U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

Pacific Northwest NATIONAL LABORATORY

T34 – Lidar Buoy Science

Offshore – specific R&D
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FY21 Peer Review - Project Overview

Project Summary:

- This project addresses a variety of technical questions associated with the ***offshore wind resource***, based on unprecedented data record from extensive lidar ***buoy field campaigns***
- We developed advanced signal processing techniques and algorithms to ***maximize the wind and wave information*** available from the buoys,
- We developed ***coupled atmospheric models*** to evaluate the sensitivity of air-sea interaction on hub-height wind speeds
- Key project partners: BOEM, NCAR, AXYS Technologies

Project Objective(s) 2019-2020:

- Develop and evaluate techniques to ***maximize the wind and wave information*** available from the buoys [Shaw et al. 2020]
- Evaluate the ***impact of sea state on hub-height*** winds [Garcia-Medina et al. 2020, Newsom et al. 2020]
- Evaluate the ability of current models to represent offshore hub-height winds in the U.S. East coast [Sheridan et al. 2020, 2021, Gaudet et al. 2021]

Overall Project Objectives (life of project):

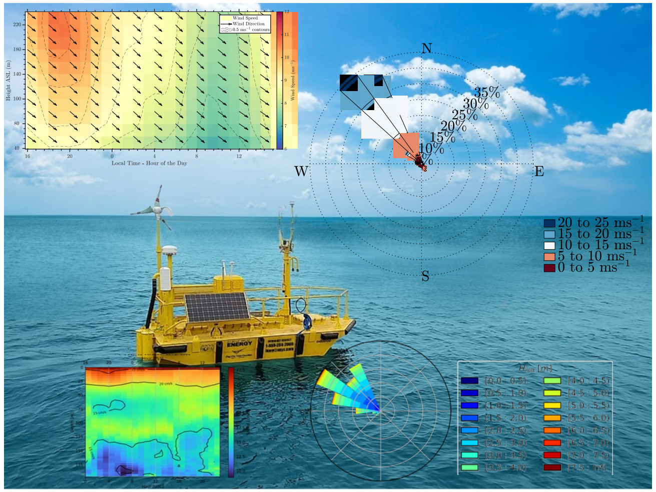
- The primary objective of this project is to use the DOE buoy data to improve our ability to ***characterize the wind energy resource offshore***.

Project Start Year: [FY19]
Expected Completion Year: FY [22]
Total expected duration: [3] years

FY19 - FY20 Budget: 1,018,406

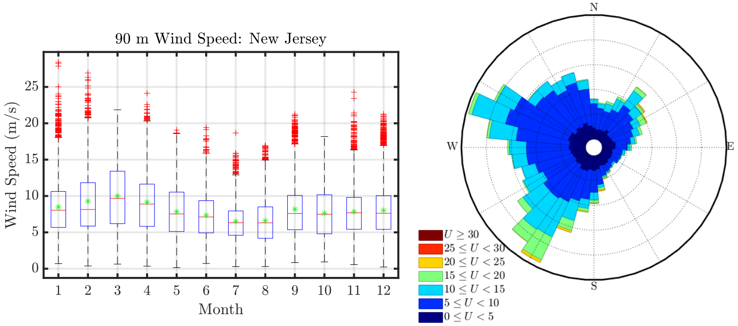
Key Project Personnel: Gabriel Garcia-Medina, Brian Gaudet, Alicia Gorton, Rob Newsom, Will Shaw, Lindsay Sheridan and Raghu Krishnamurthy

Key DOE Personnel: Shannon Davis, Mike Derby



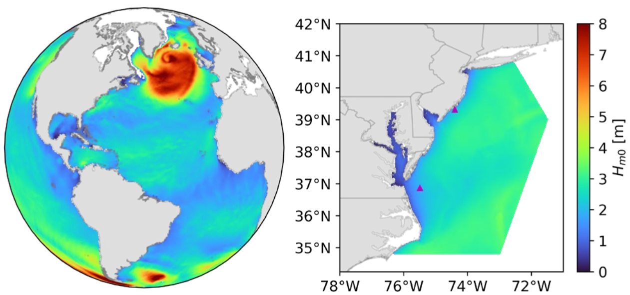
Project Impact

- What is the wind resource over the U.S. East Coast?
  - We conducted a thorough analysis of the buoy data, and provided a **climatology** of hub-height winds, surface winds, thermodynamic variables, and oceanographic observations.
  - Year-long climatology benefits wind energy industry and researchers in effective resource assessment and planning



Monthly box plots and annual wind rose at the New Jersey buoy location.

