Investigating the Spatiotemporal Variations of the PBL in the Central Valley Using CARB Ceilometer Aerosol Backscatter Observations

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Introduction

The Planetary Boundary Layer Height (PBLH) is crucial for air quality forecasting, as it determines the effective volume to which air pollution can spread. Within the Central Valley (CV), the PBLH is greatly influenced by the heterogeneity of surface properties and the surrounding mountain's thermodynamic and dynamic effects. Due to the high spatial and temporal PBLH variation and the absence of radiosonde stations in the CV for regular PBLH observations, an alternative remote sensing approach is crucial to study and predict PBL evolution. This study uses ceilometer aerosol backscatter data to detect the hourly PBLH at six sites within the CV. We then investigate the spatiotemporal variations of the PBLH on diurnal and seasonal scales, evaluating the influence of wind speed, temperature and the mountain-valley (MV) winds on PBL evolution.

Figure 1. Air basins of California (bold lines) and county borders (non-bold lines), with ceilometer stations marked in yellow. Red dots indicate surface stations used for MV wind observations.

PBLH Detection Method

- Lufft CHM15k and Vaisala CL51 ceilometer aerosol backscatter profiles were used to detect hourly PBLHs.
- PBLH Algorithm: A low-pass filter reduces noise of each vertical profile. A homogenous near-surface aerosol layer is identified and tracked for temporal continuity. The PBLH is assigned to the associated negative backscatter gradient. Nighttime PBL observations were not made due to a minimum signal height of ~185m and the high frequency of residual layers.

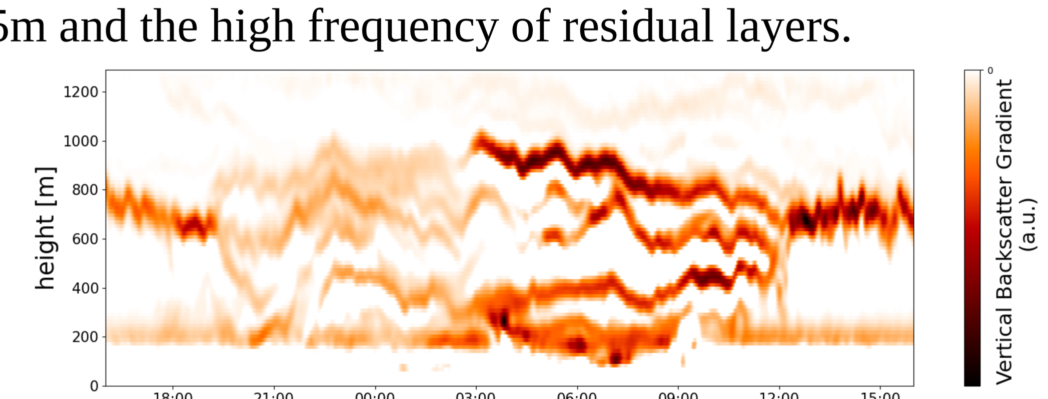


Figure 2. Negative backscatter gradients are shown in red. Multiple residual layers obscure the nocturnal boundary layer. The artificial noise at ~200m indicates the signal floor for CHM15k ceilometers.

