A study of the effects of thunderstorm distance and topography on the atmospheric electric field

Nikolaos Kastelis[1], Konstantinos Kourtidis[1], Vasiliki Kotroni[2], Konstantinos Lagouvardos[2]

[1]Lab. of Atmospheric Pollution and Pollution Control Engineering of Atmospheric Pollutants, Dept. of Environmental Engineering, Democritus University of Thrace, [2]National Observatory of Athens

Introduction

Ground measurements of atmospheric electric field, known as Potential Gradient (PG, PG=-EZ), have proven to be valuable in thundercloud and lightning research. PG has the ability to respond to the presence of high levels of charge separation in nearby clouds and observe the imposed local electrostatic field changes before, during and after the occurrence of any discharge [1].

It has been observed that absolute PG values decline exponentially with increasing distance from a thundercloud, while PG is also influenced by thunderclouds charge magnitude and topography [1, 2].These induce uncertainty over the response range of PG and its efficiency to detect thunderclouds [3].

In the current work, the operational active radius of Electric Field Meters (EFM) in thundercloud recognition in non-homogenous terrain is evaluated. Further, the effect of topography on the active radius is examined and the utilization of PG as a means of thunderstorm nowcasting is corroborated.

Experimental

An EFM (CS110, Campbell Scientific Co.) has been installed since February 2011 on the Campus of Democritus University of Thrace at Xanthi, Greece (41.15°N, 24.92°E) measuring routinely PG. The station is located at the boundary between the Rodopi mountain range and the Thracian valley.

Lightning data were provided by the long range lightning detection network ZEUS, operated by the National Observatory of Athens (NOA). The lightning dataset selected for the analysis presented here covers an area having the EFM site at its center and extending over a radius of 30 km.

PG and lightning data presented in this work comprise a full month of the warm period of year, that of May 2012. All data refer to local time (LT). PG product used is that of 1-min means.

Results and Discussion

To study the response of PG to thunderstorm distance, the area of interest, centered over the EFM site, was divided into six circular rings (0 – 30 km, interval: 5km). Then, the PG values at the moments of lightning occurrence within each ring were selected. Here, lightning data act as indicators of the existence of a thunderstorm and give information about its distance from EFM. Finally, for each circular ring, PG values were distributed in 1 kV m^{-1} bins.

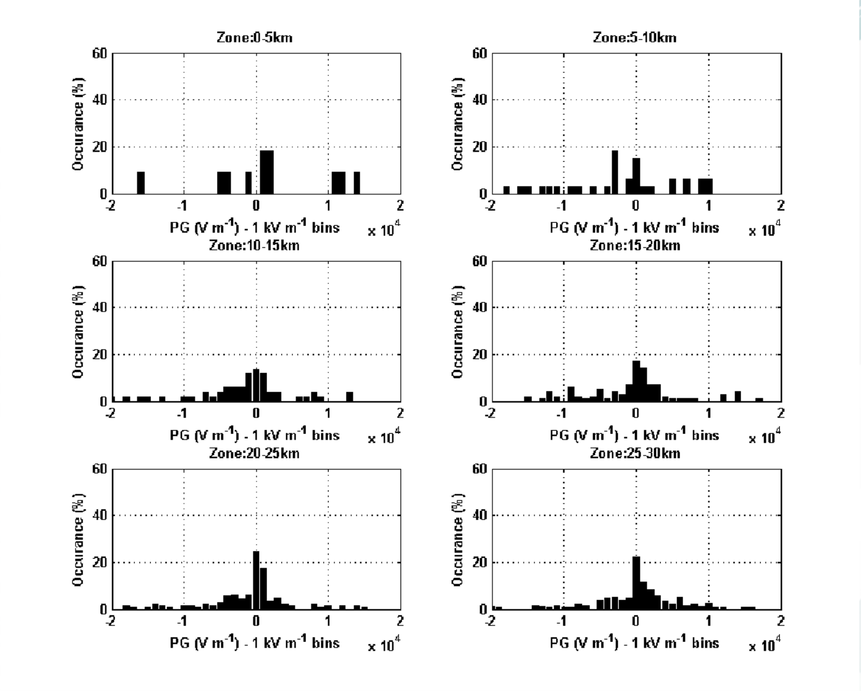

Fig. 1. Distribution of 1-min mean PG values recorded during each lightning, for six lightning distance zones, defined as circular rings with EFM as an epicenter. The X kV m^{-1} bin ranges from X-500 to X +500 V m^{-1}

