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An electrified dust storm over the Negev desert, Israel

Yoav Yair [a,*], Shai Katz [a,b], Roy Yaniv [b], Baruch Ziv [c], Colin Price [b]

[a] School of Sustainability, Interdisciplinary Center (IDC) Herzliya, 4610101, Israel
[b] Department of Geosciences, Tel-Aviv University, 6997801, Israel
[c] Department of Life and Natural Sciences, The Open University of Israel, 4353701, Israel

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ABSTRACT

We report on atmospheric electrical measurements conducted at the Wise Observatory in Mitzpe-Ramon, Israel (30°35′N, 34°45′E) during a large dust storm that occurred over the Eastern Mediterranean region on 10–11 February 2015. The dust was transported from the Sahara, Egypt and the Sinai Peninsula ahead of an approaching Cyprus low. Satellite images show the dust plume covering the Negev desert and Southern Israel and moving north. The concentrations of PM10 particles measured by the air-quality monitoring network of the Israeli Ministry of the Environment in Beer-Sheba reached values >450 μg m^{-3} and the AOT from the AERONET station in Sde-Boker was 1.5 on February 10th. The gradual intensification of the event reached peak concentrations on February 11th of over 1200 μg m^{-3} and an AOT of 1.8. Continuous measurements of the fair weather vertical electric field (Ez) and vertical current density (Jz) were conducted at the Wise Observatory with 1 minute temporal resolution. Meteorological data was also recorded at the site. As the dust was advected over the observatory, very large fluctuations in the electrical parameters were registered. From the onset of the dust storm, the Ez values changed between +1000 and +8000 V m^{-1} while the current density fluctuated between −10 pA m^2 and +20 pA m^2, both on time-scales of a few minutes. These values are significant departures from the average fair-weather values measured at the site, which are ~−200 V m^{-1} and ~2 pA m^2. The disturbed episodes lasted for several hours on February 10th and the 11th and coincided with local meteorological conditions related to the wind speed and direction, which carried large amounts of dust particles over our observation station. We interpret the rapid changes as caused by the transport of electrically charged dust, carrying an excess of negative charge at lower altitudes.

1. Introduction

The electrification of mineral dust clouds is a well documented phenomenon, which has been reported since the early days of atmospheric electricity measurements both in natural settings and in laboratory experiments (Zheng, 2013). It has also been mentioned in reports in the non-scientific literature, such as records of massive amounts of sparks from wind-mills and barb-wire fences during the "Dust Bowl" in central US in the 1930s (Egan, 2006). In his report, Gill (1948) mentions the fact that during his service in Greece he noticed that when a dust storm approached his station, there were sparks on the aerials even before the arrival of the dust, a clear indication of induced electric fields generated by or within the dust. Quantitative measurements of surface electric fields during the passage of sand and dust storms have been few and sporadic. Kamra (1969) measured the effects of wind-blown aerosol particles on the fair weather electric field in Roorkee, India, and reported negative values of several kV m^{-1} to be common, with point discharges often occurring from sharp metallic objects. A notable feature reported by Kamra (1969) was the diurnal pattern of wind-blown dust and the ensuing response of the potential gradient, indicating that the lifting of aerosol particles into the boundary layer is often accompanied by electrification. Additional studies by Kamra (1972) in several locations in South-Eastern US showed considerable variance in the behavior of the electric field during dust storms, where some events showed negative values of up to 1500 V m^{-1}, and others positive values of ~500 V m^{-1}. The fluctuations in the measured fields were on time scales of a few minutes, and coincided with gusty wind speeds (8.8–17.6 m s^{-1}) and poor visibility. The difference in polarity was attributed to composition: dust which was mostly composed of clay minerals produced negative polarity of the electrical field and dust containing mostly silica minerals produced mixed polarities. The Harmattan dust layers, prevalent in western Africa between November and March each year, exhibit diurnal electrical behavior that was measured by Harris (1967). He reported strong deviation from the fair-weather electric field in the presence of dust aloft, with negative values up to 4 kV m^{-1}, starting at mid-morning and lasting until late afternoon.

