Diurnal Variation of the Planetary Boundary Layer Height Observed from GNSS Radio Occultation and Radiosonde Soundings over the Southern Great Plains

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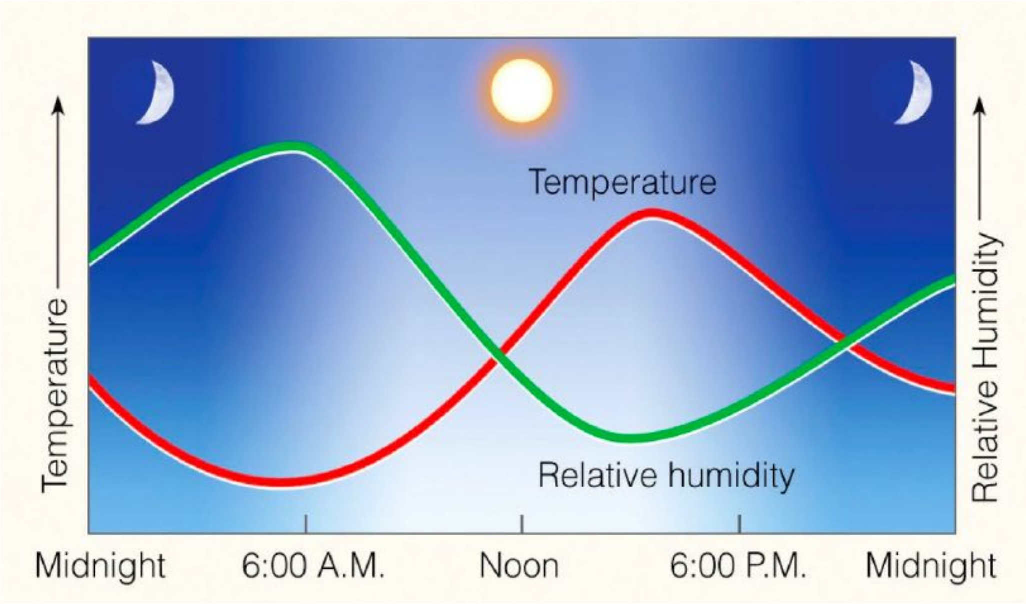
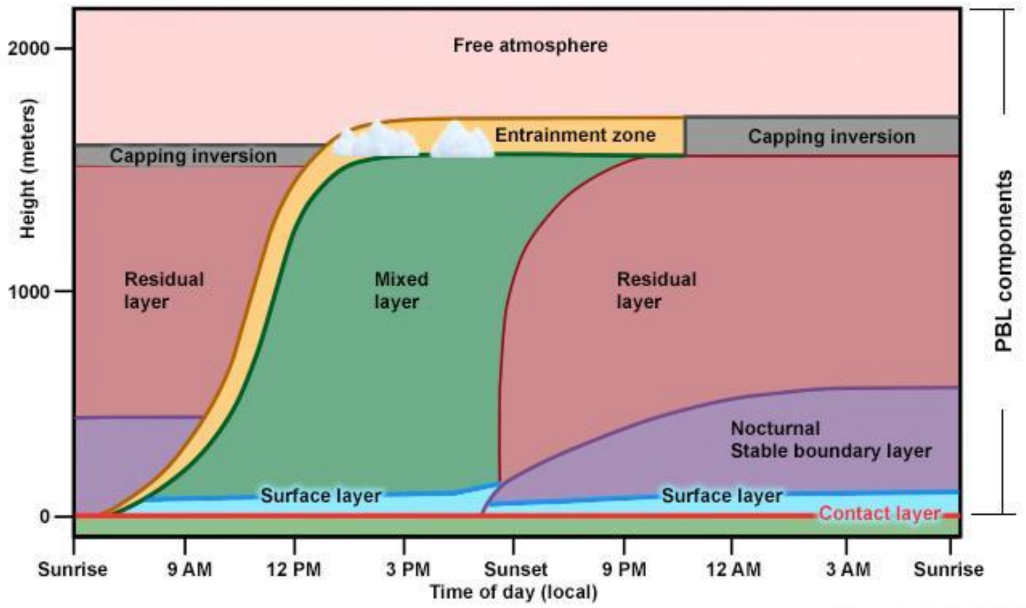
Background – Diurnal Cycle and Boundary Layers

- Solar heating induces strong oscillations in surface and atmospheric properties on 24-hr and 12-hr cycles (Dai and Trenberth, 2004)
- Amplitude and cause of diurnal cycle varies with location
  - Land: Higher amplitude; surface heating
  - Ocean: Lower amplitude, temperature mediation near coastlines
- Atmospheric (planetary) boundary layers come in many different forms depending on the local meteorological conditions
- Planetary boundary layer height (PBLH) is used to diagnose other properties in the boundary layer
- Atmospheric diurnal cycle also heavily influences PBLH
  - Vertical gradients in atmospheric properties allow for PBLH identification



