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Retrievals of density and refractive index of dry aerosols from aerosol optical parameters measured in an urban atmosphere of Nagoya

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1.Introduction

Aerosol particles can play an important role on atmospheric heat budget by scattering and absorbing light. The scattering and absorption of light by aerosol particles depend on aerosol properties. Density and refractive index are important properties of aerosols. The usual approach for determining density and refractive index is to calculate them from measured aerosol composition. It is often difficult to adequately characterize the composition of chemically complex aerosols, such as those found in an atmosphere. In addition, due to expense and expertise required, aerosol composition data are limited in both space and time. Therefore, it is necessary to look for alternative approaches to estimate density and refractive index of aerosol particles. In view of this recognition, this study was designed by collecting aerosol data in an urban atmosphere of Nagoya.

2.Study Method

The study used directly measured scattering coefficient (σ_{sca}), absorption coefficient (σ_{abs}), aerosol mass concentration, black carbon (BC) mass concentration, and size distribution of aerosols larger than 0.3μm in diameter at low RH from 23 July to 4 September 2004. At first, it is worth to mention how refractive index (m) is related to density (ρ) and BC mass fraction (X_{BC}).

Some studies (e.g., Hasan and Dzubay1983; Khatri and Ishizaka 2007) have shown equations of estimating m and ρ for a mixture of various aerosol components. By expressing BC aerosol as "BC" and aerosols other than BC (e.g., sulfate, nitrate, organics etc.) as "non-BC" and considering that real refractive indices for non-BC aerosols (n_{non-BC}) are nearly equal to each other (Lesins et al. 2002), combination of equations shown in above mentioned studies gives the following equation:

$$m = \rho \cdot \left[\frac{X_{BC} \cdot n_{BC}}{\rho_{BC}} + (n_{non-BC})_x \cdot \left(\frac{1}{\rho} - \frac{X_{BC}}{\rho_{BC}} \right) \right] - \rho \cdot \left[\frac{X_{BC} \cdot k_{BC}}{\rho_{BC}} + \sum_{x=1}^{n-1} \frac{(X_{non-BC})_x \cdot (k_{non-BC})_x}{(\rho_{non-BC})_x} \right] \cdot i$$

where X, n, and k represent mass fraction, real refractive index and imaginary refractive index, respectively. Following literature, values of n_{BC} and k_{BC} were set to 1.95 and 0.66, ρ_{BC} to 1.8 gcm^{-3}, and $(n_{non-BC})_x$ to 1.53. BC aerosol dominates total light absorption in an urban atmosphere. In our observation area (Nagoya), this fact was confirmed by analyzing wavelength dependency behavior of σ_{abs}. Therefore, $(k_{non-BC})_x \approx 0$. Hence m is a function of ρ and X_{BC}.

In this study, at the first step, ρ was set to 0.5 and size distribution of aerosols smaller than 0.3μm in diameter was estimated from total aerosol mass concentration and size distribution of aerosols larger than 0.3μm in diameter. At the same time, m was estimated from ρ and X_{BC} by using the above equation. Such retrieved values of m and total aerosol size distribution were used to estimate σ_{sca} and σ_{abs}, which were then compared with directly measured values. ρ was increased by 0.01 at each run and the same procedure was repeated until calculated values of σ_{sca} and σ_{abs} agreed well with measured values (Fig. 1). The values of ρ and m that produced such agreement were considered as the actual values.

3. Results

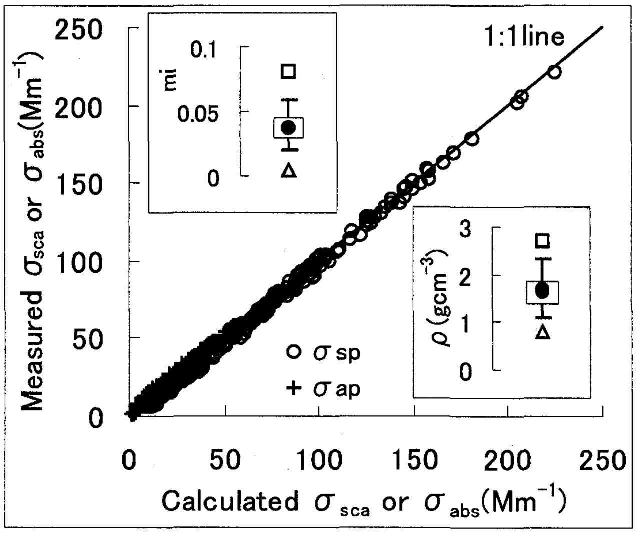

Fig.1. Calculated and measured values of σ_{sca} and σ_{abs}. Retrieved values of m_i and ρ are also shown. Closed circle: mean value, box and whisker: 75th and 95th percentiles, square: the highest value, and triangle: the lowest value.

As shown in Fig. 1, ρ was found to range from 0.8 to 2.7 with the mean and median of 1.66 and 1.7, respectively. Our retrieved mean and/or median ρ showed satisfactory agreement with reported values for urban pollutions in a number of publications (e.g., McMurry et al. 2002; Clarke et al. 2007). Similarly, m_i was found to range from 0.005 to 0.081 with both the mean and median of 0.038. Since m_i depends strongly on relative abundance of light absorbing aerosols in an atmosphere, the literature values of m_i for urban aerosols are not uniform. Nonetheless, our retrieved mean or median m_i of 0.038, which coincided with some other studies (e.g., Ebert et al. 2004; Raut and Chazette 2007), suggests light absorbing aerosol as one of the important components in an urban atmosphere of Nagoya. The real part of the refractive index (m_r) (not shown in Fig. 1) ranged from 1.53 to 1.58 with both the mean and median of 1.55. As expected, m_r showed a narrow variation because light scattering aerosols constitute a significant fraction of total aerosol mass concentration, and the real refractive indices of such light scattering aerosols are nearly equal to each other. Hence, ρ and m are likely to be estimated from above mentioned data sets.