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Unveiling Trends in Aerosol Mass Extinction Efficiency (MEE): Insights from Seven-Month Continuous Near-Ground Lidar and PM2.5 Observations in Chiba, Japan

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Abstract: Continuous near-ground lidar measurements of aerosols and dust were conducted at Chiba University, Japan, from August 2021 to February 2022, as part of preparations for monitoring radioactive dust in Fukushima. The mass extinction efficiency (MEE) of near-ground aerosols exhibited a wide range of values between 0 to 2.5 m^2g^{-1}. MEE values were primarily between 0 and 1 m^2g^{-1}, while aerosols with MEE exceeding 1 m^2g^{-1} were observed primarily in winter. Diurnal variations in MEE were also observed, with peak values generally occurring at noontime. Monthly mean MEE values ranged from 0.2611 m^2g^{-1} to 0.5397 m^2g^{-1}. These MEE values are crucial for understanding the scattering properties of aerosols in Chiba, and they provide valuable insights for evaluating the scattering properties of radioactive aerosols in Fukushima using similar techniques.

1. Introduction

The aerosol mass extinction efficiency (MEE) is a crucial parameter defined as the ratio of the extinction coefficient to the mass concentration [1-2]. This metric serves as a link between the optical and physical properties of aerosols and, thus, an essential parameter in quantifying the radiative properties of aerosols. High and low MEE values typically correspond to fine and coarse aerosols, respectively. Aerosols with a high complex refractive index, such as soot, exhibit higher absorption coefficients, which can significantly impact MEE values.

In this study, we focus on near-ground aerosols in the context of detecting radioactive aerosols in Fukushima, Japan. Monitoring near-ground aerosols and dust using a horizontal lidar is crucial for ensuring and informing communities about the quality of the air they breathe. The MEE of radioactive aerosols, like other aerosols, quantifies how efficiently aerosols scatter light relative to their mass, providing insights into their scattering properties. For example, if radioactive aerosols in Fukushima have high MEE, it could indicate that they are smaller in size. This information is beneficial for understanding the transport and dispersion of radioactive aerosols in the atmosphere, as well as their potential impact on human health and the environment.

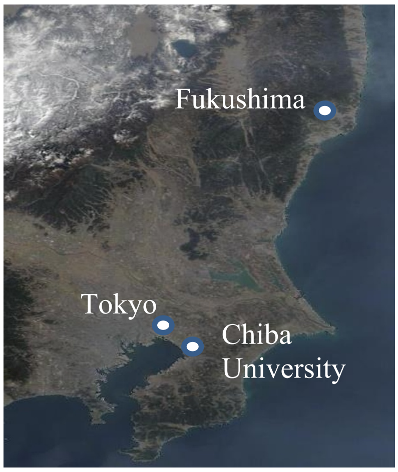

Figure 1. Location of the pre-deployment observation and proposed location of radioactive aerosol measurements (*https://worldview.earthdata.nasa.gov/*).

As part of our project, we conducted pre-deployment observations of near-ground aerosols in Chiba and investigated the influence of weather on local aerosol optical properties [3]. The techniques and findings from this pre-deployment exercise serve as a foundation for analyzing data to be collected in Fukushima. The objectives of this paper are threefold: 1) to quantify MEE of near-ground aerosols through continuous observations, 2) to characterize the diurnal and monthly variations of MEE, and 3) to establish correlations between MEE values and weather parameters, thereby enhancing our understanding of the relationship between weather conditions and MEE.

2. Measurement of MEE

This study utilizes data obtained from a DPSS horizontal lidar and PM2.5 measurements to assess MEE. Positioned on the 9th floor of the Engineering building at Chiba University (35.6278° E, 140.1031° N) (Fig. 1), the horizontal lidar operated continuously from 12 August 2021 to 28 February 2022. Table 1 outlines the specifications of the horizontal lidar. The slope method [4] was employed to derive extinction coefficients from lidar data, involving fitting a line between the maximum and minimum of the natural logarithm of the range-corrected signals within the range of 100 to 300 meters. This approach assumes minimal spatial variation in aerosol optical properties over short distances, typically within a few hundred meters.

Table 1. Specification of the DPSS lidar

Laser model	Spectra-Physics Explorer 1
Wavelength	349 nm
Pulse energy	120 µJ
Frequency	1 KHz
Beam divergence	3 mrad
Telescope diameter	10 cm
Transmitted polarization	P
Received polarization	S and P
Maximum range	700 m

$PM_{2.5}$ values are measured every 1 min in the same location as part of the international observation network (SKYNET). By taking the ratio of the extinction coefficient and $PM_{2.5}$, the MEE of aerosols with sizes less than 2.5 µm can be quantified.

