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, but 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.

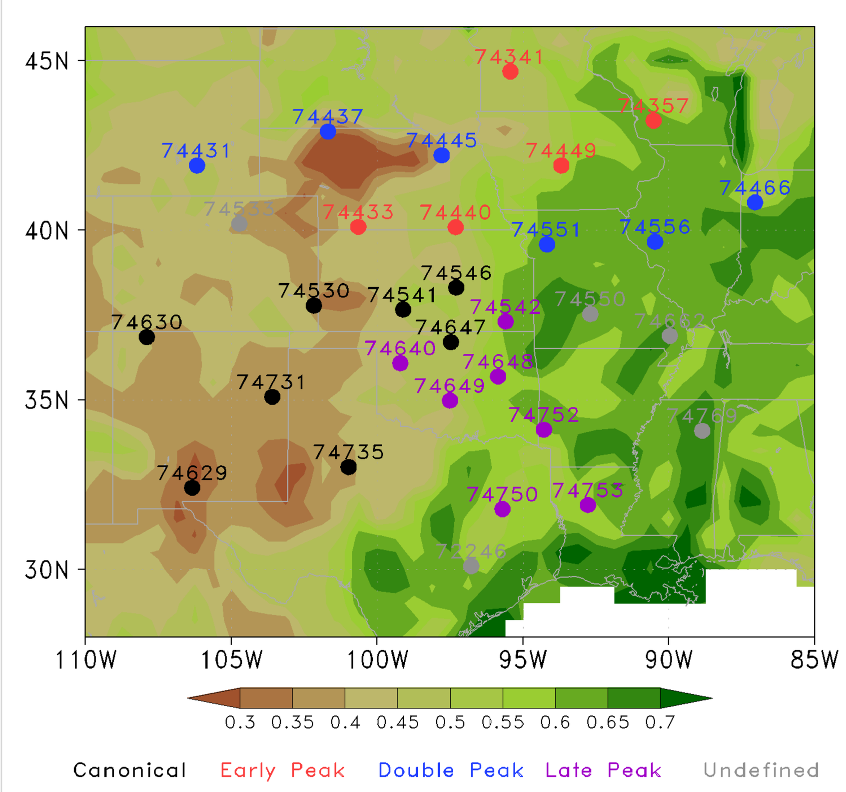

Figure 1: Map of NPN stations overlaid on the June-July-August averaged MERRA-2 column soil moisture for the period of 1980 through 2017. The colored markers correspond to categories of PBL behavior discussed below. Stations marked with a gray circle as undefined are not used in this study.

Data: Observations and Reanalysis

- Study period encompasses 1992 through 2012.
- Wind profiler data at the stations shown in Figure 1.
- The WP 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 the vertical profile represents the PBL height (Molod et al., 2015*).
- MERRA-2 estimates of PBL height and other meteorological variables were obtained from the GES DISC.

Monthly Mean Behavior

Examination of WP PBL mean annual cycles at all the stations revealed several categories of behavior, that we name 'canonical', 'early peak', 'double peak', and 'late peak'.

- The 'canonical' PBL height annual cycle is shown in Figure 2 (black circles in Figure 1). As seen in Figure 2a, the PBL height is low in the spring, rises to its maximum in June and July, and descends again in the fall, following the solar insolation. Figures 2b, c and d show that the PBL height annual cycle is dictated by the surface temperature and surface sensible heat flux, and that the soil moisture, latent heat and precipitation exert little influence on the behavior of the monthly mean PBL height.
- The `double peak' PBL height annual cycle is shown in Figure 3 (blue circles in Figure 1). Figure 3a shows a clear rise of PBL height in May, a drop in June-July and a subsequent rise in August. Figures 3b, c, and d show that the delay is related to a June-July maximum in precipitation and an associated June-July rise in soil moisture and latent heat. This leads to a suppression of sensible heat flux and hence of PBL height.