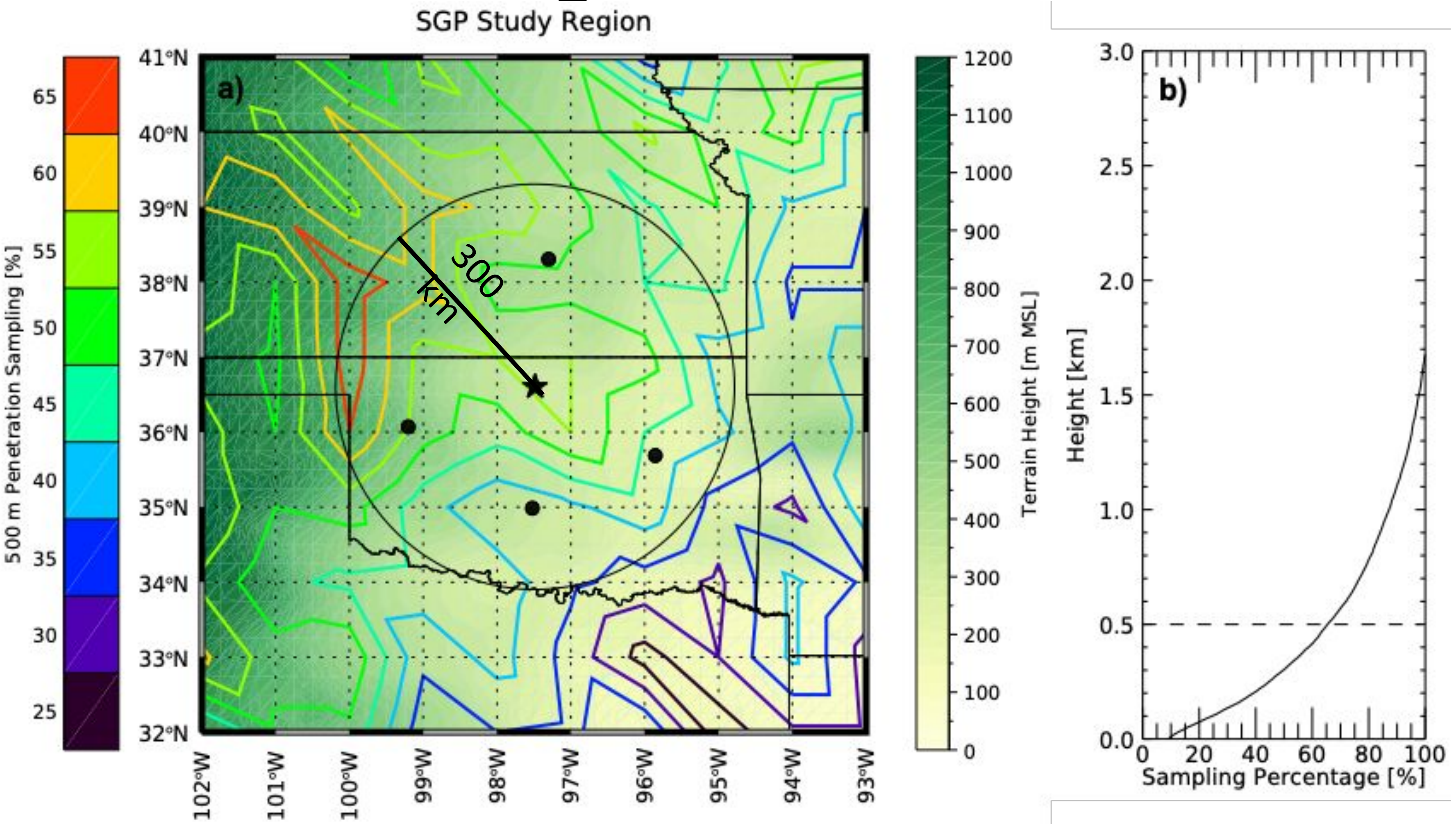


Motivation

- Previous studies have used GPS RO to diagnose PBLH in various maritime regions
  - Ao et al. (2008,2012), Xie et al. (2011,2012), Guo et al. (2011), Winning et al. (2017)
- PBLH studies using GPS RO over land are relatively limited, and regionally focused or climatological
  - Basha and Ratnam (2009), Ao et al. (2012)
- Few studies use GPS RO to diagnose terrestrial boundary layer heights and consider diurnal oscillations of the PBLH and atmospheric variables within the PBL

Data and Methods – Data Range and Colocation

- Study period from 2007 to 2013, over Southern Great Plains
  - Relatively flat terrain allows for minimal terrain interaction
- ARM radiosondes from SGP sites
  - Primary site in Lamont, OK (C1)
  - Ancillary sites surrounding C1

