InSAR Used for Subsidence Monitoring of Mining Area OKR, Czech Republic

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Abstract. The abilities of InSAR processing techniques to detect and monitor subsidence of mining areas were already proved in several works, e.g. of Dr. Perski that used them in Poland. As an ESA project of VSB-TU Ostrava using data from ERS 1,2 and Envisat ASAR, the InSAR has been applied also for the Northern Moravian OKR region in Czech republic, a region with a long black coal mining history. Mining activities in this area caused damages and destruction of many buildings, tramlines etc. The problem is still up-to-date, even that only 4 mines are active, since 2007. Via the differential InSAR processing, an evolution of subsidence during last 10 years is monitored using the Doris software. Due to highly decorrelated interferograms, the actual state is hardly interpretable though. The critical subsiding objects were detected by pointwise multitemporal InSAR techniques (MT-InSAR) – the permanent scatterers and small baselines methods using the StaMPS software. The results were compared with the in-situ levelling revealing that the estimated rate of subsidence was underestimated. Only the ERS-2 data from period 1999-2000 were successfully used in these advanced InSAR techniques to achieve some reasonable results. Because of gyroscopes failure of ERS-2, the data since January 2001 couldn't be processed successfully by StaMPS due to big differences in the Doppler centroid frequencies of each images - an abortive result of a small baselines method attempt can be presented. Because of used long-wall mining method, that evokes spatial movement of subsidence epicenters in time, a longer time period of dataset usable in MT-InSAR would decrease the processing merit (the character of subsidence in the area is not pointwise in longer time period). This project will continue with processing of newer datasets to achieve a complete overview of terrain changes in the mining area during the last decade.

Keywords: radar interferometry, subsidence, mining, Permanent Scatterers

Introduction

The region between Ostrava and Karvina cities (Northern Moravia, Czech republic), known as the Ostrava-Karvina revier (OKR), is totally undermined by several mine facilities extracting black coal from its more than 1500 km^2 huge habitat, since 18th century. Nowadays, since 2007, only 5 mines are still in an active state, even that their activity is dropping down. The mines have been changing the landscape character for a long time. The mining ways are positioned apart from the urbanized areas, but the mining still affect many buildings, roads and railways by fast subsidence. In the past, several locally important structures, such as the Orlova castle or the Orlova tramlines, were destroyed due to the subsidence.

To meet the needs of monitoring the subsidence in the area, the geodetical attempts of levelling has been used for a long time to gather very precious informations in a millimeter precision 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 quality and professional measurements.

Another alternative, developed during the last decades, is so-called differential synthetic aperture radar interferometry (DInSAR) which uses data from satellites with a radar sensor on board to detect terrain changes between two radar acquisitions. The DInSAR has been successfully used in many situations similar to the one in this region. For example, Dr. Zbigniew Perski [12] has worked for many years on the monitoring of land subsidence due to the mining activities in Southern Poland, that is very close to our area of interest, and proved that it is possible to detect subsidence effectively this way, with some limitations, nevertheless. After the fashion of his work, the VSB-TU University in Ostrava has arranged an ESA project that uses 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 has been achieved for this scientific purpose.

Results of applied InSAR

The main principle of the synthetic aperture radar interferometry techniques 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 representing radar wave phase changes 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. 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 half wavelength in the satellite line of sight direction (for ERS and Envisat satellites with radar instrument of wavelength ~5.6 cm, one fringe depicts a terrain deformation of 2.8 cm). The whole processing consists from many steps regarding a precise coregistration (referencing) of the images in a sub-pixel level, computation of an interferogram and filtering of unneeded phase contributions from ellipsoid curvature and a noise due to satellite orbit estimation errors and other imperfections (Doppler frequency deviations between image lines etc.). To achieve only phase changes due to land deformation, the topography is also filtered out using a digital elevation model (in this case, SRTM version 3 from year 2000 was used). The atmospheric contribution is possible to filter using advanced multitemporal processing - see further.

Every radar image was combined with every another one available in the achieved dataset. Most of these combinations have resulted in non-interpretable interferograms due to decorrelation phenomena (loss of phase information – defined as a different phase contribution of a scatterer that is caused by a relative scatterer movement or changes of the satellite looking angles). The only interferograms with detectable fringes were created from images with a temporal baseline less than 105 days. Usually this was because the subsidence in the area is so fast that after such a long time the count of fringes in a small area increases to exceed its separability in the resolution cell/pixel (for ERS and Envisat data the pixel size is about 30x30m), but also because of other decorrelation reasons. Another source of decorrelation is a vegetative season – a vegetation with leaves comparable to the wavelength (cca 5.6 cm) reflects the radar wave and induces decorrelation because of their instability in time (leaves are moving), so, from May to August it is almost not possible to achieve a good interferogram. Also, due to very large differences in Doppler centroid frequency (inducing different looking angles) of the ERS-2 data after 2001 (a total gyroscopes failure happened at 13th January 2001), even after a proper azimuth filtering, the results aren't operable.

