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Daytime Measurements of Water Vapor Mixing Ratio using Raman Scattering - Techniques and Assessment

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There is considerable interest in the use of Raman lidar for daytime measurements of water vapor. Daytime measurements are desired because many interesting meteorological phenomena such as convective storm development occur more often during the day than at night. We report here on progress in the use of two techniques for daytime measurements of water vapor.

The first technique to be discussed makes use of the fact that essentially all downwelling solar radiation is absorbed by stratospheric ozone at wavelengths below about 290 nm. For this reason it is called the "solar blind" technique. With this technique, an excitation wavelength is chosen such that the desired Raman shifted return signals from O_2 (1555 cm^{-1}), N_2 (2329 cm^{-1}) and H_2O (3654 cm^{-1}) are all below the solar blind cutoff. Due to absorption by stratospheric ozone, the background noise due to skylight at the desired wavelengths is negligible. However, tropospheric ozone also attenuates both the outgoing laser beam and the return Raman shifted signals. Thus, the concentration of tropospheric ozone generally must be known along the path of the measurement to correct for the differential transmission that results due to ozone absorption[1].

The second technique makes measurements at the same wavelengths as have been used for nighttime measurements[2-4]. At these wavelengths, where ozone absorption is negligible, the problem is to measure the weak Raman signals against the high solar background. This can be accomplished through the use of narrow-band filters and narrow field of view optics[3,5].

The measurements to be presented here were made using the NASA/GSFC Scanning Raman lidar system. It is based on a Lambda Physik LPX 240iCC excimer laser which can operate with either a KrF (248 nm) or a XeF (351 nm) gas mixture. The system uses a .75 m telescope aligned co-linear with a 1.1m x .8m flat mirror which can scan from horizon to horizon in a single plane. Dichroic beamsplitters and interference filters select the desired wavelengths. Two PMTs are used per wavelength in a low-gain/high-gain configuration. The detectors used for these measurements were EMI 9893/350 and Hamamatsu 1978 PMTs. The wavelengths measured when using KrF (248 nm) for O_2, N_2, H_2O are 258.4, 263.7, 273.2 nm, respectively. When using XeF (351 nm), these wavelengths are 371.2, 382.3, 402.7 nm, respectively.

Solar Blind Measurements

We have previously reported on measurements of water vapor using the solar-blind technique[6]. In that report, the differential transmission required for calculating the water vapor mixing ratio was derived using

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*Hughes-STX, 4400 Forbes Blvd., Lanham, MD 20707 an ozone measurement made by a simultaneously launched ECC (Electrochemical Cell) radiosonde. More measurements of this type have been made and will be presented at the conference.

The ozone concentration can also be calculated from the lidar data using the differential extinction between the O_2 and N_2 Raman signals. This turns out, however, to be a rather difficult measurement due to several factors: 1) the great attenuation of the outgoing laser beam due to tropospheric ozone which tends to give rise to signal induced noise in the PMTs 2) the rather small difference in ozone absorption cross-section for the O_2 and N_2 signals (see figure 1 for cross sections calculated at 298 K using Bass and Paur[7] and 3) the great influence of the lidar system overlap function in the calculation of the ozone profile within the overlap region. These factors will be addressed in greater detail during the presentation. It should be noted here, however, that the problems addressed in factors 1 and 2 would be improved through the use of longer wavelength excitation. Theoretical modeling[8] has also shown that a longer wavelength excitation is preferred in the calculation of ozone. Excitation at 263.2 nm (Raman shifted KrF using N_2) would yield O_2 and N_2 signals at 274.4 and 280.4 nm; excitation by a quadrupled Nd:YAG (266.7 nm) would yield O_2 and N_2 signals at 278.2 and 284.4 nm. Either of these choices would increase the cross-section difference between O_2 and N_2 by a factor of about 20 as compared to the KrF (248 nm) case as shown in figure 1. In addition, the reduction in ozone attenuation at these longer wavelengths allows more photons to arrive at a given range. However, the output powers available through the use of a Raman shifted KrF excimer laser or a quadrupled YAG are considerably less than can be achieved with the unaltered KrF laser thus tending to negate any advantage they might afford based on ozone cross section considerations. The modeling work mentioned above supports this conclusion.

