

Novel Measurements of Desert Dust Electrical Properties: A Multi-Instrument Approach during the ASKOS 2022 Campaign [†]

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Abstract: Synergetic measurements of the vertical atmospheric field and the total charge density in the presence of dust events are presented through the launches of balloon-borne instrumentation, including a MiniMill electrometer and a space charge sensor, under dust events during the AEOLUS Cal/Val campaign of ASKOS in Cabo Verde, in June/September 2022. The electric field profiling measurements obtained by different instrumentations are compared, and the near-ground observations are evaluated with a reference ground-based fieldmill electrometer. Moreover, their performance is assessed by utilizing measurements of the co-located Polly XT lidar and its extracted products above the launching site.

Keywords: dust particle electrification; atmospheric electric field; atmospheric



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1. Introduction

Dust Particle Size Distribution (PSD) changes rapidly after emission due to the gravitational settling of the larger particles. Observations of dust PSD gathered from experimental campaigns have revealed a longer lifetime of coarse particles than that estimated by dust transport models [1]. Four potential different mechanisms could facilitate the long-range transport of large/giant particles [2]. Among them are electrical forces that could reduce the settling velocity of the coarse mode by 80% in order for observations to match with transport models outputs [3].

The research field of Atmospheric Electricity can provide insights into electrical properties and their contribution to the transport of dust plumes. Atmospheric ions, which are primarily created by ionization by galactic cosmic rays [4], attach to atmospheric particles through the processes of ionic diffusion, Coulomb interaction and polarization due to the presence of the external electric field (see [5] and references therein), leading to their subsequent charging [6,7]. Moreover, dust particles can also be charged during collisions, a process known as triboelectric process (see [8] and references therein). When charged, dust particles experience, in turn, electrical forces in the presence of the atmospheric electric field that can influence their dynamics.

Recent theoretical models on the orientation of dust particles [9] conclude that an electric field strength of at least two orders of magnitude larger than the ambient fair-weather value is required for the electrical force to alter the particles' orientation. Additionally, models on the dust particles' electrification mechanisms [5,8], under the assumption of standard

atmosphere, show that for lofted and transported layers the ion attachment mechanism is the main contributor to the particle charging; however, the resultant force is several orders of magnitude smaller than gravity. From all the above, and since the vertical electric field strength greatly depends on ambient weather conditions and meteorological convective systems [10], the consistent profiling measurements of the electrical properties of dust layers in real conditions are of great importance.

Motivated by the current status of dust particle electrification and charging studies, we present synergetic measurements of the vertical atmospheric field and the total charge density in the presence of dust events through the launches of balloon-borne instrumentation, including a MiniMill electrometer and a space charge sensor, under dust events during the AEOLUS Cal/Val campaign of ASKOS in Cabo Verde, in June/September 2022. We compare the electric field profiling measurements obtained by different instrumentation for a specific case study, and the near ground observations are evaluated with a reference ground-based fieldmill electrometer. Moreover, the sensor performance is assessed by utilizing measurements of the co-located Polly XT lidar, for the characterization of the vertical distribution of aerosol optical properties above the launching site.

2. Data and Methodology

The dust layer electrical properties measurements were obtained during the ASKOS experimental campaign of ESA, which took place at the Sao Vicente island of Cabo Verde (lat: 16.8776, lon: -24.9953). The campaign was held during the period of June/September 2022, when dust transport above the area exhibits its yearly maximum. ASKOS aimed at providing ground-based remote sensing and surface/airborne in situ observations of aerosol, clouds, water vapor and wind, which in turn can be used for the calibration and validation of the Aeolus satellite products. The case study presented here is the result of a balloon launch that occurred in 23 June 2022 at 18:00 UTC.

2.1. Data

For the characterization of the plumes' electrical content, a total of 28 electro-sonde launches were conducted with two electricity sensors on board each balloon, under various atmospheric conditions and dust loads. Each sensor set included a prototype miniature fieldmill electrometer (MiniMill) and a space charge sensor, based on previous works (see [11,12], respectively), that were designed and assembled at NOA for the campaign purposes.

MiniMill measures the raw atmospheric electric field strength, which is sensed at the mill head through alternating capacitor vanes and is translated to a direct output of the Analog-to-Digital (ADC) converter counts. On the other hand, the space charge sensor provides the total space charge density (directly) through the induction of the electric field on a protruding spherical electrode and the electric field strength (indirectly).

