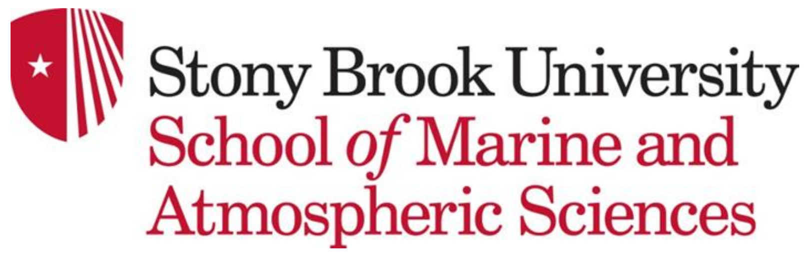

Validation of Offshore Winds in the ERA5 Reanalysis and Mesoscale Model Analyses Using Two Floating LIDARS South of Long Island, NY

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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 and its evolution over various timescales.
- Significant sources of uncertainty exist in offshore wind prediction, and can lead to large power production forecast errors.

Issues to Offshore Wind Prediction:

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

Objectives:

1. Do NWP model analyses accurately depict the warm seasonal marine boundary layer wind speed characteristics?
2. Does the ERA5, HRRR, and NREL OMA21 analyses accurately represent the observed coastal LLJ characteristics and have LLJ prediction capabilities?

DATASETS & METHODS

Study Period

- 4 September 2019 – 1 December 2022
- Warm season months defined as May-September (MJJAS).

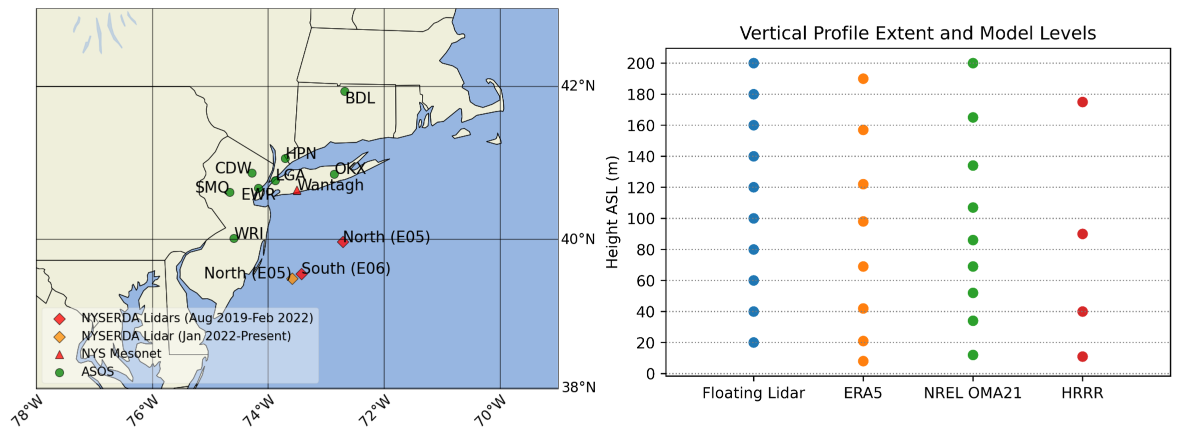
Observed Wind Speed Dataset:

1. North (E05) and South (E06) NYSERDA floating lidar systems.

Global Reanalysis & Mesoscale (WRF) Model Analyses:

1. ECMWF Global Reanalysis 5^{th} generation (i.e., ERA5)
2. National Renewable Energy Laboratory Offshore Mid-Atlantic 21-year Wind Resource Dataset (i.e., NREL OMA21).
   - WRF v. 4.1.2 model initialized and forced at the boundaries with ERA5
3. High-Resolution Rapid Refresh (HRRRv3 and HRRRv4) analysis.

Study Location, Observed Vertical Profile, & Model Levels:



Warm Season Low Level Jet Detection Algorithm and Methods:

- 3 different types of algorithms were used to detect LLJ wind speed profiles [Ref. 1, 2, and 3]
- Algorithms were slightly modified from their original usage to fit the vertical profile extent and to obtain a sufficient sample size/quality of jets cases.
- Algorithms varied in their respective below- and above-jet shear or wind speed falloff criteria.
- If **2 or more** of the algorithms had a LLJ profile on a given day, that day was counted as an event… 441 hours or 121 LLJ days were detected in the full study period warm season.

