Demonstrating Capabilities of Multiple-Fixed-Beam Airborne Doppler Lidar Using an LES-based Simulator

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ABSTRACT

Fine-scale wind measurements in the planetary boundary layer are required for understanding turbulence in complex terrain, flux of energy and aerosols, and severe weather events. The University of Colorado, Boulder (UCB) is developing an Airborne Doppler Lidar (ADL) system with 5 fixed-direction beams to improve wind measurements with large spatial heterogeneity. The 5-fixed-beam system takes continuous radial wind velocity measurements at multiple angles including a dedicated nadir beam for high-resolution vertical measurements. Results of an ADL simulator, based on a large eddy simulation (LES) with 10 m vertical and horizontal resolutions, demonstrated that the five-beam system can reduce wind profile retrieval error due to turbulence by more than 40%, is less sensitive to restrictive design parameters, and can resolve PBL 2-D roll structures.

Introduction

- **There is a need for planetary boundary layer (PBL) measurements with high spatial resolution**
  - Validate and Improve weather and climate models
  - Improve understanding of PBL processes
  - Inform wind-energy capture methods
- **Airborne Doppler Lidar (ADL) is an effective tool for PBL wind measurements**
  - Large spatial coverage
  - Quickly adapts to changing conditions
  - Able to operate over oceans and complex terrain
- **CU Boulder is developing a new ADL system that uses 5 fixed-direction beams in place of a single scanning beam**
  - Removes the need for complex scanning mechanism
  - Measures both horizontal and vertical wind speeds continuously
  - Allows for additional multi-beam analysis
- **An ADL simulator is used to compare the 5-fixed beam ADL approach to a single beam scanning approach**

