Turbulence-Coupled Electrodynamics of the MY 34 Global Dust Storm on Mars

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Introduction

Dust definition. Here, **dust** refers to wind-mobilized Martian regolith particles in the lower atmosphere: coarse saltating grains drive near-surface impacts, while micron-scale suspended aerosols control optical depth, attachment, and the volume over which charge can accumulate.

MY 34 acted as a storm-scale atmospheric-electrical organizer: dusty turbulent charging supplied the source current, reduced conductivity slowed charge leakage, and the local breakdown threshold determined where the modeled field became breakdown-capable. The result is **localized**, **vertically structured**, and **conductivity-regulated** favorability—not a claim of observed global lightning.

1. Triboelectric discharge

- **Triboelectric charging:** wind-mobilized regolith grains collide with other grains and surfaces, transferring charge and separating positive and negative charge populations.
- **Discharge onset:** if charge separation builds a vertical electric field E_z comparable to the local CO_2 breakdown field E_b, the atmosphere can become locally breakdown-capable.
- **Martian discharge type:** the relevant interpretation is local corona-like, glow-like, or short streamer-like activity in dusty CO_2, not terrestrial cloud-to-ground lightning.
- **Diagnostic boundary:** $E_z/E_b \geq 1$ marks breakdown capability or onset proximity only. It does not prove sustained channels, radio detection, or continuous global electrical activity.

2. Equation pathway: dust motion to charging

$$\Delta q_{ij}^{(\phi)} = \eta_{\mathrm{eff}}\, 4\pi\epsilon_0 R_{ij} \Delta\phi, \qquad R_{ij} = \frac{r_i r_j}{r_i + r_j},$$

$$J_{src} = n_s n_d K_{sd} \Delta q_{sd} + \frac{1}{2} n_d^2 K_{dd} \Delta q_{dd}.$$

- $\Delta\phi$ is treated as an uncertain charging parameter, not as a measured Martian dust potential.
- J_{src} is the collision-driven source current density. It increases when saltating grains, suspended dust, collision kernels, or mean charge transfer increase.

Dust becomes electrically important only when lifting and collisions are active.

3. Leakage and breakdown diagnostics

$$\sigma = e\left(n_e\mu_e + n_+\mu_+ + n_-\mu_-\right), \qquad \tau_e = \frac{\epsilon_0}{\sigma},$$

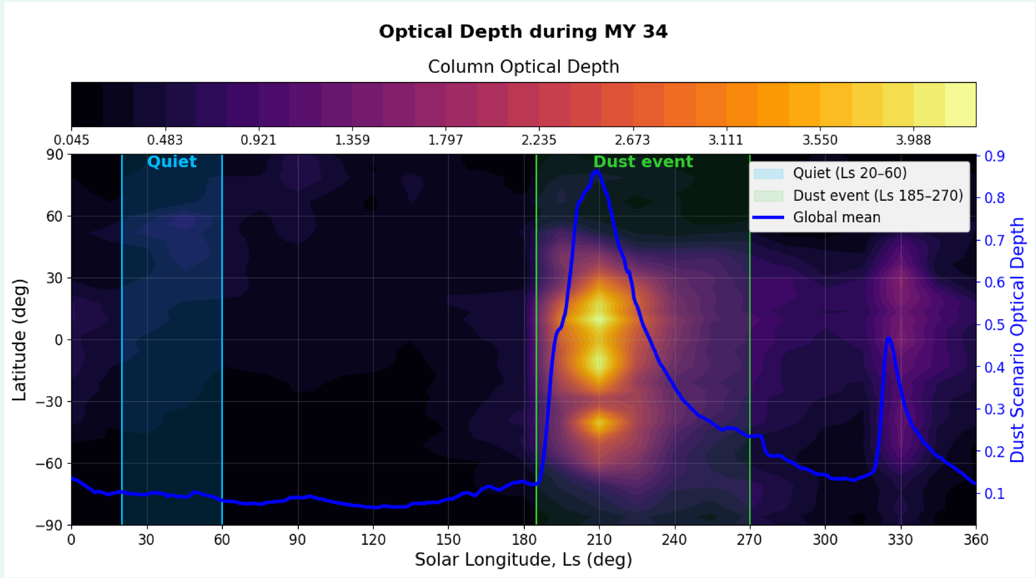
$$E_z \approx \frac{J_{src}}{\sigma},$$

$$V_b = \frac{Bpd}{\ln(Apd) - \ln\left[\ln\left(1+\frac{1}{\gamma}\right)\right]}, \qquad E_b = \frac{V_b}{d},$$

