Journal of Atmospheric and Solar-Terrestrial Physics 132 (2015) 37–47

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Application of aerosol optical properties to estimate aerosol type from ground-based remote sensing observation at urban area of north-eastern China

Huizheng Che [a,b,*], Hujia Zhao [c], Yunfei Wu [d], Xiangao Xia [e,f], Jun Zhu [e], Oleg Dubovik [g], Victor Estelles [h], Yanjun Ma [c], Yangfeng Wang [c], Hong Wang [a], Yaqiang Wang [a], Xiaoye Zhang [a], Guangyu Shi [i]

[a] Key Laboratory for Atmospheric Chemistry, Institute of Atmospheric Composition, Chinese Academy of Meteorological Sciences, CMA, Beijing 100081, China
[b] Jiangsu Collaborative Innovation Center of Climate Change, Nanjing 210093, China
[c] Institute of Atmospheric Environment, China Meteorological Administration, Shenyang 110016, China
[d] Key Laboratory of Regional Climate-Environment for Temperate East Asia (RCE-TEA), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
[e] Laboratory for Middle Atmosphere and Global Environment Observation, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
[f] Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters, Nanjing University of Information Science and Technology, Nanjing 210044, China
[g] Laboratoired'Optique Amosphérique, Université des Sciences et Technologies de Lille, 59655 Villeneuve d'Ascq, France
[h] Dept. Fisica de la Terra ITermodinamica, Universitat de Valencia, C/ Dr. Moliner 50, 46100 Burjassot, Spain
[i] State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

ARTICLE INFO

Article history:
Received 26 March 2015
Received in revised form
23 June 2015
Accepted 24 June 2015
Available online 27 June 2015

Keywords:
Aerosol
Absorption Optical properties
Aerosol type
Northeastern China

ABSTRACT

Aerosol optical properties were derived from ground-based sunphotometer observations between 2009-2013 at three urban sites of Shenyang, Anshan, Fushun in northeastern China. The annual means for extinction aerosol optical depths (EAOD) at 500 nm were 0.57 ± 0.38, 0.52 ± 0.35, and 0.41 ± 0.31 at Shenyang, Anshan, Fushun, respectively. The corresponding annual means for the extinction Angstrom exponents (EAE) computed for the wavelengths of 440 and 870 nm were 0.86 ± 0.32, 0.86 ± 0.34 and 0.91 ± 0.35, respectively, indicating that urban area of Northeast China were affected by both coarse and fine particles. Hygroscopic growth in summer and incursions of dust aerosols in spring were evidently revealed from the analysis of the relationship between EAE and δEAE (the EAE difference, δEAE = EAE(440,670) − EAE(670,870)). The annual mean absorption aerosol optical depths ($AAOD_{440\ nm}$) values at Shenyang, Anshan, Fushun were 0.15 ± 0.11, 0.10 ± 0.07, 0.08 ± 0.04, respectively. The annual mean absorption Angstrom exponents ($AAE_{440–870\ nm}$) values were 0.86 ± 0.24, 1.19 ± 0.39, 1.33 ± 0.36 at Shenyang, Anshan, Fushun, respectively. When the AAEs were close to unity at Anshan, the absorption aerosol particles evidently consisted of black carbon from coal combustion and motor vehicles. Larger AAEs at Fushun were indicative of absorbing aerosols mainly from biomass burning and mineral dust. The AAE at Shenyang was < 1 which may be consistent with black carbon particles with absorbing or non-absorbing coatings. Analysis of the relationship between the AAEs and extinction Angstrom exponents showed that the aerosol populations at these three sites could be classified as "mixed-small particles" including anthropogenic particles and secondary organic aerosol with highly variable sphericity fractions.

1. Introduction

Atmospheric aerosol populations typically include mineral dust, carbonaceous species (both black carbon and organic carbon), ionic substances (sulfate, nitrate, ammonium), and sea salt.

