26A2 A COMPARISON OF WATER VAPOR MEASUREMENTS MADE BY RAMAN LIDAR AND RADIOSONDES

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INTRODUCTION

Accurate measurements of water vapor are required to understand such important atmospheric processes as radiative transfer, cloud formation, and atmospheric circulation. Through its effect on the radiation budget as well as its relationship with cirrus cloud formation, upper tropospheric water vapor in particular has been identified as being an important variable in modeling any climate change associated with increased carbon dioxide. By virtue of its ability to provide both high spatial and temporal resolution measurements, Raman lidar has emerged in recent years as a potential tool for providing the detailed water vapor profiles required for modeling these complicated processes. These detailed water vapor measurements, especially at upper tropospheric levels, require understanding and quantifying the factors which limit the altitude range of the lidar measurements.

Using lidar water vapor measurements in climatological models also requires accurate and frequent monitoring of the lidar system water vapor calibration. A common approach to calibrating these lidar systems relies on comparisons with coincident measurements of atmospheric water vapor which typically have been provided by radiosondes. Over the past several years, we have been investigating how the water vapor profiles measured by the NASA/GSFC scanning Raman lidar compare with those measured by radiosondes. These comparisons have been useful not only for monitoring the lidar performance but also for evaluating the capabilities and limitations of various radiosonde packages. In this presentation, we discuss the factors which affect the lidar measurements of upper tropospheric

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water vapor and present the results of several lidar-radiosonde comparisons.

LIDAR SYSTEM

The GSFC scanning Raman lidar is a trailer-based system which uses a XeF laser to transmit light at 351 nm. A steerable elliptical flat provides full 180 degree horizon to horizon scan capability within a single scan plane. The combined aerosol and molecular backscattered light at the laser wavelength is detected as well as Raman scattered light from water vapor (403 nm), nitrogen (383 nm), and oxygen (372 nm) molecules. Profiles of water vapor mixing ratio are computed from the ratio of the return signals due to Raman scattering by water vapor to Raman scattering by nitrogen. An additional correction (<7% for altitudes below 12 km) is applied to account for the differential atmospheric transmission between the water vapor and nitrogen Raman wavelengths. In normal operation data from more than 23000 shots are recorded as one minute profiles with a range resolution of 75 m. The data discussed in this paper were acquired only at night to avoid interference from background skylight which interferes with the detection of the Raman signals.

The maximum altitude of the retrieved lidar water vapor profiles under cloud-free conditions is generally determined by the size of the random error which, in turn, depends on several instrumental and environmental factors. For a given output power and wavelength, the dominant instrumental factors include: background noise, averaging time, and vertical resolution while the most important environmental factors are: ambient water vapor concentration, background skylight, and atmospheric attenuation. The sensitivity of the Raman lidar water vapor retrievals to changes in these parameters was modeled using simulated lidar returns. The model used key system parameters, realistic atmospheric water vapor, density, and aerosol profiles, and measured background skylight values and produced simulated lidar return signals which were used exactly like actual lidar data. Verification tests showed excellent agreement between measured and modeled Raman water vapor lidar profiles.

The sensitivity of the Raman lidar water vapor retrievals to changes in several system and environmental factors is shown in figure 1. The reference case (denoted by the dotted line) used the following parameters: 18 Watts laser output power, 10 minute averaging period, background skylight corresponding to a moonless night, surface elevation at mean sea level, scan angle of 0 degrees (zenith), 75 meter vertical resolution, boundary layer aerosol concentration corresponding to the 23 km standard visibility model from Shettle and Fenn (1976), and a water vapor profile corresponding to a "dry" summer atmosphere. The water vapor profiles used for these models were constructed using the mid-latitude summer and winter pressure and temperature profiles given by McClatchey et al. (1971). The water vapor amounts in the "dry" cases correspond to a constant relative humidity of 10% with respect to ice while the "wet" cases correspond to a constant relative humidity of 90% with respect to ice. Figure 1 shows that the most important variable affecting upper tropospheric performance is the ambient water vapor concentration, which varies by a factor of about 50 between the extreme cases shown. Note that the effects of combining two or more factors can, in most cases, be approximated by adding (or subtracting) the changes in altitudes shown in figure 1. For example, by combining the individual effects of increasing the averaging time from 10 minutes to 1 hour and changing the vertical resolution from 75 m to 300 m would increase the maximum altitude from 7 to 9 km. Thus, by sacrificing spatial and/or temporal resolution, this lidar system can, in most cases, provide water vapor profiles extending into the upper troposphere.

