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Optical properties of size-resolved particles at a Hong Kong urban site during winter

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ABSTRACT

Visibility degradation in Hong Kong is related to the city's serious air pollution problems. To investigate the aerosols' optical properties and their relationship with the chemical composition and size distribution of the particles, a monitoring campaign was conducted at an urban site in the early winter period (from October to December, 2010). The particle light scattering coefficient (B_{sp}) and absorption coefficient (B_{ap}) were measured. Two collocated Micro-Orifice Uniform Deposit Impactor samplers (MOUDI110, MSP, USA) with nominal 50% cut-off aerodynamic diameters of 18, 10, 5.6, 3.2, 1.8, 1, 0.56, 0.32, 0.18, 0.1, and 0.056 μm were used to collect size-resolved particle samples. The average B_{sp} and B_{ap} were 201.96 ± 105.82 Mm^{-1} and 39.91 ± 19.16 Mm^{-1}, with an average single scattering albedo (ω_o) of 0.82 ± 0.07. The theoretical method of light extinction calculation was used to determine the extinction of the size-resolved particulate matters (PM). The reconstructed light scattering coefficient correlated well with the measured scattering value in the Hong Kong urban area. Droplet mode (0.56–1.8 μm) particles contributed most to the particle light extinction (~69%). Organic matter, ammonium sulphate and elemental carbon were the key components causing visibility degradation in the droplet (0.56–1.8 μm) and condensation (0.1–0.56 μm) size ranges. Five sources contributing to particle light extinction have been identified using positive matrix factorisation (PMF). Traffic/engine exhausts and secondary aerosols accounted for ~36% and ~32% of particle light extinction, respectively, followed by sea salt (15%). The remaining sources, soil/fugitive dust and tire dust, contributed by ~10% and 7%, respectively, to particle light extinction.

1. Introduction

Visibility impairment results from the scattering and absorption of incoming sunlight (Tao et al., 2009; Watson, 2002). The light extinction (B_{ext}) can be used to describe its characteristics, providing a summation of light scattering and absorption from particulate and gaseous matter (Bohren and Huffman, 2008). Natural and pollution-derived particles disturb the Earth's radiation balance and indirectly affect cloud formation and climate change (Bohren and Huffman, 2008; Ling et al., 2013; Rosenfeld, 1999; Yan et al., 2008). Particle optical properties are highly related to particle sizes, shapes and chemical components (Tsai et al., 2012; Yan et al., 2008; Yu et al., 2010).

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The frequency of low visibility days in Hong Kong has increased over the last decade (HKO, 2013). Past studies (Chang and Koo, 1986; Cheung et al., 2005; Lai and Sequeira, 2001; Lee and Sequeira, 2002; Man and Shih, 2001; Sequeira and Lai, 1998; Wang et al., 2003) have shown that ammonium sulphate ($(NH_4)_2SO_4$) and elemental carbon (EC) are the most important factors causing this visibility impairment. Ammonium sulphate is a hydrophilic compound, and its resulting increase in relative humidity (RH) can enhance its light scattering effect. Many methods have been used to determine the scattering and absorption efficiency of chemical components, including the theoretical method, the partial scattering method, the measurement method and the multilinear regression (MLR) method (Hand and Malm, 2007). The theoretical and partial scattering methods have been used to determine the scattering and absorption efficiencies of chemical components in the USA. (Lowenthal and Kumar, 2004, 2006; Malm and Pitchford, 1997; Sloane, 1986). In Hong Kong, the MLR method and the US Interagency Monitoring of Protected Visual Environments (IMPROVE) equation have commonly been used to determine the contributions of different chemical components to visibility impairment in $PM_{2.5}$ and PM_{10} (Wang et al., 2003). A small number of studies have focused on determining the optical properties of size-resolved particles (Lowenthal et al. 1995; Sloane and Wolff, 1985).

In this study, optical parameters were measured and size-fractionated chemical components (i.e., elements, water soluble ions and carbon) were analysed hourly during the winter period at an urban site in Hong Kong. The study aims to 1) determine the characteristics and variations of the optical properties of size-segregated particles in an urban environment; 2) provide insight into size-resolved particles and their chemical extinction (the summation of (mass concentration × their mass extinction efficiency) for different chemical components) by using the theoretical method; and 3) identify potential sources contributing to particle light extinction.