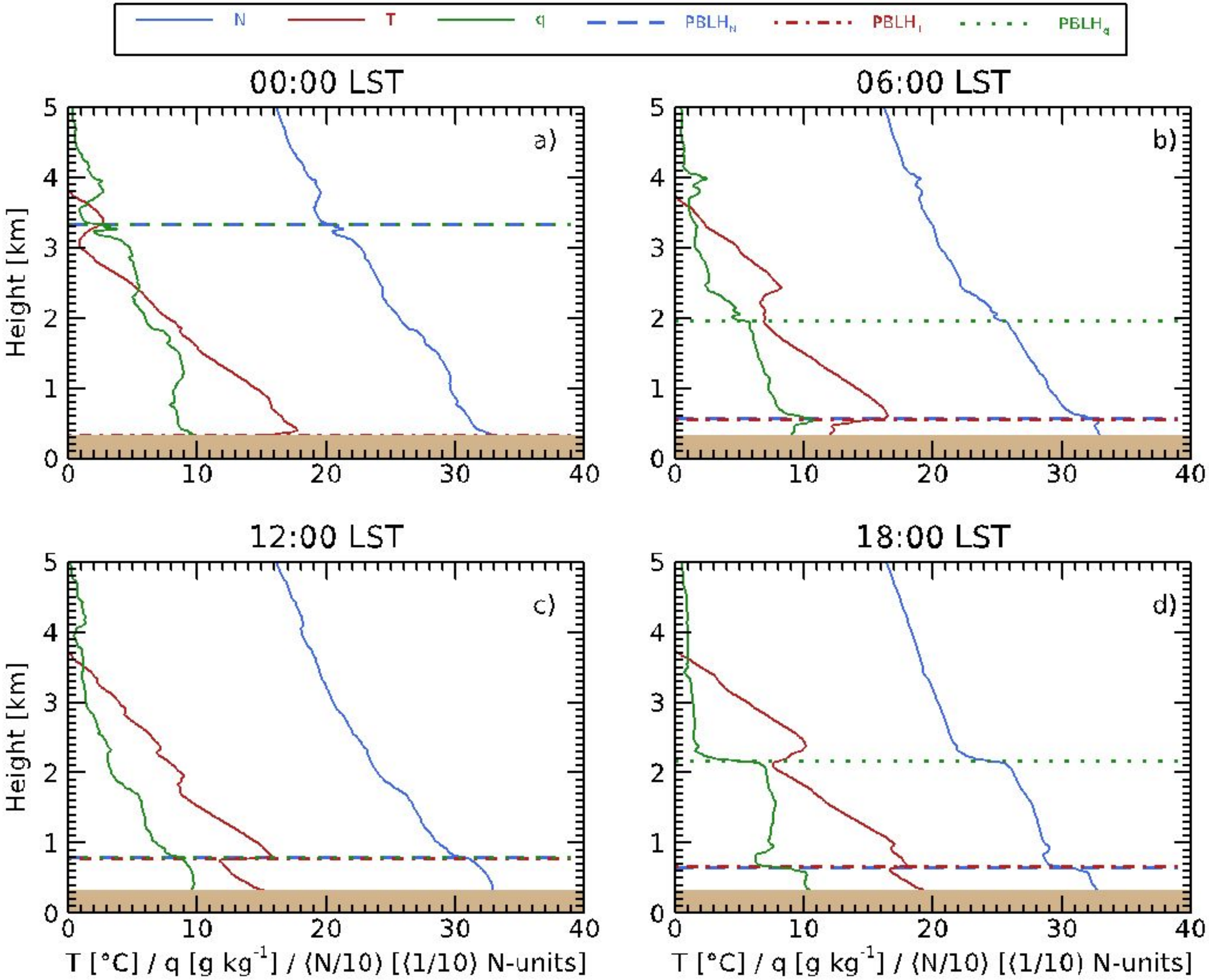


- FORMOSAT-3/COSMIC Mission Profiles
  - Co-located (with ARM SGP radiosondes) refractivity profiles within 300 km and 3 hrs

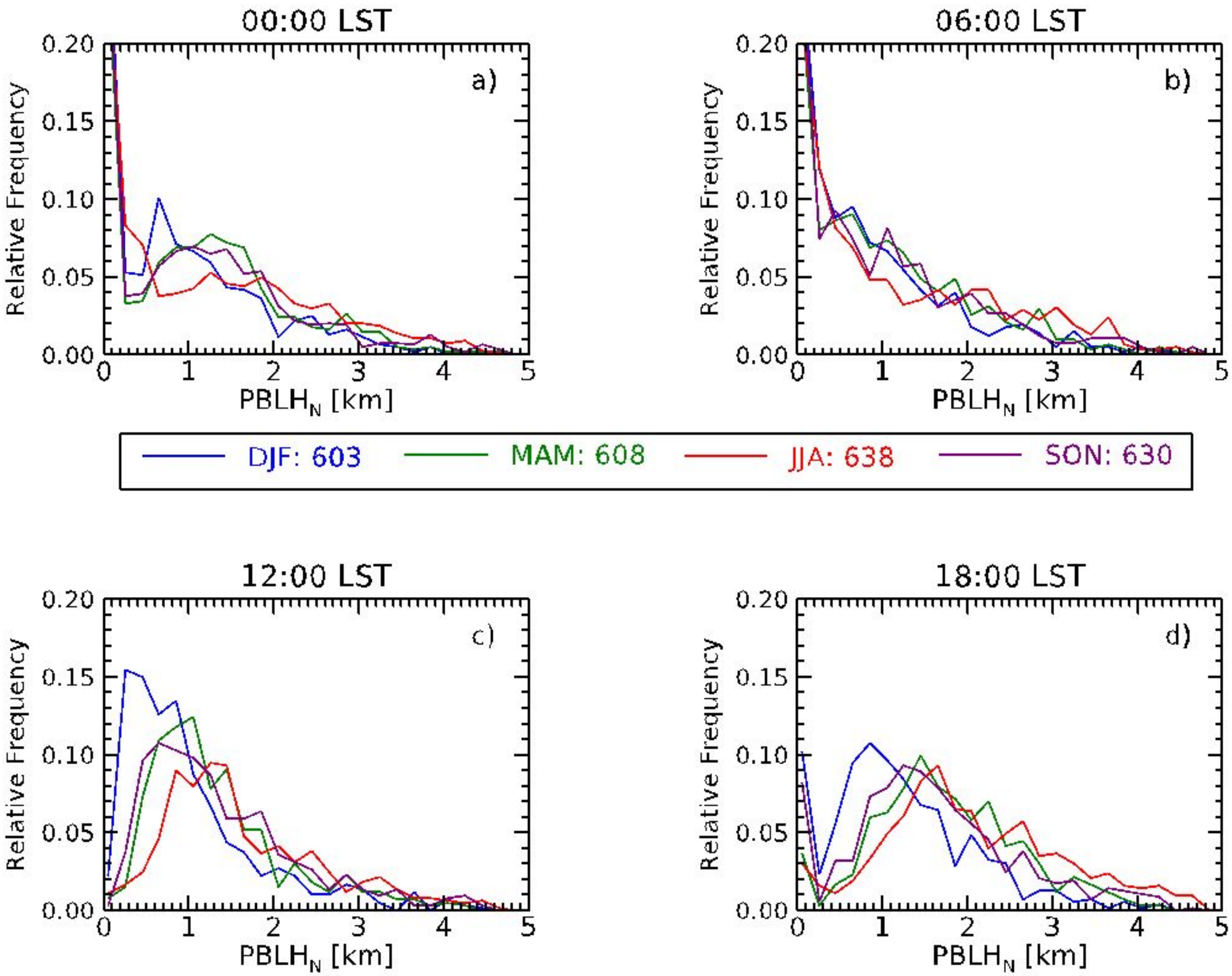
- Approximately 65% of profiles reach below 500 m, 40% reach 200 m, and 10% reach surface

