

Study on Aerosol Model and Sources at Zhoushan, China Using Sun-sky Photometer Observation

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Abstract. Aerosol models are widely used in satellite remote sensing to derived aerosol mode from aerosol optical and microphysical properties. One year of ground-based aerosol remote sensing observations were carried out using sun-sky radiometer measurements in Zhoushan (122.1897E, 29.9944N), Zhejiang Province, Eastern China. At the same time column Aerosol Optical Depth (AOD), Ångström exponent (AE), Single Scattering Albedo (SSA), asymmetry factor (g), complex refractive index and column aerosol volume spectral distribution were retrieved by mature code as well as some procedures, such as radiometer calibration, cloud screening and data selection strategies. Aerosol size parameters were separated as fine effective radius (r_{vf}) and coarse effective radius (r_{vc}) due to the column aerosol size distribution is generally bimodal lognormal distribution. The relationship between these parameters and effective radius was shown and analyzed. It is shown that aerosol in Zhoushan is urban-industrial type dominate, mixed with marine aerosol and mineral dust aerosol. As a result, this study showed a part of aerosol comes from mainland industrial areas by using the backward trajectory model.

1. Introduction

Over the last few decades, there are many research on the topic of aerosols, from its generation, transport, influence and so on, due to its great impact on light scattering and absorbing, as well as human health. Additionally, climate models rely on the aerosol optical/microphysical properties (also named aerosol model), which is one of the largest uncertainties in climate forcing assessments [1]. More recently, aerosol models for different types associated with different sources and emission mechanisms are exhibit [2,3,4,5,6]. However, there is discrepancy between the model and the actual aerosol properties measured. What's more, determination of the aerosol type for a place is also a fundamentally challenging task. In this paper, aerosol optical/microphysical properties are retrieved from remote sensing measurement of irradiance/radiance at Zhoushan, eastern China and compared with other previous models.



2. Observation and methodology

In this study, CE-318 sun/sky photometer (manufactured by CIMEL Company, France) is applied to measurement. The instrument is located at Linchen Environmental Monitoring Station, Zhoushan Environmental Protection Agency, Zhejiang Province, China (29.9944°N,122.1897°E). It contains 8 band, including 0.34,0.38,0.44,0.5,0.67,0.87,1.02,1.64 μm (nominal wavelength) with 2-10 nm bandwidth. The observation was last about one year, from February 2012 to January 2013. The instrument was inter-calibrated with AEROSOL ROBOTIC NETWORK[7] 350# instrument at Beijing with the direct sun channel in January 2012 and sky radiance was calibrated using vicarious method[8]. With the direct sun channel calibration, Aerosol Optical Depth(AOD) can be calculated by eliminating molecular scattering. At the same time, strong gaseous absorption can be avoided by instrumental design or appropriately accounted for from climatological data. 2860 AOD data were collected by eliminating the cloud. The retrieval code we used in this paper is the Dubovik's code, which is mature and widely used[9,10]. The ground reflectance is assumed to be Lambertian with albedo fixed to the values provided by Moderate Resolution Imaging Spectroradiometer (MODIS) climatology data[11]. This code provides aerosol optical and physical properties retrievals by fitting the sun and sky radiance at four wavelengths (0.44,0.67,0.87 and 1.02 μm) to radiative transfer model.

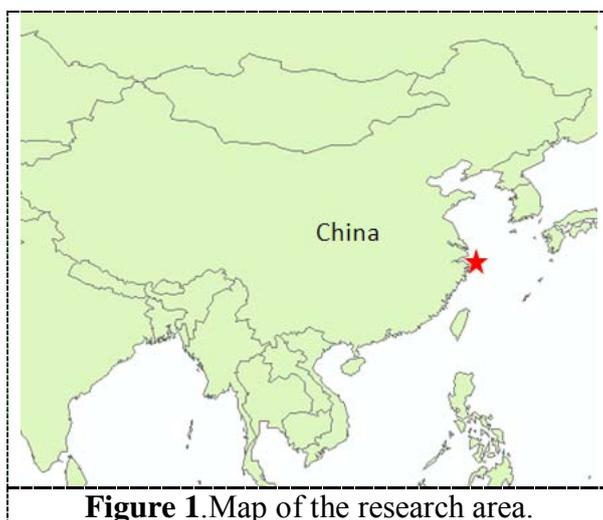


Figure 1. Map of the research area.

