Raman Lidar Measurements of Aerosols and Water Vapor

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The National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC) scanning Raman lidar (SRL) has been used during recent field experiments to measure profiles of water vapor mixing ratio, aerosol extinction, and backscattering. The SRL acquired more than 123 hours of water vapor and aerosol profile data over 15 nights of operations during the first Atmospheric Radiation Measurement (ARM) Remote Cloud Sensing (RCS) intensive observation period (IOP) held in April 1994 at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site. An additional 67 hours of data were acquired over 16 nights of operation during the CAMEX-2 (Convection and Moisture-2) and LASE (Laser Atmospheric Sensing Experiment) held at Wallops Island, Virginia, in August and September 1995.

Using data from both experiments, we have examined the lidar water vapor calibration characteristics and have compared the lidar profiles with water vapor measurements acquired by various radiosonde packages, aircraft sensors, and tower-based instrumentation. Temperature profiles derived from coincident downwelling radiances measured by University of Wisconsin AERI (Atmospheric Emitted Radiance Interferometer) instruments and from coincident radiosonde profiles are used to convert the lidar water vapor mixing ratio profiles into relative humidity profiles. These water vapor mixing ratio and relative humidity profiles derived from lidar data are then used to examine how relative humidity affects aerosol extinction.

Instrument

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 photomultiplier 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. The lidar water vapor profiles are then used in conjunction with temperature profiles measured by radiosondes, as well as derived from coincident downwelling radiances measured by the AERI instrument (Smith et al. 1995), to compute profiles of relative humidity. 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).

Water Vapor Calibration/ Comparisons

The SRL water vapor calibration is normally obtained by comparing the lidar water vapor ratios with water vapor mixing ratio profiles measured by coincident radiosondes (Ferrare et al. 1995). This calibration constant has been found to vary, depending on the type of radiosonde used for comparison. Figure 1 shows the water vapor calibration constant obtained from recent field experiments including the RCS IOP help at the SGP site in 1994 and, most recently, at Wallops Island, Virginia, in August-September 1995. There is about a 5% to 7% difference in the calibration constant, depending on the type of radiosonde sensor used in the comparison. The lidar water vapor calibration constant was found to vary by less than 5% over a 4-year period when calibrated using Vaisala radiosondes and 7% when calibrated using AIR/VIZ

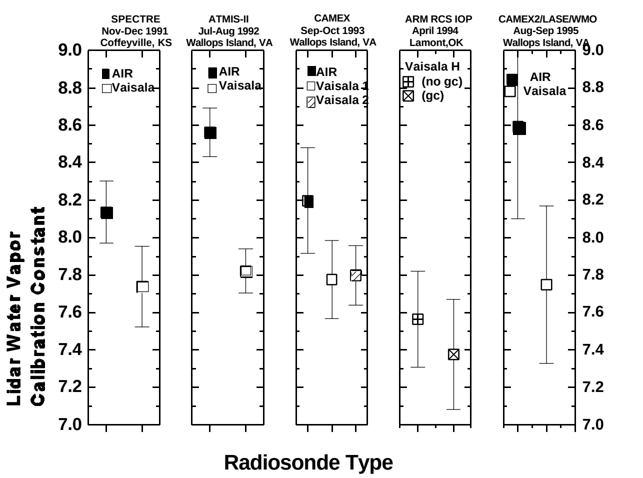

Figure 1. Lidar calibration constants obtained by comparisons with AIR, VIZ, and Vaisala radiosondes. Two separate Vaisala radiosondes were launched during the CAMEX experiment at locations separated by about 5 km. During the RCS IOP, calibrations were performed using radiosonde data procssed both with and without the ground check calibration. Error bars represent standard deviations.

radiosondes. The Vaisala sondes use a capacitive element to measure water vapor, while the AIR/VIZ sondes use a carbon hygristor humidity sensing element. Because it is not clear which calibration constant is more accurate, we have compared the lidar water vapor measurements with those derived from other instruments to assess both the accuracy and precision of the lidar water vapor data.

