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Spectral response of atmospheric electric field measurements near AC high voltage power lines

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Abstract. To understand the influence of corona ion emission on the atmospheric electrical field, measurements were made near to two AC high voltage power lines. A JCI 131 field-mill recorded the atmospheric electric field over one year. Meteorological measurements were also taken. The data series is divided in four zones (dependent on wind direction): whole zones, Z_0 ; zone 1, Z_1 ; zone 2, Z_2 ; zone 3, Z_3 . Z_3 is the least affected by corona ion emission and for that reason it is used as a reference against Z_1 and Z_2 , which are strongly influenced by this phenomena. Analysis was undertaken for all weather days and dry days only. The Lomb-Scargle strategy developed for unevenly spaced time-series is used to calculate the spectral response of the aforementioned zones. Only frequencies above 1 minute are considered.

1. Introduction

The atmosphere is weakly conducting due to the natural presence of atmospheric air-ions, which are produced by cosmic ray ionisation and ground based radioactive decay (such as Radon) near the ground. Thunderstorm activity moves charge from the ground to the ionosphere, a conducting layer of the atmosphere, which dissipates back to ground through the atmosphere completing the Global Electric Circuit [1]. The difference in potential between the ionosphere and the ground (V_i) cause a Potential Gradient¹ (PG) that can be measured at the Earth's surface using electric field mills [2].

The Earth's PG can be modified by changes in air conductivity: reduction of air ions caused by increased aerosol concentration [3]; charged clouds overhead [4] and local sources of space charge, such as high voltage power lines (HVPL) [5]. HVPL can produce so-called 'corona ions' when the electric field surrounding the cable is large enough to cause acceleration of ions leading to corona avalanching. On a 50-Hz cable, these ions largely oscillate around the cable, but some can escape in a cross wind, both positive and negative ions can be released into the environment [6].

To measure the effect of HVPL on the electrical environment over a full year, a fixed site monitoring station (FSMS) was set up in South Gloucestershire, UK, to monitor changes in PG. PG was measured at 1 Hz using a JCI 131 electric field meter at 2 m height, and local weather conditions were monitored and recorded as 10 minute averages [5].

¹ PG is defined as dV_i/dz and the vertical component of atmospheric electric field is related with this variable through $E_z = -PG$.



Discontinuities on the line such as dirt or raindrops can enhance the field on the surface of the line and increase the amount of ions produced; hence weather conditions can significantly affect the amount of ions released by the line, with higher and more negative fields being seen in wet conditions [7]. If a predominance of one polarity of ions is observed then the ions carried overhead cause significant regions of space charge that can be observed as fluctuations of electric field at ground level. As the cloud of space charge is affected by local meteorology, the time of day also has an effect on the electric field, with fluctuating fields being more seen during the day [8].

2. Data analysis

Previous analysis of data from the FSMS have looked at 10 minute averages and SD of the PG, and information within the finer structure at 1 minute has not been considered yet. This analysis looks at the data average to 1 minute to investigate the finer structure and spectral content.

As with previous research [5, 7, 8], the analysis is undertaken on four different data sets dependent on wind direction: all data, i.e. whole zones (Z_0); zone 1 (Z_1) from SSW to WNW, 175 m downwind of 400 kV HVPL; zone 2 (Z_2) from ESE to S, 750 m downwind of 275 kV HVPL; zone 3 (Z_3) from NW to E, upwind of both HVPL. The last zone, Z_3 , is the least affected by space charge produced by HVPL (as it is upwind the power-line) and is used as a reference for Z_1 and Z_2 . A full discussion of the sources of aerosol and predominance of a particular weather by wind direction is given elsewhere [5] but it is important to note that stronger winds and more clouds come from the south west (influencing Z_1) than other zones and that there is a source of aerosol in the M48 motorway, also to the south west. Winds in Z_2 are the least present and, for that reason, less data is available for this zone and this will have consequences in the results shown below. Data from the FSMS were averaged into 1-minute samples and wind directions attributed accordingly (assuming that the wind add the same direction the 10 minutes before). Data were further divided into all weather and dry days. By dry days we mean days in which no rain was measured in our weather station. This is distinct from the usual 'fair weather days' encountered in studies regarding atmospheric electricity, as charged clouds may still be present.

