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Temporal variability of the visibility, particulate matter mass concentration and aerosol optical properties over an urban site in Northeast China

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ABSTRACT

Visibility, particulate matter (PM) mass concentration, and aerosol optical properties data from June 2009 to December 2011 were obtained at Shenyang in Northeast China. The characteristics and relationships between these parameters were statistically analyzed. The results demonstrate that the monthly averaged visibility over Shenyang was higher in spring and autumn but lower in summer and winter, and had an inverse trend to PM and aerosol optical depth (AOD). Higher AOD at 500 nm was found year by year, with the maximum value (1.31 ± 0.45) occurring in June 2011, and the minimum in June 2010 (0.72 ± 0.31). The mean value of the Ångström exponent underwent a notable reduction during the period of 2011, with values less than 1.0 from February to September. The single scattering albedo was consistently around 0.90 during 2009–2011, which was higher in summer but lower in winter. The higher absorption aerosol optical depth at 440 nm in 2011 indicates that there were more absorbing aerosol particles in this period compared with the corresponding absorption Ångström exponent in the same year (about 0.75). The direct radiative forcing at the bottom of the atmosphere increased to −200 W/m^2 in 2011, compared with −150 W/m^2 from June 2009 to December 2010, suggesting a stronger cooling effect of aerosols at the surface. The positive radiative forcing at the top of the atmosphere in November and December 2009 could have been due to snow cover, which has a large surface albedo that reflects shortwave radiation to the atmosphere.

1. Introduction

Aerosol particles directly affect the earth–atmosphere radiative balance through absorbing or scattering radiation (Charlson et al., 1992; Ackerman and Toon, 1981) and can also serve as cloud condensation nuclei to change global and regional climate (Hansen et al., 1997, 2000; Twomey et al., 1984). Therefore, aerosol optical properties and size distribution are major factors influencing the radiative balance, and knowledge of them is required to predict global climate change (Myhre, 2009; Ramanathan et al., 2001; IPCC, 2013; Obregon et al., 2014; Panicker et al., 2013).

The effects of aerosols on the climate and environment have been researched and discussed worldwide (Sharma et al., 2014; Dubovik et al., 2002; Eck et al., 2005; Wan et al., 2015). For example, Breon et al. (2002) showed that aerosol optical depth (AOD) and the Ångström exponent (α) are two basic optical parameters of aerosol particles. Jacobson (2000) and Gelencser (2004) demonstrated that the single scattering albedo (SSA) is one of the most important factors indicating aerosol radiative effects. The Ångström exponent can also be used to study the size and growth of particles through its spectral dependence (Gobbi et al., 2007; Basart et al., 2009). Wang (2013) reviewed the impacts of anthropogenic absorbing aerosols on clouds and precipitation. Aerosol absorption characteristics can be used to identify the major aerosol particle types because of the spectral dependence of absorption on composition (Russell et al., 2010; Giles et al., 2012; Dubovik et al., 2002).

In China, the ground-based measurement networks of the China Aerosol Remote Sensing NETwork (CARSNET) and some aerosol robotic network stations have been established to obtain data and thereby derive aerosol optical properties (Che et al., 2009). Yuan et al. (2014) used a new aerosol relative optical thickness concept to identify particle species. Xue et al. (2011) studied the optical properties of pollution and

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dust aerosols over a polluted rural area. Wang et al. (2015) analyzed the long-term observations of aerosol optical properties at an urban site in Wuhan. However, such studies have focused mainly on the cities and highly polluted regions of China (Cheng et al., 2008; Che et al., 2008, 2014; Xia et al., 2013; Zhuang et al., 2014). Knowledge and understanding of aerosol optical properties in Northeast China remain limited (Zhao et al., 2013a; Wang et al., 2010; Wu et al., 2012). Long-term monitoring of aerosols from the ground is required to obtain the temporal and spatial variation data necessary to understand the effects of aerosols on climate, regional climate and air quality (El-Metwally et al., 2011; Sanap and Pandithurai, 2014; Dani et al., 2012).

The main purpose of this paper is to investigate the temporal and spatial variations of aerosol optical properties such as AOD, α, SSA, volumes of aerosol size distributions, absorption AOD (AAOD) and direct radiative forcing using CE-318 sun-photometer data in metropolitan Shenyang. This research not only provides information on the temporal and spatial variability of aerosol optical characteristics in this region, but also helps to better understand the air pollution of this region, which is helpful for improving regional air quality.

2. Sampling sites, instrumentation, data and methods

Shenyang is the political, economic and cultural center of Northeast China. Located in the center of the Northeast Asia and Bohai economic zones, Shenyang also has important connections to the Yangtze River delta, the Pearl River delta, the Beijing–Tianjin–Hebei region, and the Kanto region. The observation site was located on the roof of the Northeast Regional Meteorological Observation Center of China (41°77′N, 123°50′E, 60 m). Human activities are quite concentrated around the sampling points of this site, and thus the data collected are likely representative of the air pollution levels in urban Shenyang.

