INITIAL RESULTS FROM A VOLUME SCANNING THREE WAVELENGTH POLARIZATION LIDAR

M. D. O'Brien, G. R. Evanisko, C. R. Philbrick
The Pennsylvania State University, Department of Electrical Engineering
University Park, PA USA

Introduction

Clouds and aerosols play an important role in the radiative processes affecting the Earth's climate and the thermodynamic properties of the atmosphere [1]. Therefore, it is crucial to gain greater insight into the structure and composition of clouds and aerosols. One approach to achieving this consists of employing several different remote sensing systems operating at multiple wavelengths. At Penn State, an interdisciplinary group of researchers following this approach has developed a new research tool called WAVE-LARS (Water Aerosol Vapor Experiment - Lidar And Radar Sounder). This instrument includes a volume scanning 94 GHz radar, a volume scanning multi-wavelength lidar, and a vertically pointing Rayleigh/Raman lidar. The 94 GHz radar was based on a previous radar constructed at Penn State, augmented with new volume scanning and polarization capabilities [2]. The new radar is capable of determining cloud structure, liquid water content, and the presence of ice crystals within a selected volume of the atmosphere. The vertically pointing lidar is the Penn State LAMP Rayleigh/Raman lidar system. This system provides vertical profiles of atmospheric water vapor and temperature [3]. The theory, design, and initial results from the volume scanning lidar will be discussed in this paper [4].

Theory

The objectives of the volume scanning lidar are to characterize aerosols, and profile cloud structure and phase. Characterization of aerosol sizes can be achieved by monitoring the relative strength of the backscattered light at multiple frequencies [5]. Cloud structure, such as thickness and altitude, is determined from the lidar profiles. The cloud phase is inferred through measurement of the lidar depolarization ratio. The depolarization ratio is defined by,

$$\delta = \frac{P_{\perp}}{P_{\parallel}} ,$$

where $P_{\perp}$ is the power returned in the perpendicular direction and $P_{\parallel}$ is the power returned in the parallel direction, both with respect to the incident linearly polarized light. The depolarization of the transmitted signal can be caused by anisotropic particles, such as ice crystals, and by multiple scattering. Consequently, this ratio can provide a determination of the ice/water phase in clouds, under some circumstances [6], [7]. The volume scanning lidar also includes a Raman nitrogen channel which provides a measure of optical extinction for calibration purposes [8].

Design

The volume scanning lidar is housed in a standard shipping container which functions as a rugged field laboratory. A block diagram of the five subsystems of the scanning lidar is shown in Figure 1. These subsystems include the transmitter, receiver, detector, data acquisition, and safety systems.

The transmitter section consists of a laser, a beam expander, beam steering devices, and an energy monitor. The laser is a Continuum Surelite II-20 Nd:YAG laser operating at 20 Hz and transmitting at 355, 532, and 1064 nm. The laser is triggered by the data subsystem to coordinate data acquisition and the laser pulsing. A six power off-axis reflective beam expander is utilized to decrease the beam divergence and power density. A computer controlled beam steering mirror is used to center the beam in the field of view of the telescope by searching for a maximum return at a particular altitude. An energy monitor has been constructed to record the laser pulse energy.

The receiver consists of a 16 inch Ritchey-Chretien Cassegrain telescope and a polarization dividing box. The return signal collected by the telescope is first collimated by a plano-concave lens. The collimated light is directed though a calcite polarization splitting cube, which transmits the P polarization and reflects the S polarization out a side face of the cube. Each polarization is then focused by a separate plano-convex lens into an optical fiber that transfers the polarization return signals to two identical detector boxes [9].

The detector subsystem uses beam splitters and narrow bandwidth interference filters to separate the returned signal by wavelength. Both polarizations of the 355 nm and 532 nm signals are detected by photomultiplier tubes. The 607 nm Raman shifted nitrogen channel employs a cooled PMT for photon counting. The 1064 nm infrared channels are detected using PIN photodiodes.

The data acquisition subsystem consists of six A/D channels and two photon counting channels. The A/D channels sample at 20 MHz with a 12 bit resolution resulting in a vertical range resolution of 7.5 m and a sufficient dynamic range. The photon counting channels consist of multi channel scalers with a 100 MHz maximum count rate. The data is collected and stored by a 50 MHz 486 computer that is interfaced with a custom timing and control unit. This unit coordinates the functions of the transmitter, the data acquisition subsystem, the safety subsystem, and the scanning platform. The lidar data is saved in ASCII format so that it can be readily combined with data from the other WAVE-LARS instruments [10].

