UV HIGH-SPECTRAL-RESOLUTION LIDAR FOR ABSOLUTE MEASUREMENT OF AEROSOL EXTINCTION COEFFICIENT AND LIDAR-RATIO

Takao Kobayashi(1), Masaharu Imaki(1), Yoshihiro Takegoshi(1), Nobuo Sugimoto(2)

(1) Graduate School of Engineering, University of Fukui, Fukui 3-9-1 Bunkyo, Fukui, 910-8507 JAPAN
(2) National Institute for Environmental Studies (NIES), 16-2 Onogawa, Tsukuba, Ibaraki 305-8506 JAPAN
kobayasi@fuee.fukui-u.ac.jp

ABSTRACT

An ultraviolet high–spectral-resolution lidar (UV HSRL) has been developed for measuring atmospheric optical parameters such as the aerosol extinction coefficient and the lidar ratio. Measurement of absolute value of the atmospheric optical parameters without assuming typical aerosol model is possible in this system. The system employs an injection seeded tripled Nd:YAG laser at eye-safe ultraviolet wavelength of 355nm and a Fabry-Perot interferometer as a high-spectral-resolution filter. High–spectral-resolution technique is used for separating the Mie and the Rayleigh backscattering in the received signal. The measurement accuracy of the aerosol extinction coefficient was 1.6 x 10^{-2}km^{-1} at 5km range with 10^4 laser shot averaging and 700m range resolution.

1. INTRODUCTION

Aerosols and clouds significantly influence the atmosphere through the scattering and absorption of incoming solar and outgoing thermal radiation. Measurements of accurate value of optical properties of aerosol and cloud are important. The Mie scattering lidar detects combined signal of the Rayleigh and the Mie scattering and thus quantitative measurement of the aerosol properties is limited [1]. The high-spectral-resolution lidar was developed using a single-frequency laser and a narrow bandwidth filter for separately detecting the Mie scattering and the molecular Rayleigh scattering components [2], [3]. Measurement of absolute value of the atmospheric optical parameters is possible using this system.

In the HSRL, a molecular iodine absorption filter was used as the high-resolution filter to attenuate the narrow-band Mie component to 10^{-5}~10^{-7} level but the laser wavelength is limited to the visible second harmonic of the Nd:YAG laser at 532nm [4].

In this research, we have developed an UV-HSRL system using the third harmonic wavelength of 355nm of the Nd:YAG laser with a Fabry-Perot interferometer as the high-resolution filter [5] – [8].

2. UV-HSRL SYSTEM

Schematic diagram of the UV-HSRL lidar system is shown in Fig.1. The single-frequency ultraviolet third harmonic at 355nm of the injection seeded and continuously tunable Nd:YAG laser is used. Laser beam energy is 100mJ and laser beam diameter is enlarged to 60mm by the beam expander. Backscatter signal is collected by the 250mm diameter Schmidt Cassegrainian telescope and focused into the 100μm core multimode optical fiber. The fiber output is collimated and detected by two photomultipliers with a Fabry-Perot filter. The first detector is used for the Mie scattering measurement and the second detector is used for the total power measurement.

Figure 2 shows spectral profiles of the Mie and Rayleigh scattering and the Fabry-Perot high-spectral-resolution filter for discriminating the aerosol Mie scattering and the molecular Rayleigh scattering. The overall optical efficiency of the total power monitor is 0.2 and the Mie monitor is 0.22 including the optical fiber efficiency. High spectral resolution technique is used for separating Mie and Rayleigh backscattering in the received power.

Total extinction coefficient is derived by corrected Rayleigh scattering power and is given by

$$\alpha(z) = -\frac{1}{2}\frac{d\ln\left(P_m(z)z^2\right)}{dz} + \frac{1}{2\beta_m(z)}\frac{d\beta_m(z)}{dz}, \qquad (1)$$

where P_m is the Rayleigh scattering power of the correction of the Mie scattering power, β_m is molecular density distribution of the standard atmosphere and z is the observation range. The aerosol extinction coefficient $\alpha_a(z)$ is derived from

$$\alpha_a(z) = \alpha(z) - \alpha_m(z), \qquad (2)$$

where $\alpha_m(z)$ is the molecular extinction coefficient. Absolute value of the aerosol backscattering coefficient $\beta_a(z)$ is given from the ratio of the $P_m(z)$ and corrected aerosol Mie scattering power $P_a(z)$. From this method, absolute value of the lidar ratio, $S_1(z)=\alpha_a(z)/\beta_a(z)$ is derived.

