2024 NAWEA/WINDTECH CONFERENCE ABSTRACTS

Final category: Airborne Wind

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Toyota's High Altitude Aerial Platform Concept and Technology Development

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Introductory Summary

A research team at Toyota is exploring a high-altitude aerial platform concept named Mothership, known for its exceptional endurance and station-keeping capability, which can enable various applications, including wind energy harvesting. This paper aims to provide an overview of the project and offer the necessary context for more focused technical papers to be presented at NAWEA 2024 by the Toyota team. The presentation will cover key aspects of the Mothership project, highlighting the potential of airborne wind energy harvesting at high altitudes. Additionally, it will discuss insights from prototype airborne wind energy system tests, comparative analyses with simulation results, progress in flight envelope expansion, and the introduction of advanced technologies being developed for kite systems.

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Wind Adaptive Path Planning for Crosswind Flight of a Tethered Wing

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Introductory Summary

The ability to realign kite's flight trajectory with varying winds is crucial in endurance and efficiency of airborne wind energy(AWE) system. This paper introduces a velocity-based wind adaptive path planning algorithm designed for an inflatable kite performing a figure-of-eight crosswind flight. The path planner is integrated into a two-level flight controller and simulated using a dynamic model. The effectiveness of the flight control strategy was further validated through experimentation on a small-scale proof of concept (POC) kite. The test results demonstrate its efficacy in significantly extending the automated flight duration.

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Finite State Multi-Physics Modeling of Airborne Wind Turbines

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Introductory Summary

This research focuses on the development of a framework for multi-disciplinary modeling and design optimization of airborne wind energy systems including: (**1**) an arbitrary horizontal axis single turbine or turbine array, (**2**) a tether, and (**3**) generator(s) and the electrical load. The multi-disciplinary model considers free or ducted turbine aerodynamics,

single or array configurations, the tether structural dynamics, and the coupled generator electrodynamics. Parametric analyses, dynamic stability and power extraction control, and multi-disciplinary design optimization can be achieved based on the proposed multi-physics model.

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Capabilities and Gaps Analysis of Existing Airborne Wind Energy Test Sites toward an Advanced Future Test Site in the United States

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Introductory Summary

Capabilities of existing airborne wind energy system (AWES) test sites are assessed through an industry questionnaire and interviews with airborne wind energy companies. The broad ranges of existing technical readiness and automation levels suggest a three-tiered test site strategy ranging from i) short-duration, early prototype demonstrations, ii) long-duration technical assessments and power validations, and iii) long-duration airspace interaction and deconfliction studies. Notably, no existing test sites are yet able to fly multiple systems simultaneously, which will be critical to widespread deployment. Potential test sites in the United States are then considered in context of the needs of the manufacturers. Site assessments consider the wind resource, proximity to infrastructure to which airborne wind energy systems may contribute benefits (e.g. added resiliency for critical infrastructure in locations likely to experience grid interruptions) or impose complexities (e.g. airports or transmission lines). Added to this is the need for social acceptance and environmental and ecological considerations. Early findings suggest potential for near-term scenarios of mutual benefit with operator training centers located in windy, remote locations that lack reliable grid-tied electricity and which would benefit from local economic development. Experienced operators could secure longer term, highly skilled positions for future applications of airborne wind energy such as disaster relief deployment in more congested areas.

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Final category: Atmospheric Science

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Meteorological Impacts of Offshore Wind Turbines as Simulated in WRF

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Offshore wind energy projects are currently in development off the east coast of the United States, and are expected to influence the local meteorology of the region. We compare one year of simula- tions from the Weather Research and Forecasting model with and without wind plants incorporated, focusing on the lease area south of Massachusetts and Rhode Island. Because the wake behavior may be a function of boundary-layer stability, we develop and present a machine-learning algorithm to quantify the area and length of the wake generated by the wind plant, and we characterize the relationship between wake extent and boundary-layer height. We also present how offshore wind plants impact wind speeds, 2-m temperature, surface heat flux, turbulence kinetic energy (TKE), and boundary layer height during different stability classifications and ambient wind speeds over the entire simulated year.

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A novel LiDAR-met tower experiment to investigate seasonal flow variability over a tall forest canopy

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Introductory Summary

In the realm of wind resource assessment over tall forest canopies, high-fidelity numerical simulations indicate the presence of canopy-generated turbulent fluxes up to 3 times the canopy height (H) above the ground. On the experimental side, however, the availability of datasets supporting the numerical results is limited by the current constraints on the maximum height of meteorological towers, i.e. 1.5 times the average canopy height. Thus, a thorough quantification of the available wind resources above a forest cannot rely entirely upon tower measurements. In this work we describe the deployment of a profiling LiDAR on top of an instrumented meteorological tower within an old-growth forest in Washington over August-November 2023. The use of a profiling LiDAR allows us to extend the maximum probed height from 1.5H (tower height) to 4.5H. As a result, evidence of above-canopy buoyancy-driven turbulent kinetic energy (TKE) are found here through the simultaneous analysis of tower and LiDAR data. Furthermore, the diurnal and monthly variability of TKE buoyancy- and shear-production terms captured by the sonic anemometer on top of the tower is corroborated by the vertical distribution of LiDAR-measured TKE over the course of the study.

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Wind plant impacts on planetary boundary layer height at the AWAKEN field site

Aliza Abraham[1], Arianna Jordan[2], Emina Maric[1], Matteo Puccioni[3], Stefano Letizia[1], Nicola Bodini[1], Nicholas Hamilton[1], Petra Klein[2], Elizabeth Smith[4], Patrick Moriarty[1]

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Introductory Summary

extensive spatially distributed data from the American Wake Experiment (AWAKEN), PBLH is computed at sites upstream and downstream of two wind plants. Preliminary results show a statistically significant increase in PBLH within the downstream regions relative to the upstream, suggesting the wind plants are increasing the depth of the planetary boundary layer. These findings provide important insights into the interactions between wind plants and the atmosphere, with implications for future wind energy siting decisions.

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AWAKEN Campaign Observations of Precipitation from Hub Height, Inflow, and Outflow Regions of the King Plains Wind Farm

Lexie Goldberger[1], Jevin Scrivens[1,2], Colleen Kaul[1], Raghavendra Krishnamurthy[1], Patrick Moriarty[3]
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Introductory Summary

Leading edge erosion of wind turbine blades due to impacts of falling hydrometeors, such as raindrops, can reduce power production and decrease blade lifetime. Precipitation is spatially and temporally heterogeneous, varying in both total amount and in the distribution of hydrometeor sizes and fall speeds. Here, we analyze observations made with laser disdrometers deployed near and within an operating wind farm, including on a turbine nacelle, which provide simultaneous measurements of drop size distribution and fall speed.

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Cold water upwelling along coastal New Jersey and its effect on the New York Bight sea breeze and low-level jet

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Introductory Summary

The region of the New York Bight (NYB) has become increasingly important for the ongoing development of renewable energy, specifically offshore wind. With this comes the need for a better understanding of the meteorological and oceanic conditions in this region. During the warm season, the NYB frequently experiences a sea breeze, often with an associated low-level jet (LLJ). This circulation can be amplified by cold water coastal upwelling along the New Jersey coastline. However, with limited measurements (both spatially and temporally) it is difficult to fully describe this relationship. In this study, we use Numerical Weather Prediction (NWP) to study a select number of sea breeze and LLJ events and measure the influence of cold-water coastal upwelling on the sea breeze strength, onset time, and LLJ height.

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Experimental assessment of inflow turbulence for large rotors

Introductory Summary

We present novel measurements by five lidars crossing almost perpendicularly at six points at 150 to 250 m above the ocean with lateral separations up to more than 200 m. The measurements are used to calculate spectra and coherences with relevance for large turbine rotor loads and wake meandering.

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Characterizing mechanisms leading to nocturnal boundary layer turbulence at Cape Cod.

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Introductory Summary

During the U.S. Department of Energy's Wind Forecast Improvement Project 3 (WFIP3), a network of instruments for wind measurement including a tower with sonic anemometers at 2 and 10 m and two scanning Doppler lidars were installed at the Highlands Center about 100 m from the coast. In this study, we will explore the drivers behind nocturnal turbulence observed at the Cape Cod Highlands Center (CACO) WFIP3 site about 100 m from the shore of Cape Cod.

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Benchmarking Modeled Wind Field Using Multi-Source Measurements in the Southeastern United States

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Introductory Summary

Wind energy is increasingly recognized as a vital component of the renewable energy portfolio, particularly in regions like the southeastern United States, where the potential for wind power development is substantial yet underexploited. This study leverages the High-Resolution Rapid Refresh (HRRR) model alongside multi-source measurement datasets to conduct a comprehensive assessment of wind resources in diverse and complex terrains of the southeast U.S.. The study aims to validate model outputs and identify critical gaps in the current models. The findings are intended to guide improvements in wind prediction models and inform strategic planning for future field campaigns and wind energy projects in complex terrains.

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Downscaled Climate Data

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Introductory Summary

This study evaluates multiple datasets concerning their performance in hub-height wind statistics for normal and extreme conditions onshore and offshore. The datasets to be evaluated include global and regional reanalyses at high spatial and temporal resolutions. results show that for local scales and complex terrain, downscaled dataset driven by global reanalysis can capture wind statistics under all conditions much more accurately.

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Preliminary Evaluation of Offshore Wind Resource Map in South Korea

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Introductory Summary

This study investigated the offshore wind resource map of South Korea using the Weather Research and Forecasting (WRF) mesoscale model. We presented dynamically downscaled wind fields and the physical sensitivity that derived the wind conditions at near turbine height. A double-nested WRF model, integrated with the fifth generation of ECMWF global-scale reanalysis (ERA5), was used for the period from January 23, 2023 to January 29, 2023, for preliminary offshore wind analysis. The ensemble means for the sensitivity of planetary boundary-layer (PBL) physics provided a relative advantage in determining surface wind fields. A reasonable and realistic wind was identified over the West Sea of South Korea, with the value of 0.95 for coefficient of determination and 2.05 m/s for the root-mean square error. Among PBL scheme, the MYNN scheme showed slightly better results.

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Exploring the Relationship Between Model Bias and Atmospheric Stability in Offshore Wind and Turbulence Prediction for the Northeast US using a newly developed Three-Dimensional PBL Parameterization.

Introductory Summary

Offshore wind power plays a vital role in the expanding renewable energy landscape of the US. Accurate prediction of wind and turbulence is essential for optimizing the efficiency and reliability of offshore wind farms. To address this, our study proposes an approach to enhance the model prediction performance in the Northeast US region by leveraging advanced techniques, including a recently implemented 3D Planetary Boundary Layer (PBL) scheme with PBL approximation within the Weather Research and Forecasting (WRF) model. The main goal of this study is to evaluate the model's prediction capability of hub height wind speed and turbulence to provide insights into wind resource assessment for the South Fork wind farm in the North Atlantic. To accomplish these goals, we conduct high-resolution (sub-kilometric) mesoscale WRF (version 4.4) simulations and the evaluation reveals a good agreement between the modeled wind and TKE and observation.

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Impacts of wind–wave–ocean coupling on offshore wind profile

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Introductory Summary

In the absence of measurements at a study site, offshore wind developers always rely on model-based data to assess site conditions. Potential sources of model error in this environment include under-resolution or misrepresentation of coastal topographically forced flows, marine boundary layer dynamics and the evolution of their associated cloud and turbulence fields, the role of upwelling and other currents on surface heat fluxes into the boundary layer, and the impact of wave fields on surface momentum fluxes and thus the wind speed profile. Most predictive models of wind speed do not predict wave fields at all, relying on parameterizations to represent their effects. In thus study, we focus on evaluating the role of wind/wave/ocean interactions on modelled hub-height wind speed and error by using the Coupled Ocean–Atmosphere–Wave–Sediment–Transport (COAWST) Modelling System to capture two-way and three-way interactions between an atmospheric model (Weather Research and Forecasting [WRF]), wave model (WAVEWATCH III [WW3]), and an ocean model (Regional Ocean Modelling System [ROMS]) and compare to both stand-alone WRF and two-way coupled WRF / ROMS configurations. Case studies were selected during the New York State Energy Research and Development Authority (NYSERDA) lidar buoy deployments concurrent with the simulation period. Previous work on two-way coupled simulations of wave state utilizing the WW3 model and WRF are also compared to show the impact of different coupling approaches.

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Numerical Investigations of Wind over Ocean Wave Groups with Modulational Instability

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In this work, we present numerical studies of wind-wave interactions with the nonlinear wave-wave interactions considered. We employ Large-Eddy Simulation (LES) within the Weather Research and Forecasting (WRF) model to simulate atmospheric turbulence, and the phase-resolved ocean surface waves are coupled with the atmosphere using our recently developed WRF-Wave scheme. Our simulations focus on the cases where ocean surface waves evolve dynamically over time and different wavenumbers exchange energy due to nonlinear wave–wave interactions. Specifically, we investigate the impacts of modulational instability of ocean surface waves on the atmospheric boundary layer (ABL). Modulational instability occurs when a carrier wave is perturbed with two slightly detuned sideband waves. Owing to the nonlinear wave–wave interactions, the energy of sideband waves exhibits exponential growth, while the energy of the carrier wave decays. To eliminate the influence of instantaneous atmospheric turbulence fluctuations at the onset of modulational instability, we perform ensemble simulations to capture statistics of wind–wave interactions during the unsteady process of the instability-induced wave growth. Based on the numerical results, the temporal variations of wave-induced statistics in ABL are analyzed in detail. The present study provides insights into the mechanisms of wind–wave interactions within a well-controlled, complex ocean wave environment, which is crucial for offshore wind forecasts and accurate coupled ocean–atmospheric modeling in offshore wind energy research.

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Validation of Offshore Winds in the ERA5, NREL's NOW-23, and HRRR Analyses Using Two Floating LiDARs in the New York Bight

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Introductory Summary

Hourly vertical wind speed profiles from several commonly utilized numerical weather prediction (NWP) model reanalysis products (i.e., ERA5, NREL's NOW-23 WRF model, and HRRR analysis) for offshore wind assessment and forecasting are validated in the lowest 200 m above sea level (ASL) at two New York State Energy Research and Development Authority (NYSERDA) floating lidars in the New York Bight. Validation is performed under different seasons, months, and times of day, as well as under warm season low-level jet (LLJ) events. Results show that NOW-23 significantly outperforms the ERA5 in terms of wind speed bias, especially in the warm season. NOW-23 also exhibits the best performance, in terms of accurately detecting and depicting warm season LLJs, followed by the HRRR analysis and ERA5. However, all model analyses still exhibit considerably large errors on warm season LLJs. Boundary layer stability and how NWP models represent stability/turbulence appears to be one of the largest factors in understanding the degree of model analysis wind speed errors offshore during the warm season.

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Wind Turbine Wake Dynamics and Associated Thermal Interactions Over a Full Diurnal Cycle

Shuolin Xiao[1], Xiaowei Zhu[2], Ghanesh Narasimhan[1], Dennice Gayme[1], Charles Meneveau[1]

The atmospheric boundary layer (ABL) undergoes significant changes in its structure and dynamics throughout a diurnal cycle. These changes can affect the behavior of wind turbine wakes in wind farms. The wakes can, in turn, alter convective heat transfer over the ground surface, leading to two-way coupling and spatial heterogeneity in surface heat fluxes. Here, we investigate the impact of spatially heterogeneous surface heat fluxes on the temperature field, wake flow structure, and power generation within a wind farm using LES. Specifically, we apply a concurrent precursor inflow method and use an advanced filtered actuator-line approach to represent wind turbine blades in LES. To avoid specifying either prescribed surface temperature or heat flux, a local 1D soil heat conduction model is used and coupled with the LES. Additionally, we incorporate Coriolis forcing that induces wind veer, causing the mean wind direction in the precursor domain to continuously vary. After several days of low-resolution LES, an approximately periodic behavior is achieved, after which high-resolution LES is continued during a 24-hour period. LES results reveal that wind turbine wakes have a significant impact on the temperature field, causing increased surface temperature behind the wind farm at night. During the morning transition, the formation of a low-level jet and the wind farm blockage effect result in substantial thermal cooling and a reduction in wind speed at hub height upstream of the wind farm. Consequently, for a few morning hours, the first row of wind turbines generates less power compared to the last row.

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Wind Turbines in Oklahoma Attract Lightning

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Introductory Summary

Wind power growth in the United States is continuing to increase, as reported in the U.S. Department of Energy's 2023 Land-Based Wind Market Report, and wind turbine dimensions are expanding in both height and rotor diameter. In some limited studies, wind turbines seem to affect the rate of lightning occurrences. Here, the relationship between turbines and lightning in Oklahoma is investigated: Oklahoma ranked the second highest in wind capacity growth in 2022, while also being one of the top five states for highest annual lightning strikes.

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Implementation of the Newly Developed Wind Optimization Estimation (WINDoe) Algorithm on Nocturnal Low-Level Jet Evolution During the American WAKE ExperimeNt

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Introductory Summary

The American WAKE ExperimeNt (AWAKEN) is an observational field campaign in northern Oklahoma focused on better understanding wind farm-atmosphere interactions. Several remote-sensing instruments were deployed within and surrounding wind plants in the AWAKEN domain, including lidars capable of observing wind profiles of features characteristic to the boundary layer in the U.S. Southern Great Plains, such as the nocturnal low-level jet (NLLJ). Recently, an optimal estimation-based algorithm for wind profile retrieval (WINDoe) was released, which can combine multiple datastreams and estimate higher altitudes wind profiles than the standard velocity azimuth display (VAD)

compared to VAD profiles with signal-to-noise ratio lidar filtering, which often failed to encompass the full depth of the NLLJ. This work serves as beneficial information both for gaining knowledge of NLLJ evolution spatially and temporally between different locations and for the potential benefits of processing WINDoe on future data from lidars and other wind profiling instruments.

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Relationships between Wavelengths of Wind Farm-induced Atmospheric Gravity Waves and Parameters driving Wind Farm Flow Conditions.

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Introductory Summary

Wind farm-induced atmospheric gravity waves (AGWs) play an important role in the interaction of a wind plant with the atmosphere. AGWs can impact wind farm performance depending on wind farm size, layout, and atmospheric conditions that are linked to the prevailing AGW properties. AGW wavelengths are linked to the regional pressure distribution around a wind farm which is associated with the global blockage effect and wake recovery. The atmospheric conditions in wind farm flows depend on a set of non-dimensional parameters, and the relationship of AGW wavelengths to these parameters is still unknown. This research aims to establish the relationship by investigating wind farm aerodynamics with reduced-order models, complementing the findings with Large Eddy Simulation (LES) modelling.

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Evaluating the ability of the operational High Resolution Rapid Refresh model version 3 (HRRRv3) and version 4 (HRRRv4) to forecast wind ramp events in the US Great Plains

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Introductory Summary

Renewable energy is indisputably one of the viable solutions to climate change. To make it more reliable, numerical weather prediction models' prerequisites are to be able to predict the intrinsic nature of weather-dependent renewable energy resources, as grid operators need to plan accurately on what source of energy they can count on being available. For this reason, wind ramp events (rapid changes in wind speed over short periods of time) are very important to forecast with accuracy, because their consequence is that wind energy could quickly be available in abundance or temporarily cease to exist. In this study, the ability of the High Resolution Rapid Refresh operational numerical weather prediction model to forecast wind ramp events is assessed in its two operational versions, version 3 (HRRRv3, operational to the end of 2020) and version 4 (HRRRv4, operational from 2021 onward). Datasets collected in the United States Great Plains, an area with large electricity generation from wind, are used in this analysis. The results are investigated from both annual and seasonal perspectives and show how the HRRRv4 is overall more accurate at

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Improving offshore wind forecasts off the coast of New England in the United States – The Third Wind Forecast Improvement Project (WFIP3)

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Introductory Summary

The United States Department of Energy and the National Oceanic and Atmospheric Administration (NOAA) are currently conducting a multi-seasonal offshore field campaign (the third Wind Forecast Improvement Project, WFIP3) off the coast of New England in the Eastern United States. In collaboration with public and private partners, WFIP3 aims to boost offshore wind generation through better forecasting for existing, constructed, and planned wind farms in the area. Since November 2023, a comprehensive set of remote sensing and in situ meteorological instruments have been operating at several sites at the coast and on islands. These continuous land-based observations are complemented by observations on a barge and ship during several multi-week-long periods. The observations will be used to evaluate and improve NOAA's currently operational High-Resolution-Rapid-Refresh (HRRR) model as well as its successor the Rapid Refresh Forecast System (RRFS). We present an overview of the campaign, research questions, and measurement strategy and will show preliminary results from the ongoing campaign.

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Numerical Weather Prediction Modeling of Climatological Representative Days for the Investigation of Cluster Wake Conditions

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Introductory Summary

Day-periods, where one day-period is defined as 48 continuous hours, from the 21-year (2000-2020) U.S. Mid-Atlantic climate are chosen and statistically verified to represent typical offshore conditions from the region. Simulating these day-periods with a numerical weather prediction (NWP) model allows for the investigation of times that conform to the 21-year climate, without the need to model said climate. These NWP simulations can provide insight into possible wake and cluster wake conditions for current and future wind lease areas in the Mid-Atlantic region.

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Climate change and the onshore and offshore wind resource in the northeastern US

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Introductory Summary

Wind energy is playing an increasingly dominant role in supplying electricity to the nation's power grid. Seven mid-Atlantic and northeastern coastal states have contracted for or are planning to incorporate large amounts of wind power (over 25 GW of offshore wind energy) by 2030. A US Department of Interior Bureau of Ocean Energy Management lease auction on 23 February 2022 for 6 wind energy development areas totaling 488,000 acres in the New York Bight resulted in $4.37 billion in winning bids. However, little is known about the potential effects of climate change on the spatial and temporal distribution of the onshore and offshore wind resource. With support from the NYS Energy Research and Development Authority (NYSERDA), a public-private research partnership completed a comprehensive study of climate change and its potential effects on the state's renewable energy resources, and how this will affect the State's aggressive energy generation goals. Here, we present results pertaining to the effects of climate change on the onshore and offshore wind resource in the northeastern US, including the New York/New Jersey Bight (NYNJB).

