# MEASUREMENT OF LANDSLIDES IN DOUBRAVA USING RADAR INTERFEROMETRY

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**Abstract**

Landslides monitoring is one of the main areas of satellite radar interferometry usage. This project aims on application of the method for measurement of landslides in Moravian-silesian region. A slope in Doubrava city is monitored that is known for a slow landslide due to erosion activity of water. A dense vegetation cover on the slope is causing decorrelation in the interferometrical processing of the Envisat ASAR images that degrades the phase values of the images. For this reason three specially designed corner reflector of the radar signal were installed on place, attached to hydrogeological boreholes that measure a changes of ground water level in time on the place. To enhance the precision of the landslide evaluation, phase values of the images are corrected by influence of signal delay through atmosphere using GPS meteorology method. Five acquisitions from the period of May until September 2010 from the Envisat ASAR sensor were processed using Permanent Scatterers method combined with other described methods for processing using very low number of images. Corner reflectors distributed in the slope surroundings were always rotated in a slightly different way by manipulation – that caused a different amount of their reflectivity and a phase shift of the radar signal corresponding to detected position change in order of millimeters. Due to slowing down of the landslide during the year 2010 this error had a significant impact on the quality of the results, anyway the methodology was confirmed as correct and it can be used in similar incoming projects.

**Keywords:** landslides, radar interferometry, Envisat, corner reflectors

## INTRODUCTION

A hill in Doubrava with a height of 282 m and a slope of relative lift 70 m with steepness of about 30 m per 100 m distance is known to be sliding mostly due to the groundwater activity. The groundwater level is being monitored regularly by Geotest Corp. using hydrogeological drills. The landslide activity is gradually decelerating but seems to be still active. The groundwater activity is at its peak during strong rains and floods that occasionally happen in the area.

The idea of this project is to detect and measure the velocity of the landslide using satellite data. Since the hill is covered by vegetation, the radar interferometry (InSAR) results from Envisat ASAR images are totally depreciated by temporal decorrelation and therefore it cannot be monitored this way. The aim of this project was to overcome this limitation by installing corner reflectors on the site and so evaluate the slope movement during the year 2010. The hill wasn't monitored geodetically, unfortunately it wasn't possible to compare the interferometrical results with a ground truth. Anyway, in several scientific publications the methodology has been proven as reliable and the results could achieve a centimeter match (supposing high signal-to-noise ratio) in comparison with the levelling data in the areas of a slow deformation activities that are similar to expectations of this project area of interest.

This paper includes only preliminary results that need to be further enhanced.

## CORNER REFLECTORS

Usage of corner reflectors was already documented in many papers as a technique with successful results. Corner reflector is an object designed to reflect the received radar wave in the exactly same direction. Several types of corner reflectors exist. The optimal reflection is ensured by appropriate geometrical setting and orientation of the reflector and a smooth material with a high dielectric constant. As a material, the aluminum with a dielectric constant of around 9 (enough to avoid penetration of the radar wave) was chosen to create a trihedral corner reflector with square sides of 80x80 cm (see Fig. 1). The computed theoretical radar cross section (RCS) of the reflector using Eq. 1 (Hanssen, 2001) is RCS=36.92 dB. To detect the corner reflector on the SAR image, at least 15 dB difference amongst surrounding pixels should be ensured. The corner reflector is designed to be as smallest as possible with keeping its proper functionality to allow its economically effective reproduction on other projects.

**Eq. 1**

$$RCS = \frac{12\pi \cdot a^4}{\lambda^2} \quad (1)$$

The corner reflector (CR) is designed to be mountable directly on a hydrogeological drill. Three CRs have been constructed to be deployed on two drills on the observed hill and third on a stable place in the center of Doubrava city as a reference point. Because the drills are situated on an unsecured area that is visible from a nearby road, the CRs couldn't be installed permanently during the whole year. Because its construction enables to mount the CRs again on the identical location, the CRs were always mounted on place only in the acquisition day and were carried away afterwards. It wasn't practically possible to orientate the CRs identically in every installation. That's why we have to count with a lower precision of the interferometrically estimated landslide velocity, even that the theoretical tolerance of the CR orientation to the satellite line of sight to achieve its strong reflection is relatively broad – even 5 degrees difference between the CR centerline and the satellite line of sight in the azimuth direction will provide sufficient reflection (Norris et al., 2004).

