Validation of Offshore Winds in the ERA5 Reanalysis Using Two Floating LIDARS South of Long Island

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INTRODUCTION & OBJECTIVES

Background

- Increasing interest in wind energy offshore of the U.S. East Coast necessitates accurate characterization of the marine ABL vertical wind profile.[1]
- Significant sources of uncertainty exist in offshore wind prediction. Uncertainty magnitudes must be known and corrected.[1]

Issues to Offshore Wind Prediction:

- Extremely scarce long term, multi-level meteorological observations offshore of the U.S. East Coast.[1,2]
- Lack of offshore wind data at hub height necessitates use of:
  - Assumed boundary layer profiles (i.e., log-law or power-law)[1,2,3]
  - Mesoscale models and model reanalysis (i.e., ERA5).[1,3]
- Assumptions made often go unvalidated and have varying degree of success in accurately representing observed wind profiles and low-level jets (LLJs).[1,3]

Objectives:

1. What is the wind speed resource under different seasons, time of day, and LLJs in the NY Bight marine ABL?
2. When and under what atmospheric conditions do the largest or smallest wind speed uncertainties/biases occur?
3. Does the ERA5 accurately represent the observed coastal LLJ?

DATA & METHODS

Data Sources:

1. North (E05) and South (E06) NYSERDA floating lidar systems
2. ERA5 Reanalysis (on terrain following-levels)

Study Period:

- 4 September 2019 – 31 January 2022
- Warm season months (May-Sept.) are analyzed for LLJs.

Variables of Hourly Data

- Profiles of wind speed and wind direction
- Wind speed bias between ERA5 and floating lidars

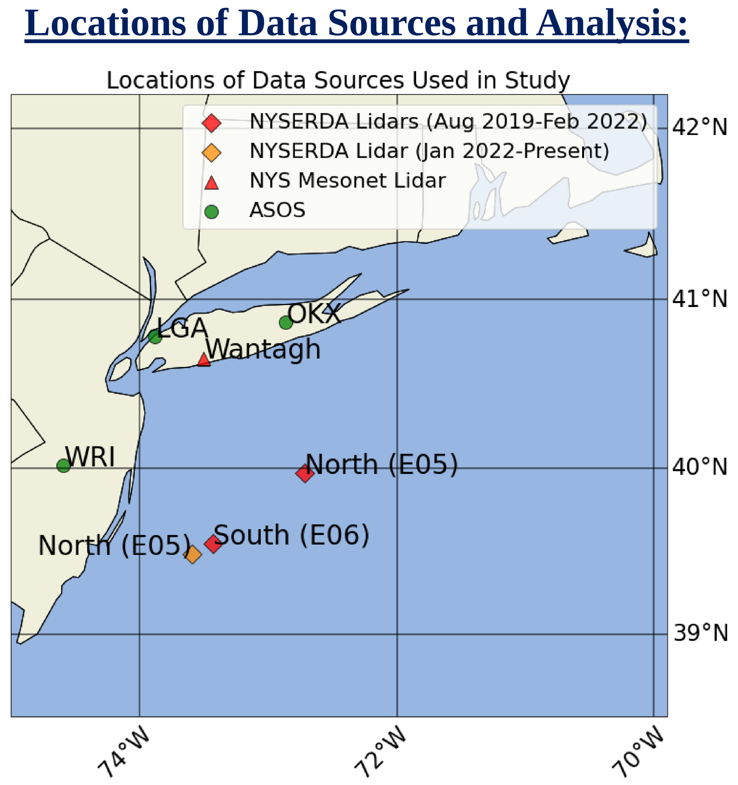
Vertical Profile Extent and Resolution:

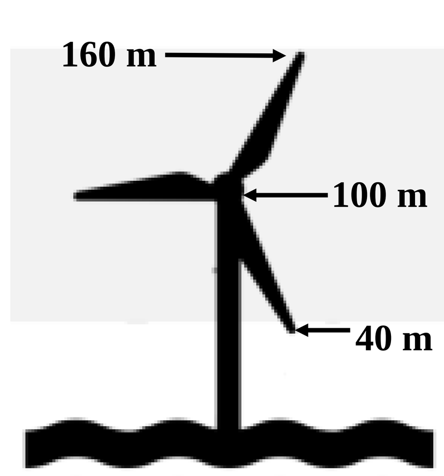
- 20-200m vertical extent at 20m vertical resolution
- 8 sigma levels in the lowest 200m ASL in ERA5 reanalysis.

