AN INSAR GROUND DEFORMATION INVERSION SCHEME USING A FEM-BASED FAULT SLIP MODEL: AN APPLICATION TO ETNA VOLCANO

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1. INTRODUCTION

Ground deformation measurements have gained an important role in the monitoring of volcanic activity and in the quantitative evaluation of the geophysical processes preceding and accompanying volcanic unrest. Despite the continuous increase of spatial and temporal coverage of ground-based stations, GPS-based volcano deformation monitoring is usually constrained to very localized areas and is relatively time-consuming and costly. During the last years, the higher spatial resolution of InSAR (Interferometric Synthetic Aperture Radar) data has been used to complement the coarse spatial resolution of GPS networks to obtain both accurate and fine spatial characterization of ground deformation. The large amount of available observations has definitely highlighted that slip along a fault rupture is usually not uniform and can be better described as a distribution of fault-slip [4]. The overall displacement at an observation point is given by the superposition of contributions (Green's Functions) from each location on the fault. Therefore, the inverse problem yields the solution of a large-scale system of linear equations to estimate the slip distribution along the fault interfaces. The computation of the Green's functions is usually based on a homogeneous elastic half-space model, although medium heterogeneity and topography are likely to affect the magnitude and pattern of the deformation field [2, 4]. To account for real topography as well as heterogeneous material properties, we propose an automated procedure where the Finite Element Method (FEM) is implemented in inverse models to estimate slip distribution from geodetic observations. The whole procedure is split up into three main sub-routines for: (i) meshing the computational domain and subdividing the fault in a finite number of patches; (ii) computing the Green's Functions for static displacements caused by unit slip over each patch using FEMs; (iii) solving an inversion problem to determine the slip distribution using a Quadratic Programming (QP) algorithm [3] with bound constraints on slip values. The procedure is applied to study the ground deformation observed on Mt Etna before the 2002-2003 eruption.

2. MODEL RESULTS AND DISCUSSION

On 22 September 2002, an M3.7 earthquake, whose epicenter was located a few kilometers south of the westernmost part of the Pernicana fault, struck the northeastern part of Mt Etna volcano. This event produced coseismic surface fractures and damage to manmade features. The comparison between the results of the GPS survey carried out in September and in July 2002 showed a ground deformation pattern that affected the whole northeastern flank of the volcano [1]. The unwrapped interferogram was obtained from two ascending ERS2 passes taken on 31 July and 9 October 2002 (Courtesy of F. Guglielmino and A. Spata from INGV- Sezione di Catania). Both InSAR and GPS data showed a ground deformation pattern which revealed a general eastward motion of the northeastern sector of the volcano [1]. A GPS data inversion based on homogeneous half-space models predicted dislocation sources that were not able to reliably predict the complex deformation pattern detected by InSAR data. This discrepancy reflects the oversimplifications in the GPS fault model and the need to use better deformation models. We use InSAR observations and FEM-based models to estimate the slip distribution along the surface ruptures. To this end, we set up a 3D numerical model using PyLith, a parallel finite element code [6]. The computational domain, centered on the volcano area, is a 100x100x50 km volume whose ground surface was generated from a digital elevation model of Mt Etna. The elastic parameters were estimated using seismic velocity tomography [5]. The fault surfaces, which represent the main seismogenic faults in the northeastern sector of Mt Etna, were divided into 248 patches requiring 744 FEM simulations to compute the Green's functions for the three fault slip components (dip-slip, strike-slip and tensile-opening). Then, we inverted the GPS and InSAR observations for the fault slip distribution using the QP algorithm [3] and obtained models that minimized the data misfit while preserving smoothness of the fault slip distribution [4]. We applied smoothing using a finite difference approximation of the Laplacian and bound constraints to avoid models with unreasonable slip values, which would be expected with an unconstrained inversion. The inverted slip distributions on the faults are shown in Fig. 1. The results show complex kinematics on the north-eastern flank of the volcano involving the main seismogenic structures. The numerical model highlights a heterogeneous slip distribution along the fault surfaces with a predominant strike-slip mechanism associated with a dip-slip movement in the western part.

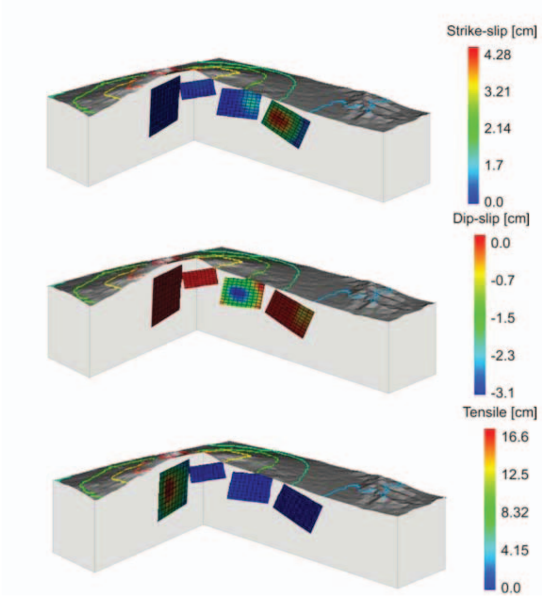

Fig. 1. Slip distributions along the seismogenic faults on the north-eastern flank of Mt Etna.

A heterogeneous distribution of the slip along the structures is able to better justify the InSAR ground deformation and also matches the GPS observations. The proposed procedure, based on the use of a FEM model and the integrated inversion of InSAR and GPS data, provides a powerful tool to estimate fault movements and predict ground deformation in a complex geomechanical system.

3. REFERENCES

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