ANALYSIS TOOLS FOR DIFFERENTIAL SAR INTERFEROMETRIC DATA

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Abstract: This paper describes two examples of deformation monitoring based on two complementary differential interferometric SAR (Synthetic Aperture Radar) techniques. The first application concerns a thin and elongated infrastructure, the main dike of the Port of Barcelona, while the second one regards a group of buildings in an urban area. In the first application, the dike was measured by using the Persistent Scatterers technique called Stable Point Network and implemented by Altamira Information. This application illustrates the high quality of the deformation estimated derived by this technique. The second application, which was measured by using a classical DInSAR approach and a small set of interferograms, shows the effectiveness of a simple analysis in an operational context.

1. Introduction

This paper presents two examples of deformation monitoring based on the differential interferometric SAR (Synthetic Aperture Radar) technique, DInSAR. The first one concerns an important infrastructure: the main dike of a Port, while the second one regards a group of buildings in an urban area.

Since its first demonstration in 1989 [1], DInSAR has been successfully used in a wide range of deformation monitoring applications. Comprehensive reviews of different DInSAR applications are provided by [2], [3], [4], [5], while an interesting link that describes the latest DInSAR results based on data acquired by the ERS and Envisat satellites is given by eopi.esa.int/esa/esa. In the last years different private companies started to provide DInSAR deformation monitoring products based on remotely sensed data. One of the most important efforts to establish a long-term market for the DInSAR products is represented by Terrafirma ("A pan-European ground motion information service in support of policies aimed at protecting citizen against natural and anthropogenic ground motion hazards"), one of the projects of the GMES (Global Monitoring for Environment and Security, www.gmes.info) Service Element Programme (see for details www.terrafirma.eu.com).

In the scientific literature the use of the DInSAR technique is documented in several disciplines, like geophysics (seismology, volcanology, glaciology, etc.), geology, geotechnics, civil engineering, etc. Considering the performances of DInSAR in the above application fields, one has to take into account that several DInSAR techniques have been developed so far, which can offer different deformation monitoring capabilities. Without the pretension of being exhaustive, we briefly mention in the following the main types of DInSAR techniques.

Firstly, we start by recalling that interferometric SAR (InSAR) is a technique to generate digital elevation models (DEM), i.e. to measure the topography of the area imaged by the SAR images, while DInSAR is a technique to measure land deformation, see for details [3],[4],[5]. During more than a decade the DInSAR results have been mainly based on the processing and analysis of single interferograms, where one interferogram is derived from a pair of complex SAR images acquired over the same area in different epochs (typically with a time separation that ranges from one day up to several years) and from slightly different viewpoints (typically up to few hundred meters). This configuration has some important limitations, which usually prevents to achieve high-quality deformation measurements. However, it is very flexible and easy to implement. Note that the majority of the most relevant DInSAR results achieved in geophysics, including several papers published in Science and Nature, has been derived with this simple configuration.

In order to improve the quality of the deformation estimates provided by DInSAR, in the last years different approaches have been proposed, which basically share the same principle: to increase the number of SAR images (i.e. move from a single pair of SAR images to multiple images acquired over the same area). This implies an increase in the available observations, i.e. in a higher redundancy, which typically results in a better quality of the deformation estimates (better precision, accuracy and reliability). In most of the techniques, it also results in an increased level of automation of the SAR data analysis. We will name hereafter all the DInSAR techniques based on the processing of multiple SAR images as Advanced DInSAR (A-DInSAR).

Depending on the way the DInSAR observations (i.e. the differential interferometric phases) are selected, one may distinguish two main classes of A-DInSAR techniques: those which select the observations using the coherence, and those based on the amplitude dispersion index, which are named Persistent Scatterers (PS) techniques. Example of coherence-based techniques are described in [6],[7],[8],[9]. Examples of PS techniques include the Permanent Scatterers technique [10],[11],[12], the Stable Point Network (SPN) technique [13],[14], and the Point Target Analysis [15].

In this paper we describe two examples based on two different DInSAR techniques:

- the monitoring of the main dike of the Port of Barcelona, one of the most important infrastructures of the city. This monitoring was realized by the SPN technique, one of the PS-based techniques;
- the measurement of the deformation of a small group of buildings, which was derived by using a classical DInSAR approach and a small set of interferograms.

2. Deformation of the main dike of the Port of Barcelona

This section describes an application of a particular A-DInSAR technique, the Stable Point Network (SPN), over the city of Barcelona (Spain). These results have been obtained in the frame of a project funded by the European Space Agency (ESA) and named “Development of algorithms for the exploitation of ERS-Envisat using the Stable Points Network” leaded by

Altamira Information, a company specialized in radar remote sensing applications (www.altamira-information.com). Over the Barcelona area, the SAR processing was performed by Altamira Information, while the validation was carried out independently by the Institute of Geomatics. More details on the above ESA funded project can be found in [16].

