High Pulse Repetition Rate, Eye Safe, Visible Wavelength Lidar Systems: Design, Results and Potential

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***Abstract*-In In 1993 the first of the eye safe visible wavelength lidar systems known now as Micro Pulse Lidar (MPL) became operational. Since that time there have been several dozen of these systems produced and applied for full time profiling of atmospheric cloud and aerosol structure. There is currently an observational network of MPL sites to support global climate research. In the course of application of these instruments there have been significant improvements in understanding, design and performance of the systems. There are addition potential and applications beyond current practice for the high repetition rate, eye safe designs. The MPL network and the current capability, design and future potential of MPL systems are described.**

I. INTRODUCTION

In the early nineties the lead author and others developed a lidar design we called micro pulse lidar (MPL)[1]. The important advance of the design was a system that, unlike most early lidar, operated at eye safe energy densities and could thus operate unattended for full time monitoring. The initial, primary application was aerosol and cloud profiling related to climate research. Even the first system could routinely profile all radiatively significant clouds and aerosol in the atmosphere. In the last decade there has been extensive application and technical development of MPL systems. In this paper we review progress.

II. .DESIGN BASICS

The two primary design considerations for MPL systems are eye safe energy densities and adequate daytime performance. Eye safety is achieved by low energy pulses that are spread to the full aperture of a transmitting telescope. The bias and noise associated with solar background radiation could overwhelm the small signals from low energy pulses, and the background must be minimized by a very small receiver FOV and optical bandwidth. The optical bandwidth is constrained by the bandwidth of the outgoing laser pulse. The effective limitation on the FOV is the system overlap distance, where the laser pulse is fully focused at the detector, and is a function of the transmit and receive FOV and their maximum aperture separation. The small FOV requirement drives the requirement for using a single telescope for transmit and receive in MPL systems, both to limit the overlap distance and because of mechanical alignment requirements. Additionally the overlap distance limits the practical aperture size. Thus to obtain adequate signals, there is large advantage to use of highly efficient detectors and the highest possible pulse repetition rate. The detectors that have been used for all of our MPL systems are silicon GAPD photon counting modules with a 70% detection probability at the 523 nm ND:YLF II laser wavelength. Typical parameters for our existing MPL systems are listed in Table 1. The separation of the transmit and receiver optical paths in existing systems is done through a passive polarization based optical design [2].

III. CURRENT INSTRUMENT APPLICATION

The first experimental application of MPL systems was in 1993 for atmospheric cloud and aerosol field studies. The initial program utilizing MPL's at full time sites was the DOE Atmospheric Radiation Measurement program [3]. By 1997 there were MPL systems operating at four DOE sites including two in the tropical Pacific region and one near Barrow, Alaska. In the last two years NASA has started a program to add additional sites for a globally distributed network of full time lidar sites employing MPL instruments. With the DOE sites, there are currently eight sites with operational MPL instruments as part of the network and approximately four more are planned. Each of the sites has a unique research focus. An example of the MPL instrument installation at the South Pole station for polar cloud studies is shown in Fig. 1. In addition to the full time MPL sites, the instruments have been used by a number of groups for atmospheric and other field studies [4]. The most significant use of the network is satellite data support, in particular the GLAS lidar [5].

Table 1 Typical Instrument Parameters

Laser	10 µJ, 2500 Hz at 523 nm Nd:YLF
Telescope	20 cm cassegrain
Beam width	Receiver – 100 µrad, Trans. – 50 µrad
Optical filtering	0.12 nm with 35% trans. Int. Filter
Cross talk	10^{-7} polarization t/r rejection
Detector	Silicon GAPD photon counting
Detection sampling	30 m vertical, 30 sec. average

Figure 1 MPL instrument with sidewall mirror scanner installation at the South Pole atmospheric research observatory**.**

In addition to the instruments, a major part of the MPL-net project and other applications is data processing. The processing involves both instrument corrections and derivation of standard data products. Instrument corrections include the overlap function in the near range, typically up to 4 km, and some detector non-linearities. Data are processed automatically for cloud and aerosol properties. The most recent discussion of the methods and results are given by Campbell, et al. [3]. The most significant application

Over the course of application of the MPL instruments there has been a steady improvement in the performance and practicality of the systems. The earliest system operated for several years without significant problems. Subsequently as more systems were deployed, some reliability and data

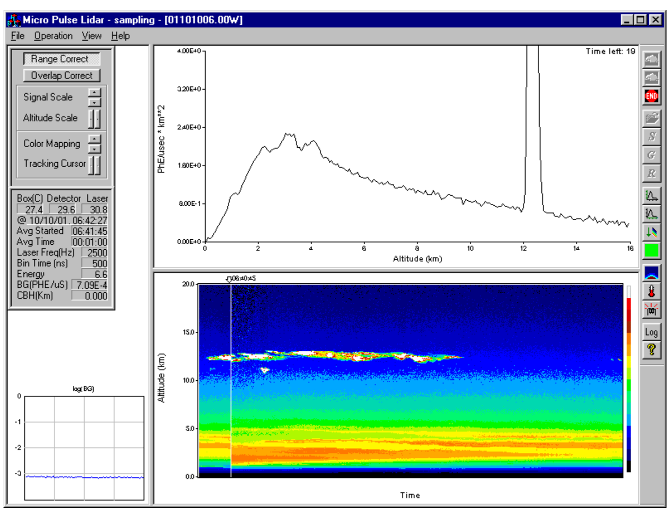

Figure 2 Data from a recent MPL with fiber coupled optics. The standard instrumentation display screen shows a single range corrected signal and the lower panel a six hour signal intensity display. The data here is not overlap corrected.

quality problems arose. The primary problem was failure of the GAPD detector, and an associated problem was maintaining optical alignments. Field replacement of detectors, with out an accurate collimator alignment as available in our lab facility, were not sufficiently accurate. The reliability of the output power of the diode pumped lasers used in MPL systems is also a maintenance problem. In order to correct these limitations, an improved optical approach for the MPL system was recently developed. The GAPD detectors are now fiber coupled for easy field replacement and a more reliable and higher performance laser can be used. The initial experience with these systems is significant improvement in data quality and reliability. A display data example from a fiber coupled system is shown in Fig. 2. Extensive data, results and more information can be found at our web site [6]

IV. FUTHER POTENTIAL

The current MPL systems in use are all single wavelength systems designed for cloud and aerosol applications. For the cloud and aerosol applications, both lidar depolarization and multi wavelength measurements have significant applications. These can be accomplished with the MPL approach, but the best optical design has been determined to be aperture splitting of the transmit and received paths, rather than the current polarization splitting. An optimal design will use the central 2/3 rd of the aperture for the transmit path and the other 1/3 for the receiver path. Multiple polarization and wavelength channels can then be accommodated without excessive cross talk. The aperture approach was not used for the original single wavelength MPL's due to greater complexity and cost. Beyond cloud and aerosol research, lidar for humidity and other measurements can be developed with the eye safe MPL approach.

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