Raman Lidar Retrievals of Mixed Layer Heights

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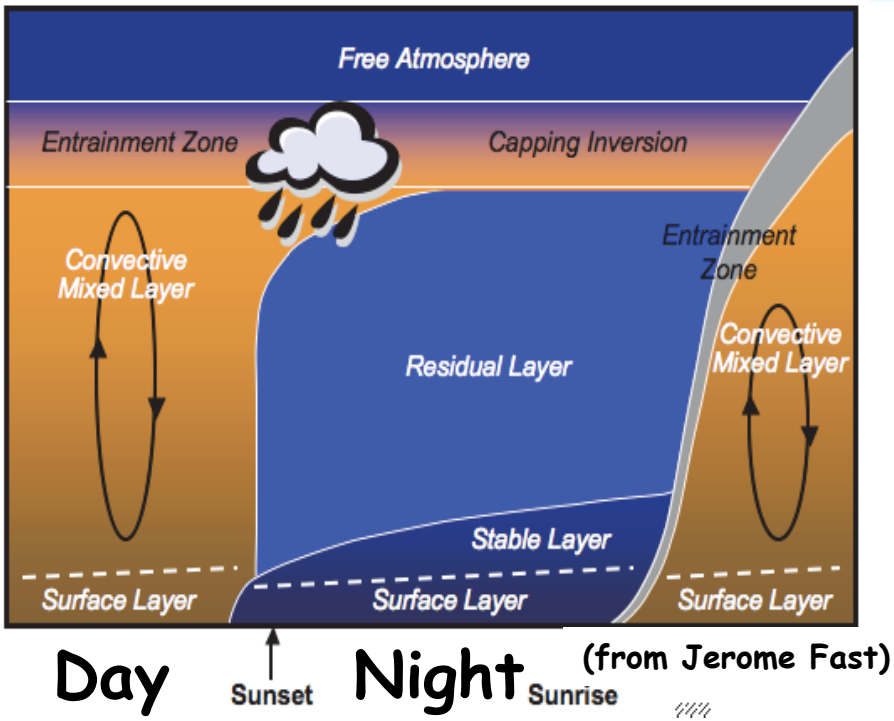
Background



(from Jerome Fast)

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

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

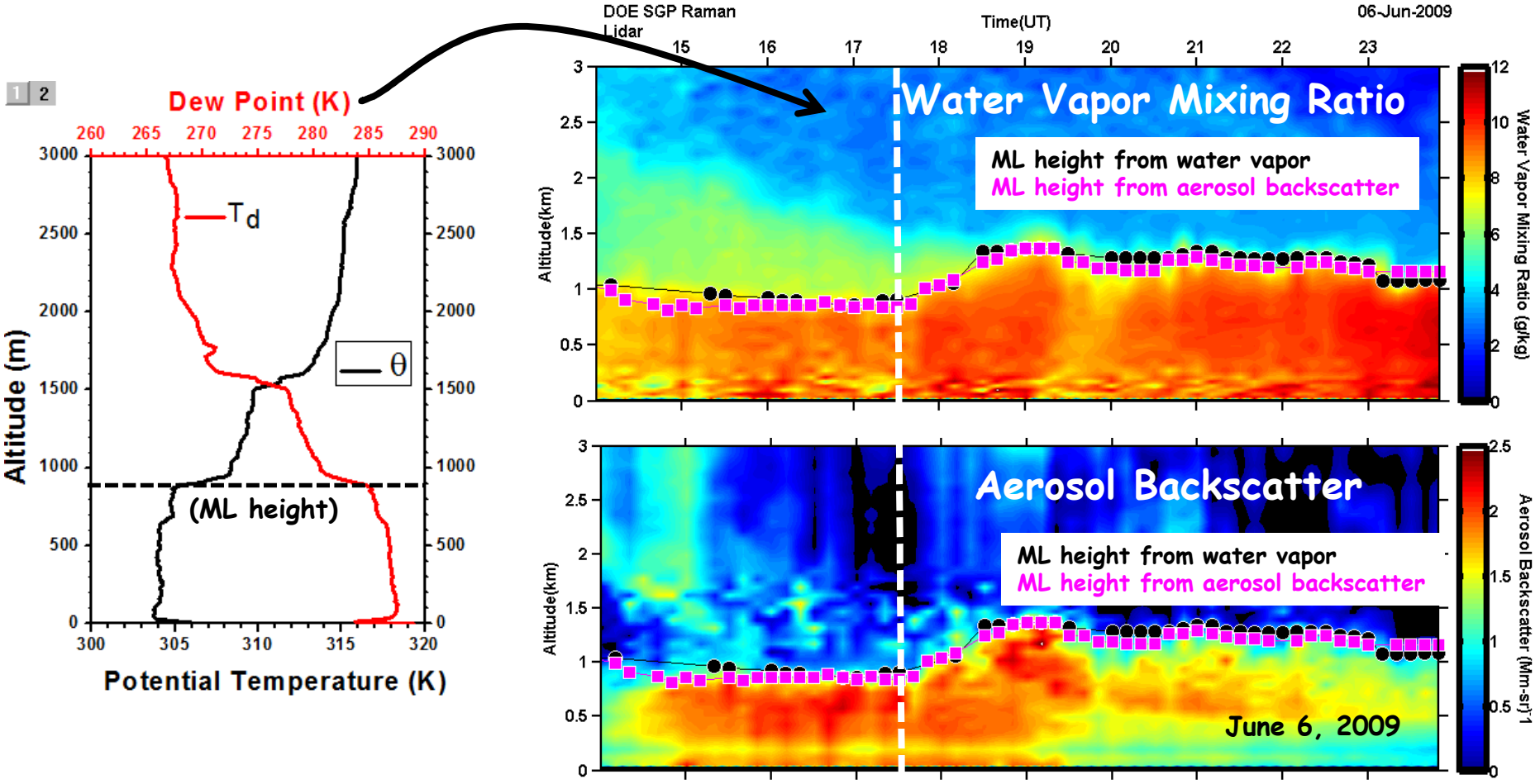
(See Jerome Fast's WG presentation – Fall 2011)

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

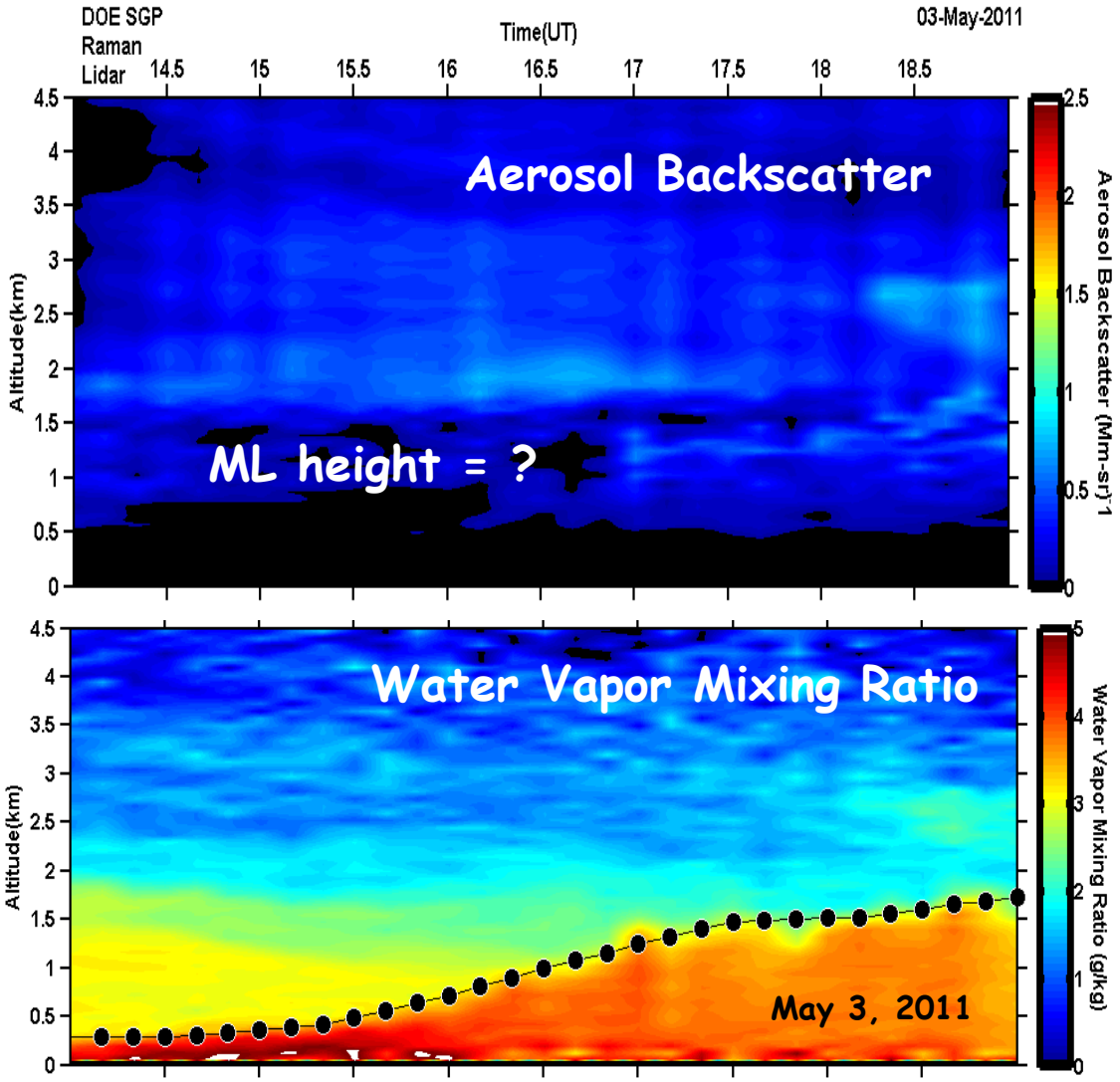
Mixed Layer Heights via Raman Lidar Measurements of Aerosol and Water Vapor Gradients

