EPJ Web of Conferences **362**, 01014 (2026) https://doi.org/10.1051/epjconf/202636201014
ILRC31/CLRC22-2024

Enhancing Atmospheric Monitoring: A Novel Approach to Determining Relative Lidar Ratio Using Combined Lidar and Camera Data

Yunki Mun[a], Juhyeon Sim[a], Dukhyeon Kim[b], Youngmin Noh[a]
[a] *Pukyong National University, Division of Earth Environmental System Science, Busan, South Korea*
[b] *Hanbat National University, School of Basic Science, Daejeon, South Korea*

Lead Author e-mail address: ansdbsrl12@gmail.com

Abstract: In this study, we explore an innovative approach to calculate Lidar ratios, an important element of atmospheric science that is generally assumed to be constant. By integrating 532nm laser lidar with camera data, we can derive extinction coefficients from Lidar and backscatter signals from laser images captured by the camera to calculate relative Lidar ratios under different atmospheric conditions. The relative Lidar ratio here is not the actual Lidar ratio because it is obtained from the backscatter signal and not the backscatter coefficient. Our method also overcomes the near-field limitation of Lidar by using camera-derived pixel values to restore the near-field extinction coefficient. These advances present more accurate techniques for determining atmospheric properties and demonstrate the potential of combining Lidar and camera data in environmental monitoring.

1. Introduction

Light Detection and Ranging (Lidar) technology has emerged as a pivotal tool in atmospheric science [1], particularly in the measurement and analysis of aerosol particles. By irradiating laser pulses into the atmosphere, Lidar systems are capable of determining key aerosol properties, such as the fine particle extinction coefficient and backscattering coefficient, from the signals received back [2]. These coefficients are essential for understanding aerosol concentration, distribution, and their potential impacts on climate and air quality. Typically, Lidar devices calculate either the extinction coefficient or the backscattering coefficient directly from the observed data. The remaining coefficient is then derived by assuming a constant lidar ratio [3]. This is a practice that simplifies calculations but may introduce inaccuracies in environments where the aerosol composition and atmospheric conditions vary significantly.

The lidar ratio, defined as the ratio of the extinction coefficient to the backscattered signal, is a critical parameter in aerosol characterization [4]. It provides insights into the optical properties of aerosols, reflecting the atmospheric state and the predominant aerosol materials. However, the common practice among fine particle measurement Lidar systems is to treat the lidar ratio as a constant, despite its inherent variability with changing atmospheric conditions. This approach can limit the accuracy of aerosol assessments, particularly in dynamic environmental settings. In this study, we address the challenge of applying a constant lidar ratio by proposing a novel methodology that calculates and applies the relative lidar ratio in real-time, leveraging integrated camera systems within Lidar devices. This method aims to enhance the precision of aerosol measurements by adapting to the variable nature of atmospheric conditions and aerosol compositions.

2. Methods

This study conducted observations in Siheung City, Gyeonggi Province, Republic of Korea utilizing Lidar technology at wavelengths of 532 nm (P, S) and 1064 nm. We utilized the same scanning lidar equipment as employed in the studies by Shin et al. (2024), Noh et al. (2020), and Kim et al. (2022) [5-7]. Observations with each Lidar were carried out over 30-second intervals, accompanied by camera captures fixed at a 10-second exposure time during the Lidar observations. This procedure allowed for precise correlation of the

LiDAR signals with the backscattered laser signals captured by the camera.

Figure 1. Lidar equipment with attached camera used for observation (MK-SMART 1)

The focal point of the analysis was calculating the lidar ratio using the extinction coefficient of the Lidar signal and the backscatter signal obtained from the camera. To calculate the extinction coefficient, a slope equation (Equation 1) that does not require the application of the Lidar ratio was used [1]. This played a critical role in observing changes in the lidar ratio through variations in the mass concentration of atmospheric aerosols.

$$\alpha(r) = -\frac{1}{2}\frac{d}{dr}\ln\big(R(r)\big) \tag{1}$$

In Equation 1, **α** refers to the extinction coefficient and R(r) refers to the range corrected signal according to the distance (r). By measuring the mass concentration of fine particles during the observation period, we investigated the impact of atmospheric particulate concentration on the lidar ratio. This analysis contributed to demonstrating the feasibility of precise calculation of the lidar ratio under various atmospheric conditions.

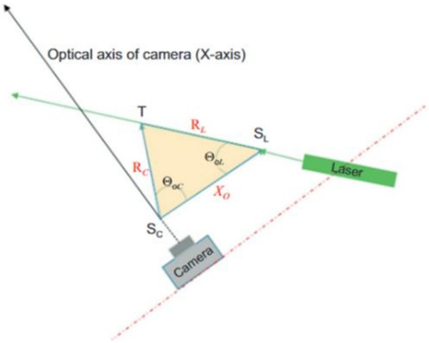

Figure 2. Schematic diagram of lidar composed of laser, camera, and target scatter.