The 'late peak' and 'early peak' PBL height annual cycles (purple and red circles in Figure 1, respectively, not shown here) are governed by the same physics as for the 'double peak'. In both of these the timing of the maxima in precipitation and latent heat flux and so the PBL heights differ from the 'double peak'.

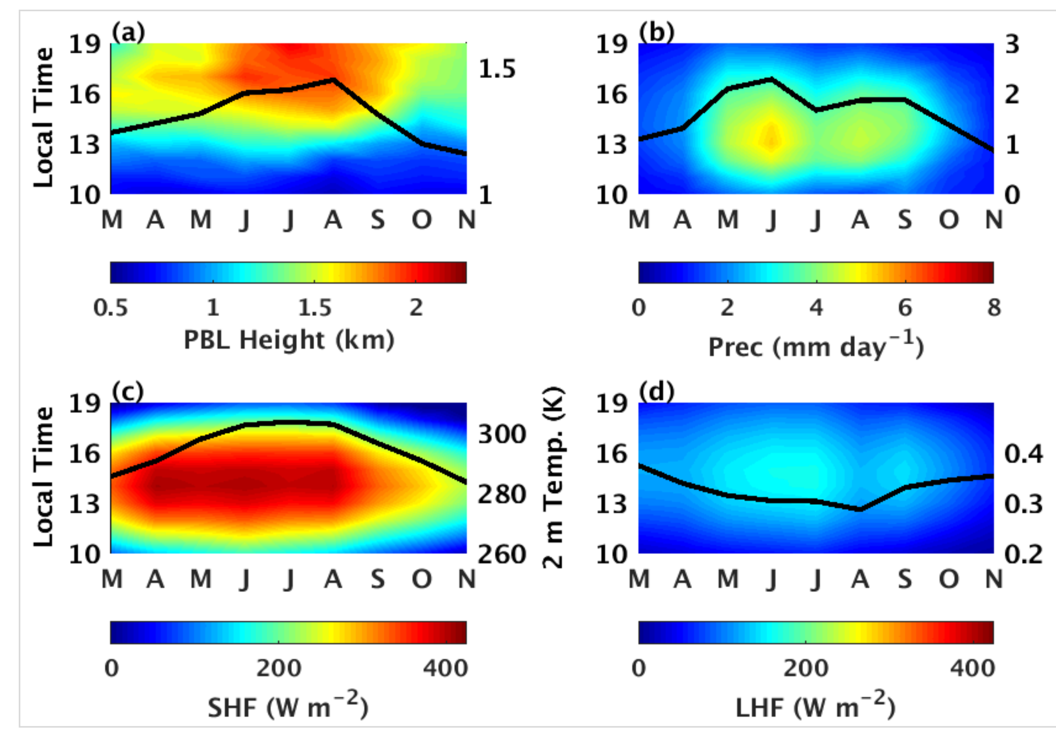

Figure 2 Month averaged diurnal cycle and monthly mean WP observed PBL height, (b) month averaged diurnal cycle and monthly mean precipitation, (c) month averaged diurnal cycle of sensible heat flux (shaded) and 2 m temperature (solid line), and (d) month averaged diurnal cycle of latent heat flux (shading) and monthly mean root zone soil wetness (solid line) at Station 74735, Jayton, TX.