- Will an ocean/wave/atmosphere coupled model improve hub-height wind speed estimates off U.S. East Coast?
  - We developed a **coupled mesoscale model framework** to investigate the sensitivities of air-sea interaction effects on hub-height wind speeds
  - Results from this analysis will facilitate a reduction in uncertainty for wind energy developers and inform researchers on the advantages/disadvantages of running a coupled model for offshore wind resource assessment



Multiple levels of nesting were implemented to dynamically downscale waves generated in far from shore to account for local wind growth.

- What have we learnt from past-deployments and analysis?
  - The data analysis conducted helped identify issues with existing buoy observations and instruments – this aided in the development of a better DOE buoy system and high-quality data for stakeholders

Program Performance – Scope, Schedule, Execution

- In FY19 (Q3 & Q4), a key milestone was to complete a general analysis of the buoy data collected at New Jersey and Virginia (Shaw et al., 2020).
  - We processed the raw data from the buoys, performed appropriate quality control, and conducted a thorough analysis of the data
  - We developed advanced signal processing and machine learning algorithms to estimate turbulence from Doppler lidars
  - We drafted a detailed technical report to highlight the key observations of winds and oceanic state from year-long buoy data at New Jersey and Virginia

- In FY20, the key task was to study the impact of sea-state on hub-height winds and develop a coupled ocean/wave/atmosphere modeling framework
  - Evaluate conventional wind profiles (based on Monin-Obukhov similarity theory) by metocean conditions (Newsom et al., 2020)
  - WaveWatch III model was developed and validated using DOE buoy and other buoy data (Garcia-Medina et al., 2020)
  - Simultaneously, characterize the magnitude of hub-height wind errors in the reanalysis products using East coast buoy data and select case studies for high-resolution coupled modeling (Sheridan et al., 2020)
  - In Q4 – Develop a coupled ocean/wave/atmosphere model framework and evaluate following modes: 1) stand-alone WRF with no wave input; 2) one-way WRF / WW3 interaction; 3) two-way WRF / WW3 interaction (Gaudet et al., 2021, In review)

Program Performance – Accomplishments & Progress

- The Businger-Dyer similarity functions comes closest to the current observations; however, for $z/L > 0$ the observed non-dimensional wind shear is larger than that predicted by any of the models at both New Jersey and Virginia sites.

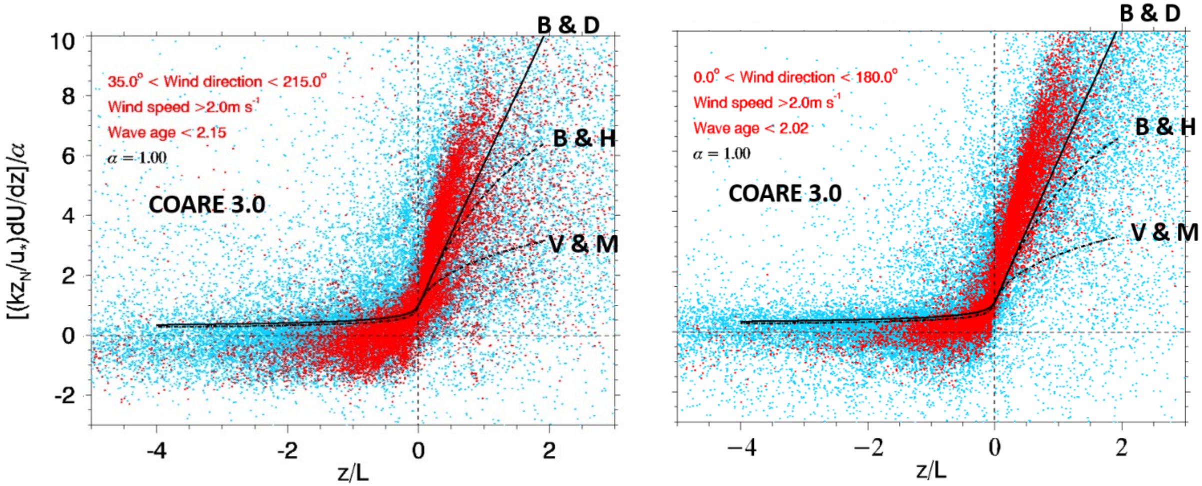


Figure: Non-dimensional shear vs stability parameter for the a) New Jersey buoy and b) Virginia buoy using COARE 3.0 fluxes. Red points indicate samples where the flow is onshore and wave age is less than 2.15 & 2.02, respectively. Also shown are Businger and Dyer (solid), Beljaars and Holtslag (dashed), and the Vickers and Mahrt (dash-dot) similarity models.

- Swells influence the wind profiles, and similarity theory performs within the same uncertainty levels as shown above under such conditions (not shown). At Virginia and New Jersey, two distinct swells are misaligned with the wind seas by more than 100 degrees.

