OPTICAL SATELLITE IMAGES FOR CO-SEISMIC HORIZONTAL OFFSETS ESTIMATE AND FAULT TRACE MAPPING USING PHASE-CORR TECHNIQUE

Marco Chini[1], *Pablo J. González*[2], *Salvatore Stramondo*[1], *and José Fernández*[2]

[1] Istituto Nazionale di Geofisica e Vulcanologia, Remote Sensing Laboratory, Rome, Italy.
[2] Instituto de Astronomía y Geodesia (CSIC-UCM), Facultad de Ciencias Matemáticas, Madrid, Spain.

ABSTRACT

In this work is presented a new robust unwrapping-free phase correlation method, for retrieving the coseismic displacement field and the surface rupture fault-trace mapping using optical data. Phase-corr method does not need phase unwrapping and has been proved to be robust under a wide variety of circumstances. The method has been applied at two different test cases, Izmit (Turkey) and Kashmir (Pakistan) earthquakes, occurred on August 17, 1999, and October 8, 2005, respectively. We measured the near-field deformations exploiting two geometrically corrected IRS images with similar look angles in the case of Izmit earthquake, while the Kashmir earthquake coseismic displacement has been retrieved by ASTER data. The results show that Phase-corr method can be used for deriving the coseismic slip offsets due to a large earthquake (and to map its fault trace) using optical data from different sensors.

Index Terms— Coseismic deformation, earthquakes, image matching (phase correlation).

1. INTRODUCTION

Recent applications of global image disparity measurements [1-2], assuming rigid body motions (translation, rotation and change of scale), has emerged as a wealth of new branch of geodetic data. It highly complements Differential Synthetic Aperture Radar Interferometry (DInSAR) and advanced DInSAR ground motion imaging (highly sensitive to vertical components), because optical and SAR image correlation methods are able to sense the horizontal components of the ground motion [3-4].

In this work, we present several examples of using optical data in a new robust unwrapping-free phase correlation method, Phase-corr [5], for retrieving the coseismic displacement field and the surface rupture fault-trace mapping of two different earthquakes.

The work is organized as follows. In section 2, we briefly describe Phase-corr method and some performance tests. Then, sections 3 and 4 are dedicated to show results for the application of Phase-corr to IRS imagery to determine coseismic effects of the Izmit earthquake and, to ASTER data for the Kashmir earthquake respectively. Finally, in section 5, we discuss the applications and provide some final remarks.

2. PHASE-CORR: A ROBUST PHASE CORRELATION METHOD

We applied a new robust phase fitting correlation method [5]. The algorithm starts from already orthorectified images, either using conventional or sophisticated methods [2]. Then, the roughly corregistered images (to the same reference system) are correlated using a small sliding window, to which a Tukey window filtering is applied to make the signal circularly symmetric. Then, we compute the discrete Fourier transform of the individual images and their

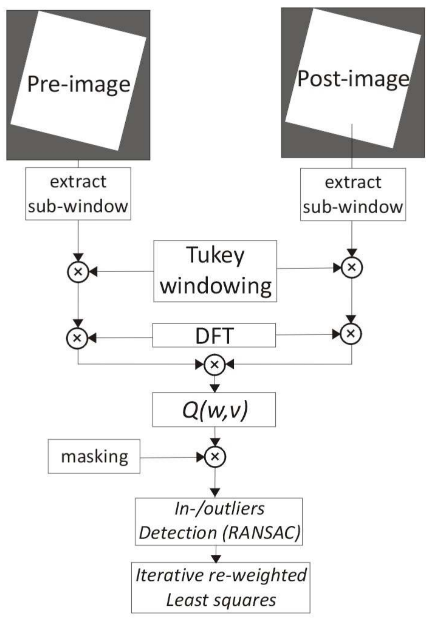

Figure. 1. Algorithm workflow diagram of the proposed robust phase fitting correlation method.

