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Seasonal variation and difference of aerosol optical properties in columnar and surface atmospheres over Shanghai

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HIGHLIGHTS

- AOT shows an obvious seasonal variation, SSA varies weak.
- Aerosol size distribution is a two-modal pattern.
- Air masses have different effects on aerosols, more complex in lower layers.
- Fine particles are primary and contribute to AOT significantly.

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ABSTRACT

Aerosol optical properties in columnar and surface atmospheres were measured at an urban station of Shanghai from December 2010 to October 2012, and their seasonal variations and differences were examined. Aerosol optical thickness (AOT) at 500 nm is on average about 0.72 over the entire campaign, relatively higher in spring and summer and lower in autumn and winter. Ångström wavelength exponent (Alfa) mainly distributes in 1.1–1.6 (72%) with an obvious uni-peak pattern, implying that fine particles are primary in the aerosol group. Aerosol single scattering albedo of columnar atmosphere (SSA) at 440 nm experiences a weak seasonal variation with an average of 0.91, indicating that aerosols are mainly composed of particles with relatively higher scattering efficiency. The aerosol volume size distribution shows one fine mode and another coarse mode, with peak radii of 0.15 μm and 3.0 μm, respectively. The volume of fine mode particles is minimum in spring and maximum in summer, while the volume of coarse mode particles is minimum in autumn and maximum in winter. The scattering coefficient (Sc) of aerosols in surface atmosphere is relatively higher in winter and spring, the absorptive coefficient (Ab) is higher in autumn and summer. The SSA of surface atmosphere (SSA-surf) at 532 nm varies weakly over time with a lower deviation, mostly scattering in the range of 0.8–0.95 (82%). Although the disconnection of aerosol properties between columnar and surface atmospheres exists, AOT and Alfa are correlated to some extent with $PM_{2.5}$ and visibility. However, the difference of SSA and SSA-surf is remarkable about 0.1. Overall, fine particles

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are dominant in aerosols and contribute to AOT significantly in this city, and their difference between surface and columnar atmospheres is unignored.

1. Introduction

Aerosols exert a variety of effects on Earth's climate, including effects on cloud microphysical properties and precipitation as well as direct radiative influence (Ramanathan et al., 2001; Andreae et al., 2005). Current understanding of the aerosol direct and indirect effects remains highly uncertain, constituting the greatest uncertainty in climate prediction (IPCC, 2007). The role of aerosols is dependent on their physical, chemical and optical properties as well as complex aerosol processes and their interactions in the atmosphere (Jacobson, 2001; Jimenez et al., 2009; Zhang et al., 2012), which vary significantly in space and time. High pollution levels in East Asia and associated outflows have raised considerable concerns because of their potential impacts on regional even global climate (Zhang et al., 2007).

Knowledge of aerosol optical properties is critical for estimating the aerosol effects on radiative forcing and climate. The determination of optical parameters as a function of wavelength has been recognized as an efficient way to distinguish between various aerosol types (Eck et al., 1999). Up to now, measurements of aerosol optical properties, including in situ and remote measurements, have been conducted worldwide. Several known networks for aerosol optical properties have been established internationally to observe aerosol optical properties and performed a long time, for example, AERONET, PHOTONS, SKYNET, AEROCAN, etc. (Holben et al., 1998; Bokoye et al., 2001; Uchiyama et al., 2005; Goloub et al., 2008). Besides spatial and temporal variations of aerosol optical properties, recently increasing studies have focused on their differences in columnar, surface and other atmospheric layers, as well as their linkage with particulate matter (e.g. $PM_{2.5}$), cloud condensation nuclei (CCN) and aerosol chemical composition (Engel-Cox et al., 2006; Cheng et al., 2008a; Andreae, 2009; Esteve et al., 2012).

