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CART and GSFC Raman Lidar Measurements of Atmospheric Aerosol Backscattering and Extinction Profiles for EOS Validation and ARM Radiation Studies

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Introduction

The aerosol retrieval algorithms used by the Moderate-Resolution Imaging Spectroradiometer (MODIS) and Multi-Angle Imaging SpectroRadiometer (MISR) sensors on the Earth Observing Satellite (EOS) AM-1 platform operate by comparing measured radiances with tabulated radiances that have been computed for specific aerosol models. These aerosol models are based almost entirely on surface and/or column averaged measurements and so may not accurately represent the ambient aerosol properties. Therefore, to validate these EOS algorithms and to determine the effects of aerosols on the clear-sky radiative flux, we have begun to evaluate the vertical variability of ambient aerosol properties using the aerosol backscattering and extinction profiles measured by the Cloud and Radiation Testbed (CART) and NASA Goddard Space Flight Center (GSFC) Raman Lidars. Using the procedures developed for the GSFC Scanning Raman Lidar (SRL), we have developed and have begun to implement algorithms for the CART Raman Lidar to routinely provide profiles of aerosol extinction and backscattering during both nighttime and daytime operations.

Aerosol backscattering and extinction profiles are computed for both lidar systems using data acquired during the 1996 and 1997 Water Vapor Intensive Operating Periods (IOPs). By integrating these aerosol extinction profiles, we derive measurements of aerosol optical thickness and compare these with coincident sun photometer measurements. We also use these measurements to measure the aerosol extinction/backscatter ratio S_a (i.e. "lidar ratio"). Furthermore, we use the simultaneous water vapor measurements acquired by these Raman lidars to investigate the effects of water vapor on aerosol optical properties.

Instruments

The CART Raman Lidar is an operational, autonomous system designed for unattended, continuous profiling of water vapor, aerosols, and clouds at the Department of Energy Southern Great Plains (SGP) site [1]. This system uses a tripled Nd:YAG laser, operating at 30 Hz with 400 millijoule pulses, to transmit light at 355 nm. A 61-cm diameter telescope collects the light backscattered by molecules and aerosols at the laser wavelength and the Raman scattered light from water vapor (408 nm) and nitrogen (387 nm) molecules. These signals are detected by photomultiplier tubes and recorded using photon counting with a vertical resolution of 39 meters. A beam expander reduces the laser beam divergence to 0.1 mrad, thereby permitting the use of a narrow (0.3 mrad) as well as a wide (2 mrad) field of view. The narrow field of view, coupled with the use of narrowband (~0.3-0.4 nm bandpass) filters, reduces

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the background skylight and, therefore, increases the maximum range of the aerosol and water vapor profiles measured during daytime operations.

The SRL operates in a similar manner but differs in that it is a mobile, trailer-based system designed for research conducted during intensive operation periods. Unlike the CART Raman lidar, which measures only vertical profiles, the SRL uses a steerable elliptical flat which provides full 180 degree scan capability within a single scan plane. This scan capability is used to increase the vertical resolution and precision of the data at lower altitudes as well as to facilitate comparisons with tower and/or surface-based instrumentation [2].

Both Raman lidar systems measure the profiles of aerosol scattering ratio, which is defined as the ratio of aerosol+molecular scattering to molecular scattering, by using the Raman nitrogen signal and the signal detected at the laser wavelength. Aerosol volume backscattering cross section profiles are then computed using the aerosol scattering ratio and molecular scattering cross section profiles derived from atmospheric density data measured by coincident and co-located radiosonde data. Aerosol extinction cross section profiles are computed from the derivative of the Raman nitrogen signal with respect to range [3]. The aerosol backscattering and extinction profiles derived in this manner are then used to measure profiles of the aerosol extinction/backscattering ratio S_a. Aerosol optical thicknesses are derived by integration of the aerosol extinction profiles with altitude.

Measurements

Direct measurements of aerosol extinction using the Raman nitrogen channel are limited to ranges where the laser beam is fully within the field of view of the telescope so that the overlap function is unity. For the CART Raman lidar, which acquires only vertical profiles, this occurs for altitudes above about 800 meters. In contrast, aerosol backscattering profiles, which are computed using the ratio of the Rayleigh/Mie and Raman nitrogen return signals, are computed for altitudes above about 60 meters [2]. Therefore, as a first approximation, profiles of aerosol extinction below 800 meters are computed by multiplying the aerosol backscattering profiles by the aerosol extinction/backscattering ratio derived for altitudes between 800-1000 meters. This assumes that the aerosol extinction/backscatter ratio is constant within the lowest 1 km.