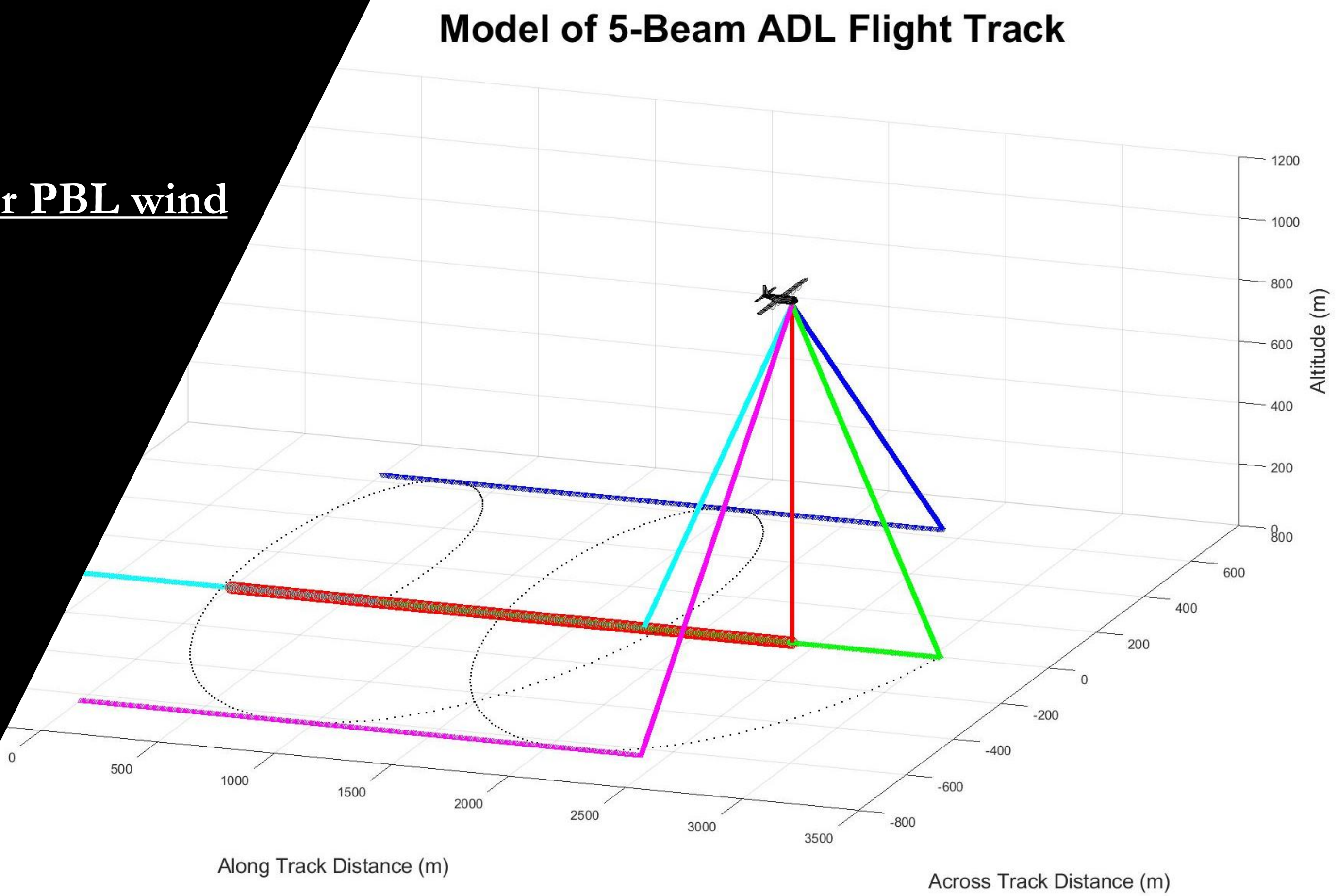


Figure 1. The geometry of the 5 fixed beams each taking continuous measurements is shown along with the beam ground tracks. An example scanning ground track (black) is shown for comparison.

Methods

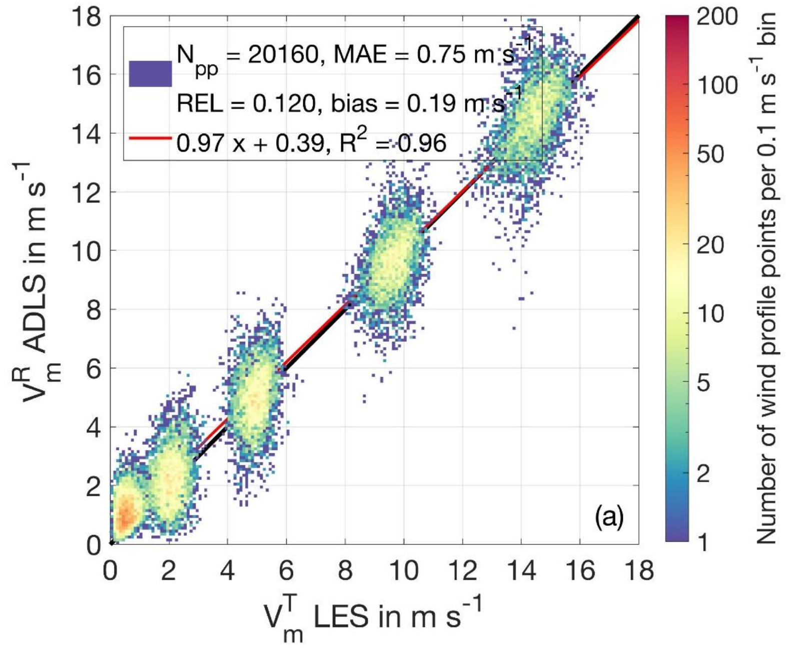
- **Airborn doppler lidar simulation (ADLS) allows 5-fixed-beam and scanning system retrievals to be compared with a known truth**
- **The ADLS uses a 23.0x17.3x2.3 km^3 large eddy simulation (LES) with 10m vertical and horizontal grid spacing**
  - Models a turbulent convective boundary layer
  - 5 background wind speed cases are simulated with 0,2,5,10 and 15 m/s mean wind
  - ADLS assumes time-fixed atmosphere
- **Mean wind retrievals are generated using the AVAD technique**
  - 30 m beam range gates
  - 5 along track retrieval distances tested
- **336 profiles are retrieved for each background wind speed, elevation angle, and averaging distance case to achieve statistical significance**
  - 7 LES time steps, 8 transects per time step, 6 profiles per transect

