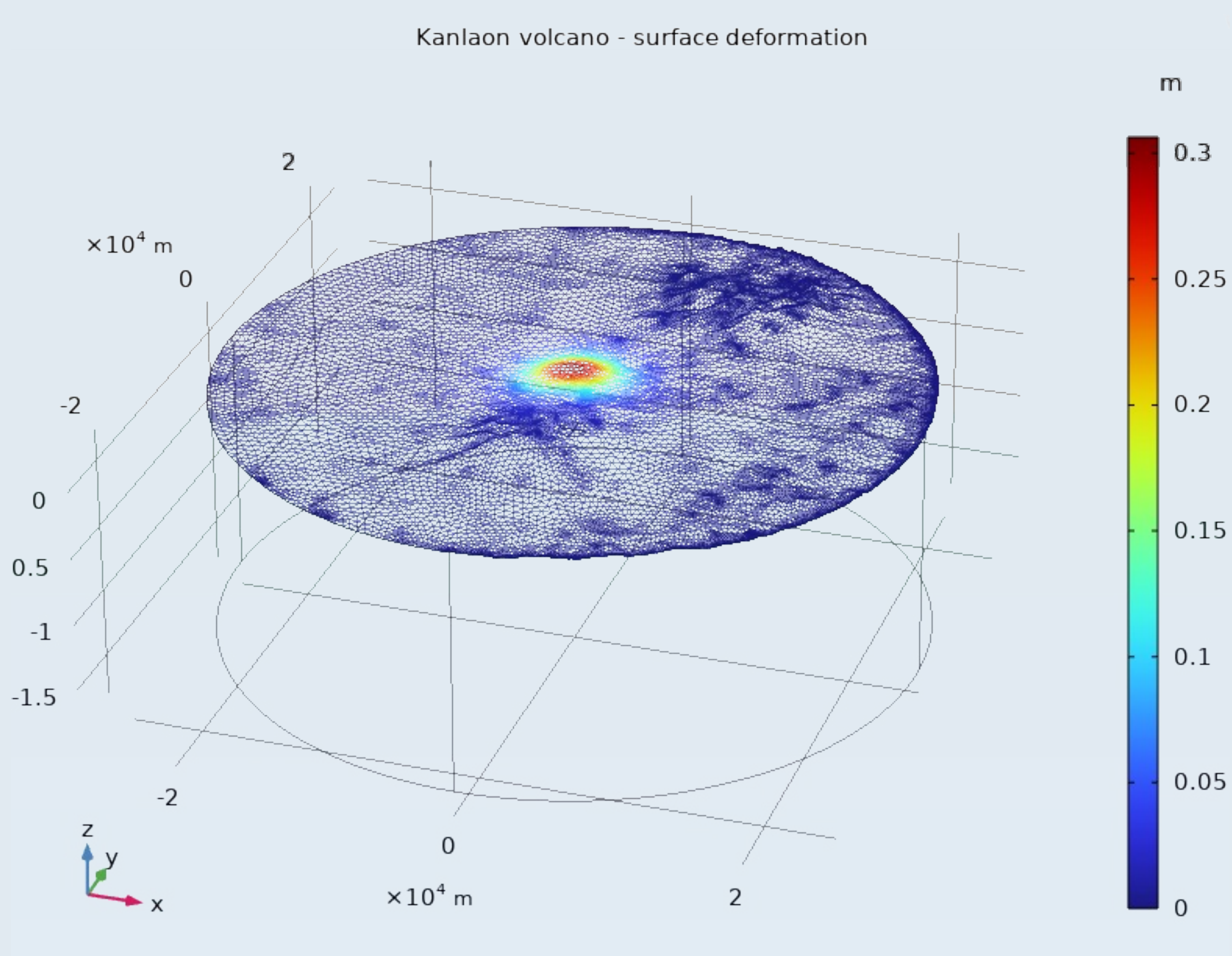

Analytical vs Numerical Models in Volcano Geodesy

Analytical, and numerical approaches are complementary and define two end members of a wide range of modeling techniques, with the optimal technique depending on the specific purpose.

M. Battaglia[1,2]
1. Volcano Disaster Assistance Program, U.S. Geological Survey, U.S.A.
2. University of Rome "La Sapienza", Rome, Italy.

Abstract

We model ground deformation, a crucial element in volcano monitoring. Geodetic monitoring assumes that surface deformation reflects deep tectonic and volcanic processes, transmitted through the crust's mechanical properties. Despite skepticism about analytical models because of their simplifications, careful use of these models with high-quality data can reveal valuable insights on the source of volcanic unrest. FEM models, which can incorporate more realistic crust and topography representations, are seen as more accurate but require dedicated studies for each volcano and event. The limited and uncertain knowledge of the crust mechanical properties represents the main limitation in the practical application of numerical models. Analytical, and numerical approaches are complementary and define two end members of a wide range of modeling techniques, with the optimal technique depending on the specific purpose.

