CART Raman Lidar Retrievals of Aerosol Extinction and Relative Humidity Profiles

R. A. Ferrare
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

D. D. Turner
Pacific Northwest National Laboratory
Richland, Washington

W. F. Feltz
University of Wisconsin
Madison, Wisconsin

L. A. Heilman
Science Applications International Corporation/
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Introduction

We have developed and recently implemented automated algorithms to retrieve aerosol extinction profiles from the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) Raman Lidar data acquired during both daytime and nighttime operations. These profiles are important for determining the effects of aerosols on the clear-sky radiative flux, as well as for validating the aerosol retrieval algorithms associated with the National Aeronautics and Space Administration's (NASA's) Moderate-Resolution Imaging Spectroradiometer (MODIS) and Multi-Angle Imaging SpectroRadiometer (MISR) sensors on the Earth Observing System (EOS) Terra satellite platform. Because relative humidity is a key parameter affecting aerosol scattering and extinction (Pilinis et al. 1995), we have also developed and implemented routines to simultaneously retrieve profiles of relative humidity. These routines utilize the water vapor mixing ratio profiles derived from the Raman Lidar measurements together with temperature profiles derived from a physical retrieval algorithm that uses data from a collocated Atmospheric Emitted Radiance Interferometer (AERI) and the Geostationary Operational Environmental Satellite (GOES) (Feltz et al. 1998). These aerosol and water vapor profiles (Raman Lidar) and temperature profiles (AERI+GOES) have been combined into a single product that takes advantage of both active and passive remote sensors to characterize the clear-sky atmospheric state above the CART site.

The CART Raman Lidar is an operational, autonomous system designed for unattended, continuous profiling of water vapor, aerosols, and clouds at the U.S. Department of Energy (DOE) SGP site (Goldsmith et al. 1998). 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 m. 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 (~0.2 nm to 0.3 nm bandpass) filters, reduces the background skylight and, therefore, increases the maximum range of the aerosol and water vapor profiles measured during daytime operations.

Profiles of aerosol scattering ratio, which is the ratio of aerosol+molecular scattering to molecular scattering, are derived 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. These density profiles are computed using coincident pressure and temperature profiles derived from radiances measured by the ground-based AERI instrument and by GOES. Aerosol extinction cross section profiles are computed from the derivative of the Raman nitrogen signal with respect to range. The aerosol backscattering and extinction profiles derived in this manner are then used to measure profiles of the aerosol extinction/backscattering ratio. Aerosol optical thicknesses (AOTs) are derived by integration of the aerosol extinction profiles with altitude.

Water vapor mixing ratio profiles are computed using the ratio of the Raman water vapor signal to the Raman nitrogen signal and are calibrated using the coincident measurements of precipitable water vapor (PWV) from the Microwave Radiometer. Relative humidity profiles are computed using these water vapor mixing ratio profiles and the temperature profiles from the AERI+GOES temperature retrievals. The aerosol calculation details given by Ferrare et al. (1998), and Turner and Goldsmith (1999) provide the details of the water vapor retrievals.

Measurements

Aerosol extinction, water vapor, and relative humidity profiles were computed using the automated algorithms for Raman Lidar data acquired after April 1, 1998. Between April and December 1998, the lidar operated nearly 60% of the time (almost 22,000 10-minute profiles), with electrical power interruptions responsible for most of the down time. A special uninterruptable power supply was installed during February 1999 at the SGP CART site for the Raman Lidar, which should significantly increase this operational time.

AOTs were computed by integrating the Raman Lidar aerosol extinction profiles between 0 km and 6 km. These values were compared with simultaneous measurements of AOT made by a Cimel Sunphotometer at the SGP CART site. Figure 1 shows a comparison between the Raman Lidar and Cimel Sunphotometer AOT for data acquired between April through October 1998. The lidar and sunphotometer AOT values generally agree within about 5% to 10% during this period. Note that the sunphotometer AOT at 340 nm is expected to be about 3.5% higher than the Raman Lidar AOT at 355 nm due to the wavelength dependence of aerosol extinction.