The safety subsystem for the scanning lidar consists of laser interlocks, a kill switch, and an airplane detection radar [11]. The airplane detection radar is constructed from a modified marine radar and will automatically suspend laser operation if an airplane is in danger of intercepting the transmitted laser beam. This will prevent the possibility of an observer on an aircraft or on the ground from directly viewing the laser beam or a specular reflection of the laser beam. This system has been successfully tested against Navy fighter jets in field tests at Pt. Mugu Naval Base, California.

The volume scanning system consists of two identical custom designed platforms and control systems to allow simultaneous scanning with the polarization lidar and radar. The transmitter and receiver subsystems of the radar and lidar are mounted to these platforms. The scanning platforms were designed to scan up to 10 degrees per second with a 1 second reversal time. The scan control system incorporates a computer interfaced controller for each axis. A particular volume of the atmosphere can be selected through the scan control software.

Summary

The volume scanning lidar is currently undergoing system tests at Penn State. An example of the first data collected by this system, on November 3, 1994, is shown in Figure 2. In the near future we plan to conduct additional tests and measurements at Penn State and other research facilities with the complete WAVE-LARS system. These measurements include studies of extinction caused by clouds and marine aerosols; studies of the evolution of contrails; and studies of the relationship of water vapor and aerosols in the vicinity of clouds.

The volume scanning lidar described here, in combination with the other WAVE-LARS instruments, is expected to become a powerful tool for atmospheric research. Future work will consist of improving data analysis procedures and conducting coordinated measurements of the type described above.

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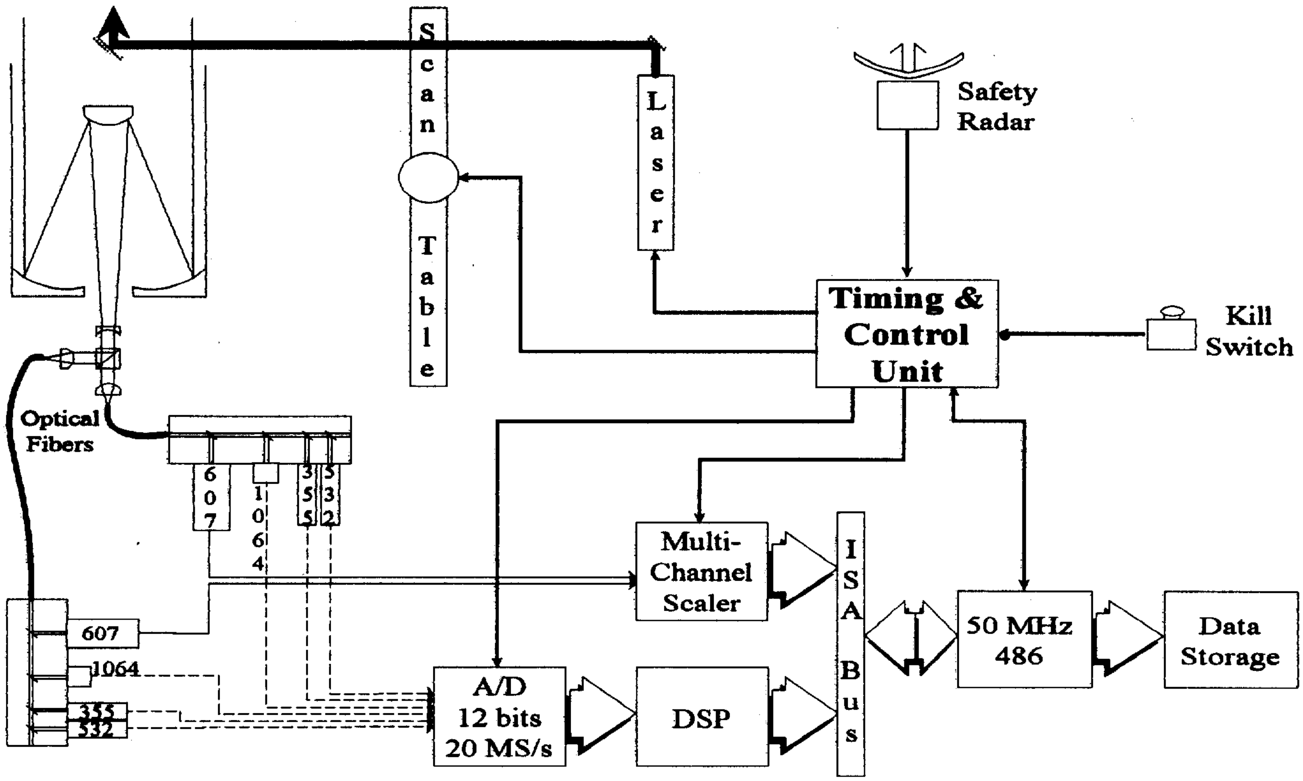