We have attempted to overcome these difficulties of signal induced noise and the system overlap function through the use of specially selected PMTs which offer both low background noise and low signal induced noise and through a careful quantification of the system overlap function. Figure 2 shows daytime lidar measurements of water vapor mixing ratio where the lidar data have been used to calculate the required ozone number density. The ozone profile calculated from the lidar data (figure 3) still exhibits a large error in the first kilometer due mainly to errors in the quantification of the system overlap function. (The system overlap function greatly affects the slope of the data curves within the first kilometer. Due to the differential nature of the ozone computation, it is extremely sensitive to errors in the slope of the data curves. This will be further explained during the presentation.)

The mixing ratio corresponding to 20% relative humidity is plotted in figure 2 as well. We believe that the measurements of water vapor are not influenced by the system overlap function above about 1km. Thus the disagreement between the lidar water vapor data and the radiosonde measurement between the altitudes of 1.3 and 2.5 km are taken to be due to the relative humidity "floor" of the capacitive hygrometer which has been previously reported[2].

Narrow band, Narrow field of View Measurements

We have also used the unaltered nighttime lidar system to make measurements of water vapor during the daytime. Our system was originally designed exclusively for nighttime measurements using the XeF (351 nm) output and thus had only a photon counting capability. In order to not saturate the photon counting data system, the data presented in figure 4 were acquired with the input to the PMTs attenuated by a factor of 200. Figure 4 shows the water vapor mixing ratio as a function of altitude on July 15, 1992 for a 50 minute averaging time. The corresponding radiosonde is plotted for comparison. The measurements have a random error of 20% at 2.5 km.

We have incorporated high current PMTs and A/D data acquisition electronics into the lidar system which will allow us to remove the factor of 200 attenuation. With these improvements, we expect to be able to make measurements of the mixing ratio during the daytime through the depth of the boundary layer in 5 - 10 minutes. Measurements using this new system will be presented along with a discussion of the important error sources in the measurement.

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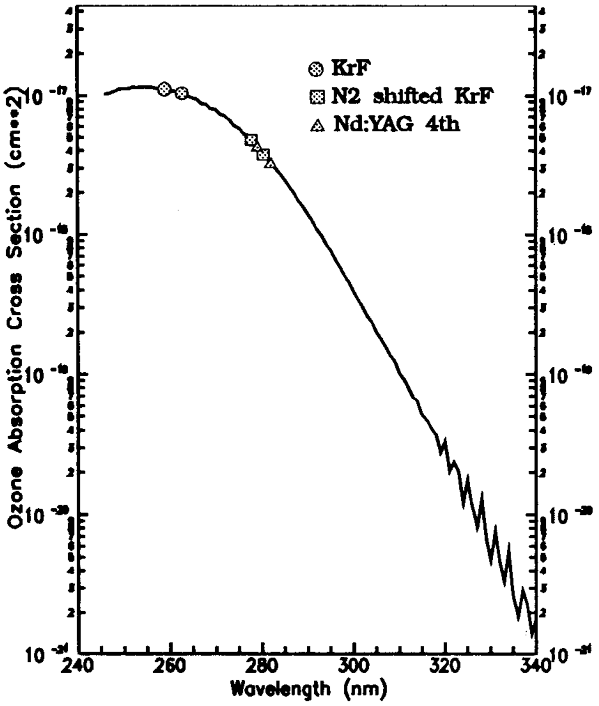

Figure 1. Ozone absorption cross section Cross sections for Raman shifted O2 (1555 cm-1) and N2 (2329 cm-1) are plotted for three excitation wavelengths:
1) 248 nm (KrF Excimer)
2) 263.2 nm (N2 shifted KrF)
3) 266.7 nm (Quadrupled Nd:YAG)

