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NEAR-IR EXTINCTION AND BACKSCATTER COEFFICIENT MEASUREMENTS IN LOW- AND MID-ALTITUDE CLOUDS

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Knowledge of the attenuation and backscattering properties of clouds is required to high resolution for several types of optical sensing systems. We obtained such data in about 15 hours of flights through clouds in the vicinity of Washington, D.C. The flights were mainly through stratocumulus, altocumulus, stratus, and stratus fractus clouds and covered an altitude and temperature range of 300 to 3200 m and -13 to 17 C.

Two instruments were flown, each of which measured the backscatter from close range in two range bins to independently determine both the extinction and backscatter coefficients. One instrument was a short-range, ≈ 6-ns pulse length lidar system using a 0.9-μm injection laser source. The two receiver channels of this system measured the backscatter from 1.5- and 4.0-m range at 30 Hz, providing an along-flight measurement resolution of about 1.3 m at a 75-kt airspeed. The other instrument was an arc-lamp source nephelometer with a 0.8- to 1.0-μm spectral response and two independent transmitter/receiver channels with optically limited sensitivity regions at ranges of 4 and 8 m. Figure 1 shows the sensitivity versus range curve of this instrument as measured with a diffusely reflecting target board. The along-flight resolution of the nephelometer was about 3 m. As illustrated in figure 2, both instruments looked in a direction perpendicular to the flight path and provided data as a function of position along this trajectory. The flight paths were generally horizontal along a straight trajectory; the processed data, therefore, provide maps of the variation of the measured parameters along a horizontal line through the clouds.

The extinction and backscatter coefficients can be obtained from the signals in the two channels of each instrument, provided that the aerosol is uniform over the measurement region. When this assumption holds, the extinction coefficient is derived basically from the ratio of the signal in the two channels; the backscatter coefficient can then be obtained from the signal in either channel. The calculation procedure takes into account the precise sensitivity versus range curve (and pulse shape in case of the lidar) of the instrument. The systems are calibrated using standard targets on the ground, and fiber-optic coupled reference pulses account for system sensitivity changes. Multiple scattering effects are minimized but not entirely eliminated by the narrowness of the fields of view.

Both channels of the nephelometer measure backscatter from an angular range of 178.2 to 179.8 deg. This slight difference from pure backscatter is insignificant for many aerosols but makes a sizeable difference for clouds. Figure 3 shows the results of Mie scattering calculations of the 0.9-μm backscatter-to-extinction ratio, or $1/4\pi$ times the normalized phase function, for Deirmendjian's[1] C1 cloud distribution, and for C1-type distributions with mode radii of 3, 6, and 8 μm instead of Deirmendjian's 4 μm. It is apparent that the backscatter-to-extinction ratio in the range of the nephelometer's angular region is significantly less than it is at 180 deg. The lidar

angular range was farther from 180 deg, and in addition was not equal in the two channels; this inequality also affects its extinction measurements. The results of the lidar measurements were therefore used mainly to confirm variation of the coefficients with position as determined from nephelometer data and to obtain approximate but very high spatial resolution maps.

Figures 4 and 5 show examples of the results calculated from the nephelometer data. Figure 4 is an extinction coefficient plot for a straight flight path at an altitude of 950 m through a stratocumulus cloud. Scattered points far removed from the main curve and widely fluctuating regions such as near the 4-km point are probably the result of lack of uniformity of the cloud in the measurement region. This cloud segment exhibits structure that is about median among our data, with many clouds being more uniform and others showing gradients as great as our instruments could resolve.

The backscatter-to-extinction ratio F of the same cloud segment is shown in figure 5. Note that F is relatively constant over the first half of this cloud, where the extinction coefficient varies roughly from 50 to 200 km^{-1}. In the second half of the cloud, F at first has a constant but lower value, then decreases slowly; F also shows a decrease at the sharp break in the middle of the plot where the extinction coefficient almost goes to zero. The general trend in these data, including the decrease in the middle, is also seen in the lidar results for this segment. Similar results were obtained in many other cloud segments, although still other segments showed a constant F while the extinction coefficient varied greatly.

