ARTICLE IN PRESS
RSE-10264; No of Pages 15
Remote Sensing of Environment xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

Large areas surface deformation analysis through a cloud computing P-SBAS approach for massive processing of DInSAR time series

Claudio De Luca *, Ivana Zinno, Michele Manunta, Riccardo Lanari, Francesco Casu

IREA-CNR, Via Diocleziano 328, 80124 Napoli, Italy

ARTICLE INFO

Article history:
Received 11 August 2016
Received in revised form 3 May 2017
Accepted 19 May 2017
Available online xxxx

Keywords:
DInSAR
P-SBAS
Cloud computing
Mosaicking
ENVISAT
Sentinel-1

ABSTRACT

We present in this work a methodology for computing surface deformation time series and mean velocity maps of large areas. Our approach relies on the availability of a multi-temporal set of synthetic aperture radar (SAR) data collected from ascending and descending orbits over an area of interest, and also permits us to estimate the vertical and horizontal (East-West) components of the Earth's surface deformation. The adopted methodology is based on an advanced cloud computing implementation of the differential SAR interferometry (DInSAR) Parallel Small Baseline Subset (P-SBAS) processing chain which allows the unsupervised processing of large SAR data volumes, from the raw data (level-0) imagery up to the generation of the corresponding DInSAR time series and maps. The solution presented, which is highly scalable, has been tested on ascending and descending ENVISAT SAR archives comprising approximately 400 GB of data, which have been acquired over a large area of southern California (US) that extends over about 90,000 km^2. Such an input dataset has been processed in parallel by exploiting 280 computing nodes of the Amazon Web Services Cloud environment. The overall processing lasted about 8 h and cost approximately $1900 USD. Moreover, to produce the final mean deformation velocity maps of the vertical and horizontal (East-West) displacement components of the whole investigated area, we also took advantage of the information available from external GPS measurements that permit us to account for possible regional trends not easily detectable by DInSAR and to refer the P-SBAS measurements to an external geodetic datum.

The results presented clearly demonstrate the effectiveness of the proposed approach that paves the way to the extensive use of the available ERS-1/2 and ENVISAT SAR data archives. Furthermore, the proposed methodology can be particularly suitable to deal with the very large data flow provided by the Sentinel-1 constellation, thus permitting the extension of the DInSAR analyses at a nearly global scale.

1. Introduction

The active remote sensing scenario is characterized by a huge availability of synthetic aperture radar (SAR) data that have been collected during the last 25 years by several space-borne missions. In this context, ESA missions made a key contribution permitting the creation of large archives of SAR acquisitions during the 1991–2011 period, covering a large part of the Earth. They comprise the C-band data sequences that have been collected by the first-generation of SAR sensors, the ERS-1/2 and ENVISAT systems, which operated with a revisit time of 35 days, a footprint of about 100 km (in the commonly used Stripmap mode) and a spatial resolution of about 5 × 20 m (in the azimuth and ground-range directions, respectively). Furthermore, we have access to the data sequences acquired by RADARSAT-1 and RADARSAT-2 C-band sensors as well as those provided by the L-band ALOS and ALOS-2 systems. In addition, significantly large SAR data archives are currently provided by the new generation of SAR sensors, represented by the Italian COSMO-SkyMed (CSK) and the German TerraSAR-X (TSX) systems. These X-band sensors, launched starting from 2007, are characterized by: 1) short revisit time (on average weekly); 2) high spatial resolution (about 3 m by 3 m for the most commonly used Stripmap mode); and 3) a spatial coverage of about 40 km (again in the Stripmap mode). Moreover, an unprecedented data flow is going to be further supplied by the C-band Sentinel-1 (S1) mission of the European Copernicus program that is composed of two twin SAR satellites, Sentinel-1A and 1B, which have been launched on April 2014 and April 2016 respectively (Copernicus – The European Earth Observation Program, http://www.copernicus.eu accessed 28/07/2016; Salvi et al., 2012). The main S1 acquisition mode on land, the so called Interferometric Wide Swath (IWS), implements the Terrain Observation by Progressive Scans (TOPS) technique (De Zan and Monti Guarnieri, 2006) 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. The Sentinel-1 revisit time is either 12 or 6 days in the case of one or two operating satellites, respectively. In addition, it is worth noting that the whole Sentinel-1 archive is available with a free and open access policy, thus easing the

* Corresponding author.
E-mail address: deluca.c@irea.cnr.it (C. De Luca).

http://dx.doi.org/10.1016/j.rse.2017.05.022

data access and enlarging the scientific community interested in its exploitation.

