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Sub-micron particle number size distributions characteristics at an urban location, Kanpur, in the Indo-Gangetic Plain

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ABSTRACT

We present long-term measurements of sub-micron particle number size distributions (PNSDs) conducted at an urban location, Kanpur, in India, from September 2007 to July 2011. The mean Aitken mode (N_{AIT}), accumulation mode (N_{ACCU}), the total particle (N_{TOT}), and black carbon (BC) mass concentrations were 12.4×10^3 cm^{-3}, 18.9×10^3 cm^{-3}, 31.9×10^3 cm^{-3}, and 7.96 μg m^{-3}, respectively, within the observed range at other urban locations worldwide, but much higher than those reported at urban sites in the developed nations. The total particle volume concentration appears to be dominated mainly by the accumulation mode particles, except during the monsoon months, perhaps due to efficient wet deposition of accumulation mode particles by precipitation. At Kanpur, the diurnal variation of particle number concentrations was very distinct, with highest during morning and late evening hours, and lowest during the afternoon hours. This behavior could be attributed to the large primary emissions of aerosol particles and temporal evolution of the planetary boundary layer. A distinct seasonal variation in the total particle number and BC mass concentrations was observed, with the maximum in winter and minimum during the rainy season, however, the Aitken mode particles did not show a clear seasonal fluctuation. The ratio of Aitken to accumulation mode particles, N_{AIT}/N_{ACCU}, was varied from 0.1 to 14.2, with maximum during April to September months, probably suggesting the importance of new particle formation processes and subsequent particle growth. This finding suggests that dedicated long-term measurements of PNSDs (from a few nanometer to one micron) are required to systematically characterize new particle formation over the Indian subcontinent that has been largely unstudied so far. Contrarily, the low N_{AIT}/N_{ACCU} during post-monsoon and winter indicated the dominance of biomass/biofuel burning aerosol emissions at this site.

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1. Introduction

Atmospheric aerosol particles are ubiquitous, which impact not only global climate but also human health, air quality and visibility. Nowadays, the effects of particles on human health are of serious concern in urban areas, particularly for nations with very fast changing economies, such as India and China. As per the National Ambient Air Quality Monitoring Program (NAAQMP) in India, particulate matter less than 10 μm (PM_{10}) has the highest exceedance rate, followed by nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). The $PM_{2.5}$, which is not widely monitored in India, is expected to be even worse (CPCB, 2012). To quote few facts from recent studies, Ramanathan et al. (2008) estimated that an increase in anthropogenic $PM_{2.5}$ concentration of 2.5 μg m^{-3} from its current value would result in 337,000 excess deaths per year, owing to outdoor exposure to air pollution in India, and exposure to indoor pollution attributable to solid fuel use is estimated to cause an additional 407,100 deaths in India. Aerosol particles also reduce incoming solar radiation to the surface in India by

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about 15 W m^{-2} or more, compared with pre-industrial values, causing solar dimming (Padma Kumari et al., 2007; Ramanathan et al., 2008) as well as reduced visibility (Singh and Dey, 2012; Wang et al., 2009). A statistically significant increasing trend in aerosol loading, about 2.3% $year^{-1}$ of its value in 1985 and more rapidly ~4% $year^{-1}$ during the last decade, over India was also observed (Moorthy et al., 2013). Moreover, black carbon (BC) aerosols, with the second or third largest global warming potential have not only attracted atmospheric and climatic scientists' attention but also attracted policy makers' due to its adverse human health effects. Thus, the observation of sub-micron particles over a wide size range (from a few nanometer to one micron), BC and chemical composition over an extended period of time is crucial to evaluate their effects on human health, the environment, air quality and the climate over Indian subcontinent, where long-term datasets are scarce, or available as a whole for only a few locations in an air quality networks.

Until now, numerous researchers have carried out continuous measurements of sub-micron particle number size distributions (PNSDs) at a variety of locations to examine their diurnal patterns and seasonal variations. Table 1 summarizes such long-term measurements of sub-micron PNDSs from selected urban areas across the globe. In these studies, the temporal evolution of particle number concentrations showed pronounced seasonal variation with lower concentrations in summer and higher concentrations during winter, whereas the diurnal patterns were mostly found to be strongly influenced by vehicular emissions. A pronounced increase in particle number concentrations, particularly the Aitken mode particles, was also observed during traffic hours (Stanier et al., 2004). Thus, the vehicular emissions have been considered as one of the major sources of aerosol loading in urban areas. Besides, the formation of new particle (i.e. nucleation) is also a further, and important, source of particles in the atmosphere (Kulmala, 2003; Shi and Harrison, 1999; Zhang, 2010). Several studies have also examined new particle formation (NPF) characteristics in diverse environments (Kulmala et al., 2004), including middle-upper troposphere (Kanawade and Tripathi, 2006), Finland boreal forest site (Makela et al., 1997), rural site (Weber et al., 1997), semi-rural site (Kanawade et al., 2012) as well as urban areas (Kanawade et al., personal communication; McMurry et al., 2005; Mönkkönen et al., 2005; Stanier et al., 2004; Young et al., 2013). These newly formed particles may further account for 3–70% of the global CCN production in the troposphere (Matsui et al., 2013; Pierce and Adams, 2009).

