Scanning Raman Lidar Measurements of Water Vapor and Aerosols During the Tropical Aerosol Radiative Forcing Observational Experiment and the Water Vapor Intensive Operations Period

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Introduction

The National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC) Scanning Raman Lidar (SRL) recently participated in two field experiments: TARFOX (Tropospheric Aerosol Radiative Forcing Observational Experiment) held at Wallops Flight Facility in July 1996, and the First Water Vapor Intensive Operations Period (IOP) held during September 1996 at the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site near Lamont, Oklahoma.

During TARFOX, the SRL operated exclusively during the daytime, acquiring 95 hours of aerosol backscattering and extinction measurements on 15 days. These lidar data are used to derive aerosol extinction and aerosol optical thickness as a function of altitude and time.

During the Water Vapor IOP, the SRL measured water vapor during both daytime and nighttime operations in order to help characterize the water vapor in the lowest kilometer of the atmosphere and to develop an accurate calibration of the Cloud and Radiation Testbed (CART) Raman lidar without relying on radiosondes. Several different instruments participated, including Raman lidars, radiosondes, microwave radiometers, dew point hygrometers, GPS (Global Positioning System), and surface and tower-mounted hygrometers.

Water vapor mixing ratio profiles measured by the SRL are compared with those profiles measured by radiosondes and the SGP CART Raman Lidar. By integrating the SRL data, we have derived precipitable water vapor (PWV) to compare with water vapor measurements made by other sensors. Recent upgrades to the SRL system permitted measurements of water vapor during the day as well as at night. Water vapor profiles extending to altitudes of about 5 km were acquired during daytime operations.

Instrument

The GSFC SRL employs two different lasers, depending on whether data are acquired at nighttime or daytime. For nighttime operations, the SRL uses an XeF excimer laser to transmit light at 351 nm. Light backscattered by molecules and aerosols at the laser wavelength is detected, as well as Raman scattered light from water vapor (403 nm), nitrogen (382 nm), and oxygen (371 nm) molecules. The signals are gathered by a 0.76-m diameter telescope, detected by photo-multiplier tubes, and recorded using photon counting. A steerable elliptical flat provides full 180 degree, horizon-to-horizon scan capability within a single scan plane. The scan capability was used to increase the vertical resolution of the data as well as to facilitate comparisons with tower instruments. The water vapor mixing ratio was derived from the ratio of water vapor to nitrogen Raman signals. Aerosol scattering ratio profiles were derived from the Raman nitrogen signal and the signal detected at the laser wavelength; the aerosol volume backscattering cross section was then computed from the scattering ratio and from the molecular volume backscatter cross section calculated from coincident density data. The aerosol extinction cross section is computed from the derivative of the Raman nitrogen return signal with respect to range. Details are discussed by Ferrare et al. (1992, 1993) and Whiteman et al. (1992).

To facilitate daytime measurements, the SRL has recently been upgraded by adding a tripled Nd:YAG laser, narrowband interference filters, and a dual (narrow and wide) field of view optics design. This laser, which transmits light at 355 nm, operates at 30 Hz, with 300 millijoule pulses giving an average power of about 9 W. The laser beam divergence is reduced to below 0.2 mrad by means of an x3 beam expander; this low divergence permits the use of a narrow (0.25 mrad) field of view in addition to the wide (2.0 mrad) field of view. The narrow field of view, coupled with the use of narrowband (~0.2-0.3 nm bandpass) filters, reduces the background skylight and, therefore, increases the signal/noise ratio during the daytime operations. During daytime operations, the light backscattered at this wavelength is detected, as well as the Raman returns from water vapor (408 nm), nitrogen (387 nm), and oxygen (376 nm) molecules.

Water Vapor Comparisons

During the Water Vapor IOP, the SRL measurements are used to compare with the water vapor measurements acquired by several other sensors in three ways: profile comparisons (i.e., radiosondes, CART Raman Lidar), point measurements (tower sensors), and integrated precipitable water vapor (microwave radiometers). Figure 1 shows examples of these comparisons for data acquired during the night of September 28, 1996.

The SRL water vapor measurements acquired on 17 nights during the first Water Vapor IOP are used to compare the water vapor measurements acquired by several other sensors. Figure 2 shows a comparison of water vapor measurements acquired by the various sensors using the SRL measurements as a transfer standard. In this case, the SRL water vapor measurements were calibrated using the ensemble of Vaisala 62 (June 1996) and 63 (August 1996) series radiosondes (Liljegren and Lesht 1997). With the exceptions of the Vaisala 62 series radiosonde and the tethersonde chilled mirror, the SRL data show that the water vapor measurements acquired during the First Water Vapor IOP generally agree within 5%.

