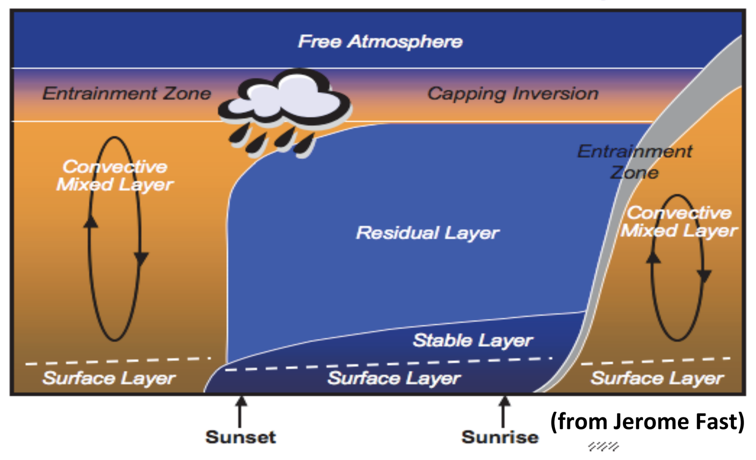
Raman Lidar Retrievals of Mixed Layer Heights over the TWP Darwin and the SGP Sites

Richard Ferrare[1], Marian Clayton[2], David Turner[3], Rob Newsom[4], Amy Jo Scarino[2]

[1] NASA Langley Research Center, Hampton, VA, USA [2] Science Systems and Applications, Inc., Hampton, VA, USA [3] NOAA NSSL, Norman, OK, USA [4] Pacific Northwest National Laboratory, Richland, WA, USA

Background



(from Jerome Fast)

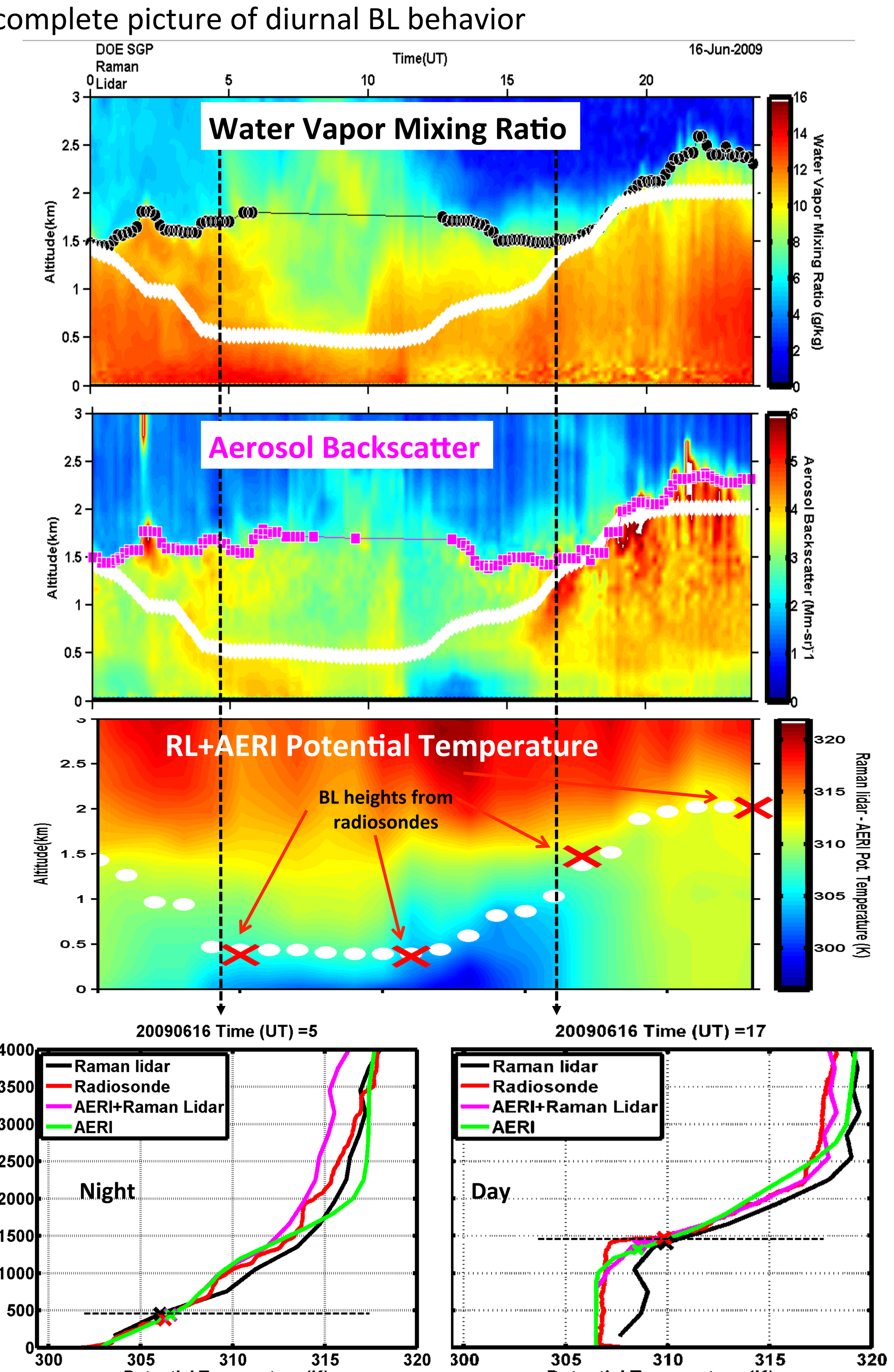
- Assessments of model PBL heights will likely require multiple measurement methodologies
- Raman lidars at SGP and TWP can provide multiple techniques

