# 25PE5 Comparison of Multiple Scattering in Cloud and Fog

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The multiple scattering is important for the lidar observation in a dense matter, especially, fog and cloud. The lidar equation treats only the single scattering process for a received signal. In the case of the lidar equation in a dense matter, a correction term was empirically added. However, the echo behavior of the multiple scattering is largely affected by the situations where the target is placed. There are two kinds of typical situations: in a "fog" and "cloud". Lidar operation in a fog often appears in the measurement of bad weather, clear night radiation, or mountain area. In this case, the lidar instrument is located in a fog and the multiple scattering occurs just after the laser pulse leaving the transmitter. The effect of multiple scattering increases with time-of-flight (distance). This effect is very important for visibility derivation based on the single scattering model.

On the other hand, the multiple scattering in a cloud behaves differently. A cloud exists above a lidar system. In order to make an optical path the shortest, usually the vertical direction is selected for the measurement. The existence of a transparent layer before the optically thick scatterer, i.e.., cloud, gives completely different behavior for the multiple scattering. The maximum for a higher order scattering appears at some distance from the cloud boundary, at further distance for a further higher order.

In this paper, the multiple scattering behavior was simulated by Monte Carlo method, where stochastic estimation[1] was introduced to save calculation time. The phase functions of "Cloud C1" and "Haze C" were used in the calculation. The former is a typical for usual fogs and clouds, and the latter has a smaller mean size for a particle size distribution, and is nearer to the isotropic phase function. The procedure of the calculation is the same as the one used in [2]. In this calculation, we assumed no effect of the ground surface reflection. The total photon number for each calculation is $3 \times 10^5$ and the field-of-view (FOV) value varies from 1 to 100 mrad. The extinction coefficient of the cloud is assumed to be 0.01725 $m^{-1}$ for all cases in the calculation. The ratio of the multiple scattering to the single scattering (M/S) into cloud for "Cloud C1" was shown as the function of distance (penetration depth in the case of cloud) in Fig. 1 (a) (the cloud base is assumed to be 1,000m from the lidar) and in (b) in fog, respectively. Although M/S values in fog (Fig.1(b)) is widely spread, both cases appear to start from -100m (optical depth (OD) of -1.75). When the FOV value becomes larger, the M/S value approaches to the asymptotic value at the nearer distance. In the case into cloud (Fig.1(a)), the converging point is nearer than 80m (optical depth of 1.4), and in the case in fog (Fig.1(b)), the the converging point is roughly 150m ( OD of 2.7).

When the phase function is different, the M/S behavior changes in large amount. The M/S behaviors of "Haze C" for the cases into cloud and in fog, are shown in Fig. 2(a) and in Fig. 2(b), respectively, as the function of distance (penetration depth in the case into cloud). The M/S value into cloud is 5 times larger than the one in fog. The starting point is not clear in "Haze C" case.

In order to make clear the difference into cloud and in fog, the M/S values for "Haze C" are plotted in Fig.3(a) and (b), respectively in log-log scale as the function of FOV. In the case in fog (Fig.3(b)), the slope is almost 45 deg., that is, the M/S value is proportional to the FOV, although the value itself is smaller than in the case into cloud. On the other hand, the M/S values in the case into cloud (Fig.3(a)), the M/S values in small FOV do not depend on the optical thickness, that is, it means almost no multiple scattering effect. Here we mentioned the different effect of phase function on the multiple scattering. The FOV dependence is easier to validate in the experiment.

[1] C.M.R. Platt: "Remote sounding of a high cloud III: Monte Carlo calculations of multiple scattered lidar returns", J. Atm. Sci., 38 (1981) 156-167.
[2] N. Takeuchi, H. Okumura, T. Sugita, H. Matsumoto, K. Noguchi, M. Moriyama: Ray trace analysis of Monte Carlo simulation for multiple scattering lidar signal in a fog. Proc. of MUSCLE6, Jan. 1993.

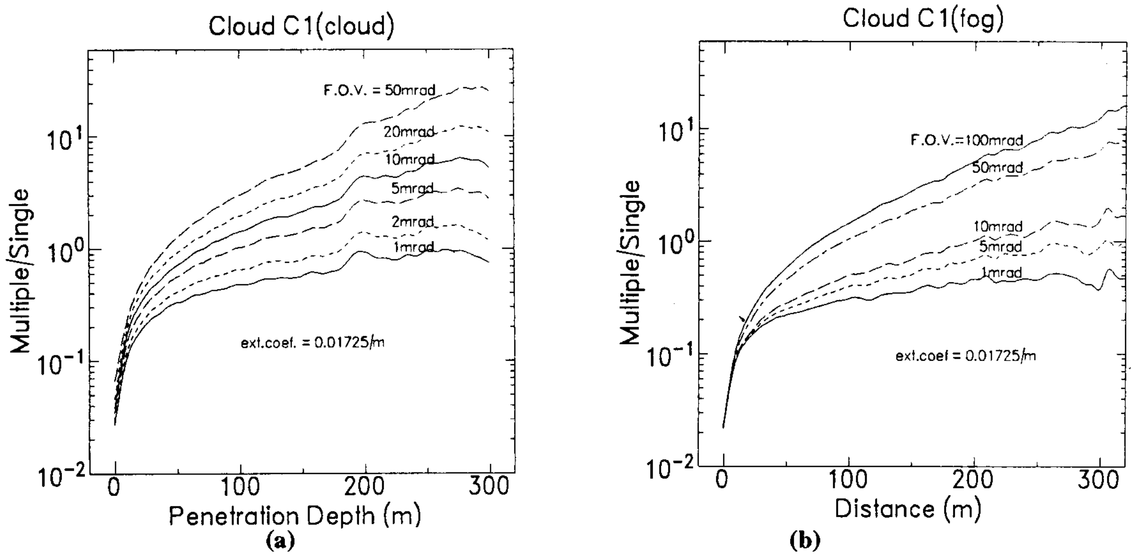


Fig1. The M/S values for the Cloud C1 model as the function of the distance for various FOV values in the cases (a) into cloud, and (b) in fog.