Aerosol extinction profiles acquired during May and August-September 1998 show episodes when high aerosol extinction was measured throughout several kilometers in the lower troposphere over several days. In particular, the Raman Lidar aerosol extinction profiles derived during May 13-21 were most likely associated with the smoke from fires in Central America since observations by several satellite sensors and trajectory analyses indicated that smoke produced by these fires traveled over northern Oklahoma (Peppler et al. 1999). Profiles from this event, which are shown in Figure 2, display large

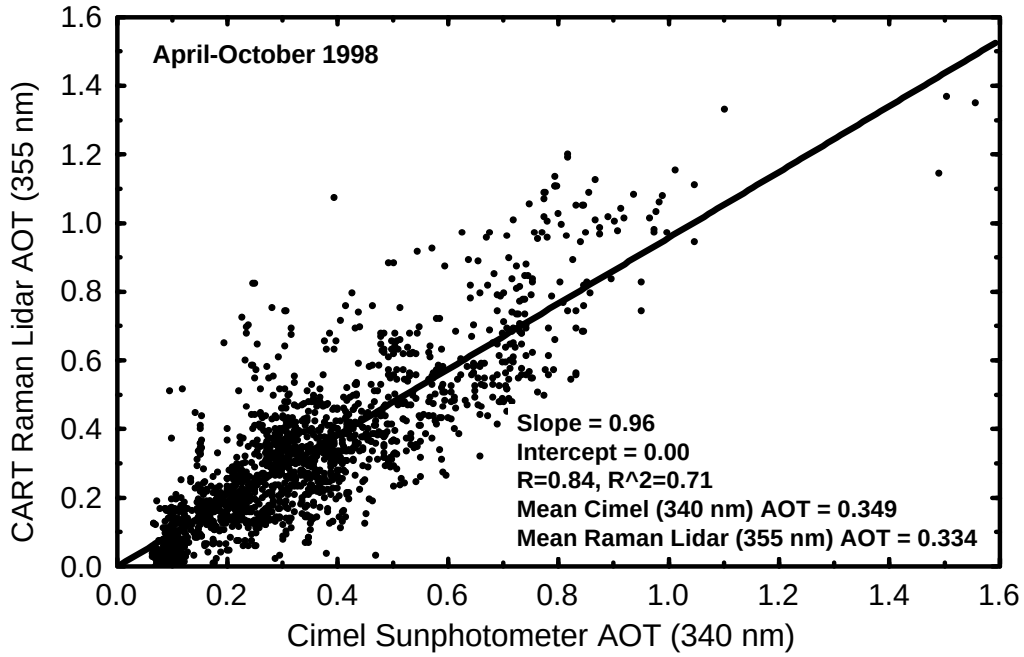

Figure 1. Comparison of AOT between the Cimel Sunphotometer (340 nm) and Raman Lidar (355 nm) between April and October 1998.

variability in both the magnitude and vertical distribution of aerosol extinction during these periods. We are using the lidar profiles to characterize the vertical distribution of aerosols. Figure 3 shows that the average altitude of aerosols increased as the AOT increased for measurements acquired between April and October 1998.

We have also begun using these lidar aerosol and water vapor profiles to investigate the relationships among water vapor mixing ratio, relative humidity, aerosol extinction, and aerosol extinction/backscatter ratio for hygroscopic aerosols. Figure 4 shows segments of the lidar profiles between 2 km to 3.5 km acquired at 01:10 Universal Time Coordinates (UTC) on September 1, 1998. Since the water vapor mixing ratio was approximately constant in this altitude region, the increase in relative humidity is due to the decrease in temperature with altitude. 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. Lidar data such as these are being used to help characterize how aerosol extinction varies with relative humidity.