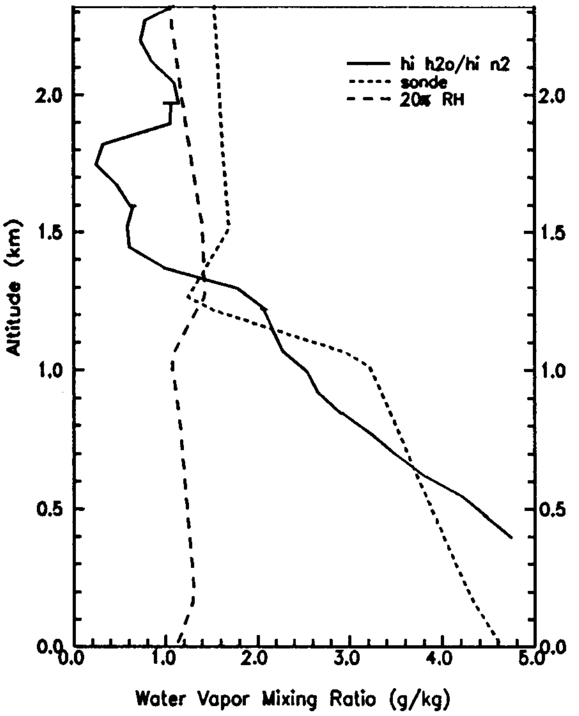

Figure 2. Water vapor mixing ratio measurements performed at Greenbelt, MD December 9, 1993 using lidar data to calculate differential transmission due to ozone.

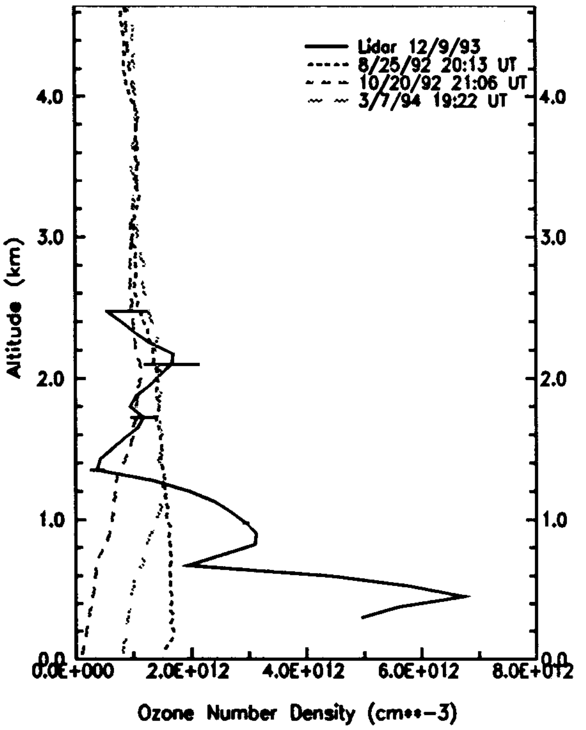

Figure 3. Lidar-derived ozone number density at Greenbelt, MD on Dec 9, 1993. Also plotted are 3 ECC measurements of ozone at Greenbelt, MD during 1992 and 1994.

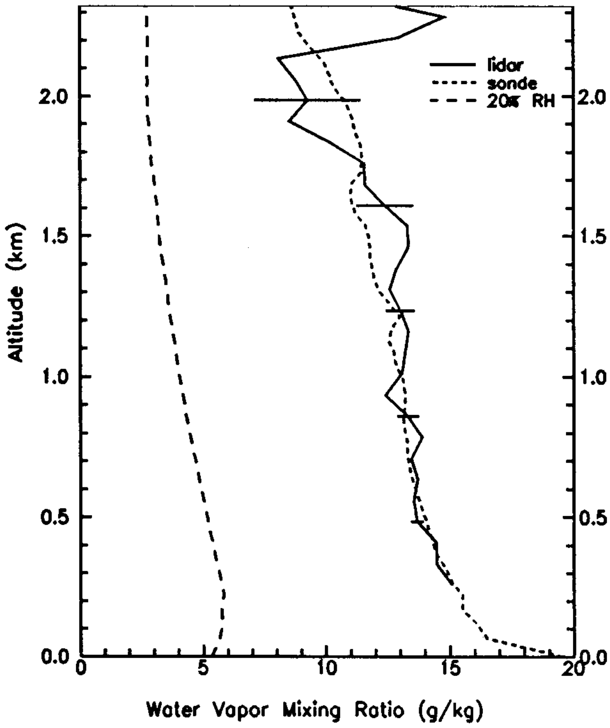

Figure 4. Daytime measurement of water vapor mixing ratio at Wallops Flight Facility July 15, 1992. XeF (351 nm) laser used. Data have been smoothed to 300m above 1 km.