Raman Lidar Retrievals of Mixed Layer Heights

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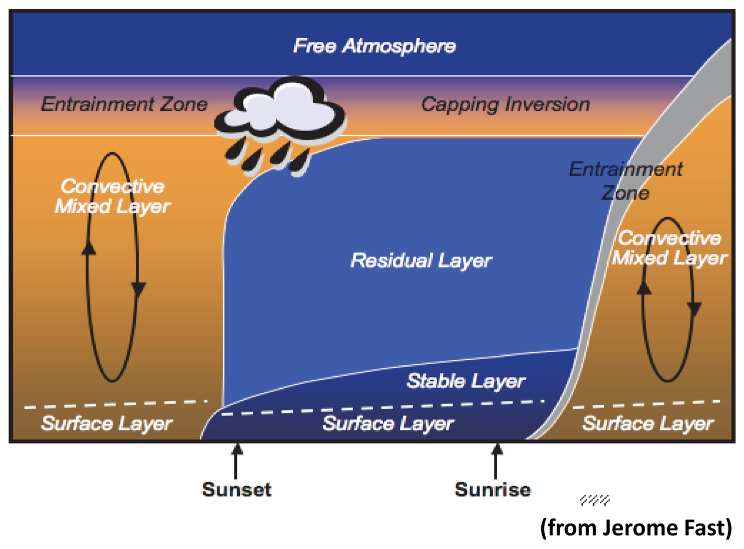
Background



(from Jerome Fast)

PBL height is a key parameter for:
- simulating climate processes
- assessing model simulations of aerosol and pollutant concentrations and transport

Uncertainties in modeled PBL heights due to:
- model parameterizations
- differences in definition

See Jerome Fast's WG presentation – Fall 2011)

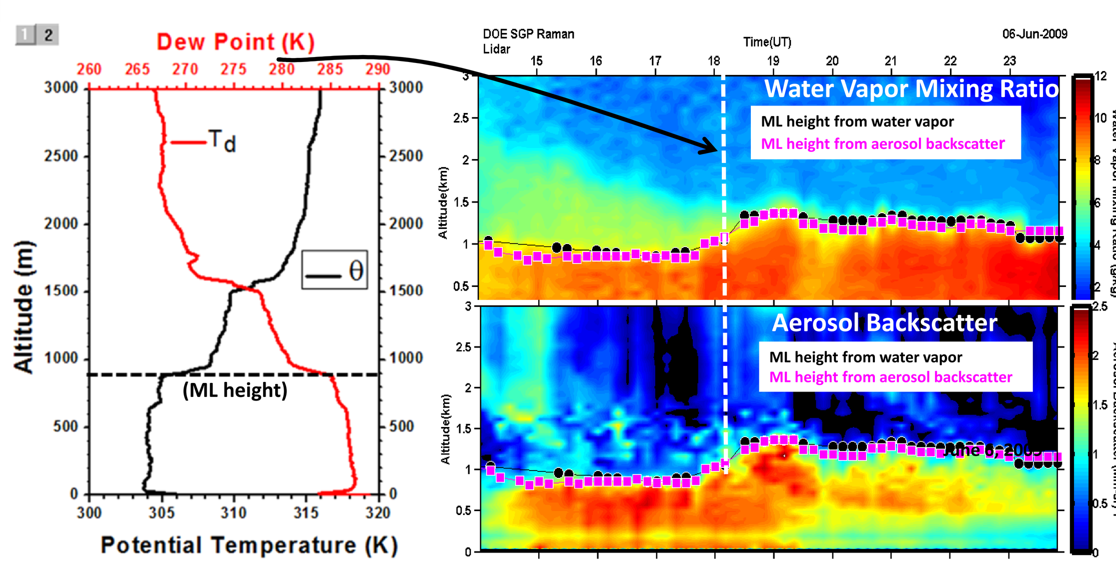
Planetary Boundary Layer (PBL): directly influenced by earth's surface (may be turbulent or stable)

Mixed Layer (ML) (or Convective Boundary Layer): subset of cases where turbulence tends to uniformly mix tracers within about an hour

- **Assessments of model PBL heights will likely require multiple measurement methodologies**
- **Raman lidars at SGP and TWP can provide multiple techniques**

