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Tropospheric Aerosol Measurements using Lidar, Sunphotometer and Particle counter

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1. Introduction

Tropospheric aerosols have effects on climate indirectly through cloud formation as well as directly through sun light attenuation. They show large variations in both time and space, depending on their sources, but are not necessarily well characterized in terms of optical properties which are governed by the physical parameters such as particle number density and size distribution, and chemical components.

The purposes of the present study are to derive an extinction-to-backscatter(S_l) ratio and to derive a complex refractive index of aerosols by combining lidar, sunphotometer and optical particle counter measurements.

2.Measurements and Data processing

Data obtained simultaneously from a lidar with a YAG 532nm, a sunphotometer with 500nm wavelength and an optical particle counter (OPC) which measures particle size from 0.12μm to over 6.12μm are analyzed.

The lidar data were analyzed by a method of Sasano and Nakane (1987)[1] on the basis of Fernald algorithm[2] with assumptions of homogeneity in aerosol optical properties in space and horizontally homogeneous distribution of aerosols. The Fernald's scheme requires a S_l as an external parameter. Aerosol extinction coefficient profiles derived are integrated from the ground level to 12 km to generate optical thickness due to tropospheric aerosols, depending upon an S_l for nine cases by assigning 10, 20, ..., and 90. From January, 1990 to March, 1992, the lidar measurements were carried out for 94 days at the NIES.

Optical thickness due to aerosols was derived independently from direct solar radiation measurements by the sunphotometer. The comparison between the optical thicknesses from the lidar and the sunphotometer make it possible to estimate a columnar mean value of S_l when contribution of aerosols over 12km in altitude is negligible and the aerosol characteristics are homogeneous in space.

Number density and size distribution of aerosols were monitored by the Optical Particle Counter. Since optically-measured sizes depend on complex refractive index of particles, it is necessary to correct the size distribution using a refractive index for actual aerosols, which is in this case, an unknown parameter.

Scattering parameters including extinction coefficient and extinction-to-backscatter ratio (S_l) were calculated from the observed size distributions using the Mie theory and assuming that following combinations of real (m_r) and imaginary (m_i) parts of refractive indices;

m_r: 1.35 <0.05> 1.70,

m_i: 0.0, -0.005, -0.01, -0.02, -0.03, -0.05, -0.08, -0.1.

3. Results and Discussion

3.1 Optical Thickness Variations and Average Extinction-to-backscatter Ratio

Variations of aerosol optical thickness derived from the lidar and the sunphotometer measurements are shown in Figs.1(a), (b). Aerosol optical depth for the troposphere (0-12km) shows a distinct seasonal variation; *i.e.*, in every winter, optical thickness became smaller compared to other seasons. The columnar optical thickness data from the sunphotometer measurements show a similar tendency. It should be noted that the minimum level of columnar optical thickness in the 1991-1992 winter was not recovered to the same level as in the 1990-1991 winter.

All the measurement data were categorized into two parts, one before and the other after the eruption of Mt. Pinatubo. Figure 2 shows the relation of optical thicknesses between the tropospheric aerosols below 12km and the columnar aerosols which were obtained by the lidar and the sunphotometer, respectively.

A mean value of S_l throughout the period before the eruption can be inferred from regression analysis for the relation between both optical thickness data. If we assume an appropriate value for S_l as the mean for the period, then the regression analysis gives a slope of unity when we assume a linear relationship between τ_{sun} by the sunphotometer and τ_{lid} by the lidar,

$$\tau_{sun}=a*\tau_{lid}+b.$$

The coefficient b means a contribution from out of the lidar range.The values of a were calculated by applying the least square method for the data sets with different S_1. The S_1 which gives a=1 was inferred by interpolation to be 54. Then the coefficient b was -0.02. The solid line in Fig.2 is for a=1 and b=-0.02, although the data points were for S_1=50.

3.2 Estimation of Complex Refractive Index

The volume size distributions measured by the OPC have peaks at around 0.2μm in radius in almost all samples. Particles in the small mode less than 0.44μm are most effective to determine optical properties of aerosols for visible lights, so the distribution was well approximated by a zeroth-order log-normal distribution. The mode radius r_0 and geometric standard deviation σ_0 are defined as follows;

$$\frac{dV}{d\ln r} = \frac{V_0 \exp\left[-(\ln r - \ln r_0)^2/(2\ln^2\sigma_0)\right]}{\sqrt{2\pi}\,\ln\sigma_0\, r_0 \exp(\ln^2\sigma_0/2)},$$

where V_0 means an aerosol volume per unit atmospheric volume. The correlation between V_0 and r_0 is positive and the particle volume increases with mode radius. This suggests that the increase in volume is due to particle growth provided that the particles have the same origin.

