HIGH RESOLUTION DIFFERENTIAL INTERFEROMETRY USING TIME SERIES OF ERS AND ENVISAT SAR DATA

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Abstract

During the last ten years, a long history of data has been acquired by the SAR sensors on board the ERS-1 and ERS-2 satellites offering a wide range of interferometric applications. With the launch of ENVISAT in 2002, the more advanced SAR (ASAR) has given continuity to the success of the remote sensing mission of the ERS satellites by ensuring and increasing the value of the archived ERS data. The subject of this study under ESA's 3rd Announcement of Opportunities is to demonstrate the continuity of the interferometric measurements obtained from the combination of long temporal series of SAR differential interferograms in order to derive small subsidence displacements. The implemented technique makes use of either ERS SAR or ASAR differential phase measurements to generate long term terrain movement maps with the same resolution as the original SAR images without spatial interpolation. The algorithm is capable of using all the available phase information even in conditions of large baselines or platform instabilities resulting in large Doppler centroid variations. Such artifacts are handled by precise location estimation of the scatterer within the pixel and accurate elevation extraction. One interesting by-product of this technique is the interpretation of the DEM errors as an approximation of a DSM (Digital Surface Model) in urban and semi-urban environments and the use of such measurements to improve precise target positioning. Continuity of the displacements measured from both sensors after atmospheric artifacts removal and some validation data will be presented in the results obtained over the city of Barcelona.

1. Introduction

Multiple applications have arisen since the launch of the ERS-1 and ERS-2 satellites which use repeat pass interferometric techniques. In order to commercialize these applications and give long term information it is required that the availability of each acquisition over a certain area is ensured with a certain frequency which is specific to each application and under certain conditions. The launch of ENVISAT in 2002 carrying onboard the more advanced SAR (ASAR) gives continuity to these data acquisitions and offers the possibility to continue providing good quality services.

The instrument's capability has been enhanced with respect to the ERS SARs by extending the acquisition modes to those in different polarization combinations and/or the use of ScanSAR to increase the swath length. However this is not always an advantage since it enters in conflict with the use of the ERS-like mode systematically necessary for the long-standing applications (Image Mode in IS2 incidence angles and VV polarization) and the acquisition does not always take place in the desired mode. Anyway the adaptation of the data acquired in the two ASAR ScanSAR modes to generate interferograms with acquisitions in Image Mode was tested in [1].

The interferometric combination of ENVISAT/ASAR (IS2) and ERS data is not as simple as it used to be with the similar constructed SAR sensors on board the ERS-1 and ERS-2 satellites. Specially, the difference of 31 MHz between both radar center frequencies prevents the simple combination of the different sensor data because the interferometric phase is obviously strongly dependent on the wavelength and thus on the radar frequency. The radar center frequency of ENVISAT/ASAR (5.331 GHz) has been slightly shifted compared to the sensors ERS-1 and ERS-2 (5.300 Hz). To compensate for this frequency change, the interferometric observation geometry needs to fulfill certain requirements, i.e. large baselines, which obviously depend on the terrain slopes [2].

The implemented technique SPN (Stable Point Network) makes use of either ERS SAR or ASAR differential phase measurements to generate long term terrain movement and precise DEM maps related to building height with the same resolution as the original SAR images. This by-product is of great importance since the information extracted can be reused to compensate the phase values of the ASAR differential interferograms when calculating the subsidence measurements. Moreover it allows to the positioning of each pixel to be corrected using its “true” height, giving the possibility to obtain a very accurate map geocoding, with an absolute positioning error of less than 2 meters.

Verification of the information continuity was tested by comparing the yearly subsidence rates of independent series of ERS and ASAR data and the scatterer vertical positioning continuity of mixed ERS and ASAR interferograms in two test sites, the cities of Paris and Barcelona. Only some results of the Barcelona processing will be presented and analyzed in this paper.