We observe that as the distance of the thunderstorms increases, the PG response decreases (Fig. 1.). In the first three zones (0 – 15 km), PG is distributed within the whole range (|20 kV m^{-1}|), responding to electrostatic changes provoked by thunderclouds. In the last three zones, the percentage of PG values falling within the -500 – 500 Vm^{-1} range gradually increases until it exceeds 20% of the total values of each zone. The gradual decrease of the PG response to thunderstorms with distance is evident beyond 15 km, making the PG a more reliable indicator for thunderstorms for the first 3 distance zones (0-15 km). Hence this distance (15 km) can be inferred as the active radius of EFM for our site and other sites with similar characteristics.

To study the effect of topography on the active radius of the EFM, the area under consideration was divided into two sectors; the valley sector and the mountain one (Fig. 2.). The boundaries between these sectors are defined by local topography, characterizing as valley lightning the ones occurring from 100° to 240° (253 incidents) and as mountainous ones the rest (292 incidents).

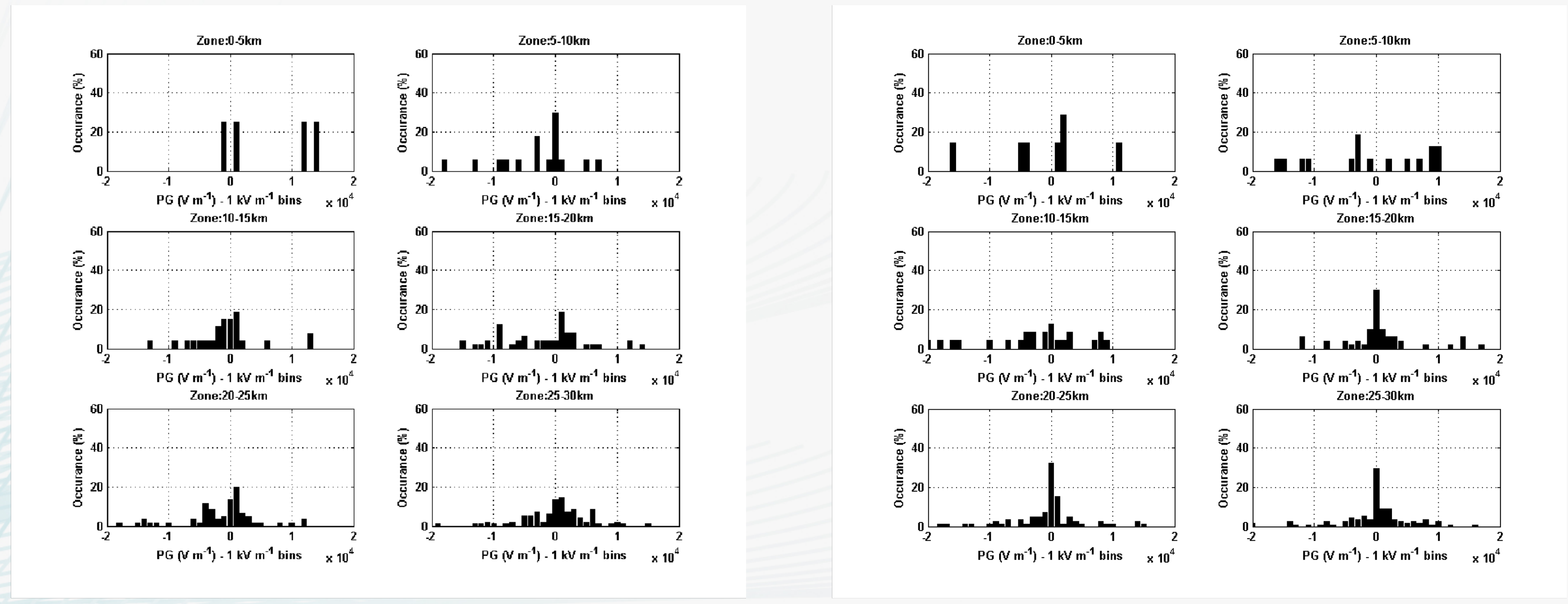

Fig. 2. Distribution of 1-min mean PG values recorded during each lightning, for six lightning distance zones, defined as circular rings with EFM as an epicenter. Left: Only values for lightning occurring at the valley side (100° – 240°) are considered. Right: Only values for lightning occurring at the mountain side (240° – 100°) are considered. The X kV m^{-1} bin ranges from X-500 to X+500 V m^{-1}.

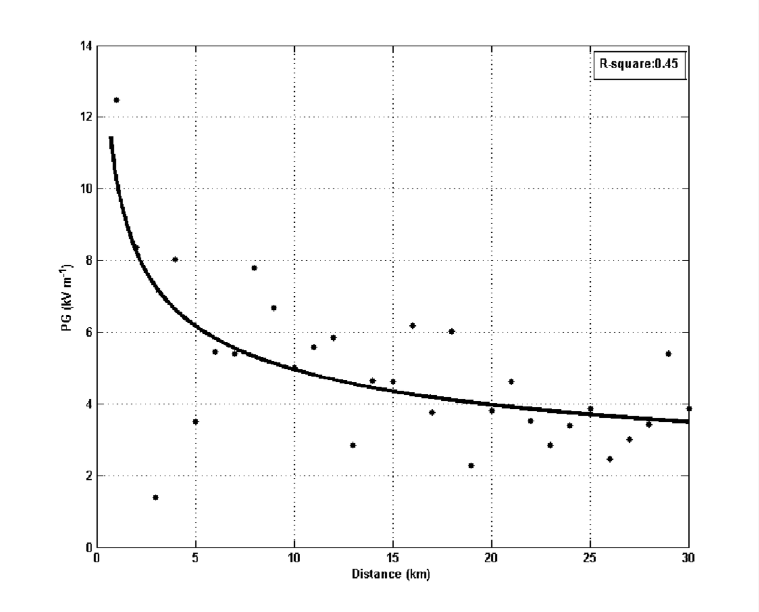

