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Extreme Conditions for Electrification during Dust Devils on Mars

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Abstract

Dust Devils (DDs) mostly occur in the Southern hemisphere of Mars, the reasons of which are not well understood. The occurrence of dust devil raises dust in the environment and sometimes, they are global in nature. It can also lead to charge build up in the whirlpool motion due to low Martian pressure and arid environment. This work presents estimation of electric field for different conductivity, which might be caused by dust devils on Mars. Results indicate conditions for the electrical discharge or lightning on Mars.

1. Introduction

Dust Devils are found to prevail near the Martian surface during the Southern hemisphere summer. A pocket of hot air is raised upward, surrounded by cold air, and under favorable conditions, it starts rotating. This lifts the smaller dust grains upward in the atmosphere, which subsequently affects optical depth and decreases ion concentration. Figure 1 shows an image of a dust devil observed by MRO [1].

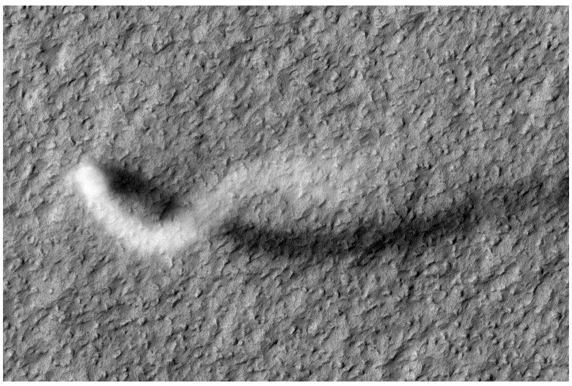

Figure 1. Photograph of a Martian dust devil obtained by MRO, which is 800 meters tall and 30 meters wide [1].

Presence of dust is known to affect atmospheric conductivity [2, 3], which can affect the wave propagation. The electric field during the DD can increase and possibly reach break down strength of Martian environment. Once, electrical discharge occurs, it emits low frequency electromagnetic waves near the surface. Such waves may be observable in the form of Schumann Resonance, discussed in our earlier work [4]. In this work, the electric field for different dust conditions are presented.

2. Electric Field during Dust Devil on Mars

Electric fields could be generated in the dust devils due to triboelectric charging process [5]. The MATADOR project [6] showed examples of the electromagnetic nature of the dust devil and studied the fluid and electrical forces. Farrell et al. [7] have shown the conductivity of Mars 100 times greater than that of Earth, which does not reduce the field but slows down the charge-up process. Due to the triboelectric process, the charge separation takes place and electric field can be generated [8]. Cardnell et al. [2] have reported a photochemical model of the dust-loaded environment on Mars and shown the conductivity under different dust conditions. Such study could be useful for understanding atmospheric electrical phenomena, such as electric discharges, currents and Schumann Resonance [2]. Cardnell et al. [2] showed that the conductivity can change from 1E-7 to 1E-13 S/m under different conditions due to dust in the atmosphere. The electric field generated under different dust conditions are estimated. The continuity equation for the electric field E is given as [7]

$$\frac{dE}{dt} = -\frac{J}{\varepsilon_0} \qquad (1)$$

where J is the current density, t is time and ε_0 is the free space permittivity and the differential equation for the solution during dust devil is given by Farrell et al. [7] as

$$E'' + \sigma\, E'/\varepsilon_0 + n_L\, \Delta\mathrm{v}\, v\, \Delta q/\varepsilon_0 = 0 \qquad (2)$$

where σ is the atmospheric conductivity, n_L is the density of large particles, $\Delta\mathrm{v}$ is the differential velocity between large and small particles, v is the collision frequency for large and small particles and Δq is the charge exchange per collision defined as [7, 9]

$$\Delta q = (1\, fC/\mu m)\, r_S \qquad (3)$$

where r_S is the radius of small grain.

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3. Results and Analysis

We considered the conductivity suggested by Cardnell et al. [2] in the present work and obtained the electric field build up for different time using Eq. (3) for the parameter values suggested by Farrell et al. [7]. Figure 2 shows the electric field build up for 100 sec duration, while Figure 3 depicts the electric field build up for 100000 sec (approximately 1 day). Both figures also show the breakdown strength of Martian environment at the surface as a dotted line.

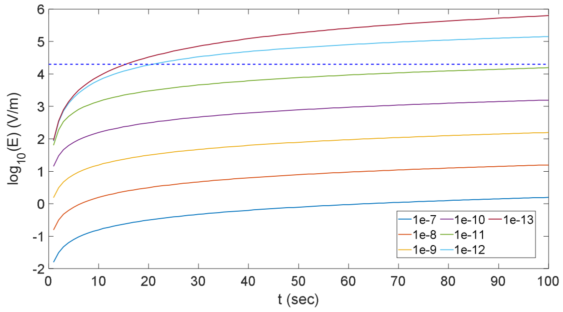

Figure 2. Electric field build up during dust devil on Mars versus time for different conductivity. The solution is for 100 sec as a very short duration dust devil. Lightning can occur for the lower values of the conductivity or larger amount of dust in the atmosphere.

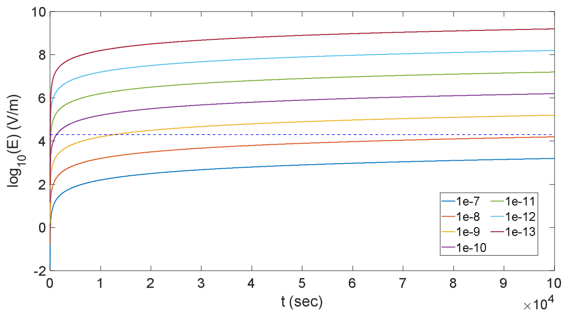

Figure 3. Electric field build up during dust devil on Mars versus time for different conductivity. The solution is for 100000 sec (approximately 1 day) as an extreme case of very long duration dust devil. Lightning can occur for the larger values of the conductivity also (i.e., lower amount of dust in the atmosphere).

It can be observed from Figure 2 that for a very short duration dust devils on Mars, the electrical discharge can occur for a low value of atmospheric conductivity of the order of 1E-13 and 1E-12 S/m. Also, one can observe from Figure 3 that the electrical discharge can occur for the large values of conductivity (of the order of 1E-9 S/m). All the other cases of dust devils could be between the two cases shown. Further, it can be observed from the results in Figure 2 and Figure 3 that approximately the electric field build up time increases as the similar order of increase in the conductivity. In other words, the occurrence of lightning on Mars can take longer time whenever the atmospheric conductivity is relatively larger. During the dust devil on Mars, dust is transported to the atmosphere and the conductivity changes inversely with the amount of dust present [2, 4]. Thus, the short duration dust devils on Mars need to be intense enough to transport the large volume of dust in the atmosphere for causing the lightning. On the other side, relatively longer duration dust devils on Mars can be poorer in their strength for initiating the lightning.

4. Summary and Conclusion

Dust devils mostly occur in the Southern hemisphere of Mars. During its formation, triboelectricity can cause the charge transfer among the rotating dust particles. The electric field may build up, leading to electrical discharge or lightning on Mars. The results obtained from the solution of electric field show that the short-lived dust devils should be intense to transport the sufficient amount of dust for the initiation of lightning, under the atmospheric conductivity as low as 1E-13 S/m. The longer duration dust devils, though poor in strength and can transport small amount of dust in the atmosphere, can produce the lightning after longer time with the atmospheric conductivity of the order of 1E-9 S/m. The results are useful to understand the conditions of lightning initiation on Mars.

5. Acknowledgements

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