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Electric Field Variations Caused by Low, Middle and High-Altitude Clouds over the Negev Desert, Israel

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Abstract: Ground-based measurements of the electric field from a station located in the arid Negev region of southern Israel have been conducted continuously since 2013. We present here results of observations of the electric field (Potential Gradient, PG) variability during 22 cloudy days, with varying cloud types and cloud base heights, and compare the measured values with the mean fair-weather PG. The results show an increase of PG (~+10 to +70 V m^{-1}) from mean fair weather values during times of low clouds. During times of mid-altitude (alto) clouds or during a superposition of low and high clouds, there were small departures in the PG values (~0 to −30 V m^{-1}) compared to mean fair weather PG values. During times of high-altitude cirrus clouds there is a clear decrease of the PG (~−40 to −90 V m^{-1}). The data was compared with the Israeli meteorological service cloud data and with MODIS 7 satellite cloud top height maps. In addition, AERONET aerosol optical depth values and wind speed magnitude from a local meteorological station were analyzed.

Keywords: potential gradient; global electric circuit; fair-weather electric field

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1. Introduction

The fair-weather part of the Global Electric Circuit (GEC) concept is manifested through several atmospheric observables, some of which had been monitored in various locations for over a century [1–3], offering a long-term record that helps in tracking global changes. The vertical component of the atmospheric electric field (Ez; sometimes referred to as the inverse of the Potential Gradient, Ez = −PG) is one of the best recorded parameters, along with the vertical current (Jz) and the ionospheric potential. The PG was shown to be affected by natural and anthropogenic processes such as pollution, dust, fog and relative humidity, as well as topographic effects and sources of ionization that depend on the local mineralogy. The well-known "Carnegie curve" shows a robust diurnal variation of the Potential Gradient at a given location with a maximum around 19 UT and a minimum around 3 UT with fair weather values ranging from +100 to +300 V m^{-1} (pointing downward), exhibiting a clear daily and seasonal variability [4–7].

Land-based observations of the atmospheric electric field show that local meteorology and aerosol variations, such as relative humidity, precipitation types and pollution [8–13] can lead to significant variability in the diurnal PG behavior. Aerosols are known to decrease conductivity and therefore, for maintaining a constant vertical current density in the global circuit (in accordance with Ohm's law), they cause an increase in the PG [1,2]. With respect to clouds, Harrison [8] found that PG values during overcast conditions are slightly reduced compared to fair weather clean conditions. The reason is an increase in the columnar resistance by the cloud layer compared with that of clear air; They found that the relative contribution will vary with the depth and height of the cloud layer. Harrison and Nicoll [14] further reported that during overcast conditions, when the cloud base is above 1 km there is little associated variability in the PG data but when the cloud base is well below 1 km, the PG variability is substantial. Nicoll and Harrison [15] sampled

22 clouds by balloon-borne platforms and showed that stratiform cloud boundaries were charged asymmetrically, with the upper part charged positively +32 pC m^{-3} and the lower −24 pC m^{-3}. This difference is attributed to temperature inversions at cloud top. Their results show that lower laying clouds (below 2 km) are charged more than higher clouds, and this affects cloud microphysics and lifetime. For cases when the cloud was in contact with the ground (fog) the measurement indicated an increase in the electric field [16] with patterns of pulsations, reflecting turbulent processes within the cloud layer.

This paper reports on ground-based PG measurements during overcast conditions by various types of clouds at the Wise Observatory in the Negev desert in southern Israel. We will use the conventional terminology of Potential Gradient throughout the manuscript.

2. Instrumentation, Observation Site and Data

As in previous studies, we used a CS110 electric field mill by Campbell Scientific Company that samples the vertical component of the electric field (Ez) at 1 Hz. The specific information on the Wise observatory can be found in [10,17,18] Measurements of the Ez at the Wise Observatory began in June 2013 and have been conducted almost continuously, with data saved in a data-logger and on an external USB drive. Most of the data had already been uploaded to the GloCAEM database at Reading University [19] and is available to the depository registered users. The Wise Observatory also operates a meteorological weather station which provides data of temperature, humidity, pressure and wind speed.

For cloudiness data, we used the data archive of the Israeli Meteorological Service (IMS) (https://ims.data.gov.il/ims/1 (Accessed on 15 July 2022)) that provides weather data from Israel including types of clouds, height of cloud base, amount of low, middle and high clouds and cloud amount in oktas eighths. The data is open for the public and available in Hebrew and copyrighted to the state of Israel.