The SPN is a PS technique implemented by Altamira Information [10],[11],[12], which provides advanced DInSAR products, like the average deformation map (i.e. the linear deformation velocity estimated over the observed period), the deformation time series of each measured point (temporal evolution of deformation in correspondence of the acquisition dates of the available SAR images), and the so-called map of the residual topographic errors (used to perform an advanced geocoding of the DInSAR products, with a precision of the order of few meters).

In this paper we consider one of the SAR datasets available over Barcelona, which is formed by 49 ERS images acquired between April 1995 and December 2000. This is a redundant dataset, useful to derive high quality estimates of deformation, which at the same time does not include those ERS2 images that are affected by Doppler Centroid variations due to attitude control problems of the ERS2 satellite.

Although the project involved the analysis of the entire metropolitan area of Barcelona, this section is only focused on the validation of the A-DInSAR results obtained over a particular infrastructure: the main dike of the Barcelona harbour. This specific feature is known to be subject to subsidence, and levelling data taken by the Surveying Service of the Port are available for validation. Using the above mentioned ERS dataset four points were measured over the main dike, see their location in Figure 1a. These points are quite close to a reference point, measured by levelling, which was used for the validation. Using the a priori available knowledge about the deformation direction (subsidence, i.e. vertical deformation) the LOS measurements of the above points were projected onto the vertical direction. The validation results are summarized in Figure 1c, where the deformation time series of the four points are compared with the reference value. Despite the slightly different observed periods (April 1995 to December 2000 for ERS vs. February 1995 to July 2002 for the reference data), there is a good agreement between the SPN estimations and the reference value: the maximum velocity difference equals 1.1 mm/yr. These good results can be explained by two factors: the high available redundancy (49 images were used) and the good quality of the measured points.

3. Deformation of a set of buildings in an urban area

The second example of application differs from the previous one by the type of deformation (which in this case is more concentrated in time and space) and by the used technique. In fact, in this second example the classical DInSAR technique based on pairs of interferograms was used, due to the limited number of available SAR images, which prevented the use of more advanced and reliable methods.

The study was performed on a small urban area, after that an event in mid 2004 generated certain structural damages (cracks in walls) on a limited number of buildings. Although some underground works (55-65 m below the surface) were active in the same zone, no deformation was expected by the experts in the area of interest. However, the authorities decided to study in depth the causes of the above damages. Since there were no available in situ deformation measurements in the area, it was decided to exploit the DInSAR technique, taking advantage of its unique capability to measure deformations “back in the past”, thanks to the continuous acquisition of SAR data, which are available in the archives of ESA.

