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Improving the efficiency of ensemble-based volcano deformation analyses using Machine Learning

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Geodetic observations are key for assessing the unrest status of volcanoes worldwide, providing critical information about magmatic systems and the potential for magma migration and eruption. Analysing these signals relies on a robust data-model framework. One such approach is the Ensemble Kalman Filter (EnKF), a data assimilation method that has been adapted for analyses of volcanic deformation. The EnKF sequentially assimilates and inverts geodetic observations, using a series of model states to 'nudge' the model parameters with each iteration, reducing the misfit between the model and observation. We construct thermomechanical Finite Element (FE) models of volcanic regions, providing the necessary flexibility to incorporate complex 3D geometries and material heterogeneity. However, these simulations are computationally expensive when incorporated into the EnKF workflow, where an ensemble of >200 model states can take several hours to evaluate. This is particularly problematic for the analysis of observational data with high temporal resolution, such as daily GPS measurements.

Here, we aim to reduce the computational cost of the EnKF-FE workflow by using regression machine learning algorithms (MLAs), focusing on reducing the number of model states that need to be evaluated by the FE models. We start by using the 'Mogi' deformation model, a simple analytical expression that calculates the three-component displacement field (Ux, Uy, and Uz) due to a point source. We employ a tuneable nearest-neighbour approach to identify model states that occupy a 'similar' parameter space, using MLAs to predict the resultant displacements. The Mogi model has significantly reduced complexity compared to that of a FE model, providing a simple platform to test different machine learning approaches. Preliminary results suggests that the k-Nearest Neighbours and Linear Regression algorithms can significantly improve the computational efficiency of the EnKF-FE workflow, with negligible impact on the inferred best-fit model parameters, when a magmatic system is in a steady-state (i.e., static overpressure). Future modelling efforts will consider FE models with a 3D deformation source within a flat-topped domain, and time-varying overpressure scenarios.