Using the relative position structure of the camera and laser in Figure 2 and the already known X_0, we were able to obtain distance information indicated by each pixel.

$$\begin{aligned} & I_{pixel} \\ & = C I_0 e^{-\alpha Rc} \\ & / \left(\pi(\phi_L R_c)^2\right) \times \beta(R_c) \\ & \times \left(\Delta\Theta_c {R_c}^2\right) dR_L(R_c) \times e^{-\alpha Rc} \\ & = C' \alpha(Rc) e^{-2\int_0^{Rc} dr' \alpha(r')} \end{aligned} \tag{2}$$

The technical specifics facilitating the integrated use of Lidar and camera are also significant [8]. The camera was fixed to the Lidar equipment, ensuring it operated simultaneously with each Lidar observation. This approach guaranteed temporal alignment between the Lidar signals and camera images. Moreover, fixing the camera's exposure time to 10 seconds was a crucial measure to optimize the backscatter signal and accurately capture the reflective properties of atmospheric particles with high precision.

3. Results

Observations were conducted for approximately 3 weeks from February 15 to March 5, 2022, in Siheung City, Gyeonggi Province, Republic of Korea (Lat-37.327891, Lon-126.689138), where a small industrial complex and a coastal area exist. During this period, the average $PM_{2.5}$ and PM_{10} concentrations were 26 $\mu g/m^3$ and 41 $\mu g/m^3$.

Figure 3. Observation site : Siheung City, Gyeonggi Province, Republic of Korea

Differences could be seen in the image data as shown in fig4 when there was a lot of scattering by particles and when it did not.

Using Equation 2, the signal and distance information for each pixel were obtained and used as a backscattering signal, and at the same time, the extinction coefficient was calculated using the signal obtained from LIDAR and Equation 1.

Figure 4. Differences in pixel signals due to different atmospheres under the same laser intensity and camera shooting parameters during nighttime, with a laser beam elevation angle of 2.2 degrees

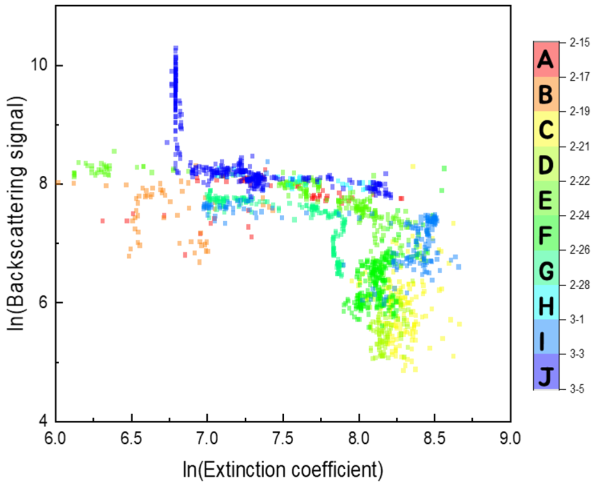

Figure 5. Extinction coefficient and backscattering signal by period

Figure 5 utilizes different colors to represent each period, illustrating the aerosol extinction coefficients measured by lidar and the backscatter signals captured by the camera. While the backscattering signal is a direct measurement susceptible to immediate atmospheric conditions, leading to higher variability, extinction coefficient is calculated based on several parameters and hence exhibits less fluctuation. It is evident that these values vary according to atmospheric conditions. The relative lidar ratio, which represents the ratio of the extinction coefficient to the backscatter signal, can be determined from the proportions depicted in this graph. Figure 6 displays the mass concentration over time, along with the $PM_{2.5}/PM_{10}$ ratios. It can be observed that similar properties in C and D are also distributed in similar regions in Figure 5.

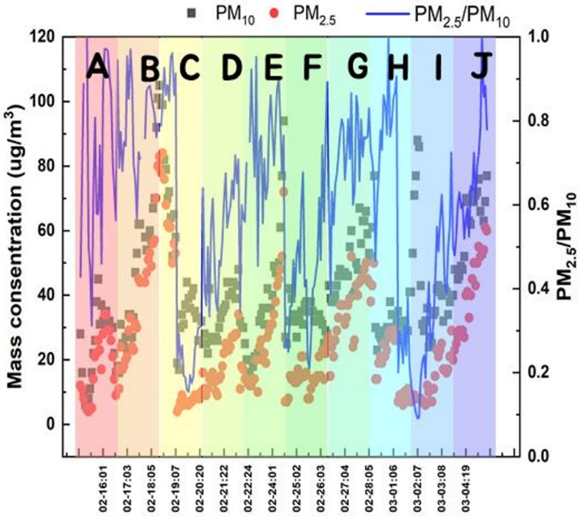

Figure 6. Mass concentration and ratio of $PM_{2.5}$ and PM_{10} by period as shown in fig 5

Further, while no direct correlation might be evident between the particulate matter concentrations ($PM_{2.5}$ and PM_{10}) and lidar measurements during the observed dates, these relationships are influenced by numerous factors including atmospheric composition, weather conditions, and temporal distribution of particulate sources. Future work will aim to dissect these complex interactions to provide a clearer understanding of the correlation mechanisms.

