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VERTICAL RESOLVED DUST MASS CONCENTRATION AND BACKSCATTER COEFFICIENT RETRIEVAL OF ASIAN DUST PLUME USING QUARTZ RAMAN CHANNEL IN LIDAR MEASUREMENTS

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ABSTRACT

In this work, we present a method for estimating vertical resolved mass concentration of dust immersed in Asian dust plume using Raman scattering of quartz (silicon dioxide, silica). During the Asian dust period of March 15, 16, and 21 in 2010, Raman lidar measurements detected the presence of quartz, and successfully showed the vertical profiles of the quartz backscatter coefficient. Since the Raman backscatter coefficient was connected with the Raman backscatter differential cross section and the number density of quartz molecules, the mass concentration of quartz in the atmosphere can be estimated from the quartz backscatter coefficient. The weight percentage from 40 to 70 % for quartz in the Asian dust was estimated from references. The vertical resolved mass concentration of dust was estimated by quartz mass concentration and weight percentage. We also present a retrieval method to obtain dust backscatter coefficient from the mixed Asian dust and pollutant layer. OPAC (Optical Properties of Aerosol and Clouds) simulations were conducted to calculate dust backscatter coefficient. The retrieved dust mass concentration was used as an input parameter for the OPAC calculations. These approaches in the study will be useful for characterizing the quartz dominated in the atmospheric aerosols and estimating vertical resolved mass concentration of dust. It will be especially applicable for optically distinguishing the dust and non-dust aerosols in studies on the mixing state of Asian dust plume. Additionally, the presented method combined with satellite observations is enable qualitative and quantitative monitoring for Asian dust.

1. INTRODUCTION

Dust has considerable influence on the Earth's radiative budget (Schwartz and Andreae, 2002). Next to the Sahara, an equally important source of dust is Central Asia from where dust is transported over East Asia to the adjacent Pacific Ocean. In Asia the problem of dust in the atmosphere is much more severe than in other areas of the world, as dust often is mixed with urban haze. Scientific knowledge on the mixing state of dust with anthropogenic pollution is very limited. Thus there is strong need the measurement technologies that allow us to monitor the vertical distribution of mineral dust immersed in continental pollution plumes. In this work, we present a method for estimating vertical resolved mass concentration of dust immersed in Asian dust plume using Raman scattering of quartz (silicon dioxide, silica). We also present a retrieval method to obtain dust backscatter coefficient from the mixed Asian dust and pollutant layer.

2. METHODOLOGY

We collected data during the Asian dust period of March 15, 16, and 21 in 2010 with multi-wavelength Raman lidar system at the Gwangju Institute of Science and Technology (GIST; 35.2° N, 126° E), Republic of Korea (South Korea). From the signals detected at 532 nm (elastic backscattering) and 607 nm (molecular Raman backscattering signals) we derive profiles of particle backscatter and extinction coefficients and the linear volume (particle plus molecule) depolarization ratio at 532 nm. The linear particle depolarization ratio follows according to the methods described by Sakai et al. (2003) and Noh et al. (2013). We installed Raman channel at 546 nm for inferring the mineral quartz concentration. The channels utilize the Raman return signals from silicon dioxide which is one main component of mineral quartz. The measurement technology is described by Tatarov and Sugimoto (2005) who use Raman return signals at 546 nm. Instrument setup, optical components, and details of the operation mode are described in Tatarov et al. (2011).

The weight percentage range from 40 to 70 % for quartz in the Asian dust was estimated from references (Feng et al., 2002; Ganzei and Razahigaeva, 2006). The vertical resolved mass concentration of dust was estimated by quartz mass concentration and weight percentage.