Figure 1a shows a correct differential interferogram (left) and a decorrelated one (right) of the same area (a 8x15km part of OKR between Orlova and Karvina – see Figure 1b for reference).

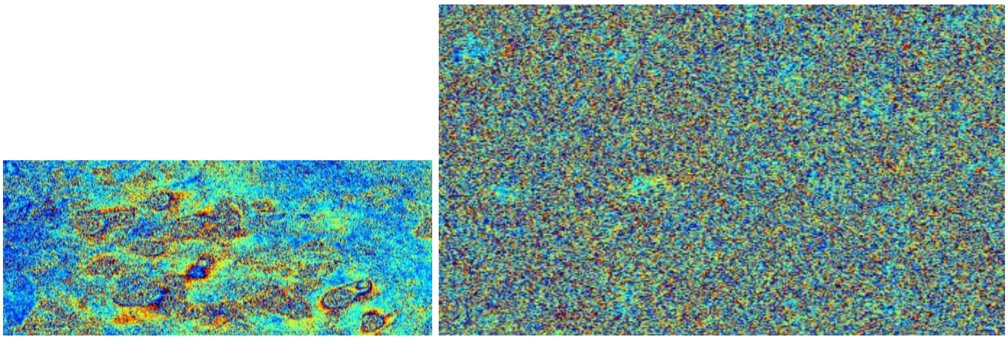

Fig. 1a – differential interferogram of an OKR crop area: ERS-2, 23.2.1998+30.3.1998 (left) and Envisat, 9.10.2006+22.1.2007 (right)

Fig. 1b – location of Fig 1a interferograms: between Orlova and Stonava

Results of multitemporal InSAR techniques

In order to overcome the decorrelations in interferograms with a high temporal baseline and with a view to detect pointwise estimations of subsidence in the OKR area, the Permanent Scatterers (PS) and Small Baselines (SB) techniques were applied to a carefully chosen dataset. The techniques can estimate a rate of subsidence for chosen pixels with an optimal reflectivity through all the interferograms in a stack. The PS is based on searching the data for so-called dominant scatterers, objects that strongly (and permanently in all images in the stack) rebounces the radar beam back to the sensor - they are selected using an amplitude dispersion analysis. After this selection, phase information of only these pixels is processed to achieve an information about the trend of their vertical movement. A similar principle is used for SB technique, the main difference is a way of selecting pixels - it selects pixels that are decorrelating very slowly in the stack of interferograms with as small temporal, perpendicular and Doppler centroid baselines. Such pixels don't need to include a dominant scattering object presence. Both PS and SB results are combined in StaMPS software - this process is not trivial because of different resolution of selected pixels (the SB pixels are spatially filtered to reduce the geometrical decorrelation). For more informations see for example [7]. Regarding maximal Doppler centroid frequency differences (about max. 600 Hz) and a minimal count of 15 interferograms used in the multitemporal techniques, ERS-2 data from 1996-2001 were chosen. The figure 2 shows their final result.

