Field-deployable diode-laser-based water vapor DIAL with modulated pulse technique: preliminary results

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***Abstract*—A diode-laser-based water vapor differential absorption lidar (DIAL) has been developed with modulated pulse technique. The laboratory prototype at Tokyo Metropolitan University was tested in nighttime June 22, 2015. The water vapor profile with 150 m range resolution agrees with the radiosonde data at Tateno station. The modulated pulse technique, applied for DIAL transmitter, enables both near-field and far-field water vapor measurements.**

I. INTRODUCTION

Water vapor is significant greenhouse gas which mostly exists in the planetary boundary layer, a bottom part of the troposphere. Spatial and temporal variations of the water vapor density contribute to the Earth's weather phenomena, circulation patterns, radiative transfer, and water cycle. Therefore, precise and high-resolution water vapor profiles are essential for weather forecast and climate study.

Traditional lidar systems including Raman lidar and injection-seeded Ti:sapphire-laser-based DIAL are able to monitor high-resolution water vapor continuously. However, these lidars require expensive instruments, high-cost operation, and powerful laser transmitter. Hence, a novel diode-laser-based lidar with the characteristics of eye-safety, low power, low cost, and compact is potential for water vapor measurements.

Currently, a series of field-deployable diode-laser-based water vapor DIALs have been developed by the researchers at Montana State University. The water vapor DIAL had been tested for continuous and autonomous long-period observation [1]. Based on this initial work, we aim at developing a water vapor DIAL for heavy rain prediction during the summer season in urban areas of Japan.

The water vapor DIAL uses a pair of lasers tuned on and off the gas absorption peak, referred as online and offline laser signal. The water vapor density is basically obtained from ratio of the return online and offline signals as well as the prior knowledge of absorption coefficients of water vapor at the online and offline wavelengths.

In addition, the modulated laser pulse technique is applied for both transmitted online and offline lasers. It utilizes a long macropulse instead of a single short pulse. Each single macropulse is modulated by an M-sequence in order to improve the range resolution.

II. WATER VAPOR DIAL INSTRUMENT

The diode-laser-based water vapor DIAL uses a pair of single-mode distributed Bragg reflector (DBR) diode lasers to seed a tapered semiconductor optical amplifier (TA), as shown in Fig. 1. The output laser beam of DBR is collimated by an aspheric lens and reshaped by an anamorphic prism pair (AP). Then laser beam passes a Faraday isolator to prevent feedback and a half-wave plate (λ/2) to align polarization. Afterward, the laser beam is coupled in a single-mode polarization maintaining fiber.

A solid-state high-speed fiber optical switch (SW) allows the transmitter rapidly alternate between online and offline laser. The output laser of SW passes through a half-wave plate, a Faraday isolator, and an aspheric lens before focusing into 4 mm long TA. The TA, driven by a pulsed current driver, is used to amplify the laser transmitter. The modulated pulse technique is achieved by directly modulating the driving current of TA. The output laser beam of TA is circularly shaped by spherical and cylindrical lenses. Finally, the laser beam is expanded for eye safety before transmitting to the air.

At the water vapor DIAL receiver, a 50 cm diameter Newtonian telescope collects the backscattering signal from the atmosphere. The photon-count number is accumulated and recorded by a photomultiplier tube (PMT) and a lidar transient recorder. The triggers of online and offline laser signals are synchronized using an arbitrary waveform generator and a digital delay generator.

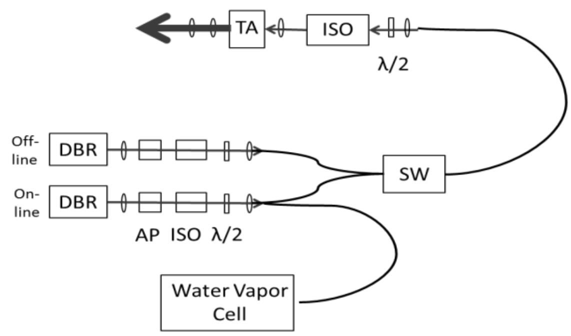

Figure 1. Block diagram of the DIAL transmitter.

III. OBSERVATIONAL TEST

The water vapor DIAL prototype was tested in nighttime June 22, 2015. The DIAL parameters for testing observation are described in Table 1. The HITRAN database of water vapor absorption line is used for computation. The DIAL operated a pair of wavelengths including the online wavelength of 829.054 nm and the offline wavelength of 829.124 nm.