WARM SEASON WIND SPEED VALIDATION: ERA5 & NREL OMA21 ANALYSES

Average Wind Speed & Performance Metric Profiles

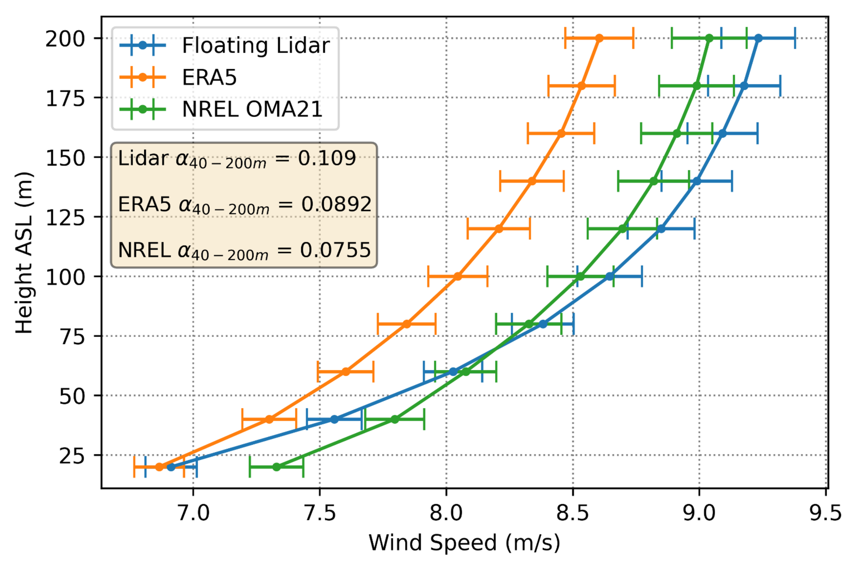


Fig 1. Average wind speed profiles from observed floating lidar (Blue), ERA5 reanalysis (Orange), and NREL OMA21 analysis (Green). 40-200m power law wind speed shear exponent ($\alpha_{40\text{-}200m}$) provided in textbox.

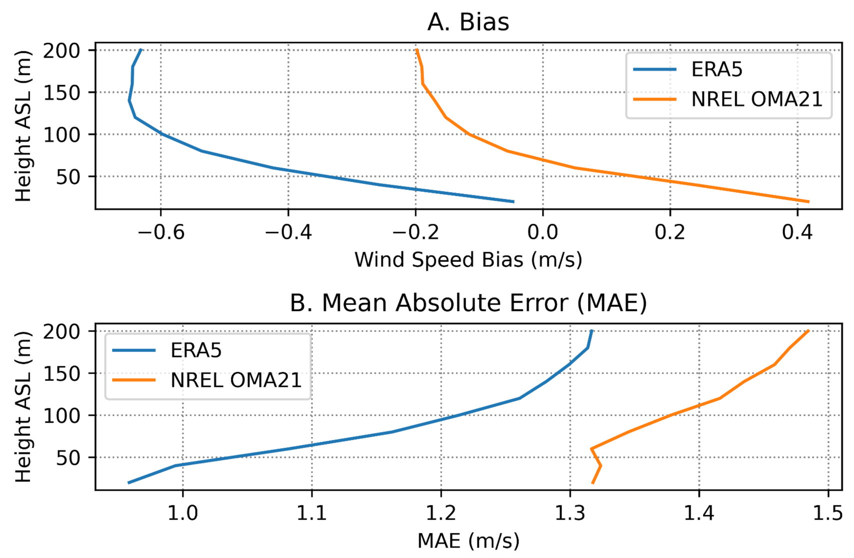


Fig 2. ERA5 (Blue) and NREL OMA21 (Orange) profiles of wind speed bias and mean absolute error (MAE) for the full warm season period.