Results

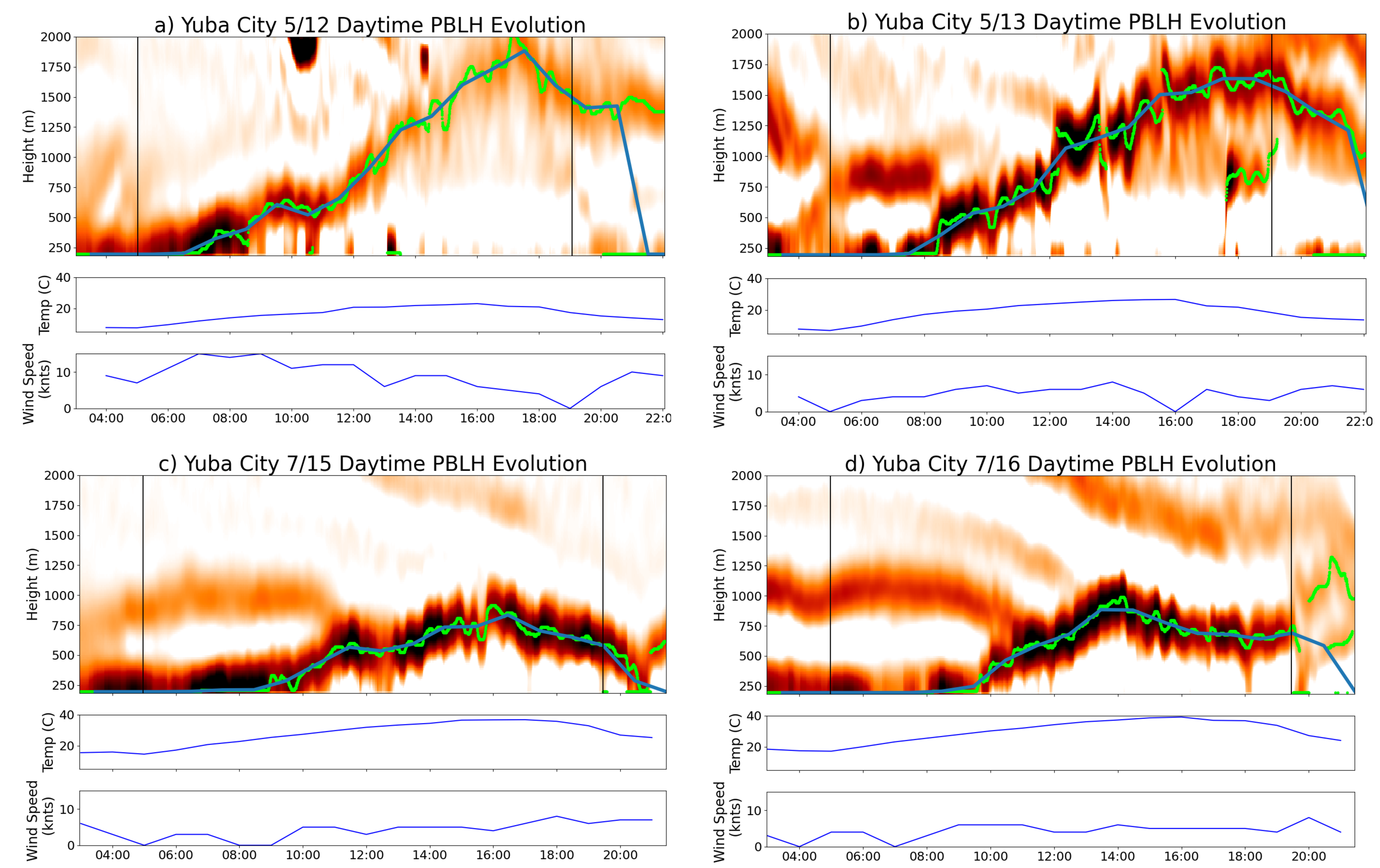


Figure 3. Negative backscatter gradient profiles (red shading) of two pairs of clear days in Yuba City: (a) 12 May, (b) 13 May, (c) 15 July, and (d) 16 July 2022. The green lines indicate significant vertical gradients, and the blue lines connect the hourly PBLH best guesses. Two black vertical lines represent sunrise and sunset, respectively. Bottom panels show hourly temperatures and wind speeds from the nearby BAB surface station (ASOS/AWOS 2022).