PBLH Identification in radiosondes and RO profiles

- Minimum/Maximum gradients in vertical profiles allow for identification of the PBLH
  - Seidel et al. (2010), Ao et al. (2008,2011,2012), Xie et al. (2011,2012)
- Some cases exhibit unique multi-layer structure
  - More difficult to detect true PBLH
- Disparities between PBLH derived from different thermodynamic variables

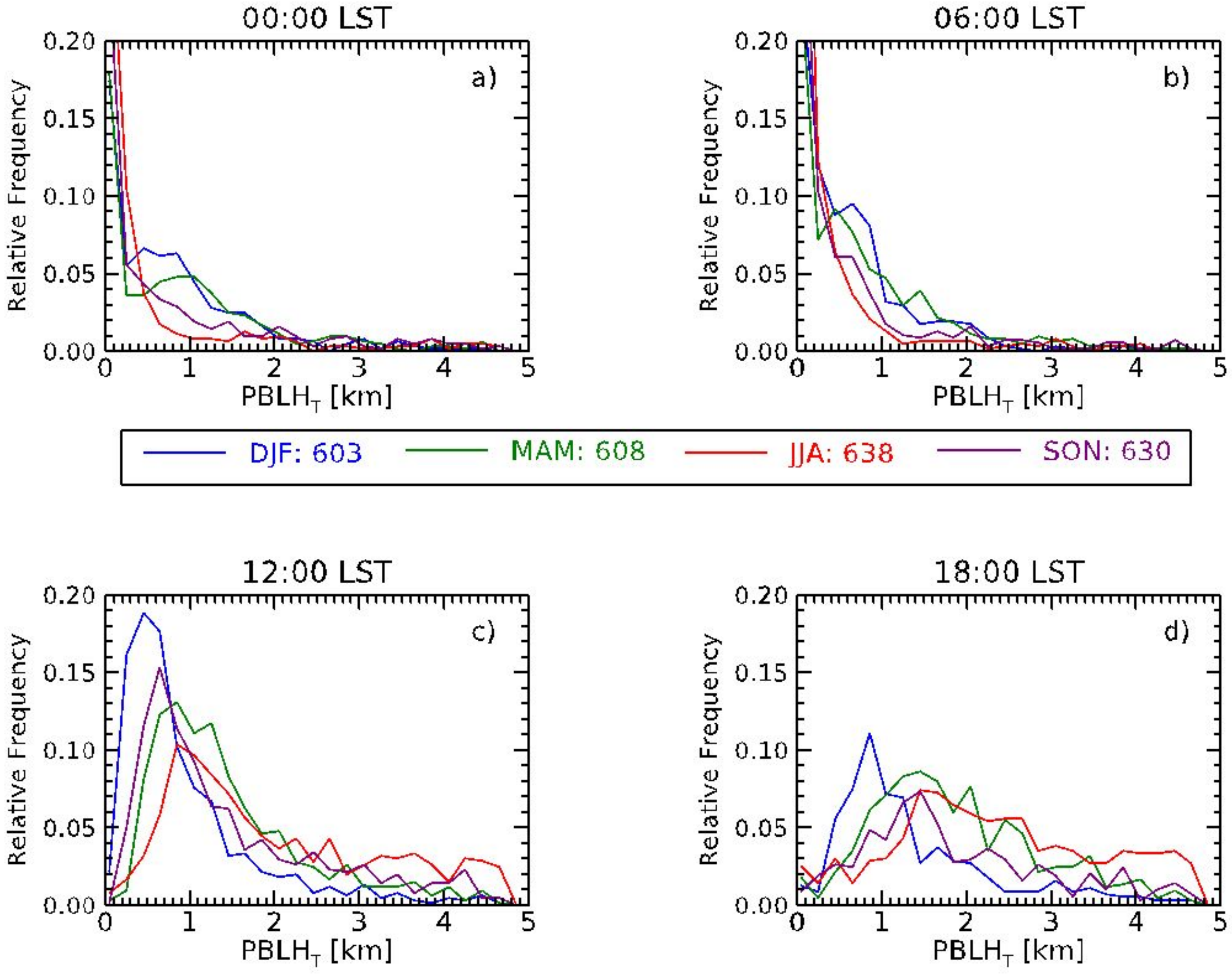


PBLH Statistics from Radiosondes - Refractivity



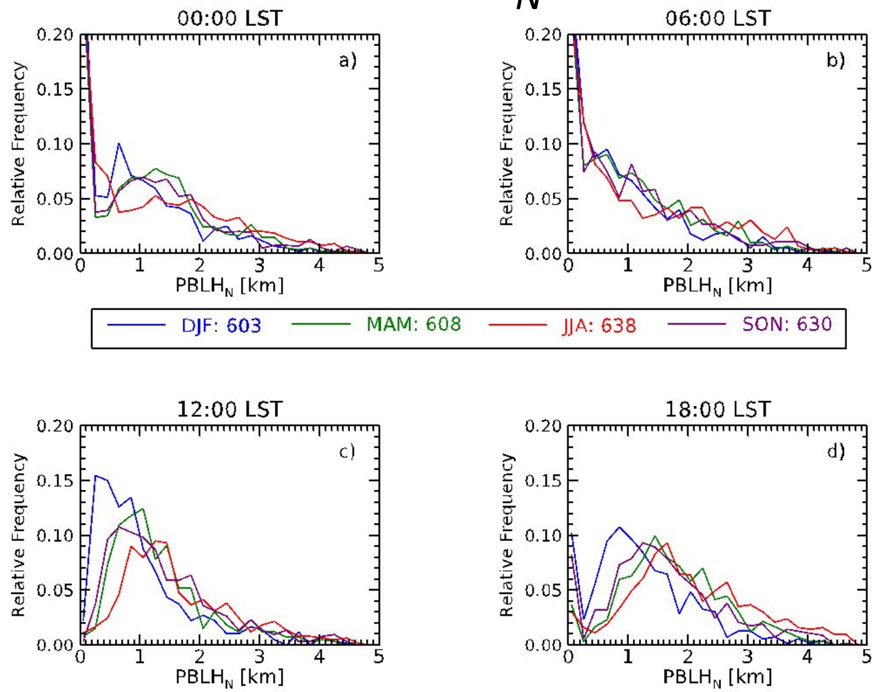
- $PBLH_N$ often found to be less than 200 m overnight
  - Higher $PBLH_N$ less frequent
