S2-5 The Size Distributions of Stratospheric Aerosol over the Tropical Region Inferred from the Measurements of Balloon-Borne Optical Particle Counter and Ground-Based Lidar

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Introduction

Measurements in the tropical region, as well as those in the polar regions, are of importance for a study of stratospheric aerosols. The stratospheric measurements and analyses presented by Brock et al. [1995] suggest that nucleation of sulfate particles occurs in the upper tropical troposphere, resulting in the appearence of a source for the non-volcanic stratospheric aerosols. Trepte and Hitchman [1992] found a reservoir for aerosol in the tropical stratosphere by using data of satellite observations (SAGE Ⅰ and Ⅱ). Aerosols cycle in the altitude range of 21-28 km between 20° N and S so that the transport into extratropics from this reservoir is hindered, whereas poleward transport occurs readily at altitudes within a few kilometers above the tropopause. It is rare that background level (non volcanic level) is achieved once aerosol loading is enhanced by tropical eruptions [Thomason et al., 1997].

Measurements of stratospheric aerosols by balloon-borne Optical Particle Counter (OPC) and ground-based lidar have been made at Bandung, Indonesia once or twice a year since April 1997. The OPCs employed in this work are designed for stratospheric aerosols [M. Hayashi, 1998] and the balloon typically reaches altitudes up to ~30 km. The flights yield vertical profiles of the integral number concentration of particles with a radii exceeding threshold sizes: 0.15, 0.25, 0.4, 0.6, and 1.8 μm. It should be noted that the number of particles are very few in the largest size range (>1.8 μm) and not always present statistically useful data in the stratosphere. The lidar system with a Nd:YAG laser is operated by MRI and CRL. By using the OPC concentration data excluding the size range >1.8 μm and the back-scattering coefficient at 532 and 1064 nm laser wavelengths, the size distributions at several altitudes in the stratosphere over Bandung are determined in this work.

The relation between particle concentration and back-scattering coefficient depends on the shape, composition, and size distribution of the aerosols. Under most stratospheric conditions it is generally accepted that aerosols can be accurately described as spherical sulfate

acid—water aerosols [Russell and Hamill, 1984] whose optical characteristics can be computed using Mie-scattering theory. Further, a number of measurements for stratospheric aerosols propose the size distribution functions such as power law, modified gamma, exponential, lognormal, and zold. Since the OPC size distribution measurements are usually described well with the use of a bimodal lognormal form, especially in postvolcanic periods [Deshler et al., 1993], this work will focus on the bimodal lognormal distribution.

Size distribution and Sensitivity

The most commonly used model for the sizes of aerosols is the lognormal distribution. The log normal size distribution is given by

$$n(r)\,dr = \sum_{i=1}^{k} \frac{N_i}{(2\pi)^{1/2} r \ln \sigma_i} \exp\left\{-\frac{(\ln r - \ln r_i)^2}{2(\ln \sigma_i)^2}\right\} dr \quad (1)$$

where $n(r)$ is the differential concentration in the radius interval dr, k is the number of modes in the distribution, N_i is the total particle number concentration, σ_i is the distribution width, and r_i is the median radius, for each of i th modes. The integral particle concentration, as measured by OPCs, are then

$$N(\geq r) = \int_r^{\infty} n(r)\,dr \quad (2)$$

The variable parameters in this function allow a large variety of size distribution types. However, if we adopt the bimodal distribution, the number of parameters to be determined is six, which can be calculated from four values of OPC data and two values of lidar data. Assuming that Mie-scattering theory is applicable, the lidar back-scattering coefficient is given by

$$\beta_p(m,\lambda) = \frac{1}{4\pi}\int_0^{\infty} \pi r^2 Q_{bs}(r,m,\lambda)\, n(r)\, dr \quad (3)$$

where $\beta_p(m, \lambda)$ is the aerosol back-scattering coefficient at wavelength λ, and $Q_{bs}(r,m,\lambda)$ is the Mie back-scattering efficient at wavelength λ for a particle of radius r. To examine the size sensitivity of the lidar backscattering, the back-scattering cross sections [$\pi r^2 Q_{bs}(r,m,\lambda)$] calculated for the lidar wavelengths 532 and 1064 nm are plotted in Figure 1 as a function of radius. In the calculation, refractive index m=1.40 is assumed. It is apparent that back-scattering at these wavelengths have poor sensitivity to particles smaller than 0.1 μm, although the sensitivity of 532 nm is a little better than that of 1064 nm for these small particles.

