Numerical modeling and inversion of multidisciplinary dataset at Mt Etna: from geophysical observations toward volcano hazard assessment

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Etna volcano has become a natural laboratory for a multidisciplinary research programme that operates in a feedback mode between advancement of new numerical modeling concepts and their validation by geophysical datasets. The multidisciplinary dataset gathered from ground-based monitoring networks at Etna during the last decades constitutes a unique opportunity to investigate the behavior of the volcano in a period in which it exhibited different styles of activity characterized by inflation, flank eruptions and fountaining episodes. The long-term data allow to investigate the response of the volcano to different processes in an iterative chain with initial models being developed to explain the available data sets. As new higher resolution data from satellites techniques have become accessible, the derived numerical models have then been tested and refined.

Integrated analysis and 3D numerical modeling of gravity, magnetic and deformation data have been performed to improve the reliability of model-based assessment of geophysical observations. We will present numerical solutions based on Finite Element Method (FEM), which have been implemented and applied to jointly interpret geophysical changes recorded during the recent Etna volcanic eruptions. Despite the capability to solve complex models, the use of FEM in geophysical inverse problem has been found to be computationally expensive since the mesh is geometry-dependent and, as the geometry interface changes, the entire domain need to be re-meshed at every inverse iteration step. Therefore, traditional FEM on unstructured mesh become impractical, because most of the time would be spent to construct a new mesh that adapts to the new geometry. A fast and efficient cutting-edge numerical method would be desired, which preserves the advantage of modelling complex structures and overcomes the drawback of meshing procedures.

To afford this issue, we propose a novel strategy based on a second order Finite Difference ghost-cell method for solving the governing equations in an arbitrary domain described by a level-set function. By allowing for the domain geometry to be modeled independently of the computational grid, we improve the computational efficiency with respect to FEM and provide an efficient method to include complex geometry and medium heterogeneity avoiding time-consuming meshing procedure. The proposed methodology has been firstly validated versus exact and analytical equations, and FEM solutions. We will present preliminary results from numerical computations of rock deformation caused by pressure and dislocation sources within the physical domain of Etna volcano. This innovative approach opens up new perspectives in geophysical inverse modeling and poses the basis for future development in a volcano hazard assessment based on a critical combination of geophysical observations and numerical modeling.