The Use of MERRA-2 Near Surface Meteorology to Understand the Behavior of Planetary Boundary Layer heights Derived from Wind Profiler Data Over the US Great Plains

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Background and Motivation:

- A new 20-year record of Planetary Boundary Layer (PBL) heights was developed using backscatter data from Wind Profilers (WP) located over the US Great Plains. The observational record does not contain enough information to explain PBL behavior.
- PBL heights from the Modern Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) are model-based and have been shown to be biased high, but observational constraints in MERRA-2 provide reliable meteorology that can be used to explain PBL behavior.
- A combination of WP PBL heights and MERRA-2 fields is used to understand the behavior in the region.

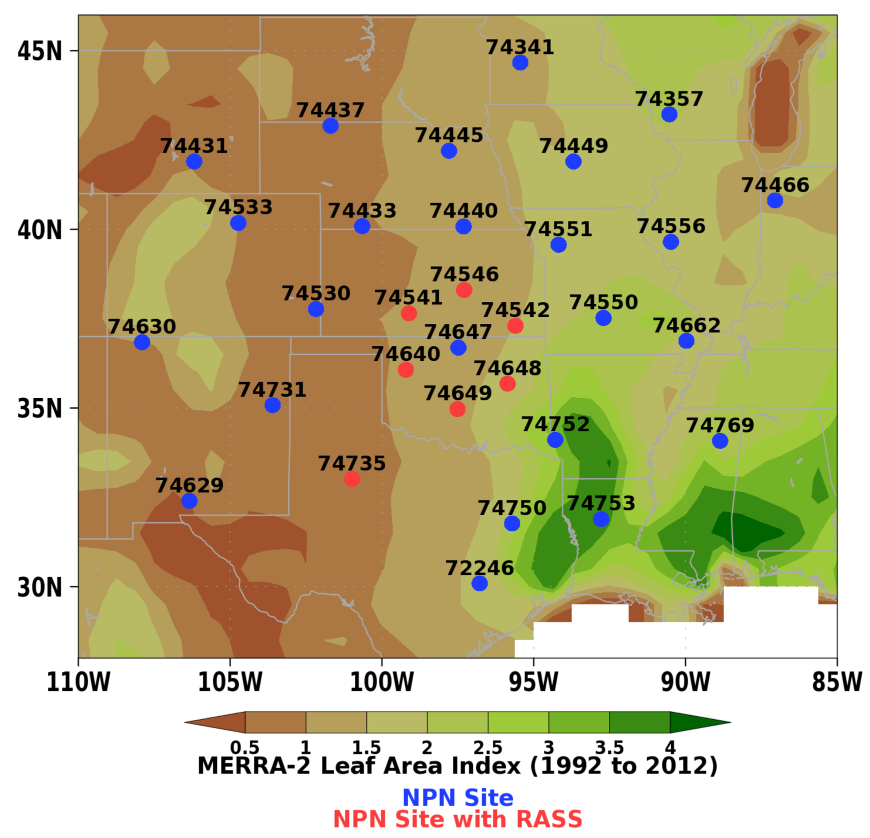

Figure 1: MERRA-2 LAI averaged over 1992-2012 overlaid with the location of WP stations used here.

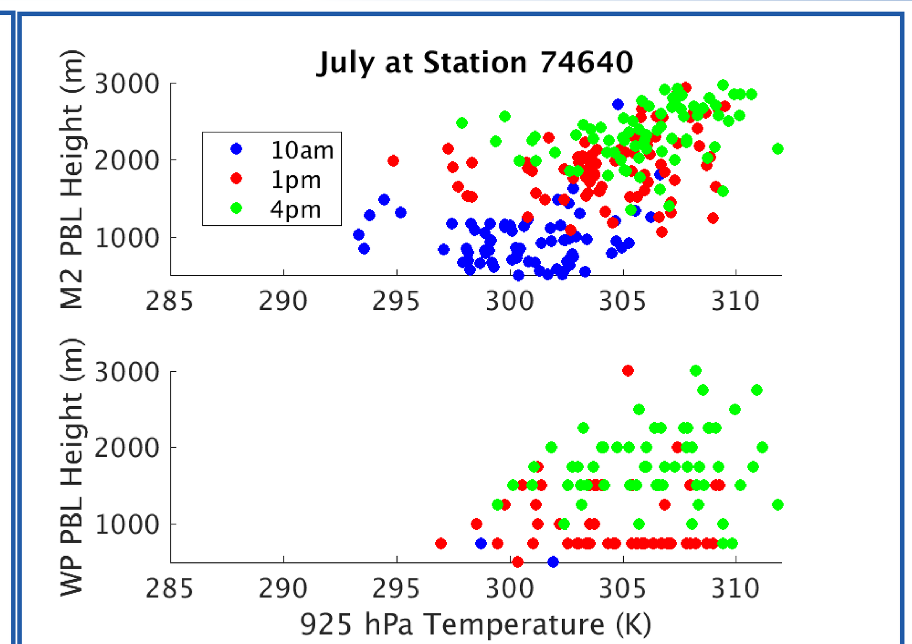

Figure 2: MERRA-2 and WP PBL height versus MERRA-2 925 hPa temperature

Agreement in the relationship of PBL height to 925 hPa T gives confidence in the use of MERRA-2 for explaining the behavior of WP PBL height