The daily average was found for each zone to see the daily cycle. As the PG was been divided into 3 zones according to wind direction, and as some data was removed due to equipment failure, each of the sub-set of PG is a non-continuous time series, and therefore frequency analysis using typical Fourier analysis is not possible. The Lomb-Scargle Spectra (LSS) technique was developed for interrupted data sets in astrophysics [9, 10], and has been used in atmospheric electricity [3]. The LSS is similar to the Fourier transform, but it estimates the frequency spectrum based on a least squares fit of the sinusoids; the LSS spectrum converges to Fourier transform spectrum in the limit of evenly spaced observations. We use MATLAB to implement the LSS [11]. The following parameters were used $hifac=1$ (that defines the frequency limit as $hifac$ times the average Nyquist frequency), $ofac=4$ (oversampling factor). It is worthwhile to mention that the resulting spectra depends on the amount of data used, for a times-series with many discontinuities the LSS will only have access to lower frequencies as it loses the high frequency resolution. This is the case of Z_2 time-series and for that reason less attention will be given to this zone.

3. Results and discussion

Figure 1a shows the daily average for zones Z_1 , Z_2 and Z_3 at a 1-minute resolution. These data have previously been presented as 1 hour averages where the negative values of PG overnight in Z_1 were attributed to the typical increase in humidity increasing negative corona production [6]. However, the previous analyses had a much lower temporal resolution. Z_2 shows a very noisy behaviour oscillating from negative to positive, though the noise may be an artefact of lower sample numbers from this wind sector. Z_3 , despite the noise, shows a 24 hour cycle similar to the Carnegie curve, the global background atmospheric electric field [1]. This is consistent with measurements in a typical rural background electric field profile. Figure 1b shows that the spectra for all zones. Z_1 and Z_3 have a peak at the daily cycle consistent with the daily behaviour shown in Figure 1a. There is not a clear signal for

the weekly cycle in any of the zones, which is indicative of urban pollution. Nevertheless, Z_3 evidences a small half-day cycle characteristic of pollution from traffic [12] and could be a result of nearby roads. As usual in spectral analysis the n -exponent is determined for each zone (above the threshold frequency of 1 day^{-1}). This exponent is defined from the asymptotic spectral amplitude, S , with the frequency, f , usually written as $S \sim f^{-n}$ [3]. The values found are: ~ 1.54 , ~ 1.05 , ~ 0.48 and ~ 1.01 for Z_0 , Z_1 , Z_2 , and Z_3 , respectively. These are relatively similar values, as compared with ones for spectra calculated from hourly values [3]. It is observed that the values found for Z_1 (more affected by the HVPL) are similar to Z_3 (least affected by the HVPL). This is an indication that rainy weather masks the impact that HVPL have in the PG spectral response reducing its response to higher frequencies. This becomes clearer when considering the results from dry days below. The spectrum of Z_2 is much smaller than the other two, not because of a physical reason, but because this zone has less observations and the LSS algorithm cannot access lower frequencies, as mentioned above.

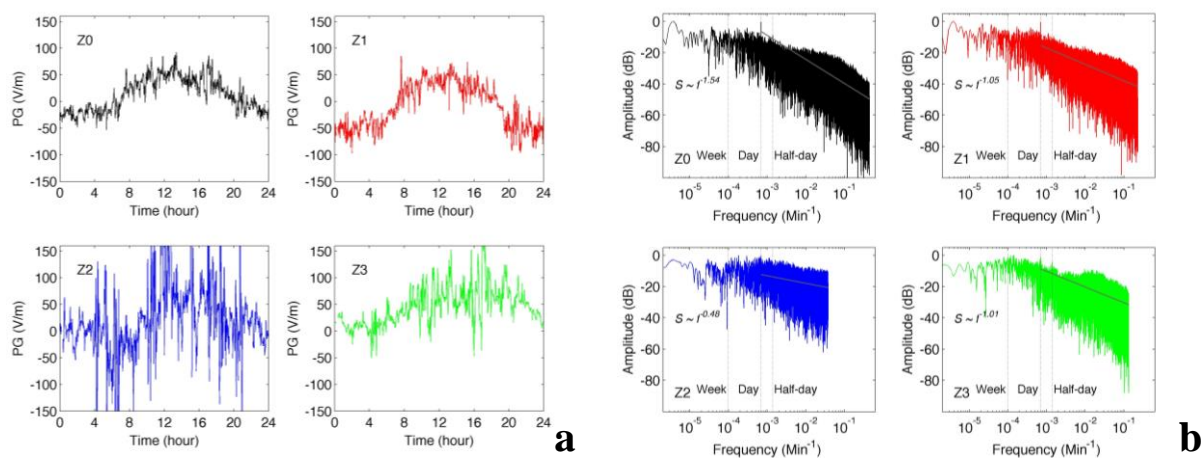


Figure 1. a) Daily behaviour for 1-minute average data in all weather conditions; b) Lomb-Scargle Spectra for all weather conditions. The grey lines represent the fit to the asymptotic spectral amplitude, S .