$$\mathcal{B} \equiv \frac{E_z}{E_b}, \qquad Q_\Omega = \sigma E_z^2.$$

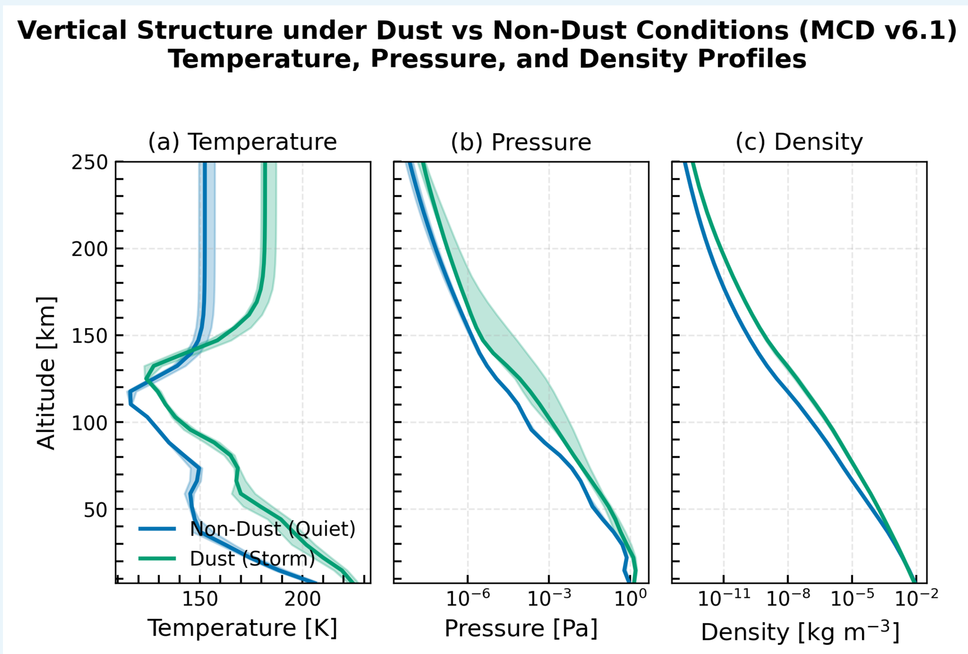
- σ is the conductive leakage pathway; τ_e is the charge-relaxation time, so lower σ allows charge to persist longer.
- E_z is a reduced quasi-electrostatic diagnostic: stronger J_{src} raises the field, whereas larger σ damps it.
- V_b and E_b come from the CO_2 Paschen breakdown relation; p is pressure, d is the effective gap, and A, B, γ are gas-dependent parameters.
- $\mathcal{B} \geq 1$ means locally breakdown-capable conditions only. It is not direct evidence of lightning, sustained discharge, or radio detection.

4. Storm context: MY 34 optical depth



Column dust optical depth rises sharply after storm onset and peaks in low-latitude to tropical sectors. In the model, this is the environmental background for heating, turbulent redistribution, suspended dust abundance, and conductivity modification.

5. Dust storms inflate the lower atmosphere



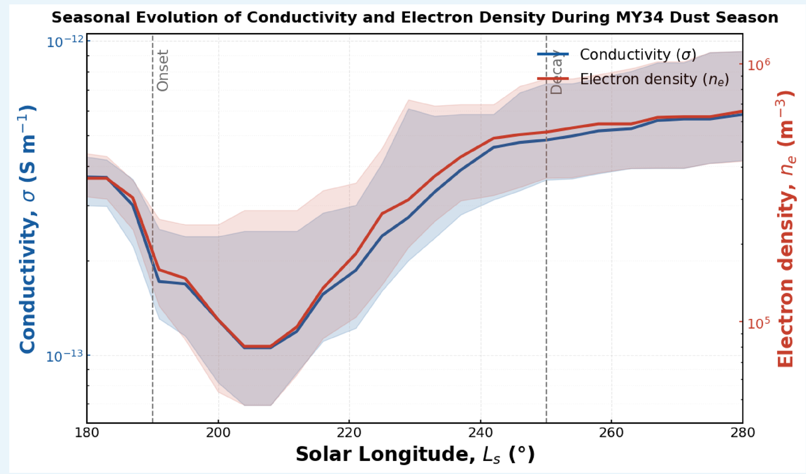
The storm atmosphere is warmer and vertically expanded relative to the clear reference state. Because the profiles are altitude-fixed, pressure and density shifts indicate column expansion rather than a direct surface-pressure comparison.

6. Why dust alone is not enough

- Dust loading supplies the large-scale perturbation, but electrical hot spots form only where the equations show three conditions overlapping.
- **Source:** turbulent grain collisions increase J_{src}.
- **Retention:** reduced conductivity increases τ_e.
- **Threshold:** the local Paschen environment determines where E_z becomes breakdown-capable.

