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GEOFIM: A WebGIS application for integrated geophysical modeling in active volcanic regions

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A B S T R A C T

We present GEOFIM (GEOphysical Forward/Inverse Modeling), a WebGIS application for integrated interpretation of multiparametric geophysical observations. It has been developed to jointly interpret scalar and vector magnetic data, gravity data, as well as geodetic data, from GPS, tiltmeter, strainmeter and InSAR observations, recorded in active volcanic areas. GEOFIM gathers a library of analytical solutions, which provides an estimate of the geophysical signals due to perturbations in the thermal and stress state of the volcano. The integrated geophysical modeling can be performed by a simple trial and errors forward modeling or by an inversion procedure based on NSGA-II algorithm. The software capability was tested on the multiparametric data set recorded during the 2008–2009 Etna flank eruption onset. The results encourage to exploit this approach to develop a near-real-time warning system for a quantitative model-based assessment of geophysical observations in areas where different parameters are routinely monitored.

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1. Introduction

Volcano monitoring involves geophysical techniques that detect magma movements and associated interactions with surrounding rocks and fluids. The ascent of magma to the Earth's surface generates a wide variety of geophysical signals, which can be detected before and during the volcanic eruptions. In particular, ground deformation, gravity and magnetic changes in volcanic areas are generally recognized as reliable indicators of unrest, resulting from the accumulation and intrusion of fresh magma within the shallow rock layers. However, the different geophysical measurements, recorded by the monitoring networks installed in volcanic areas, are generally interpreted separately from each other and the consistency of interpretations coming from different methods is qualitatively checked only "*a posteriori*". Actually, to move towards a model-based assessment of geophysical observations will require integration of different geophysical signals and models. This is probably the most effective procedure able to yield more robust estimates of source parameters and reduce the ambiguity on the range of likely solutions.

The integrated modeling of these geophysical signals could improve our understanding of volcanic processes and our ability to identify renewed volcanic activity, forecast eruptions, and assess hazards. The main purpose of geophysical modeling is the identification of the parameters of volcanic sources producing these observable changes (Currenti et al., 2007, 2011a; Napoli et al., 2008). Here, we present a WebGIS application, called GEOFIM (GEOphysical Forward/Inverse Modeling), which is able to handle a multiple geophysical dataset and perform a quick joint inversion of geophysical signals to define the underlying volcanic source parameters (Fig. 1). In particular, GEOFIM can jointly model magnetic, gravity, and deformation data by trial and errors forward modeling or through an inversion procedure based on genetic algorithm. The careful use of high quality data sets, together with efficient modeling tools, can yield valuable insights into the nature of the volcanic sources. The forward modeling allows to match measured geophysical data to identify a reasonable volcanic source by choosing among different analytical models and source geometries (sphere, ellipsoids and rectangular dislocation). However, as the geophysical models are highly nonlinear and characterized by a high number of parameters, GEOFIM uses a non-linear optimization procedure based on the Non-dominated Sorting Genetic Algorithm (NSGA-II; Deb et al., 2000), which automatically finds the best model parameter that minimizes an objective function, in an iterative way, comparing the observed data with the numerical solutions.

GEOFIM was tested on ground deformation, gravity and magnetic measurements recorded on the onset of 2008–2009 eruption of Mt. Etna (Italy). The modeling results show that the best fit source is coherent with those reported in literature (Napoli et al., 2008; Currenti et al., 2011a, 2011b), proving the potential of

