P1-15 Lidar Measurement of Cloud Depolarization Ratios and Multiple Scattering Investigation

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Introduction

LIDAR has proven to be an effective tool in obtaining information about the atmosphere. In particular, knowledge about the thermodynamic phase and structural information of hydrometeors such as clouds can be derived from polarization measurements on the laser light they backscatter.[1] The backscattering of liquid water droplets has very different polarization characteristics from the backscattering of ice crystals. Thus, it is possible to use the polarization signatures to discriminate between ice and water in clouds. Further, polarization studies also provide information regarding the amount of multiple scattering occurring within the cloud.[2] The primary effect of multiple scattering is to make the extinction coefficient of the medium appear to be less than it really is. In 1976, Kunkel and Weinman presented results of a Monte Carlo investigation in the form of correction factors which can directly be applied to extinction coefficients to account for the effects of multiple scattering.[3] Pal and Carswell (1976) had also shown that the mean-correction factor could be expressed in terms of the measured quantities of a depolarization LIDAR on the assumption that the multiple scattering is the only source of depolarization in the medium.[4] This will permit a direct comparison of the experimental values with those calculated using Monte Carlo and approximate analytical techniques by Kunkel and Weinman. This report presents preliminary observations, using the 532-nm depolarization LIDAR system of De La Salle University (DLSU), on tropical clouds at Manila, Philippines along with the depolarization ratios. In addition, this paper presents a comparison of the results from the numerical simulation done using the Monte Carlo method and the experimental results using the method proposed by Pal and Carswell (1976) applied to the DLSU LIDAR.

Theoretical Background

The depolarization ratio δ is defined as equal to the ratio of the received backscattered intensities polarized perpendicular ($P_\perp$) to and parallel ($P_\parallel$) to the transmitted laser pulse. In equation form,

$$\delta = \frac{P_\perp}{P_\parallel} \qquad (1)$$

The quantities $P_\parallel$ and $P_\perp$ are related to the atmospheric parameters using the LIDAR equation.

The principle of the Monte Carlo calculation used follows that of Kunkel and Weinman. Photon histories were constructed using the phase function, the albedo for single-scatter, and the extinction coefficient of the medium by generating random numbers to choose scattering sites and scattering probability density distributions. However, following that of Plass and Kattawar, each photon is forced to scatter before reaching the limits of a specified volume to improve the efficiency of computation.[5] The volume is defined by cloud base and cloud top and a vertical conical section, symmetrical about the transmitter cone, and corresponding to a selected receiver angle. The procedure is described fully by Platt.[6] The Deirmendjian cloud C1 size distribution function was utilized to generate the phase functions and extinction coefficients.[7]

Kunkel and Weinman incorporated the multiple scattering effect to the single scattering LIDAR equation in terms of a parameter **F** defined by the relationship

$$\bar{F}(x) = \frac{1}{2\alpha x}\ln\left(\frac{P_T}{P_S}\right) = \frac{\int_0^x F(x')dx'}{x} \qquad (2)$$

where the **pulse penetration depth** in the medium is $\mathbf{x = z - z_o}$, **z** is the distance of the scattering point from the LIDAR, $\mathbf{z_o}$ is the altitude of the cloud base, α is the extinction coefficient, while $\mathbf{P_S}$ and $\mathbf{P_T}$ are proportional to the computed probabilities at z for single and multiple scattering, respectively, obtained from the Monte Carlo results.[4] $\bar{\mathbf{F}}$ is the mean-correction factor. In terms of the measured quantities from a depolarization LIDAR, Pal and Carswell have shown that,

$$\bar{F}(x) = \frac{1}{2\alpha x}\ln\left(\frac{P_\parallel + P_\perp}{P_\parallel - P_\perp}\right) \qquad (3)$$

where $\mathbf{P_\parallel}$ and $\mathbf{P_\perp}$ are the parallel and perpendicular components of the backscattered light.

De La Salle University (DLSU) Multiple Wavelength Depolarization LIDAR System

The LIDAR system used in this study is located at the 4^{th} floor of the Science & Technology Research Building (STRC) of De La Salle University (14.339°N 120.595°E). The facility became operational early this year. It is about 14 meters above sea level and is approximately 900 meters from Manila Bay. It is roughly 13 km from the LIDAR station at the Climate Studies Building of Ateneo De Manila University (ADMU), Quezon City. The DLSU facility is close to the sea while the ADMU station is close to the mountains. Thus, due to their unique locations, the two facilities can combine their resources to do cooperative researches especially transport studies.