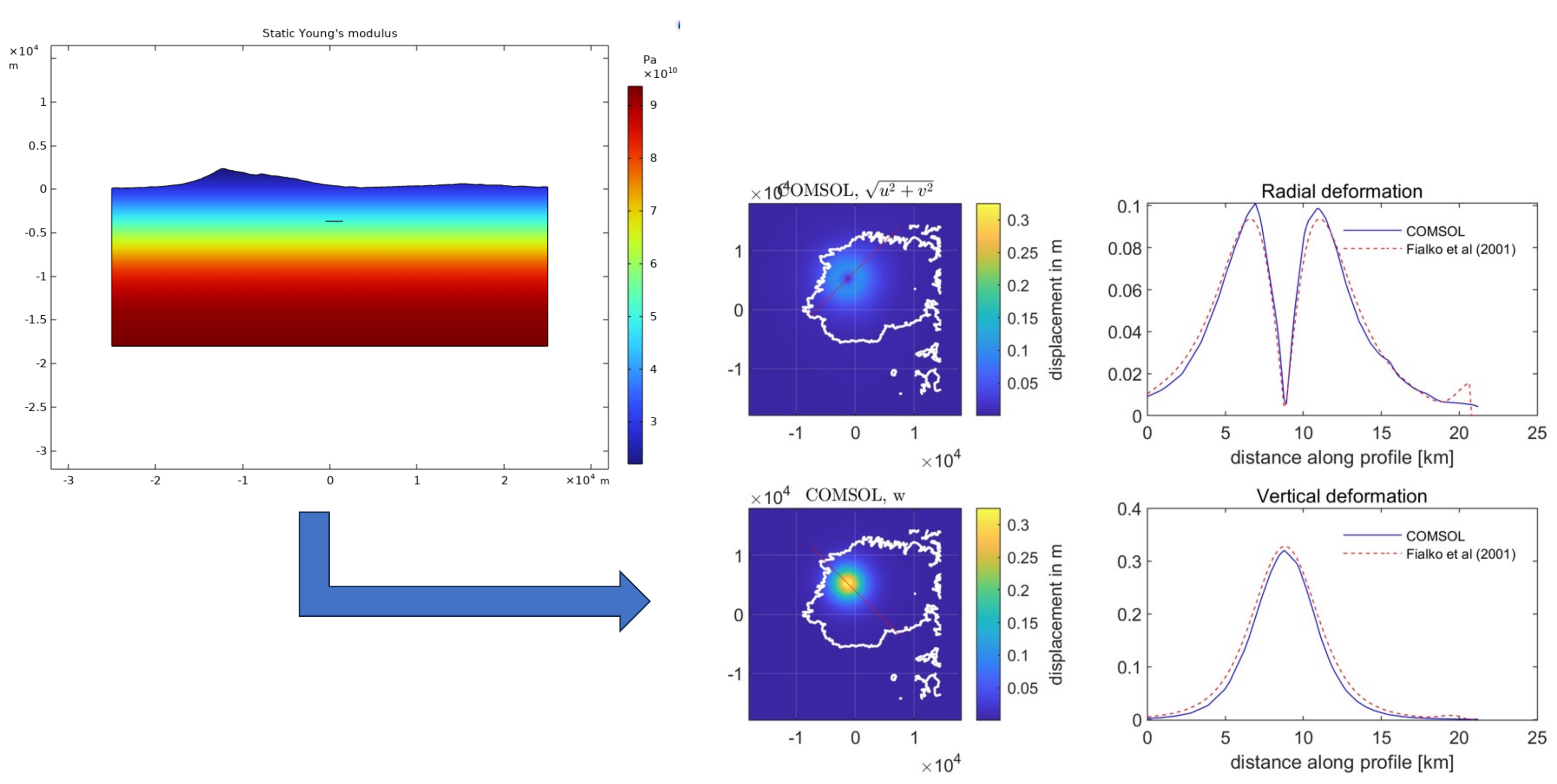

FIGURE 1. (Left) 3D model of Kanlaon Volcano; (Right) Cross validation between the numerical and analytical model

Methodology

Volcanic deformation sources are typically modeled as pressurized magma bodies within an elastic medium. Monitoring data are inverted to determine the source's location, depth, volume change, and whether it is migrating to shallower depths. In this study, we compare synthetic models of ground deformation at Kanlaon Volcano (Philippines) using 3D FEM models in COMSOL® software and equivalent analytical models in MATLAB® (Battaglia et al., 2013). The FEM models account for complexities like topography and vertical/lateral heterogeneities. Analytical models were cross-validated with FEM models to ensure accuracy. Finally, we inverted the synthetic data using the analytical models to verify their ability to infer source parameters within uncertainty.

