Implementation of Raman Lidar for Profiling of Atmospheric Water Vapor and Aerosols at the Southern Great Plains Cloud and Radiation Testbed Site

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Introduction

There are clearly identified scientific requirements for continuous profiling of atmospheric water vapor at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site. Research conducted at several laboratories, including our own collaboration in a previous Instrument Development Project for the Atmospheric Radiation Measurement (ARM) Program, has demonstrated the suitability of Raman lidar for providing measurements that are an excellent match to those requirements. We are currently building a rugged Raman lidar system that will reside permanently at the CART site and that is computer-automated to reduce 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 is intended to provide 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, as illustrated in Figure 1. For water-vapor measurements, the nitrogen Raman signal is observed simultaneously with the water-vapor Raman signal; proper ratioing of the signals yields the water-vapor mixing ratio. Similarly, when the backscatter signal at the laser wavelength (which contains contributions from both Rayleigh and aerosol scattering) is also recorded simultaneously, the ratio of the backscatter signal to the nitrogen Raman signal yields a quantitative measurement of the aerosol scattering ratio. 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, when polarizing optics and an additional direct-backscatter channel are added, depolarization measurements can provide information about the phase (water droplet or ice particle) of clouds detected by the lidar system.

Implementation of Raman Lidar for the SGP CART Site

The Raman lidar system we are building to reside at the SGP CART site will be housed in a seatainer, a metal shipping container that measures approximately 8’x8’x20’. The system will be fully self-contained, requiring only an external supply of three-phase 208-V power. The current

(a) Under contract at the Goddard Space Flight Center, Greenbelt, Maryland.

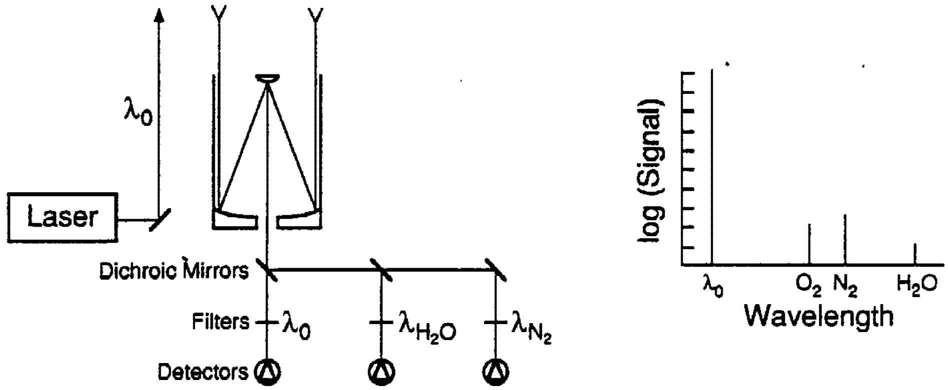

Figure 1. Schematic diagram of idealized Raman lidar system, and signals produced by the primary species in the atmosphere.

design calls for optical access to be provided by a weather-tight window in the roof of the seatainer; the window will in turn be covered by a hatch during bad weather. A great deal of attention is being paid to the climate-control system to ensure reliable operation in the non-laboratory environment of the CART site.

Two laser systems are good candidates for a Raman lidar system of this type, Nd:YAG lasers and excimer lasers; both have had considerable success in several systems. Although excimer-based systems have recently been developed at both Sandia and Goddard, we elected to use a frequency-tripled Nd:YAG laser in the CART system.

Nd:YAG lasers have four distinct advantages over excimer lasers: better beam quality (needed for narrow-field-of-view operation), more readily polarized (needed for depolarization measurements), no toxic gases required, and much lower cost for consumables and maintenance. Overall laser reliability is difficult to judge, although Nd:YAG lasers have the significant advantage of not requiring corrosive gases and having no moving parts. Excimer lasers do produce higher ultraviolet output power, but system performance modeling indicates that the higher power does not offset the other disadvantages.

Finally, a frequency-tripled Nd:YAG laser (355 nm output) also produces beams at the fundamental (1064 nm) and second harmonic (532 nm) at no additional cost. We had originally considered simultaneously recording backscatter at these wavelengths to provide some particle size information under the narrow range of conditions under which this can be done. We chose not to implement this feature because of financial constraints and because beam-expanded operation at 355 nm is eye-safe for aircraft, eliminating the need for an aircraft-detection radar; whereas the system would not be eye-safe for aircraft if the longer-wavelength beams were also transmitted.