The AERONET (AErosol RObotic NETwork) project is a federation of ground-based remote sensing aerosol networks established by NASA which provides globally distributed observations of spectral aerosol optical depth (AOD). The station is located in Sde-Boker, southern Israel (30.855 N, 34.782 E), approximately 20 km north from the Wise Observatory.

The MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument on-board NASA's Terra and Aqua satellites. The MODIS Cloud Product combines infrared and visible techniques to determine both physical and radiative cloud properties and provides cloud top height data layer which indicates the geopotential height of the highest cloud top at a retrieved cloud top pressure. The data is obtained from the worldview open-source code app website (https://worldview.earthdata.nasa.gov/ (Accessed on 15 July 2022)) and provides interactively browse global, full-resolution satellite imagery layers and then download the underlying data.

3. Results

An analysis of 22 days was performed to investigate the relationship between the types of clouds and overcast conditions in order to identify their effect on the ground measured electric field. The measured Ez values were transformed to Potential Gradient PG ($PG = |Ez|$). A summary of the results is presented in Table 1 and includes calculated average cloud-base altitude data that was retrieved from satellite images and from the Israeli Meteorological Service (IMS) archive. Data from the IMS included cloud types, cloud top and base heights as well. It should be noted that in some cases there were several layers of clouds, thus a superposition effect was considered in the analysis and an average height was considered to represent the combined effect of the cloud layers on the PG value measured at the surface. For the average height, we assumed that each cloud layer is horizontally infinite with respect to the ground station, rather than assuming a single finite cloud that approximately acts as a point charge. Thus, several layers of clouds are assumed to be acting like 2 plates with a uniform electric field.

Table 1. 22 case studies on the effect of clouds on measured PG. * This refers to cases when more than one cloud layer was present.

#	Date	Cloud Type	Mean Cloud Height [m]	Mean FW PG ($V\ m^{-1}$)	Mean PG Diurnal ($V\ m^{-1}$)	ΔPG from FW Values to Diurnal Mean ($V\ m^{-1}$)	Comments * Superposition Effect (SP)	Aeronet Value vs. FW	Wind Speed vs. FW
1	15/02/2014	Cumulus & Cirrostratus	8600	165	158.96	−6	SP—low and high clouds	FW	High
2	16/02/2014	Cumulus & altocumulus	3400	165	154.82	−10.2	SP—low and mid clouds	FW	High
3	09/03/2014	Stratocumulus & alto cumulus	3250	169	151.51	−17.5	SP—low and mid clouds	N/A	FW
4	13/04/2014	Altostratus & cirrostratus	7750	175	155.18	−19.8	SP—mid and high clouds	FW	FW
5	15/04/2014	Altocumulus	7200	175	140.96	−34		High	FW
6	05/05/2014	Altocumulus	9900	183	137.61	−45.4		High	FW
7	13/05/2014	Cumulus humilis & Cirrus fibratus	5900	183	132.26	−47.7	SP—low and high clouds	FW	FW
8	20/07/2014	Stratocumulus	1600	180	190.65	10.7		FW	FW
9	19/11/2016	Cirrus	8000	182	112.44	−69.6		High	FW
10	22/11/2016	Cirrocumulus	11,400	182	129.85	−52.5		High	FW
11	29/11/2016	Cirrus	8400	182	121.76	−60.2		FW	FW
12	30/11/2016	Cirrocumulus & alto cumulus	9000	182	85.52	−96.5	SP—mid and high clouds	FW	FW
13	14/12/2016	Cumulus & alto cumulus	1000	170	195.69	25.7	SP—low and mid clouds	High	High
14	23/12/2016	Cumulus	800	170	240.6	70.6		N/A	FW
15	01/01/2018	Stratocumulus	500	150	200.4	50.4		N/A	FW
16	04/01/2018	Stratocumulus & alto cumulus	3500	150	159.04	9.04	SP—low and mid clouds	FW	FW
17	17/01/2018	Stratocumulus	1000	155	162.23	7.23		FW	FW
18	21/01/2018	Cirrus	12,500	160	130.15	−29.9		High	FW
19	29/01/2018	Altocumulus	4000	160	159.29	−0.7		FW	FW
20	06/02/2018	Cirrostratus	11,700	170	102.26	−67.7		High	FW
21	10/02/2018	Cirrostratus	11,600	170	134.88	−35.1		High	FW
22	12/02/2018	Cirrus fibratus & stratus fractus	5750	170	171.69	1.7	SP—low and high clouds	High	FW

