Interferometric Determination of Subsidences in Prague City

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Abstract. Radar interferometry (InSAR) is a method used for deformation mapping within large areas, using radar images acquired by satellite instruments. Four ENVISAT stacks of SAR images are used, acquired from 2003 to 2009 in our project - track 43 (12 scenes acquired; ascending pass), track 122 (10 scenes acquired; descending pass), track 272 (13 scenes acquired; ascending pass) and track 351 (11 scenes acquired; descending pass). Unfortunately, no more scenes are available for the area due to conflicts with other projects. The processing of the whole scene would be too time- and memory- consuming, and that's why only the area of interest was cut from each scene and the process continued with these cuts. Several tunnels are finished after 2000 in Prague and some are still under construction. We are trying to find out whether there are subsidences within these areas. The permanent scatterers (PS) method is used for deformation detection. The processing is performed by IPTA (Interferometric Point Target Analysis) package, which is a part of the GAMMA software. Only appropriate point targets are used for further processing, while the rest of points are omitted. In conventional InSAR processing, many interferograms are obtained from all possible pairs of scenes. Unfortunately, interferograms with the perpendicular baseline longer than 300m are totally incoherent, so they are excluded from further processing. The IPTA method is iterative, so it is possible to add also the pairs with longer baselines in further steps. The topography is subtracted from the interferogram by using digital elevation model (DEM). The resulted deformation map can be influenced by the atmospheric delay variation or by inaccurate DEM, so we must examine the results and eliminate these kinds of artefacts to get the subsidences. Additionally, it is possible to compare the final deformation maps from various tracks for better results interpretation.

Keywords. Radar interferometry (InSAR), subsidence, permanent scatterers (PS).

1. Introduction

1.1. Area description

This paper is dealing with the deformation detection within the area of Prague city. Several landslides occurred in Prague in the past [2]. Nowadays, several tunnels were built in the same country after 2000 and others are still under construction. This leads to an assumption that some subsidences are possible.

The examined area is highly built-up and even small movement can cause large damage of buildings and constructions. We are trying to determine whether there are some subsidences within the examined area by IPTA method. This method is supposed to work well because sufficient amount of the stable point suitable for processing typically occurs within built-up areas (e.g. buildings, bridges).

1.2. Data description

Data of four ENVISAT stacks of SAR images were ordered from ESA. The images were acquired between 2003 and 2009; track 43 (12 scenes acquired), track 122 (10 scenes acquired), track 272 (13 scenes acquired) and track 351 (11 scenes acquired). In order to estimate the subsidences in Prague city, we decided to process first data from track 272, due to the highest number of scenes. This track was acquired during ascending passes (from south to north). That's why the images are vertically flipped. Scene 22871 was chosen as the master because it was acquired in the middle of the track acquisition time.

1.3. Method description

For deformation detection, the IPTA (Interferometric Point Target Analysis) is used. This method is based on the principle of permanent or persistent scatterers (PS) and is implemented within the GAMMA software.

Not the whole scene but only appropriate point targets are used for further processing. The process is faster, more effective and the sizes of data files are much smaller than in case of conventional interferometry. Also the pairs with long baselines can be used for the processing. On the other hand, the requirement of the critical baseline must be fulfilled in the conventional interferometry, otherwise the interferograms with baseline, longer than 300m, are totally decorrelated.

The outputs from the regression analysis include linear deformation rate corrections, height corrections, residual phases, unwrapped interferometric phases and point quality information. These results are used to improve the model [1].

2. IPTA processing

2.1. Point data generation

The scenes used for the processing were already resampled to the chosen master scene. The processing of the whole scene would be very time and memory consuming, therefore the area of interest was cut from each scene and the radiometric calibration was performed on these cuts (Figure 1). Also the Digital Elevation Model (DEM) SRTM-X was used to make the process faster and more robust. The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the Earth [3].

The model was transformed to the SAR geometry using the GAMMA DIFF&GEO software.

