Raman Lidar Profiling of Tropospheric Water Vapor

Watheq Al-Basheer

King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

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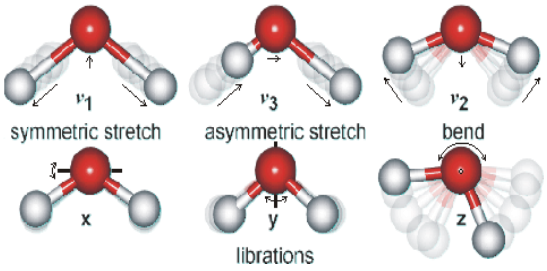
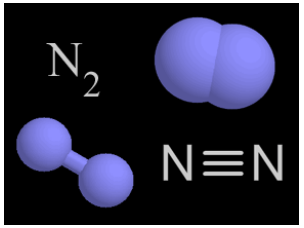
Water Vapor Raman lidar Principles

- When monochromatic light (λ_L=355 nm) interacts with molecules, a wavelength shift (usually $\lambda r > \lambda L$) in the scattered light can occur due to molecular vibrations.

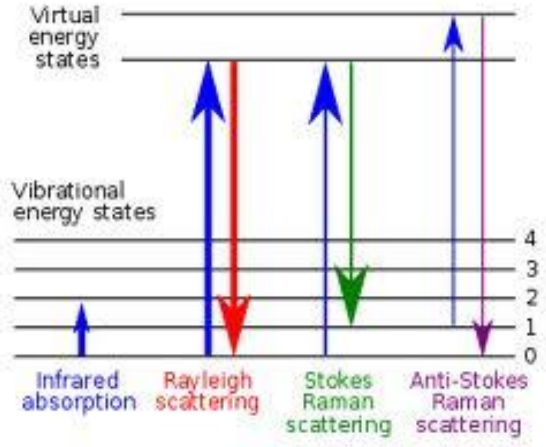
$$\frac{1}{\lambda_r} = \frac{1}{\lambda_L} - \kappa$$





- Raman lidar can measure wavelength-shifted light because each constituent of the atmosphere (H_2O, N_2) correlates to a characteristic wavelength shift.

- The most common Raman shifts for N_2 at 2330.7 cm^{-1} and H_2O at and 3652.0 cm^{-1} (ν_1).



Raman Lidar

Advantages

- *Specific to particular molecules*
- *High temporal and spatial resolution up to 20 km altitude.*
- *Ratio to N_2 directly measures mixing ratio*
- *Insensitive to extinction*
- *Many systematic errors cancel in ratio*

Disadvantages

- *Raman scattering is very weak and signal can be blocked by clouds.*
- *measurements restricted to night-time*
- *Precise alignment must be maintained*

Raman Lidar Theoretical Background

Raman lidar operates by vertical emitting of monochromatic pulsed laser beam, while simultaneously recording the inelastic backscattered signals as a function of time, to provide range dependent data.

Taking Raman lidar equation ratio between H_2O and N_2 yields

$$\frac{P(z,\lambda_l,\lambda_{H_2O})}{P(z,\lambda_l,\lambda_{N_2})} \propto R\frac{N_{H_2O}}{N_{N_2}}\frac{\left[d\sigma_{H_2O}/d\Omega\right]}{\left[d\sigma_{N_2}/d\Omega\right]}\exp\left\{-\int_0^z\left[\alpha(\lambda_{H_2O},z')-\alpha(\lambda_{N_2},z')\right]dz'\right\}$$

