VERTICAL DISTRIBUTION AND OPTICAL PROPERTIES OF AEROSOLS OBSERVED OVER JAPAN IN SPRING 2005

Tadahiro Hayasaka[1], Kazuma Aoki[2], Atsushi Shimizu[3], Nobuo Sugimoto[3], Ichiro Matsui[3], Shinsuke Satake[1], and Yoshitaka Muraji[4]

1 Research Institute for Humanity and Nature, Kyoto 603-8047, Japan, hayasaka@chikyu.ac.jp
2 Toyama University, Toyama 930-8555, Japan
3 National Institute for Environmental Studies, Tsukuba 305-8506, Japan
4 EnergySharing Co. Ltd., Toride, 302-0004, Japan

ABSTRACT

The present paper describes combined measurements of aerosols with lidar and skyradiometer, both of which can provide complementary aerosol properties. Dust and spherical aerosols were observed by lidar over Japan in the spring of 2005. The vertical distributions of these aerosols are different among the locations, Sapporo, Toyama, and Nagasaki. Dust aerosols tend to distribute up to higher altitude compared to spherical aerosols. The skyradiometer measurements indicated optical thickness and size distribution of aerosols consistent with lidar measurements.

The vertical distribution properties of aerosols were simulated by using the Chemical Weather FORecasting System (CFORS). The results suggested that dust aerosols in the higher altitude were transported from arid region in the northwest region of China, while spherical aerosols were emitted from polluted industrial and urban regions.

1. INTRODUCTION

The recent growth of economy in Asian region is being watched with interest. Various environmental issues are brought about with the rapid economic growth and the accompanying change of social system, and a lot of aerosols and greenhouse gases are emitted into the atmosphere.

In the spring of East Asia region, dust storm, so-called “Yellow Sand Event”, frequently occurs. Recent studies on the aerosols in this region revealed that dust aerosols in spring are mixed with anthropogenic aerosols such as black carbon and sulfate.

In this paper, we present vertical distribution and optical properties of aerosols observed by lidar and skyradiometer in Japan during the East Asia Regional Experiment 2005 (EAREX2005), which was carried out in the spring of 2005 as part of UNEP Atmospheric Brown Clouds (ABC) project. The observed aerosol properties are also analyzed by using atmospheric transport model.

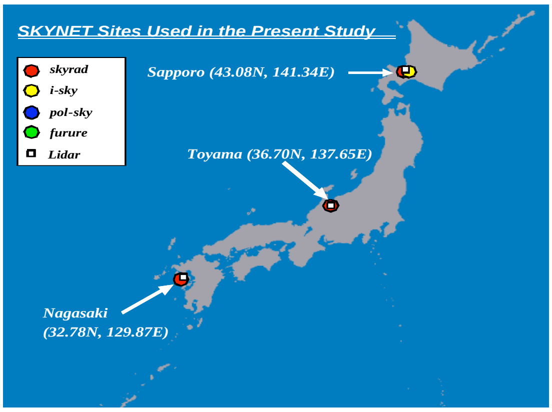

Figure 1. Locations of observation sites, Sapporo, Toyama, and Nagasaki

2. OBSERVATIONS AND DATA ANALYSIS

Figure 1 shows the locations of observation sites, Nagasaki (32.78°N, 129.87°E), Toyama (36.70°N, 137.65°E), and Sapporo (43.08°N, 141.34°E). All of the observation sites are equipped with both lidar and skyradiometer. The instruments are, in principle, automatically operated and lidar data and skyradiometer data are transferred to National Institute for Environmental Studies and Center for Environmental Remote Sensing /Chiba University, respectively.

All the data obtained under the clear sky conditions in March, April, and May, 2005 were analyzed in this study although the measurements continue up to now. Combined measurements with lidar and skyradiometer have advantages because these instruments complement each other.

2. 1. Lidar Measurements

Lidar system automatically measures vertical profiles of backscattering intensity of aerosol at two wavelengths 532nm and 1064nm, and depolarization ratio at 532nm. Discrimination of nonspherical particle is made by depolarization ratio measurement. The output power of laser for each wavelength is 20mJ with repetition rate of 10pps, and the receiver is a Cassegrainian telescope with 20cm diameter mirror. The vertical spatial resolution and measurement cycle are 6 m and 15 min. (5 min. measurement and 10 min. rest), respectively. 30m averaged data were used in this study. This lidar measurement covers aerosol vertical profile in the troposphere.

