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SARWatch - Advances in the Science and Applications of SAR Interferometry

Multi-sensor monitoring of Ciudad Guzman (Mexico) ground subsidence

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Abstract

The study of urban subsidence with multi-temporal SAR interferometry is nowadays a well-consolidated approach. Thanks to this powerful technique, it is possible to detect and to measure ground deformation velocity and time series of displacement with high accuracy. This work focuses the analysis on the subsidence phenomenon that is threating the city of Guzman (Jalisco state, Mexico) by means of multi-temporal SAR interferometry applied to a stack of COSMO-SkyMed data, from 2011 to 2015, and a stack of Sentinel-1 TOPSAR mode images, from 2016 to 2018. The work is intended to carry on the study performed with ENVISAT images covering the time span between 2003 and 2010, allowing the continuous monitoring of the deformation process.

Keywords: subsidence; geohazard; multi-temporal InSAR; urban monitoring; Sentinel-1; ENVISAT; COSMO-SkyMed

1. Introduction and geological context

Ciudad Guzman (Jalisco state, Mexico) is located in the norther side of the Volcan de Colima area, one of the most active Mexican volcanoes. On 21 September 2012, the city was struck by ground fissures of about 1.5 km of length causing the deformation of the roads and the propagation of fissures in adjacent buildings [1]. The field survey showed that fissures alignment is coincident with the escarpments produced during the 19 September 1985 central Mexico earthquake (M 8.1). The town is located in the Eastern side of a 20 km wide and 60 km long valley flanked by sharp and parallel NNE-SSW-trending active extensional faults [2]. This valley is filled by a ~1km thick sequence of quaternary lacustrine sediments, alluvium, and colluvium [3]. A system of normal fault outcropping in the Eastern and Western mountain ranges likely cuts the bedrock hidden under this recent deposits.

It is well know that SAR interferometry (InSAR) techniques can be successfully used to study surface movements caused by different phenomena, such as anthropogenic ground subsidence, mining, or withdrawal of fluids (e.g. [4-8]). This study focuses on the observation of the evolution since 2003 of the creeping phenomenon producing subsidence and ground fracturing of the Ciudad Guzman area [9]. We compare the result of the multi-temporal InSAR processings of ENVISAT, COSMO-SkyMed, and Sentinel-1 satellite images, covering a time

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span from 2003 to 2018. The work intends to continue the activity started in 2010 when the ENVISAT processing allow, for the first time, to measure the urban subsidence of Ciudad Guzman.

2. Data and method

A wide set of SAR images collected by ENVISAT, COSMO-SkyMed, and Sentinel-1 satellites have been used to detect and to measure the subsidence affecting Ciudad Guzman. The three systems have allowed the continuous monitoring of the ongoing deformation with C-band and X-band SAR sensor, for about fifteen years. The ENVISAT dataset is composed of 40 and 41 images on ascending and descending orbit, respectively. The images have been processed by using the IPTA Multi-Baseline method implemented in GAMMA software [10]. The method computes a stack of point-wise interferograms, which are generated with SAR pairs characterized by values of spatial and temporal baselines limited within specific ranges, with the aim of minimizing the interferometric coherence loss. Then, the deformation time-series and residual topographic heights are estimated by using the Singular Value Decomposition (SVD) Least-Squares inversion technique [11] applied to the interferometric stack. The same method has been adopted to elaborate the COSMO-SkyMed data. In particular, 98 images, only on ascending path, have been paired by setting 350 meters of spatial baseline and 150 days of temporal baseline, resulting in a total of 359 interferograms. The interferograms affected by phase unwrapping errors and strong atmospheric artifacts have bene removed before applying the SVD. As far as the Sentinel-1 images, we adopted two different approaches, aiming at perform a cross validation among all the results. Sentinel-1 data have been processed with two techniques: the SBAS [11] and the PS® [12], both implemented in the SARScape® software modules. The Sentinel-1 is composed of 54 images, only on ascending orbit.

