ATS.4

Aerosol Mapping of the Atmosphere Using a Multiple Wavelength Polarization Lidar

S. Rajan, G. R. Evanisko, T. J. Kane and C. R. Philbrick

The Penn State University
ARL/ PSU LIDAR Laboratory
University Park, PA 16802
Phone (814)863-0851

ABSTRACT

A multiple wavelength volume scanning lidar employing polarization techniques is being built to characterize the size and shape distribution of aerosols in the boundary layer and the troposphere. The technical opportunities of using multiple wavelength lidar have been studied in order to discriminate between various particle sizes in the lower and middle atmosphere. Though these techniques have been used to classify aerosols and other particles by size it has proved difficult to distinguish water droplets from ice crystals. Based on the Mie scattering theory, it has been stated that particles of different shapes alter the polarization of the illuminating light due to internal reflections and scattering. Hence, the depolarization observed in the backscatter of the lidar beam is a measure of the different shapes of the constituent aerosols. Our system uses three wavelengths: 355 nm, 532 nm, and 1064 nm, in addition, the polarization information from each channel is measured. This triple wavelength approach gives better particle size discrimination as well as distinct depolarization signatures. In addition, the incorporation of shorter wavelengths yields a higher resolution. A special opportunity which has been incorporated in the design of this system is its volume mapping feature. By scanning a given volume segment, it is possible to map cloud systems. Incorporation of these three techniques; multiple wavelengths, polarization measurements and volume mapping into a single lidar, will result in an extremely powerful system capable of mapping the scattering properties of clouds and aerosols more accurately. This system is designed to gather enough data to study the complex intricacies of cloud microphysics. Information gathered by this technique promises a clearer understanding of cloud composition and atmospheric thermodynamics.

INTRODUCTION

The laser backscatter depolarization technique for lidar studies of the atmosphere borrows heavily from the analogous microwave radar technique. Optical (or lidar) depolarization methods require a polarizing beamsplitter and an extra photodetector or PMT. The linear depolarization ratio, δ, is defined as the ratio of the returned power in the plane of polarization orthogonal to the linearly polarized source to the return power in the plane of polarization parallel to that of the linearly polarized source[1]. Schotland et al.[2] demonstrated that 'δ' is equivalent to the ratio of the cloud volume backscattering coefficient in the two planes, since all other terms in the lidar equation drop out when the ratio is taken. Since the depolarization ratio (δ) values, obtained by lidar methods, vary considerably in cloud backscatter due to different cloud constituents, polarization lidar displays the ability to remotely sense the basic microphysical properties of clouds and precipitation.

The use of multiple wavelengths to study the atmosphere enables deductions to be made about the aerosol size distribution, which leads to a better understanding of the microphysical and dynamical processes taking place in clouds. For very small aerosols and ice crystals, which are difficult to detect with just the depolarization technique, a combined multiple wavelength and depolarization technique will enhance our ability to detect and estimate the size distribution of small particles. The wavelengths ranging from 355-1064nm should permit the inversion of the lidar backscatter to obtain size distributions of particles smaller than 2.5μm.

Understanding the physical mechanisms involved in complicated processes such as cloud formation requires simultaneous measurements of many atmospheric parameters. However, because individual systems such as lidars and radars measure only a few quantities as functions of space and time, complete spacial and temporal data sets of atmospheric mechanisms are rarely obtained and the majority of data acquired by the individual instruments are seldom utilized. To study cloud formation and maintenance comprehensively, it is imperative to study water vapor and aerosol content as a function of both space and time. To accomplish this task, a volume mapping lidar system is necessary. Also using this high resolution water vapor and aerosol data will make it possible to study the movements of fronts, boundary layers, clouds etc.

