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Analytical and numerical optimization of gravimetric networks: case study Mount Etna, Italy

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The transport of magma and magmatic fluids is often the key process having the main control on the occurrence, duration and intensity of various volcanic crises. Volcano gravimetry allows for an unequivocal inference of the location and associated mass of accumulated or removed magmatic fluids at volcanoes. This task is best accomplished through collecting gravity time series at multiple stations simultaneously. The performance of individual gravimeters and the configuration of the gravimetric array, however, determine the threshold of detectable mass change and the ability of the array in minimizing the effect of random observation errors on the inferred quantities.

We utilize numerical optimization techniques to design a network of one absolute quantum gravimeter (AQG), two superconducting gravimeters and multiple microelectromechanical system (MEMS) gravimeters at Mount Etna. We also develop analytical solutions for simple design problems. We show that the analytical solutions are essential for validating the numerical optimization procedure. We provide practical details and caveats that must be considered in similar gravimetric network optimizations. These include 1) specifying the target zone of the network by using the eruption history, 2) calibrating the objective functions associated with various optimizations, 3) accounting for logistic and instrumental constraints in the optimizations and 4) incorporating probabilities associated with different parts of the target zone, 5) analyzing the network sensitivities to different target sources in the presence of constraints and 6) calculating the optimal number of gravimeters as a function of the sensor sensitivity and accuracies. We show that due to the existing constraints, surface topography and sensor sensitivities our optimal solution for Mount Etna provides a nonuniform detection power across the target zone. This optimal solution however, provides a minimum level of monitoring for most parts of the target zone and at the same time minimizes the impact of random observation errors on the inferred quantities.

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