Mixed Layer Heights from Raman lidar water vapor and aerosol profiles

- ML 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 ML (Brooks, JAOT, 2003)
- These heights often correspond to gradients in potential temperature

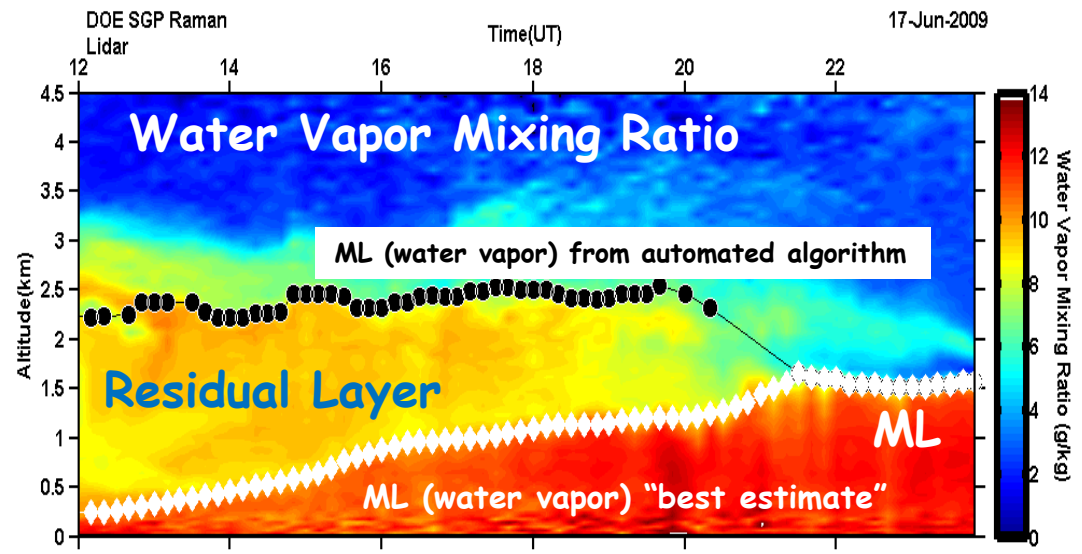


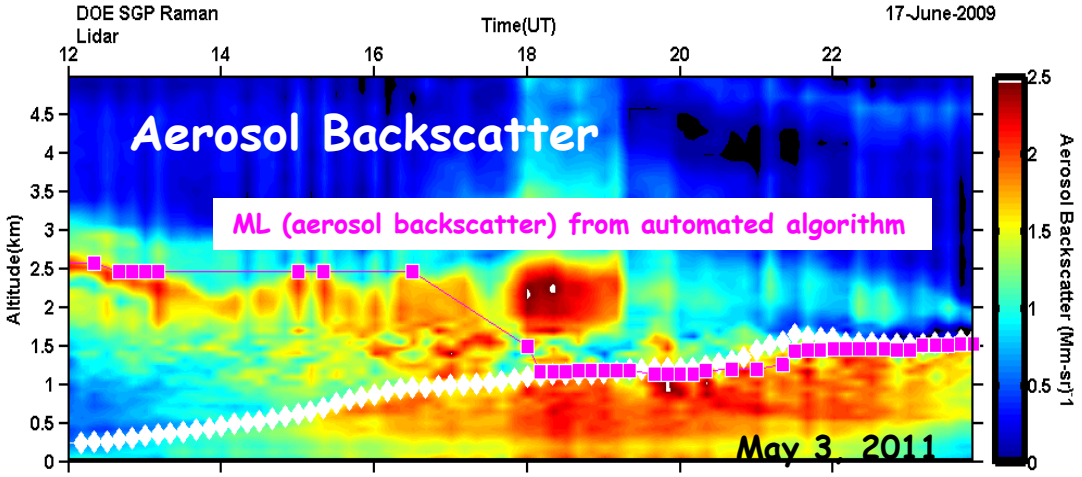
Mixed Layer Heights from Raman lidar water vapor and aerosol profiles



- In some cases, very low aerosol backscattering and/or instrument issues prevented retrieval of trustworthy ML heights
- In general, water vapor provided more reliable ML height retrievals

"Best estimate" Mixed Layer Heights from Raman lidar water vapor profiles

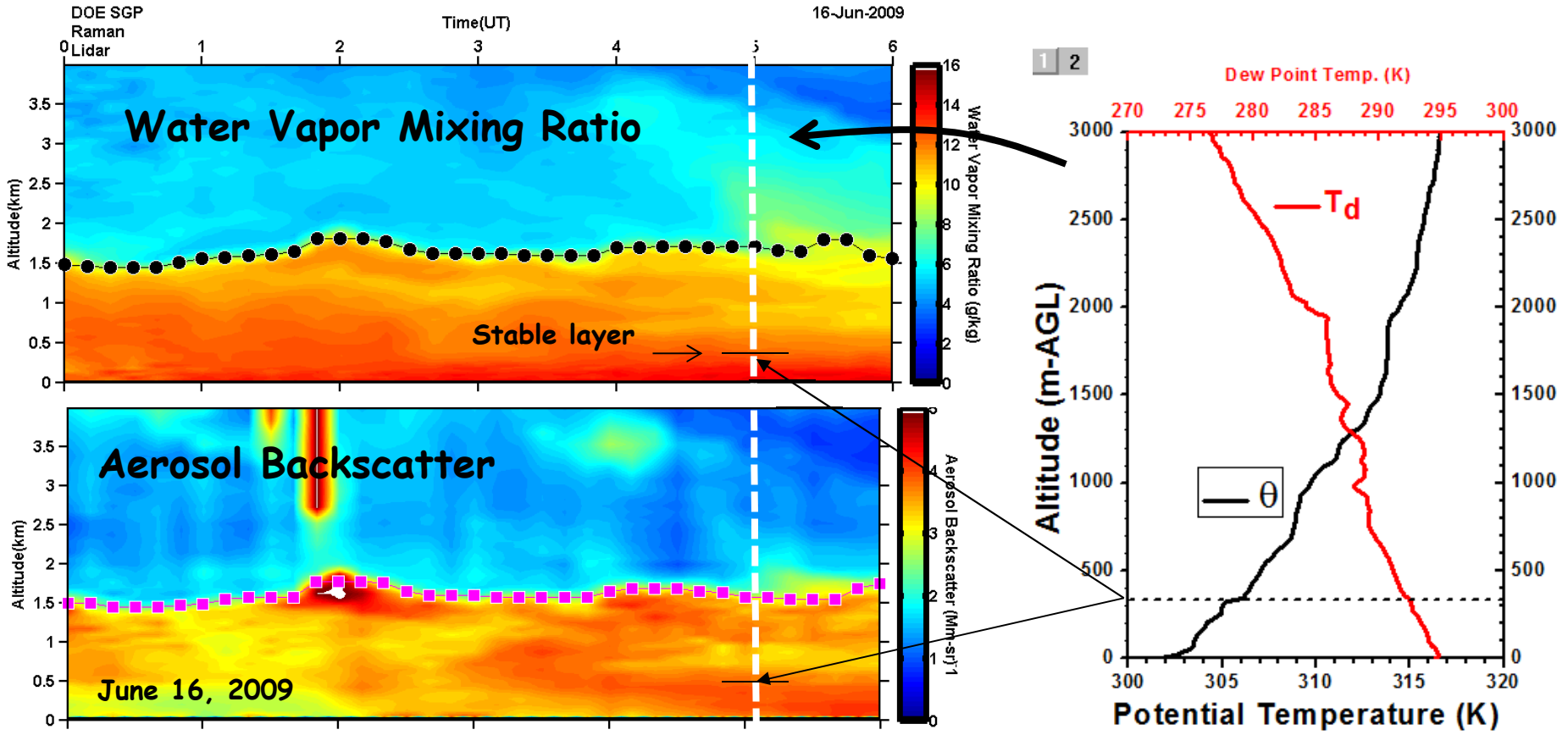




- Complicated aerosol structures within the boundary layer or residual layer(s) above boundary layer can prevent the algorithm from producing satisfactory results.
- "Best-Estimate" mixed layer heights combine results from automated algorithm and manual inspection of Raman lidar water vapor profiles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