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Sensitivity Analysis of WRF Model Simulation of a Low-level Jet Case in the NY Bight

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Introductory Summary

For numerous reasons, accurate representation of Low-level Jets (LLJs) is important in the wind energy industry. While LLJs can increase wind energy output, they can also increase stress on the turbine structure due to increased and varying wind shear and veer in the rotor-swept area. Therefore, the accurate representation and prediction of LLJs isare essential in the wind energy industry. Here, we conduct an ensemble simulations of an LLJ case occurring on 5/15/2020 off the coast of New York. This ensemble considers 6 PBL schemes, 2 initial and boundary condition datasets, using and not using dynamic SST input, and 2 modes of Four-Dimensional Data Assimilation (FDDA). These simulations are validated against the observational data provided by NYSERDA floating LIDARs. We hypothesize that this study will likely indicate no single best option among the combinations tested, instead emphasizing the need for ensemble runs

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Developing a climate change assessment of wind energy in the NE US

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Introductory Summary

Wind is often overlooked in climate change impact assessments, even though today it plays a

database with higher temporal and spatial resolution and evaluate wind power during historical periods and future projections. We employ a statistical downscaling method, the Ensemble Generalized Analog Regression Downscaling (En-GARD) technique, to downscale near-surface and hub-height wind speed across a Northeastern US modeling domain. We first explore the reliability of the En-GARD method to downscale wind speed from ERA5 reanalysis data and then apply the method to downscale wind speed from CMIP6 model outputs.

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How does an atmospheric bore and associated gravity waves affect wind farm performance?

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Introductory Summary

Simulations are performed of an observed atmospheric bore with its associated gravity waves impacting a wind farm as part of the American Wake Experiment (AWAKEN) in the U.S. Southern Great Plains. The atmospheric bore is determined to be driven by a thunderstorm downburst from a nocturnal mesoscale convective system (MCS). Large-eddy simulation with a novel two-domain nested setup (Δx = 300 m and 20 m) in the Weather Research and Forecasting (WRF) model is used, forced with data from the High-Resolution Rapid Refresh (HRRR) model to capture the necessary dynamics for resolving the gravity waves. A generalized actuator disk wind turbine parameterization is used on the finest domain to simulate turbine wakes. On the coarse domain, the full MCS is resolved, and the structure of the simulated gravity waves is found to be especially sensitive to cloud and precipitation processes. On the fine grid, the gravity waves have very strong effects on the flow in the upper atmosphere; however, closer to the surface where there is additional ambient and wake-generated turbulence, the effect of the waves is more nuanced. Notably, the waves induce local wind direction variations correlated with fluctuations in pressure, which leads to fluctuations in the power output as various turbines within the farm are subjected to waking from nearby turbines. Additionally, the gravity waves modulate the mesoscale environment by weakening the existing low-level jet, which reduces hub-height wind speed and, in-turn, power output.

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Impact of waves in conventionally neutral and stably stratified marine boundary layers: insights from Large Eddy Simulation

Aditya Aiyer[1], Ghanesh Narasimhan[2]
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Introductory Summary

Optimizing offshore wind energy systems requires an accurate understanding of the effects of thermal stability on marine atmospheric boundary layer (MABL) flows. Atmospheric stability significantly influences wind speed, wind

odeled Large-Eddy Simulations (LES) of MABL flows under varying atmospheric stability conditions, incorporating the impact of progressive ocean surface waves. The LES simulations employ a phase-aware sea surface wall model (Dyn-WaSp) to precisely capture wave-induced drag forces on the atmospheric boundary layer flow. The primary objective is to investigate the combined effects of sea surface waves, Coriolis forces, and buoyancy forces on atmospheric boundary layer wind profiles, which are crucial for accurate wind energy assessments.

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Impact of Compressibility Approximations on Atmospheric Gravity Wave characteristics

Hrishikesh Sivanandan[1], Mehtab Khan[2], Ben Kravitz[1,3], Matthew Churchfield[4,1], Jovanka Nikolic[1]
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Introductory Summary

The present work analyzes the impact of compressibility approximations on Atmospheric Gravity Wave (AGW) characteristics excited by a 2D ridge (shaped as the Witch of Agnesi) for varying Froude numbers and slope parameters using linear theory, an incompressible Large Eddy Simulations (NREL SOWFA) and a fully compressible (WRF LES). Further, we compare the AGW characteristics (amplitude, wavelengths, path of propagation, phase angle, phase velocity and group velocity) and link them to the compressibility approximations.

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The Rutgers University Weather Research and Forecasting Model (RU-WRF)

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Rutgers University, New Bruneswick, New Jersey, USA

Introductory Summary

Since 2011, the Rutgers University Center for Ocean Observing Leadership (RUCOOL) has conducted extensive research on the Mid Atlantic Bight (MAB) offshore wind resource, supported by the New Jersey Board of Public Utilities (NJBPU). A cornerstone of these efforts has been the development and application of the Rutgers University Weather Research and Forecasting Model (RU-WRF). This mesoscale model has been crucial in generating innovative products, datasets, and modeling tools that delineate the oceanic and atmospheric processes unique to New Jersey's offshore wind resource.

Three-dimensional Planetary Boundary Layer Parameterization

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Introductory Summary

Cold air outbreaks (CAOs), excursions of cold polar air toward the equator, are a common occurrence along the East Coast of the United States in winter and spring. CAOs are characterized by high wind speeds and can represent a significant source of renewable power. When the cold polar air flows over the warmer ocean, mesoscale convective circulations (MCCs) form. Under high winds, convection organizes into helical streamwise rolls that transition to convective cells as the wind speed decreases. Resolving MMCs requires high-resolution simulations with grid-cell sizes in the “gray zone” or *Terra Incognita* (Wyngaard 2004) with grid cell sizes smaller than 1 km. Because one-dimensional (1D) planetary boundary layer parameterizations (PBLs) are not able to correctly resolve MCCs (Ching et al. 2014, Zhou et al 2014), we have therefore implemented a three-dimensional (3D) PBL in the Weather Research and Forecasting (WRF) model to better represent the impact of MCCs on hub-height wind speed and turbulence. We compare high-resolution simulations of several cold air outbreaks observed since 2011 conducted using the WRF model with 1D and 3D PBL parameterizations (Kosovic et al. 2020, Juliano et al. 2022).

Final category: Blade Design & Manufacturing

81

Impacts of alternative composite materials for edgewise reinforcement of wind turbine blades

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Introductory Summary

Edgewise reinforcement is a critical structural component for large wind turbine blades. The edgewise reinforcement resists the gravitational loading cycle that occurs within each rotor revolution and helps to prevent coupled flap-edge aeroelastic instabilities. As blades continue to increase in length, they become exponentially more massive and fatigue damage in the edgewise direction starts to drive the design. The edgewise reinforcement in commercial wind turbine blades is typically constructed using infused E-glass, but there are opportunities that alternative material systems can outperform the current material choices and yield system benefits.

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End-of-Life Management of Wind Turbine Blades: Challenges, Innovations,and Comparative Perspectives on Composite Material Recycling

Saher Hamid, Christopher Niezrecki
Center for Energy Innovation, University of Massachusetts Lowell, Lowell, MA, USA

Introductory Summary

Although most components of a wind turbine are recyclable, wind turbine blades (WTBs) pose challenges for disposal due to their material composition. Typically, WTBs are composed of a fiber glass or carbon fiber combined with thermostat polymer. Numerous technologies including mechanical, thermochemical, chemical, and enzymatic methods have been developed to address the WTBs disposal. However, not all of these methods are optimized for their decommissioning requirements. Therefore, this study focuses on addressing the challenges and opportunities for recycling and repurposing the WTBs by examining current disposal practices, innovations in recycling techniques, and promising opportunities for repurposing. Moreover, a comparative analysis between waste disposal generated from WTBs and other industries relying on composite materials such as plastics, construction, aviation, and transportation is carried out. The objective of this work is to encourage research and development efforts aimed at sustainability by emphasizing that the key issue is not the WTBs disposal but the effective recycling or repurposing of the composite materials.

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Numerical modeling and CFD simulation of nozzle-diffuser augmented dual vertical axis hydrokinetic Banki-Michell turbine by adapting the Vertical axis Wind turbine design procedures.

Nebiyu Bogale Mereke
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Introductory Summary

Hydrokinetic Banki turbines offer an affordable, technically feasible, and environmentally friendly solution for ultra-low head applications. Their construction avoids the need for expensive structures such as diversion weirs, canals, forebays, and penstocks, resulting in significantly lower initial investment compared to horizontal Banki turbines of the same capacity. Moreover, these turbines can be installed in existing canals, further motivating this research. The study focuses on a system with two Banki runners without internal shafts, mounted vertically side by side and surrounded by nozzle and diffuser structures. Two scenarios were analyzed: one with just a nozzle and the other with both nozzle and diffuser augmentations, aiming to enhance the runner speed for ultra-low head applications. The effects on speed, pressure, and power output were analyzed using design procedures similar to those for vertical axis wind turbines. For the commonly used Banki turbine without nozzle and diffuser augmentation, the speed for ultra-low head applications was determined to be 344 rpm, significantly below the recommended 800 rpm for safe operation at a flow rate of 1 m^3/s. In the present study, the enhanced speed due to improvements was found to be 850 rpm without the diffuser and 1025 rpm with the diffuser assembly. Additionally, the performance improved by 7.6% with the diffuser compared to the scenario without it. Detailed simulation results are presented and discussed, with 3D ANSYS-FLUENT optimization revealing the optimum number of blades for each runner to be 19 and the optimal throat width to be 202

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Airfoil Optimization in Unsteady Aerodynamic Conditions

Ryan Cameron, Matthew Lackner
University of Massachusetts Amherst, Amherst, MA, USA

Introductory Summary

Wind turbine airfoils were originally designed for fixed-bottom applications, so the introduction of floating platforms in turbines necessitates a re-design of the rotors and airfoils. As a result of the unsteady environment, aerodynamic models that designers use are no longer appropriate. This means that new optimizers for fundamental airfoil shapes will also be needed to account for the different flow environment. The proposed investigation will implement class shape transformations to give new parameters to shape optimizers, as well as create a design objective that accounts for unsteady conditions, and airfoil performance over a range of expected states.

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Predicted and Measured Deflection of a Modular, 3D-Printed Wind Turbine Blade Tip and Winglet

Brent C. Houchens[1], Kyle K. Wetzel[2], James A. Payant[2], David C. Maniaci[1], Tim Gornet[3], Trey McIntosh[3]
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Introductory Summary

Modularity, advanced design, and system integration for wind turbine blade tips is studied through the Additively-Manufactured, System-Integrated Tip (AMSIT) project, with the goals of increasing aerodynamic performance and reducing costs of transport and repairs. Robustness of the joint and the 3D-printed tip and winglet is critical to success of this approach. Here a static maximum design load test is performed to mimic tip loading expected for a 13 m/s wind speed with the rotor operating at 48.4 rpm when an emergency stop is performed that decelerates the blades to rest in 3 seconds. The resulting load state is applied in a ground-test to a 3D-printed tip and winglet, bolted to a stub of a traditionally manufactured fiberglass blade. Experimentally measured deflections are compared to finite element analysis predictions.

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Free form multidisciplinary optimization of reference wind turbine using high fidelity structural modeling tools.

Jose Mora, Matthew Lackner
University of Massachusetts - Amherst, Amherst, MA, USA

Upscaling wind turbines has been a technological trend in the past decade. To this effect, methods that employ radius as a design variable have been proposed as an alternative approach to the Betz optimal rotor. This design approach has led to the incorporation of structural and cost analysis to realize feasible designs, integrated into a multi-disciplinary design optimization problem. The work in this paper provides a method to increase structural modeling resolution in this optimization design problem evaluation through the predefinition of the blades using NuMAD.

Final category: Controls

35

Quantifying the energy gain of wind farm control co-design along the wind rose

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Introductory Summary

Wake steering can be integrated within the wind farm layout optimization adopting a control co-design approach. This method ensures a higher annual energy production in the below rated region and such gain becomes more evident for the dominant wake directions. Therefore, the benefits of this strategy increase in case of a negative correlation between electricity prices and wind speed.

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Periodic Wake Estimation for Synchronized Wake Mixing Control

Aemilius van Vondelen[1], Marion Coquelet[1], Sachin Navalkar[2], Jan-Willem van Wingerden[1]
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Introductory Summary

Wind farms face efficiency reductions in downstream turbines due to wake effects. This work proposes a novel estimator for synchronized wake mixing control of downstream turbines using the helix approach to mitigate wake effects. Unlike previous methods focused on upstream turbine wake mixing, this strategy applies wake mixing controls to downstream turbines by estimating and exploiting the structured wake through phase synchronization, enhancing overall farm efficiency. The current study tests the phase estimator by simulating three IEA 15MW reference turbines, using the large-eddy solver AMR-Wind coupled with OpenFAST. Results are compared against a ground truth and show the method estimates the collective wind speed closely and the periodic wind components with a slight offset.

103

Offshore Wind Farm for Frequency Support: A Clustering-BasedAutonomous Control to Avoid Secondary Frequency Drop

Zhuzhu Wang, Lei Wu
Stevens Institute of Technology, Hoboken, New Jersey, USA

provide temporary primary frequency support against frequency events of the main AC grid. The proposed coordinated control method consists of 3 parts: clustering, sequential frequency response, and adaptive update of droop control coefficients. To reduce computation and communication burdens, we consider the wake effect and divide OWTs with similar rotor speeds into the same cluster. Each cluster adopts the inertial and droop control with adaptive coefficients, and all OWTs work at the maximum power point tracking mode without energy reserve. A sequential control scheme is employed to activate the frequency response of individual clusters successively. That is, after turbines of the first cluster enter the rotor speed recovery phase, the next cluster starts to release KE for mitigating the second frequency drop. Droop control coefficients are updated adaptively after each cluster is activated to improve frequency response accuracy. Simulation results via Matlab verify the effectiveness of the proposed scheme.

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CoFlexOpt: Control set-points optimization framework for large-scale flexible turbines

Guido Lazzerini[1], Jacob Deleuran Grunnet[2], Tobias Gybel Hovgaard[2], Fabio Caponetti[2], Ebbe Nielsen[2], Delphine De Tavernier[1], Sebastiaan P. Mulders[1]

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Introductory Summary

The wind energy community is increasingly interested in large-scale wind turbines to meet offshore power demand. However, as turbines scale up and materials are optimized, their structural components become very flexible. Current control strategies, based on rigid structure assumptions, do not account for this flexibility, which plays a crucial role in performance and loads. For the first time, this work presents CoFlexOpt: a control set-point optimization framework, to find variable, optimized operating points for large, flexible wind turbines. CoFlexOpt enables to find operational set-points while imposing constraints on a wide variety of operational, structural and load properties. To illustrate the capabilities of CoFlexOpt, the computation of rotational speed and collective pitch angle set-points across the entire operational range of the IEA 15 MW was performed, allowing for the maximization of power coefficient while imposing an out-of-plane tip displacement limit. Results show that accounting for flexibility leads to non-constant optimal tip-speed-ratio set-points in the below-rated region and the collective pitch angle can be used to counteract blade torsion, maximizing power coefficient while complying with imposed constraints.

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Output-constrained individual pitch control methods using the multiblade coordinate transformation

Jesse I.S. Hummel, Jens Kober, Sebastiaan P. Mulders

Delft University of Technology, Delft, Zuid-Holland, Netherlands

Introductory Summary

As wind turbines become larger, they become more susceptible to fatigue loading. Individual pitch control (IPC) can alleviate such loads but at the cost of increased pitch activity. In this work, we propose two output-constrained IPC control methods based on the multiblade coordinate (MBC) transformation that enable the trade-off between load reduction and pitch actuation by keeping the tilt and yaw moments within certain bounds. The first method, ℓ_∞-IPC, individually drives the tilt and yaw moment to some nonzero reference; the second method, ℓ_2-IPC, directly targets the

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Obtaining fatigue-based frequency domain specifications for the design of controllers in wind turbines

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Introductory Summary

This work presents a methodology to generate specifications for the design of controllers based on the mechanical fatigue caused by driving loads. The method is intended for frequency domain design techniques such as QFT or H-infty and is based on Dirlik's method for fatigue assessment. The method has been validated using simulation results obtained with OpenFAST for a 5MW wind turbine model.

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Control Co-Design with Varying Available Information for a Low-Order Model of a Spar Floating Offshore Wind Turbine

Saeid Bayat, James Allison
University of Illinois Urbana-Champaign, Champaign, Illinois, USA

Introductory Summary

Designing active engineering systems involves crafting both control and physical system (plant) designs. In practice and in the literature, a sequential method is typically, where plant design is performed first, followed by controller design for the already designed plant. Sequential strategies cannot fully capitalize on the coupling between plant and control design decisions. In contrast, Control Co-Design (CCD) methods simultaneously consider plant and control design, explicitly leveraging the synergy between these design decisions. The way control decisions are structured in CCD is impactful. Many recent CCD optimization studies employ open-loop optimal control (OLOC), which is a flexible approach that helps at early design stages to discover the best possible physical performance and potentially reveal new insights. OLOC CCD can then be followed by closed-loop control (CLC) design for implementation. However, a gap may exist between OLOC results and what is possible for CLC. Here we study this gap from the perspective of real-time information limitations, and use Model Predictive Control (MPC) to analyze the impact of varying available information in the controller architecture on optimal plant design and system performance. A case study is presented using a spar floating offshore wind turbine, a system with numerous interacting components where even seemingly minor design enhancements can lead to significant energy production improvement. Results indicate that altering the amount of information in the control design produces distinct plant designs with different behaviors, and insights can be gained from optimization patterns revealed through MPC studies.

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On the feasibility of measuring the Helix wake using LiDARs

Marion Coquelet[1], Stefano Letizia[2], Joeri Frederik[2], Jan-Willem van Wingerden[1]

Introductory Summary

Wind farm flow control is used to limit power losses associated with wake interactions in wind farms. While the faster wake recovery associated with the Helix control has been observed in simulations and measured experimentally using Particle Image Velocimetry (PIV), measuring the wake in the field on a full-scale turbine is challenging. This work investigates the use of a nacelle-mounted scanning LiDAR to do so. A virtual LiDAR is emulated to sample an LES flow field of the Helix wake. Results show that, after flow field reconstruction, the faster recovery of the Helix wake compared to a baseline one is retrieved by the virtual LiDAR measurements.

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An open-source model to investigate wake dynamics in response to wind farm flow control strategies

Marcus Becker[1], Maxime Lejeune[2], Philippe Chatelain[2], Dries Allaerts[1], Jan-Willem van Wingerden[1]
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Introductory Summary

Wind Farm Flow Control (WFFC) is the science of manipulating the flow between wind turbines such that a farm wide goal is achieved. This can be power tracking, load mitigation, and/or power maximisation. Steady state control approaches have shown promising results for the latter, in both theory and practice. But how are they expected to perform in a dynamically changing environment? This paper presents an open-source wake modeling framework that allows to approximate the performance of wind farm flow control strategies in response to environmental changes at a low computational cost. It is rooted in previously published dynamic parametric engineering models and is built to be flexible and adaptable to further explore these types of models. The presented study tests the modelling framework by investigating the performance of a wake steering controller in a 10-turbine wind farm case study based on a subset of the dutch wind farm Hollandse Kust Noord (HKN). First results highlight how dependent yaw travel is on the controller settings and suggest where a balance could be struck between power gains and actuator usage.

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End-to-end analysis of active wake control-induced flow instabilities in a stable atmospheric boundary layer

Gopal Yalla[1], Kenneth Brown[1], Lawrence Cheung[2], Dan Houck[1], Nathaniel deVelder[1], Nicholas Hamilton[3]
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Introductory Summary

Drawing from recent advancements in the fluid dynamic understanding of active wake control (AWC) strategies, a spectral proper orthogonal decomposition is used to track the evolution of instability modes excited by AWC from the induction field to several turbine diameters downstream. This modal description is connected to a spectral analysis of the blade loading as well as to wake mixing metrics such as turbulent entrainment and velocity recovery statistics to provide an end-to-end description of the actuated flow.

Actuation-induced entrainment dynamics simulated on a large-scale wind plant domain

Gopal Yalla[1], Kenneth Brown[1], Lawrence Cheung[2], Dan Houck[1], Nathaniel deVelder[1], Balaji Jayaraman[3]
[1]Sandia National Laboratories, Albuquerque, NM, USA. [2]Sandia National Laboratories, Livermore, CA, USA. [3]GE Research, Niskayuna, NY, USA

Introductory Summary

The performance of emergent active wake control (AWC) strategies will be investigated through large-eddy simulations of a 5 x 5 wind farm on a 20 x 20 km domain situated in an atmospheric boundary layer representative of stable offshore conditions. An examination of the deep-array effects of AWC will include comparisons of generated power and fatigue loading across the wind farm to a baseline case (without AWC). The effects of AWC on wake-mixing dynamics, including turbulent entertainment and velocity recovery statistics, will also be investigated.

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Preview Reference Governors and Extremum Seeking Control for Floating Offshore Wind Turbines

Juan López Muro[1,2], Jean-Philippe Condomines[2], Onur Bilgen[1], Laurent Burlion[1]
[1]Rutgers University, New Brunswick, New Jersey, USA. [2]ENAC, Toulouse, Occitania, France

Introductory Summary

In this paper, a novel control strategy that combines Extremum Seeking Controllers with Preview Reference Governors to maximize the power coefficient while mitigating the loads on the structure is presented. In particular, the strategy is applied to a floating offshore wind turbine system considering a semi-submersible platform, endowed with passive up righting and damping mechanisms, and active stabilizing systems.

Final category: Current options do not apply / Highly cross-disciplinary – Please help me choose

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Study on effect of wind characteristics due to topography and turbine wake in complex terrain using SCADA data

Nanako Sasanuma[1], Akihiro Honda[2], Christian Bak[3], Niels Troldborg[3], Mac Gaunaa[3]
[1]Hirosaki University, Hirosaki, Aomori, Japan. [2]Aomori Public University, Aomori, Aomori, Japan. [3]Technical University of Denmark, Roskilde, Zealand, Denmark

Introductory Summary

Effective and reliable utilization of wind power requires deep understanding of both wind conditions and wind turbine wake behavior in the turbine site. Erecting turbines on mountain is expected to provide favorable wind speeds due to acceleration effect, and to minimize disturbance to humans due to the lower population density. However, studies of

compared with the flow results by a combination of from a mid-fidelity flow simulation software, WAsP Computational Fluid Dynamics (CFD) , which can calculate nonlinear models using the EllipSys3D code, and superimposed wake models for topography and wake effects, respectively. Ultimately, the insights gained from this study can be applied to other complex terrains.