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

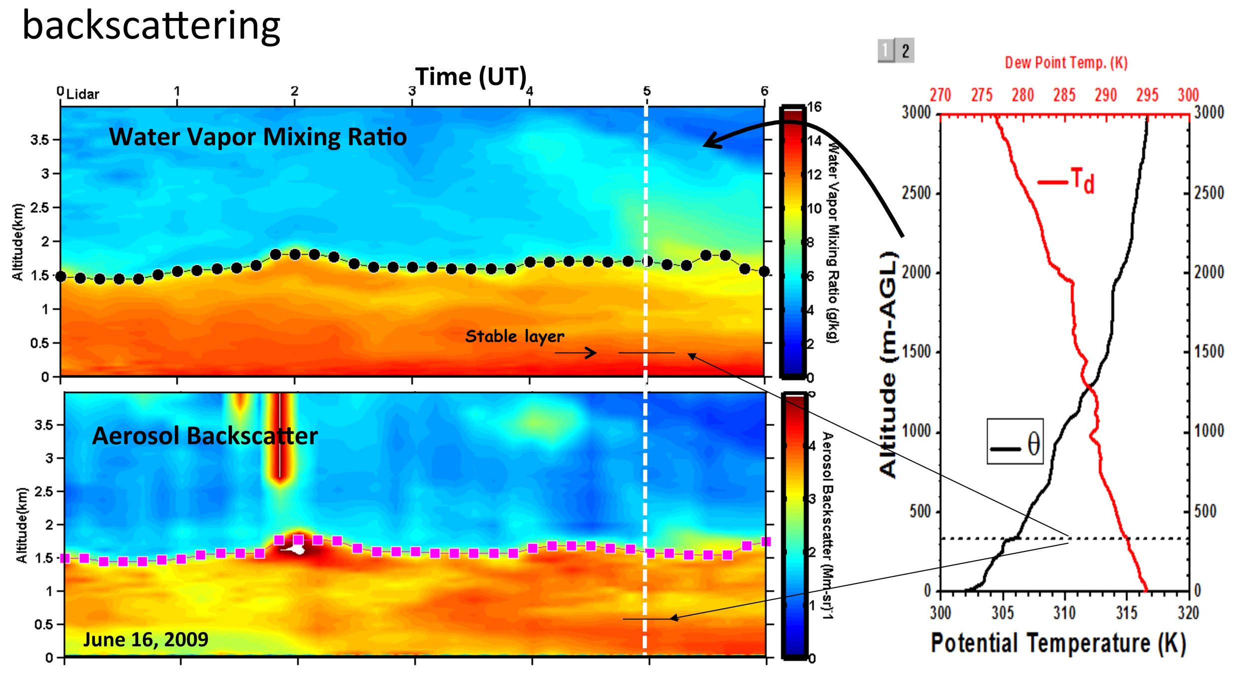
BL heights from Raman Lidar using water vapor, aerosol backscatter, and potential temperature

