Identification of Urban Aerosols during Wintertime Pollution Event in Baltimore

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ABSTRACT

During February 6-9, 2009, a wintertime pollution event developed over Baltimore as meteorological conditions (warm air aloft, moisture and strong surface temperature inversion) enhanced particle matter formation. The temporal evolution of the vertical distribution of particulate in the lower troposphere was monitored by the Elastic Lidar Facility (ELF) at the University of Maryland, Baltimore County (39.25°N, 76.71°W). The elastic lidar measurements (532 nm) indicate a dominant presence of non-spherical particles within the planetary boundary layer. The increase in the LIDAR scattering signal throughout the pollution event shows a good agreement with the temporal trend of particulate matter concentrations recorded in downtown Baltimore. Ambient urban particulate matter collected on filters were examined with a Scanning Electron Microscope (SEM) interfaced with an energy dispersive X-ray analysis and with particle induced X-ray emission (PIXE) to characterize quantitative size, volume and mass distribution as well as elemental composition.

1. INTRODUCTION

Urban air quality is influenced by the spatial and temporal distribution of emissions in cities, the topography of the urban area and its vicinity and the weather, including its atmospheric circulation patterns. Atmospheric particulate matter (PM) pollution events are enhanced by temperature inversions that trap pollutants near the surface from reduced turbulence and mixing with air aloft. Surface temperature inversions play a major role in air quality, especially during the winter when these inversions are the strongest. The warm air aloft on top of cooler air acts like a lid, suppressing vertical mixing and trapping the cooler air at the surface. As pollutants are emitted into the air, the inversion traps these pollutants near the ground, leading to poor air quality.

Elevated $PM_{2.5}$ events have been observed during strong winter inversions [1,2]. During these events $PM_{2.5}$ formation is dominated by nitrate, sulfate, ammonium and organic carbon. Long-term exposure to $PM_{2.5}$ mass loadings can result in decreased respiratory capacity, chronic bronchitis, and premature death. Short-term exposure may cause acute asthma and bronchitis, and lead to increased risks of heart attacks and arrhythmias [3].

We present in this paper elastic lidar measurements of the vertical distribution of particulate confined in the lower troposphere, the evolution of the planetary boundary layer, as well as the chemical composition, quantitative size, volume and mass distribution of ambient urban particulate matter collected during a wintertime pollution event in Baltimore, Maryland.

2. METEOROLOGICAL CONDITIONS

The February 6-9, 2009 weather during in the US Mid-Atlantic states was dominated by a high pressure system. Warm air aloft, increasing moisture and strong surface temperature inversion associated with this system led to an enhancement of PM formation. Figure 1 shows temperature profiles from radiosonde launches recorded at Dulles International Airport (IAD) in Virginia during this period. February 6 exhibits a temperature inversion below 850 m after 12:00 UTC. Inversions below 600 m were recorded between February 7 and 8, leading to the development of shallow vertical mixing layer, trapping pollutants near the surface.

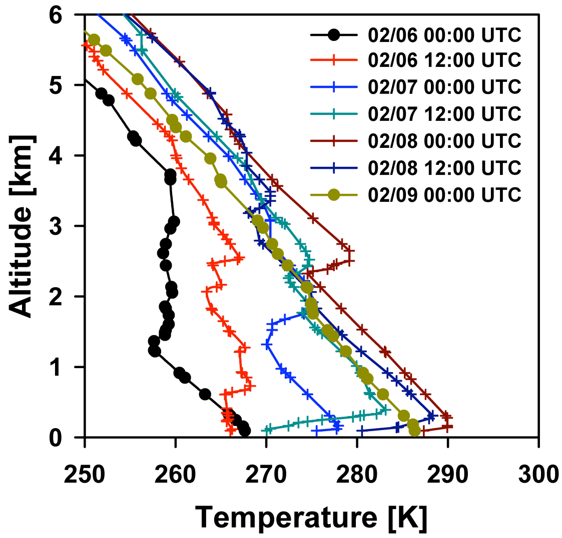

Figure 1. *Temperature profiles from radiosonde launches at Dulles International Airport, Virginia during February 6-9, 2009. Profiles with cross symbols show temperature inversions below 850 m during pollution event.*

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3. RESULTS

3.1 Lidar

*LI*ght *D*etection *A*nd *R*anging (*lidar*) measurements during atmospheric pollution events provide a real-time monitoring of the evolution of pollutants and the Planetary Boundary Layer (PBL), as aerosols can be used as tracers during mesoscale weather events. Elastic lidar measurements are routinely performed by the Elastic Lidar Facility (ELF) at the University of Maryland, Baltimore County (39.25°N, 76.71°W). Active measurements from ELF also support the NOAA CREST network (which monitors air quality in the vertical from multiple locations on the East Coast of the US), the North American part of the Global Atmospheric Watch Aerosol Lidar Observation Network (GALION), and for validation of the CALIPSO/OMI instruments on the NASA's A-Train.

