

MONITORING LONG-TERM GROUND MOVEMENTS AND DEEP SEATED GRAVITATIONAL SLOPE DEFORMATIONS BY INSAR TIME SERIES: CASES STUDIES IN ITALY

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ABSTRACT

We propose a multidisciplinary approach to study surface soil movements. They can be the expression of gravitative or tectonic events. The proposed method is based on the use of aerial photo analysis and SAR Interferometry (InSAR) techniques. The agreement of InSAR results and aerial photo interpretation allowed to detect and quantify the deformation patterns imputable to tectonics or gravitative causes. The study areas have been selected in some sectors of the Apennine chain.

1 INTRODUCTION

Surface soil movements can be the expression of gravitative or tectonic events. Two techniques like InSAR and aerial photo analysis (Volo Italia, 1988-89) have been combined to study these movements. Previously published papers (Saroli et al., 2004) presented significative results in the Northern Sicily region. Here we present further studies performed in Abruzzi Region, in the Mt. Maiella area and in Umbria- Marche region.

This integrated approach allows to detect and classify slow movements as Deep Seated Gravitational Slope Deformations (DSGSD). The investigated areas are morphologically characterized by significant elevation changes due to the presence of high mountainous peaks, separated from surrounding depressed areas by steep escarpments.

Consequently, relief energy favours the development of gravity-driven deformations. They seem to be superimposed on and influenced by the inherited structural and tectonic pattern, related to the sin- and postthrusting evolution.

Recent improvements of the classical Differential SAR Interferometry have expanded the field of application of this technique to the detection of very slow deformations, providing measurements of ground velocity with accuracies of mm/years (Berardino et al., 2002). In these new techniques, long time series of SAR images are used, and, provided that sufficient multi-temporal coherence exists, the displacement time history is computed for each coherent pixel or stable ground scatterer. A specific filtering algorithm is then used to remove the tropospheric contribution from the phase signal, restoring the ground displacement velocity in the line of sight of the SAR antenna (LoS). We present the application of the Small Baseline Subset technique (Berardino et al., 2002) to large datasets of ERS images for the selected areas.

