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Aerosol optical absorption coefficients at a rural site in Northwest China: The great contribution of dust particles

Xueqin Wu[a], Jun Liu[a], Yunfei Wu[b,*], Xin Wang[a,**], Xiaowei Yu[c], Jinsen Shi[a], Jianrong Bi[a], Zhongwei Huang[a], Tian Zhou[a], Renjian Zhang[b]

[a] Key Laboratory for Semi-Arid Climate Change of the Ministry of Education, College of Atmospheric Sciences, Lanzhou University, Lanzhou, 730000, China

[b] CAS Key Laboratory of Regional Climate-Environment for Temperate East Asia (RCE-TEA), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029, China

[c] South China Institute of Environmental Sciences, Ministry of Environmental Protection, Guangzhou, 510655, China

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ABSTRACT

An intensive measurement campaign was conducted at a rural site in Northwest China to investigate aerosol optical absorption properties, using the ground-based mobile facility of the Semi-Arid Climate and Environment Observatory of Lanzhou University (SACOL). The average mass concentration of $PM_{2.5}$ was 103 ± 4 μg m^{-3} during the 20-day campaign in April 2014. Black carbon (BC) only accounted for ~0.4% of the $PM_{2.5}$ on average, with the mean concentration of 443 ± 12 ng m^{-3} measured using a single particle soot photometer (SP2). The aerosol absorption coefficient (σ_{ap}) was 5.69 ± 0.01 Mm^{-1} on average, recorded by a multi-angle absorption photometer (MAAP) at the wavelength of 637 nm. It showed a linear relationship with BC mass concentration during non-dust periods, especially at their diurnal peaks of 07:00–09:00 a.m. (local standard time), deriving a bulk mass absorption efficiency (MAE) for BC of 8.5 ± 1.1 m^2 g^{-1}. The σ_{ap} increased sharply during the dust storm, while the BC remained at a lower concentration than other moments, implying that the dust particles had a considerable contribution to light absorption. On average, dust particles accounted for 26.7% of the aerosol absorption and increased to 71.6% during the dust storm. The MAE of dust was calculated to be 0.014 ± 0.00028 m^2 g^{-1}, which was comparable to that measured in the downwind regions in East Asia. Based on the Mie theory for spherical particles, the refractive index (m) of natural mineral dust particles was estimated to be 1.50–0.0007i in Northwest China.

1. Introduction

Certain aerosol components can enhance solar light absorption in the atmosphere, resulting in a warming effect on the regional and global climates (Ramanathan and Carmichael, 2008; Uno et al., 2009). Black carbon (BC) is a strongly light-absorbing aerosol of the incoming solar radiation, emitted from incomplete combustion of fossil fuels or biomass (Novakov et al., 2003). Although BC has a short atmospheric lifetime of a few weeks at most, the mixing of BC with other aerosol components can lead to varying degrees of enhancement in the BC absorption (Ramanathan and Carmichael, 2008). In addition, the deposition of BC aerosol can reduce the albedo of surfaces such as snow and ice. BC has a strong absorption centered in the visible and parts of the infrared spectrum with a small variation range of light absorption (Bergstrom et al., 2007). Generally, its absorption shows an inverse relation with the incident light wavelength (λ). Brown carbon (BrC) and mineral dust are considered as the other important contributors to aerosol absorption in the atmosphere. However, they strongly absorb solar radiation in near ultraviolet (UV) and blue light region, exhibiting a stronger wavelength dependence than BC (Kirchstetter et al., 2004; Andreae and Gelencser, 2006; Bond and Bergstrom, 2006; Yang et al., 2009). Alexander et al. (2008) pointed that massive BrC aerosols exist in East Asia (e.g., Beijing), derived from low-temperature biomass and biofuel burnings as well as multiphase processes (Lukács et al., 2007). Nevertheless, mineral dust dominates the aerosol mass over some regions in China and the mineral dust emitted in the desert regions of northwestern China contains 600 Tg, which may reach the half of that on the global scale (Husar et al., 2001; Boucher et al., 2013). Dust aerosols can travel eastward over long distances in the lower troposphere and then trigger more dust events (Uno et al., 2009; Pu et al., 2015; Wang et al., 2015b). They also absorb effectively in the infrared region, acting like a greenhouse gas with trapping outgoing radiative

* Corresponding author.
** Corresponding author.
E-mail addresses: wuyf@mail.iap.ac.cn (Y. Wu), wxin@lzu.edu.cn (X. Wang).

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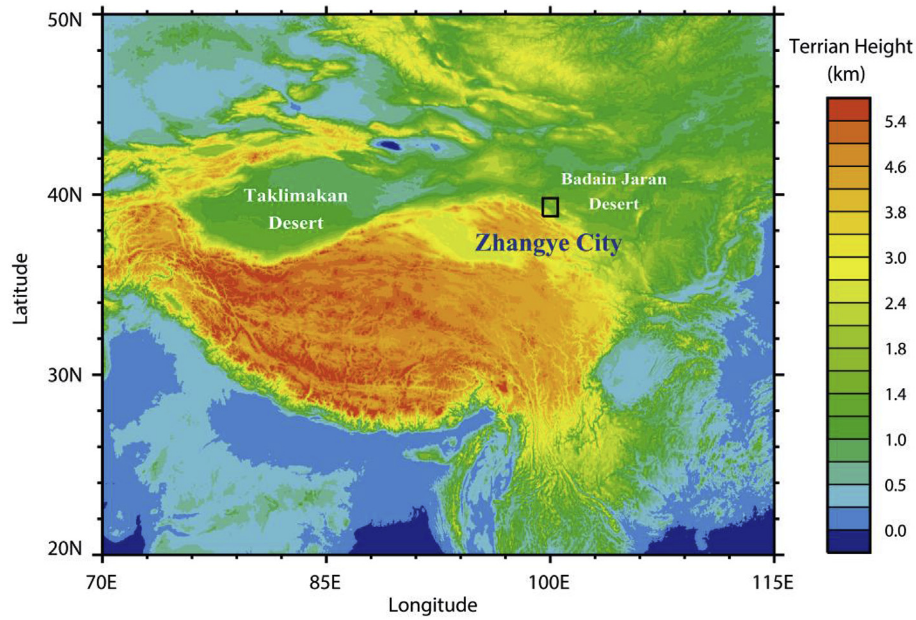