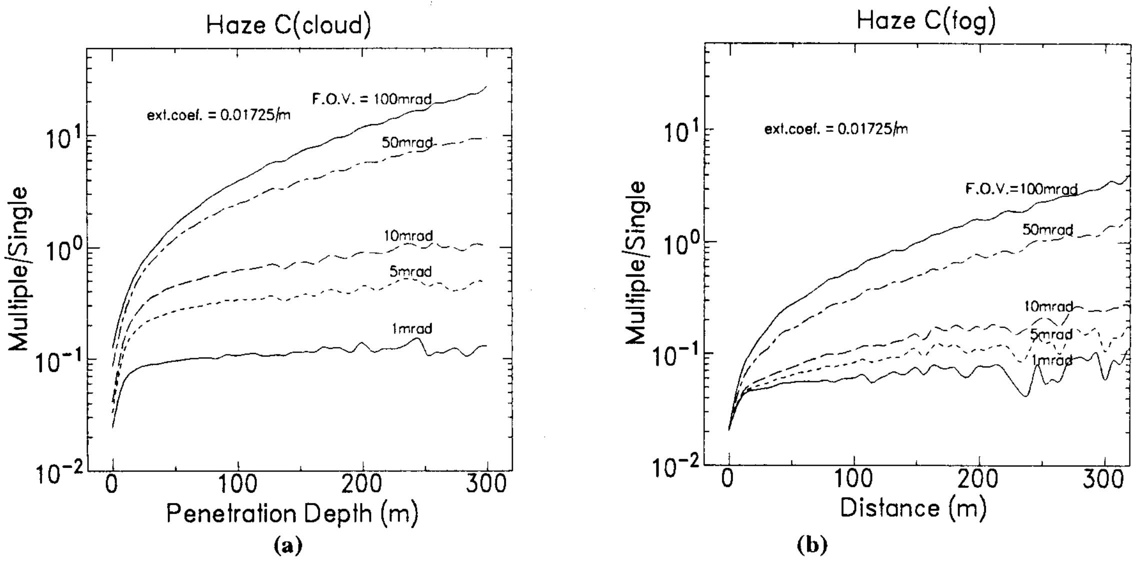


Fig2. The M/S values for the Haze C model as the function of the distance for various FOV values in the cases (a) into cloud, and (b) in fog.

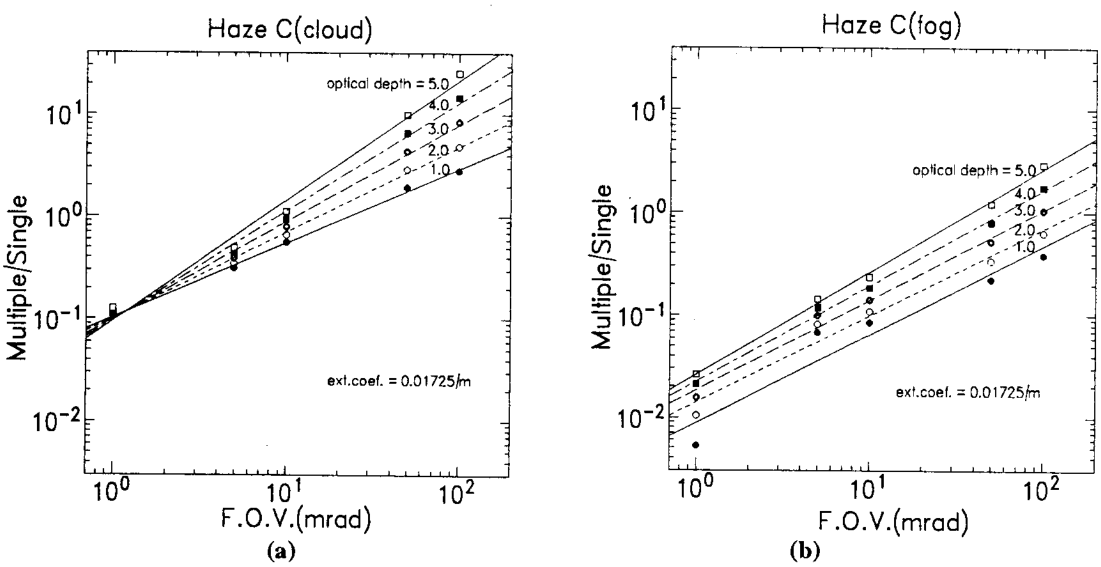


Fig3. The FOV dependence of M/S values for the Haze C model for various values of optical thickness (a) into cloud and (b) in fog.