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Investigating the relationship between volcanic eruption parameters and radio-frequency emission with a multiphysics simulation

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Recent measurements of radiofrequency (RF) emissions from volcanos have identified discrete RF spikes occurring at rates of thousands or tens of thousands per second as a discriminant of volcanic eruptions (Behnke et al. 2018). This continuous RF (CRF) emission commences simultaneously with eruption onset. Sustained high discharge rates make volcanic CRF distinct from the RF emission associated with meteorological lightning. Experiments generating discharges in a particle-laden gas jet formed during the decompression of a shocktube filled with coarse and fine ash (Cimarelli et al., 2014) suggest that these discharges are closely related to the compressible fluid dynamics of a standing shock wave (Mach disk) forming at the vent (Méndez-Harper et al. 2018). The sources of RF emission are hypothesized to be numerous streamer or coronae discharges forming between triboelectrically charged ash particles, as they pass through the rarefaction region of the shock where the discharge threshold drops with the pressure.

In order to exploit the CRF signals for volcano monitoring, we need quantitative relationships between the eruption parameters and the occurrence and intensity of RF emission. To enable this, we have developed a model for volcanic discharges which simulates 1) the compressible outflow of a dusty shocktube, 2) the triboelectric charging of dust particles, 3) the separation of dust particles by their inertia, and 4) the formation of sparks through streamer breakdown. We implemented this model in the Adaptive Mesh Refinement code AMRex allowing us to resolve shock and turbulent structures in the gas flow. The fine dust advecting with the gas is implemented as a modified gas law considering the reduced volume and mass fraction of the gas. Coarse particles decoupling from the gas flow are implemented as a separate fluid. A triboelectric charging model tracks the transfer of high energy state electrons between particles during collisions. Breakdown events are identified by calculating the Townsend ionization coefficient with the Boltzmann solver Bolsig+ and comparing integrals of the coefficient along electric field lines to the Raether-Meek breakdown condition. Our simulation indicates that explosively-driven volcanic ash jets close to the vent present a qualitatively different electrostatic environment than is present in steady flows. The high-gradient conditions inherent in the vicinity of the shock alter the processes that generate a spark. For example, charge magnitude and polarity are sensitive to the shocked drift.

We validate the simulation against a large set of volcanic shocktube experiments varying the mass of ejected particles (eruption magnitude), the pressure within the tube (eruption intensity), and the amount of fine particles (grain size distribution). This will allow us to test the hypotheses of breakdown occurring preferentially in the rarefaction region, relate the frequency of RF discharges to the spatial distribution of charge clusters, and extrapolate our model to volcanic scales.

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