2 The study areas

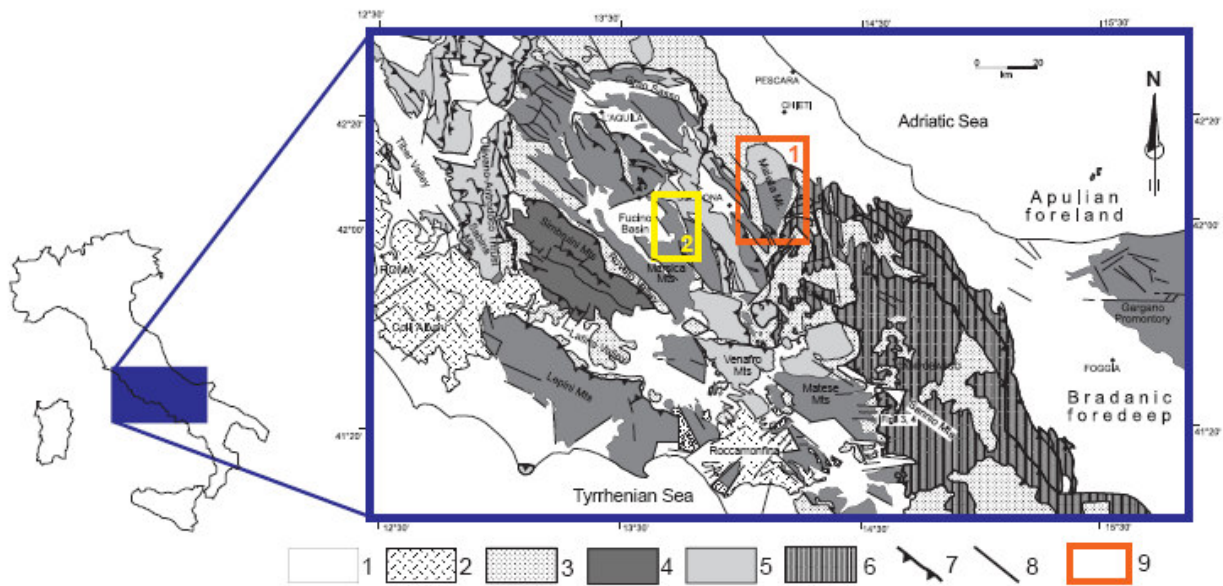
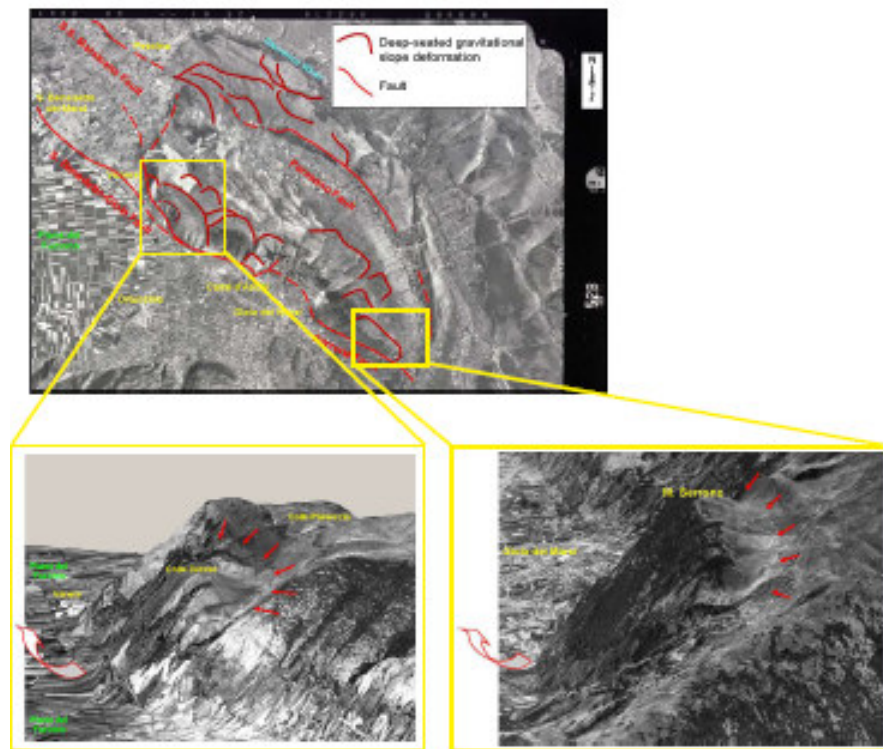


Figure 1: Simplified geological and structural map of the central Apennines. Key to legend: 1) marine and continental clastic deposits (Pliocene-Quaternary); 2) volcanic deposits (Pleistocene); 3) synorogenic hemipelagic and turbiditic sequences (Tortonian-Pliocene); 4) carbonate platform deposits (Trias-Miocene); 5) slope and pelagic deposits (Lias-Miocene); 6) Molise-Sannio pelagic deposits (Cretaceous-Miocene); 7) main thrust; 8) main normal and/or strike-slip fault; 9) study areas.