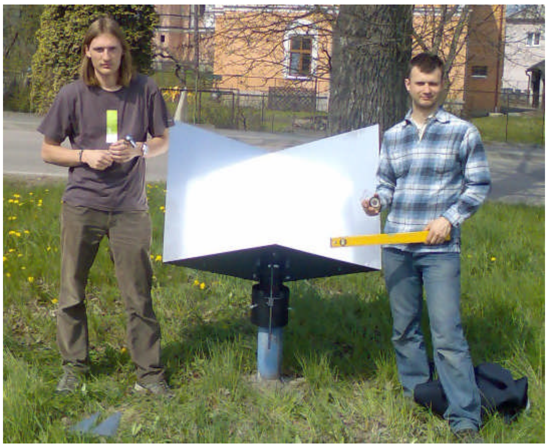

**Fig. 1.** Corner reflector mounted on a hydrogeological drill

## CORNER REFLECTORS IN SAR DATA ACQUISITIONS

Only five Envisat ASAR acquisitions of Doubrava surroundings could be planned for the year 2010. On 22nd October 2010 Envisat has changed its orbit descending of 17.4 km. There is no inclination drift control anymore, the perpendicular baselines can reach values even 20 km, while the limit for InSAR is around 1 km. Only areas in 38 degrees of latitude are covered by InSAR available acquisitions (Miranda, 2010).

Acquisitions were planned in advance for the year 2010 (until the October). Because of conflict with projects of higher priorities, the acquisitions of 15th February and 22nd March couldn't be ordered and the acquisition of 26th April had to be achieved in H/H polarization mode (means sent and received horizontally oriented radar wave) while other executed acquisitions at 31st May, 5th July, 9th August and 13th September had to be ordered in polarization V/V. In the end, only 5 acquisitions could be ordered that will include installed corner reflectors. Normally it is not eligible to combine images with different polarization interferometrically since the physical objects reflect such waves in different ways, based mostly on different geometrical orientation. But in the case of corner reflectors this is theoretically of no concern because if the reflectors are oriented correctly, they would reflect the waves identically.

An example of a corner reflector visibility in a radiometrically calibrated intensity SAR image is figured on Fig. 2. The value of reflectance in dB is 35.9 dB. Because of coarse resolution of ASAR data (approximately 30x30 m per pixel) the intensity of pixels containing CRs is influenced also by other surrounding strong reflectors. The georeference errors could easily overcome 100 m and the surroundings contain other sources of quite strong reflectance (possibly a nearby water well etc.), therefore it is sometimes not possible to certainly identify the location of CRs.

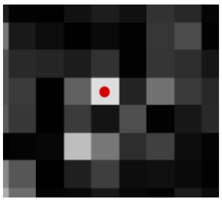

**Fig. 2.** Corner reflector visibility in a 31-05-2010 Envisat ASAR image.

## INSAR PROCESSING

Theoretically, the radar interferometry has the abilities to evaluate terrain deformations in the order of millimeters but the radar phase measurements can be influenced by many factors increasing noise and can often discredit their successful interferometrical combinability. The applied Doris interferometrical processor includes several modules to filter out main noise and decorrelation errors. In addition, to maximally improve the InSAR evaluation accuracy, the errors caused by radar wave delay through the atmosphere are to be removed by GPS meteorology - modeling of the amount of atmospheric moisture and evaluating of thereby delay. The atmosphere moisture phase contribution appears in interferograms as a false terrain deformation of a relatively large scale. It can be modeled and removed also by using algorithms working with a stack of many radar images, such as Permanent Scatterers technique. Unfortunately, during 2010 only 5 images are available. This count is not sufficient for certain model of atmospheric errors. Another ongoing project will model the atmospheric influence using 6 more images of 2009 and the results will be compared to that from GPS meteorology attempt.

