TOWARDS A MULTI-WAVELENGTH DEPOLARIZATION LIDAR USING A COHERENT WHITE LIGHT CONTINUUM

Toshihiro SOMEKAWA(1), Chihiro YAMANAKA(1), Masayuki FUJITA(2), Maria Cecillia GALVEZ(3)

(1)*Department of Earth and Space Science, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan, some@pumice.ess.sci.osaka-u.ac.jp*
(2)*Instiitute for Laser Technology, 2-6 Yamadaoka, Suita, Osaka 565-0871, Japan*
(3)*Physics Department, De La Salle University, 2401 Taft Avenue, Malate, Manila 1004, Philippines*

ABSTRACT

We propose a new method for the white light lidar by depolarization signals. The white light lidar system employs a coherent white light continuum whose wavelength ranges from the UV to the IR region as the light source and has a potentiality of simultaneous multi-wavelength measurements. In addition, the white light continuum showed the linear polarization similar to the original laser pulse. We carried out depolarization lidar at 450 nm for the first time using a coherent white light continuum. The obtained signals showed relatively high ratios as water droplet clouds. To confirm the wavelength dependence of the depolarization lidar signals, we developed the simultaneous multi-wavelength lidar system. The new lidar system consisted of three depolarization channels at 450, 550 and 800 nm. We evaluated the polarization properties of this 3-wavelength depolarization backscattering spectrometer and performed a preliminary field experiment for some targets at the distance of ~40 m from the receiving point.

1. INTRODUCTION

A high-intensity ultrashort pulse focused into a transparent medium generates a white light continuum ranging form the UV to the IR region. Fig. 1 shows the white light spectra generated in Kr gas as the nonlinear materials, as compared to the case in air. These white light continuum have spatial and frequency coherence and carry intensities over several kilometers and is utilized as an ideal light source for lidar [1] [2]. We developed and constructed the white light lidar system applied to several atmospheric species such as loess, pollen, methane and VOCs.

Recently, we showed that the generated white light continuum have a potentiality for multi-wavelength depolarization lidar measurements [3]. The depolarization ratios of backscattered white light were showed the relatively high ratios as the water clouds. This difference is probably caused by the forward scattering at the wavelength of the probe light [4]. Moreover, theoretical studies showed that particles with smaller dimensions compared with the wavelength of the LIDAR do not show depolarization even if they are nonshperical [5]. Therefore, simultaneous multi-wavelength depolarization measurements are required.

In this paper, we reported an example of the depolarization measurement using the white light lidar system and a new system designed to permit the simultaneous multi-wavelength depolarization measurements.

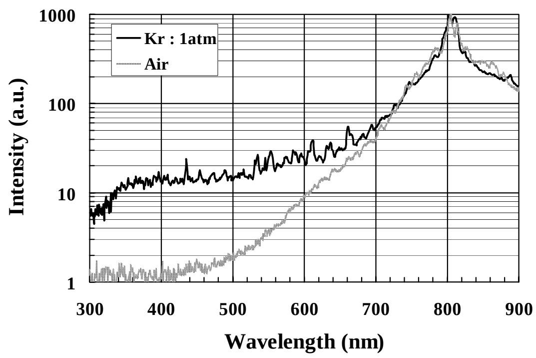


Fig. 1. White light spectra generated in atmospheric-pressure Kr and air. The laser wavelength and laser power are 800 nm and 1.0 TW, respectively.

