Ground based Synthetic Aperture Radar (GBSAR) interferometry: which advantages for the monitoring of concrete and earth-filled dams?

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Abstract

In this work we presents the results which have been obtained using the Ground-based Synthetic Aperture Radar (SAR) interferometry to measure the surface displacements of the whole dam surface.Two case studies are presented, all located in Italy. Both concrete and earth-filled dams are studied. The topics of synergy between GBSAR measurements and finite element models and merging of SAR measurements acquired by different GBSAR locations and/or spaceborne SAR sensors are discussed.

Key words: Synthetic Aperture Radar (SAR), Ground-based SAR (GBSAR), SAR interferometry (InSAR), concrete dam, earth dam

1 INTRODUCTION

The technique of Ground-Based Synthetic Aperture Radar (GBSAR) intterferometry has been applied in the last decade in application such as monitoring of landslides (see (Antonello, G., et al. 2004) and (Nico, G. et al., 2015) and references therein), bridges .(Pieraccini, M. et al, 2006), dams (Mascolo, L., et al. 2014) and terrain mapping at a local scale (Nico, G. et al. 2004), (Nico, G. et al. 2005). The advantage of GBSAR interferometry with respect to many traditional techniques is its capability to provide areal information on the displacement field rather than measurements of displacements in only a few points. When using this technique in the monitoring protocol of a dam there could be two questions:

a) How can we assess the precision of GBSAR measurements in the field?
b) How can we use the GBSAR measurements to assess the output of Finite Element Models?
c) How can we estimate the displacement vector starting from the LOS displacement maps provided by GBSAR interferometry?
d) Is it possible to assess the quality and consistency of a GBSAR measurement even in absence of measurements from other traditional techniques?

In this paper we will present a few case studies of monitoring of both concrete and earth-filled dams by GBSAR interferometry trying to provide answers to the above questions.

2 ACCURACY AND PRECISION OF GBSAR DISPLACEMENT MEASUREMENTS

In this section we describe an experiment which has been carried out to assess both the precision and accuracy of GBSAR displacement measurements in the field. A corner reflector mounted on a micrometric screw was used. A set of fourteen SAR images were acquired as well as the corresponding positions of the micrometric screw. A set of thirteen interferograms was generated by processing each SAR image with the subsequent one. The horizontal displacement of the corner reflector was obtained using the relationship

$$D_{DS} = \frac{\lambda}{4\pi} \cdot \frac{1}{\cos\alpha} \Delta\varphi \qquad (1)$$

where α is the radar antenna elevation angle..The final result is estimated in Fig. 1, which reports the position of corner reflector along the time needed to acquire the fourteen SAR images. The estimated position of corner reflector is represented as a green star. These estimated displacements have been compared with the true positions of corner reflector. It has been found that GBSAR interferometry can estimate the position of corner reflector with a sub-millimeter accuracy and precision.

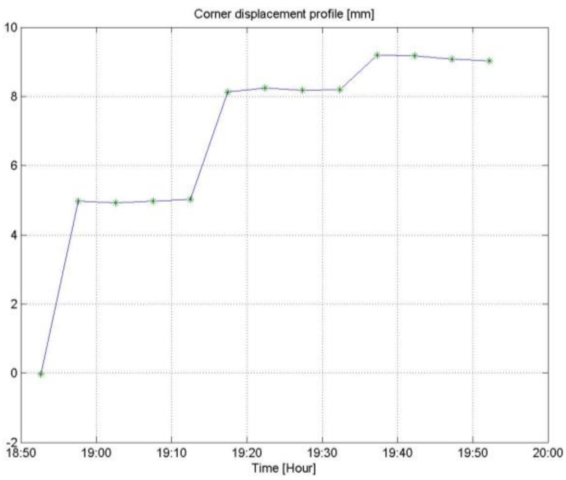


Fig. 1 Displacements of corner reflector measured by GBSAR interferometry vs acquisition times of SAR images

3 CASE STUDIES

In this section we present some results of different monitoring campaigns of both concrete an earth-filled dams. We start with the description of results which have been obtained during a study of displacements of a concrete dams, focusing more on the comparison with finite element modelling. Radar images are acquired every 5 minutes and the time series of dam displacement maps is estimated. Repeated campaigns have been carried out by-re-installing the radar system at the same location. GBSAR measurements have been compared with the displacements of three marks installed along the dam crown and measured by traditional topographic instruments. Furthermore, numerical simulations are used to investigate the advantage of displacement information provided by GBSAR when compared to point-like topographic measurements. Fig. 2 displays an example of displacement map provided by GBSAR. The map is rendered on the mesh of the dam surface. Positive displacements mean that the dam distance from the radar increased, i.e. a up-stream displacement occurred. A maximum displacement of about 3 mm in the up-stream direction was observed at the centre-top of dam. This maximum displacement is not located at the crown where a mark of the permanent topographic monitoring system is installed, but a few meters below.