Fig. 3. PG and lightning distance relationship, with a corresponding power function fit with R^2=0.45. PG values were calculated from 1-min means for corresponding strikes that fell in each distance bin (bin size: 1 km).

Distributing the corresponding PG values the same way as in Fig. 1., a difference in PG sensitivity for the zones 15 – 30 km becomes apparent between the valley and the mountain sector, while the 0 – 15 km zones follow the general tendency described above. The PG for valley lightning shows a wide distribution for all zones, thus appearing to respond to thunderstorms as far as 30 km (Fig. 2., Left). For lightning occurring over the mountain side at distances of 15 to 30 km, about 30% of the 1-min mean PG values are aggregated within the -500 – 500 Vm^{-1} range, indicating that PG is less sensitive to thunderclouds evolving in this sector (Fig. 2., Right). Hence the EFM active radius for lightning occurring over the valley sector is around 30 km, while for lightnings occurring over the mountain it is confined to 15 km.

The data in Fig. 3. are mean absolute PG values of 1-min means for every 1-km bin. PG is inversely correlated with thunderstorm distance, declining exponentially with distance (R^2=045). Implications about the active EFM radius can be derived, since a sharp PG decrease is apparent for the first three zones, while for the outermost zones the PG response tends to be less.

On May 15th the most severe thunderstorm of the study period occurred. The thunderstorm started at 00:24, 260 km SW from the station. As the thunderstorm approaches and enters the study area (4:30-6:00), the PG variability and amplitude increase, providing a means of lightning event nowcasting. At the same time (5:30-6:00), intense precipitation occurs, coinciding with part of the closest strikes to the EFM.