Monthly & Diurnal Performance

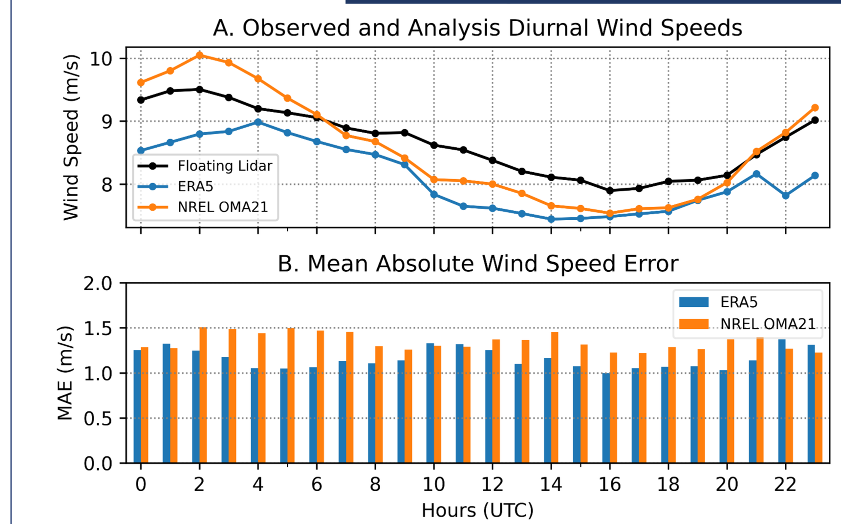


Fig 3.A. Average diurnal cycle of observed floating lidar, ERA5, and NREL OMA21 mean 40-200m wind speeds. **Fig 3.B.** Comparison of ERA5 (Blue bars) and NREL OMA21 (Orange bars) mean absolute error per hour for the full warm season period.

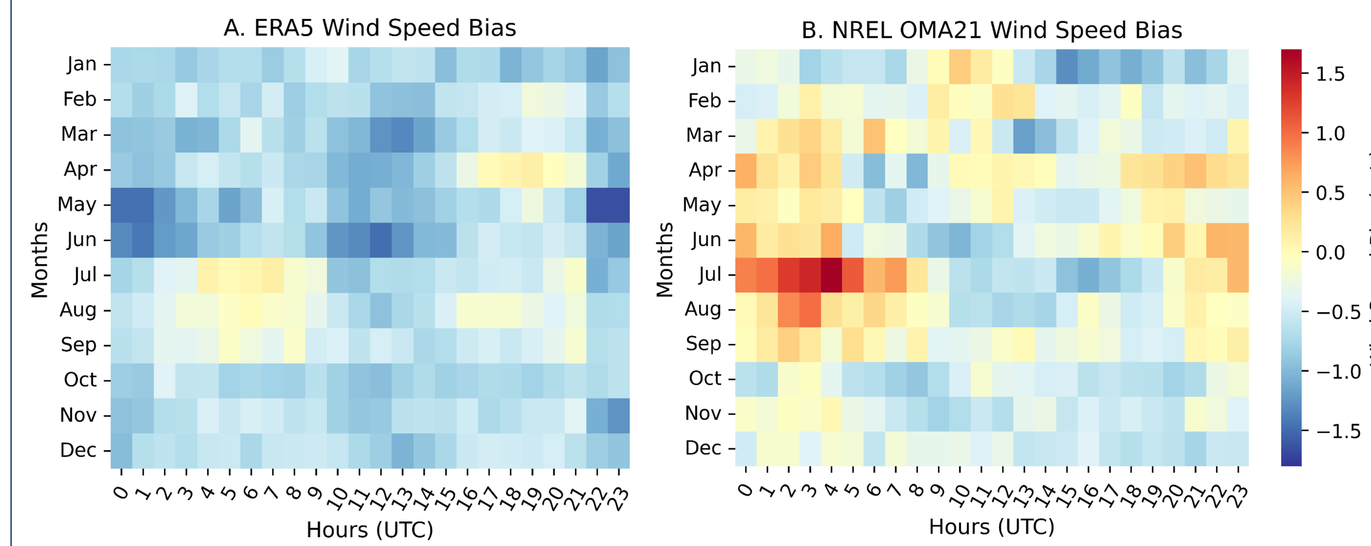


Fig 4. (12 months x 24 hours) heatmaps of mean 40-200 m wind speed bias at the North (E05) floating lidar from ERA5 (panel A) and NREL OMA21 (panel B) analyses.

WARM SEASON LOW-LEVEL JETS (LLJs)