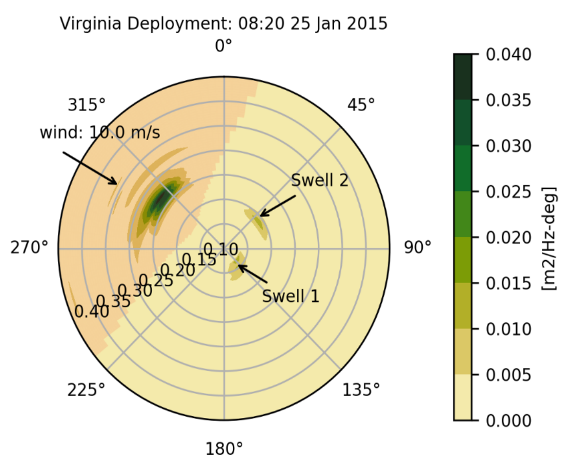


Figure: Partitioned spectrum in Virginia buoy. Radial direction shown in Hz.

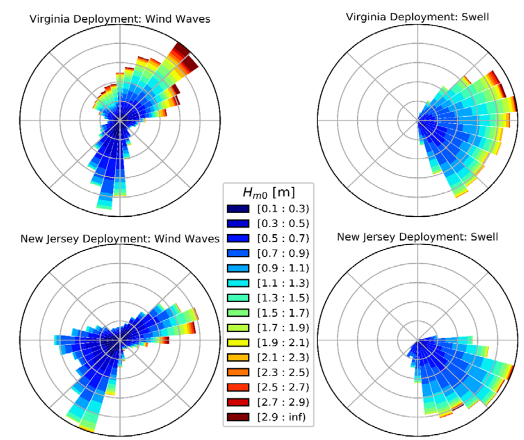


Figure: Wave roses for wind waves and total swell. Radial axes are on different scales to show distributions.

Program Performance – Accomplishments & Progress

- Performance of the reanalysis datasets was assessed for specific phenomenon observed along US East Coast.
  - ERA5 and RAP commonly captured various phenomena with low bias and root-mean square error compared to buoy surface and hub-height measurements (Sheridan et al., 2021).

Table. Summary of performance of reanalysis data during typical offshore conditions observed along the U.S. East Coast.

Phenomenon	Spatial Scales	Temporal Scales	Season	Best Reanalysis to Capture Phenomenon
Sea Breeze	Mesoscale	Hours	Warm	RAP & ERA5
Ramp Events	Multi-scale	Minutes/Hours	All	RAP
Tropical & Winter Storms	Synoptic	Hours/Days	All	ERA5
Onshore Flow	Mesoscale	Hours	All	RAP & ERA5
Offshore Flow	Synoptic	Hours/Days	Cold	MERRA-2, RAP, ERA5
Upwelling/Downwelling	Multi-scale	Hours/Days	Warm/Cold	RAP & ERA5

- Modeled wind speeds tend to be faster than the observed wind speeds during onshore wind directions (esp., for NJ)
  - Coastal effects such as internal boundary layers can drastically alter the offshore wind profile (Garratt, 1990; Davis et al., 2019; Jiang et al., 2020).
- Along-shore wind directions, model winds are biased low
  - Coastal upwelling and downwelling conditions explain some of the differences.

Figure. (a), (e) MERRA-2, (b), (f) RAP, (c), (g) NARR, and (d), (h) ERA5 hub height (90 m) wind speed error (model - obs) roses for the Virginia (top) and New Jersey (bottom) deployments. The 90 m lidar wind direction observations are used to bin the errors.

(Sheridan et al., 2021)

Program Performance – Accomplishments & Progress

Baseline vs One-way vs two-way Coupled mesoscale models

- Representative physics in 2-way coupled simulations
- More accurate representation of waves
- Improved trends in hub-height wind speed estimation, especially in stable conditions, was larger than 10% or more (MAE).

Figure: Schematic showing interactions between WRF and WW3 in simulation experiments.

Figure: Time evolution of the variance wave spectrum at the Virginia deployment from measurements (left column), stand-alone WW3 (middle column), and two-way nested WW3 (right column). Wave frequency [Hz] shown in the radial direction.

Figure: a) Observed and baseline model 90-m and 4-m wind speeds; b) observed, baseline, one-way WW3/WRF, and two-way WW3/WRF 90-m wind speeds.