3. Results: past and present outcomes

The result of COSMO-SkyMed data processing is reported in Fig. 1. The map reports the Line-of-Sight (LoS) mean ground velocity. It shows a clear pattern of deformation velocity that highlights a low rate (or no deformation) zone of subsidence (light blue area), and a high rate zone in the north-west sector of the city (yellow to red area). The rates reach values of more than 6.5 cm per year.

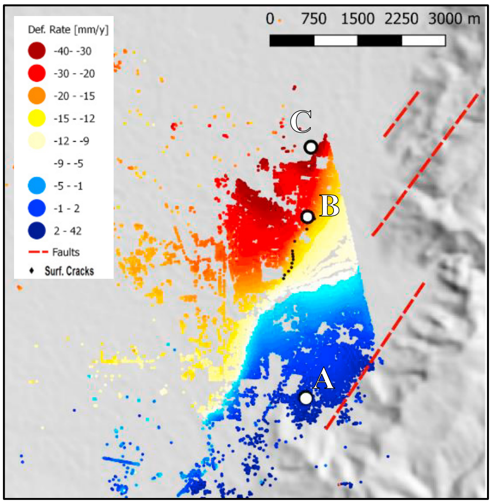

Fig. 1. Mean ground velocity estimated by exploiting CSK images. The spatial pattern of the deformation rate is very similar to the one measured with ENVISAT data stack [1]. The black dots represent the fractures observed in September 2012. Dashed lines are the main faults of the study area. The white circles refer to points deformation time series examples shown in Fig. 3.

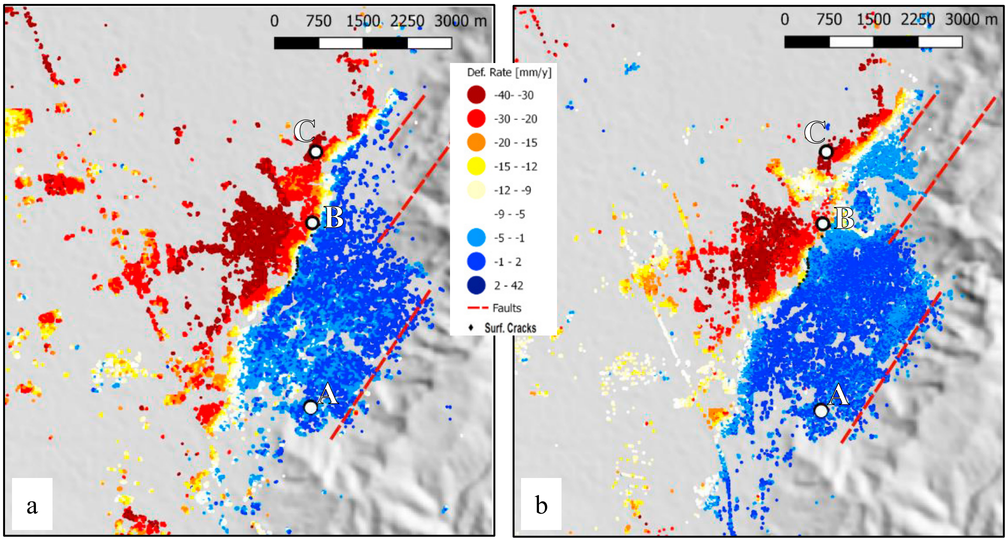

Fig. 2. Mean ground velocity estimated by exploiting Sentinel-1 images. (a) SBAS outcomes; (b) PS outcomes. The spatial patter of the deformation rate is very similar to the one measured with ENVISAT and COSMO-SkyMed datasets. The black dots represent the fractures observed in September 2012. Dashed lines are the main faults of the study area. The white circles refer to points deformation time series examples shown in Fig. 3.