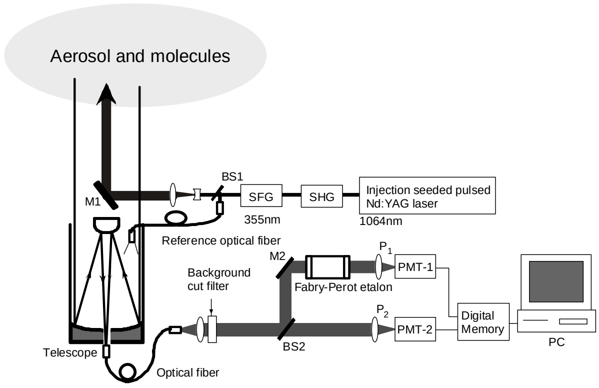


Fig. 1 Schematic of the UV high-spectral resolution lidar system. PMT-1 and PMT-2 are the photo-multiplier detectors for the detection of the Mie and the total scattering signals, respectively.

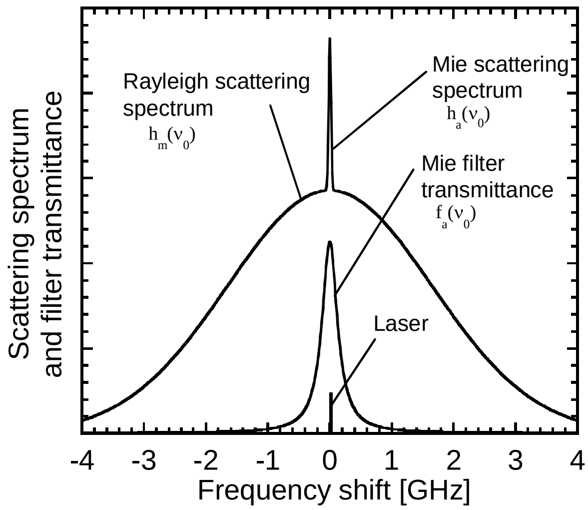
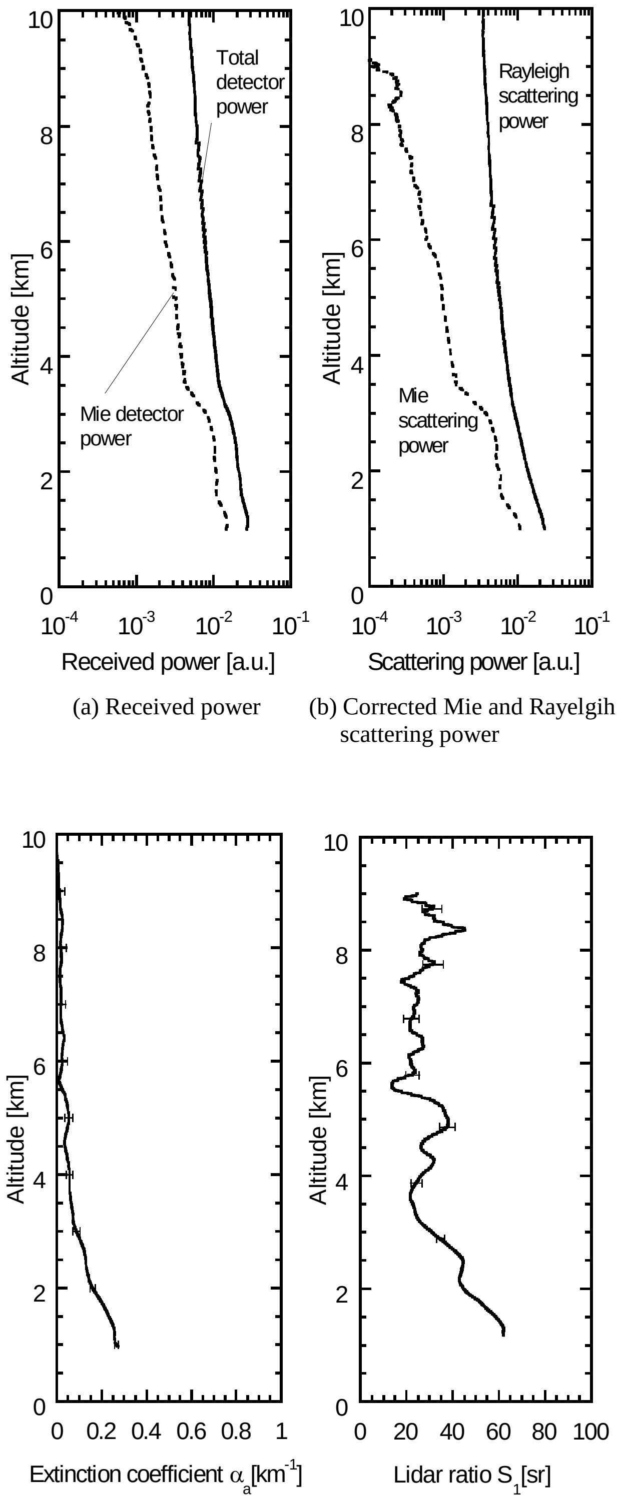


