DEPOLARIZATION STANDOFF LIDAR FOR DISCRIMINATION OF BIOLOGICAL WARFARE AEROSOLS

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ABSTRACT

A compact 523nm elastic lidar was built and used to measure depolarization ratios from bio-warfare agent (BWA) simulant and interferent aerosol cloud releases in a recent field test. Strong depolarization ratios were obtained for several of the simulants, while the interferents such as smoke gave very low depolarization ratios. Measurements of depolarization together with laser induced fluorescence can improve discrimination between BWA and non hazardous aerosols and reduce false alarms.

1. INTRODUCTION

An important need for defense and civilian agencies in the USA and all over the world is for remote detection and discrimination of BWA aerosols at sufficiently long standoff ranges of 1 to 5 km to provide adequate warning time for taking protective measures. We have developed a fluorescence lidar that has undergone numerous field tests and has established its capability to meet the US Department of Defense's requirements for detecting and discriminating bio-aerosol hazards. This lidar is based on commercial low power pulsed IR and UV lasers and utilizes a unique common transmitter-receiver optical configuration that makes its optical alignment robust and maintenance free. It is also made eye-safe by expanding the transmitted beam to the full aperture of the telescope. It employs photon counting detection for high sensitivity, and customized software to provide real time detection and discrimination. This lidar became the Joint Biological Standoff Detection System (JBSDS) for the Joint Program Executive Office (JPEO) for Chemical and Biological Defense (CBD) and is now in low rate initial production. The two main drawbacks of the fluorescence lidar are its tendency to false alarm on diesel and other hydrocarbon emissions and the severely reduced performance of the fluorescence channel when operating in bright daylight.

Measurement of the depolarization ratio of aerosols has been suggested as an alternative approach for discrimination between BWA and non-hazardous aerosols clouds. The effects of particle sphericity and non-sphericity on aerosol extinction, backscatter cross-sections, and backscatter depolarization were computed [1] and it was concluded that lidar depolarization measurements have the potential to discriminate between different types of aerosols. Depolarization ratios were measured from many simulant and interferent aerosol cloud releases in a field experiment using a 1.54 µm elastic scatter lidar [2]. Earlier depolarization measurements of BG (a spore bacterial simulant) were done with a 1.06µm lidar [3]. Although these depolarization measurements showed some potential for discrimination between the simulants and interferents, the results were not conclusive. We have developed a compact eye-safe lidar operating in the visible wavelength (523 nm) for providing precise depolarization measurements by utilizing photon counting detection and the common transmitter-receiver architecture.

An excellent opportunity for accurate depolarization measurement was provided in a recent (April 2006) field experiment sponsored by the JPEO CBD, wherein metered releases of numerous aerosol clouds of BWA simulants and interferents were made at Dugway Proving Grounds, Utah in a large ambient breeze tunnel and also in cross wind. Here a brief description of our depolarization lidar and the results obtained from these tests are presented.

2. SESI DEPOLARIZATION LIDAR

A two-channel elastic scatter depolarization lidar (optical layout is shown in Fig. 1) was built using an integrated transceiver architecture based on a 20 cm commercial Cassegrain Telescope with < 100 µ-radian field of view, and a home-built frequency doubled diode-pumped Nd-YLF laser at 523.5 nm, operating at 2 micro-joules per pulse at 2.5 KHz. Both receiver channels use single photon counting detectors (E G &G SPCM) coupled to multi channel scalers and a digital data system with

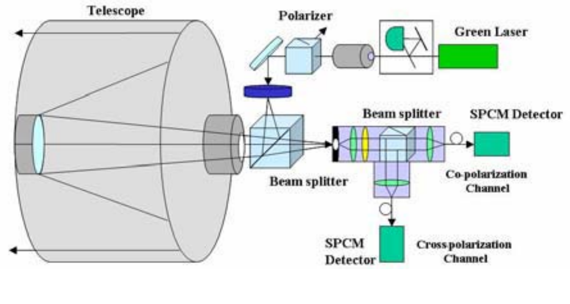

Fig. 1. Optical layout of the 523 nm depolarization lidar used in the experiments.

acquisition software modeled on our JBSDS system. Data was acquired with averaging over 2.5×10^3 to 2.5×10^4 profiles (1 or 10 sec averages). It is noted that photon counting detection enables accurate measurement of depolarization ratios over a large dynamic range of six to seven orders of magnitude, similar to that of our Micro Pulse Lidar and JBSDS systems. The transmitted beam is eye-safe for the un-aided human eye. Daylight operation was enabled by using a narrow (0.2 nm wide) bandpass filter and a narrow FOV for the receiver.

