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BACKSCATTER AND EXTINCTION MEASUREMENTS IN CLOUD AND DRIZZLE AT CO_2 LASER WAVELENGTHS*

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The backscatter and extinction of laboratory generated cloud and drizzle sized water drops have been measured at CO_2 laser wavelengths (predominately at λ = 10.591 μm). Two distinctly different drop size regimes were studied: one which covers the range normally encompassed by natural cloud droplets ($1 < \text{radius } (r) < 20$ μm) and the other representative of mist or drizzle sized drops ($20 \lesssim r \lesssim 150$ μm).

BACKSCATTER AND EXTINCTION FOR LARGE WATER DROPS

We consider cloud and drizzle sized drops with size parameter $x \gtrsim 12$, ($r \gtrsim 20$ μm at λ = 10.591 μm). The efficiency factor for extinction, Q_e, approaches 2 asymptotically for an absorbing droplet as x gets larger.[1] Also, the backscatter gain G approaches the geometrical limit which equals the reflectivity R of the material at normal incidence[2] where $R = \{(n-1)^2 + k^2\}/\{(n+1)^2 + k^2\}$, n and k are the real and imaginary indices of refraction; R equals 0.0078255 for water ($m = 1.179 - 0.0718\,i$) at λ = 10.591 μm. [The calculated Mie value for G(m,x) at λ = 10.591 μm for x = 150, is equal to 0.0078258.]

The asymptotic values of Q_e and G in the expressions for extinction and backscatter coefficient lead to an appealingly simple form, independent of size distribution

$$\sigma_e/\sigma_b = 4\pi\, Q_e/G = 3.21 \times 10^3 \text{ sr} \tag{1}$$

Numerical calculations of extinction to backscatter ratio at λ = 10.591 μm for water droplets up to radius 50 micrometres plotted in Fig. 1 show the extinction to backscatter ratio oscillating about a relatively constant value of 3.40×10^3 sr, some six percent larger than the asymptotic limit of Eq. (1).

EXPERIMENTAL APPARATUS AND TECHNIQUES

The apparatus used to measure backscatter and extinction in water cloud is shown schematically in Fig. 2. A 1 m^3

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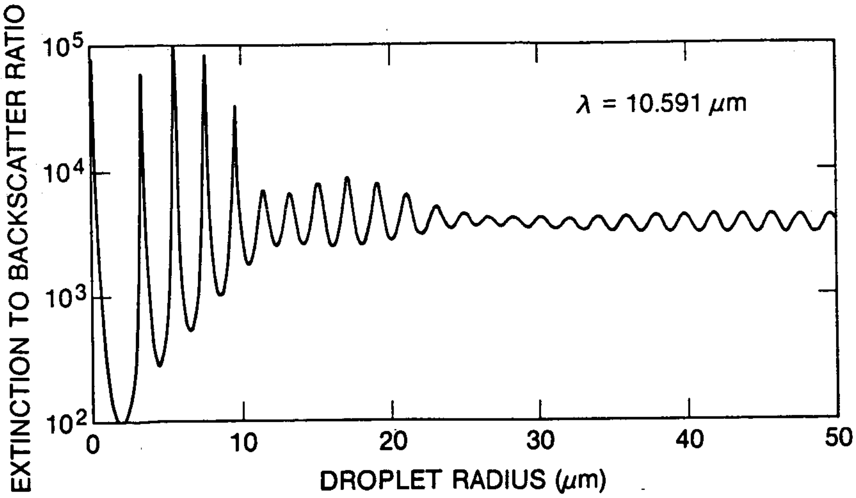

Figure 1. Extinction to backscatter ratio for water droplets versus droplet radius at wavelength λ = 10.591 μm (index of refraction m = 1.179-0.0718 i).

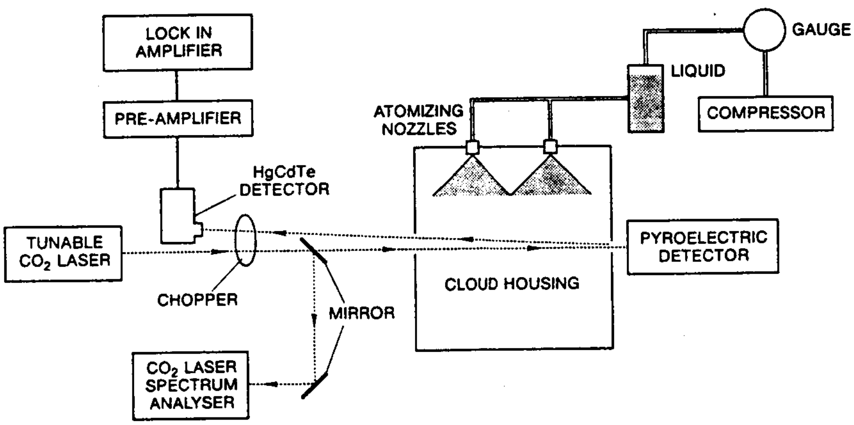

Figure 2. Schematic diagram of the experimental apparatus.

chamber of path length L = 1 m was used for all measurements. The optical arrangement used a tunable vertically polarized CO_2 laser source (Sylvania Model 941S). The main beam and reference detectors consist of a pyroelectric laser probe together with a synchronous radiometer readout.