The water vapor profiles with 150 m range resolution and 5 minute time resolution retrieved from continuous observation are plotted in Fig. 2. In addition, 1 hour average water vapor density is compared to the radiosonde data at Tateno station, as shown in Fig. 3. Although the radiosonde station is not at the right time and location of DIAL observation, there is a good agreement of two profiles.

Table 1. The water vapor DIAL parameters

Online wavelength	829.054 nm
Offline wavelength	829.124 nm
Pulse energy	0.7 μJ
Pulse width	1 μs
Repetition rate	10kHz
Optical efficiency of filter	50%
Quantum efficiency	10%
Telescope diameter	50 cm
Field of view	3 mrad

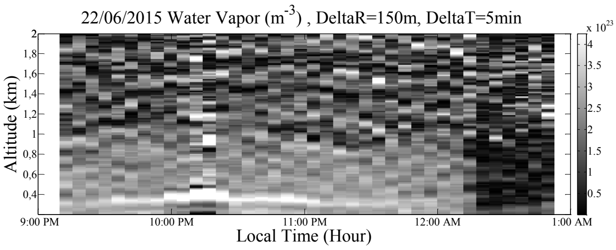

Figure 2. The water vapor profiles observed in nighttime June 22, 2015 with 150 m range resolution and 5 minute time resolution.

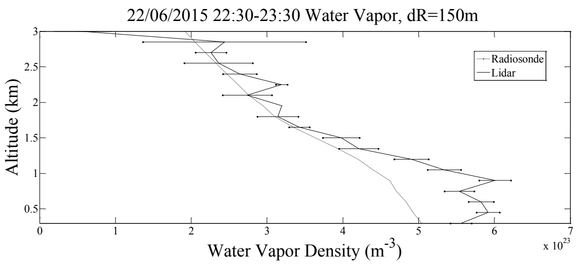

Figure 3. The 1 hour average water vapor density with 150 m range resolution and the radiosonde data.

IV. MODULATED PULSE TECHNIQUE

The concept of modulated pulse technique is illustrated in Fig. 4 [2]. Instead of single short pulse, a longer macropulse modulated by M-sequence is used. The modulated pulse technique and simulation results were described in previous work [3]. In this paper, we presented the observational test in nighttime June 25, 2015. The water vapor DIAL with 7-bit pulse modulation and 15-bit pulse modulation are compared to the single short pulse.

Figure 5 shows the photon-count numbers of the online signals after background subtraction and range correction with single pulse, 7-bit pulse modulation, and 15-bit pulse modulation. It is evident that 7-bit pulse modulation and 15-bit pulse modulation with higher pulse energy compared to single pulse are able to reach higher altitude. In future, we plan to make a long-period observation in order to compare water vapor profile of pulse-modulated DIAL with radiosonde profile.

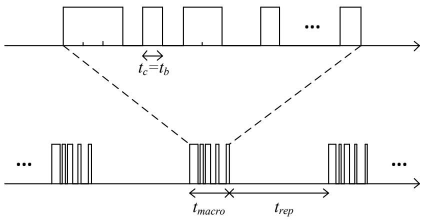

Figure 4. The concept of modulated pulse technique.

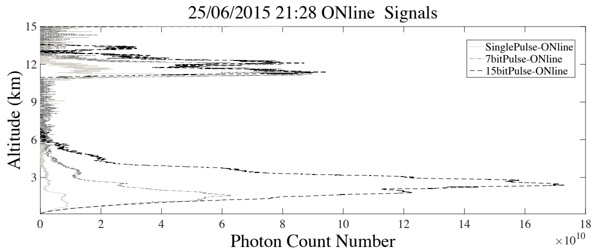

Figure 5. The photon-count numbers of the online signals with single pulse, 7-bit pulse modulation, and 15-bit pulse modulation.

V. CONCLUSIONS

In this research, we are developing a field-deployable diode-laser-based water vapor DIAL with modulated pulse technique. The nighttime observation was conducted to evaluated DIAL performance. As a result, the water vapor profile agrees with the referenced radiosonde profile. The modulated pulse technique shows potential results compared to short pulse technique. In future, we will apply modulation pulse technique and wavelength locking system as well as improve the TA efficiency for the DIAL transmitter.

ACKNOWLEDGEMENT

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