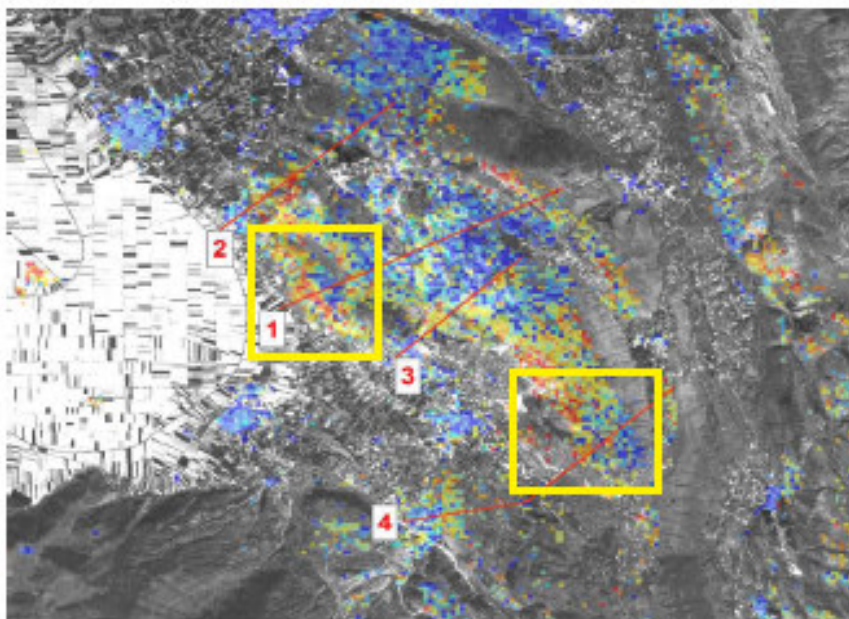
3 The western portion of the Fucino plain

The average velocity map of the western portion of the Fucino Plain has been obtained by DIFSAR SBAS technique using about 70 ERS-SAR images along descending orbits and spanning 1992-2000. To extract informations about the possible trends of surface displacements 4 profiles along SW-NE directions have been traced. Six SBAS processing have been performed to evaluate the effects of parameter changes on the resulting velocity map. Therefore two DEMs (SRTM and IGM-Military Geographic Institute) have been used to investigate possible effects of residual topography; maximum temporal and spatial baselines for each interferogram have been also modified. In the following only Profile 1 is shown, running along the Colle Cerese - Mt. Parasano alignment. The average velocity indicates a clear trend (see red circles) with 3-4 mm/y maximum. Such behaviour seems in agreement with already detected Deep Seated Gravitational Slope Deformations in Colle Cerese. The topographic profile in this sector clearly confirms the effects of the relief energy generating gravitative movements. A possible hypothesis is that such movements have been originally due to a fault below. In the following figures are showed the test area and in particular the high slope relief and the DSGSD, the InSAR time series and the surface displacements along some profiles.

a)



b)