2. SPN processing chain

The Stable Point Network is an advanced differential interferometric processing technique developed at ALTAMIRA INFORMATION. It is the result of three years of research projects inside the DInSAR data analysis field for CNES (French Space Agency) and ESA (European Space Agency). The SPN tool was the first advanced interferometric processor capable to merge the new ASAR DATA with the historical ERS1/2 [2]. The SPN software relies on the DIAPASON interferometric chain for all the SAR data handling, corregistration work and interferogram generation. The DIAPASON processing software has become, since its creation in 1992, one of the most important differential interferometric tools. More then 50 companies and research laboratories around the world use it.

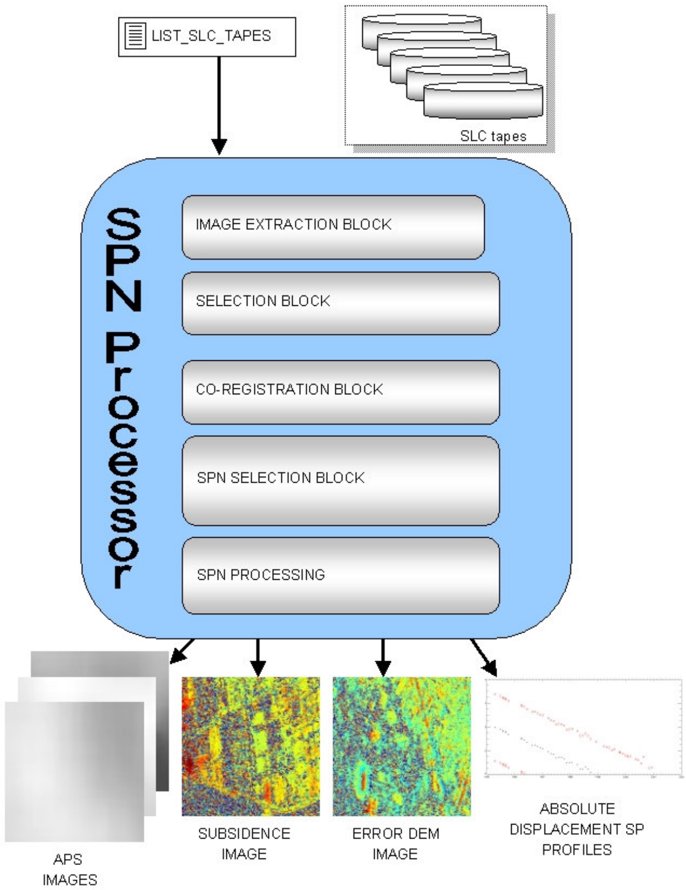

Figure 1: Stable Point Network processing chain

Figure 1 describes the very high level of SPN processing chain. The Stable Point Network procedure generates three main products for a subsequent set of ERS and/or ENVISAT SLC images. The mean subsidence rate, which can be derived using only 6 images. A DEM error map, produced at any resolution. Finally, the extraction of subsidence profiles, that requires from 15 to 30 images, depending on the velocity of displacement versus the intervals between image acquisitions. In any case, an increase in number of images improves the quality of the estimate.

The basis of the technique is the separation of the different artifacts from all the input data, see equation 1. Step by step, the dataset is processed taking into account the physic behavior of the characterized effects versus the radar signal reflection and the acquisition geometry. Finally, the atmospheric artifacts can be estimated and removed from all the interferometric pairs as low wavelength effects. A high frequency analysis of the data is then carried out in order to extract the profiles of absolute displacement for any point selected by the user. If a DEM of the area is available, the software is also able to give the exact UTM coordinates of the analyzed points with the precision given by the DEM used and the estimated final point height (achieving a final geocoding precision of about 2 meters).

$$\Phi_{INTERF} = \Phi_{TOPO} + \Phi_{MOV} + \Phi_{APS} + \Phi_{NOISE} \tag{1}$$

One important point of the chain is its flexibility: the software can work at any resolution and with extracted pieces of images. Moreover there is no maximum image size that constrains memory requirements, although large images increment considerably the execution time. The most critical step in CPU load, related with the image size is the subsidence rate derivation and the DEM error estimation, since this is done pixel by pixel at the end of the process.