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Defining the Design Space of a Wind-Powered, HydrogenElectrolyzer for Agriculture Applications

Collin Goldbach, Bryony DuPont, Amos Winter
Massachusetts Institute of Technology, Cambridge, MA, USA

Introductory Summary

We present a first-order estimation of the key inputs for a wind-powered, hydrogen-producing electrolyzer for use in fueling hydrogen-powered farm machinery and fertilizer production. Using simple analysis and data-driven assumptions, We explore the design space and develop insights about the potential cost of such a system. Using public data from the US Department of Agriculture and the Department of Energy, the average cost of diesel fuel per acre is calculated for 13 states and the US as a whole. It is also calculated how much it would cost to produce the hydrogen required to replace diesel for farming applications. By subtracting the projected cost of hydrogen fuel from the calculated cost of diesel fuel, we establish a "cost budget" within which the remainder of the system of must cost in order to meet price parity with existing methods. For the US as a whole, such a system must cost less than \$26.02

Final category: Digitalization, AI, Machine Learning

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Extreme-Value Aware Loss Function for Short-term Wind Power Forecasting

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Introductory Summary

Extreme scenarios in wind power generation occur with higher frequency and larger magnitude in the recent years due to the ever-increasing extreme meteorological factors. Accurate forecasting of the occurrence of extreme values in wind power generation is of great concern to ensure reliable power system operation. Recently, deep learning models have surged in popularity for wind power forecasting, with the mean squared error (MSE) loss function being commonly used. However, the MSE loss function, being sensitive to extreme values, disproportionately penalizes larger errors, cannot adequately capture the extreme values present in wind energy data, and novel loss functions have seldom been tailored for wind power forecasting. To this end, we introduce a novel loss function specifically crafted to capture extreme values in wind power forecasting. The experimental results with four fundamental deep learning methods on open source wind power dataset validate that the new loss function is efficient and superior in all cases compared to MSE in capturing extreme values while maintaining forecasting performance.

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Georgios Fragkos[1], Birk Jones[1], Michael McCarty[2], Venkatesh Venkataramanan[3]
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Introductory Summary

There are several locations in wind sites and turbines where network traffic could be analyzed to provide high-fidelity data and cyber-physical situational awareness of adversary actions. The potential of harnessing this threat intelligence remains untapped due to the wind industry's skepticism towards integrating such technologies, as existing commercial solutions do not provide capabilities for high-dimensional analysis solutions. Artificial Intelligence (AI) and Machine Learning (ML) offers a promising solution for analyzing complex, high-fidelity datasets derived from wind networks to effectively detect and mitigate cyber-physical threats. In this abstract, a novel Long Short-Term Memory (LSTM)-based Autoencoder (AE) model for wind data fusion and threat detection is proposed and performs better than other common approaches, like an Isolation Forest (iForest) model. The threat scenario under consideration includes the effective detection of a physical disturbance; specifically, white gaussian noise (WGN) caused by a stealthy false data injection attack (FDIA) in all the channels of the wind turbine's controller traffic, gathered from a General Electric (GE) 1.5MW turbine at National Renewable Energy Laboratory's (NREL) Flatirons Campus.

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Multi-Fidelity Artificial Neural Network for Wind Turbine Blade Design

Apurva Anand, M Muneeb Safdar, James Baeder
University of Maryland College Park, College Park, Maryland, USA

Introductory Summary

Designing an airfoil shape with specific performance characteristics is a fundamental problem in the field of wind turbine blade design which plays a crucial role in improving the performance of wind turbines. The state-of-the-practice wind turbine blade design process involves designing the rotor using pre-selected airfoil shapes to capture the required power under steady-state conditions. Conventional airfoil design method involves iterative optimization of shape using high-fidelity codes (like Computational Fluid Dynamics (CFD)) which is computationally exhaustive. The objective of this research is to demonstrate the use of Machine Learning architecture for performance polar prediction as well as for airfoil inverse-design with practical design constraints. In this paper, we propose and implement a unique multi-fidelity artificial neural network (MFANN) architecture that takes low-fidelity data as inputs and maps/transforms it to high-fidelity data, requiring much lesser (one-order) training data as compared to the conventional artificial neural networks. The MFANN is also used for the inverse design of airfoils. The study on wind turbine blade design with a focus on the inverse design of airfoils, and optimization of twist and taper is also presented.

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Application of LOF-BP Neural Network Fusion Algorithm in Wind Turbine Blade Fault Diagnosis

Shiwen Zhao, Junhao He, Fukang Wei, Yutian Zhu, Aiguo Zhou

To address the issue of damage detection in wind turbine blades, a wind turbine blade fault diagnosis model combining unsupervised Local Outlier Factor (LOF) and Back Propagation (BP) neural networks was established. The collected strain signal data were preprocessed, and multi-dimensional time-frequency domain features were extracted to create a dataset. The LOF-BP neural network fusion algorithm was used for model training, ultimately yielding a wind turbine blade fault diagnosis model based on strain data. Experiments show that the LOF-BP neural network fusion algorithm can effectively avoid the problem of sample data imbalance, and the model established using this method can effectively diagnose whether the blade is faulty, with an accuracy rate of over 80%.

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Extrapolating turbulence measurements to the long term

Gerard Cavero Siscart, Marta Gil Bardají, Pau Casso Torralba
Vortex FdC, Barcelona, Catalonia, Spain

Introductory Summary

We propose a methodology for **turbulence calibration** in long-term, high-resolution synthetic time series by combining real-world measurements with wind modeling results. This integration enhances model accuracy, creating long-term turbulence time series useful for event classification and extreme episode descriptions.

Our effort represents the first industry-scale attempt to fill this gap, utilizing the *Weather Research and Forecasting (**WRF**)* model to downscale *ERA5* data to the **microscale**. This process generates a comprehensive turbulence dataset, surpassing standard references like reanalysis data and mesoscale models.

Our methodology refines turbulence characteristics by incorporating actual measurements through a combination of **machine learning** techniques. This cost-effective approach improves modeled wind speed and its standard deviation, ensuring the resulting turbulence aligns with natural physical patterns.

The presentation will detail our calibration methodology, and an **extensive validation at over 100 sites worldwide** will demonstrate its robustness and reliability for wind resource assessment.

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A Farm-Based Virtual Sensing Strategy for Predicting Bending Moments in Offshore Wind Turbines Using SCADA-Informed Gaussian Processes

Eleonora Maria Tronci[1], Bridget Moynihan[2], Babak Moaveni[2], Eric Hines[2]
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Introductory Summary

The accurate prediction of stress responses along offshore wind turbines is critical for fatigue analysis and remaining life estimation, which are essential for ensuring the resilience of these structures under harsh loading conditions.

the majority are only partially instrumented with the latter.
This study addresses this challenge by training a Gaussian Process (GP) model designed with a physics-informed kernel to predict the bending moment response of the structure at different locations. The input to the model consists of the SCADA system quantities such as wind speed, power output, pitch, yaw position, and acceleration response. The kernel integrates critical SCADA parameters to capture the complex relationships between the measurements collected at the top of the tower and the target bending moment responses. This model is then adapted via transfer learning to perform on partially instrumented turbines, which lack direct measurements along the tower and foundation and where only SCADA measurements are available.
This study will be implemented for the study case of Coast Virginia Offshore Wind Farm, which consists of two 6 MW offshore wind monopiles. The two structures are fully and identically instrumented turbines, enabling the testing and validation of the proposed strategy.

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Pattern Recognition and Damage Detection in Wind Turbine Monitoring through Cepstral Coefficients and PLDA

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Introductory Summary

Traditional pattern recognition and damage assessment methods for civil and mechanical dynamic systems typically rely on binary classification, distinguishing only between intact and damaged states. This approach lacks the precision to differentiate between the various damage severities or to identify new, previously unrecognized types of damage. The method proposed in the paper addresses these gaps by implementing a probabilistic framework that leverages advanced machine-learning techniques to refine damage classification.

The proposed framework focuses on using probabilistic linear discriminant analysis combined with cepstral coefficients. These coefficients, commonly used in speaker and speech recognition, have effectively captured the unique structural properties of dynamic systems such as wind turbines. They simplify the analytical process and improve the detection accuracy, making it more efficient and effective.

The proposed methodology is tested and validated using the experimental data from the Aventa AV-7 wind turbine owned by ETH Zurich. This wind turbine is currently reaching the end of its design lifetime and has been instrumented and used as a research platform for system identification, operational modal analysis, faults or damage detection, and classification since 2020.

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Reinforcement Learning Based Path Planning for Airborne Wind Energy Systems

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future society has led to different opportunities to harvest and use wind energy. The Airborne Wind Energy (AWE) systems have been used for energy harvesting and have great potential to produce significant amounts of energy with considerably fewer materials than wind combines. Wind kites, a type of AWE system, allow for continuous adjustment to the kite's position to maximize the energy harvesting from the wind while decreasing the environmental impact. However, wind kites are subject to unpredictable wind fields and unique operational constraints. Their complicated dynamics challenge path planning and control for such AWE systems. In this work, we propose a model-free deep reinforcement learning (DRL) technique that plans the path for the kite to maximize its energy harvesting. We used real-flight test data to train the DRL agent offline. The trained DLR agent is tested in a simulator and the results show its effectiveness.

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Secure Data Sharing Protocol for Advancing Floating Wind Energy: A Cryptographic Approach

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Introductory Summary

Floating wind energy offers vast potential for offshore wind deployment in deep waters, with dataenergy technoloFloating wind energy offers vast potential for offshore wind deployment in deep waters, with data sharing among stakeholders playing a crucial role in realizing this potential. Accessible data fa- cilitates informed decision-making and innovation, but managing large datasets while protecting intellectual property is challenging. A proposed cryptographic framework aims to address this by ensuring data integrity without revealing additional information, enabling secure and confidential data exchange among stakeholders, thereby fostering collaboration and advancing floating wind energy technology.

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Physics-Informed Feature Engineering for Improving Machine Learning-based Day-Ahead Forecasting Accuracy of Modeled Wind Farms in California

Ashish Sedai, Suhas Pol
Texas Tech University, Lubbock, Texas, USA

Introductory Summary

wind power, precise forecasting becomes very crucial. Achieving accurate forecasts for wind power output, however, remains a challenging task due to the inherent variability of wind. The conventional Numerical Weather Prediction (NWP) forecasting approach faces forecasting accuracy limitations while requiring high computational capacity, which has shifted focus toward a data-driven machine learning (ML) approach recently. However, there is a notable gap in research that integrates physics-based information with these data-driven ML techniques. This study leverages physics-informed feature engineering (FE) in ML-based forecasting models, such as the Bulk Richardson Number (RiB), Discrete Wavelet Transformations (DWT), wind gradient, polynomial features of wind speed, sine-cosine transformations of time, and physics-based empirical power generation equation. The models considered for the study like Random Forest (RF), Light Gradient Boosting Machine (L-GBM), Long Short-Term Memory networks (LSTM), Gated Recurrent Units (GRU), Convolution Neural Network (CNN), and Extreme Gradient Boosting (XGBoost), show notable improvements with above mentioned FE. Results indicate that the inclusion of these features boosts hourly day-ahead forecasting accuracy by over 10%, demonstrating the efficacy of tailored physics-informed feature engineering in wind power forecasting.

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3D Bat Tracking System using Multi-Thermal Video Cameras

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NREL, Golden, CO, USA

Introductory Summary

Wind power technology has advanced rapidly in recent decades, leading to the deployment of a great number of large wind turbines across diverse natural landscapes, which can result in adverse wildlife interactions. Certain species of bats exhibit a consistent vulnerability to collisions mortality with moving wind turbines blades, for reason that remain unclear. Bat fatalities at wind turbines have been documented worldwide at an estimate range in the hundreds of thousands of individuals per year within North America and Europe. Studies of bat behavior and interactions with turbines have occurred for nearly two decades and yet, little is still known about their behavior and interactions with turbines during their active period, limiting the research community's understanding of the risk. The capability to closely monitor the real-time behavioral states or mere presence of bats flying in the rotor-swept airspaces around wind turbines during nights is crucial. It facilitates expedited data retrieval, providing valuable insights to enhance our understanding of the factors driving risks to bats from wind energy. To leverage the potential of real-time thermal-imaging methodologies in quantifying nocturnal bat activities at wind turbines, we have pioneered 3D computer vision techniques within a deep learning framework. This innovation enables the automatic detection and classification of bats, birds, and insects in thermal-imaging videos captured at wind turbine sites, facilitating efficient and accurate data analysis for enhanced understanding and mitigation of bat-wind turbine interactions.

Generative AI for wind-wave inflows

Alexandre Cortiella, Alex Rybchuk, Andrew Glaws, Ryan King
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Introductory Summary

Floating offshore wind turbine (FOWT) and platform design processes require expensive aeroelastic simulations with coupled wind-wave inflow conditions that are challenging to create in a self-consistent manner. Existing wind-wave inflow precursors require expensive coupled, multi-physics simulations that make extreme event exploration and uncertainty quantification tasks inviable. This work proposes a Latent Diffusion Model (LDM) capable of efficiently generating consistent, coupled wind-wave inflows conditioned on turbine loading cases. This approach will dramatically reduce the computational barriers to performing floating offshore wind turbine simulations, studying extreme load conditions, and enhancing current FOWT designs.

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Using Machine Learning to Improve Offshore Wind Resource Assessment and Forecasting

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Introductory Summary

Because wind power production is proportional to the cube of wind speed, even slight errors in wind speed data lead to significant errors in power production forecasts. The fifth generation ECMWF atmospheric reanalysis (ERA5) is the current state-of-the-art model for wind speeds at turbine hub heights, but it exhibits significant biases, especially during the warm season. This study investigates the effectiveness of various machine learning (ML) methods in improving ERA5 wind speed data during the warm season—when energy demands peak. Four ML models—a Random Forest Regressor, a Support Vector Machine, a Feedforward Neural Network, and a Convolutional Neural Network—were created to improve the ERA5 winds. The Random Forest Regressor exhibited superior performance, reducing the mean absolute error of ERA5 wind speed data over all 10 vertical levels.

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Estimating high-resolution wind speed profiles from a reanalysis

Introductory Summary

Reliable estimation of vertical wind profiles is crucial for accurate wind power prediction and comprehensive wind turbine performance assessment. Traditional methods relying on empirical equations or similarity theory face challenges due to their limited applicability beyond the surface layer. In a recent study, we proposed a proof-of-concept methodology using TabNet, a deep learning (DL) model, to predict vertical wind speed profiles utilizing input features extracted from a global reanalysis dataset. The present study extends this methodology to lidar-based wind speed profiles collected over one year in Germany. Due to the limited sample size of the lidar data, an imbalanced data issue arose, particularly with some significant events (such as low-level jets) not being adequately represented in the dataset. To address this issue, we propose a transfer learning approach that combines long-term simulated wind profiles with the lidar data. Our results show that the wind profiles predicted by the transfer-learned TabNet model are superior to those trained solely on observations or reanalysis data. These results pave the way for further analysis to generalize the proposed methodology across geographically and climatically diverse locations.

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Reduced Order Modelling for Performance Prediction of Small-Scale Wind Turbines

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Introductory Summary

Wind energy is a crucial component of the global transition to sustainable energy sources. Optimizing the efficiency and reliability of wind turbines is essential for maximizing energy production and minimizing operational costs. Traditional high-fidelity models, although accurate, demand substantial computational resources and time, making them impractical for real-time and large-scale analyses. Reduced Order Modelling (ROM) offers a promising solution by simplifying complex systems while retaining essential dynamic characteristics, enabling faster computations without significantly compromising accuracy. This research focuses on applying ROM to predict the aerodynamic torque and, consequently, the annual energy production (AEP) of small-scale horizontal axis wind turbines (S-HAWTs). These turbines are particularly relevant for deployment in various settings, including urban, rural, and off-grid locations, offering localized and sustainable energy solutions. Accurate performance prediction is critical for optimizing their design and ensuring economic viability.

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Cyber-Informed Engineering for Wind Energy: Building Resilience Through Security-By-Design

Megan Egan, Megan Culler, Jake Gentle
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Introductory Summary

Alongside the significant growth of wind energy as a core component of U.S. power generation capacity, the sector has seen an increase in cyber-attacks targeting and impacting wind energy assets and supporting infrastructure. Low-cost and reliable electricity production from wind relies on automation and control systems, arguably even more so than

to needing to build this resilience. This session will explain CIE and secure-by-design concepts, provide an overview of the CIE implementation guide, and demonstrate how it can be applied to wind energy systems, assets, and infrastructure.

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AIRU-WRF: A Machine-Learning-Based Wind Forecasting Model for the U.S. Mid-Atlantic Offshore Wind Energy Regions

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Introductory Summary

The reliable integration of offshore wind energy into modern-day electricity systems heavily relies on accurate short-term wind forecasts. We propose a spatio-temporal model called AIRU-WRF (short for the AI-powered Rutgers University Weather Research & Forecasting), which combines numerical weather predictions (NWPs) with local observations in order to make offshore wind speed forecasts that are short-term (minutes to hours ahead), and of high resolution, both spatially (site-specific) and temporally (minute-level). Tested on real-world data from the U.S. Mid Atlantic where several offshore wind projects are in-development, AIRU-WRF achieves notable improvements relative to various forecasting benchmarks. The development of AIRU-WRF is supported by the National Offshore Wind Research & Development Consortium (NOWRDC), Project #133/192900.

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Damage Detection in Wind Turbine Blades with Infrared Thermography and Deep Learning: Data Augmentation Using Finite Element Model

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Introductory Summary

The implementation of deep learning algorithms in damage detection of wind turbine blades using thermal images is limited by insufficient and imbalanced training datasets. In this research, a data augmentation method is developed to tackle this challenge by generating a large simulation dataset using finite element models. The dataset is created by performing transient thermal analysis which simulates IR thermography on epoxy resin plates. A UNet is trained with this simulation dataset to detect subsurface damage with different geometry. In addition to the simulation dataset, a small experiment dataset of a composite plate with subsurface defects is also created and used to test the UNet in this research, in order to investigate the ability of generalization of the deep learning model. In further research, a transfer learning framework will be developed by re-training the UNet with the small dataset of composite plates obtained in this work.

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Upscaling Low-Fidelity Wake Data to High-Fidelity Models Using

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Introductory Summary

The accurate prediction of wind turbine wake velocity deficits is crucial for optimizing wind farm layouts. Traditional analytical wake models, while computationally efficient, often oversimplify wake behavior, leading to inaccurate predictions, especially for non-axisymmetric wakes. This research evaluates a novel discrepancy modeling approach that combines a computationally efficient Bivariate Gaussian (B-Gaussian) model with a Bidirectional Convolutional Recurrent Neural Network (BCRNN) to improve wake prediction accuracy. The B-Gaussian model is computationally efficient representation of the wake that representation of the wake that captures the general wake characteristics including asymmetric decay of wake due interactions with the Atmospheric Boundary Layer, wake meandering behavior, near wake characteristics and wake changes as a function of turbine yaw misalignment. The BCRNN, trained on high-fidelity wind tunnel data, learns to predict the discrepancies between the simplified B-Gaussian predictions and the complex real-world wake behavior. This approach leverages the strengths of both analytical and machine learning models, leading to more accurate and robust wake predictions. The BCRNN, by capturing spatial and temporal information from the data, enhances the B-Gaussian model's ability to predict non-axisymmetric wakes. In the real world, the wake has complex dynamics, influenced by a multitude of factors, including the shape and size of the object creating it, the properties of the fluid, and the presence of other objects or disturbances, such as wind wake, the atmospheric boundary layer, and inter-turbine wakes. This research applies the discrepancy modeling technique to bridge the gap between simplified wake models and complex real-world wake dynamics.

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Machine learning enabled evaluation of wind farm flow control data on a large wind plant: a novel approach to feature engineering

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Introductory Summary

The effectiveness of wind farm flow control is typically analyzed for individual pairs of turbines as a function of wind direction. Because the effect of wake steering on the power is relatively small compared to other environmental variables, experimental analysis requires at least a few months of data to converge. The analysis becomes more complicated with the ability to control many turbines on a large plant. In the present work we engineer features for evaluating experimental wind farm flow control data by combining the data of many pairings of turbines simultaneously and across multiple wind directions. Results of this feature engineering can be used to train machine learning models and compared to predictions from control optimization tools. This will enable faster and more accurate assessment of the controller and its impact.

Final category: Distributed Wind

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GIS-based mini-grid wind energy technical and economic potential

Introductory Summary

This study presents a comprehensive assessment of the technical and economic potential of mini-grid wind energy systems in Ethiopia, a country endowed with significant wind resources yet facing a substantial deficit in electricity access, particularly in rural areas. Leveraging Geographic Information System (GIS) tools and the Open-Source Spatial Electrification Tool (OnSSET) methodology, the study examines the practical power generation potential of 600 W/ m² mini-grid wind turbines at a hub height of 55 meters across Ethiopia. The study considers various geospatial factors such as land cover, terrain slope, human settlements, and wind speeds above 3 m/s to evaluate the technical potential of these systems. The economic viability is assessed by calculating the LCOE for each settlement. The results show an average wind capacity factor of 5%, with some areas reaching up to 47%. The technical potential is estimated at an average of approx. 113 kWh/m²/year, and up to 2,400 kWh/m²/year in favorable conditions. Most settlements exhibit an LCOE ranging from $0.20 to $1.00 per kWh. By combining technical and economic assessments, this study provides valuable visual insights for policymakers, energy planners, and stakeholders involved in the development of mini-grid wind energy projects. The findings can inform strategic decision-making processes, prioritize investment opportunities, and contribute to the design of effective policies and incentive mechanisms to accelerate the deployment of renewable energy technologies in remote and underserved areas.

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Doubly-Fed Induction Generator Wind Turbine Model for Distribution Analysis

Mobolaji Bello, Curtiss Fox
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Introductory Summary

One challenge that prohibits the development of the distribution-connected wind turbines is the lack of appropriate models to allow utility engineers understand the potential impacts of wind turbines on the distribution feeder. This paper presents an OpenDSS implementation of wind turbine generator model specifically suited for distribution analysis. The model is validated against lab test results obtained by the wind turbine manufacturer. Finally, possible distribution analysis enabled by this model is demonstrated.

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Mapping Distributed Wind Opportunity in the Continental USA – A Parcel-level Evaluation

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National Renewable Energy Laboratory, Golden, Colorado, USA

Introductory Summary

Distributed energy resources offer localized energy solutions tailored to communities, individuals, and regions. Within the wind energy sector, distributed wind encompasses turbines ranging from 10 to 60 meters, ideal for diverse settings like homes, farms, industries, and campuses. Understanding the scale and distribution of opportunity for deploying these systems broadly is of critical importance for assessing how they should fit into a transitioning energy supply. Accurate estimates of technical and techno-economic potential can provide significant value to policymakers so that they can understand how best to design incentives and devote resources, industry, so they can design a marketization strategy that is aligned with opportunity, and property owners, to understand whether their site is suitable for wind

Model (Sigrin 2016) to estimate technical and economic potential of US national distributed wind deployment, but make significant improvements as well. We leverage a detailed parcel-level dataset for the continental US (CONUS) and take an exhaustive approach, computing technoeconomic potential for every suitable parcel. In doing so, we improve upon prior studies' results that depended on broad extrapolations from a sampled subset of parcels. This study is the first of its kind to perform an exhaustive analysis of all 150+ million parcels in CONUS.

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Distributed Wind Market Report: 2024 Edition

Lindsay Sheridan, Kamila Kazimierczuk, Jacob Garbe, Danielle Preziuso
Pacific Northwest National Laboratory, Richland, WA, USA

Introductory Summary

The annual Distributed Wind Market Report provides the wind energy community with statistical and analytical insights into market trends and characteristics for wind technologies used as distributed energy resources. In this presentation, we will recount the story of distributed wind in 2023, including newly installed capacity, capital investment, and project performance. Additionally, we will highlight projects installed in 2023 to share the innovative ways that distributed wind is supporting a diverse customer base.