First, the baseline file and itab table was created by the base_calc programme. Itab is an ASCII file containing a list of interferometric pairs which will be processed. Each pair has validity flag which is possible to change (from 1 to 0). The maximum perpendicular baseline (bperp) was set to 350m and 27 interferograms were obtained. The range of perpendicular baselines varies from approx. -317 m to 347 m and temporal baselines vary from 70 days to 1680 days.

Then, the point list (plist) is created from registered SLCs by the pwr_stat programme. Candidate points selection is based on the low temporal variability of the SLC intensity and an SLC intensity above an threshold relative to the spatial average (minimum threshold set to 1). To evaluate the temporal variability of the candidate points, the mean/sigma ratio was calculated (minimum threshold set to 1.5).

The created plist contains the coordinates (range and azimuth pixel number) of the candidate point targets which will be evaluated during further processing. Our plist contains 56001 candidate points.

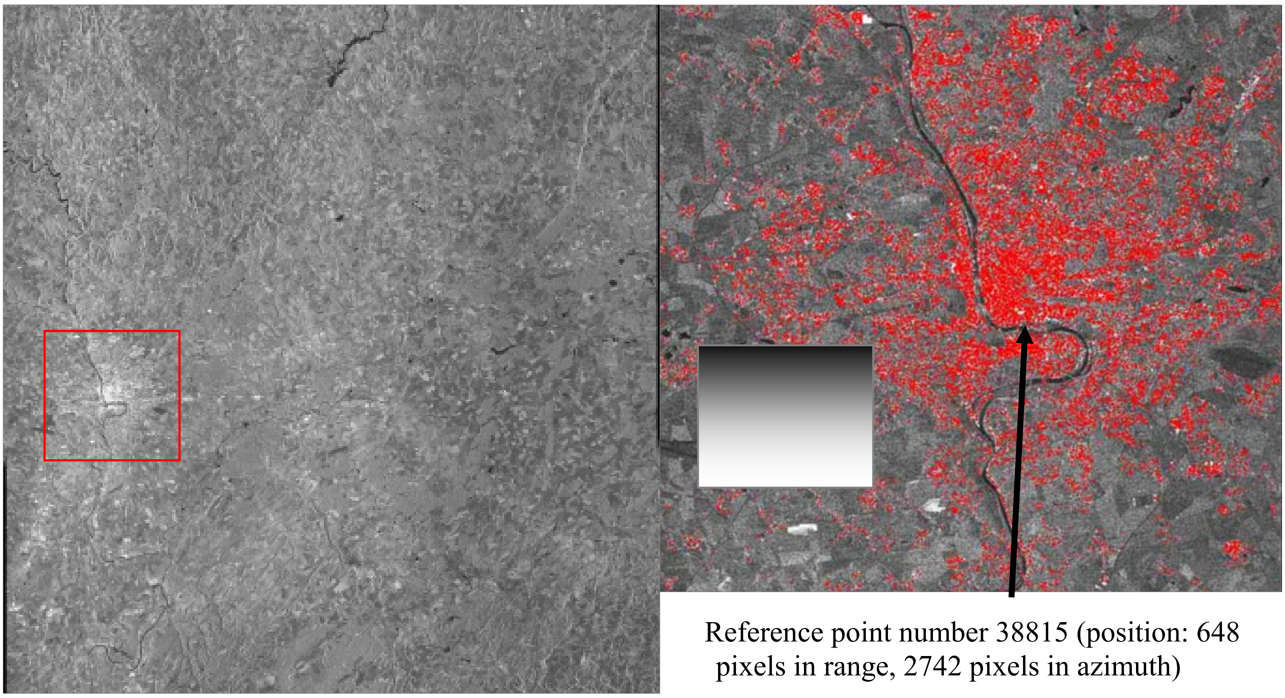


Figure 1: The whole scene (left) and the used cut (the red rectangle on the left of the scene covering Prague city area with candidate points (red dots, right). The images were displayed in multilook (1 in range ang 5 in azimuth) for easier interpretation.