We interpret the variations in F as evidence of different size distributions. This does not contradict Derr[2] and Pinnick et al,[3] who obtained a relatively constant $F(\pi)$ by Mie calculations for various size distributions appropriate for clouds. While our calculations also show that $F(\pi)$ varies little for Cl clouds with mode radii varying from 2 to 8 μm, they show that F(178 to 180 deg) varies considerably for those same clouds. This variation, seen in figure 3, results because the backscatter lobe width is strongly size-dependent.

The median value of the extinction coefficient for all our nephelometer-obtained data was 70 km^{-1}. This compares well with values calculated by Carrier et al.[4] for his continental stratus and stratocumulus models. The maximum levels attained in all our flights, where we endeavored to sample the densest clouds we could reach, was around 300 km^{-1}.

The median value of the backscatter-to-extinction ratio F for all our data was 0.034 sr^{-1}. This compares to a median of 0.038 sr^{-1} from Mie calculations in the same 178 to 180 deg angular range for Deirmendjian Cl clouds with mode radii of 3, 4, 6, and 8 μm. (The same calculations show a median $F(\pi) = 0.052\ sr^{-1}$.) The median values for individual flights ranged from 0.024 to 0.051 sr^{-1}. The variation of F within a given flight was usually 20 to 25 percent to the 3-dB points of the distribution, including both the apparently real variations due to different size distributions and variations due to cloud nonuniformity within the measurement volume and instrumentation noise.

References

1. Deirmendjian, D., "Electromagnetic Scattering on Spherical Polydispersions," American Elsevier, 1969.

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3. Pinnick, R. G., Jennings, S. G., Chylek, P., and Ham, C., "Backscatter and Extinction in Water Clouds," Conf. Abstracts, Tenth International Laser Radar Conference, 6-9 Oct 80, pp 40-41.

4. Carrier, L. W., Cato, G. A., and Von Essen, K. J., "The Backscattering and Extinction of Visible and Infrared Radiation by Selected Major Cloud Models," Appl. Opt. 6, 1209 (1967).

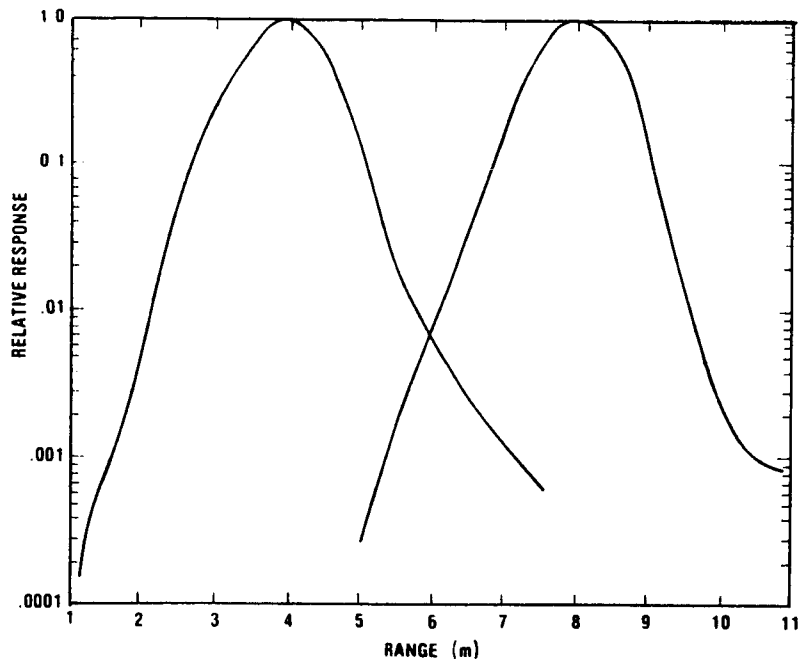

Figure 1. Sensitivity versus range curve for the two nephelometer channels.

