DEFORMATION MAPPING IN THE NORTHERN-BOHEMIAN COAL BASIN BY MEANS OF RADAR INTERFEROMETRY

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Abstrakt. Radarová interferometrie umožňuje mapování deformací zemské kůry pomocí satelitních snímků, bez nutnosti pozemních měření, která jsou zdlouhavá a drahá. Její přesnost může teoreticky dosáhnout až několika mm/rok. Interference však vzniká jen na objektech, které nemění své vlastnosti v dlouhém časovém horizontu - většinou jde o objekty umělé (silnice, budovy apod.). Tímto způsobem se snažíme spočítat poklesy na několika místech Severočeské hnědouhelné pánve, kde byly některé komunikace postaveny na výsypkách.

Klíčová slova: InSAR, deformace zemské kůry

Abstract. Radar interferometry allows for Earth-crust deformation mapping with the use of satellite images, without the necessity of expensive on-site measurements. Its accuracy may even reach several mm/yr in the theoretical case. However, it works only on objects which are stable in a long-time horizon - typically, these are artificial objects, such as roads, buildings etc. We use the radar interferometry to compute the subsidences on various places at the Northern-Bohemian coal basin where several communications were built on waste dumps.

Keywords: InSAR, deformation mapping

1 Introduction

SAR interferometry (InSAR) allows mapping Earth-crust deformation using satellite data, i.e. without the necessity of in-situ measurements, which are considered very expensive. However, this method is only usable in areas with no vegetation and for object, which are not expected to change during monitoring. Generally considered, it can be said that InSAR is suitable for artificial objects, such as building, roads, railways, etc. In addition, it is more important to measure the deformations for these artificial objects, than for forests or agricultural fields.

We concentrate on the Northern-Bohemian brown coal basin where mining has been performed for several centuries, using different mining methods. In past, lots of deep mines were opened - however, these areas are expected not to subside any more. Currently, most coal is being mined using open-pit mines, which are then mostly recultivated to forests, lakes, agricultural fields etc.

However, there are some areas where an artificial object was built on a waste dump, such that the well-known Ervěnice corridor (between Most and Chomutov), or the road between the villages Košťany and Mstišov (near Teplice). We decided to map deformations in these two areas using InSAR.

2 Theory

InSAR uses two SAR scenes, acquired by a satellite carrying SAR, which is ERS-1/2, ENVISAT, RADARSAT, JERS-1/2 and others. These scenes are complex-conjugate-multiplied, giving the multiple of their magnitudes (not important) and the difference of their phases, which is related to the difference of the distances between the satellite and the reflector in the two scenes. The phase map is called an interferogram. However, before actual postprocessing, the phase given by the flat-Earth and phase given by the DEM must be subtracted from the interferogram, and then the interferogram is considered to contain only the atmospheric signal, deformation signal and noise.

Atmospheric signal is kind of strong, however, it is assumed to change only slowly in the space, and if not processing large area (which is our case), only a constant can be subtracted from the whole interferogram - we call this process phase reference to a certain point. The deformation signal is what we are looking for.

The most significant limitation of InSAR is the ambiguity of the phase - the measured phase is always within the $(-\pi, \pi)$ interval; however, the multiple of 2π to be added to the measured phase is never known. The step where the phase is converted from the ambiguous interval to the unambiguous real number is called phase unwrapping. Classically, this is performed in 2D array of the interferogram and the criterion is set for the unwrapped interferogram to have as little phase jumps (more than 2π difference between the neighbouring pixels) as possible. However, this criterion is set artificially and the result may be unreliable, especially in low-coherent areas (where the phase value is also considered unreliable).

We propose a method suitable for processing of stack of data where phase unwrapping errors are estimated iteratively in the third dimension - time. The method is not tuned yet - however, the preliminary results are promising. The method is described in the next section.

3 Iterative adjustment

We generate as many interferograms as possible from the available data. That means each scene is paired with each other, with previous resampling all scenes to a selected master. Then, the most coherent points are selected from the interferograms (most of them are contained in the object we are monitoring) and then the most coherent interferograms are selected which enter further processing (about 100).

First step to be performed is referencing each interferogram to a single point, which is ideally stable. This step is performed to eliminate a large part of the atmospheric influence, together with other systematic errors which may originate e.g. from orbit errors.

The following processing is performed for each point individually, starting at the reference point and when selecting the following point, the point which has the most already-processed neighbouring points, is selected.

Interferograms doubles and triples are constructed. In these cycles, the phase sum must be close to zero [1]. This is one of the criteria for the iterative adjustment - the other is the unique standard deviation, which is required to be as small as possible. The interferograms, for which the sum is larger than a threshold, are then excluded (for the particular point). The phase sum is first computed using complex multiplication, i.e. the unwrapping errors are not counted for in this step.

The unwrapping errors are then estimated from the neighbouring points (the unwrapping errors are assumed to change slowly in the space). For the first point, zero unwrapping errors are assumed (this is the unwrapping seed and the reference point so the phases are zero or close to zero here).

