram (B), the area of interest

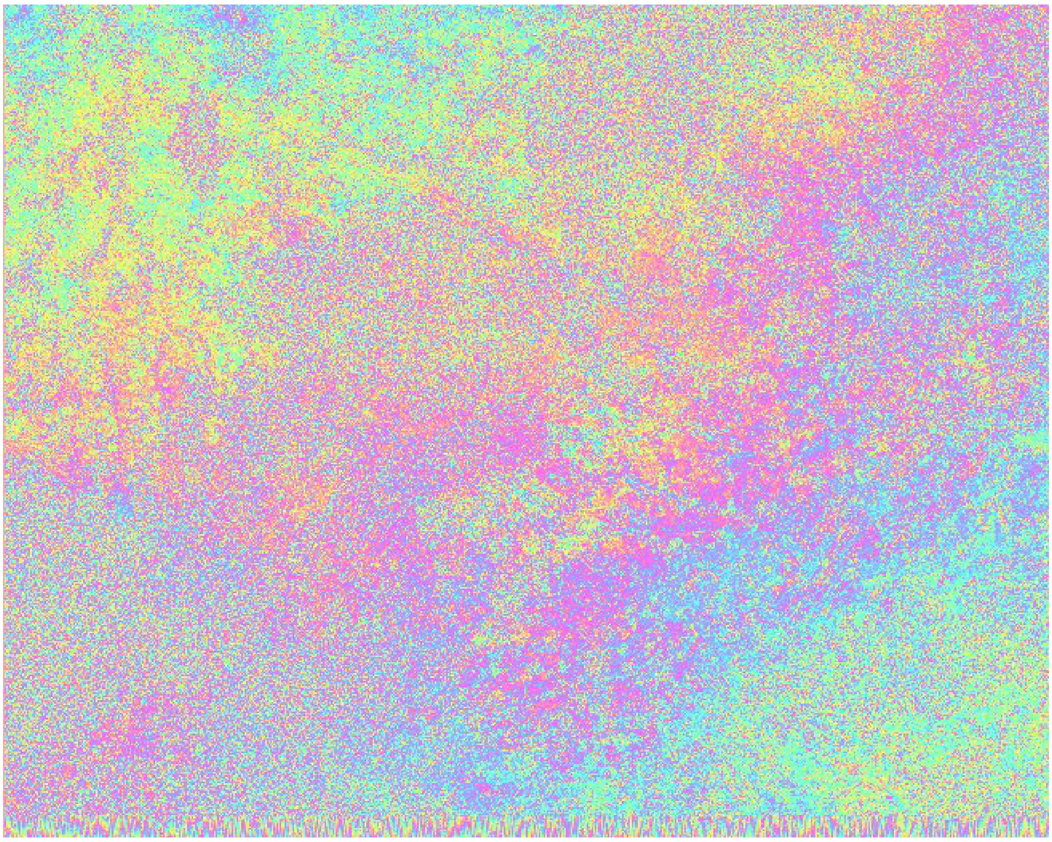


Figure 6: interferogram of the northern-bohemian coal basin obtained by three-pass interferometry, orbit errors are clearly visible. The area of interest is contained as well.

