Paper Presentation

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Electrostatic forces alter particle size distributions in atmospheric dust

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Background

- The global climate is largely governed by balance between incoming solar radiation and outgoing thermal radiation from the Earth. This balance depends on interactions between matter and radiation.
- Smaller-sized particles tend to have a cooling effect on the climate. In contrast, larger-sized particles have a heating effect on the climate.

Therefore, it is important to characterize dust distribution in the atmosphere.

Effects of Dust

Delivery of nutrients

Delivery of nutrients by dust 🌲

- The growth of many ocean biota, such as phytoplankton, depends on the iron available. This demand is largely met by on the dust transport.
- Dust-borne phosphorus are critical to ecosystem productivity (i.e. primary biomass production). For example, the productivity of the Amazon rainforest is probably limited by dust-borne phosphorus deposition.
- Dust emission reduces the soil fertility by carrying away nutrients, causing desertification.

Hydrological cycle

- The atmospheric dust interacts with solar radiation and causes changes in the climate, with larger-sized particles having a heating effect, and smaller-sized particles having a cooling effect.
- Serves as a nuclei for the condensation of water which in turn effects formation of clouds and rain pattern.
- The deposition of dust on glaciers and snow packs decreases the albedo (reflectivity) of these features, which produces a positive (warming) climate forcing and an earlier spring snowmelt.

SCIENCE ADVANCES | RESEARCH ARTICLE

ATMOSPHERIC SCIENCE

The mysterious long-range transport of giant mineral dust particles

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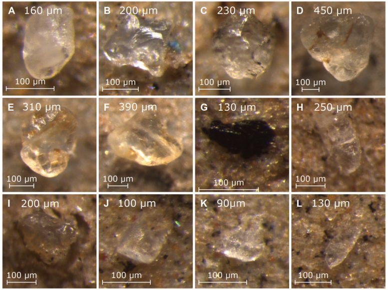
R. Giles Harrison[3], Jan-Berend W. Stuut[1,4]

Giant mineral dust particles (>75 μm in diameter) found far from their source have long puzzled scientists. These wind-blown particles affect the atmosphere's radiation balance, clouds, and the ocean carbon cycle but are generally ignored in models. Here, we report new observations of individual giant Saharan dust particles of up to 450 μm in diameter sampled in air over the Atlantic Ocean at 2400 and 3500 km from the west African coast. Past research points to fast horizontal transport, turbulence, uplift in convective systems, and electrical levitation of particles as possible explanations for this fascinating phenomenon. We present a critical assessment of these mechanisms and propose several lines of research we deem promising to further advance our understanding and modeling.

Long-range transport of giant mineral aerosol particles

P. R. Betzer, K. L. Carder, R. A. Duce, J. T. Merrill, N. W. Tindale, M. Uematsu, D. K. Costello, R. W. Young, R. A. Feely, J. A. Breland, R. E. Bernstein & A. M. Greco

Nature **336**, 568–571(1988) | Cite this article



Introduction

- Studies have shown that smaller and larger partilces tend to charge with opposite polarities. 1) smaller: negative, and 2) larger: positive.
- The particle-size-dependent polarity of charge, combined with the separation of small and large particles in a gravitation field generates electric fields in dust storm.
- Based on experimental results a theroretical model was developed which was applied to large scale dust transport to elucidate the effect of electric field.

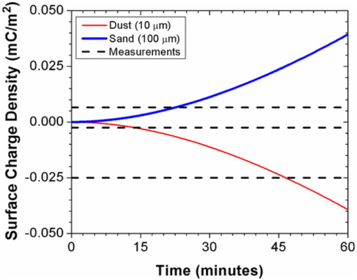


Figure 2: An experimental schematic of the dust system. [a]

[a] https://doi.org/10.1103/PhysRevE.79.051304

Experimental methods

1. Two plates parallel electrodes (85 cm $\times$ 12 cm) were connected to a DC voltage supply.
2. The distance between the electrodes was kept at 12 cm, and the electric field was varied between -125 to 125 kVm^{-1}.
3. A 250 g of sand sample with mean diameter $\sim$ 132 µm was used for the experiment.
   - 40 % by mass of this was less than 105 µm.
   - 60 % by mass are between 105 µm 450 µm.
4. A fan was placed 15 cm upstream of the sand bed with wind blown over the sand bed at an average air speed was 6.7 ms^{-1}.

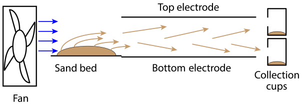


Figure 3: An experimental schematic of the dust system.

Dust Collection

1. Two collection cups were placed 11 cm dowstream of the electrode with slit opening 2.2 cm tall and 11 cm wide.
    - The bottom cup collected particles between heights of 0 and 2.2 cm, and the top cup collected particles between heights of 8.8 and 11 cm.
2. The particles collected in the two cups were sieved using a 105 µm mesh sieve.
3. All particles which passed through the seive were considered as smaller particles otherwise larger particles.
4. After sieving the particles in each cup, the mass of the smaller and larger particles collected in each cup were determined.

Monte-Carlo method was used to model the effect of dust transport in electric fields.