Water vapor profiles derived from SRL data acquired during the CAMEX2/LASE/WMO experiments were compared with water vapor profiles acquired by several instruments, including Vaisala and VIZ radiosondes, the LASE water vapor DIAL (differential absorption lidar) lidar flown on the NASA ER-2 (Browell 1995), and GE 1011 chilled mirror dew point hygrometers flown on two additional aircraft (Lear jet and a C-130). In addition, pointing the SRL nearly horizontally enabled us to compare the lidar water vapor measurements with those measured by an hygrometer mounted on top of a building 3.2 km away. Examples of these comparisons are shown in Figure 2. Bias and root-mean-square differences between the lidar water vapor mixing ratio profiles and those from the instruments listed above were found to be generally less than 1 g/kg, as shown in Figure 3.

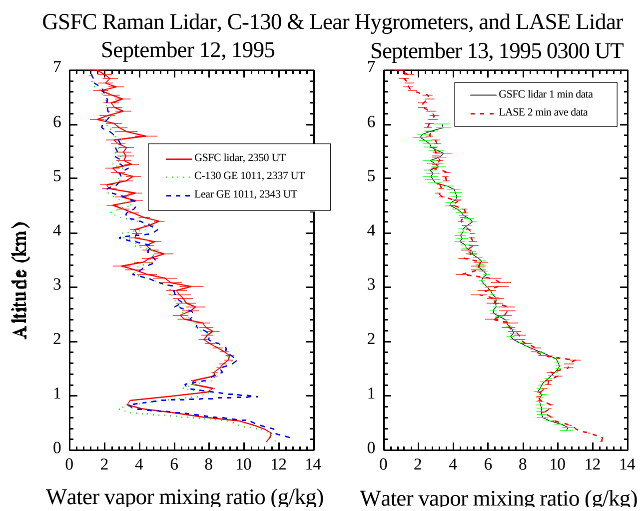

Figure 2. The left graph shows a comparison between the Raman lidar 1-minute data, the C-130 GE 1011 hygrometer data**,** and the Lear GE 1011 hygrometer data. The right graph shows a comparison of Raman lidar 1-minute data with the Laser Atmospheric Sensing Experiment (LASE) 2-minute average data. All three aircraft were flying in the vicinity of the Raman lidar, located at the Wallops Flight Facility, Wallops, Virginia, for coincident measurements.

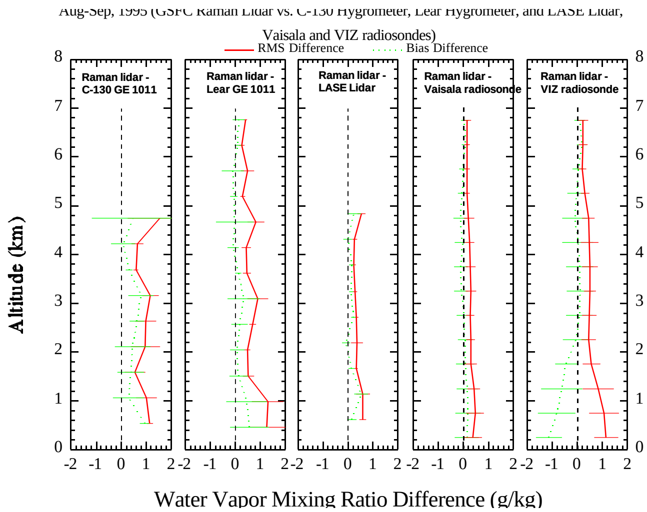

Figure 3. Bias and root-mean-square differences between the SRL and various sensors. Data were grouped into 525-meter bins to compute these differences.

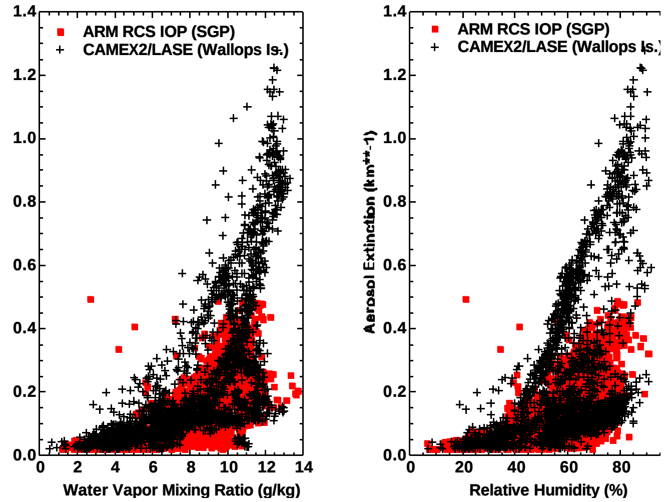

Figure 4. Relationship between water vapor mixing ratio, relative humidity, and aerosol extinction measured by the SRL during the RCS IOP and CAMEX2/LASE/WMO experiments.