Where the WVMR (in g/kg) as a function of altitude z can be denoted by

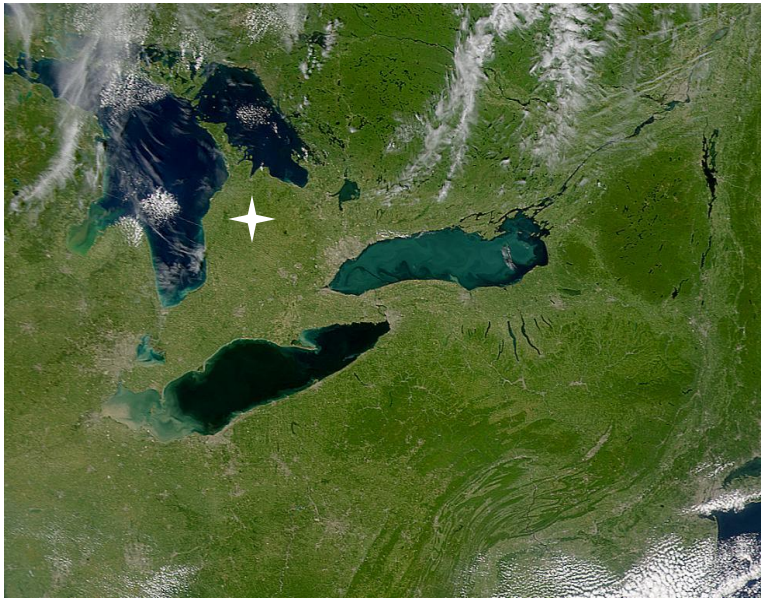
$$w(z)=\frac{MW_{H_2O}}{MW_{DryAir}}\frac{N_{H_2O}(z)}{N_{DryAir}(z)}\approx\frac{MW_{H_2O}}{MW_{DryAir}}\frac{N_{H_2O}(z)}{N_{N_2}(z)/0.78}\approx 0.485\frac{N_{H_2O}(z)}{N_{N_2}(z)}$$