Acknowledgments

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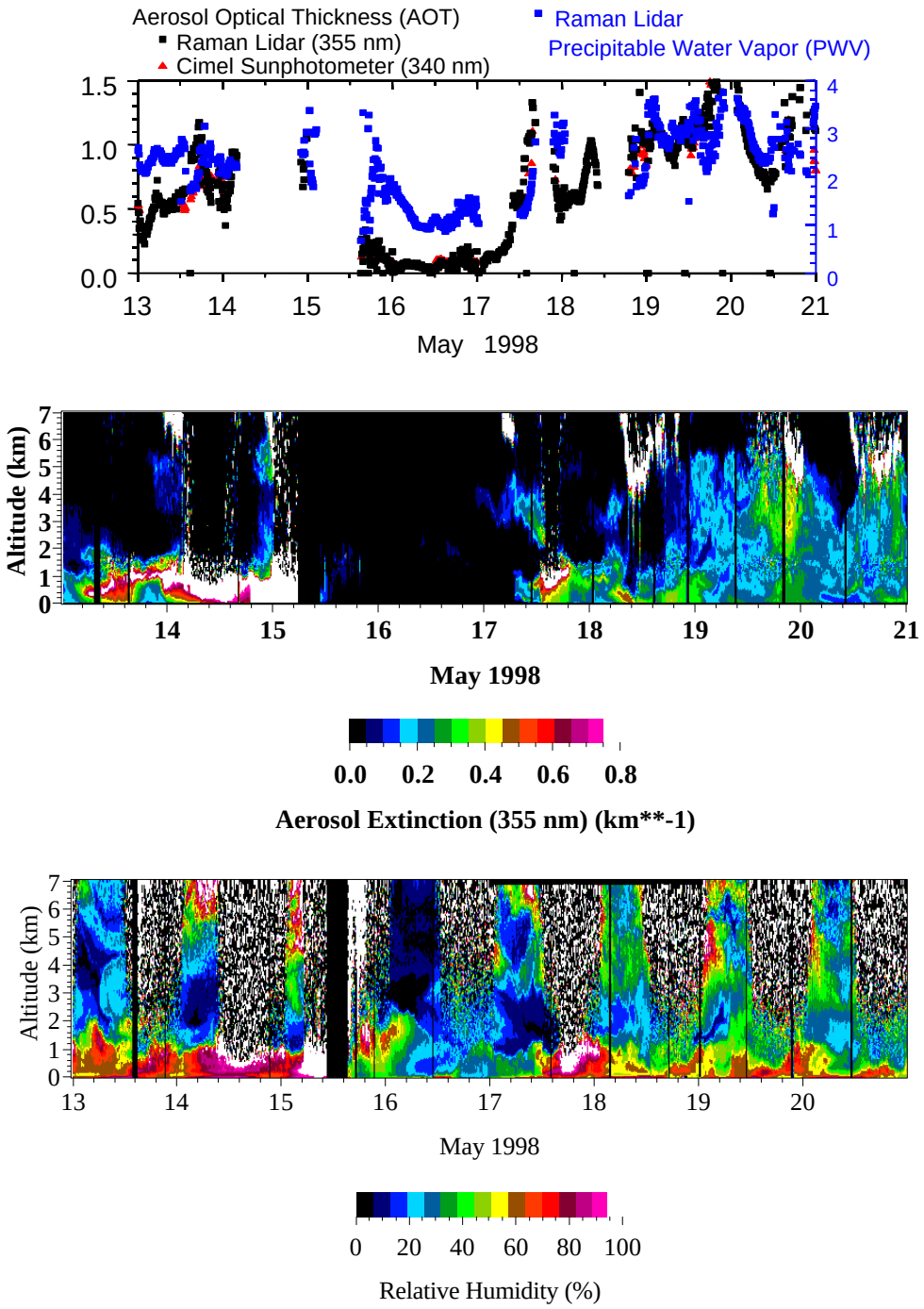

Figure 2. (top) AOT and PWV measured by the SGP CART Raman Lidar during May 13-20, 1998. AOT measured by the SGP Cimel Sunphotometer is also shown. Aerosol extinction (middle) derived from the Raman Lidar and relative humidity (bottom) derived from the Raman Lidar and AERI+GOES temperature data. White areas in the images denote clouds while the stippled regions above 3 km in the relative humidity image is due to the increased solar background during the daytime.

