ADVANCES IN THE GENERATION OF DEFORMATION TIME SERIES FROM SAR DATA SEQUENCES IN AREAS AFFECTED BY LARGE DYNAMICS

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1. INTRODUCTION

Differential Synthetic Aperture Radar Interferometry (DInSAR) is a remote sensing technique that allows producing spatially dense deformation maps of the Earth surface. To this end, the phase difference of SAR image pairs acquired before and after a deformation episode has to be properly exploited. This technique, originally applied to investigate single deformation events, has been further extended to analyze the temporal evolution of the deformation field through the generation of displacement time-series. Among several, a well-established approach is represented by the Small BAseline Subset (SBAS) technique [1], whose capability to analyze deformation events at low and full spatial resolution has largely been demonstrated [2].

However, in areas where large and/or rapid deformation phenomena occur, the exploitation of the differential interferograms, therefore the generation of displacement time-series, can be strongly limited by severe misregistration errors or by very high fringe rate interferograms .

In this work, we propose advances on the generation of deformation time-series in areas affected by large deformation dynamics. First, we present an extension of the amplitude-based Pixel-Offset analyses by applying the SBAS strategy, in order to move from the investigation of single (large) deformation events to that of dynamic phenomena. Secondly, we suggest mitigating the limitations of phase unwrapping techniques for high fringe rate interferograms, by exploiting synthetic deformation models.

2. METHODS

2.1. Pixel-Offset SBAS analysis

In case of misregistration errors due to large deformation, the information on the occurred displacements may be estimated by computing the Pixel-Offset (PO) retrieved from the amplitude of the investigated SAR image data pair. Indeed, these amplitude-based analyses have already been successfully exploited, although for single deformation events only, and with accuracies that are significantly worse (typically more than one order of magnitude) than that achieved through the interferometric phase signal [3-4]. In particular, we extend the amplitude-based Pixel-Offset analyses in order to move from the investigation of single (large) deformation events to that of dynamic phenomena. We apply the SBAS strategy to the sequence of the range and azimuth amplitude-shifts estimates, achieved from the selected (small baseline) data pairs, in order to generate the corresponding across-track and along track deformation time-series. The proposed approach, namely PO-SBAS, permits therefore to have displacement measurements in areas hardly reachable by exploiting the phase information only.

This approach has been tested on an ENVISAT ASAR data archive (Track 61, Frames 7173-7191) related to the Galàpagos Islands, focusing on Sierra Negra caldera (Galàpagos Islands), an active volcanic area characterized by large and rapid deformation events leading to severe image misregistration effects [4]. A summary of achieved results is presented in Figure 1. We also carried out a validation of proposed technique by comparing Pixel-Offset deformation estimates to continuous GPS measurements. Accuracy is on the order of 1/20th of pixel, estimated by computing the time series standard deviation in a non-deforming area and through comparison to the available GPS measurements.

Finally, implications of new generation sensors like TerraSAR-X and Cosmo-SkyMed, that can reach spatial resolution up to 3 and 1 meter in Strip Map and Spot Light mode respectively, will be discussed.

2.2. Model-Based Fringe Rate Reduction

The approach proposed in the previous section allows us to provide an estimate of the detected displacements with decimeter accuracy, and permits to effectively register the interferometric SAR data pairs. At this stage, a more accurate deformation time-series retrieval can be carried out, but this requires the exploitation of interferograms with high fringe rates, which are extremely critical to be processed by the available phase unwrapping algorithms. In order to mitigate this unwrapping limitation, we propose to exploit analytical models of the deformation field to generate synthetic deformation patterns. This step is performed on wrapped interferograms, by maximizing a cost function k defined as:

$$k = \frac{1}{N}\left|\sum_{n=1}^{N} \exp\left[-j\left(\nabla\varphi_o(n) - \nabla\varphi_m(n)\right)\right]\right| \qquad (1)$$

where $\nabla\varphi_o(n)$ is the mean value of the wrapped phase variation between adjacent pixels, $\nabla\varphi_m(n)$ is its homologous for the modeled deformation signal, and N is the number of the investigated pixels. By exploiting eq. (1) for the sequence of the computed interferograms, we may retrieve the model-based deformation time series by applying the conventional SBAS strategy. This result can be easily attained in order to “flatten” the high fringe rate interferograms, thus helping the subsequent Phase Unwrapping step carried out on the residual phase component.

