Effects of dust on aerosol scattering enhancement factor as measured with a ground-based slant path lidar in Chiba, Japan

○Nofel Lagrosas[1,2], Hayato Saito[2], Tomoaki Tsuneyoshi[2], Naohiro Manago[2], Hiroaki Kuze[2]

[1]Manila Observatory, Katipunan Ave., Quezon City Philippines
[2]Center for Environmental Remote Sensing (CEReS), Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba, Japan

Abstract: Aerosol scattering enhancement factor, *f*(*RH*), was derived from the concurrent data of slant-path lidar, nephelometer, aethalometer, optical particle counter and weather monitor at the end of spring season at the Center of Environmental Remote Sensing (CEReS), Chiba University. The *f*(*RH*) values obtained ranged from 1.1 to 2.1 in the *RH* range of 32% to 57%. Occurrence of dust in the lower troposphere caused the decrease in *f*(*RH*) with increasing *RH*.

I. INTRODUCTION

Relative humidity, *RH*, greatly affects the size, shape and scattering properties of aerosols, resulting in changes in radiative forcing in the atmosphere. Recent studies involving multi-wavelength lidar and skyradiometer show the effects of *RH* in the seasonal analysis of the data.[1)] When ambient *RH* increases, sizes and scattering coefficients of hygroscopic aerosols also increase.[2,3)] From the viewpoint of remote sensing, the growth of aerosols with increasing *RH* is described[4)] using the scattering enhancement factor, *f*(*RH*), defined as

$$f(RH) = \frac{\sigma_{sca}(RH,\lambda)}{\alpha_{sca}(RH_{dry},\lambda)}, \qquad (1)$$

where $\sigma_{sca}(RH, \lambda)$ and $\sigma_{sca}(RH_{dry}, \lambda)$ are the aerosol scattering coefficients (ambient and dry, respectively) at wavelength λ; RH_{dry} indicates the *RH* value at which the hygroscopic growth is negligible (normally RH_{dry} <35%). This parameter increases with increasing *RH* and should be equal to unity if aerosols are in dry state. In this study, we present the results of *f*(*RH*) values obtained during a campaign in May 2015 conducted at the Center for Environmental Remote Sensing (CEReS), Chiba University using a slant path lidar (532 nm, 1 kHz), nephelometer (700, 550, and 450 nm), aethalometer (seven wavelengths between 370 to 950 nm), optical particle counter and weather monitor instruments. The optical particle counter was used to determine the existence of dust using the size counts between 3-5µm. Any increase in the number of particle detected in this size bin can imply dominance of large particles in and beyond this size range. This measurement campaign was performed to understand the effects of *RH* on the dynamic local weather conditions and of dust occurrence on aerosols during the end of spring in Chiba.

II. INSTRUMENTS

Ground instruments, i.e., a nephelometer (TSI 3563), aethalometer (Magee AE31), optical particle counters (OPC) (Rion KC-22B and KC-01D) and weather monitor (Vantage Pro 2), were operated simultaneously with the slant-path lidar. These instruments are installed in CEReS for the purpose of measuring the optical properties of aerosols at and near the ground level. The nephelometer, aethalometer, OPC and weather monitor provide scattering coefficients, absorption coefficients, number of particles and ambient relative humidity, respectively, which are the parameters used in this study. The slant-path lidar, located on the top floor of CEReS building, is oriented at an elevation angle of 30°, facing north. During the campaign period, the lidar was normally operated from 10:00 to 20:00 (JST local time). When there were no rain forecasts, lidar data were collected overnight.

III. METHODOLOGY

To obtain *f*(*RH*), a reference scattering coefficient (7.00×10^{-5} m^{-1}, at λ = 550 nm) was used. This value corresponds to the aerosol scattering coefficient measured with the nephelometer at *RH*=31% at around 14:00 on 02 March 2013 when the visibility (reported by the Japan Meteorological Agency) was around 19.1km. At the same atmospheric pressure and height, we can assume that there is little difference between the number of ambient and dry particles. It is noted that although the *RH* inside the instrument is kept below 50%, not all the observed values can be considered as those under the dry state. Here we set the criteria of <35% for the dry state aerosol.

The dry calculated scattering coefficient at 532nm is 7.2×10^{-5} m^{-1} by employing the power law relationship between wavelengths and scattering coefficients[5)]. The extinction coefficients from the slant-path lidar at the full-overlap height of ~600 m are measured and compared with ground measurements data from other instruments. The ambient scattering coefficient is obtained by subtracting the absorption coefficient (at 532nm, from aethalometer) from the near ground-level extinction coefficient estimated from the lidar data. The ratio of the ambient and reference dry scattering coefficients provides the value of *f*(*RH*).

IV. RESULTS

Figure 1 shows the time-height indication of the aerosol extinction coefficient observed with the slant-path lidar from 11:00 to 20:30 (JST) on 13 May 2015. No data were gathered between 13:30-15:30 due to unforeseen heating of the laser head. The figure shows that around noontime, the lower atmosphere is highly convective and aerosol updrafts are observed. This is due to the increasing atmospheric temperature that ranged from 21°C to 26°C. Wind speed and RH ranged from 2.7 to 5.6 m/s and 37 to 57%, respectively. Wind direction was primarily from the south. After 15:00, traces of downdrafts near the ground are observed. Figure 1 also shows a possible layer of dust between 2-3km.

