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Automatic and Systematic Sentinel-1 SBAS-DInSAR processing chain for deformation time-series generation.

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Abstract

Sentinel-1 is the first of a family of satellites designed to provide a data stream for the European environmental monitoring program known as Copernicus. Sentinel-1 constellation has been specifically designed to perform, over land, advanced Differential Interferometric Synthetic Aperture Radar (DInSAR) analyses for the investigation of Earth's surface displacements. In particular, owning to its 6-day revisit time and its innovative acquisition mode, which is referred to as Terrain Observation by Progressive Scans (TOPS) and is fundamental for guaranteeing a global spatial coverage, Sentinel-1 constellation is contributing to the creation of a framework for the exploitation of "Big Data" for Earth Observation (EO) applications.

In this paper, we present an efficient and automatic implementation of the Parallel Small BAseline Subset (P-SBAS) DInSAR algorithm, specifically intended for the processing of Sentinel-1 SAR data. The algorithm is able to run on distributed computing infrastructures by effectively exploiting a large number of resources, and allows the generation of ground displacement time-series. The aim of this paper is to show that it is possible to automatically and continuously process, in a short time frame, very large sequences of Sentinel-1 data, thus allowing us to perform advanced interferometric analyses at an unprecedented large scale. In addition, the proposed Sentinel-1 P-SBAS algorithm has also been tested on commercial public cloud computing platforms, such as those provided by the Amazon Web Services.

The presented Sentinel-1 P-SBAS processing chain is well suited to build up operational services for the easy and rapid generation of advanced interferometric products, which can be very useful not only for scientific purposes but also for the risk management and the natural hazard monitoring.

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Keywords: Sentinel-1, P-SBAS, DInSAR, Cloud Computing, AWS

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1. Introduction

On April 3, 2014, the first sensor of the Sentinel-1 (S1) constellation, Sentinel-1A (S1A), was launched, providing the scientific community with C-Band SAR data collected in continuity with the first generation ERS-1/2 and ENVISAT missions. It is characterized by significant enhancements in terms of revisit time, coverage, timeliness and service reliability. In particular, S1A Interferometric Wide Swath (IWS) scenes are collected through the innovative acquisition mode referred to as Terrain Observation by Progressive Scans (TOPS), which allows a significant improvement of the range coverage (of about 250 km) with respect to the conventional Stripmap mode, Moreover, on April 25 2016 the twin sensor Sentinel-1B was also launched, thus forming a constellation with a revisit time of 6 days. Of particular relevance is also the limited extension of the S1 orbital tube, which has got a diameter of about 200 m. Hence, thanks to both its small spatial and temporal baselines, the Sentinel-1 constellation is specifically oriented to interferometric applications. Such characteristics, coupled with the adopted free and open access policy for data dissemination, foster the exploitation of interferometric methodologies and the relevant products.

In this paper, we focus on Differential SAR Interferometry (DInSAR) technique, which is a well-established microwave remote sensing methodology that allows us to estimate the ground deformations with a centimeter-to-millimeter accuracy [1, 2]. Over time, DInSAR has moved from the analysis of single deformation episodes towards the study of the temporal evolution of the detected displacements, thanks also to the availability of large sequences of SAR data. A well-known DInSAR algorithm is the one referred to as Small BAseline Subset (SBAS) [3], which is able to process large sets of multi-temporal SAR images, thus retrieving mean deformation velocity maps of the investigated areas and, for each coherent target on the ground, the relevant displacement time-series.

Recently, a parallel version of the SBAS algorithm referred to as P-SBAS (Parallel Small BAseline Subset), able to properly exploit distributed computing infrastructures (i.e. cluster, grid, cloud), has been developed. It makes use of both multi-core and multi-node programming techniques and is based on an "*ad - hoc*" designed distributed storage implementation, which is aimed at guaranteeing sustained scalable performances also for massive amounts of data to be processed.

