Linking thermomechanical models with geodetic observations to evaluate the 2018 eruption of Sierra Negra Volcano, Galápagos

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Ensemble based data assimilation approaches, such as the Ensemble Kalman Filter (EnKF), have been widely and successfully implemented to combine observations with dynamic models to investigate the evolution of a system’s state. Such inversions are powerful tools for providing forecasts as well as “hindcasting” events such as volcanic eruptions to investigate source parameters and triggering mechanisms. In this study, a high performance computing (HPC) adaptation of the EnKF is used to assimilate ground deformation observations from interferometric synthetic-aperture radar (InSAR) into high-fidelity, multiphysics finite element models to evaluate the prolonged unrest and June 26, 2018 eruption of Sierra Negra volcano, Galápagos. The stability of the Sierra Negra magma system is evaluated at each time step by estimating variations in reservoir overpressure, Mohr-Coulomb failure in the host rock, and tensile stress and failure along the reservoir boundary. The deformation of Sierra Negra is tracked over a decade, during which almost 5 meters of surface uplift has been recorded. The EnKF reveals that the evolution of the stress state in the host rock surrounding the Sierra Negra magma reservoir likely controlled the timing of the eruption. While increases in magma reservoir overpressure remained modest (< 10 MPa) throughout the data assimilation time period, significant Mohr-Coulomb failure is indicated in the lead up to the eruption coincident with increased seismicity along both trapdoor faults within Sierra Negra’s caldera and along the caldera’s ring faults. During the final stages of pre-eruptive unrest, the EnKF models indicate limited tensile failure, with no tensile failure along the northern portion of the magma system where the eruption commenced. Most strikingly, model calculations of significant through-going Mohr-Coulomb failure correspond in space and time with a Mw 5.4 earthquake recorded in the hours preceding the 2018 eruption. Subsequent stress modeling implicates the Mw 5.4 earthquake along the southern intra-caldera trapdoor fault as the potential catalyst for tensile failure and dike initiation along the reservoir to the north. In conclusion, the volcano EnKF approach successfully tracked the evolving stability of Sierra Negra, indicating great potential for future forecasting efforts.