COSEISMIC INVESTIGATION THROUGH THE INTEGRATION OF DINSAR MEASUREMENTS AND GEOLOGICAL AND SEISMOLOGICAL DATA IN A FINITE ELEMENT ENVIRONMENT

R. Castaldo
Istituto per il Rilevamento Elettromagnetico dell'Ambiente, Consiglio Nazione delle Ricerche (IREA-CNR), Napoli, Italy

Introduction. In the last decades, DInSAR measurements have been increasingly exploited to infer the coseismic deformation patterns due to their wide spatial coverage and high accuracy (Massonet *et al*., 1993). The inversion of the DInSAR measurements represents a powerful approach for better understanding the fault-zone mechanisms and, consequently, for improving the seismic risk mitigation strategies. Originally, the inversion procedures have been developed by considering an analytical model, often referred to as Okada model (Okada, 1985), based on the hypothesis of an homogeneous-isotropic and elastic half-space and on the assumption of simple planar faults (Pritchard *et al*., 2002). More recently, in order to take into account the complexity of the investigated faults involved in the coseismic phase, an effective solution is provided by the joint exploitation of DInSAR measurements and of geological and seismological information within a numerical framework, such as the Finite Element (FE) method (Fagan, 1992). This approach make possible to consider the available information relevant to both the coseismic fault segments and the surrounding faults system, allowing to evaluate the stress and strain field changes (Perniola *et al*., 2004): these values represent key elements for characterizing the seismogenic rupture mechanism and for the estimation of its effects on the surrounding region. Hence, the generation of a coseismic model has to benefit of a large amount of geological and seismological data including the information on the medium scale crustal heterogeneities derived from the regional seismic tomography. In order to carry out the modeling procedure, we generally follow five main steps:

1. generation of a fault model based on the interconnected active faults system, extended over a large area containing the involved seismic sequence, as well as on the neighboring active structures;
2. implementation of a model setup, in a FE mechanical environment by exploiting the elastic dislocation theory and integrating the information on the curved geometries of the 3D fault model and those available, through seismic tomography, on the crust heterogeneities;
3. optimization of the model unknowns represented by the rupture patches extent and by the forces applied to the hanging wall and footwall unlocked crustal blocks;
4. evaluation of the stress and strain field changes associated to the earthquake;
5. comparison between the modelled displacement and stress and strain principal axes and those retrieved from geodetic measurements and the independent geological, seismological data.

The proposed procedure is applied on three different main shocks episodes taken place in Italy in last decade: the events occurred on 20 May (Ml 5.9) and 29 May (Ml 5.8), 2012 in Emilia region (Tizzani *et al*., 2013), the L'Aquila earthquake occurred on April 6, 2009 (Mw 6.3) and the Amatrice main shock on 24 August 2016 (Ml 6.0) (Lavecchia *et al*., 2016).

Emilia 2012 earthquake. We provide new insights into the two main seismic events that occurred on 2012 in the Emilia region, Italy. We extend the results from previous studies based on analytical inversion modeling of GPS and RADARSAT-1 DInSAR measurements by exploiting RADARSAT-2 data. Moreover, we benefit from the available large amount of geological and geophysical information through FE method modeling implemented in a structural-mechanical context to investigate the impact of known buried structures on the modulation of the ground deformation field (Fig. 1). We find that the displacement pattern associated with the 20 May event is consistent with the activation of a single fault segment of the inner Ferrara thrust, in good agreement with the analytical solution. In contrast, the

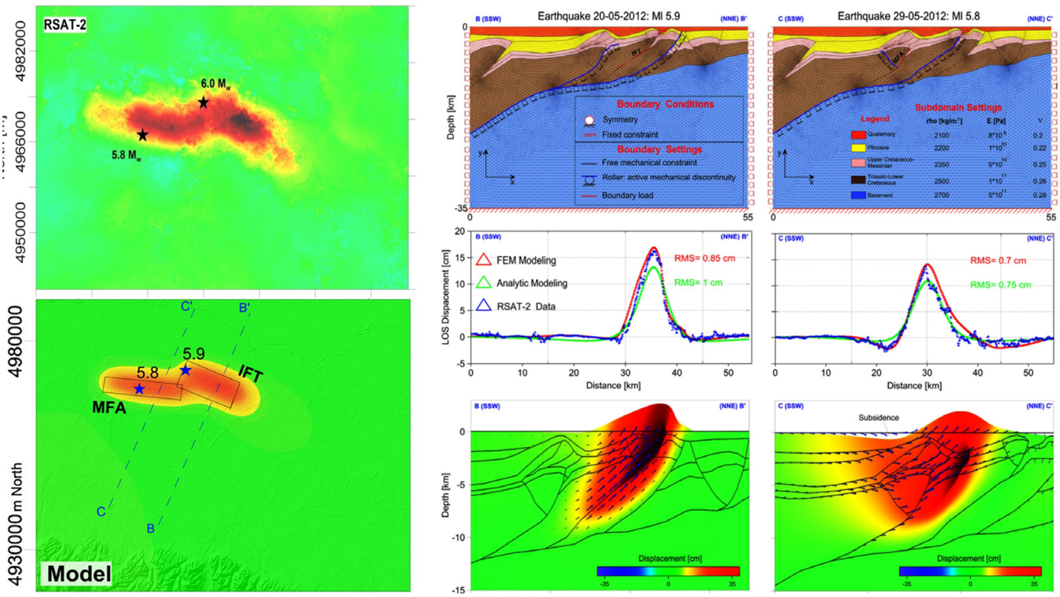

Fig. 1 - RADARSAT-2 DInSAR measurements and modelled LOS displacement for the two analyzed main seismic events. The FE model setup is showed.