Figure 3 shows an example of S_1 values as a function of an imaginary and real part of m. The relation of m_r and m_i is complementary so that the estimation of m_i can be inferred with the certain m_r. In this figure S_1=61 is estimated by a comparison between the lidar and the sunphotometer data.

4. Summary

Analytical results are summarized as follows;

(1) Variation of optical thickness due to tropospheric aerosols shows that the atmospheric loading is lighter in winter than in summer. Comparison of optical thickness data from the two instruments clearly shows the effect of Mt. Pinatubo's eruption and the temporal variation of optical thickness in the stratosphere over 12km.

(2) Simultaneous measurements of the lidar and the sunphotometer can allow to estimate the extinction-to-backscatter ratio, which ranged from 20 to 70 in this experiment. The larger S_1 is due to more contribution of the small mode aerosols to extinction coefficient which directly corresponds to the larger optical thickness.

(3) The possible range of complex refractive index for the columnar mean aerosols can be deduced from the probable range of S_1 derived in (2) above, using a S_1 diagram as a function of complex refractive index (m). The imaginary part of m can be estimated provided that the real part of m is known.

References

1. Y. Sasano and H. Nakane, Appl. Opt. **26**, 615-616(1987).

2. F.G. Fernald, Appl. Opt. **23**, 652-653(1984).

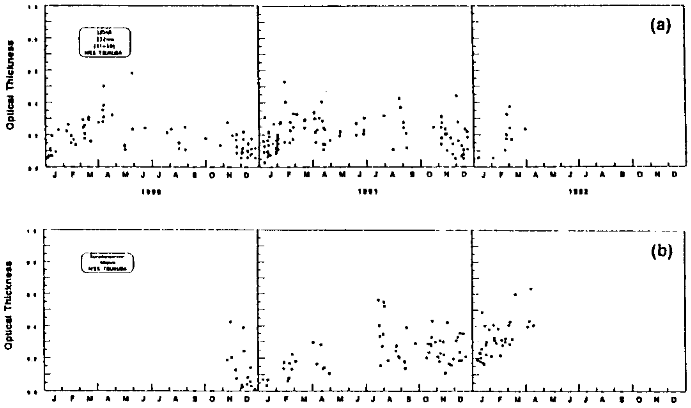

Fig. 1 Variations of Optical Thicknesses by Lidar(a) and by Sunphotometer(b).

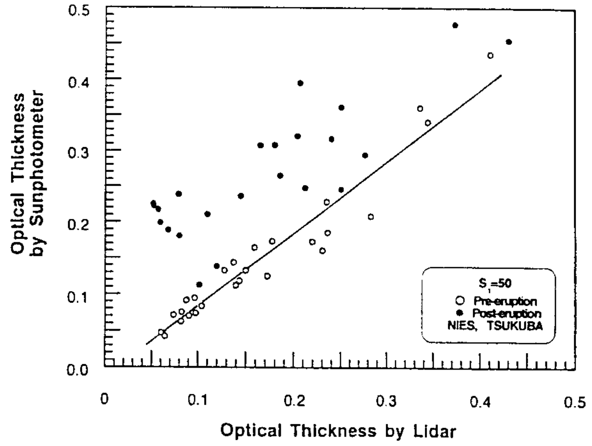

Fig. 2 Comparison between both optical thicknesses.

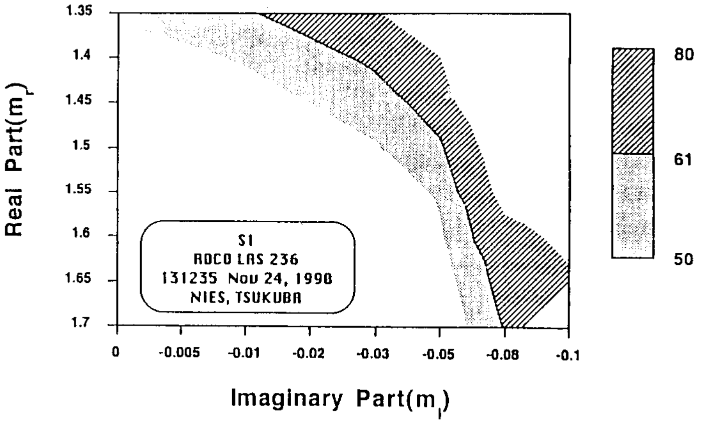

Fig. 3 Relation between S_1 and m