Similar considerations can be done for the ground velocity maps obtained by processing Sentinel-1 images. The spatial patterns are in good agreement with the one from COSMO-SkyMed and the previous ENVISAT analysis, even though a higher rate of deformation is captured in the north-west sector of the city. The outcomes from SBAS and PS® (map (a) and (b) in Fig.2, respectively) seem to show the same general trends, excepting for some areas, such as the region between point B and C, where 5 to 10 mm/yr difference is found. It is worth to note that a strong increase of the subsidence rate is observed when crossing the points where the fractures occurred in September 2012: this fully agrees with the ground velocity map obtained by ENVISAT dataset [9].

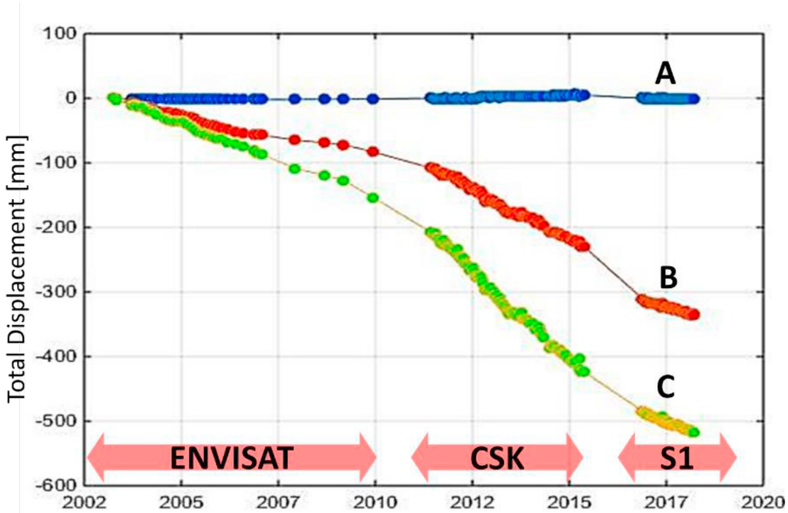

Fig. 3. Plot of the displacements time-series of the three selected points, A, B, and C reported in Fig. 1 and Fig.2.

A direct comparison among all the satellites data outcomes is showed in Fig.3. The figure reports a plot of three time-series of deformation corresponding to three points selected in the low, medium and high rate of deformation regions (A, B, C in Fig. 1 and Fig. 2). Note that the COSMO-SkyMed and Sentinel-1 data have been re-projected along the ENVISAT LoS. For such re-projection we assumed that the horizontal component of the movement is negligible. Moreover, for the whole 2003-2018 displacement observed in A, B and C, we have assumed a linear trend for the deformation, so that the gaps between each series are filled with a linear fitting obtained by extrapolating the slope of the deformation. The plot highlights that ENVISAT, COSMO-SkyMed, and Sentinel-1 time-series agree, indicating increasing rates by moving from the more stable part of the city, in the south-east area, to the north-west region of CG. Moreover, both COSMO-SkyMed and Sentinel-1 estimated rates seem to show an increasing velocity of the ground subsidence in recent years, as already discussed previously.

4. Conclusion and future work

The multi-temporal analysis of the subsidence affecting Ciudad Guzman is here presented. The outcomes of multi-sensor analysis carried out by exploiting ENVISAT, COSMO-SkyMed and Sentinel-1 data stacks, show that the phenomenon is continuously threating this Mexican city. Moreover, is seems that an increase of subsidence rate is acting since 2011.

It is worth to note that the present results are not exhaustive. Additional check will be done to refine the CSK deformation rates, and additional data from the Sentinel-1 mission, will be considered. Actually, for this first assessment we have used only the images taken along the ascending orbit to be compared with the COSMO-SkyMed one, for which no descending data stack is available to perform a multi-temporal InSAR processing. Moreover, to continue the analysis, and complement it, we plan to process Senitinel-1 descending orbit images with the objective to extract the real vertical component of the deformation rate. The analysis will be completed with a modeling of the ongoing subsidence with these new data, to update the work done in [1].

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