SURFACE DISPLACEMENTS OF THE 2014 CEPHALONIA (GREECE) EARTHQUAKE USING HIGH RESOLUTION SAR INTERFEROMETRY

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ABSTRACT

The island of Cephalonia, Western Greece, was struck by two strong seismic events, with magnitudes, ML= 5.8 and ML = 5.7 which occurred on Jan. 26, 2014 and Feb. 3, 2014 respectively. The first event was located near Argostoli's town, whereas the second one was located at the north part of Livadi village. These two strong earthquake events followed by smaller aftershocks provoking extensive crustal movements and structural damage effects. Differential Synthetic Aperture Radar Interferometry (DInSAR) is a powerful remote sensing tool for ground motion monitoring. The last two decades, DInSAR is widely applied to a variety of applications including natural hazards such as earthquakes. In 2007, a high resolution X-band satellite namely TerraSAR-X was launched. Due to its short revisit cycle of 11 days and its short wavelength, there is a good potential to capture faster surface movements. This study refers to the application of the DInSAR using TerraSAR-X strip map data to monitor the co- and post-seismic surface deformation caused by the second earthquake event. Hence, based on the interferometric processing of multiple scenes, several differential interferograms calculated showing the deformation patterns which caused before and after the seismic event. First results show that the main part of the island shows stability or a small uplift whereas the western part shows a significant deformation pattern. Those results permit to identify the local tectonic setting of the study area and investigate the reasons that some of settlements affected more

INTRODUCTION

On January 26 and February 3, 2014, two strong seismic events took place in the island of Cephalonia at a shallow depth causing catastrophic consequences in the western region of the island. According to NOA (National Observatory of Athens) those events were measured at 5.8 and 5.7 ML respectively (Figure 1). Cephalonia Island is located in western Greece which is the area of interaction between the African and the Eurasian lithospheres. Eastern Mediterranean lithosphere, which is the front part of the oceanic-like African lithosphere, is subducted beneath the Aegean continental lithosphere, which is the front part of the Eurasian lithosphere, along the Hellenic Arc – Trench system (1)(Le Pichon&Angelier, 1979). Four major tectonic blocks can be distinguished on the island, based on lithology, on similar structure features and on a common evolution during the upper Quaternary: (a) the Erissos peninsula block (northern part of the island); (b) the Paliki peninsula block (western part of the island); (c) the Ainos block (central and eastern part of the island); (d) the Argostoli block (southwestern part of the island). Each of these major blocks consists of several subordinate units and is flanked by a major thrust fault. The seismicity of the area, has been analysed by Kokinou et al. (2006) (2), gathering focal mechanisms of M>5 earthquakes that occured between 1972 and 2003. Also several authors (e.g. Scordilis et al. 1985; Kiratzi& Langston 1991) (3,4) studied the major event of of January 17, 1983 (Ms=7.0) and its aftershocks.To the latter family are more likely to belong the MS=7.2 earthquake of 1953 (5) and the Ms= 5.8 of 2002 (6)and to the former, the MS=6.3 earthquake of 1972 (7), the MS=7.0 of 1983

(8) and those of 2014. A dextral fault with small reverse component, striking NNE-SSW, was the cause of the recent seismic activity event of January/February as shown by the preliminary focal mechanisms of the main shock. An area covering the entire extent of Paliki Peninsula has been indicated by the distribution of aftershocks, whereas preliminary focal mechanism analysis shows that they have been caused by both dextral and reverse faults, striking approximately NNE-SSW and NW-SE respectively. Factors like the epicentral depth of the main shock and the aftershocks (up to 15 km), the geometrical characteristics (strike and dip angle) of the planes in the preliminary focal mechanisms, as well as their deformation pattern show that this earthquake sequence can be interpreted as an activation of a transpressional bend of the CFZ with no expression of the causative fault on land, considering the proximity of the area to the CFT. Uplift and bending of the overlying Eocene to Miocene sediments, has been caused by this transpressional bend that is expressed as a series of blind thrust faults (9).