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The Distributed Wind Explorer: Navigating geospatial data for distributed wind deployment

Danielle Preziuso, Micah Taylor, Marcus Perry, Kamila Kazimierczuk
Pacific Northwest National Laboratory, Richland, Washington, USA

Introductory Summary

As adoption of renewable energy technologies increases across the United States, distributed wind turbines remain underutilized. To support increased deployment, researchers at Pacific Northwest National Laboratory developed the Distributed Wind (DW) Explorer, an easy-to-use web-based application that curates relevant data sources from several repositories into a single site. The DW Explorer is designed to increase information dissemination, allow decision-makers to interact with data that was previously siloed, and let interested parties identify geographic areas where distributed wind may be profitable. This talk will describe how the DW Explorer was built, how it may be used, and avenues for future work.

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Building a Diverse and Equitable Distributed Wind Workforce: A Strategic Approach to Collaborator Selection

Kendall Parker, Kamila Kazimierczuk, Danielle Preziuso, Micah Taylor, Andrew White
Pacific Northwest National Laboratory, Richland, Washington, USA

Introductory Summary

promote fair and equitable outcomes in workforce development as these challenges are addressed, efforts should encourage participation from under-resourced and under-represented populations. One way to do this is by identifying collaborators outside of traditional networks. Doing so forges new relationships that focus on inclusivity and diversity rather than solely relying on established partnerships that had not previously accounted for these considerations. The Diverse and Equitable Workforce in Wind Energy (DEWWind) project has developed a replicable equity-driven rubric to identify potential industry and academic collaborators for workforce development programming. This rubric provides a way to identify and consider collaborators across locational, institutional, and socioeconomic criteria to advance new partnership-building opportunities in areas favorable for DW.

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Journey Mapping the Distributed Wind Deployment Process for Customers and Installers

Jacob Garbe, Danielle Preziuso, Kendall Parker, Andrew White, Malcolm Moncheur De Rieudotte, Justin Wells-Driscoll
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Introductory Summary

Distributed wind energy technologies have been deployed across the United States, yet the rate of deployment does not align with existing market potential. While deployment barriers are well known, the way in which they manifest for customers and installers is not as well documented; this limits the support mechanisms that policy- and decision-makers can employ to alleviate pain points. Informed by semi-structured interviews and a best-fit framework to code the results, this work leverages journey maps to depict experiences of installers and customers through the distributed wind deployment process. Journey maps are a human-centered design tool that visually organize important stages of a process for individual entities in chronological order. After developing individual journey maps for distributed wind installers and customers, the journey maps are linked together to identify where shared pain points exist to inform potential support mechanisms to increase successful deployment.

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WINDVALT: The Distributed Wind Investment and Valuation Analysis Tool Demonstration and Case Study

Abigail King, Sarah Barrows, Daniel Boff, Avinash Joshi, Gwendolyn Kidd, Justin Wells-Driscoll, Casmine Brown, Jessica Kerby
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Introductory Summary

As distributed energy resources (DERs) increase in deployment, there becomes a greater need to understand the costs and benefits associated with different DER systems. Distributed wind (DW) is a DER that can provide numerous benefits (e.g., energy benefits, economic benefits, and system peaking charge savings) and has been used to support the electrification goals of communities, businesses, schools/campuses, agricultural operations, and households. There is immense capacity potential for DW (~1,400 GW); however, deployment has been limited. To address barriers to DW implementation, the Pacific Northwest National Laboratory (PNNL) presents WINDVALT: The Distributed Wind Investment and Valuation Analysis Tool. PNNL describes the tool's primary functions and demonstrates the tool's valuation capabilities through

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Small-Scale Wind for Rooftop Applications

Elan Fullmer, Kendra Miller, Sydney Jud
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Introductory Summary

Implementation of small-scale horizontal axis wind turbines (HAWTs) is a relatively new field of research that has gained popularity in the last two decades. Unlike utility-scale wind turbines, small-scale wind is generally used for mobile and microgrid applications with a peak power capacity of 10kW per turbine. This project has a focus on analyzing small-scale HAWTs for rooftop applications in partnership with Aerovec, Inc, a company who is developing a HAWT prototype with a rotor diameter of 2.2m. A fully optimized wind turbine of this size is estimated to produce 845 kWh annually. The following analysis investigates small-wind turbines' feasibility of design and implementation. The project includes an investigation of fixed and active yaw motion control, an optimization of the turbine's rotor diameter, an analysis of rooftop noise and vibration constraints, and a feasibility study of potential utilization of a rooftop HVAC unit to supplement the annual energy production (AEP) of the roof-mounted HAWT. In addition to these deliverables, an experimental analysis was performed on the blade design and cowling design of the HAWT.

Final category: Education

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A Comprehensive exploration of Renewable Energy Education Landscape in Ethiopian Public Universities

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Introductory Summary

The renewable energy sector has experienced a rapid expansion, driven by rising fossil fuel costs, increasing concerns about energy security, and the imperative to electrify rural areas. This growth creates a demand for skilled professionals, and higher education institutions must respond by providing comprehensive and practical renewable energy education. Thus, this study aims to analyze energy education landscape in Ethiopian public universities, considering program offerings, content, geographical distribution, challenges and opportunities. A multifaceted methodology involving systematic curriculum reviews, targeted surveys, data compilation, and interactive spatial mapping is employed. Findings indicate a diverse landscape, with both standalone programs and integrated courses available. Among the 45 public universities, only 22% of them have Institutes of Technologies (IoTs), indicating a significant technology-focused institute gap. None of these universities provide standalone energy programs at the BSc level, and less than 10% offer such programs at the MSc level. Notably, Key energy courses like "Energy Conversion and Rural Electrification" and "Hydropower Engineering" are identified, taught in 78% of public universities, integrated within Electrical Power Engineering programs at BSc level. However, the evident lack of practical training and experiential learning in energy education has implications for the sector's development in Ethiopia. Targeted interventions are essential to address these gaps and promote energy access development.

OPENFAST WIND TURBINE SIMULATION USER MANUAL

Matt Thomas, Noah Boettcher, Abdennour Seibi, Mohammad Shekaramiz, Mohammad Masoum
Utah Valley University, Orem, Utah, USA

Introductory Summary

A clear, concise, easy to follow users guide for using OpenFAST, Turbsim and MLife

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Using Open-source Software for Reliable Wind Turbine Design and Engineering

Matt Thomas, Praveen Shakya, Abdennour Seibi, Mohammad Shekaramiz, Mohammad Masoum
Utah Valley University, Orem, Utah, USA

Introductory Summary

Using an open-source software such as Ondsel Engineering Suite, FreeCAD, OpenFOAM, OpenFAST, MLife, and others to SAFELY and RELIABLY design wind turbines or other engineering projects.

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Experiential Learning of Micrositing and Instrumentation of Met Tower in Laboratory Setup

Ram Poudel, Brain Raichle
Appalachian State University, Boone, NC, USA

Introductory Summary

We summarize the experience of training students on micrositing and instrumentation of wind met towers at Appalachian State. Many of our students are visual learners. The students gain hands-on experience working with sensors and data loggers and, at the same time, learn best industry practices to estimate the hub height wind speed, and associated parameters that influence uncertainty in wind speed.

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New Datasets to Power Advanced Workforce Analysis

Jeremy Stefek, Brinn McDowell, Adam Kanter, Bailey Pons, Meghan O'Reilly
NREL, Golden, Colorado, USA

Introductory Summary

A wind energy occupational map and education and training database are new resources developed by the National Renewable Energy Laboratory with support from the Wind Energy Technologies Office (WETO). These two datasets when combined with existing datasets, such as the Justice40 Climate & Economic Justice Screening Tool, can identify opportunities for maximizing benefits of workforce development for the land-based and offshore wind industries. This

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Match Making in the Wind Energy Industry: Connecting Communities, Training Programs, and Industry to Build a Diverse Workforce

Brinn McDowell, Ruth Baranowski, Jeremy Stefek, Heidi Tinnesand, Adam Kanter, Elena Smith, Amanda Cushman, Dennis Parnell Jr., Meghan O'Reilly
National Renewable Energy Laboratory, Golden, CO, USA

Introductory Summary

The National Renewable Energy Laboratory (NREL) with support from the U.S. Department of Energy Wind Energy Technologies Office (DOE-WETO) has developed a tool for wind energy developers and operators to connect with education and training programs in upcoming land-based wind markets. This new mapping tool is intended to highlight education and training programs that teach skill sets foundational for not only the long-term operations of land-based wind energy farms, but also the development and operations of various clean energy technologies. This mapping tool, paired with a methodology developed by NREL researchers to support local communities and training programs in facilitation of an inclusive and diverse wind energy workforce, could aid in increasing the accessibility to wind energy careers for communities directly impacted by wind energy development.

Final category: Environmental

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Testing the Efficacy of an Automated Detection and Audio Deterrence System to Reduce Collision Risk for Golden Eagles

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Introductory Summary

Reducing Golden Eagle collision risk poses a serious challenge to the successful development and operation of wind energy in the western U.S. As a potential solution to this challenge, DTBird® is an automated detection and audio deterrent system intended to discourage birds from approaching spinning wind turbines. We evaluated DTBird's efficacy for Golden Eagles at two commercial facilities in California and Washington, conducting 1) *in situ* behavioral studies of eagles and soaring raptors in response to the DTBird system and 2) flight trials with UAVs to evaluate the system's detection capabilities. We set up a field experiment to evaluate the difference in avian responses between spinning turbines with and without active deterrents broadcasting. The overall estimated probability of detection was similar at the two sites (64–66%), though sun positioning influenced overall detection probability, while UAV flight speed, angle, and model, cloud cover and site influenced the system's detection distance. The behavior study revealed the following trends relative to raptor responses 1) lower for all analyzed species groups at the Washington facility; 2) positive relationship with wind speed for eagles and vultures, but a negative relationship for smaller buteos; and 3) mostly highest for birds at medium risk rather than at high risk. The presumed effective deterrent responses for Golden Eagles was 79% at the California site and 61% at the Washington site. The Washington experiment further revealed the addition of audio deterrents generally at least doubled the probability of effective deterrence compared to spinning turbines alone.

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Blades

Evan Anderson[1], Charles Seeley[2], Myra Blaylock[3], Rudy Haluza[1], Svetlana Bakhmatova[2]
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Introductory Summary

Finite element models are developed to simulate the transient response of wind turbine blades to bird strike impact. Experimental testing is performed on a small blade specimen to determine vibration modes and measure impact response for comparison with models, and to predict responses of large offshore wind blades. Detection of bird strikes on turbines in operation is the ultimate objective in the present work.

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Bird and Bat Collision Force Calculations for Blades of an Offshore Wind Turbine

Myra Blaylock[1], Stephanie Schneider[2], Sharon Kramer[2], Scott Terrill[2]
[1]Sandia National Labs, Livermore, CA, USA. [2]H.T. Harvey & Associates, Los Gatos, CA, USA

Introductory Summary

Collision force calculations were made for an IEA 15MW offshore reference turbine and four species: short-tailed albatross, Heermann's gull, Hawaiian petrel, and hoary bat. These calculations included force, velocity, and area data, which will be used as input into a Finite Element Model (FEM) model and experimental testing on blades to help evaluate collision detection mechanisms currently in development.

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Design of a Launcher for Wildlife Collision Simulation on Wind Turbines To Validate Strike Detection Systems

Jason Roadman, Chris Ivanov, Rob Goldhor, Samantha Rooney, Cris Hein
NREL, Golden, CO, USA

Introductory Summary

Design and construction of a custom launcher and projectiles to simulate wildlife collisions with wind turbines is investigated. The various design features that led to success of the launcher are enumerated and described in detail. These features include custom projectiles, precision aiming capabilities, repeatable launch parameters, and azimuthal control over projectile launch. Success is investigated in terms of an overall hit percentage.

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A Probabilistic Framework for Assessing Collision Risks Between Birds, Bats, and Wind Turbine Blades

The escalating deployment of offshore wind energy (OWE) raises a grave concern about the avian and chiropteran interactions with turbine infrastructure. This study proposes the development of a probabilistic theoretical framework based on animal flight mechanics aimed at quantifying the collision risks bats and birds face with wind turbine blades. The primary objective is to enhance the structural design of wind turbines to minimize environmental impacts while improving their operational efficiency. This framework adopts a simplified numerical model with environmental and biological data, providing a holistic approach to risk assessment. By simulating various interaction scenarios, the model aims to identify critical risk factors and predict collision probabilities under different environmental conditions and turbine configurations. The implications of this research extend beyond engineering solutions, offering valuable insights into the behavioral patterns of affected wildlife species. Furthermore, the findings are expected to inform the development of mitigation strategies that reduce collision risks and facilitate the ecological integration of wind energy projects. This study not only contributes to the sustainable advancement of renewable energy but also aligns with global conservation efforts by addressing key challenges at the intersection of energy production and wildlife preservation.

Keywords: Environmental Impact Assessment, Bird and bat collision risk, wildlife, Ecological Conservation

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Assessing Offshore Wind Sustainability through Life Cycle Assessment

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Introductory Summary

This study employs life cycle assessment (LCA) to evaluate the environmental impact of a hypothetical offshore wind farm and its domestic supply chain in New Jersey, aiming to identify key areas for improvement and assess the sustainability of the offshore wind sector's development.

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GEOLOGICAL DATA OF THE MID-ATLANTIC BIGHT CONTINENTAL SHELF FOR THE PURPOSE OF OFFSHORE WIND TURBINE FOUNDATION RECOMMENDATIONS

Ophelia Christoph
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Mid-Atlantic Bight.

Final category: Experiments and Instrumentation

15

Resolving the lidar-turbulence paradox

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Introductory Summary

We suggest a methodology to correct turbulence measures from Doppler wind lidars measuring in a velocity-azimuth display mode, i.e., typical wind lidar profilers. The method is based on a physics-based model that predicts both the variances of the reconstructed velocities from a wind lidar profiler and those from an ideal anemometer. The outputs of the physics-based model are used to construct physics-based datasets, which are used to train neural networks. The neural networks can then be used to correct measurements from a wind lidar profiler to be equivalent to measurements from standard anemometers on meteorological masts.

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Acoustic Multilateration of Impact Events in Composite Structures with Fiber Optic Accelerometers

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Introductory Summary

The goal of this work was to demonstrate the use of accelerometry data to detect and localize the point of origin of vibrations in a structure. This will serve to identify the point of damage occurring within a turbine blade, even if there is no sensor in the immediate proximity. When the damage occurs it will result in a vibratory impulse which propagates outwards from the point of damage. By determining the point of origin of that impulse, the system can then establish the location where the damage occurred. The underlying principle of multilateration is that by determining the relative time at which the signal arrives at the various sensors, and with some knowledge of the structure geometry, there is a unique point of origin which must have been the source of the vibration in order for all the signals to arrive at the specific times which they did. In effect, this is equivalent to the opposite operation performed in global positioning systems. In that case a collection of different signals is sent from known positions (the satellites) and by knowing when each of those signals arrive at the receiver, the position of the receiver can be computed. In this instance, the locations of the receivers are known, and the source of the signal is being solved for.

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Biaxial Load Fatigue Test Strain and Damage Analysis of Full-Size Wind Turbine Blades

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loading method of full-scale fatigue testing of wind turbine blades. By discretizing the structural parameters and vibration state parameters of the blade, the strain expression for each node of the biaxial loading is derived, the strain coupling and cyclic characteristics are analyzed, and the fatigue cumulative damage model is established. The biaxial loading fatigue test of the 90m class blade shows that the strain-based fatigue cumulative damage analysis method can realize the real-time assessment of the fatigue cumulative damage at each strain measurement point of the blade.

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Characterizing Turbine Inflows and Interactions via Radar-Derived and SCADA-Retrieved Wind Measurements

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Introductory Summary

The American Wake Experiment (AWAKEN), sited in north-central Oklahoma, was designed to measure atmospheric variables from the planetary boundary layer (PBL) to better understand how turbine-to-turbine interactions affect wind farm performance.[1] This study specifically merges wind turbine response to remotely-sensed flow measurements acquired by a dual-Doppler (DD) radar system. Two main AWAKEN datasets are used: (1) radar-derived measurements of wind speed and direction; and (2) wind turbine measurements collected by supervisory control and data acquisition (SCADA) systems, including quantities such as nacelle wind speed and direction and turbine rotor speed and power output.

Strong agreement is evident between the remotely-sensed measurements collected by radars and the ground-truth measurements collected by turbine SCADA systems, especially the wind speed. Radar-derived wind speed is also a strong predictor of turbine power output, attesting to the capability of DD radar to not only characterize active inflow and wake flow conditions for the sake of understanding changes in power production, but also to forecast flow features which may affect turbine behavior or performance. Future work aims to predict turbine inflow wind speed and power output with longer lead times, and to diagnose and quantify power losses as a product of turbine-to-turbine and farm-to-farm wake interference.

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Experimental and Numerical Comparison of Loads and Aeroacoustics between Upwind and Downwind Wind Turbine Rotors

Jason Roadman, Pietro Bortolotti, Arlinda Huskey, Jon Keller, Chris Ivanov, Mark Iverson, Emina Maric, Derek Slaughter, Syhoune Thao, Consuello Wells
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Introductory Summary

This abstract discusses the design, execution, and findings of the Big Adaptive Rotor (BAR) downwind experiment, which aimed to characterize the loads and the noise emissions of a GE 1.5-megawatt wind turbine when operating in a

The analysis of the data is ongoing and the results will be presented at the conference. The team expects to be able to answer decade old questions about the increase in aeroacoustic emissions and fatigue loads of downwind rotors compared to more conventional upwind rotors.

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A fleet of small multicopter UAS for inflow and wake turbulence measurement.

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Introductory Summary

A fleet of small multicopter uncrewed aerial systems (UAS) is used in this study to collect distributed measurements of the three-dimensional wind field and temperature at the WiValdi research park. Measurements in the vicinity of an array of meteorological masts and in the wake of one of the research wind turbines are presented. The UAS allow unprecedented insights into inflow and wake turbulence.

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Evaluation of an automated eddy covariance air-sea flux package on a lidar buoy

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Introductory Summary

A Pacific Northwest National Laboratory (PNNL) floating lidar buoy was equipped with an eddy covariance (EC) package that measures air-sea fluxes of momentum and sensible and latent heat. The EC system was designed to be robust, with dual 3D ultrasonic anemometers, both open- and closed-path InfraRed Gas Analyzers (IRGAs), and a liquid water rejection system. Platform motion corrections of the 10 Hz 3D wind vector are computed in real time by a commercial datalogger, enabling calculation of motion-corrected 10-minute turbulent air-sea fluxes that are transmitted to shore-based servers. The "Flux-Lidar Buoy" was anchored near the Martha's Vineyard Coastal Observatory's Air-Sea Interaction Tower (ASIT) between Jan-May 2024. More than 8000 10-minute momentum fluxes measured during this period were used to compute preliminary estimates of the drag coefficient. Close agreement was found with a simple bulk drag parameterization. Future work will include comparison of air-sea fluxes with the NOAA COARE bulk algorithm and integration of the fluxes with vertical wind profiles measured by the lidar to evaluate marine surface and boundary layer parameterization schemes.

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Flexural Tests on Large-Scale Thin-Walled Steel Tubes for Wind Turbine

Introductory Summary

Thin-walled steel circular tube sections, known for their large diameter-to-thickness ratios, are increasingly used in constructing wind turbine towers due to the growing wind energy industry. As these tubes become more prevalent, optimizing their design becomes more important. This optimization, however, raises concerns about local buckling under compressive loading, which is a key limit state for efficiently designed thin-walled tubes. Currently, there is a scarcity of flexural test data for tubes with high diameter-to-thickness ratios, which challenges the ability of design methods to generate optimal designs. To better understand the behavior under these conditions and improve design methods, a series of static, flexural tests have been conducted. The tests involved nine ~1:4 scale steel tubes with 1m diameters and diameter-to-thickness ratios ranging from 150 to 300. These specimen geometries are scaled representations of typical sections used in wind turbine towers. Deformations in the compressive region of the tubes are measured with a laser scanner both before and during testing, allowing for the detailed characterization of deformation modes due to local buckling. The experimental results from these tests will be presented and analyzed, providing insights for future optimized designs.

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An adaptive system for detecting rotor layer turbulence with Halo Photonics Doppler lidars using Waggle

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Introductory Summary

We are designing and testing an adaptive sensing system for detecting rotor layer turbulence using the Waggle Node, an outdoor-rated edge computer capable of interacting with connected instrumentation using user-supplied software to automatically trigger Halo Photonics Doppler lidar scan strategies. We demonstrate how Waggle can remotely trigger scan strategies for the Halo Photonics XR Doppler lidar installed at the Nantucket Wastewater Treatment Facility for the U.S. Department of Energy's Wind Forecast Improvement Project 3 (WFIP3). Finally, we will highlight preliminary results of a week-long Intensive Operating Period, to be held August 2023 during WFIP3 testing automated triggering of the Doppler lidar to perform sector scans of the rotor level off the southern coast of Nantucket.

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An Overview of DOE's Tall Turbines Onshore Field Campaigns: Using Doppler Lidar to Provide New Insights into the Wind Resource over Forests

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Introductory Summary

The atmospheric boundary layer above forest canopies is difficult to measure in practice, and our understanding of its flow physics, including the potential wind resource, is limited in part by observational constraints. Most available

use scanning and profiling lidar to measure wind flow, including its mean and turbulent properties, across tall turbine rotor heights above forested regions, which are currently underutilized for wind energy in the U.S. We describe here the experimental set-up lidar scan strategies and collocated publicly available datasets. These data are being collected as part of the DOE "Addressing Challenges in Wind Forecasting for Tall Turbines Across Regions with Terrain and Land Surface Heterogeneity" project and will be used for analysis of forest-atmosphere interactions and numerical model validation.

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A Deformation Estimation Device for Flexible Structures

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Introductory Summary

A Toyota research team has been investigating a high-altitude aerial platform, known as the Mothership, envisioned for various missions, including airborne wind energy (AWE) harvest. A small 1.5kW AWE prototype system has been developed and tested. In parallel, various kite flight tests have been carried out to expand the flight envelope. During these tests, we observed that the kite experienced roll divergence and subsequently crashed. Our simulation indicates that such roll divergence can be caused by asymmetric wing deformation. Monitoring structural deformations during flight tests is highly desirable for understanding kite structure behaviors in different flight conditions. Traditional monitoring methods often use bulky and rigid sensor systems, such as resistive bend sensors, which may interfere with the structural properties of the kite. To Address this challenge, our study introduces an innovative sensor tape that is both flexible and lightweight, enabling accurate deformation measurements without compromising the structure's functionality.