(Gaudet et al., 2021, In review)

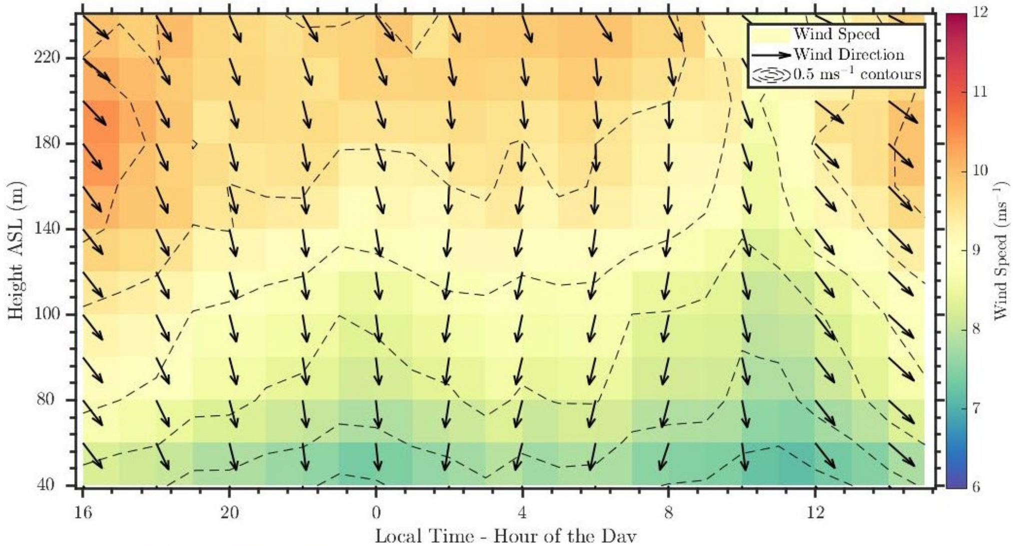
Project Performance - Upcoming Activities

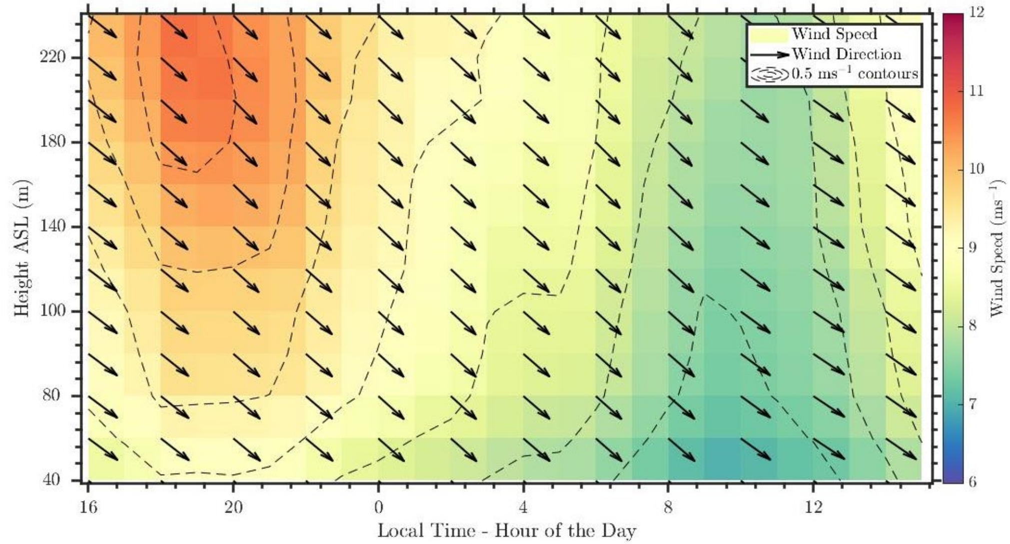
FY21 and beyond, we plan to extend our analysis on the West Coast buoy data.

Specifically:

- ➢ Thoroughly analyze the west coast buoy data and provide a climatology of the region
- ➢ Develop spatial and temporal variation of sea surface temperature using reanalysis models and conduct preliminary comparisons with available West Coast buoy data
- ➢ Conduct preliminary analysis to categorize conventional wind profile errors according to observed met ocean conditions with available West Coast data
- ➢ Evaluate reanalysis model errors for the deployment period at Humboldt and Morro Bay sites
- ➢ Perform high-resolution case studies for cases of large error using COAWST-like model over West Coast buoy locations

Hourly Averaged Doppler Lidar Profiles at Humboldt from Oct – Dec 2020





Hourly Averaged Doppler Lidar Profiles at Morro Bay from Oct 2020 – May 2021

Stakeholder Engagement & Information Sharing

The project has continuously engaged in various means to share our findings, mainly via journal publications and conferences. The team members have also participated in multiple webinar series presentations.

Journal/Conference/Webinar	Presentations
Journal Publications	2
Technical Reports	4
Conferences	6
Webinars	3