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An intensive study on aerosol optical properties and affecting factors in Nanjing, China

Fenping Cui[2,3,4], *Mindong Chen*[1,2,3,*], *Yan Ma*[1,2,3], *Jun Zheng*[1,2,3], *Yaoyao Zhou*[1,2,3], *Shizheng Li*[1,2], *Lu Qi*[1,2], *Li Wang*[1,2]

1. *School of Environmental Science and Engineering, Nanjing University of Information Science & Technology, Nanjing 210044, China*
2. *Jiangsu Key Laboratory of Atmospheric Environment Monitoring & Pollution Control, Nanjing 210044, China. E-mail: cuifenping@nuist.edu.cn*
3. *Collaborative Innovation Center of Atmospheric Environment and Equipment Technology, Nanjing 210044, China*
4. *School of Physics & Opto-electronic Engineering, Nanjing University of Information Science & Technology, Nanjing 210044, China*

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ABSTRACT

The optical properties of aerosol as well as their impacting factors were investigated at a suburb site in Nanjing during autumn from 14 to 28 November 2012. More severe pollution was found together with lower visibility. The average scattering and absorption coefficients (B_{sca} and B_{abs}) were 375.7 ± 209.5 and 41.6 ± 18.7 Mm^{-1}, respectively. Higher Ångström absorption and scattering exponents were attributed to the presence of more aged aerosol with smaller particles. Relative humidity (RH) was a key factor affecting aerosol extinction. High RH resulted in the impairment of visibility, with hygroscopic growth being independent of the dry extinction coefficient. The hygroscopic growth factor was 1.8 ± 1.2 with RH from 19% to 85%. Light absorption was enhanced by organic carbon (OC), elemental carbon (EC) and EC coatings, with contributions of 26%, 44% and 75% (532 nm), respectively. The B_{sca} and B_{abs} increased with increasing N_{100} (number concentration of $PM_{2.5}$ with diameter above 100 nm), PM_1 surface concentration and $PM_{2.5}$ mass concentration with good correlation.

Introduction

As is well-known, aerosol can be emitted by anthropogenic and natural sources and strongly perturbs the Earth's energy budget. Aerosol particles interact with solar radiation through scattering and absorption, which are referred to as direct radiative forcing. The Intergovernmental Panel on Climate Change (IPCC) 2013 (Stocker et al. 2013) reported that scattering aerosol such as ammonium sulfate, ammonium nitrate and sea salt tends to cool the climate system, while absorbing aerosol has the opposite effect. Many studies have focused on local radiative effects from anthropogenic and natural aerosol (Anderson et al. 2003; Cappa et al. 2012). However, the uncertainty in determining the radiative forcing of atmospheric aerosol, especially black carbon (BC), is still large (Anderson et al. 2003; Stocker et al. 2013), which may be related to the great temporal and spatial variation of aerosol optical properties. In addition, aerosol extinction (scattering and absorption) leads to the degradation of atmospheric visibility and the formation of haze. The optical parameters of aerosols display large differences between clean and polluted days (Kang et al. 2012; Noh et al. 2009; Zhang et al. 2013b).

Aerosol scattering, absorption and extinction coefficients (B_{sca}, B_{abs} and B_{ext}) represent the ability of aerosols to interact with solar radiation. The aerosol scattering coefficient has usually been measured based on Mie theory. The traditional instruments to measure absorption coefficients are associated with significant uncertainties. Recent methods using photo-acoustic and extinction-minus-scattering techniques are

* *Corresponding author*. E-mail: chenmd@nuist.edu.cn (Mindong Chen).

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considered more accurate (Moosmüller et al. 2009; Stocker et al. 2013). Aerosol optical properties are most affected by the aerosol size distribution, chemical components and mixing state. The Ångström scattering exponent (A_{sca}) for atmospheric aerosol varies, with lower values for larger particles and vice versa (Redmond et al. 2010). Cao et al. (2012) found that ammonium sulfate and organic matter were the main contributors to light extinction in Xi'an, China. Concentrations of secondary inorganic aerosols were found to be higher during haze days. Meteorological factors such as relative humidity (RH), wind speed and direction have close correlation with aerosol scattering and absorption. Wind from the west brought higher aerosol loading than those from the Northeast and Southeast in Shanghai (Li et al. 2013). Liu et al. (2012) found that the atmospheric extinction coefficient increased by ~51% at ambient conditions at Guangzhou. The aerosol direct radiative forcing increased by around a factor of three compared to that under dry conditions.