These large SAR data volumes clearly testify to how the remote sensing scenario is moving toward the Big Data concept; indeed, managing and storing such a huge amount of data (Volume), processing it in an effcient way (Velocity) and maximizing the available archives exploitation (Variety) are becoming high priority issues [Big Data "V"] (Laney, 2001).

Among the techniques aimed at extracting value added information from SAR data, differential synthetic aperture radar interferometry (DInSAR) has continuously developed in the last decades, becoming a very important tool for Earth's surface deformation investigation thanks to its capability to observe very large areas of the globe with a very high cost effectiveness (Burgmann et al., 2000; Massonnet and Feigl, 1998).

The DInSAR techniques have a very wide range of applications. In particular, they are largely exploited within the natural hazards scenario to study the geophysical processes related to tectonics, volcanoes and landslides (Calò et al., 2014; Tizzani et al., 2009; Lanari et al., 2002; Massonnet et al., 1993). Moreover, the DInSAR products are very useful to monitor surface displacements due to anthropogenic actions, as in the cases of ground-water exploitation (Hsieh, 1996), oil and gas extraction (Yerkes and Castle, 1969), gas capture and storage (Orr, 2009; Rackley, 2009), mining activities (Gourmelen et al., 2007 and Shixiang and Dade, 2004), tunneling, building and management of dams and flood defenses, and transportation (Clough and Woodward, 1967; O'Reilly and New, 1982).

Basically, the DInSAR techniques allow generating spatially dense deformation maps with centimeter to millimeter accuracy by exploiting the phase difference (interferogram) between pairs of complex SAR images, usually referred to as single look complex (SLC) images, relevant to acquisitions gathered at different times, but with nearly the same illumination geometry and from sufficiently close flight tracks, whose separation is typically referred to as the baseline (Burgmann et al., 2000; Franceschetti and Lanari, 1999; Massonnet and Feigl, 1998). More specifically, DInSAR analyses the so called differential interferograms; they are generated through the difference between an interferogram and its topography-related phase component (Franceschetti and Lanari, 1999), the latter being calculated by exploiting the sensor orbital information and an external digital elevation model (DEM) of the illuminated scene, properly converted in the SAR coordinates system (Franceschetti and Lanari, 1999). For the sake of simplicity, in the following of this paper the terms interferogram and differential interferogram are considered as synonyms. Note also that the DInSAR techniques permit estimation of the surface displacement component along the radar line of sight (LOS) and they properly work in areas where the computed interferograms are characterized by high coherence, i.e., in zones that are not significantly affected by phase noise effects, usually referred to as the decorrelation phenomena (Zebker and Villasenor, 1992).

Originally, the DInSAR methodology has been applied to analyze single deformation episodes such as earthquakes and volcanic unrests (Fialko et al., 2001; Massonnet et al., 1995; Peltzer and Rosen, 1995); however, especially thanks to the availability of long SAR data time-series collected in the last decades, the interest of the scientific community has significantly moved toward the study of the temporal evolution of the detected deformations (Lundgren et al., 2001, 2004). This is possible through the exploitation of the advanced DInSAR techniques, which properly combine the information available from a set of multi-temporal differential interferograms relevant to the Area of Interest (AoI), in order to compute the deformation time series (Sansosti et al., 2010).