Consequently, WVMR can be related to the H_2O and N_2 Raman lidar signals by

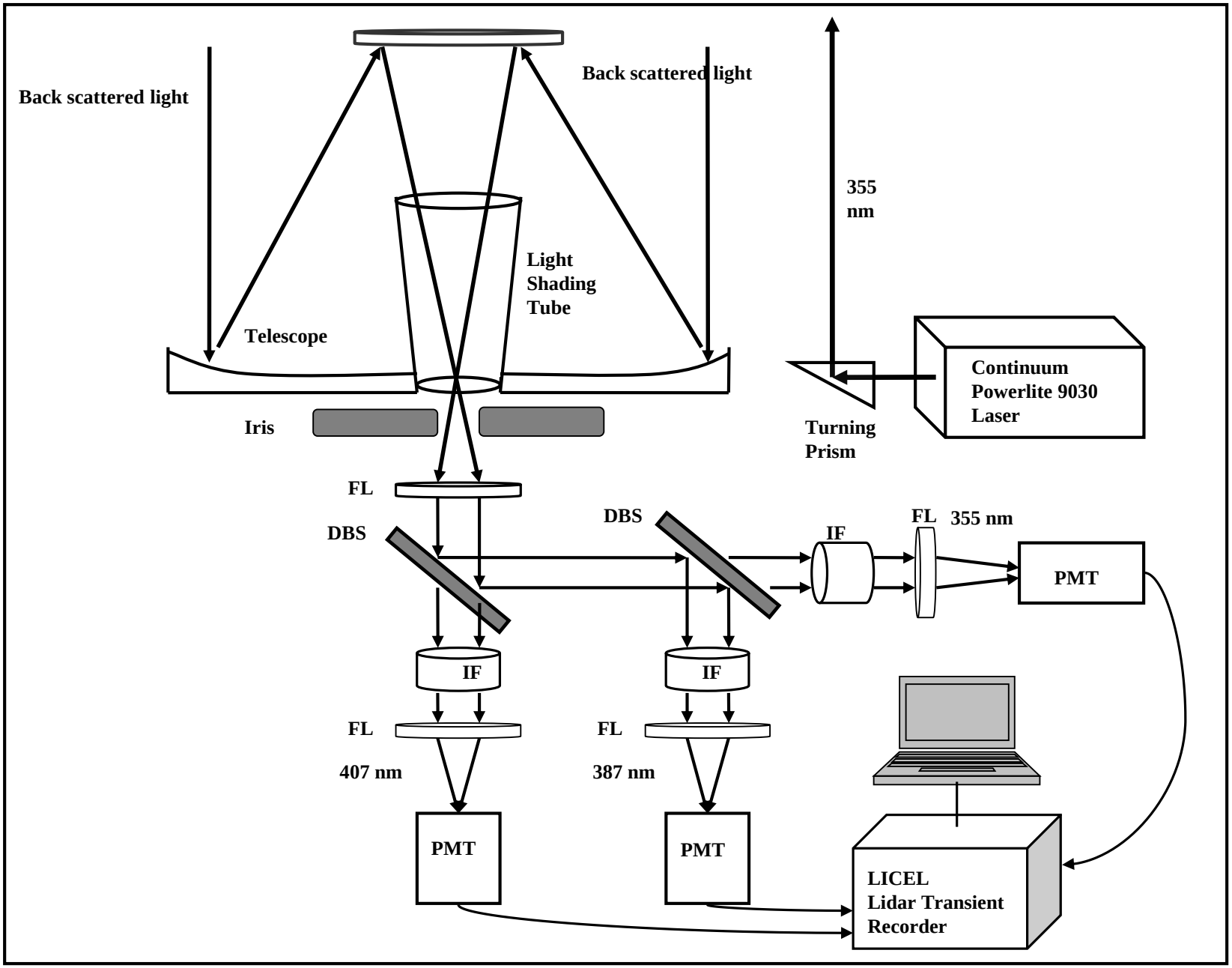
$$w(z)=D\frac{S_{H_2O}}{S_{N_2}}$$

Study Motivation and Importance of Geographic Location

- Tropospheric water vapor is the most active green-house gas.
- To understand Tropospheric water vapor molecules distribution and interaction with aerosols.
- Effect of Egbert location on Tropospheric water vapor levels in the heart of the Great lakes, in addition to its proximity to major North America industrial centers.