In this paper, we present an innovative P-SBAS processing chain for Sentinel-1 data, which has been designed with a strategy that strongly takes into account the data acquisition characteristics of the TOPS mode [4]. Indeed, IWS scenes consist of series of bursts that can be considered as independent, separate acquisitions. This makes a large part of the processing inherently parallel at a burst granularity level; such a condition implies that the processing time can significantly be reduced thanks to the availability of large computing resources. Moreover, we discuss about the implementation of the presented P-SBAS S1 processing chain within the Amazon Web Services cloud environment, showing some preliminary results.

2. P-SBAS processing chain for Sentinel-1 data

The SBAS approach [3] relies on a proper selection of differential SAR interferograms that can be profitably used to generate spatially dense displacement maps and the corresponding time-series. Recently, a parallel implementation of the SBAS approach, referred to as P-SBAS [5], able to efficiently run in large computing infrastructures (grid and cloud), has been developed to allow for an effective computation of large SAR data sequences with advanced DInSAR approaches. Such a topic is therefore gaining importance due to the large availability of SAR sensors able to provide a very high data stream, as in the case of the Sentinel-1 constellation.

2.1 Sentinel-1 P-SBAS processing chain implementation

The TOPS acquisition mode, designed to collect Sentinel-1 IWS images, requires proper processing solutions to tackle its specific peculiarities. Indeed, the TOPS mode is quite similar to the ScanSAR one, since during the acquisition time the antenna beam is switched cyclically among the different sub-swaths. However, unlike ScanSAR, in the TOPS mode the sensor scans the image with very long bursts by rotating the antenna throughout the acquisition from backward to forward, resulting (differently to the spotlight mode) in a worsening of the azimuth resolution. Such a new acquisition mode leads to the necessity of developing original, and innovative, processing algorithms for the proper extraction of Earth Observation information from SAR data (with particular emphasis on image co-registration and interferogram generation procedures). Indeed, contrary to the standard stripmap acquisition mode, TOPS is characterized by high azimuth Doppler centroid variations that cause non-negligible phase artefacts, also in the presence of small mis-registration errors, which need to be properly estimated and filtered out.

In order to effectively exploit the parallel processing on large computing environment, the developed P-SBAS S1 processing chain exploits the burst composition characterizing the IWS data, thus benefiting from the intrinsic granularity of S1 data. Therefore, the burst partitioning is preserved during the co-registration and interferogram generation steps, as well as during the residual phase shift estimation through the spectral diversity (SD) method [6]. This allows us to distribute the processing of different bursts among different computing nodes, following the same strategy presented in [5] for parallelizing both the SAR image processing and the interferogram generation.

After the co-registration operation, the interferogram generation and the residual phase shift estimation steps, all implemented on a burst-by-burst basis, the mis-registration residuals ramps are removed. Subsequently, for each interferometric data pair, the whole differential SAR interferogram and the coherence map are generated by properly mosaicking the previously computed burst-by-burst InSAR data products, in order to generate single maps covering the whole investigated area on the ground.

Once a sequence of differential SAR interferograms is generated, they are then used to compute deformation time-series by applying the SBAS algorithm. SBAS basically consists in the cascade of the Phase Unwrapping (PhU) operation and the inversion of unwrapped interferograms through the Singular Value Decomposition (SVD) method. In particular, PhU step is performed by using the Extended Minimum Cost Flow (EMCF) approach [7].

It is worth noting that, when the processing of large DInSAR datasets characterized by hundreds of SAR acquisitions (and, consequently, by a huge number of interferograms) is concerned, the network, the Input/Output (I/O) and the storage bandwidth capabilities can become a bottleneck for the parallel performances of the algorithm. To overcome these scalability limitations, the implemented S1 P-SBAS processing chain has been properly designed to effectively exploit the capabilities of the Distributed Storage (DS) architecture [8], developed to minimize the I/O and data transfer overhead. In particular, the S1 P-SBAS solution benefits from a proper distribution of the produced intermediate results on the storage units of all the exploited computing nodes. The adopted rationale consists in distributing the data I/O among the different nodes, and making the parallel processes work as much as possible with data that are physically present on the local storage of the specific node, thus performing local reading/writing operations.