Results

Although analytical models rely on simplifications, such as assuming the Earth's crust is homogeneous, isotropic, and elastic, they can still account for different source geometries and topographic effects. When applied with precision and supported by high-quality datasets, they can produce meaningful results. While more complex numerical models may be required to capture mechanical heterogeneities and density discontinuities, analytical models remain valuable for calibrating and validating numerical simulations

Figure 2 shows the results of attempts to recover source parameters from numerical simulations of increasing complexity, using analytical models.

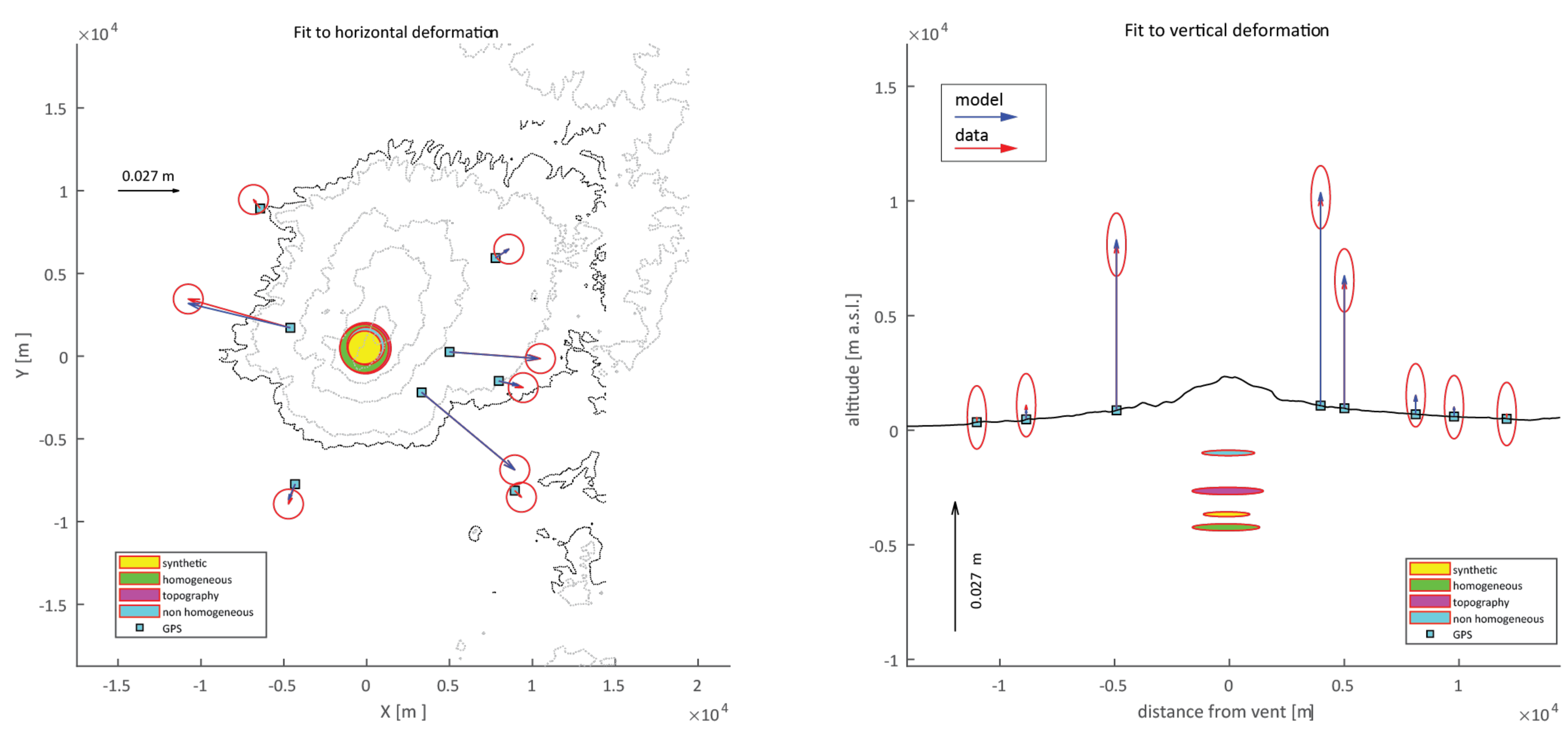

FIGURE 2. Recovered source parameters from numerical simulations of increasing complexity, starting from a homogeneous flat half-space to a non-homogeneous medium with 3D topography, simulating sill intrusion. The synthetic data sets were inverted using an analytical model of a penny-shaped crack source. The yellow disk marks the original location of the synthetic source.

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