2.1. SPN main outputs

Broadly, the main products obtained from the processing chain are the mean subsidence rate and the mean residual heights referred to the used DEM. Together with these estimates a quality measurement and a dispersion index of the measurements is given. Due to the high number of images available for this experiment, the results have a very high accuracy, with values around 1 mm/year for the mean subsidence and 2 meters for the DEM errors. It is important to note that there is no interpolation in the final estimate maps, which are obtained at the original resolution of the SLC's. This is very important in order to increase the accuracy and to avoid false alarms.

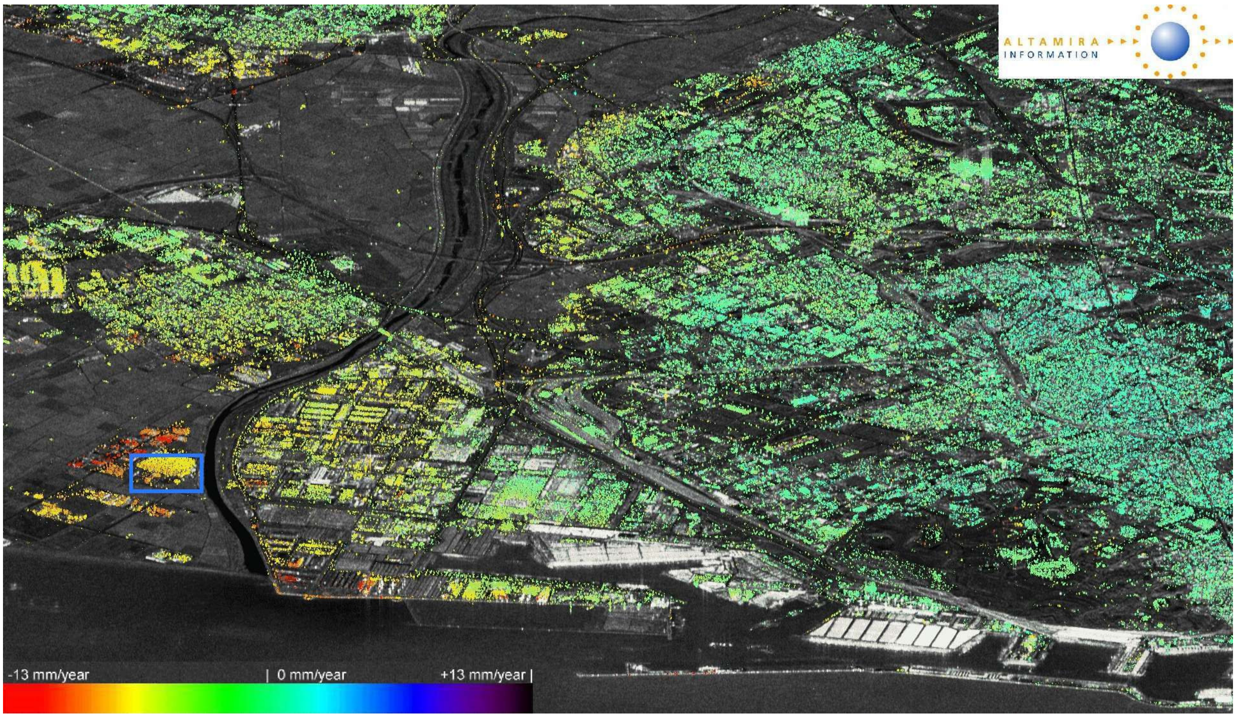

Figure 2: Mean subsidence rate obtained from a dataset of 68 ERS1/2 for the time period 95-01 on the city of Barcelona.