This article discusses the development of a high-precision, lightweight sensor system designed to measure deformations in airborne wind energy kite structures during flight tests. The system utilizes a flexible PCB integrated with MPU6050 motion sensors and an ESP32-S2 microprocessor to estimate and record structural deformations in real time.

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Methodology for Correcting Wave Elevation Data for Radiated and Diffracted Effects Near Floating Offshore Structures

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Introductory Summary

A reliable estimation of wave elevation data from full scale measurements is required for model correlation studies for floating offshore structures, but radiated and diffracted effects from the structure itself can significantly degrade the quality of these wave measurements. To solve this issue a methodology utilizing potential flow software, WAMIT, was developed to predict the undisturbed environmental wave surface elevation in the presence of radiated and diffracted effects from a floating offshore structure. A scaled model test was conducted in a wave tank to test the efficacy of this methodology under design load conditions (DLCs) for a barge-type floating offshore wind platform. The experimental campaign enabled: (1) identification of the ideal location to mount wave probes to avoid interference from the structure, (2) determination of which environments radiated and diffracted effects were significant in, and (3) evaluations of the methodology's ability to correct the wave height time series and power spectra. This method will be tested on a field deployed floating wind turbine in the near future.

Porosity Detection and Quantification in Glass Fiber Reinforced Polymer

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Introductory Summary

Characterization of porosity content in glass fiber reinforced polymers (GFRP) through Microwave (μT) NDT.

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Acoustic Travel-Time Tomography of the Atmosphere: A Large Eddy Simulation Optimization Study

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Introductory Summary

Acoustic travel-time tomography (AT) of the atmosphere utilizes the travel time of sound and an inversion algorithm to infer turbulent velocity and temperature fields within a volume of interest. This study employs Large Eddy Simulations (LES) of the pioneering AT array at the National Renewable Energy Laboratory's (NREL) Flatirons Campus to optimize the time-dependent stochastic inversion (TDSI) algorithm. By implementing LES, we reverse the TDSI to refine the selection of model parameters and temporal datasets, and investigate sensitivity to measurement noise. This approach aims to evaluate the reliability of the algorithm for wind energy applications.

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Experimental Validation of Parked Loads for a Floating Vertical Axis Wind Turbine: Wind-Wave Basin Tests

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Introductory Summary

Parked loads are a major design load case for vertical axis wind turbines (VAWTs) because of persistent high loads on the rotor when in standstill conditions. This paper examines the aerodynamic parked loads of model-scale floating troposkein VAWTs tested in a wind-wave basin. We analyze the effects of wind speed, and turbine solidity (varying number of blades) on parked loads and investigate the impact of different platform conditions (comparing locked (fixed base) versus floating cases with and without waves). Additionally, we study the variation of parked loads under different operating conditions, including only wind, and combined wind-wave cases. The experimental results indicate that both parked loads (for both locked and floating platform conditions) and amplitude of turbine tilting increases with the wind speed, which is expected. If only aerodynamic parked loads are considered, the turbine with a floating platform exhibits lower parked loads compared to turbine with a locked platform (fixed base) due to the effect of the tilted condition of the floating platform. The results from varying solidity and operating conditions studies will be added in the final paper and presentation. Additionally, UTD's semi-numerical tool for estimating parked load of VAWTs was validated and improved to predict the floating case parked loads. The analytical model accurately

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Inflow and pressure belt measurements on the GE 1.5MW turbine in the downwind experiment at NREL

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Introductory Summary

We present the inflow- and pressure belt instrumentation of the GE 1.5 MW turbine operating in a downwind configuration (Bortolotti et al. 2023). Specifically two pressure research belts were installed on the blade at two radial positions together with a five hole pitot tube close to each of the same positions. In addition a third pressure belt was installed on the tower at a height corresponding to the position of the outboard pressure belt for the blade in the downward position. This instrumentation makes it possible to study the details of the complicated aerodynamics of the blade/tower interaction of a downwind turbine which is one of the main objectives of the downwind experiment in the BAR II project.

Initial results comprising pressure distributions on the blade and on the tower will be presented as well as analysis of the unsteady pressure response interaction between the blade and tower during the blade passage. This comprises also the procedure to reconstruct the unsteady pressure signal from the pressure belt due to the length of the tubing system.

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Validation of the open-source GE2.8-127 OpenFAST turbinemodel against field data for the AWAKEN campaign

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Introductory Summary

This goal of this study is to validate an open-source turbine model being used in simulations related to the American WAKE ExperimeNt (AWAKEN) campaign such that modelers are aware of potential errors.

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An Investigation into the Vibrational Behaviors of Large-Scale Blades Subject to Non-Linear Damping During Fatigue Testing

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an equivalent dynamic model of the blade under the influence of square damping. The nonlinear amplitude-frequency response of the blade testing system is thoroughly analyzed. Furthermore, based on the principle of energy equivalence, a mathematical relationship is derived among the blade's equivalent damping ratio, response amplitude, and excitation force amplitude. The results of the blade fatigue testing validate the nonlinear relationship between the blade's response amplitude and excitation force amplitude, as well as the linear positive correlation between the blade's response amplitude and the equivalent damping ratio. These findings also highlight the significant role of square damping as a crucial factor contributing to the nonlinear behavior of large-scale blades.

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Tilted lidar profiling: development and testing of a novel scanning strategy forinhomogeneous flows

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Introductory Summary

How do we measure wind profiles with lidars in the presence of flow inhomogeneities? This question arose during the American WAKE experimeNt (AWAKEN) campaign, where lidars were required to be placed in proximity to wind turbines. In this study, we address this challenge from an experimental standpoint by developing and testing novel scanning strategies that mitigate the impact of the regions of inhomogeneous flow on the wind estimates.

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Investigation on nonlinear out-of-plane deformation of thin-walled box beam element joining segmented wind blades using 3D digital image correlation

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Introductory Summary

In this paper, the thin-walled rectangular box beam was proposed as one of candidates of the connecting elements to carry the dominant bending moment in a flapwise direction. Since a large bending moment to the thin-walled member could cause the nonlinear deformation which might cause the fracture of the thin-walled structure, the comprehensive understanding of the nonlinear deformation behavior is highly important to make sure the structural integrity of wind blade box structure. In the current research, the components with a rectangular thin-walled cross-section representing connecting element of segment blades were manufactured and tested experimentally with 3-points bending test configuration. With traditional measurement techniques using strain gauges, it can only measure in-plane point-wise deformation and also have limitations in measuring the overall deformation on the deformed structure. Recently, non-destructive measurement technologies (NDT) including three-dimensional digital image correlation (3D DIC) have been widely accepted to experimentally measure nonlinear deformation. For the current 3-points bending test, 3D DIC system was used to capture the overall nonlinear out-of-plane deformation. The finite element analysis (FEA) was also performed for the comparison. The conclusion on the experimental outcome and comparison with FEA results would

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Deflection sensing of a wind turbine blade with scanning automotive lidars

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Introductory Summary

Deflections and twisting of full-scale wind turbine blades are typically measured with traditional sensors, including optical or electrical strain gauges and optical fibers embedded inside the blades, which can be costly, time-consuming, and impossible to repair if they malfunction. In this study, we propose to use automotive lidars to inspect the deflections and twisting of turbine blades. A proof-of-concept experiment was conducted at the Large Scale Facility of the Technical University of Denmark (DTU) to scan a full-size 12.6 m long wind turbine blade with a commercial automotive lidar. The free-hanging blade was artificially excited at its tip. It was observed that the maximum flap-wise deflection along the blade was about 30 cm at the tip. According to the power spectral density diagram obtained, the blade's first out-of-plane bending mode has an eigenfrequency of 3.3 and its second harmonics 6.7 Hz, respectively. In light of these results, automotive lidars may be an attractive option for wind energy industries that require accurate measurements of blade deflections and twisting, resulting in a faster testing process and a shorter time to market for new turbine models.

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The Potential of Combining Static Wake Control with Wake Mixing Techniques for Faster Wind Turbine Wake Recovery

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Introductory Summary

This study investigates the potential of enhancing wind turbine wake recovery by integrating static wake control with wake mixing techniques. If successful, such a combination could lead to more efficient wind farm control strategies, potentially improving power output through a quicker wake recovery. Specifically, the research focuses on the combination of static induction control and wake steering (both lateral and vertical by rotor tilt) with the wake mixing techniques Helix and dynamic yaw. Experiments were carried out in a closed-loop wind tunnel using two G1 scaled model wind turbines. Actuator-line Large Eddy Simulations are used to confirm the experiments and provide a deeper insight into the effects of the controls on wake behavior.

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Experimental Investigation of the Coupling between an Unsteady Periodic Inflow Velocity and Blade Pitching

Jaylon McGhee[1], Brooke Stanislawski[2], Ganesh Vijayakumar[2], John Farnsworth[1]

Introductory Summary

This study aims to characterize how the pitching motion of a wind turbine blade section couples with an unsteady inflow velocity on a wind turbine blade section to alter the unsteady aerodynamic loads it experiences. During the first phase of this project, simulations of two IEA 15-MW wind turbines were performed for a range of atmospheric stability states. The azimuthally (spatially) averaged statistics of the angle of attack, relative velocity, and loads for each blade section were computed. In the second phase of this study, wind tunnel experiments were conducted with com- parable reduced frequencies and amplitudes for the angle of attack and relative velocity to those observed in the simulations. In the experiments, unsteady surface pressure measurements of an FFA-W3-301 airfoil were collected and integrated to determine the time-varying aerodynamic force coefficients experienced by the blade sections. Preliminary analysis shows that there are frequencies observed in the experiments that are not apparent in the simulations. This discrepancy is likely due to the nonlinear coupling between the unsteady inflow velocity and the angle of attack, which occurs in reality; however, it is often assumed to be negligible in many aerodynamic models.

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The "Testfeld BHV" wind field validation experiment

Julia Gottschall
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Introductory Summary

We present measurements of an extensive wind field validation experiment and in particular a methodology that allows us to combine all the measurements from various sensors in one dataset. This facilitates the study of both the wind field complexities and its uncertainties at points were measurements overlap. Processed data are published and shared within the EU funded project "FLOW".

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Rotor Aerodynamics, Aeroelastics, and Wake (RAAW): Test Campaign Summary and Next Steps

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Introductory Summary

The Rotor Aerodynamics, Aeroelastics and Wake (RAAW) effort is a validation-focused campaign that considers the inflow, rotor response, and wake of a single turbine. Field testing of the turbine was completed in October 2023, and a large database of measurements has been obtained. A brief summary of the measurements obtained as well as the use of the data for future analysis and validation efforts is presented.

REAL-TIME HYBRID SIMULATION FOR FLUID-STRUCTURE INTERACTION TESTING OF FLOATING OFFSHORE WIND TURBINE

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Introductory Summary

Floating offshore wind turbines (FOWT) are expected to play a pivotal role in the energy transition to renewable energy. Therefore, it is critical to develop analysis and design approaches that result in reliable and economic wind energy devices. However, FOWTs are subject to complex loading conditions due to the actions of coupled wind and wave conditions offshore, acting in combination with control and structural dynamics. The multiple dynamics simultaneously acting on FOWT are hard to simulate in a laboratory setting due to conflicting scaling laws and the restricted space of existing experimental facilities. To address this, a real-time hybrid simulation (RTHS) approach has been developed that more realistically simulates the coupled dynamics of FOWT. The RTHS approach can virtually extend existing laboratory environments by coupling numerical models with physical experiments using sensors and actuators. This presentation will describe the application of RTHS to simulate the response of a 5-MW FOWT defined by NREL, including numerical aerodynamics interacting with a 1:50-scale physical experiment including the tower, platform, moorings, and hydrodynamics. Results demonstrate that the RTHS can simulate combined aero-hydro-structural response of FOWT, which cannot be obtained using conventional approaches without distorted similitude effects.

Final category: Extreme Weather

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Influence of veer on blade and tower loads - implications for design and risk assessment

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Introductory Summary

The rapid growth of offshore wind energy in the United States, driven by ambitious 2030 goals, brings with it several challenges, especially in hurricane-prone areas. For instance, the recent approval of the New England Wind project is situated within a hurricane cyclone zone off the coast of Massachusetts. In these regions, veer, which is defined as the variation of wind direction with height, may potentially impact turbine blade and tower loads. A large-eddy simulation (LES) from a previous study provides the wind characteristics during tropical cyclones in Category 1 hurricanes. The International Energy Agency (IEA) 15MW turbine is simulated subjected to these hurricane wind characteristics. The blade loads are analyzed with particular attention paid to the role of wind veer on the loads. The result indicate up to 21% and 42% increase in the load due to the effect of veer on the tower and mudline, respectively.

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An Experimental Study on the Detrimental Effects of Rainfall on Wind Turbine Performance

Introductory Summary

An experimental investigation was conducted to examine the detrimental effects of rainfall on the aerodynamic performance of wind turbine blade models under various test conditions. The experimental study was performed with a typical wind turbine airfoil/blade model mounted inside a unique Icing Research Tunnel of Iowa State University (i.e., ISU-IRT). In addition to using high-sensitive load cells to measure the variations of aerodynamic forces (i.e., both life and drag forces) acting on the airfoil/blade model as a function of the incoming airflow speed and rainfall rate, a high-speed imaging system was also used to record the dynamic impingement of airborne raindrops and transient behavior of the wind-driven water runback over the surface of the test model. A high-solution digital PIV system was also used to quantify the evolution of the airflow characteristics over the surface of the airfoil/blade model induced by raindrop impingement and its correlations with rainfall-induced aerodynamic degradation under various test conditions. By applying a superhydrophobic coating to coat the surface of the airfoil/blade t model, the effects of the surface wettability of the airfoil/blade model on the rainfall-induced aerodynamic degradation were also evaluated quantitatively in comparison to those of the uncoated case.

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Evaluation of Parametric Vortex Model Description of Hurricane Winds at Turbine Heights

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Introductory Summary

Parametric models are commonly used to approximate the near-surface wind fields of hurricanes offshore and over coastal areas for risk assessment purposes due to their simplicity and low computational load. Typically, these have been applied at 10-m height for storm surge and wave generation or building and infrastructure damage. A few studies have used parametric models for offshore wind energy risk assessments, but there has yet to be a thorough investigation of how effective the vortex models are at describing the range of hurricane wind fields at turbine heights (up to 250 m). In this study, we present an initial step at this understanding by evaluating two advanced parametric models for recent hurricanes (e.g., Henri in 2021). The comparison is made against high-resolution fully coupled atmosphere-ocean-wave numerical model simulations that have been conducted by the authors and a range of high-quality measurements. For Hurricane Henri, we find that the Generalized Asymmetric Holland Model performs best in representing the hurricane wind fields over the Martha's Vineyard/Nantucket wind farm lease areas where they are maximum. In addition, a reduction factor of 0.9 from the top of the boundary later provides a reasonable agreement to dropsonde measurements of wind speeds averaged over the bottom 150-m.

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Impact of Atmosphere-Ocean-Wave Coupling on Hurricane Simulations with Implications for Offshore Wind Energy

Introductory Summary

Offshore wind turbines along the U.S. East Coast face significant risks from hurricanes, characterized by strong wind speeds, abrupt changes in wind direction, and high ocean waves, all of which pose hazards to their structural and operational stability. While previous modeling studies using idealized setups have offered valuable insights into these risks, they often do not account for the interactions between atmosphere, ocean, and surface waves. In response, this study introduces a new fully coupled atmosphere-ocean-wave model and applies it to simulate past hurricane events along the U.S. East Coast. By incorporating the coupling effects between the atmosphere, ocean and surface waves into the model and simulating real hurricanes, we aim to better understand hurricane development and its impact on winds and waves, as well as their interactions. This study provides valuable insights for offshore wind energy infrastructure planning and risk assessment.

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Uncertainty Quantification of Wind Gust Predictions in the Northeast USA with a Deep Evidential Model

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Introductory Summary

Wind gusts have significant impacts on wind energy generation and power outages, emphasizing the importance of accurate forecasts for wind power plants and electric utilities. However, various small-scale atmospheric phenomena make gust predictions a challenging task and less accurate even for advanced numerical weather prediction models. Previous research using machine learning algorithms showed promise in mitigating bias in gust predictions. However, challenges persist, particularly in accurate prediction of high gust values, due to their infrequent occurrence in observation datasets. To address this problem, we aim to quantify uncertainty in gust predictions, using data from storms characterized by high wind values that occurred in the Northeast USA from 2017 to 2021. This study employs an evidential deep learning model trained on gust data from weather stations and various WRF variables. By assessing uncertainty at a 4 km grid scale, the research seeks to identify regions with higher uncertainty, aiding decision-making for potentially intense gusts. Additionally, explainable artificial intelligence (XAI) techniques will be utilized to explain model insights and feature variable sensitivity in gust predictions.

Assessing the Impact of Projected Climate Change on the Structural Integrity of U.S. Offshore Wind Turbines Exposed to Tropical Cyclones

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Introductory Summary

The susceptibility of U.S. offshore wind (OSW) infrastructure to tropical cyclones (TCs) is a pressing concern, particularly in light of projected climate change[1]. While previous studies have developed extensive frameworks for quantifying TC risk to wind energy infrastructure, they have not incorporated the potential changes in TC climatology under a future climate. This study aims to address this critical gap by assessing the impact of projected future changes in Atlantic TCs on U.S. OSW infrastructure at the basin scale. Employing the Risk Analysis Framework for Tropical Cyclones (RAFT)[2], our approach generates large ensembles of synthetic TCs, consistent with a given climate, to provide a robust assessment of risk that accounts for the projected changes in the climate system and their consequent impacts on storm patterns, intensity, and frequency. This comprehensive analysis is essential for understanding and mitigating the evolving risks to the sustainability and resilience of vital renewable energy resources.

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Hurricane wind speed maps and vertical profiles for offshore wind turbine design

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Introductory Summary

Offshore wind turbines installed in hurricane-prone regions may be subject to extreme wind conditions. International design standards (IEC 613400-1,3) already provide extreme wind speed models, however, their suitability to characterizing hurricane-driven extreme wind speeds has recently been questioned (Worshop et al 2017, Sanchez Gomez et al 2023). In this work, we make recommendations for an extreme wind speed model similar to the model proposed in the American Society of Civil Engineers (ASCE) onshore building codes ASCE 7-22. To obtain offshore extreme wind maps, storm tracks datasets (IBTRaCS, HURDAT2) are used as an input to a synthetic model to derive a larger catalog of events that is subsequently used to obtain extreme wind speed maps for 1, 10, 50, 500 and 1000-year return periods. Site-specific extreme wind speed profiles are then derived using the 1-minute sustained maximum wind speed and gust factors to obtain 10-minute averaged wind shear profiles, commonly used in the design of offshore wind turbines. Our approach suggests that design requirements within the current IEC standards can be exceeded in parts of the Gulf of Mexico whereas standards remain sufficient for most parts of the US East Coast.

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Introductory Summary

The objective of this study is to provide insight into the process for calculating long mean return periods of the significant wave height for locations along the US Mid/North Atlantic coast, a region exposed to waves caused by both tropical and extratropical cyclones. The study uses a 32-year wave hindcast, developed by the Water Power Technologies Offices (WPTO) of the U.S. National Renewable Energy Laboratory (NREL), to calculate mean return periods of significant wave height up to 500-years, the largest return period of significant wave height currently required by the most commonly used standard for the design of offshore wind turbines. Extreme values of significant wave height are extracted from the hindcast and are divided into sea states caused by tropical cyclones (TCs) and sea states caused by extratropical cyclones (ETCs) using the HURDAT2 dataset to define TCs and the North America Extratropical Cyclone (NAEC) dataset to define ETCs. The relative contributions of TCs and ETCs to the overall wave hazard are examined for sites along the US Mid/North Atlantic coast. Sea state characteristics that influence risk of offshore wind infrastructure, such as duration and seasonality, are investigated separately for TCs and ETCs.

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Implication of extreme weather events on wind turbine power fluctuations in mountainous region

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Introductory Summary

As the wind energy sector expands into mountainous regions to advance Power-to-X projects, interpreting wind power fluctuations remains challenging due to atmospheric turbulence and complex terrain. Mountain-induced turbulence and wind intermittency cause electrical power fluctuations and fatigue loading of wind turbine structures, making the analysis of pitch control and structural dynamics crucial. To explore the impact of mountain-induced wind intermittency, high-fidelity large-eddy simulations over a region with 25 Gaussian hills are first conducted. Next, a wavelet-based autoencoder is used to separate the time-varying mean and subgrid fluctuations based on the cut-off frequency. Finally, the open-source aeroelastic software OpenFAST is used, coupled with a Simulink model and controller for the hydraulic pitch system, to analyze the impact of the extracted time-varying mean on the pitch system and structural dynamics of the NREL 5MW wind turbine.

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Differences in mesoscale and LES wind fields of tropical cyclones

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Introductory Summary

storms. We find the mesoscale- and LES-generated wind fields display critical differences throughout the entire boundary layer given that turbulence fluxes are misrepresented in the mesoscale boundary-layer parameterization. Furthermore, we find the idealized storms do not represent the typical structure of historical events.

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Establishing a Lightning Climatology for Offshore Wind Farm Development in the New York Bight and Current Onshore Wind Farms on the Tug Hill Plateau

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Introductory Summary

Using data from the National Lightning Detection Network (NLDN) from 1989-2020 (Orville, 1991), this work aims to create a detailed lightning climatology for areas of proposed offshore wind farm development, with focus on the New York Bight (NYB), encompassing off the New York, New Jersey, Rhode Island, and Massachusetts coastlines. This includes diurnal, seasonal, and annual breakdowns of flash density, polarity, and whether each flash is cloud-to-ground (CG) or cloud-to-cloud (CC). This climatology will help provide knowledge of potential lightning impacts to long-term wind turbine deployment in the area. Finally, this work will also examine the impacts of current onshore wind farms, over the Tug Hill Plateau in New York, to flash density, by looking at NLDN data from before and after the development of these farms in the late 2000s, and early 2010s.

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Topographic multiplier of the design wind speed considering the effect of wind direction in Northern Japan

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Introductory Summary

A topographic multiplier for design wind speed in Northern Japan where extreme wind event is caused by extratropical cyclones was estimated by considering the effect of the wind direction characteristic of extreme wind events. The mesoscale model with the correction of CFD flow model can predict the extreme wind speed with reasonable accuracy and estimated wind direction dependent topographic multiplier is much lower than the maximum value for all the wind direction.