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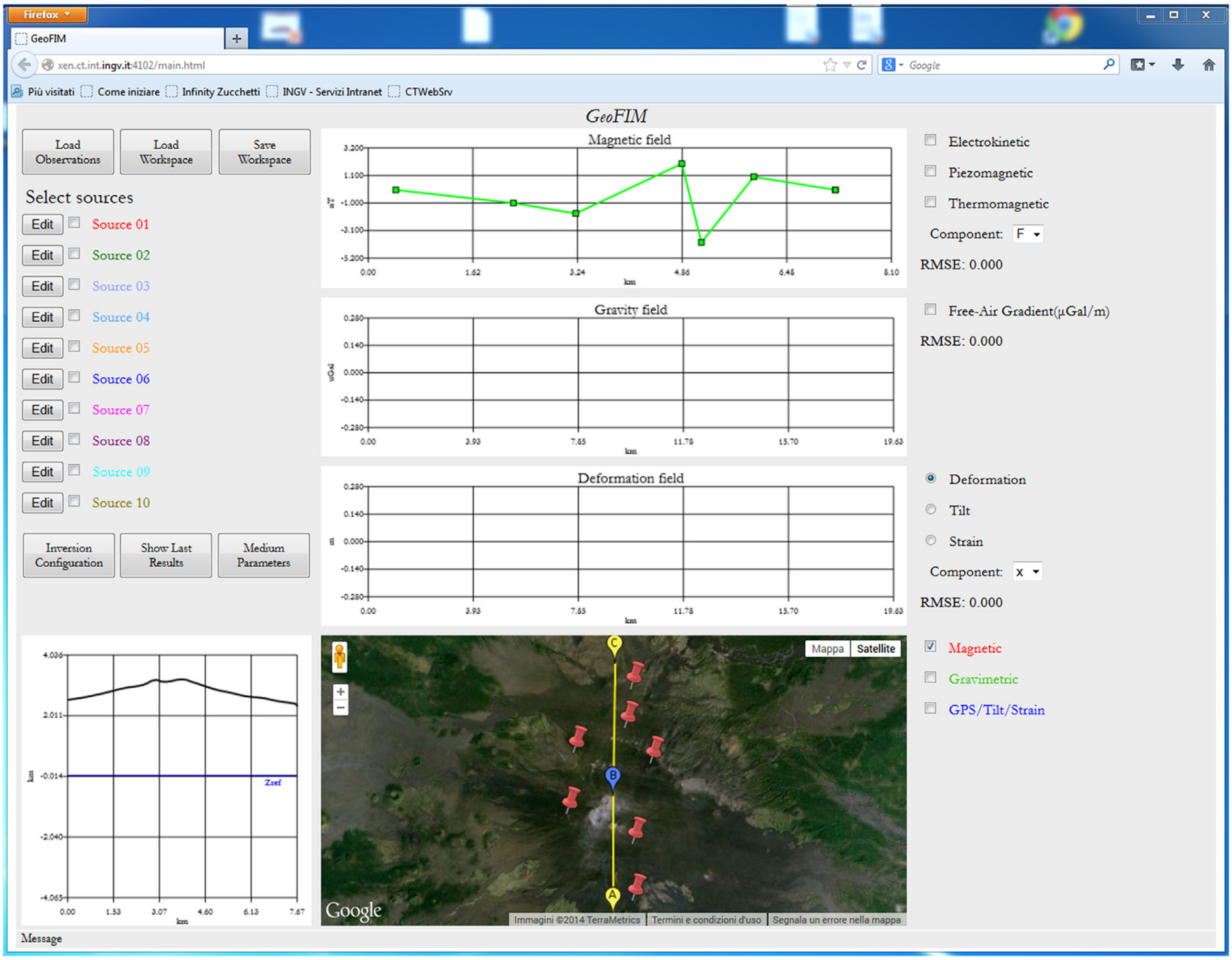

Fig. 1. GEOFIM forward modeling main window.

GEOFIM to interpret different geophysical dataset and to constrain the active magmatic source in near-real-time.

2. Forward models

A key point in the geophysical modeling is the choice of the appropriate forward model relating the magmatic source to the expected geophysical changes recorded by the monitoring networks. Magma ascent to the Earth's surface forces surrounding crustal rocks apart perturbing the thermal and stress state and producing ground deformation and variations in the magnetization and in the density distributions of rocks. Ground deformation produced by ascending magma are usually computed solving the elasto-static equations (Mogi, 1958; Yang et al., 1988). Gravity changes are estimated computing the gravity field engendered by the density redistribution due to arrival of additional mass and deformations of the surrounding rocks (Hagiwara, 1977; Okubo, 1992). Magnetic variations can be attributed to different mechanisms engendered by the perturbation of the stress field, such as piezomagnetic (Sasai, 1986; Utsugi et al., 2000) and electrokinetic effects (Fitterman, 1979; Murakami, 1989), and by changes in the rock magnetization, such as those produced by thermal demagnetization/remagnetization mechanisms. Therefore, in GEOFIM a library of forward models has been implemented to compute the expected geophysical changes using analytical solutions available in literature (Fig. 2). Although analytical models are based on a number of simplifications, they provide a first approximation of the expected geophysical changes for a variety of source geometries. Geophysical changes produced by magma accumulation have been traditionally interpreted by idealized spherical and ellipsoidal sources. Whereas magma intrusion processes are usually represented by opening cracks and/or a rectangular dislocations. For each model a short description, a schematic representation and references to analytical formulations used as computational routines are given below. The list of volcano sources available in GEOFIM is reported in Table 1. The analytical solutions have been compared and validated with numerical solutions performed with Finite Element Method (Currenti et al., 2007, 2008, 2009).

2.1. Spherical model

The simplest way to model the inflation or deflation of a magma chamber at depth is a dilatation point source (Mogi's source), which is quite appropriate to approximate spherical overpressured source when the radius is far smaller than its depth. Therefore, in GEOFIM the general Mogi model (1958) simulating a spherical source embedded in a homogeneous elastic half-space medium was implemented to compute ground deformation generated by pressure changes within the magmatic source. To compute gravity and piezomagnetic changes, which are expected to accompany inflation or deflation of a magma chamber, the analytical solutions devised by Sasai (1986) and Hagiwara (1977) have been used, respectively. For spherical sources no electronkinetic

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