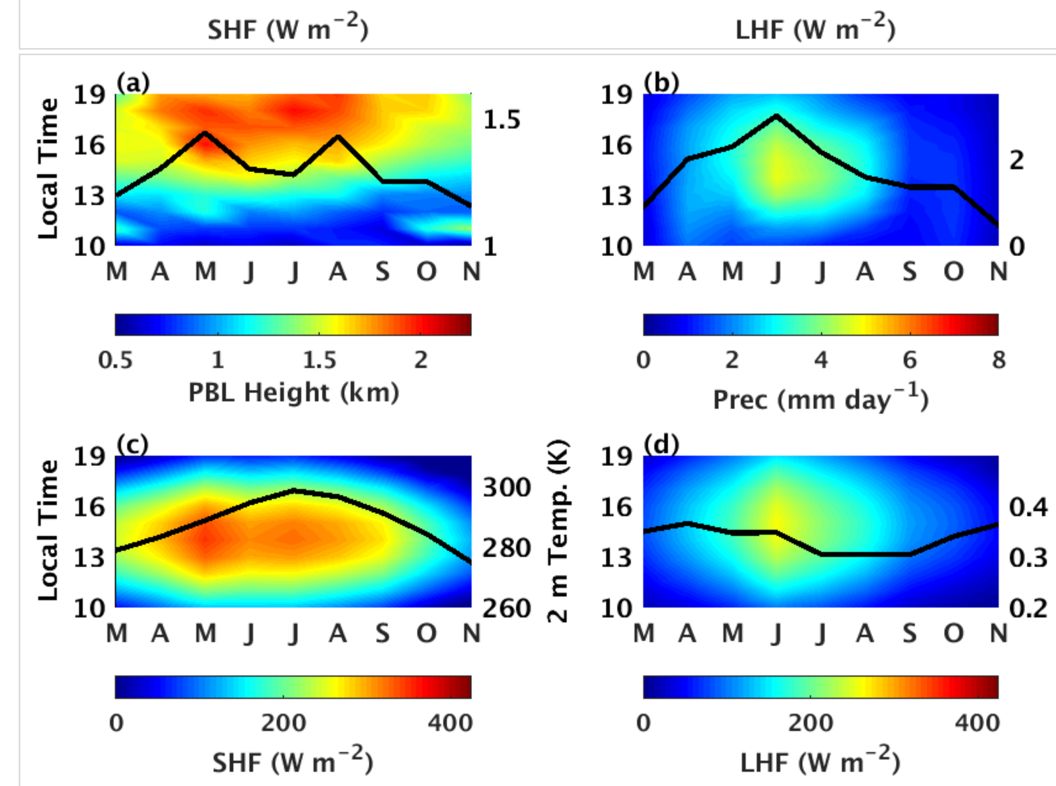

Figure 3 Month averaged diurnal cycle and monthly mean WP observed PBL height, (b) month averaged diurnal cycle and monthly mean precipitation, (c) month averaged diurnal cycle of sensible heat flux (shaded) and 2 m temperature (solid line), and (d) month averaged diurnal cycle of latent heat flux (shading) and monthly mean root zone soil wetness (solid line) at Station 74437, Merriman, NE.