Nighttime BL Heights from water vapor and aerosol backscatter are problematic

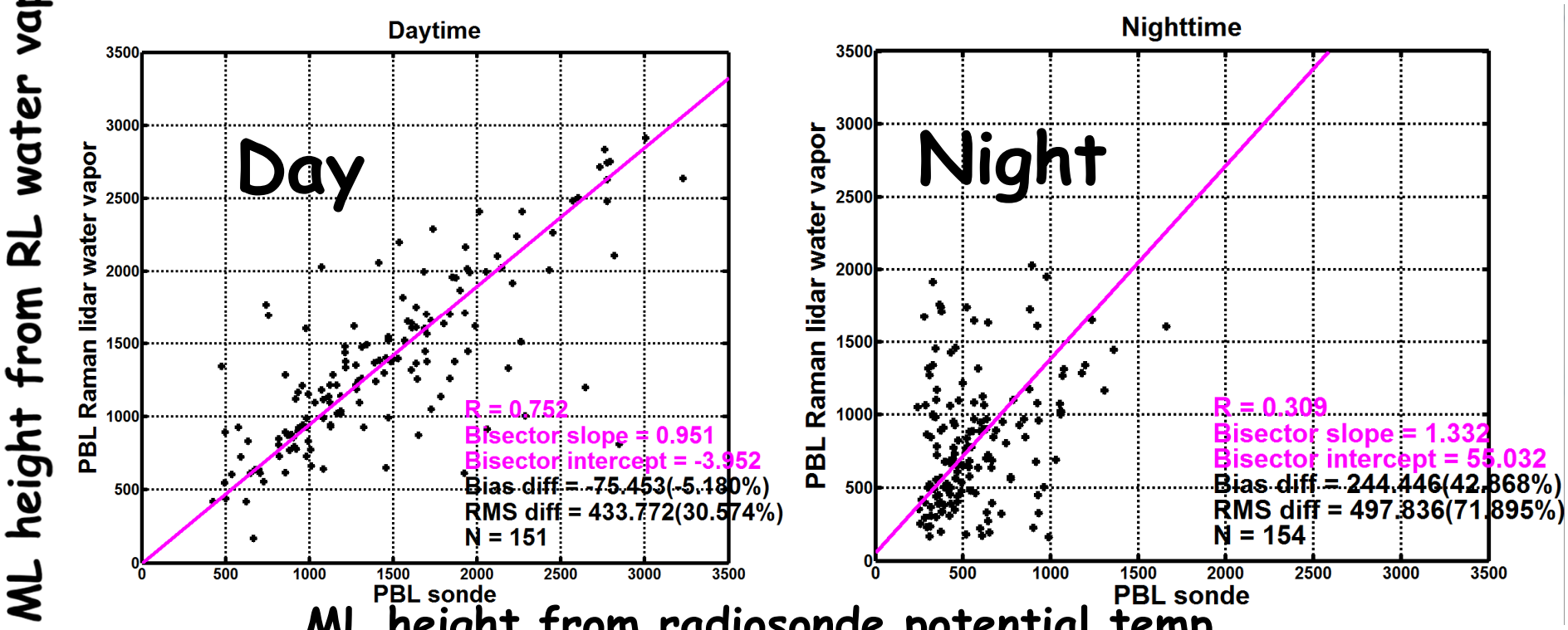
At night, largest water vapor and aerosol gradients are often associated with residual layer(s) above the nocturnal BL, confounding algorithms that use water vapor and aerosol backscattering



Nighttime vs. Daytime BL heights from Raman lidar water vapor

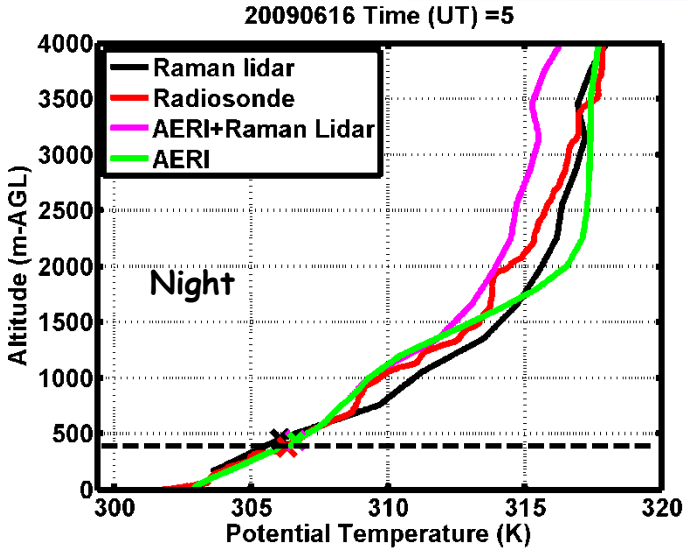
For data collected during June 2009 and April-June 2011:

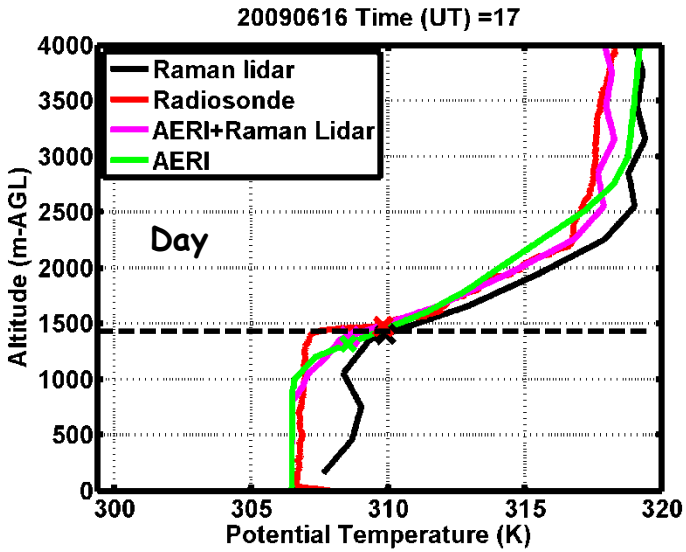
- Daytime: ML heights from derived from Raman lidar water vapor gradients and radiosonde potential temperature are comparable
- Nighttime: ML heights from Raman lidar water vapor have large high bias as compared to BL heights from radiosonde potential temperature



Boundary Layer Heights via Raman Lidar Measurements of Potential Temperature

BL heights from Raman Lidar + AERI potential temperature profiles





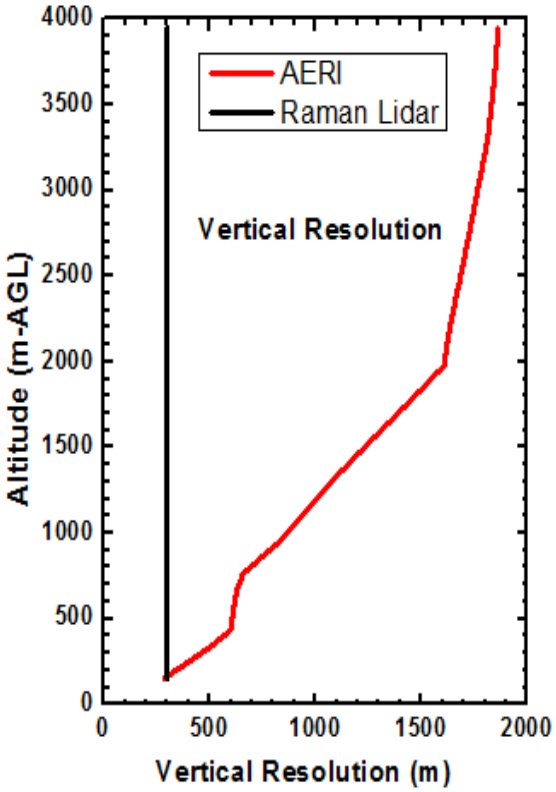
- Potential temperature profiles derived from a combination of AERI + Raman lidar temperature retrievals
- AERI temperature profiles are spliced onto the bottom of Raman lidar temperature profiles
  - Raman lidar rotational Raman scattering ($z > 700$ m)
  - AERI radiances ($z < 700$ m)
- PBL heights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