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



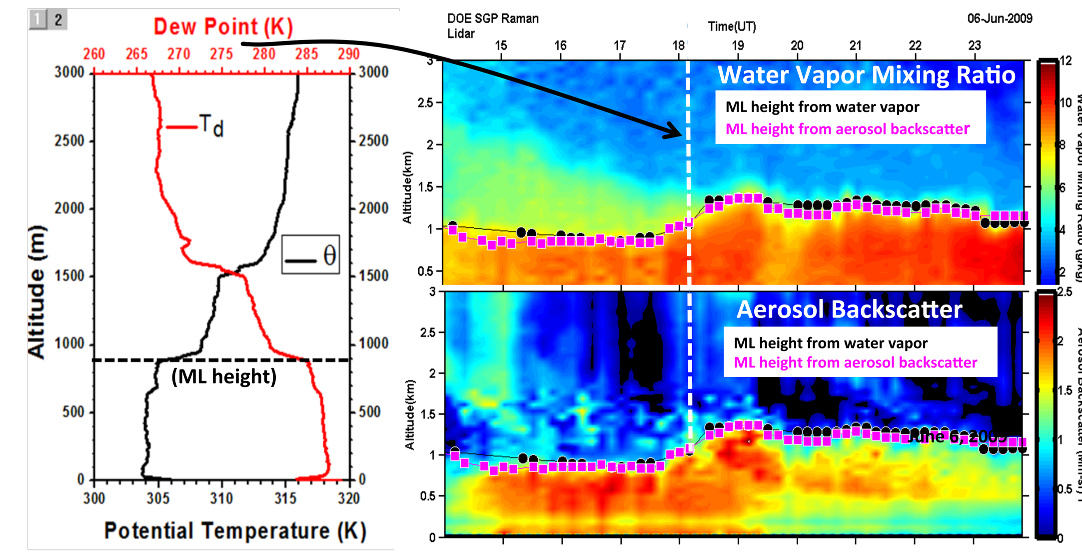
Limitations using water vapor aerosol gradients

At night, the 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



Mixed Layer (ML) Heights 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 and water vapor
- 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 are available for April-June 2011 period (e.g. MC3E) and June 2009 (e.g. RACORO)

Boundary Layer Height using RL+AERI potential temp

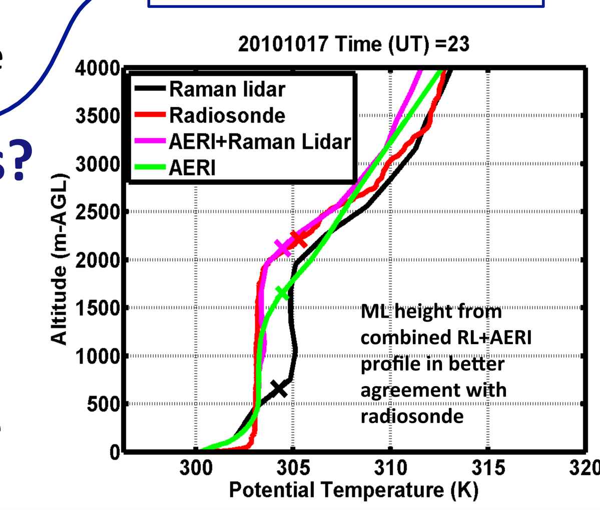
- Potential temperature profiles derived from a combination of AERI + Raman lidar temperature retrievals. These are available for 2009-2011 as a PI product from DOE ARM archive (see http://www.arm.gov/data/pi/65).
- AERI temperature profiles are spliced onto the bottom of Raman lidar temperature profiles
  - 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

