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Automatic generation of co-seismic displacement maps by using Sentinel-1 interferometric SAR data

Fernando Monterroso[a,b], Claudio de Luca[b] , Manuela Bonano[c,b], Riccardo Lanari[b], Michele Manunta[b], Mariarosaria Manzo[b], Ivana Zinno[b], Francesco Casu[b,d,*]

[a] *Universitá degli Studi di Napoli "Parthenope", Centro Direzionale di Napoli, Isola C4, 80143 Naples, Italy.*
[b] *Institute for Electromagnetic Sensing of Environment (IREA) - National Research Council (CNR), via Diocleziano 328, 80124 Naples, Italy.*
[c] *Institute of Methodologies for Environmental Analysis (IMAA) - National Research Council (CNR), C.da S. Loja, 85050 Tito Scalo (PZ), Italy.*
[d] *Institute for Electromagnetic Sensing of Environment (IREA) - National Research Council (CNR), via Bassini 15, Milan, Italy.*

Abstract

We present a tool for the automatic generation of co-seismic Differential Synthetic Aperture Radar Interferometry (DInSAR) products by using space-borne SAR data. In particular, the implemented tool relies on the large availability of Sentinel-1 SAR data and on-line earthquake catalogues (e.g. USGS, INGV) to generate co-seismic Line Of Sight (LOS) interferograms and displacement maps. The processing is triggered by the occurrence of a main seismic event, according to the accessible earthquake catalogues. The tool automatically retrieves all the needed SAR acquisitions that cover a defined area across the epicentre and generates the DInSAR products that will be then openly available through the European Plate Observing System (EPOS) portal. Moreover, the possibility to implement the presented tool into the upcoming Copernicus Data and Information Access Services (DIAS) will significantly reduce the product processing time, thus implying a faster product generation and delivery. Accordingly, such a tool not only will contribute to expand the use of DInSAR products in the geoscience field, but also will play a key role on the support of the Civil Protection authorities during the management of seismic crisis.

Keywords: Earthquakes; DInSAR; Sentinel-1; Automatic Processing.

* Corresponding author. Tel.: +39-02-23699-595.
E-mail address: casu.f@irea.cnr.it

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1. Introduction

To measure the Earth's surface deformation after an earthquake is a crucial information for investigating the source of the seismic event. Indeed, having a clear idea of the induced displacements not only permits improving the knowledge of the occurred phenomena, but also could support the activities of the Civil Protection Authorities involved in the seismic risk management. In this sense, the space-borne Differential Synthetic Aperture Radar Interferometry (DInSAR) has proven to be one of the key methods for the quantitative measurement of the Earth's surface deformation, with centimetres to millimetres accuracy [1-2]. DInSAR relies on the evaluation of the phase difference between two complex-valued SAR images, acquired from different orbital positions and at different times [1-3]. Depending on the system configuration, the footprint of space-borne SAR acquisitions can span from a few kilometres up to hundreds of kilometres, making it particularly suitable for accurate investigations of wide areas at relative low cost. Accordingly, the use of space-borne DInSAR to set up operational monitoring services over seismic areas is strongly envisaged. To do this it is, anyway, mandatory to dispose of SAR data archives that are worldwide acquired over seismic areas in a systematic way. Moreover, the satellite revisit time should be as short as possible to make it compatible with the analysis of short-term phenomena as the earthquake ones.

In this context, the recent Sentinel-1 (S1) satellite constellation, of the European Copernicus program, that is composed by two twin SAR satellites, Sentinel-1A and Sentinel-1B, which have been launched on April 2014 and April 2016 respectively, represents the game changer in terms of space-borne DInSAR operational services set up [4]. Indeed, the main Sentinel-1 acquisition mode on land, the so called Interferometric Wide Swath (IWS), is specifically designed for DInSAR applications and implements the Terrain Observation by Progressive Scans (TOPS) technique [5] that guarantees a very large spatial coverage: indeed, the nominal footprint of the S1 TOPS mode extends for about 250 km, thus allowing the constellation to operate with a global coverage acquisition strategy. Moreover, the Sentinel-1 revisit time is either 12 or 6 days in the case of one or two operating satellites, respectively. These characteristics sum up with the huge open access SAR data archive, which has already been acquired worldwide since October 2014 and that nowadays shows an acquisition rate of ten of TByte per day. In this scenario, some operational service based on Sentinel-1 data is already active [6-9].

Accordingly, taking benefit from the operational capability of the Sentinel-1 constellation, the aim of this work is focused on the development of a tool for the systematic generation of Sentinel-1 DInSAR co-seismic maps. In particular, it has been implemented a fully unsupervised end-to-end procedure for the generation of displacement maps after an earthquake. This procedure is automatically triggered by the occurrence of a main seismic event and starts from the collection of SAR data up to the dissemination of the achieved results. The developed system, relies on widely common IT methods and protocols, making it not specifically tied to a defined architecture, thus implying its relative large portability, in view also of the upcoming European Commission Data and Information Access Services (DIAS) [10] where satellite data (mainly Sentinel) and processing facilities will be co-located to reduce the transfer time during their processing.