* Corresponding author at: School of Sustainability, Interdisciplinary Center (IDC) Herzliya, P.O. Box 167, Herzliya 4610101, Israel.
E-mail addresses: yoavyair@gmail.com, yoav.yair@idc.ac.il (Y. Yair).

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Oluwafemi and Ette (1974) also measured electrical parameters during the Harmattan, and found a similar diurnal variation, although they measured much lower fields of several tens of volts per meter.

Also in Africa, Williams et al. (2007) observed electrical and other parameters of dust-lofting gust fronts in Niger, using Doppler radars and electric-field mills. The dust was lofted to considerable heights (average 3.5 km ASL) and aerosol (CN) concentrations at the passage of the front were of the order of 2000 cm^{-3}, with visibility reduced to a few km. The disturbed values of the electric field were in the range of 1–8 kV m^{-1} and persisted for a few hours after the passage of the front. The polarity of the charge carried by the dust was not of a preferred sign, and both positive and negative polarity aloft was deduced based on the values measured on the ground. In their Fig. 4, Williams et al. (2007) show that there is a positive correlation between mass loading (μg m^{-3}) and electric field (kV m^{-1}), obtained for 30 gust front events, some mono-polar and some bipolar in nature. The strongest events in terms of mass loading exhibit the strongest electric fields and had a mono-polar structure, with positive charge aloft. Sow et al. (2011) conducted electrical field measurements of the soil and dust during the monsoon period in Niger and found that after the passage of a dust storm, the small particles are charged positively, while larger ones are negative. Their explanation for the apparent contradiction with earlier results is explained by the very fine negatively charged fraction which is missed by their instruments. Balloon-borne observations conducted in Cape Verde by Nicoll et al. (2011) of the Saharan Dust Layer (SAL) showed that dust plumes carried westward from the Sahara desert are electrified. They reported maximum charge densities of ~5–25 pC m^{-3}, in distinct dust layers between 2 and 4 km. These values are 3 orders of magnitude lower than those reported by Kamra (1972), as can be expected due to the large distance from the source region, where the dust was lofted and initial electrification took place. Seemingly the observed charge is due to charging that occurred during dust advection, either internally through particle interaction or by diffusion of atmospheric ions (Hoppel and Frick, 1986; Yair and Levin, 1989). The charging of aerosol particles has implications for electromagnetic radiation that interacts with the suspended dust. For example, Ulanowski et al. (2007) showed that the observed vertical alignment of Saharan dust particles was likely to be due to the presence of a 2 kV m^{-1} electric field within the dust. Such alignment has implication for the radiative balance of the atmosphere because of the "Venetian Blind" effect. Charge carried by dust particles also affects the interpretation of the brightness temperature for remote-sensing applications by as much as 10 K, leading to an overestimation of dust particle concentrations (Zheng, 2013).

Smaller-scale dust events known as "dust devils" also exhibit strong electrification, although they persist for several minutes and are limited in their vertical and horizontal dimensions. Frier (1960) reported negative values of the electric field peaking around 450 V m^{-1} during the close passage (30 m from the sensor) of large dust devil with an 8 m diameter, extending to ~200 m. This reversal of the sign was interpreted as a bipolar structure of the dust devil, with positive charge below the negative. Crozier (1970) conducted a study of 17 dust devils in New-Mexico, and was able to estimate the charge density of 8, obtaining values of 10^6 elementary charges per cm^3. Similar measurements of dust devils were reported by Farrell et al. (2004) and Renno et al. (2004) who conducted multi-instrument observations in the framework of the MATADOR campaigns in the US. In a case when 6 small rotating dust evils passed near the field mill, a negative electric field ~10 kV m^{-1} was measured for 9 s, an indication of strong electrification of the dust aloft.