In order to deal with huge volume of lidar data, a scale height was used as a measure of vertical distribution of aerosols (Hayasaka et al., 1998). The scale height in this study is obtained by dividing the optical thickness, i.e., vertically integrated extinction coefficient by the extinction coefficient in the lowermost 90m layer. The comparison with skyradiometer measurements shows that the aerosol optical thickness obtained from lidar measurements is generally consistent with that measured by skyradiometer except for some cases.

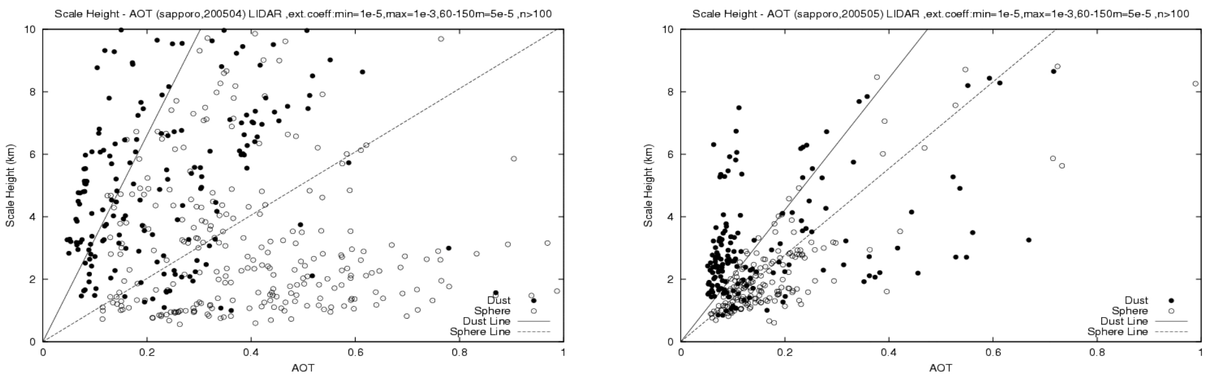

Figure 2. The relationship between optical thickness and scale height of aerosols observed in Sapporo in April (left) and May (right).