Warm Season Low Level Jet Detection:

- Applied a modified detection algorithm from Debnath et al. (2021)[4]
- Detected 289 LLJ hours or equivalent to 91 days with a LLJ.

Locations of Data Sources and Analysis:





ERA5–LIDAR WIND SPEED CHARACTERISTICS & VALIDATION

Seasonal & Monthly

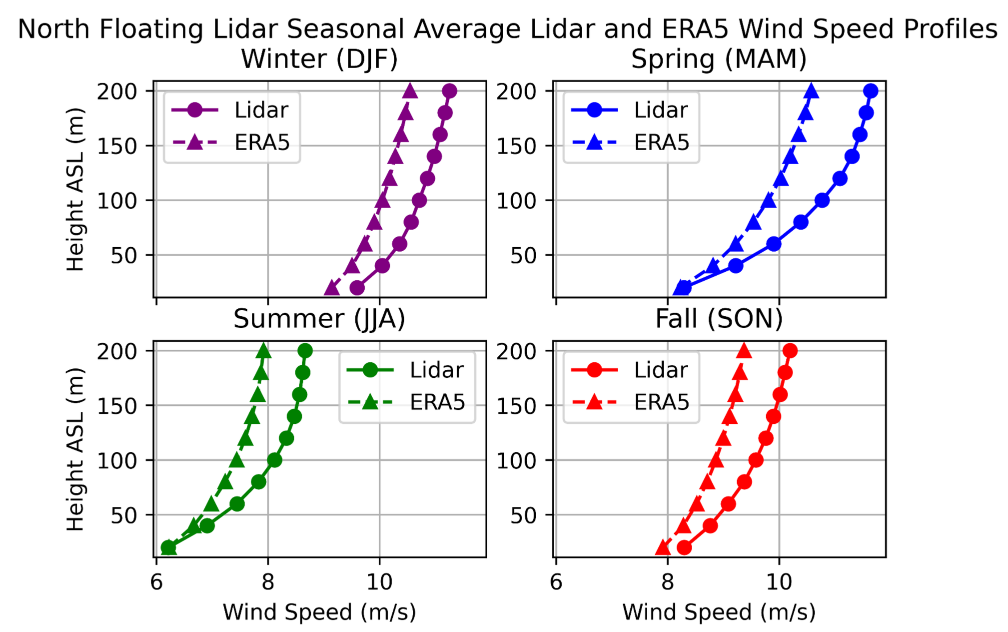


Fig 1. Seasonal breakdown of ERA5 (dashed triangles) and observed North floating lidar (solid dotted) wind speed profiles.

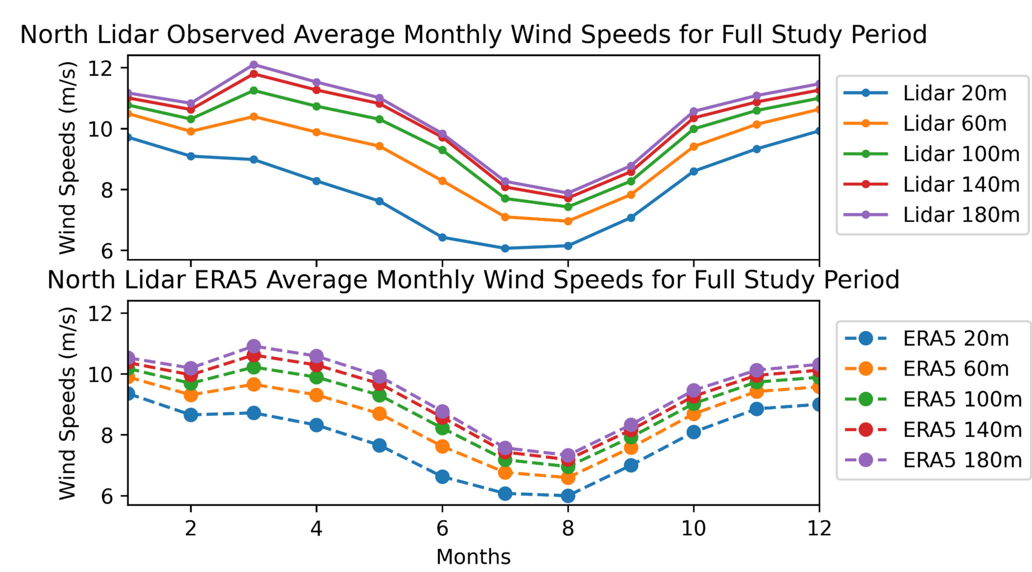


Fig 2. Observed (top panel) and ERA5 (bottom panel) average monthly wind speeds per height level at North floating lidar.