2. Automatic DInSAR processing workflow

In this section, we provide the details of the implemented procedure for the automatic generation of DInSAR displacement maps triggered by main seismic events, based on Sentinel-1 acquisition. The procedure workflow is depicted in Fig. 1 and is explained below. It is worth noting that, apart the single processing blocks, the described procedure is coded in Linux Bash, making it highly portable and avoiding the installation of any additional software, tool or library.

2.1. Earthquake information retrieval and identification

The procedure starts from the retrieval of the earthquake information (Block A of Fig. 1), such as magnitude, time and epicenter location, from on-line public available catalogues as those provided by main international geophysical institutions (e.g. USGS [11], INGV [12]). Such services systematically provide real-time earthquake information in different standard formats (QuakeML, geoJSON, ...) and are accessible via subscription feeds that are updated with a defined frequency. The system herein presented implements, but it is not limited to, an interface with the USGS earthquake catalogue and retrieves earthquake information in geoJSON format, which is a standard format designed to represent simple geographic elements, together with their non-spatial attributes, based on JavaScript Object Notation [13]. This format provides, among others, earthquake information related to: magnitude, epicentre location (latitude, longitude, depth), UTC time of the event, location description (distance to the nearest town center), pager. This information is available every five minutes at global scale [11].

2.2. Earthquake data analysis

Once an earthquake occurs, only the relevant information in accordance to an empirical magnitude and depth relation is collected (Step B of Fig. 1). Indeed, only high magnitude (> Mw 6.0) and relatively shallow earthquakes (typically < 20 km) very likely induce a surface deformation that is detectable via DInSAR. Among the earthquakes that respect the relation, only those with the epicentre on land (or even on water but that can likely induce detectable deformation on land) are actually processed according to the next steps of the procedure.

2.3. SAR Data identification and retrieval

On the selected earthquakes, an automatic query of the available SAR data catalogues is performed (Step C of Fig. 1). This query permits to identify all the satellite tracks, from both ascending and descending passes, that cover the area very likely interested by the earthquake-induced deformation. Accordingly, the query is performed over an area whose extension depends on the earthquake magnitude and depth. In general, while the area extension could not have significant impact on satellites characterized by wide swaths (as for instance the Sentinel-1 one), it could be of crucial importance for those with small footprints (e.g. COSMO-SkyMed, TerraSAR-X, ...), meaning the data fetching of several tracks. In any case, for the implementation herein presented, the Sentinel-1 catalogue has been considered. The relation between magnitude, depth and area is derived from theoretical and empirical considerations and is susceptible of further tuning and refinement. As a rule of thumb, we assume an area of 50x50 km for an earthquake of Mw 6.0, that increases to 100x100 km for a Mw 8.0 event.

Once the tracks covering the earthquake area have been identified, the system retrieves all the available SAR data up to 30 days before the event (or at least 1 pre-event image even in a larger time span), in order to allow the generation of the co-seismic interferograms. The data retrieval, and accordingly the subsequent DInSAR processing, remains active up to 30 days after the event.

2.4. DInSAR Processing and result dissemination

Once the relevant pre-event data are downloaded, the subsequent DInSAR processing (Block D of Fig. 1) is carried out by using the Parallel Small BAseline Subset (P-SBAS) processing chain [14-15] implemented at IREA-CNR. Indeed, instead of performing the whole SBAS processing, the P-SBAS chain is exploited up to the interferogram generation step, so that the processing can also benefit of the parallelization strategies implemented within P-SBAS. In principle, the processing of the different tracks can be carried out in parallel, while actually their execution depends on the available computing resources and on the effective temporal acquisition of the SAR data. A processing prioritization of the different tracks on the basis of the post-event acquisition time has been implemented (according to a First come-First served policy). The tool provides wrapped interferograms and displacement maps (unwrapped interferograms converted in centimetres) in the satellite Line of Sight (LOS). For the latter, an automatic identification of the reference point has been implemented based on: the epicentre location, the footprint and the spatial coherence. The output data are provided according to the file formats defined within the European Plate Observing System (EPOS) [16] research infrastructure. In particular, the products are provided in geoTiff, while metadata follow the ISO 19115, and will be made openly available through the EPOS portal, to be investigated and interpreted by the scientific community.

