Diurnal Behavior of Aerosol Extinction Coefficient Based on Lidar and Ground Sampling Instruments

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Abstract: One of the important factors that contribute to air visibility is the aerosol extinction coefficient. In this paper, we derive the diurnal behaviour of aerosol extinction coefficients at 349 nm from the data of the plan-position indicator (PPI) lidar and ground sampling instruments, namely a nephelometer and an aethalometer. For both instruments, the diurnal behavior of the aerosol extinction coefficients is shown to appear in-phase in every change of the ambient relative humidity (RH), which tends to be higher at night and lower at the mid-day.

Key Words: Lidar, Ground Sampling Instruments, Aerosol Extinction Coefficient

1. Introduction

An extensive long-term monitoring of the visual air quality is of importance to be able to establish the current visibility conditions, track changes over time and determine the contributing factors of visibility changes[1-3]. One parameter that controls visual air quality is the aerosol extinction coefficient. In this report, we examine the diurnal behavior of the aerosol extinction coefficient with respect to the atmospheric conditions, especially the ambient relative humidity (RH).

2. Instruments

All the instruments used to measure the aerosol extinction (Plan-Position Indicator (PPI) lidar), scattering coefficients (nephelometer), and equivalent black carbon (EBC) (aethalometer) are located on the rooftop of the 8-story CEReS building in Chiba University (35.63°N, 140.10°E), about 30 m above ground. The site is also equipped with a weather monitor that measures the ambient RH, rain, wind speed and direction every 5 minutes routinely.

2.1. PPI Lidar

The PPI lidar is based on a diode-laser pumped Nd:YLF with 349 nm wavelength and 60 μJ/pulse at 300 Hz pulse repetition rate. Figure 1 illustrates the schematic configuration of the PPI lidar system. A photomultiplier tube (PMT, Hamamatsu H10304-00) is used as the receiver sensor. The PMT is connected to the Licel transient recorder (TR20-160) for data recording of the backscattered signal every 5 min. These values are then used to calculate the aerosol extinction coefficient. In addition, the PPI lidar was set to measure in fixed direction facing the north direction.

2.2. Nephelometer and Aethalometer

The three-wavelength (450, 550 and 700 nm) integrating nephelometer (TSI 3563) is used to measure the aerosol scattering. It can measure the scattered light with scattering angles between 7° and 170°. In CEReS, the nephelometer makes a scattering measurement every minute.

The seven-wavelength (370, 470, 520, 590, 660, 880, and 950 nm) aethalometer (Magee AE31) is used to measure the equivalent black carbon (EBC), which is then used to derive the absorption coefficient of the aerosols given by the following equation:

$$\alpha_{abs}(\lambda) = EBC * \left(\frac{14625}{\lambda}\right), \quad (1)$$

where $\alpha_{abs}(\lambda)$ [m^{-1}] is the absorption coefficient, EBC is measured in units of ng·m^{-3}, and $\left(\frac{14625}{\lambda}\right)$ is the mass extinction efficiency factor [m^2·g^{-1}] [4]. The aethalometer is set to measure the average value over 5 min.

The measured scattering coefficients by the nephelometer and the derived absorption coefficients by the aethalometer are used to compute the extinction coefficient, and then categorized as the result from the ground sampling instruments.

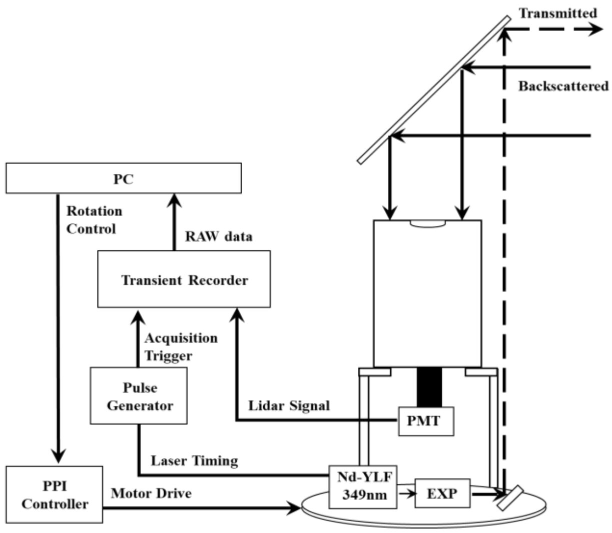

Fig. 1. PPI lidar system: schematic configuration

3. Methodology

The PPI lidar was operated continuously from July 14 to 17, 2017 to investigate the diurnal behaviour of the aerosol extinction at 349 nm wavelength. The aerosol extinction coefficients were derived using the Klett method[5] given the assumption of atmospheric homogeneity in the lower atmosphere in addition to the small (10°) elevation angle of the PPI laser beam.

To obtain the extinction coefficient from the ground sampling instruments at the wavelength similar to the PPI lidar, a linear extrapolation was necessary from the logarithmic relation of the scattering coefficient (nephelometer) and absorption coefficient (aethalometer) with wavelength. These optical data (taken every 5 min) are then plotted against the RH from the meteorological data with respect to the hour of day for the entire 3-day period.

4. Results

During the observation period from July 14 to 16 (afternoon) the atmosphere was relatively clear with slight cloud cover, especially on the 16th. We experienced small rainfall at 20:00 JST of July 16 and at 08:00 JST of July 17. A summary of weather data for this rain period is presented in Table 1. The RH for the 3-day duration was consistent to have a mid-day minimum with a slight abrupt increase during the short rain period, as can be seen in Fig. 2. As expected due to temperature dependence, the RH is higher at night and lower during mid-day, and its difference is about 30-40% per day.