Water Vapor Raman lidar Experimental setup



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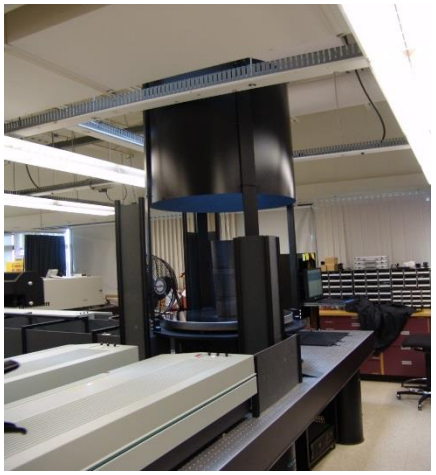
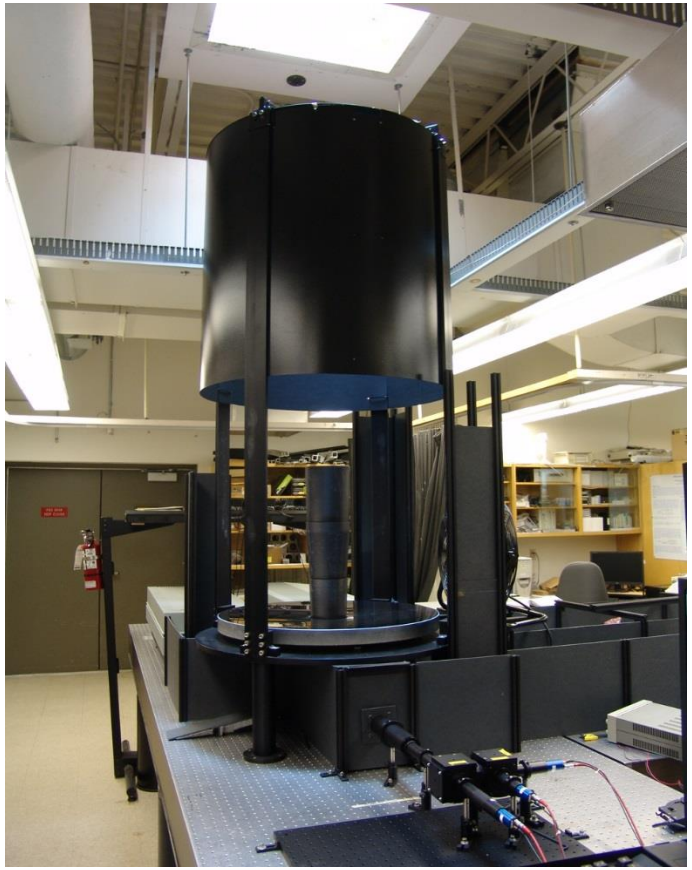
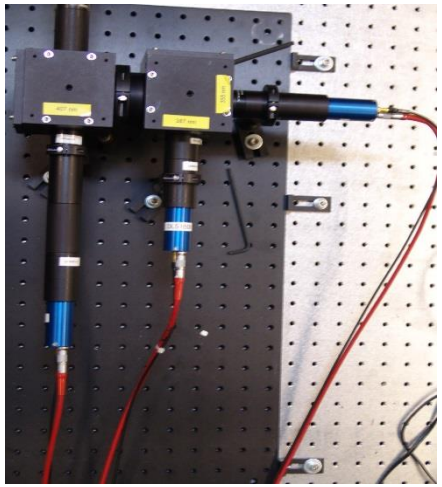
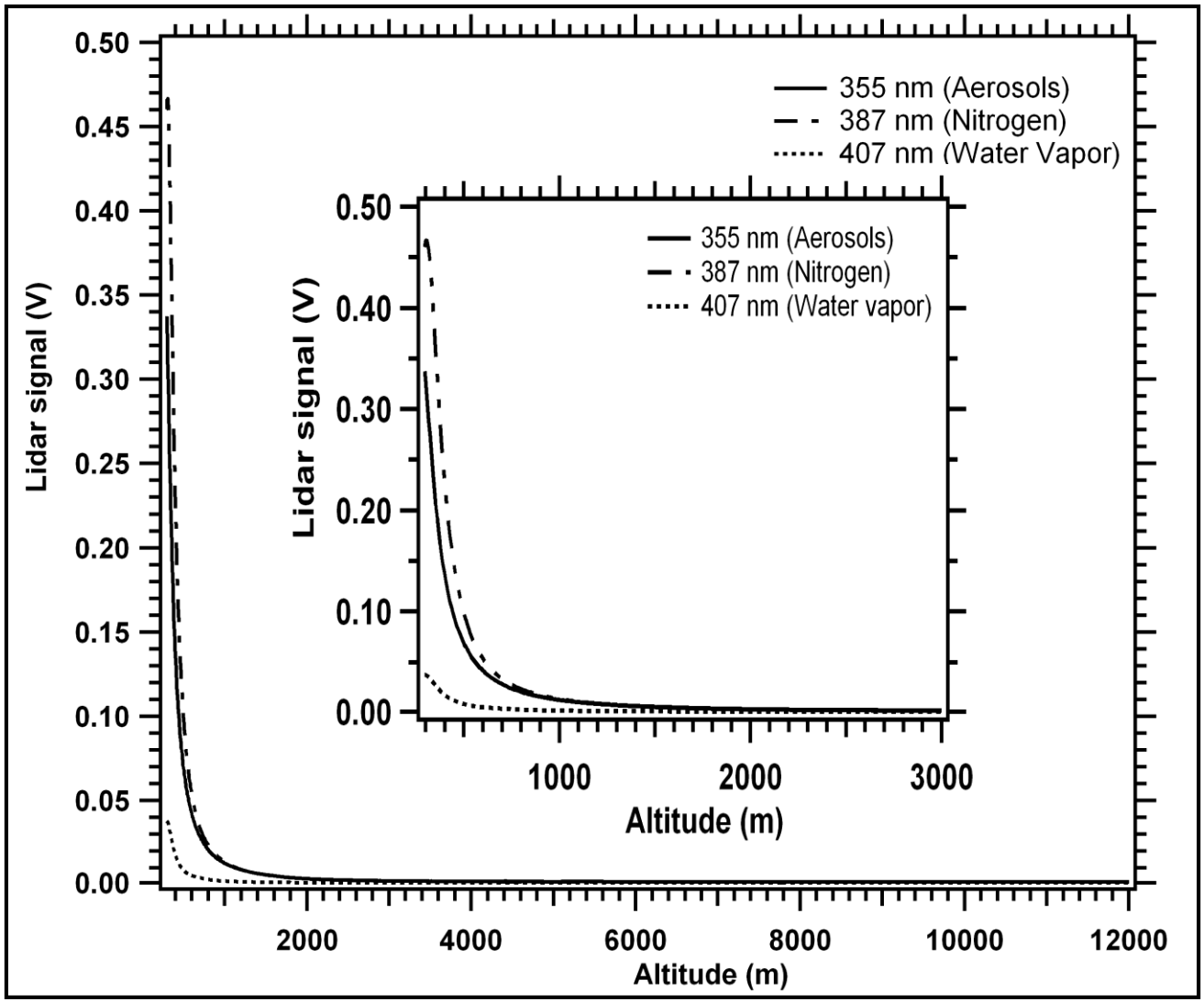