3. Results

The column aerosol optical depth indicated the extinction of light by aerosols. Monthly average AOD at 0.44 μm data was derived, while Ångström exponent(AE), which usually indicated as a factor of aerosol size distribution, was calculated from AOD of 0.44 μm and 0.87 μm . Figure 2(a) shows monthly average AOD and AE in Zhoushan in a whole year. From the figure, AOD is higher in June, while lower in the months of July and August and the annual average of AOD is 0.54. AE is range from -0.2 to 1.7 with an average 1.0 in the whole year of 2012. Single Scattering Albedo(SSA) refers to the ratio of the scattering coefficient and the extinction coefficient, which is an important parameter for estimating the aerosol climate effect. The average SSA at 0.44 μm is 0.93, and it is range from 0.84-0.95. From Figure 2(b), it's presented that SSA is decreased with wavelength increased. This could result from aerosol particle size, shape and other microphysical characteristics of the aerosol. Asymmetry factor(g) is obtained from aerosol scattering phase function, which represents the distribution of light after aerosol scattering in all scattering directions(0 degree to 180 degree). Annual average for asymmetry factor in Zhoushan is between 0.6 and 0.75 for different wavelength.

Aerosols complex refractive index is defined as the ratio of light refractive in aerosol and air,

including characterization of the aerosol scattering properties (real part of the complex refractive index, m_r), as well as characterization of the aerosol absorption characteristics (imaginary part of complex refractive index). In this article, we set the aerosol complex refractive index changes from 1.33 to 1.7 for the real part and the imaginary part from 0.0005 to 0.5, due to most of the real mix aerosol refractive index between in. The real part of complex refractive index is relatively stable (with 1.48). In fact, many studies show that there is no severe change of real part for different wavelength. The imaginary part of refractive index for Zhoushan region are 0.008, 0.009, 0.12, 0.12 for 0.44, 0.67, 0.87 and 1.02 μm , respectively.

The column aerosol volume spectral distribution is defined as the volume of aerosol for an air column of unit cross section, within a unit of logarithmic radius interval: $dV/d \ln r$ (in cubic micrometers per square micrometers)[12]. Figure 2 (d) is demonstrated the annual mean volume spectral distribution, it is shown in bimodal with peaks in 0.17 μm and 2.76 μm , separately.