3. Results

Figure 2 provides a detailed depiction of the temporal dynamics of MEE throughout our comprehensive 7-month observation period. This graphical representation shows a notable pattern in the observed MEE values, delineating them into two discernible clusters: those falling below and those surpassing 1 m^2g^{-1}. Particularly striking is the prevalence of MEE values exceeding this threshold during the winter season (December to February), as visually highlighted by the distinct clustering of data points within the demarcated orange box.

The observed predominance of MEE values surpassing 1 m^2g^{-1} during winter months is a locally interesting trend, and its underlying causes warrant closer examination. This phenomenon can be intricately linked to heightened concentrations of soot particles during winter, primarily originating from the increased combustion of fuels for heating purposes [5]. The combustion of heating fuels releases a plethora of aerosols, including fine particulate matter rich in soot, which significantly influences the optical properties of the atmosphere. These elevated levels of soot particles contribute to the observed increase in MEE values, underscoring the significant

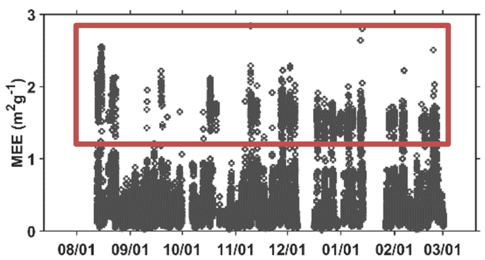

Figure 2. MEE values of near-ground aerosols from 12 August 2021 to 28 February 2022.

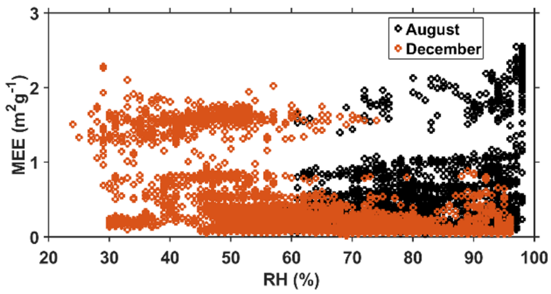

Figure 3. Comparison of MEE values in August 2021 and December 2021 with RH.

impact of seasonal variations in atmospheric composition on aerosol properties.

MEE values surpassing 1 m^2g^{-1} are notably less frequent during the summer (August) and fall months (September to November). The lower MEE observed during this period suggests a significant difference in the optical properties of aerosols between seasons with high (summer) and low (winter) RH.

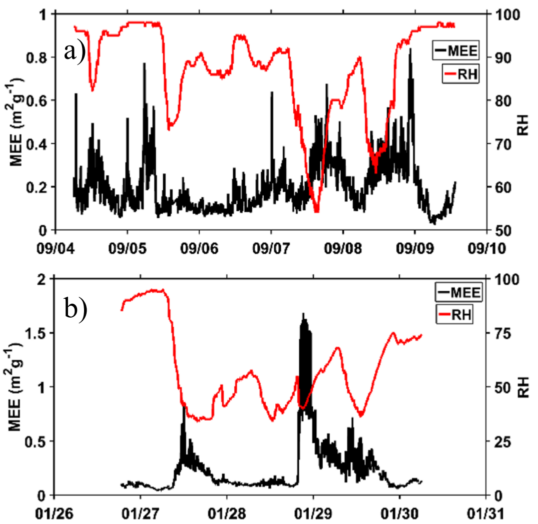

Figure 4. Diurnal changes of MEE from a) 04-09 September 2021 and b) 27-30 January 2022.

This phenomenon becomes particularly evident when examining the relationship between MEE values obtained in August and December 2021 and relative humidity (RH) (Fig. 3). In August, MEE values of aerosols tend to increase with rising RH, indicating a positive correlation between MEE and RH during the summer months. This relationship suggests that aerosols in August undergo hygroscopic growth processes, where aerosol particles increase in size as they absorb water vapor from the atmosphere. This growth can lead to changes in aerosol optical properties, potentially resulting in higher MEE values.

Conversely, the MEE values observed in December show an opposite trend, with MEE values decreasing as RH increases. This inverse relationship suggests that other factors, such as changes in aerosol composition or sources, i.e., the dominance of soot and fine particles [5], are more dominant during winter, leading to lower MEE values at higher RH levels.

The succeeding discussion focuses on specific MEE diurnal trends and RH relationships in fall and winter conditions.

