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WATER MEASUREMENTS USING A RAMAN LIDAR

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INTRODUCTION

The research record for the usefulness of Raman Lidar in addressing a broad range of important atmospheric research topics is well established. Raman lidar technology has been used to measure tropospheric aerosols (Ansmann, 1990, Ferrare, 1998, Müller, 2000, Veselovskii, 2002), stratospheric aerosols (Ferrare, 1992) and cirrus clouds (Ansmann, 1992, Reichardt, 1999, Whiteman, 2001). Arguably the most important measurements offered by Raman lidar for both dynamic and radiative studies, however, is that of water vapor (Whiteman, 1992). We will describe large improvements in Raman lidar measurements of water vapor made possible through recent technology upgrades. Furthermore, we will present the use of Raman lidar to study liquid water in the atmosphere and describe current research into the use of Raman lidar measurements to estimate ice water content of cirrus clouds.

DAYTIME WATER VAPOR MEASUREMENT IMPROVEMENTS

Traditionally the Raman lidar measurement of water vapor mixing ratio during the daytime has presented numerous technical challenges due primarily to the relatively small cross section that characterizes the Raman scattering process. Over the last several years, various research groups have focused on the use of a combination of narrow spectral bandwidth and narrow field of view to decrease the large signal due to skylight permitting the weak Raman signals to be measured. This is the approach in use by the DOE Raman lidar in Oklahoma (Goldsmith, 1998, Turner, 2002). However, due to the counting rate limitation of the data acquisition electronics available when that system was constructed, only 10% of the water vapor signal is used during the daytime when solar background greatly increases the photon arrival rate. The Raman nitrogen signal, required to normalize the water vapor measurement in the calculation of water vapor mixing ratio, is attenuated by approximately a factor of 20 under both daytime and nighttime conditions for the same reason.

Recent advances in interference filter technology and in data acquisition electronics now make it possible to use the full intensity water vapor and nitrogen signals even under bright daytime conditions. The NASA/GSFC Scanning Raman Lidar (SRL) and Raman Airborne Spectroscopic Lidar (RASL) both use this new approach. Two examples of data acquired using these new technologies are presented in figure 1.

This improved daytime water vapor measurement capability permits boundary layer moisture evolution to be studied in a manner never before possible using Raman lidar. On the left is shown the water vapor

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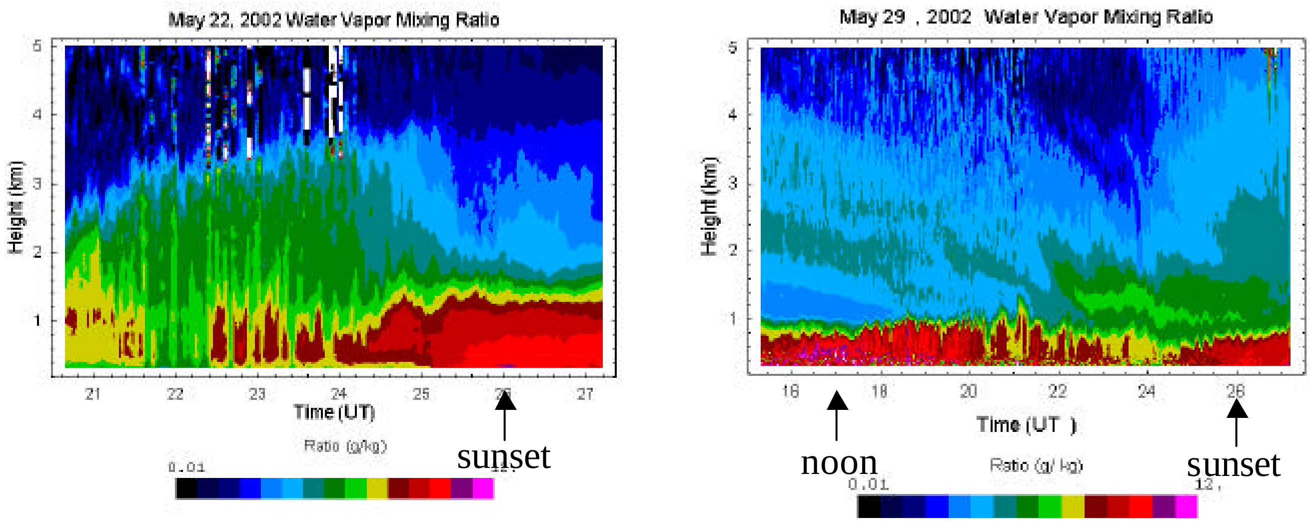