The remote sensing of cloud structure and position can be measured accurately by radar, because of its ability to penetrate through individual clouds as well as multiple cloud layers. However, the remote sensing of water vapor and aerosols, which are the nuclei for cloud condensation, can only be accomplished by lidar techniques. Since cloud formation and maintenance is crucially dependent on the temperature and moisture of the atmosphere, as well as on its dynamics, an integrated lidar/radar system should greatly enhance our understanding of global environmental changes as well as cloud microphysics. In view of such needs an integrated lidar and radar sounder system, LARS (Laser And Radar Sounder), is currently under construction at the Penn State University. The combination of lidar and radar (94GHz) measurements will permit the profiling of aerosols, water vapor and temperature in the vicinity of clouds and enable the simultaneous measurements of cloud properties and atmospheric thermodynamic functions. The variation of these parameters as a function of distance from the cloud will provide detailed information on environmental factors pertinent to the growth and sustenance of clouds. In addition reflectivity measurements coupled with multiple wavelength and polarization data will be used to understand the structure, thickness and particle size of cloud layers. In addition the volume scanning capability of the LARS system should shed some light on the mechanics of cloud formation.

DESCRIPTION OF THE LARS SYSTEM

The LARS system is designed to perform field studies of the lower atmosphere during varied weather conditions and is therefore housed in a 8'x20'x8' standard shipping container, rendering it

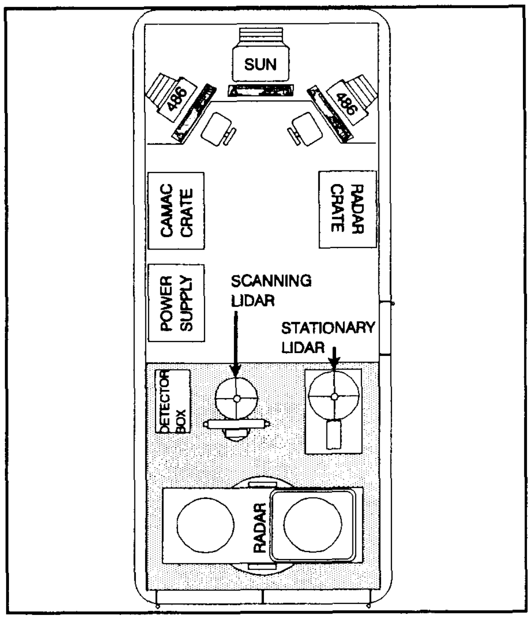

Fig. 1 Top view of container housing the LARS field instrument.

both mobile and weather proof. Figure 1 shows the floor plan of the LARS container. The container is fitted with three console units adjacent to one another. Each console unit contains display monitors and control systems for the scanning lidar, stationary lidar and the radar systems. During operation of the system, the lidar and radar transmitting and receiving systems are slid out of double doors on the front of the container in order to take measurements.

This paper will be concerned primarily with the LARS lidar systems. The LARS system employs two separate lidar instruments, one of which is stationary while the second system is continuously scanning a given volume segment of the atmosphere. The primary function of the stationary lidar system is to measure both aerosol content and water vapor using the 532 nm and 355 nm wavelengths, from a Nd:YAG laser, to measure the Rayleigh scattering from the atmosphere. Concurrently the Raman shifted frequencies (607 nm and 660 nm) for nitrogen and water vapor are monitored in order to study the water vapor content of the atmosphere.

The second lidar, the volume scanning lidar system, utilizes a second Nd:YAG laser which emits at 355nm, 532nm and 1064nm. The scanning lidar system monitors the backscatter signal from these three wavelengths, in both the orthogonal and parallel planes of polarization. Data from this lidar system will be used to measure both the aerosol content and reflectivity. In addition, the polarization data will be collected to study the constituent elements of the cloud as well as the various cloud thermodynamic processes.

Each lidar system consists of five basic subsystems: a transmitter, receiver, detector, the data acquisition system, and the control/safety system. The scanning lidar system will be discussed first. The transmitter consists of a Nd:YAG laser, a beam expander, and optics. The laser operates at 20 Hz, with pulse energies of 650mJ at 1064nm, 300mJ at 532nm, and 150mJ at 355nm. The laser beam is expanded to reduce its energy density and is reflected into the atmosphere by a beam steering mirror located in the plane of the receiving telescopes secondary mirror. Precise adjustments of this mirror are used to align the beam in the field of view of the receiver. This tedious alignment procedure will be semi-automated with the help of a combined CCD camera unit placed behind the telescope and a motorized control system for steering the mirror.