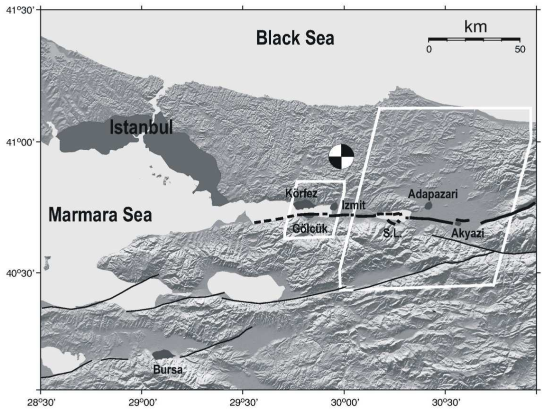

Figure 2. Shaded relief of the segment of the NAF that ruptured during the Izmit earthquake. We show the mainshock focal mechanism, (dark gray polygons) main cities, (white polygons) footprints of the used PAN images, (black thin lines) main mapped faults in the region, and (black thick lines) surface earthquake faulting ruptures. S.L. indicates the location of the Sapanca Lake.

cross product. We extract the phase difference of the cross product, using a masking to a cut-off half of the normalized sampling frequency, then we detect in- and outliers using the RANSAC algorithm. Finally, we solve for the best fitting plane using a re-weighting iterative least squares with bisquare weights. The entire processing chain is summarized in Fig.1. The method has also been tested under several relevant performance scenarios to show its robustness (addition of white noise, aliasing and bits quantization). In [5], we present a longer discussion on the coseismic effects and more details about the processing using Phase-corr technique.

3. 1999, MW 7.4, IZMIT (TURKEY) EARTHQUAKE

On August 17, 1999, a strong earthquake (Mw 7.4) occurred along the western sector of the North Anatolian Fault System in Turkey. The epicenter was located nearby the city of Izmit, 50 km east of Istanbul (Fig. 2). In 1999, the orbiting highest spatial resolution camera was the panchromatic sensor (PAN), a 5.8 m pixel on-board of IRS (Indian Remote Sensing) satellite. We have correlated the images using a correlation window of 64 by 64 pixels, with a step of 16 pixels (ground resolution of 80 m). The EW offset map shows clearly a straight slip discontinuity (Fig. 3).

Comparisons with different fault-slip data (GPS, geological field mapping and SPOT correlograms) indicate a good level of agreement [5].

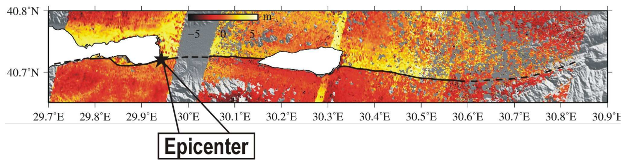

Figure 3. Coseismic displacement field measured by IRS correlation images. We show with a star the location of the located epicenter. Note the step-over structure West of the epicenter, this area recorded the largest vertical motions (subsidence).

4. 2005, MW 7.6, KASHMIR (PAKISTAN) QUAKE

On the 8 October 2005, a moment magnitude earthquake of 7.6 struck a large are in Kashmir (North Pakistan) causing a toll dead of more than 74,500 (14th deadliest earthquake of all time) and 106,000 injured [6]. There is a large consensus on the earthquake faulting mechanism that generates the earthquake and several groups have studied the quasi-static ground deformation field [7-8] (Fig. 4). For this study, we used the same pre- and post-event ASTER images used by [8].

The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) pushbroom sensor onboard of the Terra satellite provides medium-to-high resolution images of the Earth from 15 different bands, ranging from visible to infrared frequencies.

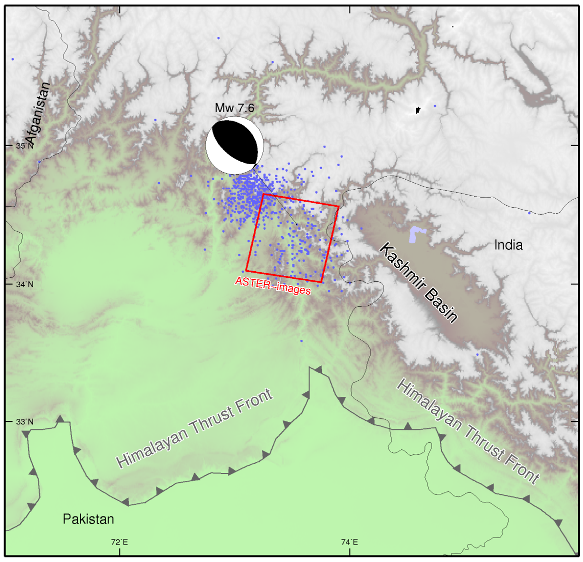

Figure 4. Main shock and focal mechanism of the Pakistan earthquake. The red polygon represents the footprint of the ASTER data used.