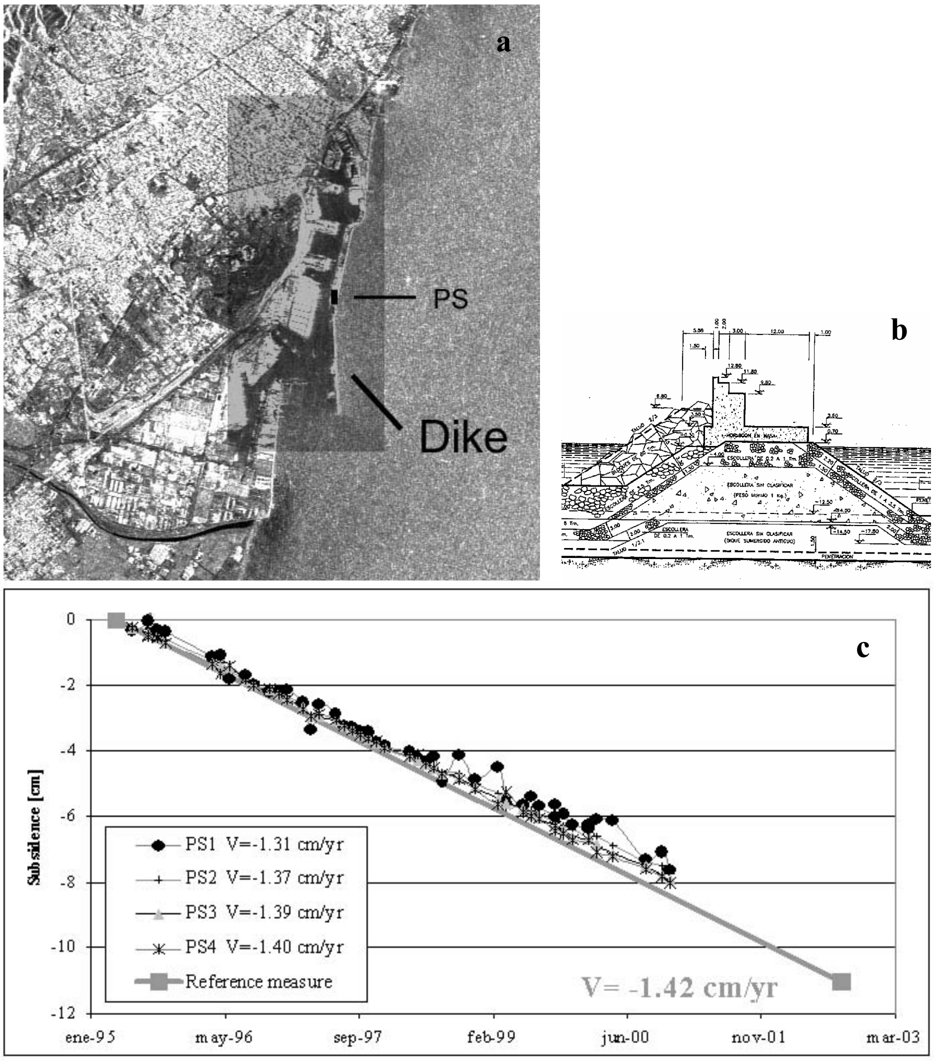

Figure 1: SAR amplitude image of the Barcelona area, with the location of the main dike and of the measured points, named PS (1a); section of the dike (1b); subsidence profiles of the four points measured by the SPN technique on the main dike, compared with the reference one, measured by the Surveying Service of the Port of Barcelona (1c).

For the study 10 SAR images of the Envisat ASAR sensor were used, which cover the period from July 2003 to January 2005. In addition, 21 ERS images were used to study the deformation of the same area in the period 1995-2000, in order to highlight potential pre-existing deformation phenomena. Again, this represents an unmatched capability of DInSAR in comparison with other deformation monitoring techniques. In the 1995-2000 period no deformation was detected: the area of interest was stable.

As mentioned above, the analysis of deformation in 2004 was based on a set of interferograms generated from the 10 available Envisat images. By simple visual inspection of the interferograms was possible to detect the deformation in the area at hand. Figure 2 illustrate a portion of an interferogram over this area, which covers a period of 105 days. Despite the presence of noise, in this interferogram two contiguous deformation areas of about 60 by 80 m wide can be clearly identified. Note that besides the phase noise another phase component, the so-called residual topographic phase, has the same effect, while at this scale the atmospheric effects are negligible.

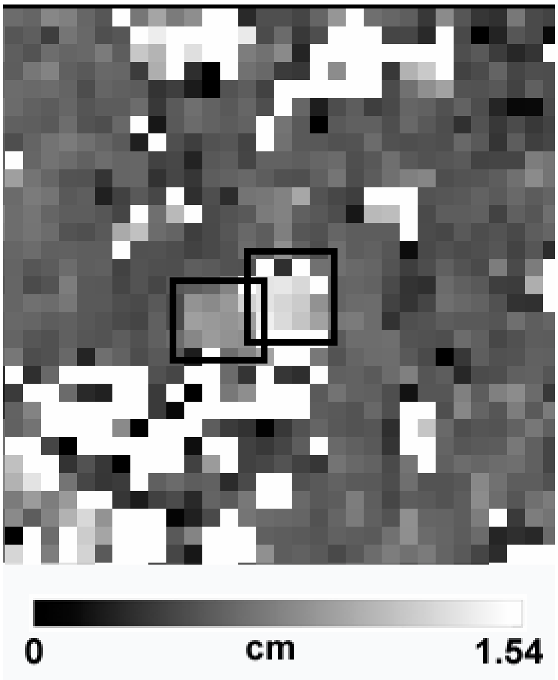

Figure 2: Deformation of a set of buildings. Example of interferogram over the area of interest, which covers a period of 105 days. Although noise and residual topographic error make the interferogram rather difficult to interpret, one may identify two deformation areas (highlighted by two black frames). The maximum deformation is about 1.5 cm.