interpretation of the 29 May episode requires the activation of three different fault segments and a block roto-translation of the Mirandola anticline. In particular, the performed analysis permitted (i) to detect the active seismogenic structures responsible for the observed ground deformation, (ii) to evaluate the impact of the regional tectonic constraints on the modulation of the retrieved deformation field, and (iii) to provide a detailed characterization of the rock failure mechanisms.

L'Aquila 2009 earthquake. We investigate the earthquake by exploiting ENVISAT DInSAR and GPS measurements and an independently generated fault model. We show that our modelling approach allows us to reproduce the coseismic surface displacement, including its significant asymmetric pattern, as shown by the very good fit between the modelled ground deformations and the geodetic measurements (Fig. 2). Our model permits to investigate the coseismic stress and strain field changes, their relationships with the surrounding geological structures; moreover, it highlights the very good correlation with the seismicity spatial distribution. The retrieved stress field changes show different maxima and in detail, the main event hypocenter is localized in a region of high-gradient strain field changes, while a deeper volumetric dilatation lobe involves the largest aftershock zone. From these findings we argue that the AQE hanging wall downward movement along the steep portion of PFS might have been modulated by the underlying basal detachment; on the other hand, the coseismic eastward motion of the PFS footwall might have triggered further slip on the OS, thus releasing the largest aftershock on an independent source.

Amatrice 2016 earthquake. We investigate the ground deformation and source geometry of the 2016 Amatrice earthquake by exploiting ALOS2 and Sentinel-1 coseismic DInSAR measurements. They reveal two NNW-SSE striking deformation lobes, which could be the effect of two distinct faults or the rupture propagation of a single fault. We examine both cases through a single and a double dislocation planar source. Subsequently, we extend our analysis by applying a FE approach jointly exploiting DInSAR measurements and an independent structurally-constrained fault model. Our inversion shows that the coseismic deformation partitioned on the two Northern Gorzano and Redentore-Vettoretto faults (NGF and RVF) which, at the hypocentral depth (8 km), merge into a single WSW-dipping surface (Fig. 3).