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

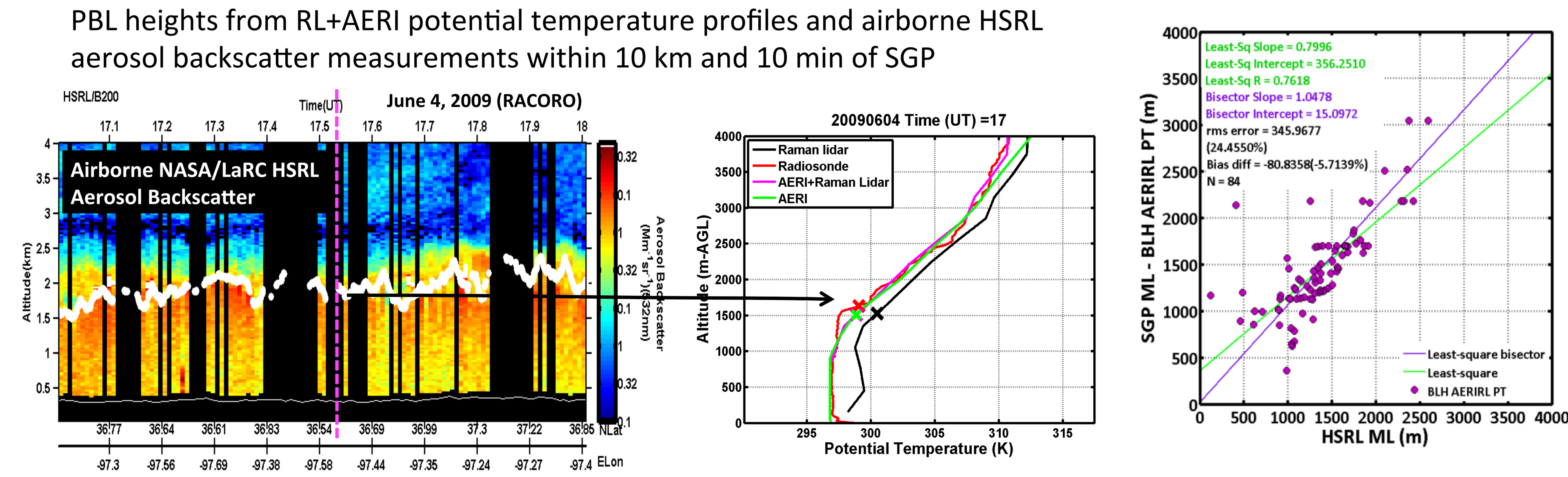


Why combine Raman lidar and AERI temperature profiles?

- 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

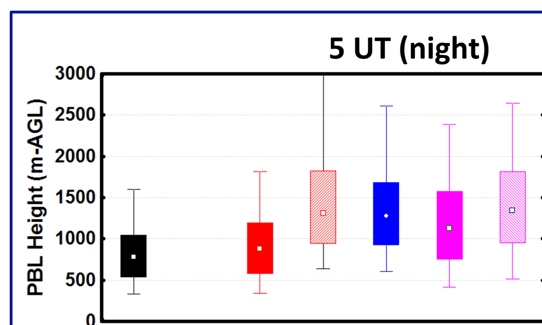
Comparison of Raman lidar and Airborne HSRL PBL heights

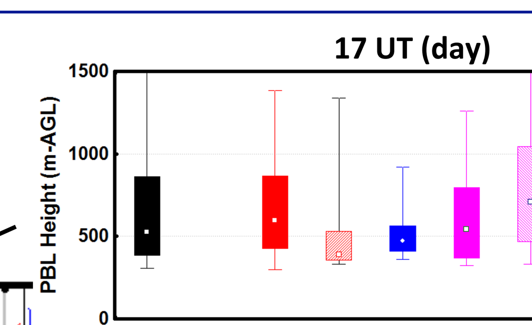
PBL heights from RL+AERI potential temperature profiles and airborne HSRL aerosol backscatter measurements within 10 km and 10 min of SGP