The mean electric field (PG) data for each day was calculated from 11–17 LT and was compared to the mean PG fair-weather (FW) values taken from present and past measurements (Yaniv et al., 2016) to calculate the difference ΔPG during times of overcast skies with clouds at various altitudes. "High" and "FW" in Table 1 refer to higher or identical values compared with the values measured during fair weather conditions, respectively. In the same manner, the measured wind speed values were compared to the fair-weather criteria of wind speed in the range 1–8 m s^{-1} (Harrison and Nicoll 2018) and noted as "FW" or "High" values. The obtained Aeronet AOD values vs. fair weather conditions will be explained in Figure 4.

Figure 1 presents two examples for the usage of satellite images and the PG variations during daytime hours (11–17 LT). Slightly higher PG values (mean ~160 V m^{-1}) compared with normal fair-weather values (mean ~150 V m^{-1}) were recorded for the 4 January 2018 event, which was dominated by a low cloud layer (Figure 1 top). Substantially lower PG values (mean ~102 V m^{-1}) relative to the normal fair-weather values (mean ~170 V m^{-1}) were recorded for the 6 February 2018 event, which was dominated by a high cirrus cloud layer (Figure 1 bottom).

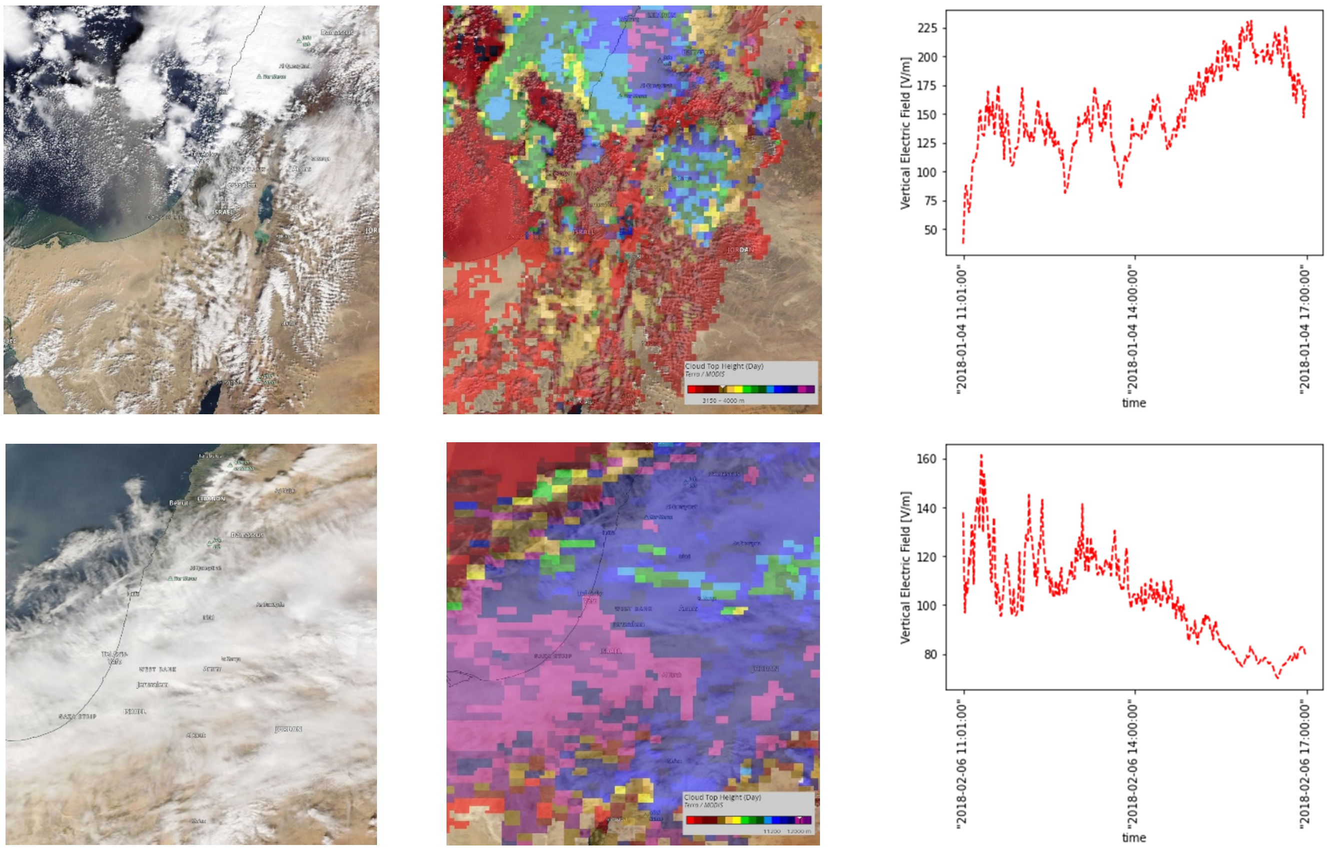

Figure 1. Data for two case studies: 4 January 2018 (**top**) and 6 February 2018 (**Bottom**). In each row: (**left**) Satellite image of clouds above Israel in visible light. (**center**) Measured cloud top height by Terra MODIS with colors indicating approximate height. (**right**) Observed PG values at ground level in Mitzpe Ramon.

The integrated results depicting cloud effects on the mean PG values for the 22 days that were analyzed in the present study are shown in Figures 2 and 3. It is clearly seen that low cloud layer corresponds to PG values that are higher than fair weather conditions in Mitzpe Ramon (Figure 2). Middle level clouds (alto) tend to result in PG values that are slightly lower than fair weather values while high cirrus cloud layers PG values effects tend to lower the PG values compared with the mean fair-weather values.

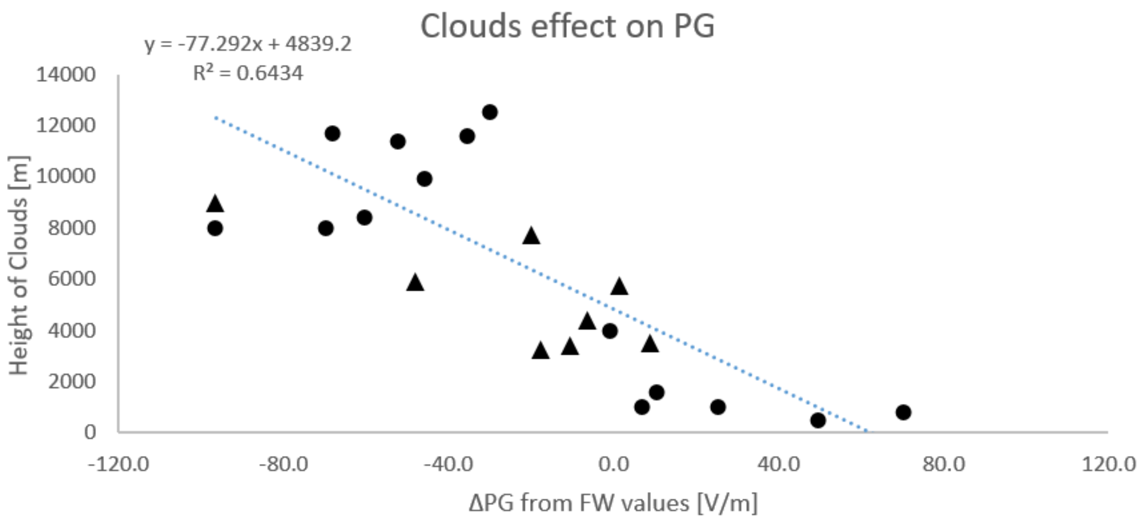

Figure 2. The height of clouds and their effect on the measured ground level PG. Circles are single layer of clouds while the triangles are a superposition of two or three types of clouds and are the average height. (for example, a presence of a ~10 km high cirrus cloud together with a ~1500 m stratus layer is indicated as a single combined height of 5750 m).