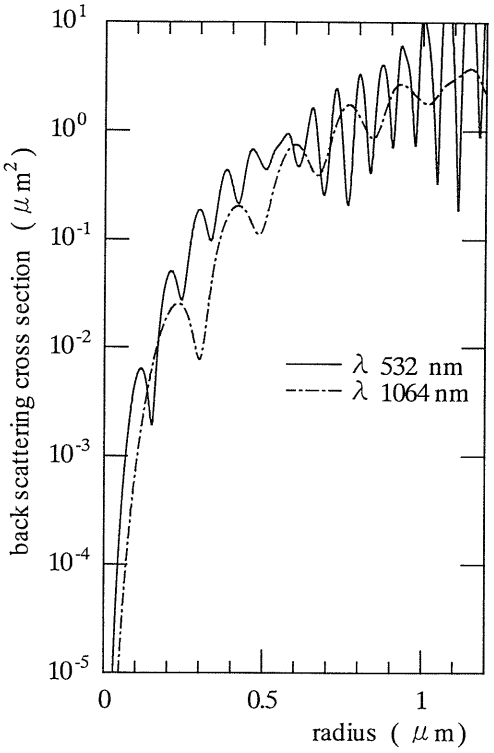

Figure 1. Backscattering cross section as a function of particle radius at the lidar measurement wavelengths 532, 1064 nm. The particle refractive index is defined to be m=1.4.

Result

The balloon-borne OPC and lidar measurements were made simultaneously at Bandung, Indonesia on March 25, 1998. The balloon reached only ~27 km. The integral concentration data obtained form this flight, excluding >1.8 μm data, and back-scattering coefficients at 532 and 1064 nm wavelengths were used to infer the six parameters in bimodal lognormal distribution function to obtain the aerosol size distribution at each measurement

altitudes. Figure 2 shows an example of the differential concentration versus radius. In the calculation, both OPC and lidar data were averaged over the height range 19-20 and 23-24 km. All the parameters are then shown in Table 1. In the 19-20 km range, the total number concentration calculated here is much larger than the generally accepted value (~1 to ~10 cm^{-3}). The distribution of this altitude rage are dominated by smaller particles, which can not be detected by our OPCs, and have poor sensitivity to lidar measurements. On the other hand, in the 23-24 km range, the total particle number decreases remarkably and the mean radius increases. It appears that the distribution is acceptable.

Summery

The results of parameter solutions at altitudes within a few kilometers above the tropopause indicate that unrealistic value of total number is required for the size distribution to be consistent with both OPC and lidar mesurements. However, it is suggested by Brock et al. [1995] that nucleation of sulfate particles in the upper tropical troposphere and subsequent coagulation during the upward transport occur, resulting in the decrease in particle concentration with increasing altitude above tropopause. Hence one might expect that the nucleation near the tropopause occurred on that day. Nevertheless the distributions were obtained from the poor information for small particles. It should be important in evaluating these distributions to compare with the results of other independent measurements such as satellite observations.

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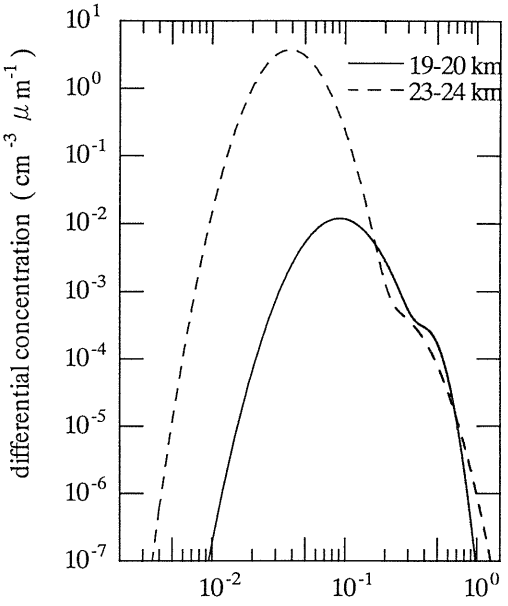

Figure 2. The particle size distribution versus radius in the altitude range 19-20 km and 23-24 km on March 25, 1998 over Bandung, Indonesia.

	N_1 cm^{-3}	r_1 μm	σ_1	N_2 cm^{-3}	r_2 μm	σ_2
19-20 km	157.7	0.05	1.50	0.12	0.27	1.51
23-24 km	1.4	0.11	1.60	0.05	0.44	1.24

TABLE 1. Bimodal Lognormal Distribution Parameters ; Total Number Conc. N_1, Mean Radius r_1, and Distribution Width σ_1.

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