- $PBLH_N$ distribution shifts toward higher $PBLH_N$ during daytime
- $PBLH_N$ in DJF trends toward lower values and $PBLH_N$ in JJA trends toward higher values
  - Influence of temperature on refractivity
- MAM and SON have very similar distributions of $PBLH_N$
  - Transition seasons

PBLH Statistics form Radiosondes - Temperature



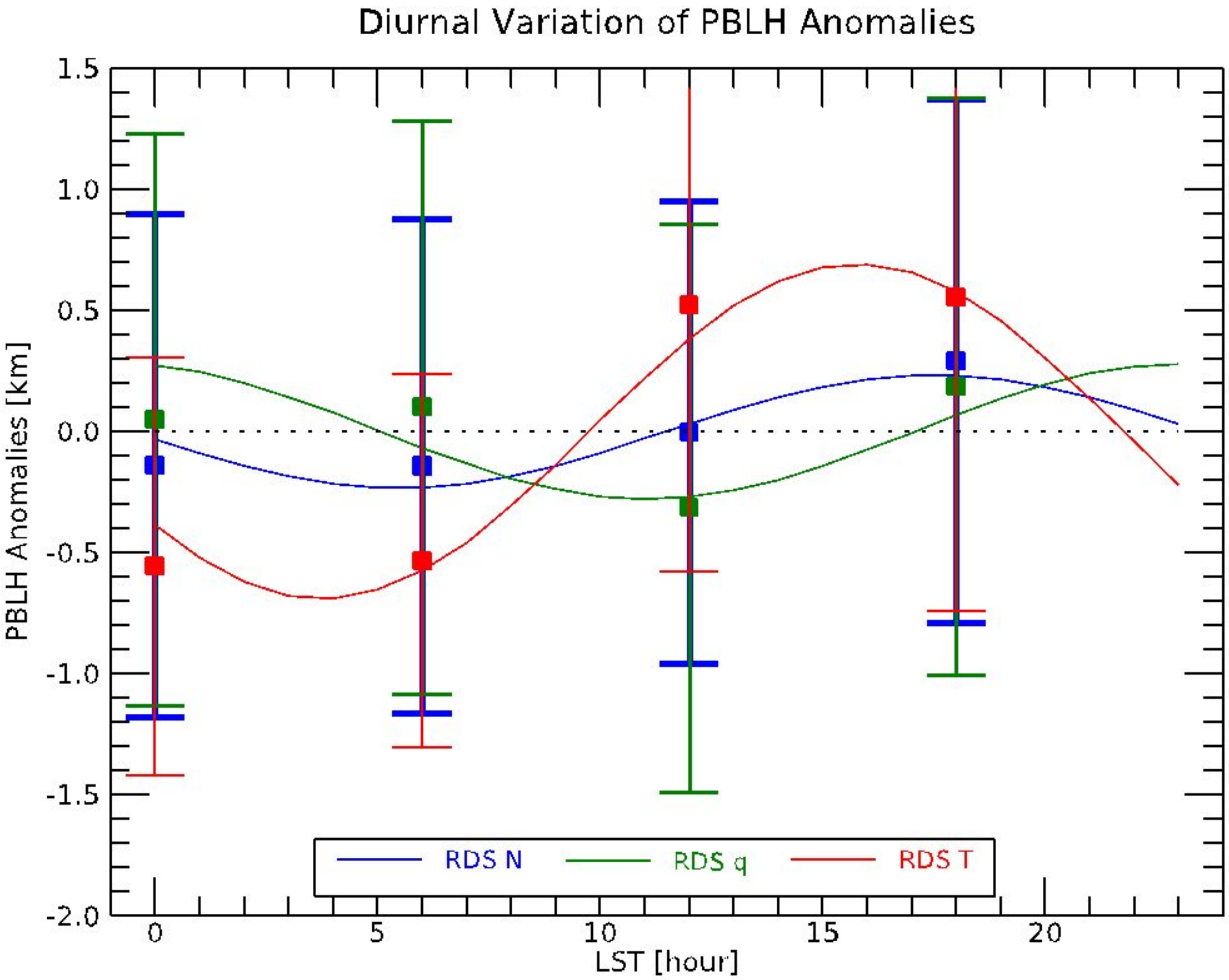
- Seasonal distributions of $PBLH_T$ are similar to those of $PBLH_N$
  - Higher frequency at 12:00 LST
- Sharper decrease in $PBLH_T$ during overnight hours
  - Fewer $PBLH_T$ greater than 2 km