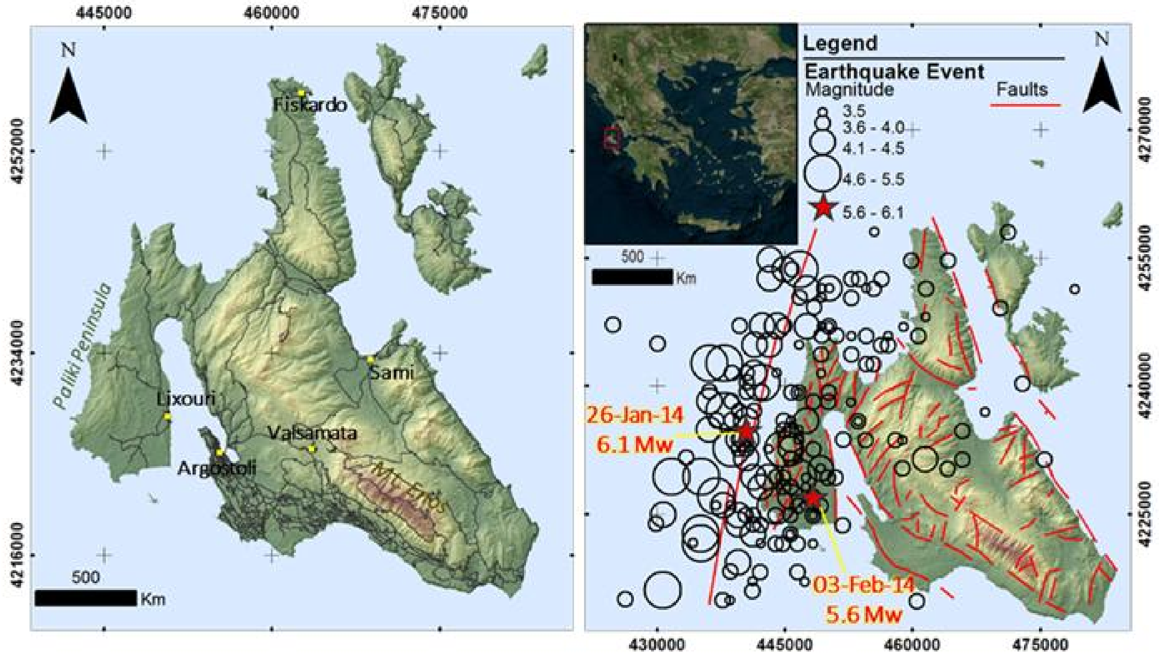

Figure 1: Location map of the Cephalonia Island (left pane) and the seismological map (right pane) (Source: European - Mediterranean Seismological Center).

Differential Synthetic Aperture Radar Interferometry (DInSAR) technique has been widely used to identify ground deformation caused by different natural and anthropogenic phenomena. Many scientists are motivated by the potential of SAR interferometry to be applied for a wide range of applications related to seismotectonics (10,11). The utilization of an appropriate interferometric dataset allows measuring the various components of the seismic cycle, namely the pre-seismic, co-seismic, and post-seismic deformation (12, 13, 14, 15, 16, 17). The aim of this study is to measure the ground motion, which caused by the two latest strong seismic events in Cephalonia Island, using the DInSAR method. Three high resolution StripMap scenes acquired from TerraSAR-X satellite are used. DInSAR is applied and three differential interferograms were calculated showing the displacement of both co-seismic and post-seismic periods. Results indicate the seismic behavior in the area of interest and further analysis demonstrates the reason that some areas had suffered more damages in contrast to other parts of the island.

DATA & METHODOLOGY

We analyzed the induced deformation field by exploiting SAR scenes acquired from the TerraSAR-X (X-band) satellite. The scenes acquired in StripMap mode with a high resolution of about 3 m and with small temporal baseline (repeat cycle 11 days). In order to monitor the deformation which caused due to the seismic events, three Single Look Complex (SLC) ascending scenes with acquisition dates 28/01/2014, 08/02/2014 and 19/02/2014, were selected. In addition, a Digital Elevation Model (DEM) with a very high resolution of 5 m per pixel and a vertical accuracy better than 5 m, was used. The analysis has been done using the GAMMA software.