The receiver for this system is a 16.5 inch f/6 Ritchey-Chretien telescope. The Ritchey-Chretien telescope was chosen over other telescopes because of its compact size optical quality and polarization maintaining property. The backscattered light collected is divided into two beams using a calcite prism. The plane of polarization of each of the resulting beams are orthogonal and parallel, with respect to the emitted laser beam. These two beams are guided into the detector boxes using 1mm optical fibers. A combination of analog and photon counting detectors are used to detect the two polarization components of the 355nm, 532nm and 1064nm wavelengths. Photon counting of the 607nm wavelength, corresponding to Raman shifted nitrogen, will also be detected in the parallel polarized plane. The data acquisition system consists of an integrated Sun workstation and a Camac crate containing 12 bit A/D converters operating at 20MHz. This will enable us to obtain a range resolution of approximately 7.5 meters.

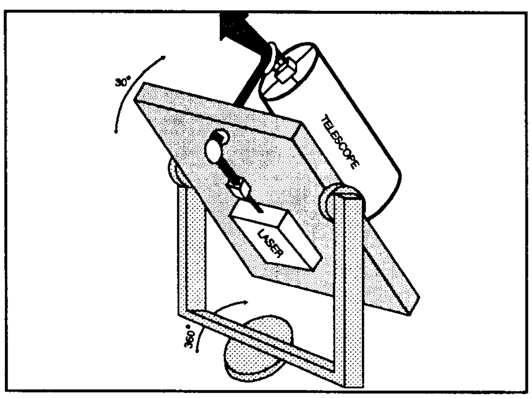

Fig. 2 Mounting used to scan a volume segment of the atmosphere.

The transmitter and receiver sections (as depicted in Figure 2) of the scanning system are first mounted on a rugged optical table made of a graphite composite material. The entire table is capable of scanning a 30° x 30° segment of the sky in 1° increments by utilizing precision motors. The scanning movements of the table, and hence the entire system are governed by a computer driven control system. The entire region can be mapped in approximately five minutes, but due to the need of averaging in the signal count, the table will probably be scanning at one degree per second with sections being averaged over one degree, i.e. by averaging 20 shots at a time.

Since the LARS system will be operating in a variety of environments it is essential that safety be given due consideration. With that in mind the beam divergence was calculated such that the energy density of the beam was within eyesafe limits for aircraft flying overhead. In addition a safety radar is incorporated in the system. Should any aircraft be detected within the region of operation the lidar will be automatically shut down. The system will be restarted only after five seconds of "unobstructed path" signals.

The stationary lidar is essentially similar to the scanning lidar system. The transmitter operates with a 20 Hz Nd:YAG laser with pulse energies of 1.2 J at 1064nm, 600mj at 532nm, and 250mJ at 355nm. The beam is expanded and reflected of a beam steering mirror into the atmosphere. The telescope used will be a 20" f/8 Ritchey-Chretien telescope. The collected light will is separated into three near field channels and three high altitude channels. The three low altitude channels are dedicated to measuring the Raman shifted frequencies due to nitrogen and water vapor. These channels utilize photon counting detectors and narrowband filters. These narrowband filters are essential to separate the required Raman signals and reject the laser frequencies. The rejection ratio is high (on the order of 10^{12}) in order to eliminate the laser frequencies which are much stronger than the Raman shifted signals. The high altitude channels will measure the Rayleigh scattering at the 532 and 355 nm wavelengths. The acquisition system will consist of a 486 computer with a Camac crate operating at 20MHz.