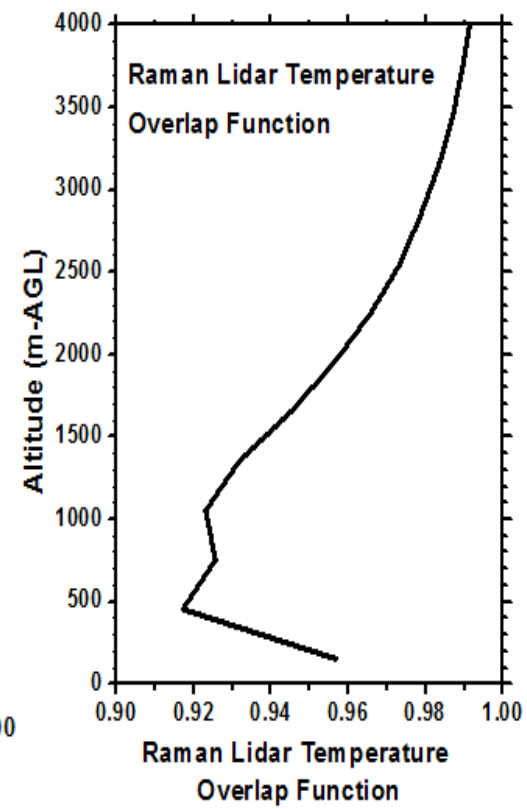
Lapse rate $\frac{\Delta\theta}{\Delta z} \geq 0.001\ ^{o}K/m$

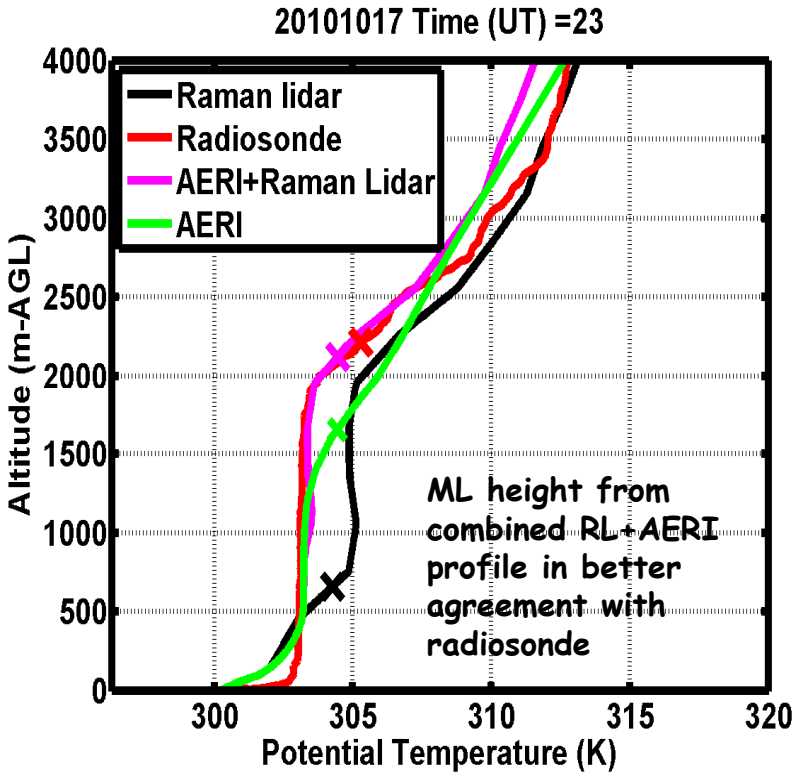
Inversion strength $\theta_{top} - \theta_{base} \geq 2\ ^{o}K$