Fig. 2 Spectral profiles of the Mie and the Rayleigh backscattering and the transmission function of the high-spectral resolution filter.

3. DETECTION OF AEROSOL PARAMETERS

Aerosol signal distribution was observed as a function of the altitude in the clear atmosphere with the UV-HSRL and the data are shown in Fig. 3. Laser shot averaging is 10^4 and the range resolution Δz [m] was set by the relation $\Delta z=10z^{1/2}$. Height distribution of the range corrected detector power is shown in Fig.3(a) and the corrected Rayligh and Mie scattering power is shown in Fig.3(b). Aerosol layer was observed below 4km altitude and the corrected Rayleigh power is attenuated by the aerosol layer. The aerosol extinction coefficient is shown in Fig.3(c) and the lidar ratio $S_1=\alpha_a/\beta_a$ is shown in Fig.3(d). The aerosol extinction coefficient α_a is derived



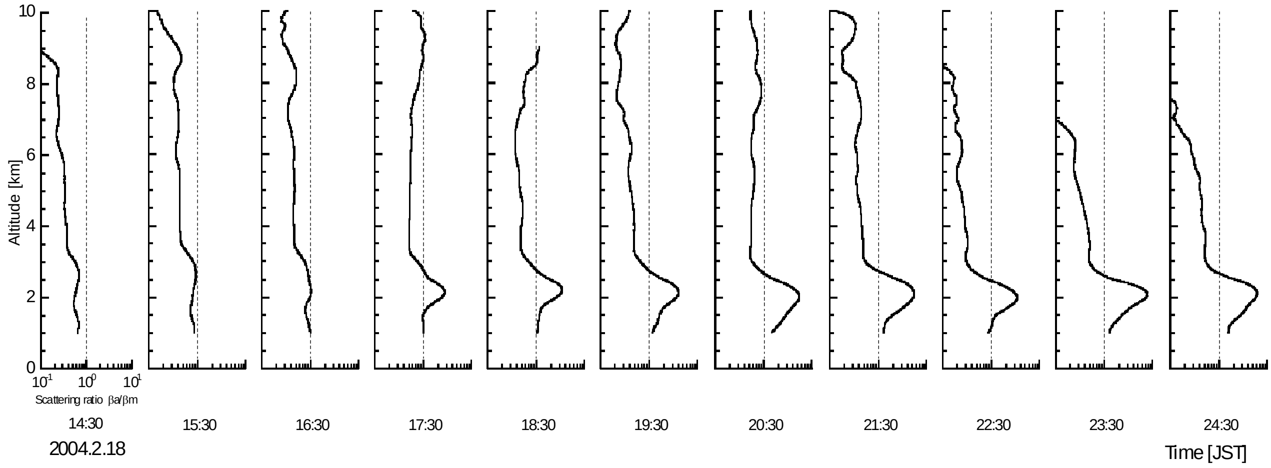
(a) Received power

(b) Corrected Mie and Rayelgih scattering power

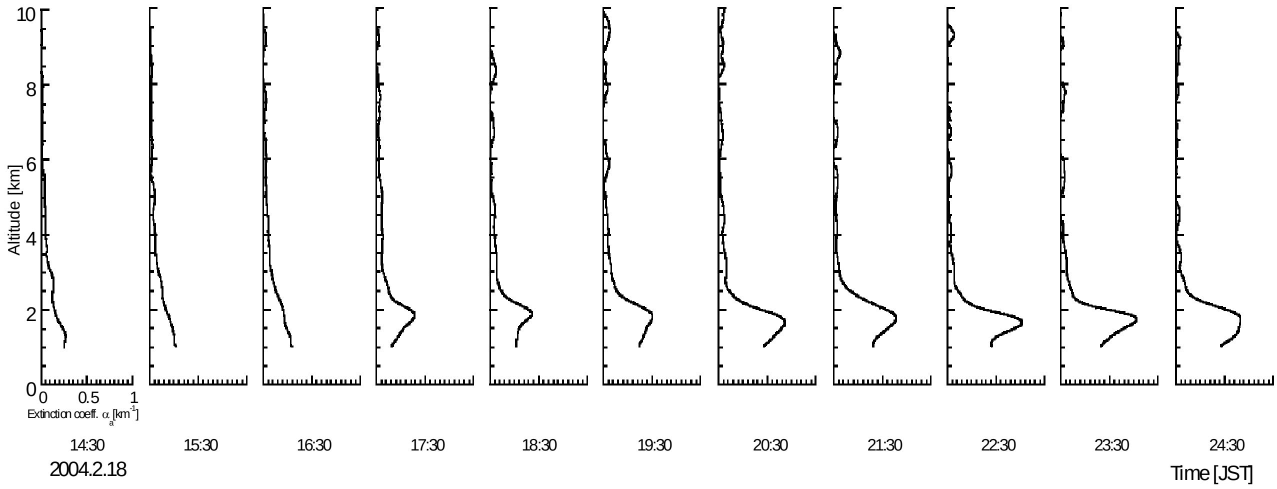
(c) Extinction coefficient

(d) Lidar ratio

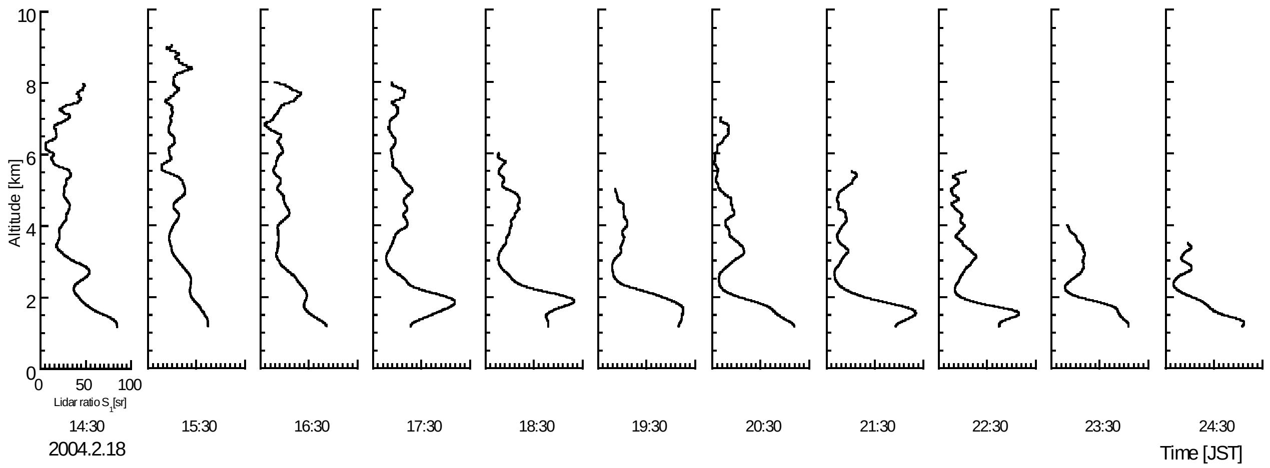
Fig. 3 Height distribution of aerosol signals. (a) is range corrected power of two detectors, (b) Rayligh and Mie backscattering power, (c) aerosol extinction coefficient and (d) lidar ratio.