Diurnal

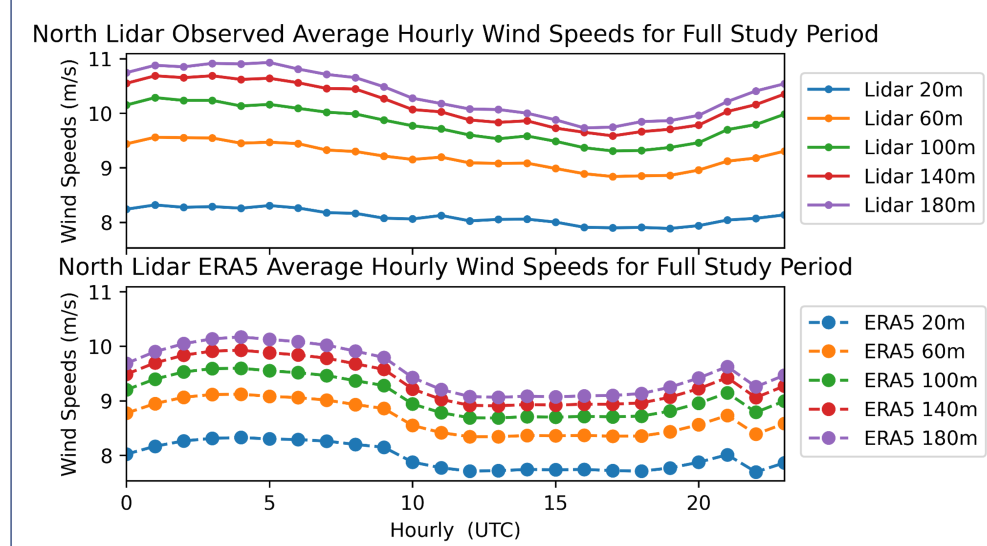


Fig 3. Observed (top panel) and ERA5 (bottom panel) average hourly horizontal wind speeds per height level for full study period.

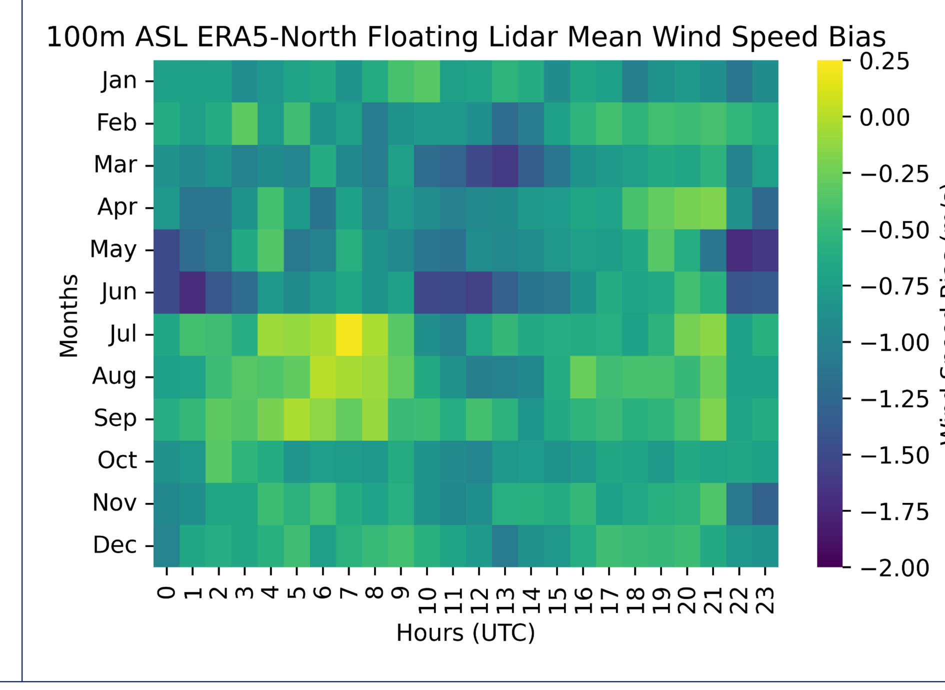


Fig 4. (12 months x 24 hours) heat map of 100m ERA5-Lidar mean wind speed bias at the North floating lidar. Dark blue and purple colors are large negative wind speed biases. Yellow-green is near zero to positive biases.