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Introductory Summary

The East China Sea and the South China Sea are frequent paths for typhoons, presenting substantial economic risks to coastal cities. Along coastal regions, China has constructed numerous large-scale wind farms. Investigating whether large-scale wind farms can mitigate the impact of typhoons and assessing their operational status under such extreme conditions is important. This paper examines the micro-scale distribution of wind speed, turbulence intensity, and rainfall during the passage of Typhoon "In-Fa" through hypothetical large coastal wind farms. In the Weather Research and Forecasting (WRF) model, the Wind Farm Parameterization model (WFP) is employed to simulate wind turbines. The operational status of turbines during typhoons is obtained via an ultra-low speed control strategy implemented in OpenFAST, and these parameters are supplied to the WRF model to simulate wind farm performance under the influence of typhoons. Additionally, atmospheric data during typhoons is utilized to drive the FAST.Farm for a comprehensive comparison, enabling the calculation of turbine aerodynamic responses. The analysis provides valuable insights into the design and operation of future wind farms under extreme weather conditions.

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Marine Heatwaves and Atmospheric Rivers: Implications for Offshore Wind Energy at the US West Coast

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Introductory Summary

Along the US West Coast, extreme warm sea surface temperature (SST) events, known as marine heatwaves (MHWs), exert strong and persistent air-sea heat flux forcing on the lower troposphere, altering the stability and wind profiles in the atmospheric boundary layer on subseasonal timescales. The region also experiences extreme wind and precipitation events, often accompanied by atmospheric rivers (ARs), incurring strong diabatic heat exchanges across the air-sea interface on synoptic timescales. The diabatic heat exchanges associated with MHWs and ARs are likely important factors for determining changes in local and regional wind climate by the anticipated build-outs of floating offshore wind farm clusters on the US West Coast. Using a series of simulations from a fully coupled high-resolution ocean-atmosphere model, we show that large-scale MHW SST anomalies lead to enhanced latent heat flux and evaporation to the atmosphere. The added moisture energizes ARs propagating across the MHW and, upon landfall, increases precipitation along the coastline and inland. The subsequent discussions will focus on 1) how this MHW-AR interaction is affected by the planned offshore wind energy enterprises and 2) how diabatic heat exchanges affect the atmospheric boundary layer stability and winds near the lease areas as it relates to wind resource modeling and characterization of the wind wakes.

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High-Resolution Large-Eddy Simulation of the Hurricane Boundary Layer

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Introductory Summary

studying the hurricane boundary layer is through turbulence resolving flow simulation with large-eddy simulation. We outline our progress toward and methods for coupling regional-scale weather modeling of hurricanes with microscale LES that can ultimately be used for assessing hurricane turbulence and its impact on wind turbines.

Final category: Floating Wind Systems

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OpenFAST development to support simulations with large heading changes of the floating support structure

Lu Wang, Jason Jonkman, Derek Slaughter, Andy Platt
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Introductory Summary

Floating offshore wind turbine systems may experience large heading changes under certain conditions such as after the loss of a mooring line. Some recent novel floating concepts with single point moorings also rely on the weathervaning of the entire structure instead of an independently yawing nacelle. As a result, there is a need for simulation tools to be able to simulate such transient events. In response, we are currently developing and implementing the necessary capabilities within OpenFAST to accommodate large transient heading change (yaw motion). The adopted formulation and example results will be presented.

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Dynamic modelling of HiveWind floating wind substructure in OpenFAST

Iñaki Zabala[1], Roger Bergua[2], Alvaro Gomez[1], Lu Wang[2], Oier Peña[1], Jason Jonkman[2], Jorge Peña[1]
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Introductory Summary

The optimization of floating offshore wind substructures requires solvers capable of capturing member-level loads. In this work, this functionality of OpenFAST has been applied to the HiveWind platform.

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Simulating Floating Wind Turbine Wakes: A Multi-Fidelity Analysis based on the NETTUNO Project

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Introductory Summary

A better understanding of floating wind turbine wakes and how they are influenced by the motion of the turbine is of utmost importance for the development of the technology. As some recent studies have shown, turbine motion can affect wake dissipation and consequently loads and power output of neighboring turbines. A deeper understanding of

ranging from lifting-line simulations to blade-resolved CFD, while also including ALM LES simulations.

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Investigation of Viscous Forces on Floating Semisubmersibles using CFD

Yingqian Liao, Lu Wang, Amy Robertson, Jason Jonkman
National Renewable Energy Laboratory, Golden, CO, USA

Introductory Summary

In the IEA Wind OC6 project, work packages significantly improved the capabilities of mid-fidelity tools to predict the nonlinear, low-frequency responses of floating offshore wind turbines (FOWTs). To further enhance the low-frequency load and response prediction, we aim to utilize Computational Fluid Dynamics (CFD) to investigate the viscous effects on rectangular pontoons in the new IEA Wind OC7 project.

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Considerations for Predicting Viscous Contributions to Hydrodynamic Excitations of Floating Semisubmersible Components

Yingqian Liao, Lu Wang, Amy Robertson, Jason Jonkman
National Renewable Energy Laboratory, Golden, CO, USA

Introductory Summary

This presentation will summarize and conclude findings from Phase Ia of the new OC7 project. In this task, we investigate the viscous load contribution to hydrodynamic excitation on fixed cylindrical columns and heave plates. Specifically, we develop models following the setup of the component test campaign in the former OC6 project[1] using mid-fidelity tools. We compare the models and parameters that are tuned against experimental measurements using an optimization approach across different configurations, sea states, and different modeling formulations. The goal is to develop guidance on model formulations and hydrodynamic coefficient selections based on the sea state and geometry to accurately capture the viscous contribution to the hydrodynamic excitation, contributing to the overarching goal of OC7 Phase I to improve the modeling practices for general floating offshore substructures.

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Extending OpenFAST to Support Multi-Rotor Systems

Jason Jonkman, Derek Slaugther, Andy Platt, Hannah Ross
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There are a couple trends driving interest in multi-rotor wind energy systems, where more than one rotor is placed on a single support structure. The design of modern wind energy systems is based on a loads-analysis process that relies on physics-based engineering tools supporting coupled aero-hydro-servo-elastic dynamics. However, the state-of-the-art OpenFAST tool has historically only supported single (horizontal axis) rotor systems. This work highlights recent OpenFAST developments to extend the capability to multi-rotor land-based and offshore fixed-bottom and floating wind energy systems, as well as the concepts and background needed to understand and apply it correctly. While not the focus of this work, the new OpenFAST capability also supports multi-rotor marine hydrokinetic (MHK) systems (underwater turbines generating power from current and/or tides). The extended version of OpenFAST should facilitate practical design and loads analysis of novel multi-rotor systems not previously possible with the tool.

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Case Study in Main Bearing Fatigue Life of Bottom Fixed and Floating Offshore Wind Turbines

Jakob Gebel[1], Pieter-Jan Daems[2], Veronica Liverud Krathe[1], Kostas Papaioannou[2], Kayacan Kestel[2], Jens Jo Matthys[2], Adithya Vemuri[2], Amir R. Nejad[1], Jan Helsen[2]

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Introductory Summary

This work presents a case study identifying detrimental environmental conditions for the main bearing of offshore wind turbines. It compares the behaviour of main bearing fatigue life in a bottom fixed and a floating configuration of the same turbine, focussing on the use of field data and model-based simulations. The simulation model is validated based on vibration and SCADA data measured during the operation of a bottom fixed turbine in the Belgian North Sea. Operational modal analysis is used to identify the dynamic behaviour of the deployed wind turbine, allowing for model tuning and validation. The SCADA data is used to ensure the representative behaviour of the turbine model, which is then used to estimate the main bearing damage in different environmental conditions, using historical weather data as input. The turbine model is adapted for a floating configuration, for which main bearing damage is calculated as well. This aims to give insight into the effect the additional degrees of freedom of a floating turbine have on the main bearing fatigue life in different sea states.

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Flexible-Joint Semi-Submersible Floating Offshore Wind Substructure

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Introductory Summary

Extensive wind resource exists off the coasts of the United States over waters too deep for fixed-bottom offshore wind turbines. Technically viable floating offshore wind turbines are still significantly more expensive than their counterpart. One of the primary cost drivers is the requirement for designing floating substructures capable of withstanding wave loading without incurring penalties in the performance and loading of the turbine. This paper discusses modifications to the joints of a semi-submersible floating substructure to significantly reduce the transfer of wave loading to its members and turbine by adding flexibility in the substructure at the buoyancy-can (or column) connection.

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Turbine using Model-Scale Tow Testing

Samuel Davis[1,2], Amrit Verma[2]
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Introductory Summary

An experimental basin towing test was conducted on a barge-type floating offshore wind turbine (FOWT) in two different towing orientations with varying towline configurations. Tow runs were conducted at a range of towing speeds to collect data on the towline tension, the motions of the FOWT, and the wake profiles during testing. Analysis of the experimental data allows for the calculation of the drag coefficient of the FOWT foundation in the two towing orientations across a range of tow speeds. Further analysis of the FOWT motions and wake profiles may reveal how tow speed and flow-induced motions (FIM) influence the behavior of the FOWT during towing. A comparison of the two towing orientations will characterize the expected loads and towing behavior of the FOWT, informing future decisions on towing operations of similar barge-type FOWTs.

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Sensitivity Analysis of Numerical Modeling Input Parameters on Floating Offshore Wind Extreme Storm Condition Loads

Will Wiley, Jason Jonkman, Amy Robertson
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Introductory Summary

Floating offshore wind turbine systems are subject to complex environmental loads, with significant potential for damage in extreme storm conditions. Simulations in these conditions are required to assess the survivability of the device with some level of confidence. Aero-hydro-elastic modeling tools can be used with a reasonable balance of accuracy and computational efficiency. The models require many input parameters to describe the air and water conditions, the system properties, and the load calculations. Each of these parameters has some possible range, either due to statistical uncertainty or variations with time. Uncertainty in the input parameters can have an important influence on the uncertainty in the resulting loads, but it is not practically possible to perform detailed assessments for every input parameter. This work demonstrates a method to identify the input parameters that have the most significant impact on the loads for further inspection. The process is specifically done for the extreme storm load cases defined in the International Electrotechnical Commission (IEC) design requirements for floating offshore wind turbines.

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CFD Investigation of the Center of Rotation of Floating Offshore Wind Turbines for Improved Dynamic Analysis

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Introductory Summary

In this work, the center of rotation of floating offshore wind turbines (FOWTs) is investigated using computational fluid dynamics (CFD) simulations and kinematics. This study serves to better understand FOWT system dynamics and support de-coupled analysis techniques.

A Modular Design and Installation of Foundation for ETLP FOWT

Rathinam Periyaiah, Mustafa Erten, Zhaoxiang Tang
Genesis/Technip Energies, Houston, Texas, USA

Introductory Summary

The Modular Steel Gravity Foundation (MSGF) as Tension Leg Platform (TLP) Floating Offshore Wind Turbine (FOWT) Tendon foundation is an innovative method of installing the traditional gravity base foundation. The proposed modular solution offers a simple, noiseless, and environmentally friendly installation process. A simple decommissioning process, adaptability to all types of seabed soil conditions, and executability with locally available installation vessels of this MSGF results in a significant reduction in the installation schedule and cost of a FOWT. This paper contains the MSGF configuration and sizing for TLP with pontoon Extension (ETLP) tendon for the US west coast 15MW FOWT, including the design load conditions and design loads. It also provides details of foundation modules and the sequences of module fabrications, transportation, and installation. Additionally, this paper includes the execution plan for foundation installation, addressing the local supply chain and logistics, as well as providing a high-level cost estimate. This study finds that the MSGF option for ETLP FOWT reduces the foundation component level LCOE significantly compared to the traditional pile foundation.

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Probabilistic Modeling and Structural Reliability of Floating Offshore Wind Turbine Structural Components

Doeun Choe
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Introductory Summary

This study presents a computational and mathematical framework to assess the reliability of structural components in Floating Offshore Wind Turbines (FOWTs), accounting for various uncertainties, including those related to parameters, modeling, and interactions between structural, hydrodynamic, and aerodynamic analyses. The framework includes models for structural capacity and environmental demands, considering uncertainties in environmental loads, material properties, and structural geometries. Structural failure modes, such as bending, shear, and drift, are defined in limit state functions. To demonstrate the developed framework, fragility surfaces are developed for one of the benchmark FOWTs in both operating and parked conditions. The impact of wind speed uncertainties on structural reliability is analyzed, with fragility estimates provided for 50-year and 100-year conditions in U.S. coastal regions, including Central California, the West Central Gulf of Mexico, the North Atlantic, and the South Atlantic.

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Effective strategies for wind power integration in the context of dominant hydropower-case of Ethiopia

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Introductory Summary

Hydropower is the dominant source of Ethiopia's power generation accounting for over 90% of its electricity production. Heavy reliance on hydro has left Ethiopia's power sector vulnerable to dry years due to drought and climate change impacts. This has resulted in severe power cuts due to falling reservoir levels of large hydropower plants. In response, the government has started to diversify the country's energy mix with variable renewable resources – mainly wind energy. However, diversification of the power mix cannot be the only strategy to efficiently manage the dry-year challenge. The purpose of this paper is therefore to draw and investigate effective strategies for synergistic operation of wind and hydropower systems in Ethiopia so that the country can parallelly address wind integration impacts and take advantage of the techno-economic opportunity for its renewable resources.

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Grid Classification for Wind Farm and Wind Turbine Design

Eric Loth
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Introductory Summary

As we approach deeply decarbonized electrical grids worldwide, wind energy shares are rapidly rising and projected to reach or even exceed 40% of all energy generation within a few decades for many parts of the world. With the associated intermittency (variability) of wind energy, this large wind energy penetration will lead to progressively problematic mismatches between energy generation and grid demand. Several wind-heavy grids are already experiencing low (or even negative) energy prices when wind energy supply is high and/or grid demand is low, where the result is generation devaluation of wind. This effect can be quantified by the Net Value Factor (NVF), which is the ratio of annual capture price for wind energy relative to that for all forms of energy. Recent data for US grids with wind shares approaching 40% indicate that NVF will also approach 40%, representing a 60% loss in energy revenue due to wind intermittency (variability). However, these losses can be avoided (NVF increased) through three main factors: high-capacity grid transmission, government subsidies/support, and high-capacity long-duration energy storage. To design and develop new concepts of wind turbines and wind farms in such cases, a new grid classification system is proposed based on NVF. Given a Grid Class and Wind Class, a wind energy system and integrated energy storage can be based on annual system costs relative to spot market energy annual revenue.

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Wind Farm Inertia Forecasting Accounting for Wake Losses, Control Strategies and Operational Constraints

Andre Thommessen[1], Abhinav Anand[2], Carlo L. Bottasso[2], Christoph M. Hackl[1]
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Future inverter-based resources (IBRs) will provide inertia emulation functionalities due to decreasing power system inertia. Wind turbines (WTs) can emulate inertia, e.g. by extracting kinetic energy reserves, but this capability depends on volatile operating conditions. Thus, the ability to forecast inertia is of interest for grid and wind farm (WF) operators. In this paper, we propose a method to forecast inertia that accounts for wake effects in a WF. The approach is based on mapping forecasted site conditions to each single WT in the WF through a wake model. The resulting inflow conditions are used to predict the WT inertial emulation capabilities, taking WT control strategies and operating limits into account.

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Impact of wind-wave misalignment on grid integration of offshore wind turbines

Kevin Wyckoff[1,2], Farrah Moazeni[1,2], Javad Khazaei[1,2], Arindam Banerjee[1,2]
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Introductory Summary

Integrating offshore wind turbines into the grid requires accurate modeling of environmental conditions and optimization to ensure the most efficient and economical system. One environmental effect that has not been adequately quantified for power grid integration is wind-wave misalignment. This study seeks to better understand this effect by considering site-specific wind, wave, and regional demand data. Power production estimates will be simulated for a 5MW National Renewable Energy Laboratory reference turbine in an aero-hydro-elastic-servo program, OpenFAST, with particular attention to wind and wave misalignment and directional spreading of waves. The turbine data will be scaled into a farm of up to 20 turbines and connected to a modified IEEE 57 bus system, including storage nodes. The optimal power flow problem will be formulated, and results will be presented to show the effects of wind/wave misalignment, directional spectra, and farm and storage sizing on the grid performance, line voltages, and power losses. Results of the average costs of the system will also be presented.

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Analysis of Data Value in Stochastic Distribution System Optimization with Multiple Data Providers

Mehrnoush Ghazanfariharandi, Robert Mieth
Rutgers University, New Brunswick, NJ, USA

Introductory Summary

Advanced data technologies optimize power distribution but raise privacy concerns. Existing data protection methods can compromise the effectiveness of data-driven tools. To address this, we provide tools for operators to integrate data quality information into decision-making and assess data usefulness. We propose an AC optimal power flow model (OPF) with stochastic parameters and a data quality metric, offering a tractable reformulation and marginal sensitivity analysis as proxies for data value.

Final category: Hybrids and Power to X

Integrated Offshore Wind and Hydrogen Production in the Gulf of Mexico: A Techno-Economic and Environmental Analysis

Honglin Li, Jie Zhang
The University of Texas at Dallas, Richardson, Texas, USA

Introductory Summary

This study explores the sustainable production of hydrogen using exclusively offshore wind energy in the Gulf of Mexico, addressing the critical need for transitioning away from fossil fuels towards more renewable sources. The research employs a multi-objective optimization strategy to effectively reduce costs and maximize hydrogen production. The methodology contrasts the use of centralized versus distributed electrolyzers, assessing their impact on efficiency and scalability in harnessing offshore wind power. It also investigates the optimal integration of onshore grid electricity with offshore wind to exploit subsidy variations for different levels of green hydrogen production. This includes evaluating transport solutions like submarine pipelines for hydrogen and assessing storage solutions such as salt caverns. Anticipated findings aim to demonstrate the feasibility and environmental advantages of offshore wind exclusive hydrogen production, offering significant implications for energy policy and the development of a robust, low-carbon economy.

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Optimal Wind Supported Microgrid Design for Rural Community Resilience Improvement and Stacked Benefit Analysis

Mobolaji Bello, Curtiss Fox
EPRI, Palo Alto, CA, USA

Introductory Summary

Guaranteeing uninterruptible power supply is of paramount importance for critical infrastructure like hospitals, industries and emergency services. This objective becomes challenging when the critical facility is in a rural location mainly supported by wind generation and DER at the end of the feeder and/or is prone to frequent weather hazards. This leads to situations whereby the time required to restore power to the customers during outages can take even up to a few days, in some cases. This is primarily because it's difficult to economically justify employing traditional reliability improvement techniques like vegetation management and installing underground cables in rural locations which are usually sparsely populated large geographical areas. One of the approaches to improve resilience at remote rural communities is to employ microgrids that provide electric service capacity during blackouts. Once the microgrid is designed to meet the minimum reliability target of the critical facility, it can also be used for other secondary applications which increase the economic value that the microgrid offers to the customer.

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Modeling of Wind-Hydrogen Integrated Systems for Resilient Microgrid Operation

Jack Cimorelli, Victor Fnjolo, Christopher Niezrecki, Xinfang Jin, David Willis

In direct response to the Climate Action 2030 initiative, the Department of the Navy has committed to achieving climate strategy objectives with a paramount focus on energy resilience, actively engaging in the development of carbon-free microgrid systems. The zero-carbon emission characteristics of renewables, along with their decreasing cost, make renewable energy sources a great option for microgrids [1]. Microgrids must rely on various energy sources to provide reliable power to the load. Many microgrids do not have access to a utility electrical grid, so they must be capable of supplying their own power despite intermittency from renewables or other energy disruptions. Renewable energy can enhance sustainability and increase the resiliency of a microgrid when coupled with energy storage. This presentation focuses on the use of wind energy for a microgrid that provides direct power and generates hydrogen for energy storage. The technical and economic performance metrics of the system are measured and compared across different scenarios.

113

Supervisory Control of Hybrid Power Plants using Online Feedback Optimization

Wenceslao Shaw Cortez[1], Sayak Mukherjee[1], Genevieve Starke[2], Michael Sinner[2], Brooke Stanislawski[2], Zachary Tully[2], Paul Fleming[2], Sonja Glavaski[1]
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Introductory Summary

This research investigates designing a supervisory feedback controller for a wind-based hybrid power plant that coordinates the wind, solar, and battery energy storage systems to meet desired power demands. We have utilized an online feedback control design that does not require detailed knowledge about the models, known as feedback optimization. This enables us to adjust the active power references of wind, solar, and storage plants to meet the power generation requirements set by grid operators. The methodology also ensures robust control performance in the presence of uncertainties in the weather. In this abstract, we develop a feedback optimization-based supervisory control formulation for wind-based hybrid power plants. Initial numerical experiments show promising results validating the efficacy of the approach.

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Optimizing Wind-Hydrogen Integrated Microgrid Design: Accounting for Wind Speed Fluctuations

Victor Eniola, Jack Cimorelli, Christopher Niezrecki, David Willis, Xinfang Jin
University of Massachusetts, Lowell, Massachusetts, USA

Introductory Summary

Addressing resource intermittency is one of the key factors in sizing and deploying renewable energy systems. Prior studies have acknowledged the potential role of hydrogen as a long-term energy storage medium to increase renewable energy system penetration. Wind-H_2 integrated systems require a system-level sizing of each subcomponent. In this work, a hybrid wind-H_2 microgrid is examined as an alternative to the diesel generators currently used to power the San Nicolas Island (SNI) Navy base in Southern California. The effect of wind speed fluctuations on the optimal sizing of the subcomponents is examined using a rule-based optimization

the Navy facility with several different hypothetical wind speed profiles. The findings reveal that for a fixed mean wind speed, fewer wind turbines and more tanks are needed for higher wind speed fluctuation. On the other hand, the frequency of wind speed had a negligible impact on the sizing of the optimal hybrid wind-H_2 energy storage system. The developed system model can support microgrid system optimization, aiding the U.S. Navy with power-system explorations and comparisons.

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Profit-optimal Data-Driven Operation of a Hybrid Power Plant Participating in Energy Markets under Forecast Uncertainties

Abhinav Anand[1], Jonas Petzschmann[2], Katharina Strecker[2], Robert Braunbehrens[1], Anton Kaifel[2], Carlo Bottasso[1]
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Introductory Summary

An energy management system (EMS) is formulated for a hybrid power plant (HPP) participating in bidding stages in the German energy market. The stochastic optimization within the EMS aims to maximize the HPP economic profit by balancing the revenue obtained by market bidding and the cost of battery cyclic damage, while explicitly considering the uncertainties associated with generation and price forecasts. The formulation utilizes data-driven probabilistic models trained using site-specific historical measurements, as well as a novel online cycle counting approach. When compared with standard formulations, the proposed approach shows an accurate estimation and balancing of revenue and costs and a significant reduction in the power deviation penalty, which leads to significantly higher overall profit.