All available Envisat ASAR images were combined using Differential InSAR technique (creating an interferogram from two images and subtracting a DEM to remove topography phase contribution). The achieved results were affected by temporal decorrelation so much that they couldn't be interpreted, as it was expected. Because of a longer wavelength (that penetrates through the vegetation) Alos PALSAR data were also available, we have created an interferogram from them presented in Fig. 3 b. The interferogram shows a relative terrain changes in the period between 27-01-2008 and 13-03-2008 (46 days) with a scale of 11,8 cm per one colour cycle. The monitored hill is located in the area visible as a reddish mark in the north-west part of the image. This can be interpreted as a detected slope movement of several centimeters towards the satellite line of sight, i.e. the landslide could be moving slightly to the west or it can be an uplift. Unfortunately, due to relatively large perpendicular baseline between acquiring satellite position (493 m) the interferogram is more sensitive to the topography. Therefore this artifact will be interpreted as caused only by a DEM error.

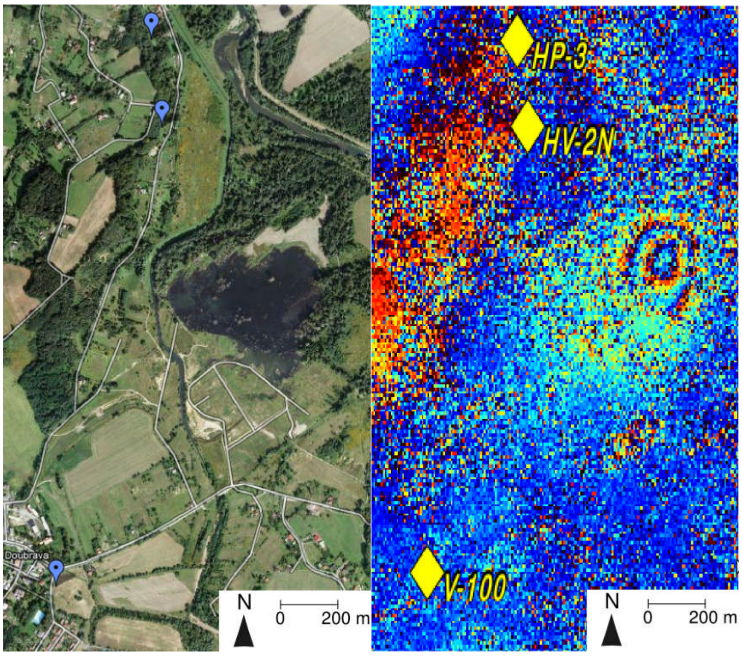


**Fig. 3.** Locations of installed corner reflectors in Doubrava. Right part represents Alos PALSAR interferogram between 27-01-2008 and 13-03-2008.

The main processing has been performed by StaMPS software package. As expected, a very few (and not very reliable) evaluated points called persistent scatterers were found on the monitored hill. Because of a very small number of 4 images processed it seems not possible to correctly evaluate DEM error and atmospheric phase screen. More processing will take place using earlier datasets without installed corner reflectors. The configuration of processed images with regard of their Doppler centroid used for focusing and perpendicular baselines of the satellite position between the images (see Fig. 4) seems optimal to achieve good results. The outlying image taken at 26-04-2010 was included only for processing of pixels containing corner reflectors since its polarization is H/H while the other images are polarized on V/V.