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

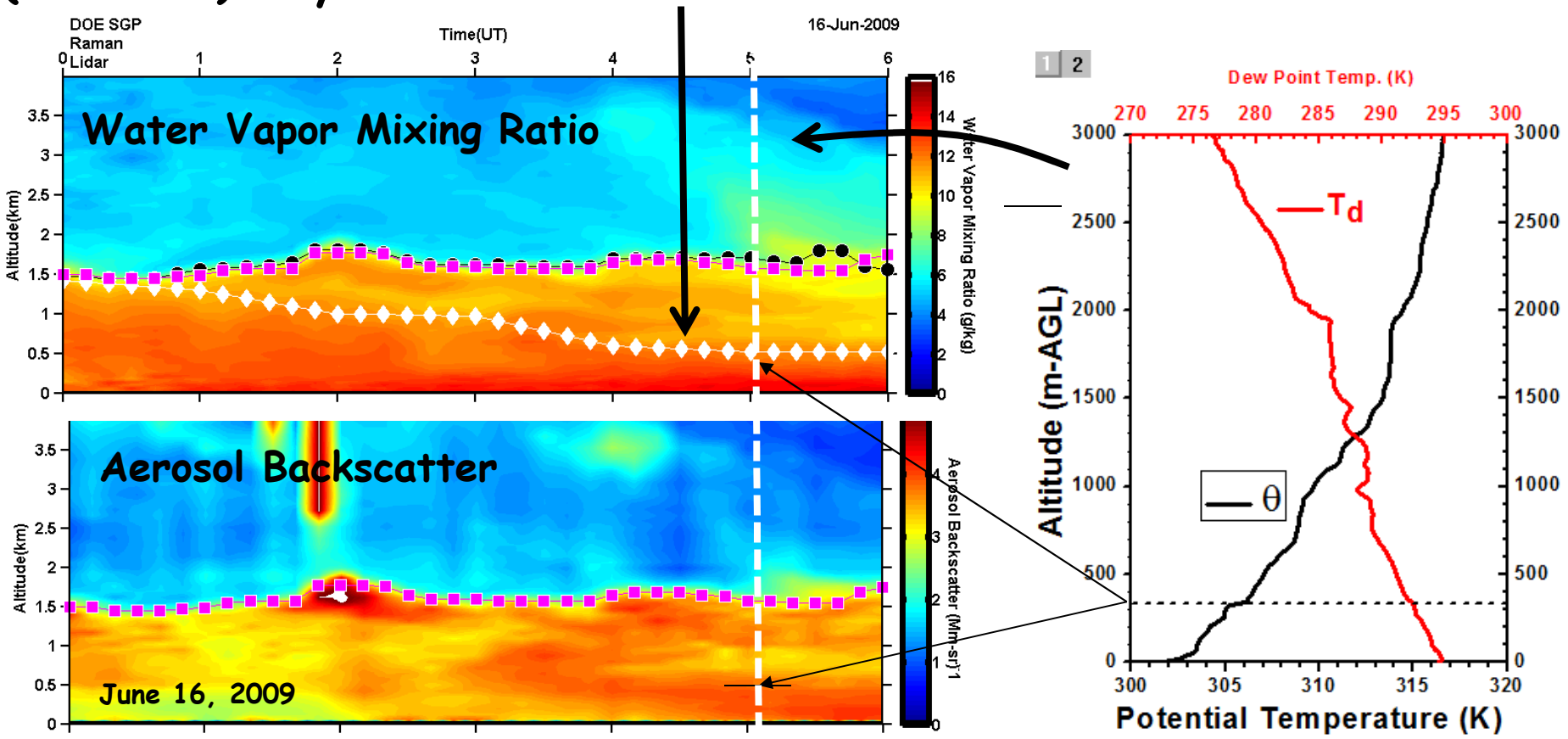






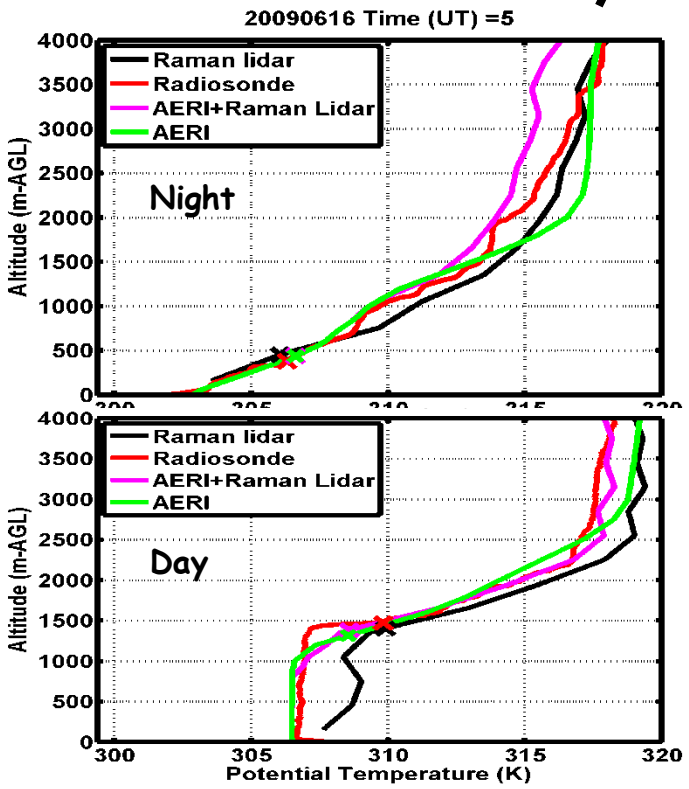
Nighttime BL Heights from RL+AERI potential temp. profiles

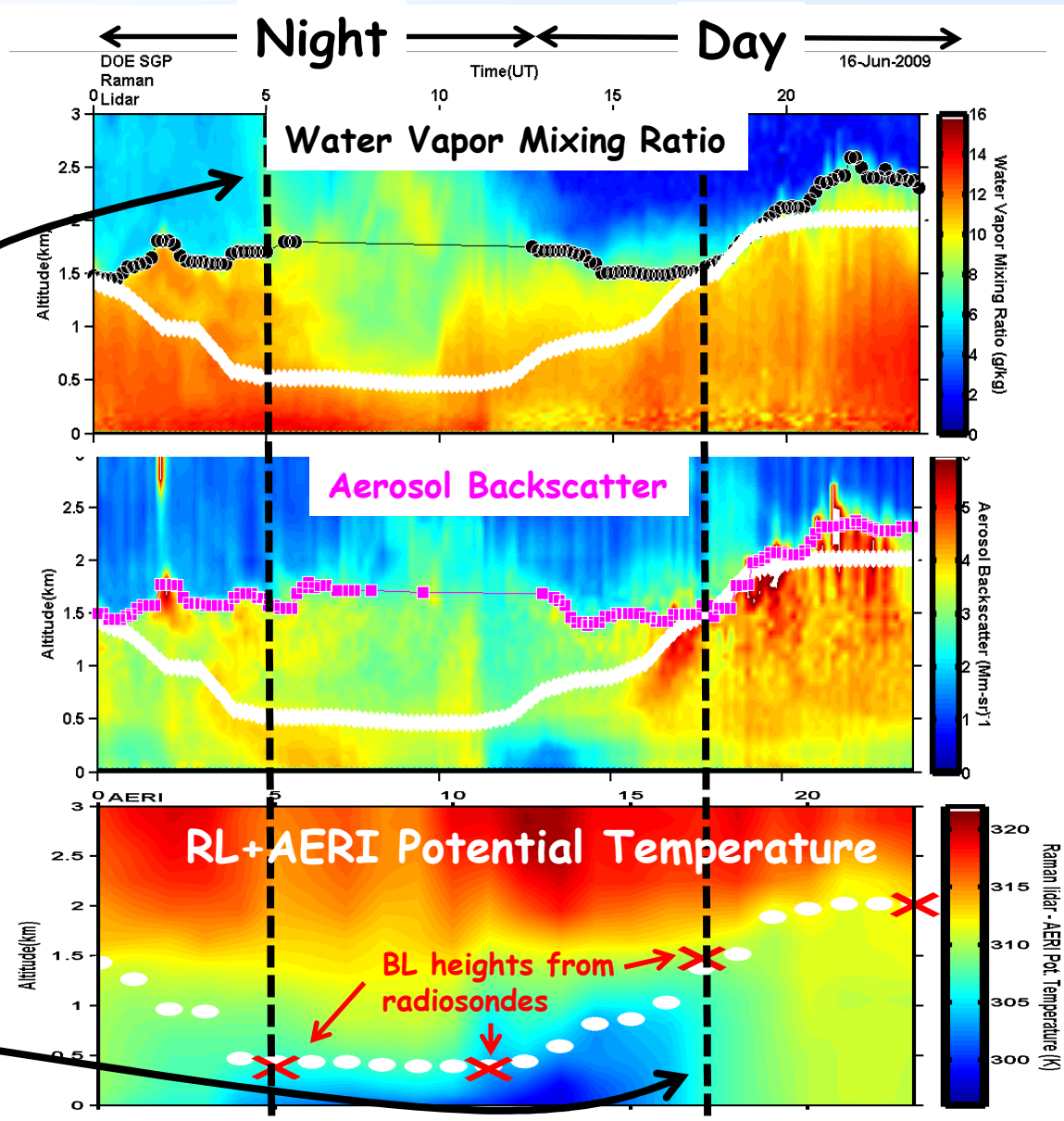
- At night, largest water vapor and aerosol gradients are often associated with residual layer above stable layers, confounding algorithms that use water vapor and aerosol backscattering
- BL heights from potential temperature gradients as measured by (RL+AERI) may be more relevant



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

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

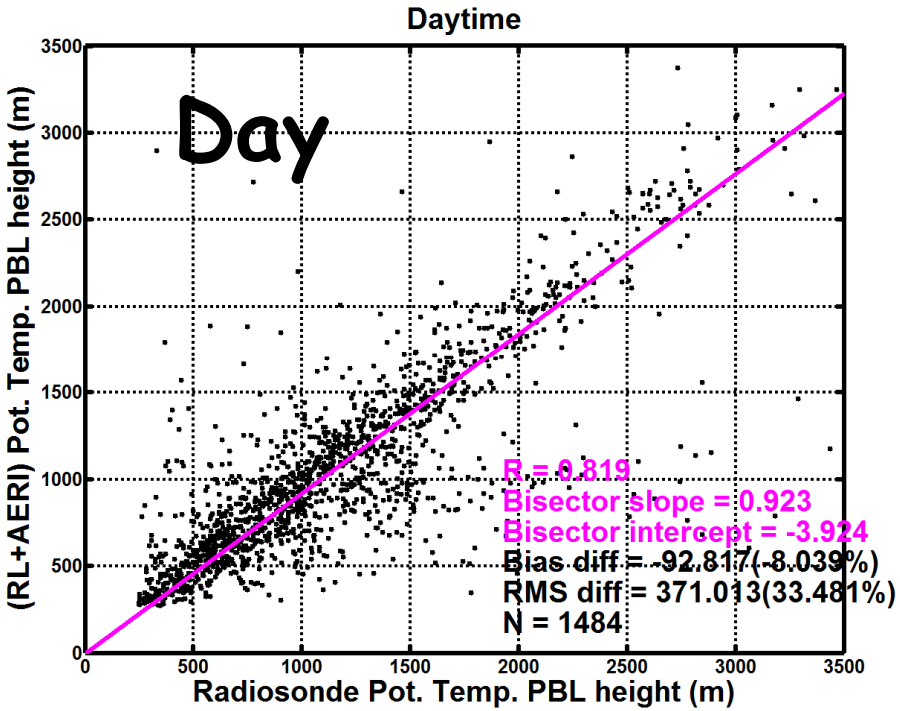


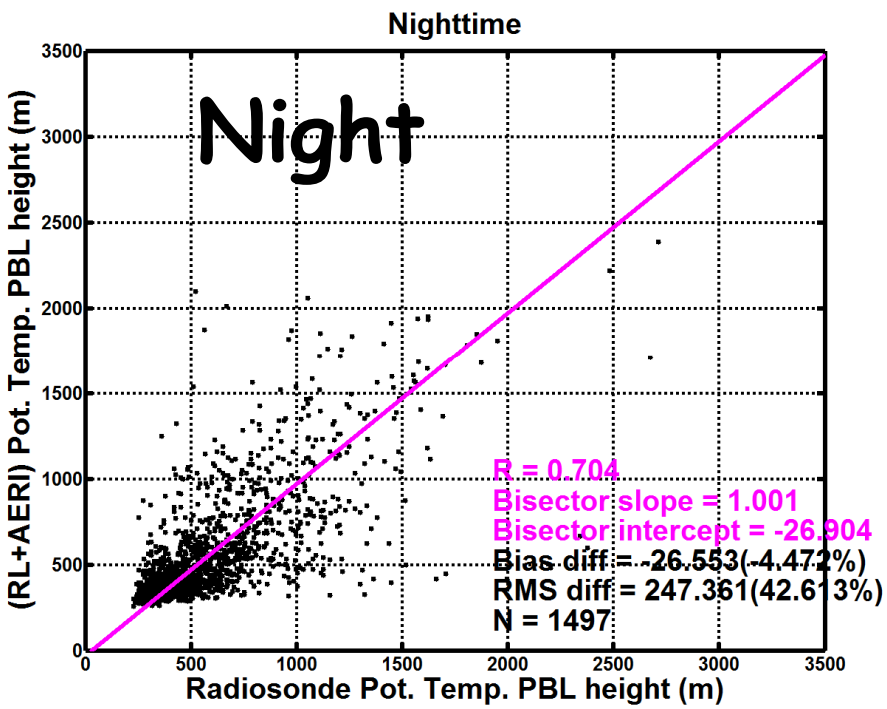


Comparison of BL heights from Raman lidar+AERI and radiosonde potential temperature profiles

