Atmospheric Environment 95 (2014) 552–562

Contents lists available at ScienceDirect

Atmospheric Environment

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

Characterization and source apportionment of aerosol light extinction in Chengdu, southwest China

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HIGHLIGHTS

- Aerosol optical and chemical properties in an urban environment were characterized.
- Aerosol hygroscopic curves were developed based on field measurements.
- Source apportionment of aerosol light extinction was estimated.

ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form
3 July 2014
Accepted 4 July 2014
Available online 5 July 2014

Keywords:
Aerosol scattering coefficient
Aerosol absorption coefficient
Hygroscopic growth
Urban aerosols

ABSTRACT

To investigate aerosol properties in the Sichuan Basin of China, field aerosol sampling was carried out in Chengdu, China during four one-month periods, each in a different season in 2011. Aerosol scattering coefficient (b_{sp}) at dry (RH<40%) and wet (40% < RH<90%) conditions and aerosol absorption coefficient (b_{ap}) were measured. Additionally, daily $PM_{2.5}$ and PM_{10} samples were also collected. $PM_{2.5}$ samples were subject to chemical analysis for various chemical components including major water-soluble ions, organic and elemental carbon (OC and EC), trace elements, as well as anhydrosugar Levoglucosan (LG) and Mannosan (MN). A multiple linear regression analysis was applied to the measured dry b_{sp} against $(NH_4)_2SO_4$, NH_4NO_3, organic mass (OM), fine soil (FS), and coarse mass (CM, $PM_{2.5-10}$), and to the measured b_{ap} against EC in all the four seasons to evaluate the impact of individual chemical components of $PM_{2.5}$ and CM on aerosol light extinction ($b_{ext} = b_{sp} + b_{ap}$). Mass scattering efficiency (MSE) and mass absorption efficiency (MAE) of the individual chemical components of $PM_{2.5}$ were estimated based on seasonal regression equations and were then used for estimating b_{ext}. The annual b_{sp}, b_{ap} and single scattering albedo (SSA) at dry conditions were 456 ± 237 Mm^{-1}, 96 ± 48 Mm^{-1} and 0.82 ± 0.05, respectively. The annual average b_{sp} at ambient conditions estimated through hygroscopic curve of aerosol (f(RH)) was 763 ± 415 Mm^{-1}, which was 1.7 times of the dry b_{sp}. The annual average SSA at ambient conditions also increased to 0.88 ± 0.04. The estimated dry b_{ext} was only 2 ± 9% higher than the measurements and the estimated ambient b_{ext} from individual chemical components was only 1 ± 10% lower, on an annual basis, than that estimated from using f(RH). Secondary inorganic aerosols, coal combustion, biomass burning, iron and steel industry, Mo-related industry, soil dust, and CM to b_{ext} were estimated to account for 41 ± 19%, 18 ± 12%, 14 ± 13%, 13 ± 11%, 5 ± 4%, 5 ± 7% and 4 ± 3%, respectively, of the estimated ambient b_{ext}.

1. Introduction

Atmospheric aerosols influence climate directly by scattering and absorbing solar radiation and indirectly by modifying clouds

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http://dx.doi.org/10.1016/j.atmosenv.2014.07.017
1352-2310/

microphysical properties. Due to the complexity of aerosol optical properties and aerosol–cloud interactions, large uncertainties remain in the quantification of the net impact of atmospheric aerosols on climate (Solomon, 2007). To reduce these uncertainties, a better understanding of aerosol physical, chemical and optical properties is needed at local, regional and global scales. Aerosol single scattering albedo, i.e., the ratio of aerosol scattering coefficient to extinction coefficient, is one of important aerosol optical properties that, to some extent, determines whether aerosols warm or cool the Earth system. A small variation of SSA could alter the estimated net impact of aerosol direct radiative forcing, e.g., from negative impact to positive or vice versa (Haywood and Boucher, 2000). It is well known that b_{sp} and thereby single scattering albedo changes dramatically with aerosol hydroscopic growth that is dependent on aerosol chemical components. Measurements of the aerosol hydroscopic growth are therefore required for better knowledge of SSA. Further understanding of these aerosol properties is helpful for chemical model simulations and satellite remote sensing of aerosols.

Comprehensive observations involving aerosol optical properties have been widely conducted around the world such as a series of Aerosol Characterization Experiments (ACE-1, ACE-2 and ACE-Asia) (Bates et al., 1998; Huebert et al., 2003; Raes et al., 2000) and Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) (Russell et al., 1999). Extensive studies focusing on aerosol optical properties in eastern Asian were only conducted during the most recent decade (Alam et al., 2012; Andreae et al., 2008; Cheng et al., 2008; Lee et al., 2009; Li et al., 2007, 2011; Marcq et al., 2010; Wang et al., 2010; Xu et al., 2002). There are evidences that aerosol chemical properties control their optical properties and thus affect climate via direct and indirect radiative forcing (Li et al., 1995; Menon et al., 2002; Xia, 2010). Studies have been conducted to quantify the relationship between aerosol optical properties and their chemical properties (Malm et al., 2003; Pitchford et al., 2007). In China these studies were based on the Mie theory (Cheng et al., 2008), IMPROVE formula (Cao et al., 2012; Yang et al., 2012), and multiple linear regression (Tao et al., 2014a). Using Mie theory method is challenging since this method requires long-term continuous measurements of particle size distributions. IMPROVE formula was originally developed for rural/remote areas and may not be directly applicable to urban environments (Tao et al., 2014a). Thus, multiple linear regression method might be a good alternative quantifying the relationship between aerosol optical and chemical properties in urban areas in China.