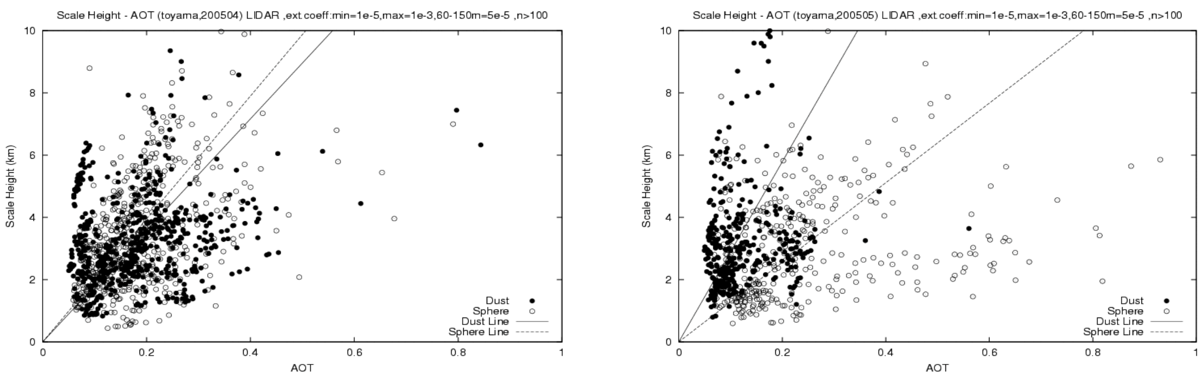

Figure 3. Same as Figure 2 except for the location, Toyama

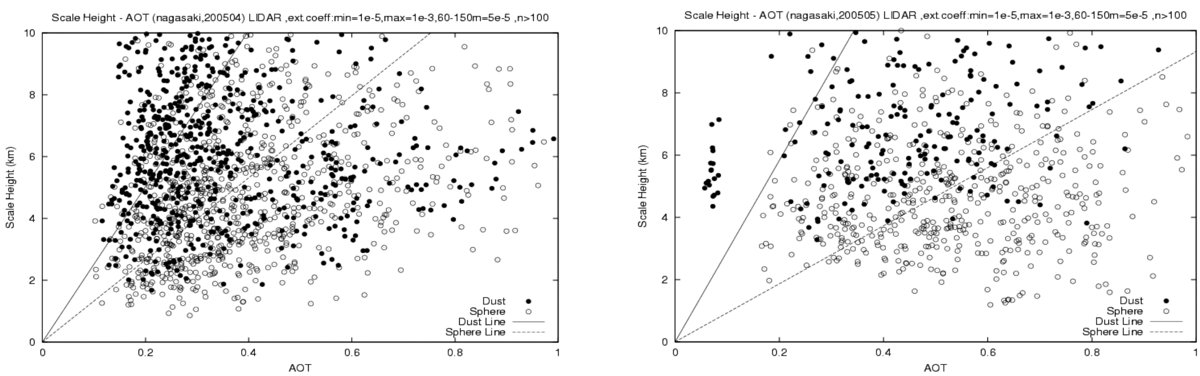

Figure 4. Same as Figure 2 except for the location, Nagasaki

Figures 2, 3 and 4 show the relationship between aerosol optical thickness (AOT) and scale height of extinction coefficient retrieved from lidar measurements in Sapporo, Toyama and Nagasaki, respectively. The data obtained under clear sky condition in April (left) and May (right), 2005 are shown here although data analysis was carried out also for Match. In these figures, the data of dust aerosols are indicated by black circle and those of spherical aerosols are indicated by white circle.

It is found from the comparison among three figures that vertical distribution and optical thickness of dust aerosols are different in each location. In Sapporo, optical thickness of dust aerosols is generally small while the scale height is distributed up to higher altitude in April. The aerosols consisting of spherical particles are loaded in the lower layer. On the other hand, a few cases with large optical thickness and scale height of middle troposphere are found in May.

In Nagasaki, both of dust and spherical aerosols appear to have similar properties as shown in Fig. 4, that is, large ranges of scale height and optical thickness. It is interesting that large optical thickness with small scale height was not observed here. This property is quite different from the results in Sapporo. It can be pointed out that the minimum of aerosol optical thickness in Nagasaki is ~0.1 which is larger than that in the other two locations.

On the other hand, in Toyama, variability of both optical thickness and scale height is smaller than those in Sapporo and Nagasaki. The minimum value of optical thickness is the smallest among all three locations.

2. 2. Skyradiometer Measurements

Skyradiometer measures both direct and scattered solar radiation at wavelengths of 400, 443, 500, 675, 870, 940, and 1040nm. Since the phase function and extinction coefficient of aerosols are expressed as an integral of size distribution and efficiency factor, aerosol size distribution is obtained by solving the integral equation, i.e. inversion process. Aerosol size distribution, optical thickness, Angstrom exponent (wavelength dependence of optical thickness), and single scattering albedo are determined so as to be consistent with the observed direct and scattered solar radiation at respective wavelengths except for 443nm and 940nm incorporating multiple scattering process (Nakajima et al., 1983; Aoki and Fujiyoshi, 2005).

Figures 5, 6, and 7 show the relationship between optical thickness and Angstrom exponent of aerosols in April in Sapporo, Toyama, and Nagasaki, respectively. Aerosols with large optical thickness mainly correspond to large particles in Sapporo and to both large and small particles in Toyama, while those seem to correspond to small particles in Nagasaki. It is suggested from the lidar measurements as shown by Fig. 4 that these small particles over Nagasaki were transported in higher layer.

The single scattering albedo is retrieved from skyradiometer measurements. The results revealed that small single scattering albedo corresponds to small Angstrom exponent, which suggests the contribution of dust particles in the middle and higher layer to absorbing properties of aerosols in the spring of this region.

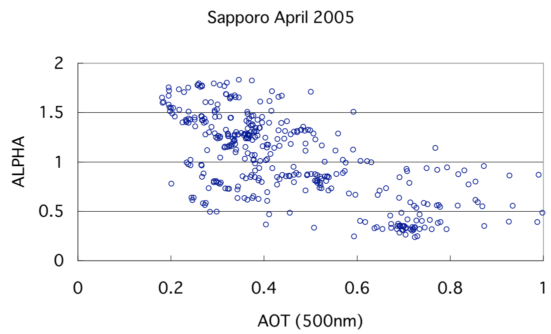

Figure 5. The relationship between aerosol optical thickness (AOT) and Angstrom exponent (ALPHA) observed in Sapporo.

