# Lidar observations by circling the London orbital motorway

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**ABSTRACT**

A field campaign was conducted in London between 15 and 23 June 2009 in order to study the influence of emissions from within the London orbital motorway (M25) in terms of aerosol concentrations within the planetary boundary layer (PBL). The instrumental set-up involves a compact aerosol backscatter lidar, onboard a mobile van, developed by the CEA/LSCE and commercialized by LEOSPHERE Company and in situ instrumentation onboard the British Facility for Airborne Atmospheric Measurements (FAAM) BAe 146 research aircraft devoted to aerosol and gas measurements. For this experiment, the eye-safe lidar has been working at the wavelength of 355 nm. These observations represent the first application of this lidar around the London area. Thanks to the excellent manoeuvrability of the van, we monitored the particulate emissions from vehicles on the M25 by circling the M25.

## 1. INTRODUCTION

Forecasting atmospheric pollution peaks in urban areas becomes a relevant research topic for air quality and public health concerns in megacities, whose number is projected to increase. The European Union only contains two megacities: Greater London with ~14 M inhabitants and the Paris area with ~12 M inhabitants. Such large cities act as important sources of pollution, essentially from an automobile origin [1]. Paris has been fully investigated in terms of particulate and gas pollution in the framework of national (LISAIR, [2]) and international measurement campaigns (ESQUIF, [3]) using synergies between various observation platforms, in particular mobile vans and research aircraft. Similar studies have not yet been conducted in the London area to our knowledge. Such approaches nevertheless present a tremendous potential in improving our knowledge about pollution processes, in modelling and forecasting pollution events, and in setting up decision making tools for emission reduction strategies. Moreover, the organization of the next summer Olympic Games (2012) has been awarded to the city of London, which consequently requires validated forecasting tools for predicting polluting events.

We present here a field campaign carried out in London between 15 and 23 June 2009 devoted to the influence of emissions from within the London orbital motorway (M25) in terms of aerosol concentrations within the planetary boundary layer (PBL). The purpose of this experiment was to provide first observations enabling to assess the performance of chemistry-transport models devoted to air quality forecasting. This study will also help us to understand the microphysical and optical properties of aerosols above London, whose harmful impact on cardiovascular system has clearly been established [4])). In this paper, we present the first results obtained on the M25 on the 18 June 2009.

## 2. STRATEGY

The Aerosol Lidar System (ALS) is a custom-built backscatter lidar emitting in the ultraviolet (355 nm) developed by the Commissariat à l'Energie Atomique (CEA) and the Centre National de la Recherche Scientifique (CNRS). It is now available commercially from the LEOSPHERE Company under the name of EZ Lidar® (www.leosphere.com). For this experiment, the ALS version was operated onboard a small van circling the M25, which allows assessment of the role of the M25 in the production of anthropogenic aerosols (Fig. 1). The lidar signals have been calibrated, corrected from the background sky radiance and range-corrected. The main features of the lidar are reported in Table 1.

Figure 1: *ALS lidar onboard the mobile van at the Imperial College of London.. The ALS is positioned in horizontal shooting mode. The electronic acquisition system has been adapted for mobile measurements.*

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Table 1: *Lidar characteristics*

| | |
|---|---|
| Wavelength (nm) | 355 |
| Mean pulse energy (mJ) | 16 |
| Max pulse repetition rate (Hz) | 20 |
| Pulse length (ns) | ~5-7 |
| Beam diameter (mm) | ~20 |
| Beam divergence (mrad) | < 0.2 |
| Reception diameter (mm) | 150 |
| Filter bandwidth (nm) | 0.3 |
| Field of view (mrad) | ± 2 |
| Detector | Photomultiplier |
| Detection mode | Analog |
| Vertical resolution (m) | 1.5 |
| Lidar head size (cm) | ~65 x 35 x 18 |
| Lidar head weight (kg) | ~18 |
| Weight of the electronics (kg) | ~20 |
| Power supply (V) | 220 |