WARM SEASON LOW-LEVEL JETS (LLJs)

Average LLJ Profiles from ERA5 and Lidar

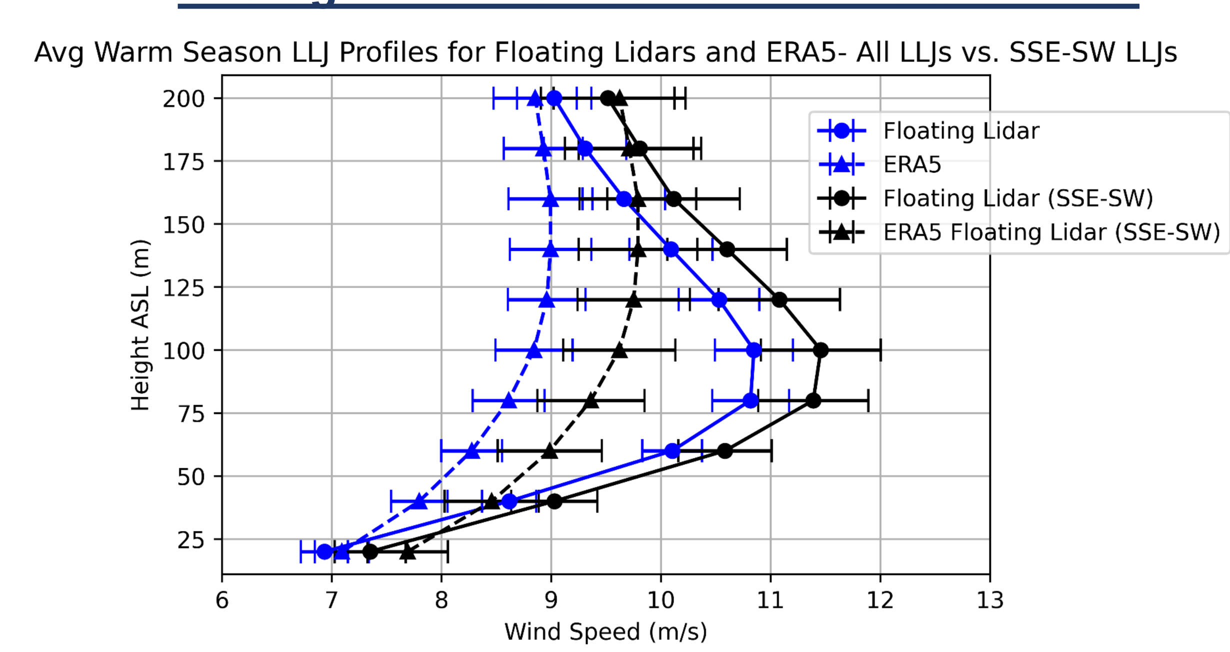


Fig 5. Blue lines show the average of all 289 detected warm season LLJ hours. **Black** lines show the average of the SSE-SW NY Bight LLJ (135 hours).