After the detection of the deformation, a detailed temporal analysis of the interferograms was performed, with the objective of estimating the beginning of the deformation phenomenon. This type of analysis, which clearly requires more than one interferogram, is very useful to correlate the deformation (i.e. the effect) with its driving causes. In the specific case, for the final users this represented the most important outcome of the analysis. The beginning of the deformation was estimated by using the six interferograms shown in Figure 3. In Figure 3a the six periods covered by these interferograms are shown, indicating for each interferogram the estimated deformation. One may notice that one interferogram shows no deformation. In Figure 3b is shown the outcome of the analysis, obtained by interpreting the results of Figure 3a: the deformation started between March and June 2004.

Finally, another important result was obtained by extending the above described analysis to the neighbouring areas around the area of interest. Surprisingly, other two areas show a similar behaviour, see Figure 4. Both areas are affected by other underground construction works, which were unknown to the authors. For the final users this represented another important outcome of the analysis.

4. Conclusions

Two applications based on two different types of analysis tools for DInSAR data have been presented. The first one concerns the deformation of the main dike of the port of Barcelona, which has been measured by using a PS technique named Stable Point Network, implemented by Altamira Information (www.altamira-information.com). The second application has been focused on the deformation of a small set of buildings located in an urban area. It has been measured by employing a classical DInSAR approach and using a small set of interferograms.

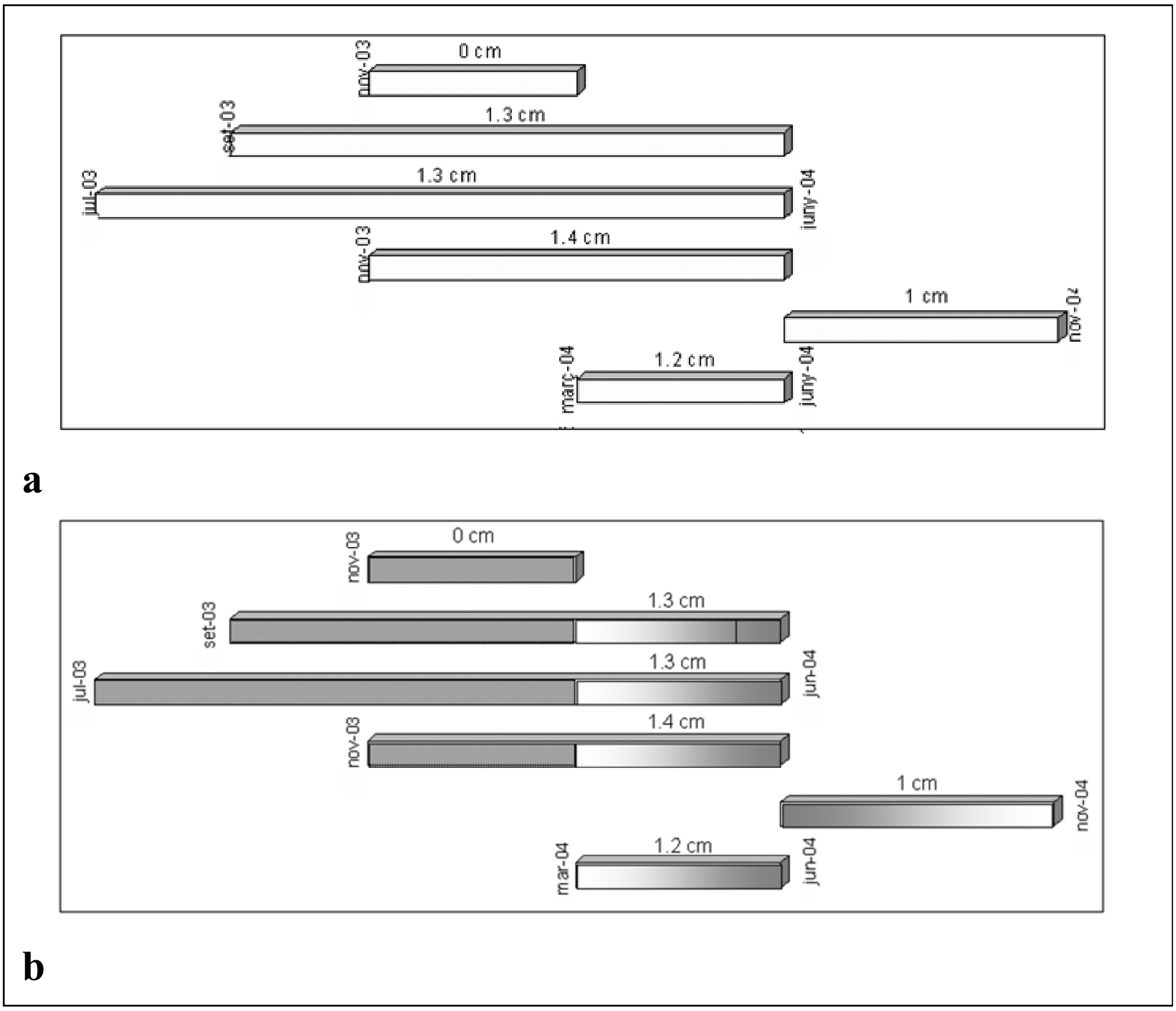

Figure 3 : Deformation of a set of buildings. Analysis of the temporal evolution of the deformation based on six interferograms: magnitude of the estimated deformation and temporal distribution of the interferograms (3a); interpretation of the above results (3b): the deformation started between March and June 2004.