Areas at risk can be identified with the mean subsidence rate and further careful surveillance can be made with the point profiles. The plots of the total displacement give a more detailed idea of the local phenomena that might be affecting some structures in the areas at risk and serve to discriminate those risk pixels (which require further observation) from the rest.

As an example, an area at the south of Barcelona city with a mean subsidence rate of about 1.25 mm/year is presented in the figure 2. Only points with a coherence value higher than 0.7 are color plotted overl the mean amplitude in the radar geometry. Some geological reports, published in local newspapers, are also informative for this subsidence problem close to the Llobregat River.

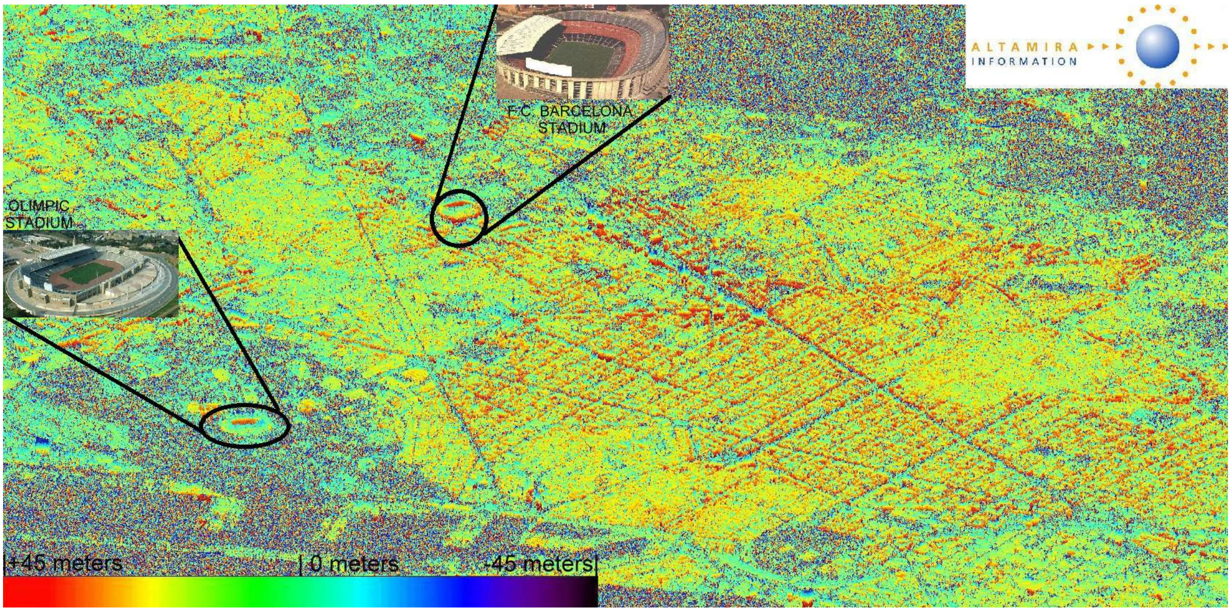

Figure 3: DEM error obtained from a dataset of 68 ERS1/2 for the time period 95-01 on the city of Barcelona.

In figure 3 the mean DEM error map estimated in the city of Barcelona is exposed. Due to the lack of interpolation and the coherence masking the topography of the city can be clearly identified. Building heights and street profiles are seen in the image. In a qualitative way, some big structures can be identified in order to validate the results, as for example the F.C. Barcelona stadium with a maximum height of 48 meters. It is also informative to visually correlate these results with an optical image of the city in order to verify the grid distribution of the streets in the city. This is a very interesting product since this kind of information is very difficult and expensive to obtain for the whole city using current techniques.

3. High resolution analysis

The scope of this experiment is to prove the continuity of the deformation measurements based on SAR phase imagery between ERS/SAR and ENVISAT/ASAR. This demonstration is the most crucial point of the SAR remote sensing from an operational point of view. It includes the integration of ASAR acquisitions in a set of ERS acquisitions and the control of the accuracy of the performed measurement. The word “demonstration” means test of continuity between ERS and ENVISAT in a qualitative and quantitative way.

