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Turn-Key Raman Lidar for Profiling Atmospheric Water Vapor, Clouds, and Aerosols at the US Southern Great Plains Climate Study Site

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Abstract

We describe an automated Raman lidar system developed for routine nighttime *and daytime* profiling of water vapor, clouds, and aerosols at remote climate-study sites.

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There are clearly identified scientific requirements for continuous profiling of atmospheric water vapor at the Department of Energy, Atmospheric Radiation Measurement program, Southern Great Plains CART (Cloud and Radiation Testbed) site in northern Oklahoma. Research conducted at several laboratories has demonstrated the suitability of Raman lidar for providing measurements that are an excellent match to those requirements. We have developed and installed a ruggedized Raman lidar system that resides permanently at the CART site, and that is computer automated to eliminate the requirements for operator interaction. In addition to the design goal of profiling water vapor through most of the troposphere during nighttime and through the boundary layer during daytime, the lidar provides quantitative characterizations of aerosols and clouds, including depolarization measurements for particle phase studies.

Raman lidar systems detect selected species by monitoring the wavelength-shifted molecular return produced by Raman scattering from the chosen molecule or molecules. For water-vapor measurements (the key measurement provided by the CART Raman lidar), a nitrogen Raman signal is observed simultaneously with the water-vapor Raman signal; proper ratioing of the signals yields the water-vapor mixing ratio. Similarly, by simultaneously recording the backscatter signal at the laser wavelength (which contains contributions from both Rayleigh and aerosol scattering), the ratio of the backscatter signal to the nitrogen Raman signal yields a quantitative measurement of the aerosol scattering ratio, and a variety of aerosol and cloud parameters can be derived from this measurement. In aerosol-free regions of the atmosphere, temperature profiles can be derived from the density measurements obtained from the nitrogen Raman signal. Finally, polarizing optics and an additional direct-backscatter channel provide depolarization measurements, yielding additional information on particle shape, of special interest for identifying the phase (water droplet or ice particle) of clouds.

The CART Raman lidar uses a Nd:YAG laser operated with third-harmonic generation to produce a 355-nm (near-uv) output beam. Dichroic beamsplitters located after the receiving telescope separate the backscattered photons into three channels, the water-vapor Raman return at 408 nm, the nitrogen Raman return at 387 nm, and the combined Rayleigh/aerosol return at 355 nm. The combination of a dual-field-of-view design and high-transmission, narrowband interference filters provide excellent daytime capabilities without sacrificing nighttime performance. The entire system is computer-automated using a LabVIEW-based program; after responding to a few dialog boxes during system start-up, no further operator attention is required. The system is housed in a seatainer, a metal shipping container that measures approximately $8' \times 8' \times 20'$. The system is fully self-contained, requiring only an external supply of three-phase 208-V power. Optical access is provided by a weather-tight window in the roof of the seatainer; the window is covered by a motorized hatch during bad weather. A great deal of attention has been paid to the climate-control system to ensure reliable operation in the non-laboratory environment of the CART site.

The system employs photon counting for both the long-range (narrow field of view) and short-range (wide field of view) channels. The finest vertical resolution is 39 m, determined by the minimum bin time of the photon-counting electronics. The nominal temporal resolution is one minute, although measurement periods as short as 10-30 seconds are possible. Because the system literally counts photons in equal-sized spatial and temporal bins, information is always recorded with 39-m vertical and (nominal) one-minute temporal resolution. However, *during post-acquisition signal processing*, additional averaging can be performed to trade off spatial and/or temporal resolution for improved sensitivity. In particular, this makes it possible to take advantage of the slower (in time and in space) variation of water vapor at higher altitudes to obtain higher sensitivity by post-acquisition averaging, while still having the high-resolution measurements at lower altitude. The system characteristics are summarized in Table 1.

Table 1. Lidar Specifications

Transmitter		Receiver	
Wavelength	355 nm	Diameter	61 cm
Laser	Nd:YAG third harmonic	Channel bandpass	0.3 nm (narrow fov) 1.2 nm (wide fov)
Energy/pulse	400 mJ	Filter transmission	30-40%
Repetition rate	30 Hz	Field of view	Dual, adjustable (typically 0.3 mr, 2 mr)
Beam Diameter	13 cm (~0.1 mr divergence)	Species	Rayleigh/aerosol (355 nm) Aerosol depol. (355 nm) Water vapor (408 nm) Nitrogen (387 nm)
Bandwidth	~2 cm^{-1}	Electronics	Photon counting 39 m range resolution

Figures 1 and 2 display water-vapor profiles recorded at the CART site during nighttime and daytime operation, respectively (a logarithmic scale is used for the abscissa in Fig. 1 to demonstrate the nighttime performance of the system in the upper troposphere). Altitude-dependent averaging was applied (indicated by the vertical spacing of the error bars), producing vertical resolutions varying from 39 m near the ground to coarser resolution at higher altitudes (312 m in Fig. 1, 156 m in Fig. 2). The error bars were calculated using Poisson statistics for the observed photon counts.

This system is now being operated routinely by CART-site personnel, and runs around the clock under reasonable weather conditions. We anticipate that the addition of *routine*, continuous, high-resolution water-vapor profiling to the other measurements performed at the CART site will have a significant impact on climate studies based on CART-site measurements.

This research was supported by the Environmental Sciences Division of the U.S. Department of Energy as part of the Atmospheric Radiation Measurement program. We wish to thank Harvey Melfi, Rich Ferrare, Dave Whiteman, and Keith Evans for their technical assistance during the early phases of this project.