Mixed Layer Height via Water Vapor and Aerosol Gradients

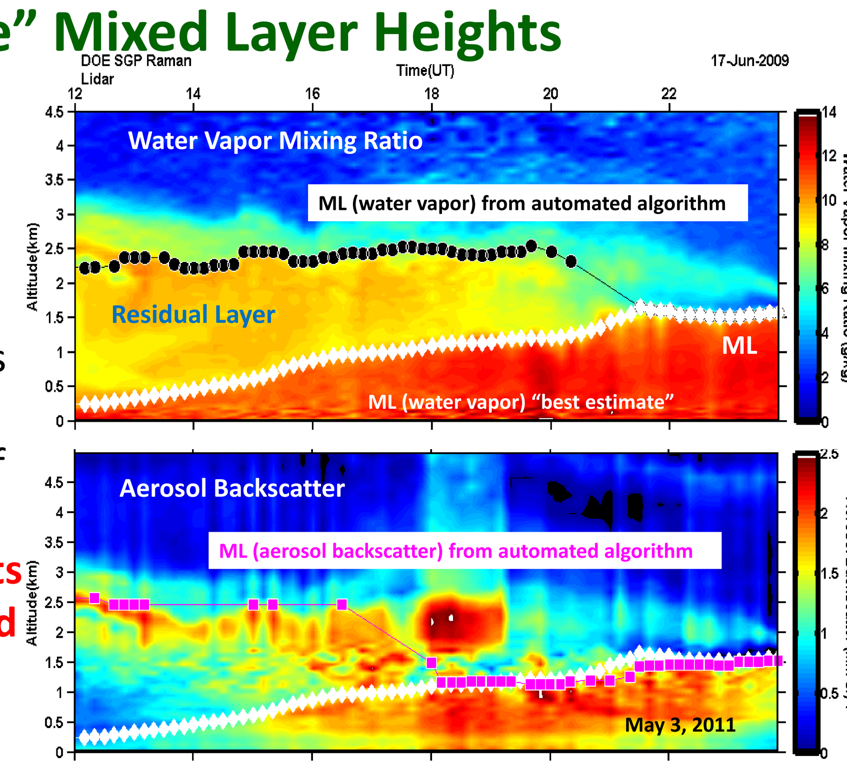
- PBL heights derived from Raman lidar cloud-screened aerosol backscatter and water vapor profiles
- Automated technique uses a Haar wavelet covariance transform to identify sharp aerosol and water vapor gradients at the top of the PBL (Brooks, JAOT, 2003)