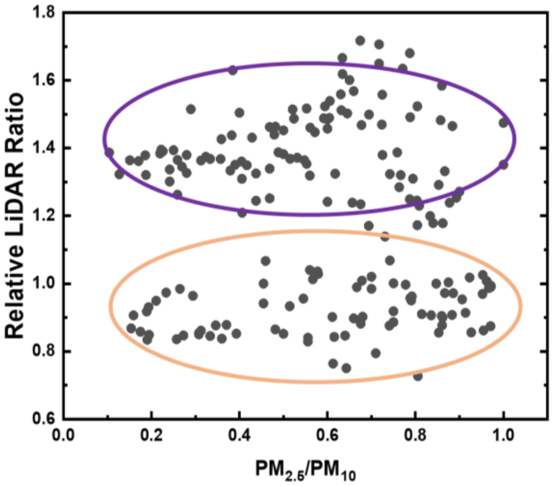

Figure 7. Indicates relative lidar ratio according to PM ratio

To ensure clarity in our presentation of data, it should be noted that for Figure 7, data points were selectively used from measurements taken on the hour every hour, with a consideration for data within 20 minutes of these times. This methodological choice leads to a reduced number of data points compared to Figure 5, where broader criteria were applied for data inclusion. When the relative Lidar Ratio is represented according to the PM ratio, it can be observed that it divides into two major groups. Further research will be conducted to identify the specific conditions of each group and to categorize them.

4. Discussions

In this study, we have identified two significant possibilities that underscore the advancements in our research:

Enhanced Accuracy: Traditional methodologies have applied a uniform lidar ratio across varying atmospheric conditions without considering the dynamic nature of these environments. Our research found by integrating camera-derived data to compute real-time, condition-specific relative lidar ratios. This approach not only tailors the calculation to the immediate atmospheric state but also significantly improves the precision of our observations.

Proximity Signal Calculation Enabled by Camera Integration: Previous constraints limited our ability to calculate near-ground backscatter signals due to the inherent field of view (FOV) limitations associated with standard lidar systems. However, by incorporating camera technology, our study successfully captures backscatter signals from as close as 50 meters. This capability allows for the precise calculation of near-range aerosol extinction coefficients using appropriately adjusted lidar ratios. Our methodology not only overcomes the limitations posed by traditional FOV constraints but also paves the way for more accurate near-ground atmospheric measurements.

Through these findings, our research contributes significantly to the field by demonstrating the feasibility and benefits of integrating camera data with lidar systems. This integration not only enhances the accuracy of atmospheric observations but also extends the capabilities of lidar technology to measure previously inaccessible near-ground signals, offering a comprehensive approach to atmospheric measurement and analysis.

5. Acknowledgment

This work was supported by a grant from the National Institute of Environment Research (NIER), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIER-2024-01-02-028).

6. References

[1] V.A. Kovaley and W.E. Eichinger, “Elastic Lidar: Theory, Practice, and Analysis Methods,” (John Wiley & Sons,2004).

[2] Y. Sasano et al., "Error caused by using a constant extinction/backscattering ratio in the lidar solution," Appl. Opt. 24, 3929-3932 (1985).

[3] Y. Noh et al., “Aerosol lidar ratio characteristics measured by a multi-wavelength Raman lidar system at Anmyeon Island, Korea,” Atmospheric Research Vol. 86, 76-87(2007).

[4] M. Kim, “The CALIPSO version 4 automated aerosol classification and lidar ratio selection algorithm,” Atmospheric Measurement Techniques Vol. 11, 6107-6135(2018).

[5] J. Shin et al., “Multi-section reference value for the analysis of horizontally scanning aerosol lidar observations,” Atmospheric Measurement Techniques Vol. 17, 397-406(2024).

[6] Y. Noh et al., “High Resolution Fine Dust Mass Concentration Calculation Using Two-wavelength Scanning Lidar System,” Korean Journal of Remote Sensing Vol. 36, 1681-1690(2020).

[7] G. Kim et al., “Estimation of Emission Flux of Particulate Matter by Agricultural Burning in Rural Areas using Scanning LIDAR,” Journal of Korea Society for Atmospheric Environment Vol. 38, 414-420(2022).

[8] J. Sim et al., “A Study of the Characteristics of Highly Spatially Resolved CW-laser-based Aerosol Lidar,” Korean Journal of Optics and Photonics Vol. 33, 1-10(2022).