Aerosol extinction profiles computed from the CART Raman lidar are compared with aerosol extinction directly measured by the SRL. By scanning, the SRL acquires data at low elevation angles and can, therefore, directly measure profiles of aerosol extinction using the Raman nitrogen channel for altitudes as low as 100 meters. Aerosol extinction/backscattering profiles measured using scan data acquired in April 1994 at the SGP site have shown that in several cases S_a is constant to within about 10-20% in the lowest kilometer [4]. Figure 1 shows an example of the aerosol backscattering and extinction profiles measured simultaneously by both lidar systems at 02:25 UT on September 23, 1996 during the 1996 Water Vapor IOP. The CART Raman lidar aerosol extinction profile was derived from the aerosol backscattering profile using S_a=62 sr. We are continuing to use the SRL aerosol data sets in assessing the aerosol extinction computed using the CART Raman lidar data.

During the 1997 Water Vapor IOP, the CART Raman lidar measured aerosol and water vapor profiles between September 25 through October 6. Aerosol extinction/backscattering ratios derived from these data for altitudes between 0.8-1.4 km varied

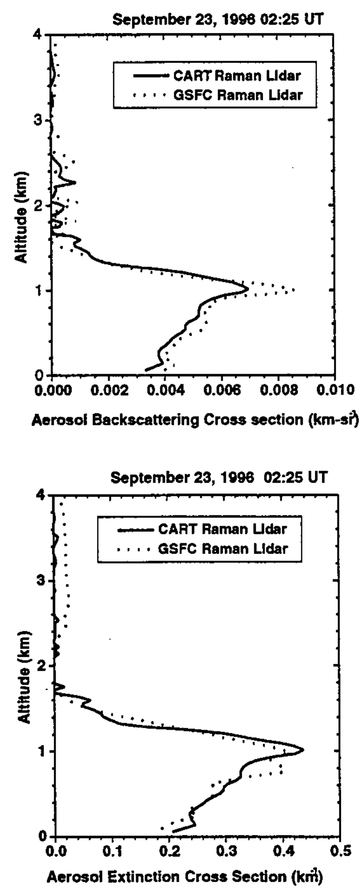

Figure 1. Aerosol backscattering (top) and extinction (bottom) profiles measured by CART and GSFC Raman Lidars at 02:25 UT on September 23, 1996.

between 45-75 sr, with an average value of 57 sr. These values are consistent with previous GSFC Raman lidar measurements [4] as well as the values reported by other investigators [5]. Preliminary investigations using the CART Raman lidar measurements have not revealed any significant relationships between S_a and either aerosol extinction or relative humidity.

The aerosol extinction profiles derived from the CART Raman Lidar data were integrated between 0 to 4 km to estimate the aerosol optical thickness. Figure 2 shows these values along with the aerosol optical thicknesses measured at 340 nm by a Cimel sun photometer located at the SGP site. The sun photometer measurements are restricted to cloud-free

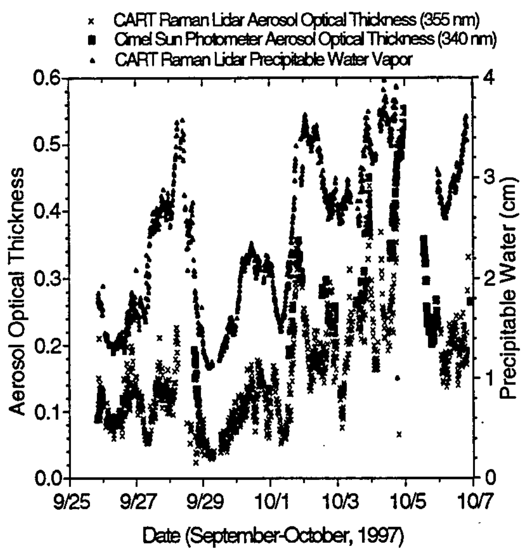

Figure 2. CART Raman Lidar and Cimel sun photometer aerosol optical thicknesses (left axis) and CART Raman Lidar precipitable water vapor (right axis) during the 1997 Water Vapor IOP.

daytime periods. The excellent agreement between the aerosol optical thickness measurements from the two instruments is also shown in figure 3. The sun photometer aerosol optical thicknesses at 355 nm were determined by interpolating between the sun photometer measurements at 340 nm and 437 nm. The results indicate that, for this period, aerosols above 4 km have a negligible contribution to the total aerosol optical thickness. Figure 2 also shows that the precipitable water vapor derived from the simultaneous CART Raman lidar water vapor measurements is highly correlated with aerosol optical thickness. This indicates: 1) aerosol and water vapor concentrations within various air masses were highly correlated over the SGP site during this experiment,

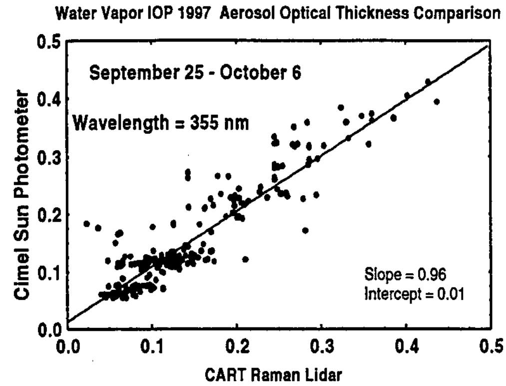

Figure 3. Correlation between CART Raman lidar and Cimel sun photometer aerosol optical thickness (355 nm) measurements during the 1997 Water Vapor IOP.

and 2) these aerosols tend to be hygroscopic so that the aerosol extinction increases with relative humidity.