Finally, it is worth noting that the implemented P-SBAS processing chain for Sentinel-1 data may be also profitably used to “append” new interferograms to already processed DInSAR archives, as soon as new Sentinel-1 acquisitions are available. This processing strategy is particularly suitable to work in operational contexts aimed at the risk management and the natural hazards monitoring, because of the significant reduction of the overall computational time for the generation of updated deformation time-series when new Sentinel-1 data are acquired.

2.2 Preliminary large scale Sentinel-1 P-SBAS analysis: dataset and P-SBAS results

The experimental analysis was carried out by exploiting 5 Sentinel-1A interferometric SAR data stacks acquired over the southern part of Italy and including also the active Campi Flegrei caldera and the Vesuvius volcano within the Napoli Bay area.

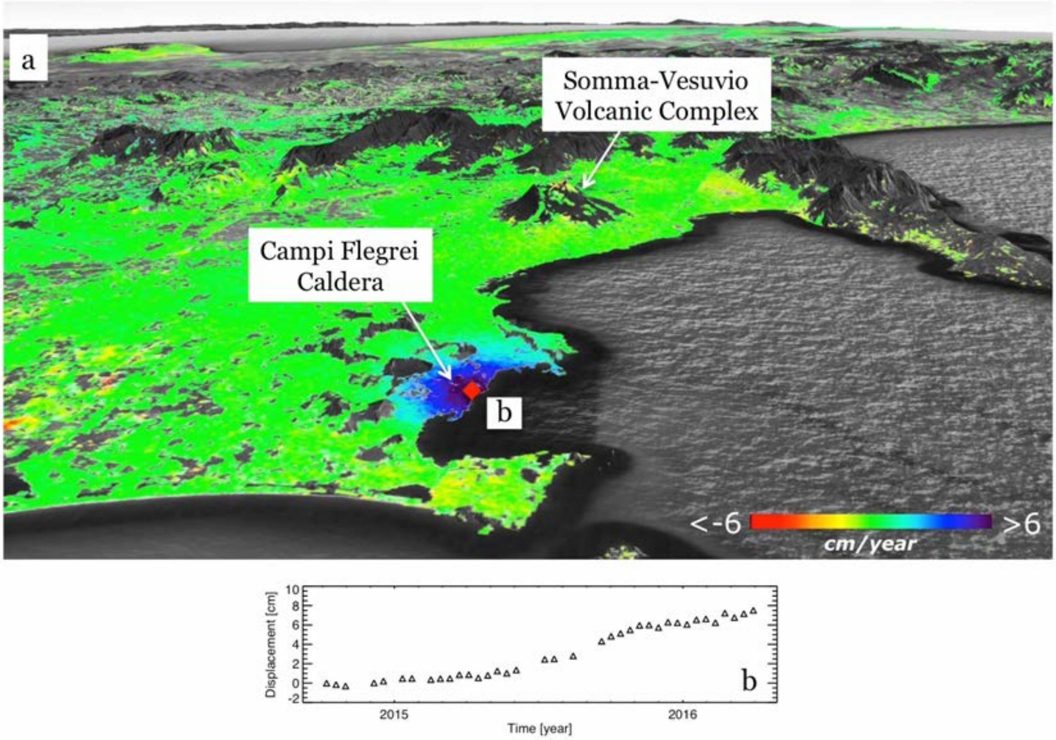

Fig. 1: (a) Line of Sight (LOS) mean deformation velocity map of the Napoli Bay Area, which has been generated via the presented Sentinel-1 P-SBAS processing chain. (b) Plot of the retrieved displacement time-series relevant to a pixel located within the area of maximum deformation of the Campi Flegrei caldera.

To totally cover the areas of interest, we exploited about 270 S1A frames acquired from descending orbits (Tracks 22, 124, 51), spanning the time interval from October 2014 to March 2016 and approximately covering an area of about 95.000 km^2. We exploited for such an analysis more than 500 differential interferograms.