Among several advanced DInSAR algorithms, a well-known approach is the one referred to as Small BAseline Subset (SBAS) (Berardino et al., 2002) that allows the computation of displacement time series and the corresponding mean deformation velocity maps in different scenarios (tectonic areas, volcanoes, landslides, anthropogenic induced land motions) from a temporal sequence of SAR acquisitions. The SBAS algorithm is also capable of performing analyses at different spatial scales and with multisensor data, thus underlying its versatility and enlarging its application field (Bonano et al., 2012; Lanari et al., 2004b; Manunta et al., 2008; Pepe et al., 2005).

It is evident that the full exploitation of the available large SAR archives needs effective solutions to deal with the transfer, the storage and, above all, the processing of this massive data stream. From the processing point of view, within the framework of the advanced DInSAR methodologies, a parallel algorithmic solution for the SBAS approach has recently been developed, referred to as P-SBAS (Casu et al., 2014), which implements in full the complex SBAS processing chain (from the SAR raw data focusing up to the displacement time-series and deformation mean velocity map generation) and is able to exploit distributed computing architectures. This solution has also been implemented within the European Space Agency (ESA) Grid Processing on Demand (G-POD) environment (ESA Grid Processing on Demand, https://gpod.eo.esa.int, accessed 28/07/2016) to make available the SBAS technique to the EO community for the on-demand DInSAR processing (De Luca et al., 2015). Moreover, some studies on the P-SBAS algorithm migration to public cloud computing (CC) environments, particularly the Elastic Cloud Compute (EC2) of Amazon Web Services (AWS) (Amazon EC2, http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/concepts.html, accessed 28/07/2016) have already been carried out. Note that the exploitation of customized computing infrastructures built up within CC environments is becoming crucial in the scientific context (Gupta et al., 2014; Hardman et al., 2012; Rehr et al., 2010; Rosen et al., 2012), for many reasons; first of all, because of the practically unlimited data storage and computing facilities they make available; secondly, for the flexibility they provide, which allows extensive resources optimization. The above-mentioned works, which concerned the evaluation of the P-SBAS parallel performances achievable on a CC infrastructure, allowed proposing a CC architecture specifically tiled for preserving the P-SBAS scalability. The achieved results clearly showed the capability of the developed P-SBAS CC solution to efficiently use increased processing resources, even when dealing with huge SAR data volumes (Zinno et al., 2015a, 2015b).

It is evident from the above discussion that, the EO community can take great benefit from the depicted scenario characterized by i) huge SAR data volumes, ii) effective DInSAR techniques to retrieve information from such extended datasets and iii) a large availability of computing resources provided by CC infrastructures. In particular, an extensive exploitation of the first-generation SAR data archives (firstly ERS-1/2 and ENVISAT), which have been only partially explored during recent years (Fusco et al., 2003), may represent a key element for the comprehension of the Earth's surface dynamics of large areas. Therefore, it is not surprising that some relevant efforts in this direction have been already carried out (Adam et al., 2013; Hardman et al., 2012; Rosen et al., 2012). Moreover, the EO community puts a strong interest toward the exploitation of the Sentinel-1 new data archives that, thanks to the systematic and global acquisition strategy of this constellation, will permit the study of natural and anthropogenic phenomena at an unprecedented scale, thus strongly increasing our knowledge of the Earth.

In this work we present a methodology for processing and analysing large SAR data volumes to generate deformation time series and mean velocity maps at very large spatial scale, in an efficient and cost effective way; moreover, our approach also permits us to estimate the vertical and horizontal (East-West) components of the detected Earth's surface deformations, benefiting from the SAR data collected from ascending and descending orbits. Our methodology jointly exploits the P-SBAS algorithm for advanced DInSAR processing of SAR data and a CC infrastructure; it is highly scalable and it has been tested on an ascending and descending ENVISAT SAR archives acquired over a large area of Southern California (US) extending for about 90,000 km^2. Our results demonstrate the effectiveness of the implemented approach, which can be easily extended to process other SAR satellite data, particularly those acquired by the Sentinel-1 constellation.

Please cite this article as: De Luca, C., et al., Large areas surface deformation analysis through a cloud computing P-SBAS approach for massive processing of DInSAR time series, Remote Sensing of Environment (2017), http://dx.doi.org/10.1016/j.rse.2017.05.022