The presented test was carried out in the city of Barcelona (Spain) using the Stable Point Network analysis, developed by ALTAMIRA INFORMATION to merge the available ENVISAT/ASAR images (only 5) in a set of 68 ERS images. The software has been updated in order to perform the common co-registration of ERS and ENVISAT images which is a pre-requisite to any work of phase integration. For this demonstration part, additional tools to the DIAPASON INSAR processing chain, currently being adapted to ASAR, facilitate the task considerably.

On this example on the city of Barcelona, the mean subsidence and the DEM error maps are estimated with an accuracy better than 1 millimeter/year and 2 meter at SLC radar full resolution. This is a key point because, in order to check the phase continuity between both sensors, the time series of the estimated displacement in the satellites line of sight of coherent pixels are investigated. This is the main reason for working at full resolution, because the phases must be analyzed as clean as possible, taking into account only single target contributions. The correlation between the phase behavior of the ENVISAT and ERS-1/2 time series must be verified in both a qualitative as well as in a quantitative way.

3.1. Precise stable point geocoding

The geocoding procedure is carried out using the DEM error obtained with the complete ERS1/2 dataset by means of the SPN software without using any prior information. In order to achieve an accurate geocoding, the final point position is corrected by taking into account the detected vertical height of every point in the radar geometry. Thus, the obtained final results can be combined with any georeferenced map as a background. Therefore, the validation of the precise point geocoding will assess implicitly the DEM error detected by the SPN, i.e.: the difference between the DEM used to remove the interferometric topography and the actual height where the reflection of the radar signal took place.

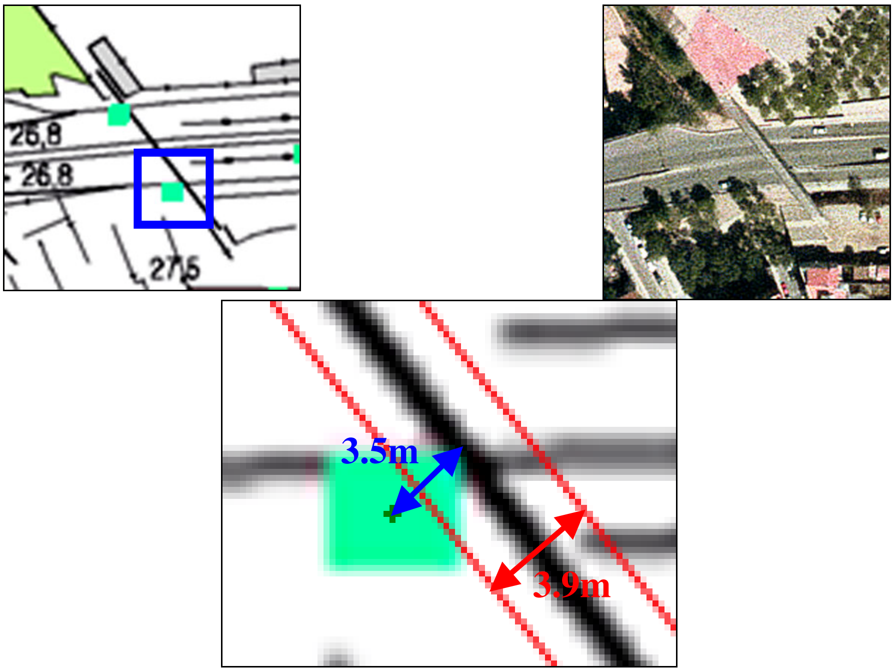

Figure 4: geocoded topographic map with the radar points at 0.8m/pixel (upper left) compared with an aerial ortophotos at 0.5m/pixel (upper right) of the same area. The lower image is a zoom of the upper left image.