The Facility for Airborne Atmospheric Measurement (FAAM) BAe 146 research aircraft made 4 research flights and contains a comprehensive suite of instruments [5] measuring standard meteorological variables, solar and terrestrial radiative fluxes, chemical tracers (CO, $O_3$, $SO_2$) and aerosol properties (size distribution, scattering and absorption coefficients). In particular, a TSI 3076 nephelometer measured aerosol scattering coefficients at wavelengths of 0.45, 0.55, and 0.7 µm, which correspond to blue, green, and red light, respectively. This enabled calculation of the Angström exponent in the UV-visible and extrapolation of the scattering coefficient at the wavelength of the lidar (355 nm). Measurements have been corrected from the non-observed angles of the nephelometer chamber, and from the hygroscopic growth of the particles above the deliquescence point (55 % relative humidity) assuming a scattering growth factor [6]. Values have finally been converted into extinction coefficients assuming typical dry single-scattering albedo for urban aerosols (0.85) supposed similar to that found over Paris.

Coordinated FAAM flights and lidar-van circuits were carried out around the M25 (Fig. 2). Trajectories were slightly different between the two platforms due to airborne safety regulations above London. The possibility for the aircraft to perform vertical profiles into and out of airports gives us the opportunity to compare in situ measurements with lidar vertical profiles in terms of aerosol extinction coefficient (Fig. 3).

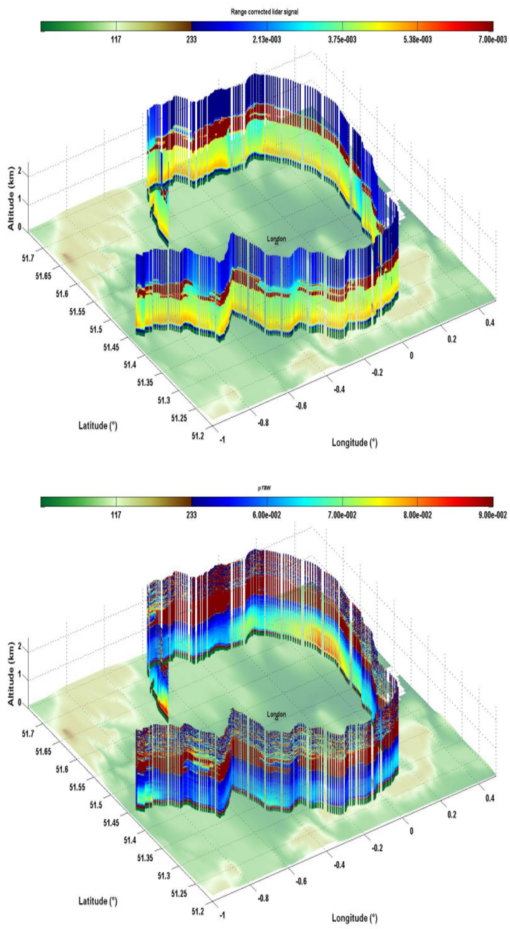


Figure 2: *Range corrected lidar profiles (top) and raw depolarized ratio (bottom) obtained from lidar instrument onboard the mobile van by circling the M25 on 18 June, 2009. The brown parts correspond to the clouds.*

## 3. COHERENCE OF THE OBSERVATIONS AND DISCUSSION

Regarding at the vertical structures of aerosols in the tropospheric column, we use the particulate extinction coefficient derived from nephelometer measurements. This result is compared to the vertical profiles retrieved from lidar measurements circling the M25 (Fig. 3).