The ASTER highest spatial resolution is provided by the VNIR channels/bands (15 meters). Three of the VNIR bands are acquired with nadir pointing (B1-VNIR1, B2-VNIR2 and B3-VNIR3N), whereas a fourth VNIR band is acquired with a backward pointing angle, which makes possible to obtain stereoscopic pairs (B4-VNIR3B).

For this study, we explored the performance of the three nadir bands to quantify co-seismic ground displacements. First, Level 1A images need to be orthorectified into a common reference frame to minimize unwanted distortions. The COSI-CORR software [9] has been used for the orthorectification step. Once the images have a common reference system (in this case a cartographic one) we applied the Phase-corr.

In Fig. 5 is shown the obtained co-seismic ground deformation field using ASTER images taken on November 14, 2000, and October 27, 2005. Fig. 5a) shows the North-South and East-West coseismic displacement, when we correlate the pre- and post-event VNIR1 bands. Results obtained with the VNIR2 bands of the both images are presented in Fig 5b). Finally, VNIR3N band results are displayed in Fig. 5c). All displacement maps use the same color palette in a range of -10 to 10 meters. Positive displacements (red colors) indicate northward and eastward motion, and negative (blue colors) southward and westward displacements.

Phase-corr results are similar in each correlated band pairs, even if some offset deviations of the VNIR3N with respect to VNIR1 and VNIR2 pairs are significant in north component at the hanging wall. We have also confirmed the detection of the unrecorded pitch variations (sensor attitude information), which affect the accuracy of the orthoimages [10]. Moreover, the wave pattern along the rows which would correspond to unrecorded pitch variations also dramatically affects the east-west component in the same column. In [11], such artifact has been quantified with amplitudes of 6-7 meters and frequency of ~1.6 Hz, attributed to aliased jittering attitude recording of the Terra satellite. Our results indicate that such oscillations can exceed such bounds with amplitudes >10 meters.

5. CONCLUSIONS

We present two examples of application to earthquake and seismic activity using a new robust unwrapping-free phase correlation method, Phase-corr method [5]. Phase-corr has been applied to optical data (IRS and ASTER) for the retrieval of the coseismic displacement field and the surface rupture fault-trace mapping. Results indicate that phase correlation methods are suitable to complement the ground deformation data provide by DInSAR displacement maps with information about the horizontal components of the ground motion. As previously reported [10], accurate ephemerides and attitude sensor data is a sensitive step to obtain precise orthoimages useful to correlation.