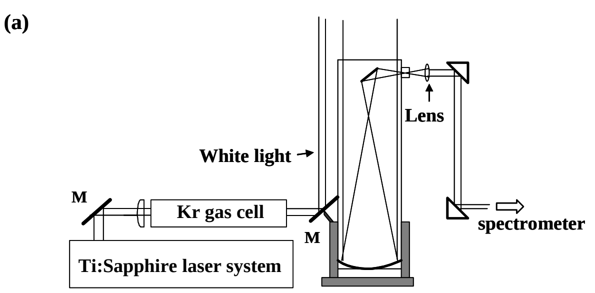
2. EXPERIMENT

Several experimental setups are shown schematically in Fig. 2. These experiments were performed using a Ti:sapphire chirped-pulse amplification (CPA) laser system. The femtosecond laser source is a combination of a Ti:sapphire oscillator pumped by a laser diode(LD)-pumped green Nd:YVO4 cw-laser and a regenerative amplifier pumped by a LD-pumped green Nd:YLF laser operated at 1 kHz. This beam is sent to a four-pass Ti:sapphire amplifier which is pumped by the second harmonic of two Nd:YAG lasers. The final output energy is about 100 mJ per pulse with a pulsewidth of 100 fs and a repetition rate of 10 Hz. This femtosecond terawatt laser pulse is focused by a lens with a focal length of 5 m into 9-m-long Kr gas cell and converted into the white light continuum which has a linear polarization similar to the original 800 nm. One of the principal reasons for choosing Kr gas is because Kr gas gives a higher intensity at visible region than air as shown in Fig. 1.

The setup of the white light lidar experiment is shown in Fig. 2a. The lidar system is in a biaxial configuration.

As shown in Fig. 2b, in order to measure the backscattered signals of the ground depolarization measurements at different wavelengths, we performed a preliminary field experiment for some targets at the distance up to ~40 m using the 450 nm depolarization channel. The receiver is formed by a Newtonian telescope (30 cm in diameter). In the focal plane of the telescope an iris was inserted in order to reduce the receiver's field of view. The output signals are collimated by a lens and introduced into 450 nm depolarization channels. We utilized a thick paper and water droplet (3~5μm) atomized by the supersonic humidifier as the target. The targets is put ~26-m away from the last sending mirror in the beam path. A paper was inserted perpendicularly in the beam path. The beam crossed a perpendicular water droplet. The white light continuum was blocked by the beam stop after ~40 m from the last mirror. The measurements have been performed by integrating 600 laser shots to reduce the pulse-to-pulse fluctuations of the white light.

Fig. 2c shows a 3-wavelength depolarization backscattering spectrometer. The beam separated into three wavelengths using dichroic mirrors and the interference filters with center wavelengths at 450, 550 and 800 nm, each has a 10-nm-bandwidth. After the interference filters the λ/2 plate and beamsplitter cube polarizers are placed. This detection unit is aligned by a He-Ne laser. Fig. 3 shows the polarization properties of the 3-wavelength depolarization backscattering spectrometer. The measurements have been performed by integrating 600 laser shots to reduce the pulse-to-pulse fluctuations of the white light. The solid curve gives the fitting curve by a sine relationship. This spectrometer was shown to have the potentiality of the simultaneous 3-wavelength depolarization measurement.



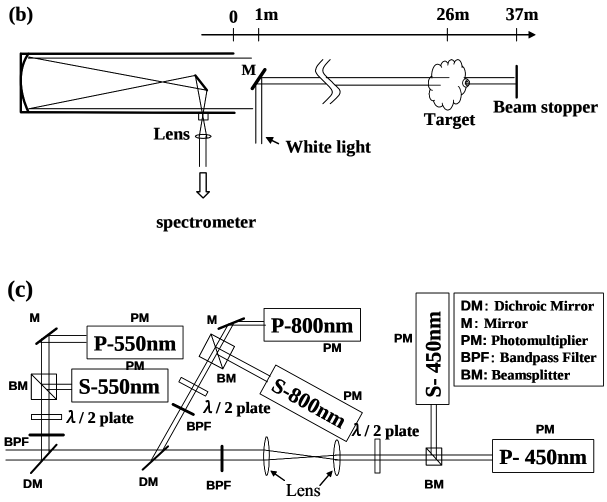


Fig. 2. Schematic diagrams of experimental setup; (a) lidar, (b) ground experiment, (c) the 3-wavelength depolarization backscattering spectrometer