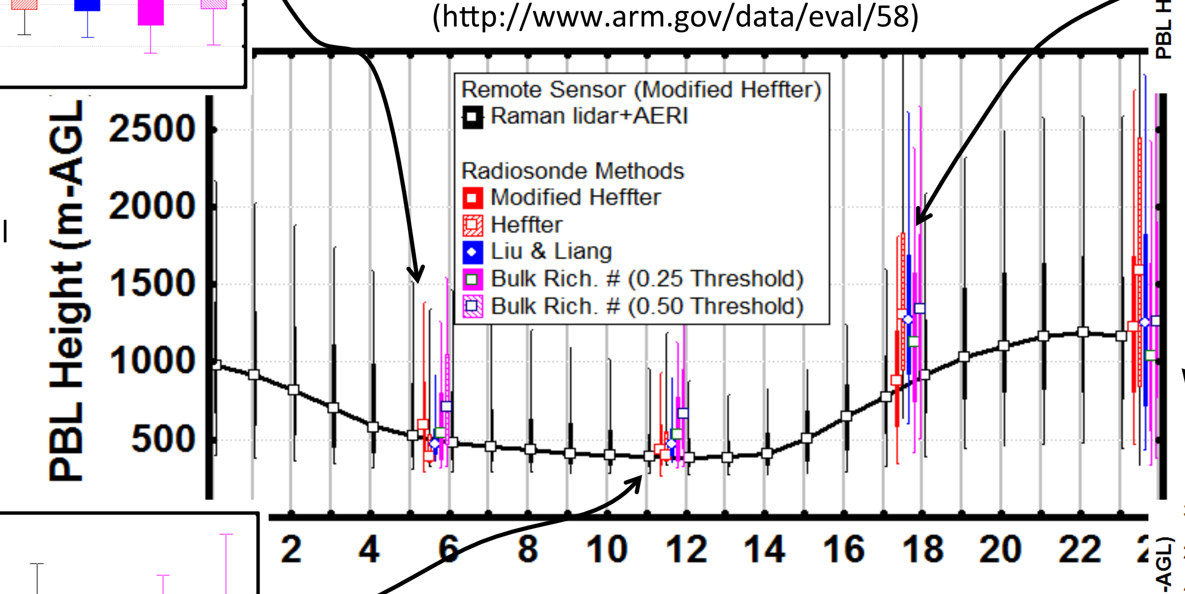
PBL VAP from 2009-2011

The PBL heights determined from the Raman lidar+AERI potential temperature profiles during 2009-2011 were compared with those included in the PBL height VAP (http://www.arm.gov/data/eval/58)

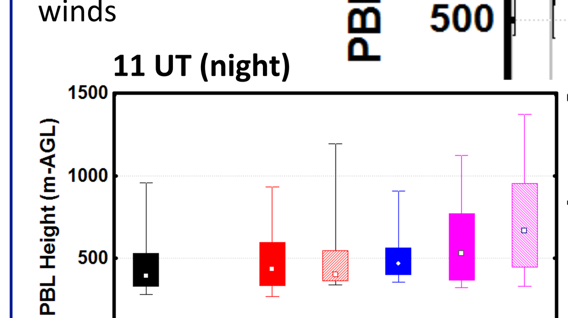


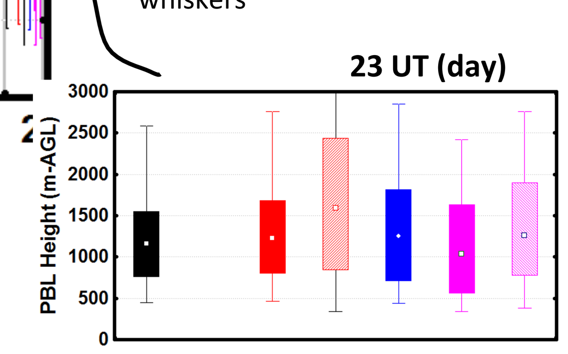


The PBL VAP computes PBL heights with several methods that use radiosonde measurements of temperatures and winds



- At SGP radiosondes are normally launched four times per day (5 UT, 11 UT, 17 UT, 23 UT)
- The median values are shown as the open symbols in the center of the bars, 25-75 percentiles are shown by the bars, and 5-95 percentiles are shown by the whiskers





PBL VAP heights for the 2009-2011 period were compared with those derived via the modified Heffter technique using
1) Raman lidar+AERI and
2) radiosonde potential temperature profiles

