Vertical profiling of the electrical properties of charged desert dust during the pre-ASKOS campaign

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Abstract Numerous studies of the electrical properties in dusty environments, related to lofted particle charging, indicate that it is a rather complex mechanism which greatly affects the particle dynamics. The electrification of desert dust particles can differentiate their settling velocities and, therefore, can affect the removal of large particles from the atmospheric circulation. A systematic effort to orderly measure the electrical properties of elevated dust layers, with the subsequent monitoring of the respective parameters on a ground reference level, will be made in the major AEOLUS Cal/Val campaign of ASKOS in Cape Verde, in June/July 2021. The preparatory phase of the campaign was carried out in Cyprus, in November 2019, where the initial prototypes of disposable atmospheric electricity sensors were tested on-field. We report here, measurements of the vertical atmospheric electric field and atmospheric ion density through the launches of balloon-borne instrumentation under dust event conditions. We observed perturbations of the E-field within the dust layers which could be attributed to the stratification of charges within the layer, regardless of the layer structure, due to either gravitational settling or possible updraft mechanisms. To verify our findings, we plan to launch the complete instrumental suite in Cape Verde over Saharan dust elevated layers.

1 Introduction

The Global Electric Circuit (GEC) electrically links the surface to the Mesosphere/Ionosphere (Williams 2009) through the conductive atmosphere. Atmospheric electric parameters, such as the vertical Electric Field strength (E_z), greatly depend on ambient weather conditions and convective meteorological systems (Kourtidis et al. 2020) due to the re-distribution of charged or uncharged aerosols and terrestrial radioactive particles in the Earth's atmosphere (e.g. Harrison and Ingram 2005). Amongst aerosols that greatly affect the atmospheric electrical content (Whitby and Liu 1966), mineral dust represents one of the most significant contributors due to its mineralogical composition that results in different electrical properties of the dust particles (Kamra 1972). Atmospheric ions within this conducting medium, resulting from ionization by galactic cosmic rays, attach to dust particles through the processes of ionic diffusion and electrical attraction (Gunn 1954, Klett, 1971), leading to their subsequent charging (e.g. Zhou and Tinsley 2007). Particle collisions consist also a domineering dust charging mechanism, known as triboelectrification (Eden and Vonnegut 1973, Kamra, 1972). These mechanisms enhance the large scale electric field within the dust layer.

While ground-based electric field measurements can be indicative of the electrical behaviour of elevated dust layers (Daskalopoulou et al. 2021), systematic profiling of their electrical properties is needed in order to quantify their impact in particle dynamics, such as particle settling velocity, particle orientation (Mallios et al. 2021, Ulanowski et al. 2007) and, ultimately, gravitational sedimentation. Previous balloon-borne observations of charged dust particles within lofted layers in Cape Verde, indicated space charge densities of up to 25 pC m^{-3} cumulated in layer top and bottom boundaries (Nicoll et al. 2011). In the specific study, we report on the first extensive measurements period that targeted on charged dust profiling with complementary sensors and attempt to interrelate the measured physical quantities.

2 Data and Methodology

An extensive preparatory measurements period was organized in Cyprus during November 2019, in the framework of the ASKOS 2021 (https://askos.space.noa.gr/) ESA Cal/Val activities, coordinated by the NOA-ReACT team. The campaign aimed, also, at monitoring the electrical properties of lofted dust layers along with meteorological conditions over the wider residential area of Nicosia (Aglantzia-CyI, 35°08'30.8"N 33°22'51.8"E) and the rural site of Orounda (CyI-UAV Research Laboratory site, 35°05'41.3"N 33°04'53.8"E). Balloon launches were instrumented from both locations during early morning and mid-noon hours (Table 1) under varying dust load conditions.