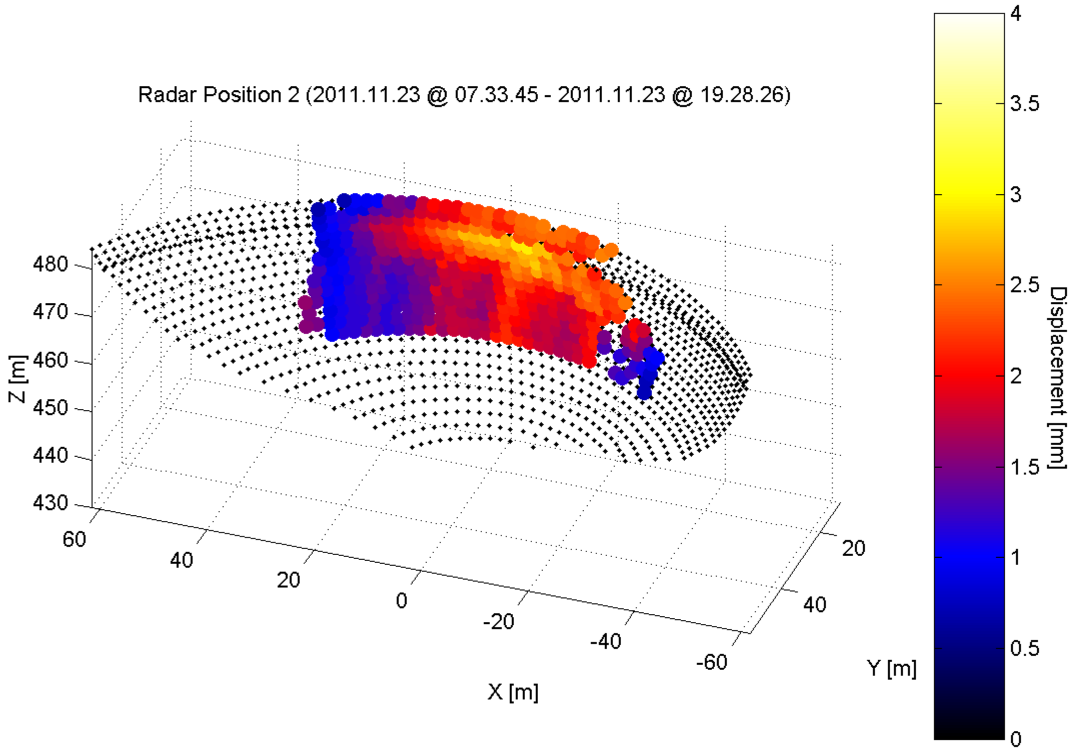


Fig. 2 Map of dam displacements rendered on the dam surface

To facilitate the inspection of displacement maps, the time series of GBSAR measurements can be extracted at any point of the dam mesh. A simulation of the elastic behaviour of the dam between two successive campaigns was run and compared with the corresponding GBSAR displacement map shown in Fig. 3. Both changes in the water level and temperatures was taken into consideration. The result of simulation, shown in **Chyba! Nenašiel sa žiaden zdroj odkazov.**, seems to confirm the differential displacement of the dam, a up-stream movement at the top and a down-stream displacement at a lower height. This comparison also shed light on the usefulness of the 2D displacement information provided by the GBSAR.