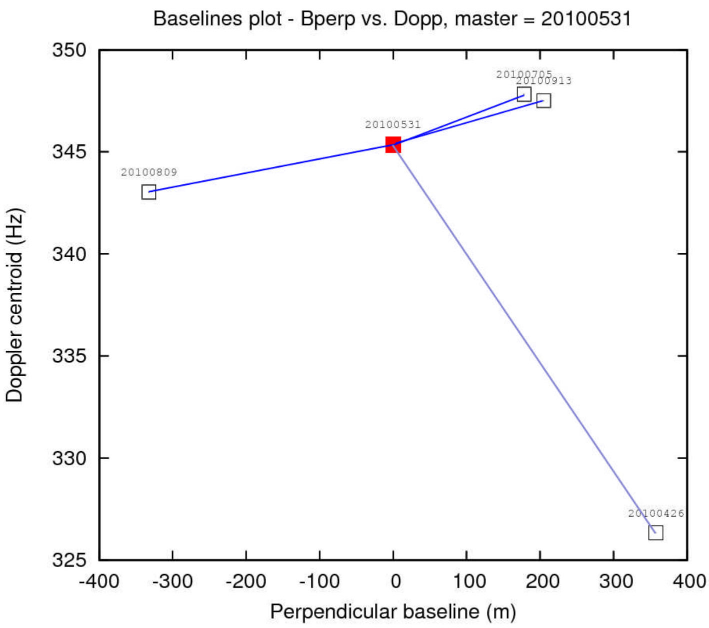


**Fig. 4.** Baseline plot – configuration of acquisitions used for corner reflectors InSAR processing

Unfortunately the corner reflectors were not detected or removed after their manual addition by the StaMPS algorithms. This seems to be a problem with installation of the reflectors on place or setting of higher confidence of adjacent persistent scatterers by StaMPS that caused the reflectors removal in the weeding stage. At the moment, there are no successful results that can be presented in this paper.

## GPS METEOROLOGY FOR ATMOSPHERE DELAY CORRECTION

There exists an unquestionable fact that signals emitted by InSAR passing through the atmosphere are being affected by it and a delay of the signal occures. Total delay of the signal in the zenith angle can be separated in two parts - larger quantity which is caused by the hydrostatic part of the atmosphere (zenith hydrostatic delay) and smaller quantity caused by the wet part of the atmosphere (zenith wet delay, ZWD). The hydrostatic part is dependent mainly on the surface pressure and temperature and the wet part on the water vapour. Atmospheric water vapor effects represent one of major limitations to accuracy in InSAR applications mainly due its large spatial and time variability. Knowledge of ZWD values would help to reduce this limitation to minimum.

In general, the atmosphere and water vapor in particular affects GPS and InSAR signals similarly. From this reason it is possible to determine delays from GPS measurements and use them as a correction for InSAR. (Xiaogang et al., 2008, Onn, 2006). GPS measurements are being succesfully used for water vapour determinations for long time. Those products can be used in numerical weather prediction models. Processing GPS ground measurements in proper software like Bernese GPS SW give zenith total delay values for location of GPS receiver in chosen time steps. For subsequent ZWD determination atmospheric pressure and temperature values measured at the same location and time are neccesary. (Bevis et al., 1992, Duan et al., 1996). Better results are acquired when differenced ZWD value from different times is applied on interferogram instead of using absolute values of ZWD for individual InSAR image. (Li et al., 2006).

In the time of writing this paper the GPS meteorology method wasn't applied to the processing for correction of radar wave delay through the atmosphere. During several radar acquisitions the atmosphere contained a strong moisture, only in the 13-09-2010 there was no rain over the area of interest. It is necessary to correct interferograms for this delay to achieve reasonable results.

## CONCLUSIONS

Because of a short time dedicated to the processing, the project is not finished yet. Because of manipulation of corner reflectors between the acquisitions, some extra errors could have been caused lowering the expected precision of measurement evaluation. Furthermore, only 5 acquisitions are hard to investigate with standard multitemporal methods that assume usually 15 or more acquisitions to achieve a reasonable overview about terrain deformation in time. The project will continue developing a methodology of using define pixels to evaluate the rate of terrain deformation even from a few acquisitions. Most probably it will be in the form of a custom scripts using StaMPS processing software.

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