The PS-based results over the Port of Barcelona represent a good example to illustrate the capabilities of an advanced DInSAR technique for long-term deformation monitoring. If large sets of images are available (in this case 49 images were used), high quality deformation measurements can be achieved. In the dike of the Port, which represents a very thin infrastructure if compared with the SAR resolution, the discrepancies between PS and reference deformation rates are around 1 mm/yr. It is worth noting that the processing of tens of SAR images requires a non negligible computational effort.

The classical DInSAR technique, which in principle can be used with a single pair of interferometric SAR images, is an interesting complementary technique. In fact, it can be useful for all applications where only few SAR images are available. Note that in practice this occurs rather frequently.

From the two applications described in this paper it is worth stressing the DInSAR capability to describe the temporal evolution of the deformation. This property, which plays a key role in many applications in order to relate the observed deformations with their causes, can be clearly exploited by using large SAR datasets and A-DInSAR techniques.

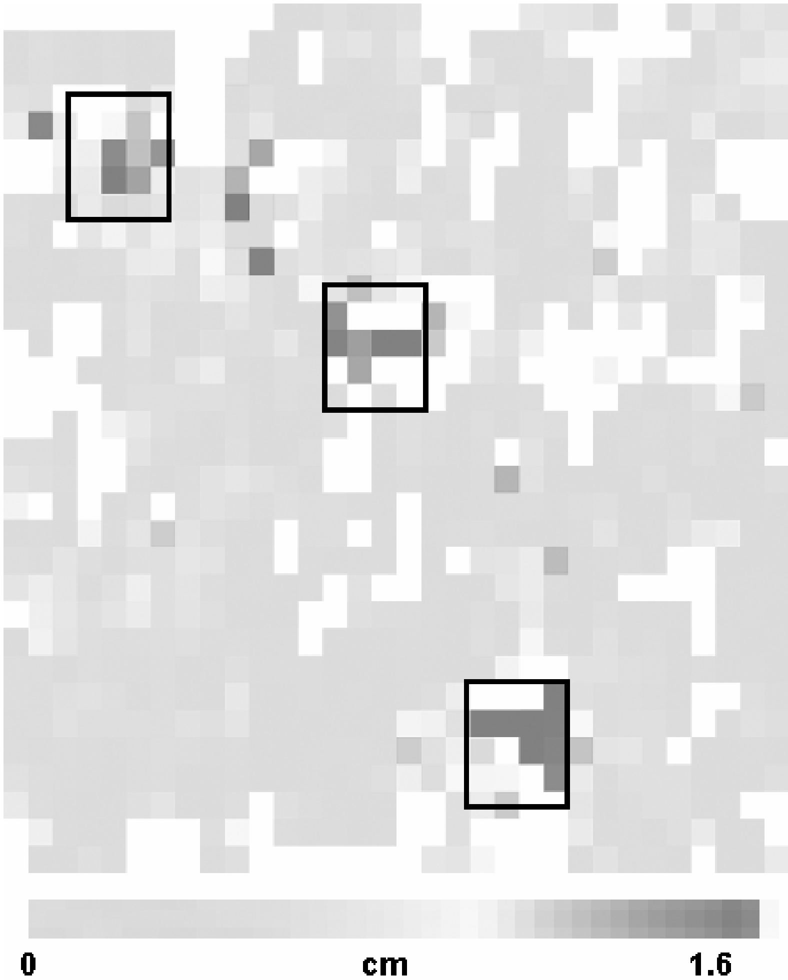

Figure 4: Deformation of a set of buildings. The main area of interest corresponds to the black frame in the bottom part of the image. Other two areas show a similar deformation behaviour. For both areas the deformation is probably caused by underground construction works, which were not known by the authors previous to the analysis.

Furthermore, it can also be exploited by using the classical DInSAR approach with few interferograms, as it has been demonstrated in the temporal analysis of the deformation of a small group of buildings. In this case, one has to take into account the limitations that are due to the reduced number of available images.

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