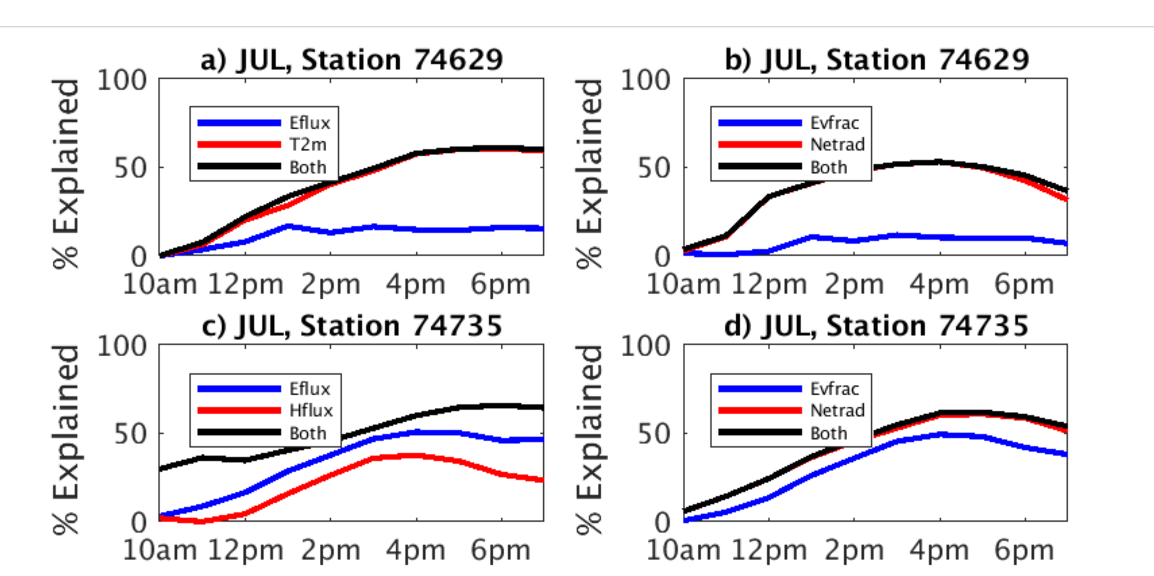

Figure 4 a) Fraction of total PBL height variance explained by latent heat flux, 2-meter temperature, and both at Station 74629 in July, b) fraction explained by evaporative fraction, net surface radiation and both at Station 74629 in July, c) fraction explained by latent heat flux, sensible heat flux and both at Station 74735 in July, d) fraction explained by evaporative fraction, net surface radiation and both at Station 74735 in July.

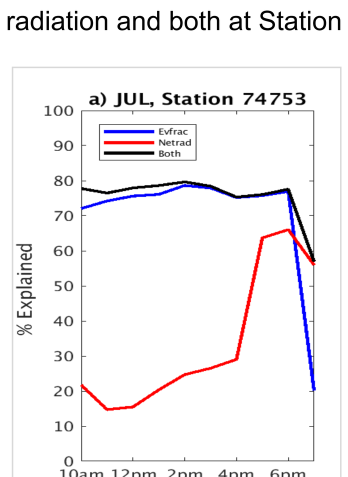

Figure 5 Fraction of total PBL height variance explained by evaporative fraction (blue), net radiation (red) and both (black) at Station 74753 in July.

Variations About the Monthly Mean

To examine the processes related to variations about the monthly mean PBL heights we performed an analysis of variance (ANOVA) using several different statistical models based on relevant fields. Results are presented from empirical models using three pairs of predictors: latent heat flux and 2-meter temperature, latent heat flux and sensible heat flux, and evaporative fraction and net radiation at the surface.

The variability of PBL height during the peak mean PBL height months at the 'canonical' stations was divided into two general behavior regimes: (i) a drier regime in the stations in the western geographical sector characterized by small amounts of vegetation and dry soils (see Figure 1) and (ii) a wetter regime in the stations further to the east that are more vegetated and have wetter soils. The behavior in the drier regime is shown in Figures 4a,b. These figures show the small contribution of latent heat flux and evaporative fraction to the total PBL height variability relative to the contributions of the 2-meter temperature and net radiation. Figures 4c,d show the behavior in the wetter regime, where the latent heat flux and evaporative fraction determine as much or more of the variability of PBL height as the temperature and net radiation.

The stations in the 'late peak' category are located in the wetter areas of the geographical domain. ANOVA results from July (the peak month of monthly mean PBL height) are shown in Figure 6. The figure shows that up to 80% of the PBL variations are explained by evaporative fraction.

Summary

- MERRA-2 can be used to understand the behavior of the monthly mean and variability of the observed PBL heights.
- WP PBL height monthly mean annual cycles were grouped into four general categories of behavior, 'canonical', 'double peak", 'early peak' and 'late peak' categories, each named for the month relative to July at which the PBL height reached its maximum. These cycles are governed by the annual cycles of sensible and latent heat fluxes, which are controlled by the local hydrologic cycle.
- ANOVA determined that the role of latent heat in determining the PBL height variations was found to be large (explaining up to 40% of PBL height variability) even in the 'canonical' category for which latent heat played no role in setting the monthly mean, and for other stations the latent heat explained up to 80% of the PBL height variations.

*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.

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