- These heights often correspond to gradients in potential temperature

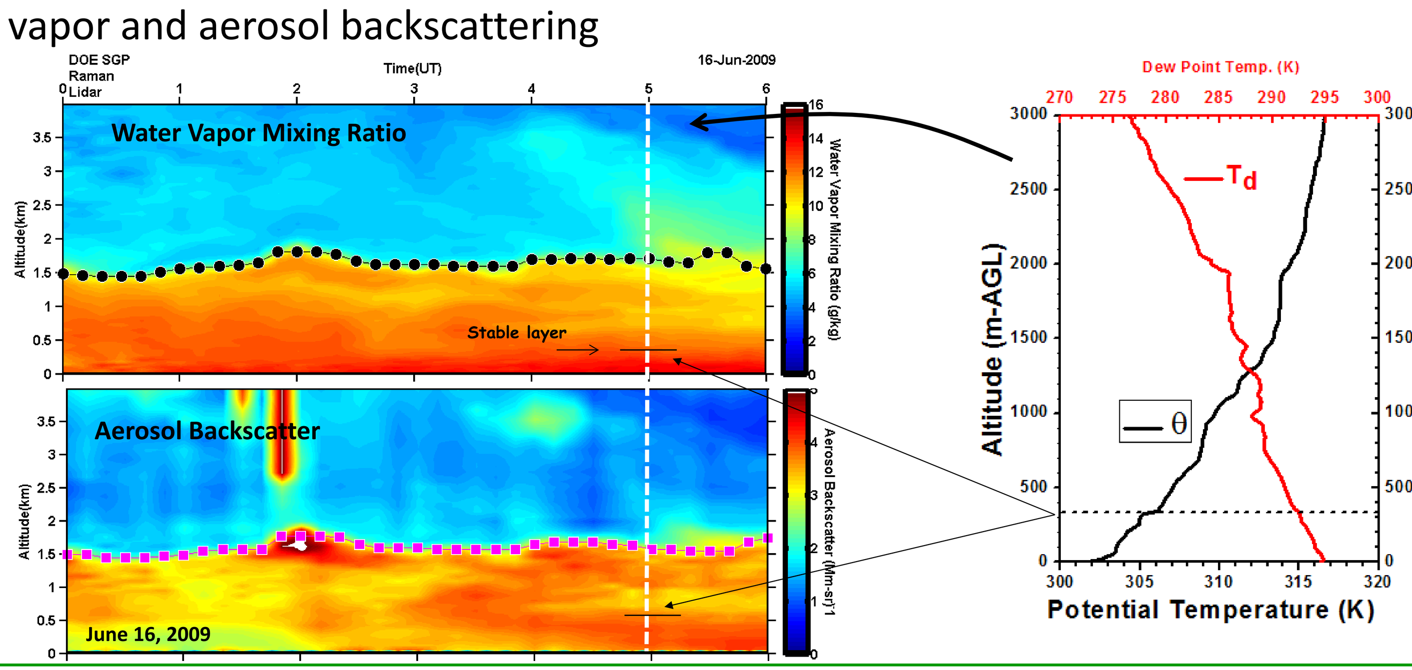
"Best estimate" Mixed Layer Heights

- Complicated aerosol structures within the boundary layer or residual layer(s) above boundary layer can prevent the algorithm from producing satisfactory results.
- "Best-Estimate" mixed layer heights combine results from automated algorithm and manual inspection of Raman lidar water vapor profiles
- **"Best-Estimate" mixed layer heights available for April-June 2011 period (e.g. MC3E) and June 2009 (e.g. RACORO)**



Limitations of ML heights via water vapor & aerosol gradients

At night, largest water vapor and aerosol gradients are often associated with residual layer(s) above the nocturnal BL, confounding algorithms that use water vapor and aerosol backscattering



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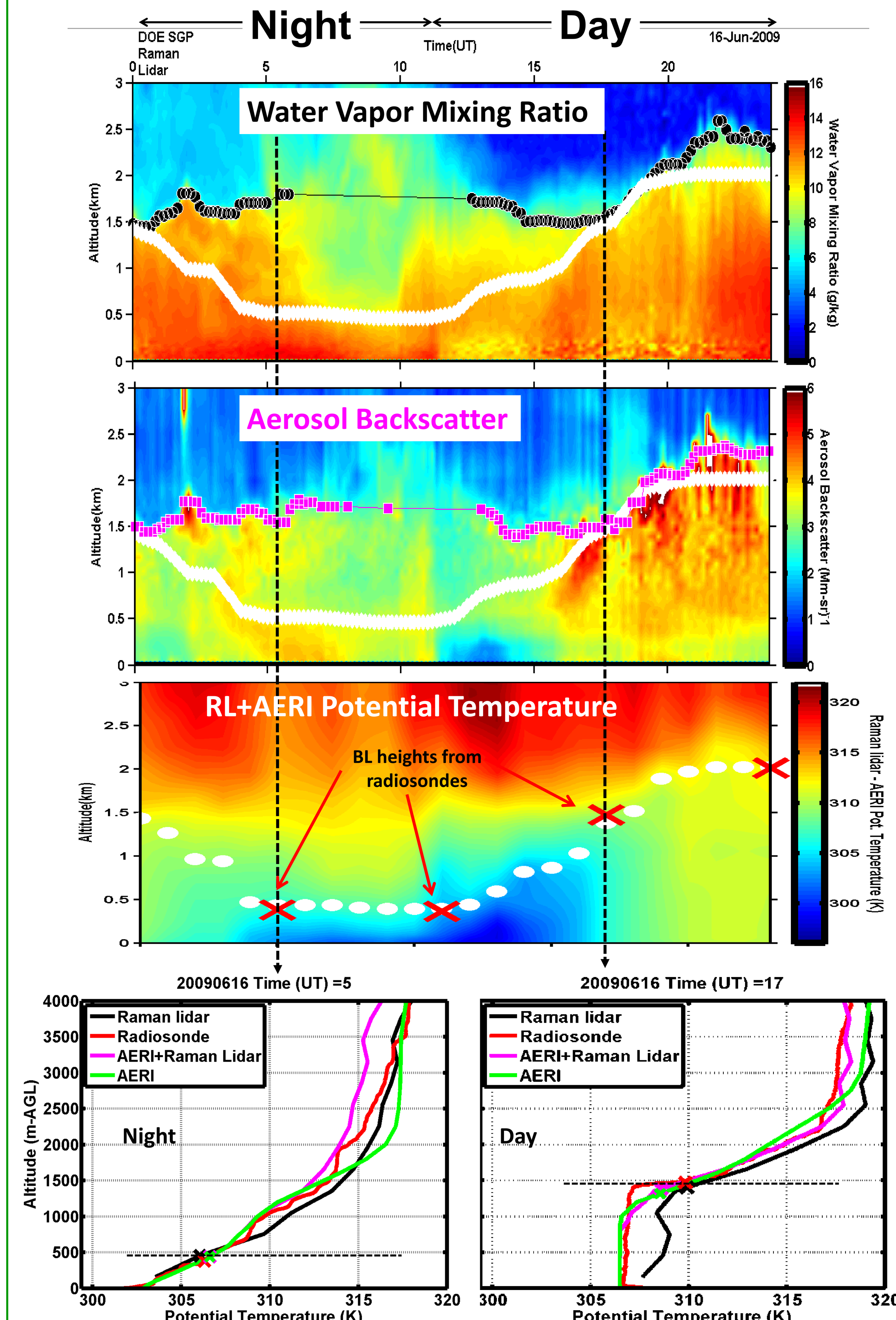
BL heights from Raman Lidar using water vapor, aerosol backscatter, and potential temperature

