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FEM-based linear inverse modeling using a 3D source array to image magma chambers with free geometry. Application to InSAR data from Rabaul Caldera (PNG).

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In this study, we present a method to fully integrate a family of finite element models (FEMs) into the regularized linear inversion of InSAR data collected at Rabaul caldera (PNG) between February 2007 and December 2010. During this period the caldera experienced a long-term steady subsidence that characterized surface movement both inside the caldera and outside, on its western side.

The inversion is based on an array of FEM sources in the sense that the Green's function matrix is a library of forward numerical displacement solutions generated by the sources of an array common to all FEMs. Each entry of the library is the LOS surface displacement generated by injecting a unity mass of fluid, of known density and bulk modulus, into a different source cavity of the array for each FEM. By using FEMs, we are taking advantage of their capability of including topography and heterogeneous distribution of elastic material properties. All FEMs of the family share the same mesh in which only one source is activated at the time by removing the corresponding elements and applying the unity fluid flux. The domain therefore only needs to be discretized once. This precludes remeshing for each activated source, thus reducing computational requirements, often a downside of FEM-based inversions. Without imposing an a-priori source, the method allows us to identify, from a least-squares standpoint, a complex distribution of fluid flux (or change in pressure) with a 3D free geometry within the source array, as dictated by the data.

The results of applying the proposed inversion to Rabaul InSAR data show a shallow magmatic system under the caldera made of two interconnected lobes located at the two opposite sides of the caldera. These lobes could be consistent with feeding reservoirs of the ongoing Tavuvur volcano eruption of andesitic products, on the eastern side, and of the past Vulcan volcano eruptions of more evolved materials, on the western side. The interconnection and spatial distribution of sources find correspondence in the petrography of the volcanic products described in literature and in the dynamics of the single and twin eruptions that characterize the caldera.

As many other volcanoes, Rabaul caldera is an active and dangerous volcanic system whose dynamics still need to be understood to effectively predict the behavior of future eruptions. The good results obtained from the application of the method to Rabaul caldera show that the proposed linear inversion based on the FEM array of sources is suitable to generate models of magmatic systems. The method can image in space and time the complex free geometry of the source that generates the deformation, widening our understanding of deformational sources and their dynamics. This takes source modeling a step towards more realistic source models.