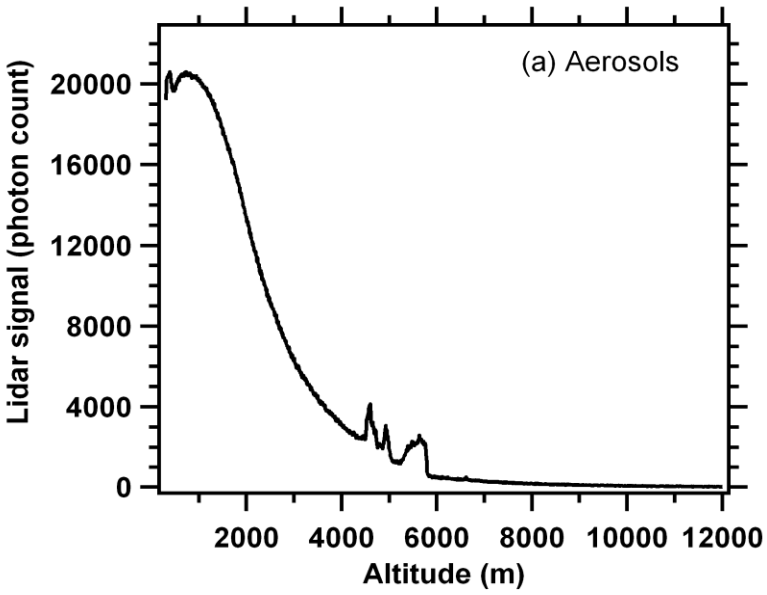


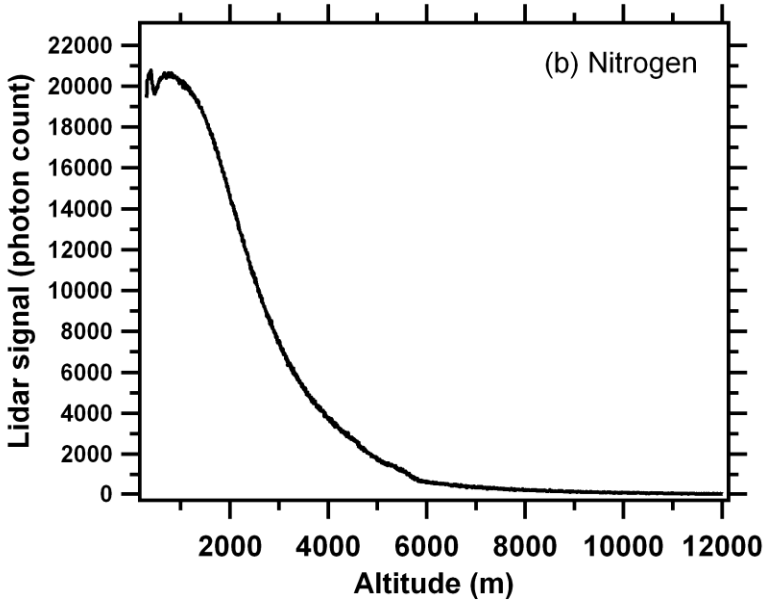


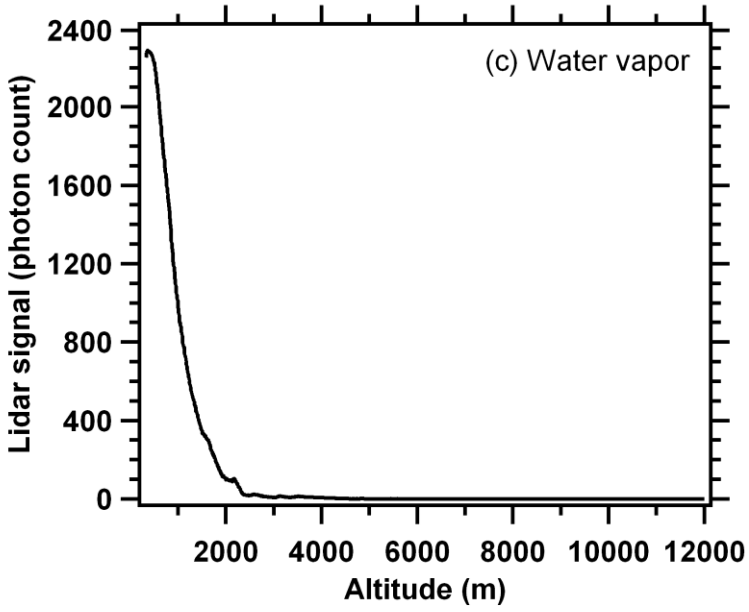
WV Raman lidar raw data (Analog Voltage signal)



