Atmospheric Research 160 (2015) 59–67

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

The optical properties of urban aerosol in northern China: A case study at Xi'an

Chong-Shu Zhu [a,b], Jun-Ji Cao [a,b,d,*], Kin-Fai Ho [c,**], L.-W. Antony Chen [a,g], Ru-Jin Huang [e], Yi-Chen Wang [a], Hua Li [a,h], Zhen-Xing Shen [f], Judith C. Chow [a,g], John G. Watson [a,g], Xiao-li Su [a], Qi-yuan Wang [a], Shun Xiao [a,i]

[a] Key Laboratory of Aerosol Chemistry & Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China
[b] SKLLQG, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China
[c] The Jockey Club School of Public Health and Primary Care, The Chinese University of Hong Kong, Shatin, Hong Kong
[d] Institute of Global Environmental Change, Xi'an Jiaotong University, Xi'an, China
[e] Laboratory of Atmospheric Chemistry, Paul Scherrer Institute (PSI), 5232 Villigen PSI, Switzerland
[f] Department of Environmental Science and Engineering, Xi'an Jiaotong University, Xi'an, China
[g] Division of Atmospheric Sciences, Desert Research Institute, Reno, NV, USA
[h] Key Scientific Research Base of Ancient Polychrome Pottery Conservation, SACH, Emperor Qin Shihuang's Mausoleum Site Museum, Xi'an, China
[i] Shaanxi Meteorological Bureau, Xi'an, China

ARTICLE INFO

Article history:
Received 26 September 2014
Received in revised form 6 March 2015
Accepted 15 March 2015
Available online 24 March 2015

Keywords:
PAX
SSA
Scattering coefficient
Absorption coefficient
Xi'an

ABSTRACT

Simultaneous measurements of particle scattering coefficient (B_{scat}) and absorption coefficient (B_{abs}) were conducted at Xi'an from mid-August to mid-October 2012 to estimate the particle single scattering albedo (SSA) and the Ångström coefficients in highly polluted urban air. The hourly averaged B_{scat} was 272 Mm^{-1} at 532 nm and 82 Mm^{-1} at 870 nm, while hourly averaged B_{abs} was 31 Mm^{-1} at 532 nm and 19 Mm^{-1} at 870 nm. Similar diurnal variations for B_{scat} and B_{abs} were observed between the two wavelengths. The averaged SSA was 0.88 at 532 nm and 0.78 at 870 nm. Based on the Ångström coefficients, anthropogenic fine particles show dominant contribution during the sampling period, accompanied by occasional dust events. Moreover, the major contributors to aerosol optical properties are attributed to the mixture of black carbon (BC) and brown carbon (BrC) with non-absorbing components over urban area in northern China. The findings provide useful insights into the factors affecting the visibility in northern Chinese cities and therefore essential knowledge for improving the air quality.

1. Introduction

The light extinction of aerosol particles, including scattering and absorption, affects visibility and climate (e.g., Ackerman et al., 2000; Watson, 2002; Jacobson, 2006; Koren et al., 2008; Ramanathan and Feng, 2009; Cao et al., 2012a). The scattering aerosol species such as sulfate and nitrate contribute to atmospheric cooling, while light absorbing aerosol species such as black carbon (BC), brown carbon (BrC) and dust exert a positive radiative forcing and reinforce the atmospheric warming due to an increase in the greenhouse gases (IPCC, 2007; Ramanathan and Carmichael, 2008).

The scattering coefficient (B_{scat}) and absorption coefficient (B_{abs}) are two important optical parameters describing the scattering and absorption cross sections in a unit volume of air at a wavelength of λ. These two optical parameters are important for modeling atmospheric radiation transfer (Clarke et al., 1987). The sum of B_{scat} and B_{abs} is the particle extinction coefficient (B_{ext}) determining the attenuation of light in the atmosphere, while the particle single scattering albedo (SSA) is defined as the ratio of B_{scat}/B_{ext} (Bodhaine, 1995):

$$SSA = B_{scat}/B_{ext} = B_{scat}/(B_{scat} + B_{abs}). \quad (1)$$

The wavelength dependence of SSA is determined by the size, chemical composition, and mixing state of particles (Kokhanovsky, 2008; Moosmüller et al., 2009; 2012). Though visibility and climate modeling should consider aerosol optical properties across the tropospheric solar spectrum (300–900 nm), SSA at mid-visible wavelength is often used to evaluate the aerosol radiative forcing. For example, Hansen et al. (1997) showed that a decrease of SSA at 550 nm from 0.9 to 0.8 may change the radiative forcing from negative (cooling) to positive (warming), depending on the surface albedo and aerosol optical depth. In general, the optical properties of atmospheric particles show a great spatial and temporal variability, due to the difference in concentration, particle size, chemical composition and mixing state (Kokhanovsky, 2008).