In Fig. 1(a), an insight of the large scale results achieved over the Napoli Bay area is shown. The analysis highlights a significant deformation pattern in correspondence to the Campi Flegrei caldera that is confirmed in the plot pictured in Fig. 1(b) with the chronological sequence of the computed displacements, for a specific pixel located within the maximum deformation area.

3. Sentinel-1 P-SBAS processing chain in AWS environment

As already mentioned in the previous paragraphs, Sentinel-1 system is changing the remote sensing scenario, owing to its big data size, high revisit time and global scale coverage. In particular, to effectively exploit this large amount of available data, adequate computing resources, both in terms of number of nodes and features, are required. In the perspective of dealing with huge data flows, platforms such as dedicated cluster can turn out to be limitative; hence, the migration towards Cloud Computing environments is a promising solution to overcome such computing resources bottleneck.

According to [8], in this work, preliminary results relevant to the Sentinel-1 P-SBAS deployment on Amazon Web Services (AWS) Cloud are presented. As an experimental analysis, we performed the generation of a single differential interferogram in order to evaluate the P-SBAS S1 scalable performances. This test has been made by adopting a computing architecture with a DS solution [8], which also implies the possibility to exploit processing facilities with performances not very high in terms of I/O and network bandwith, thus reducing the costs of the relevant analysis.

For this experiment, among the Amazon Elastic Compute Cloud (EC2) available instances, we chose the m4.2xlarge, which are equipped with 8 vCPUs and 32 GB of RAM (see Table 1). Moreover the selected m4.2xlarge instance has got an amount of RAM sufficient to run the P-SBAS S1 test case, and has got a network bandwidth (1 GB/s) which is big enough especially with the developed DS solution.

Table 1. AWS Instance Configuration

	m4.2xlarge
Architecture	64 bit
Processor	Intel Xeon E5-2676 v3
vCPU	8
RAM	32 GB
Network	High (around 1Gb/s)

Finally, in Table 2 the elapsed time relevant to the P-SBAS test aimed at generating a single differential interferogram and corresponding cost are shown.

Table 2. Preliminary Experiment on S1 Interferogram on AWS

# AWS Instance	2
Instance type	m4.2xlarge
Processing Time	≈ 3 hours
Processing Costs	≈ 5 USD

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References

1. R. Burgmann, P. A. Rosen, and E. J. Fielding, "Synthetic aperture radar interferometry to measure Earth's surface topography and its deformation, " Annu. Rev. Earth Planet. Sci., vol. 28, pp. 169-209, May 2000.
2. G. Franceschetti and R. Lanari, Synthetic Aperture Radar Processing. Boca Raton, FL, USA: CRC Press, 1999.
3. Berardino, P., Fornaro, G., Lanari, R., Sansosti, E., “A new Algorithm for Surface Deformation Monitoring based on Small Baseline Differential SAR Interferograms”, IEEE Trans. Geo. Rem. Sens., 40, 11, 2375-2383, 2002.
4. F. De Zan and A. M. Monti Guarnieri, "TOPSAR: Terrain Observation by Progressive Scans," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 44, no. 9, pp. 2352-2360, Sept. 2006.
5. F. Casu, S. Elefante, P. Imperatore, I. Zinno, M. Manunta, C. D. Luca, and R. Lanari, "SBAS-DInSAR Parallel Processing for Deformation Time-Series Computation," Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of 2014.
6. R. Scheiber and A. Moreira, "Improving co-registration accuracy of interferometric SAR images using spectral diversity," *Geoscience and Remote Sensing Symposium, 1999. IGARSS '99 Proceedings. IEEE 1999 International*, Hamburg, 1999, pp. 1709-1711 vol.3.
7. A. Pepe and R. Lanari, “On the extension of the minimum cost flow algorithm for phase unwrapping of multitemporal differential SAR interferograms”, *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 9, pp. 2374-2383, 2006.
8. I. Zinno, S. Elefante, C. De Luca, M. Manunta, R. Lanari and F. Casu, "New advances in intensive DInSAR processing through cloud computing environments," 2015 IEEE International *Geoscience and Remote Sensing Symposium (IGARSS)*, Milan, 2015, pp. 5264-5267.