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Analysis of size-segregated winter season aerosol data from New Delhi, India

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ABSTRACT

Size distributions of particulate matter and twelve constituent elements were measured at a high traffic site in New Delhi, India during winter 2013. While PM was found to be trimodal, individual elements showed varying size distribution patterns. Three key types of size distributions were observed including unimodal with peaks either in the coarse (Al, Si) or fine (Pb) modes, bimodal with peaks in the fine range (S) and multimodal with peaks in accumulation and coarse (Cu, Sb) modes. Elements such as Al, Si and Fe were found to be in predominantly in the coarse range while Cu, Zn, Pb and Sb were found to be in the fine size range. Two modes dominate the size distribution. One is coarse (ca. 3 μm) and contains mainly crustal elements and hence arises from sources such as soil, road dust, construction dust and possible coal fly ash. The other, more intense mode is fine (ca. 0.6 μm) and appears to comprise sulphate and anthropogenic trace metals which have entered the droplet mode through hygroscopic particle growth in the very high humidity conditions of the Delhi winter. A third, less intensive mode ca. at 0.2 μm probably arises from relatively fresh anthropogenic emissions which have not grown into the droplet mode.

1. Introduction

Particulate matter (PM) is one of the key pollutants found in the ambient air, and despite stringent pollution control programmes, cities across the world often exceed the local and/or national air quality standards. PM is known to have adverse effects on human health including respiratory and heart diseases, circulation disorders and in extreme cases, premature death. Urban air quality features among the major environmental concerns in cities around the globe, and much research has been undertaken to understand the sources and properties of PM. Many sources contribute to PM concentrations in urban areas including anthropogenic sources such as fossil fuel combustion (gasoline, diesel and coal), biomass combustion, building and construction, industrial processes and natural sources including marine aerosol (or sea salt), crustal dust and biological materials. Respiratory deposition and hence the health hazards posed by PM are crucially dependent upon the size distribution (Harrison et al., 2010).

Transition metals (e.g. Cu, Zn) are emitted from a range of sources including traffic (exhaust and non-exhaust), industries and coal combustion. Such elements are thought to be particularly detrimental for health due to their role in reactive oxygen species (ROS) formation (Kelly, 2003). Particle size is characteristic of the emission sources with some sources emitting coarse particles (PM with aerodynamic diameter between 2.5 and 10 μm) and others emitting fine (<2.5 μm) and ultrafine particles (<0.1 μm). The size distribution of a particular element or compound not only influences the potential health impact (in terms of respiratory deposition) (Harrison et al., 2010), but also influences the extent of

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atmospheric dispersion (Allen et al., 2001a). Size distributions can be measured in terms of mass, number or surface area (Harrison et al., 2000). A number of factors can influence the size distribution including, but not limited to, source type, meteorological conditions and extent of atmospheric aging (Zhu et al., 2006; Beddows et al., 2009; Hays et al., 2011).

Several studies in India have focused on the particle size distributions including mass size distributions (Khemani et al., 1982; Balachandran et al., 2000; Venkataraman et al., 2002; Reddy et al., 2007; Chelani et al., 2010), number size distributions (Monkkonen et al., 2005), or both (Sharma and Patil, 1992; Monkkonen et al., 2004; Baxla et al., 2009). However, there is a lack of detailed analysis on size distributions of elements in particulate matter samples from India.

The main objective of this study was to analyse the size distribution of PM mass and associated chemical compounds in New Delhi, India in relation to sources and atmospheric processing. Diurnal properties of $PM_{2.5}$ are also examined.

2. Methods

2.1. Sampling sites

Sampling was conducted at Mathura Road (New Delhi, India), one of the major arterial roads in Delhi, with an average traffic flow of 170 000 vehicles per day (Pant et al., 2015). The road also constitutes a part of a major national highway (NH 2) providing connectivity in the northern part of the country. As a result, a large volume of inter-city diesel buses as well as trucks (diesel, BS-III, 350 ppm sulphur) ply on this road. While the sampling location is primarily a traffic site, there are other major sources of pollution located in the vicinity of the site. These include an industrial hub within three kilometres of the sampling site (Okhla Industrial Area) and residential and waste burning in nearby low-income settlements in addition to resuspended dust. Trucks are not allowed between 0730 to 1100 h and 1700–2130 h, while buses, light duty vehicles (LDVs) and two and three wheelers are not restricted (Delhi Police, 2014). It is important to note that Bharat Standard IV (BS-IV, 50 ppm sulphur) standards are applicable to the vehicles within Delhi (one of the 14 cities in India with BS-IV fuel) and vehicles from outside Delhi are often BS-III (equivalent of Euro III) because of universal availability of BS-III fuel in India. Similarly, buses plying within Delhi are CNG-based while inter-city buses run on diesel. A summary of the modal variations through the day is presented in Fig. 1.