In figure 4 an example linear feature is analyzed at a very particular area of the city of Barcelona. The geocoding quality can be seen visually. Looking at the zoomed window of the figure 4 it can be stated that the point geocoding errors on ground are approximately 1.6 m, less than one third of the pixel footprint.

4. SPN ERS/ASAR comparison results

The main idea is to compare the movements estimated by the two sensors (ERS vs. ASAR), and especially the absolute displacement along the satellites line of sight. In addition, these results were compared with external measurements obtained with precise leveling and with in situ validation.

The mean subsidence velocity fields estimated over the entire city using the ERS (68) series and the short ASAR (5) series are shown in Figure 5. One may observe that the two maps show a very similar subsidence pattern. The results are also quite similar in terms of estimated mean velocity of the subsidence, with maximum values of about 1 cm/yr in the delta of the Llobregat river. Therefore, in a global way the measurements are in agreement, however, there is more high frequency noise in the ASAR estimation due to the reduced number of data.

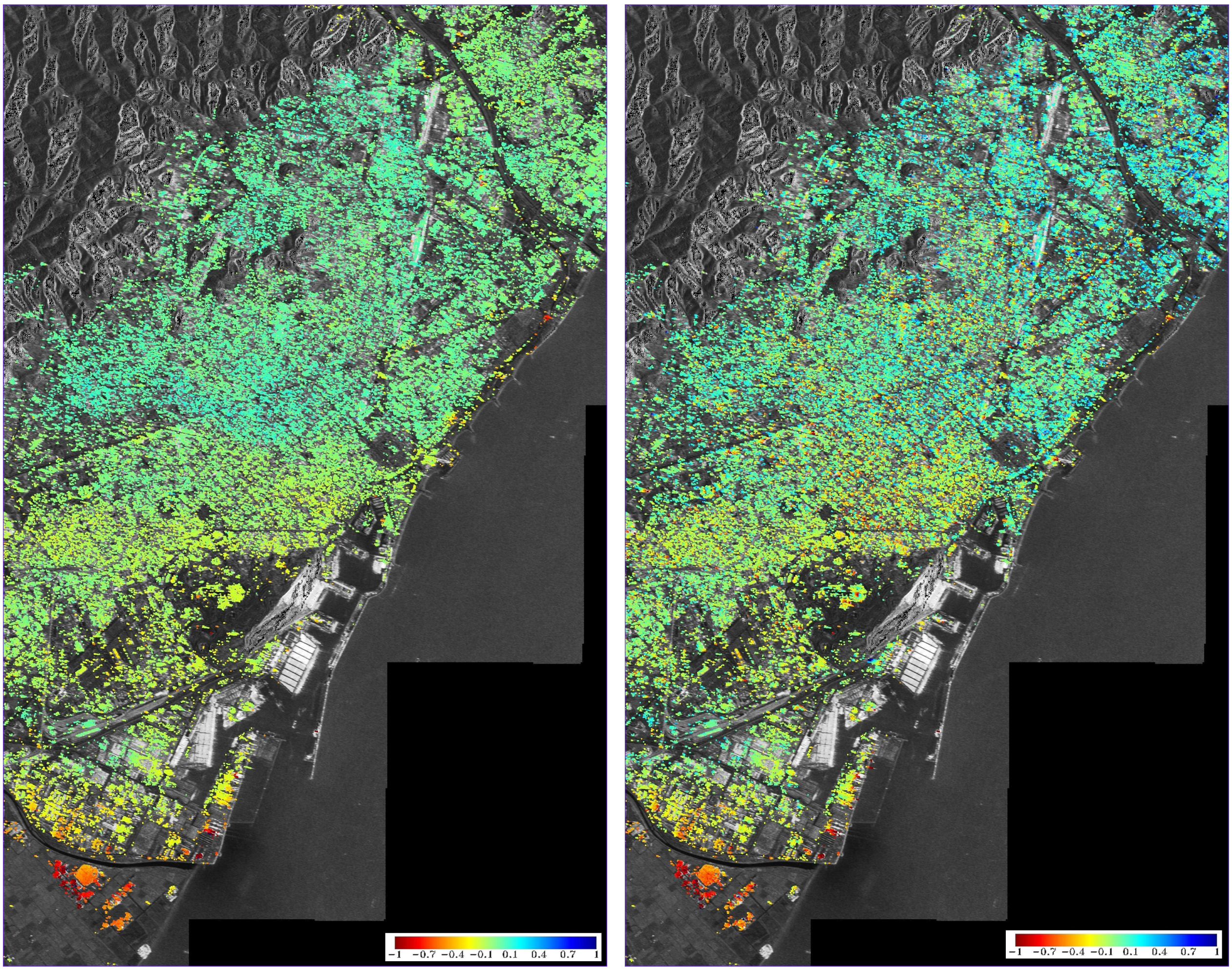

Figure 5: Geocoded mean subsidence velocity fields estimated with the ERS1 and 2 series (left), and geocoded mean subsidence velocity estimated from a short series of five ASAR images. The observed period for the ERS dataset spans from April 1995 to December 2001, while the ASAR data covers about one year, from April 2003 to March 2004.