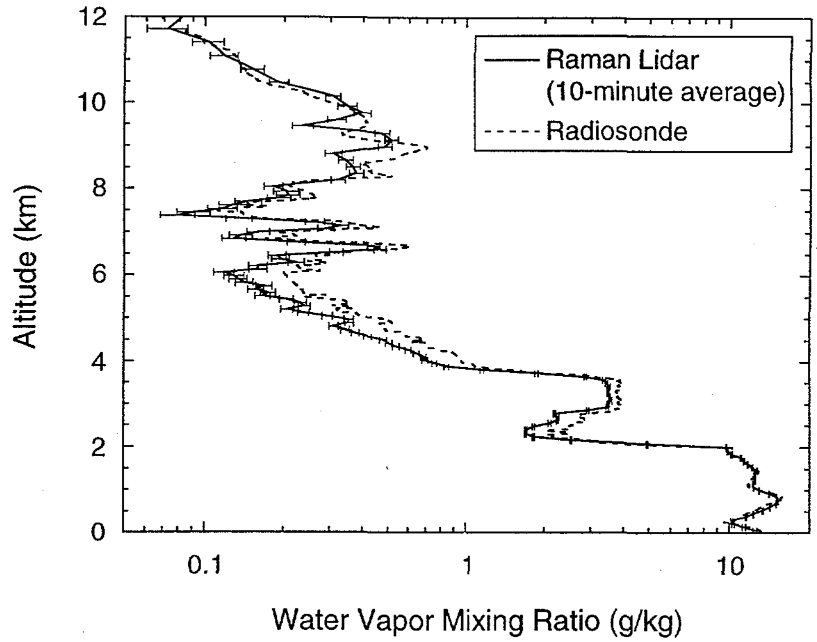

Figure 1. Nighttime profiles of water vapor recorded at the CART site at 3:30 am (local time) on July 16, 1996. The logarithmic abscissa emphasizes the performance of the system in the upper troposphere.

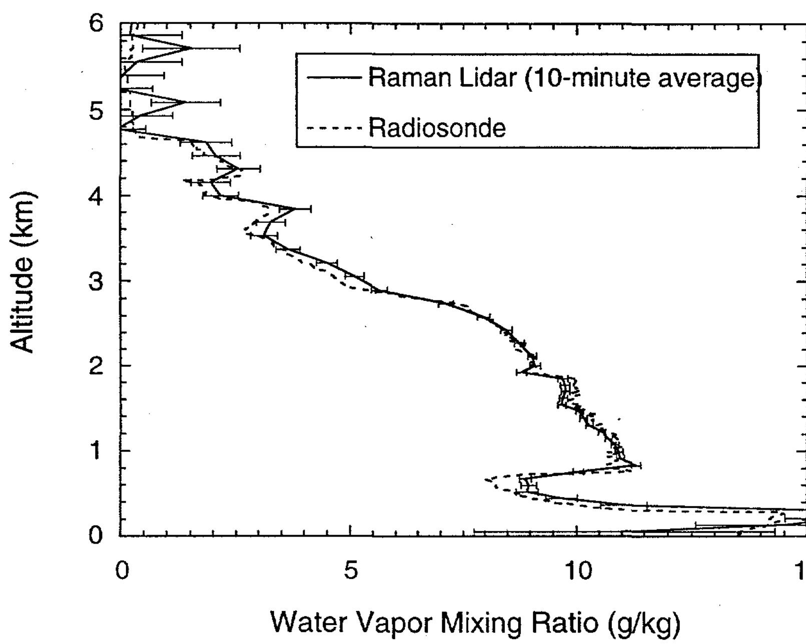

Figure 2. Daytime profiles of water vapor recorded at the CART site at 9:30 am (local time) on June 13, 1996.

OPTICAL REMOTE SENSING OF THE ATMOSPHERE

February 10-14, 1997

Abstract and Summary Deadline
September 25, 1996

SCOPE

This meeting will focus on the latest developments in passive and active optical sensing of the atmosphere. The primary aim is to highlight the rapid advancements in the field, including instrumentation, retrieval techniques, knowledge of the molecular species spectral parameters, measurement approaches, and changes in measurement objectives. Contributions describing new advancements in remote-sensing techniques and demonstration of measurement systems are solicited for the meetings. This meeting will provide a forum for the presentation and discussion of the latest advances in all remote sensing related topics and for future developments as well.

TOPICS TO BE CONSIDERED

- Global measurement of trace gases
- Development in lidar measurements of aerosols
- Advances in laser development for lidar applications
- Algorithm development
- Laboratory spectroscopy of molecules of atmospheric interest
- Remote wind measurements
- Novel lidar instrumentation
- Lidar studies of tropospheric air pollution
- Measurements of atmospheric constituents (O_3m H_2O, NO_x, Cl_x, etc.)
- Passive remote sensing in the EOS era
- Cloud and aerosol passive remote sensing

INVITED SPEAKERS (PRELIMINARY LIST)

Aircraft Remote Sensing of Cloud Microphysics, Steve Ackerman, *University of Wisconsin*

Remote Sensing of the Tropospheric Ozone and Its Precursors with TES and AES, Reinhard Beer, *Jet Propulsion Laboratory*

LASE Measurements of Tropospheric Water Vapor, Aerosol, and Cloud Distributions, Edward V. Browell, *NASA Langley Research Center*

Retrieval of Altitude Distributions of Trace Gases From Ground-based Spectra, Brian Connor, *National Institute for Water and Atmospheric Research*

Lidar and Radar Sensing of Clouds: A Perspective, Wynn L. Eberhard, *NOAA Environmental Technology Laboratory*

Atmospheric Properties in the Tropical Pacific From Raman Lidar, William E. Eichinger, Daniel Cooper, Larry Tellier, Michael Osborne, *Los Alamos National Laboratory*

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