Parameter	System Setting
Aircraft flight altitude	1100 m
Scan elevation angle	30º, 40º, 50º, 60º, 65º, 70º, 75º, 80º
Along track averaging distance	325 , 650, 975, 1300, 2600 m
Lidar measurement frequency	10 Hz
Height used for retrieval	0-800 m
Indicated air speed	65 ms^{-1}
Vertical averaging distance	60 m
Scan rotation speed	18º s^{-1}
Fixed-beam directions	Forward, right, backwards, left, nadir
Background wind speed	0, 2, 5, 10, 15 ms^{-1}
LES time steps sampled	7
Transects flown per time step	8
Profiles retrieved per transect	6
Time separation between time steps	20 min

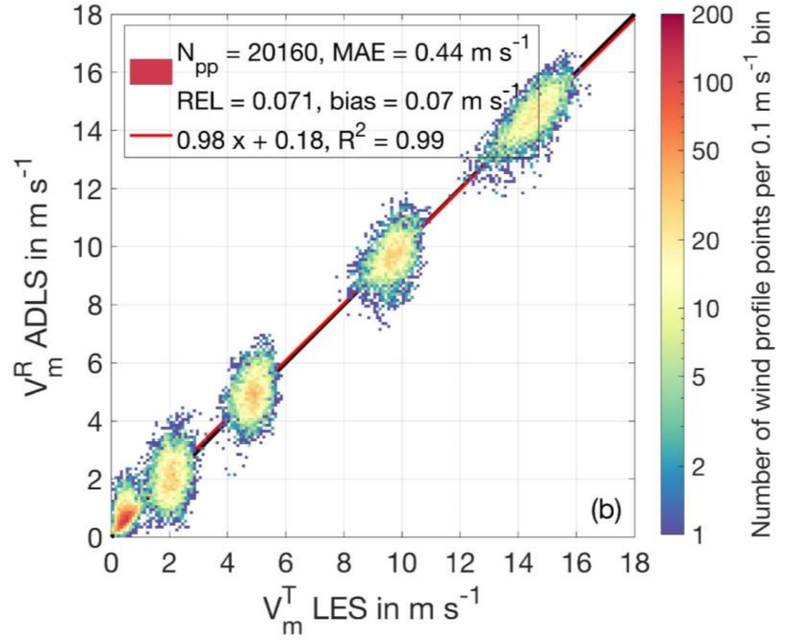
Results

- **<u>5-fixed-beam system shows reduced error due to turbulence with mean horizontal wind retrievals</u>**
  - 0.44 m/s vs 0.75 m/s mean absolute error
  - 0.07 m/s vs 0.19 m/s bias
  - 0.99 vs 0.96 R^2 fit to true wind
  - 0.071 vs 0.12 relative error

