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WAVELENGTH DEPENDENCE OF AEROSOL BACKSCATTER COEFFICIENTS OBTAINED BY MULTIPLE WAVELENGTH LIDAR MEASUREMENTS

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Aerosols are often classified into several general types according to their origin and composition, such as maritime, continental, and stratospheric aerosols, and these aerosol types generally have different characteristics in chemical and physical properties. The present study aims at demonstrating the potential for distinguishing these aerosol types by the wavelength dependence of their backscatter coefficients obtained from quantitative analyses of multiple wavelength lidar signals. Information on aerosol types obtained by this technique would contribute greatly to understanding transport and radiative effects of aerosols on a global scale.

The present study utilized data from the NASA Airborne DIAL System (Browell et al., 1983), which can measure aerosol backscatter profiles at wavelengths of 300, 600, and 1064 nm and ozone profiles from DIAL wavelengths at 286 and 300 nm. Profiles of backscatter coefficients for these three wavelengths were derived from the observations of aerosols of different types (maritime, continental, Saharan desert, rain forest, and stratospheric aerosols in a folded tropopause). Observations were carried out over the Atlantic Ocean, the Southwestern United States, and French Guyana.

Quantitative analysis of the lidar signal at each wavelength is required to obtain information on the wavelength dependence of the aerosol backscatter coefficients. Difficulties in this analysis are, in general, associated with calibrating the total optical efficiency (system constant) of the lidar system and correcting the attenuation of the laser light due to extinction by aerosols.

The solution of the two-component (aerosols and air molecules) lidar equation (Fernald, 1984) was applied in the present data analysis to correct for the laser beam attenuation. This analysis assumes that the aerosol extinction coefficient is proportional to the aerosol backscatter coefficient and that the proportionality factor, which is often

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called an extinction to backscatter ratio, is constant with range. The solution is written as

$$\beta_1(R) + \beta_2(R) = \frac{X(R)\exp\{-2(S_1 - S_2)\int_{R_O}^{R} \beta_2(r)dr\}}{\dfrac{X(R_O)}{\beta_1(R_O) + \beta_2(R_O)} - 2S_1\int_{R_O}^{R} X(r)\exp\{-2(S_1 - S_2)\int_{R_O}^{r} \beta_2(r')dr'\}dr} \quad (1)$$

where: β and S_1 are the backscatter coefficient and extinction to backscatter ratio, respectively; the subscripts 1 and 2 represent the values for aerosols and air molecules, respectively; R is the range from the lidar; X(R) is the lidar signal corrected for range-squared dependence; and R_O is the range where a boundary condition is assigned as described below.

Calibration of the system constant was done by giving a boundary condition at a certain range $R=R_O$ in the solution. In practice, the so-called matching method was applied to the lidar signal--an aerosol free layer was assumed at $R=R_O$.

Backscatter coefficient profiles derived from lidar signals through Eq. (1) depend on the extinction to backscatter ratio S_1 as well as on the optical thickness and aerosol distribution. The extinction to backscatter ratio is considered to have a value between about 10 and 90. The solution profile may sometimes be quite different from the true profile when an erroneous extinction to backscatter ratio is assumed.

New methods were proposed and applied to the multiple wavelength lidar signals to reduce uncertainties in the derived backscatter profiles. In the first step of the analysis, the extreme values of the extinction to backscatter ratio (e.g., 10 and 90) are assumed to get possible ranges in the derived backscatter coefficients. The profiles thus obtained sometimes show negative values for the aerosol backscatter coefficient and sometimes diverge. This results from an assumed extinction to backscatter ratio that is unrealistic. The second step restricts the solution by requiring that the backscatter coefficient never takes a negative value and that the solution never diverges. The third step is based on the assumption that the solution profiles obtained from the lidar signals for three wavelengths should have similar shapes. In general, the backscatter coefficient profile for the longer wavelength has less dependence on the extinction to backscatter ratio S_1, because the optical depth for longer wavelength is smaller than that for shorter wavelengths. Therefore, the profiles solved with S_1=10 and 90 for the lidar signal at 1064 nm can be used as references, although they do not necessarily coincide with each other. Solution profiles for the other two wavelengths can be obtained with appropriate extinction to backscatter ratios which give profiles similar to the standards.

