Ground-based SAR data analysis tools for deformation monitoring

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Abstract. In the last years, the Ground-Based SAR (GBSAR) technique has proved to be a reliable tool for deformation measurement and monitoring. Compared with other point-wise geodetic techniques it can provide "continuous" displacement measurements over areas of few squared kilometers, with a high spatial resolution and precision up to millimeter level.

The process of estimating deformation from the GBSAR data is not always straightforward: it requires appropriate data processing and analysis tools. One of the main critical steps is the phase unwrapping, which can critically affect the deformation measurements and hence the interpretation of the deformation phenomenon at hand. This paper is addressed to a specific type of GBSAR data acquisition: the so-called discontinuous mode.

The paper includes two main parts. In the first one we describe the procedure used at the CTTC to process and analyze discontinuous GBSAR data. The second part of the paper discusses the performances of the proposed procedure in a real case study: the deformation monitoring of the village of Barberà de la Conca, located in Southern Catalonia.

Keywords. SAR, interferometry, deformation monitoring, deformation analysis.

1 Introduction

Terrestrial or Ground-Based SAR interferometry is a radar-based terrestrial remote sensing technique that can be used to generate Digital Elevation Models or to measure and monitor deformation, e.g. see the review provided in Monserrat et al. (2014). In this paper we only consider the deformation monitoring application. The GBSAR deformation monitoring can be performed using two main types of acquisition modes: the continuous (C-GBSAR) and the discontinuous (D-GBSAR) ones. In the continuous mode, the radar is installed permanently in the area of interest, acquiring data periodically, with a period that can be as short as a few minutes, if needed. This is the most commonly used configuration, which can be used to carry out near real-time deformation monitoring (Casagli et al.; 2003; Tarchi et al., 2003; and Tarchi et al., 2005). In addition, it offers the best performances in terms of measurement density, precision and robustness. Some of the most important C-GBSAR applications include: slope monitoring in open pit mines for operational early warning systems (Noon et al., 2007; Farina et al., 2012); slope instability monitoring related to rockslides (Tarchi et al., 2005), landslides (Barla et al., 2010) or volcanoes (Casagli et al. 2010); urban monitoring (Pipia et al., 2013); structure monitoring (Tarchi et al., 1997); dam monitoring (Tarchi et al., 1999); dike monitoring (Monserrat, 2012); glacier monitoring (Noferini et al., 2009).

In the D-GBSAR acquisition mode, the radar is installed and dismounted at each acquisition campaign, revisiting a given site periodically, e.g. every month, year, etc. The revisiting time depends on the characteristics of the deformation phenomenon at hand and on the requirements of the monitoring at study. This configuration is appropriate to monitor slow deformation phenomena, where the continuous acquisition is usually unnecessary. This is the same configuration usually adopted by many other deformation monitoring techniques. The main advantage of D-GBSAR is the reduced monitoring cost by sharing the same instrument over several sites. Its drawbacks include a more complex data processing and, in general and in comparison with C-GBSAR, a reduced density, precision and reliability of deformation measurements. In the literature there are only a few works that describe D-GBSAR applications, e.g. see Noferini et al. (2008), Wujanz et al. (2013) and Crosetto et al. (2014).

The paper discusses the specific aspects of the D-GBSAR processing chain implemented by the authors. This is followed by the description of a D-GBSAR monitoring of an urban area.

2 D-GBSAR data processing

This section briefly discusses the D-GBSAR data processing procedure implemented by the authors. This procedure shares several points in common with the processing chain used with C-GBSAR data. In addition, both processing chains share common processing tools with the procedure to analyse satellite-based SAR interferometric data. The main steps are concisely listed below, see for details Monserrat (2012) and Monserrat et al. (2014):

- The procedure starts with the acquisition of N sets of images, typically using N different campaigns.
- The images are firstly focused.
- Usually, the images of each campaign are coherently averaged.
- The resulting images are then co-registered, usually taking the geometry of the first image as reference.
- This is followed by the generation of N-1 interferograms and the associated coherence images.
- Using the coherence images or, alternatively, the so-called Dispersion of Amplitude (the ratio between the standard deviation and the mean of image amplitudes), a pixel selection is performed, which aims at separating the pixels that contain useful information from those that are dominated by noise.
- A spatial phase unwrapping is performed on the selected pixels (i.e. on an irregular set of points) for the N-1 interferograms using an implementation of the Minimum Cost Flow method (Costantini, 1998). This is one of the most critical steps of the procedure.
- The resulting phases are temporally integrated to obtain a set of phases, which are temporally ordered, in correspondence of the N acquisition campaigns. This is done by setting to zero the phases in correspondence of the first image.
- An Atmospheric Phase Screen (APS) estimation follows, which makes use of known stable areas located in the observed scene. The geometry and distribution of these areas strongly influences the APS estimate quality.
- The APS component is then subtracted from the image phases.
- The APS-cleaned phases are the converted in Line-Of-Sight (LOS) displacements.
- Finally, the data are geocoded, obtaining the two main GBSAR products: (i) the geocoded accumulated deformation maps and (ii) the geocoded deformation time series.

3 Analysis of a case study

We describe in the following the D-GBSAR deformation monitoring of the village of Barberà de la Conca (Catalonia, Spain). This village has experienced deformations since 2011 that have caused cracks in the church and several surrounding buildings. Four D-GBSAR campaigns are considered in this work: 14 November 2011, 19 December 2011, 8 May 2012 and 20 March 2013.

The campaigns cover a total observation period of about 16 months. The village was monitored using a Ku-band GBSAR: the IBIS-L manufactured by IDS Spa (www.idscorporation.com). The radar was installed outside the village at an average distance of 0.5 km. The data analysis was based on 10 SAR images acquired in each campaign, from which four coherently averaged images were derived. After the second campaign, the measurement density achievable over the area of interest was checked. As it can be observed in Figure 1, over the observed scene there is a dense set of measurements, which cover a great number of buildings and structures. This proves the feasibility of D-GBSAR monitoring without deploying corner reflectors. A key additional characteristic of this area is the favourable geometry to estimate the APS: the deformation area is surrounded by stable areas, see Figure 1a. Between the first two campaigns, the displacements are imperceptible. However, from the third campaign they are clearly visible (Figures 1b and 1c). They include two main deformation areas characterized by opposite slope aspects. The area in yellow to red colours, which indicate deformation toward the radar up to 14.6 mm, and the area in light blue to blue colours, which indicates deformation values away from the radar up to -8.9 mm. This result proved to be essential to understand the deformation mechanism of this area.

Fig. 1. Displacement maps of Barberà de la Conca between 14/11/2011 and 19/12/2011 (a); 14/11/2011 and 08/05/2012 (b); and 14/11/2011 and 20/03/2013 (c). The blue polygons on the top indicate the stable areas. Figure from Crosetto et al. (2014).

4 Conclusions

This paper describes the deformation monitoring based on the discontinuous GBSAR configuration. This acquisition mode is useful to monitor slow deformation phenomena The D-GBSAR data processing procedure implemented by the authors has been outlined. An example of D-GBSAR monitoring based on a Ku-band GBSAR has been discussed. This case study represents a positive deformation monitoring example, which was derived in a fully remote mode, positioning the radar at a distance of 0.5 km. In this case a high density of deformation measurements has been achieved. This case has a favourable geometry to estimate the APS: the stable areas surround the deformation areas. This is key to properly separate the deformation and atmospheric phase components and hence correctly estimate the deformations. The results showed in this paper proved to complement other types of in-situ deformation measurements (extensometers and topographic surveys) and to understand the deformation mechanism of the studied village.

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