In India, there are several long-term studies on aerosol physical and optical properties based on satellite datasets (Dey and Di Girolamo, 2011; Kaskaoutis et al., 2013; Ramachandran et al., 2013), Aerosol Robotic Network (AERONET) measurement stations (Dey and Tripathi, 2008; Eck et al., 2010; Kaskaoutis et al., 2012; Singh et al., 2004), and Aerosol Radiative Forcing over India NETwork (ARFINET) (Moorthy et al., 2013). However, to the best of our knowledge, there are currently no reports published on long-term measurements of sub-micron PNSDs in urban areas of India, except two studies which examined seasonal characteristics of PNSDs at the semi-urban site, Gual Pahari (Hyvarinen et al., 2010), and the Himalayan background site, Mukteshwar (Komppula et al., 2009).

Here, we analyze four-year measurements of sub-micron PNSD to examine diurnal patterns of size-segregated particle number concentrations and seasonal variations of particle size distributions at an urban location, Kanpur, in the Indo-Gangetic Plain (IGP) of India. We measured PNSDs using a scanning mobility particle sizer (SMPS) in the size range of 13.8–685 nm at Kanpur during September 2007–July 2011. Simultaneously, BC measurements were also made using the seven channel Aethalometer. Previously, we have analyzed PNSDs (Baxla et al., 2009) and BC mass concentrations (Ram et al., 2010) from ~1 year of measurements at this site, but the present study focuses on statistical analysis of long-term measurements of PNSD, in particular for an improved understanding of atmospheric aerosol processes, and BC, due to its importance for climatic and human health studies over this region (Ramanathan et al., 2008).

Table 1
Comparison of total particle number concentrations at Kanpur with those reported from other urban locations worldwide based on long-term observations.

Location	Lat. [deg.]	Long. [deg.]	Site type	Period [month/year]	Size range [nm]	Particle conc. [N_{TOT}, 10^3 cm^{-3}]	Reference
Kanpur, India	26.46	80.32	Urban	12/2006–11/2011	14–685	31.9 ± 29.7	This study
Beijing, China	39. 54	116. 23	Urban	03/2004–03/2006	3–1000	32.7	(Wu et al., 2008)
Pittsburgh, USA	40.44	−80.00	Urban	07/2001–06/2002	3–500	22.0	(Stanier et al., 2004)
Atlanta, USA	33.76	−84.39	Urban	08/1998–08/1999	10–100	21.4	(Woo et al., 2001)
Rochester, NY, USA	43.16	−77.60	Urban	01/2002–12/2009	10–500	7.6	(Wang et al., 2011a)
Birmingham, UK	52.48	−1.89	Urban	10/2002–03/2004	7–3000	18.8	(Puustinen et al., 2007)
London, UK	51.52	0.13	Urban	04/2004–04/2005	10–415	11.4	(Rodríguez et al., 2007)
Milan, Italy	45.48	9.17	Urban	11/2003–12/2004	10–800	25.8	(Rodríguez et al., 2007)
Barcelona, Spain	41.38	2.12	Urban	11/2003–12/2004	10–800	16.8	(Rodríguez et al., 2007)
Leipzig, Germany	51.33	12.38	Urban	02/1997–02/2001	3–800	21.0	(Wehner and Wiedensohler, 2003)
Bern, Switzerland	46.95	7.44	Urban	01/2009–12/2009	7–1000	28.0	(Reche et al., 2011)
Huelva, Spain	37.25	6.95	Urban	01/2009–12/2009	3–10,000	17.9	(Reche et al., 2011)
Helsinki, Finland	60.16	24.95	Urban	01/1998–12/2000	8–400	17.2	(Hussein et al., 2004)
Budapest, Hungary	47.47	19.06	Urban	11/2008–11/2009	6–1000	11.8	(Salma et al., 2011)
Amsterdam, Netherlands	52.37	4.89	Urban	10/2002–03/2004	7–3000	18.1	(Puustinen et al., 2007)
Athens, Greece	37.96	23.71	Urban	10/2002–03/2004	7–3000	20.3	(Puustinen et al., 2007)
Brisbane, Australia	−27.5	153.0	Urban	07/1995–11/2000	15–630	5–17	(Mejía et al., 2007)
Gual Pahari, India	28.43	77.15	Semi-urban	11/2007–01/2010	4–10,000	21.8	(Hyvarinen et al., 2010)
Mukteshwar, India	29.43	79.62	Background	11/2005–11/2008	10–800	2.7	(Komppula et al., 2009)

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