2. Methods

2.1. Sampling site

Hong Kong occupies an area of 1104 square kilometres, with a population of seven million; it is one of the developed cities in the world (World Bank, 2011). The sampling site was located on the rooftop of an eight-floor building on the campus of the Hong Kong Polytechnic University (HKPU) (22.30°N, 114.17°E), as shown in Fig. 1. This site is close to the Cross Harbour Tunnel, subject to heavy traffic activity and regional pollutant transport.

2.2. Continuous optical, gaseous and meteorological parameter measurements

The particle light scattering coefficients (B_{sp}) for fine suspended particles were measured hourly using an integrating nephelometer (wavelength, $\lambda = 525$ nm) with a heater (Aurora-1000 Ecotech, Melbourne, Australia) to maintain the RH of <60%. The heated nephelometer may have caused some evaporation of ammonium nitrate, (NH_4NO_3), which is one of chemical components leading to visibility impairment (Watson et al., 2008b). To restrict the nephelometer uncertainty to within ±10%, its sampling tube was designed based on Bergin et al. (1997). Calibration was performed by a daily zero check (to within ±1 Mm^{-1}) and a monthly span check (not more than 10% of the recommended value). The zero check was performed automatically by pumping in particle-free air. The span check was performed manually using carbon dioxide (CO_2), as recommended by the manufacturer (Aurora-1000 User Manual, 2008). Hourly black carbon (BC) concentrations ($\mu g/m^3$) were measured using an aethalometer with a flow rate of 5 L/min (Magee Scientific Company, Berkeley, CA, USA, Model AE-31). The particles absorption coefficient (B_{ap}) (Mm^{-1}) at $\lambda = 532$ nm was calculated from the BC

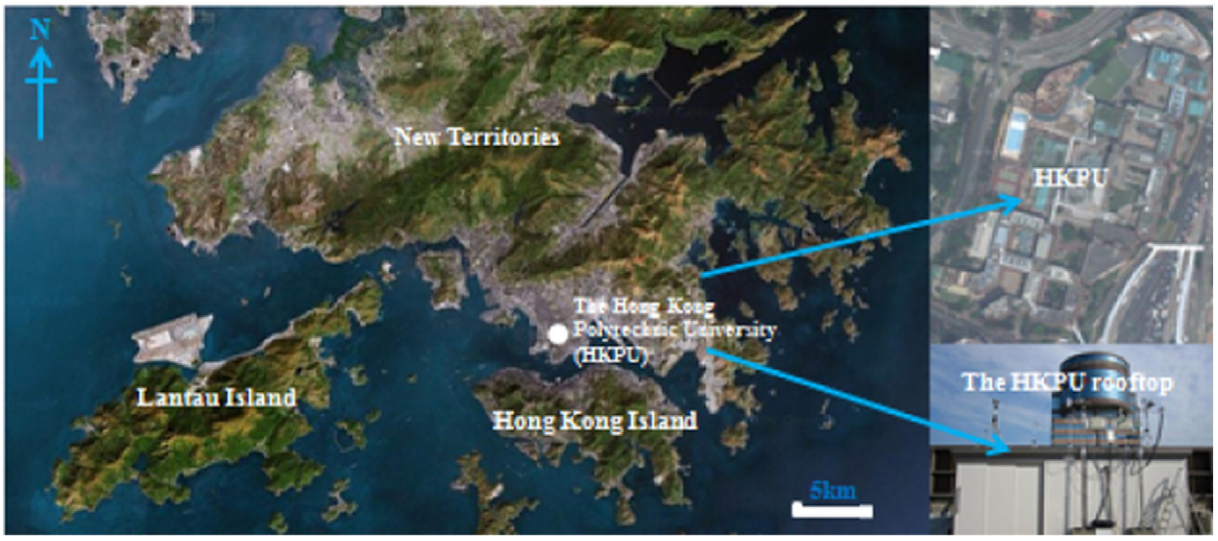

Fig. 1. Location of the sampling site, at the Hong Kong Polytechnic University, Kowloon.