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Aerosol optical properties over urban and industrial region of Northeast China by using ground-based sun-photometer measurement

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HIGHLIGHTS

- This manuscript firstly shows the aerosol optical property over Northeast China.
- High AOD in spring and summer but low AOD in autumn are found in the northeast region of China.
- Results in this manuscript will be helpful to improve aerosol optical property comprehension in Northeast China.

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ABSTRACT

The special and temporal characteristics of aerosol optical depth (AOD) and Angstrom exponent (Alpha) were analyzed by using the data from a CE318 sun-photometer at Shenyang, Anshan, Benxi and Fushun in urban and industrial region of northeastern China. The high AODs over Shenyang and Fushun occurred in the summer and winter with two peaks. In contrast, the monthly averaged AODs at Anshan and Benxi have a single peak distribution. The AOD frequency distribution at Shenyang and Benxi can be well fit by a bi-modal normal distribution with $r^2 = 0.94$ and 0.91. The AOD frequency distribution at Anshan and Fushun have identical peak value at approximately 0.40. The seasonal AOD at Benxi is larger than the other three stations, and the seasonal Alpha at Shenyang is the largest of all stations followed by Anshan, Fushun and Benxi. An analysis of the AOD and Alpha scatterplots suggests that the aerosol size in Shenyang, Anshan, Benxi and Fushun can be affected by both fine and coarse particles.

1. Introduction

Aerosol particles play an important role in the studies of global and regional climate change (Charlson et al., 1992). The effect of aerosol on climate and environment has also been a significant problem for the international scientific research community (IPCC, 2007). Aerosol can result in direct and indirect radiative forcing on clouds, which effect droplet properties, cloud dynamics, albedo and lifetimes (Twomey et al., 1984; Hansen et al., 2000). Aerosol particles can serve as cloud condensation nuclei (CCN) or ice nuclei (IN) to change the microphysical structure, optical properties and precipitation efficiency of clouds, which could affect the climate (Hansen et al., 1997). The aerosol particles could also contribute to global and regional dimming (Stanhill and Cohen, 2001; Che et al., 2005) and changes in regional precipitation (Menon et al., 2002) and visibility (Che et al., 2007). Aerosol particles could change the earth–atmosphere radiation balance and affect the climate directly by absorbing and scattering solar radiation and radiation from the earth–atmosphere system (Ackerman and Toon, 1981). Aerosol optical depth (AOD) and Angstrom exponent (Alpha) are two basic optical parameters of aerosol particles and key factors for climate change research (Breon et al., 2002).

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The majority of researches regarding aerosol optical characteristics and the effects on the climate and environment in East Asian have also been discussed. Kim et al. (2004) studied the aerosol optical properties over East Asia using long-term measurements of sky radiation at Mandalgovi, Dunhuang, Yinchuan, and Sri-Samrong sites of the Skyradiometer Network (SKYNET). Eck et al. (2005) investigated the spectral and temporal variations of aerosol optical depths (AOD) observed over central eastern region of Asia and midtropical Pacific. There are also many studies regarding the characteristics of AOD and Alpha over different regions in China (Li et al., 2005; Huang et al., 2009; Wang et al., 2001; Pan et al., 2010; Che et al., 2011; Cheng et al., 2006a). All this studies are important to comprehend the aerosol variation of China.

Currently, observations of aerosol optical properties in northeastern China are still limited (Wu et al., 2012; Zhang et al., 2012). Cheng et al. (2006b) examined the aerosol optical properties in Hunshan Dake desert of Northeast China. Wang et al. (2010) measured and analyzed the optical characteristics of aerosol in Longfengshan which is the regional background station in Northeast China. Xin et al. (2011) investigated regional aerosol optical depth and aerosol type over Bohai Rim in Northeast China from 2004 to 2010.