A closer examination of the temporal variation in mass extinction efficiency (MEE) reveals intriguing diurnal fluctuations, with peak MEE values predominantly occurring during the daytime hours, as illustrated in Fig. 4a. These elevated MEE values during daylight hours suggest the intrusion of optically “new” aerosols into the region. These aerosols likely exhibit optical properties influenced by lower relative humidity (RH) during the day and potentially originate from new aerosol sources.

Under high RH conditions, water vapor tends to condense on aerosol surfaces, leading to aerosol growth and enhanced scattering properties. This phenomenon has been quantified in our previous work [3], demonstrating the complex interplay between RH, aerosol properties, and light scattering.

While it is true that the scattering properties of aerosols are enhanced at high RH, leading to an increase in the extinction coefficient, the mass of the aerosols also increases. Theoretically, this increase in mass should compensate for the increase in the extinction coefficient, resulting in a constant MEE in a region where RH can be approximated to increase linearly with the extinction coefficient, as seen on 06 September in Figure 4a when RH is below 90%.

However, the optical enhancement due to increased RH can be more substantial than the increase in mass, especially for higher RH levels (RH > 90%), where the extinction coefficient increases exponentially. The exponential increase in the extinction coefficient with RH results in a sharp rise in MEE, as observed on 05 September and 09 September in Fig. 4a.

The peaks of MEE at lower RH levels, such as between 07 and 08 September, indicate the detection of possible new aerosols with high extinction coefficient properties. These findings underscore the complex nature of aerosol behavior and the importance of considering RH and other meteorological factors when studying aerosol optical properties and their impact on atmospheric dynamics.

The data from 27 January 2022 presents a case study of how mass extinction efficiency (MEE) values vary with relative humidity (RH) changes (Fig. 4b). On this particular day, MEE values remained relatively constant at around 0.08 m^2g^{-1} when RH was at 90%. However, as RH decreased, a notable increase in MEE values was observed, reaching a peak of 0.7. Subsequently, as RH increased to 60%, MEE values decreased once again. This trend starkly contrasts what was typically observed in the fall or summer months. The subsequent decrease in MEE values as RH increases to 60% could be attributed to aerosol properties or source changes.

This specific example highlights the dynamic nature of aerosol behavior and the importance of considering multiple factors, including RH, when interpreting MEE data. Further studies are needed to fully understand the underlying mechanisms driving these trends and their implications for atmospheric processes and air quality.

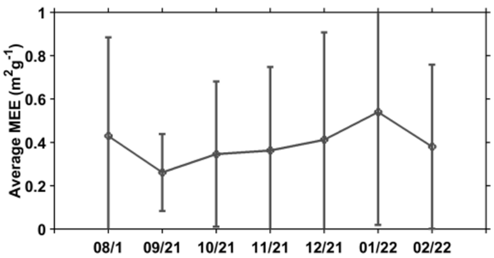

Figure 5. Montly MEE averages from August 2021 to February 2023.

The average MEE shows an increasing trend in the winter months (Fig. 5). This could be due to the effect of soot or black carbon in the near-ground atmosphere. As the temperature decreases in winter, more soot particles are expected to be released into the atmosphere. From the observations, the average MEE increases by 0.075 m^2g^{-1} per month. The utilization of lidar measurements in this study provides a valuable perspective on the horizontal distribution of aerosols and their optical properties, complementing the surface-level measurements obtained from PM2.5 data.

4. Conclusion

This study presents an analysis of near-ground aerosols in Chiba, Japan, using data from a horizontal lidar, with a focus on understanding their MEE and its implications for detecting and monitoring radioactive aerosols, particularly in Fukushima. Continuous observations using a DPSS horizontal lidar and PM2.5 measurements have gained valuable insights into MEE's temporal and seasonal variations and their relationship with weather parameters.

Our findings reveal distinct seasonal patterns in MEE, with higher values observed during winter compared to summer and fall. This seasonal variation can be attributed to increased soot concentrations during winter, primarily from the combustion of heating fuel. The diurnal changes in MEE further highlight the influence of daytime conditions, with higher MEE values occurring in the middle of the day, possibly due to lower relative humidity and the presence of new aerosol sources.

The observed MEE values provide valuable information for understanding the scattering properties of aerosols in the region, including radioactive aerosols. The relationship between MEE and scattering properties is crucial for accurately monitoring and assessing the impact of radioactive contamination on air quality and human health. By quantifying MEE and its variations, we can improve our understanding of aerosol behavior and enhance our ability to predict and mitigate the effects of aerosol pollution.

Our study demonstrates the importance of continuous lidar monitoring of aerosol properties, including MEE, for effective air quality management and environmental monitoring, especially in regions affected by radioactive contamination. The techniques and findings from this study can serve as a valuable reference for future studies on aerosol dynamics and their impact on atmospheric processes.

5. References

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