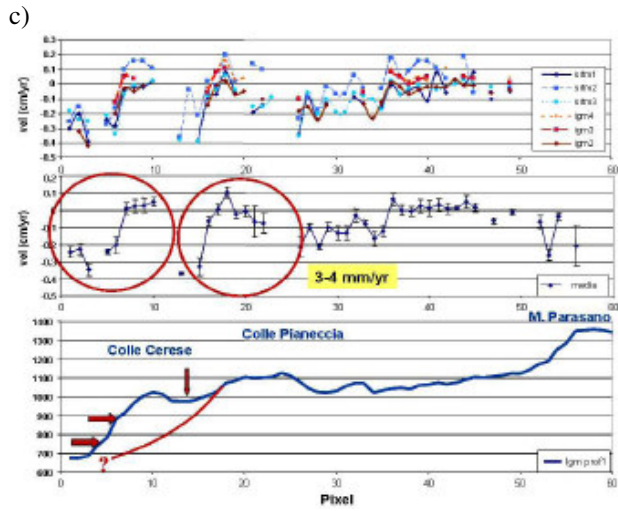
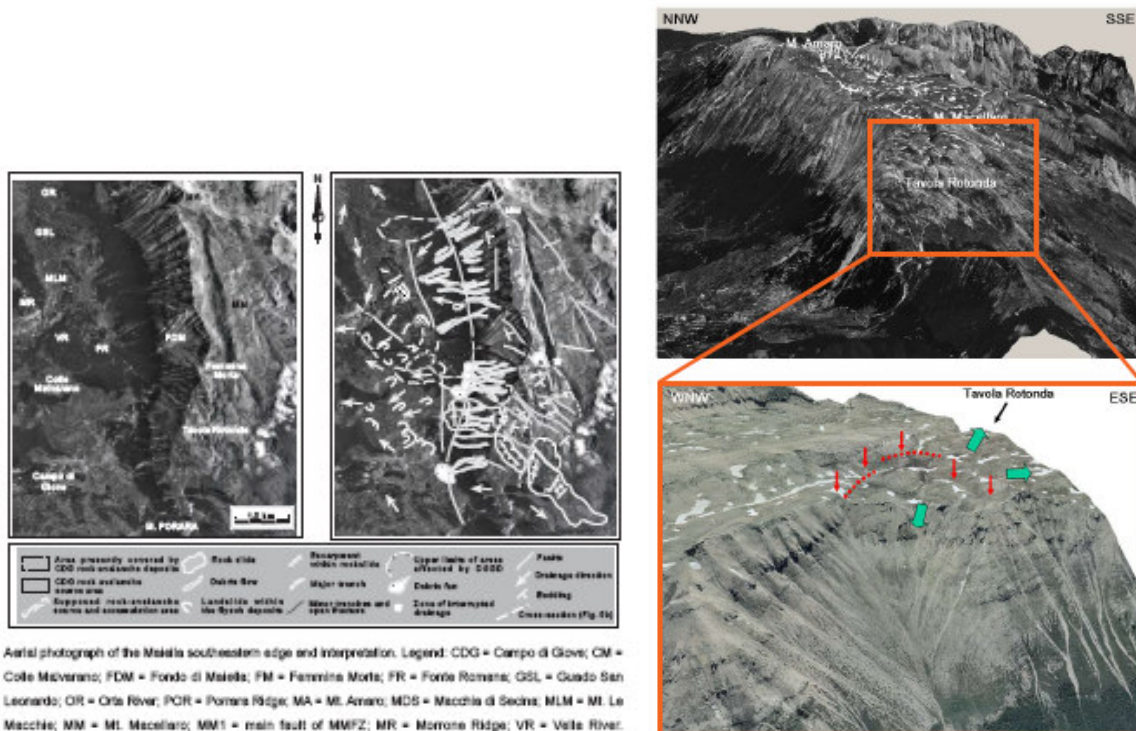


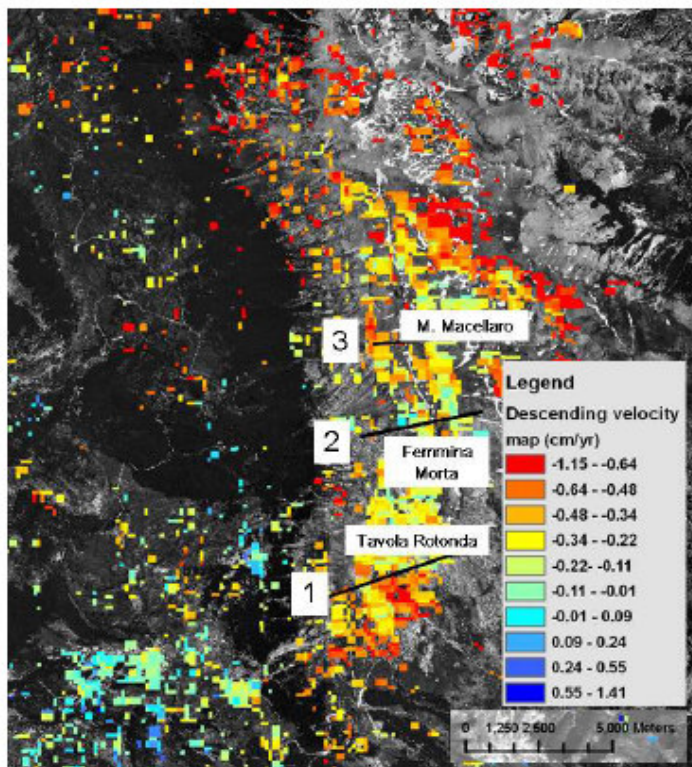
Figure 2: a) the DSGSD of the study areas detected from aerial photo analysis; b) the InSAR-SBAS results; c) comparison between the profiles showing surface displacements and the topographic relief.