Figure 2a shows the daily average time series of the three zones but for dry days. The results are similar to those for all weather but exhibit less noise. This indicates that the increase in noise in Figure 1a can be attributed to the increase in PG fluctuations caused on rainy days [7]. Z_1 seems to present a clear feature every approximately half-hour. This periodicity appears in the LSS and can be tentatively attributed to the effect of HVPL. Z_2 shows oscillating/noisy negative-positive values from 00:00 until 08:00 returning to a normal behaviour after that. Z_3 shows a daily behaviour similar to the Carnegie curve [1] confirming that this is the zone least affected by the HVPL. However, a peak is observed around 22:00 in this zone that coincides with strong oscillations in Z_1 , this may be due to extreme weather outliers. Figure 2b shows the LSS for dry days. The n -exponent values, in this case, are: ~ 0.78 , ~ 0.81 , ~ 0.87 and ~ 1.09 for Z_0 , Z_1 , Z_2 , and Z_3 , respectively. Zones 1 and 2 have similar values and could be an indication of HVPL effect, despite Z_2 having less data. This means that the HVPL would increase the PG response to higher frequencies with a slight tendency to flatten the spectra. This is a consequence of the dispersion of the spectral energy to higher frequencies and could be another result of HVPL activity. It should be noted that the n -exponent for Z_1 is reduced to values around ~ 0.8 while Z_3 shows more or less the same value compared with the spectra in Figure 1b. This could be an indication that rainy days mask the spectral dispersion as mentioned above. Z_1 exhibits an increase in amplitude at a half-hour periodicity that is not present in Z_3 and is suppressed in the all-weather Figure 1b. This could correspond to the features observed in Figure 2a.

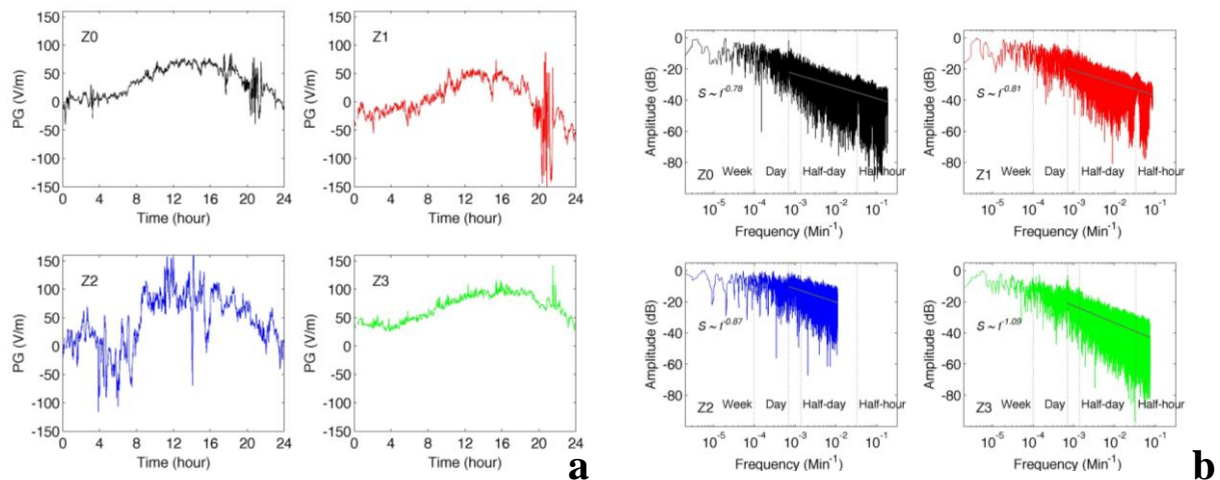


Figure 2. a) Daily behaviour for 1-minute average data for dry days only. b) Lomb-Scargle Spectra for dry days only. The grey lines represent the fit to the asymptotic spectral amplitude, S .

4. Conclusions

The effect of HVPL is studied with 1-minute resolution of PG measured in a FSMS. Several features are seen. Comparison between all weather and dry days only is made. All zones evidence a daily cycle for both conditions. It is seen that rainy days tend to increase noise in all zones and reduce the high frequency response of Z_1 . There is evidence that rain masks the effect of HVPL has in the LSS of Z_1 , while for dry days the presence of the HVPL tend to flatten the spectra promoting the dispersion of spectral energy for higher frequencies. The spectra for Z_3 is almost unaffected by weather conditions and present a half-day periodicity tentatively attributed to traffic pollution. Finally, a clear perturbation is observed in the daily behaviours of Z_1 and Z_3 for dry days only at around 22:00, which may be due to extreme weather outliers.

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