EPJ Web of Conferences **119**, 06001 (2016) DOI: 10.1051/epjconf/201611906001
ILRC 27

IMPLEMENTATION OF MICROPULSE LIDAR AT 4.5 µM AND 1.5 µM FOR AEROSOL AND CLOUD STUDY

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ABSTRACT

Identifying and quantifying ambient aerosols and their interactions with clouds are important for air-quality and climate studies. Advances in infrared technologies on fiber lasers, quantum cascade lasers and IR detectors have made developing micro-pulse (low energy) IR lidar systems operating in the infrared spectral range feasible. We present in this contribution a micropulse dual channel (IR wavelength) lidar system for studying aerosol and cloud optical properties. The system operates at 1.545 µm (6472.5 cm-1) and at 4.55 µm (2197.8 cm-1) with high repetition rates and microjoule pulses. The system is intended to be coupled with an existing UV, visible, near infrared lidar system at the city college of New York, part of the CREST lidar network Preliminary backscattered signals from this system are here presented and compared to SNR simulation.

1. INTRODUCTION

The study of aerosols is important in order to better understand the effects on health and climate. PM2.5 aerosols have been linked to health issues including lung cancer [1], and cardiopulmonary syndromes which can lead to mortality [2]. Recent studies [3] show that particle matter suspended in air is responsible for 370,000 premature deaths every year in Europe. In addition, atmospheric aerosols play a key role in the Earth's atmosphere radiative balance both directly, by light extinction, and indirectly, through complex processes, with cloud formations for example, involving physical and chemical properties of aerosols [4]. However, their contribution to the Earth's radiative budget is still subject to large uncertainties [5] and in need of further studies.

In this context, the lidar is a very efficient tool to remotely provide range-resolved measurements of the optical properties of aerosols, such as absorption and scattering [6]. Advances in technologies, such as IR fiber lasers, Quantum Cascade (QC) lasers and improvement in IR light detector sensibility and operating temperatures, make new IR lidar systems possible for research and development. These innovations make way for building a low energy IR lidar that is compact, lightweight and runs at room temperature. Despite being of much less energy as typical YAG:Nd based lidars, these lasers offer much higher repetition rates making aerosol or cloud backscattering measurements possible with sufficient SNR.

This project outlines the design of a two channel micropulse IR backscatter lidar system and presents results obtained using this lidar to study aerosol and cloud base observations. This IR system adds two additional channels to the NOAA CREST Center lidar facility at the Optical Remote Sensing Lab at CCNY which currently runs at 3 elastic channels; 1064 nm, 532 nm and 355 nm and 2 Raman channels [7]. Larger spectral coverage can improve the separation of fine and coarse aerosols, as well as advance our knowledge of aerosol and cloud interactions.

2. METHODOLOGY

The system runs with two channels at wavelengths of 1.545 µm (6472.5 cm-1) and at 4.55 µm (2197.8 cm-1). The 1.545 µm laser source is a 20 kHz Keopsys fiber laser with a peak power of 4 kW and pulse width of 7 ns (30 µJ/pulse). The laser source for the 4.55 µm channel is a 100 kHz Pranalytica Inc. QC laser which can deliver a peak power of 4.5 watts with a pulse width of 202 ns (0.9 µJ/pulse). Quantum-Cascade lasers offer several Watts of pulsed peak optical power, while retaining a good far field pattern as required for laser remote sensing techniques in atmospheric research. Mid-IR QC lasers produce pulsed signal at room temperature and are compact in size.

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The receiver consists of an f/3 10" primary mirror with a focal length of 762 mm focusing on a Vigo PVI-4TE-5 detector for the 4.55 µm channel and a Thorlabs APD110C for the 1.545 µm channel.

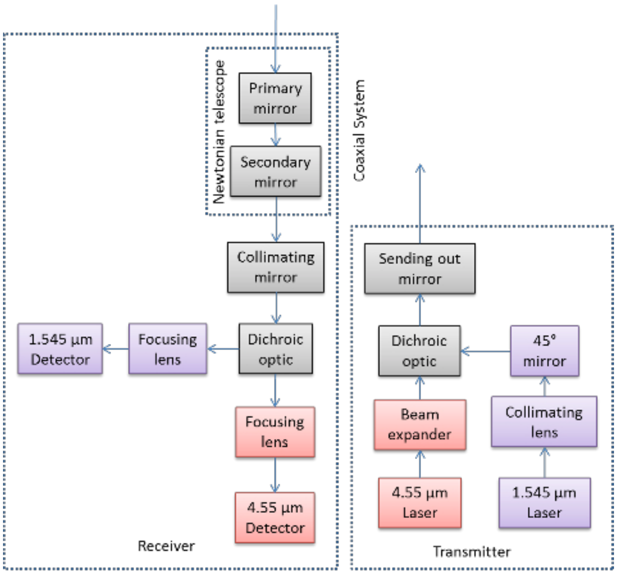

Figure 1: System Design

The signal is then recorded by a 16 bit Gage digitizer with an onboard FPGA card for a maximum of 1024 hardware averages. This acquisition system has a maximum sampling rate of 200 MS/s.

