MONITORING OF A LANDSLIDE INDUCED BY NEW HIGHWAY CONSTRUCTION

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ABSTRACT

During a highway construction, a nearby slope was discovered to be sliding down due to the geological character of the area. Our aim is to find the extent of the landslide and to find out whether the landslide was active even before the start of the highway construction.
Persistent scatterers InSAR method has been applied using two tracks of Envisat ASAR data. The area of interest has a rural character. The time-series of ASAR data suffer from a couple of 1-year time gaps as well as long perpendicular baselines.
Exclusion of the scenes from the processing was not feasible, because in that case there would be too few scenes for processing. On the contrary, we try to estimate the approximate accuracy empirically and separately for each date of acquisition.

1. INTRODUCTION

During the first decade of the new century, many kilometres of new highways were built in Czech republic. A segment of D47 highway in eastern Moravia was built on a slight slope and cut the Lysůvky village into two parts. After the construction started it was found out that due to unfavourable geological conditions resulting from concealed layers of quaternary deposits the slope is sliding down. Traditional means of monitoring including inclinometers and extensometers had been applied together with the mitigation measures. However, the extensometers provide only pointwise measurements and they had been installed very close to the highway itself. Moreover, the area is subject to complex geological conditions: it is located at the border of undermined area related to Stařič coal mine, where significant annual subsidence rate has been reported by other studies.
The aim of this project is to investigate spatial and temporal pattern of the slope movement: whether the slope was sliding down even before the highway construction started and to discover the extent of the landslide in order to estimate potential risk to the nearby houses in the village, if also affected.

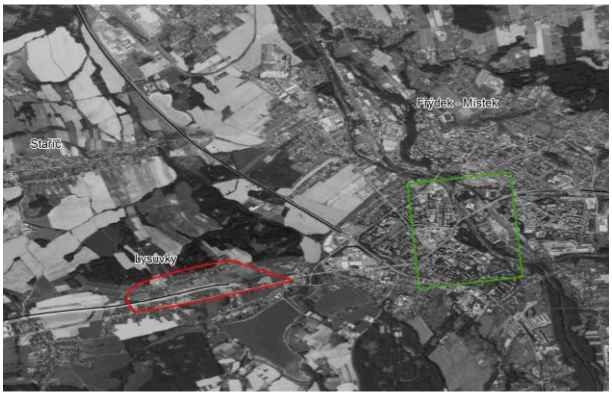

Figure 1. The area of interest (AOI) and its surrounding. Red line marks the area of interest, green line the reference area.

2. DATASET

For the area of interest, two ASAR datasets were available for the period 2003-2010:

- descending track 222, with 30 acquired scenes
- descending track 494, with 29 acquired scenes

As the area is rural and perpendicular baselines are not always short, the small baseline (SBAS) technique was utilised.
The selection of interferograms for processing was performed manually, considering their overall coherence. However, to compute the time series, it is necessary to connect all scenes within one cloud, and in addition, it is a general processing prerequisite of the StaMPS software [1].
As a consequence of not excluding a large part of the scenes, interferograms with lower quality had to be mixed with interferograms of higher quality. This came true especially for track 494, where longer perpendicular baselines resulted in lower coherence. Figures 2 and 3 display the baseline plots for both tracks.

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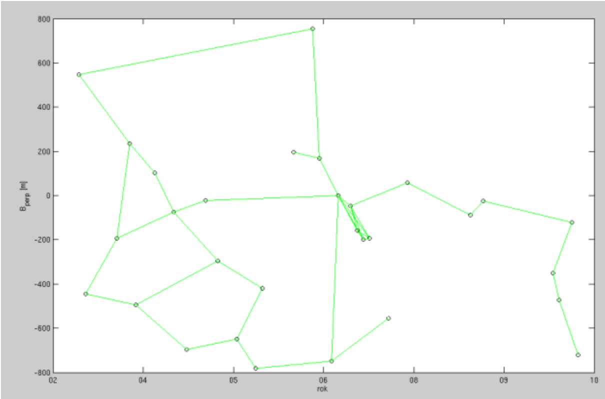

Figure 2. Baseline plot (track 222)

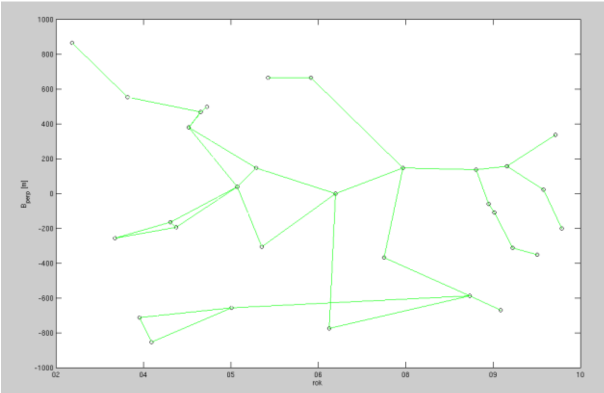

Figure 3. Baseline plot (track 494)

In both datasets, there are few redundant interferograms. This fact itself makes the evaluation of the accuracy more complex (the accuracy of movement estimated for each time of acquisition is different), and the accuracy is also significantly influenced by the coherence of the interferograms used (in a unevaluable way).

