Daytime Boundary Layer Heights at Tonopah, Nevada, from M^2HATS

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Objective:

To determine the daily 10 AM and 3 PM boundary layer height (BLH) over Tonopah, NV, for the Multipoint MOST Horizontal Array Turbulence Study (M^2HATS) (23 July - 22 September, 2023). The height of the capping inversion, z_i, is needed as a scaling variable for surface layer turbulence statistics.

Boundary layer height may be identified by:

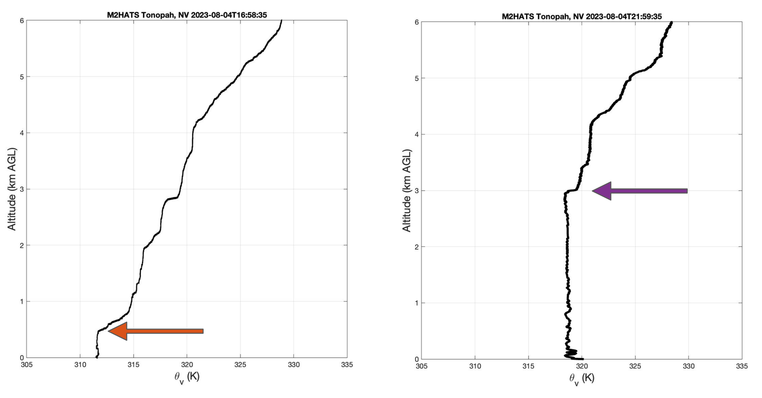
- Slopes in virtual potential temperature (static stability and mixing potential)
- Vertical velocity variance (actual mixing)
- Aerosol backscatter (recent mixing history)
- Bragg scattering peaks (entrainment zone detection)

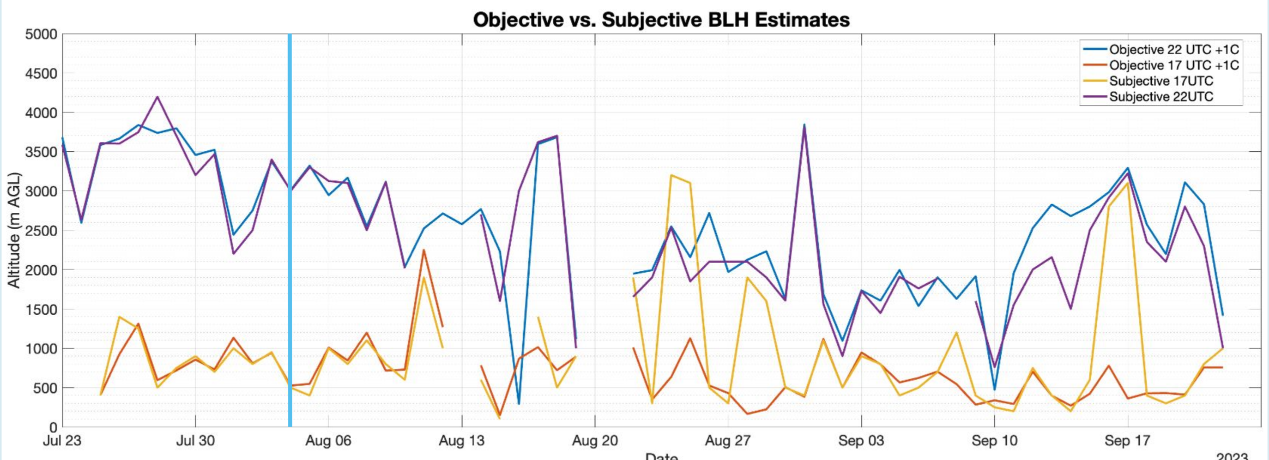
Our objective is not to evaluate the reliability or quality of any particular instrument or method for determining boundary layer depth. Instead, it is to provide the best possible assessment of mixing height given the multiple observing systems available. We limited our work to 10 AM and 3 PM each day because that is when the two daily radiosonde soundings were made.