The first step of the interferometric processing was the coregistration of the images in order to obtain the same geometry. The three images coregistered using as master the scene with date 28/01/2014. Additionally, the 5 m DEM was used and its heights transformed in SAR geometry in order to introduce them in the SLC coregistration. After a refinement step, we estimated the offsets between the datasets showing low standard deviations below 0.05 pixel. Afterwards, a total number of three differential interferograms were estimated, two for the co-seismic period and one for the post-seismic. The differential interferometric pairs are shown in Table 1. Firstly, the initial differential interferograms were estimated. The topographic phase component has been removed from each interferogram using a very high resolution Digital Elevation Model (DEM). These flattered interferograms were filtered using an adaptive Goldstein noise filter with a small size window (12×12 pixel) and then the unwrapping procedure was followed using the Minimum Cost Flow (MCF) algorithm (18) and a qualitative coherence threshold ($\gamma > 0.3$). Additionally, a baseline refinement was performed in order to further improve the baseline estimation and consequently mitigate the errors. Finally, a 5×5 multi-looking in range and azimuth was applied which corresponds to about 15 m × 15 m pixel size on the ground.

Table 1: Differential Interferometric Pairs and their Baseline Spatio-temporal Characteristics

	No.	Differential Interferometric Pairs	Spatial Baseline (m)	Temporal Baseline (days)
Co-seismic	A	28/01/2014 - 08/02/2014	108	11
	B	28/01/2014 - 19/02/2014	170	22
Post-seismic	C	08/02/2014 - 19/02/2014	62	11

RESULTS

The estimated interferograms were introduced in a GIS environment in order to analyze the spatiotemporal displacement which caused by the seismic event (Figure 2). It is evident that the Cephalonia Island has been affected from the seismic event. Particularly, the two co-seismic interferograms (A & B) show that the western area of the island has been influenced the most from the earthquake. In the central-south part of Paliki peninsula, these interferograms demonstrate a maximum motion of ~+12 cm in the line of sight (LOS) direction towards the satellite sensor whereas in the north and east part of the peninsula a maximum LOS motion of ~-7 cm away from the satellite is observed.

The comparison of the co-seismic results show an interesting finding. In contrast with the first interferogram, the second one shows a diminution at the uplifted area and an increase of subsidence at the east coast and north part of Paliki's peninsula.Specifically, in the first co-seismic pair is observed an uplift motion between +6 cm and +12 cm whereas in the second co-seismic pair with the longer temporal baseline the uplift motion decreased from +6 cm to +2 cm.

On the east coast part the coseismic (A) revales a subsidences from - 5.5cm to -1cm and at the coseismic (B) the observed motion moved southern at Lixouri Village an increased between -7cm to -1cm. The same deformation pattern identified at the north part of Paliki's peninsula, the (A) coseismic deformation map showing values from -4cm to -2cm and the (B) coseismic increased to -7.5 to -2 cm. The post-seismic (C) deformation map covering the period 08/02/2014 - 19/02/2014 and illustrates stability. That reveals that after the two strong seismic events and the followed aftershocks, the Cephalonia Island and mainly the center-south of Paliki peninsula shows low displacement rates.