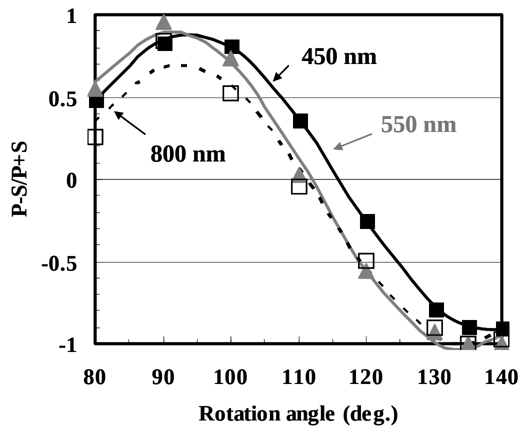


Fig. 3. Polarization properties of the 3-wavelength depolarization backscattering spectrometer

3. RESULT and DISCCUSION

Fig. 4 shows an example of 30-minutes period, range-squared corrected simultaneous backscattering profiles at 350, 450, 550, 700 and 800 nm wavelengths. Each output signal from the photomultipliers was accumulated using a digital oscilloscope triggered by a common pulse signal synchronizing to the laser emission at 10 Hz. The measurement was carried out on March 23, 2005 at 1:53~2:22 AM taking the average of 500 shots at 1 minute intervals on the condition that the P-polarization channel is at the maximum and the S-polarization channel is zero.

Backscattering peaks corresponding to 0.6 km and 1.0 km in height were caused by running clouds and observed in all channels. The linear depolarization ratio ($\delta = S/P$) is the ratio of the perpendicular signal (S-polarization) to the parallel signal (P-polarization). The observed value δ of in 1.0 and 0.6 km were, respectively, 0.58 and 0.63. These depolarization ratios are relatively high as compared as the water droplet clouds. This may be partially attributed to the wavelength effect on the forward scattering [4]. To provide an explanation of these high depolarization ratios, we need the multi-wavelength depolarization lidar measurements in order to evaluate the wavelength dependence.

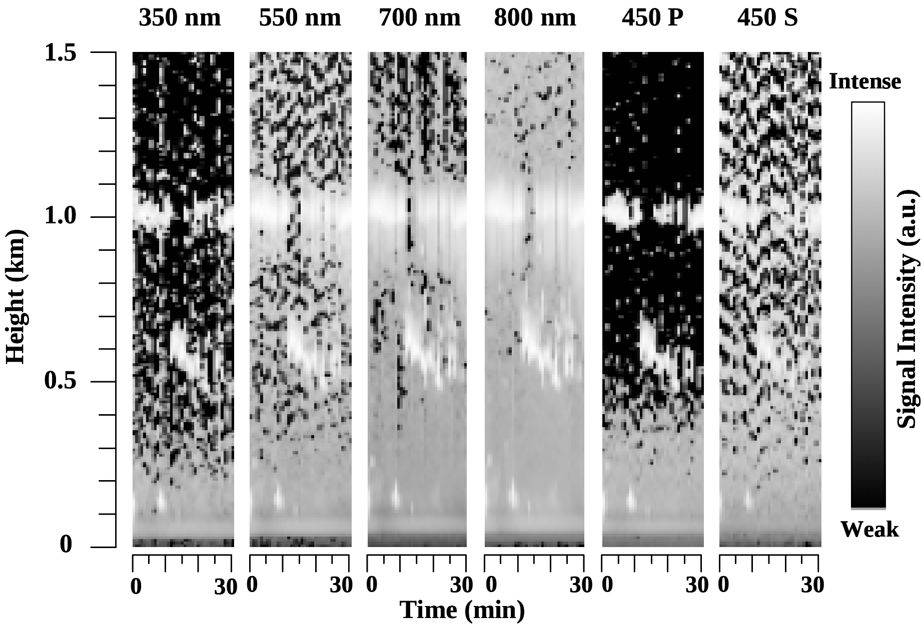


Fig. 4. Simultaneous measurements of the range squared corrected backscattered signal from atmosphere (2005/03/23 1:53~2:22 AM)

To verify the wavelength dependence of the depolarization ratio in lidar measurements, we constructed the 3-wavelength depolarization backscattering spectrometer and performed a preliminary field experiment. In Fig. 5, we present the typical single-shot polarization signals detected by PMT (Hamamatsu R6429, with 4-ns response time) through a lidar system when the rotation angle of the λ/2 plate is 80 degree and the target is the paper and the water droplet. The PMT is connected to a 1-GHz-bandwidth oscilloscope (Tektronix TDS 680B, 5-GHz-sampling rate) having a 50-Ω input impedance. In Fig. 5a and b, the first peak is due to the scattering from the paper and the water droplet, respectively, and the last peak is from the beam stopper. In the water droplet as the target, the detected signals are attributed to the backscattering from the droplets and the white light propagates almost unaffected by absorption by water droplets [6].