BL heights from potential temperature may help provide a more complete picture of diurnal BL behavior



Summary

- **Mixed Layer (ML) heights are derived from SGP Raman lidar measurements of water vapor and aerosol gradients**
- **"Best estimate" ML heights are derived from the water vapor gradients after manual inspection of results from automated algorithm.**
  - **June 2009 (RACORO)**
  - **April-June 2011 (MC3E)**
- **ML heights derived from water vapor & aerosol gradients have limitations**
  - **Elevated layers can be mistaken for the Mixed Layer**
  - **Nighttime Boundary Layer is difficult to detect**
- **To overcome these limitations, Boundary Layer (BL) heights are derived from combined (Raman lidar + AERI) potential temperature profiles for 2009-2011**
  - **Better agreement with BL heights from radiosondes**
  - **More consistent diurnal BL representation**
- **Much of AOT and PWV remain above BL**
- **Work in progress:**
  - **Improving automated algorithms**
  - **Retrieving BL heights from Darwin Raman Lidar**

Boundary Layer Height using RL+AERI potential temp

- Potential temperature profiles derived from a combination of AERI + Raman lidar temperature retrievals
- AERI temperature profiles are spliced onto the bottom of Raman lidar temperature profiles
  - Raman lidar rotational Raman scattering (z > 700 m)
  - AERI radiances (z < 700 m)
- PBL heights derived from these profiles using modified Heffter technique tailored to SGP site (Della Monache et al., JGR, 2004)

Lapse rate

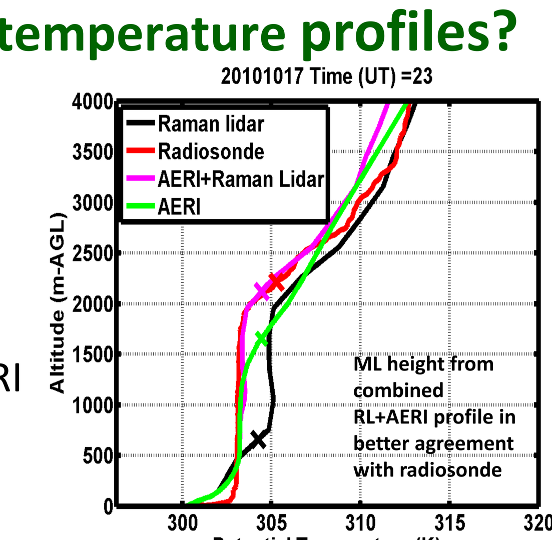
$$\frac{\Delta\theta}{\Delta z} \geq 0.001\,{}^{\circ}K/m$$