WV Raman lidar raw data (Photon count signal)







Jun. 27th 2011

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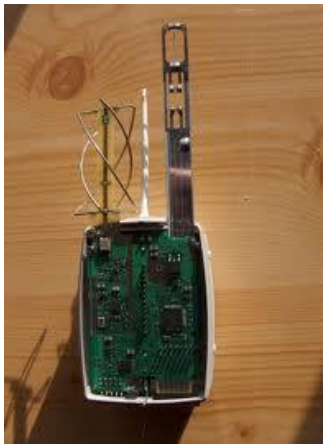
Radiosonde Measurements and Calibration

- Radiosonde can yield real time data of Height, Atmospheric Pressure, Temperature and Relative humidity.

- Employing Clausius-Clapeyron equation to deduce water vapor mixing ratio (WVMR) in g/kg.

$$\ln\left(\frac{e}{6.11\times RH}\right)=\frac{L}{R_V}\left(\frac{1}{273.15}-\frac{1}{T}\right)$$

$$\mathrm{WVMR\,(g/kg)}=\frac{0.622\times \mathrm{e}}{\mathrm{P-e}}$$



- Utilizing radiosonde sounding as a calibration tool has few limitations, such as vulnerability to wind.

WV Raman lidar Summer Vs Winter Measurements

Jun. 27th

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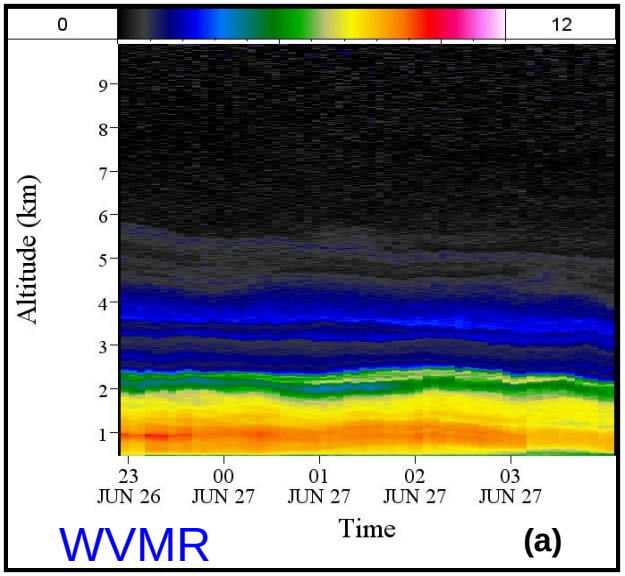
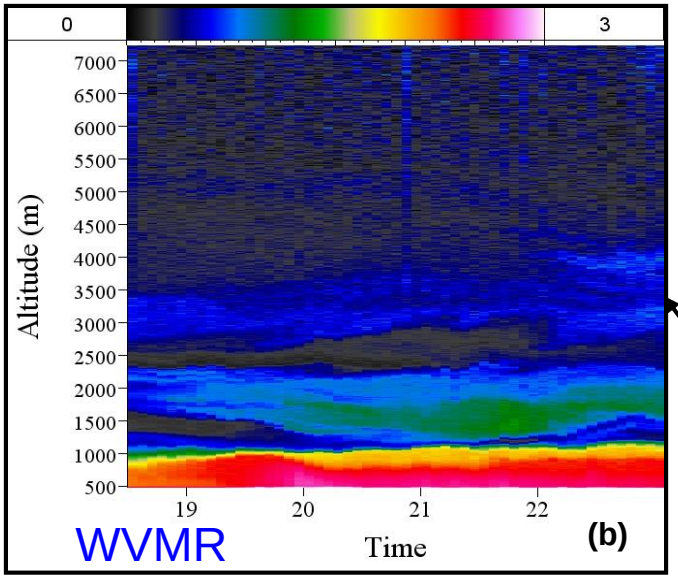
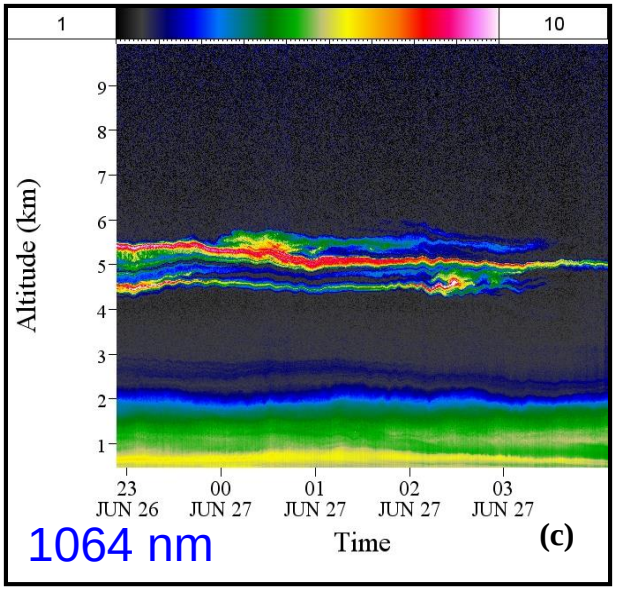
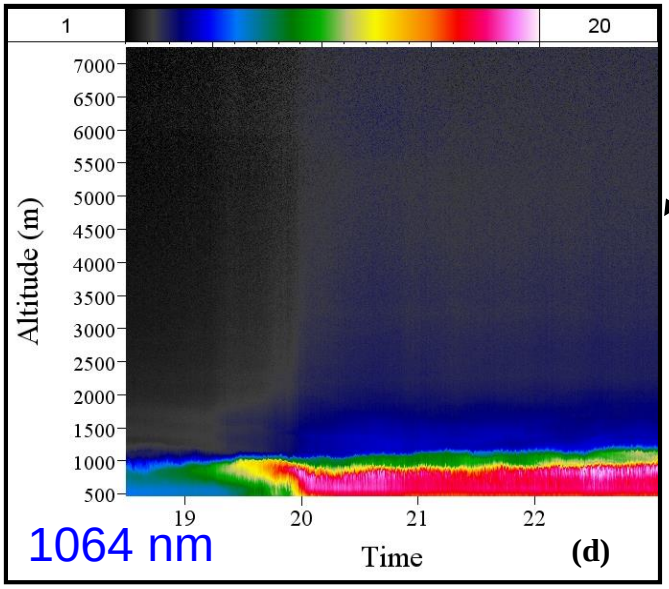
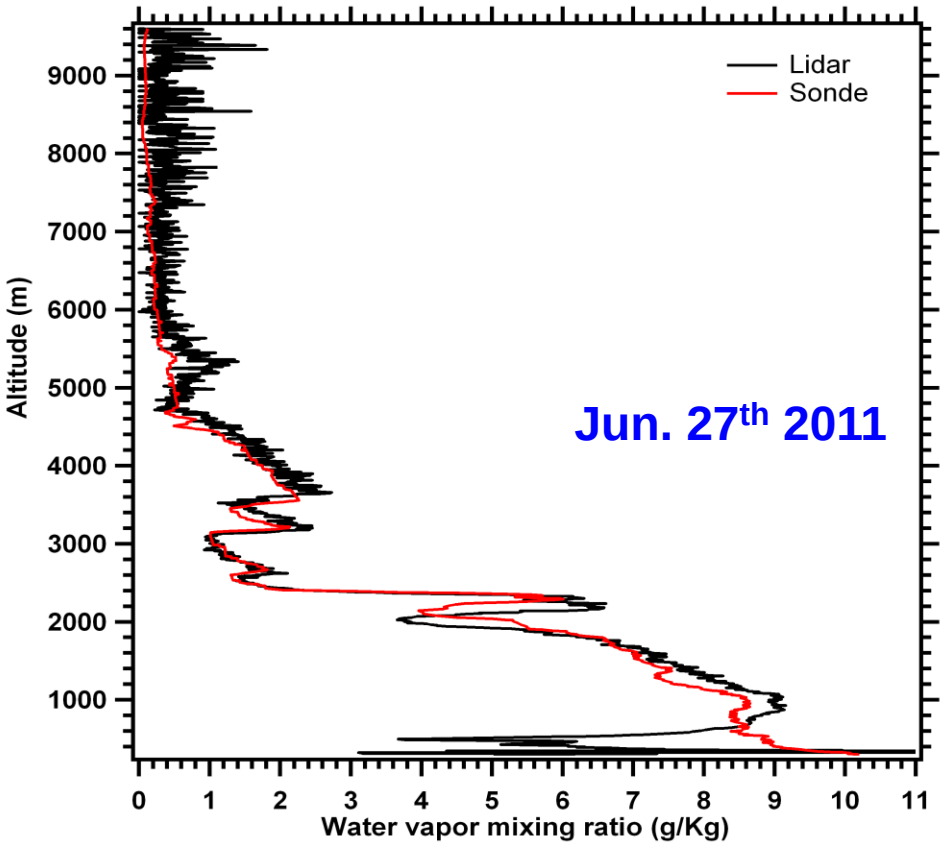