DEM data was transformed from raster data to point data stack by the data2pt programme. Also the values from SLC at the target points were extracted and written to the point data stack by SLC2pt programme. Initial estimates of the interferometric baselines were calculated from the satellite state vectors by base_orbit_pt.

2.2. Differential interferograms calculation

The interferograms were calculated by the intf_pt programme which generates the interferogram from SLC point data stack. Then the simulation of the unwrapped interferometric phase was performed by the phase_sim_pt programme. Finally the differential interferogram was created by the subtraction of the unwrapped simulated phase from the complex valued interferogram by the sub_phase_pt programme (Figure 2).

All measurements were relative in interferometry. For the deformation detection a point must be determined to which the changes will be related. This reference point must be either stable or its deformation must be known. It is assuming that the area of Prague city is stable and a reference point will be stable too.

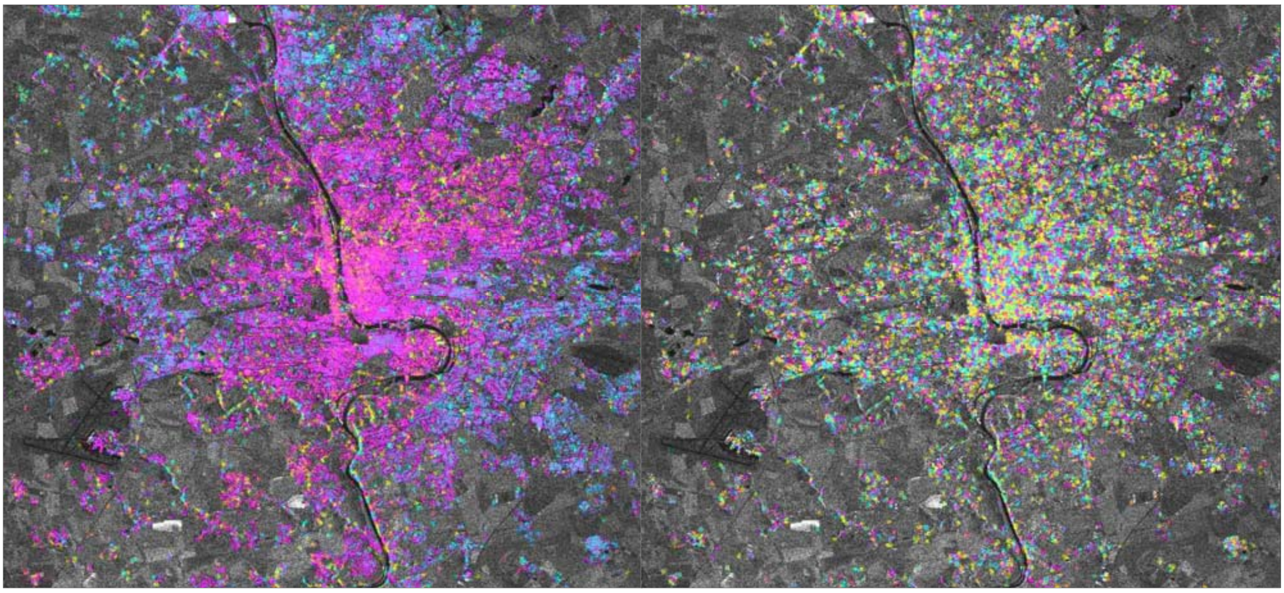


Figure 2: Differential interferogram obtained in an initial processing run for an interferometric pair with short perpendicular baseline (12 m, left). On the right the differential interferogram from last iteration for an interferometric pair with long baseline (803 m) is shown. One colour cycle corresponds to a 2π phase cycle. It is clearly seen that the differential interferogram with the short baseline is smooth while the other is decorrelated.