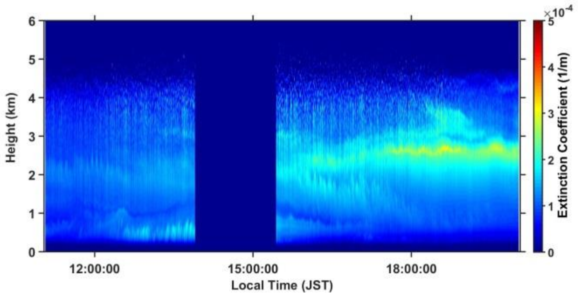

Figure 1. Extinction coefficient values from slant-path lidar taken on 13 May 2015 showing the occurrence of updrafts near the ground and dust at around 6km after 15:00 (JST).

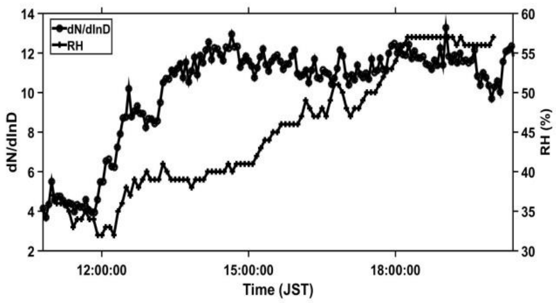

Figure 2. Size number distribution in the 3-5µm bin from optical particle counter showing increasing number of coarse particles from 12:00 noon and onwards as RH increases in the same time interval.

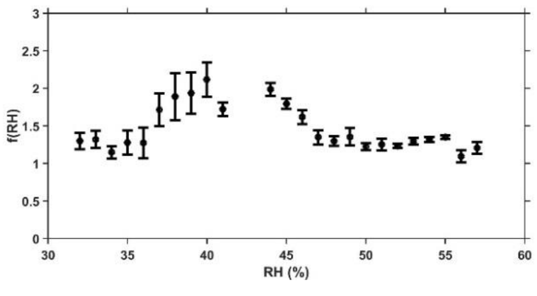

Figure 3. Measured *f*(*RH*) values with *RH* showing increasing values with *RH*. However, the decrease in *f*(*RH*) with *RH* was coincident with the occurrence of dust.

From 12:00 onwards, the OPC registered increasing counts from 0.01 to 1 count/L in the 3-5µm bin. Figure 2 shows the temporal change of the number density, d*N*/d(ln*D*), observed in the 3 to 5 µm bin. Higher counts have been consistently measured until the middle of the third day of the measurement campaign. Increasing counts from smaller sizes were also observed, indicating that the "front" of the dust is composed of small particles that are sensitive to *RH* changes. This is manifested in the high variability of *f*(*RH*) values in the 30-40% *RH* range (Figure 3) that correspond to the *RH* change between 11:00 to 13:00. This type of aerosols in the dust can be considered as hydrophilic in nature and scatter light twice as much compared to its dry state. After 15:00, when the number of 5 µm counts is steadily high, the *f*(*RH*) values decrease. This behavior suggests that the presence of dust in the atmosphere effectively lowers the *f*(*RH*) values, though the RH recorded in the meantime exhibited a slight increase from 43% (15:00) to 58% (20:00). Since *f*(*RH*) values usually increase with increasing *RH*, the slight variability of *f*(*RH*) values strongly suggests that the optical properties of observed dust are insensitive to changes in *RH*. This can be due to the absorptive properties of dust. Absorption coefficients at 532 nm measured from aethalometer during this time interval showed increasing values from 1.0×10^{-5} to 2.3×10^{-5} m^{-1}. This lasted until the middle of the third day. Previous studies have reported that dust aerosols become absorptive during transport as they mix with other aerosol types such as soot.[6)] The increasing absorptive properties of dust lead to decrease in the single scattering albedo and scattering coefficient and effectively lowers *f*(*RH*).

V. CONCLUSION

Slant-path lidar data combined with ground instruments can measure the *f*(*RH*) of aerosols near the ground. Measurements on 13 May 2015 have shown that the existence of dust in the atmosphere effectively lowers *f*(*RH*). Temporal evolution of dusts' optical scattering properties show insensitivity to changes in RH.

REFERENCES

1) Manago, N., et al.: Seasonal variation of tropospheric aerosol properties by direct and scattered solar radiation spectroscopy, J. Quant. Spect. & Rad. Trans., 112, 285-291, 2011.
2) Mabuchi, Y. et al.: Multi-wavelength lidar system for the characterization of tropospheric aerosols and clouds, Proceedings of Geoscience Remote Sensing Symposium, 2505-2508, 2012.
3) Bagtasa, G. et al.: Correction in aerosol mass concentration measurements with humidity difference between ambient and instrumental conditions, Atmos. Env. 41, 8, pp. 1616-1626, 2007.
4) Zieger, P. et al.: Influence of water uptake on the aerosol particle light scattering coefficients of the Central European aerosol, Tellus B, 66, 22716, 2014.
5) Moomüller, H. and Chakrabarty, R.K.: Technical note: Simple analytical relationships between Angstrom coefficients of aerosol extinction, scattering, absorption and single scattering albedo, Atmos. Chem. Phys., 11, 10677-10680, 2011.
6) Yi, B. et al.: Impact of pollution on the optical properties of trans-Pacific East Asian dust from satellite and ground-based measurements, J. Geophys. Res., 119, 5397-5409, 2014.