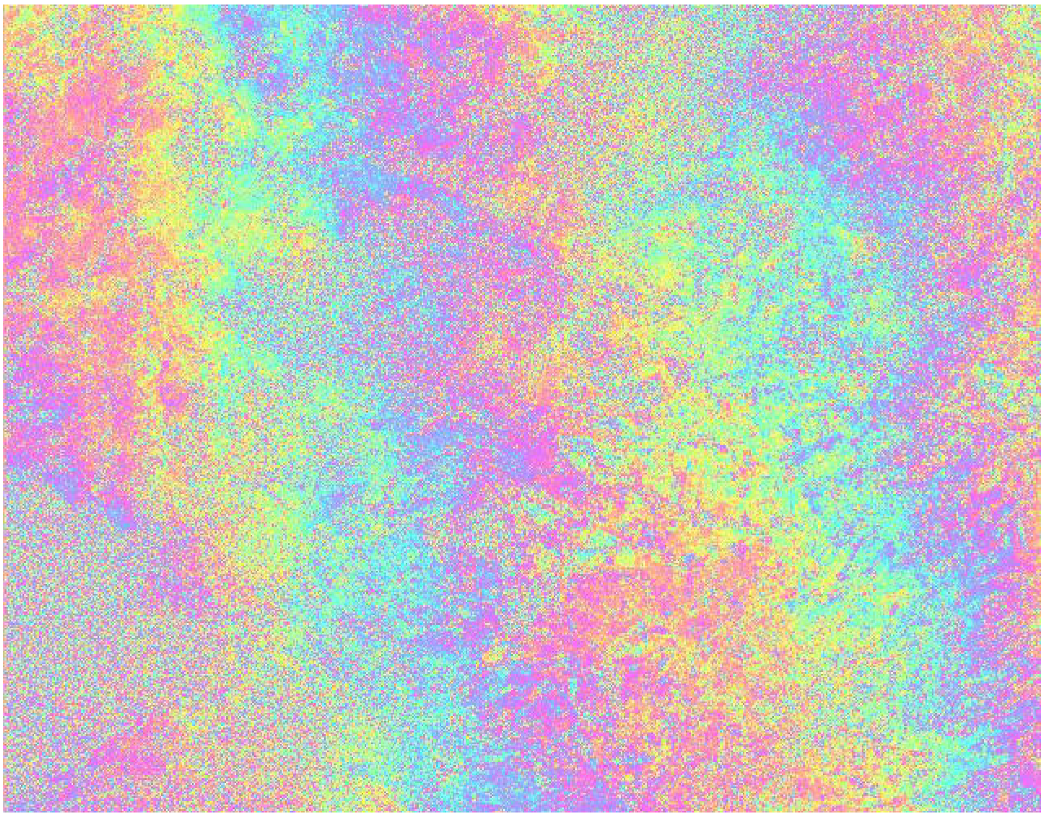


Figure 7: interferogram of the northern-bohemian coal basin obtained by two-pass interferometry (defo pair, using SRTM), also possible to see the trend caused by not accurate orbits.

Figures 6 and 7 show the difference between the two-pass and three-pass methods: in the two-pass interferogram there are more than two fringes caused by orbit errors causing the interferogram waving (sloped in fact); there is just a fraction of fringe in the three-pass interferogram.

In both interferograms, there are differently-colored spots (details are in figures 8 and 9). These are probably agricultural fields and the displacements are caused by different farming methods. This deformation is not bigger than 2 cms.

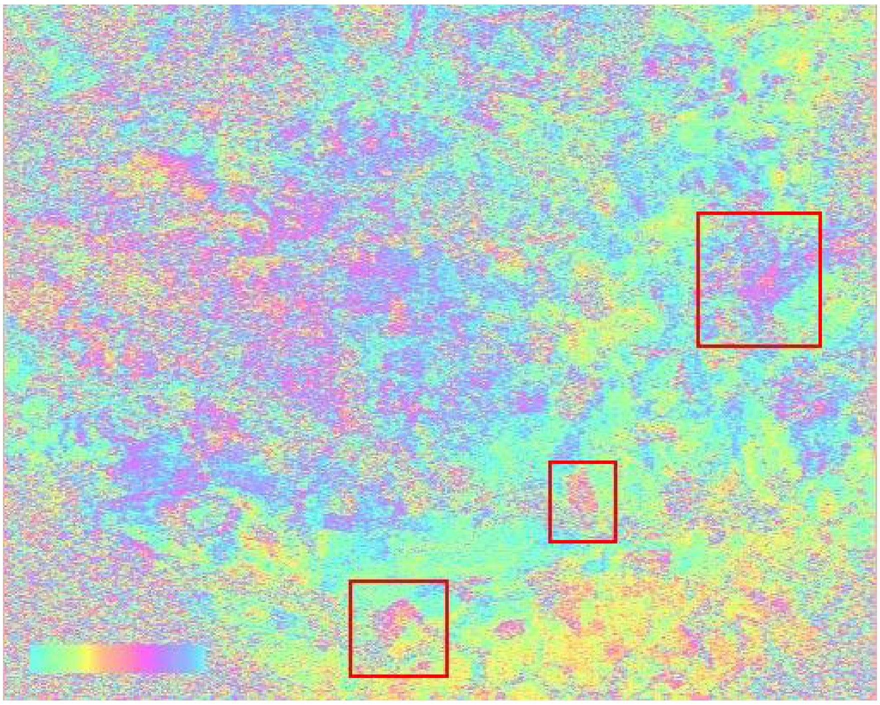


Figure 8: deformation interferogram of the south-western part of the coal basin (three-pass)

