A Comparison of Modeled and Observed Boundary Layer Depths Over Washington, D.C.

Wesley Taylor[1], Natasha Miles[2], David Miller[2], Eliott Foust[2], Ken Davis[2]
[1]Millersville University, [2]The Pennsylvania State University

A WRF Total Kinetic Energy Approach to PBLH Shows Strong Potential to Match LiDAR PBLH Determined by Vertical Velocity Variance and Fuzzy Logic Adjustments

Abstract:

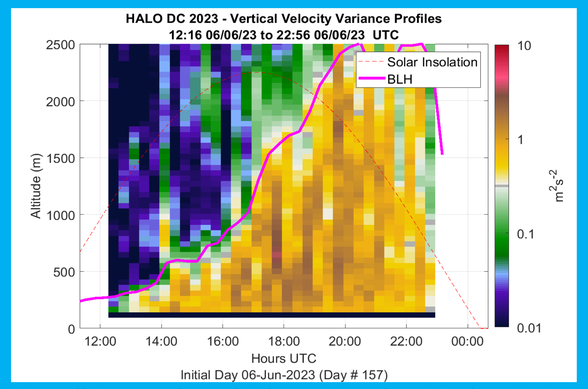
- Greenhouse gas and aerosol concentrations are strongly influenced by Planetary Boundary Layer Height (PBLH), which determines the volume contaminants will be mixed through. Air quality alerts rely on PBLH predictions being accurate to be released.
- A Light Detection and Ranging (LiDAR) device with Vertical Velocity Variance (VVV) detection provides a method robust to high backscatter to detect PBLH
- LiDAR data was processed using Haar wavelets and fuzzy logic to determine PBLH, similar to an earlier project that took place in Indianapolis[1]
- The Weather Research and Forecasting Model (WRF) predicts PBLH using total kinetic energy (TKE)
- As a LiDAR is being prepared for usage in the Baltimore Social-Environmental Collaborative, a comparison dataset from a local environment was deemed beneficial
- WRF and LiDAR together show overall agreement in results, though improvement is shown to still be necessary
- High backscatter environments, as detected by the LiDAR, may hinder the performance of PBLH determination

Methods:

- WRF operated at a 1 km resolution, over the length of the 2021 calendar year, and was reinitialized each month over the course of the calendar year.
- The WRF model calculates PBLH where calculated atmospheric TKE falls off
- The LiDAR, part of the Northeast Corridor Urban Testbed, provides measurements of PBLH every 20 minutes
- The LiDAR used in the experiment is the HALO Photonics Stream Line XR Doppler LiDAR
- Vertical Velocity Variance (VVV) tends to be preferred over backscatter concentrations when determining PBLH during LiDAR data processing
- Haar Wavelets are used to reduce noise, and a determining nonbinary function, known as fuzzy logic, dictates the location of the LiDAR's detection of PBLH
- Morning was defined to be 5:00 – 8:59 am, and afternoon was defined to be 2:00 – 5:59 pm

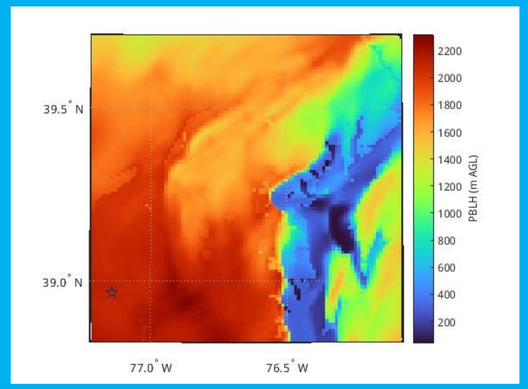
https://halo-photonics.com/lidar-systems/stream-line-series/

(a) LiDAR Vertical Velocity Variance Time-Height Profile with Derived PBLH From June 6th, 2023