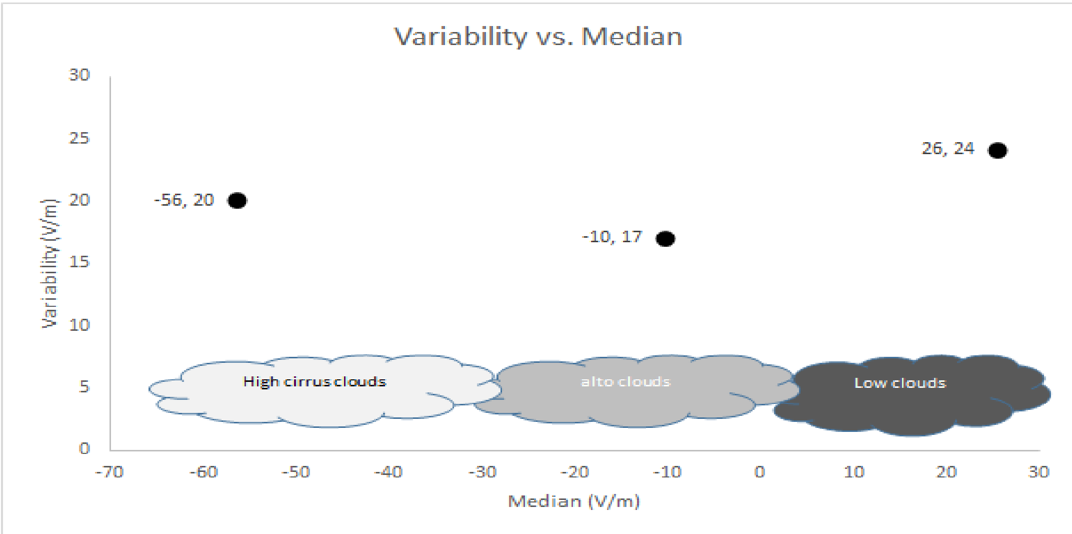

Figure 3. The variability of PG for different types of clouds at Mitzpe Ramon. Variability is expressed in terms of the Inter-Quartile Range and is scaled to one standard deviation for a normal distribution.

Figure 3 shows the median value as a function of the variability representing the effects of the various cloud layers. The ΔPG from fair weather values of low clouds is 26 ± 24 V m^{-1}, middle level clouds (alto) is -10 ± 17 V m^{-1} and for high cirrus layers it is -56 ± 20 V m^{-1}.

Figure 4 shows for each of the 22 days presented in Table 1 the mean value of the Aerosol Optical Depth (AOD) between 11–17 LT. For 19 days data was available. It also presents a comparison to the range of fair-weather mean AOD value (0.17–0.3 nm) derived from [10,20]. Higher aerosol concentrations were recorded on days 5, 10, 20, 22 in Table 1, but the values of PG that were recorded were lower or the same compared with fair weather conditions. This is likely due to the overcast conditions by high and mid-altitude clouds or a superposition effect of both clouds and high aerosol concentrations. During the events with the very high aerosols concentration, wind speed values were low in the range of fair-weather criteria (e.g., 1–8 m s^{-1}) [14].