Inversion strength

$$\theta_{top} - \theta_{base} \geq 2\,{}^{\circ}K$$

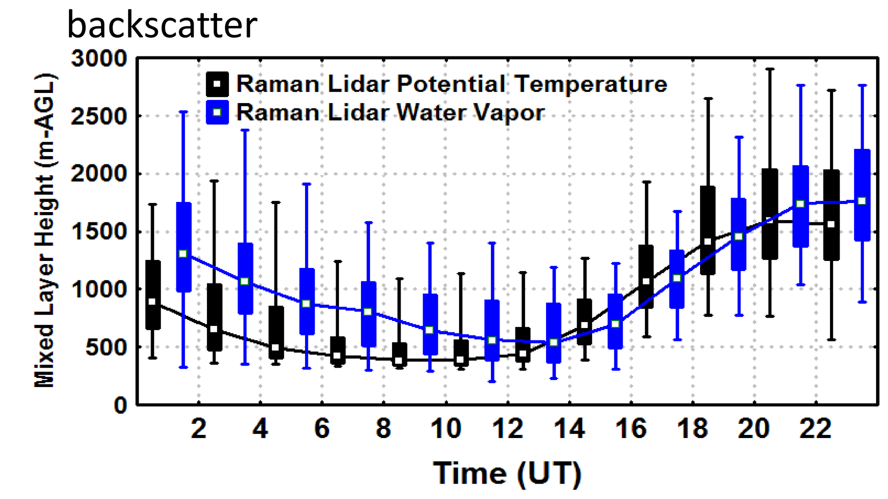
Why combine Raman lidar and AERI temperature profiles?

- AERI vertical resolution quickly increases with altitude
- Raman lidar temperature profiles require significant correction for non-unity overlap function near the surface
- Splicing profiles takes advantage of better AERI performance near the surface and higher resolution Raman lidar profiles farther away from the surface

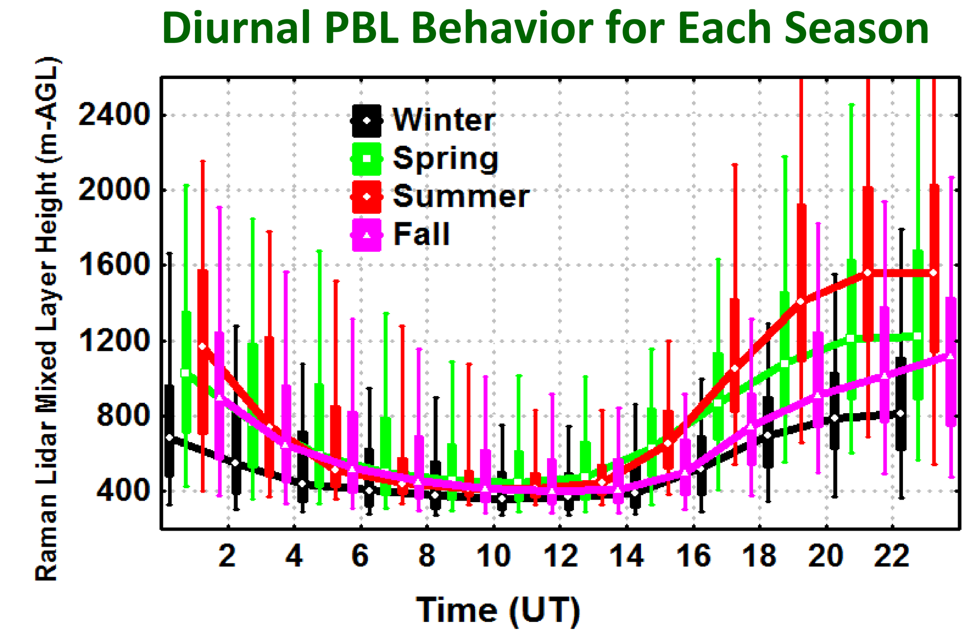


Comparison of BL heights from RL water vapor and RL+AERI potential temp. profiles

For data from June 2009 and April-June 2011:
- Daytime: ML heights derived from potential temperature and water vapor are comparable
- Nighttime: ML heights from potential temperature are considerably (100-500 m) lower than heights from water vapor and aerosol backscatter