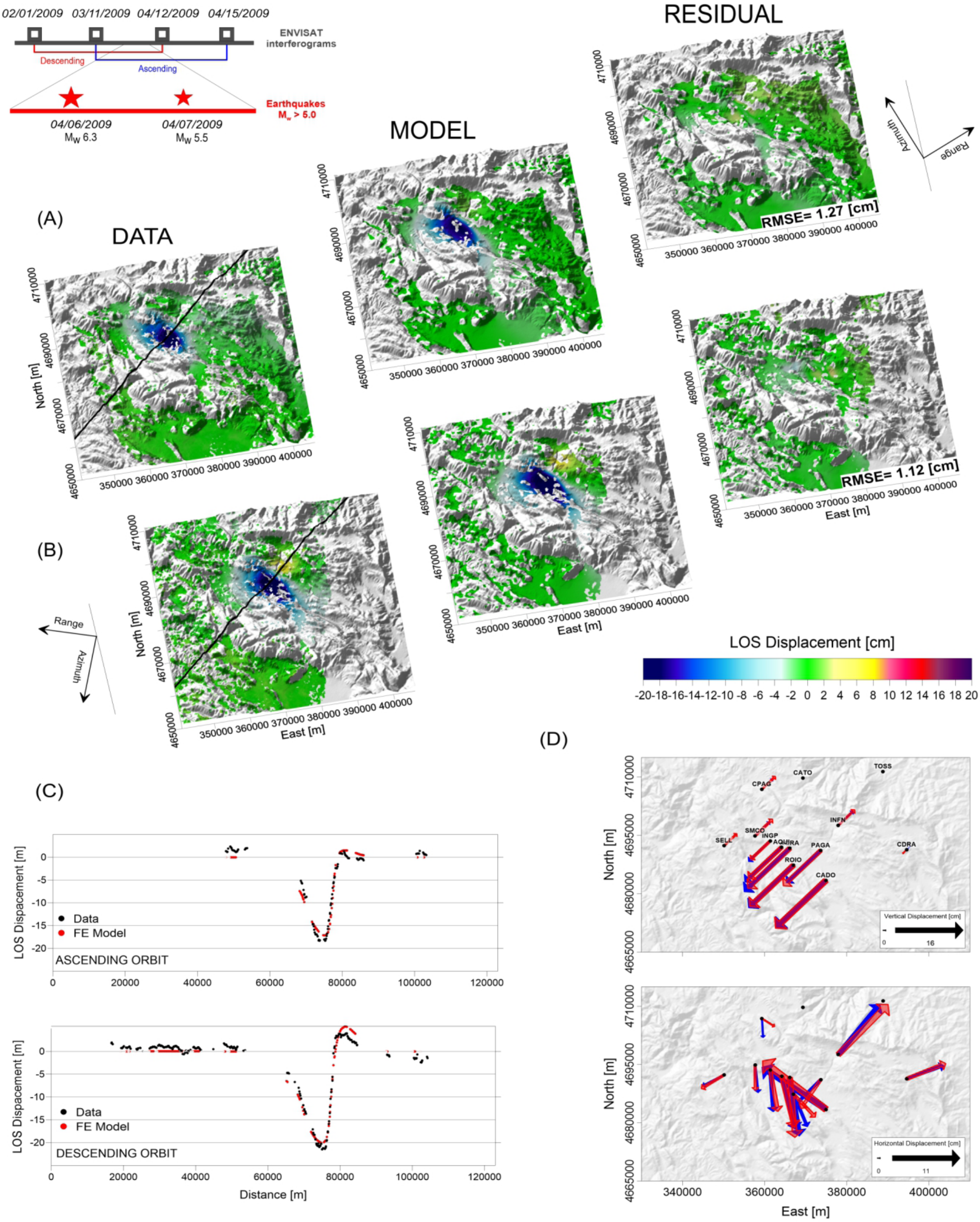

Fig. 2 - Comparison between radar LOS displacements (computed in coherent areas) retrieved from the DInSAR analysis of ENVISAT SAR images, and the modelling results. In the upper left corner, we report the time spans relevant to the exploited ENVISAT interferograms and the dates and magnitudes of the 6 April 2009 main shock and the 7 April 2009 largest aftershock. Comparison between observed (red arrows) and computed (blue arrows) GPS vertical displacement component and horizontal one.

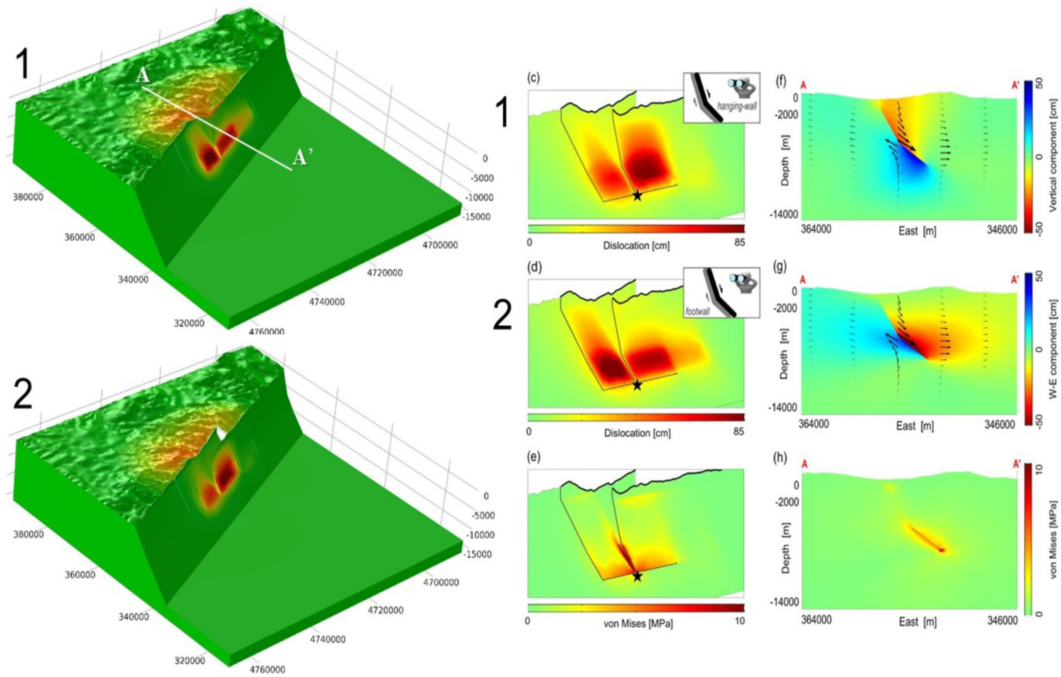

Fig. 3 - Maximum total displacement and von Mises stress distribution showed to emphasize the dislocation effect on the hanging wall and footwall of VRF and NGF. Results relevant to the selected 2D cross-section (N= 4733000).

Maximum deformation occur at 5–7 km depth with total displacements reaching 90 cm on the RVF footwall and 80 cm on the NGF hanging-wall. The von Mises stress field confirms the retrieved seismogenic scenario.

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