DATA

A 10 shot plot of data from the PSU LAMP (Laser Atmospheric Measurement Program) system is shown in Figure 3. Since the existing LAMP system

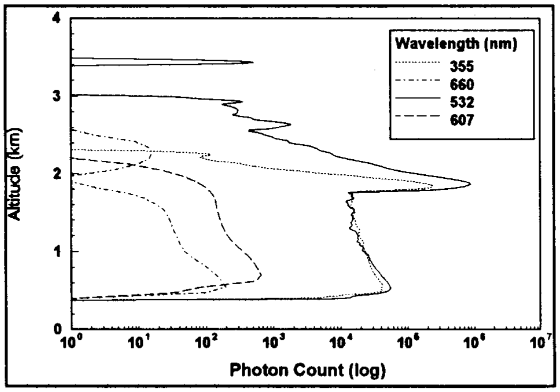

Fig. 3 Ten shot data taken on November 7, 1992 during cloudy conditions, PSU station height is 360 meters.

is similar the LARS system it is convenient to use its data to extrapolate the real abilities of the LARS system. From Figure 3, the thick cloud present at approximately 1.9 km is evident from the strength of the molecular scattering seen for the 355nm and 532nm. Below 1.9 km, the extinction of both 532nm and 355nm takes place at the same rate. Also the 660nm wavelength corresponding to the Raman shifted water vapor line shows the change of water vapor to a liquid phase in the cloud. Hence, one sees a drop in water vapor signal. Above the cloud layer, the water vapor content increases again. Since such data can be obtained from ten shots, a volume map of the cloud layer and regions below it can be scanned quickly (2° per second). For a much faster scan of the atmosphere it would be essential to be able to obtain data without averaging. Data collected by the LAMP system leads us to believe this is possible, in order to preview a weather system, however inaccuracies due to noise and statistical errors can be decreased by averaging the data for more accurate results.

CONCLUSIONS

In conclusion, the faculty staff and students of the ARL/PSU Lidar Laboratory, together with the Departments of Electrical Engineering and Meteorology are constructing a combined lidar and radar remote sensing system, LARS. The instrument is currently being fabricated and will be operational in Summer 1993. This system should provide a new and comprehensive method of mapping clouds, water vapor and aerosol content of the lower and middle atmosphere.

ACKNOWLEDGEMENTS

We would like to acknowledge the Department of Energy, the National Science Foundation and the Naval Environmental Systems Program Office (PMW-165) for their financial support of this project. We would like to acknowledge the efforts of Dr. G. A. Lesieutre of the Aerospace Engineering Department as well as Dr. T. P. Ackerman and Dr. B. A. Albrecht of the Meteorology Department. This project is a joint effort of the entire lidar team at Penn State, faculty, staff and graduate students whose efforts, energies and time made this paper possible.

REFERENCES

1. Sassen, K. "The Polarization Lidar Technique for Cloud Research: A review and current assessment", Bull. Amer. Meteor. Society, 72, 1848-1866, 1991.
2. Schotland, R. M., K. Sassen,and R. J. Stone, "Observations by lidar of linear depolarization ratios by hydrometers. J. Appl. Meteor., 10, 1011-1017, 1971.
3. Stefanutti, L., et al, "A Four-wavelength Depolarization Backscattering LIDAR for Polar Stratospheric Cloud Monitoring", Appl. Phys. B Photophysics and Laser Chemistry, B55, 13-17,1992.
4. Philbrick, C. R, "Lidar Profiles of Atmospheric Structure Properties," SPIE 1492, Earth and Atmos. Remote Sensing, 76-84, 1991.
5. Eloranta, E. W. and D. K. Forrest, "Volume Imaging Lidar Observations of the convective Structure Surrounding the Flight Path of a Flux-Measuring Aircraft", J. of Geophysical Research, Vol 97, D17, 18383-18393, 1992.
6. Measures, K. L., *Laser Remote Sensing*, Wiley-Interscience, 1988.
7. Stevens, T. D. , S. Maruvada, T. J. Kane and C. R. Philbrick, "Lidar Observations of Mt. Pinatubo Aerosols: Effects on the Global Radiation Budget", to be published.