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Influence of floating offshore wind turbine dynamics on bubble covering in proton exchange membrane electrolysers

Carl Nenoff, Johannes Höflinger
Fraunhofer Institute for Wind Energy Systems, Leuna, Saxony-Anhalt, Germany

Introductory Summary

This study investigates the influence of floating offshore wind turbine (FOWT) motion on bubble dynamics and hydrogen production in a proton exchange membrane electrolyser (PEMEL). Modeling and simulation are used to characterize the coupled dynamics between a FOWT and a PEMEL system. The IEA Wind 22 MW Offshore Reference Wind Turbine model simulates the FOWT dynamics, with outputs passed to a PEMEL model considering bubble coverage effects. The results aim to assess the feasibility and impacts of this novel offshore application of electrolysis using floating wind power.

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Eric Loth
Charlottesville, Charlottesville, Charlottesville, USA

Introductory Summary

A new concept is introduced: the super-rated energy-storing wind turbine, which allows for additional power to be generated by the rotor in Region 3, whereby this surplus energy is diverted to compressed air energy storage. This concept may be well suited for grids which have fluctuating energy prices, especially for grids with high wind shares. Super-rated operation in Region 3 can be designed so that thrust and rotor RPM does not exceed their rated values. This stored energy can be regenerated during Regions 1 and 2, when energy prices are typically highest. The result can allow for energy dispatchability while also boosting the overall Annual Energy Production per turbine, all without changing the size of the rotor, tower, generater, foundation, and export cables. As a case study, super-rating was applied to a 15 MW Offshore Reference turbine by taking into account roundtrip energy storage losses. The results show that annual power production and capacity factor may increase by more than 10% (and more so if larger rotor diameters are employed). Moreover, the dispatchability may create even greater increases in annual energy revenue based on spot market pricing. However, many difficult challenges remain for implementation.

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Replacing Natural Gas Combined-Cycle Plants with Renewable Hybrids

Kaitlin Brunik, Jennifer King, Paul Fleming
NREL, Golden, Colorado, USA

Introductory Summary

The levelized cost of energy has been the primary metric for evaluating the profitability of variable renewable energy (VRE) plants for years. However, as the grid further decarbonizes, the added value of new VRE plants is diminishing. VRE is effective for base-load demand but struggles with intermediate and peak loads, typically managed by carbon-intensive methods like natural gas combined-cycle (NGCC) plants. Hybrid renewable power plants, combining multiple VRE technologies, may mitigate these issues by reducing variability and enhancing resilience. The study explores if fully coupled wind-based hybrid systems, evaluated using a new value metric aimed at accounting for when energy is put on the grid, the Cost of Valued Energy, can be cost-competitive with NGCC plants and meet similar demand profiles.

265

Optimization of Hydrogen Production using Stranded Wyoming Wind

Sarah Buckhold, Jonathan Naughton, Eugene Holubnyak
University of Wyoming, Laramie, WY, USA

Introductory Summary

The state of Wyoming boasts some of the greatest wind resource in the United States. However, much of it remains difficult to develop for wind power due to its distance from existing electrical infrastructure. This leaves the resource stranded, or unable to be utilized. If the electricity generated from the wind turbine could be converted into another form of energy, such as hydrogen that can be transported through means other than the electrical grid, Wyoming could make use of this stranded resource. Hydrogen is expected to play a large role in the energy transition with the DOE releasing goals of producing clean hydrogen for under $2/kg by 2026 [1]. The objective of this study is to highlight specific regions of stranded wind in the state of Wyoming that are near other forms of potential energy transportation, such as rail, highway, or pipeline, and evaluate potential off-grid hybrid power plants including wind to hydrogen and subsequently methanol, ammonia, and SAF. Potential sites will be identified through use of the WIND

final cost per kg of produced hydrogen will be calculated and used to estimate the feasibility of such a project as a means of utilizing Wyoming's stranded wind resource.

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Hercules: A High-Fidelity Co-Simulation Platform Demonstrated by a Reference Hybrid Plant

Genevieve Starke[1], Michael Sinner[1], Brooke Stanislawski[1], Zachary Tully[2], Paul Fleming[1]
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Introductory Summary

This work presents a novel high-fidelity hybrid energy system co-simulation platform called Hercules along with a reference hybrid plant controller for wind, solar and battery storage hybrid plants. This platform is open source code and includes wind, solar, battery and hydrogen modules. The platform is demonstrated using a wind, solar and storage reference plant with a simple controller. The controller is a power tracking proportional controller that can be used to benchmark the performance of future hybrid plant controllers.

Final category: Ocean Sciences

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ECO-Gliders: An autonomous-based oceanographic and ecological mission to inform offshore wind development

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Introductory Summary

With offshore wind construction scheduled to begin in this region within the next few years, it is critical that oceanographic and ecological baseline monitoring begins quickly and considers time scales of natural variability from seasons to years. Our team is initiating a comprehensive "ecoglider" program that will provide a baseline dataset of necessary oceanographic and ecological parameters to inform the responsible development of offshore wind, and provide valuable information relevant to ongoing environmental and ecological change in this productive ecosystem. This survey is being conducted with a pair of gliders deployed in each season over two years with a full complement of available sensors to simultaneously map oceanographic and ecological variables. These ecoglider data map seasonal trends in ecologically relevant oceanographic parameters in wind energy lease areas and explore overlap between oceanographic features and distribution of fishes, marine mammals and their prey.

How Does Coastal Upwelling Influence Offshore Wind Energy?

L. Fernando Pareja Roman, Travis Miles, Scott Glenn
Rutgers University, New Brunswick, NJ, USA

Introductory Summary

Coastal upwelling, characterized by cool sea surface temperatures, affects wind stress and heat fluxes at the air-sea interface. This study uses satellite SST data and a numerical model to explore how coastal upwelling influences the diurnal evolution of the marine boundary layer, with a focus on offshore wind energy in New Jersey. Results show that a stable, upwelling-cooled boundary layer leads to reduced air-sea drag, higher wind speeds at hub height, and greater vertical shear compared to scenarios without upwelling. Coastal upwelling intensifies a local sea breeze that is superimposed on a background shoreward wind. Experiments with parameterized turbines indicate that the 18-hour cumulative power generation at a lease area within upwelling was 6.5% higher than without. While upwelling can influence offshore wind, its impact depends on boundary layer regimes, background wind direction, and larger-scale weather patterns.

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Cold Pool Stratification Influences on Commercial Species Dynamics in the Mid-Atlantic Bight

Samantha Alaimo[1], Bill Bright[2], Jeff Brust[3], Colleen Brust[3], Jeff Kaelin[4], Josh Kohut[1], Daphne Munroe[5]
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Introductory Summary

The Mid-Atlantic Bight Cold Pool is a dynamic oceanographic feature with strong seasonal cycles that supports a diverse array of species. Within the Mid-Atlantic region, development of utility-scale offshore wind facilities could have impacts on the regions associated ecology. This research aims to establish connections between commercially relevant fish species and the regional oceanography associated with the Mid-Atlantic Cold Pool. Baseline results of this work can aid future research studies to distinguish between offshore wind impacts and other drivers.

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Overlap between the Mid-Atlantic Bight Cold Pool and offshore wind lease areas

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Introductory Summary

The Mid-Atlantic Cold Pool is a seasonal mass of cold bottom water that extends throughout the Mid-Atlantic Bight (MAB). Formed from rapid vernal surface warming in the spring, the Cold Pool dissipates in the fall due to mixing events such as storms. The Cold Pool supports a myriad of MAB coastal ecosystems and economically valuable commercial and recreational fisheries. Offshore wind energy has been rapidly developing within the MAB in recent

evaluated using output from a data-assimilative ocean model. Results highlight overlap periods as well as a thermal gradient that persists after bottom temperatures warm above the threshold typically used to identify the Cold Pool. These results also demonstrate cross-shelf variability in Cold Pool evolution. This work highlights the need for more focused ocean modeling studies and observations of wind farm effects on the MAB coastal environment.

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Coastal upwelling off the California coast – a satellite perspective

Ulrike Egerer[1], Geng Xia[1], Virendra Ghate[2], Raghavendra Krishnamurthy[3]
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Introductory Summary

The planning of offshore wind farms off the California coast, near Humboldt Bay in northern CA and Morro Bay in central CA, raises concerns about their potential influence on local wind patterns and, consequently, coastal upwelling dynamics. The coastal upwelling phenomenon is responsible for transporting cold, nutrient-rich waters from the deeper ocean to the surface, nurturing the area's ecosystems and fisheries that are deeply intertwined with the region's cultural identity. As stakeholders voice concerns about the impact of the wind farm developments, this study endeavors to shed light on the interactions between offshore wind conditions and coastal upwelling processes using satellite data. We aim to provide observational insights from a multi-decade time period that deepen the scientific understanding of coastal upwelling processes and eventually inform sustainable energy policies with broader implications for coastal ecosystems.

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Quantifying Tropical Cyclone-Generated Waves in Extreme-Value-Derived Design Input for Offshore Wind

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Introductory Summary

Limited guidance is provided in major offshore standards (API RP 2MET, 2019; DNV, 2018; IEC-614000-3, 2019) for the minimum requirements of ocean models and methods for ocean-model-derived design parameters. This study investigates representation of significant wave height in the mixed-storm climate of the US Atlantic coast for use in offshore wind project N-year design values. Contributing factors are discussed and recommendations provided.

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Risk Assessment of Underwater Glider Turbine Collision

Julia Engdahl, David Aragon, Kaycee Coleman, Travis Miles, Grace Saba, Josh Kohut
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offshore wild by 2030. Offshore structures impact marine surveys and pose entanglement risks, especially for bottom trawling gear. Autonomous underwater vehicles, a staple in oceanographic and ecosystem monitoring surveys, face collision risks with offshore wind infrastructure and entangled gear. This research aims to assess these risks using historical glider tracks and develop strategies to improve glider navigation and obstacle avoidance.

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Ocean-atmosphere coupled effects of offshore wind farms

Hyodae Seo[1,2], César Sauvage[3], Christoph Renkl[1], Anthony Kirincich[1], Julie Lundquist[4,5,6]
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Introductory Summary

By extracting kinetic energy from the atmosphere and altering adjacent flow fields, large-scale, high-density offshore wind farm clusters will modify air-sea flux and marine boundary layer processes. Yet, significant knowledge gaps exist regarding the role and impacts of ocean and air-sea interaction for wind resource modeling and assessments of hydrodynamic and ocean ecosystems. By exploiting cutting-edge, high-resolution, fully coupled ocean-atmosphere-wave model simulations, this study examines coupled ocean-atmosphere processes induced by hypothetical build-outs of offshore wind farm clusters in the MA/RI lease areas. The result shows that if the wind wake effects are represented, the wind speeds are reduced while the planetary boundary layer height (PBLH) increases over the wind plants. Furthermore, during these stably stratified conditions, the sea surface temperature (SST) cools less (i.e., warms anomalously) in the presence of operating wind turbines, which is attributed to reduced shear-driven and breaking wave-induced vertical mixing and advection in the ocean. Complementary atmosphere-only simulation, where the warm SST response to wind farms is removed in the SST forcing, indicates that this warm SST was responsible for ~20% of the PBLH increase and ~20% of the wind deficits seen from the coupled simulations. The SST impacts are limited within the atmospheric surface layer, with little impact on hub-height wind fields. However, the ocean coupling effects significantly influence the air-sea momentum and heat fluxes, which are critical for oceanographic investigations and monitoring wind farm effects.

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Spectral Analysis of Power Fluctuations of a Scaled Tidal Turbine subjected to Homogeneous Grid Turbulence

Mohd Hanzla[1,2], Arindam Banerjee[1,2]
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Introductory Summary

Tidal turbines operate in highly turbulent environments, affecting performance and causing power fluctuations that require costly grid synchronizers. Understanding how flow turbulence influences these power fluctuations is crucial for optimal design and operating protocols. An experimental study was carried out using a 1:20 scaled turbine (diameter, D=0.28m) in a water tunnel equipped with a novel active grid turbulence generator. Spectral analysis on turbine power fluctuations examined the effects of turbulence intensity, integral length scale, periodic/coherent structures, and tip-speed ratios. The study identified three distinct frequency

elevated turbulence causes steeper decay and dampening of the spectral peaks. The presence of a larger integral length scale $\sim\mathcal{O}(D)$ shifts the decay region to lower frequencies with an increase in amplitude in the low-frequency region while it drops in the mid-frequency region compared to the elevated turbulence case. Meanwhile, the turbine shows signatures of the periodic/coherent structures, which can significantly enhance blade fatigue loading.

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Using autonomous gliders to understand baleen whale habitat use in the New York Bight

Katherine Gallagher[1], Lesley Thorne[1], Maha Alnajjar[1], Jack McSweeney[1], Charles Flagg[1], Joseph Warren[1], Travis Miles[2], Josh Kohut[2], Julianne Wilder[3], Mark Baumgartner[4]

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Introductory Summary

Passive acoustic monitoring (PAM) is a key tool for assessing cetacean populations and when mounted on autonomous systems, provides the opportunity to survey these populations in traditionally under-surveyed regions without significantly increasing man hours. We use autonomous glider deployments in the New York Bight, an area with historically limited marine mammal survey effort, to describe baleen whale habitat use in this region. Offshore wind development is planned for the region, so understanding baleen whale habitat use prior is necessary to reduce human impacts on local species.

222

Large-eddy simulations of the offshore atmospheric boundary layer with waves using the volume of fluid method

Luis Martinez Tossas

NREL, Arvada, Colorado, USA

Introductory Summary

The US has ambitious goals to install 30 GW of offshore wind generation capacity by 2030. Unlike on land, oceanic atmospheric boundary layer conditions are influenced by wave dynamics, which affect the airflow through wind turbines. In this work, we seek to understand the interactions between the waves and the atmospheric boundary layer using large-eddy simulations and the volume of fluid method.

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Introductory Summary

Sea surface waves influence the vertical structure and turbulence characteristics of the marine atmospheric boundary layer (MABL) flow. In this study, we develop a novel model to predict wave-induced airflow fluctuations above monochromatic surface waves by building upon a linearized viscous curvilinear model previously derived in Ref. [1] (Cao et al., J. Fluid Mech., vol. 901, 2020, p. A27). We extend the model by incorporating turbulent stress terms which are modeled using the Boussinesq eddy viscosity hypothesis. The eddy viscosity is further parameterized with Prandtl's mixing length model in curvilinear coordinates. We conduct a range of Large Eddy Simulations (LES) of wind-over progressive waves for wind-following and wind-opposing wave scenarios for different values of wave steepness and wave ages. The model is fine-tuned using these simulations, resulting in an Orr-Sommerfeld-like ordinary differential equation (ODE) with additional eddy viscosity terms. Our findings demonstrate that solving the viscous curvilinear model equations, along with closure modeled turbulence stress terms, yields better predictions of wave-induced vertical fluctuations compared to the linearized model, across different wave scenarios.

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Application of a moving surface drag model to realistic multiscale ocean surfaces

Manuel Ayala[1], Zein Sadek[2], Ondrej Fercak[2], Raul Bayoán Cal[2], Dennice Gayme[1], Charles Meneveau[1]
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Introductory Summary

Investigating the impact of wave motion on wind turbine power output in large offshore wind farms over the full parameter range of interest requires a computationally efficient approach. Recently, Ayala (2024) proposed and validated the moving surface drag (MOSD) model, which enables wall-modeled Large Eddy Simulations (LES) to capture critical features of wave-wind interactions, including phase information and the momentum transfer in a cost-effective manner. This study demonstrates the model's robustness and accuracy in predicting momentum transfer under realistic wind-wave conditions. Using LES, we simulate neutral atmospheric flow over various ocean wavefields with realistic spectra. Results of LES with the MOSD model closely match first-order turbulent statistics from more computationally intensive simulations. Preliminary comparisons with data from a fully resolved offshore wind farm highlight the applicability of this approach as a practical method for incorporating wave effects in wind energy studies

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Surface wave response to offshore wind farms off the Coast of New England

Cesar Sauvage[1], Hyodae Seo[1,2]
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Introductory Summary

Offshore wind turbines extract kinetic energy from the atmosphere at wind plant scales, reducing wind speeds and

response to hypothetical large-scale wind farms in the Northeast of the U.S. Coast. Preliminary analysis shows that reduced hub-height wind speeds in the wind farm areas and the downstream extensions (wind wakes) are manifested strongly in some (but not all) of the surface wave fields. Indeed, the significant wave height, wave-supported wind stress, wave-to-ocean stress, and wave-to-ocean energy flux are consistently reduced by 10-30% in response to decreased wind speed near the wind plants. The magnitudes and the downstream extensions of these responses depend on background wind direction, with onshore winds causing stronger responses in height and direction near the coasts and offshore winds generating far-reaching wave wakes of similar scale to the wind wakes. Because of the strong modulation of the turbulence and thermodynamics processes in the upper ocean by the surface waves, this study emphasizes the need for accurate monitoring and modeling of the upper ocean mixing and the wave-ocean coupling effects near the wind farms.

Final category: Offshore Infrastructure, Supply Chain, and Policy

16

Feasibility study on monitoring scouring for subsea cables of offshore wind turbines using distributed fiber optic sensors

Rojyar Barhemat, Yi Bao
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Introductory Summary

Subsea cables are critical components of offshore wind turbines and are subjected to scouring. Monitoring the scouring conditions of subsea cables plays significant roles in improving the operation efficiency and reducing the levelized cost of electricity. This paper presents a feasibility study on monitoring the scouring conditions of subsea cables using distributed fiber optic sensors, aiming at evaluating the technical and economic feasibility as well as the performance in detecting, locating, quantifying, and visualizing scouring conditions. A finite element model was developed to evaluate the impact of scouring on the mechanical responses of subsea cables, and laboratory experiments were conducted to validate the finite element model and verify the performance of distributed fiber optic sensors in monitoring scouring effects. The results showed that the proposed method was feasible for monitoring subsea cables technically and economically. This research offers insights into monitoring subsea structures for offshore wind turbines.

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A Comparison of HVAC and HVDC Export Cables for Offshore Wind Transmission

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Introductory Summary

A comprehensive analysis is performed assessing the differences in performance, cost, and industry trends of offshore wind farms that utilize HVAC and HVDC export cables for submarine power transmission.

and HVAC can be complex and will impact the wind farm's performance, capital cost, cable manufacturing and installation schedules, and substation equipment needs.

To aid in navigating these complexities, a comprehensive analysis of cost estimates, power losses, and the supply chain is completed. Historical trends for export cable types are determined based on projects that are existing, or actively under construction. Correlations are made between distance to shore, wind farm capacity, and export cable types. Industry personnel can use this research to understand deciding factors for the export cable types in offshore wind farms, and market trends for specific countries.

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Quantifying the Gap: A Supply and Demand Assessment of U.S. Offshore Wind Vessels Over the Next Decade

Daniel Mulas Hernando, George Hagerman, Matt Shields
NREL, Denver, Colorado, USA

Introductory Summary

American Clean Power estimates that each offshore wind project requires two to three years for offshore installation, requiring a minimum of twenty-five vessels per project across all stages. In 2023, the National Renewable Energy Laboratory (NREL) reported that without a significant investment in large installation vessels like Wind Turbine Installation Vessels (WTIVs), Heavy Lift Vessels (HLVs), and feeder barges, over half of the U.S. offshore wind projects could face delays beyond 2030. With U.S. developers revealing project plans, the simultaneous scheduling of multiple projects with similar Commercial Operation Dates may suppose a high demand for the key offshore wind construction and Operation and Maintenance vessels over the next decade. Varying project characteristics and construction plans make it challenging to predict when vessels will be required to meet project schedules. Through our assessment, we analyzed Construction and Operation Plans from multiple U.S. projects to estimate vessel demand, considering their proposed installation schedules. This approach allows us to forecast vessel needs for Crew Transfer Vessels, Service Operation Vessels, Wind Turbine Installation Vessels, Feeder Barges, Heavy Lift Vessels, and Cable Lay Vessels throughout the 2020s and 2030s. By tracking the availability of Jones Act compliant vessels, we identify gaps in vessel supply, highlighting the need to source vessels from international markets in the short to medium term and promoting U.S. built or retrofitted vessels for long-term solutions. This assessment helps governmental bodies understand the magnitude of the problem and creates awareness in the industry for short- and long-term solutions.

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Capacity Density Considerations for Floating Offshore Wind Farms in Deep and Ultradeep Waters

Daniel Mulas Hernando, Patrick Duffy, Aubryn Cooperman, Stein Housner, Matt Hall
NREL, Golden, CO, USA

Introductory Summary

Capacity density, measured in megawatts per square kilometer (MW/km2), is crucial for state and federal planning and

limited data on commercial-scale floating projects. Moving forward, a detailed investigation into factors influencing capacity density in floating offshore wind projects is essential. These factors include considering turbine-to-boundary distances and turbine spacing requirements to accommodate the mooring systems in the wind plant layout. In this analysis, we compare estimates of capacity density for commercial-scale floating offshore wind farms with different mooring system topologies (tension-leg platform [TLP], catenary, taut, and semi-taut) and different anchor configurations (shared and non-shared anchors) over a range of deep (300 - 1,300 meters) and ultradeep waters (1,300 - 3,000 meters). This analysis helps determine the achievable capacity densities of commercial-scale floating offshore wind projects and informs strategic planning requirements necessary for meeting supply chain and policy targets.

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Reference monopile designs for US East Coast sites supporting the IEA 15 MW reference turbine using a novel conceptual design methodology

Maciej M. Mroczek[1,2], Sanjay Raja Arwade[1], Michael Davis[1], Spencer Hallowell[3], Andrew Myers[4], Raditya Danu Riyanto[4], Weichiang Pang[5]

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Introductory Summary

The presentation is intended to disseminate the findings published in Mroczek et. al. (2024). Reference monopile designs for US East Coast sites supporting the IEA 15 MW reference turbine using a novel conceptual design methodology.

A novel monopile conceptual design methodology was developed and implemented considering position specific environmental conditions at four US East Coast sites. The design methodology considers the ultimate limit state (ULS), fatigue design, serviceability requirements, and natural frequency limitations. Time domain simulations were carried out in OpenFAST, considering an intentionally reduced set of design load cases defined in IEC 61400-3-1. The monopile diameter and wall thicknesses at mudline were found to be governed by fatigue in 11 of 12 cases, with the maximum ULS utilization ratio varying between 0.63 – 0.81. The one exceptional case exhibited a combination of breaking waves and a large significant wave height leading to high ULS loading. The novel design methodology includes a preliminary FLS design step which was found to be an efficient method for selecting an initial foundation geometry for further detailed calculations, while providing a 92% computational efficiency improvement. The resulting reference monopile designs are available for use by the research community for further studies.

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A Multi-Criteria Compatibility Analysis to support Decision-Making on Offshore Wind Areas in Atlantic Canada

Ryan Kilpatrick, Kaniz Sultana, Gemma Caesar

Natural Resources Canada, Ottawa, Ontario, Canada

Introductory Summary

Offshore wind represents a potentially significant source of low-carbon energy for Canada, and ensuring that relevant,

geographic information system (GIS) software and methods and engaged with multiple federal government departments and agencies to acquire relevant data and obtain insights from subject matter experts on the appropriate use of these data in the context of the analysis. The purpose of this work was to support the identification of candidate regions within Atlantic Canada that could become designated offshore wind energy areas in the future.

