Development of water vapor DIAL and comparison with Raman lidar

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Abstract: Vertical profile measurements of water vapor are important for improving early prediction accuracy of heavy rainfall. Developing a low-maintenance lidar is expected to establish an extensive lidar observation network to reduce water-related hazards such as torrential rains and floods. In this study, we developed a differential absorption lidar (DIAL) as a low-maintenance lidar. We continuously observed the vertical water vapor profiles with the DIAL and compared them with those of the collocated Raman lidar. The results of the two lidars were in good agreement.

1. Introduction

Water vapor plays an important role in atmospheric processes, and its distribution is related to clouds and precipitation. Therefore, water vapor is important in understanding localized extreme weather events such as torrential rains and floods. Information on water vapor distribution with high spatio-temporal resolution is beneficial for improving the accuracy of weather forecasting. We have developed a Raman lidar using a laser with a wavelength of 266 nm and the results indicated that the Raman lidar can measure water vapor with high accuracy and reliability [1,2]. On the other hand, low-maintenance lidars are expected to construct a more detailed observation network by installing multiple lidars. The differential absorption lidar (DIAL), which does not require radiosonde calibration, is one of the promising technologies [3]. In this study, we present the results of continuous observations of water vapor with our DIAL and compare them with our collocated Raman lidar.

2. Lidar setups

The developed DIAL system consisted of a transmitter, a telescope, and a receiver (Figure 1). Two semiconductor lasers with a wavelength of 829 nm were used as light sources, and pulsed lights of two wavelengths with different water vapor absorption cross sections were alternately irradiated into the atmosphere. A repetition rate was 10 kHz and the pulse energy was 2.5 µJ. The wavelengths of the two lasers were monitored by a wavelength meter and stabilized by feedback control. The scattered light received by a 40-cm-diameter Newtonian telescope was detected by an avalanche photodiode (APD) after passing through an interference filter and etalon. The water vapor mixing ratio (WVMR) was calculated using the altitude derivative of the two-wavelength scattering ratio and the water vapor absorption cross section obtained from the HITRAN database [4].

For the Raman lidar, the setup is the same as in [2] except for the laser and the telescope. A laser with a repetition rate of 20 Hz, and with a pulse energy of 9 mJ, and a telescope having a diameter of 25 cm were used. WVMR was obtained with radiosonde calibration.

Both lidar data were accumulated for 20 min and the vertical resolution was 150 m.

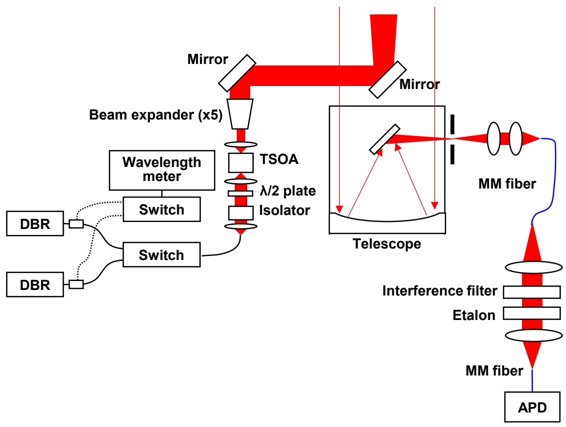

Figure 1. Schematic setup of DIAL. DBR: distributed Bragg reflector laser, TSOA: tapered semiconductor optical amplifier, APD: avalanche photodiode.

3. water vapor measurement results and comparison with Raman lidar

The two lidars were placed on the rooftop of the building of the EKO Instruments, Tokyo, Japan (35°40’N, 139°40’E, 50 m a.s.l.). Figure 2 shows the time-height series of the WVMR profiles with the DIAL and the Raman lidar for 1 week (29 Oct. - 6 Nov. 2023). Relative backscattered signals with the DIAL were also shown. Both lidars can observe WVMR up to an altitude of about 1.5-2 km. Except for low cloud altitudes, there is little difference between day and night for the Raman lidar, whereas the DIAL tends to relatively lower the measurable altitude around noon due to the solar background. The WVMR data from 300 m to 2,000 m and the same period in Figure 2 observed by the two lidars were compared in Figure 3. The correlation coefficient was 0.89 and the root mean square error was 0.88 g/kg, indicating that the WVMR obtained with the DIAL was in good agreement with that of the Raman lidar even though radiosonde calibration was not required.