<u>Scanning</u>



<u>Multiple-Fixed-Beam</u>

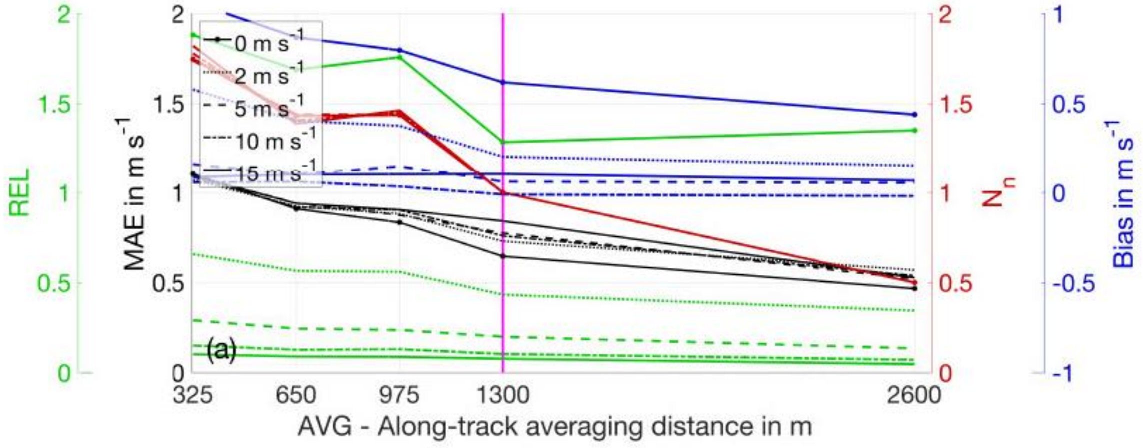


<u>Figure 2.</u> Mean horizontal wind retrievals are compared for fixed and scanning systems using 1300 m along track retrieval distance. Retrieval profiles are plotted as points with retrieved wind speed as the y coordinate and true wind speed as the x coordinate.

Results

- **<u>The 5-fixed-beam configuration is better suited for short along track averaging distance retrievals</u>**
    - Scanning system's along track retrieval distance is limited by scan speed
    - At 325 m along track averaging distance and 0 m/s mean wind, the fixed-beam system has mean absolute error of 0.52 m/s vs 1.08 m/s for the scanning system

<u>Scanning</u>



<u>Multiple-Fixed-Beam</u>

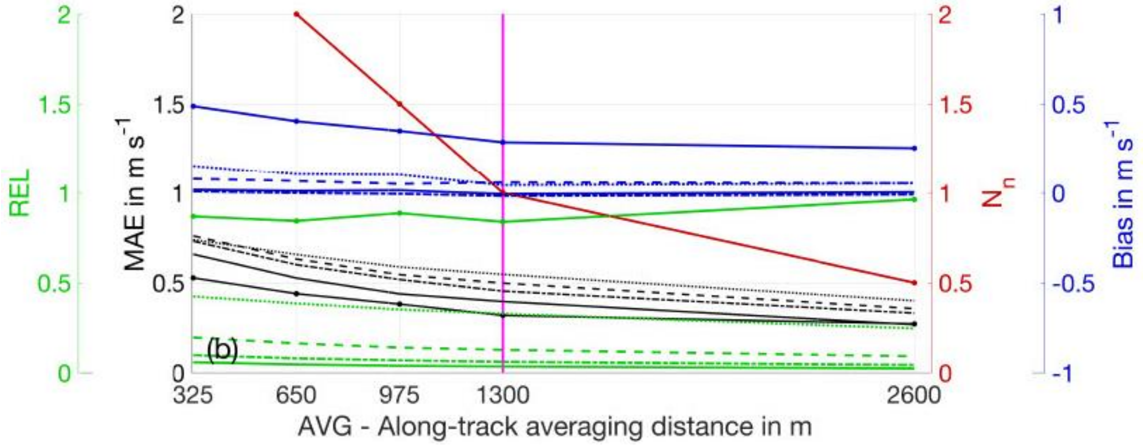
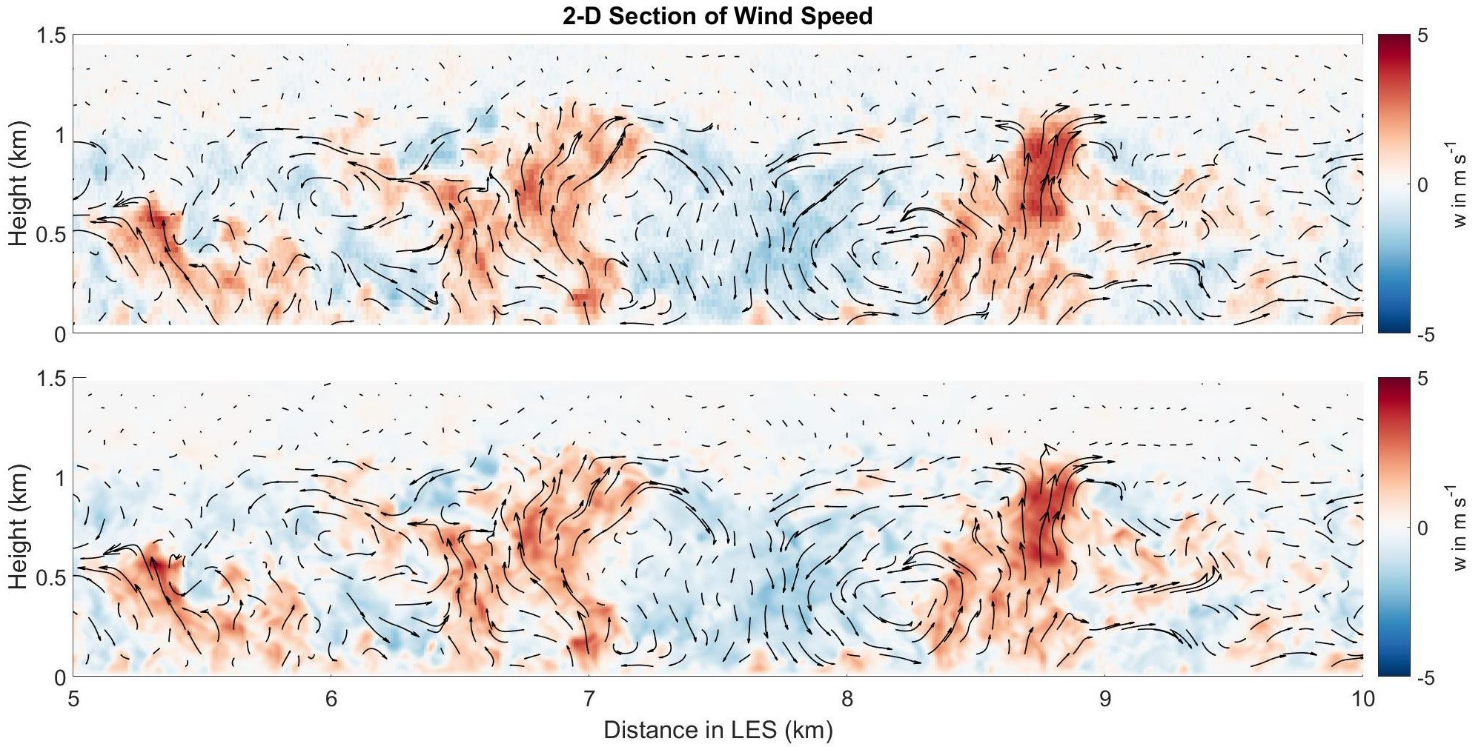