Monthly and Diurnal Distributions

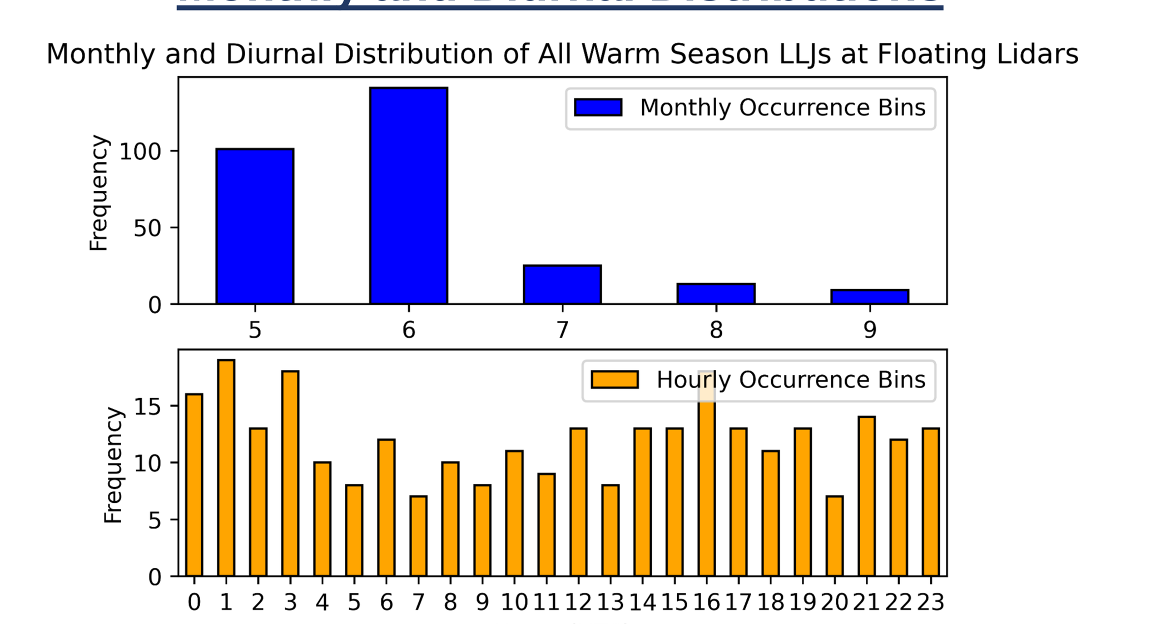


Fig 7. Monthly (Top panel, Blue bins) and diurnal (Bottom panel, Orange bins) distribution of all 289 detected warm season LLJ hours.

ERA5-Lidar Mean Wind Speed Bias

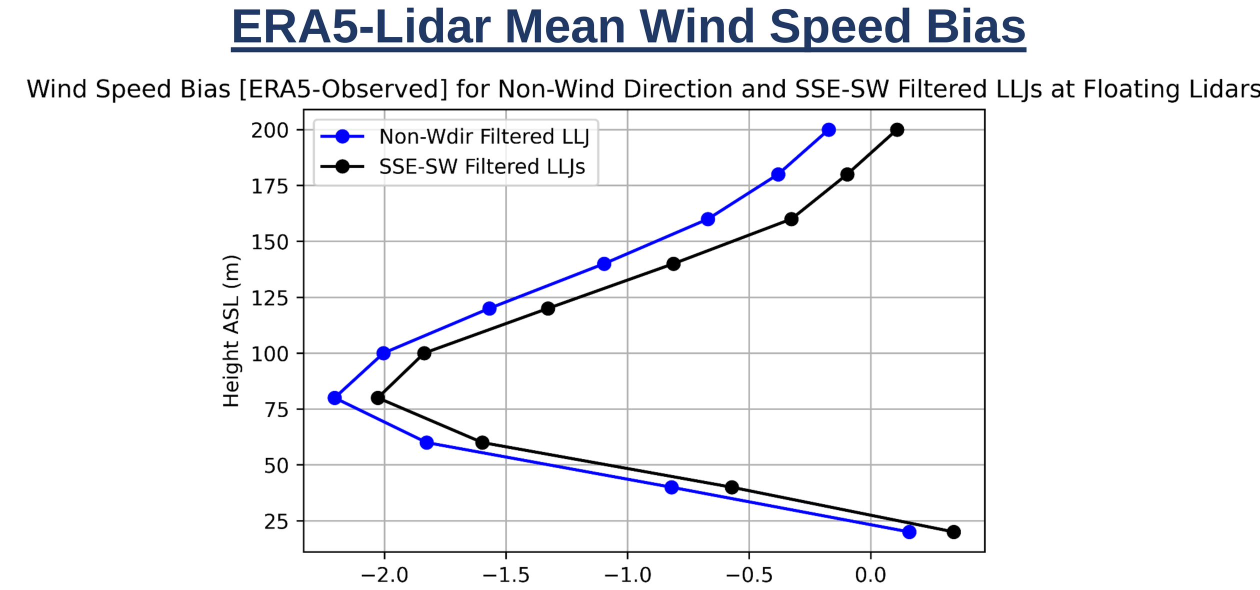


Fig 6. Blue profile shows the mean wind speed bias profile for all 289 warm season LLJ hours. **Black** profile shows the mean wind speed bias profile for the SSE-SW LLJ hours.