Fig. 6 shows the polarization ratio of the backscattered light from the water droplets and paper at 450 nm channel. The solid curve gives the fitting curve by a sine relationship. We observed the tendency to keep the linear polarization in the case of the water droplets as compared to the paper. This tendency is in agreement with the fact that the depolarization ratio is close to zero for spherical particles such as water droplets.

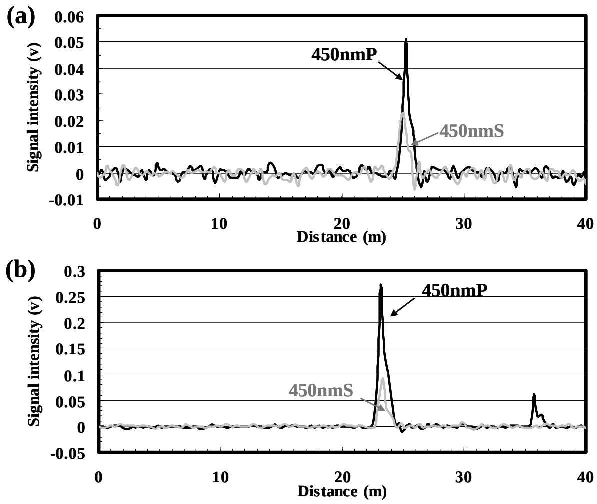


Fig. 5. Single-shot polarization signals from the paper (a) and the water droplet (b) at 450 nm depolarization channel

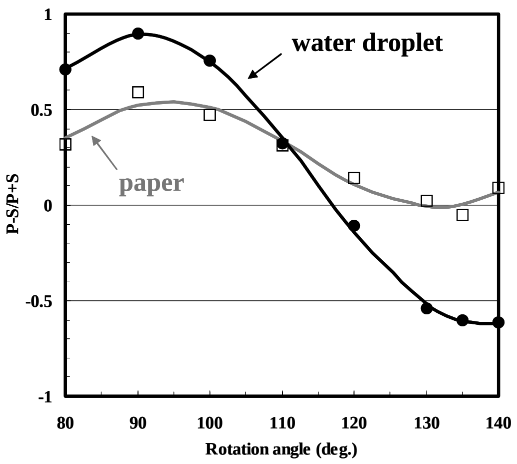


Fig. 6. Rotation angle dependence of the backscattered light from the water droplets and paper

4. SURMMARY

We have observed the depolarization lidar signals at 450 nm using the white light lidar system. The observed depolarization ratios were high as compared as the value of water droplet clouds. We consider these high ratios as the wavelength dependence of the forward scattering and developed the simultaneous multi-wavelength depolarization measurement system.

References

1. Kasparian J., et al. White-Light Filaments for Atmospheric Analysis, *Science*, Vol. 301, 61-64, 2003

2. Galvez M. C., et al. Three-Wavelength Backscatter Measurements of Clouds and Aerosols Using a White Light Lidar System, *Jpn. J. Appl. Phys*, Vol. 41, L284-L286, 2002

3. Somekawa T., et al. Depolarization Light Detection and Ranging Using a White Light Lidar System, *Jpn. J. Appl. Phys*, Vol. 45, L165-L168, 2006

4. Pal S. R. and Carswell A. I., Polarization properties of lidar scattering from clouds at 347 nm and 694 nm, *Appl. Opt*, Vol. 17, 2321, 1978

5. Mishchenko M. I. and Sassen K., Depolarization of lidar returns by small ice crystals: An application to contrails, *Geophys. Res. Lett*, Vol. 25, 309-312, 1998

6. Courvoisier F., et al. Ultraintense light filaments transmitted through clouds, *Appl. Phys. Lett*, Vol. 83, 213-215, 2003