Data: Observations and Reanalysis

- Study period encompasses 1992 through 2012.
- Wind profiler data at the stations shown in Figure 1 were originally obtained from the NOAA Profiler Network (NPN) archive site (http://www.profiler.noaa.gov/npn/index.jsp) and are now available from the MADIS site.
- MERRA-2 estimates of PBL height and other meteorological variables were obtained from the surface turbulent flux dataset (tavg1_2d_flx_Nx), land surface diagnostics dataset (tavg1_2d_lnd_Nx), single level variable dataset (tavg1_2d_slv_Nx), and the assimilated meteorological fields dataset (inst3_3d_asm_Np).

WP Algorithm:

- A modified version of the algorithm of Molod et al. (2015) is used here. The algorithm is based on the assumption that the gradients of moisture, hydrometeors, and particles are manifest as maxima in the signal backscatter.
- Unique aspects of the algorithm are the establishment of an emergence time (when the PBL reaches the lowest range gate at 500 m) and the method to determine which of the many signal maxima within a vertical profile represents the PBL height.
- The new version of the algorithm includes adjustments to both unique elements as well as a more strict determination of when PBL heights are successfully retrieved.
- Figure 3 illustrates the results of these changes.

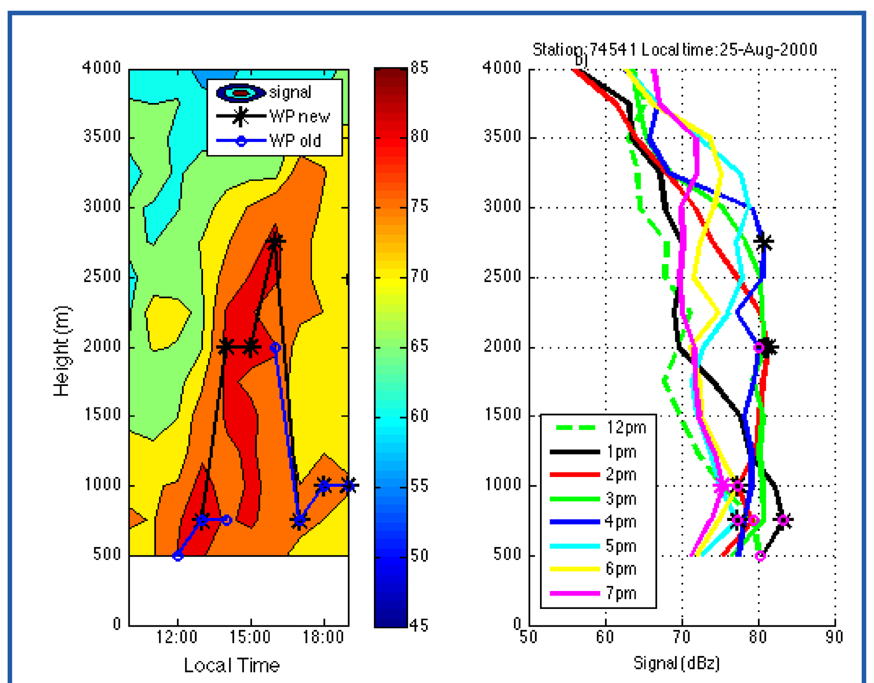

Figure 3: WP backscatter at station 74541 on August 25, 2000. (a) Time-height contours, (b) hourly vertical profiles. Asterisks indicate the height of the PBL

