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Retrieval of Global Atmospheric Electrical Activity at a Polluted Urban Site

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Abstract. The atmospheric electrical Potential Gradient (PG) arises from global thunderstorm activity, but surface measurements of the atmospheric Potential Gradient (PG) are influenced by global thunderstorms and local aerosol concentration changes. The local aerosol change can be monitored independently, and in some cases the concentration changes are closely related to PG changes. For these circumstances, a general theory to remove the local aerosol influence on PG measurements has been developed. Continuous measurements of PG and aerosol mass concentration were made during 24-31 Dec, 2005 within an urban environment at Reading, UK. The average diurnal variation of PG showed a double diurnal cycle, with maxima in the early morning and evening hours. The aerosol concentration has similar double maxima. Removing the aerosol using from the PG and aerosol correlation returns a single diurnal cycle, suggestive of the more global PG diurnal cycle.

1. Introduction

Electric fields exist in the atmosphere in all meteorological situations. In fair weather conditions, these arise from the action of the global atmospheric electric circuit linking the electrical output of tropical thunderstorms with meteorologically undisturbed regions elsewhere on the planet. In the meteorologically fair weather regions, the vertical electric potential gradient (PG) is weak (~100Vm⁻¹), but can show identifiable global characteristics in clean air. The principal global feature in the PG is a diurnal cycle which closely follows the variation in active global thunderstorm area[1]. This is known as the Carnegie curve, after the sailing vessel on which the original marine measurements were made from which it was identified. In polluted surface regions, however, the Carnegie variation in atmospheric PG is not found, as the local effects of aerosols dominate the variations. In general, therefore, the surface PG in urban air is determined by a combination of local aerosol pollution and the long-range effects of the global atmospheric electrical circuit. The PG measured at the surface depends on global and local effects in a complicated fashion: although the air-earth current density arises from the global atmospheric electrical circuit, the surface PG also depends strongly on the local air conductivity, which is modulated by the atmospheric aerosol. In the present study we distinguish global and local effects on PG using a theoretical relationship between aerosol concentration and the PG. Separating the two factors permits the effects of pollution to be removed from the PG measurements.
2. Methodology

Natural variations in aerosol concentrations, for example, associated with the production and dispersion of pollution in the planetary boundary layer, result in changes in ion concentrations \[^2\]. In the limiting case when ion-aerosol attachment dominates over ion-ion recombination as the principal mechanism of ion loss, the steady state ion concentration \( n \) is

\[
n = \frac{q}{\beta Z}
\]  

where \( q \) is the ionisation rate, \( \beta \) is the ion-aerosol attachment coefficient and \( Z \) is the aerosol number concentration. A related consequence is that the aerosol may then carry a large proportion of the space charge. Previous work \[^3\] has shown that, in polluted air, a linear relationship is expected between \( M \) and the PG,

\[
PG = \left[ \frac{3}{8\pi\rho r^3} \beta \left( \frac{J_s}{\mu e q} \right) \right] M
\]

where \( M \) is the particle mass concentration, \( r \) the particle radius, \( J_s \) the air-earth current density, \( \mu \) the mean ion mobility and \( \rho \) the particle density. (This linear relationship between PG and \( M \) assumes a constant aerosol size distribution.) In our experiments, the aerosol mass concentration in the radius range 0.1μm-15 μm has been measured using an optical sensor (TSI DustTrak Model 8520), and PG is measured by an Electric Field Mill (Model JCI131) in urban air at the Reading University Atmospheric Observatory.

3. Results and Discussion

Fig. 1 shows the time series of “fair weather” PG and aerosol mass concentration \( (M) \) between 24th and 31st Dec 2005. There is generally a double diurnal cycle with a morning peak and an evening peak. The morning peak occurs between 7:00-9:00UT and the evening peak at around 17:00-20:00UT. Otherwise, \( M \) remains steady between 11:00-16:00UT. The maxima in aerosol mass concentration are very likely to be aerosol generated from routine anthropogenic activities like traffic and heating, and the horizontal convergence of aerosols in the boundary layer. As night advances, there is a reduction in the anthropogenic and urban aerosol production, while the aerosols closer to the surface are lost by sedimentation. This leads to a decrease in the concentration, as is seen in the early morning hours.
The solar heating of the land also increases during the day resulting in increased convective activity leading to an increase in the boundary layer height. The increase in boundary layer ventilation results in decrease in concentration of aerosols. By evening, solar forcing is cut off and the boundary layer height decreases, with an associated increase in aerosol concentration of particles.

The Christmas period was selected because of its reduced anthropogenic aerosol variation from to traffic at the beginning and end of normal working days. The PG measurements during 24 - 31 Dec 2005 showed a single diurnal cycle, indicating that the aerosol population appears is of relatively low concentration and less charged then unusual.

![Figure 2 Optical aerosol mass concentration plotted against Potential Gradient for 24- 31 Dec 2005, selecting PG values>50Vm⁻¹](image)

Fig. 2 shows the relationship obtained using the hourly average values of PG and M during 24 - 31 Dec 2005. The intercept (M=0) represent the zero pollution case, with the PG approximating the clean air fair weather value expected. The relationship has been used to remove the local aerosol effect on PG, with the expectation of a more globally representative PG diurnal cycle, such as that found in marine air by the Carnegie.

Over the sea, a single diurnal oscillation of PG is mainly observed, the Carnegie curve, depicting the global thunderstorm activity. This is observed because of the low aerosol content of marine air. In contrast, a double diurnal cycle is commonly observed at continental urban sites because of the aerosol effect. For example, a double diurnal variation in PG at Kew observatory extends back to the 1840s (Harrison and Aplin, 2002), with almost identical time of occurrence of morning and evening peak to the present results. The standard diurnal cycle of PG found by the Carnegie voyage for November-December-January (NDJ) has been compared with PG determined at Reading for 24-31 Dec 2005 (Fig. 3).

In the uncorrected case, the mean values are given; in the detrended case the aerosol relationship of Fig. 2 has been used to correct for the aerosol changes. If the relationship between aerosol properties and the PG is known, then it is possible to correct for local effects on the PG. If a linear relationship between PG and aerosol concentration is used to de-trend the influence of aerosol on PG, the correlation between the diurnal cycle of PG and the Carnegie curve is improved, since the local influence of aerosol is suppressed. Correlation between Carnegie curve and corrected PG showed R² = ~0.90 compared with R² = ~0.85 for the pre-detrended PG data. Comparison of corrected mean PG with global mean PG variation shows the procedure is effective in removing the local influence.
4. Conclusions
The present study shows that the particulate pollution has a substantial effect on the electrical properties of atmospheric air, reducing the air conductivity and increasing the Potential Gradient. Removing the aerosol effect from the PG allows the more global contribution to electric field diurnal cycle to be found. This could allow more globally representative PG measurements, if the local aerosol changes can be accounted for, like in this study.

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