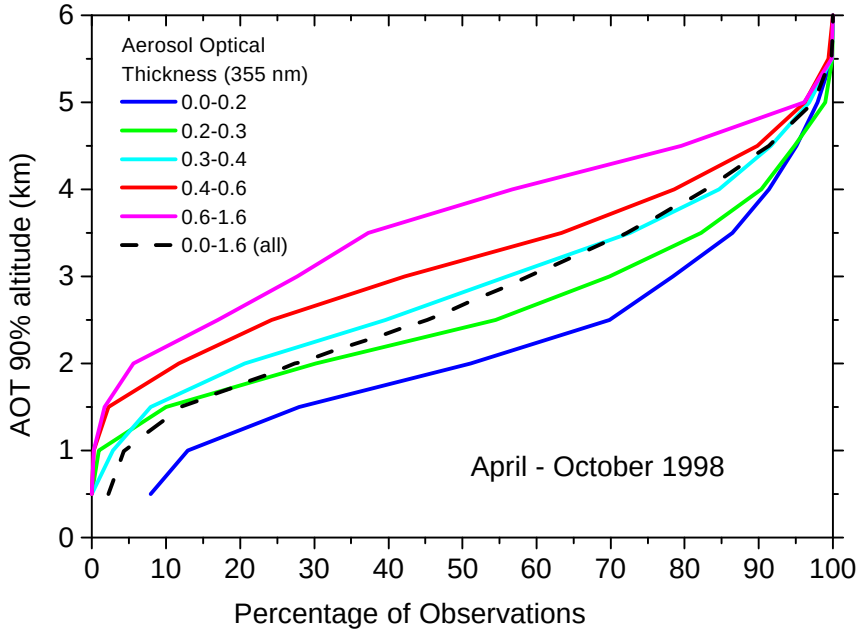

Figure 3. Altitude below which 90% of AOT was measured for various ranges of AOT as derived from Raman Lidar aerosol extinction profiles measured between April and October 1998.

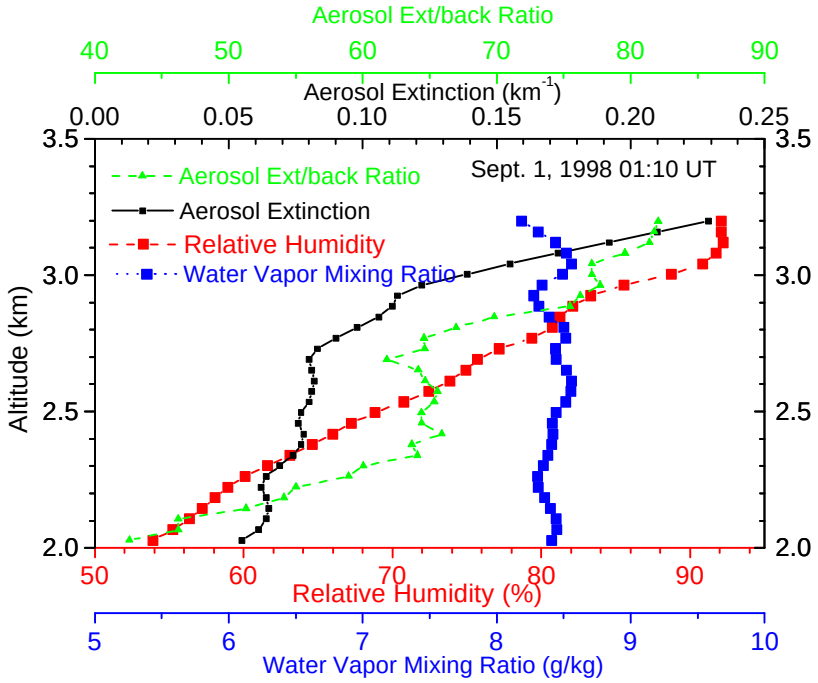

Figure 4. Water vapor and aerosol profiles derived from Raman Lidar data on September 1, 1998.

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