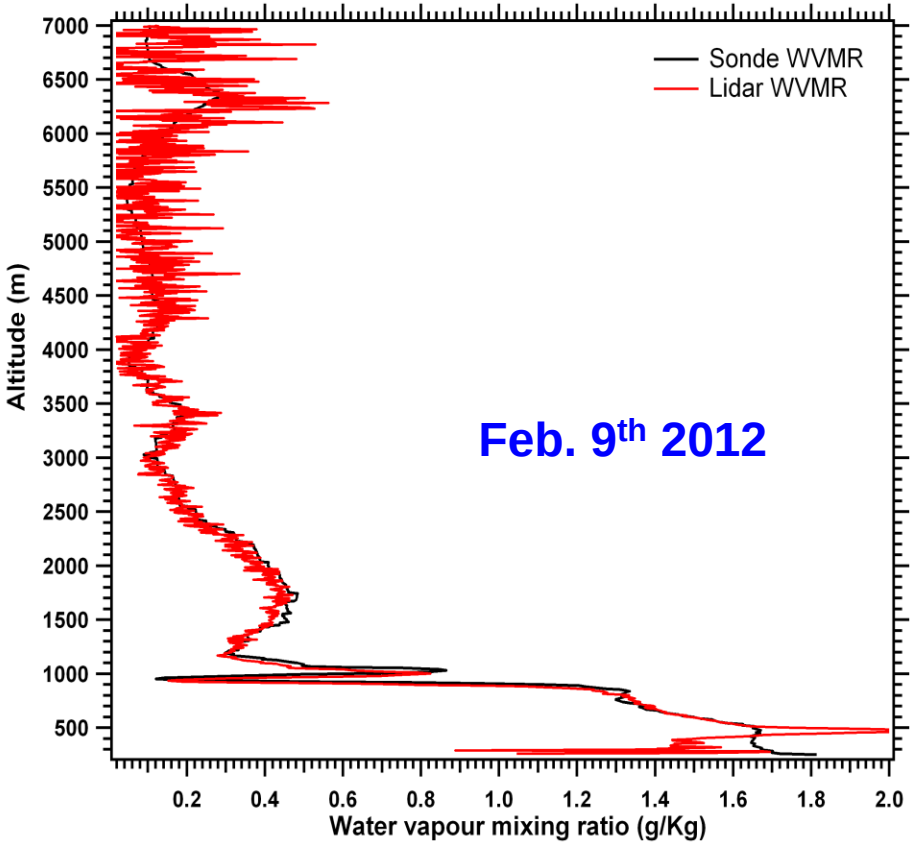






WVMR (g/kg) Summer VS Winter Measurements





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Results and Discussions

- Night time measurements were performed throughout this study to minimize interference with background sky light.
- The return signals from H_2O and N_2 were utilized to conclude the vertical profile of the water vapor mixing ratio up to 9.5 km geometrical altitude
- The methodology to validate and calibrate WVMR vertical profile is to use the Radiosonde processed data to calibrate the Raman Lidar WVMR profiles.
- The discrepancy between WVMR profiles over the low troposphere region is related to the instrumental limitations of the field of view of the transmitted laser beam which restricts the detection of H_2O molecules at altitudes close to surface
- The deviation in WVMR profiles at the upper half of the troposphere is attributed to the widely known weak performance of radiosondes in observing water molecules in the upper troposphere

Summary & Conclusions

- WVMR profiles were normalized using calibration constant obtained by manipulating raw data from simultaneous and collocated radiosonde profiles.

- Water vapor Raman lidar data obtained were shown to effectively yield high temporal and spatial resolution measurements of WVMR, with efficient dual detector capability both in the near-and-far fields.

- When compared to other types of return signals, i.e. raw voltage and photon count, the transient recorder merged photon count rate was observed to yield the best agreement between sonde and lidar measurements WVMR profiles.

THANK YOU FOR YOUR ATTENTION! ANY QUESTIONS?