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Multiphysics numerical models of resurgent calderas ground deformation: The 1982-2010 Campi Flegrei (Southern Italy) case studies

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Ground deformation signals in caldera region are the expression of near-surface and/or deep-seated physical processes. As most of the geophysical analysis, the interpretation of the deformation data is usually performed setting up inverse problems, which often use Monte Carlo optimization techniques like the Simulated Annealing and the Genetic Algorithm, in order to constrain the nature of the causative sources at depth. Usually, these methods exploit the problem's solution space by iterating forward analytical models, which consider simplified geometries and homogeneous linear elastic material properties. However, several recent studies have shown that oversimplified forward models may lead to misinterpretations of the retrieved source parameters.
To overcome these limitations we consider the Finite Element (FE) method as a powerful numerical tool that allows implementing models with complex geometries, material heterogeneities, as well as time dependent physical processes. For this reason, FE models are a suitable candidate to fill the gap between the accuracy achieved on the observation of ground deformation in volcanic areas and the models used for its interpretation.
In this context, we investigate the driving forces responsible of the long-term ground deformation of the Campi Flegrei (CF) caldera, Southern Italy, during the 1982-2010 time interval. To this purpose, we propose a new multiphysics numerical model that takes into account both the mechanical heterogeneities of the crust and the thermal conditions of geothermal system beneath the volcano. We perform a numerical Chain Rule Optimization Procedure (CROP) in a FEM environment, that considers different physical contexts linked along a common evolution line: starting from the thermal proprieties and mechanical heterogeneities of the upper crust, we develop a 3D time dependent thermo-fluid dynamic model of CF caldera. More specifically, by carrying out two subsequent optimization procedures based on Genetic Algorithm, we search for the 3D distribution of unknown physical parameters (temperature and viscosity distributions) that might help explaining the data observed at surface (geothermal wells and deformation measurements).
The first step of the CROP approach allows retrieving the heat production and heat flux parameters providing the best-fit of the geothermal profiles data measured at seven boreholes, by solving the Fourier heat equation over time in conductive regime. The 3D thermal field resulting from this optimization is used to calculate the 3D brittle-ductile transition that represents the sub-domain setting for the subsequent fluid dynamic optimization.
In the numerical fluid dynamic context, we solve the Navier-Stokes equation over time, by using two different dataset: high precision levelling for the 1982-1995 time interval and DInSAR displacements, retrieved through the inversion of the SAR data, acquired by ERS - 1/2 and ENVISAT sensors for the 1992-2010 time periods.
The optimization results show that the stress accumulated during the 1982-1985 unrest phenomenons has been balanced by non-Newtonian properties of the crustal material inside the ductile region in 2005, when a new phase of background uplift is found. In terms of rheology, this new phase could represent a period of stress accumulation in the brittle region.