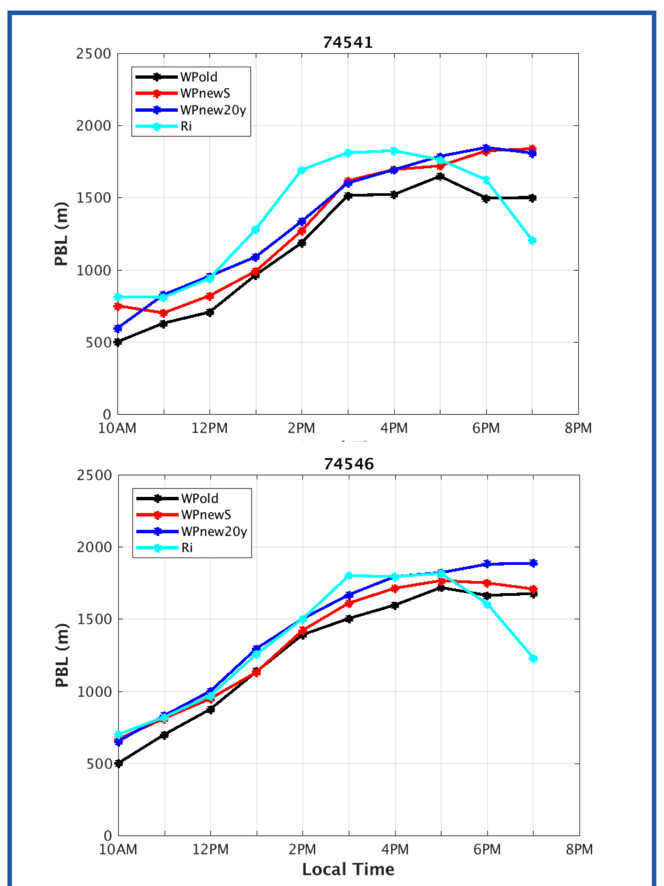

Figure 4: PBL heights from the old and new algorithm and from the Richardson number estimates at stations (a) 74541 and (b) 74546.

Results of algorithm changes:

Subjective assessment of the backscatter signal contours seen in Figure 3 would suggest that the maximum PBL height occurs at 2750 m at 4 PM local time. This subjective assessment is more consistent with the results of the modified algorithm. The profiles at 2 PM (and at 4 PM) local time show a local maximum at 750 m (2000 m) that was accepted as the "true maximum" (PBL height) in the old algorithm but was properly rejected in favor of the maximum at 2000 m (2750 m) in the new version of the algorithm.

Figure 4 shows that the JJA mean PBL heights using the new algorithm and a longer sampling record are higher and in better agreement with other estimates. The improvements shown are the result of both algorithm and record length.

Results/Analysis of PBL Height:

Examination of WP PBL mean annual cycles at all the stations revealed three general categories of behavior: (1) "canonical", (2) "delayed annual cycle" and (3) "double maxima". The use of MERRA-2 fields helps understand the different behaviors.

(1)"canonical" - Jayton, TX (Sta. 74735) is a characteristic example of this behavior. As seen in Figure 5, the PBL height is low in the spring, rises to its maximum in June and July, and descends again in the fall. Figure 1 shows this station to be located in an area of little vegetation. Figure 6 shows that the PBL height annual cycle is dictated by the relationship among the surface temperature, surface sensible heat and PBL height, and that the soil moisture and latent heat are both small and exert little influence on the PBL height.

(2)"delayed" – DeQueen, AR (Sta. 74752) is a characteristic example of this behavior. The PBL height rises later in the year than in the "canonical" case, as shown in the middle panel of Figure 5. Figure 6 shows that the delay is related to a May-timeframe maximum in soil moisture (and probably precipitation) and latent heat. This leads to a suppression of sensible heat flux and hence of PBL height. The soil dries down by July and the sensible heat flux takes over leading to a rise in PBL height in the late summer.

(3)"double maxima" – Merriman, NE (Sta. 74437) is a characteristic example of this behavior. The bottom panel of Figure 5 shows a clear rise of PBL height in May-June, a drop in July and a subsequent rise in August. Figure 6 shows that the July minimum is related to an increase in latent heat and local minimum in the sensible heat flux.