$PBLH_N$



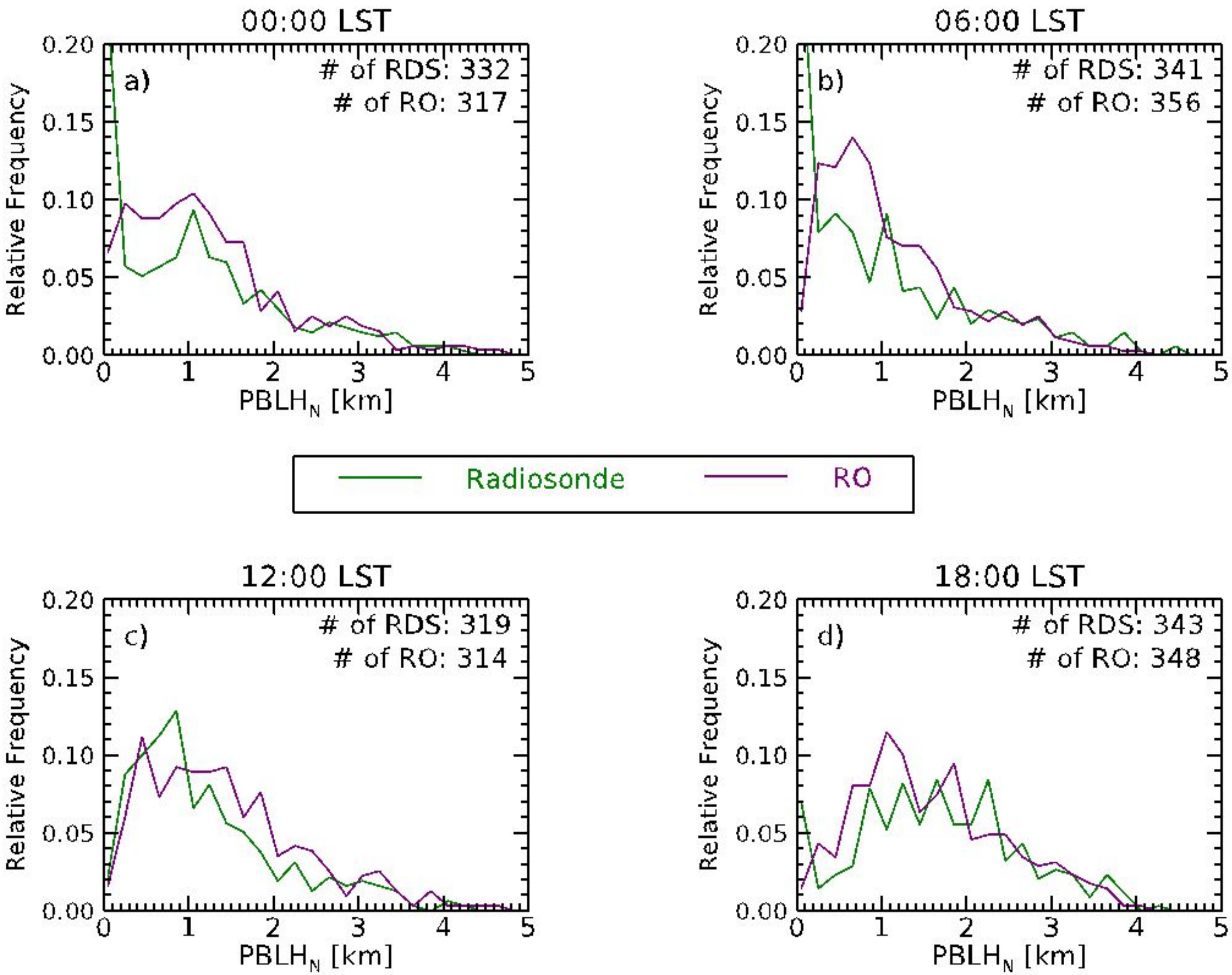
Diurnal PBLH Results – Radiosondes

- Diurnal amplitude of PBLH calculated with multilinear harmonic analysis
  - Dai et al. (2002), Xie et al. (2010)
  - PBLH anomaly calculated by removing mean PBLH for each variable
- $PBLH_T$ amplitude peaks at 0.691 km around 15:00 LST consistent with daytime heating
- $PBLH_q$ anomaly amplitude peaks at 0.3 km around 00:00 LST
- $PBLH_N$ anomaly amplitude peaks at 0.232 km around 17:00 LST