Liaoning province is a heavy industry base that plays an important role in the economic development of China. The rapid development of urbanization caused serious particle pollution in the air (Ma et al., 2010), such as the expanding scale of urban construction, population growth, the increase in vehicles etc., which caused the degradation of visibility (Zhao and Ma, 2011; Ma et al., 2005a) and air quality (Ma et al., 2011). Xia et al. (2007) analyzed the optical characteristics of aerosol in Liaozhong during the spring based on sun-photometer and surface irradiance data. Zhao et al. (2012) studied the AOD affected by the heavy aerosol loading at Anshan of Liaoning province. Therefore, studying atmospheric aerosol optical properties in urban and industrial area of northeastern China is significant and will be an important reference for future research regarding atmospheric aerosol optical properties.

The aim of this paper is to investigate the distribution and variation of aerosol optical properties using the CE-318 sun-photometer data from urban and industrial region of northeastern China.

2. Site, instrument and data

2.1. Site distribution

In this study, sun-photometers were installed at four observation sites in northeastern China: Shenyang, Anshan, Benxi and Fushun as shown in Table 1 and Fig. 1. The Shenyang site could represent the aerosol properties of metropolitan area in northeastern China. The Anshan site was located in the largest iron and steel industrial city in the northeastern region of China. The observations at this site could represent the aerosol characteristics over the industrial region. Mountains encircle the Benxi site, and the observation data could represent the characteristics of aerosol optical properties in the mountainously industrial region of Liaoning Province. The Fushun site can be regarded as a suburban site. The atmospheric pollutant emissions in the two cities of Fushun and Shenyang are interactive and mutually influenced (Ma et al., 2005b; Zhu and Fang, 2009).

2.2. Instruments, data and methodology

The Cimel Electronique CE-318 sun-photometer in this article has eight channels, including 1640, 1020, 870, 670, 500, 440, 380 and 340 nm and one 940-nm water vapor channel with a 1.2° full field-of-view (Holben et al., 1998). Measurements at 1640, 1020, 870, 670, 500, 440, 380 and 340 nm can be used to retrieve AOD, and measurements at 940 nm are used to obtain the total precipitable water content in centimeters. The total uncertainty in the aerosol optical depth is approximately 0.01–0.02 (Eck et al., 1999).

Measurement data from Shenyang, Anshan, Benxi and Fushun from June of 2009 to October of 2012 were selected in this study. The AOD data are calculated by using the ASTPwin software (Cimel Ltd. Co.) for Level 1.0 AOD (the raw results without cloud-screening), Level 1.5 AOD (cloud-screened AOD based on the work of Smirnov et al., 2000) and the Alpha between 440 and 870 nm.

The value of daily AOD with observation number >3 may be seemed as effective values and the value of monthly AOD with observation days >10 can be calculated. Daily and monthly mean values of AOD and Alpha were investigated using statistical analysis to characterize the aerosol columnar properties. The multi-peak *Gaussian* regression method was used to fit the frequency distribution of AOD and Alpha (Che et al., 2011).

3. Results analysis

3.1. Variation of monthly averaged AODs over the four stations

The monthly averaged AOD at 500 nm, Alpha and the number of days over Shenyang, Anshan, Benxi and Fushun have been shown in Fig. 2 and Table 2. The instrument at Benxi is failed to obtain data in winter over the four years because the continuous measurement at Benxi is during June 2009 to October, 2010. There are no measurements from November, 2010 until September 2012. So there is only one winter season data (2010) observation at Benxi station. Unfortunately, the data quality is not so good because the instrument problem.

In this paper, four seasons are divided into spring (March–May), summer (June–August), autumn (September–November) and winter (December–February) to investigate the seasonal variations of aerosol optical properties. There are two peaks in the AOD distributions at Shenyang and Fushun (Fig. 2). High AODs over

Table 1
Site distribution.

Station	Shenyang	Anshan	Benxi	Fushun
City	Liaoning, China	Liaoning, China	Liaoning, China	Liaoning, China
Location	E 123.50°, N 41.77°	E 123.00°, N 41.08°	E 123.78°, N 41.32°	E 123.95°, N 41.88°
Altitude	60 m	23 m	183 m	80 m
Position	Installed on the roof of the Northeast Regional Meteorological Observation Center	Installed on the roof of the Anshan Meteorology Bureau	Installed at the observation field of the Benxi Meteorology Bureau	Installed on the roof of Fushun City Government Building
Running time	June of 2009–now	June of 2009–now	June of 2009–now	June of 2009–now