The sensors were secured tightly together (with the MiniMill pointing downwards) to minimize relative movement and perturbations due to the balloon trajectory. An embedded three-axis accelerometer was also used for information on the instrument rotation during the flight. Data were transmitted through an XDATA protocol chaining to the DFM-09 GRAW meteorological radiosondes, which provided a co-location with the P, T, U wind speed/direction basic parameters in 1 Hz transmission frequency.

Finally, a ground-based fieldmill electrometer (a commercial JCI 131 FM) was installed on the rooftop of the Ocean Science Center Mindelo (OSCM), which was the basic operations station, in order to minimize human and electrical interference with the instrument. The fieldmill was operational during the aforementioned period 24/7, provided the near-ground electric field vertical component strength at instrument height, and was also used as a reference instrument for the electro-sonde electric field outputs.

2.2. Methodology

In this subsection, the post-processing procedure of the measurements is described for the derivation of the final values of the electric field vertical profiles.

2.2.1. MiniMill

The electric field measurements from the MiniMill were found to be sensitive to its rotation with respect to the vertical axis (the roll and pitch angles). Therefore, a correction is necessary in terms of the following expression:

$$E_z^{cor} = E_z^{meas} \cos \theta_{roll} \cos \theta_{pitch}, \quad (1)$$

where E_z^{cor} is the corrected value of the vertical electric field component, E_z^{meas} is the measured value, θ_{roll} is the roll angle and θ_{pitch} is the pitch angle. Moreover, values of the electric field strength that corresponded to angular difference larger than π radians between two consecutive measurements of the roll and pitch angles were neglected, because for these values the mill plates would point upwards instead of downwards.

2.2.2. Charge Sensor

The measurements from the charge sensor were less sensitive to its rotation, due to its symmetric spherical electrode. Under the assumption that the electric field is mainly vertical everywhere except on the boundaries of the charge layer (since its horizontal extend is much larger than its vertical depth), the electric field can be calculated from the measured total charge density using the following expressions:

$$\frac{d^2V}{dz^2} = -\frac{\rho_{tot}}{\epsilon_0}; E_z = -\frac{dV}{dz}, \quad (2)$$

where V is the electrical potential, ρ_{tot} is the total charge density and ϵ_0 is the vacuum permittivity. Equation (2) is solved using a Successive-Over-Relaxation algorithm, with the value of the electrical potential being set equal to zero at the ground and equal to 250 kV at 40 km altitude (from the Global Electric Circuit considerations).

Another issue that has to be addressed is the self-calibration feature of the space charge sensor. Every 5 min the space charge sensor enters a self-calibration mode, which lasts approximately 20 s. Being at this mode, the sensor measurements are discarded, which results in the appearance of measurement gaps and therefore discontinuities in the space charge vertical profile that influence the derived potential and electric field values.

The gap problem can be solved by taking advantage of the Poisson's equation linearity. The domain can be divided into sub domains, each one between the calibration states of the sensor. The values of the total charge density outside the range of the sub-domain were set equal to zero. The electric field distribution as calculated from the Poisson's equation at each sub domain, at the electro-sonde altitude range of 0–15 km, and the total vertical profile is the summation of the electric field values due to all the sub-domains.

As the balloon ascended, the atmospheric conditions (such as the temperature which falls to values below zero) deteriorated the battery life and the reliability of the measurements could become questionable. Therefore, not all sub-domains were taken into account for the calculation of the electric field vertical profile, only those whose total contribution led to electric field values at the ground closest to the values measured by the ground fieldmill or by the MiniMill (if for some reason the ground fieldmill measurements were not available during the electro-sonde launch period).

3. Results and Discussion

Figure 1a depicts the vertical profile of the corrected electric field vertical component derived from the MiniMill and the space charge sensor for the selected day. It is clear that both instruments were, in principle, in good agreement. Moreover, the electric field strength value had the same order of magnitude as the one that corresponded to the fair

weather conditions at about -100 V/m (the minus sign means that the electric field points downwards to the Earth's surface).