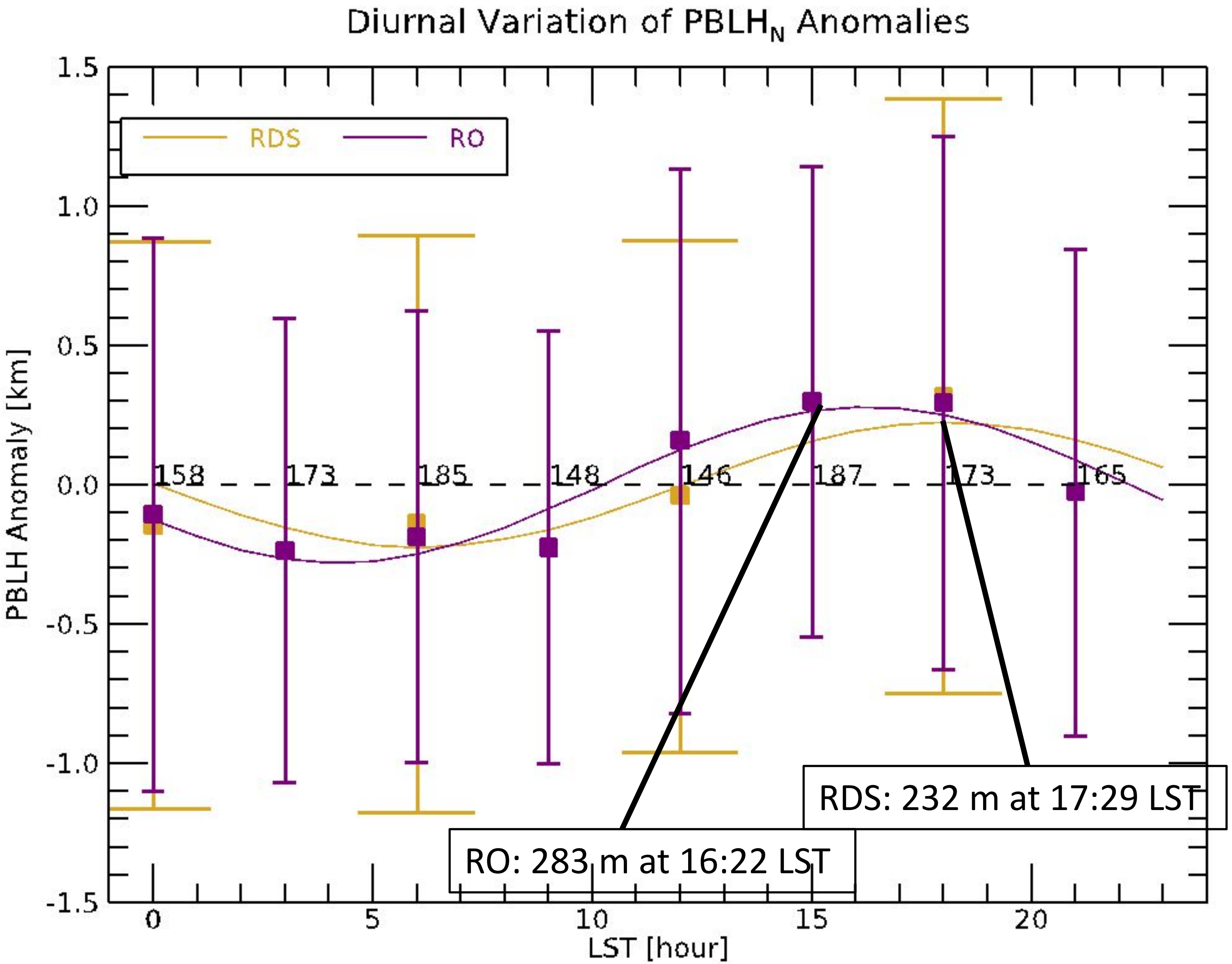


PBLH Statistics from Co-located GNSS RO Profiles

- $PBLH_N$ from GNSS RO *N* profiles consistent with those from radiosondes
- Shallow (100-200 m) $PBLH_N$ observed during nighttime in radiosondes only seen in RO profiles about 50% of the time.
    - Penetration and vertical resolution
    - Along-path averaging vs. “single point” profiles
    - Uneven topography and surface heating