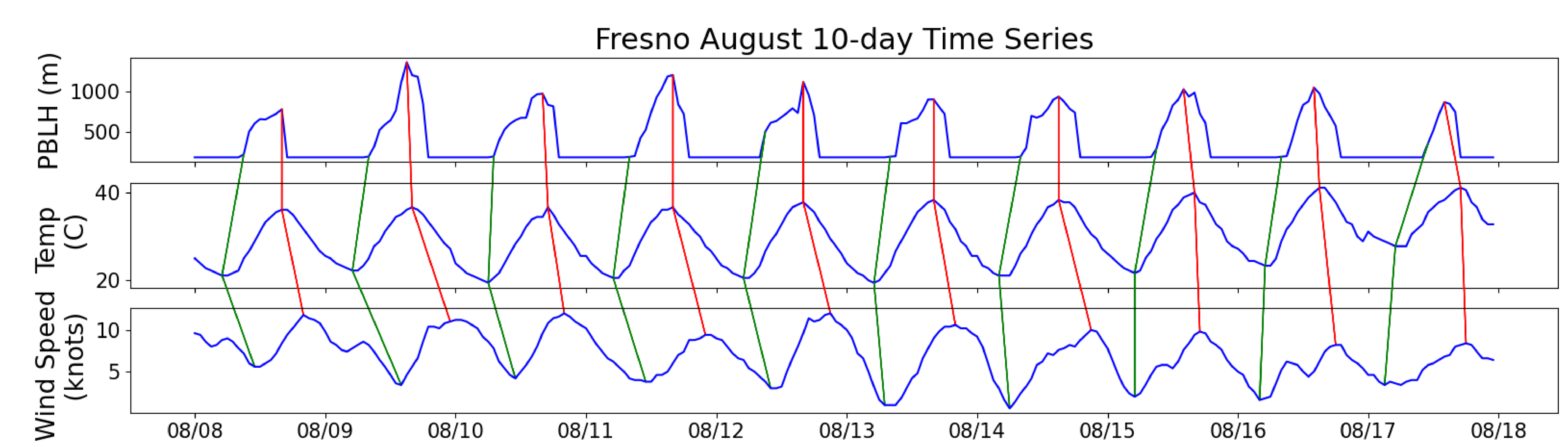
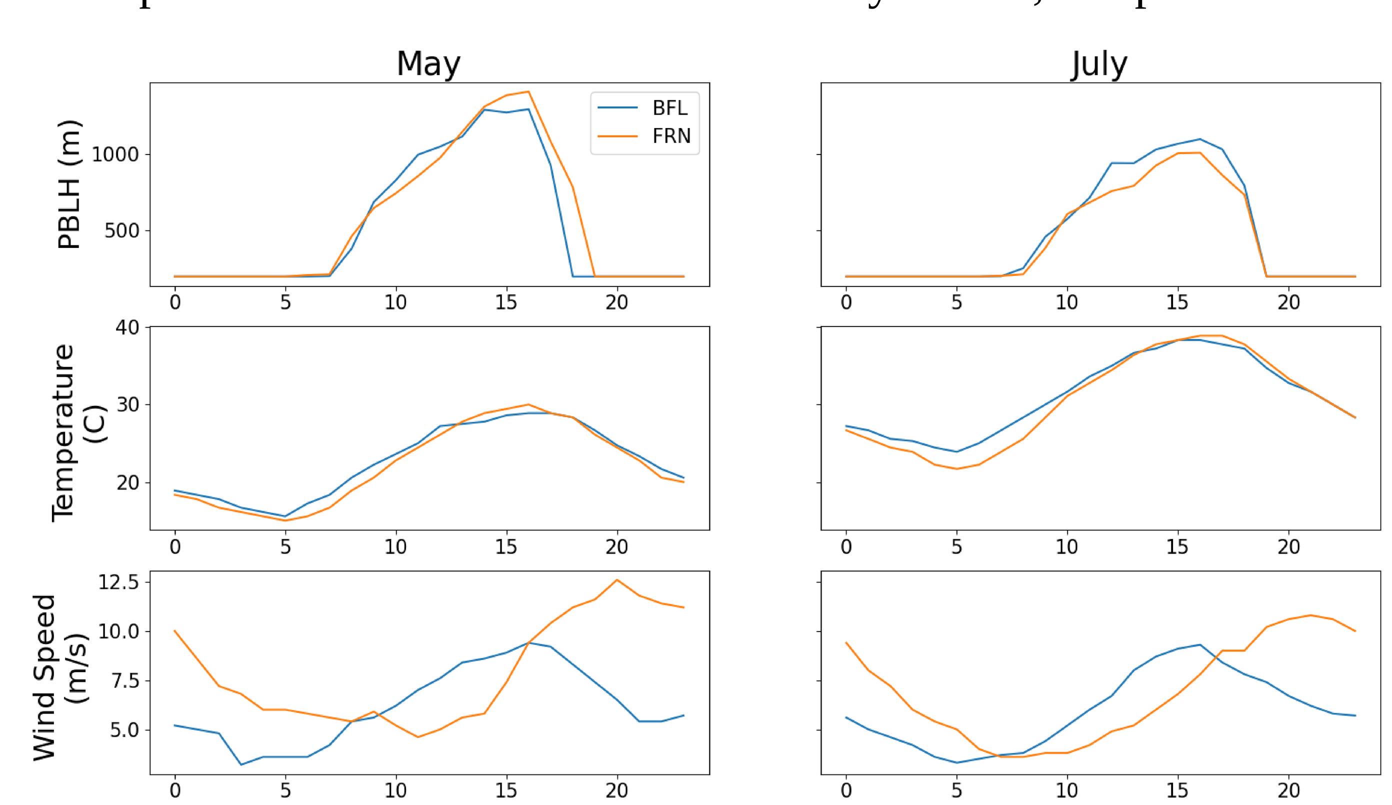


