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A theoretical interpretation of the “giant” dust particle conundrum

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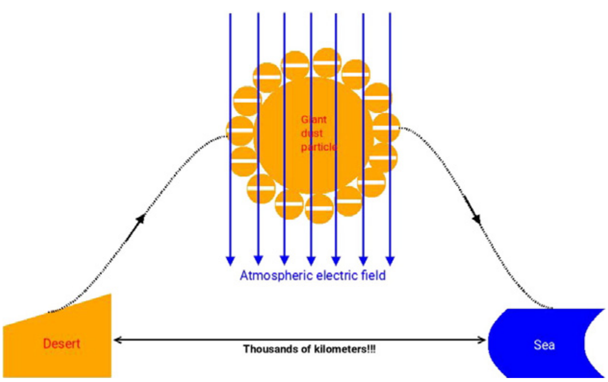
GRAPHICAL ABSTRACT



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ABSTRACT

The effects of electric force were used to interpret a well known conundrum about the long-term (or long-distance) dust transport in the atmosphere.

The entrainment, transport and deposition of aeolian dust are significant for environment, ecosystems and climate. It is generally recognized that desert dust particles only smaller than 20 μm in diameter can be transported in long-term suspension (Pye, 1987; Shao, 2008). However, sand-sized particles have been found in both continental and marine circumstances, even thousands of kilometers away from their desert sources (Betzer et al., 1988; Middleton et al., 2001; Goudie and Middleton, 2001). Such a “giant” dust particle conundrum cannot be explained by using currently acknowledged atmospheric transport mechanisms (Goudie and Middleton, 2006; Stuut, 2014).

From the viewpoint of classical mechanics, the motion of an individual dust particle is determined by the external forces acting on it. Two types of external forces, *i.e.* field force and aerodynamic force, can be distinguished (Wang et al., 2013). In our current understanding of the

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physics of wind-blown sand and dust, field force includes gravity and electric force. Since the settling velocity derived from the balance of gravity and drag is so large that giant dust particles cannot remain suspended for a long period of time except that ground surface rapidly decreases along with dust transport pathways, why not investigate the possible effects of electric force?

The electrification phenomenon of aeolian sand and dust particles has long been known (Kanagy and Mann, 1994; Renno and Kok, 2008; Zheng, 2013). Measurements indicate that smaller particles are negatively charged and larger particles are positively charged. The variation of charge polarity occurs at the particle size of 60 μm (Greeley and Leach, 1978). A range of this critical particle size, *i.e.* 250–500 μm, was also reported (Zheng, 2013). The possible physical mechanisms responsible for the electrification and charge transfer of aeolian particles include contact electrification, triboelectrification, pyroelectrification, and piezoelectrification *etc.*, see (Kanagy and Mann, 1994) for details. In my opinion, triboelectrification seems plausible in arid environments. At the present time, this is an ongoing research topic (Pähtz et al., 2010; Merrison, 2012; Angus et al., 2013; Wei and Gu, 2015).

Generally speaking, the direction of electric force on a positively charged particle in the atmospheric electric field is similar to that of gravity. Electric force should be helpless to the long-term suspension of sand-sized particles. Fortunately, the previous micromorphological studies of Asia and Saharan dusts, *e.g.* (Coudé-Gaussen, 1989; Middleton et al., 2001; Jeong et al., 2014), can provide some valuable information. As revealed by scanning electron microscopy observations, some of the so-called giant particles are clay agglomerates actually, and some are coarse quartz grains coated by clay. A giant particle could possess a negative charge if numerous clay-sized particles adhere to its surface. It will suspend freely when the electric force is close to gravity in magnitude. Assuming the giant particle is electroneutral, the force balance equation on this extreme condition can be written as,

$$\frac{1}{6}\rho_s g\pi D^3 + \frac{m}{6}\rho_s g\pi d^3 = mqE \tag{1}$$

where ρ_s is the particle density, g is the gravitational acceleration, D is the diameter of the giant particle, E is the atmospheric electric field intensity, d, m, q are the diameter, number, charge of the clay-sized particle, respectively.

The layers of small particles on the surface of the giant particle can be estimated by,

$$n = \frac{m\pi\left(\frac{d}{2}\right)^2}{4\pi\left(\frac{D}{2}\right)^2} = \frac{m}{4}\left(\frac{d}{D}\right)^2. \tag{2}$$

Detailed field measurement of charges on individual aeolian particles is still scarce. It was estimated to range from 10^{-1} to 10^2 pC (Kanagy and Mann, 1994). Here we use Bailey's formula,

$$q \approx q_{max} = 1.03 \times 10^{-4}\left(\frac{d}{2}\right)^{1.7} \tag{3}$$

where the units of q and d are coulomb and meter.

The net charge is,

$$Q = mq \tag{4}$$

The surface layers of clay-sized particles and the net charge can be computed from Eqs. (1)–(4). In the calculation, the related parameters were set to the following common values: $g = 9.81$ m/s^2, $E = 130$ V/m, $\rho_s = 2.65 \times 10^3$ kg/m^3, $d = 2.0$ μm. Numerical results are shown in Fig. 1. Just as one would expect, both of m and Q are monotonic increasing functions of D. For an aeolian giant particle with the diameter of $D = 100$ μm, the coated layers and net charge are predicted to be $n = 1.85$ and $Q = 120.2$ pC, respectively. Two coated layers or even more are required for the long-term transport of the particles larger than 100 μm. For the giant Asian dust particles studied by (Jeong et al., 2014), the needed surface layer is less than one. Note giant particles are often tightly surrounded by numerous small particles, it is expected that these results are reasonable.

Consequently, the effects of electric force provide an optional interpretation of the well known "giant" dust particle conundrum. This interpretation might be helpful to climatologists, although more delicate works such as the field measurement of electric charges on individual dust particles are required to verify it. Particle size of sediments is a common proxy for paleoclimate. It should be cautious to reconstruct paleoclimatic characteristics from a loess stratigraphy by using this proxy because suspended sand-size particles could play a role in the process of loess deposition. Moreover, desert dust is an important issue in climate change models. A numerical module for the emission, transport, and deposition of charged dust particles should be specially developed in future.

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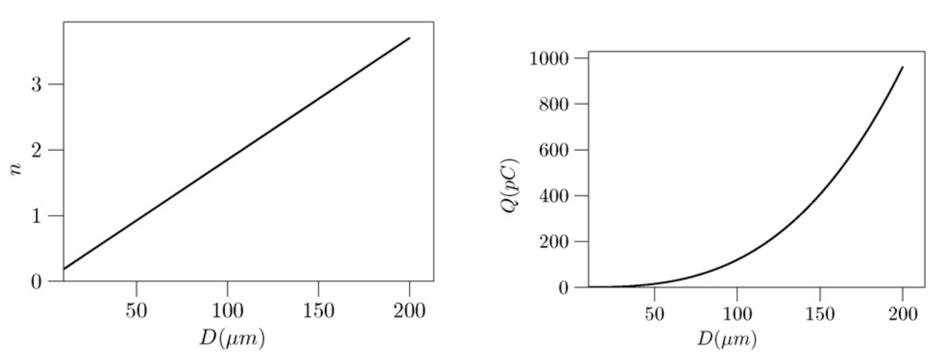

(a) change of surface layers n of clay-sized particles with the diameter D of the central giant particle.

(b) change of net charge Q with the giant particle diameter D.

Fig. 1. The numerical results computed from Eqs. (1)–(4).

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