The need to have a system that operates in both daytime and nighttime and that can make accurate measurements both near the ground and at long ranges places somewhat conflicting constraints on the system design. We have chosen to implement a dual-field-of-view design to provide the best compromise among these requirements (see Figure 2). The first beamsplitter in the path marked “from telescope” in Figure 1 directs 5% of the light collected by the telescope through a relatively large aperture, which defines the “wide” field of view necessary to establish a transmitter-receiver overlap function that can record signals at short range. Dichroic beamsplitters direct the three wavelengths of interest through narrowband interference filters to photomultiplier tubes. This wide field of view produces a large solar background during the daytime, but this large background is offset by the large close-range signal. The remainder of the light collected by the telescope passes through a smaller aperture, which defines the “narrow” field of view, followed again by dichroic beamsplitters and narrowband interference filters, with an added polarizer and a second 355-nm channel for making depolarization measurements. The narrow field of view produces far less solar background and provides optimum long-range signal. Our modeling indicates that this design will provide excellent daytime performance without sacrificing any nighttime capability.

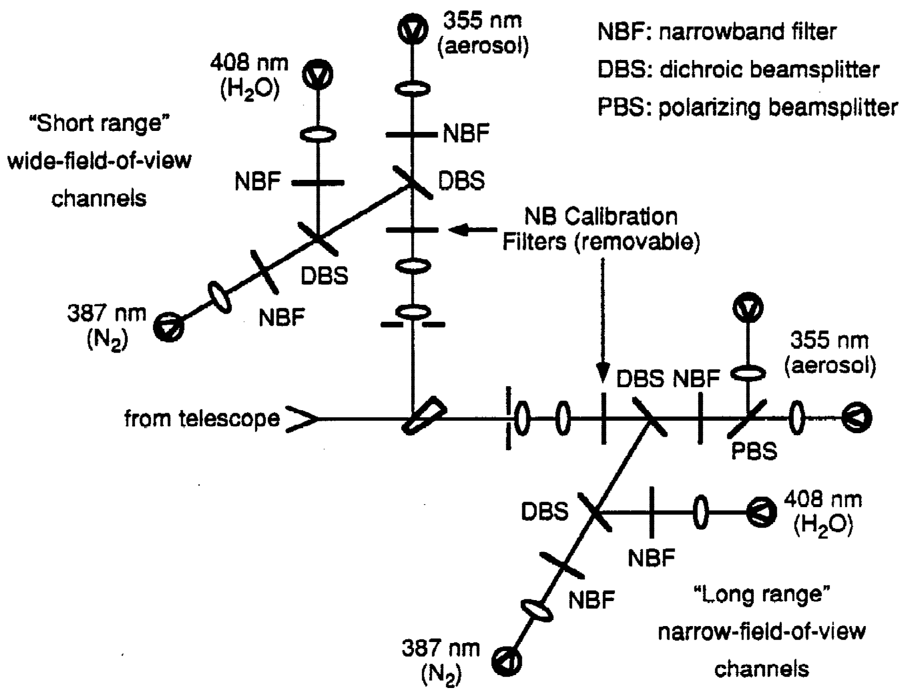

Figure 2. Optical layout for dual-field-of-view Raman lidar receiver.

The lidar electronics have also been designed to optimize the performance of the dual-field-of-view design. Analog-to-digital conversion is being used for the wide field-of-view channels, where large signals (especially at close range) make photon counting very difficult. Photon counting is used for the narrow field-of-view channels to provide optimum long-range performance. Both systems record signals at 100-ns intervals, providing 15-m range resolution, with profiles recorded at intervals of one minute or less. The system thus provides excellent spatial and temporal resolution suitable for boundary-layer studies. To provide higher sensitivity for longer-range measurements that do not require such high resolution, the profiles can be averaged in time and/or space during post-processing. The system thus provides complete flexibility in tradeoffs among sensitivity, spatial resolution, and temporal resolution; these tradeoffs can be explored at any time and with any range dependence desired.

The entire system is operated by a LabView-based program implemented on a conventional Windows-based PC. The program optimizes the doubling and tripling crystals in the laser, centers the laser beam in the receiver field-of-view, interchanges interference filters for a calibration procedure, acquires the data, processes it in real time, and produces real-time displays of the raw and processed data. The raw and processed data are stored on the PC and are also transferred over the ethernet to the central CART computer system for storage on that system.

Conclusion

The Raman lidar system described here provides an excellent match to the scientific requirements for continuous profiling of atmospheric water vapor at the SGP CART site. Because the system is under construction even as this paper is being written, we cannot present any measurements at this time. However, our previous experience with Raman lidar indicates that this system can provide measurements of the quality desired. Much of the challenge in building the system comes from the desire to make the transition from a research-style system that is partially automated to a field-hardened, CART-ready system that has a greater degree of computer automation and requires significantly less operator attention.