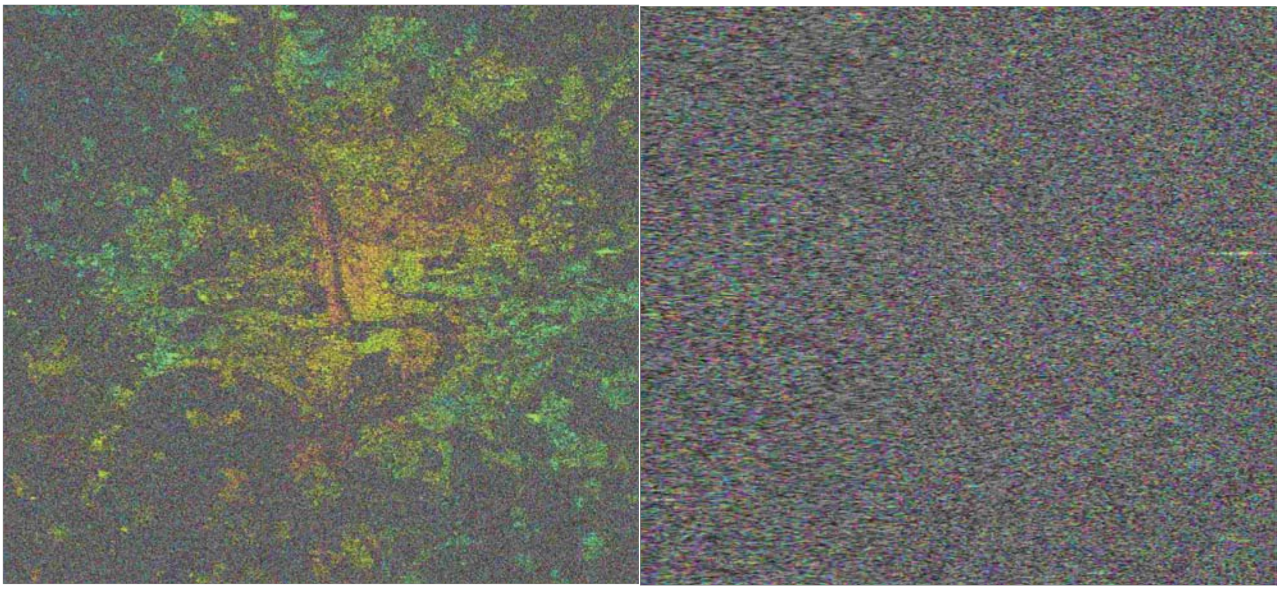


Figure 3: An example of the differential interferogram for the interferometric pair with short baseline (12 m, left) and for long baseline (802 m, right) from the conventional interferometry processing. The interferogram with long baseline is totally decorrelated and cannot be further processed.

The amount of the processed points depends not only on the quality of the target point itself but also on the quality of the reference point. Hence, several reference points were selected for processing and the number of used points for each reference point was compared. Since the number of points is about similar order, only one reference point was chosen for further processing – point 38815 (Table 1). It is located roughly in the center of the scene on the bridge. The scene size is 1100 pixels in range and 5000 pixels in azimuth (the multilook 1 pixel in range and 5 pixels in azimuth are used for the image generation).

Table 1. Table showing various tested reference points including their position within the image (range and azimuth pixel position) and the amount of processed target points with dependency on the used reference point. The reference point chosen for further processing is highlighted in bold.

Ref. point number	Range [pixel]	Azimuth [pixel]	Number of points
2306	685	337	14579
30067	766	2332	23910
38815	**648**	**2742**	**18054**
38816	649	2742	15339
38919	649	2750	14299
39788	573	2820	28270
39875	572	2826	28715
39888	574	2827	27509
39905	572	2828	27230
39973	574	2832	28129
44483	767	3079	27818
44565	767	3082	18388
44606	767	3084	27627
46394	693	3200	14836
49568	942	3516	13348
51150	159	3711	22237
55628	800	4871	18328

2.3. Regression analysis

In the next step, the regression analysis of the differential interferograms was performed using the def_mod_pt programme. The resulted height corrections were added to the heights used in the simulation by programme lin_comb_pt. Then the pairs with the perpendicular baselines up to 500 m were added to the process and the next iteration was performed, until all pairs were processed.