Fig. 2 shows a photograph of the lidar. It is mounted on a tripod to allow easy deployment and alignment to the target. It is provided with a motorized rotary stage to allow azimuthal scanning. Lidar elevation is manually controlled with a micrometer screw.

Fig. 2. Photograph of the depolarization lidar. It is equipped with a motorized azimuthal scanner and the whole assembly is mounted on a tripod.

3. SIMULANT & INTERFERENT AEROSOL DEPOLARIZATION RATIOS

Nearly 70 aerosol clouds – (about 40 in the ambient breeze tunnel and 30 in cross wind) were released during the two weeks of testing at Dugway with most of them occurring at night and a smaller number during daylight. The ambient breeze tunnel was equipped with calibrated aerodynamic particle samplers that sampled the aerosol release along the length of the cloud to provide an accurate measure of the number density of particles as a function of the particle size. Aerosol cloud concentrations ranged from very high (~80,000 ppl) to fairly low (~2000 ppl). At standoff ranges of approximately 1 km, our depolarization lidar was able to locate and measure all of the tunnel and crosswind releases both at night and in daylight.

We show the preliminary results from the analysis of several BWA simulant and interferent aerosol releases – wet and dry BG, EH and Killed YP, (a bacterial simulant and agent, respectively), MS2 (a viral simulant), OV (a toxin simulant), Diesel, Yellow and White Smoke (interferents). Fig. 3 shows range resolved lidar elastic return raw signal profiles for the two polarizations taken during a release of wet BG aerosol in the ambient breeze tunnel. Signals are given in units of photo-electron counts per microsecond.

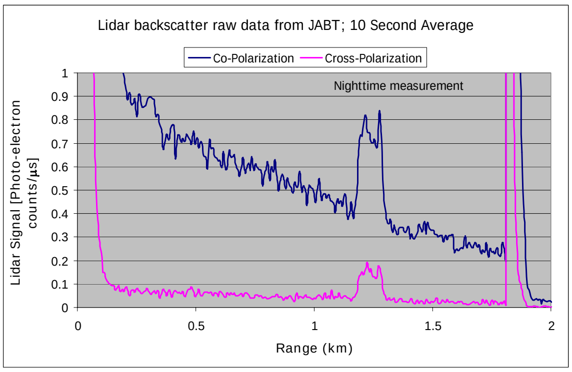

Fig. 3. Lidar signal in co- & cross-polarization channels from wet BG release (at 1.2 km range) in the ambient breeze tunnel. The strong peak at 1.8 km is from a beam stop (wall) at the back of tunnel.

Fig. 4 shows a time series plot of the depolarization ratio expressed as the ratio of cross to co-polarization signal taken for the range bin at 1.2 km in the middle of the aerosol cloud. The simulant release started at about 3:10:15 am continued up to 3:15:15 am.

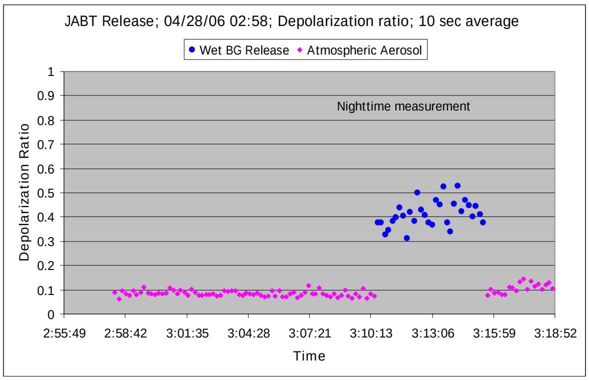

Fig. 4. Depolarization ratio for the stimulant Wet BG released from 3:10:15 to 3:15:15 in the joint ambient breeze tunnel (JABT). Note that the depolarization ratio for atmospheric aerosols is nearly constant.

The signal excess due to the aerosol release was computed by first locating the cloud in the lidar profile and then subtracting the background atmospheric aerosol contribution. The depolarization ratios shown before and after the release correspond to that of ambient atmospheric background aerosol present in the tunnel. It is seen that the depolarization ratio for the background atmospheric aerosol is nearly constant, whereas it varies more during the simulant release. This is perhaps due to variations in the sample, its concentration and the dissemination process itself. Although the depolarization ratio is itself not concentration dependent, secondary effects due to changes in concentration are seen, such as, particle agglomeration, stratification of larger and smaller particles, etc, that affect the result.

