Measuring Aerosol and Cloud Vertical Structure using First Micro-Pulse Lidar System (MPL) in New York City

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Abstract: Micro pulse Lidar (MPL) is an eye-safe elastic backscatter Lidar, developed at NASA, deployed at a number of locations worldwide for autonomous aerosol and cloud monitoring required for Atmospheric studies and climate change investigations. This paper will report on the first polarization MPL system in New York City located at the City University of New York (40.74° N, 73.93° W). MPL operation, setup, data collection and correction will be introduced. Preliminary results and analysis of full time distribution for cloud vertical structure above NYC will be discussed. Applications of the MPL tow-polarization channels will be investigated. Potential future studies and collaborations in protecting NYC against environmental disasters by employing more devices along with MPL real-time data will be emphasized. For pedagogical purposes, an experimental module was developed to be implemented in the new Earth System Science and Environmental Engineering (ESE) track/curriculum. More details about the MPL module will be presented.

Keywords: MPL, Polarization, Aerosol, Pollution, Clouds, Traffic Density, LIC/NYC, Matlab, MPLNET

1. Introduction

Clouds are playing an important role to regulate and stabilize the hydrological circulation of the earth. Vertical structure of aerosol and cloud in the atmosphere, e.g. amounts of water and ice, cloud thickness and layers, cloud heights, etc., is a critical element for understanding the Earth’s climate, the vertical distributions of latent heat release [1], satellites measurements, ocean color investigations [2], and satellite data corrections [3]. Light Detection And Ranging (Lidar) system is a sophisticated remote sensing instrument which capable of providing vertical distribution of aerosol and cloud [4]. NASA Micro Pulse Lidar Network (MPLNET) is a network of MPL systems designed to measure aerosol and cloud vertical structure (CVS) continuously, day and night, over long time intervals required to climate change assessments and provide a field measurement validation for models and satellite sensors in the NASA Earth Observing System (EOS) [5]. Compared to the traditional Lidar systems, which have many disadvantages (e.g., not an eye safe, bulky, and expensive) [6], Micro pulse Lidar (MPL) is an eye-safe compact system (achieves the American National Standards Institute (ANSI) eye-safe standards), suitable for cruise deployments, capable of profiling aerosols and clouds autonomously by transmitting a fast pulse-repetition-frequency (2500 Hz, to maintain a good signal-to-noise ratio (SNR)) of low energy laser (6-10 µJ) into the atmosphere. The duration of the traveled signal, from transmitter to receiver telescope, is measured and converted to range and then corrected (R²). The returned signal, as a function of time, is proportional to the amount of light backscattered by atmospheric molecules (Rayleigh scattering), aerosols, and clouds [7]. In MPL, the received backscattering signals multiple scattering effects are absent and the MPL field-of-view (FOV) is small (less than 100 micro-rad) [4]. According to Sigma Space [8], the MPL has been employed successfully worldwide, more than 80 units are operating continuously, unattended for long-term investigations [9, 10].
As mentioned in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [11] recommended a routine ground-based collection of aerosol and cloud vertical structure for future earth observations. Furthermore, many studies investigate relationship between the traffic pollution and the damage in human brain and to analyze the effects of traffic pollution on the genome of a newborn and prematurity and preeclampsia issues [12].

In this study, one of the main goals is to investigate the cloud vertical structure (CVS) including discrimination between backscattered polarization states, cloud presence, cloud contents, and cloud layers vertical heights in NYC. Additionally, examining the rush hour pollution and boundary layer above NYC will be discussed.

2. Data Collection and Methodology

Located at the City University of New York (CUNY), LaGuardia site hosts a single wavelength (532 nm) dual-polarization Micro Pulse Lidar (LaGCC-MPL) instrument. The LaGCC-MPL measurements were preformed next a large highway network associated with heavy traffic most of the day (at Long Island City, Queens, New York City: 40.74° N, 73.93° W), as shown in Figure 1. LaGCC-MPL is equipped with two polarization channels [8].

Using the MPL dual-polarization package, one can discriminate between backscattered polarization states, e.g. water droplets and ice clouds. The MPL transmitted laser has a specific polarization state. The returned signal from spherical droplets will arrive with the same transmitted polarization (co-polarized channel), while asymmetrical ice and ash particles depolarize part of the backscatter signal (cross-polarized channel) [8]. LaGCC-MPL is capable to detect and displays both depolarized signals simultaneously. Data analysis was applied to data collected during the month of August 2015, which ranked as “above average” regionally since 1895 [13]. Data collected from the surface to ~25 km with 178 mm receiver diameter twice a day; in the morning and at night to address the rush hour pollution and boundary layer issues in NYC. The routine launch operations was schedules from 07:00 am to 12:00 pm, and from 05:00 pm to 09:00 pm EST.