For data collected from 2009-2011:

- PBL heights computed from Raman lidar + AERI potential temps compare well with those derived from coincident radiosondes
- Nighttime performance still worse than daytime, but considerably improved over ML heights derived from Raman lidar water vapor and aerosol backscatter gradients

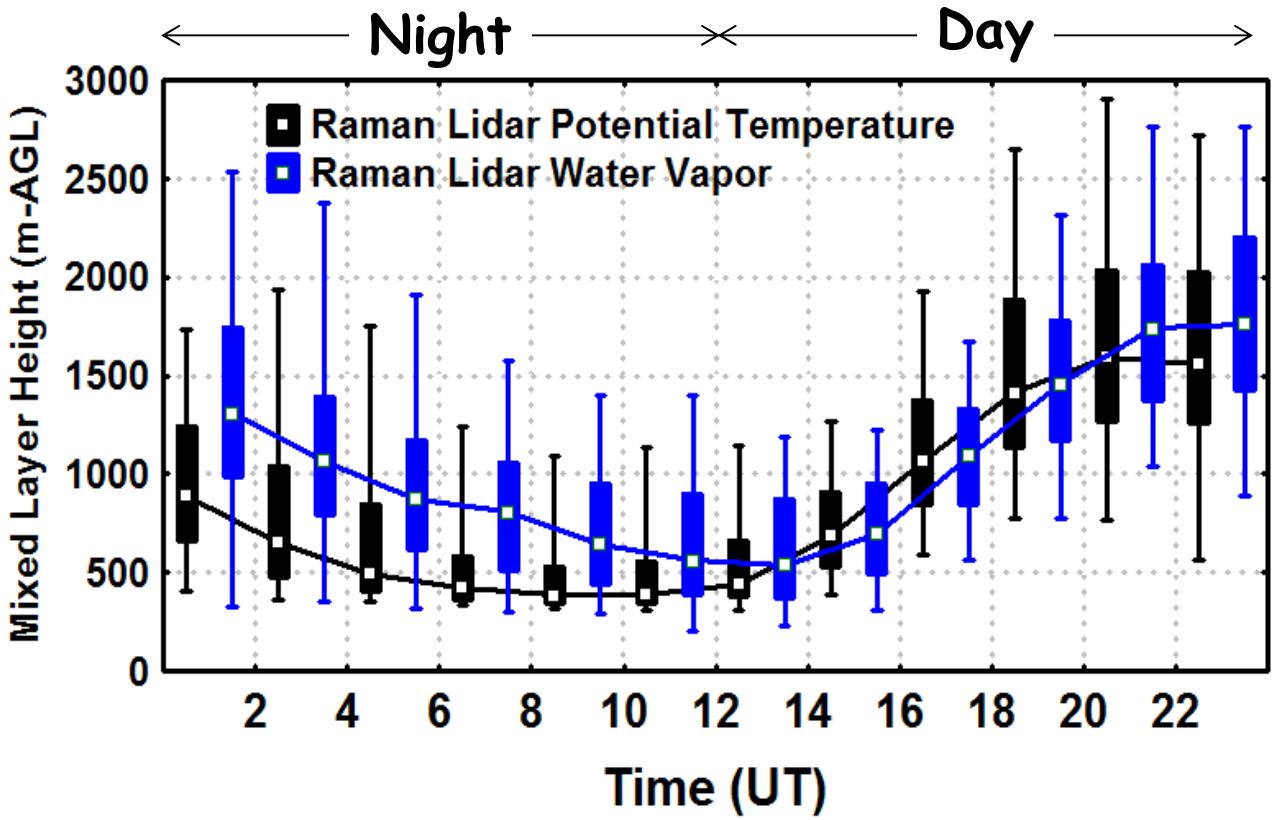




Comparison of BL heights from RL water vapor and RL+AERI potential temp. profiles

For data collected during June 2009 and April-June 2011:

- Daytime: ML heights from derived from Raman lidar potential temperature and water vapor gradients are comparable
- Nighttime: ML heights from potential temperature are considerably (100-500 m) lower than heights from water vapor and aerosol backscatter gradients

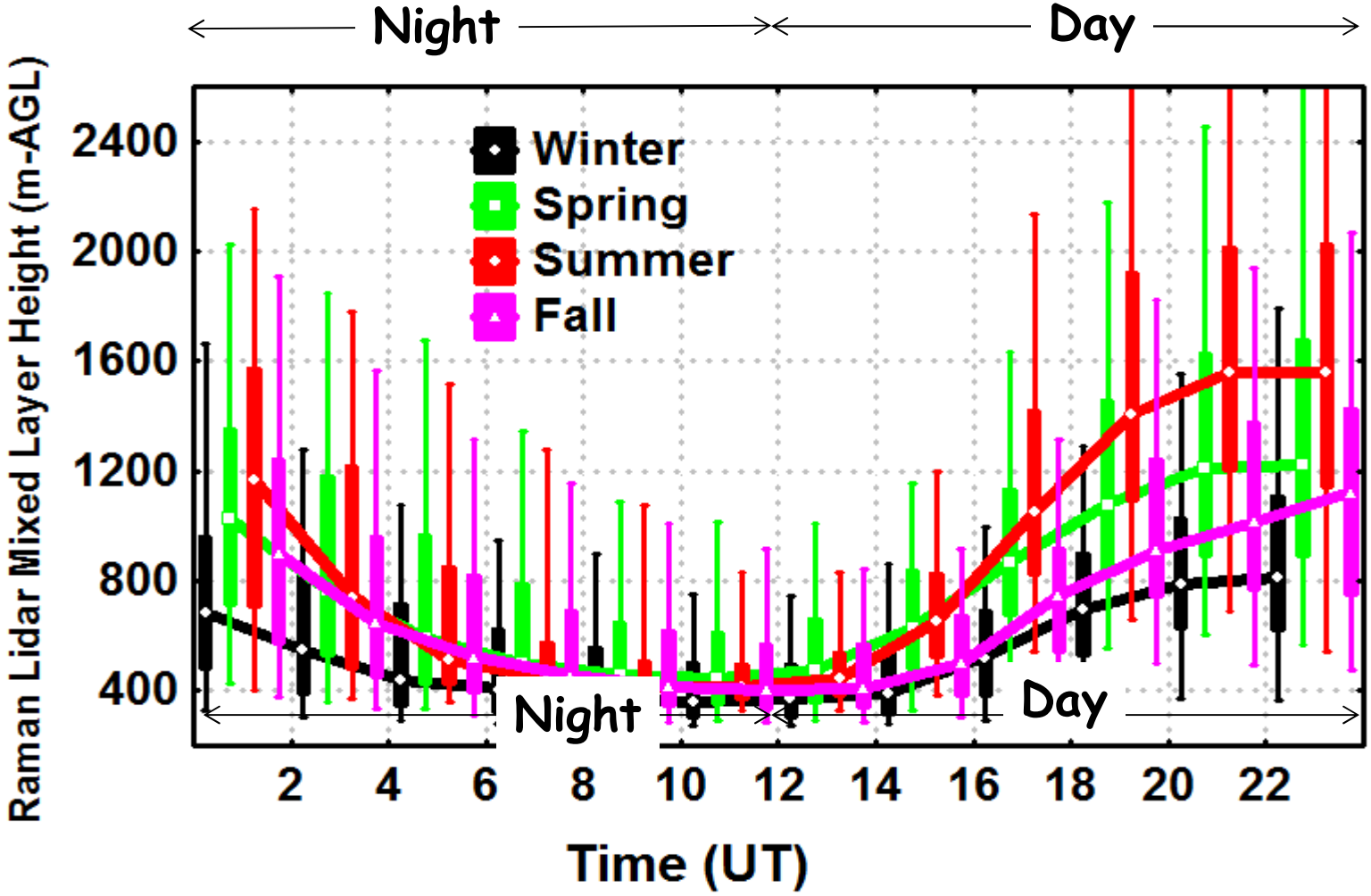


Boundary Layer Heights

Diurnal PBL Behavior for Each Season

PBL heights derived from RL+AERI potential temps from 2009-2011:

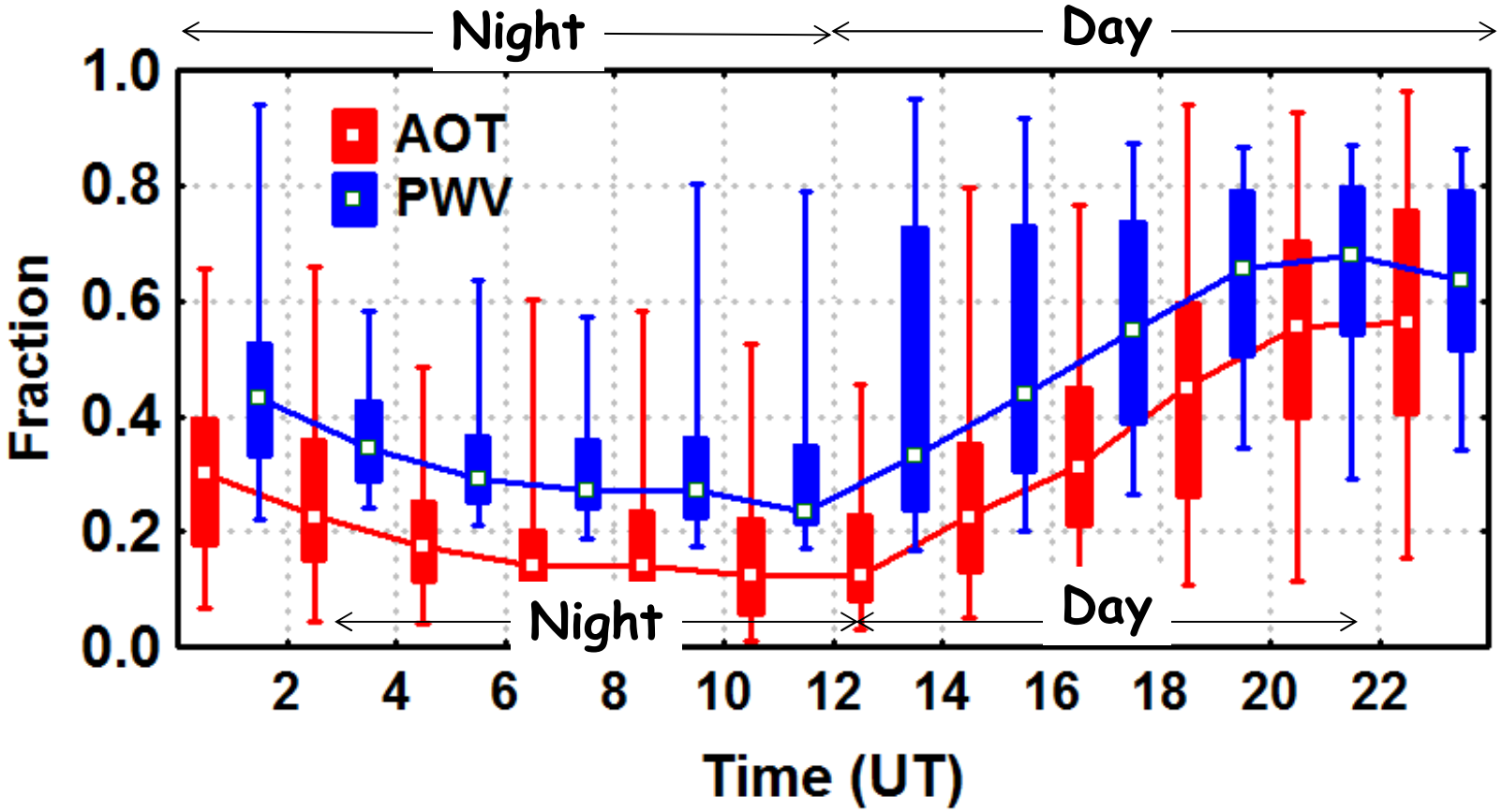
- highest PBL during summer
- lowest PBL during winter



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



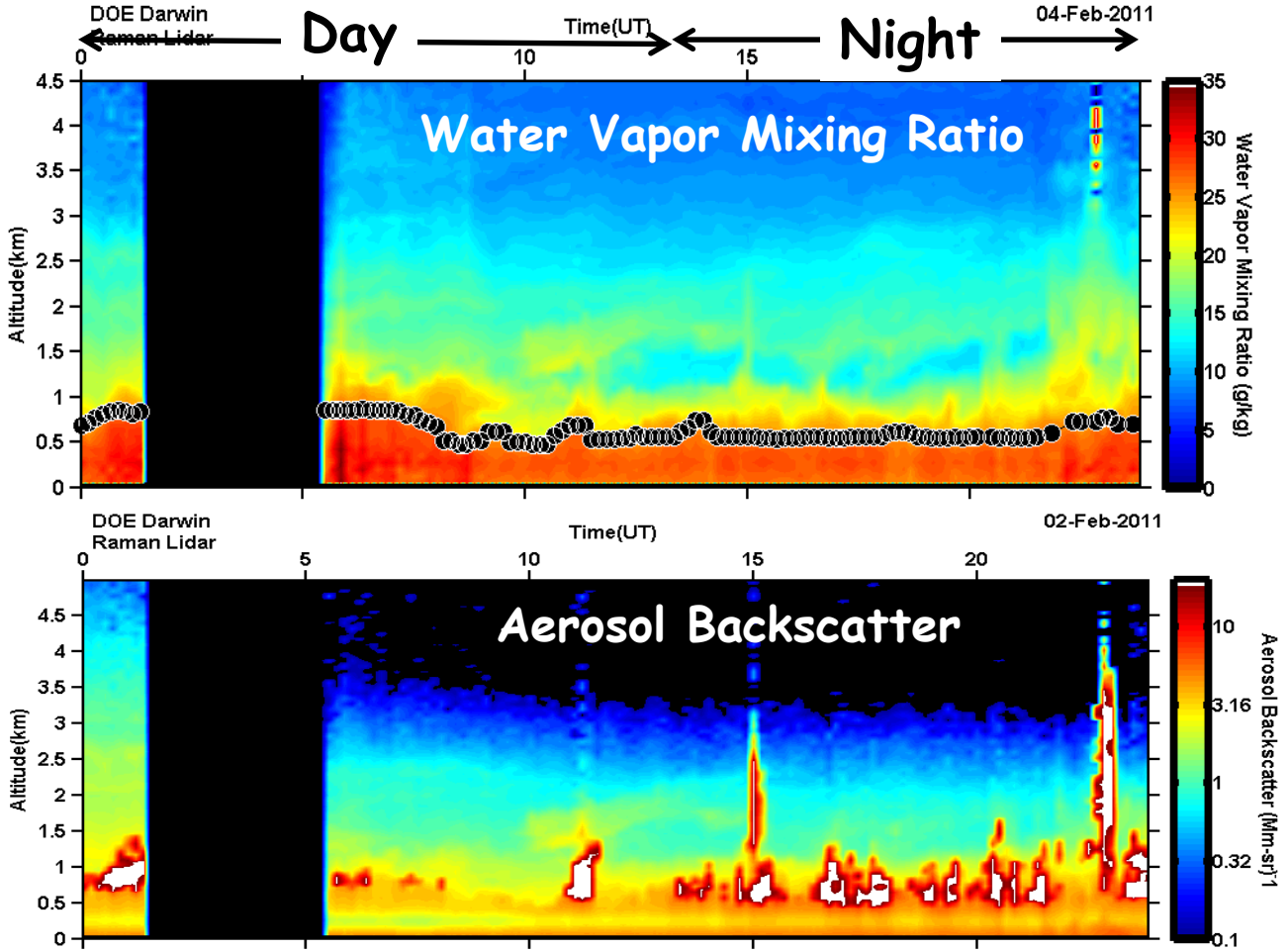
Preliminary Look at Darwin Raman Lidar Measurements