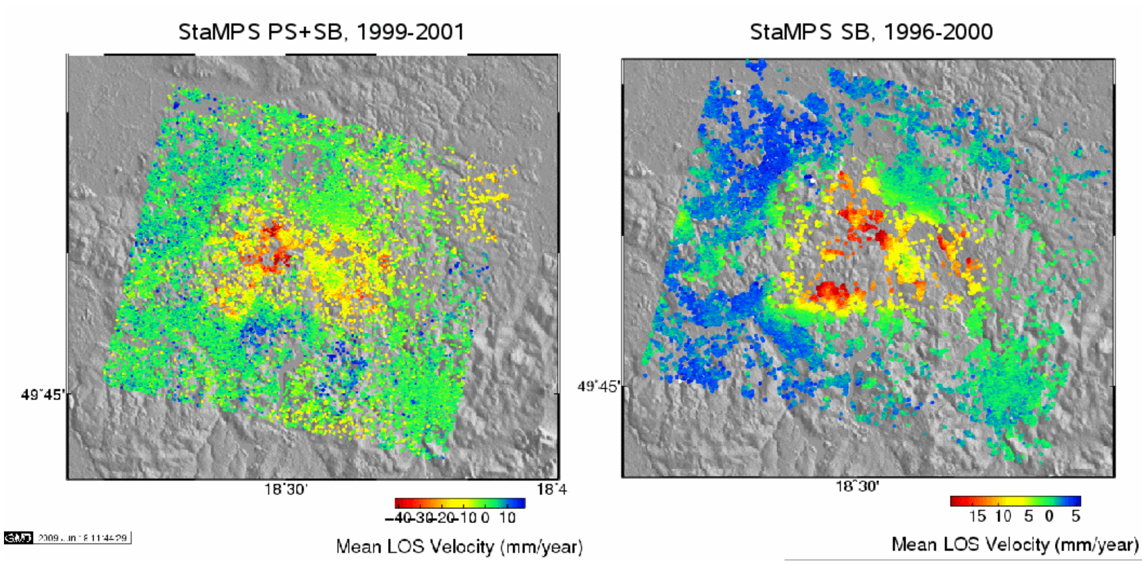

Fig. 2 – PS and SB processing of ERS-2 data using software StaMPS

Several data subsets were inspected. Best results were achieved from 21 ERS-2 images from 1999-2001. When using larger temporal borders of a dataset (since 1996), the temporal differences were too high to create correct interferograms with a common image (denoted as a master image), only a

SB method that uses only optimal combinations through all the images (without a common master) was applicable.
The multitemporal InSAR techniques best fit to monitor a slowly subsiding areas, they can detect even a millimetre subsidence per year. For the OKR, the situation is much more critical, the subsidence is very fast (sometimes even more than a metre per year). Therefore the phase values are wrongly unwrapped (maximal measurable phase value corresponds with a half of wavelength 2.8 cm – a higher terrain deformation value cause a so-called phase jump). As a result of many phase jumps and so the unwrapping errors, the rate of subsidence was always strongly underestimated (expected decimetres and more per year, computed centimetres) – one of these estimation errors is visible in the figure 3 – comparison of a PS point with a nearby situated levelling point. The estimated value is about 10x smaller. Anyway, the positions of selected subsiding points mostly fits the real subsiding places.

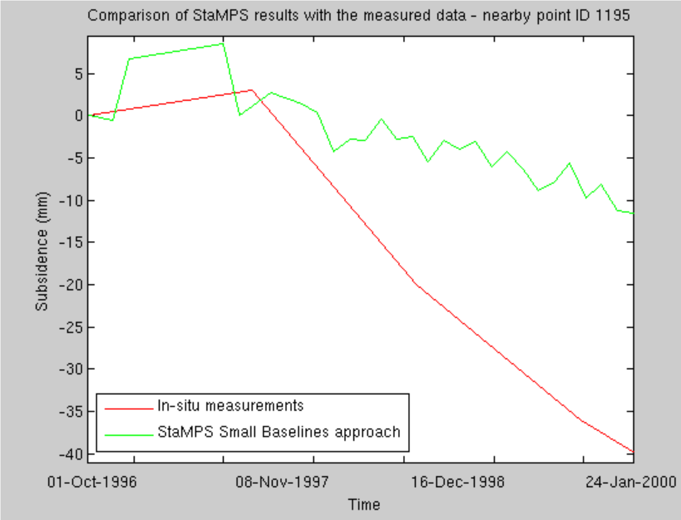

Fig. 3 – comparison of an SB point with a levelling point situated nearby (about 30 m further)

Conclusions

The InSAR processing of the mining area proves that it is possible to detect the land deformation from the satellite radar acquisitions. The multitemporal InSAR techniques are useful for 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 permanently subsiding areas, eventually the subsidence epicenters.
Problems of the OKR region that discredit many radar images from their usage in InSAR are:

- too much of trees and other vegetation over the subsiding areas
- due to the topography and an industrial zone, there is often a strong unwanted phase contribution from the atmosphere
- too high rate of subsidence causing phase jumps in pixels and a high slope of fringes

Some of these limitations can be evaded by using data from radar instrument with a higher resolution and longer wavelength – for example L-band SARs of cca 24 cm wavelength on board of satellites JERS (data of resolution about 18x18m until year 1998) or Alos (data of resolution cca 7x7m since year 2007). These data will be inspected during the next processing.
Another future plan is to create and emplace several corner reflectors in low reflecting critical subsiding areas to get a proper phase change information in future radar image acquisitions.
The existing interferograms show a coarse evolution of subsidence in the region during last 10 years. The consecutive closing of most of the mines brings about slowering down the subsidence in the area. A processing of Envisat data of 2009 is now a plan of the nearest future to get the most actual informations about subsidence.

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