SAND--95-8503C
Conf-950277--2

Measurements of Daytime and Upper Tropospheric Water Vapor Profiles by Raman Lidar

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1. Introduction

One of the most important atmospheric constituents needed for climate and meteorological studies is water vapor. Water vapor plays an important role in driving atmospheric circulations through latent heat release and in determining the earth's radiation budget, both through its radiative effects (water vapor is the major greenhouse gas) and cloud formation. The vertical distribution of water vapor is particularly important because it not only determines convective stability but radiative effects are also strongly altitude dependent. In fact, several one-dimensional radiative convective models[1] have shown that although upper tropospheric water vapor concentrations are 2-3 orders of magnitude less than those near the surface, upper tropospheric water vapor exerts an important influence on climate. What these models show is that for a given *fractional* increase in water vapor at a given altitude the response or change in surface temperature is qualitatively the same. At present, considerable controversy exists over the nature of the vertical redistribution of water vapor in a changing climate, and particularly the distribution of water vapor in the upper troposphere. Understanding upper tropospheric moistening processes such as deep convection are therefore of prime importance in addressing the water vapor feedback question. Accurate measurements of the vertical and temporal variations of water vapor are therefore essential for understanding atmospheric processes and hence model refinement.

A powerful, proven technique for the continuous measurement of nighttime water vapor profiles (in clear skies or up to the lowest cloud level) with high spatial and temporal resolution is Raman lidar.[2,3] Raman lidar has routinely demonstrated the ability to measure nighttime water vapor profiles up to 9 km with 90% accuracy. The influence of solar radiative forcing and the need for continuous data records provides strong motivation for the development of similar daytime capabilities. Daytime measurements are limited, however, by the difficulty of detecting the relatively weak backscattered Raman signal against the large solar background.

As part of the U. S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) program, we have developed a high performance dual field-of-view (fov), narrowband Raman lidar system capable of both *daytime* and nighttime operation. In this paper, we discuss the Sandia Raman lidar system and its application to two problems of current interest: daytime tropospheric water vapor profile measurements and upper tropospheric water vapor. We present recent measurements of upper tropospheric moisture made at the DOE Cloud and Radiation Testbed site (CART) in Oklahoma. Recent daytime measurements are also presented.

DISCLAIMER

2. Upper Tropospheric Water Vapor Measurements

Given the radiative importance of minute amounts of upper tropospheric water vapor on climate, it is important to understand the processes which distribute water vapor in the upper troposphere; namely deep convection. Recently, we fielded the Sandia Raman lidar at the DOE CART site in north central Oklahoma during the April 94 Intensive Observational Period (IOP). During this period, numerous instruments (including another Raman lidar) monitored the atmosphere, both at the central facility and at three boundary facilities located some hundreds of kilometers away in a triangular configuration. The CART site is an ideal location to study deep convection. Meteorological data for nearby Ponca city show that the frequency of thunderstorms during April is approximately 9-10 storms per month. Furthermore, thunderstorm activity peaks near midnight in this region, when Raman lidar measurements are most accurate and extend to highest altitude. Such activity affords the opportunity to study the pre-storm and post-storm environments which provides insight into which aspects of model parameterization need refinement.

During the three week period of the IOP from 4/11 to 4/29 the Sandia Raman lidar operated for 13 nights, during which it collected 68 hours of data. Several in-situ intercomparisons were made with dew-point and cryogenic hygrometers onboard the University of North Dakota Citation aircraft. These measurements were very valuable as radiosondes have well known difficulties at cold temperatures. We have used this data to examine the variability of water vapor at different altitudes. Figure 1 shows the clear sky, nighttime variability of upper tropospheric water vapor at the 250 and 500 mbar levels for the three week IOP period. The bimodal distribution at 500 mbar is thought to be due to the occurrence of frontal passages which do not extend deep into the upper troposphere. The utility of Raman lidar for such studies lies in its ability to make accurate water vapor measurements over short temporal and spatial scales. This allows us to assess the upper tropospheric water vapor variability associated with events that occur on short time scales such as isolated air mass thunderstorms.