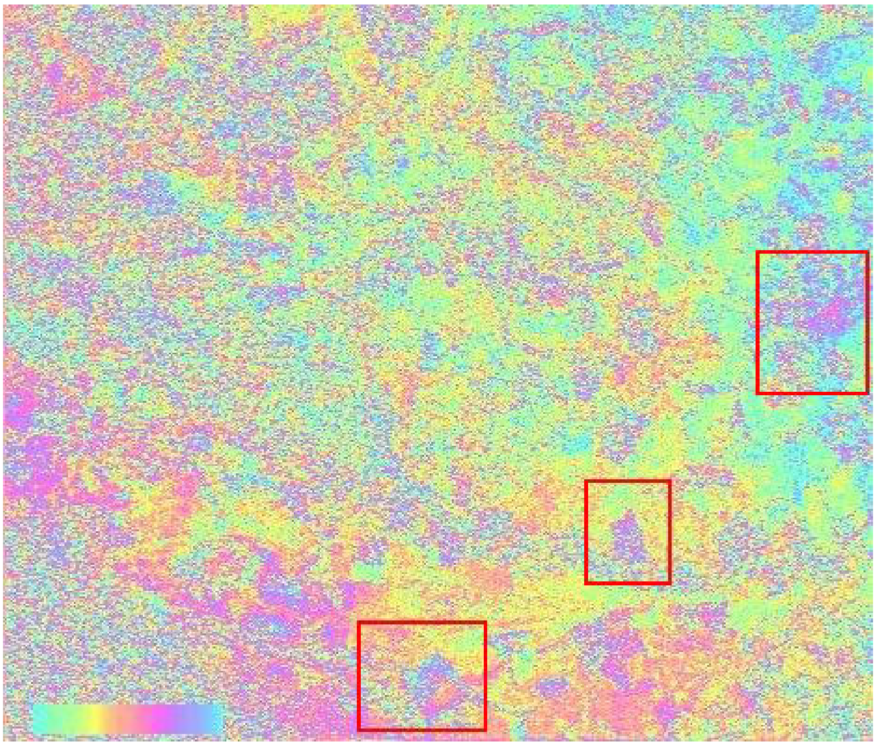


Figure 9: deformation interferogram of the south-western part of the coal basin (two-pass)

Problems

There are several problems in our project. First of all, we don't have enough data to produce reliable estimates of deformations. For data selection, very strict criteria were used because of the fear of coherence lost due to vegetation and atmosphere. Fortunately, even the interferogram with temporal baseline longer than two months and spatial baseline of approx. 100 m shows good coherence in more than 50 % of the area.

There is also another deformation pair selected, but there are some problems with coregistration so an interferogram cannot be generated. This problem is probably caused by convergence of orbits and therefore the resampling step cannot be covered by the polynomial transformation.

Another problem of our application are the orbit and atmospheric errors which cannot be distinguished (their influence is very similar and both can be corrected by the same procedure – setting the „artificial" baseline – see e.g. [6]).

Future work

First, we plan to order another data; the criteria for data selection should not be so strict now. We would like to process data with shorter perpendicular baseline (in order to prevent such a strong influence of errors) and different seasons (not just winter). We would also like to improve results by testing other algorithms.

We would also like to implement interferogram adjustment in order to eliminate the orbit errors: we would like to adjust the measurements to a plane (but this procedure is dependent on the success of phase unwrapping which is not certain), implement some sophisticated methods both with and without use of tie points.

Acknowledgements

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Bibliography

[1] Bert Kampes and Stefania Usai. *Doris: The Delft Object-oriented Radar Interferometric software.* In: proceedings ITC 2nd ORS symposium, August 1999.
[2] Výsledky projektu ze severních Čech, http://gama.fsv.cvut.cz/~ivana/sc/
[3] SNAPHU: Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping, http://www-star.stanford.edu/sar_group/snaphu/
[4] Bernhard Rabus, Michael Eineder, Achim Roth, Richard Bamler: The shuttle radar topography mission – a new class of digital elevation models acquired by spaceborne radar, in ISPRS Journal of Photogrammetry and Remote Sensing 57 (2003): 241-262
[5] Didier Massonnet and Kurt L. Feigl: Radar Intereferometry and Its Application to Changes in the Earth's surface, Reviews of Geophysics, 36, 4 (11/1998):441-500
[6] H. Tarayre and D. Massonnet: Atmospheric Propagation Heterogeneities Revealed by ERS-1 Interferometry, Geophysical Research Letters, vol. 23, No. 9: 989-992, 1996