The Sichuan Basin is one of the heavily polluted regions in China or even in East Asia due to strong anthropogenic emissions and special terrains, as shown in Fig. 1. Annual mean aerosol optical depth of the Moderate Resolution Imaging Spectroradiometer (MODIS) in the Basin is close to unit which is even higher than observations in the North China Plain and Yangtze Delta region (Li

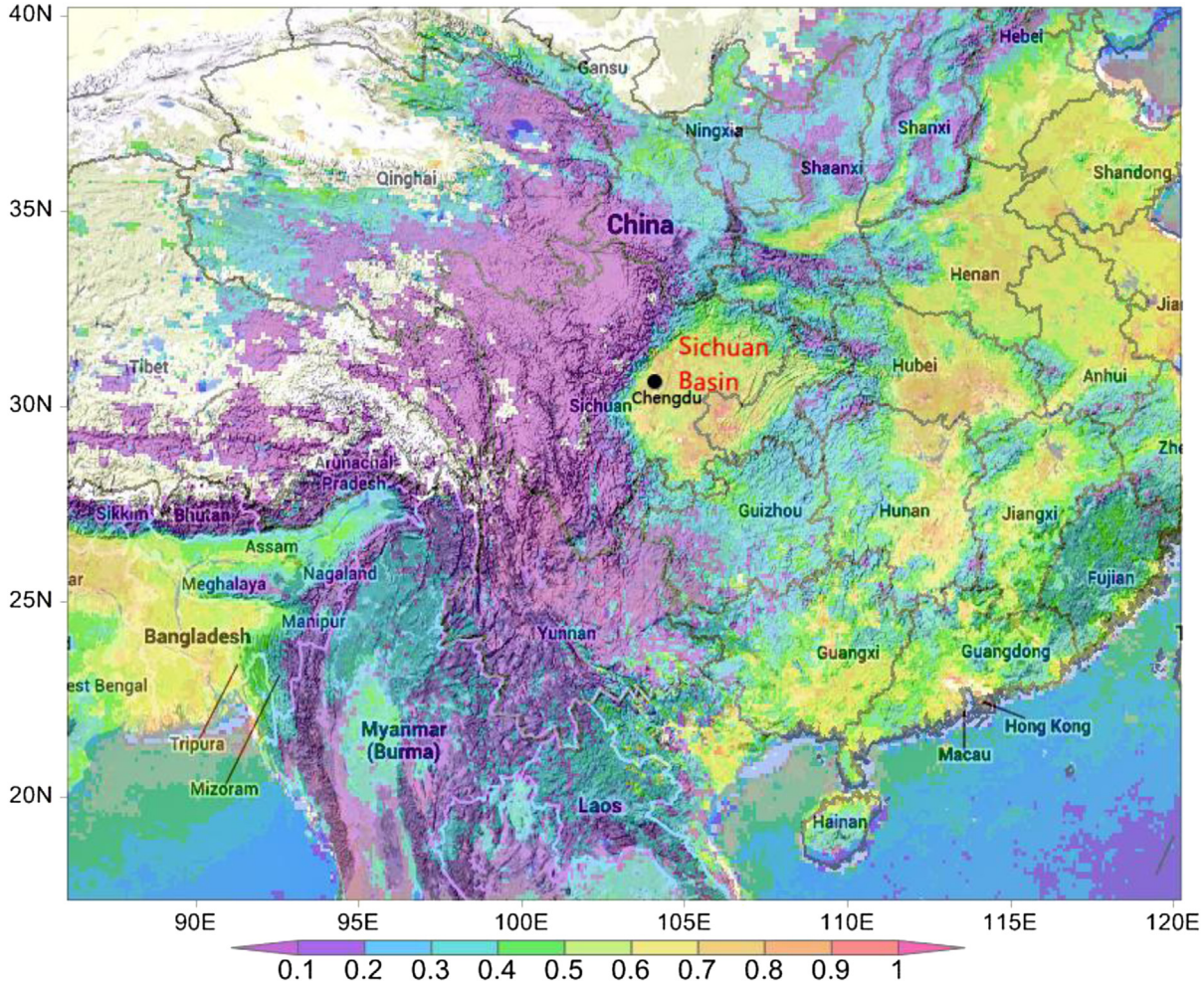

Fig. 1. The sampling location (30.65°N, 104.03°E) in Chengdu on a regional map superimposed with spatial distribution of annual mean fine aerosol optical depth (AOD) retrieved from MODIS satellite remote sensing in 2011.