2.1 Data

Measurements of the vertical electric field strength and atmospheric ion (single polarity) density along the altitude were performed with the initial prototypes of tethered low-cost, portable and disposable atmospheric electricity sensors. The first instrument, and most widely used, is a miniature field mill electrometer, similar to the instrumentation discussed by Harrison and Marlton (Harrison and Marlton 2020). During the soundings, the mill was mounted, with the rotating vane flat-ground, on a DFM-09 Graw radiosonde providing pressure, temperature, wind speed/wind direction measurements while the mill data were interfaced to the embedded XDATA radiosonde protocol. Complementarily to the electric field measurements, atmospheric ion density was measured with the use of the commercially low cost KT-401 Air Ion Tester Counter, that logs the maximum value of either the positive or negative ion population at each recording. In order to have co-located measurements with the varying electric field, the ion counter was also mounted close to the mill during launch and the data were transmitted through a dedicated Lora long-range telemetry system.

Moreover, the aerosol optical depth (AOD) was monitored by co-located Cimel sunphotometers in Agia Marina Xyliatou and Nicosia, respectively, integrated in the Aerosol Robotic Network (AERONET, https://aeronet.gsfc.nasa.gov/, last access: 3 February 2021).

2.2 Methodology

For the specific study, we exploit the collected dataset from between November 12th to November 18th and, as a first step, compare the mill outputs with the fair weather electric field in order to qualitatively distinguish the field perturbations attributed to charged dust. Ideally, under strict fair weather conditions, complete lack of aerosol particles in the atmospheric circulation is expected, since it guarantees that the only mechanism of atmospheric ions loss is the ion-ion recombination. As the concentration of aerosols increases, additional loss can be due to ions attaching to the particles, which leads to a perturbation of the ion density from fair weather values. In the steady state of a fair weather electrified atmosphere, the total current (conduction current) equals to zero, hence the vertical electric field strength is given by:

$$E_{z,FW} = \frac{J_z}{\sigma} = -\frac{\Delta V}{\sigma R_c} \tag{1}$$

where $\sigma = \sigma_0\, exp\left(\frac{z}{l}\right)$ the atmospheric conductivity at height z (km), σ_0 and l = 6 km represent the near ground atmospheric conductivity and the atmospheric scale height, respectively (Kalinin et al. 2014; Stolzenburg and Marshall 2008) and $\Delta V = V_{ion} - V_0$ the potential difference ($V_{ion} = 250\ kV$ and $V_0 = 0$). Therefore, the columnar resistance, R_c, can be expressed as (Rycroft et al. 2008):

$$R_c = \int_0^H \frac{dz}{\sigma} = \frac{l}{\sigma_0}\left(1 - \exp\left(-\frac{H}{l}\right)\right) \tag{2}$$

for H = 70 km the ionospheric height. From Eqs. (1) and (2), the distribution of the electric field is:

$$E_{z,FW} = -\frac{V_{ion}}{l\exp\left(\frac{z}{l}\right)\left(1-\exp\left(-\frac{H}{l}\right)\right)} \tag{3}$$

3 Results

We present the profiles of the electric field strength (V m^{-1}) measured with the miniature field mills during the dust cases over Cyprus from the two locations of Orounda and Aglantzia (Fig. 1) and the atmospheric ionic content (ions cm^{-3}) as measured by our custom ion counters (Table 1). All data represented here are from the radiosonde ascending course as cross-communication over the occupied territories in forbidden and telemetry was manually terminated in some cases.

Areas of increased electric field become apparent above the planetary boundary layer,1 where dust downward mixing occurs. The increases coincide with the presence of elevated dust layers at the specific altitudes, as inferred from the daily average AOD values, but for a better characterization of the optical properties of the particles aloft other retrievals of aerosol profiling are needed (e.g., lidar time-height profiles). Furthermore, smooth ion density profiles, such as the one over the 12th of November (blue/dark gray markers) exhibit stratifications at altitudes similar to the mills, indicating areas of dust particle accumulation within the layers (Fig. 1 top and bottom panels). That could potentially explain the loss of ions due to them being attached to the particles, but field values are fairly larger than what is expected through modeling of these attachment rates. This relation between the measured electric field strength and ion attachment rates will be further examined in future research.

