EXTRACTING THE HEIGHT OF THE PLANETARY BOUNDARY LAYER IN SMOKY CONDITIONS

A Doppler LiDAR analysis of Canadian wildfire smoke in Chicago

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CROCUS

- Community Research on Climate and Urban Science (CROCUS) is an Urban Integrated Field Laboratory led by Argonne National Laboratory
- We explore urban climate change through implementation of novel observational science and development of highly accurate climate models.
- Alongside this we study the implications for environmental justice in the Chicago region
- We aim to understand our climate and atmospheric processes at the city-level and even neighbourhood level, resolving specific local effects

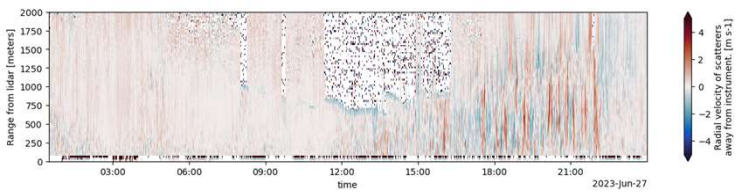
MOTIVATION OF THIS WORK

- Measuring the height of the planetary boundary layer (PBL) is key to estimating mass fluxes, and thus a variety of other important meteorological parameters.
- However, in conditions with smoke aloft in the atmosphere, the height of the PBL is often difficult to measure.
- We aim to develop a boundary layer retrieval package that is effective even in thick wildfire smoke.
  - Require initial success in clear conditions
  - Able to identify a priori expected diurnal cycle, with boundary layer growth in the morning
  - Performs well with clouds present

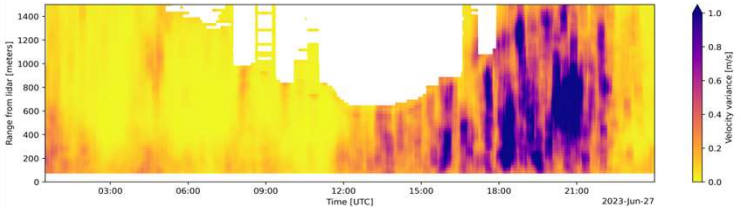
INSTRUMENTATION

- The bulk of the analysis uses data from a Doppler LiDAR deployed at Northeastern Illinois University, Chicago in June 2023
- Doppler LiDAR measures the backscatter intensity from atmospheric particles and their radial velocity relative to the instrument
- Compared with PBL height retrieved from dual-polarization ceilometer data (Vaisala CL-61)

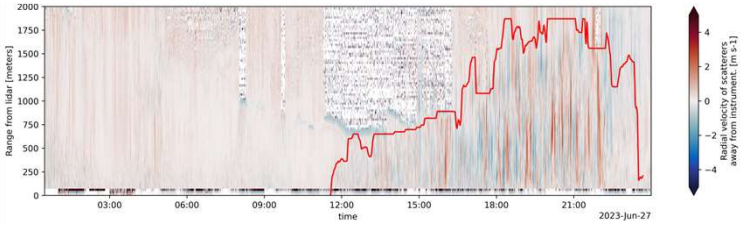
METHODOLOGY



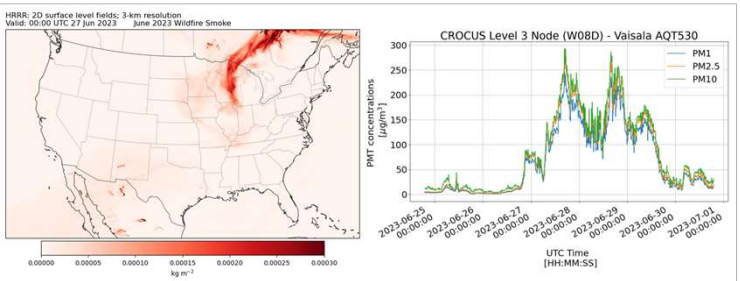
- Doppler LiDAR radial velocity profile with time, after filtering all points by SNR. The LiDAR was oriented vertically, making this is a profile of vertical velocity. Up and downdrafts are distinctly observable. Fewer data points at higher range.



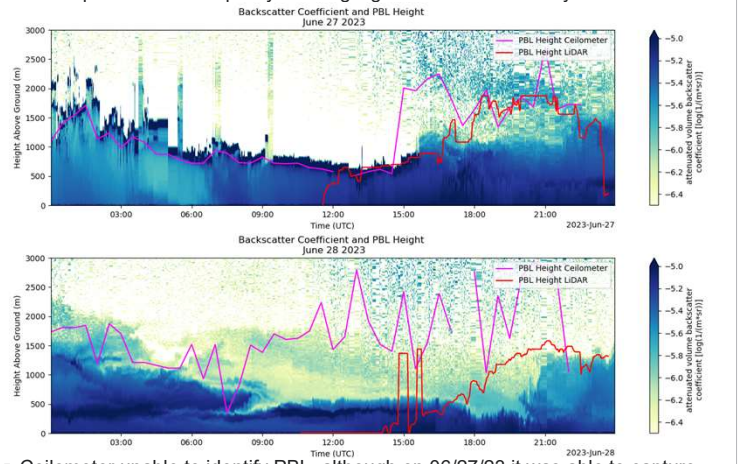
- Variance of vertical velocity, convoluted with nearby time steps used to quantify turbulence. The boundary layer is defined by the high turbulence region.
- Using OpenCV, utilize an edge map to extract data region, then use a binary threshold to divide the space into a low and high turbulence region. Retrieve the associated heights bounding this region for PBL.
- Plot below shows an example of a measured profile overlayed on the vertical velocity data from the LiDAR. This profile appears to accurately capture the region of turbulent eddies seen in the velocity data.



CASE STUDY APPLICATION



- Here we focus on three days for our boundary layer height retrievals. These are June 27-29, 2023, where smoke reaching Chicagoland was thickest. HRRR smoke product and air quality data highlight the severe intensity of the smoke.



- Ceilometer unable to identify PBL, although on 06/27/23 it was able to capture the daily maximum PBL height. Heights of strong intensity features from clouds were identified by the Haar wavelet technique instead.
- LiDAR captures the growth of the PBL in the morning -- distinct diurnal cycle observed. Two spikes in the LiDAR profile were traced to particularly strong downdrafts, their scale still smaller than ceilometer retrieved profile spikes.

CONCLUSIONS

- We characterized turbulence by considering the variance of vertical velocities from scanning Doppler LiDAR data
- Application of image processing techniques utilizing the Python package OpenCV allowed for boundary layer height retrievals on this data
- After success on clear days, where other techniques perform well, we focused on a case study in wildfire smoke
- In smoke-heavy conditions, the image processing method with LiDAR data was able to identify PBL height throughout the day and retrieved a distinct diurnal cycle, whilst the ceilometer failed to accurately capture boundary layer growth

NEXT STEPS

- Review LiDAR data from SAIL (Surface Atmospheric Integrated Laboratory) in Colorado, we hope to identify further wildfire smoke case studies
- Compare the LiDAR observed boundary layer profiles identified here to modelled PBL height from the HRRR. Do models accurately predict PBL height in complex wildfire smoke conditions? Do they have a bias?
- Refine methods into a simplified package and introduce processes to remove anomalous spikes automatically

REFERENCES

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