Both platforms highlight a well-developed planetary boundary layer (PBL) reaching 2 km. The inversion of lidar profiles is done for non-cloudy situations (37 profiles). This approach relies on the assumption of a constant BER (backscatter-to-extinction) in the PBL column, which has been assessed to be ~0.025 $sr^{-1}$ at 355 nm through an iterative method converging when the optical thickness retrieved by the lidar is equal to that derived from the nephelometer. This value is much more significant than that obtained above Paris (0.011 $sr^{-1}$,[2]), which has to be validated with data from the other measurement periods. Also the effect of relative humidity (here, often higher than 70% in the PBL) on the extinction coefficient can lead to a vertical variability of BER values in the column. However, the aerosol extinction coefficient values shows spatial heterogeneities around the M25 and strong discrepancies are noticed between nephelometer and lidar measurements at 760 m (Fig. 5).

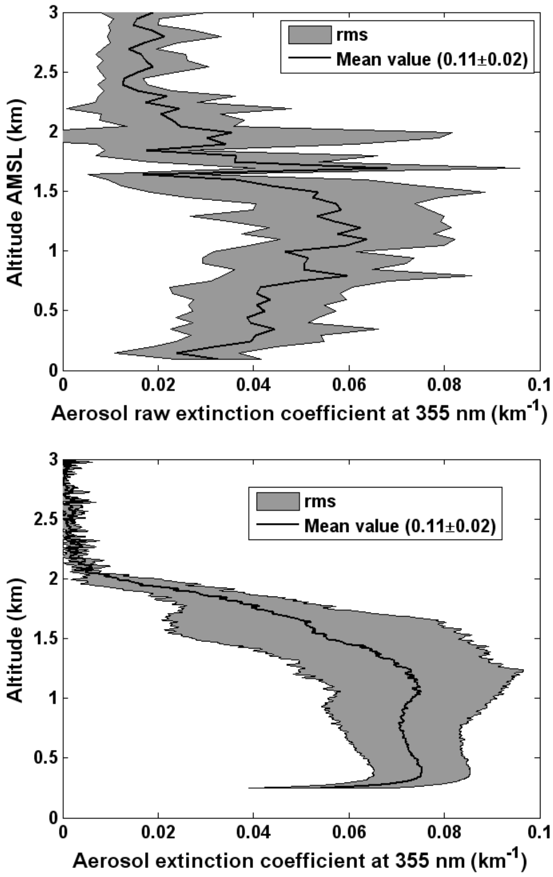


Figure 3: *Vertical profiles of the aerosol extinction coefficient derived from airborne nephelometer (top) and lidar onboard the mobile van (bottom). The value of the integrated aerosol optical thickness is also given between parentheses. The variability (rms) at each altitude level is given in grey.*

The localization of the London plume is readily detected in the north-eastern sector both by lidar retrievals and CO measurements, results which are in accordance with the south-westerly winds recorded by the aircraft (Fig 4). The fact the ozone peaks are detected in the South-east portion can be explained by the reaction $NO+O_3$ in the plume where the photochemical process are likely attenuated by the presence of dense cloud cover. The ozone plume at the South-East is generated by air masses that have not passed over London. The severe discrepancy between lidar and nephelometer measurements (Fig. 5) needs further investigation: the impact of clouds might be stronger and the correction of nephelometer values from relative humidity may be different, as suggested by lidar polarization observations (Fig. 2) showing higher values when relative humidity is lower (Fig. 6). This feature is well highlighted in the north-eastern part of the London megacity where