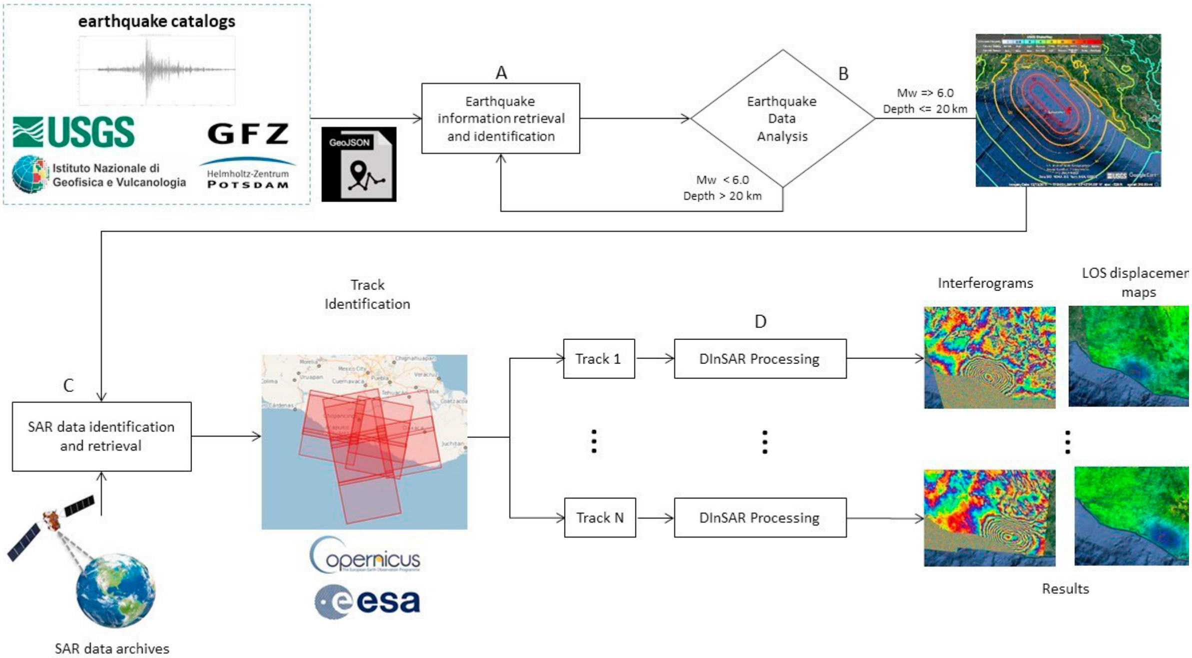

Fig. 1. Automatic displacement map generation workflow.

As final consideration, it is worth noting that, although tested with Sentinel-1 data, the implemented tool is independent from the exploited SAR acquisitions. The only dependency is on the catalogue interface that, if does not respect an Open standard, requires the implementation of an appropriate wrapper.

3. Preliminary Results

The proposed system has been implemented on in-house computing facilities and has been tested through a controlled experiment. In particular, as a real test case it was selected the seismic sequence that struck the Mexico in the late 2017 and early 2018 [11]. Indeed, during September 2017 three large magnitude earthquakes occurred: the first one was registered on September 7th off the coast of Chiapas region, with a Mw of 8.2 and a depth of 47.7 km; fifteen days later, specifically on September 19th, another significant earthquake struck the central part of Mexico (Ayutla, Mexico) with a Mw 7.1 at a depth of 48.0 km; then, on September 23th, an event occurred in Oaxaca, in southern Mexico, with a Mw of 6.2 at a depth of 9.2 km. Finally, after several months, in the February 16th, 2018, a new Mw 7.2 event occurred close to San Pedro Jicayan (Mexico).

The occurrence of such huge events in these periods represents a very valuable test case to verify and validate the implemented procedure. An example of the obtained results is depicted in Fig. 2, which is relevant to the San Pedro Jicayan event; each colour cycle corresponds to a LOS displacement of 2.8 cm. Fig.2 also provides and example of the expected results of the implemented system, once put in operation.

4. Discussion and conclusions

We presented a tool to generate in a completely automated way the DInSAR co-seismic displacement maps from Sentinel-1 data once an earthquake occurs. Even if the system has been tested with Sentinel-1 data, the implementation is platform independent, being the dependencies on the catalogue interface of the exploited SAR sensor. It is then possible to port the proposed system into different platforms such as the ESA's Geohazards Exploitation Platform (GEP), any public Cloud platform that provides standard interfaces, and the upcoming Copernicus DIAS. In this last case, a strong benefit will come from the co-location of SAR data and processing

