RESPONSE TO REFEREE#2 COMMENTS AND PEER-REVIEW REPORT

Manuscript Title: **"The Electrical Activity of Saharan Dust as perceived from Surface Electric Field Observations in Greece"**

revised per **reviewer#1** comments as:

"The Electrical Activity of Saharan Dust as perceived from Surface Electric Field Observations"

Authors (as declared in the submitted manuscript with an addition of Ms. Ioanna Tsikoudi, justified contribution to the declaration of author contributions):

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Dear respected Editor/Reviewers,

The authors highly appreciate the comprehensive feedback throughout the review process and kindly integrate the reviewer comments in the revised preprint manuscript, as follows:

REFEREE#2 COMMENTS:

"The authors study four dust events in Greece, using a combination of ground-based electric field measurements and lidar.Â˘a The events involve dust that originated in the Sahara 48 to 72 hours previously.Â˘a Two of the events enhance the electric field relative to the reference fair weather field, and the other two events diminish the electric field.

This paper presents a simple model to describe these electrical effects.Â˘a There are two components of the model.Â˘a First, that the dust will reduce the conductivity in the region it occupies by scavenging ions; this effect occurs even with neutral dust particles. Â˘a Second, there could be regions of charged dust – this is modeled as cylinders of monopolar charge (there could be two cylinders, one of positive and one of negative charge). Some of the parameters for the model can be obtained from the lidar, while other parameters cannot be independently obtained.

Here is where I get lost.Â ˘a I found the results section very hard to follow.Â˘a It appears to me the authors show experimental results for dust event (Figs 4-7), and then present results of the model under various parameters (Figs 8-13)."

Author's Response: The authors are grateful to the respected reviewer for the constructive comments, up to this point concerning the readability of the manuscript. We agree that the results section appeared perplexed to the first read, therefore we have strongly revised the structure of this section by keeping the synergistic observations between the E-field and the dust layer optical properties, which are the paper's highlighted significance to our perspective, and have given to the physical reasoning behind our findings, through the 1D model outputs, a separate section (section 3). We believe that according to the referee's guidelines this further fortifies the paper and clarifies the distinction the authors attempt to do for lofted electrified dust.
All the structural changes are listed under the respective comment sections in detail.

Line 258 updated to **Line 288:** Section 3 from "Results" becomes "Model outputs", where we keep only the model results for the different cylinder configurations.

Section 3 is now subdivided to the following paragraphs:

- **Lines 289 – 295:** introductory paragraph, "As a result of the mathematical formalism…distances."

- **Lines 323 – 333 & 346 – 352** become **Lines 296 – 311:** section **3.1 E-field below Fair weather field**, "In this section, we describe the possible cases under which lofted dust layers...lidar PLDR profiles (Table 1)."
- **Lines 353 – 390** modified to **Lines 312 – 346:** section **3.1.1 Balanced/Imbalanced dipole field below Fair weather**, "We consider the case of two oppositely charged cylinders …below the fair weather value"
- **Lines 391 – 393** become **Lines 347 – 349:** section **3.2 E-field above Fair weather field**, "We examine…the LREF."
- **Lines 394 – 412** modified to **Lines 350 – 360: s**ection **3.2.1 Balanced/Imbalanced dipole field above Fair weather field**, "For the same…location (below point A)."

Section 4 named "Experimental Results" and is subdivided to:
- **Lines 259 – 261** modified to **Lines 343 – 366:** introductory paragraphs to the section, "The near ground electric… supported by the model configuration described in the previous sections."
- **Lines 262 – 270** modified to **Lines 370 – 388:** section **4.1 Dust Layer characterization through lidar**, "The July 2017 and… very low concentrations of dust particles are also present within the MABL."
- **Lines 271 – 279** modified to **Lines 389 - 399:** section **4.2 Local mean E-field behaviour**, "Considering the electrical properties… the expected fair weather value."
- **Lines 283 – 295** become **Lines 400 – 414: s**ection **4.3 Observed E-field enhancement as compared to LREF**, "In Fig. 6 and Fig. 7… for even smaller charge separation distances."
- **Lines 296 – 312** become **Lines 415 – 431:** section **4.4 Observed E-field reduction as compared to LREF**, "Several dust load cases…of the dust layer aloft."
- **Lines 444 – 450** become **Lines 432 - 438:** section **4.5 Reversed E-field polarity**, "If a reversed polarity…to be electrified."