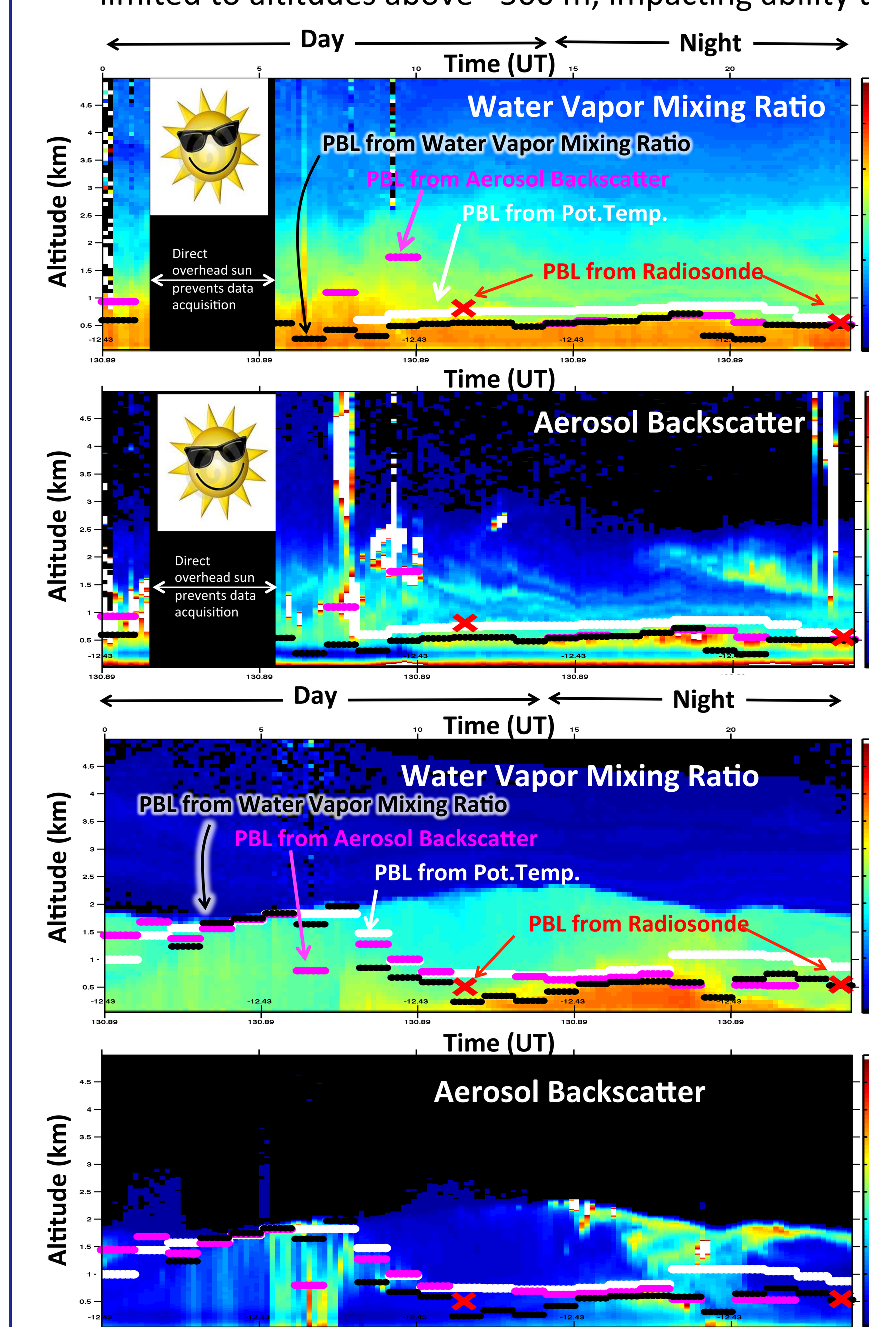
- The PBL VAP computes PBL height using the Heffter technique except that the critical threshold for the potential temperature lapse rate is (0.005 K m^{-1}) instead of the (0.001 K m^{-1}) used in the modified Heffter technique that Della Monache et al. (2004) developed for the SGP and what was used for the Raman lidar+AERI PBL height analyses
- Another technique used in the PBL Height VAP uses the techniques described by Liu and Liang (2010) that computes PBL heights using potential temperature gradients and/or wind shear depending on the convective regime
- The PBL VAP also provides PBL heights derived using the bulk Richardson number, which relates vertical stability to vertical shear; the PBL height is given by the height where the Richardson number exceeds a threshold value (0.25 or 0.5)
- The differences among the results are due primarily to the differences in PBL techniques rather than the sources of the potential temperature profiles