Figure 1 Water vapor mixing ratio (g/kg) acquired in western Oklahoma during the International H2O Project (IHOP) in 2002. The data are presented with 3-minute temporal resolution and vertical resolution ranging between 200 and 400 meters. On the left is shown the evolution of moisture during the passage of a dryline over the lidar site. On the right is shown data acquired during a boundary layer evolution mission during IHOP. These measurements possess a factor of 2-3 larger signal to noise due to the technology upgrades used in the SRL

mixing image acquired during the passage of a dryline on May 22, 2002 near the lidar site in western Oklahoma as a part of the International H_2O project – 2002. The increase in the boundary layer height is evident until 2400 UT when the moisture profile changes dramatically due to a better definition of the dryline features. On the right is shown measurements acquired during a boundary layer evolution mission on May 29, 2002 during IHOP. The turbulent structure on the top of the shallow boundary layer is clearly visible. These measurements possess 3-minute temporal and between 200 – 400 m spatial resolution. The random error is <10% throughout the boundary layer.

RAMAN LIDAR MEASUREMENTS OF LIQUID WATER

The measurement of Raman scattering from cloud droplets has been demonstrated (Melfi 1997) and used to create a retrieval technique for cloud liquid water, cloud droplet radius and droplet number density (Whiteman 1999). Other groups have developed lidar systems specifically tailored to these cloud measurements (Rizi, 2002). The previous measurements made with the SRL were somewhat serendipitous in that both liquid and vapor were present in the same instrument channel. For the deployment to IHOP, the SRL was outfitted with separate channels for vapor and liquid. We present here some of the first measurements made using this new experimental configuration. These recent measurements confirm the sensitivity of the Raman lidar to liquid water in clouds but they also apparently reveal a high sensitivity to small amounts of liquid water in hydrated aerosols. Figure 2 shows side-by-side images of quantities proportional to aerosol depolarization ratio and liquid water mixing ratio. (At the time of this abstract, absolute calibrations were not available for these quantities). Thin clouds were present only at approximately 2 km in altitude at the following times: 27.5-27.75, 28-28.5 UT.

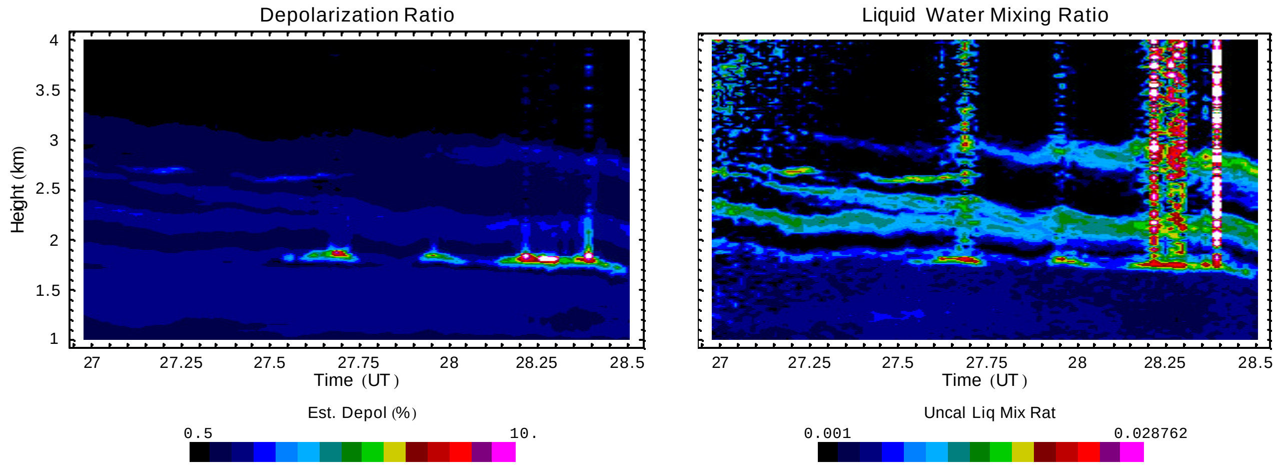

Figure 2 Aerosol depolarization and liquid water mixing ratio (uncalibrated) measurements from the night of May 25, 2002 during the IHOP field campaign. The high correlation between the aerosol layers and the liquid water signal is evident. The strong scattering from aerosols (in addition to the previously measured liquid water in clouds) points toward a new technique for measuring the liquid water content of aerosols in the atmosphere.