The point quality was re-calculated in each run. The standard deviation of the phase from the regression was used as a quality measure, permitting for example to detect and reject points which were not suitable for IPTA analysis. The regression was successful only if the phase standard deviation was smaller than 1.2 rad [1].

The table below shows the number of processed pairs with dependency on the baseline (Table 2). For our purpose (deformation detection) the temporal baseline was not important and it was not procesed. The table also shows the decreasing amount of the processed points for each iteration with the dependency on the baseline length.

Table 2. Number of processed pairs and target points with dependency on the length of the perpendicular baseline

Set bperp_max	Number of pairs	Real bperp_min	Real bperp_max	Number of points
350	27	-317	347	18054
500	37	-495	406	10550
600	46	-585	521	8805
700	54	-692	660	7288
800	58	-789	793	7149
900	61	-832	801	6397
1000	67	-990	945	5889
all	78	-1493	1427	4849

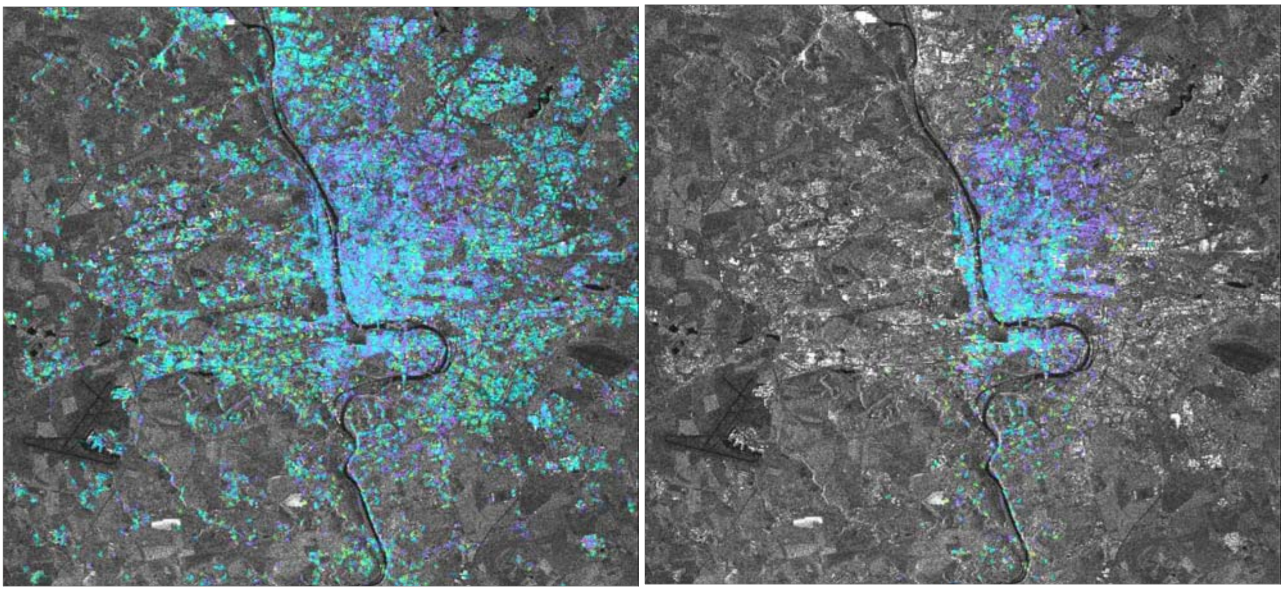


Figure 4: Relative linear deformation rate for the initial iteration cycle (maximum perpendicular baseline set to 350 m, left) and for the last iteration (all interferograms, right). One colour cycle corresponds to 0.05 m/year relative linear deformation rate. One can clearly see the decreasing amount of the processed points (relation to the baseline length) in the pictures.