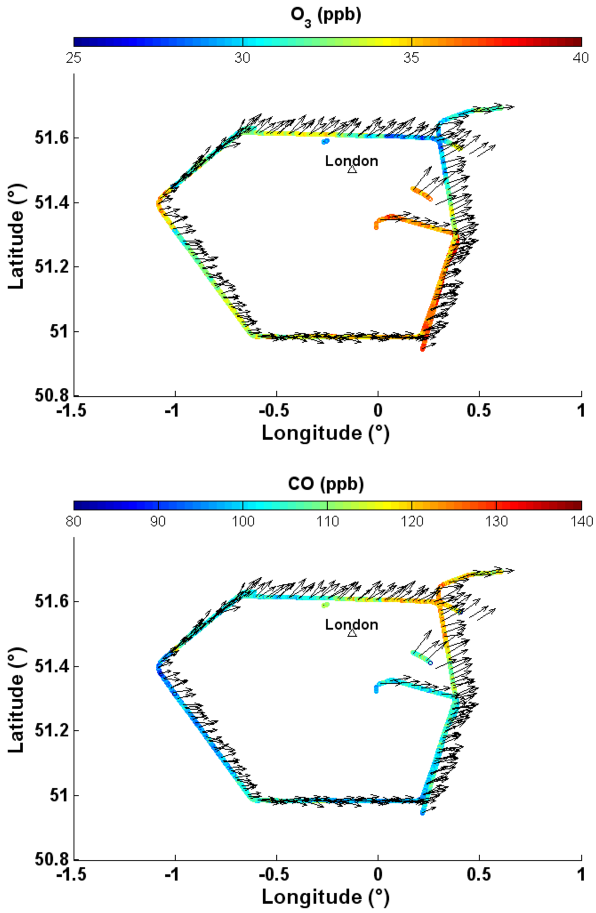


Figure 4: *Ozone (top) and carbon monoxide (bottom) mixing ratios measured from the FAAM aircraft. The wind direction is also drawn with black arrows.*

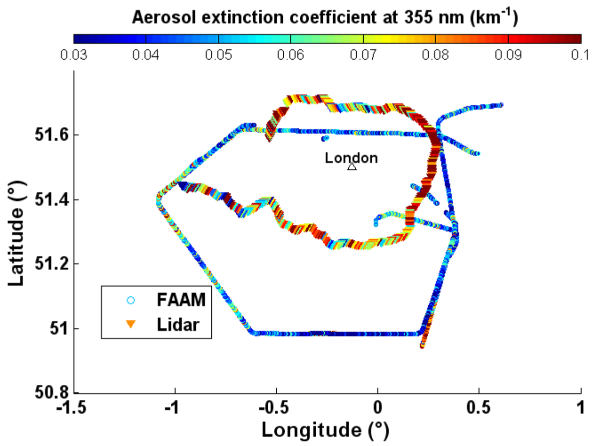


Figure 5: *Aerosol extinction coefficient retrieved at the altitudes close to 760 m by circling the M25 for the airborne nephelometer (closed circles) and lidar onboard mobile van (closed triangles).*

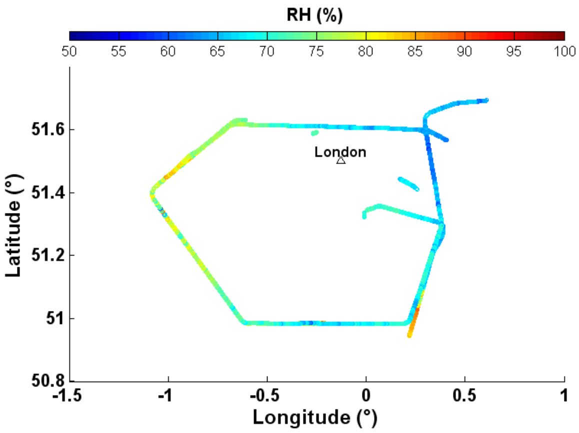


Figure 6: *Relative humidity from the FAAM aircraft.*

## 4. CONCLUSION

This work presents the first results of the spatiotemporal variability of aerosol concentrations in the London area. The future work particularly focuses on the link between the height of the different aerosol layers (convective PBL, nocturnal layer, residual layers…) and the aerosol loading in the low tropospheric column. The research aircraft enables a more accurate characterization of the detected plumes in terms of aerosol microphysical and optical properties. The coupling between active remote sensing and in situ measurements will allow the retrieval of vertical profiles of mass concentrations (PM10) in this urban environment with a very high vertical resolution (30 m).

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