Darwin Raman Lidar Data (February)

- 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

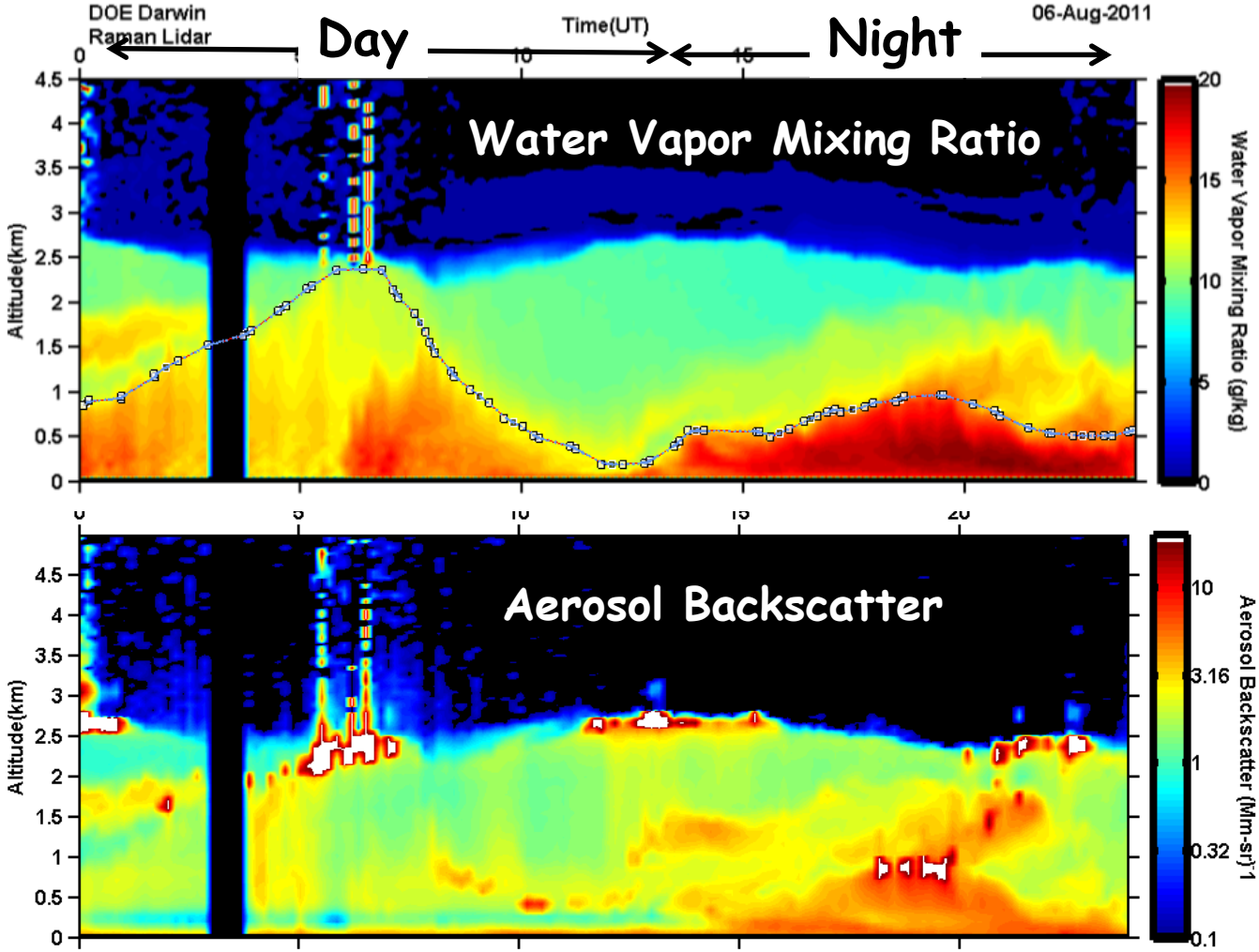


Darwin Raman Lidar Data (August)

- Beginning analyses of data from Raman lidar at Darwin, Australia
- Data available from December 2010 to October 2011
- Raman lidar temperature profiles not yet available

August

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



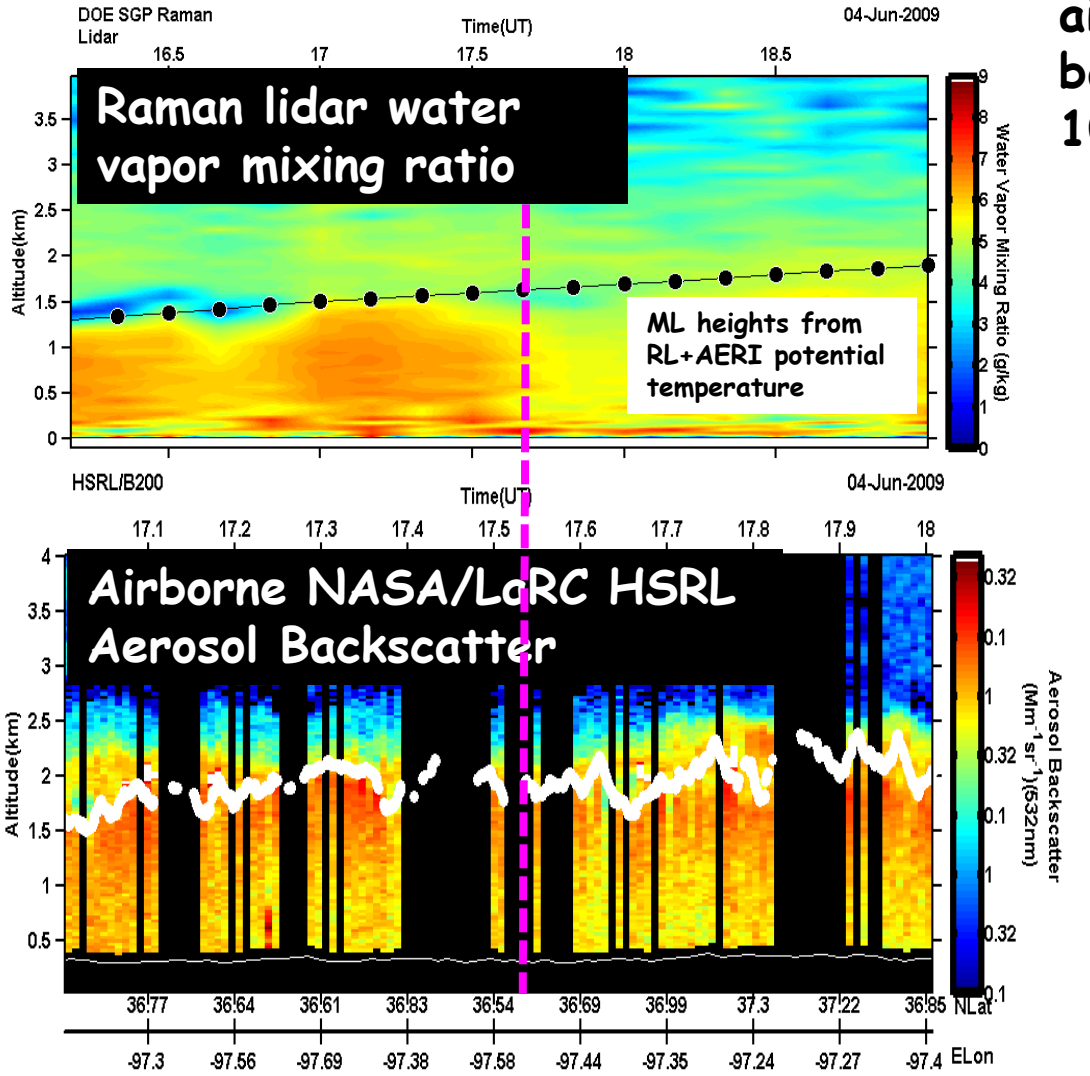
Summary

- Mixed Layer (ML) heights are derived from SGP Raman lidar measurements of water vapor and aerosol gradients
- "Best estimate" heights are derived from water vapor gradients after manual inspection of results from automated algorithm. These are available for:
  - June 2009 (RACORO)
  - April – June 2011 (MC3E)
- ML heights derived from water vapor and 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 were derived from combined (Raman lidar + AERI) potential temperature profiles for 2009-2011. These have:
  - 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

EXTRA SLIDES

Comparison of Raman lidar and airborne HSRL ML heights

June 4, 2009 (RACORO)



ML heights from RL+AERI potential temp. profiles and airborne HSRL aerosol backscatter measurements within 10 km and 10 min of SGP