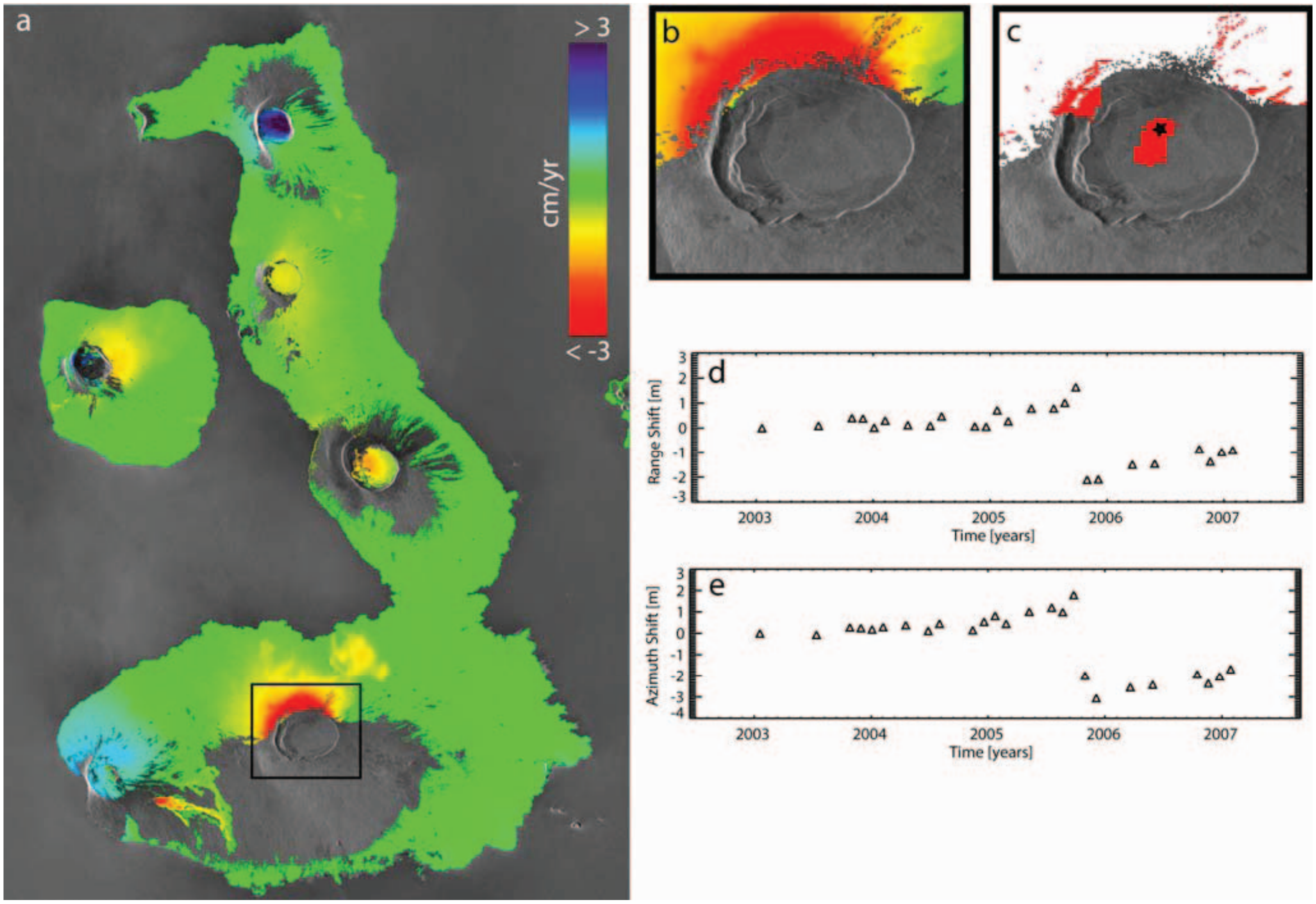

Figure 1. a) Mean deformation velocity map of Galàpagos Island, in Line of Sight, computed via the conventional SBAS algorithm. b) Zoomed view of the Sierra Negra caldera area highlighted in the box of Figure 1.a; note the lack of coherence inside the caldera area, interested by a large eruption event in October 2005. c) Mask of pixels investigated by conventional SBAS and PO-SBAS algorithms, in white and red, respectively; note that are now present deformation measurements in the inner caldera. d-e) Range and Azimuth displacement time series relevant to the pixel marked by a black star in Figure 1.c.

Accordingly, the final deformation time-series can be successful generated by summing the retrieved modeled displacements to the residual signal components. Moreover, information coming from independent measurements (such as GPS or sensors operating in a different band) could be easily exploited as external source.

The proposed approach has been tested on ENVISAT data acquired on Kilauea volcano (Hawaii) in both ascending (T93) and descending (T429) passes during the 2003-2008 time period. In particular, we focus on the 2007 dike intrusion on the East Rift zone.

3. REFERENCES

[1] P. Berardino, G. Fornaro, R. Lanari, and E. Sansosti, “A new algorithm for Surface Deformation Monitorino based on Small Baseline Differential SAR Interferograms,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 40, 11, pp. 2375-2383, 2002.

[2] R. Lanari, F. Casu, M. Manzo, G. Zeni, P. Berardino, M. Manunta, and A. Pepe, “An overview of the Small Baseline Subset Algorithm: a DInSAR Technique for Surface Deformation Analysis,” *Pure And Applied Geophysics* (PAGEOPH), vol. 164, 4, pp. 637-66, 2007.

[3] R. Grandin, A. Socquet, R. Binet, Y. Klinger, E. Jacques, J.-B. de Chabalier, G. C. P. King, C. Lasserre, S. Tait, P. Tapponnier, A. Delorme, and P. Pinzuti, “September 2005 Manda Hararo-Dabbahu rifting event, Afar (Ethiopia): Constraints provided by geodetic data,” *J. Geophys. Res*., vol. 114, B08404, 2009.

[4] S-H. Yun H. Zebker, P. Segall, A. Hooper, and M. Poland, “Interferogram formation in the presence of complex and large deformation,” Geophys. Res. Lett., vol. 34, L12305, 2007.