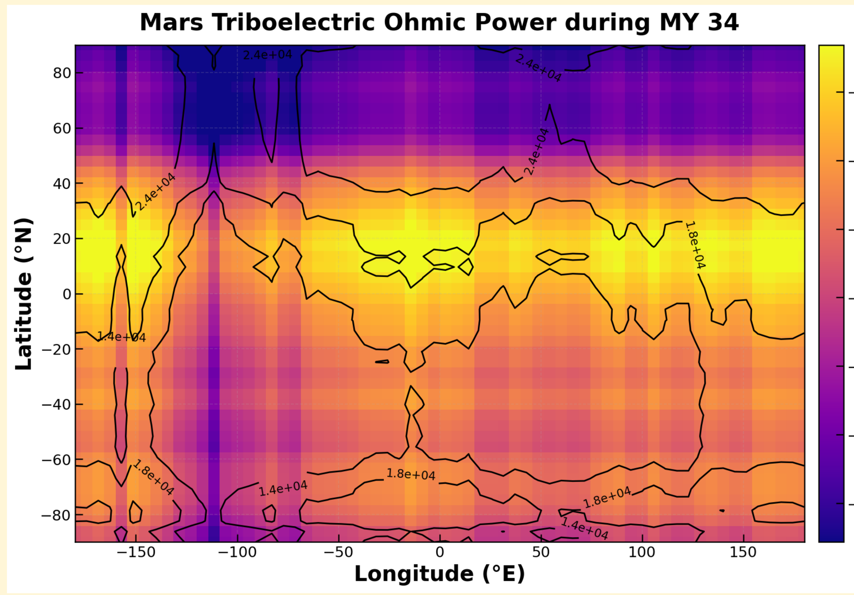
Dustier air is not automatically more electrical.

7. Conductivity controls field persistence



Conductivity and electron density decrease during the early storm. Lower σ lengthens $\tau_e = \epsilon_0/\sigma$, allowing separated charge to survive longer. Conductivity reduction alone is not sufficient; an active charging source is also required.

8. Ohmic dissipation identifies electrical hot spots



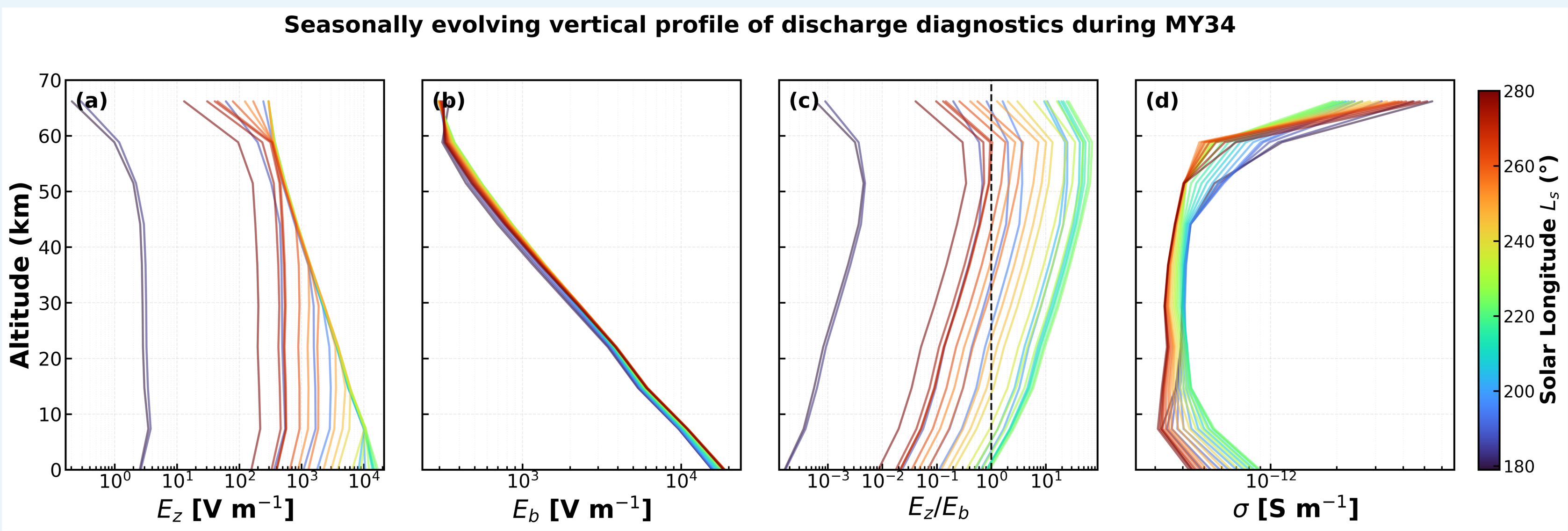
The diagnostic $\log_{10}(\sigma E_z^2)$ highlights where field amplification and conductive loss coexist most effectively. Enhanced dissipation is organized in low- to middle-latitude storm-active regions, not uniformly over Mars.

9. Main conclusions

1. MY 34 created a warmer, deeper, dust-loaded lower atmosphere favorable for electrical organization.
2. Breakdown-capable conditions were localized in season, geography, and altitude.
3. Conductivity suppression lengthened charge-retention time and allowed amplified E_z to persist.
4. Layer geometry and Ohmic dissipation identify where electrical activity is most physically plausible.

$E_z/E_b \geq 1$ **means capability, not detection.**

10. Strongest result: breakdown favorability develops as a vertical layer



Interpretation: E_z grows where charging outpaces leakage; E_z/E_b identifies breakdown-capable altitude ranges; layer metrics (z_{on}, z_{top}, D, $P_{occ,rel}$) separate coherent layers from isolated crossings.

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