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Numerical simulations of geophysical signals in response to magma chamber dynamics at Campi Flegrei volcanic complex, Italy.

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Understanding the complex relationships between geophysical signals recorded by volcano surveillance networks and magmatic processes occurring at depth is a crucial step toward a better knowledge of volcanic processes and the assessment of the related hazards. Such problems are particularly relevant for the Campi Flegrei area, where the combination of dense urbanization, recent eruptive activity and short-term unrest signals make the volcanic risk very high.

In this study we analyze the dynamical processes associated with the replenishment of a possible, shallow magma chamber at Campi Flegrei. The system initial and boundary conditions are defined on the basis of the results obtained through a multi-disciplinary research project which, over the past 2 years, has involved several tens of geophysicists, petrologists, geochemists, field volcanologists, and numerical modellers. The simulation domain is represented by a long dyke feeding a shallow and small magma chamber. While the chamber initially hosts a magma with phonolitic composition, the dyke provides CO_2-rich magma with trachytic composition. For these calculations we use a numerical code which describes the time-dependent 2D dynamics of a compressible-to-incompressible homogeneous multicomponent mixture made of liquid in equilibrium with an H_2O+CO_2 gas phase at local P-T-X conditions. The finite element numerical algorithm consists in a time-space discretization with Galerkin least-squares and discontinuity capturing terms, which allow high numerical stability.

The code is implemented with the most updated models for non-ideal multicomponent gas-liquid thermodynamics and for the relevant properties density and viscosity, under the assumption of Newtonian magma rheology. Several simulations are performed accounting for different composition of either the resident or incoming magma, different CO_2 - H_2O contents and feeding overpressure, and varying geometry of the conduit-chamber system. The results well illustrate the dynamics of light magma plume rise, convection, and mixing with the resident magma, and other dynamic aspects of such processes which were not known before. By integrating the contribution from any point in space in the simulated domain, we model the expected free-air corrected gravity change associated with the simulated dynamics. The computed gravity changes are negative, due to the replacement at shallow depth of the denser phonolitic magma by the CO_2-rich, lighter trachytic magma, with maximum values of some tens of μgal above the chamber. Associated with the complex dynamics of the mixing process is a time-varying pressure field acting at the side walls of both the feeding and storage systems. We analyze the resulting displacement field using a numerical approximation to the elasto-dynamical equations based on a elastic lattice, in which the reciprocal interactions between adjacent particles are governed by Hooke's law. This method allows for an easy treatment of both medium heterogeneity and complex surface topography. Ground displacement are dominated by a quasi-static component, which accounts for surface deformations on the order of few cm. Over the frequency band of seismological interest (0.01-10 Hz), ground displacement mostly reflects the dynamics of magma convection inside the chamber, with maximum vertical displacements on the order of mm and typical periods spanning the 1-50 s range. The potential of our methods in the recognition of geophysical signals associated with deep magma dynamics in volcanic environment, and in the identification of short-term precursors of volcanic eruptions, is presently under investigation.