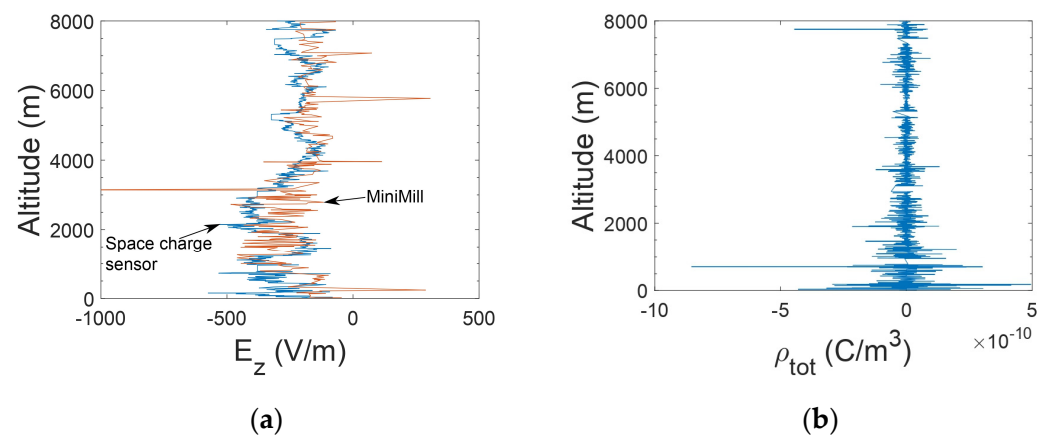


Figure 1. Vertical profiles of the electric field vertical component and the total charge density: (a) the corrected vertical profiles of the electric field vertical component measured by the MiniMill and the space charge sensor; (b) vertical profile of the total charge density measured by the space charge sensor.

Figure 1b shows the vertical profile of the total charge density. As shown, the charge density had its highest values at altitudes below 500 m, and as the altitude increased the value decreased.

Figure 2 illustrates an assessment of the performance of the MiniMill and the space charge sensor, while at the same time it provides insights into the behavior of their measured quantities. In Figure 2a, we obtained a time–height plot of the attenuation backscatter coefficient (top panel) and the depolarization ratio (bottom panel) from the Polly XT lidar, that were characteristic of dust presence in the area and could delineate the dust layer's structure. It is apparent that up to 1 km there were low altitude clouds resulting in large backscatter values, and then the dust layer gradually ascended to an altitude range between 2 and 4 km. It was expected for the electric field to increase inside the cloud and within the dust layer and to decrease in the intermediate regions [5,13]. On the other hand, an enhancement of the total charge density at the boundaries of both the cloud and the dust layer was anticipated, and a decrease in the intermediate regions [13].

At the top panel of Figure 2b, the smoothed vertical profile of the electric field vertical component as derived by the MiniMill and the space charge sensor is depicted. The smoothing was performed by a running average algorithm with a time window of 3 min for the elimination of fast temporal variations. According to the MiniMill, there was a gradual increase in the electric field strength, up to 1.5 km altitude, and then a gradual decrease. This does not coincide with the expected behavior. Contrarily, the results of the space charge sensor showed a gradual increase in the electric field up to 1 km (which is approximately the top of the cloud) and then a gradual decrease up to 1.5 km altitude (the intermediate region between the cloud and the dust layer). Then, there was a gradual increase in the altitude inside the dust layer up to 3 km altitude (which was approximately the center of the layer) and then a decrease as the altitude increased to values higher than 4 km (the top of the dust layer). The two peaks at 2 km altitude and 2.7 km altitude were most likely due to internal stratification of the layer. Therefore, it can be concluded that the profile obtained by the space charge sensor is in better agreement with the expected profile by the theory.

