Aerosol characterization in the lower atmospheric boundary layer from lidar and DOAS measurements

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Abstract: A plan-position indicator (PPI) lidar and LED-DOAS system are operated simultaneously to measure and characterize temporal changes of aerosol parameters in the lower atmosphere during clear and cloudy conditions in summer over Chiba University. In this work, aerosol extinction coefficient values at 349 nm are derived using Fernald's method. The temporal trends of lidar and DOAS derived optical depth values are compared and shows similar temporal behavior for cases where the visibility is less than 35 km. For high visibility, extinction coefficients do not follow the trend of the extinction coefficient values from LED DOAS. The results also show extinction coefficients from PPI are more sensitive to relative humidity changes.

Key Words: LIDAR, aerosols, DOAS, lower atmosphere, extinction coefficient

1. Introduction

Optical parameters (e.g., extinction coefficient, Angstrom exponent) of aerosols in the atmosphere can be quantified using lidar and differential optical absorption spectrometer (DOAS). In an ideal situation, these parameters are best quantified if a number of instruments are operated simultaneously. In this work, a PPI lidar (349nm) and LED-DOAS (590 nm) are operated simultaneously to explore the possibility of charactering aerosols and to observe the temporal change of aerosol extinction coefficients and consequently aerosol optical depths during summer at Center for Environmental Remote Sensing (CEReS), Chiba University. This observation also intends to look at the performance of each instrument during a 24 hour operation.

2. Description of the systems

The PPI lidar (λ=349 nm, f=1 kH) and LED DOAS are placed on the 9^{th} floor of CEReS building and was continuously operated[1]. A retroreflector is placed inside the 9^{th} floor of the Science building, 320m north of CEReS building to reflect the light from the DOAS transmitter. During the operation, the PPI lidar is angled at 10^{o} above the horizontal and is pointed north so that both instrument observe the same spatial location. The LED DOAS is operated using 2 colors (590 nm and 625 nm). PPI and LED DOAS data are recorded every 5 min and 30 s, respectively. In addition to the lidar and LED-DOAS system, additional ground instruments are also simultaneously operated: nephelometer (TSI 3563), visibility meter (Vaisala PWD52), optical particle counter (Rion KC-22B & KC-01E) and weather monitor. The results of simultaneous operation of these instruments provide a better description the effect of weather parameters on the optical properties of aerosols and even on the performance of the instruments. Table 1 shows the summary of the specifications of the instruments used in this work.

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Table 1. Specification of the instruments

	PPI
Wavelength (nm)	349
Frequency (Hz)	1000
	LED DOAS (Thorlabs LED4D067)
Wavelength (nm)	*590 and 650
	Nephelometer (TSI 3563)
Wavelength (nm)	450, *550, 700
	Visibility meter (Vaisala PWD52)
Output Wavelength (nm)	550 (measured at 875 nm)
Optical particle counter (OPC)	*KC-22B and KC-01E (Rion)
Particle sizes (μm)	0.08, 0.1, 0.2, 0.3, 0.5
	Weather monitor
Measurements	RH, temperature, wind speed, wind direction, rainfall

* employed here

3. Methodology

The extinction coefficient from PPI are obtained by using Fernald's method[2]. The extinction to backscatter coefficient, S_1, is set between 40-70 sr^{-1} [3]. Since the measurements are near the ground, the extinction coefficient (at 550nm) obtained from visibility meter is used as a boundary value for the inversion of the lidar data and converted to 349nm using the factor (550/349).

In the case of the LED DOAS data, the aerosol optical depth is obtained by first implementing a linear fit on the logarithm of nighttime LED DOAS data plotted against the nephelometer data. When the aerosol scattering coefficient is zero, the y-intercept of the linear fit represents the contribution from both molecular optical depth and system constant.

4. Results

The operation of the PPI lidar and LED DOAS started at around 19:00 JST on 27 July 2017 until 30 July 2017. During the three-day continuous operation, observed rainfall is zero. However, relative humidity

(RH) values range from 56% at daytime to 96% at nighttime. The RH usually peaks after midnight and starts to decrease after sunrise. Wind speed range from 0 to 5 m/s while temperature range from 22°C to 34°C. Atmospheric conditions range from clear to cloudy. Nighttime is usually cloudy as reported from the Japan Meteorological Agency (*http://www.data.jma.go.jp*).