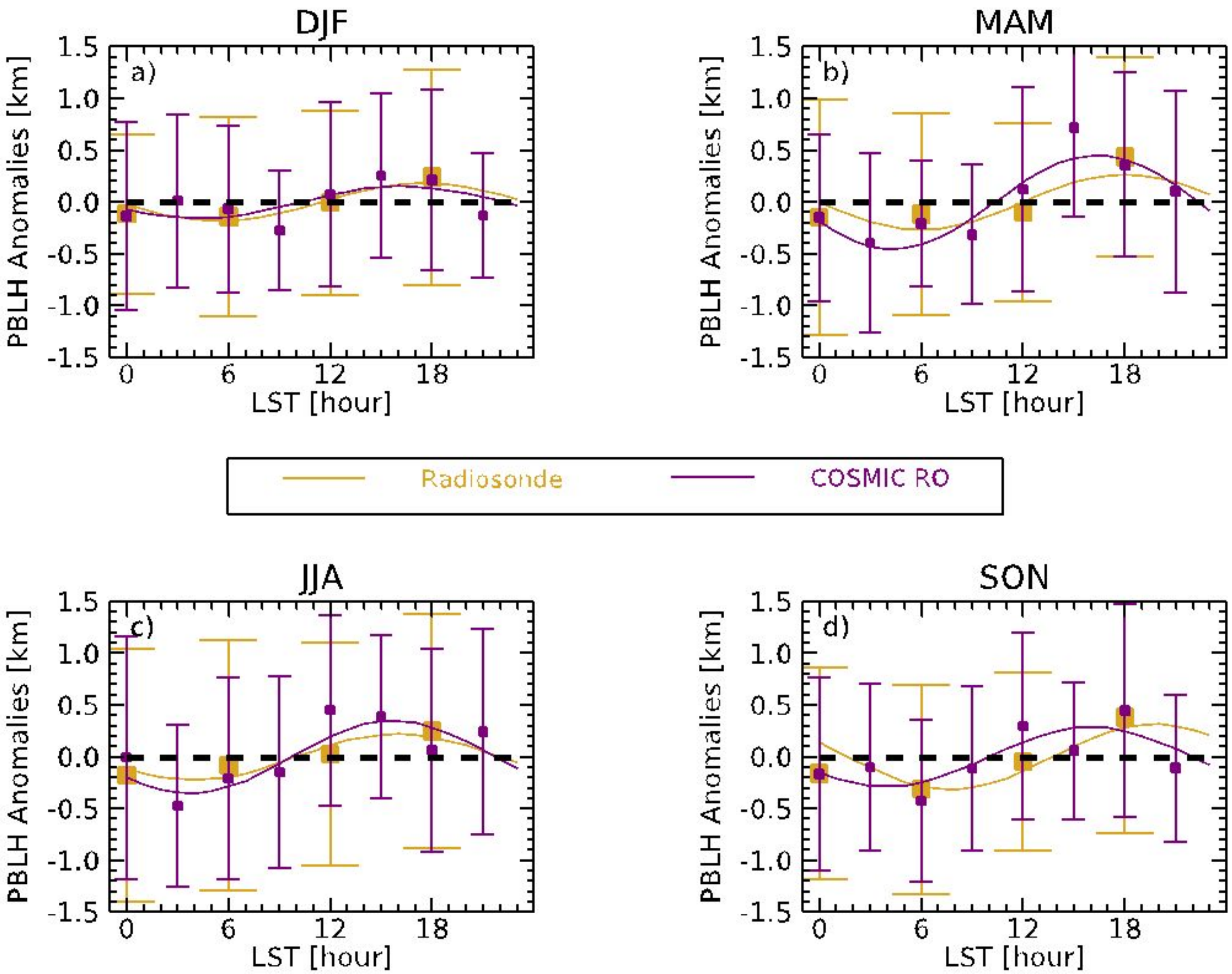


Annual Diurnal PBLH – Co-located GNSS RO Profiles



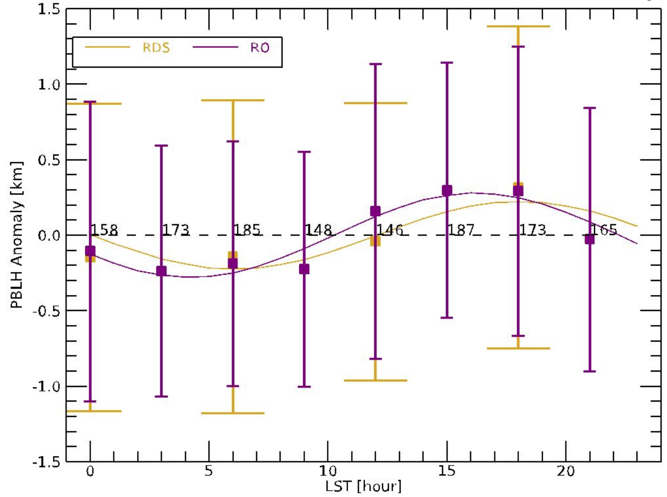
- Good agreement between diurnal PBLH$_N$ anomalies from radiosondes and from GNSS RO profiles
  - Radiosonde PBLH$_N$ amplitude: 232 m, GNSS RO RO PBLH$_N$ amplitude: 283 m
  - Radiosonde PBLH$_N$ peak time: 17:29 LST, GNSS RO PBLH$_N$ peak time: 16:22 LST
- Conclusion: GNSS RO can resolve diurnal cycle of terrestrial PBLH with little amplitude or phase difference and similar margins of error

Seasonal Diurnal PBLH – Co-located GNSS RO Profiles



- Differences between GNSS RO and radiosondes are slightly larger due to smaller sample size in each bin, but still consistent with annual diurnal cycle
- $PBLH_N$ amplitude changes due to seasonal temperature changes
- MAM and SON have characteristics of surrounding seasons and higher variability

Annual Diurnal PBLH Anomaly



Conclusions and Future Work

- GNSS RO able to observe fine structures in vertical profiles of atmospheric refractivity without significant bias compared to co-located radiosondes
- Gradient method of PBLH detection works well for both datasets to determine the PBLH derived from various thermodynamic variables
- GNSS RO PBLH distributions is consistent with that of radiosondes
  - Shallow PBLH is difficult to retrieve via remote sensing, but GNSS RO resolves approximately 50% of the shallow PBLH
- GNSS RO clearly detects diurnal cycle in $PBLH_N$ consistent with radiosondes overall; DJF and JJA very consistent, slight phase shifts seen in MAM and SON
- Future Work:
  - Account for multi-layer structures in PBLH detection algorithm
  - Evaluate the impact of ducting on PBLH detection
  - Analyze the diurnal cycle analysis at different levels within boundary layer
  - Understand limitations of RO data in lowest 500 m above surface

Questions?

Acknowledgements:

- NASA grant number NNH14ZDA001N-GNSS
- NASA grant number NNX15AQ17G
- NASA JPL Visiting Researcher Internship, Summer 2019
- TAMUCC CMSS Research Assistantship Funding