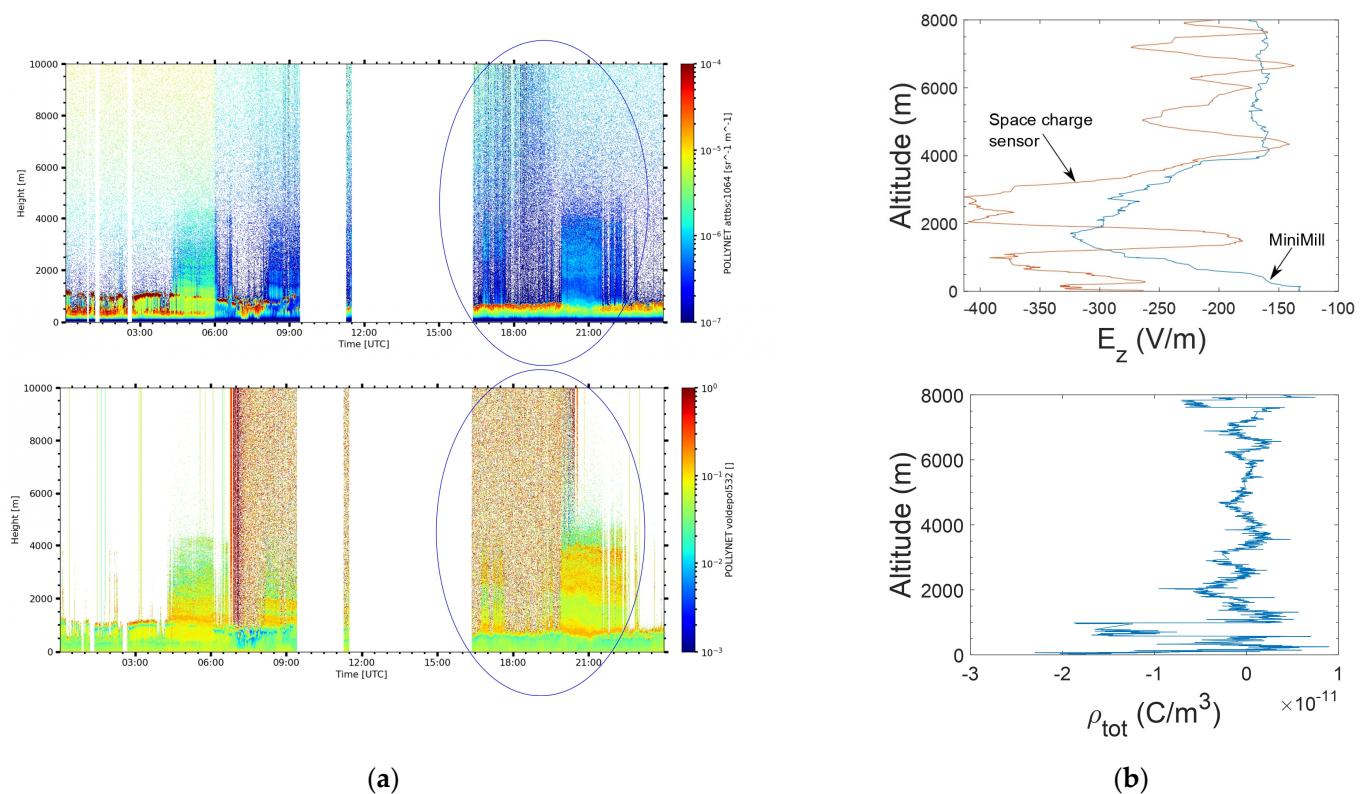


Figure 2. Assessment of the measurements with the Polly XT lidar products: (a) attenuated backscatter coefficient at 1064 nm (top panel) and volume depolarization ratio (bottom panel); (b) smoothed vertical profiles of the electric field vertical component (top panel) and smoothed vertical profile of the total charge density (bottom panel).

Similar conclusions can be derived from the vertical profile of the total charge density (bottom panel of Figure 2b). In this case, the extremum values of the charge density (maximum values of opposite polarity) indicate the boundaries of a particle layer (either a cloud or a dust layer). The presented profile shows a stratification inside the dust layer. One sub-layer can be identified in the range 1.5–3 km, and another sub-layer in the range 3–4.5 km. This is in agreement with the bottom panel of Figure 2a, where there is a layer between 2 and 3.5 km and a layer between 3.5 and 4 km.

4. Conclusions

Synergistic measurements of the vertical atmospheric field and the total charge density in the presence of dust events are presented through the launches of balloon-borne instrumentation, including a MiniMill electrometer and a space charge sensor, under dust events during the AEOLUS Cal/Val campaign of ASKOS in Cabo Verde, in June/September 2022. There was an agreement in the values of the electric field vertical component strength measured by the two different instruments, which in turn was of the same order of magnitude as the fair-weather electric field strength. However, the vertical profile obtained by the space charge sensor was more accurate than the one obtained by the MiniMill, as can be seen in conjunction with the lidar products. This difference can be attributed to the high sensitivity of the MiniMill to the meteorological conditions, which cause perturbations to its axis with respect to the vertical direction. Further work that will characterize the sensors' responses for various of the measured cases is intended.

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