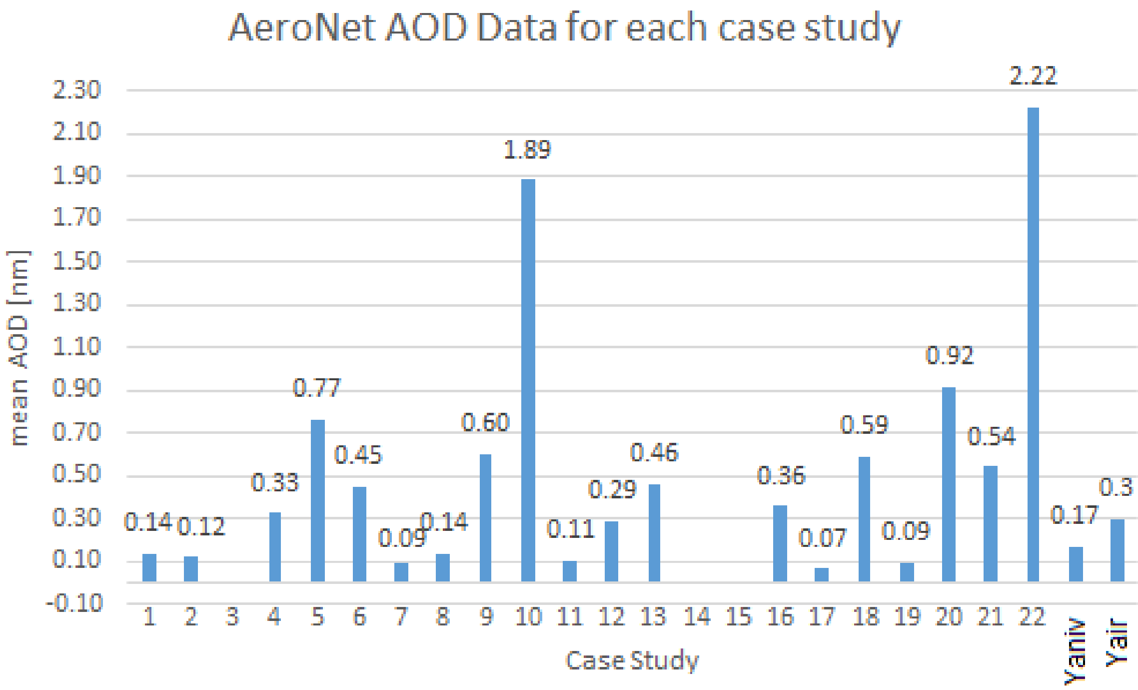

Figure 4. Mean Aerosol Optical Depth values [nm] for 19 out of 22 days and the 0.17–0.3 range of AOD mean fair weather values from previous studies [10,20].

Only 3 days (1, 2, 13) out of the 22 were found with higher wind speed values that were greater than the 8 m s^{-1} maximum value of fair-weather condition criteria [14] (the values were 2–14 or 6–20 m s^{-1}). Figure 5 shows the 3 case studies and the effect of the wind speed on the PG. During case study 2 (16 February 2014) and case study 13 (14 December 2016) there were transient periods of high PG values, which appear as peaks in the record. Data from the IMS and local weather stations in Sde-Boker and Mitzpe Ramon indicates that a short period of light rain (up to 4.2 mm/h) was present during case study 2 and (up to ~2 mm/h) during case study 13. Overall, the higher wind speed values did not affect the mean pattern of PG behavior. During case study 1, the PG decreased and during case studies 2 and 13, the PG mean value was quite low compared with fair weather values (~154 and ~195 V m^{-1} respectively) except for the short duration episode of rain. The effect of heavy rain on the Potential Gradient has been discussed by [8] and shown to decrease considerably and reverse the polarity exhibiting a large variability.