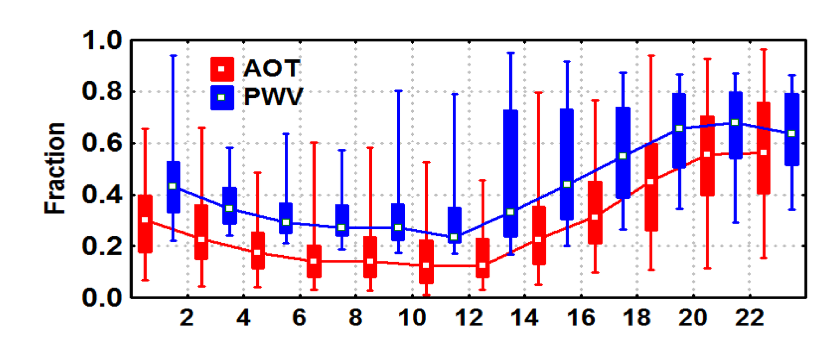
Diurnal PBL Behavior for Each Season



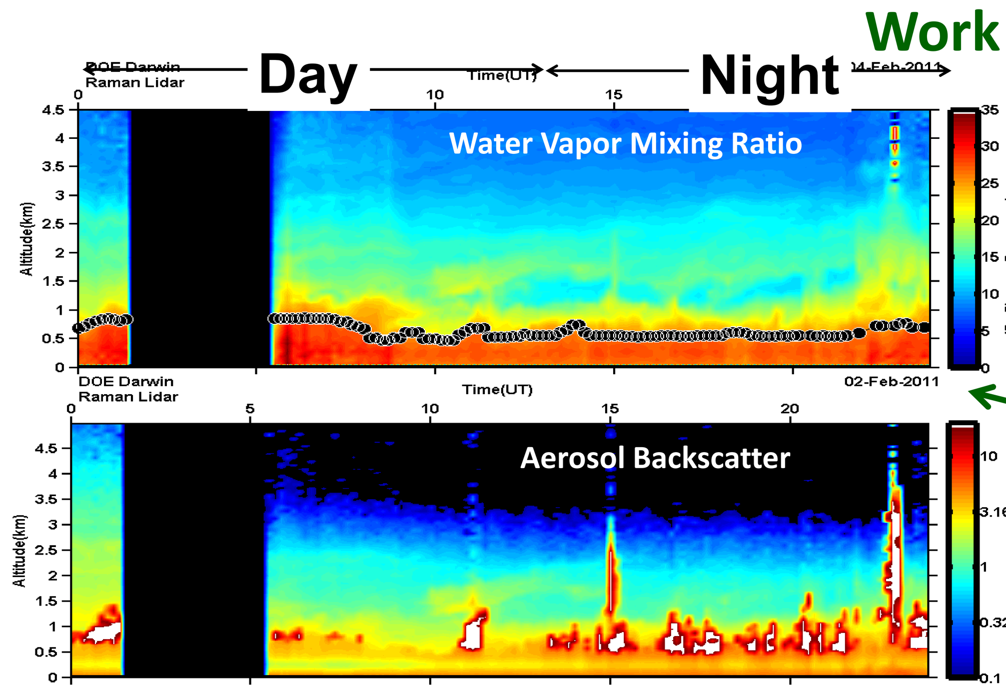
PBL heights derived from RL+AERI potential temps from 2009-2011:
- highest PBL during summer
- lowest PBL during winter

Aerosol Optical Thickness and Precipitable Water Vapor within PBL

Fraction of Aerosol Optical Thickness (AOT) and Precipitable Water Vapor (PWV) within the PBL as derived from RL+AERI potential temps from 2009-2011:
- During nighttime, most (60-80%) of AOT and PWV above PBL
- During daytime, much (30-60%) of AOT and PWV above PBL



Work in Progress – Darwin Raman Lidar



- We are starting to study data from Raman lidar at Darwin, Australia
- Data available from December 2010 to October 2011
- Raman lidar temperature profiles not yet available

February
- Shallow moist, cloud topped ML
- Little diurnal variability

August
- Deeper ML
- More diurnal variability
- Sharp top of moist layer at 2-3 km