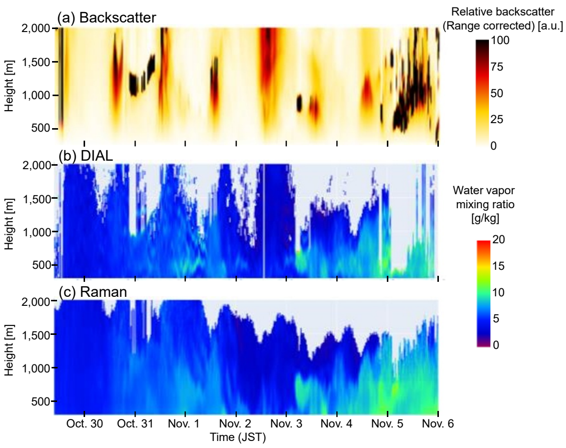

Figure 2 Time height series of (a) range corrected backscatter signals of DIAL, (b) WVMR obtained with DIAL, and (c) WVMR obtained with Raman lidar.

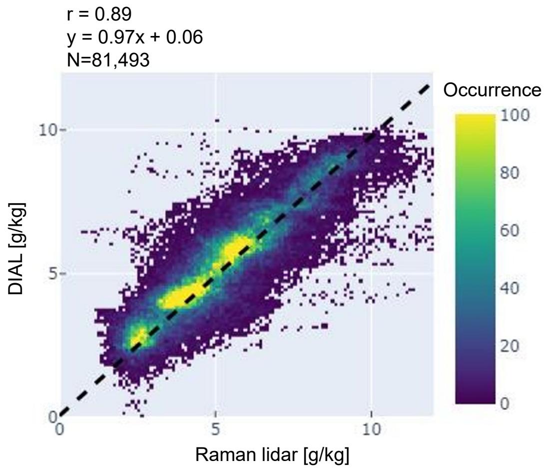

Figure 3 Two-dimensional histogram comparison of WVMR measurements with Raman lidar and DIAL. The dashed line shows the fitted line represented by the above equation.

4. Conclusions

We observed water vapor mixing ratio (WVMR) profiles with the DIAL and compared them with the Raman lidar. The DIAL data agreed well with that obtained with the Raman lidar. We continue to develop a more stable DIAL system.

5. References

[1] M. Yabuki, Y. Kawano, Y. Tottori, M. Tsukamoto, E. Takeuchi, T. Tsuda, A Raman lidar with a deep ultraviolet laser for continuous water vapor profiling in the atmospheric boundary layer. In *Proceedings of the EPJ Web of Conferences*, **237**, 03001 (2020).

[2] Y. Uchiho, K. Matsuki, E. Takeuchi, T. Hasegawa and M. Yabuki, Observation of Water Vapor Profiles by Raman Lidar with 266-nm Laser in Tokyo. In: Sullivan, J.T., et al. *Proceedings of the 30th International Laser Radar Conference, ILRC 2022*, Springer Atmospheric Sciences, Springer, Cham, pp. 373–378 (2023).

[3] S. Spuler, M. Hayman, R. Stillwell, J. Carnes, T. Bernatsky and K. Repasky, MicroPulse DIAL – a diode-laser-based lidar architecture for quantitative atmospheric profiling, Atmos. Meas. Tech., **14**, 4593-4616 (2021).

[4] I. Gordon, L. Rothman, C. Hill, R. Kochanov, Y. Tan, P. Bernath, … and E. Zak, The HITRAN2016 molecular spectroscopic database. J. Quant. Spectrosc. Radiat. Transf., **203**, 3-69 (2017).