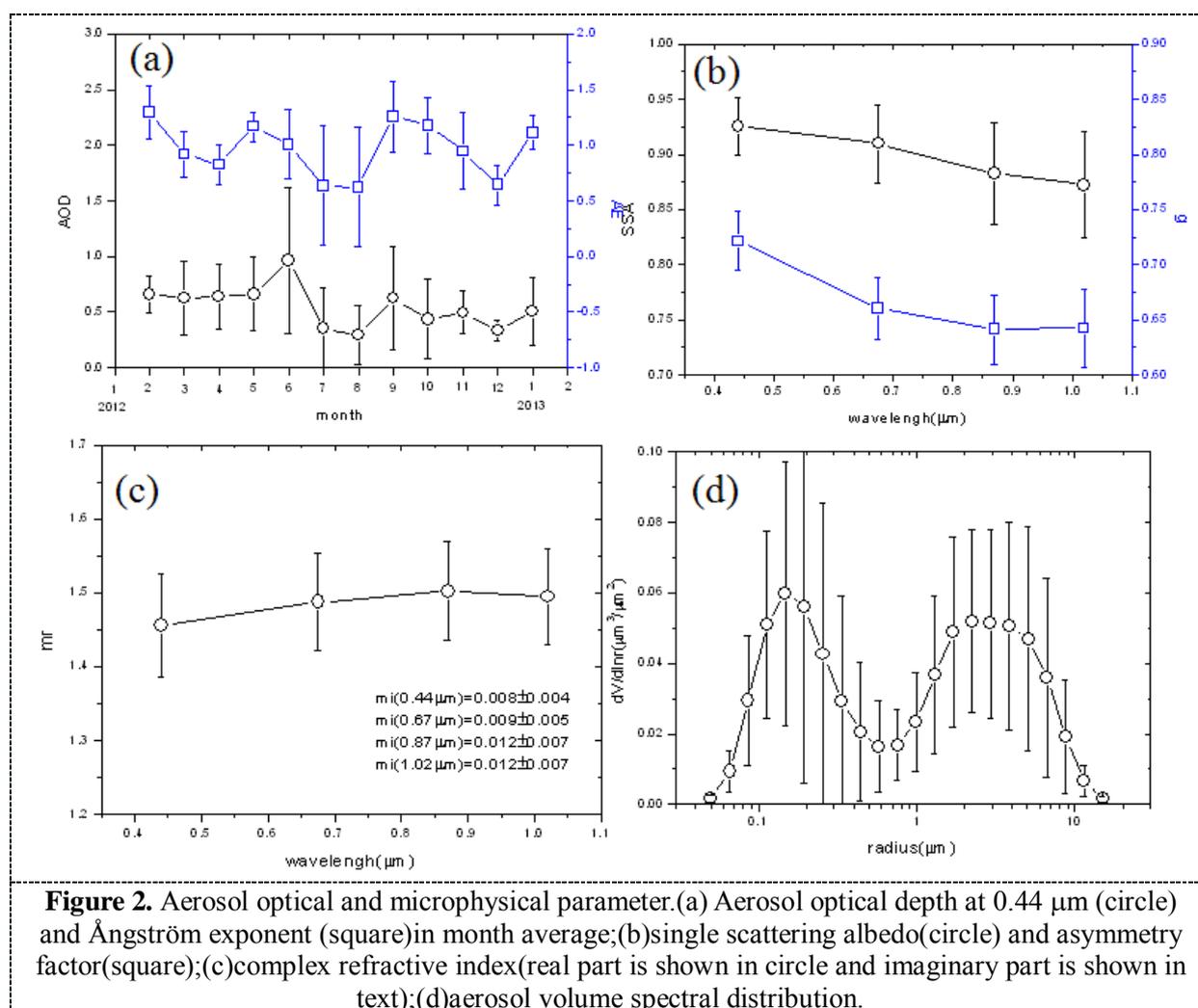


Figure 2. Aerosol optical and microphysical parameter. (a) Aerosol optical depth at 0.44 μm (circle) and Ångström exponent (square) in month average; (b) single scattering albedo (circle) and asymmetry factor (square); (c) complex refractive index (real part is shown in circle and imaginary part is shown in text); (d) aerosol volume spectral distribution.

It's analyzed Zhoushan aerosol optical and microphysical characteristics above. It's difficult to define aerosol type for Zhoushan area, because the aerosol type involved in local environment, weather and other conditions, but we still want to determine aerosol type according to the parameters we retrieved. Many studies had done a statistical summary of the main four categories of aerosol according to optical and microphysical characteristics. These four types of aerosols include:

urban–industrial, biomass burning, marine, and mixed type. It's similar for these types of aerosol parameters in AERONET using sun/sky photometer inversion. Table 1 compares aerosol optical and microphysical parameters between Zhoushan and Mexico city (urban–industrial type aerosol)[6]. It can be seen from the table, most part of the parameters are very close. For example, AOD range in Zhoushan is 0.1 to 2.2, and the average value is 0.54; while Mexico city AOD variation range is 0.1 to 1.8 with the average value is 0.47. In terms of particle size, fine effective radius(r_{vf}) and coarse effective radius(r_{vc}) for Zhoushan is $0.17\mu\text{m}$ and $2.76\mu\text{m}$, for Mexico city is $0.14\mu\text{m}$ and $2.98\mu\text{m}$.

Table 1. Comparison of Zhoushan and Mexico city aerosol properties.

	Zhoushan	Mexico City(Urban–industrial)
AOD(440nm)	$0.1 \leq \tau \leq 2.2; \langle \tau \rangle = 0.54$	$0.1 \leq \tau \leq 1.8; \langle \tau \rangle = 0.43$
AE	$-0.2 \leq \alpha \leq 1.7$	$1.1 \leq \alpha \leq 2.3$
$g(440/670/870/1020)$	$0.72/0.66/0.64/0.64 \pm 0.03$	$0.68/0.61/0.58/0.57 \pm 0.07$
n, k	$1.48 \pm 0.07; 0.01 \pm 0.005$	$1.47 \pm 0.03; 0.014 \pm 0.006$
$\omega_0(440/670/870/1020)$	$0.93/0.91/0.88/0.87 \pm 0.04$	$0.90/0.88/0.85/0.83 \pm 0.02$
$r_{vf}(\mu\text{m}); \sigma_f$	$0.17 \pm 0.03; 0.51 \pm 0.06$	$0.14/0.02; 0.43 \pm 0.03$
$r_{vc}(\mu\text{m}); \sigma_c$	$2.76 \pm 0.45; 0.68 \pm 0.06$	$2.98/0.23; 0.63 \pm 0.05$
$C_{vf}(\mu\text{m}^3/\mu\text{m}^2)$	0.085 ± 0.05	0.052 ± 0.03
$C_{vc}(\mu\text{m}^3/\mu\text{m}^2)$	0.11 ± 0.05	0.047 ± 0.03

