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Electric Field Generation in Martian Dust Devils

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Abstract

Triboelectric dust charging physics via the Macroscopic Triboelectric Simulation (MTS) code has been added to the Mars Regional Atmospheric Modeling System (MRAMS) in order to simulate the electrodynamics of dust devils and dust disturbances on Mars. Using the model, we explore how macroscopic electric fields are generated within storms and attempt to quantify the time evolution of the electrodynamical system.
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1. Introduction

Dust charging studies with Mars soil simulant [1,2] suggest triboelectric charging of dust is very possible on Mars. A typical terrestrial dust devil has been found to generate macroscopic electric field perturbations in excess of 100 kV/m [3]. Once charged, some of these grains are injected further into the air where they are transported upward by atmospheric currents. Differential transport and gravitational sedimentation sorts the dust devil aerosols so that the lighter and predominantly negatively charged particles populate the higher portion of the disturbance while the heavier, positively charged particles fall to the ground or remain in the lower portion of the vortex.

2. Modeling

MRAMS is a nonhydrostatic model which permits the simulation of atmospheric flows of large vertical accelerations, such as dust devils. Dust particles are represented by discrete mass bins; each bin is carried in the model as a scalar species that can be advected and diffused. The dust lifting scheme includes multi-size dust transport capability. The dust surface source is parameterized based on the work of [4,5]. Laminar wind and dust devil lifting are implicitly included in this single scheme. Dust devils occupy the tail end of the Weibull distribution in unstable (Ri<0) conditions. MTS quantifies charging associated with swirling, mixing dust grains. Grains of pre-defined sizes and compositions are placed in a simulation box and allowed to move under the influence of winds and gravity. The model tracks the movement of grains in prevailing winds and charge exchange upon grain-grain collision. The composition of the grains is also a predefined variable and we impose a compositional mix to maximize the triboelectric surface potential difference between larger and smaller grains. Specifically, we apply the grain/grain contact electrification algorithm presented in [6]. Information describing each MTS dust particle (i.e., charge, radius, and mass) are fed into the MRAMS dust lifting scheme for each MRAMS model grid-point (Fig. 1). The coupled model enables the ability to simulate charging with a fully dynamic model in a manner that allows the wind field, dust distribution, and charging to be physically consistent.

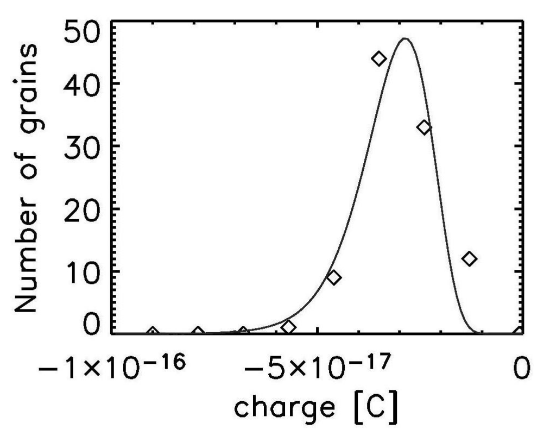
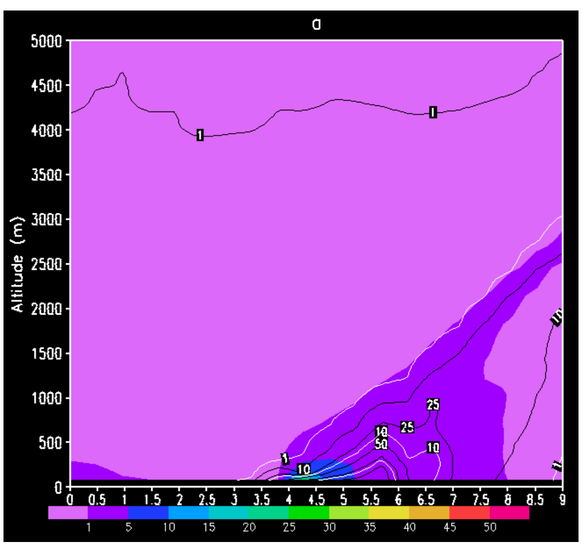


Figure 1: Each of the MTS dust grains are sorted into the microphysics mass bins, and a log-normal function is fit to the charge data. The first and second moments of the charge distribution are sent as tracers to MRAMS so that as the dust grains move around in the MRAMS domain, the charge distribution across a particle size bin can be reconstructed at any point.

3. Dust Devil Simulation Results

The coupled model is run over a 15 km x 15 km domain up to a height of about 8 km. The MTS dust particles are classified as either metals or silicates based on their charge sign (negative or positive, respectively). The metals range from 0.5 – 2 μm in radius, with most particles having a radius of 1 μm; the silicates are 2 – 100 μm in radius, with the peak of the size distribution at 4 μm. Because the silicates are much less dense than the metals, the smaller silicate particles fall at speeds comparable to the metal particles. A number of neutral particles are also present. The charge on individual particles ranges from about 10^{-18} to 10^{-15} C. There are about 3 times as many metal grains as silicates, but the entire population of the surface dust reservoir is net neutral. The atmosphere is initialized using temperature and wind profiles from a Viking 1 landing site LES model at approximately 10:00 LMST.

The electric field generated in a simulated dust devil is shown in Fig. 2. There is a brief spike in the E-field for one minute (Fig. 2b) as dust is lifted from the surface. This spike coincides with a number density of dust particles in the atmosphere of 500 cm^{-3}. The decline in the magnitude of the E-field corresponds to a drop in the number of dust particles by about a factor of 4. While the dust particles can be seen to rise several kilometers (Fig. 2a), their numbers are insufficient to generate strong E-fields above about 300 m.



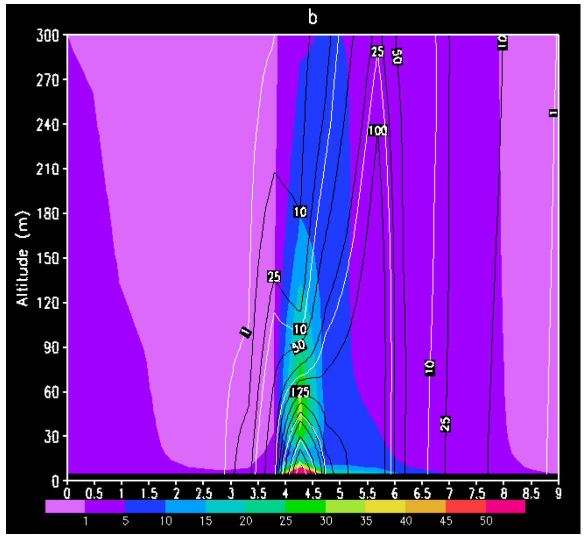


Figure 2: Electric field in a vertical slice tracking the dust devil core. (a) Entire height of dust devil, (b) Zoom in on peak of E-field. Colored contours are magnitude of the E-field in kV/m. Black contours show the number concentration (cm^{-3}) of negatively charged particles and white contours correspond to the positively charged particles. The x-axis is time in minutes.

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