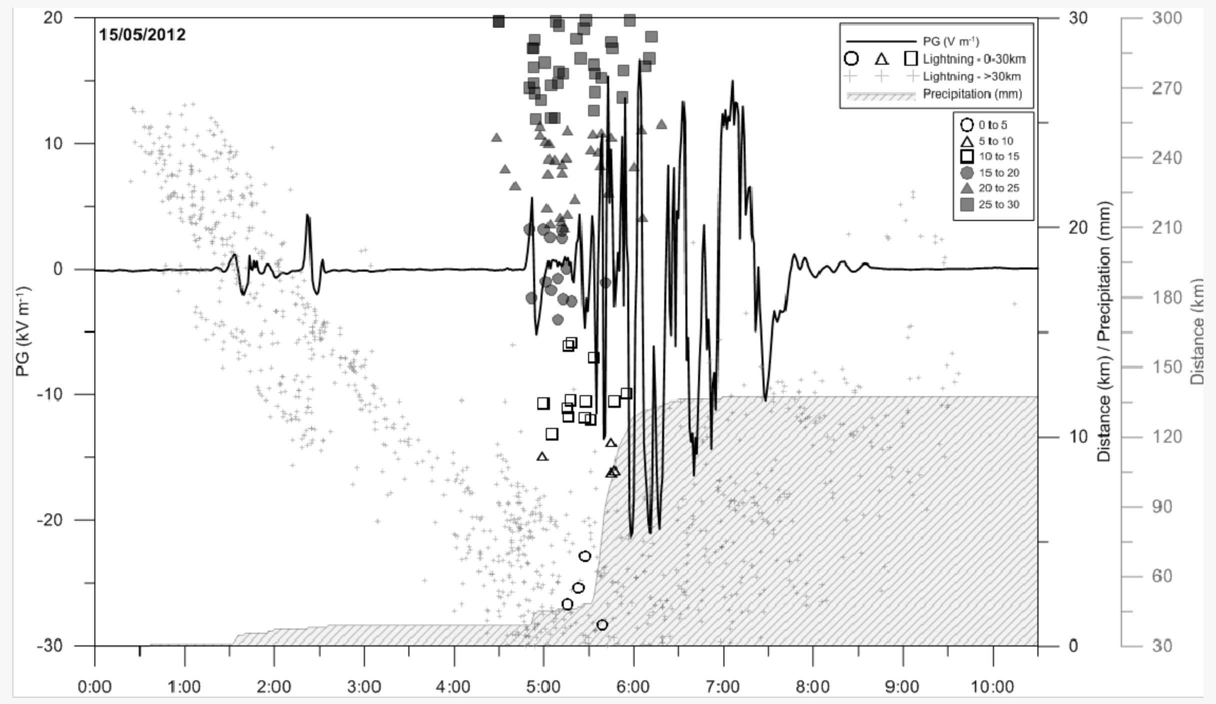

Fig. 4. The thunderstorm of 15 May 2012. PG is in 1-min means (solid line), distant lightning (30 – 300 km) are denoted with grey symbols (crosses), nearby lightning (0 – 30 km) are denoted with different black symbols depending on the distance (label) and accumulated precipitation is denoted with the shaded grey area.

References

1. MacGorman, R. D., & Rust, W. D. (1998). The electrical nature of storms (1st ed., p. 432). New York, USA: Oxford University Press.

2. Aranguren, D., Montanya, J., Solá, G., March, V., Romero, D., & Torres, H. (2009). On the lightning hazard warning using electrostatic field: Analysis of summer thunderstorms in Spain. Journal of Electrostatics, 67(2-3), 507–512.

3. Heitkemper, L., Price, R. F., & Johnson, D. B. (2008). ACRP-Report8_Lightning-Warning Systems for Use by Airports (p. 81). Washington, D.C.

Correspondence: nkasteli@env.duth.gr & kourtidi@env.duth.gr