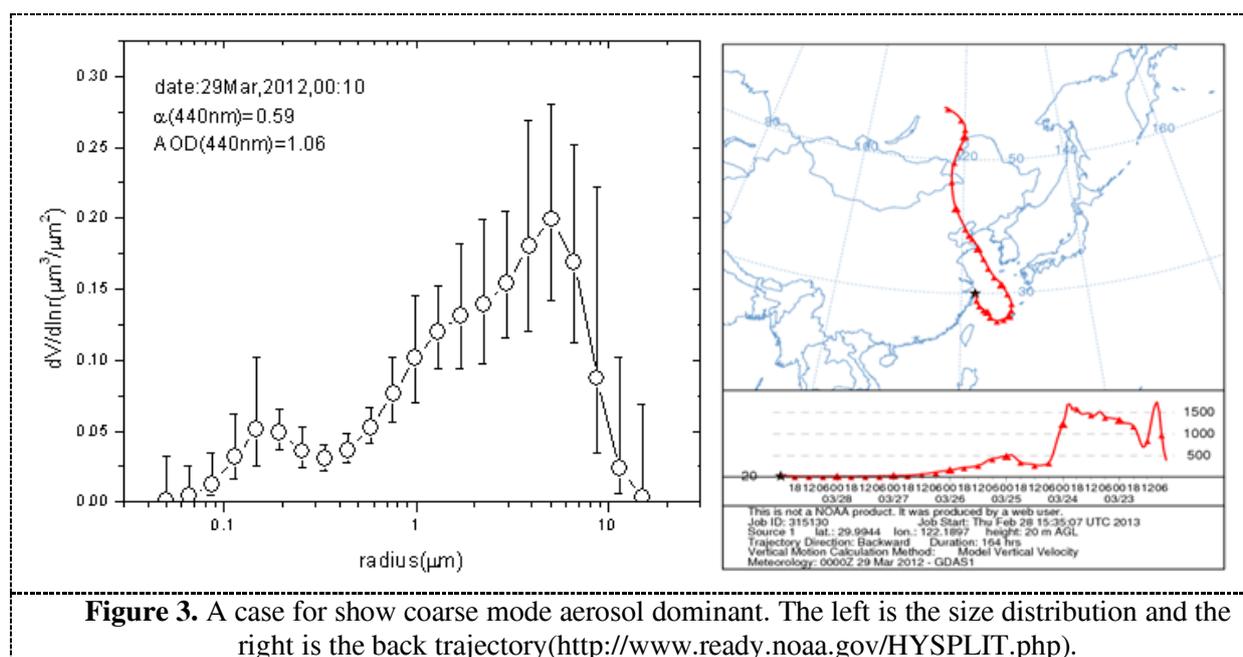


Figure 3. A case for show coarse mode aerosol dominant. The left is the size distribution and the right is the back trajectory(<http://www.ready.noaa.gov/HYSPLIT.php>).

4. Conclusions and Discussions

In this paper, the one year ground-based observations to characterized aerosol at Zhoushan were shown. Overall, aerosol type for Zhoushan is in favor of the urban–industrial type, with mixed marine aerosol and mineral dust aerosol. This paper summarizes the aerosol optical and microphysical parameters in Zhoushan for the application of satellite remote sensing to provide priori knowledge for aerosol. It should be noted that determination of aerosol type requires many observations, not only aerosol measurement, but also meteorological data. In many cases, it can not be simply classified somewhere as a certain type of a specific type of aerosol. It is necessary to improve the observation for

more accurate refinement aerosol characteristics in the following studies.

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