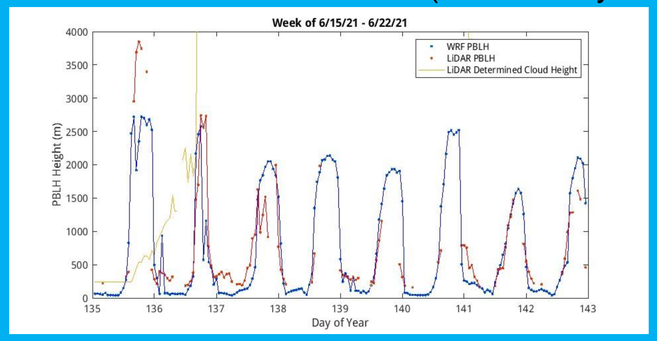


https://csl.noaa.gov/groups/csl3/measurements/2021dcflux/latest.html

(b) Sample WRF Output 99km x 99km Grid Showing PBLH (Star Shows Washington, D.C.)

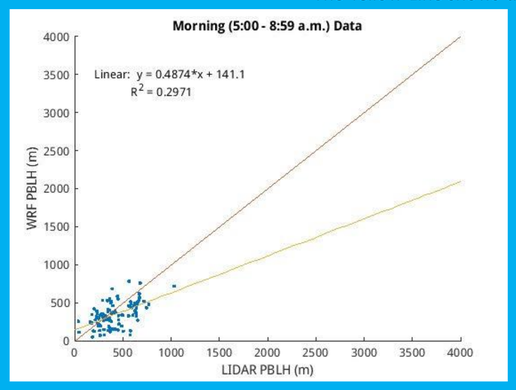


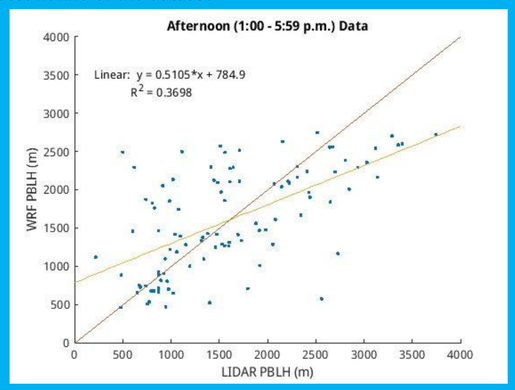
(c) Sample Time Series of Week of WRF and LiDAR PBLH Data, with LiDAR Cloud Data for Reference (Start of Day at 00 UTC)



(d) and (e) Scatter Plots of Morning and Afternoon PBLH Data

The Red Line is a 1:1 line for reference
The Yellow Line shows the best fit line of the dataset





Results:

- The R^2 values for each the morning and afternoon separately are relatively low; including all the data produces an R^2 of .6
- The afternoon scatterplot's mean bias is –2.44m, with a mean absolute error of 500.7m
- The morning scatterplot's mean bias is –71.1m, with a mean absolute error of 141.2m

Summary and Discussion

- The afternoon R^2 (.37) is higher than that of the morning (.30)
- The WRF model shows to be capable of correctly anticipating boundary layer early morning transitions due to a relatively low mean absolute error with the LiDAR
- High mean bias also shows that the WRF-anticipated PBLH is also lower than that detected by the LiDAR by an average margin of about 10%
- Afternoon WRF models have less accuracy predicting the true height on a given day due to a much higher mean absolute error, but have a reliable average prediction rate from low mean bias

Future Projects

- Further work should be done to determine if WRF metrics other than TKE are better able to match LiDAR-determined VVV PBLH
- Case studies of LiDAR cloud detection should be conducted for its efficacy at both low and high altitudes to assess the effects of fog and smoke impairment and low cloud ceiling reflectivity respectively

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References

1. Bonin, T. A., B. J. Carroll, R. M. Hardesty, W. A. Brewer, K. Hajny, O. E. Salmon, and P. B. Shepson, 2018: Doppler Lidar Observations of the Mixing Height in Indianapolis Using an Automated Composite Fuzzy Logic Approach. *J. Atmos. Oceanic Technol.*, **35**, 473-490, https://doi.org/10.1175/JTECH-D-17-0159.1