The DLSU LIDAR facility employs a 20-Hz Nd:YAG laser with an output of 175 mJ at 532 nm. An 8-inch telescope, with a FOV of 0.5 mrad, collects the backscattered light that is converted into an electrical signal by a photomultiplier tube. Data storage and processing is accomplished with the use of computers. Since the Nd:YAG laser used had simultaneous outputs at 1064 nm, 532 nm and 355 nm, the receiving system was originally configured to simultaneously detect the perpendicularly-polarized and parallel-polarized backscatter signals at 1064 nm and 532 nm along with the total backscatter signal at 355 nm. However, only the 532-nm wavelength was used at present due to difficulties in the alignment of the telescope and the transmitting system for the 1064 nm and 355 nm wavelengths. Further, the DLSU LIDAR is only vertically pointing at this time but scanning capabilities will be incorporated within a year.

Results and Discussion

Figure 1 shows a THI plot of the LIDAR data obtained on February 4, 1999 for the power received polarized parallel to the incident laser pulse. The plot shows a thin cloud about 2.9 km above the LIDAR site and the overlap point 100 meters above the site. The LIDAR data was processed and plotted using the Windows-based LIDAR Data Plotter software utilizing Visual Basic version 5.

The depolarization plot corresponding to the February 4 data is shown in Figure 2. As shown in the color scale to the right of the depolarization plot, the depolarization ratio for this cloud varies from 0.1 to 0.8. Previous studies have determined that clouds at this altitude that exhibit δ values of 0.35 to 0.4 may be ice in its initial stage of formation.[8] Those clouds that have higher values of δ may contain pure ice crystals.[9] Derr reported highly glaciated condition for δ equal to 0.8.[10] During the collection of data for this day, an altostratus cloud can be physically observed. Such clouds usually exist at altitudes between 2 km to 8 km in the tropical regions and are composed of layers of water droplets and ice crystals.[11] The depolarization plot shows that the cloud may be a mixed phase cloud since the first part of the depolarization plot indicates a constant δ while the last part has higher δ values.

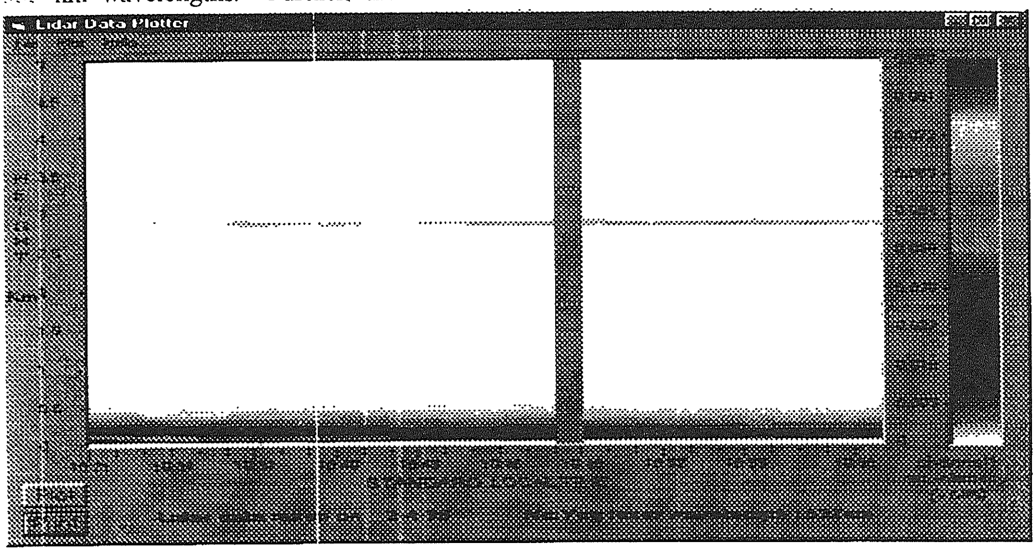

Fig. 1. LIDAR data on February 4, 1999 for the power received polarized parallel to the incident laser pulse. A thin cloud can be observed about 2.9 km above the LIDAR facility. The color scale to the right of the plot gives the intensity of the received signal.