LLJ Nose Wind Speed and Height Distributions

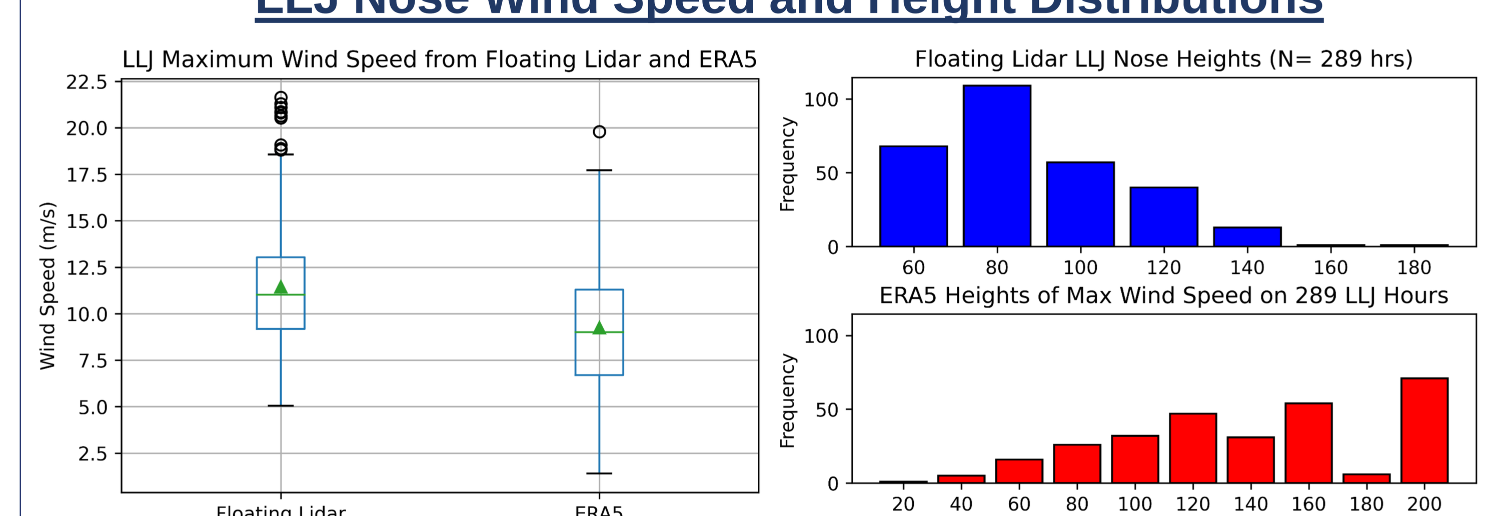


Fig 8. (Left panel) Boxplot distributions of floating lidar detected LLJ nose wind speeds and ERA5 maximum wind speeds on the corresponding LLJ hours. **(Right panel)** Height distributions of floating lidar detected LLJ noses (**blue**) and ERA5 maximum wind speeds (**red**) on corresponding LLJ hours.

CONCLUSIONS & FUTURE WORK

Seasonal & Monthly:

- Strong seasonality exists in wind speed profile characteristics (e.g., average wind speed and shear) due to changes in synoptic/ambient conditions.
- All seasons exhibit an ERA5 slow bias, with Spring having the largest negative bias of ~0.6 - 1.0 ms^{-1} at rotor plane heights.
- ERA5 well-depicts the trend in average monthly wind speeds, but at a slow bias.

Diurnal:

- ERA5 exaggerates the changes in the diurnal wind speed evolution. This is very likely due to ERA5's 4-D var data assimilation scheme.[3]
- 1000-1300 UTC and 2200-0000 UTC have persistent ERA5-Lidar slow bias, especially in Spring.
- May and June from 2200-0300 UTC exhibits largest negative bias… Impact of LLJs and stable stratification of marine ABL.

Warm Season LLJs:

- June and May have the largest LLJ frequency, and LLJs more frequently occurred at 21-03UTC.
- ERA5 poorly depicts the average LLJ wind speed profile. ERA5 jet nose is elevated, weaker, and "smeared out."
- Largest model wind speed bias occurs at 80 m with magnitudes of -2.0 - -2.20 ms^{-1}.
- Observed LLJ nose wind speed distribution exhibits faster and more extreme wind speeds, as compared to the ERA5.
- Heights of observed LLJ noses range from 60-180 m, with the highest frequency occurring at 80m ASL.
- ERA5 poorly depicts the heights of maximum wind speeds on the warm season LLJ hours.

Future Work:

1. Use of principal component analysis (PCA) to understand how the synoptic and mesoscale temperature, pressure, and flow patterns affect the wind speed bias.
2. Can knowledge of the dependence of model error on the ambient conditions be used to construct a bias correction algorithm using machine learning?

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4. Debnath, M., P. Doubrawa, M. Optis, P. Hawbecker, and N. Bodini, 2021: Extreme wind shear events in US offshore wind energy areas and the role of induced stratification. Wind Energy Science, 6, 1043–1059, doi:10.5194/wes-6-1043-2021.

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