Example Day: August 4th, 2023

Textbook convective boundary layers (CBLs) feature a sharp capping lid that is easy to identity in data from most observing systems. Of the 64 official days of the experiment, August 4, is a good example of a textbook day. Shown below are 6 ways we can identify CBL height:

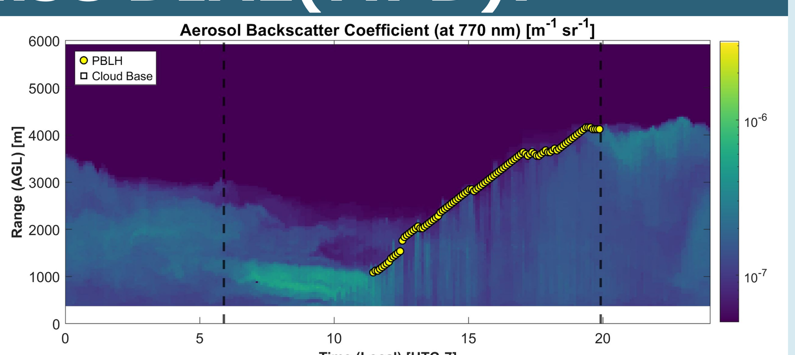
Radiosonde:

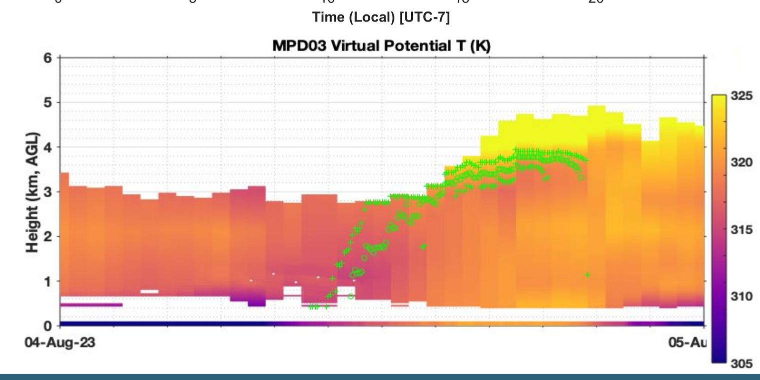




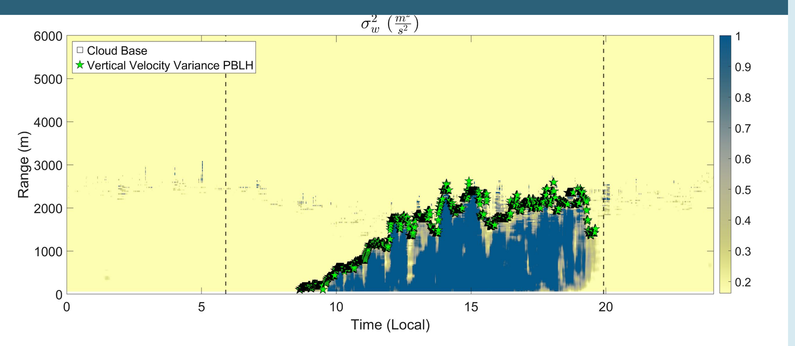
NCAR Micropulse DIAL(MPD):

The MPD measures calibrated aerosol backscatter, water vapor, and temperature profiles. Water vapor and temperature are used to calculate virtual potential temperature (right).