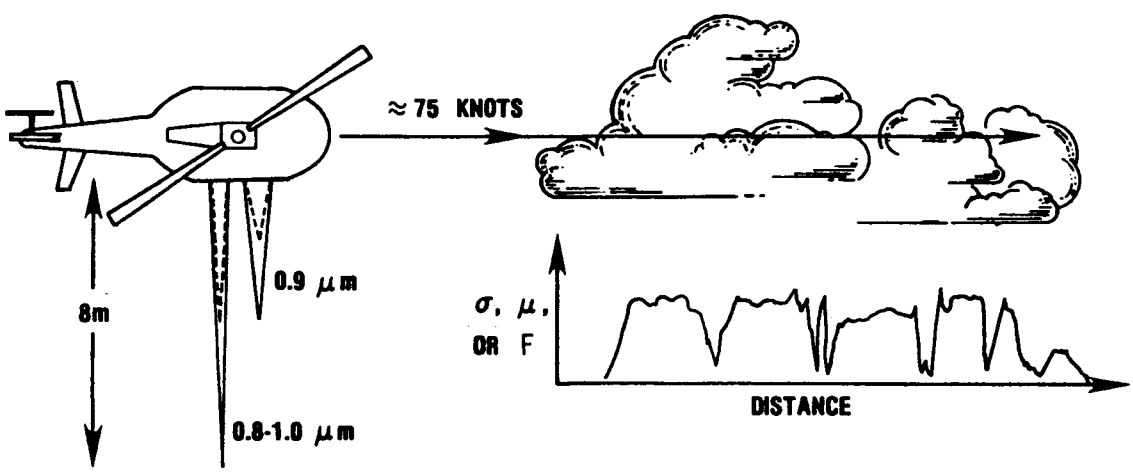

Figure 2. Schematic of cloud parameter measurements.

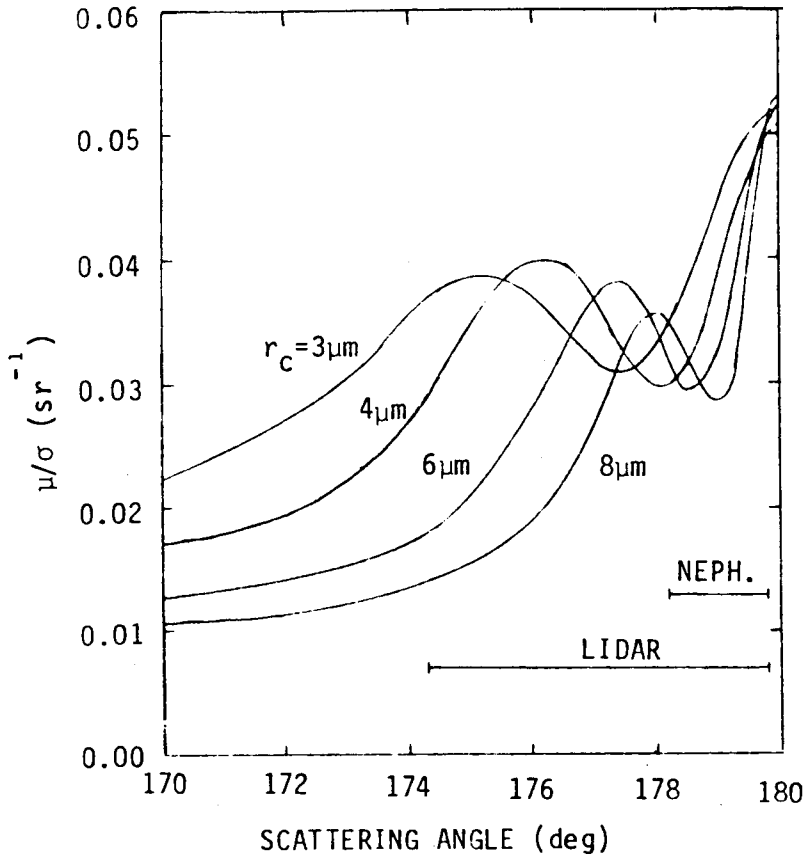

Figure 3. Calculated backscatter coefficient to extinction coefficient ratio for Cl cloud distributions with various mode radii r_c.