3 The Maiella test site

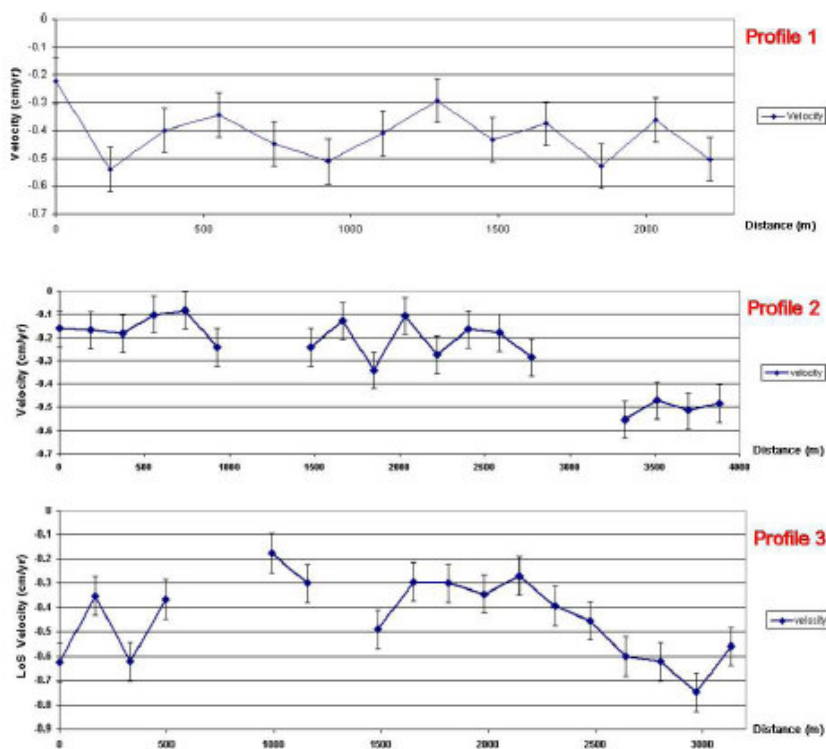
The average velocity map of the Maiella has been obtained by DIFSAR SBAS technique using a large number of ERS-SAR data (about 70) covering the time interval 1992-2000. Detected surface displacements ranges $-1.15/+1.41$ cm/y along the satellite Line Of Sight. Three SW-NE trending profiles show different behaviours. In Profile 1 the signal seems close to the error bar (1.5 mm/y) value, being the recorded oscillations of about 2 mm/y. The main part of Profile 2 shows a quite flat signal while the mean velocity increases up to 5 mm/y in the last portion. Profile 3 points out a clear signal close to Mt. Macellaro. The range min-max velocity is up to 5 mm/y. Data gaps are due to the lack of coherence in such sectors of the map.



a)



b)