Section 5 becomes the "Discussion" section and is subdivided to:
- **Lines 413 – 443** section 3.4.3 becomes **Lines 440 – 467** section **5.1 "E-field dependence on the bottom charged are height"**, kept as was in previous manuscript only section numbering changes.
- **Lines 452 – 463** become **Lines 471 – 482** section **5.2 Chauvenet criterion validity**, and is kept the same as in the previous manuscript, only section numbering changes.
- **Lines 464 – 477** become **Lines 483 – 496 s**ection **5.3 Generalization of the cylindrical model and the LREF methodology** and is kept the same as in the previous manuscript, only section numbering changes.

Lines 497 – 518: **Section 6** as "Summary and Conclusions", no changes only different numbering

"I do not think there is much interest in the results of the simple model under various parameters.Â˘a I think these figures and the associated text should be removed. Rather, I think they should focus (succinctly) on using the model to rationalize the experimental results.Â˘a This must be done much better in order for the paper to be publishable."

Author's Response: In this study, we also focus on the solution of the problem of charged cylindrical areas placed within a conducting medium, in order to simulate the charge structure within elevated dust layers and deduce the E-field behavior near the sensor. Since there is a lack of vertical mapping of these structures and only a recent study by Zhang and Zhou, 2020, attempted to construct a map of the electrical structure of dust storms through surface observations, we have selected this formalism to better represent our experimental findings and used it as a proof of concept for our conclusions. The model is indeed a simplistic approach to the structure of charged areas and is based on previously used geometries on cloud electrification, but never before on dust layers. Its purpose is to give physical insights regarding the parameters that influence the electrical properties of dust layers, rather than reproducing the measurements.
Therefore, we believe that it is imperative to maintain the model outputs that are used to rationalize the E-field behavior (previously Figures 9 to 12), but to comply with the referee's kind comments and to diminish the size of relevant information within the main text, we have condensed the information of Fig. 9 – 10 to a single figure, now Fig. 4 (a & b) and that concerning the reduction of the E-field below the fair weather values contained in Fig. 11 – 12, to Fig. 5 (a & b) in section 3/Model outputs. Moreover, the authors consider the sensitivity study of the ground E-field to the basic parameters given in Eq. 11 (previously section 3.3.1 Dust layer acting as a passive element, Fig. 8) to be redundant for the main text, but an important addition as to why the conductivity reduction factor plays a significant

role in the E-field effects and the selection of n based on experimental data. As a result, the respective section is removed from the text and added to Appendix A.

More analytically the changes are:

Lines 319 – 322: "Following this formulation…separation distances" updated to **Lines 291 – 295**, section Model outputs.
Lines 355 – 345: added to **Appendix A** updated to **Lines 520 – 353**, as "Dust layer acting as a passive element"

Lines 280 – 282: "According to the effect…to the local field." updated to **Lines 364 – 3367** and added the phrase "Through these observations we attempt to provide evidence of electrically active dust only by ground-based methods."
updated Lines 426 – 430: added the following paragraph "Following the 1D model outputs for such a case (see Section 3.1.1), this observed reduction could be attributed to either electrically neutral dust aloft or to electrically active dust with the charged regions in relatively small separation distances within the layer. Under the electrically active dust case, a charge imbalance of less than 10%, can be adequate to interpret the observed reduction of the E-field below the LREF for even smaller separation distances. But the detection of such an E-field reduction below the LREF cannot conclusively characterize the electrical activity of the dust layer aloft."

updated Lines 458 – 459: added the phrase "As such, observations of enhanced E-field above the fair weather values, for dust driven days, can be reproduced only when an electrically active dust layer is transported above the fieldmill."

Reference:

Zhang, H. and Zhou, Y. H.: Reconstructing the electrical structure of dust storms from locally observed electric field data, Nat. Commun., 11(1), doi:10.1038/s41467-020-18759-0, 2020.

"Also, it is important to justify the assumptions in the model (this is much more important than the mathematical details, which they cover in great depth). – give physical reason why eqn 4 has this form – why do uncharged aerosol particles scavenge ions?Â˘a This is a key assumption for their model, as it leads to the reduction factor n, but its not clear to me that this is physically correct. The authors must provide strong evidence to support this."