- The electrostatic force, F_G, is given by

$$F_{\mathrm{G}} = \frac{\pi D^3}{6}\rho g \tag{1}$$

- The electrostatic force, F_E, is given by

$$F_{\mathrm{E}} = \pi D^2 \sigma E \tag{2}$$

- and, The electrostatic force, F_D, is given by

$$F_{\mathrm{D}} = -\frac{1}{8} C_{\mathrm{D}} \rho_f \pi D^2 v^2 \hat{v} \tag{3}$$

- The equations governing the motion of the particle in the vertical direction are

$$\frac{\mathrm{d}v}{\mathrm{d}t} = \left(\frac{6}{\pi D^3 \rho}\right) F_{\mathrm{net}} \tag{4}$$

$$\frac{\mathrm{d}y}{\mathrm{d}t} = v \tag{5}$$

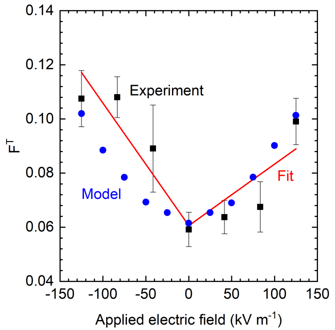


Figure 4: Plot of the fraction of total particles collected in the top cup (F^T) as a function of applied electric field.

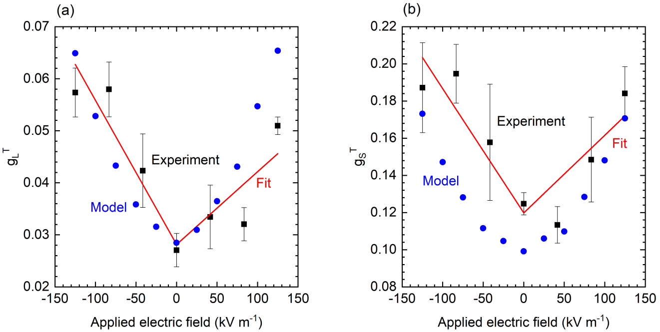


Figure 5: Fraction of total (top and bottom) large particles in the top cup (g_L^T) (a) and fraction of total (top and bottom) small particles in the top cup (g_S^T) (b) as a function of the applied electric field.

As the magnitude of the electric field increases, more of the airborne dust remains suspended at higher elevation and fraction of particles collected in top cup increases.

Applying model to field studies

- Used the model to study the effects electrostatic forces on long-range transport of dust.
- Several field studies have found presence of large particles at elevated height which could not be explained by current models.
- Futhermore, studies also suggested little variation in the particle size distribution over several kilometer elevation.

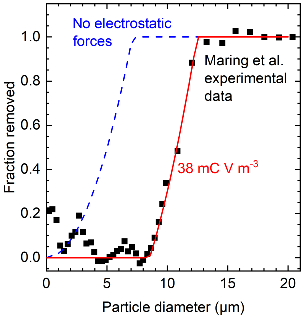
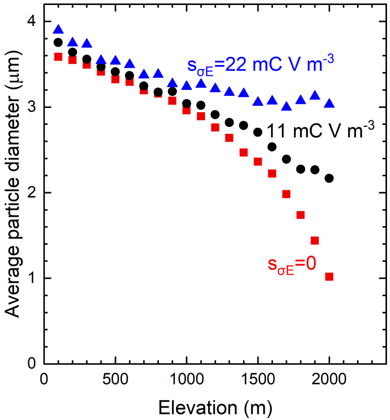
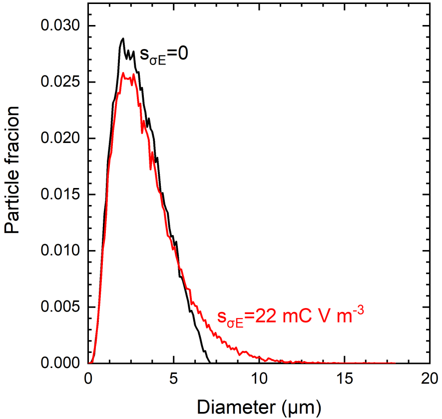


Figure 6: Fraction of particles removed by settling (experimental data collected from Maring et al. (2003)).



(a) Model results for the average particle diameter as a function of elevation after 5.5 d of transport at various standard deviations of electric field and particle charge density products, $s_{\sigma E}$.



(b) Remaining particle size distributions within a 2000 m window after 5.5 d of transport at different values of $s_{\sigma E}$, with a bin size of 0.1 μm.

Figure 7

Conclusions

1. Using both experiment and modelling they showed that the electrostatic forces helps maintain particles at higher altitude and increases the concentration of larger particle.
2. Extented the model to long-distance dust transport to show that by introducing sufficient electrostatic forces large particles that would otherwise settle down during transport remain suspended, thereby increasing the concentration of large particles in atmospheric dust.
3. Since large particles have a heating effect due to absorption and scattering of radiation, results suggest that electrostatic forces could contribute to the warming of the climate.
4. Sufficient electrostatic forces may explain unexpected size and elevation distributions of atmospheric dust.

Thank You!

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