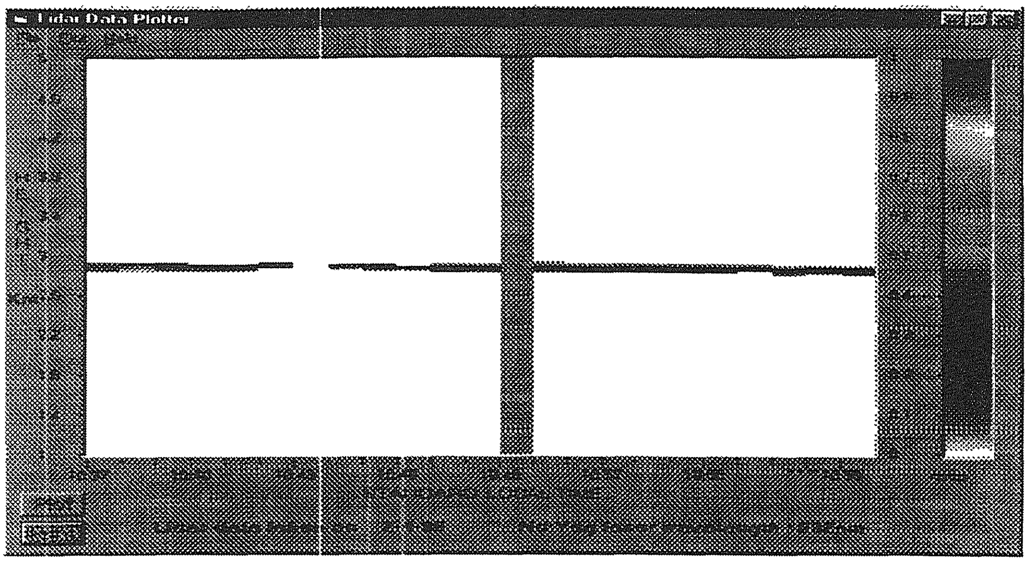

Fig. 2. Depolarization ratios obtained for the February 4, 1999 LIDAR data. The color scale to the right of the plot gives the depolarization values.

Figure 3 shows the photon penetration depth as a function of the mean correction factor for the February 4 LIDAR data. Using the data profile for 10.51 AM local time, simulation results were obtained assuming a homogenous cloud with an index of refraction of 1.33. An extinction coefficient of 0.01663 m^{-1} (C-4) and 0.065 m^{-1} (C-8) was utilized in the simulation and obtained from MIE scattering theory employing a cloud C1 distribution function and a single-scatter albedo of unity. 10^5 photon histories were simulated but we found out that 50,000 photons revealed the same result. The data show a strong dependence of $\bar{F}$ on the penetration depth for both methods. $\bar{F}$ decreases for increasing penetration depth until it approaches constant value of approximately 0.03. As pointed by Kunkel and Weinman, the physical basis for this behavior is to due to the forward diffraction peak of the phase function.

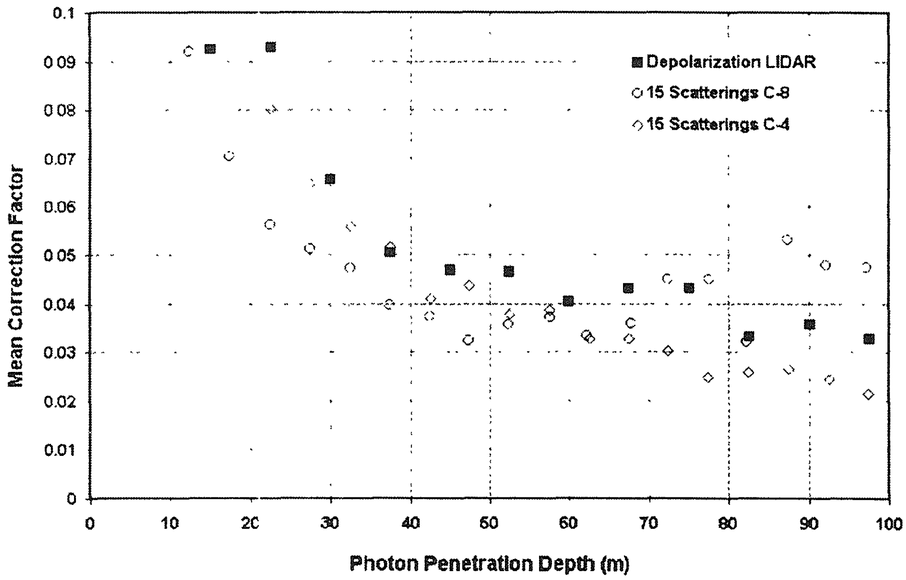

Fig. 3. Dependence of the mean correction factor on photon penetration depth for the Monte Carlo and depolarization LIDAR methods. 50,000 photons were used for the Monte Carlo simulation.

The results of the study indicate the importance of considering the effect on multiple scattering on the LIDAR data. Further, the study showed that a strong correlation exists between the Monte Carlo and depolarization LIDAR techniques. Both techniques also point out that the mean correction factor $\bar{F}$ depends on the penetration depth and that $\bar{F}$ approaches a limiting value as the penetration depth increases. The dependence of $\bar{F}$ with penetration depth must be considered in the LIDAR inversion process. Further studies are being performed to investigate the dependence of the correction factor on the wavelength of the incident radiation and on the size and composition of the particles.

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