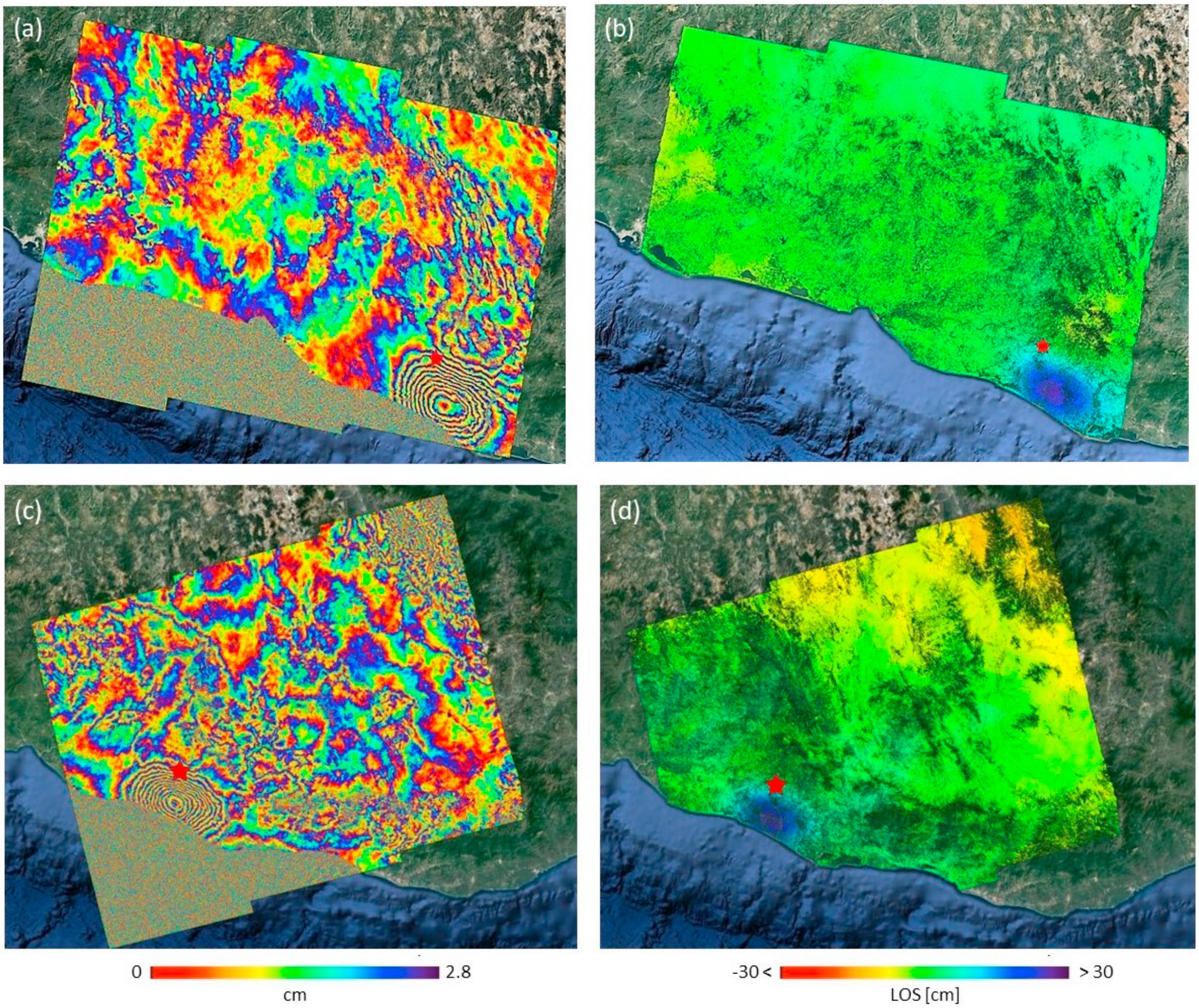

Fig. 2. Sentinel-1 wrapped (a) (c) and unwrapped (b) (d) co-seismic interferogram spanning the Mw 7.2 – 3km S of San Pedro Jicayan, Mexico seismic event, occurred on 2018-02-16 23:39:39 UTC. The master and slave data have been acquired on 2018-02-14 and 2018-02-20 from descending orbits (Track 143) and on 2018-02-05 and 2018-02-17 (Track 05) from the ascending ones.

facilities, thus strongly reducing the data access time. The DInSAR results generated by the proposed tool will be openly available through the EPOS research infrastructure, making them accessible to a wide geoscience community and thus contributing to the dissemination of the DInSAR results across geoscience disciplines.

The proposed system can also be easily extended to include additional processing tools that add value on the generated outputs. It is for instance the case of tools able to automatically model the seismic source starting from the ascending and descending displacement maps obtained via the proposed system.

Finally, it is worth noting the implication of such a system within the Civil Protection scenario. Indeed, the possibility to obtain in a short time frame a detailed picture of the displacement induced by an earthquake is of crucial importance to correctly understand the on-going phenomena and to support the seismic emergency management.

Acknowledgements

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