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EXTENDED ABSTRACT

Aerosols are tiny particles in the atmosphere that originate from either natural or anthropogenic sources and play a strong role in Earth's radiation budget. However, distributions of atmospheric aerosols vary greatly both over time and location making it challenging for in-situ aerosol profiling. Knowledge of aerosol profiles (temporal and altitude dependent extinction) in various parts of the world is essential for air pollution compliance, climate change studies, precipitation pattern research, and investigations on the health effects. Traditional lidars, widely used optical remote sensing techniques, require expensive electronics to measure the time of flight of the backscattered light and its corresponding altitude.

A ground-based inexpensive portable remote sensing technique called CLidar (Barnes & Sharma, 2012; Sharma, Barnes, Kaplan & Clarke, 2011; Barnes, Sharma & Kaplan, 2007; Kabir, Sharma, Barnes & Butt, 2017) is utilized to profile aerosols in the atmosphere of The Bahamas. Measurements are performed at various seasons and at various key locations to monitor aerosol profiles. To better understand the aerosol optical properties measured by CLidar, radiosonde data (pressure, temperature, humidity, wind speed, dew point, etc.) obtained from Lynden Pindling International Airport (Nassau) observation are compared. Aerosols originated from a local source of pollution are expected to be efficiently detected using our CLidar which does not suffer overlap effect near ground level compared to the traditional lidar.

CLidar geometry is demonstrated in Figure1 (a). A portable laser of 532-nm CW laser (2W) was pointed vertically to transmit light in the atmosphere. A CCD camera fitted with a wide-angle lens is separated a distance D (52 m) away from the laser beam. Use of wide-angle lens (angle of view 154^0) allows imaging the entire beam from ground to zenith onto the CCD without the need for scanning. At the ground level the scattering angle θ is 90^0 and at the zenith it approaches to 180^0. Each pixel in the CCD image has a constant angular field of view, $d\theta$ (0.03^0/pixel), which results in a variable altitude resolution dz because of the different length of beam which enters CCD from different altitude z. R is the slant range from the scatterer to the camera. A laser line filter at 532-nm with 10-nm FWHM was used to reduce the background noise. A quarter waveplate was used to change linearly polarized laser light to

circularly polarized light. During the CCD camera image exposure time of several minutes, the circularly polarized light imitates unpolarized light to the particle scattering thus making the polarization angle unimportant and simplifying the analysis. Scattering altitude is determined simply from the geometry of the CLidar in contrast to monostatic lidar which requires expensive electronics to measure the time of flight of the returned signal. Figure 1 (b) shows a CCD image in the night sky of Nassau, Bahamas which was taken on 11 November 2016 at local time UT-2.5h. The camera was oriented to place the vertically pointing laser beam along the diagonal of the CCD chip. The ground with few buildings is visible at the lower left corner of the image. Currently the setup is limited to nighttime measurements only.

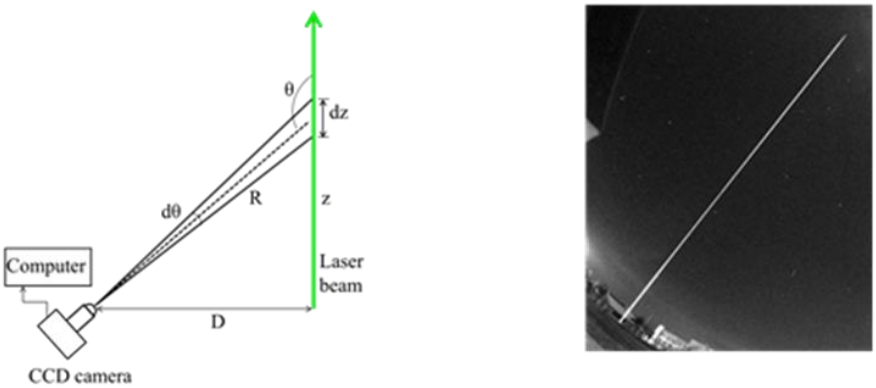

Figure 1. (a) CLidar setup. (b) CCD image of the laser light (image 2 in Figure 2a) in the night sky of Nassau, Bahamas.

The experiment was conducted at the playground of University of The Bahamas located about 2 km from the shoreline and at an altitude of a few meters from sea level. Nassau has a size of 210 km^2 and is situated in the Atlantic Ocean at 25.06 ^{0}N and -77.35 ^{0}W. The site is surrounded by several local roads with moderate traffic during the day. Images were taken on 11 November 2016 between local times UT-3h and UT-1.5h in a cloudless sky with nearly zero wind speed. A charcoal grill was on at a location ~90 m away from the laser beam during the first two exposures of the experiment. The smokes from the grill was passing over the laser path near ground levels producing sparkles in the laser beam. The CCD exposure time was 10 minutes for each image which contains both molecular and single angle aerosol scattering. A cloud free image is used to normalize the signal intensity to a model of molecular scattering at a region free of aerosol layer. Then, molecular portion is subtracted to retrieve single angle aerosol scattering. An aerosol phase function was assumed to convert single angle scatter to aerosol extinction. Corrections due to transmission effects are then iteratively calculated until convergence is reached.

