Electric Field Development within a Dust Devil on Mars. S. Uttam[1], V. Sheel[1] and S. K. Mishra[1], [1]Physical Research Laboratory, Ahmedabad – 380009, Gujarat, India (u.shefali92@gmail.com, shefali@prl.res.in).

Introduction: Dust devils provide an essential mechanism for lifting dust into the atmosphere in localized regions. The winds within the dust devil are strong enough to lift dust from the surface and distribute it throughout its spatial extent. In this process, the dust particles get electrically charged by triboelectric mechanism, based on their size and composition [1], [2], [3]. Mass stratification of dust occurs within a dust devil on the basis of particle size [4], due to which an electrostatic field is developed. Terrestrial observations show that the electric fields within dust devils can vary from a few kV/m to ~100 kV/m [6], [8]–[10]. Although multiple observations of dust devils (images and various meteorological parameters like pressure, temperature, wind) are made for Mars, using both orbiters and surface-based instruments, none of them has recorded any direct measurement for the electric field within the Martian dust devils.

In this study, we discuss about the mechanism of electric field generation, within a dust devil in the Martian atmosphere, based on analytical and numerical methods. We will take into consideration the presence and absence of dust storm on Mars to determine the possibility of lightening generation within a dust devil.

Methodology: In triboelectric mechanism, larger particles get positively charged and smaller particles get negatively charged. We estimate the charge exchange per collision between two particles based on its composition and size. The equation for charge exchange per collision (Δq) can be given as [3],

$$\Delta q \approx 2668(\Delta\varphi/2V)(r_f/0.5\mu m)e \qquad (1)$$

where, r_f is the reduced radius $r_f = (r_L^{-1} + r_S^{-1})^{-1} \sim r_S$, and e is the elementary charge. We then analytically solve the continuity equation to determine the electric field E within the dust devil by considering charge relaxation due to conduction in the atmosphere. The analytical solution is given as,

$$E = \frac{n_L \upsilon \Delta V \Delta q}{\sigma}\left[te^{-\sigma t/\varepsilon_o} - \frac{\varepsilon_o}{\sigma}\left(1 - e^{-\sigma t/\varepsilon_o}\right)\right] \qquad (2)$$

where, n_L is the number of large particle concentration, υ is the collision frequency, ΔV is the velocity difference between large and small particles, Δq is the charge exchange per collision, and σ is the atmospheric conductivity. We take $r_S = 1\,\mu m$, $r_L = 20\,\mu m$, $n_S = 50\,cm^{-3}$, and $n_L = 1\,cm^{-3}$ for the calculation of the electric field [11]. We take the value of vertical wind to be $\sim 5\,ms^{-1}$ and then use equation (17) of Farrell et al., (2006) [11] to determine the value of $\Delta V \approx -3\,ms^{-1}$. We take the conductivity of the Martian atmosphere to be $\sim 8 \times 10^{-14}\,Sm^{-1}$ in presence of dust, whereas $\sim 5 \times 10^{-12}\,Sm^{-1}$ in absence of dust [12].

We also perform a numerical simulation of the electric field generation within a finite-sized dust devil. We assume our dust devil to be in a cylindrical coordinate system with symmetry about the z-axis. The dust devil is at the center of the domain, which is modeled by a cylinder of radius 5 m, and the outer region is modeled by a cylinder of radius 100 m. The height of the dust devil is taken to be 100 m. In earlier studies [2], [13], an equal distribution of charge within the dust devil (dipole configuration) was assumed to solve for the electric field within the domain. However, in real scenario, the number density of the particles decreases rapidly with altitude. The number density of the larger particles falls sharply than the number density of the smaller particles [4]. We also consider the charge density at each altitude to fall as r^{-4} along the radial distance, such that the charge density only remains present within the dust devil in our calculation domain. At each time, we compute the electric potential first for the obtained charge density within the domain using Poisson's equation. Then, using this electric potential, we calculate the corresponding electric field.

Results: The analytical solution suggests that the electric field build-up is stronger in the presence of dust in the atmosphere. Moreover, without charge relaxation the growth of the electric field is higher.

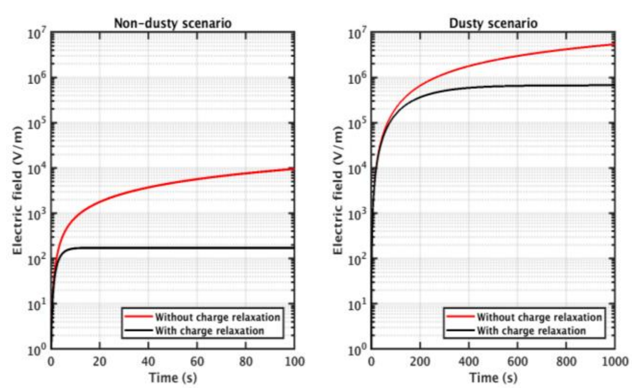

Figure 1: Variation of electric field with time in presence and absence of charge relaxation for (a) Non-dusty scenario, and (b) Dusty scenario of Martian atmosphere.