We also retrieved dust backscatter coefficient from the Asian dust mixed with pollutants by OPAC (Optical Properties of Aerosol and Clouds) simulations. The retrieved dust mass concentration was used as an input parameter for the OPAC calculations. It was assumed that the Asian dust is composed of nuclei, accumulation, and transported mode with mass mixing ratio of 0.110, 0.747, 0.153, respectively. The concentration of Asian dust by quartz measurements was converted as number concentration of each mode by following equation (1) :

$$N_i = \frac{D_z R_i}{M_i^*} \quad (1)$$

Where N_i represent the number concentration of Asian dust mode i, D_z denotes mass concentration of Asian dust at height z, M_i^* is weight per unit of grain. The number concentration of each component was used as an input parameter for the OPAC calculations to retrieve extinction coefficient.

3. RESULTS

3.1. Vertical resolved mass concentration of Asian dust

Figure 1 shows the vertical profiles of the aerosol extinction coefficient at 532 and quartz backscatter coefficient at 546 nm measured on three days, i.e., on 15, 16 and 21 March 2010.

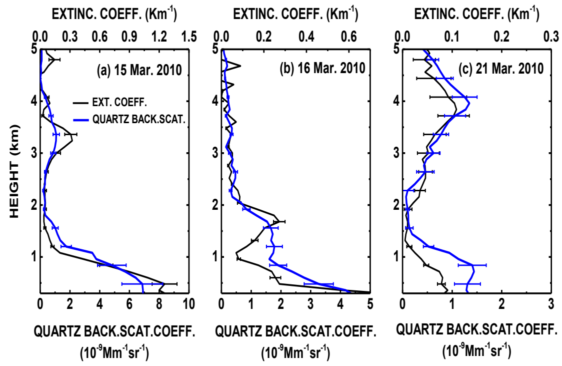

Figure 1. Extinction coefficient (black) and quartz backscatter coefficient (Blue).

Figure 2 shows the profiles of the mineral quartz and dust concentration. The profiles were obtained from the profiles of the quartz-backscatter coefficient and the values of the Raman scattering cross-section for quartz. We find 5-100 μg/m^3 mineral quartz. Dust concentration was calculated by assuming the ratio of quartz in the Asian dust as 40 – 70 %.

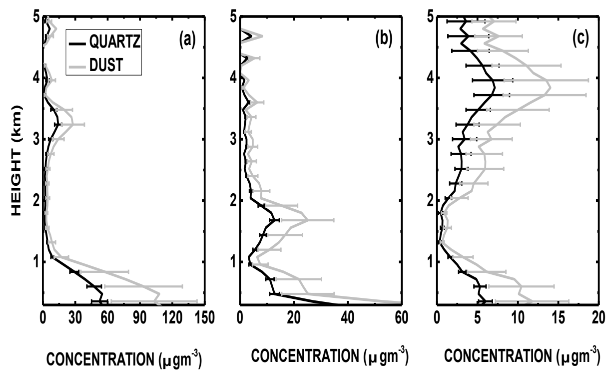

Figure 2. Vertical resolved mass concentration of quartz (black) and dust(gray).

Measurements of PM-10 are done on a routine basis by the Korea Meteorological Administration (KMA) in Gwangju. Table 1 shows PM-10 concentration observed at the surface, mineral quartz and dust concentration at the height of 360 m. The surface-level observations were 210 ± 110, 124 ± 6, and 42 ± 3 μg/m^3 as an average value during lidar measurement period. The concentration of dusts is 49.8, 55.6 and 19.0 % in Asian dust plumes on 15, 16, and 21 March 2010, respectively. This means we can double the dust concentration values we derived from our lidar observations. Our lidar derived dust concentration means pure dust originated from dust source regions. However, the surface measured PM-10 concentrations can include urban anthropogenic particle or local dust particle. Another reason for the higher in-situ values may be mixed with anthropogenic aerosols originated from industrial region of China during long-range transport. Since the dust plumes originated from dust source regions have to pass over industrial areas of China, anthropogenic aerosols can be mixed with dust plumes.

Table 1. PM-10 by in-situ measurement and quartz and dust concentrations by lidar measurements.