Then, adjustment is performed, modelling that each interferogram is a difference of two scenes. The aim of the adjustment is to estimate the phases of the scene, which can be directly computed into deformations. After the initial adjustment, the residues are checked and if any of them is larger than $\pm\pi$, the phase is corrected by an appropriate multiple of 2π (only one residue at a time). While the unique standard deviation is getting lower, this process is continued. When all residues are smaller than $\pm\pi$, or the unique standard deviation is higher, the phase sums in cycles are checked (now also considering unwrapping errors). If the cycle conditions are filled, the adjustment is finished for the point. If not, the space of ambiguities is searched for the best solution; however, it is not possible to search the whole ambiguity space because of its size - the search is limited to about 100 searches, and the information from the unfilled cycle conditions is used. If the ambiguity search improved the solution, it is used as the starting point for a new iteration.

However, due to a number of measurements excluded during the check process, it may happen that a scene is totally excluded, i.e. all interferograms containing a particular scene are excluded, making it impossible to compute the deformation for the particular scene for the point. This must be counted for when creating the adjustment matrices.

We plan to implement statistical tests, which decide whether the particular point fulfils precision expectations, and can therefore be said to be "right". However, the implementation of such test requires setting the precision expectations and correct systematic errors (at least partially), which enter to the system by referencing to the single point.

4 Preliminary results

We are not yet sure how to display our results. Some results are shown in figure 1 - these are the deformation maps for the Ervěnice corridor at different acquisition times. Also, it would be interesting to plot temporal deformation development for a single point - however, this is probably to be largely influenced by atmospheric delay, which is temporally almost uncorrelated - we decided to filter the atmospheric influence post-ex. In addition, it is useless to plot the temporal behaviour for as many as 3500 points.

We therefore plan to think more about the result representation. GIS is possible, but what GIS (except for GRASS) allows to import binary data?

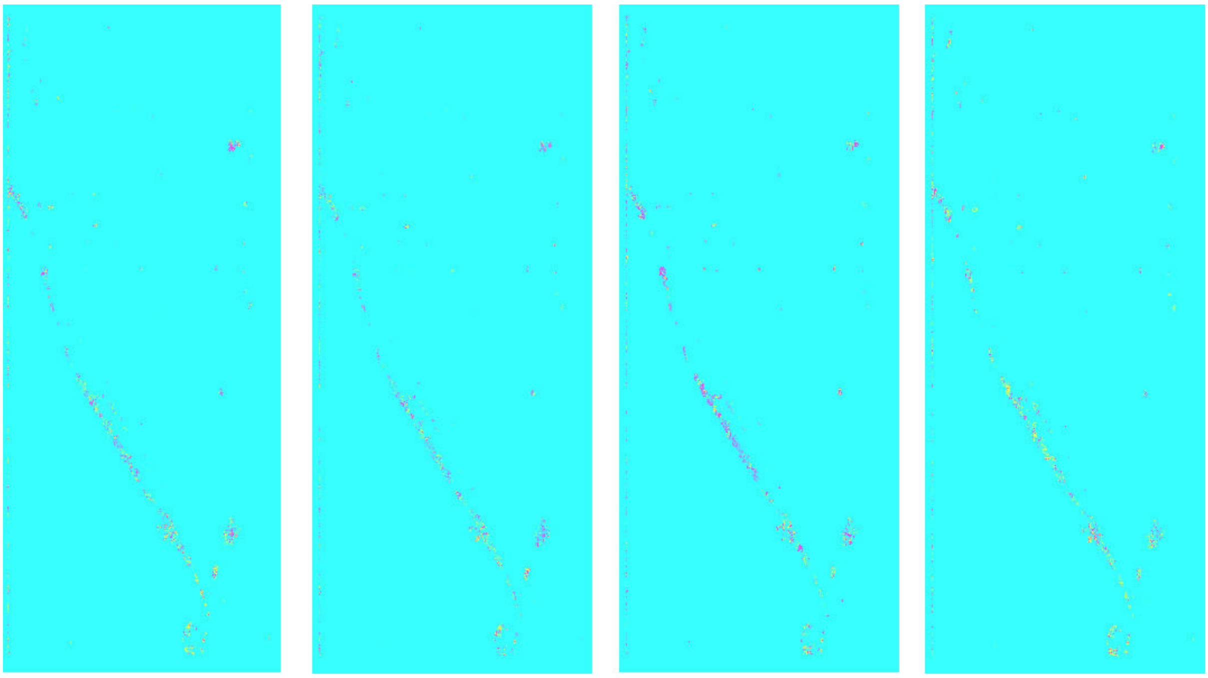

Fig. 1. Deformations computed for 1996-03-17, 1996-06-30, 1997-09-29, and 1998-04-27. The colour scale is shown in figure 2.

Fig 2. Colour scale, -3π on the left border, +3π on the right border

However, we found out that there is an error in referencing, making the referenced phase erroneous which causes that:

- the phase sums in cycles are far from zero,
- although the phases are spatially continuous, it is more complicated to find the right ambiguities,
- the results, which correspond to the temporal dimension, are not reliable,
- statistical test cannot be used to filter out the imprecise points, because phase standard deviation cannot be reliable enumerated.

However, the idea of referencing the phase with regard to one point is correct. What is not correct is the phase of the reference point, and although its precision is improved using the average of the neighbouring points, there still remains a large error (in addition, the average of the wrapped phase is ambiguous). We are still working on improving the computation of the reference value.

5 Conclusions

The results are only preliminary; however, it seems that the results can be made spatially continuous, even if the unwrapping errors are estimated iteratively during adjustment. However, interferogram referencing seems to be a key problem with not so evident solution. We will continue working on it.

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7 Reference

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