Cloud and Aerosol Characterization for the ARM Central Facility: Multiple Remote Sensor Techniques Development

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Our research program to establish how active and passive remote sensing information can best be applied to the problem of characterizing the cloudy atmosphere has two basic components. The first task, which we have nearly completed, is the fabrication of a state-of-the-art dual-wavelength Polarization Diversity Lidar (PDL) system to thoroughly evaluate the various lidar polarization techniques for cloud and aerosol research. As recently reviewed in Sassen (1991), the basic two-channel method for measuring linear depolarization has been highly effective as a cloud microphysical research tool. Through the use of linear depolarization ratios, water and ice particle clouds can be unambiguously discriminated, and a number of ice particle types and orientations can be identified. (These capabilities should improve as geometrical optics ray-tracing theory is applied to predicting ice crystal habit depolarization ratios.) Nonetheless, there is still much to be explored in the polarization lidar field, including the information contents of additional backscatter polarization (i.e., four-channel Stokes) parameters, simultaneous multiple-wavelength and multiple-polarization state (including circular) laser probing, and the variable receiver field-of-view (FOV) technique for studying multiple scattering depolarization and particle size inversion.

The University of Utah PDL system has been explicitly designed to evaluate these applications for cloud and aerosol research, using a rapidly scannable, mobile (i.e., truck-mounted) platform. The specifications of the unit are provided in Table 1. The most important capability the system possesses, which is required for both scanning and variable FOV studies, is that the data acquisition and handling (33/486-based) host computer can simultaneously keep track of four-channel returns at the maximum 10-Hz pulse repetition rate of the dual-wavelength Nd:YAG laser transmitter. This capability is the result of recent major improvements in microcomputer technology which have overcome the poor data-handling capabilities that handicapped multiple-channel lidar studies in the past. The true diversity of transmitted and received polarization states of our system is illustrated at the bottom of Table 1.

Note that the first full PDL field tests will be made at the upcoming 1991 Project First ISCCP Regional Experiment (FIRE) Intensive Field Observations II campaign, where our unit will be one of several lidars and radars located at a central site serving as the hub for research aircraft operations. The increasingly complex data collected by the PDL and other remote sensors using different wavelengths and techniques, e.g., at the FIRE or Cloud and Radiation Testbed (CART) sites, present a unique opportunity to characterize the microphysical and radiative properties of clouds from the ground and, at the same time, a significant challenge to assimilate the combined dataset to provide this knowledge.

The second component of our record program addresses the approaches, and their optimization, for inverting multiple remote sensor datasets to yield information characterizing the cloudy atmosphere. Studies using both computer simulation and empirical analysis approaches are jointly under way at the University of Utah and the National Oceanic and Atmospheric's (NOAA) Wave Propagation Laboratory (WPL). Based on the microphysical predictions from a detailed cloud growth model, remote sensing returns from realistic, vertically inhomogeneous clouds can be generated at various wavelengths using Mie (for water spheres) and approximate (for ice particles) scattering theories. We have recently incorporated a multiple scattering approximation in our model, which is necessary to treat lidar depolarization in water and mixed-phase clouds (Sassen et al. 1992). Other approaches involve examining and comparing multiple remote sensor datasets collected previously during winter mountain storm research

Table 1. University of Utah Two-Color Polarization Diversity Lidar (PDL) System Specifications[a]

Operational	
Wavelength (Nd:YAG)	0.53 and 1.06 µm (simultaneous)
Peak Energy	0.5 J each color
Maximum PRF	10 Hz
Pulse Width	10 ns
Beamwidths - Transmitter	0.5 mr
Receiver	0.25 - 5.8 mr, high-speed shutter
Receiver Diameter	35 cm (each telescope)
Detectors - Visible	4, Gated Photomultiplier tubes
IR	2, Avalanche photodiodes
Maximum Scan Rate	~$5°s^{-1}$
Data Handling	
Host Computer	33/486
Number of Channels	4 (simultaneous)
Sample Width (resolution)	6 m
Range Gates	1-8 k (each channel)
Pulse Averaged	1-10
Maximum Throughput	328 k samples/second
Digitizer Resolution	8 bits
Storage	Hard disk + 8 mm video tape backup
Polarization Properties	
Transmitted[b]	Vert. (Vis) + Horiz. (IR)
Received - 2λ operation	Vert. + Horiz. (Vis + IR)
1λ operation	Four channel Stokes (Vis)

(a) Additional Equipment:
All-sky video imager with time-lapse VCR
Narrow beam (0.14°) mid-IR (9.5-11.5µm) radiometer (aligned parallel to transmitter on lidar table).
Camcorder video camera (aligned parallel to transmitter on lidar table)
(b) For one-color (1λ) visible operation, a 1/4 plate can be used to transmit circularly polarized 0.532 µm energy.

experiments and those collected during the NOAA WPL CLARET I and II field programs. Empirical relationships between various lidar, radar, and passive radiometric instruments are being studied to identify particularly synergistic ensembles of remote sensors for characterizing various cloud properties. The availability of the uniquely comprehensive Project FIRE dataset, which will include coordinated instrumented aircraft support, will provide additional opportunities for this research.

Finally the recent eruptions of the volcano Pinatubo have injected into the stratosphere a significant amount of SO_2, which will be evolving into a global aerosol cloud for years to come. The aerosol processes involve the formation and growth of sulfuric acid droplets, whose size distribution will vary with time and place, and the eventual crystallization of the droplets into ammonium sulfate particles in the lower stratosphere and upper troposphere. The PDL capabilities are ideally suited for this research, which has implications for the remote sensing of haze and aerosols throughout the troposphere.

References

Sassen, K. 1991. "The Polarization Lidar Technique for Cloud Research: A Review and Current Assessment." *Bull. Amer. Meteor. Soc.* 72:1848-1866.

Sassen, K., H. Zhao, and G. C. Dodd. 1992. "Simulated Polarization Diversity Lidar Returns from Water and Precipitating Mixed Phase Clouds." *Appl. Opt.* 31:2914-2923.