Author's Response: Thank you again for the comments. We added the following sentences in **Line 209**, that explain the choice of conductivity distribution with form as in Eq. 4: "The given mathematical formalism of the atmospheric conductivity is adopted by Ilin et al, 2020. The authors demonstrated that such a profile adequately describes the main aspects of the real conductivity distribution, and can be seen as a global mean conductivity profile."

Reference (*not previously included in the manuscript*):

Ilin N.V., Slyunyaev N.N., and Mareev E.A., Towards a realistic representation of global electric circuit generators in models of atmospheric dynamics, J. Geophys. Res. Atmospheres, 125, doi:10.1029/2019JD032130, 2020.

Regarding Eq. 8., we rephrased **Lines 217 – 223** (updated to **Lines 243 – 251**) as follows:

"However, the presence of aerosols in the atmosphere and consequently dust particles, affects atmospheric conductivity (Siingh et al., 2007; Tinsley and Zhou, 2006; Zhou and Tinsley, 2007). Aerosols tend to scavenge atmospheric ions due to electrostatic interactions and ion thermal diffusion, leading to a reduction of the atmospheric ion density, and consequently of the atmospheric electrical conductivity. The process of ion attachment to aerosols has been exhaustively investigated in the past literature. A review paper by Long and Yao, 2010 contains a summary of all models and theories regarding the aerosol charging by ions. The case of a steady state atmospheric desert dust layer that does not exhibit charge stratification is examined below. The layer acts as a passive electrical element (resistor), and reduces the fair weather atmospheric conductivity due to the ion attachment to dust particles, by a reduction varying factor *n*. Fig. 3b, represents the above layer configuration, where the new conductivity profile within the layer will be:”

Reference (*not previously included in the manuscript*):

Long Z, and Yao Q, Evaluation of various particle charging models for simulating particle dynamics in electrostatic precipitators, J. Aerosol Sci., 41, doi:10.1016/j.jaerosci.2010.04.005, 2010.

“And overall, I think the paper needs to be communicated much more clearly, and walk the reader through the results and the logic behind their ideas.Â˘a Figure captions should clarify what the data represents (cannot assume someone knows this).Â ˘a As I said above, I got lost and couldn’t understand things.”

Author’s Response: We would like to think that the present format of the paper is much more reader friendly and easy to follow from the wide scientific community of ACP.

Fig. 4 (previously Fig. 9 & 10) caption updated to: “Vertical electric field strength at ground level, $\boldsymbol{E_{z_0,dipole}}$, below the fair weather field, for a dipole of: (a) finite uniformly charged cylinders and (b) non uniformly charged cylinders exhibiting charge imbalance, within an elevated dust layer as a function of the cylinder radius $\boldsymbol{R}$. $\boldsymbol{E_{z_0,dipole}}$ is calculated for separation distances of 0 (electrically neutral dust), 100, 200, 400 and 800 m (balanced dipole case only) between the charged layers. As the separation distance increases, the E-field increases due to the stronger influence of the lower cylinder to the surface resistance as it moves towards the ground. In (b), the dipole exhibits charge imbalance as a relative charge density difference of 8%, with the upper negative cylinder having smaller charge density. As the charged layers move apart the E-field increases more rapidly than in (a) for the same separation distances, since the influence of the upper cylinder is dominant. The enhancement effect in both cases is not significant enough to overcome the fair weather values.”

Fig. 5 (previously Fig. 11 & 12) caption updated to: “Vertical electric field strength at ground level, $\boldsymbol{E_{z_0,dipole}}$, for a dipole of: (a) finite uniformly charged cylinders and (b) non uniformly charged cylinders exhibiting charge imbalance, within an elevated dust layer as a function of the cylinder radius $\boldsymbol{R}$. $\boldsymbol{E_{z_0,dipole}}$ is calculated for separation distances over 1 km between the two charged layers. The influence of the lower cylinder to the ground E-field becomes more prominent as the separation distance increases. In (b), the dipole exhibits charge imbalance as a relative charge density difference of 8%, with the upper negative cylinder having smaller charge density. As the charged layers move apart the E-field increases more rapidly than in (a) for the same separation distances, since the influence of the upper cylinder is dominant. For these separation distances, the enhancement effect in both cases is significant enough to overcome the fair weather values.”