Some particular areas of the city, presented in figure 5, were analyzed also at high resolution. In one of them, an in situ validation was carried out and presented in figure 6. At that area the buildings at risk, with high subsidence rates (red ones on the maps) could be clearly identified and checked. Some photos taken recently show some extensive cracks to the external walls of buildings affected by high subsidence rates (about 0.8 cm/year), an example is shown in figure 8. The aim is to show how the subsidence maps are correlated between isolated datasets of ERS1/2 and ASAR, despite the different observation periods.

From figure 6 it can be noted how the risk points remain red in the measurements obtained with both sensors. The subsidence rates of those points are slightly different but the fact that the result are from different time periods must be taken into account. Some false alarms on the ASAR subsidence rates can also be noticed. This can be explained by the fact that only 5 ASAR images were available.

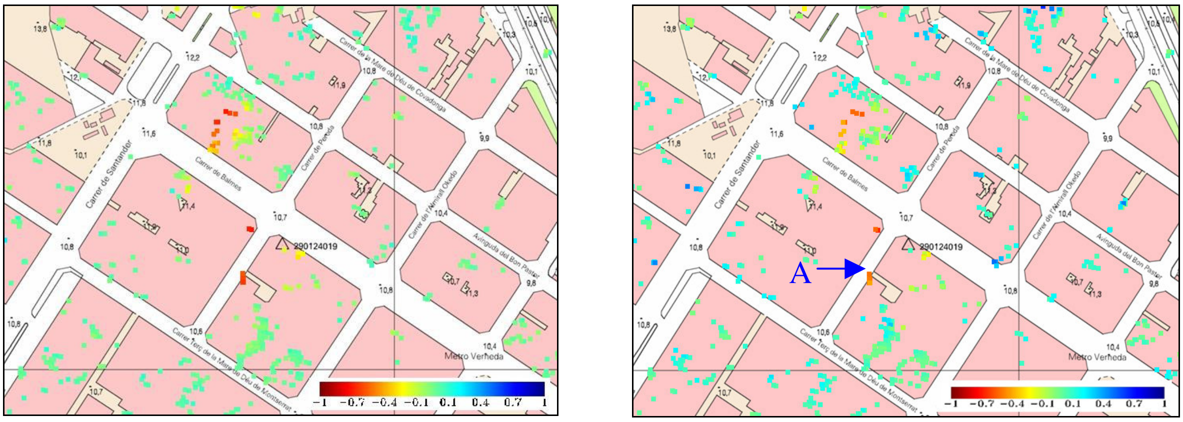

Figure 6: geocoded mean subsidence velocity fields estimated with the ERS1 and 2 series (left), and geocoded mean subsidence velocity estimated with only 5 ASAR (right). The stable points are geocoded over a topographic map at 0.8 meters/pixel

Once the interferometric phases are completely modeled and after the separation of the different effects, the profiles of the coherent points due to the terrain displacement can be analyzed. The basic idea is to see that the ASAR values are correlated with the ERS time series values. As previously stated [3], the major problem here is to handle the high ERS-2 Doppler values from 2000 onwards. The profiles included hereafter in figure 7, still show high frequency fluctuations on the images affected by high Doppler centroid due to slight inaccuracies in the Doppler compensation scheme.