Table 1. Weather data of the period with rain.

days with rain	rain (mm/h)	wind speed (m/s)	wind direction (deg)	wind direction
July 16 (19:55-20:00)	12	0.4-1.8	202-247	SSW-WSW
July 17 (08:00-08:10)	3	0.4-1.8	0	N

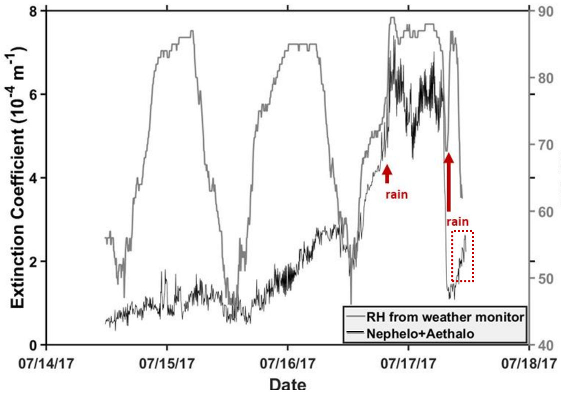

Fig. 2. Extinction coefficients at 349 nm derived from the data of ground sampling instruments (nephelometer and aethalometer) plotted against the ambient RH over the 3-day period.

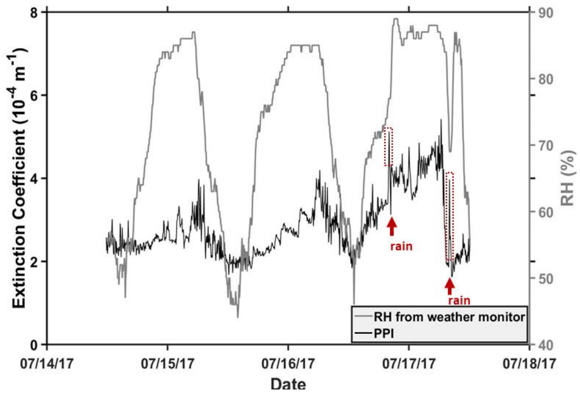

Fig. 3. Extinction coefficients 500 m away from the PPI lidar plotted against the ambient RH over the 3-day period.

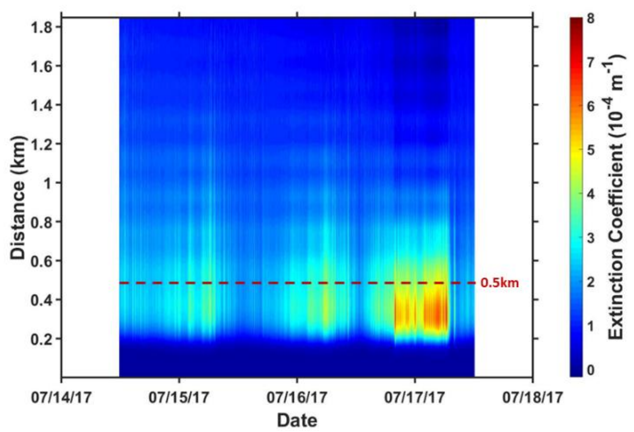

Fig. 4. Time-distance profile of the extinction coefficients from the PPI lidar data at 349 nm wavelength.

Figure 2 also presents the extinction coefficients from the ground sampling instruments plotted over time. From Fig. 2, it is apparent that the temporal change of aerosol extinction is in phase with the ambient RH. Also, during the onset of the 1st rain (July 16) there is a noticeable, rapid increase in the extinction coefficient. Despite the fact that the rain lasted for just a few minutes, the number of aerosol particles after the rain remained to be high for the whole night. This might be due to the increase in the number of hygroscopic aerosol particles during this time and the RH in nighttime is at its maximum, i.e. 70% or higher[3]. Interestingly, the usual drop of the RH in the morning due to the temperature change, drastically drop the aerosol extinction to a minimum even for just a very short period of time. The onset of the 2nd rain (July 17) did not alter the aerosol extinction right away. This might be due to the level of the RH, which is below 70%, just before the precipitation. In addition, as the RH increased to more than 80%, the aerosol extinction started to increase rapidly (inset red dotted line).

A similar analysis was carried out on the PPI lidar data (Fig. 3). The in-phase relation with RH is found also for the extinction coefficients from the lidar data throughout the 3-day period. However, the minimum aerosol attenuation is in the order of about 2.0x10^{-4} m^{-1} or 20% light attenuation per km, slightly higher than the ground sampling instruments. It is also interesting to see the sensitivity of the lidar system in measuring the aerosol extinction during the onset of rain, especially the 2nd rain (July 17). As seen in Fig. 3, there is apparent spike of aerosol extinction in every rain occurrence before it gradually neutralizes back close to its original value (see inset red dotted lines). This is not the case for the nephelometer and aethalometer data.

Figure 4 is the time-distance profile of the aerosol extinction coefficients derived from the PPI lidar measurements. The range covered here is up to 1.8 km away from the lidar. As observed from the previous figures, there is a good correspondence of aerosol increase/decrease in every increase/decrease of the ambient RH. The only difference is that, this figure added the spread of the aerosol extinction over certain range along the field of view of the lidar receiver telescope.

5. Conclusion

We have derived the aerosol extinction coefficients at 349 nm from the data of the PPI lidar and ground sampling instruments, a nephelometer and an aethalometer. For both schemes, the diurnal behavior of the aerosol extinction coefficient was found to be in-phase with the change in the RH in the 3-day period. Moreover, the observed RH exhibits a pattern of a mid-day minimum and nighttime maximum due to its temperature dependence.

For future work, it is planned to make an extensive seasonal analysis of the aerosol extinction behavior.

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