Fig. 6 (previously Fig. 4) caption updated to: “Top panel: Timeseries of the vertical electric field strength (orange), the Localized Reference Electric Field (red) and the reconstructed mean electric field variation (black) plotted with the time-height evolution of the attenuated backscatter coefficient (1/Mm sr) and the Particle Backscatter coefficient (β) profile (1/Mm sr, black vertical line) averaged between 18:00 and 21:00 (UTC), for the 25/07/2017 dust layer in Finokalia station. Areas of increased particle concentration are denoted with reddish tones, while the β values are between 3 to 4 (1/Mm sr). The mean E-field appears enhanced and is above the reference field. Bottom panel: Volume Linear Depolarization Ratio (δ_v, %) for the same dust layer as obtained from the Polly^{XT} lidar and the Particle Linear Depolarization Ratio (δ_p, %) profile (black vertical line). High δ_v values (>17%) are indicative of dust particle presence and δ_p values between 25% - 30% in the afternoon are characteristic of pure dust.”

Fig. 7 (previously Fig. 5) caption updated to: “Top panel: Timeseries of the vertical electric field strength (orange), the Localized Reference Electric Field (red) and the reconstructed mean electric field variation (black) plotted with the time-height plots of the attenuated backscatter coefficient (1/Mm sr) and the particle backscatter coefficient (β) profile (1/Mm sr, black vertical line) averaged between 18:00 and 21:00 (UTC), for the 20/10/2018 dust layer in Antikythera station. Areas of increased particle concentration are denoted with red tones, while the beta values reach up to 5 1/Mm sr. The mean E-field appears enhanced and is consistently above the reference field showing an increase at ~21:00 (UTC), when dust deposition becomes prominent. Bottom panel: Volume Linear Depolarization Ratio (δ_v, %) for the same dust layer as obtained from the Polly^{XT} lidar and the Particle Linear Depolarization Ratio (δ_p, %) profile (black vertical line). High δ_v values (>20%) are indicative of dust particle presence and δ_p values between 25% - 30% in the afternoon are characteristic of pure dust."

Fig. 8 (previously Fig. 6) caption updated to: "Top panel: Timeseries of the vertical electric field strength (orange), the Localized Reference Electric Field (red) and the reconstructed mean electric field variation (black) plotted with the time-height evolution of the attenuated backscatter coefficient (1/Mm sr) and the particle backscatter coefficient (β) profile (1/Mm sr, black vertical line) averaged between 18:00 and 21:00 (UTC), for the 16/03/2018 dust layer in Finokalia station. Areas of increased particle concentration are denoted with red tones, while the β values reach up to 15 (1/Mm sr). The mean E-field remains positive but well below the reference field, exhibiting an increase as particle injection initiates at ~11:00 (UTC) and then a decrease along the plume's progression. Bottom panel: Volume Linear Depolarization Ratio (VLDR, %) for the same dust layer as obtained from the Polly^{XT} lidar and the Particle Linear Depolarization Ratio (PLDR, %) profile (black vertical line). VLDR values close to 30% are indicative of high dust particle concentration and PLDR values persistently of 30% are characteristic of pure dust within the entirety of the layer (1-4 km)."

Fig. 9 (previously Fig. 7) caption updated to: "Top panel: Timeseries of the vertical electric field strength (orange), the Localized Reference Electric Field (red) and the reconstructed mean electric field variation (black) plotted with the time-height evolution of the attenuated backscatter coefficient (1/Mm sr) and the particle backscatter coefficient (β) profile (1/Mm sr, black vertical line) averaged between 18:00 and 21:00 (UTC), for the 23/06/2019 dust layer in Antikythera station. Areas of increased particle concentration are denoted with yellow to reddish tones, while the β values are between 3 to 4 (1/Mm sr). The mean E-field is positive and consistently below the reference field, exhibiting an increase when particle injection begins towards noon and further drops as the layer progresses to lower altitudes. Bottom panel: Volume Linear Depolarization Ratio (δ_v, %) for the same dust layer as obtained from the Polly^{XT} lidar and the Particle Linear Depolarization Ratio (δ_p, %) profile (black vertical line). High δ_v values (>15%) are indicative of dust particle presence and δ_p values between 25% - 30% in the afternoon are characteristic of pure dust."

Fig. 10: added $E_{z_0,dipole}$ to the caption.

Fig. A1 (previously Fig. 8)**:** "…(d) the separation distance." to "…(d) the dust layer depth."