Average LLJ Profiles from Observed & Model Analysis

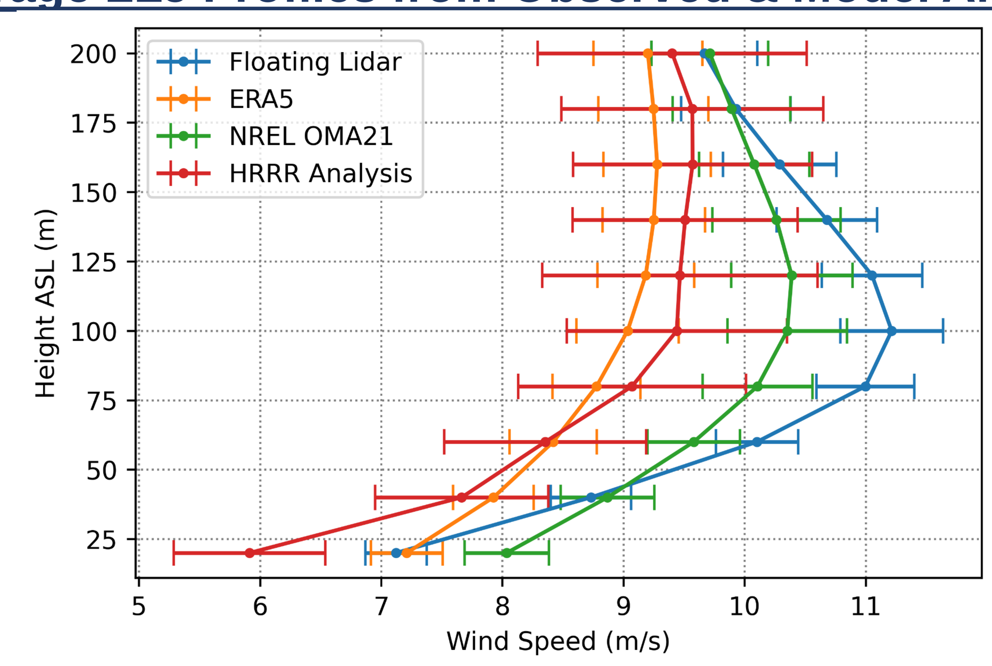


Fig 5. Average LLJ profiles from observed floating lidar (Blue), ERA5 reanalysis (Orange), NREL OMA21 (Green), and HRRR (Red) analysis products.

Model Analysis Wind Speed Performance Metric Profiles

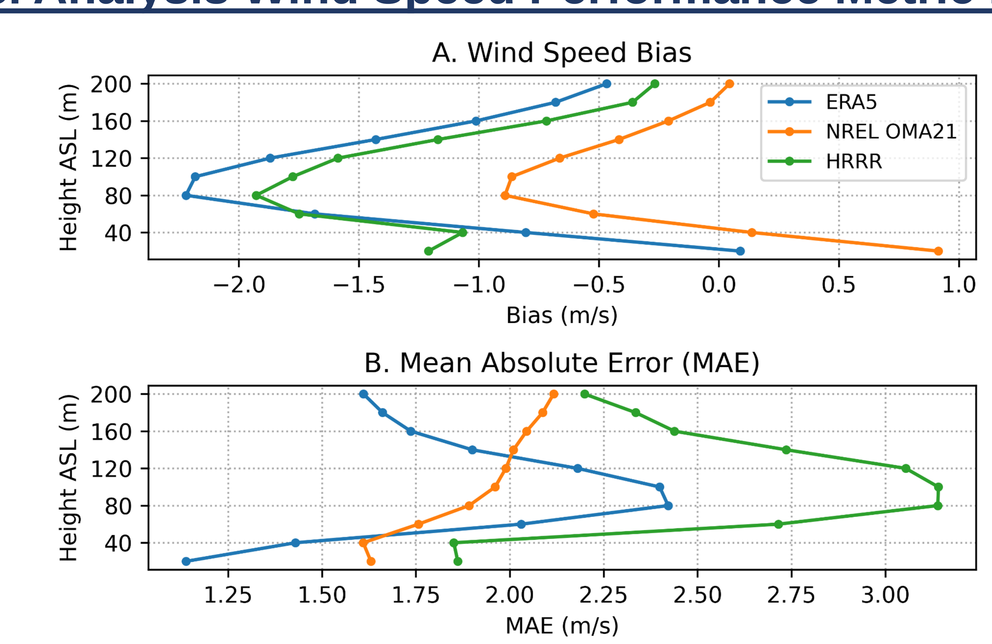


Fig 6. ERA5 (Blue), NREL OMA21 (Orange), and HRRR (Green) profiles of wind speed bias and mean absolute error (MAE) on 2019-2020 warm season LLJ events (N = 50 days).