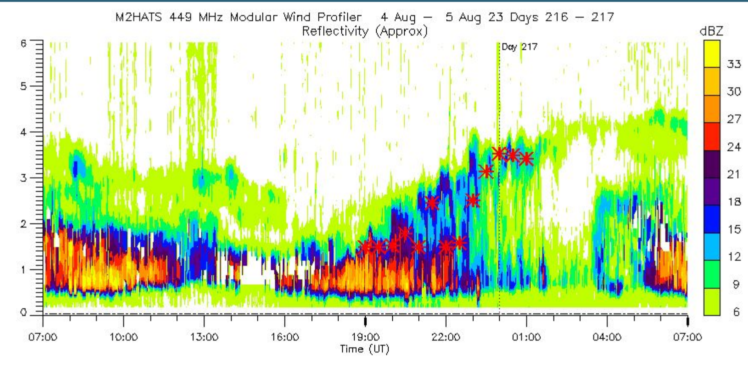




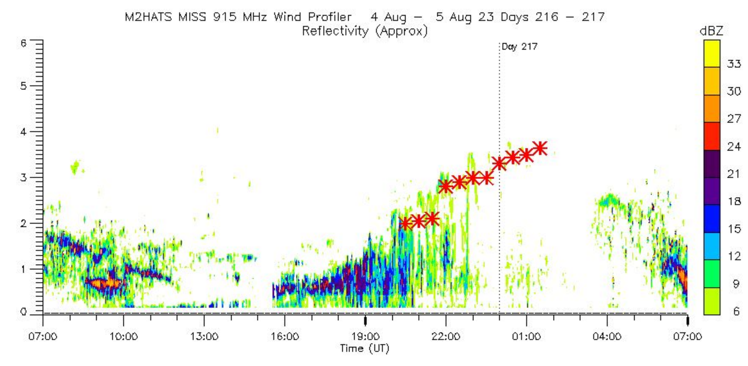
Doppler lidar:



449 MHz Doppler Radar Profiler:



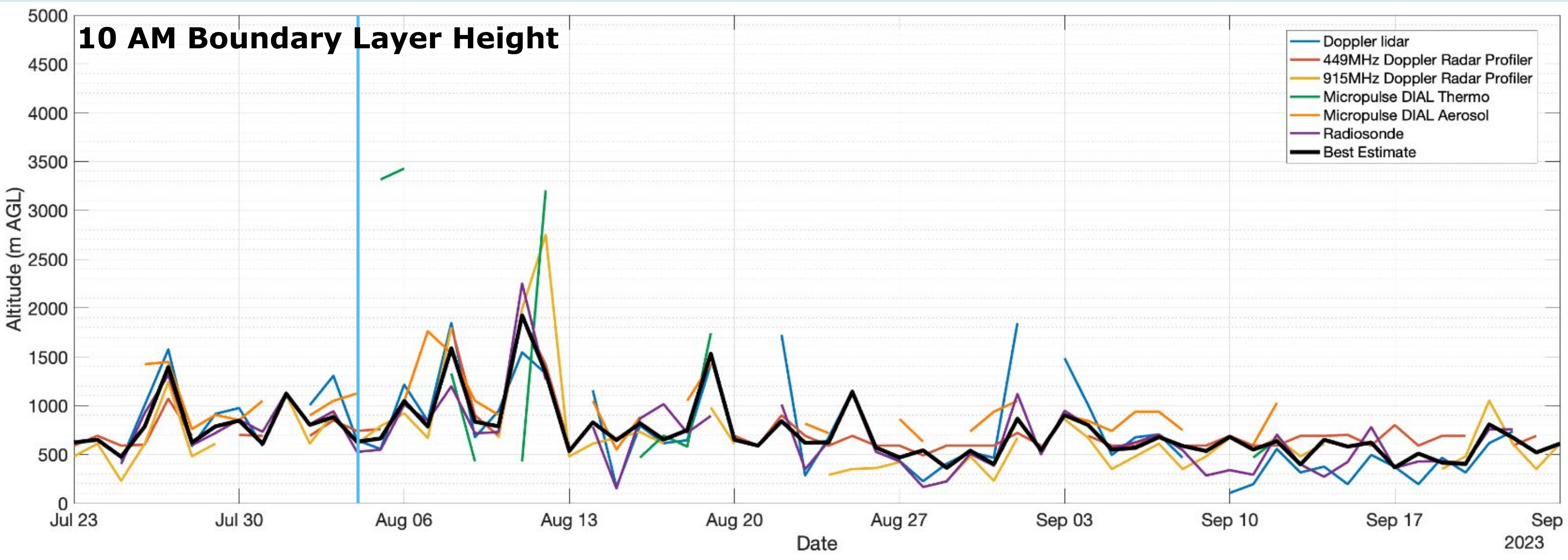
915 MHz Doppler Radar Profiler:

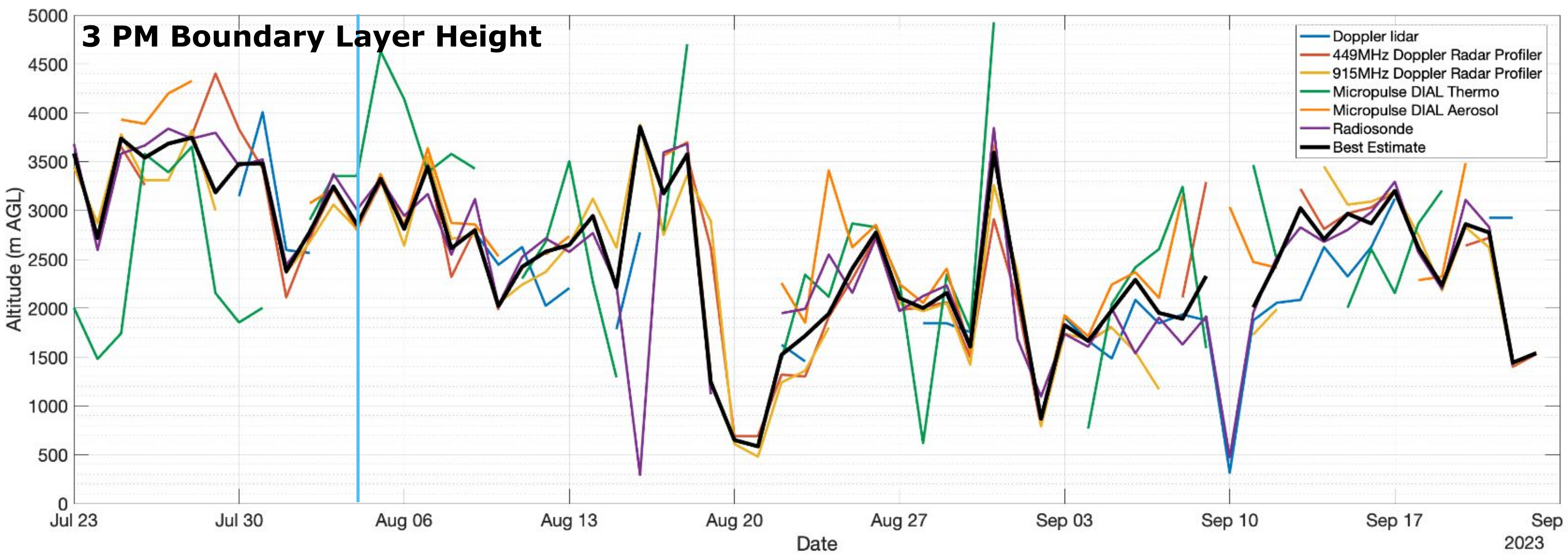


Methods:

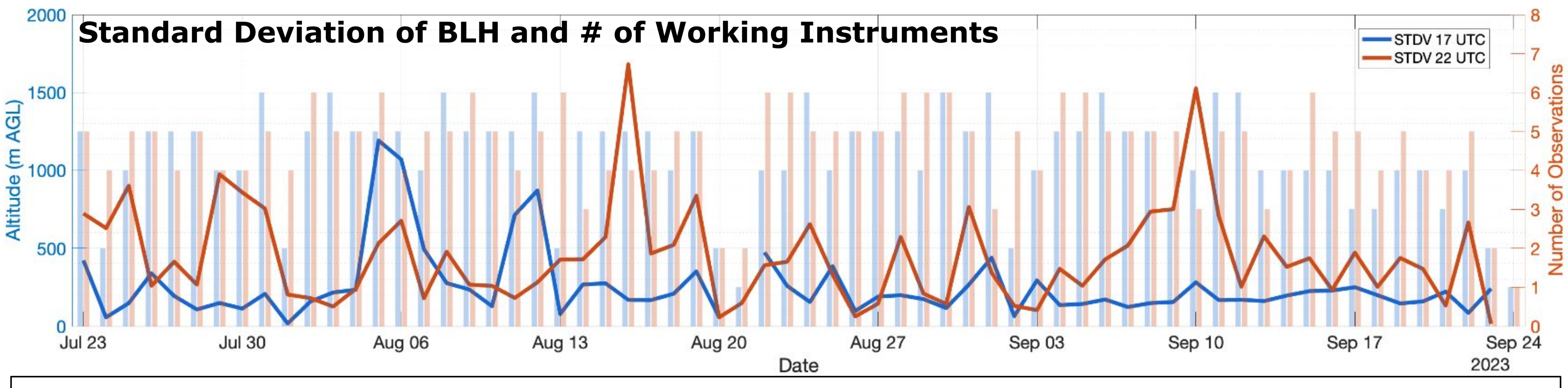
We used data from five observing systems to determine the daytime boundary layer height including:

1. Radiosondes: Vaisala MW41 / RS4
   a. Identification of the base of the capping inversion in the virtual potential temperature profile
2. NCAR Micropulse DIAL (Spuler et al. 2021)
   a. Identification of the top edge of aerosol scattering in the 770 nm aerosol backscatter profiles (Colberg et al. 2022)
   b. Identification of the base of the capping inversion in virtual potential temperature profiles (using remotely sensed water vapor and temperature)(Hayman et al. 2024)
3. Vertically pointing Doppler lidar
   a. Identification of the top edge of vertical velocity variance field from a vertical staring system (Tucker et al. 2009, Schween et al. 2014)
4. 449 MHz Radar wind profiler
   a. Identification of the maximum in Bragg scattering profiles (Angevine et al. 1994)
5. 915 MHz Radar wind profiler
   a. Identification of the maximum in Bragg scattering profiles (Angevine et al. 1994)

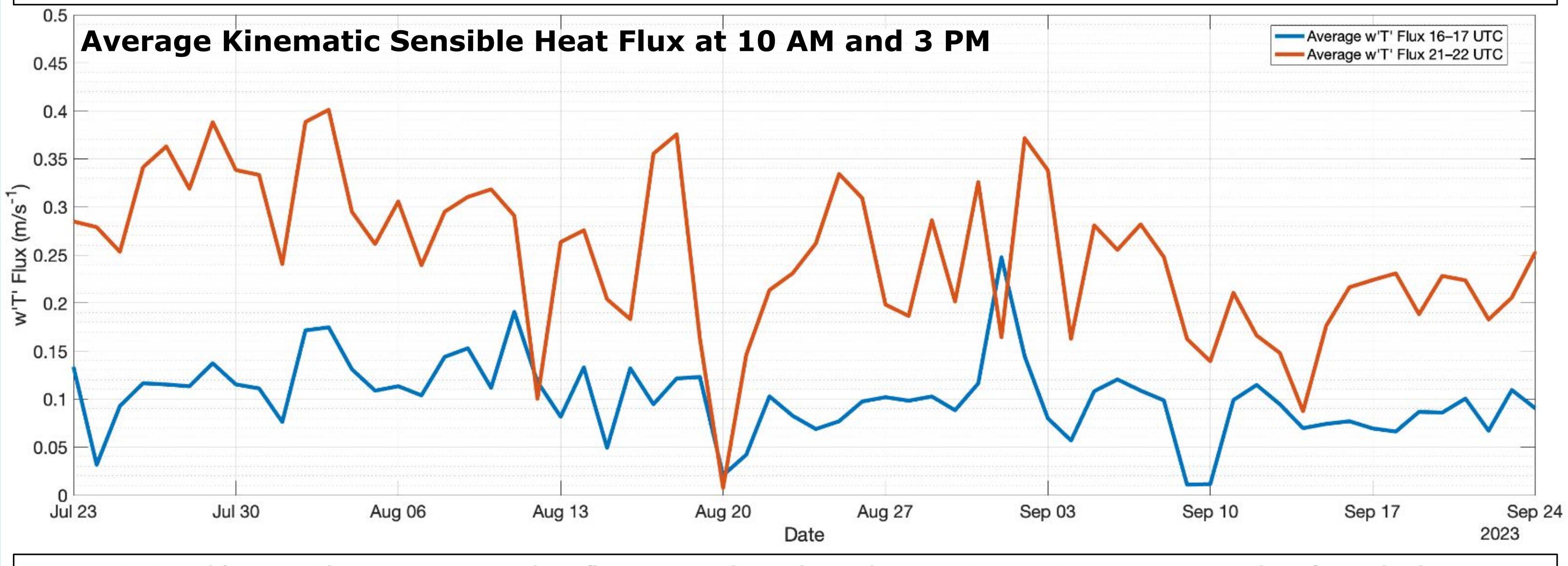




10 AM BLH estimates averaged 781.5 [762.2, 800.9] m AGL. 3 PM BLH estimates averaged 2529.5 [2496.1, 2562.9] m AGL. Single BLH estimates were made using the "ensemble method" (Smith and Carlin, 2024), in which the average of all instruments was taken after accounting for outliers. It is essential to note that it is challenging to provide a definitive single boundary layer height estimate due to the instruments measuring different variables within the boundary layer.