3. Daytime Measurements

Although the nighttime capabilities of Raman lidar are well established, the daytime capabilities are not. The influence of solar radiative forcing, and the need for continuous data records provides strong motivation for similar daytime capabilities. The central problem in the development of a daytime capable Raman lidar is the detection of the relatively weak backscattered Raman signal against the large solar background. There are several approaches to this problem: solar blind operation in which one operates at wavelengths below 290 nm where the sky is effectively black; narrow-band, narrow field-of-view operation and a hybrid approach. While operation in the solar blind region of the spectrum effectively reduces the solar background, attenuation of the laser beam and the backscattered Raman radiation by tropospheric ozone is a serious problem. However this method has been used to make daytime water vapor measurements in the 1-2 km range.[4,5] In the narrow-band, narrow field-of-view approach, the background skylight is reduced by narrowing the receiver field-of-view while operating the laser outside the solar blind region (wavelengths longer than about 290 nm) thus avoiding the ozone attenuation problem. Narrow band detection is also employed to reduce the solar background without substantially reducing the weak Raman return signals. Ansmann et al.[6] have used this approach and have obtained daytime water vapor profiles up to 2.5 km with 180 m range resolution using integration times of approximately 15 min. At Sandia, we have developed a high performance, narrow-band, narrow field-of-view Raman lidar capable of daytime water vapor measurements up to 4 km or more depending on conditions. One of the problems introduced by narrow field-of-view operation is that the short range performance suffers due to poor overlap of the laser beam and telescope field-of-view at low altitudes. To overcome this problem, we have developed a dual field-of-view receiver which provides higher dynamic range and substantially better laser beam-telescope field-of-view overlap. The weak high-altitude signals are detected by a narrow fov channel, and the low-altitude signals are detected by a wide fov channel, in which the stronger signal levels compensate for the higher background level. Narrow band detection is achieved through the use of high performance UV interference filters. A recent daytime measurement made with this system in Livermore Ca., is shown in Fig. 2. Although it is a one hour average a ten minute average is similar. A neutral density filter of 1.0 was placed in both the water vapor and nitrogen Raman channels to reduce the background photon count rate to approximately 6 MHz. This was necessary as photon pile up was encountered at rates much above this. We plan to add a high speed photon counting system to avoid this problem. One of the key advantages of a narrow-band, narrow field-of-view is the ease with which one can transition from daytime to nighttime operation. This is accomplished merely by swapping the filter in the water vapor channel with a larger bandwidth one and removing the neutral density filters.

4. References

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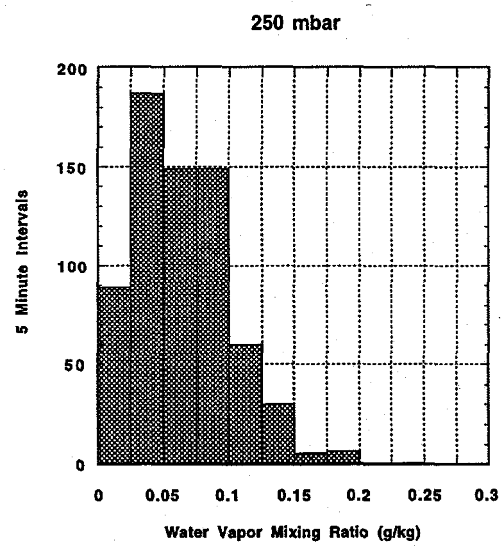

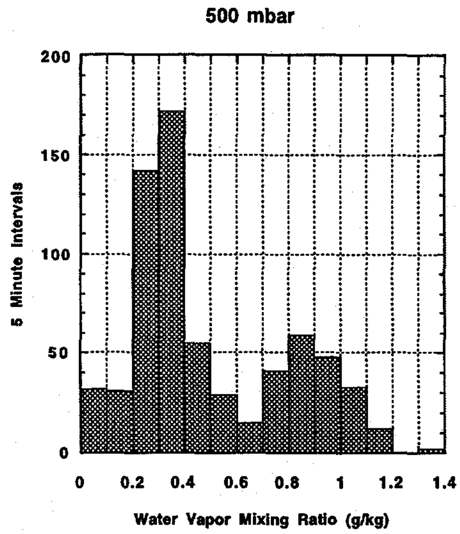

Figure 1. Clear sky, nighttime variability of upper tropospheric water at the DOE CART site during the three week period from 4/11 to 4/29.

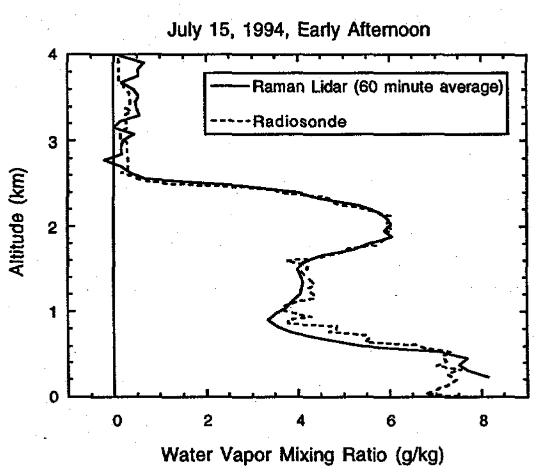

Figure 2. Daytime water vapor measurement made by the Sandia Raman lidar in Livermore, Ca. Average time was 1 hour and vertical resolution was 75 m. Although this was a one hour average a ten minute average is similar.

This work was supported by the U. S. Department of Energy, Atmospheric Radiation Measurement (ARM) Program.