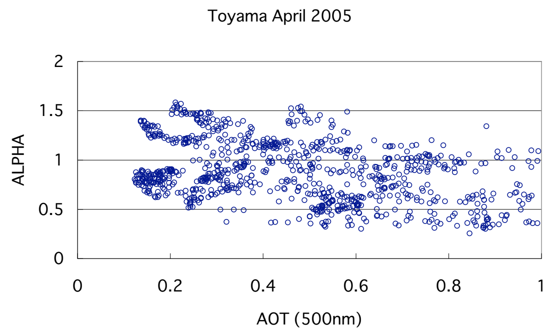

Figure 6. Same as Figure 5 except for the location, Toyama.

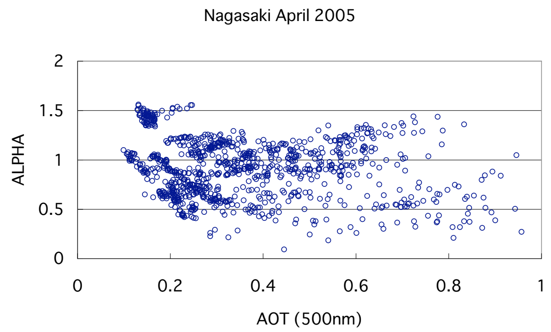

Figure 7. Same as Figure 5 except for the location, Nagasaki.

3. DISCUSSION AND SUMMARY

As shown by the lidar and skyradiometer measurements, the aerosols transported over Japan in the spring are mixture of dust particles and spherical particles. In order to investigate the validity of these results, we simulated the vertical distribution of both kinds of aerosols by using the Chemical Weather FORecasting System (CFORS).

The CFORS is designed as a multi-tracer chemical transport model built within the regional scale meteorological model (RAMS; Regional Atmospheric Modeling System) (Pielke et al., 1992), and treats about 20 chemical transport species including the major tropospheric aerosol types (i.e., sulfate, carbonaceous, dust, sea salt aerosols). In the CFORS model, all of the anthropogenic emission inventories are calculated using the dataset taken from Streets et al. (2003), and natural dust emission is calculated using a fourth power law function of surface friction velocity with a 12 bin mode (0.1-20 μm in radius). The simulation domain encompassed East Asia; its rotated polar stereographic mapping center was set at 30° N and 115° E. The horizontal grid consists of 100 by 70 grid points, with resolution of 80 km. In the vertical, model domain cover surface to 23 km with the 23 non-uniform grids varying from 150 to1800 m thick. More detailed model description of CFORS and concept of aerosol transport are presented by Uno et al. (2003).

Figure 8 shows the simulated monthly scatter plot of the relationship between scale height and aerosol optical thickness for dust and sulfate over Toyama in May. In this figure, black and gray dots represent dust and sulfate aerosol, respectively. It should be noted that all the values

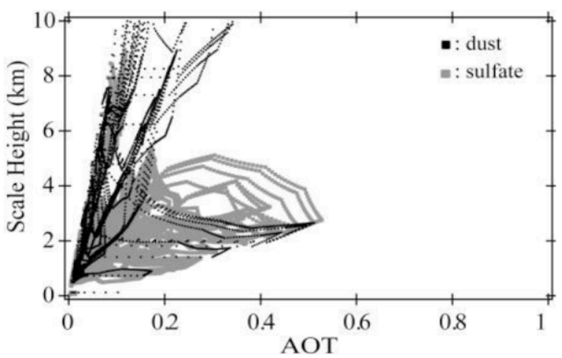

Figure 8. The relationship between scale height and optical thickness for dust and sulfate aerosols over Toyama in May simulated by CFORS.

shown in figure 8 are extracted from model results based on the altitude information of lidar observation because of the differences of temporal and vertical resolutions between CFORS model and observation. It is found that the simulated results are consistent with those of lidar measurements (Figure 3). Therefore, the aerosols observed might be mixture of dust particles and polluted aerosols due to anthropogenic emission.

In summary, dust and spherical aerosols were observed over Japan in the spring of 2005. The vertical distributions of these aerosols are different among the locations, Sapporo, Toyama, and Nagasaki. The both types of aerosols were also observed by skyradiometer. Dust aerosols tend to distribute up to higher altitude compared to spherical aerosols. These vertical distribution properties were simulated by CFORS and the results were consistent with the measurements.

Acknowledgments

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