Modeling Ground Deformation At Campi Flegrei Caldera Using COMSOL Multiphysics

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Abstract

Campi Flegrei (CF) is the largest active urbanized caldera in Europe, currently experiencing slow but progressive ground uplift and increasing seismicity since 2005. This deformation is marked by transient variations in uplift rates, with monotonic episodes lasting weeks to years. In addition to these, subtle aseismic transients—characterized by small amplitudes and short durations—have been detected using high-sensitivity instruments such as strainmeters and long-baseline tiltmeters. These signals are often below the resolution of standard geodetic techniques, making their interpretation particularly challenging.

Understanding the interplay between magmatic and hydrothermal processes is key to interpreting these signals, but it is complicated by the coexistence of multiple subsurface reservoirs. A shallow hydrothermal system may account for non-eruptive uplift-subsidence cycles, driven by the balance between magmatic input and surface fluid discharge. Disentangling these sources requires a detailed modeling framework that can simulate complex thermo-poro-elastic behaviors.

To this end, we employed COMSOL Multiphysics as the primary tool for constructing a fully-coupled finite element model of the CF caldera. This platform allowed us to simulate the mechanical response of the crust to pressure and temperature variations at various depths, integrating multi-physics capabilities in a single modeling environment. Particular attention was given to representing the rheological layering of the subsurface and the dynamics of a pressurized fluid reservoir. COMSOL's versatility made it possible to import pressure and temperature fields derived from external simulations of multiphase flow, effectively coupling source dynamics with mechanical deformation. The model was validated using GPS/GNSS and strainmeter time series, showing a strong correspondence between simulated and observed surface displacement patterns. This match confirms the reliability of the finite element approach for interpreting geodetic signals in active volcanic areas.

The integration of COMSOL-based modeling with high-resolution deformation data represents a significant step forward in constraining subsurface processes at Campi Flegrei. Our results suggest that coupled thermo-mechanical modeling is a powerful tool for distinguishing between magmatic and hydrothermal contributions to caldera unrest. This approach improves our ability to forecast the evolution of volcanic systems and contributes to more informed hazard assessment.