* Correspondence to: 46 Zhongguancun South Avenue, Beijing 100081, China. Fax: +86 10 62176414.
E-mail address: chehz@cams.cma.gov.cn (H. Che).

http://dx.doi.org/10.1016/j.jastp.2015.06.015
1364-6826/

Mixtures of these compositions are common, and variability in the aerosol populations, both temporally and spatially, is driven by sources, transport, and removal processes (Cao et al., 2003, 2007; Jeong and Li, 2005; Levy et al., 2007; Kalapureddy et al., 2009; Lee et al., 2010; Kahn et al., 2010; Russell et al., 2010; Zhang et al., 2013; Wang et al., 2007; Wan et al., 2015). In addition, the aerosol populations differ in size, composition, optical properties, etc., and so they have varying levels of influence on the Earth's radiative balance and hence climate (Diner et al., 1999; Satheesh and Moorthy, 2005; IPCC, 2007, 2013; Myhre, 2009; Ramanathan et al., 2001; Wang et al., 2013). As a result, aerosol optical and microphysical properties have been a major focus of studies on particles from both natural and anthropogenic sources (Kaufman et al., 2002; Yu et al., 2009; Xue et al., 2011; Wang et al., 2015).

In addition to using information on particle size and chemical composition, aerosol absorption characteristics can be used to distinguish aerosol type (Schuster et al., 2005, 2009; Wang et al., 2010a, b; Yuan et al., 2014). Indeed, studies by several groups (Omar et al., 2005; Levy et al., 2007; Mielonen et al., 2009; Lee et al., 2010; Russell et al., 2010; Dubovik et al., 2002) have used data for aerosol absorption and particles size from the Aerosol Robotic Network (AERONET) to obtain the information about major aerosol particle types. The Angstrom exponent (α) is a term in an equation that relates the aerosol optical depth (or extinction coefficient) to wavelength, and α has been used to draw inferences about aerosol types and sizes (O'Neill et al., 2001; Eck et al., 1999; Kalapureddy et al., 2009; Boselli et al., 2012). More specifically, Gobbi et al. (2007) and Basart et al. (2009) used α and its spectral dependence in studies of aerosol particle size and growth. Kaufman (1993) and Schuster et al. (2006) used the spectral curvature of α to obtain information on aerosol size distributions.

Here we add the qualifier "extinction" (that is, scattering plus absorption) to Angstrom exponent (EAE) to distinguish it from the absorption Angstrom exponent (AAE) which expresses the wavelength dependence of absorption alone. The EAE is commonly used as an indicator of particle size (Eck et al., 2005; Che et al., 2009a), and it also can be used to gain insights into the composition of the particles (Russell et al., 2010). The AAE, on the other hand, can be used to infer the type of dominant aerosol, such as black carbon, organic matter, and mineral dust in the atmospheric aerosol. This is because the spectral dependence of absorption by the aerosol is an intrinsic property closely related to its composition (Chul et al., 2012; Bahadur et al., 2012). Giles et al. (2012) used AERONET measurements to test the ability of absorption and size relationship to distinguish aerosol types. Along these lines, Russell et al. (2010) and Zhu et al. (2014) used data for both AAEs and EAEs from AERONET stations in studies of aerosol types.

In China, investigations into the types of aerosols and classifications of ambient populations by size and absorption were limited (Guo et al., 2010; Wang et al., 2009). Yang et al. (2009) studied the attribution of aerosol light absorption to black carbon, brown carbon in China. Che et al. (2009b) used the Angstrom exponent spectral curvature ($d\alpha/d\lambda$) to investigate the aging of fine particles and the addition of coarse particles to the aerosol at Yulin, China. Wang et al. (2010a) used the Angstrom exponent curvature to analyze aerosol properties at Longfengshan, a regional background station in northeastern China. A study by Zhu et al. (2014) showed EAE and AAE values at Xinglong, a background station in the North China Plain, were about ~ 1.25 and $\sim 1.0-1.5$, respectively.