(The increase in depolarization in the clouds is an indication of multiple scattering in the clouds since depolarization should be small for the spherical droplets that populate clouds.) The other layers present in the depolarization image are boundary layer aerosols and not clouds. The correlation between the depolarization, either for aerosols or clouds, and the liquid water signal is striking. A large body of empirical (Whiteman 1999) and theoretical evidence (Veselovskii, 2002) indicates that the intensity of signal from Raman scattering by spherical droplets is proportional to the volume of the droplet and thus the liquid water content of the droplet. If the same proportionality is assumed between intensity of scattering and water content for the ydrated aerosols shown here, unrealistically large estimates (by >2 orders of magnitude) of the liquid water content are determined. The provisional conclusion that we have drawn from these measurements is that the liquid water signal from aerosols is enhanced by several orders of magnitude perhaps due to surface enhanced Raman scattering. Clearly this new measurement capability requires further study to understand, but the anomalously strong signals from hydrated aerosols offers the possibility of measuring the liquid water content of aerosols, which is a measurement that was not previously thought to be possible.

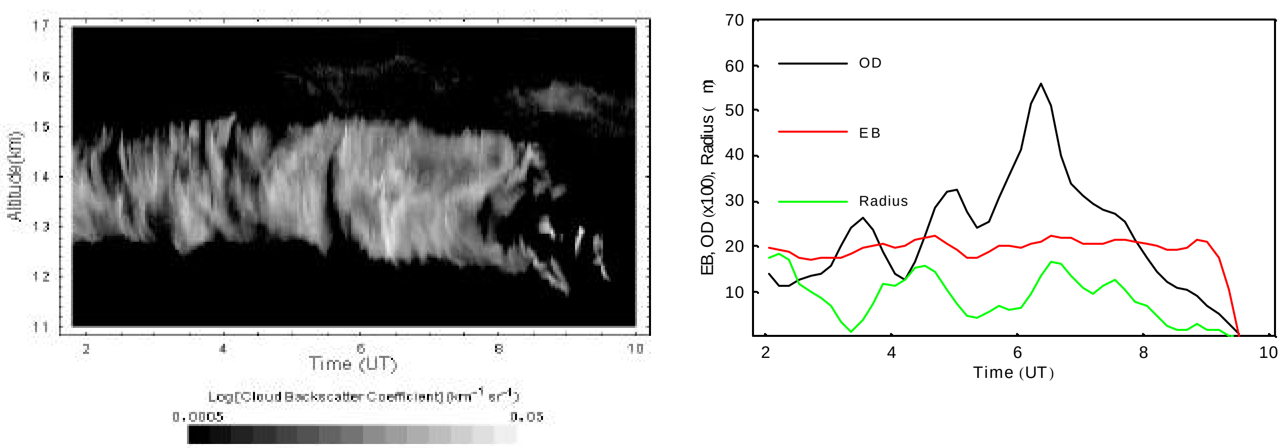

Figure 3 On the left is shown the backscatter coefficient measurements for cirrus cloud on the night of August 23, 1998 during the CAMEX-3 field campaign. The multiple scattering corrected optical depth, layer mean extinction to backscatter ratio and equivalent particle radius are shown on the right.

CIRRUS CLOUD OPTICAL DEPTH, PARTICLE RADIUS MEASUREMENTS

Optical depth measurements have been made using lidar for a number of years. In any dense medium, one needs to consider the influence of multiple scattering on the quantification of optical depth since the influence of multiple scattering is to decrease the apparent extinction in a cloud (Eloranta, 1998). However, multiple scattering also provides another piece of information that can be used to derive information about the size of the ice crystals in the cloud (Whiteman, 2001). Figure 3 shows the results of an iterative technique that simultaneously solves for the layer mean extinction to back scatter ratio and diffraction equivalent particle radius in a cirrus cloud. Knowledge of these two quantities permits a correction to be made for the influence of multiple scattering on cirrus cloud optical. If the mean particle size in the cloud is known, an estimate of the liquid water content is possible since the Raman lidar also measures cirrus cloud optical depth. However, the mean particle size that is retrieved with this lidar-based technique is that of the sphere that exhibits similar diffraction properties to the actual crystals in the cloud. A detailed study of the diffraction properties of various crystal shapes along with that of the equivalent spheres needs to be performed to estimate the ice water content of the cloud from these lidar measurements.

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