Date (2010)	PM_{10} (μg m^{-3})	SiO2 (μg m^{-3})	Dust (μg m^{-3})	Dust/ PM_{10}
03.15	215 ± 110	70 ± 25	107 ± 30	0.498
03.16	124 ± 6	45 ± 10	69 ± 16	0.556
03. 21	42 ± 3	5 ± 2	8 ± 3	0.190

3.2. Retrieval of dust backscatter coefficient

The dust backscatter coefficient was retrieved from vertical resolved dust concentration by OPAC. Figure 3 shows the backscatter coefficients of dust, non-dust, and total dust plumes. The backscatter coefficient of non-dust particle was calculated by subtracting dust backscatter coefficient from backscatter coefficient of total dust plume.

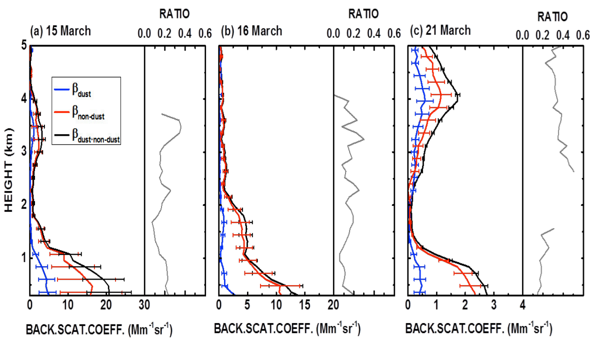

Figure 3. Backscatter coefficient of dust (blue), non-dust (red) and all (dust + non-dust) particles. The ratio of dust to the total aerosol backscatter coefficient is shown as gray line.

Figure 3 also shows the ratio of the dust backscatter coefficient to the total aerosol backscatter coefficient. The average ratios are 0.19 ± 0.07, 0.14 ± 0.06 and 0.31 ± 0.10 on 15, 16 and 21 March 2010, respectively. The ratios at the lowest lidar observation height (300 m) are 0.22, 0.17 and 0.15 on 15, 16 and 21 March 2010, respectively. These values are lower than the ratio of dust/PM_{10} in Table 1. The difference of the mass-scattering efficiency of dust and non-dust particles can be one reason for the low value of the dust backscatter coefficient. The aerosol mass-scattering efficiency (m^2g^{-1}), which is also referred to as mass-scattering coefficient or specific light-scattering is determined using concurrent measurements of the aerosol light-scattering coefficient and some estimate of particle mass (Charlson et al., 1999). Andreae et al. (2002) find that the fine-mode aerosols play a dominant role in the optical characteristics of the atmosphere in desert regions in spite of the desert location and the large contribution of mineral dust to the aerosol mass burden. Titos et al. (2012) report from one year of measurements (from March 2006 to February 2007) performed at an urban site in Southern Spain (Granada) that sulfate exhibits the largest mass scattering efficiency (7 ± 1 m^2g^{-1}) and dust aerosols present the lowest mass-scattering efficiency (0.2 ± 0.1 m^2g^{-1}). Hand and Malm (2007) reviewed the values of mass-scattering efficiencies of common aerosol species obtained from 60 studies carried out since 1990. The data represent a variety of time periods and locations on Earth. Hand and Malm (2007) recommend a value of 0.7 m^2g^{-1} of the mass-scattering efficiency for coarse mode dust while the mass-scattering efficiency of other anthropogenic aerosols is 2 – 6 m^2g^{-1}.

4. CONCLUSIONS

This research presents, for the first time, a new retrieval method to obtain dust backscatter coefficient from the mixed Asian dust and pollutant layer by combining quartz Raman measurement and OPAC simulation. OPAC (Optical Properties of Aerosol and Clouds) simulations were conducted to calculate dust backscatter coefficient. The retrieved dust mass concentration was used as an input parameter for the OPAC calculations.

Our research confirmed that the quratz Raman measurement is useful for estimating vertical resolved mass concentration of dust. It will be also especially applicable for optically distinguishing the dust and non-dust aerosols in studies on the mixing state of Asian dust plume. Additionally, the presented method combined with satellite observations is enable qualitative and quantitative monitoring for Asian dust.

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