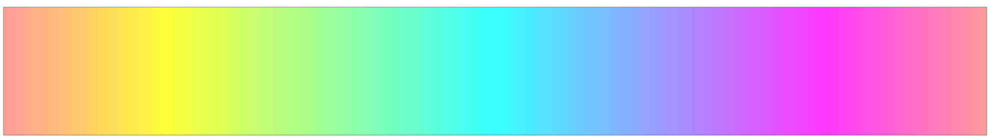


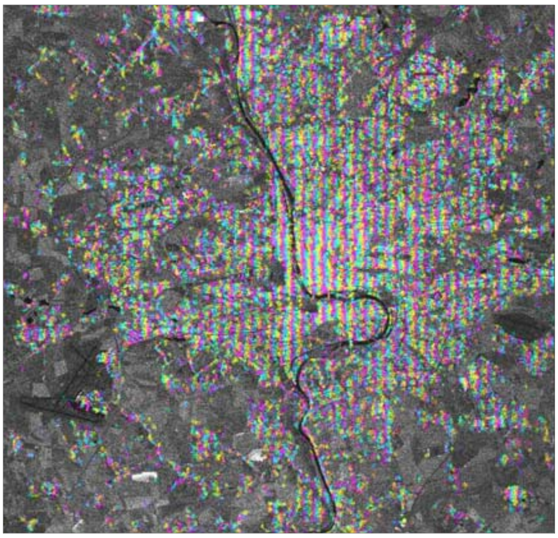
Figure 5: Colour scale for the deformation map, with the edges of ± 2.5 cm/year.

3. Conclusions

According to our results we are able to claim that there are no subsidences within the examined area with the obtained precision of the 1 cm/year. It is still possible that there are smaller subsidences which we are not able to detect now. In future, we plan to improve the processing estimating and subtracting the atmospheric influence, and possibly to exclude some interferograms from the processing.

Future work

The analysis of the interferograms of the 272 track will be finished (precision baseline estimation, atmosphere estimation). Some scenes can be excluded from the processing if it is necessary for the model improvement. After that, also the 43, 122 and 351 tracks will be processed and evaluated.



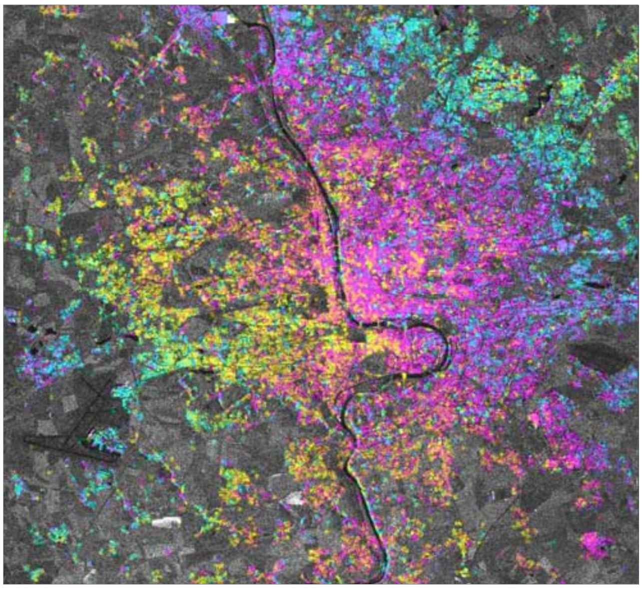


Figure 6: Example of the suspicious interferograms which will be further analysed. On the left there is an interferogram with errorneous flat-Earth phase subtraction. The precision orbits will be re-estimated for this pair and evaluated again. If the interferogram will not improve the scene will be excluded from the whole processing. On the right there is an interferogram in which the trend is clearly seen so it is candidate for the atmosphere influence removing.

Acknowledgements

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References

[1] GAMMA Interferometric Point Target Analysis Software (IPTA): Users Guide.

[2] Inženýrsko-geologické poměry (Engineering-geological conditions) via http://envis.praha-mesto.cz/rocenky/neziva/kap24.htm.

[3] http://www2.jpl.nasa.gov/srtm.