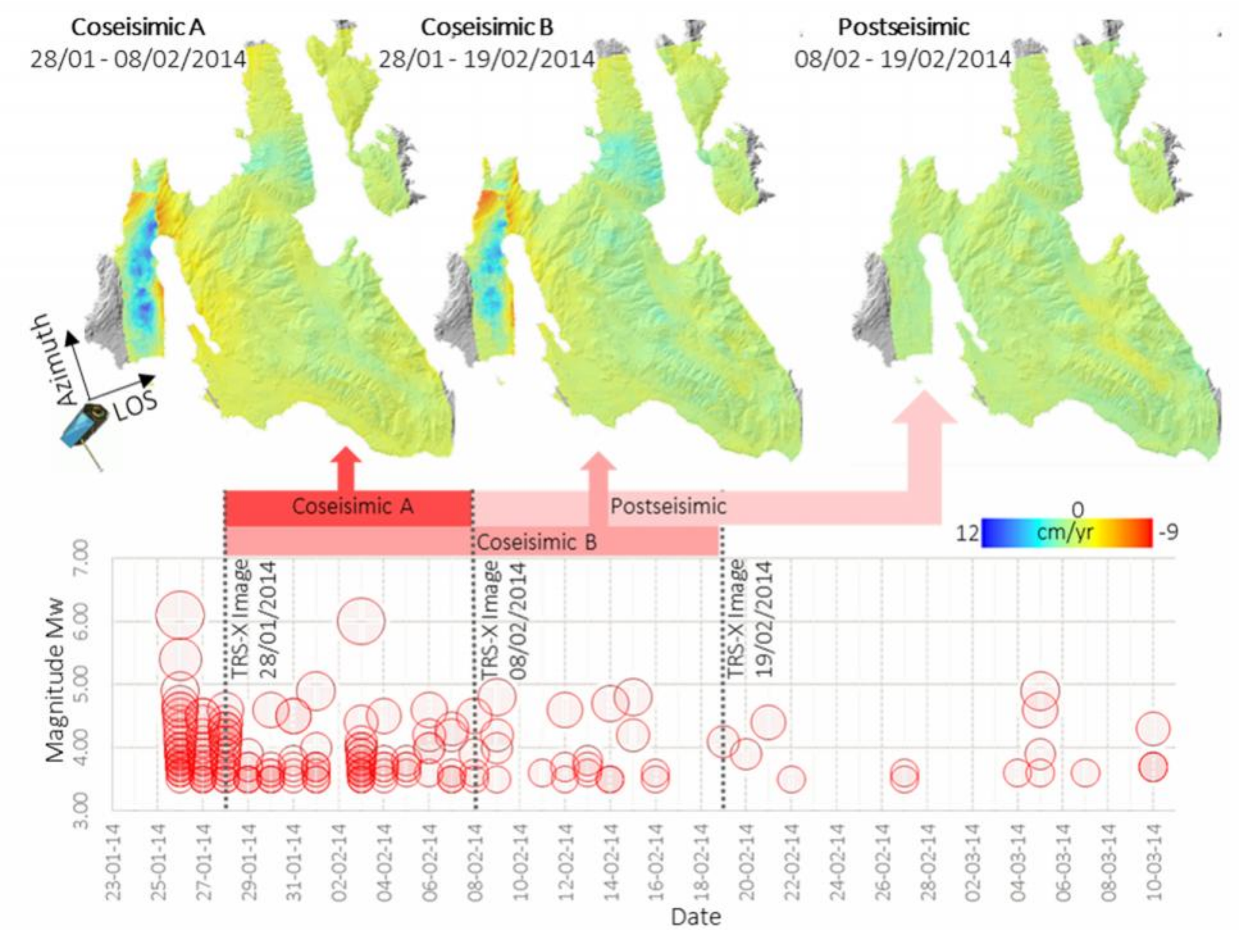

Figure 2: Three Differential Interferometric Pairs (two coseismic and one postseismic). On the bottom is presented the seismic sequence (Source: European - Mediterranean Seismological Center) Coseismic A period is illustrated with an intense red color, the Coseismic B with a less intense red color and with the pink is presented the postseismic period.

CONCLUSIONS

In this study, we have applied a DInSAR technique and we detect crustal movements due to a major earthquake event. The method was applied using three temporal TSX images covering the Cephalonia Island before and after the 3 Feb.2014 Cephalonia's earthquake. With high resolution data we managed to measure a wide area with a high spatial density of deformation trend measurements mapping the seismic crustal movements

ACKNOWLEDGEMENTS

The authors would like to thank Christian Minet for the TerraSAR-X data from Deutsches Zentrum für Luft- und Raumfahrt (DLR) and Associate Professor Issac Parcharidis for the for the organization of the research process. Especially we would like to thank the PhDcandidate Penelope Kourkouli for the significanthelp at the processing chain and for the helpful advices for the paper's writing. The seismic events were retrieved from European - Mediterranean Seismological Center.

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