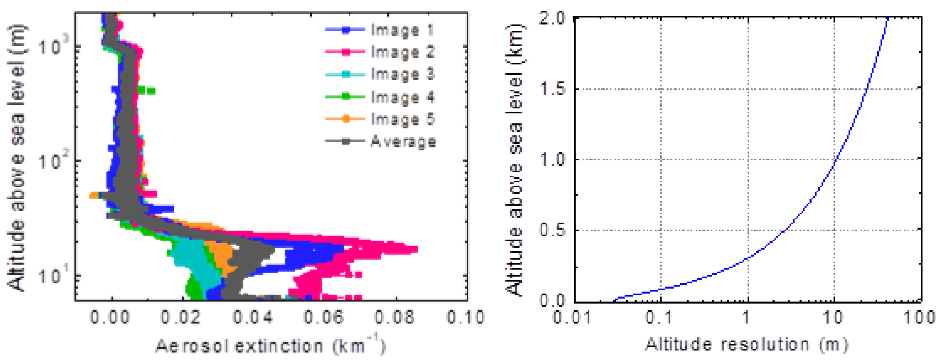

Figure 2. (a) Aerosol extinction at various times (image 1-5) and the average extinction during UT-3h to UT-1.5h in 11 November 2016. (b) Altitude resolution calculated using the CLidar geometry.

Figure 2 (a) demonstrates aerosol extinction at various times (image01-05) between UT-3h and UT-1.5h on 11 November 2016. Average aerosol extinction between UT-3h and UT-1.5h was calculated using all five images. Aerosol extinction is prominently higher in image 2 at 0-15m altitudes and moderately higher in image 1 at 10-15m altitudes compared to the extinctions at these altitudes for other images. Aerosol extinction at 20m above sea level is $0.085km^{-1}$ during grilling compared to $0.03km^{-1}$ during no grilling. The high aerosol extinctions in image 1 and 2 near ground levels are originated by smokes from the grill which was operating during these exposure times. Figure 2 (b) shows the CLidar altitude resolution as a function of altitude above sea level. The resolution is excellent at the ground levels (e.g., at 100m it is 0.1m) compared to the traditional lidar which suffers overlap effects at the ground levels. High altitude resolution of the CLidar utility will allow in the profiling of aerosols at the ground levels efficiently. Figure 2 (a) further shows that aerosol extinction becomes low at 40m altitude above the sea level. Extinction then increases gradually up to 0.9 km and then drops off sharply beyond this altitude. Extinction is close to zero above 1 km altitude indicating the top of atmospheric boundary layer beyond which aerosol concentration is very low. The drop-off of the relative humidity at this altitude obtained from radiosonde data of the Lynden Pindling International Airport observation by Station 78073 MYNN at UT-5h local time on 11 November 2016 (Barnes, Sharma & Kaplan, 2007) agrees well with our CLidar data (Zierger, Fierz-Schmidhauser, Gysel, Strom, Henne, Yttri, Baltensperger & Weigartner, 2010; Ansmann, Riebesell & Wadinger, 1992) indicating the capability of our setup in characterizing environments for in-situ aerosol sampling.

In conclusion, we have measured aerosol scattering profiles in The Bahamas using CLidar. High altitude resolution near ground levels allow the CLidar setup to profile aerosol extinction efficiently from a local source of pollution near ground levels compared to the traditional lidar which suffers overlap effects. We will take several measurements at various seasons and at various key locations using our portable CLidar. In the future, we plan to use two cameras to detect two mutually perpendicular polarization lights from a single laser source to measure aerosol intrinsic properties.

Keywords: *Optical remote sensing, Bistatic Camera Lidar (CLidar), Aerosol extinction, Wide-angle lens, Excellent altitude resolution*

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Dr. Kabir has been working as an Assistant Professor of Physics at University of The Bahamas (UB) since August 2013. He obtained his B.Sc. in Physics from the University of Dhaka, Bangladesh in 2001. He earned his M.Sc. in Physics in 2005 and Ph.D. in Physics in 2010 from the University of Cincinnati. He was awarded a University Graduate Scholarship (UGS) at the University of Cincinnati from 2003 to 2010.

His Ph.D. research work was focused on nonlinear optics and photonics in semiconductor nanostructures. During the Ph.D. programme he had an excellent opportunity to teach undergraduate recitation classes in cooperative learning formats. He was inspired by the effectiveness of these interactive teaching methods and became passionate in teaching Physics. He has been nominated by the Physics Department of the University of Cincinnati for the Excellence in Teaching Award in 2010.

After his Ph.D., Dr. Kabir worked as a postdoctoral researcher in the Terahertz spectroscopy group at the University of Alberta, Canada, from 2010 to 2012. He worked extensively on crude oil optical properties using Terahertz time domain spectroscopy in collaboration with the Schlumberger oil company in Alberta. In 2012, he joined Ultrafast spectroscopy group at McGill University as a postdoctoral fellow and worked on coherent multidimensional spectroscopy in nanostructure samples until he joined UB as an Assistant Professor in 2013.

Dr. Kabir has presented his research works in many international scientific conferences and published articles in high-impact scientific journals. He constantly works on the development of the Physics lecture and laboratory classes at UB. In collaboration with Central Connecticut State University and NOAA/ESRL/Global Monitoring Division, he has established an optical atmospheric research project (optical remote sensing) at UB to monitor aerosols (particulates), air pollution and climatology in The Bahamas. Dr. Kabir received a UB research grant for this project and an additional grant for students who work as research assistants under his supervision.