(a) Scattering ratio: β_a/β_m



(b) Aerosol extinction coefficient: α_a



(c) Lidar ratio: $S_1=\alpha_a/\beta_a$

Fig. 4 Observation of the aerosol optical parameters using the UV-HSRL. (a) is the scattering ratio β_a/β_m, (b) the aerosol extinction coefficient α_a and (c) the lidar ratio $S_1=\alpha_a/\beta_a$.

from the profile of the corrected Rayleigh scattering power. The measurement accuracy of the extinction coefficient was 1.6 x 10^{-2}km^{-1} at 5km altitude. The lidar ratio $S_1=\alpha_a/\beta_a$ is derived from the scattering ratio β_a/β_m and the aerosol extinction coefficient α_a. Large value of the lidar ratio of 60 sr were observed in the lower aerosol layer and decreased to 20 sr in the upper layer. From this result, it is that larger size aerosol particles were dominated in the lower aerosol layer. The accuracy of the measurement of the lidar ratio was 3sr at 5km altitude.

Figure 4 shows indicated observation results during 10 hours. The data are, (a) scattering ratio β_a/β_m, (b) the aerosol extinction coefficient α_a, and (c) lidar ratio α_a/β_a. Starting at 17:30, dense aerosol layer was observed under 2km altitude. The extinction coefficient increased from 0.3km^{-1} to 0.8km^{-1}, due to an increase in the aerosol density, large value of the lidar ratio of 80 sr was observed from 17:30 to 24:30 at 2km altitude. By the Asian dust lidar network (AD-NET) [9], presence of the Asian dust was reported in Japan around this observation time. Therefore, the UV-HSRL observation data of Fig.4 may correspond to the Asian dust profiles.

4. CONCLUSION

The UV high-spectral-resolution lidar system has been developed for measuring aerosol optical parameters such as the aerosol extinction coefficient, the scattering ratio and the lidar ratio. Direct and absolute value measurements are possible without assuming typical aerosol profile. Like Klett's inversion technique used in the conventional single frequency Mie scattering lidar. In this system, a single Fabry-Perot filter was used as the high-spectral-resolution Mie scattering filter and high efficiency and simple filter system was realized.

In the experiment, the optical properties of the aerosol layer were obtained up to 9km altitude in the clear atmosphere. This system will be useful as a practical tool in meteorology with ground-based, air-borne and space-borne system.

REFERENCES

1. M. McGill, D. Hlavka, W. Hart, V. S. Scott, J. Spinhirne, B. Schmid, "Cloud Physics Lidar: instrument description and initial measurement results", App. Opt., **41**, 3725-3734 (2002)
2. S. T. Shipley, D. H. Tracy, E. W. Eloranta, J. T. Trauger, J. T. Sroga, F. L. Roesler, J. A. Weinman, "High spectral resolution lidar to measure optical scattering properties of atmospheric aerosols. 1: Theory and instrumentation", **22**, 3716-3724 (1983)
3. J. T. Trauger, E. W. Eloranta, S. T. Shipley, F. L. Roesler, P. J. Tryon, "High spectral resolution lidar to measure optical scattering properties of atmospheric aerosols. 2: Calibration and data analysis", **22**, 3725-3732 (1983)
4. J. W. Hair, L. M. Caldwell, D. A. Krueger and C. Y. She, "High-spectral-resolution lidar with iodine-vapor filters: measurement of atmospheric-state and aerosol profiles", App. Opt., **40**, 5280-5294 (2001)
5. T. Kobayashi, M. Imaki and K. Doukai, "UV scanning Doppler lidar for multiple detection of atmospheric parameters", Proceedings of 21st International Laser Radar Conference, Quebec, Canada, 837 – 840 (2002.7)
6. T. Kobayashi, M. Imaki and K. Doukai, "Feasibility study of UV high-spectral resolution lidars for atmospheric sensing", Proceedings of EarthCARE workshop, Tokyo, 47 - 51 (2002)
7. M. Imaki, D. Sun and T. Kobayashi, "Direct-detection Doppler lidar for two-dimensional wind field measurements of the troposphere", in Lidar Remote Sensing for Industry and Environment Monitoring III, Proc. SPIE 4893, Hangzhou, China, 303 - 310 (2002)
8. D. Hua, M. Uchida, M. Imaki and T. Kobayashi, "Development of practical UV Rayleigh lidar for measuring atmospheric temperature profiles in the troposphere", in Lidar Remote Sensing for Industry and Environment Monitoring III, Proc. SPIE 4893, Hangzhou, China, 488 - 495 (2002)
9. NIES, AD-NET lidar data exchange page, *http://info.nies.go.jp:8094/AsiaNet/*