The mechanism by which charge is generated and maintained within dust storms has been the subject of many laboratory studies of granular materials and sand particles, particularly with intent to find analogues to charging on the surface of Mars, which has obvious operational implications for future space missions, but also because of the industrial implications (Zheng, 2013). Latham (1964) suggested that the electrification of snowstorms (e.g. by the thermoelectric effect in ice; Yair, 2008) will be parallel to the electrification of sandstorms, and hence smaller and colder particles will carry an excess of negative charge, while larger, warmer ones will be positive. However it seems unlikely that the temperature gradient and differential ionic mobility within the dust will be effective in the short contact time of colliding dust particles. Triboelectric charging takes place during saltation, when wind-driven particles are lifted and impinge on solid surfaces as they move horizontally while ejecting additional particles. Zheng (2013) reviews 7 possible mechanisms that are responsible for the electrification of sand and dust particles (see Table 2 there), among which are fracto-electrification, piezoelectrification, contact electrification and polarization by the fair-weather electric field. Laboratory studies (Sickafoose et al., 2001; Zheng et al. (2003); Shinbrot et al., 2006; Rasmussen et al., 2009; Pähtz et al., 2010; Xie et al., 2016) and numerical simulations (Zheng et al., 2003, 2004; Kok and Renno, 2008) made considerable progress in giving microscopic descriptions of the charging process. Lacks and Levandovsky (2007) used a numerical model to evaluate the effect of particle size distribution on charging and found that smaller particles tend to carry negative charge and larger ones positive charge, in agreement with observations in nature. Additional numerical modeling of the microphysical aspects of triboelectric charge generation in sand was conducted by Zheng et al. (2006) and Hu et al. (2012). We refer the interested reader to recent reviews by Merrison (2012) and Zheng (2013).

This paper describes a massive dust storm that engulfed the eastern Mediterranean on February 10–11th, 2015 (Fig. 1). We report electrical measurements conducted during the storm and show that the lifted dust was positively charged, leading to strong surface fields reaching ~8 kV m^{-1}. Section 2 describes the methodology and data sources,

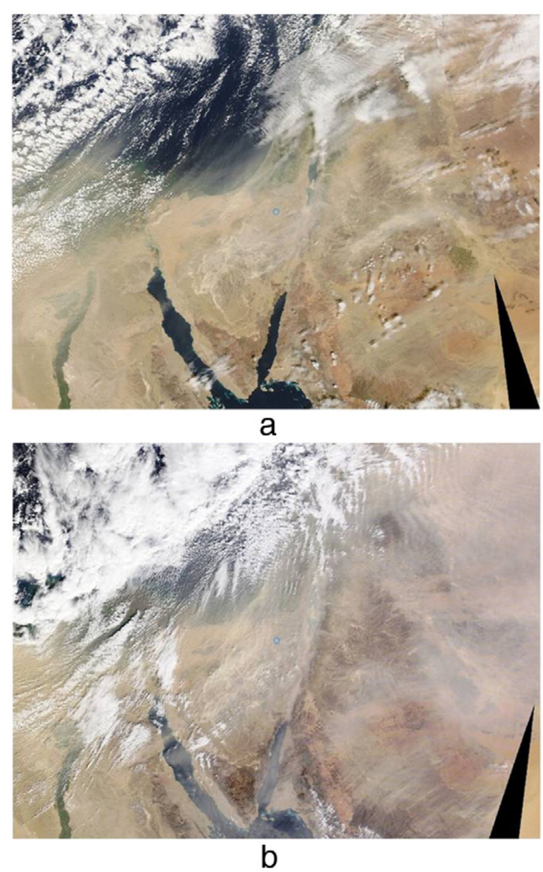

Fig. 1. Visible-light satellite images obtained from NASA Terra (MODIS) showing the advancement of the dust from Egypt and the Sinai Peninsula. (Top) February 10th, 11:30 UT (Bottom) February 11th, 11:30 UT.