A HgCdTe liquid nitrogen cooled 8-13 μm radiation photoconductive detector with sensing area 1 mm^2 was used for measuring the backscattered radiation. The detector was placed close to the CO_2 laser axis in the backward direction, subtending an angle not less than 177.4° with the forward direction, at the chamber centre. The signal from the detector was fed via a pre-amplifier into the input of a lock-in amplifier. The backscatter output signal from the lock-in amplifier was calibrated by directing a range of known low CO_2 laser radiation signals onto the HgCdTe detector.

Water droplet clouds were normally produced by a pair of Hankscraft spinning disk humidifiers diagonally positioned within the cloud chamber. The cloud droplet size distribution was determined by a Particle Measuring Systems (PMS) classical scattering aerosol spectrometer probe (CSASP). A modified two-stage impactor[3] mounted in a wind tunnel allowed droplet sizes greater than 14 μm radius (upper limit of the particle scattering counter) to be measured.

Drizzle sized drops with radius ranging from 20 to about 150 μm were produced by a pair of fine spray atomizing nozzles. Hydraulic pressures from 20 to 60 psi from a compressed nitrogen line applied to a stainless steel vessel containing doubly distilled water produced a cone spray drizzle pattern.

BACKSCATTER AND EXTINCTION MEASUREMENTS

Measurements of backscatter coefficient and extinction coefficient in laboratory cloud at wavelength λ = 10.591 μm are presented in Fig. 3(a). Measured values taken in steady state cloud conditions using a pair of spinning disk humidifiers are indicated by the solid dots "●". The experimental points "o" represent measurements of backscatter and extinction coefficients made at five second intervals during cloud decay. Steady state measurements using a combination of two spinning disk devices together with an ultrasonic nebulizer are indicated by the points "▲" in Fig. 3, while decay values are shown by the symbol "Δ". A measurment made at λ = 10.247 μm is indicated by the symbol "■", while decay values are given by symbol "□". The horizontal and vertical "error" bars shown for a representative measurement result from an estimated ±2 percent variation in pathlength coverage by the water droplets.

The results of the measurements for larger sized drops at wavelength 10.591 μm are shown in Fig. 3(b). Steady state measurements are represented by solid symbols (example ●) while

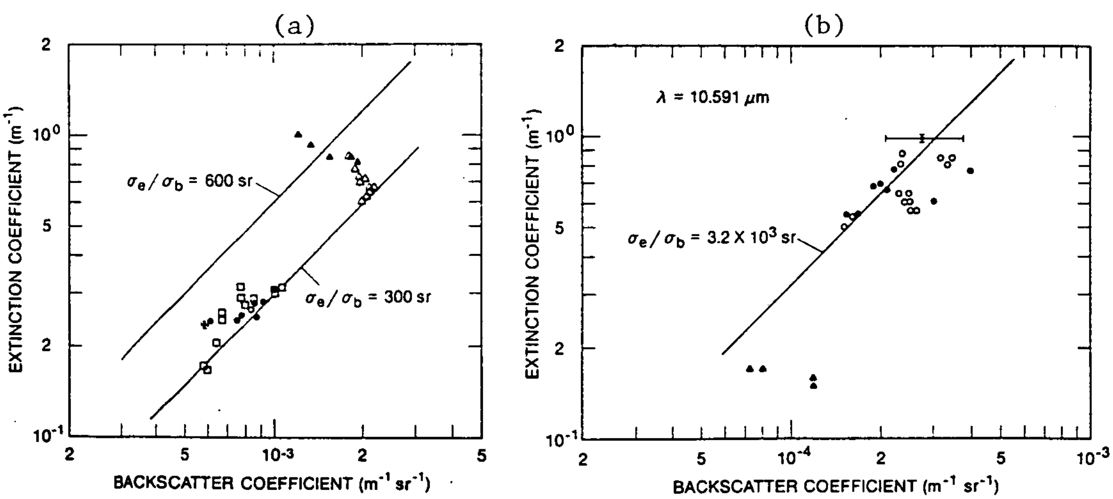

Figure 3. Measured values of backscatter and extinction coefficient for (a) laboratory cloud and (b) for larger sized (drizzle) drops at wavelength λ = 10.591 μm.

measurements made under cloud growth or decay conditions are shown by open symbol (example o). Most measurements were made for drizzle sized drops produced by the atomizing spray nozzles while some (represented by triangular symbols) were produced by a Micromax spinning disk spraying device.

DISCUSSION AND CONCLUSIONS

Measured extinction to backscatter ratios were generally found to range from 300 sr to about 600 sr for laboratory clouds produced by a pair of spinning disk humidifiers at $\lambda = 10.591$ µm which broadly agrees with lower bound numerical values mainly representative of small scale cumulus and stratocumulus cloud calculated by Pinnick et al.[4]

The measured backscatter to extinction ratio values for drop size > 20 µm shown in Fig. 3(b) are in reasonably good agreement (generally better than a factor 2) with the asymptotic value of 3.2×10^3 sr. The measurements also compare favorably with calculation which predicts extinction to backscatter ratios of between about 3 to 4×10^3 sr for $20 < r < 50$ µm as shown in Fig. 1.

The derivation and verification of the relation, Eq. (1) between extinction and backscatter at CO_2 laser wavelengths should allow the determination of large cloud drop and drizzle extinction coefficient solely from a lidar return signal without reguiring knowledge of the drop size distribution. This result will also apply to precipitation sized drops so long as they are spherical.

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