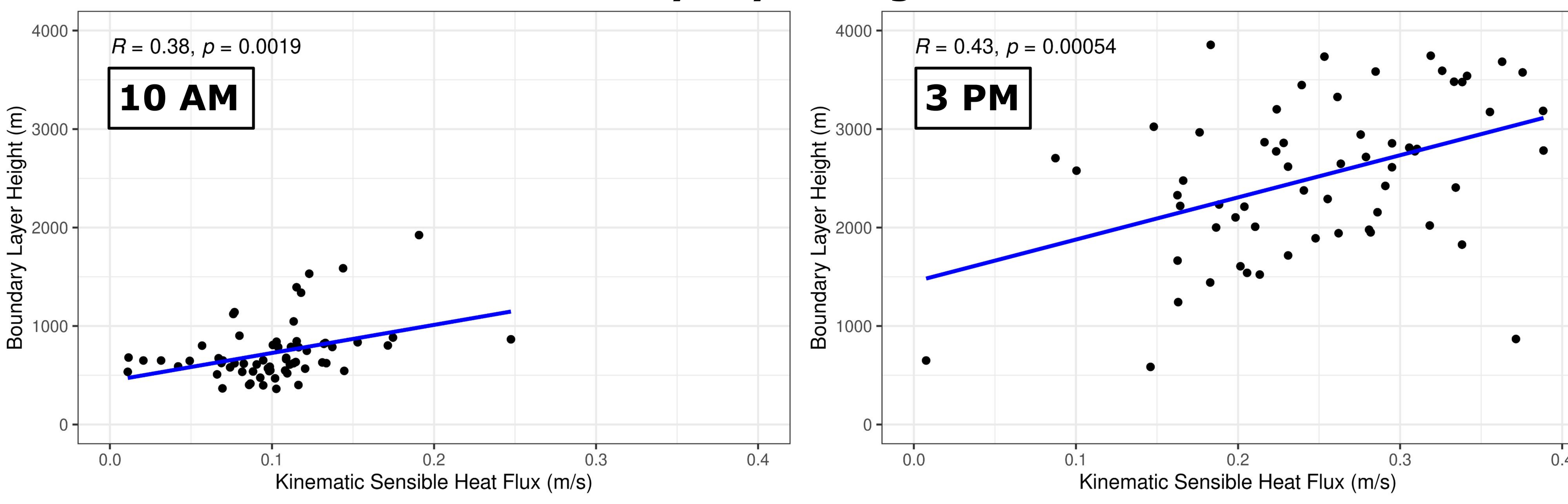


A standard deviation was taken of all instruments, as well as the number of working instruments from each day of the experiment. This helps to demonstrate which days may have the strongest measurements.



Kinematic Sensible Heat Flux was measured on flux towers throughout the experiment. Averages were taken from the hour preceding each radiosonde launch to understand what other factors may impact boundary layer height estimates.

Correlation between Boundary Layer Height and Sensible Heat Flux



A statistically significant ($p<0.05$) but weakly correlated relationship was seen between the boundary layer height best estimate and Kinematic Sensible Heat Flux for both 10 AM and 3 PM.

Conclusions:

We employed five observing systems and utilized seven different analysis methods to measure the boundary layer height at one time on every morning and afternoon during M2HATS. The measurements tend to agree more at the 10 AM hour than the 3 PM hour. Each method has strengths and weaknesses and measures a different attribute of the vertical dimension of the boundary layer. A single boundary layer height estimate for each observing time was determined by a subjective removal of outliers and subjectively averaging the remaining values. The data reveal the boundary layer typically soars between 10 AM and 3 PM.

A weak positive correlation exists between boundary layer height and surface sensible heat flux. Other processes, such as the mechanical production of turbulence, and the strength of the capping inversion (which are related to wind shear and subsidence) must effect the entrainment rate.

References:

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