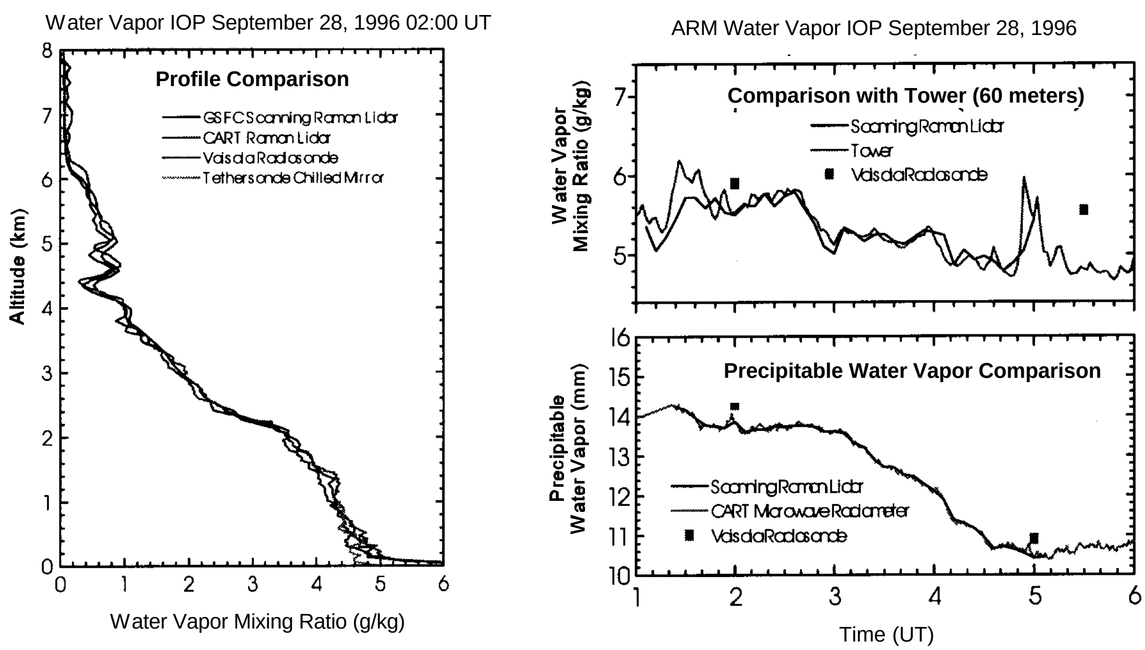

Figure 1. SRL water vapor comparisons for data acquired on the night of September 28, 1996.

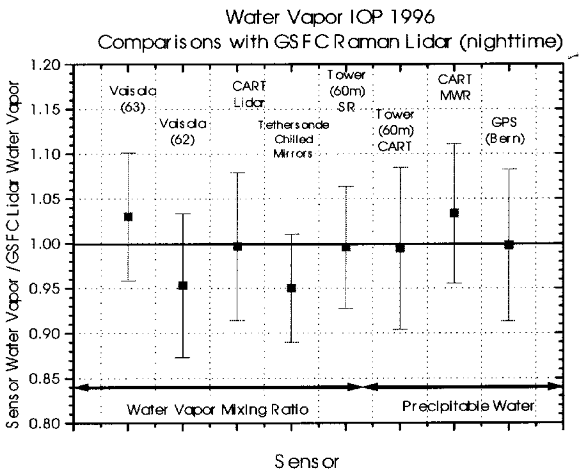

Figure 2. Comparison of water vapor measurements made by several sensors during the First Water Vapor IOP as determined from SRL data. The horizontal line at 1.0 represents a single SRL water vapor calibration using both (63 and 62) Vaisala radiosondes.

The SRL acquired daytime water vapor measurements as well as nighttime. Figure 3 shows an example of the daytime water vapor measurements as well as a comparison of a daytime water vapor profiles with one measured by a radiosonde.

TARFOX

The Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) was conducted during July 1996 with aircraft and surface measurements based at NASA Wallops Flight Facility in Virginia. This experiment was designed to perform a radiative "column closure" experiment by measuring the direct effects of tropospheric aerosols on regional radiation budgets of the cloudfree atmosphere while measuring the chemical, physical, and optical properties of the aerosols (Russell 1996; 1997).

During TARFOX, the SRL measured aerosol backscattering and extinction profiles in order to assess the contributions of different aerosol layers to the column integrated measurements acquired by surface and satellite based sensors. Figure 4a shows an example of the aerosol extinction coefficient measured by the lidar during daytime operations on July 17; Figure 4b shows the integrated aerosol optical thickness measured by the lidar during this same day. Comparisons of aerosol optical thickness