Figure 4. A 10-day time series of the PBLH, temperature and 5-hour averaged wind speed in Fresno from Aug 8 to Aug 18, 2022. Offsets between PBLH, temperature and diurnal cycle patterns are depicted by green and red lines. Green lines connect the morning PBLH rise with temperature minima and wind speed minima. Red lines connect daily PBLH, temperature and windspeed maxima.

Figure 5. Monthly averages of the PBLH, temperature, and 5-hour wind speed diurnal cycles in Bakersfield (blue) and Fresno (orange) from May and July 2022.



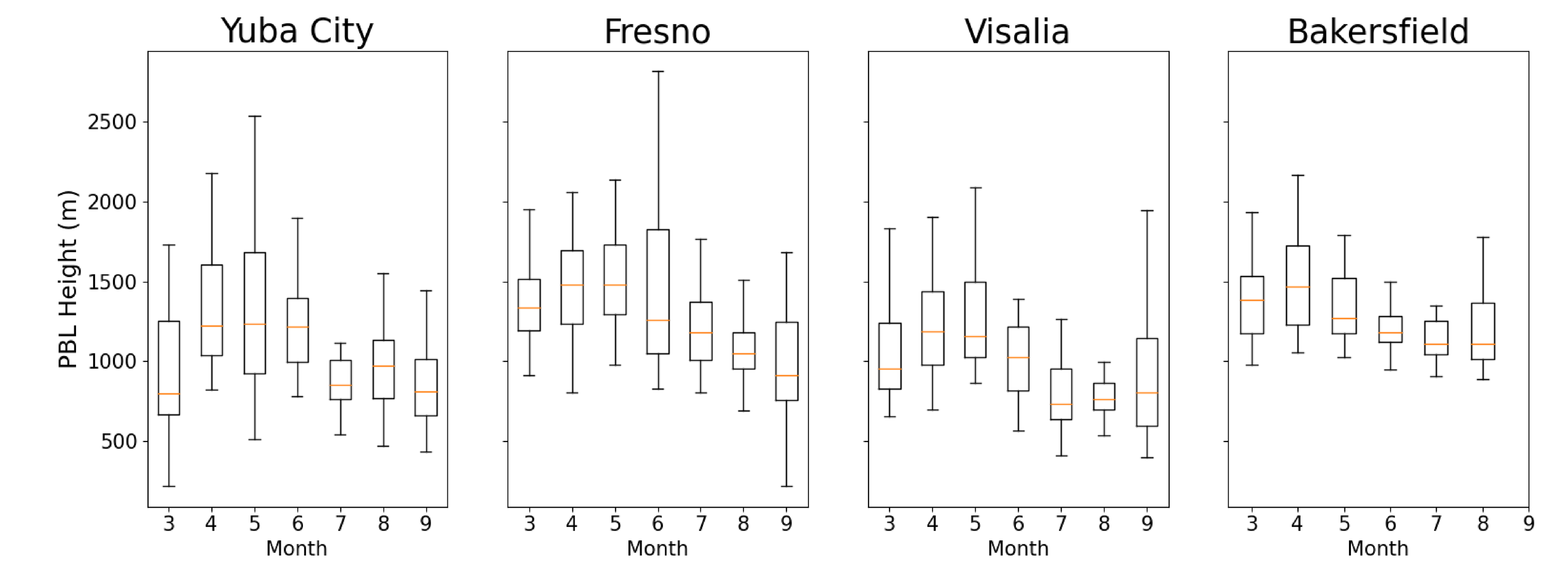


Figure 6. Daily PBLH-max distributions of each month, organized by station from northernmost to southernmost. Monthly median PBLH-max is marked in orange.

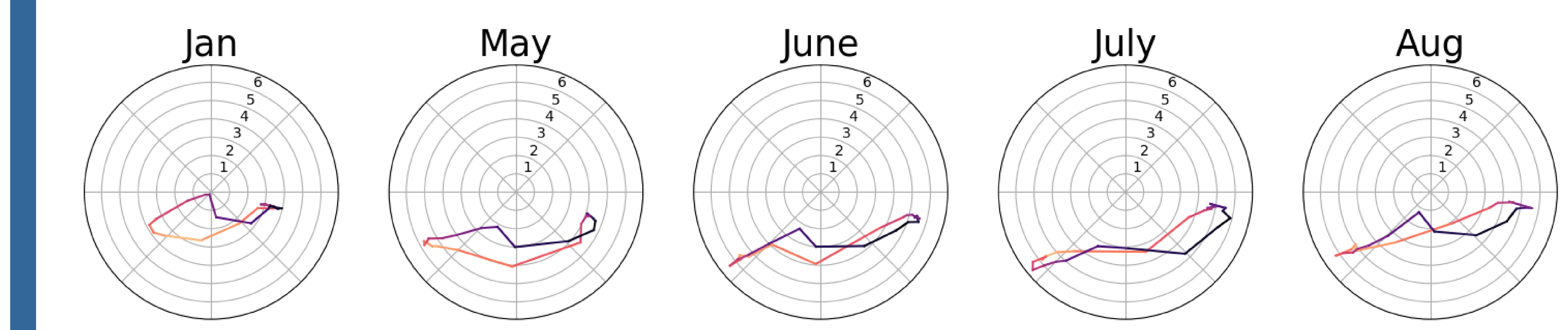


Figure 7. Directionally averaged mountain-valley wind measured at the AUN surface station in Auburn, on the Sierra foothills (ASOS/AWOS 2022). Points correspond with the hourly averaged two-dimensional wind vector; magnitude is measured in knots. Connecting lines between wind vectors are color coded for the time of day (yellow = noon, black = midnight).

Conclusions

- The PBLH diurnal cycle is directly correlated with temperature and wind speed diurnal cycles.
- Generally, the morning PBL begins to develop 2 to 4 hours after the initial rise in surface temperature, which occurs at sunrise.
- The maximum PBLH is reached at or just before the time of maximum surface temperature. The time of maximum wind speed varies by location but generally follows the time of maximum temperature by 1 to 5 hours.
- The afternoon PBL collapses soon after sunset, but the mixed aerosol layer may remain as a residual layer.
- Despite higher surface temperatures in the summer, the PBL reaches a higher maximum in the spring than in peak summer months. In the CV, the highest PBL is expected in late spring, peaking at 4:00 pm PST.
- Springtime PBL heights regularly reach 1000m, occasionally exceeding 2000m. On average, summertime PBL heights are ~300m lower, remaining near or below 1000m.
- Mountain-valley winds are a potential explanation for this seasonal cycle. Stronger summertime thermal forcing increases valley winds, which induces subsidence in the CV. This represses the PBL development. However, diurnal wind data in the foothills of the Sierras does not show significant differences in upslope and downslope flow between spring and summer. Thus, the increased magnitude in MV circulation cannot be supported with this measurement.

Reference:

ASOS/AWOS, 2022: California ASOS. Iowa Environmental Mesonet, accessed 1 December 2023, https://mesonet.agron.iastate.edu/request/download.phtml

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