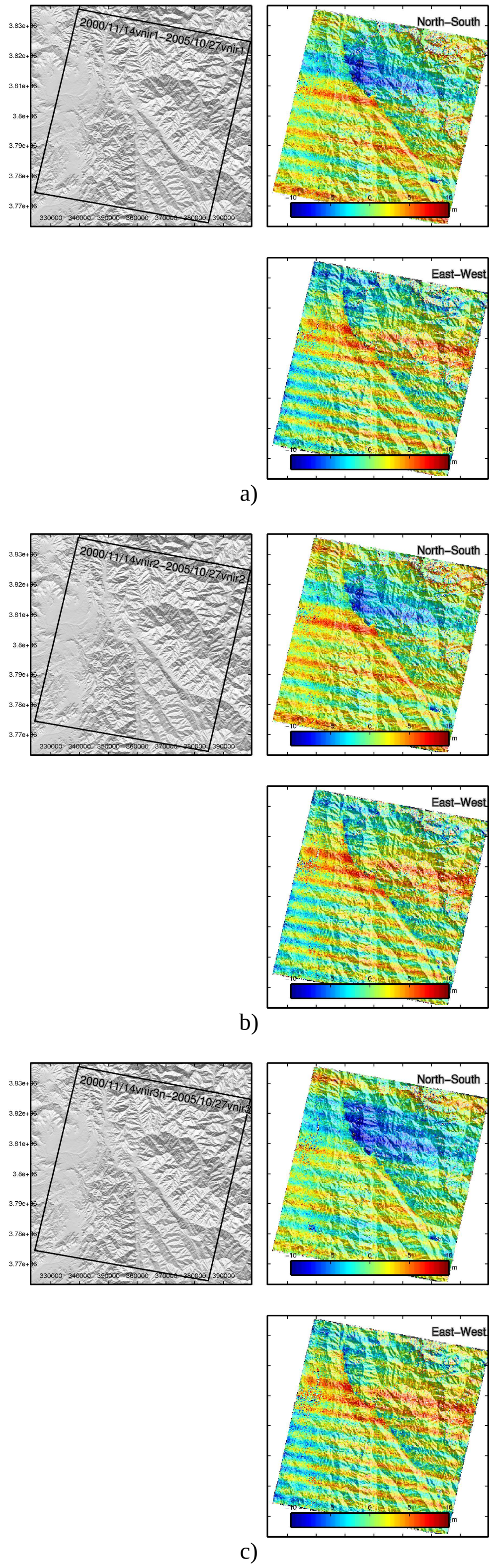

Figure 5. Horizontal co-seismic displacement maps obtained correlating 3 nadir VNIR ASTER bands. a) VNIR1, b) VNIR2 and c) VNIR3N.

6. REFERENCES

[1] R. Michel and J-P. Avouac, "Deformation due to the 17 August 1999 Izmit, Turkey, earthquake measured from SPOT images", J. Geophys. Res., vol. 107, no. B4, 2062, 2002.

[2] S. Leprince, S. Barbot, F. Ayoub and J-P Avouac, "Authomatic and precise orthorectification, coregistration, and subpixel correlation of satellite images, Application to Ground Deformation measurements," IEEE Trans. Geosci. Remote Sens., vol. 45, no. 6, pp. 1529-1558, 2007.

[3] R. Michel, J.P. Avouac, and J. Taboury, "Measuring ground displacements from SAR amplitude images : Application to the Landers earthquake", Geophys. Res. Lett., 26, 875-878, 1999

[4] E. Berthier, H. Vadon, D. Baratoux, Y. Arnaud, C. Vincent, K.L. Feigl, F. Rémy and Legrésy B. "Surface motion of mountain glaciers derived from satellite optical imagery", Remote Sensing of Environment, vol. 95, pp. 14-28, 2005.

[5] P.J. Gonzalez, M. Chini, S. Stramondo, and J. Fernández, "Co-seismic horizontal offsets and fault trace mapping using phase correlation of IRS satellite images: the 1999 Izmit (Turkey) earthquake", IEEE Trans. Geosci. Remote Sens., vol. 48, no. 5, pp. 2242-2250, May 2010.

[6] http://en.wikipedia.org/wiki/2005_Kashmir_earthquake

[7] E. Pathier, E.J. Fielding, T.J. Wright, R. Walker, B.E. Parsons, "Displacement field and slip distribution of the 2005 Kashmir earthquake from SAR imagery", Geophys. Res. Lett., 33, L20310, doi:10.1029/2006GL027193.

[8] J. P. Avouac, F. Ayoub, S. Leprince, O. Konca and D. Helmberger, "The 2005, Mw 7.6 Kashmir earthquake, rupture kinematics from sub-pixel correlation of ASTER images and seismic waveforms analysis", Earth and Planetary Science Letters, vol. 249, no. 3-4, 2006, pp. 514-528.

[9] http://www.tectonics.caltech.edu/slip_history/spot_coseis/index.html

[10] S. Leprince, F. Ayoub, Y. Klinger and J.P. Avouac, "Co-Registration of Optically Sensed Images and Correlation (COSI-Corr): an Operational Methodology for Ground Deformation Measurements", IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2007), Barcelona, Spain, July 2007.

[11] F. Ayoub, S. Leprince, R. Binet, K.W. Lewis, O. Aharonson and J.P. Avouac, "Influence of camera distortions on satellite image registration and change detection applications", IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2008), Boston, MA, USA, July 2008.