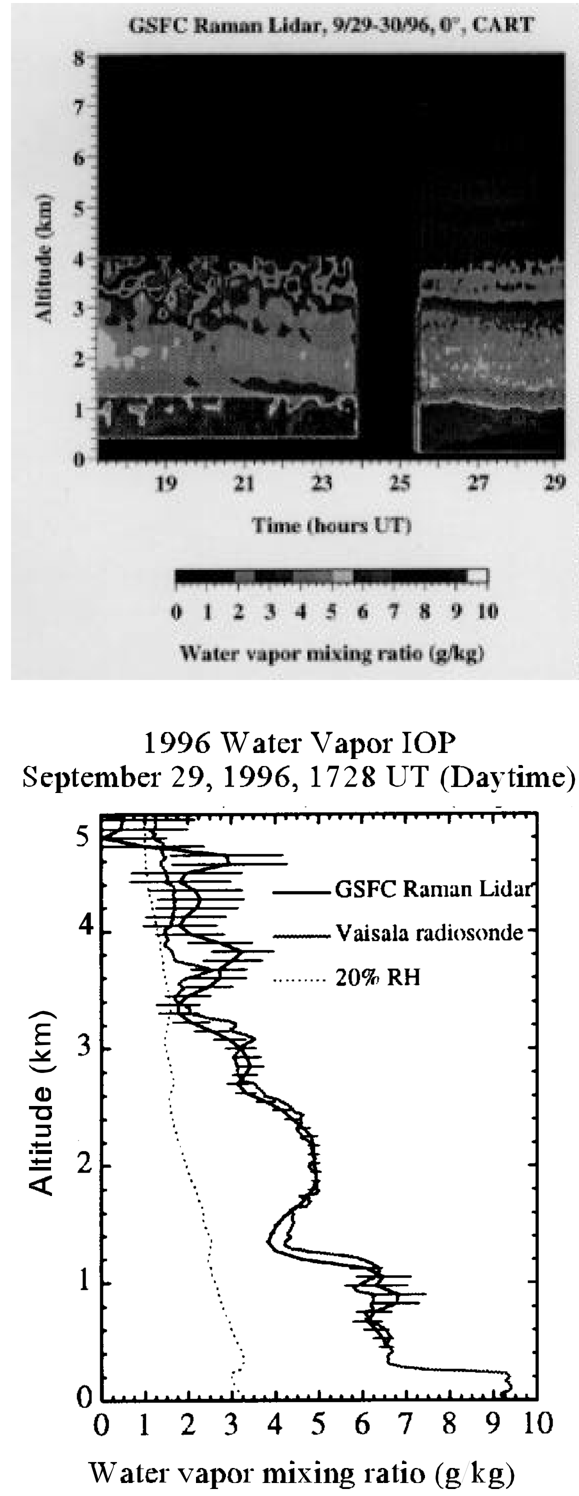

Figure 3. The top image shows both daytime and nighttime data, while the graph on the bottom shows a comparison between the GSFC Raman lidar and a radiosonde.

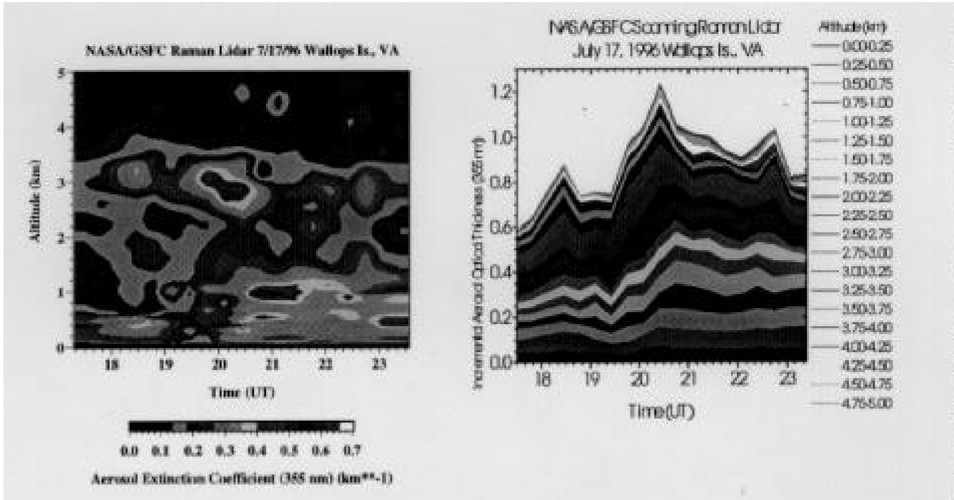

Figure 4. (Left) Aerosol extinction coefficient derived from the SRL aerosol backscattering profiles at 355 nm during measurements acquired on July 17, 1996, at TARFOX. Figure 4b (right) shows the aerosol optical thickness in each 250-meter thick layer between 0-5 km on this same night. The incremental aerosol optical thickness in each 250-meter thick layer is shown as a different color; the thickness of each line represents the aerosol optical thickness in the layer. The total aerosol optical thickness between 0-5 km is given by the total area.

measured by the SRL with those measured by airborne and ground-based sun photometers have shown agreement to within about 10% (Ferrare et al. 1997).

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