The master scene from February 2007 has been chosen for both tracks assuming the baseline plot (acquisition date is approximately in the middle of the temporal span) and that there are many coherent interferograms connected to the respective scenes.

3. ACCURACY ASSESSMENT

Accuracy estimation is an important part of the processing, especially in a rural area. It is obvious that in a case of combining high-quality interferograms with low-quality ones the accuracy of the movement estimate for each date of acquisition shall be different. However, it is not easy to evaluate the accuracy for the movement time series at all, as there are never more measurements available under the same conditions. In addition, the accuracy evaluated from the model residues is not applicable as we do not expect linear progress of movement due to possible break at the start of the construction or its slowing down later on.

Moreover, for retrospective monitoring of rural area it is difficult to find a quality reference point. Stability of the Lysůvky village, where a couple of persistent scatterers were detected, is unknown. Another nearby village to the North, is well known to be subject to subsidence due to undermining with subsidence rate exceeding 1 cm/year. Therefore we decided to use a reference point located in the Frýdek-Místek city which is expected to be stable. Because of relative flatness of landscape in the city with lack of significant buildings identifiable as persistent scatterers in the medium resolution ASAR images, we decided to use a phase mean of a larger reference area instead of a reference point. Outlines of the reference area are displayed in Figure 4.

The reference area was also used for accuracy estimation. The chosen reference area has approx. 300 detected PS (for both tracks, slightly less for 494). These PS were divided into 5 groups according to their coherence and averaged (coherence-weighted). The average phase was then used as the reference phase for the area of interest. In addition, phase standard deviation is computed for points in each coherence group (for each acquisition date), and this value is also used for the accuracy of the time series in the AOI (for the same coherence intervals).

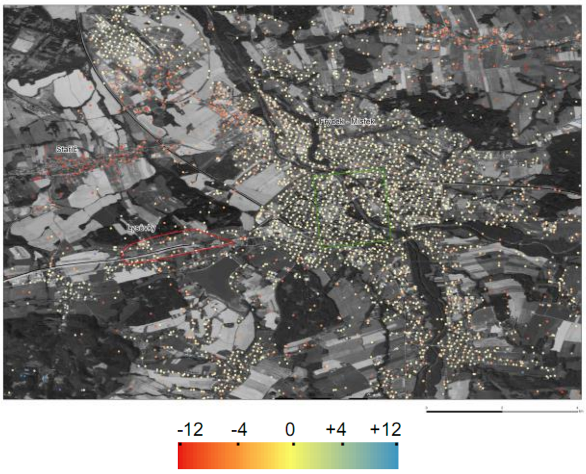

Figure 4. Estimated deformations in the area of interest and its surroundings. Green points display the reference area. The deformation scale is in mm/year and in LOS.

4. SENSITIVITY TO THE RADAR

The SAR instrument placed on-board a satellite measures the distance between itself and a reflector on the ground. Therefore, it is not possible to measure the movement in different direction than in radar line-of-sight (LOS). In a theoretical case, 2-dimensional movement information can be obtained by processing 2 datasets from different tracks and evaluation of the obtained results together, but this procedure is not possible in our case due to the fact that the adjacent tracks are both descending with difference of incidence angle of only 3^{o}. Therefore, the movement information from the second track can only be used for verification purposes and for point scatterers densification.

Therefore, we idealized the character of the slope movement assuming its direction to be known a priori: to be occurring exactly in the slope direction. The slope steepness is around 5^o, i.e. almost horizontal. In all cases, the SAR can "see" only a part of the real deformation, which is expressed by sensitivity (adapted from [2, 3]):

$$s = \cos\theta \sin\vartheta + \sin\theta \cos\vartheta \sin\alpha \qquad (1)$$

where θ is the radar incidence angle, ϑ is the steepness of the slope (negative if the movement is expected in the top-down direction) and α is the angle between the slope and the heading of the satellite.
Therefore, achievable sensitivity for the slope in the AOI was only 25%. In other words, we could detect only one quarter of the movement magnitude assuming its idealized direction.

5. RESULTS

The map of the detected deformations can be found in figure 4 (both tracks together). Time series for selected points in the AOI Lysůvky and in the Stařič village can be found in Figures 5-8. In these figures, the blue circles stand for the time series, with the blue line displaying the estimated velocity, and the blue points mark the 2-multiple of the estimated standard deviation (different for each acquisition date). Master acquisition is marked with the point inside a circle.
While homogenous pattern of deformation velocities was detected for Stařič village area, the PS points detected in the AOI Lysůvky have shown variable pattern resulting in higher amount of ambiguity. Similarly, the average velocities in the AOI were significantly lower (in the order of 1-2mm/year). The extent of the landslide could not be proved due to lack of PS points detected in the Lysůvky village.
The green and red sets of data help to identify phase unwrapping problems (if suitable, they can replace a blue circle). In some cases, the probability intervals blend, meaning that the standard deviations are so high that the deformations can be almost arbitrary.
The black dotted line refers to the velocity estimated only from the second half of the data, approximately from the start of the highway construction. Unfortunately, to compute this velocity, data with long time gaps and low-coherence interferograms had to be used and reliability of this estimate is inferior.