Lidar signals were analyzed by combining the three steps above to get quantitative profiles for aerosol backscatter coefficients with the minimum uncertainty. The wavelength dependence of the backscatter coefficient was evaluated assuming a power-law relationship. The following equation gives the exponent of the wavelength dependence:

$$\delta(\lambda, \lambda_O) = - \frac{\ell n\{\beta_1(\lambda) \ / \ \beta_1(\lambda_O)\}}{\ell n(\lambda/\lambda_O)} \qquad (2)$$

where λ and λ_O are the measurement wavelengths.

Fig. 1 summarizes the results of the analyses, showing a two-dimensional diagram of wavelength dependence parameter δ derived from combinations of lidar returns at wavelengths of 300 and 600 nm and 600 and 1064 nm. Uncertainties in δ are represented by rectangles for maritime, continental and tropopause fold aerosols, while uncertainties were too small to draw for the Saharan and the rain forest aerosols. Characteristic features found in the figure are that δ (300, 600) for the Saharan aerosol show negative values and that δ (300, 600) and δ (600, 1064) for the folded tropopause aerosols have higher values than the others studied. In addition, Fig. 1 shows that each aerosol type investigated occupies a unique location on the δ diagram. This suggests that it may be possible to distinguish between major aerosols types by observing backscatter coefficients at multiple wavelengths. Further studies are planned to provide additional data sets for further evaluation of this technique.

References

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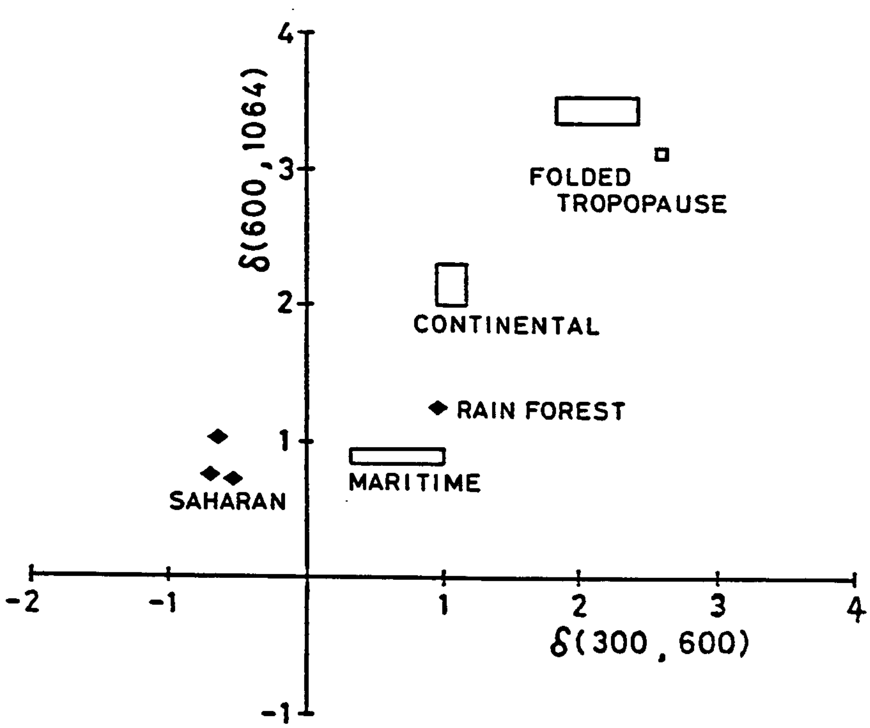

Fig.1 Diagram which shows the relationship between δ (300 nm and 600 nm) and δ (600 nm and 1064 nm) determined from the lidar observations for various kinds of aerosol types.