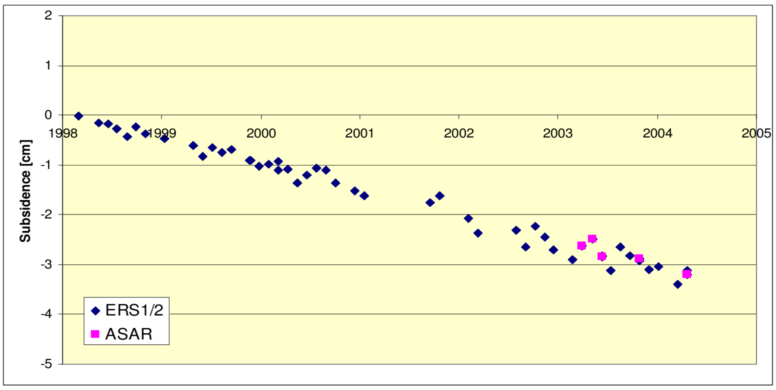

Figure 7: subsidence profile of the point A measured on figure6, see location on the image above. The estimation was based on the fusion of ERS and ASAR images.

By comparing the ERS1/2 data (blue ones) with the ASAR (5 pink ones) in figure 7 it can be verified that the behavior of the two series are consistent. This means that the phase continuity on the measurements is ensured. From an operational point of view this is a very good and important result in order to follow slow terrain deformations taking into account the historical data of ERS-1 and ERS-2.

Most of the pixel series in the same test sites show a similar behavior, which guarantees the integration of the ASAR data. However, in some other points showing low coherence, the continuity is not followed possibly due to a bad Doppler compensation since those pixels were not point targets, and a more complex model is most probably needed to compensate the phase within the resolution cell introduced by high Doppler values.

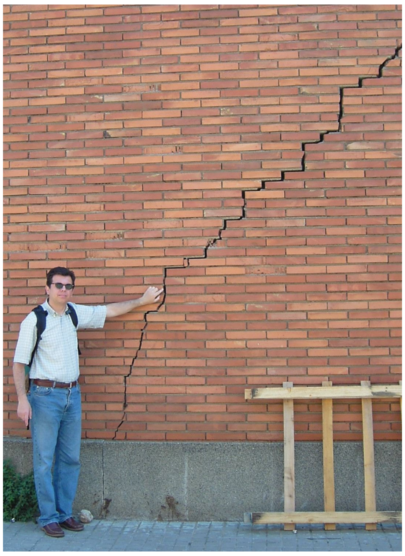

Figure 8: picture taken as part of the in situ validation carried out for the point A marked in figure 6.

5. CONCLUSION

The possibility of ERS/ENVISAT single cross-interferograms was presented in the precedent experiments, demonstrating that cross-interferometry is not just a theoretical possibility but feasible in practice. The results extracted from the performed study show in a qualitative way that continuity on the phase measurements between both sensors is possible. This is very important because from an operational point of view, millimetrical ground movements can be monitored by using the ERS-1/2 archived data. The major problem in the merging process is not the sensor differences but the high Doppler values of the last ERS-2 images. Even if the processing of the data requires working at high resolution and some additional care, surprising results can be obtained due to the introduced phase corrections. Maps of mean subsidence and of the building heights can be estimated over the whole city at full SLC radar resolution without the use of interpolation.

ACKNOWLEDGMENTS

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6. REFERENCES

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