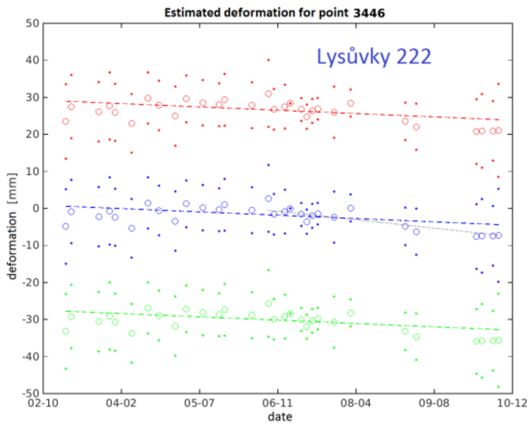

Figure 5. Estimated deformations for one point in the AOI (track 222).

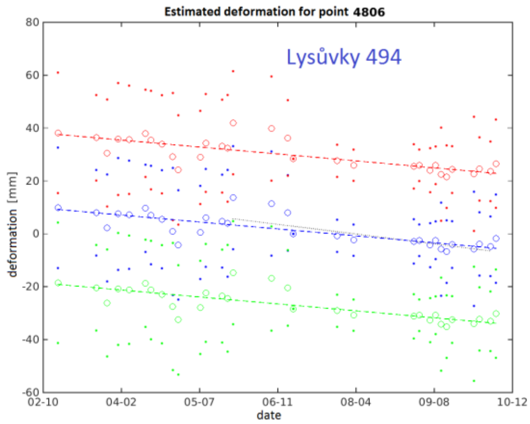

Figure 6. Estimated deformations for one point in the AOI (track 494).

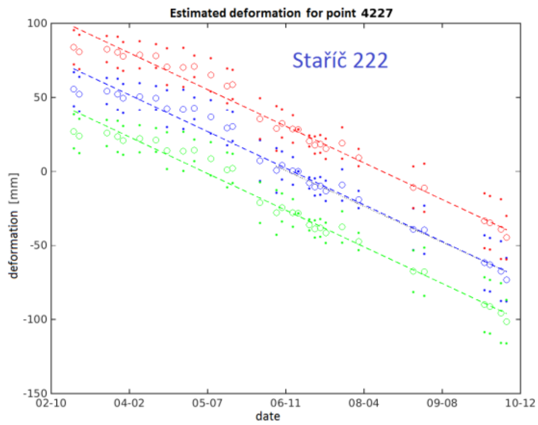

Figure 7. Estimated deformations for one point in the Stařič village (track 222).

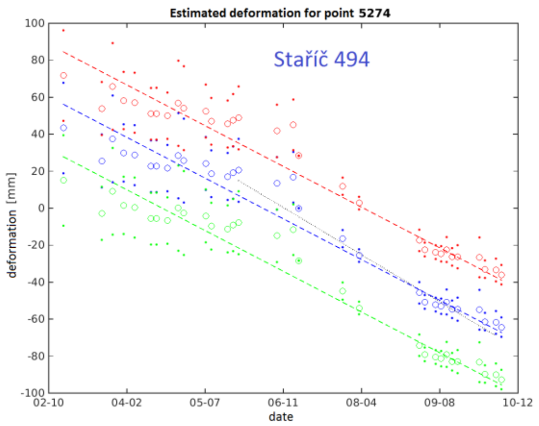

Figure 8. Estimated deformations for one point in the Stařič village (track 494).

6. CONCLUSION

The selected method has proven subsidence detection in the area surrounding the Stařič mine and village, where the identified extent coincides well with undermining extent shown in geological maps. The large scale of phenomenon, significant and stable magnitude of respective subsidence rate facilitated its detection by means of persistent scatterers technique using SBAS despite certain unfavourable properties of the data series (spatial resolution, irregular temporal coverage with long time gaps, relatively long perpendicular baselines).
However, the slope movements in the AOI of Lysůvky village were not detected by the technique. Most likely, magnitude of deformations is at the limits of detectability of the method, given by the character of the data as mentioned above, area (PS density) and also by the low sensitivity of available InSAR to this specific direction of movement.
Retrospective monitoring is always an issue especially due to lack of reliable reference sources and inability to perform parallel measurements or artificial corner reflection installation. Anyway, in case the phenomenon is above detectability limits, the archive InSAR could provide invaluable insight into its past development supporting early risk estimate and adoption of mitigation measures.

7. REFERENCES

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