The urban areas in northern China are one of the most polluted regions in the world (e.g., Cao et al., 2012b; Zhang et al., 2013). However, direct measurements of aerosol optical properties in this region are very

* Correspondence to: J.-J. Cao, Institute of Earth Environment, Chinese Academy of Sciences (CAS), No. 10 Fenghui South Road, High-Tech Zone, Xi'an 710075, China. Tel: +86 29 8832 6488; fax: 86 29 8832 0456.
** Correspondence to: K.-F. Ho, The Jockey Club School of Public Health and Primary Care, The Chinese University of Hong Kong, Shatin, Hong Kong.
E-mail addresses: cao@loess.llqg.ac.cn (J.-J. Cao), kfho@cuhk.edu.hk (K.-F. Ho).

http://dx.doi.org/10.1016/j.atmosres.2015.03.008
0169-8095/

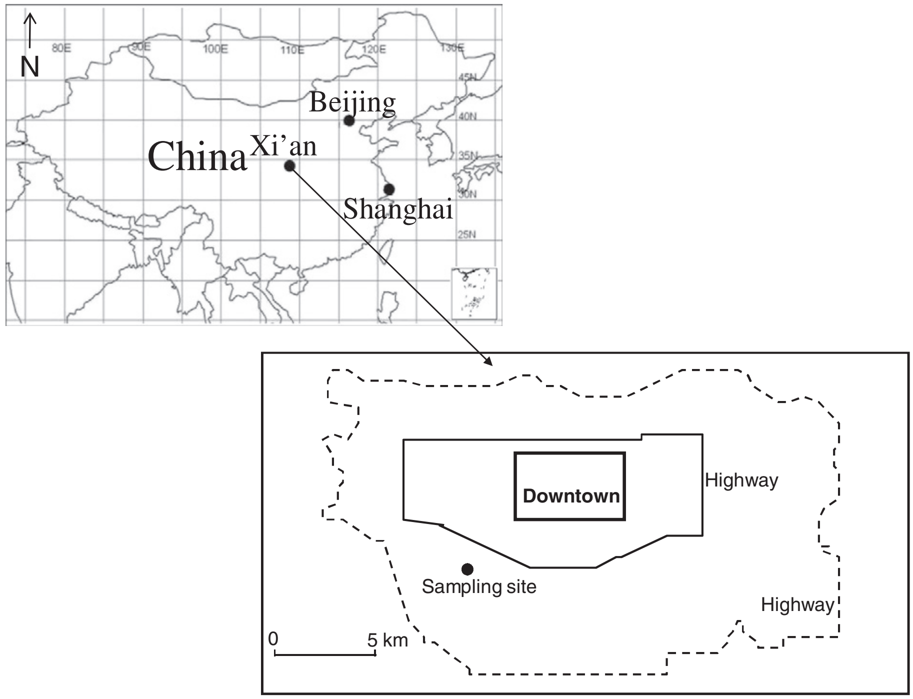

Fig. 1. Sampling location, Xi'an.

scarce to date, significantly hindering our understanding of the impact of aerosol on visibility and regional climate. Here, we present results of a 2-month field campaign carried out at Xi'an with a specific focus on aerosol scattering and absorption properties at both visible (532 nm) and near-infrared wavelengths (870 nm). The objectives of this study were: 1) investigating the variations of B_{scat}, B_{abs}, and SSA, 2) establishing a conceptual equation for visibility degradation in Xi'an, and 3) estimating the main contributors to light extinction by using the Ångström coefficient.

2. Measurements

The measurements were conducted from mid-August to mid-October 2012 at the Institute of Earth Environment, Chinese Academy of Sciences in Xi'an, China (Fig. 1). Xi'an is located on the Guanzhong Plain at the south edge of the Loess Plateau 400 m above sea level. Samples were taken on the roof of a two-story building ~10 m above ground level (34.23°N, 108.88°E), ~50 m west of a moderately traveled 4-lane round and ~25 m north of a lightly traveled 2-lane road. The monitoring site was located in an urban-scale zone of representation, where there are no major industrial activities (Cao et al., 2005). Xi'an is a megacity in northwestern China, characterized by high $PM_{2.5}$ (particles with aerodynamic diameter ≤2.5 μm) pollution (Cao et al., 2012b). Coal combustion, biomass burning, vehicle emissions, and fugitive dust (airborne particles that originate from unpaved roads, agricultural cropland and construction sites) are reported to be the main contributors to the high particle pollution at this region (Cao et al., 2005, 2007, 2009; Shen et al., 2009). The average values of temperature, relative humidity

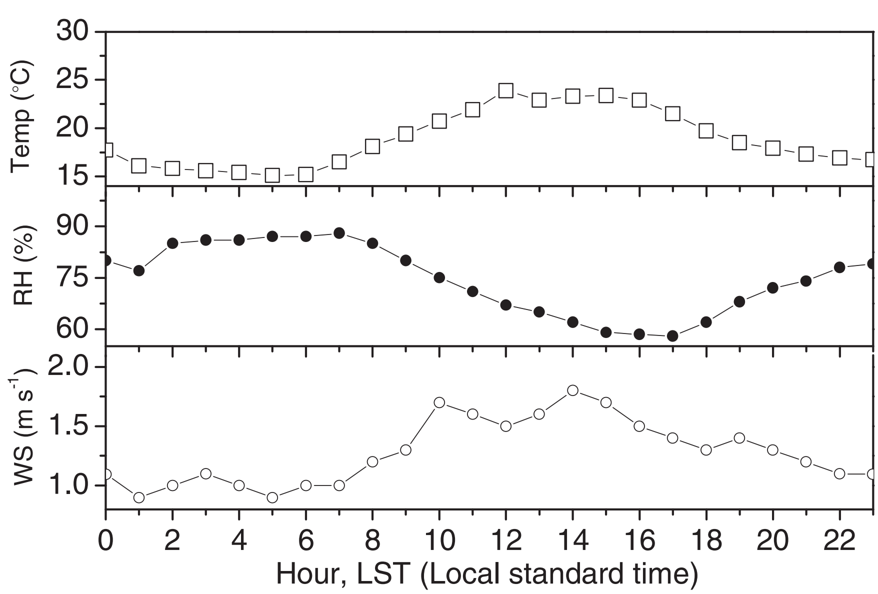

Fig. 2. Hourly average temperature (Temp), relative humidity (RH) and wind speed (WS) throughout the day during the sampling period.