An FD12 visibility automatic observation instrument and a GRIMM180 particle instrument were installed at the Shenyang site to measure visibility and PM_{10}, $PM_{2.5}$ and $PM_{1.0}$, respectively (Zhao et al., 2013b). The data collected include 10-min average visibility values and 5-min averages of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ mass concentrations. The daily and monthly values of visibility and PM were then investigated based on these 10-min average visibility measurements and 5-min average mass concentration measurements. In addition, meteorological data [hourly relative humidity (RH) and wind speed] were also collected from June 2009 to December 2011. The daily averaged meteorological data were then calculated based on these hourly RH and wind speed observations.

The CE-318 sun-sky photometer (Cimel Electronique, Paris, France) used in this study was calibrated according to the method of Che et al. (2009) and Tao et al. (2014). The AOD data were processed using the ASTPwin software (Cimel Ltd. Co), to calculate the raw result without cloud-screening (Level 1.0 AOD), with cloud-screened AOD (Level 1.5 AOD) (Smirnov et al., 2000), and with AE between 440 and 870 nm. In order to further rule out cloud contamination, the daily AOD data with observations of less than 10 times per day were deleted. In addition, large daily AOD values (>3.0) were checked against MODerate-resolution Imaging Spectroradiometer (MODIS) images, to further determine if there was any cloud contamination.

Aerosol optical properties such as SSA, volume size distribution (dV(r)/dln(r) from 0.05 to 15 μm), effective and median radii of fine and coarse mode aerosols, AAOD, and absorption Ångström exponent (AAE) were retrieved according to the methods described in Dubovik and King (2000) and Dubovik et al. (2002, 2006). In this algorithm, the photometer sky radiance measurements in the almucantar plane (fixed elevation angle equal to solar elevation and a full 360° azimuthal sweep) at 440, 675, 870, and 1020 nm (nominal wavelengths) are combined with the direct measured AOD at these same wavelengths in the retrieval process (Eck et al., 2010). The radiative forcing and the forcing efficiency data in this study were calculated by the same radiative transfer module which has been incorporated into the operational AERONET inversion code (García et al., 2012). The broadband fluxes from 0.2 to 0.4 μm were calculated by the corresponding module of the radiative transfer model GAME (Global Atmospheric ModEl) (Dubuisson et al., 1996, 2006; Roger et al., 2006), which provided the fluxes and aerosol radiative forcing values. The module used the detailed size distribution, complex refractive index, and fraction of spherical particles retrieved from the photometer sky radiance measurements in the almucantar plane. The surface albedo (SA) data are from the MODIS albedo product MCD43C3, which has been interpolated at 440, 670, 870, and 1020 nm. The water vapor content is based on the instantaneous water vapor values retrieved by the 940 nm channel of the sunphotometer. The ozone content was fixed using the monthly climatological values of the total ozone content obtained from NASA Total Ozone Mapping Spectrometer measurements from 1978 to 2004. Other atmospheric gaseous profiles were obtained from the US standard 1976 atmosphere model. As Dubovik and King (2000) and Dubovik et al. (2002) discussed, AERONET-retrieved radiative forcing depends strongly on

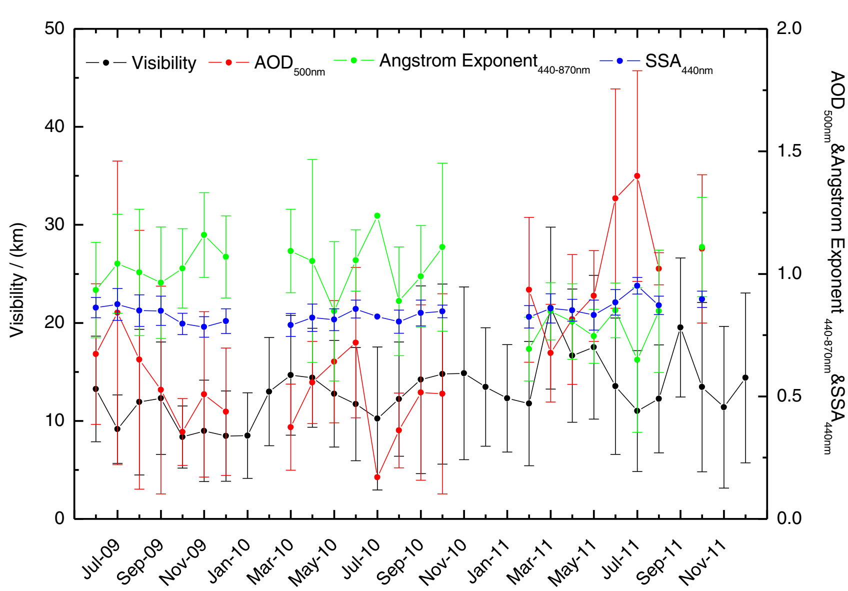

Fig. 1. Variability of monthly visibility, AOD, Ångström exponent, and SSA at Shenyang from June 2009 to December 2011.