3. Preliminary Results and Analysis

LaGCC-MPL has been adjusted to generate a profile every 30 seconds with a 30-meter range resolution. The following MPL snapshots of atmospheric aerosols and clouds real time profiles illustrate backscatter intensity versus range (altitude), \( R \), measured in km. These profiles show the difference between the water clouds and the ice clouds using the dual-polarization package in the MPL system in addition to the boundary layer. In figures 1 and 3, red and green traces are corresponding to co-polarized signal (returned by both spherical particles such as liquid spherical droplets (e.g. water clouds), and asymmetric particles such as ash and ice clouds), and cross-polarized backscatter signal (returned only by asymmetrical ice and/or ash particles). In figure 1, between 11.8 km and 12 km, the green peak corresponds to a thin aerosol or a cloud layer, while, at the same altitude, the red peak corresponds to asymmetric particles and/or thin ice cloud layer, i.e., this cloud layer contains both water droplets and ice crystals which is confirmed in the upper part of figure 2 (cross-polarized backscatter signal). Figure 2 represents the time sequence plot provides information on developing weather fronts above NYC by showing sequential and spatial trends in aerosol and cloud structure. The normalized relative backscatter (NRB) intensity is represented on a color scale. On the contrary, there are multiple thin water cloud layers between 2 km and 6 km on which appears in the left side of figure 1 and in the lower part of figure 2.
Figure 1. MPL real-time aerosol and cloud profiles taken over 30 min in Aug 18, 2015

The 30-second averaged profiles correspond to the time indicated at the red box (23:15 hr. in Aug. 17, 2015) on the left side of the time sequence plots (figure 4). The profiles show a thin water cloud (~300 meter) near 4 km. The MPL time sequence plot (figure 4) shows optically low clouds at night, indicated by high backscatter intensity near 3km around 23:15 hr. and a higher ice cloud layer at 5km between 22:30 and 22:45 hr. Aerosols and greenhouse gases, in particular CO$_2$, accumulate in the Planetary Boundary Layer (PBL) - the closest atmospheric layer to the Earth’s surface. Since the PBL is playing a major role in the exchange of heat, moisture, momentum, and atmospheric constituents between the surface and the free troposphere and helps in calculate top-down emissions estimates and to develop accurate Meteorological models [8], accurate and continuous measurements of PBL depth and monitoring the real-time vertical structure and dynamics of the NYC PBL are needed. Over the 4 hours of data collection, shown in figure 4, declining level of PBL form daytime (~4 km at 19:42 hr.) to nighttime (~3 km at 23:15 hr.) is observed as the falling yellow signal level from the right side of the plot to the left side, which is corresponding to NYC afternoon rush hour (3pm to ~7pm).

Figure 2. MPL real-time sequence data: temporal and spatial trends in aerosol and cloud structure taken over 30 min shown two polarization channels in Aug 18, 2015

Figure 3. MPL real-time aerosol and cloud profiles taken over 4 hours: in Aug 17, 2015

Figure 4. MPL real-time sequence data: temporal and spatial trends in aerosol and cloud structure taken over 4 hours shown two polarization channels: in Aug 17, 2015

4. MPL Lab Module and Future Work

A new MPL lab module was developed to be implemented in Systems Analysis of the Earth course, MAE217, which part of the Environmental Engineering (ESE) track at LaGCC. PreLab assignment, a short video, a PowerPint presentation, and a module instructions were developed. Module will be piloted in 2016/2017. Potential future studies and collaborations with NASA, MPLNET, and other agencies in protecting NYC against hurricanes, environmental disasters by employing more instruments (e.g., Sunphotometer) and operate the MPL autonomously for long-term data collection.
5. Conclusion

Located at the City University of New York, we operated the first dual-polarization Micro Pulse Lidar (LaGCC-MPL) instrument in NYC, for the first time in Aug 2015, to investigate the vertical structure of aerosol and cloud in the atmosphere (~25km). Preliminary results and analysis depicted the benefit of using a dual-polarization package (Co-Pol and Cross-Pol) to discriminate between spherical droplets and asymmetrical ice clouds and/or ash particles in an active urban area surrounded by a major-highway network in NYC. MPL real-time temporal and spatial trends in aerosol and cloud structure showed the rising level of PBL depth in NYC during the rush hour and descends at the nighttime. Several cases of different cloud types were discussed. A new MPL lab module was developed to be implemented in Systems Analysis of the Earth course, MAE 217, in 2016/2017 academic year at CUNY.

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6. References