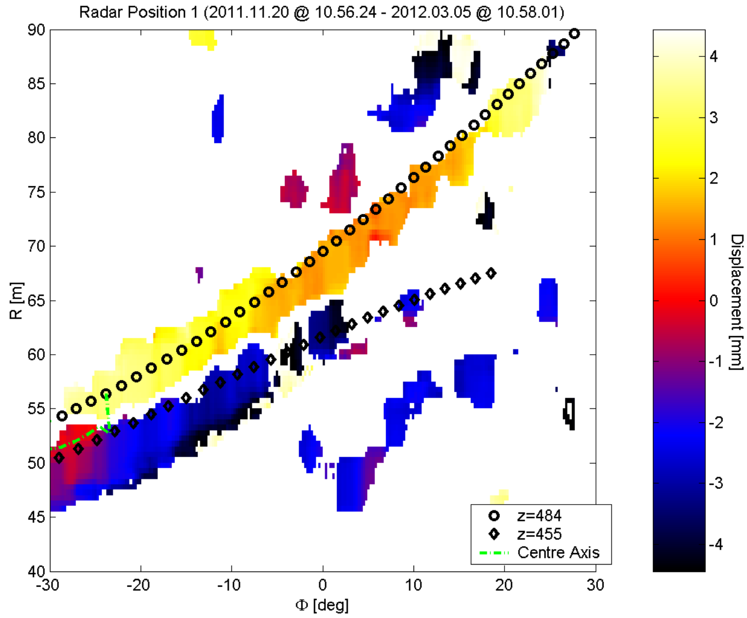


Fig. 3 Displacement map referred to the time interval between November 20th at 10:56 a.m. and March 5th at 10:58 a.m.

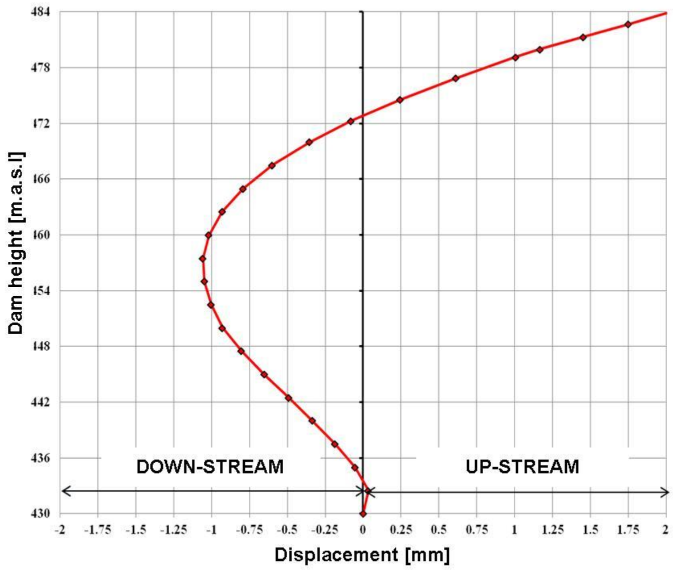
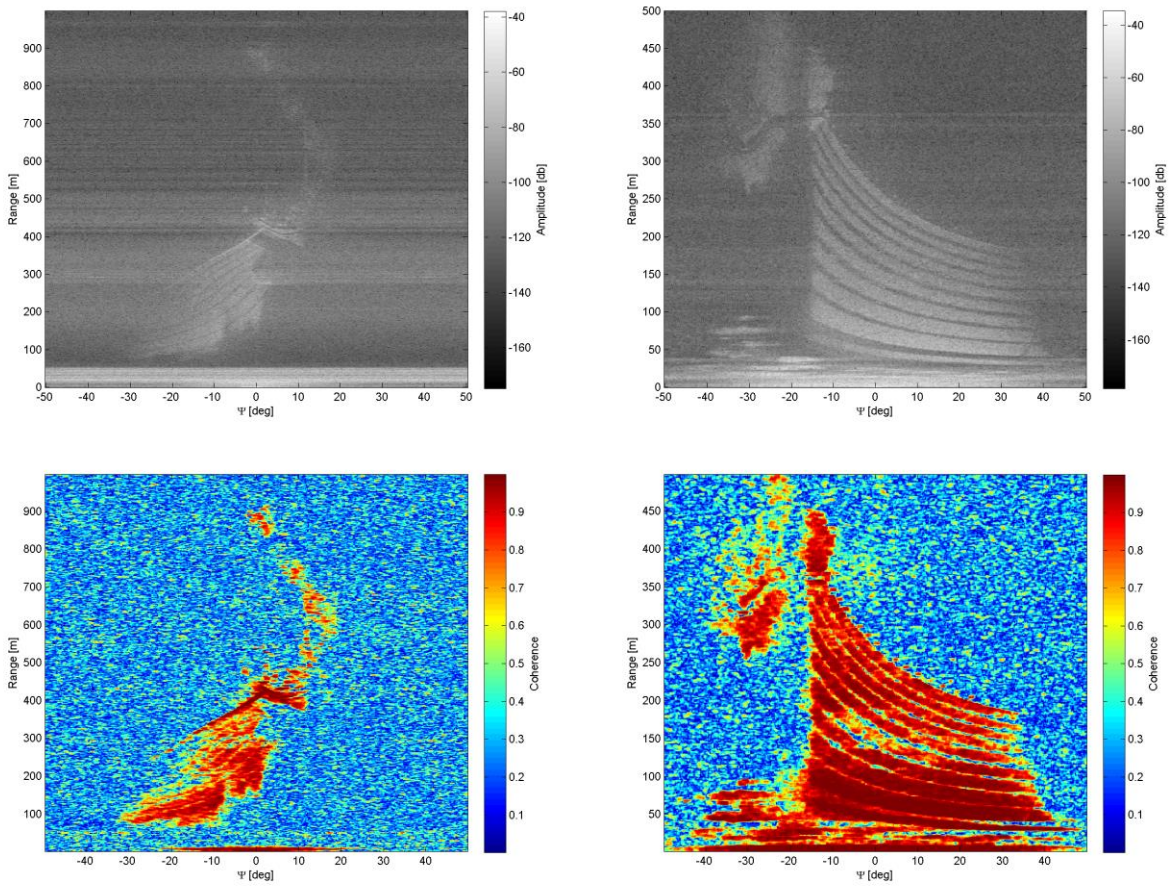