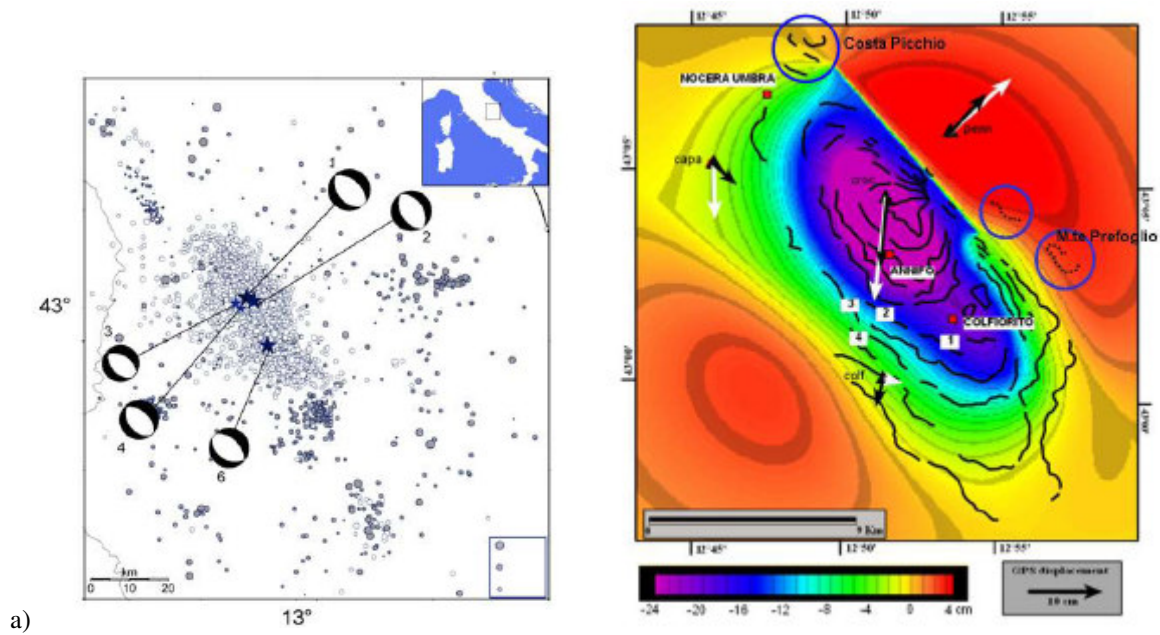


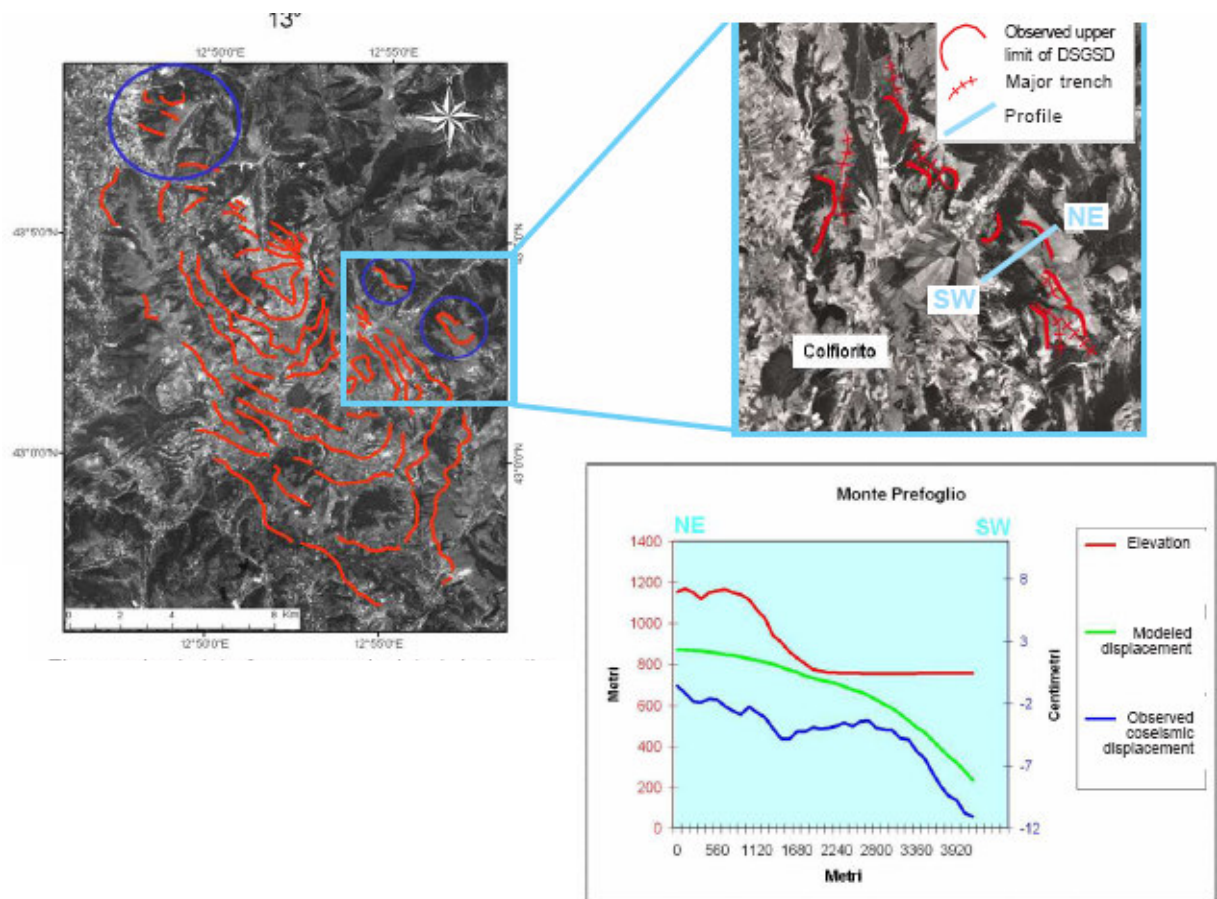
c)