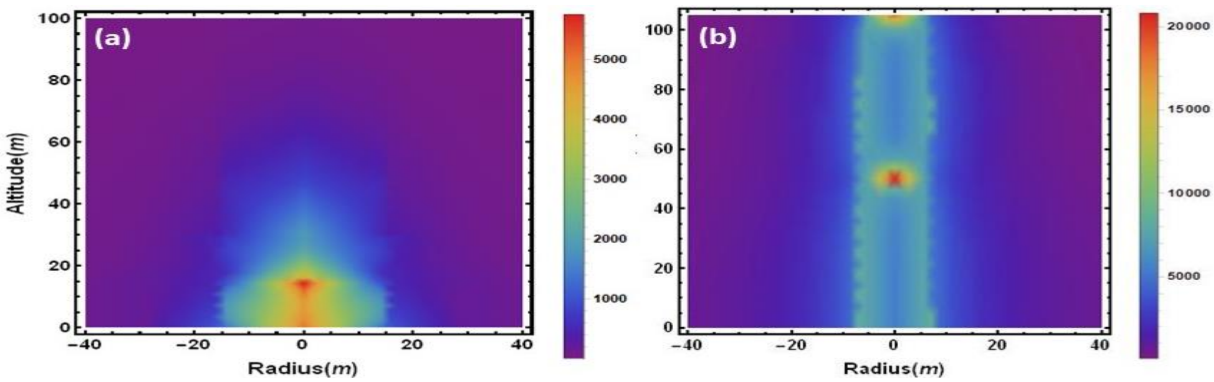

Figure 2: Electric field distribution within our simulation domain at 500 s due to (a) vertically decreasing particle density, and (b) dipole charge configuration. Color bars on right represents the magnitude of the electric field in Vm^{-1}.

Numerical simulations suggest a maximum electric field of $\sim 5.5\ KVm^{-1}$ at 500 s, within our simulation domain. Whereas, when we simulate the electric field in our domain with dipole charge density configuration, i.e., bottom half is positively charged and upper half is negatively charged, we obtain the maximum electric field to be $\sim 20\ KVm^{-1}$.

Discussion and Conclusion: Figure 1 suggests that in the presence of dust in the atmosphere the electric field is high. It is so because during the presence of dust, the conductivity of the atmosphere decreases by two orders as compared to the non-dusty atmosphere [14]. Even when a moderate electric field is developed in the Martian atmosphere, a substantial dissipation current is generated, which increases exponentially with increasing electric field. Thus, a significant competing dissipation current develops in the atmosphere that acts to deplete the development of large separated charge centers and reduces the electric field. The electric breakdown value for the Martian lower atmosphere is $\sim 20\ kVm^{-1}$ [2], [13]. If we are neglecting the charge relaxation process and consider the dust devil to be in steady state, we can see that in the initial 30 seconds the electric field reaches the breakdown value in a dusty atmosphere, whereas it takes more than 100 seconds to reach the same in a non-dusty atmosphere. Thus, the chance to detect lightning inside a dust devil on Mars is higher if the atmosphere is covered with dust. If we consider charge relaxation, we observe that the growth of electric field is affected, with a reduction in its maximum value, for both dusty and non-dusty scenarios. In non-dusty scenario, the conductivity is high, which leads to a faster relaxation and transfer of charges among the particles, thus leading to an early saturation of the electric field. Whereas in the dusty scenario, the atmospheric conductivity is lower, thus leading to a higher timescale required for charge relaxation as compared to non-dusty scenario. Due to this the charge relaxation becomes slow with time and makes electric field reach saturation late as compared to its non-dusty counterpart. The inclusion of relaxation makes the electric field to saturate at a lower value in a longer time, as compared to its earlier counterpart in which charge relaxation was ignored.

Even though an analytical solution provides a useful understanding of the electric field generation within the dust devils, but more realistic insight into this physical phenomenon is given by its numerical simulation. A vertically decreasing particle distribution is considered to determine the final charge distribution within the dust devil. We observe that in such a charge distribution, the maximum magnitude of the electric field is ~ 4 times less than what is obtained for a dipole-like configuration. A dipolar vertical charge distribution can not be realized within an atmospheric dust devil. Thus, the chances of detecting lightning within dust devil in the Martian atmosphere becomes sparse. But for larger sized dust devils, we can expect an increase in the strength of electric field generated within the dust devil for a vertically decreasing number density of particles. So, in the Martian atmosphere electric fields within larger size dust devils can reach breakdown and cause lightning.

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