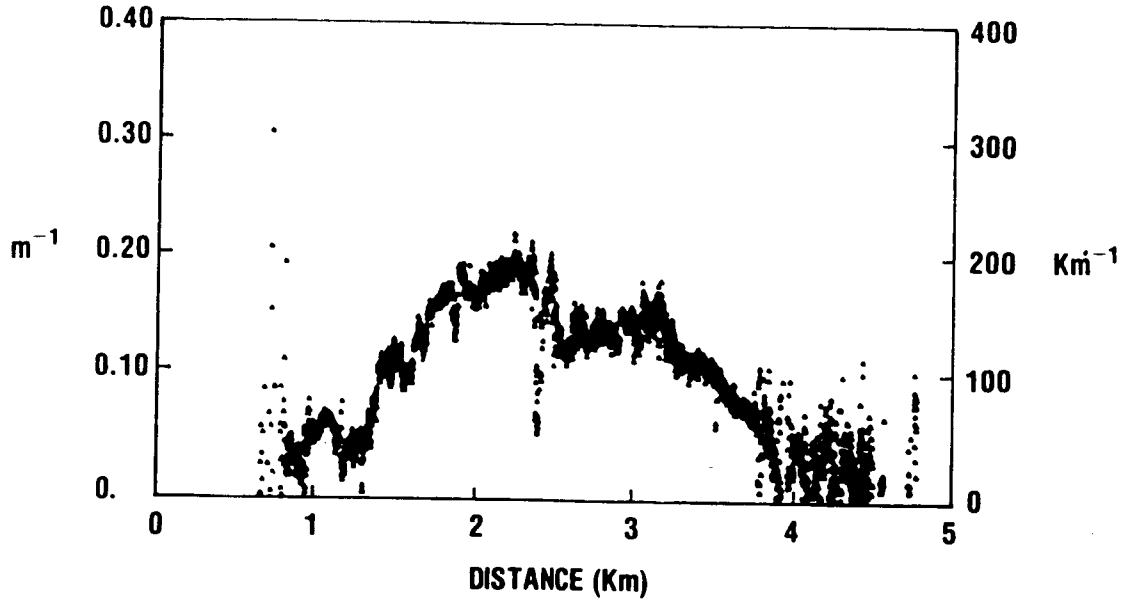

Figure 4. Extinction coefficient versus distance in stratocumulus cloud.

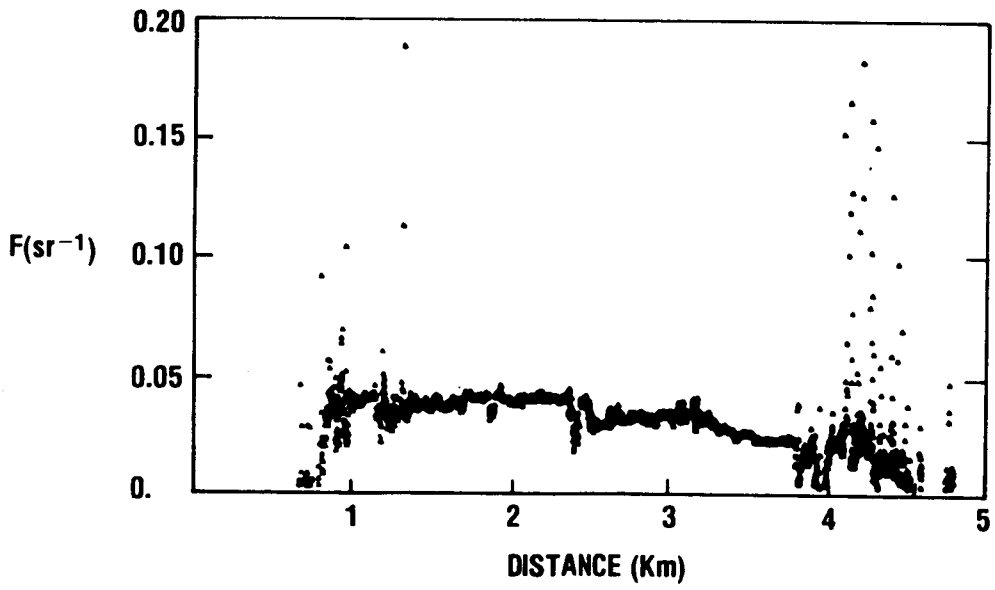

Figure 5. Backscatter coefficient to extinction coefficient ratio versus distance in same cloud segment as figure 4.