China is situated in the eastern part of Asia, with large population, agriculture, production and consumption. In recent decades, environmental pollution has become more and more severe and results in more frequent haze episodes (Che et al. 2007). Many studies have been carried out focusing on aerosol optical properties in some regions such as the Beijing–Tianjin–Hebei economic band (Cheng et al. 2011; He et al. 2009; Ma et al. 2011), Yangtze River Delta (Deng et al. 2011; Huang et al. 2014; Kang et al. 2012; Li et al. 2013) and Pearl River Delta (Lin et al. 2013; Liu et al. 2012; Tao et al. 2012). Nanjing is one of the most important cities in the Yangtze River Delta region. With the influence of human activities, air pollution is very serious. The overall annual haze days have showed a rising trend year by year. In the past 20 years, the aerosol optical properties in Nanjing have been studied (Deng et al. 2011; Shen et al. 2014; Zhuang et al. 2014), but there have been few studies focusing on the optical properties and their impact factors (Deng et al. 2011).

In this study, a field observation campaign was designed to monitor optical properties, size distributions and chemical compositions of aerosols in autumn in Nanjing, China. The effect of RH, organic carbon (OC), elemental carbon (EC), EC coatings and particle size distribution on optical properties was investigated.

Fig. 1 – Schematic diagram of the observation location.

1. Methodology

1.1. Measurement period and location

The campaign was carried out in autumn from 14 to 28 November, 2012 (15 days). The monitoring station (118.7°E, 32.02°N, see Fig. 1) is situated on the campus of NUIST (Nanjing University of Information Science & Technology) in the northern suburb of Nanjing about 15 km away from the city center. Investigations of aerosol optical properties, chemical components and size distributions were conducted simultaneously inside a trailer. A steel factory is situated 2 km to the east of the sampling site, a chemical industry park is about 10 km to the northeast, and there are residential areas and farmlands to the west and north of the campus.

1.2. Sampling collection and meteorological parameters

A $PM_{2.5}$ cyclone (URG-2000-30EH, Chapel Hill Inc., USA) was used to collect aerosol particles at a cutoff size of 2.5 μm at a rate of 16.7 L/min. Using a medium-volume $PM_{2.5}$ sampler (Model: HY-100 $PM_{2.5}$ 100 L/min, Qingdao Hengyuan S.T. Development Co., Ltd., China), daily 12-hr integrated $PM_{2.5}$ (from about 7:00 to 19:00 (local time) and 19:00 to 7:00 for daytime and nighttime samples, respectively) samples were collected on quartz micro 90 mm fiber filters (QMA, Whatman, UK).

Meteorological parameters, including visibility (Vis), RH, wind direction (WD), wind speed (WS) and temperature were acquired from an automatic weather station close to the observation trailer. Visibility was measured by a forward scattering visibility meter (CJY-1A, CAMA Measurements & Controls Co., Ltd., China).

1.3. Instrumentation

1.3.1. Aerosol scattering and absorption coefficient

The B_{sca} and B_{abs} were simultaneously measured by a three-wavelength photo-acoustic soot spectrometer (PASS-3, DMT Inc., USA) with 405, 532, and 781 nm diode lasers, with the time resolution of 2 sec. A scattering sensor with a photomultiplier tube (PMT) detector gives B_{sca}. B_{abs} can be measured based on an advanced photoacoustic technique. The B_{sca} and B_{abs} data were calibrated with high concentration ammonium sulfate for scattering and nitrogen dioxide for absorption before the campaign. A bypass flow through the zero-air filter every 5 min measured the background values. More detailed description on PASS-3 has been given in previous publications (Arnott et al. 2005; Flowers et al. 2010; Lan et al. 2013; Moosmüller et al. 2009).

1.3.2. The measurement of chemical components

A 0.523 cm^2 sample filter was analyzed by a thermal/optical carbon analyzer (DRI2001A, Desert Research Institute, USA) for OC and EC mass concentration. With heating in pure