Figure 1. Block diagram of the five subsytems of the volume scanning lidar: transmitter, receiver, detector, data acquisition, and safety.

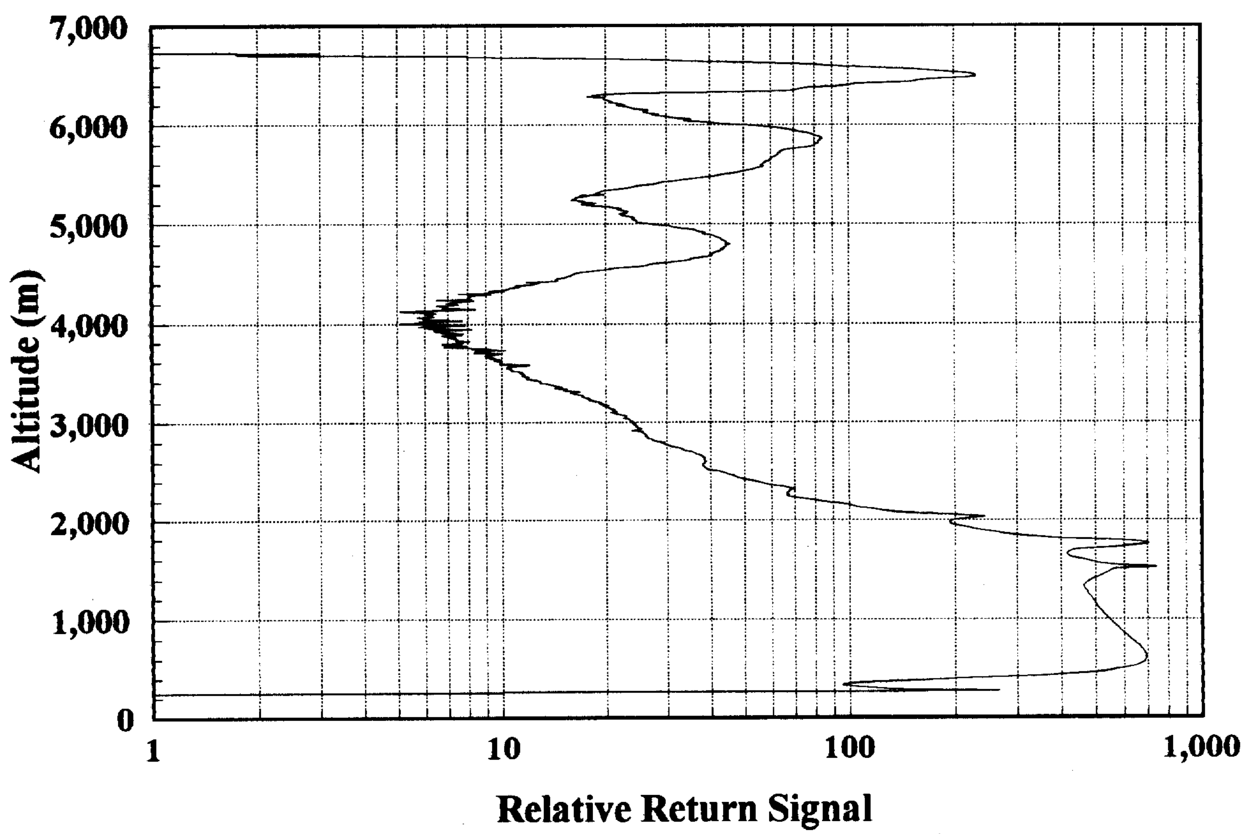

Figure 2. 532 nm backscatter return showing several cloud layers on November 3, 1994, averaging for ten minutes. (State College , PA, elevation 360 m)