East Asia is a fast developing and densely populated region, especially the Yangtze River Delta (YRD), where anthropogenic emissions of particles and gaseous precursors have increasing significantly over recent decades (Che et al., 2007; Streets et al., 2008; Tie and Cao, 2009). Kim et al. (2007) discussed seasonal variations of aerosol optical properties from multi-year MODIS, LIDAR and AERONET measurements over eastern Asia. Although there is a similar trend in the distribution of aerosol optical thickness (AOT), their quantitative comparability is poor due to a lack of systemic ground-based network measurements as well as the large errors in satellite retrievals. Recently, as AERONET, aerosol experiments have been conducted in mainland China, such as EAST-AIRE, CARSNET, and so on (Li et al., 2007a; Che et al., 2009). For the YRD region, early, Xu et al. (2002) measured aerosol chemical, physical and radiative properties. Also, Xia et al. (2007a,b) analyzed aerosol optical properties and estimated aerosol radiative effects. Pan et al. (2010) compared aerosol optical properties measured by sun photometer at five sites. He et al. (2010) validated AOTs derived from MODIS using sun photometer measurements at seven sites. Liu et al. (2012) reported the seasonal variation of aerosol optical properties, vertical distribution and associated radiative effects using long-term measurements at Taihu site. He et al. (2012) exhibited aerosol optical properties retrieved from sun photometer continuous measurements in Shanghai, and Xu et al. (2011) assessed AOT impact on surface solar radiation in this city. Recently, Han et al. (2015) and Tang et al. (2014) characterized aerosol optical properties, chemical composition and mixing states in the winter of Shanghai. However, the study of aerosol properties and their spatial and temporal variations is still deficient in this region.

This paper presents aerosol optical parameters derived from sun photometer measurements from Dec. 2010 to Oct. 2012 in Shanghai. The aim is to elaborate the long-term characteristics of aerosol optical properties, and compare their differences in columnar and surface atmosphere layers. The results will rich our understanding of Asian aerosols to reduce uncertainties of aerosol climate and radiation effects over the Chinese continent.

2. Experiment

2.1. Observation site

The measurement station is mounted on the top of a building in the campus of Fudan University (31°18′N, 121°29′E), which is about 20 m above ground, roughly 10 km northeast of the city center of Shanghai (population 24 millions) and 40 km east to the East China Sea. The site is located in an urban zone surrounded by populated residential and commercial areas. Shanghai is influenced by Asian monsoon climate, with four distinct seasons, that is, sunny in spring and autumn and rainy in summer. The annual mean precipitation is 1119 mm, about 60% of which concentrates between May and September. The prevailing winds are southeasterly in summer and northeasterly in winter. Aerosols are possibly influenced by both local and remote emissions, including urban, continental and oceanic sources through atmospheric transportation (Du et al., 2011). By the way, the local time (LT) hereafter employed in this study is 8 h ahead of UTC.

2.2. Instrumentation

The ground-based sun photometer (CE318, Cimel Electronique, France) as a useful tool is able to measure direct solar radiation within a 1.2° full field-of-view at nine channels. The bandwidth of 1640, 1020, 940, 870, 675, 500, 440 nm is 10 nm, and 2 nm in 380 nm and 340 nm. A detailed description of sun photometer and its products has been presented by Holben et al. (1998). In this study, the sun photometer was calibrated annually to assure the accuracy and reliability of data through inter-comparing with the reference instrument, which was calibrated at Izana Observatory of Spain by the facilities following the AERONET calibration protocol method (Che et al., 2009), at the Chinese Academy of Meteorological Sciences (CAMS) in Beijing.

Measurements at 940 nm can be used to retrieve precipitable water content, and measurements at other wavelengths are always used to retrieve AOT. Aerosol size distribution, refractive index, single scattering albedo (SSA) are always retrieved using sky radiance almucantar measurements at 440, 675, 870 and 1020 nm (Dubovik et al., 2000; Dubovik and King, 2000) as well as polarize radiances in sun-principal plane (Li et al., 2006). The data used here were prefield and postfield calibrated and automatically cloud screened based on the method of Smirnov et al. (2000). The AOT data (e.g. 500 nm) were derived using the ASTPwin software