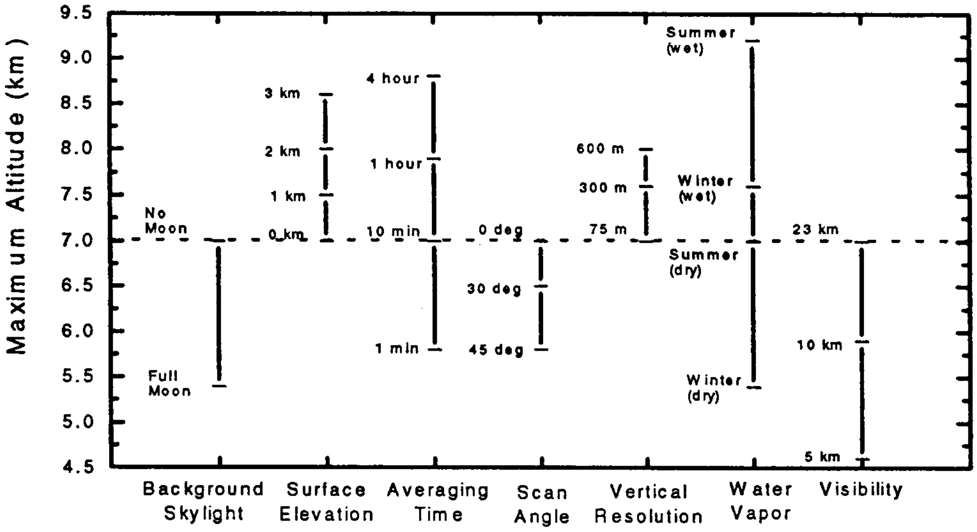

Figure 1. Maximum altitude for GSFC Raman lidar moisture measurements as a function of various system and environmental factors. Maximum altitude is here defined as the altitude below which the random error of the water vapor measurements is less than 20%.

LIDAR-RADIOSONDE COMPARISONS

The lidar and radiosonde data presented here were acquired during three experiments: FIRE-II[First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment] /SPECTRE [Spectral Radiation Experiment] held near Coffeyville, KS in November-December, 1991; ATMIS-II (Atmospheric Moisture Intercomparison Study) held at Wallops Island, VA in July-August, 1992; and CAMEX (Convection and Moisture Experiment) conducted at Wallops Island, VA in September-October, 1993. Radiosondes manufactured by the AIR and Vaisala corporations were used in each of the three field experiments. The moisture sensors on the AIR sensors were carbon hygristors while the Vaisala radiosondes carried thin film Humicap capacitive elements. During the FIRE-II/SPECTRE experiment, these radiosonde packages were launched on separate balloons normally launched a few hours apart; in the ATMIS-II and CAMEX experiments these sensors were carried aloft by the same balloon. During the CAMEX experiment, a second balloon launched by personnel from the University of Wisconsin-Madison also carried a separate Vaisala package.

The lidar water vapor mixing ratio profiles were calibrated using a least-squares regression of the lidar ratios to the water vapor mixing ratios measured by each of these radiosondes. Only radiosonde data for relative humidities above 30% were used to calibrate the lidar because of potential unreliable moisture measurements in dry conditions. A single, range-independent calibration constant corresponding to each radiosonde moisture sensor type was computed for each experiment; these constants are shown in figure 2. These data indicate that the water vapor measured by the Vaisala capacitive moisture element was systematically 7-10% lower than that measured by the AIR carbon hygristor sensor. It is currently not clear which radiosonde sensor provides the more accurate water vapor measurement. Over this two year period, the lidar calibration constant varied by less than 5% when computed using AIR moisture data and less than 1% when computed using the Vaisala moisture data.

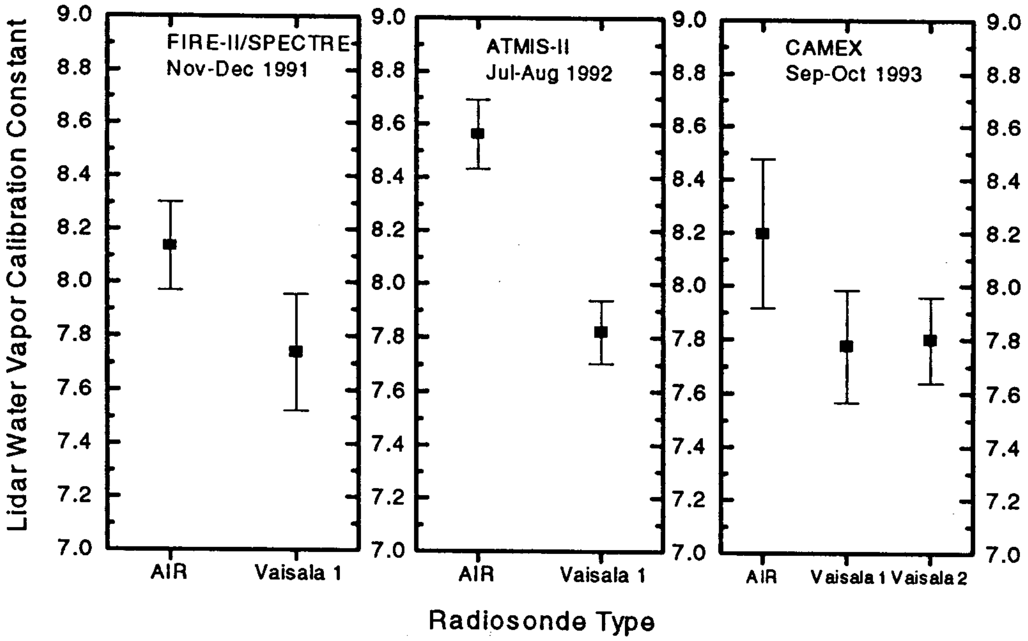

Figure 2. Lidar water vapor calibration factors corresponding to each radiosonde sensor type for three field experiments. Error bars represent 95% confidence limits.

Comparisons between the water vapor mixing ratios measured by the lidar and the various radiosondes confirm that the AIR sensors normally did not provide accurate water vapor measurements for relative humidities below 25-30%. In addition, the 7-10% difference between the water vapor amounts measured by the AIR and Vaisala sensors was generally observed for all relative humidities above 30%.

We will present other comparison results obtained from these and additional data to be acquired during April, 1994 at the Department of Energy (DOE) Cloud and Radiation Testbed (CART) site in northern Oklahoma.

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