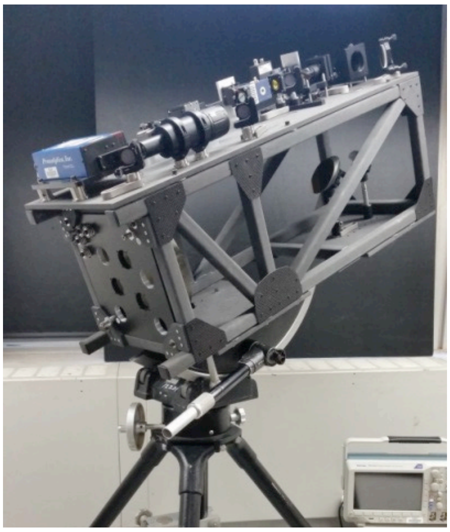

Figure 2: IR lidar

The dual channel IR lidar was designed to be light and compact, weighing less than 30 lbs; therefore making it portable. The lidar structure has a carbon fiber frame making it ideal for transporting and running in outdoor conditions.

3. RESULTS

At 1.545 µm, backscattered aerosol signal was collected on a clear day with the lidar pointing at a slant angle of 30° from horizontal within the planetary boundary layer. Figure 3 shows the processed aerosol data as a function of range. Pulses were averaged in the time domain for approximately 15 minutes or 15 x 10^6 pulses, and then averaged over 30 m in the spatial domain to further improve the SNR. Results show a good agreement between the simulated and measured SNR (assuming a reasonable aerosol backscattering coefficient of 10^{-7} $m^{-1}.sr^{-1}$).

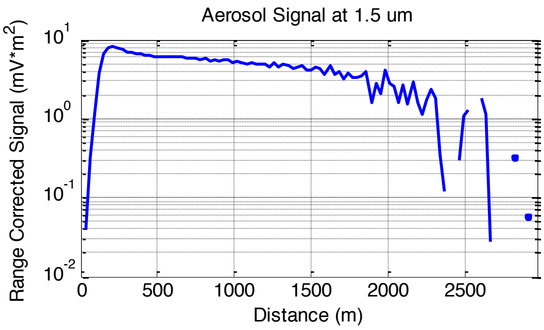

Fig. 3: Aerosol backscattered signal from the 1.5 µm wavelength channel

At 4.55 µm, backscattered cloud signal was collected with the lidar also pointing at an angle of 30°. Pulses were averaged in the time domain with a 60 second time resolution and then averaged in the spatial domain with a resolution of 36 m. Figure 4 displays the cloud peak at approximately 900 m. As for the 1.5 µm channel, a simulation of the SNR was implemented for comparison using the backscattering coefficient of 2 x 10^{-4} $m^{-1}.sr^{-1}$ retrieved from a ceilometer. At 900 m distance the simulated SNR is ~500 and the SNR from the collected run is 270.

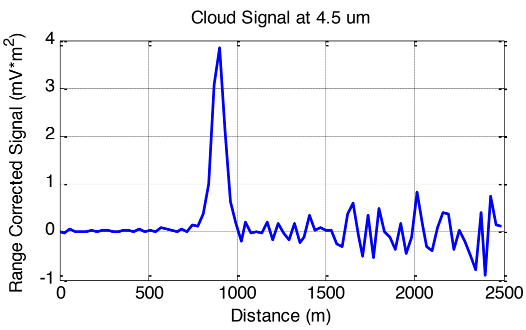

Fig. 4: Cloud backscattered signal from the 4.5 µm wavelength channel

4. CONCLUSIONS

We present in this contribution a micropulse dual channel infrared lidar operating at 1.545 µm (fiber laser) and at 4.55 µm (quantum cascade laser). The two lasers have low energy (resp. 30 µJ and 0.9 µJ) with high repetition rate (resp. 20 kHz and 100 kHz). Results showing aerosol backscattering as well as cloud backscattered signal are presented showing that these laser types can be suitable for atmospheric study in the infrared spectral range. The signal to noise ratio obtained on measured signals is in good agreement with the simulated SNR. The system is planned to be implemented with an existing Raman-Mie lidar operating in the UV, visible and near infrared wavelength for further studies on urban aerosols as well as cloud base dynamic.

ACKNOWLEDGEMENT

This study was supported by National Oceanic and Atmospheric Administration (NOAA) under the NOAA CREST Grant # NA11SEC4810004. *The statements, findings, conclusions, and recommendations presented in this manuscript are those of the authors and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.* This research was also supported by the Mid Infrared technologies for Health and the Environment (MIRTHE) Center and the National Science Foundation (NSF) under grant # EEC-0540832.

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