The ELF lidar transmitter consists of Continuum Surelight II 532/1064 nm Nd:YAG laser that operates at a 10 Hz repetition rate and average pulse energy of 300 mJ. The receiver system consists of a 0.4 m Celestron Schmidt-Cassegrain telescope that collects the backscattered light. The output from the telescope is focused, after separation through a polarizing cube, to two Hamamatsu H6780 photomultiplier tubes (PMT) for detection of the 532 perpendicular and parallel channels. Detailed ELF system specifications and data analysis algorithms have been reported elsewhere [4,5].

3.2 Particulate Matter Sampling

Coarse ($PM_{2.5-10}$) and fine ($PM_{2.5}$) particulates were collected on two separate 47mm Nuclepore filters with 8 μm pores for the coarse fraction samples and 0.4 μm pores for the fine fraction samples. The filters were equilibrated for 24 hours, weighed in an air-conditioned room, and stored in airtight Petri slides. After sampling, the sample holder (stack filter unit) was returned to the laboratory for recovery of the filters, and the samples were equilibrated under the same conditions.

Particulate matter collected on filters was examined with a scanning electron microscope (SEM) interfaced with an energy dispersive X-ray analysis and with particle induced X-ray emission (PIXE) to characterize quantitative size, volume and mass distribution as well as elemental composition.

4. RESULTS AND DISCUSSION

Figure 2 shows the 532 nm elastic lidar measurements from midday on February 6 to 61 hours later. The observations indicate that besides the occasional clouds (reddish counts above 1.5 km) advecting over the field of view of ELF, the greatest amount of particulate scattering occurred within the first 650 meters of the troposphere during the winter pollution event. Maxima of backscatter intensities close to the surface may be ascribed to enhancement in the production of $PM_{2.5}$. Increase of the lidar backscatter temporally correlates to increases in $PM_{2.5}$ concentrations (Figure 3, recorded at the Maryland Department of the Environment Oldtown monitoring station in downtown Baltimore).

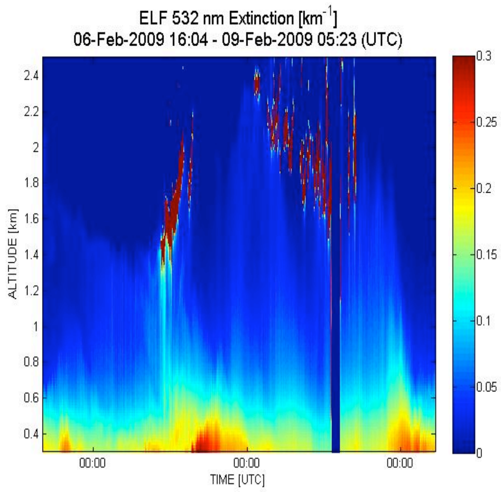

Figure 2. *Elastic lidar timeseries for February 6-9, 2009 during wintertime pollution event.*

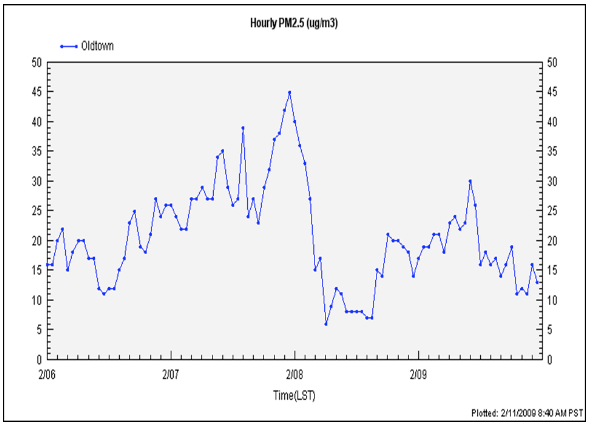

Figure 3. *Hourly PM2.5 concentrations recorded at Maryland Department of the Environment Oldtown Monitoring Station during the elastic lidar observations.*

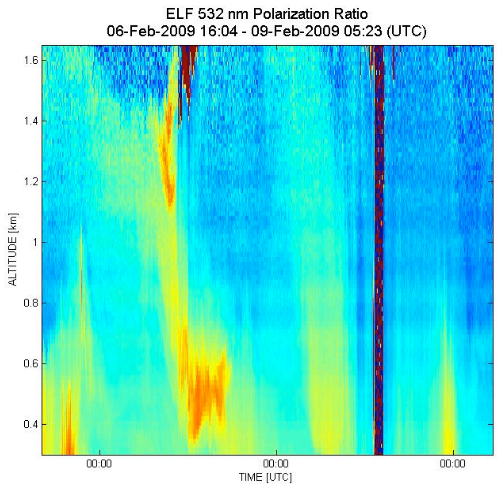

Figure 4. *Elastic lidar polarization ratio timeseries for February 6-9, 2009. Particle scattering within boundary layer are due to non-spherical particles.*

ELF, as described above, is a two channel lidar system that allows polarization ratio measurements of natural and human-made aerosol particles in the atmosphere. The polarization ratio divides the aerosols into two categories: spherical (like haze and forest fire smoke particles) and non-spherical (desert dust and biogenic debris like pollen). Figure 4 shows the vertical and temporal distribution of these non-spherical particles that are trapped within the PBL and their abundance is greater near the surface.