Fig. 1. The sampling site of Linze farm in Zhangye city and surrounding dust source areas.

(Andreae, 1996). As the predominant absorptive components of aerosols (Niu and Zhang, 2010), all three play an active role in heating the aerosol layer and promoting the increase in air temperature. Due to the high temporal and spatial variability in aerosol optical and physical properties, including refractive indices, size parameters and mixing states, large uncertainties exist in the assessment of the radiative effect induced by aerosol absorption (Boucher et al., 2013).

The most important sources for East Asian mineral dust has been identified as the northwestern regions of China, with the Taklimakan Desert, Gobi Desert and Badain Jaran Desert as their centers (Zhang et al., 2003; Huang et al., 2006; Wang et al., 2008, 2018a). Compared to background aerosol, the heating effect in the atmosphere of dust aerosols during dust event periods is more significant, and the contribution to averaged shortwave radiative forcing by the dust effect in the atmosphere was $\sim 28.21\,\mathrm{W\,m^{-2}}$ in Lanzhou (Liu et al., 2011). Furthermore, dust has a warming influence at the top of atmosphere when it exists under a cloud, reducing the cloud cooling effect (Su et al., 2008; Huang et al., 2014). Some evidence suggests that dust can produce the longwave warming effect at the surface during the night, because of their high absorption within the infrared spectrum (Choobari et al., 2014). Large size and non-spherical morphology make dust particles have greater optical depth and be better absorbers. Although the absorption efficiency of dust aerosols is generally smaller than that of BC aerosols, its contribution to the bulk absorption cannot be ignored during heavy dust pollution episodes due to the substantial atmospheric mass loading of dust particles. The magnitude of dust absorption and refractive indices differ according to the particle size distribution, composition and shape (Sokolik and Toon, 1999), which vary and depend on the source regions of emission (e.g., African and Asian dust), on the surface wind velocity (Jeong, 2008; Laurent et al., 2008), and especially on the physical and chemical aging degree during transport (Sullivan et al., 2007). Anthropogenic aerosol components such as BC, sulfates and nitrates can attach to the dust surfaces, eventually modifying the dust absorption properties (Falkovich, 2004).

In previous studies, different regions and emission sources exhibited disparate values of mass absorption efficiency (MAE) for BC, which vary to a large extent ($3.4–16.8\,\mathrm{m^2\,g^{-1}}$). It is also suggested that enhancement of MAE by the mixing of BC with non-refractory particulate matter largely depends upon the coating chemicals and mass (Lan et al., 2013). A much larger MAE of BC aerosol was observed at urban sites ($11.3 \pm 2.2\,\mathrm{m^2\,g^{-1}}$) than rural sites in India ($6.1 \pm 2.0\,\mathrm{m^2\,g^{-1}}$), indicating a high fluctuation in it (Ram and Sarin, 2009). Numerous discussions and analysis were addressed about absorption coefficient and relevant variation characteristics of BC in northwestern China. For example, Cao et al. (2014) mentioned that aerosol absorption coefficient had apparent daily variation almost the same as BC mass concentration on normal weather conditions. However, there was insufficient information on BC mass absorption efficiency in this area, which is widely used as a quantitative parameter for estimation in BC absorption. Unlike in the other regions, abundant dust particles of the northwest can act as an outer covering on the BC as well, further strengthening the BC absorptive capacity (Oshima et al., 2009). The supplementation of MAE data is of great importance to the accurate evaluation and improvement of environmental quality. To understand the radiation characteristics of atmospheric aerosols more comprehensively and more deeply, we carried out a surface observation in spring (frequent occurrences of dust events) and discuss the absorption properties of dust and BC aerosols in the northwestern desert regions in this study.

2. Methodology

2.1. Site description and meteorological conditions

The field experiment was conducted on farmland in Zhangye city, Gansu Province in northwest China (39.04°N, 100.12°E); this area is situated in the middle of the Hexi Corridor (1578 m above sea level). A ground-based mobile facility of the Semi-Arid Climate and Environment Observatory of Lanzhou University (SACOL) was used for this campaign from 9 to 28 April 2014. The north and south sides of the Hexi Corridor are both flanked by mountains, leading to the formation of a long and narrow area which runs approximately northwest-southeast. Such terrain can result in a funneling phenomenon when wind blows over the area, increasing the wind speed (Dong et al., 2014). The site is located near the southwest edge of the Badain Jaran desert, with the Taklimakan desert to the west. As shown in Fig. 1, this location is also affected by human activities focusing on agriculture and animal husbandry. The climate over there is dry and lacking in rain, along with strong evaporation under ample sunshine (Xuan et al., 2000).

It was mostly fair to cloudy during the sampling period, except for a severe sand-dust storm from 09:00 p.m. on the 23rd to 02:00 p.m. on the 25th April (shaded area in Fig. 2) and two floating dust episodes