Aerosol/Water Vapor Variability

The ability of the SRL to remotely measure both water vapor and aerosol backscattering and extinction in the same volume is ideal for studying how aerosol optical properties vary with water vapor. Water vapor profiles computed from the SRL data and relative humidity profiles derived from SRL water vapor and AERI/radiosonde temperature data were used to study the hygroscopic nature of aerosols. Data from the SGP site and from Wallops Island were included to determine how these aerosol properties vary among these sites. When all data are grouped together, there is a general increase in aerosol extinction with both water vapor mixing ratio and relative humidity, as shown in Figure 4. Since aerosol extinction is affected by changes in both the number and physical properties of aerosols, there is no simple relationship relating aerosol extinction to either water vapor mixing ratio or relative humidity.

However, by isolating periods of constant mixing ratio so that changes in relative humidity were due to changes in temperature only and by normalizing the measured aerosol extinction to a constant relative humidity, we attempted to characterize the observed humidity dependence of aerosol extinction. Figure 5 shows that the dependence of aerosol extinction on relative humidity as derived from these measurements can be used possibly to identify aerosol types.

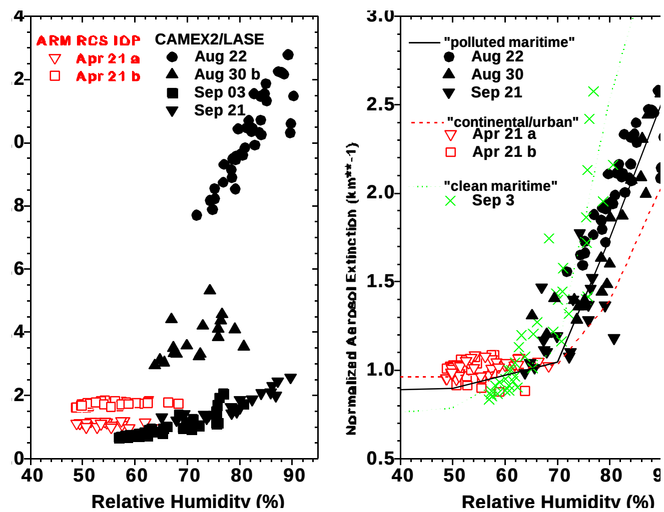

Figure 5. (Left) Aerosol extinction vs. relative humidity for periods and altitude regions of constant water vapor mixing ratio. (Right) Same, except aerosol extinction has been normalized to unity at a relative humidity of 62%. Also shown are the relative humidity dependences for three aerosol models.

References

Browell, E. V., 1995: Airborne Lidar Measurements, *Rev. of Laser Engineering*, **23**, 2, 135-141.

Ferrare, R.A., S.H. Melfi, D.N. Whiteman, and K.D. Evans. 1992: Raman lidar measurements of Pinatubo aerosols over southeastern Kansas during November-December 1991, *Geophys. Res. Letters*, **19**, 15, 1599-1602.

Ferrare, R.A., S.H. Melfi, D.N. Whiteman, and K.D. Evans, 1993: Coincident Measurements of Atmospheric Aerosol Properties and Water Vapor by a Scanning Raman Lidar, *Optical Remote Sensing of the Atmosphere Technical Digest*, (Optical Society of America, Washington, D.C.), **5**, 11-14.

Ferrare, R.A., S.H. Melfi, D.N. Whiteman, K.D. Evans, F.J. Schmidlin, and D.O'C. Starr, 1995: A Comparison of Water Vapor Measurements made by Raman Lidar and Radiosondes, *J. Atmos. Oceanic Tech.*, **12,** 6, 1177-1195.

Smith, W.L., W.F. Feltz, R.O. Knuteson, and H.E. Revercomb, 1995: PBL Sounding and Cloud Emittance Observations with ARM-CART AERI Observations, *Proceedings of the Fifth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, U.S. Department of Energy, Washington, D.C.