2.2. Sampling

Sampling was undertaken from December 16 through December 22, 2013. PM_{10} and $PM_{2.5}$ was monitored using a DustTrak DRX aerosol monitor (Model 8533, TSI Inc., USA). The instrument was pre-calibrated to 29% RH and Arizona Road Dust. Correction factors (internal size-calibration, RH correction and difference between Arizona dust and Delhi aerosols) were applied to the data before analysis. Size-segregated PM samples were collected using 10-stage non-rotating Micro-Orifice Uniform Deposit Impactor (MOUDI) (Model 110, MSP Corporation, Minneapolis, Minnesota, USA) at a flow rate of 30 Lpm. Samples were collected for a period of 6 h each (0000-0600; 0600-1200; 1200-1800 and 1800-2400) using 47 mm polytetrafluoroethylene (PTFE) filters (pore size of 1.0 μm) as impaction substrates and 37 mm quartz fibre filters as back-up. The samples were collected in the flow-corrected size ranges between 0.06 and 20.2 μm. The sampler was placed at a distance of 2 m from the main road at a height of two metres from the ground.

It was a dry period (no rainfall during the sampling period) with fog and haze (RH varied from 79 to 93.5% on average), and wind speeds were less than 5 km/h for most days (lowest wind speed of 1 km/h). High relative humidity was observed (>75% across all days) and the maximum and minimum temperatures were 23 °C and 5.2 °C.

2.3. Chemical analysis

Gravimetric analysis was performed on the PTFE filter samples using an MC5 Sartorius microbalance. Before weighing, all filters were equilibrated in a humidity (35–45% relative humidity) and temperature (25° Celsius) controlled windowless room for 24 h. An ionizing blower and an α-particle source (^{210}Po) were used to reduce the effects of static electricity.

Extraction of the trace metals was performed using reverse aqua regia solution by a quality assured procedure which is described in detail elsewhere (Allen et al., 2001a; Birmili et al., 2006). Briefly, each filter was extracted using 2 ml of 189 cm^3/L Aristar Grade hydrochloric acid (HCl) and 66 cm^3/L Aristar Grade nitric acid (HNO_3) per sample. The samples were heated followed by mild sonication and were diluted before analysis. Inductively Coupled

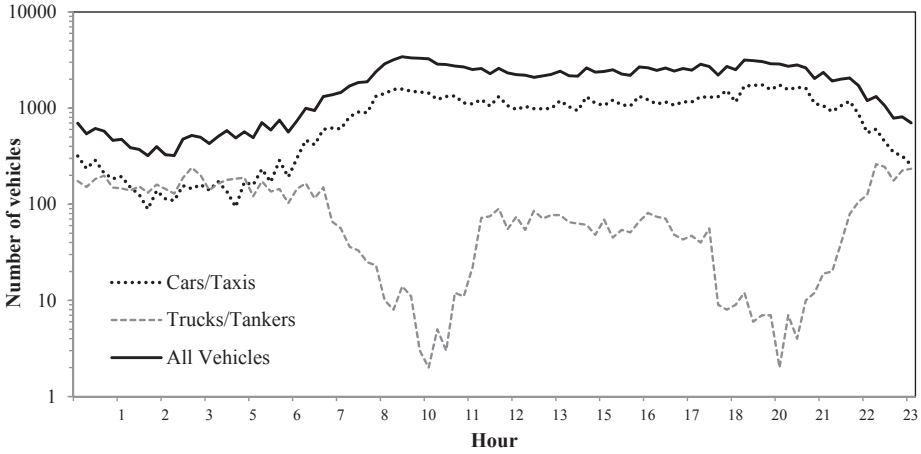

Fig. 1. Temporal variation of traffic at the sampling site.