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Analytical modelling and joint inversion of surface displacements and gravity changes at volcanoes

Mehdi Nikkhoo and Eleonora Rivalta
GFZ - German Research Centre for Geosciences, 2.1, Potsdam, Germany (mehdi_nikkhoo@yahoo.com)

Gravity change observations at volcanoes provide information on the location and mass change of intruded magma bodies. Gravity change and surface displacement observations are often combined in order to infer the density of the intruded materials. Previous studies have highlighted that it is crucial to account for magma compressibility and the shape of the gravity change and deformation source to avoid large biases in the density estimate. Currently, an analytical model for the deformation field and gravity change due to a source of arbitrary shape is lacking, affecting our ability to perform rapid inversions and assess the nature of volcanic unrest.

Here, we propose an efficient approach for rapid joint-inversions of surface displacement and gravity change observations associated with underground pressurized reservoirs. We derive analytical solutions for deformations and gravity changes due to the volume changes of triaxial point-sources in an isotropic elastic half-space. The method can be applied to volcanic reservoirs that are deep compared to their size (far field approximation). We show that the gravity changes not only allow inferring mass changes within the reservoirs, but also help better constrain location, shape and the volume change of the source. We discuss how the inherent uncertainties in the realistic shape of volcanic reservoirs are reflected in large uncertainties on the density estimates. We apply our approach to the surface displacements and gravity changes at Long Valley caldera over the 1985-1999 time period. We show that gravity changes together with only vertical displacements are sufficient to constrain the mass change and all the other source parameters. We also show that while mass change is well constrained by gravity change observations the density estimate is more uncertain even if the magma compressibility is accounted for in the model.