In the present study, aerosol absorption parameters, including the extinction and absorption aerosol optical depths (EAODs and AAODs) and extinction and absorption Angstrom exponents (EAEs and AAEs), were determined for the first time at Shenyang, Anshan and Fushun, which are all located in northeastern China. The relationships between absorption properties and particle size were evaluated to infer the dominant aerosol types at each of these sites. The main purpose of this paper is to show that the aerosol absorption properties retrieved from sun–sky measurements can be related to aerosol composition and type. This research will not only contribute to a better understanding of the distributions and spatial variability of absorbing aerosols in this region but also provide information relevant for assessments of environmental pollution and aerosol climate effects.

2. Sampling sites, instrumentation, data and methods

As Fig.1 shown, Shenyang, Anshan, Fushun are three CARSNET (China Aerosol Remote Sensing NETwork) sites in Northeastern China. Among them, the Shenyang, the capital of Liaoning province, has more typical urban features with a dense population, rapid economic development and vehicle's increasing than the other two sites, while Anshan and Fushun have more characteristics of industrial base. For the regional characteristics, there have been some substantial environmental concerns on the air quality in this region (Zhao et al., 2013a; Zhao and Ma, 2011).

Both solar and sky radiance measurements were made with a sun–sky photometer (CE-318, Cimel Electronique, Paris, France) that was standardized and calibrated according to procedures in Holben et al. (1998), Che et al. (2009b), and Tao et al. (2014). The EAOD are calculated using the ASTPwin module offered by Cimel Ltd. Co. This module can provide Level 1.0 EAOD (raw result without cloud-screening), Level 1.5 EAOD (cloud-screened EAOD based on the method of Smirnov et al. 2000), and EAE between 440 nm to 870 nm. Che et al. (2009b) pointed out that there is good consistency between the CARSNET Level 1.5 EAOD calculation results and those of AERONET/PHOTONS (EAOD difference of $\delta_{EAOD} < 0.02$). In this study, the spectral EAODs at 7 wavelengths of 340, 380, 440, 500, 675, 870, and 1020 nm were obtained based on the direct solar measurements from June 2009 to December 2013 at the three sites of Shenyang, Anshan, and Fushun.

The retrieval method of sky radiance measurements used by CARSNET is very similar to the Version 2 AERONET algorithm (Dubovik et al., 2006). This algorithm focused on a detailed statistical optimization of the influence of noise in the inversion procedure and the atmospheric radiative transfer modeling has also been implemented. The Cimel 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) in conjunction with the direct sun measured AOD at these same wavelengths ($EAOD_{440\ nm}$ should be larger than 0.40) were used to retrieve column-

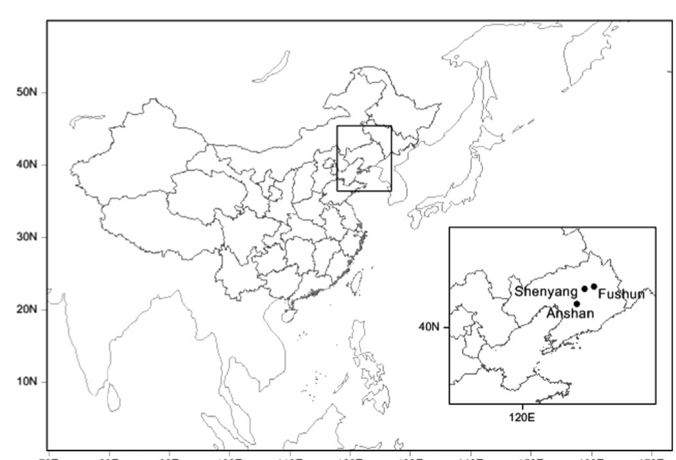

Fig. 1. Sites distribution of Shenyang, Anshan and Fushun over Liaoning Province, China.