Summary

- Mixed Layer (ML) heights were derived from SGP Raman lidar measurements of water vapor and aerosol gradients. "Best estimate" heights were derived from these ML heights after manual inspection of results from the automated algorithm. These are available for June 2009 (RACORO) and April – June 2011 (MC3E).
- SGP Boundary Layer (BL) heights were derived from combined combined (Raman lidar + AERI) potential temperature profiles for 2009-2011. These are available as a PI product from ARM archive (see http://www.arm.gov/data/pi/65). Compared to the ML heights derived from water vapor and aerosol gradients, these show:
  - Better agreement with PBL heights from radiosondes
  - More consistent diurnal PBL representation
  - Generally good agreement with the PBL heights from the PBL VAP
  - Good agreement with ML heights derived from the NASA LaRC airborne HSRL during RACORO
- ML and PBL heights were computed over TWP Darwin via Raman lidar water vapor, aerosol, and potential temperature profiles in a similar manner.
- AERI temperature profiles are not available from TWP Darwin so the PBL heights derived from the Raman lidar potential temperature profiles alone are limited to altitudes above about 500 m.

ML and PBL Heights from TWP Darwin Raman Lidar

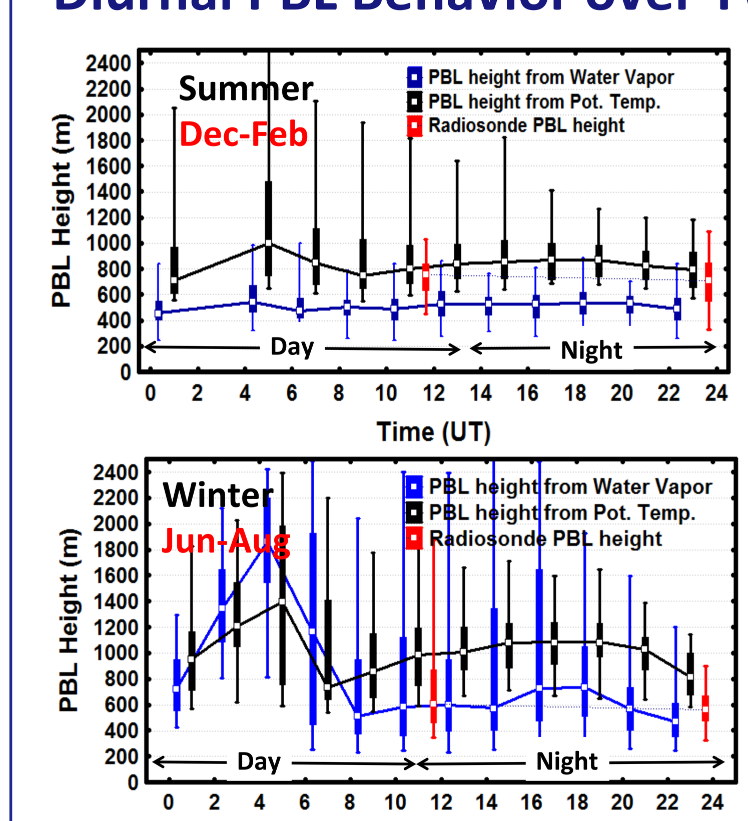
- ML and PBL heights computed over Darwin via Raman lidar water vapor, aerosol, and potential temperature profiles
- AERI temperature profiles are not available from Darwin
- Because of the lack of AERI retrievals over Darwin, and the uncertainty in lidar overlap function, PBL heights derived from Raman lidar potential temperature profiles alone are limited to altitudes above ~500 m, impacting ability to capture diurnal variability



February 2, 2011 (Austral Summer)
- Shallow, moist ML
- Little diurnal variability

July 27, 2011 (Austral Winter)
- Deeper ML
- More diurnal variability

Diurnal PBL Behavior over TWP in Summer and Winter



Darwin PBL heights from Dec. 2010 to Apr. 2012

- larger diurnal change in winter
- smaller diurnal change in summer
- PBL heights from water vapor lower than from potential temperature. This is due at least in part to 500 m lower limit for PBL heights derived from Raman lidar potential temp. profiles

Acknowledgements

We thank Laura Riihimaki for providing the PBL VAP results and thank the NASA Langley B200 King Air flight crew for their outstanding work supporting research flights during RACORO. This research was supported in part by the U.S. Department of Energy's Atmospheric System Research, an Office of Science, Office of Biological and Environmental Research program, under Interagency Agreement DE-SC0005521.