Figure 3. The retrieval error of the scanning system (a) and the fixed beam system (b) when using various along track averaging distances. Shown are the mean absolute error (black), the bias (blue), the relative error (green), and the normalized number of retrieval points (red). Different line styles represent different mean wind speed cases. These results use an elevation angle of 60º.

Results

- **<u>The 5-fixed-beam system is capable of multi-beam analysis not possible with a scanning system</u>**
- **<u>A high-resolution 2-D cross section of wind below the aircraft can be generated</u>**
  - Forward, nadir, and backwards beams cross roughly the same path
  - Nadir beam isolates vertical wind
  - Resolution is limited only by aircraft speed and sampling frequency
  - 2-D roll structures can be resolved



<u>Figure 4.</u> Section of 2-D wind profile generated by multi-lidar analysis compared to LES truth. Background color scale represents vertical wind measured by nadir beam and streamlines follow retrieved 2-D wind profile. Retrieval generated by performing lease squared fit on 3 beam overlap with 10 m averaging distance. Radial wind measurement and beam direction error are applied with standard deviation 0.2 m/s and 0.01⁰ respectively.

Conclusion

Based on results of ADLS modeling, the 5-fixed-beam ADL system under development at CU Boulder will have decreased retrieval error compared to a single beam scanning systems and is more suitable for generating retrievals with short along track averaging distances. ADL simulations showed greater than 40% reduced error in mean wind retrievals compared to a scanning system, and greater than 50% reduced error when a short along track averaging distance is used. The 5-fixed-beam system is also capable of multiple beam analysis that is not possible with a single scanning beam, such as high resolution 2D curtain retrieval. ADL simulation is a valuable tool for investigating ADL performance since it allows for comparison with a known truth. Ongoing research is using ADLS to further understand additional capabilities of the 5-fixed-beam ADL.

References

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