Figure 3: a) aerial photo and DSGSG; b) InSAR SBAS results; c) surface displacements along the profiles in fig. 3b

4 The Umbria Marche 1997 earthquake

The coseismic interferogram calculated during the Umbria-Marche earthquake sequence has been reanalyzed. The differential interferogram obtained from ERS1-ERS2 satellite data showed a clear surface displacement pattern in agreement with the seismological and geological observations (Stramondo et al., 1999). Moreover GPS measurements also confirmed such results. Comparing the DIFSAR detected displacement with the fault model (Salvi et al., 2000) and the topography, it appears the expected movements do not agree with observed displacements. In fact the coseismic deformation and the topography have a similar behaviour. Revisiting such statements we recently observed that a part of detected deformation is due to the gravitative movements induced by the earthquake. Being the post-earthquake image some days after the mainshocks the reactivation of DSGSD generated surface effects.





b)

Figure 4: a) the epicentral area, showing also the mainshocks and the aftershocks, and the modelled surface displacement from SAR and GPS data; b) the fringes in the circles coincide with DSGSDs. Therefore we traced a profile to compare the InSAR detected surface displacement, the modelled displacement and the topography.

3 DISCUSSION

The DIFSAR technique has been used to study displacement patterns, surface effects of gravitative and/or tectonic activity. A multidisciplinary approach has been proposed, involving DIFSAR and photogeological analysis. The latter allowed to study each area in its own structural and geological context, in relation with the evolution of the "ridge valley floor system". The morphostructural conditions of "ridge valley floor systems" have been studied in different geological and structural context. Nevertheless they show rigid lithologies laid on plastic lithologies, whose behaviours are characterized by thrusts, quaternary tectonic discontinuities and quaternary seismogenetic faults. Three test areas have been chosen. In each of them the velocity maps resulting from DIFSAR SBAS application allowed to point out active DSGSD previously and independently detected from aerial photoanalysis.

The velocity patterns of the Abruzzi region and the Mt. Maiella show some surface effects coinciding with areas of very high relief energy and in a rigid/plastic geological context. The 1997 Umbria-Marche earthquake sequence is a "cause-effect" example of DSGSD and seismic events. In particular it clearly shows that the "coseismic deformation" is not completely due to the seismogenetic active fault, but also to gravitative effects induced by the seism.

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