During the launches, wind perturbations and differential positioning of the radiosonde might result in the overestimation of the recorded electric field, discussed above, due to the mill vanes being exposed to the x-y components of the field or due to the scavenging of charged particles to the sensing electrode by side drifts. To provide a first estimation of the similarities between the trends of the electric field and the co-located meteorological parameters, we perform a wavelet correlation analysis on wind speed interpolated DFM-09 data to the measured mill altitudes (Fig. 2).

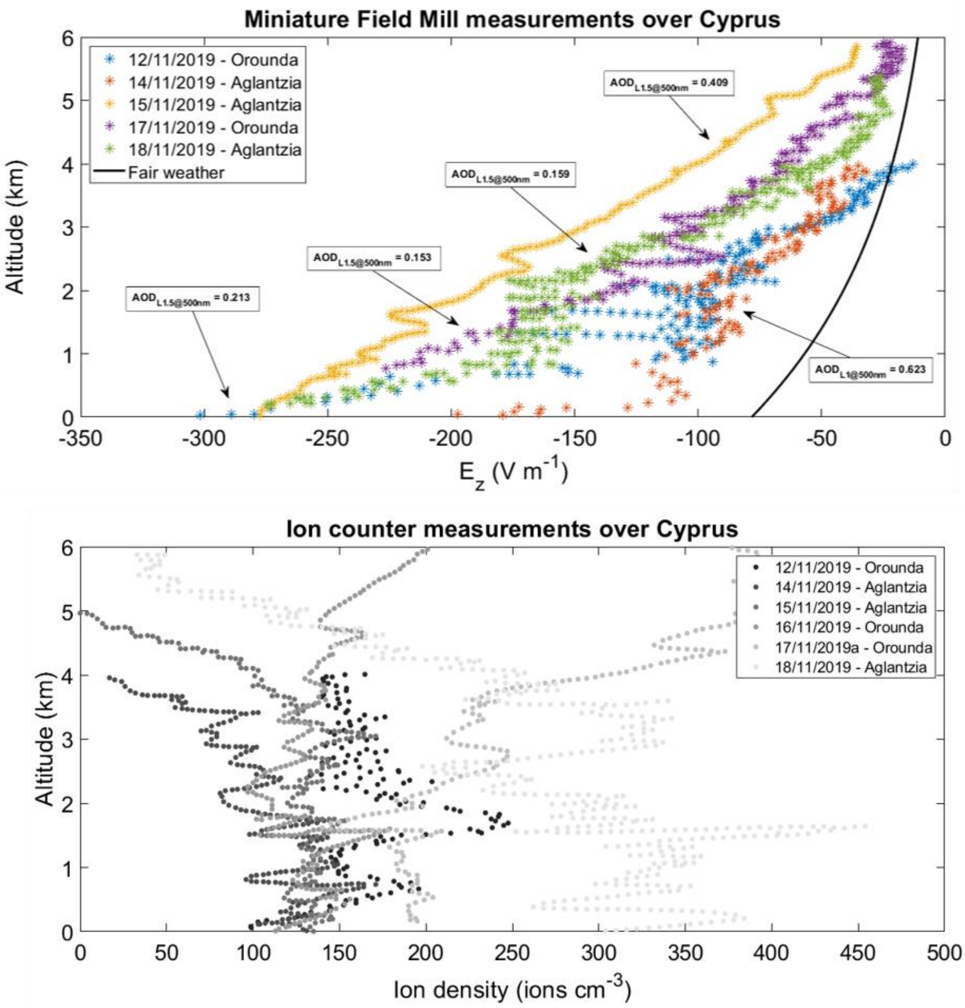

Fig. 1. Top panel: Vertical distribution of the electric field strength measured by the miniature field mill electrometers on board the balloons, the minus sign indicates that the field points downwards. AOD products are of L1.5 or L1 at 500 nm, when the latter was not available for the specific day. Bottom panel: vertical distribution of the ion density measured by the custom ion counter.