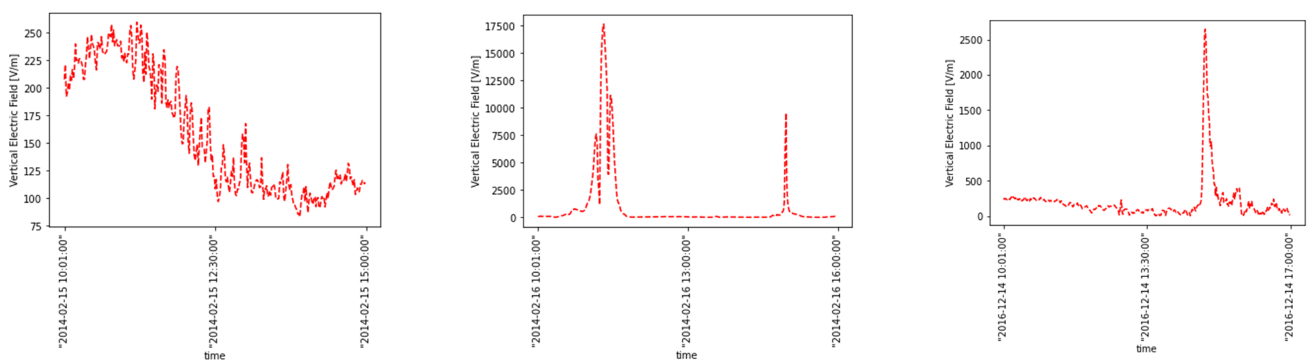

Figure 5. *Cont.*

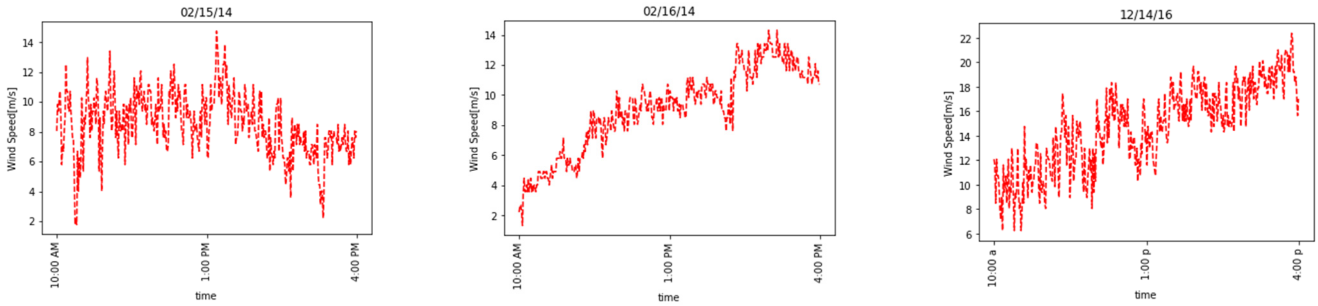

Figure 5. The vertical electric field (**top**) and wind speed results (**bottom**) for 3 events. 15 February 2014 (**left**), 16 February 2014 (**middle**) and 14 December 2016 (**right**). High values were recorded during short periods of light rain.

4. Summary

Clouds act as resistors in the Global Electrical Circuit [3,6,21], as they increase columnar resistance due to the reduced mobility of charge carriers due to the attachment of atmospheric ions to cloud particles. Layer clouds acquire positive charge on their upper part, and negative charge at the bottom. We can expect that the overall effect of cloud layers on the measured surface electric field (Potential Gradient) will depend on the amount of charge and the height (distance) of the layer from the surface.

The Potential Gradient (PG) at ground level is affected by local conditions such as passing charged layers of clouds, transient events like wind gusts and the ambient concentration of aerosols in the air. Our results show that during times of regular fair-weather conditions, namely non-extreme aerosol concentration and wind speed values, the effect of cloud layers on the PG are altitude dependent. High cirrus layers decrease the PG that was measured on ground while lower cloud layers increase the measured PG. The impact of wind speed and aerosols concentration, that in some of the cases were slightly above the normal fair-weather conditions, was found to be negligible compared to the effect of overcast conditions. These results are consistent with the 2010 data analyzed by [8] for Reading, UK that showed decreased values of PG during broken clouds (mean 91.1 V m^{-1} with Inter-quartile range of 30.9 V m^{-1}) and in overcast conditions (81.4 V m^{-1} and 33.1 V m^{-1}, respectively) compared with clear sky (93.5 V m^{-1}). It should be noted that in the total accumulated 828 h of data in that study there was no reported distinction between cloud types and their specific heights (see Table 2 there). Harrison and Nicoll [19] showed that for clouds with base height lower than 1 km the negatively charged bottom part of the cloud layer effect on the surface PG was pronounced. Their results demonstrate little sensitivity for cloud-bases above 1 km and large fluctuations in PG for cloud-base heights above 1.5 km (their Figure 4). Lucas and Deierling [22] analyzed 18 years of PG data at the Kennedy Space Center in Florida and showed that clouds reduce the PG by values of up to ~30 V m^{-1} in overcast conditions and ~10 V m^{-1} for scattered clouds compared with clear-sky conditions, however no dependence on cloud type, depth or cloud depth was reported.

In the present study we showed that the PG during overcast condition is clearly affected by the presence of clouds and that the effect is more pronounced for high clouds and is opposite in polarity but of the same magnitude for low clouds (Figure 1). While the 22 days in the present study cannot be considered to be fair-weather by the orthodox definition [14p, they are clearly not within the disturbed weather category either. Such clouds can be considered as a unique type of non-precipitation shower clouds, even though they are distinctly different from the low clouds this definition usually refers to (stratus or stratocumulus). Bearing in mind that significant parts of the planet are covered by cloudiness for prolonged periods of time, it means that a robust global record of the PG cannot be obtained without considering different cloud types and their effects on the GEC. This suggests a need for a different classification of conditions under which global fair-weather PG values are obtained.

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Data Availability Statement: The Potential Gradient data (PG) is available through the GLOCAEM network in the University of Reading, UK https://catalogue.ceda.ac.uk/uuid/bffd0262439a4ecb8fadf0134c4a4a41. Israel Meteorology data are accessible online at: https://ims.data.gov.il/ims/1. Accessed on 15 July 2022.

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Conflicts of Interest: The authors declare no conflict of interest.

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