Figure 1 shows the temporal change of extinction coefficient from both PPI lidar (349 nm) and LED DOAS data (590nm). The extinction coefficients from lidar are taken at a distance 450m north of the lidar location. The increasing extinction coefficient values from PPI and LED DOAS at nighttime can be attributed to increasing RH. The results also show that the deterioration of extinction coefficients from PPI is likely correlated to increasing RH compared as to LED DOAS. When RH values reach more than 90%, the PPI signals deteriorate producing unreliable extinction coefficients and are not shown in the graphs (Figs. 1 and 2). This occurred on the night of 27-28 and 28-29 of July when the RH reached above 91%. A minor deterioration of lidar signal occurred on the night of 29-30 July when RH values are just below 90%.

During daytime, the extinction coefficients from both instruments are comparatively lower than that of nighttime. The RH values during daytime range from 56-77% that result to the evaporation of water adhered to the surface of the aerosol droplets and consequently decreasing aerosol size.

Figure 2 shows the temporal development of Angstrom exponent (AE) and RH from the night of 27 to the night of 29 July 2017. The Angstrom exponent is quotient of the logarithm of the ratio of extinction coefficients from PPI and LED to the logarithm of the ratio of wavelengths from LED and PPI. The increasing Angstrom exponent on the night of 27-28 July can be attributed to the influx of fresh fine aerosols that contribute to high and increasing

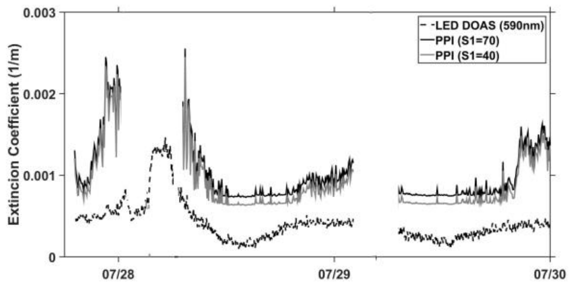

Fig. 1. Extinction coefficient values from PPI lidar and LED DOAS measurements (27-30 July 2017).

scattering coefficient from nephelometer data (~0.10/km at 450nm) even though the RH during this time increases from 90% to 94% before midnight. The OPC at CEReS registered increasing counts in the 0.2, 0.3 and 0.5 size range. After midnight, when RH increases up to 96%, aerosol growth could have happened as seen from the lower Angstrom exponent values during the early part of the day on 28 July. The increasing Angstrom exponent at daytime on the 28th can be attributed to the decreasing RH (94% to 57%) from 07:00 to 14:00. After this time, RH increases until past midnight contributing to aerosol growth as seen in the decrease of Angstrom exponent values. The increase of Angstrom exponent from early evening to midnight can be observed and is common to all three nights. This can be attributed to the influx of fresh aerosols in the area, possibly from evening traffic/rush. This diurnal pattern is observed each day during the measurement. From the data, it can be inferred that the effect of RH on aerosol growth happens after midnight when RH is at its maximum value (~94%-96%) and when there is minimum influx of aerosol in the atmosphere. High Angstrom exponent occur during daytime when RH is at its lowest (~59%). Evaporation of water may have completely occurred during this time effectively drying-up of aerosols even though clouds are present.

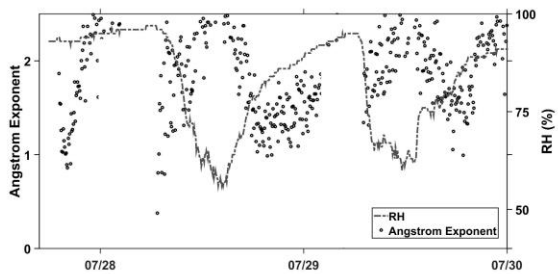

Fig. 2. Extinction coefficient values from PPI lidar and LED DOAS measurements and ambient RH (27-30 July 2017).

5. Conclusion

This work has shown the capability of an LED DOAS and lidar systems to characterize the aerosols in the atmosphere over Chiba during summer. The diurnal trend shows extinction coefficient values from PPI lidar are more sensitive to changes in ambient relative humidity compared to the extinction coefficients from the LED source. When ambient RH is more than 90%, PPI signals deteriorate and cannot provide reasonable extinction coefficients. The results of this work also show the diurnal pattern of aerosol growth in the atmosphere. The combined operation of these two instruments shows that aerosols in the lower troposphere can be characterized to effectively understand the changes of aerosol optical properties in the atmosphere.

References

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