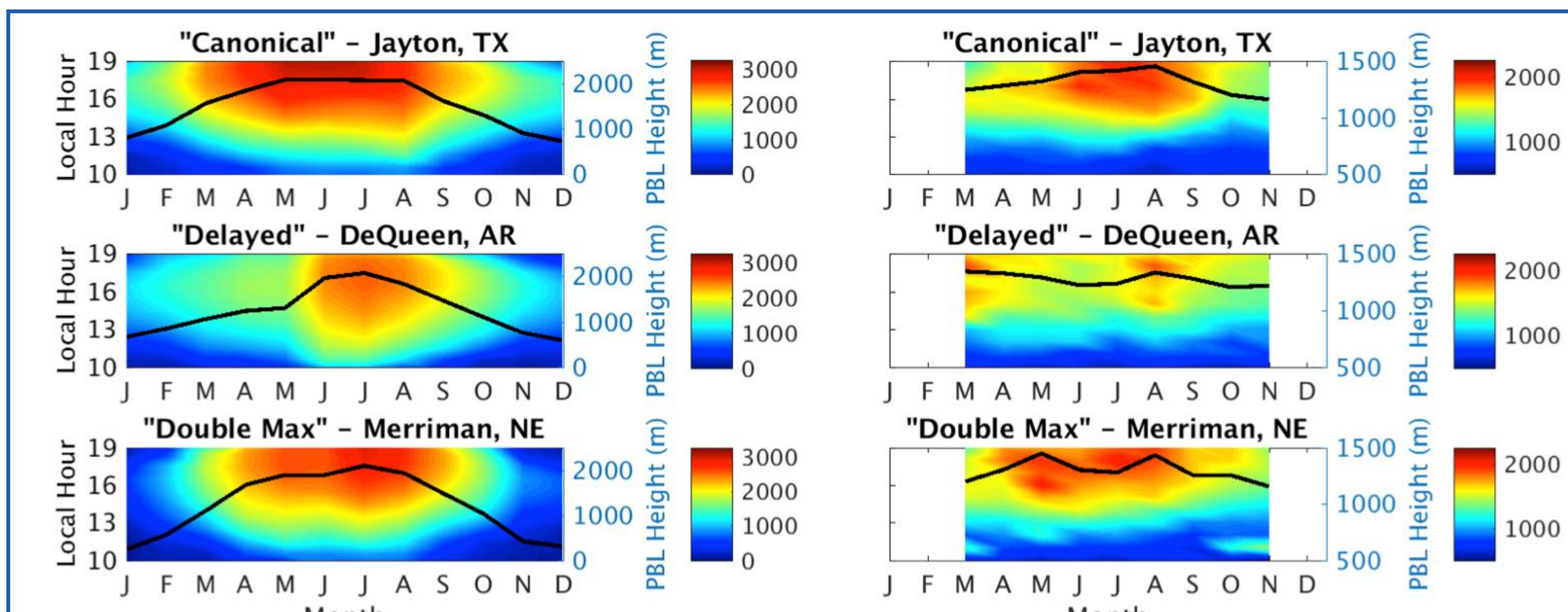

Figure 5: Monthly mean annual and diurnal cycle of PBL height in (left) MERRA-2 and (right) from WP at stations representing the three classes of behavior for the US Great Plains region: "canonical", "delayed", and "double maxima".

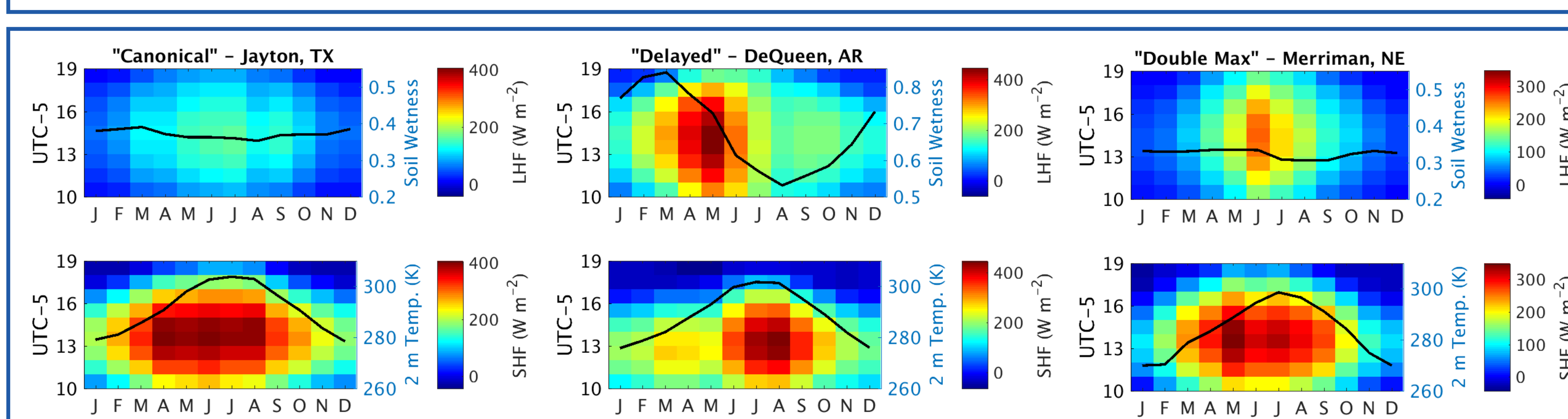

Figure 6: Monthly mean annual and diurnal cycle of (top row) latent heat flux, overlaid with root zone soil moisture and (bottom row) sensible heat flux overlaid with 2 m temperature at the three representative stations in Figure 5.

Summary:

- Adjustments made to the algorithm give a more reasonable representation of the PBL height.
- MERRA-2 can be used to understand the behavior of observed PBL heights.
- The annual cycle of PBL height in the US Great Plains can be grouped into three regimes: "canonical", "delayed", and "double maxima". These annual cycles are related to the annual cycles of the sensible and latent heat fluxes, which are also related to the local hydrologic cycle.

Reference: Molod, A., H. Salmun and M. Dempsey, 2015. Estimating Planetary Boundary Layer Heights from NOAA Profiler Network Operational Wind Profiler Data. *Journal of Atmospheric and Oceanic Technology*. Vol. 32, No. 9, 1545-1561.