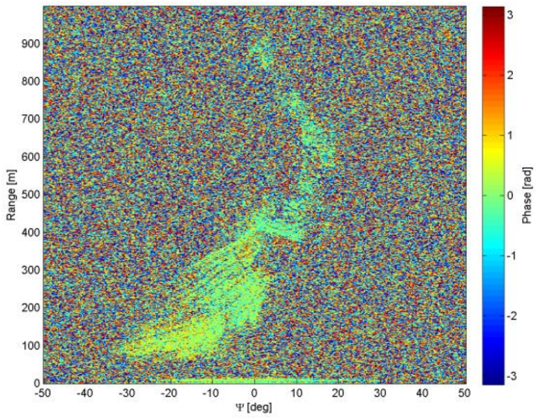
Fig. 4 Dam displacement at the centerline simulated by the SAP 2000. Displacement are referred to the time interval between the first and the second campaign.

In the following we present the results of two experiments carried out to demonstrate a possible measurement protocol based on GBSAR measurements. The first experiment aimed to reply the first question. It has been carried out on a earth-filled dam. Two GBSAR installation sites were selected at the downstream side of dam on the left and right sides respectively. The idea is to get two displacement maps of the dam surface and verify if these maps have an overlapping area where to use the two LOS components as an estimate of the displacement vector along the two GBSAR lines-of-sights. Fig. 5 shows the results. The left column refers to the left GBSAR site and the right one to the right GBSAR site. From the top to the bottom, the SAR amplitude, coherence and phase images are reported. Images have been acquired the same day with a constant water level. The amplitude image provides a mapping of the main structures of the dam as observed by the radar position. The coherence image gives an estimate of the spatial distribution of the quality of interferometric measurements. This can be used as a mean to derive a map of precision of GBSAR displacement measurements. The two phase images have an overlap around the center section of the dam which is also the most important one when monitoring the up-stream and down-stream displacements due to changes in water level. In this portion of the dam, the two geolocated phase images provide a measurement of two projections of the displacement vector. Outside these overlapping areas, the phase images acquired from the two GBSAR stations refer to different portions of the dam and are still useful because extend the fraction of the whole dam which can be monitored even if in these two no-overlapping portions only the measurement of a projection of the displacement vector is available.

4 CONCLUSIONS

In this work we presented the results of a few experiments for the measurement of dam deformation patterns by GBSAR interferometry.
Results have been obtained on both concrete and earth dams can be useful to set a protocol for the application of GBSAR interferometry to the measurement of 2D displacement vectors due to changes in water level has been defined and the modelling of these deformations by numerical modelling. Furthermore, the first results of spaceborne SAR data suggest that a further protocol for the measurement of 3D displacement vectors could be defined based on the merging of spaceborne and ground-based SAR data.





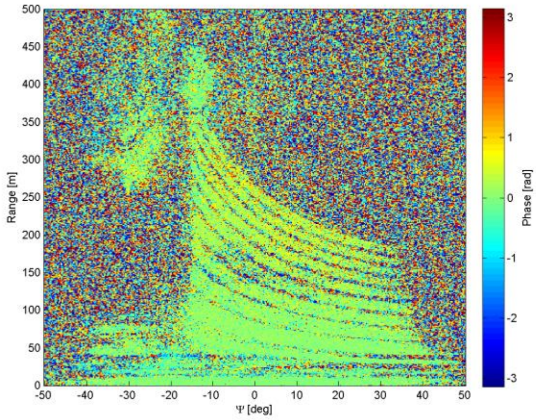


Fig. 5 Ground-based interferometric SAR data of the area around the Occhito dam. From the top to the bottom: SAR amplitude, interferometric coherence and interferometric phase. Data are referred to the left (left column) and right (right column) views of upstream surface and have been acquired on 03/03/2014

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