The relationship between aerosol extinction and relative humidity over the SGP site on October 6, 1997 is shown in figure 4. Aerosol extinction profiles measured by the CART Raman lidar and relative humidity profiles derived from the CART Raman lidar water vapor mixing ratio profiles and radiosonde temperature profiles are shown. Temporal resolution is 10 minutes while the vertical resolution is 39 meters. An increase in aerosol extinction and relative humidity below about 0.3 km, which occurred shortly after sunset at 00 UT, is followed by a decrease in aerosol extinction and relative humidity after sunrise at 12:30 UT. The increase in aerosol extinction with relative humidity between 01:00-09:00 UT is plotted in figure 5. Since the water vapor mixing ratio was approximately constant in this region during this period, this increase in relative humidity is due to the decrease in temperature associated with radiational cooling. Under these conditions, the increase in aerosol extinction is due to the change in aerosol physical characteristics (i.e. size and composition) rather than variations in the aerosol number concentration associated with varying air mass characteristics.

Summary

CART Raman lidar data collected during the 1997 Water Vapor IOP were used to derive profiles of aerosol backscattering and extinction during both nighttime and daytime operations. While initial comparisons of aerosol extinction profiles measured by the CART Raman lidar and GSFC Scanning Raman lidar show good agreement, additional comparisons are required to more fully evaluate the

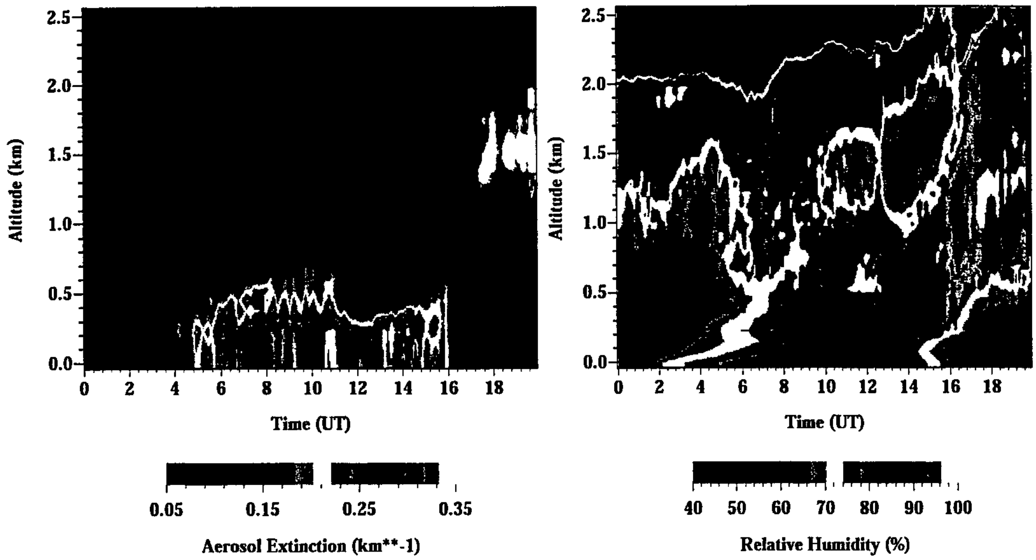

Figure 4. Aerosol extinction (left) and relative humidity (right) derived from CART Raman lidar measurements on October 6, 1997.

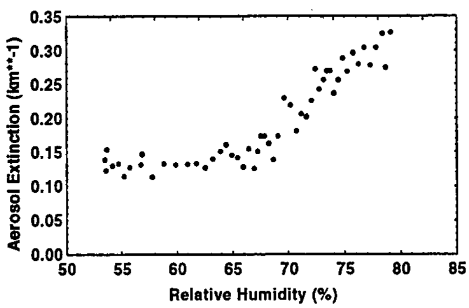

Figure 5. Aerosol extinction as a function of relative humidity derived for altitudes between 60-300 meters from CART Raman lidar measurements between 01:00-09:00 UT on October 6, 1997.

ability of the CART Raman lidar to measure aerosol extinction near the surface. Aerosol optical thicknesses derived from the aerosol extinction profiles measured by the CART Raman lidar in the daytime were shown to be in excellent agreement with those measured by a ground-based sun photometer. Aerosol extinction/backscatter ratios measured by the CART Raman lidar ranged between 45-75 sr, with an average value of 57 sr. The simultaneous aerosol and water vapor measurements were used to demonstrate how lidar data can be used to investigate the relationships between relative humidity and aerosol extinction and backscattering under ambient atmospheric conditions.

Acknowledgments

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