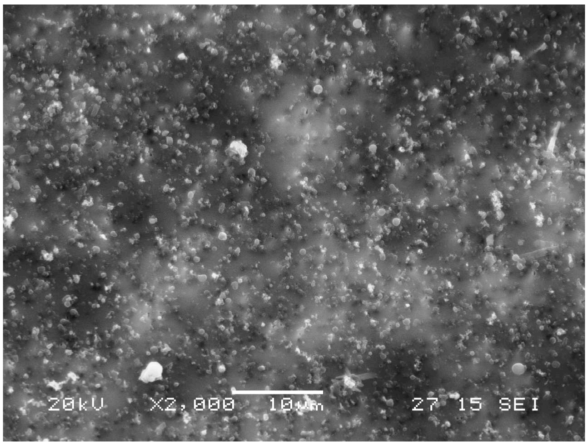

Figure 5. *SEM image for $PM_{2.5}$ filter collected on February 7, 2009.*

The morphology and elemental composition of coarse and fine particulate matter collected at the surface was determined from SEM and PIXE analysis. As it can be seen in the scanning electron micrograph represented in Figure 5, $PM_{2.5}$ particles appear irregular in shape and have an inhomogeneous nature. Figure 6 shows the number size distribution of the particles, obtained from both the coarse and fine filter samples. There is a high frequency (73%) of fine particles from 0.53 to 1.5 µm in diameter.

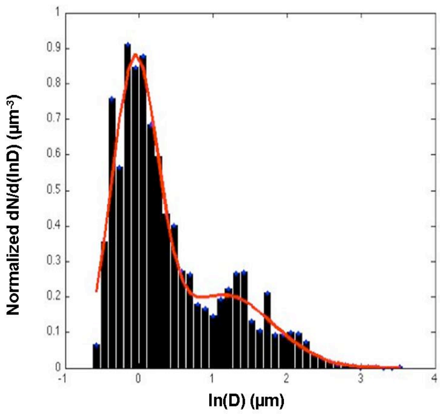

Figure 6.*Normalized number size distribution of particles according to the logarithm of their Ferret diameter.*

PIXE analysis, Figure 7 indicated that the most predominant elements on the fine and coarse sample filters are S, Si, Fe, Ca, and Cl.

Reconstruction of chemical composition of aerosols [6] and enrichment factors of elements [7] indicate that the enhancement on the formation of particulate matter was caused by the presence of suspended road salt from the Interstate 695 and 95. These two freeways average more than 100,000 vehicles per day, and snow events on days prior to February 6 necessitated recurrent application of salt to the roads.

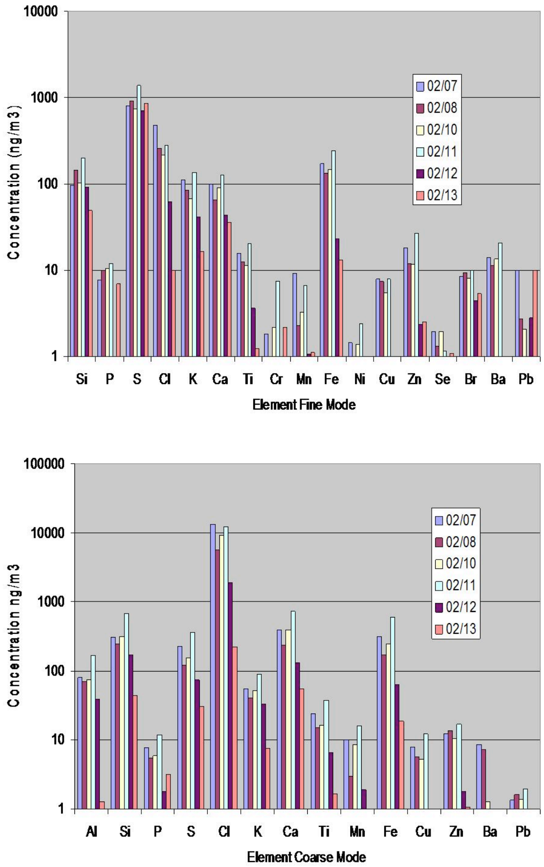

Figure 7.*Elemental composition of fine and coarse particulate matter samples analyzed with PIXE.*

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