For the purposes of identification of the possible correlation between measured electric filed and wind speed, a Multiscale correlation using the maximal overlap discrete wavelet transform was performed (Percival and Walden 2000, Whitcher et al. 2000, Benjamini and Yekutieli 2001). Results indicate the existence of anticorrelation in medium scales which can be explained since the increase of wind speed (which is expected to produce mill's deviation from the vertical position) produces a decreased detection of the vertical component but not rapidly (this is why the anticorrelation is not present in lower scales which correspond to lower periods).

4 Conclusions

We present the preliminary profiling results of the electrical properties of Saharan dust layers in the framework of the pre-ASKOS Cal/Val activities and the D-TECT ERC project. A suite of low-cost and disposable atmospheric electricity sensors was tested and tethered to meteorological balloons over

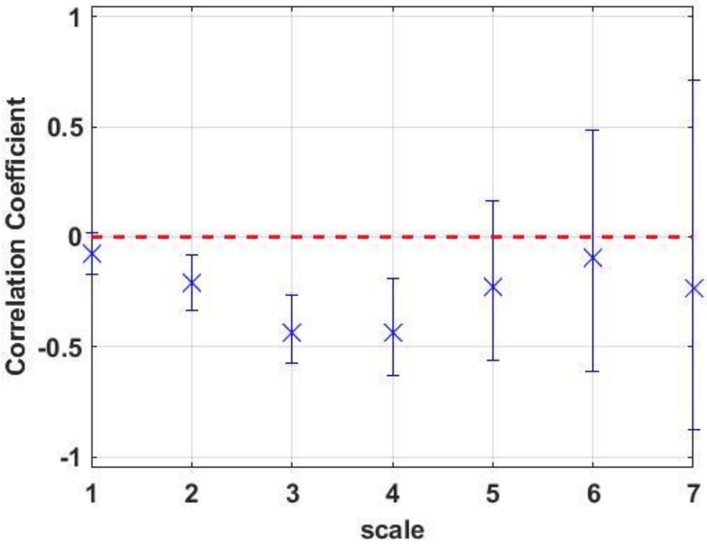

Fig. 2. Multiscale correlation using the maximal overlap discrete wavelet transform between the measured electric field strength and co-located wind speed values.

dust episodes in Cyprus. The profiling information reveals the presence of charged dust particles within the elevated plumes with accumulation of charges on layer boundaries, as expected. Mill measurements appear to be smooth with perturbations over the transition of the mill within the layer, but significantly deviated due to possible anticorrelation with wind speed. Further analysis with a wavelet correlation technique reveals the potential similarities between these physical parameters. Future work will include the implementation of an upgraded ion mobility sensor and the testing of the miniature field mill under diverse conditions for the integration in the ASKOS.

Table 1. Launches calendar during pre-ASKOS.

Observational Day	Launch (UTC)	Instruments[1]	Measured quantities
12/11/2019	12:38:28-13:30:56	Mill, IC	E-field (Vm^{-1}), ion density (cm^{-3})
14/11/2019	12:51:23-13:54:50	Mill, IC	E-field (Vm^{-1}), ion density (cm^{-3})
15/11/2019	11:07:51-12:41:23	Mill, IC	E-field (Vm^{-1}), ion density (cm^{-3})
16/11/2019	13:00:33-14:06:30	IC	ion density (cm^{-3})
17/11/2019a	08:05:46-08:49:33	IC	ion density (cm^{-3})
17/11/2019b	10:29:26-11:36:19	Mill, IC	E-field (Vm^{-1}), ion density (cm^{-3})
18/11/2019	11:08:44-12:37:42	Mill, IC	E-field (Vm^{-1}), ion density (cm^{-3})

[1] IC: ion counter

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