Fig. 5 shows the depolarization ratio obtained during a crosswind release of wet BG during daytime. A much higher variation of the depolarization ratio is seen for the cross wind release - caused by the dynamics of release

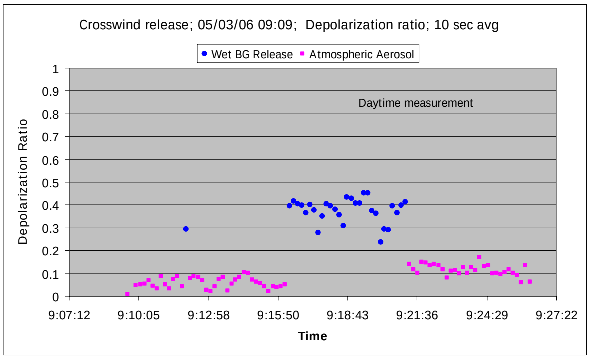

Fig. 5. Depolarization ratio for the stimulant Wet BG during daytime crosswind release from 9:15 to 9:21 am. Note that the crosswind depolarization ratio fluctuation is more than that for JABT release.

and dispersion in open air, in addition to the other variabilities listed above. The results can however be improved further by improved data processing such as increasing the averaging period, including a larger extent of the cloud in the analysis, and better quality control of the data. These depolarization ratios were fairly consistent through multiple trials in both day and night, inside the tunnel and outside in crosswind. We also found that the depolarization ratios were most consistent under steady-state conditions; e.g., in the middle portion of a constant rate of release.

We also examined the potential for maximum useful range in daylight. By taking atmospheric measurements at horizontal elevation, we obtained good signals at up to 10 km and signals from hard targets even at 23 km.

Fig. 6 summarizes the measurements from the test. Shown in the Fig. are the depolarization ratios for various simulants and interferents. Each data point shows the average of one complete release (such as the ones shown in Figs. 4 and 5). The standard deviations (error bars) of these depolarization ratios were estimated to be ± 20%. As mentioned earlier we expect to reduce the error by improvements in data processing by increasing the averaging time and including a larger extent of cloud for analysis.

4. DISCUSSIONS AND CONCLUSIONS

The data indicates that fairly large depolarization ratios are obtained for several bio-simulants such as BG and OV, while the depolarization ratios for several of the interferents are smaller. The depolarization ratios measured here for BG are much larger than those reported earlier [2] possibly because the wavelength they used (1.54 µm) was much longer than the one (523 nm) used here. Examination of our data shows that while the depolarization lidar alone cannot conclusively discriminate between BWA and non-hazardous aerosols the depolarization ratios can be used to provide additional "screening" to improve the discrimination achieved by fluorescence lidar. By combining depolarization measurements with the fluorescence lidar,

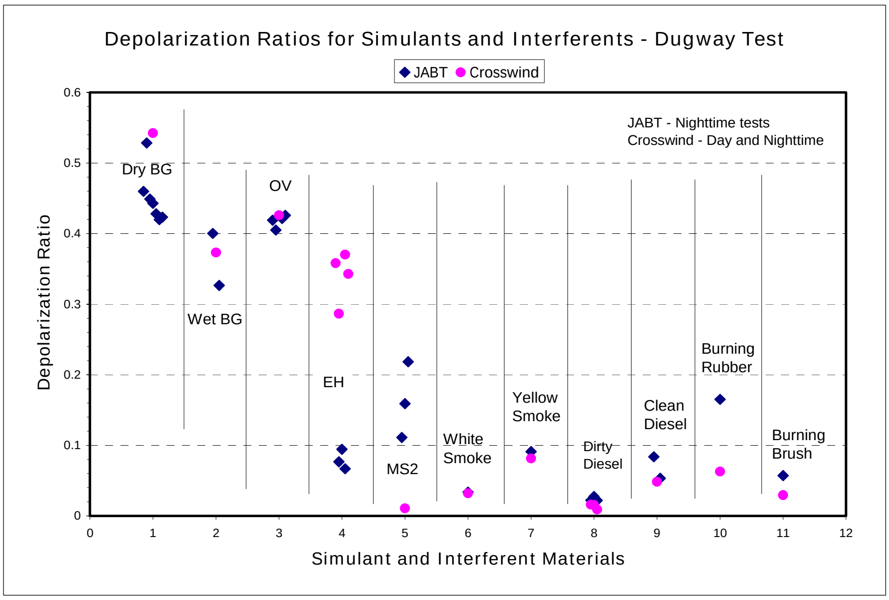

Fig. 6. Average depolarization ratios for simulants and interferents. Each data point is an average for one complete release. Depolarization ratios are nearly the same for both tunnel and crosswind releases except for EH and MS2.

enhanced discrimination and reduced false alarm rates are expected. Also, the depolarization lidar can operate effectively in daylight as demonstrated by our system which operated at 523nm.

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