Model Analysis Nose Wind Speed & Height Errors

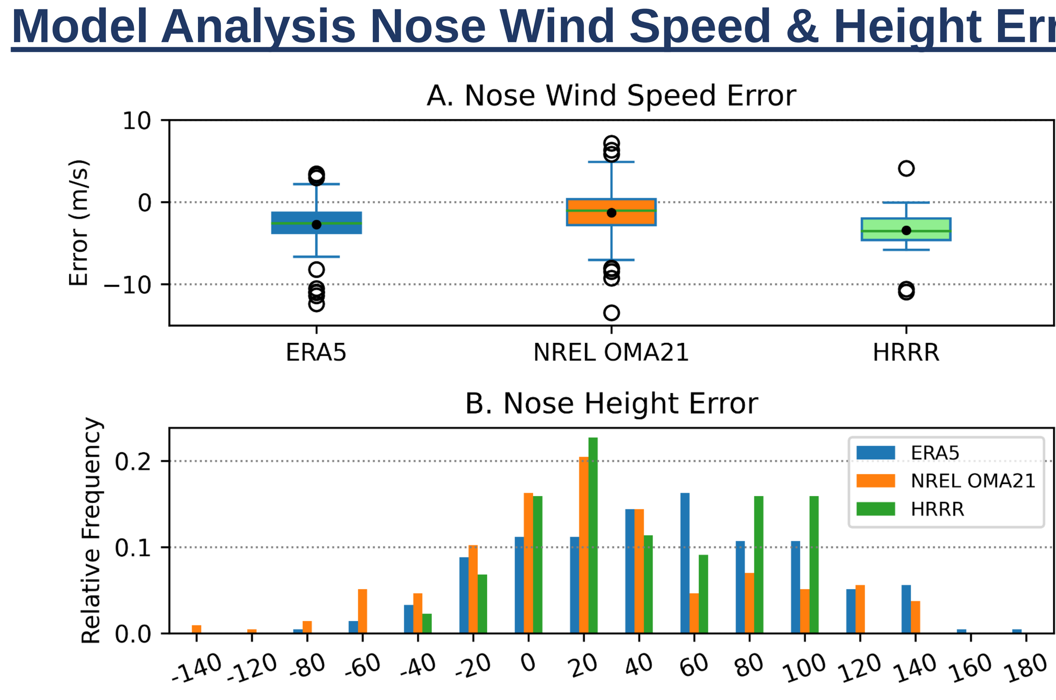


Fig 7. Comparison of model analysis LLJ nose wind speed error (panel A) and nose height error (panel B) distributions on warm season LLJ events.

Model Analysis LLJ Forecasting Skill

- LLJ detection method used to detect LLJs in the observed floating lidar dataset was applied to the ERA5, NREL OMA21, and HRRR analyses.

NREL OMA21 Low-Level Jet Forecast Skill	
Hits (a) = 17 days	False Alarms (b) = 2 days
Misses (c) = 31 days	Correct Rejections (d) = 130 days
Skill Scores	
Critical Success Index (CSI)	0.34
Frequency Bias	0.40
Probability of Detection (POD)	0.35
False Alarm Ratio (FAR)	0.11
False Alarm Rate	0.015
Symmetric Extreme Dependency Score (SEDS)	0.51

- **ERA5**: 0 LLJ events detected in the lowest 200 m ASL and the poorest forecast skill score.
- **HRRR analysis**: 4 LLJ days were detected in the 2019-2020 warm season, which results in a POD = 0.083.

CONCLUSIONS & FUTURE WORK

Full Warm Season Validation:

- At 95% confidence, NREL OMA21 has similar 60 – 200m wind speeds compared to the observed profile.
- Within the 40 – 200m layer, ERA5 exhibits larger negative wind speed bias per height level [-0.26 m s^{-1} to -0.65 m s^{-1}] compared to NREL OMA21 [+0.24m s^{-1} to -0.20 m s^{-1}].
- ERA5, despite having larger systematic wind speed bias, has smaller MAE per height level and larger R^2 value [0.864 compared to 0.799; *result not shown*].
- Both analyses underrepresent the 40-200m layer wind speed shear exponent.

Warm Season Monthly & Diurnal Validation:

- Both model analyses tend to exaggerate diurnal wind speed cycle amplitude, but NREL OMA21 captures the late-evening wind speed ramp-up period well.
- ERA5 tends to exhibit its largest negative wind speed and MAE at 1000 – 1300 UTC and 2200 – 0300 UTC, and within the months of May-June.
- NREL OMA21 has large (~ 1.5 m s^{-1}) MAE and positive wind speed during ~ 0100 – 0800 UTC within the months of July-September.

Warm Season LLJs:

- ERA5 global reanalysis has the poorest LLJ performance in terms of LLJ structural characteristics and its ability to forecast event occurrence.
- Mesoscale model analyses (HRRR and NREL OMA21) performs better in their abilities to forecast LLJ event occurrence.
- NREL OMA21 has statistically smaller mean LLJ nose wind speed errors, as it can depict a pronounced jet nose structure, unlike the ERA5 and HRRR.
- NREL OMA21 has the smallest mean nose height error, but this error is **not** statistically different compared to the HRRR's.
- NREL OMA21 best depicts the above-jet wind speed falloff/shear structure, but still significantly underpredicts this LLJ feature.

Future Work:

1. Investigate model physical parametrizations and schemes within the ERA5, HRRR, and NREL OMA21 analyses that led to large wind speed errors and poor LLJ performance metrics.

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