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Race To The Bottom: A Comparison Between Gravity-Base Foundations and XXXL-Monopiles for U.S. Offshore Wind

Nicholas Riccobono, George Hagerman, Garrett Barter, Matt Shields
NREL, Golden, CO, USA

Introductory Summary

Today, monopiles are the most common foundation for offshore wind turbines. Despite their significant market share, monopiles may not be suitable for all projects. Depending on water depth, soil conditions, environmental or ecological constraints, and supply chain issues for a given project, an alternative foundation may be more beneficial. Gravity-base foundations (GBF) have been demonstrated as viable foundations for offshore wind turbines in Europe. We will use open-source optimization and modeling software for the analysis in this comparative study between monopiles and GBFs. We include case studies to compare the levelized cost of energy (LCOE) at different wind sites in United States waters as well as a qualitative evaluation of supply-chain factors needed to mitigate project risks.

Final category: Reliability, Operations, and Maintenance

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In-Situ Optical Composite Rotor Damage Detection

Dan Kominsky, Jessica StClair, Charles Backlund
Luna Innovations, Blacksburg, VA, USA

Introductory Summary

A Rapid In-Place Composite Rotor Damage Detection (RIPCoRDD) System was developed for determining and tracking the structural health of composite turbine blades. This system allows for both the complete characterization of the strain state of a blade, as well as detection and characterization of changes in the residual strain present in the composite. This fulfills the need for accurate and reliable assessment of the condition of composite parts which may have been damaged through impacts or fatigue, especially for cases where damage is not visible from the surface. The approach utilizes high-definition fiber optic strain sensors (HD-FOS). Sensor lengths up to 100 m can be embedded during fabrication and provides spatially dense strain measurements (sub-millimeter) from within the composite structure. In this work, HD-FOS is used to build a system of spatially distributed strain rosettes over flat and curved surfaces. The software and algorithmic work developed for interpreting the RIPCoRDD system output is described. Finally, the system is characterized through a series of impact tests performed on panels and beams. This data is used as a training data set to distinguish impact based on distance to the fiber sensor as well as energy content. Blind testing of the impact damage detection algorithms is shown to achieve a success rate of 94%. This approach can be applied to a variety of composite structures as a means of assessing if they have sustained damage during service.

Enhanced Blade Reliability Through Advanced Blade Testing Methods

George Blagdon, Carly Lavender, Connor Read, Larry Trentin, Nic Lawson, Rahul Yarala
MassCEC, Boston, MA, USA

Introductory Summary

All wind turbine blade models must undergo structural testing following the IEC 61400-23 standards to receive required type certification.

Current testing includes static and fatigue testing in the edgewise and flapwise directions and is not a full representation of blades in operation [1]. The Massachusetts Clean Energy Center's Wind Technology Testing Center (WTTC) has compiled a research portfolio for test methods to enhance blade reliability through advanced testing based in three methods; Subcomponent Testing, Torsion Loading, and Combine Fatigue Loading.

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The Importance of Surface Preparation in Leading Edge Protection Durability

Marianne Rodgers
Wind Energy Institute of Canada, Tignish, PE, Canada

Introductory Summary

Harsh weather can erode the surface coating and protective layers of wind turbine blades, eventually affecting the structural integrity of the blades. Many types of leading edge protection (LEP) materials have been designed to help prevent the erosion of the blade edge. Since 2016, WEICan has carried out a field test of five different LEP materials. This field test provides an operational perspective on the effectiveness of different types of LEPs for wind turbine blades. We will discuss the surface preparation and application techniques required for installation of each of the types of LEP and investigate observed issues, their causes and their effects on performance and maintenance costs.

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Advanced Joint Optimization of Predictive Maintenance Scheduling and Spare Parts Ordering for Offshore Wind Farms

Marco Borsotti, Rudy Negenborn, Xiaoli Jiang
TU Delft, Delft, Netherlands, Netherlands

Introductory Summary

This paper introduces a novel optimization framework for improving Operation and Maintenance (O&M) of Offshore Wind Farms. Unlike previous models, this framework combines short and medium-term decision-making processes by integrating prognostic analytics with Model Predictive Control (MPC) principles to optimize both spare parts logistics and maintenance scheduling. The first phase of the model uses probabilistic Remaining Useful Life (RUL) predictions to

utilization.

The adoption of this model addresses critical gaps in current O&M practices by effectively utilizing condition-based monitoring (CBM) and RUL predictions to reduce maintenance cost for Offshore Wind Farms.

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Enhancing Offshore Wind Farm Reliability: The Role of Distributed Fiber Optic Sensing (DFOS) in Operations and Maintenance

Yangmin Ding[1], Yue Tian[1], Junhui Zhao[2], Rojyar Barhemat[3], Ting Wang[1]

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Introductory Summary

Offshore wind farms (OWF) are essential for achieving renewable energy targets, but their efficient operations and maintenance (O&M) are crucial for ensuring reliability and maximizing energy output. Traditional monitoring solutions, while useful, are often complex and resource intensive. This work introduces a transformative approach using Distributed Fiber Optic Sensing (DFOS) to monitor and maintain offshore wind farms. By integrating DFOS with Finite Element Analysis (FEA) and advanced machine learning algorithms, the proposed solution can predict and mitigate potential failures in offshore wind infrastructures. Initial validation results confirm the accuracy of the FEA model for thermal analysis of a submarine cable. Future work will include real-time data integration from DFOS interrogators to further enhance predictive maintenance capabilities.

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Generation of Synthetic SCADA Signals using Conditional Generative Adversarial Networks for Enhanced Wind Turbine Fault Detection and Prognosis

Ali Eftekhari Milani[1], Donatella Zappalá[1], Francesco Castellani[2], Simon Watson[1]

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Introductory Summary

Wind turbine SCADA datasets available for research purposes usually include very few failure events for any given component. This hinders the successful application of Deep Learning (DL) methods for fault detection and prognosis since they require large datasets for robust training and generalisation. This work proposes a method using Conditional Generative Adversarial Networks (CGANs) to generate synthetic SCADA signals that reproduce the wind turbine behaviour under various operational and environmental conditions. Results show that augmenting the training set of an Artificial Neural Network (ANN) failure detection model with these synthetically generated signals significantly reduces the false alarms occurring due to the availability of only one failure event for training, leading to a blind detection of a fault in one of the test wind turbines.

200

Christoph Bleicher, Jörg Baumgartner, Jan Niewiadomski
Fraunhofer LBF, Darmstadt, Hessen, Germany

Introductory Summary

Reliability, safety, and the lifetime of wind energy systems are mainly driven by the quality of the single components. Especially, larger structures made of cast material and the welded structures are subjected to cyclic loading. In these cases, local material defects or on the other hand improved microstructures lead to a lower or higher strength of the material and drive reliability concerns. While defects need new and practical methods to assess their negative influence on fatigue strength, wind energy components can profit from new cast materials and welding procedures with improved microstructures to enable a lightweight and more reliable component design.

The paper discusses reliability aspects and the lifetime assessment of cast and welded wind energy components based on production quality. Therefore, new methods based on the quality assurance process are presented coupling digital non-destructive test results with local fatigue strength of cast and welded components with defects. Moreover, newer achievements in improved materials and production quality and their benefit for lifetime and lightweight are discussed based on modern cast iron materials like high silicon nodular cast iron.

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Opportunities in O&M Costs by Fixing Right the First Time

Amin Ahmadi, Hans Fernandez
AP Renewables, Hamilton, ON, Canada

Introductory Summary

Inefficiencies in troubleshooting and corrective maintenances result in loss of production and added labor and parts costs that increase the Cost Of Energy(COE) and hurt the project ROI. A more methodical approach to maintenance, including the use of data and AI, to enable fixing assets on the first visits, bundling activities, and reducing unnecessary revisit will reduce the total operating cost. To quantify the opportunity, this work presents a budgetary analysis of the prevalence of the number of revisits for a possible single root cause in the pitch system and hydraulics of 200 turbines over 5 years. It focuses on quantifying the downtime and labor costs of multiple visits for the same root cause. Many wind analytics systems focus on performance optimization of running assets for residual gains and analysis of the downtime and failure prediction, and less so on assistance in troubleshooting. This work shows the potential for gains by accelerating the troubleshooting.

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A Time-Frequency Analysis Approach for Multi-Class Fault Diagnosis of Wind Turbine Drive Trains

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[1]New Jersey Institute of Technology, Newark, New Jersey, USA. [2]City University of Hong Kong, Kowloon, Hong Kong SAR, Hong Kong

Introductory Summary

Signal processing and fault indicator analysis enable early anomaly detection, accurate fault

from traditional condition monitoring systems e.g., SCADA systems exhibit non-linear and non-stationary characteristics, reflecting intermittent conditions. Although conventional signal processing techniques like Fourier transform analysis have been applied to interpret these signals, they have not been commercialized due to concerns regarding their complexity, accuracy, and lengthy response times, especially in accurately extracting discriminative features robust to non-linearities and non-stationarities present in the signals. This renders multi-class classification techniques ineffective. This work proposes to employ a Time-Frequency analysis approach using Hilbert-Huang Transform (HHT) on the magnetic flux density fault data to adaptively decompose the signal into a series of time and frequency dependent components. The magnetic flux density data contains the fault signatures of both mechanical and electrical components of the wind turbine drive train. Unlike traditional signal processing methods, HHT exploits relationships between signals and local extrema to derive the instantaneous spectral representation, without assuming signal linearity or stationarity. By integrating HHT with a supervised machine learning algorithm, a remote condition monitoring system is showcased, capable of extracting fault signatures from non-linear and non-stationary signals. This will not only enhance real-time monitoring and fault detection but also reduce downtime and maintenance costs, thereby lowering levelized cost of energy for wind turbines.

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Operational Blade Monitoring using a Sparse Acoustic Sensor Array

Murat Inalpolat, Christopher Niezrecki
University of Massachusetts Lowell, Lowell, Massachusetts, USA

Introductory Summary

Wind energy capacity has increased nearly tenfold in the United States over the last decade, driven by a transition to renewable energy and a reduction in costs for new wind projects. Compared to a total project budget, operation and maintenance (O&M) can be a significant portion of a project's final levelized cost of energy. O&M costs can include scheduled and unscheduled inspection, maintenance, and repairs. Frequently scheduled inspections can identify damage before failure but are costly and time-consuming. Reducing the frequency of scheduled inspections and eliminating unscheduled repairs would reduce the total O&M costs, however some components – such as the turbine blades – require frequent inspection. Damage to turbine blades is both common and expensive. Blades are one of the five most frequently damaged components of a wind turbine, and per-repair, blade damage is one of the three costliest components to restore. To reduce the need for scheduled inspections and unscheduled repairs of turbine blades, a passive acoustic monitoring system using a sparse sensor array has been developed and tested in operation. Initial data collected from this monitoring system in the field will be discussed along with practical explanations on the benefits of using such systems for operational monitoring of wind turbines.

Final category: Rotor Aerodynamics and Aeroelasticity

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Reduced-order model to study the impact of nonlinearaerodynamics on

Introductory Summary

We explore the aeroelastic stability of wind turbine blades using a reduced-order model. Our “quasi-3D” model resembles a 2D cross-section model but incorporates some three-dimensionality of the blade structure and aerodynamics. By utilizing 2D nonlinear aerodynamics as inputs, we gain insights into how different aerodynamic models influence wind turbine blade stability. Additionally, we compare our quasi-3D approach with the full 3D approach of OpenFAST and conduct parametric studies to investigate the factors affecting aeroelastic stability.

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On the unsteady aerodynamics of two-dimensional Gaussian body forces

Emanuel Taschner[1], Georgios Deskos[2], Jan-Willem van Wingerden[1], Luis 'Tony' Martinez-Tossas[2]
[1]Delft University of Technology, Delft, South Holland, Netherlands. [2]National Renewable Energy Laboratory, Golden, Colorado, USA

Introductory Summary

The actuator line model is a popular approach to simulate wind turbines in large-eddy simulations (LES) given its balance between computational cost and accuracy. However, the required projection of the ALM forces using a Gaussian regularization kernel is a source of intrinsic error since its optimal width is known, but hardly to fulfill in LES for wind turbine applications. As a remedy various successful corrections were proposed which, however, resort to the assumption of quasi-stationary conditions or neglected spanwise shed vorticity. In this work we develop an unsteady solution to take the impact of suboptimal Gaussian kernel widths on the unsteady loading explicitly into account. A further future extension to three dimensions could result in an unsteady filtered lifting line theory.

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Unified Momentum Model for wind turbine aerodynamics across operating regimes

Jaime Liew, Kirby Heck, Michael Howland
Massachusetts Institute of Technology, Cambridge, MA, USA

Introductory Summary

Aerodynamic modeling of wind turbines largely relies on classical, one-dimensional momentum theory, derived in the late 19th century. However, momentum theory is well known to break down at higher thrust coefficients as well as in situations of misalignment between the inflow and the rotor, which is commonly encountered in practice and especially when applying wind farm flow control. This abstract reports a Unified Momentum Model to efficiently predict power production, thrust force, and wake dynamics of rotors under arbitrary inflow angles and thrust coefficients without empirical corrections. The model is validated against large eddy simulations in uniform and turbulent atmospheric boundary layer conditions. The Unified Momentum Model is additionally coupled with a blade element model to enable blade element momentum modeling predictions of wind turbines in high thrust coefficient and yaw misaligned

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Relevance of second order dynamic stall models in predicting turbine blade vibrations at high angles of attack

Tanmoy Chatterjee
GE Vernova Advanced Research Center, Niskayuna, NY, USA

Introductory Summary

Severe fatigue damage can occur due to stall or vortex induced vibrations (SiV, ViV) of wind turbine blades operating in idling or parked conditions as a part of installation or maintenance procedure. Conventional unsteady legacy aerodynamic models like Beddos-Leishman (BL) model fails in the deep stall region at higher angles of attack ($\alpha > 50^\circ$) when vortex shedding occurs. Several ODE-based complex non-linear second order models have been explored in the past, but the errors against experimental data cannot be reduced below ~ 20%. This manuscript attempts to dissect the under-pinning physics of the second order models and provides a way to adapt to a more simplified & interpretable model without jeopardizing with the accuracy. Additionally, the current work will further analyze and highlight how these second order models can be implemented in the deep-stall regime and what needs to be done to improve the adaptability of these stall models for ViV.

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Experimental analysis of dynamic stall at large angles of attack

Guanqun Xu, Pepijn Slooter, Wei Yu, Andrea Sciacchitano, Carlos Ferreira
Delft University of Technology, Delft, South-Holland, Netherlands

Introductory Summary

The dynamic stall effect on airfoils has been extensively studied within a limited range of angles of attack (AoA). However, in wind turbine applications where the turbine may be at a standstill, larger mean AoAs are expected, potentially leading to vortex-induced vibration (VIV). This research aims to study the dynamic stall effect of an airfoil above 25° as these angles hold significance related to turbines at standstill turbine conditions. Surface pressure measurements and Particle Image Velocimetry (PIV) measurements were performed on a NACA 643418 airfoil within a low-turbulence tunnel. Tests were conducted across a range of reduced frequencies (k) from 0.05 to 0.21, and pitch amplitudes ($\Delta\alpha$) varying from 5° to 15°, encompassing large mean AoAs up to 160°. Further analysis will be conducted to understand the influence of k and $\Delta\alpha$ on the hysteresis loop. By conducting the frequency analysis, the connection between the static shedding frequency and the motion frequency will be established. Furthermore, by comparing the results between pressure and PIV measurement, deeper insights will be gained into flow field characteristics, especially the influence of vortex separation on force outcomes.

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Preliminary Design of an Offshore Rotor for Low Wind Speed Regions

Francesco Papi, Alessandro Bianchini
Università degli Studi di Firenze, Florence, Italy, Italy

Offshore wind energy has experienced significant growth in recent years. The vast majority of offshore turbines currently in operation are fixed-bottom turbines, located in coastal areas with shallow waters and high wind speeds. Floating wind turbines are designed to operate in deeper waters and have the potential to enable new markets for offshore wind energy. Among them are sea basing with lower wind speeds such as the Mediterranean Sea. However, current-generation offshore turbines feature high specific power, leaving significant potential for optimization when installed in lower wind speed basins. In this study an offshore rotor designed for low-wind speed regions is conceived to have a specific power of approximately 200 W/m2. The preliminary design presented herein will act as baseline for future studies and optimizations.

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Rapid System Identification of Rotor Aerodynamics: Comparison of Models Derived from Wind Tunnel and Static Thrust Experiments

Gregory Methon, Mohammad Katibeh, Onur Bilgen
Rutgers University, New Brunswick, New Jersey, USA

Introductory Summary

This research examines theoretical and experimental methods to rapidly model the impact of pitch angle variation on power generation of a wind turbine rotor. The research ultimately aims to deduce all the necessary aerodynamics coefficients from static thrust experiments as opposed to using highly complicated and expensive wind tunnel experiments. Critical yet hard-to-determine coefficients such as lift, drag, and pitch coefficients, span efficiency, etc., as a function of pitch angle, tip-speed-ratio, Reynolds and Mach numbers, and other critical operational and environmental conditions are of interest. This research will consider both theoretical and experimental processes to estimate power generation from static thrust experiments and validate/compare these predictions to results from experiments conducted in a wind-tunnel.

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Influence of Wake Turbulence and Atmospheric Stability on the Aerodynamics of Large-Scale Wind Turbine Blade Sections

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[1]University of Colorado, Boulder, Boulder, Colorado, USA. [2]National Renewable Energy Laboratory, Golden, Colorado, USA

Introductory Summary

As wind turbines continue to grow in size, understanding the impact of atmospheric conditions on their performance becomes increasingly important. This study explores the influence of atmospheric stability and wake turbulence on large wind turbines through high-fidelity simulations of two IEA 15-MW turbines separated by seven rotor diameters. By analyzing inflow profiles and blade section loads, the authors aim to quantify the effects of shear and freestream turbulence on a wind turbine's unsteady loads. The results reveal that transitioning from neutral to convective atmospheric stability leads to decreased shear in the mean velocity profile and increased turbulence levels. Wake turbulence increases the magnitude of inflow turbulence levels for a downstream wind turbine, leading to greater deviation in wind turbine loads. The findings of this study aim to contribute to the development of more resilient wind turbine designs by providing insights into the relative importance of shear and turbulence intensity in the dynamic loads experienced by wind turbine blade sections.

Boundary Layer Transition Characteristics of DU00-W-212 Wind Turbine Airfoil: 2D RANS Simulations and Experimental Measurements

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Dept. of Aerospace Engineering, METU Center for Wind Energy Research (RÜZGEM), Middle East Technical University (METU), Ankara, N/A, Turkey

Introductory Summary

Significantly affecting lift and drag characteristics, laminar-to-turbulent boundary layer transition is of paramount importance in wind turbine airfoil aerodynamics and blade design. Therefore, prediction of transition location is crucial for accurate determination of airfoil aerodynamic polars. This study aims to investigate boundary layer transition characteristics of DU00-W-212 wind turbine airfoil through comparisons between experimental results obtained using infrared thermography (IRT) and CFD simulations obtained using two different CFD solvers. Using various turbulence and transition models, lift-to-drag ratio (Cl/Cd) predictions and comparisons with two-different experimental datasets ([9] and [15]) for an angle of attack range varying from -10° to 20° are performed at $Re=3x10^6$. Although fully turbulent models show poor agreement when compared to experiments, both the GEKO and SA-LM transition models demonstrate significantly better agreement with experiments regarding Cl/Cd. In addition, transition locations on suction side of DU00-W-212 wind turbine airfoil predicted by CFD simulations are compared with the experimental data [9]. The transition positions are predicted accurately by the transition models when $\alpha<6°$. However, a noticeable decrease in agreement between the CFD simulations and experimental data is observed when angle of attack is increased.

202

Validation of Inflow Creation Methods Using Data Assimilation Against SCADA Data: Trends from a field campaign

Dan Houck, Nathaniel deVelder, Tommy Herges, Kenneth Brown, Chris Kelley
Sandia National Labs, Albuquerque, NM, USA

Introductory Summary

This presentation will provide results comparing four different inflow generation methods assimilating varying amounts of field measurements to drive OpenFAST simulations using two controller methods to ultimately determine trends upon processing approximately 5,000 10-minute bins.

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Observation informed, LES inflows for one-to-one validation of utility-scale turbines: a computational and real-world study

Alex Rybchuk[1], Luis A. Martínez-Tossas[1], Stefano Letizia[1], Nicholas Hamilton[1], Andrew Scholbrock[1], Daniel R. Houck[2],

Introductory Summary

We present an approach to enable one-to-one validation of utility-scale turbines using large-eddy simulation (LES). Our technique leverages a combination of machine learning (ML) as well as traditional analysis techniques in the wind sector. We validate our technique using a combination of real-world field campaign measurements as well as synthetic field campaigns.

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Aerodynamic Characterization of 3D Scanned Wind Turbine Blades Using Experimental and Computational Methods

Aaron Rosenberg[1], Christopher Kelley[2], Murray Fisher[1], Joe Lotuaco[1]
[1]Gulf Wind Technology, New Orleans, LA, USA. [2]Sandia National Laboratory, Albuquerque, NM, USA

Introductory Summary

Details of the development of an industrial wind tunnel for use on wind turbine problem statements is outlined, including validation of tunnel with experimental and CFD campaigns. Application and use of the tunnel and CFD methods for the validation of wind turbine blade manufacturing defects on turbine performance and loads is presented as an example use case.

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Avoiding Mistakes with the Actuator Line Method: Verification and Validation Techniques

Michael B. Kuhn, Luis A. Martinez-Tossas
National Renewable Energy Laboratory, Golden, CO, USA

Introductory Summary

Verifying the accuracy of an actuator line method (ALM) implementation is important, as this model has widespread use in a variety of fluid dynamics solvers for wind energy modeling. However, the most common approaches involve steady-state simulations of static wings or full turbine simulations in uniform flow. The former lacks motion, a key feature of the ALM, and the latter is dependent on the tunable epsilon parameter, preventing direct conclusions about accuracy. Verifying an actuator line implementation directly is difficult due to the assumptions made in the model, the interplay between the momentum forcing and the velocity sampling, and the reliance of steady-state actuator line theory on linearization of the governing equations. Despite these challenges, we propose a technique for verifying an actuator line in motion, along with other validation checks. Finally, we discuss how implementation errors can significantly impact turbine predictions.

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Reynolds Scaling of Wind Turbine Rotors Using Compressed Air

Mark Miller, Desirae Major, Kyle Devlin, Sven Schmitz
Penn State University, University Park, PA, USA

Information on wind turbine scaling performance is sparse because flow similarity requirements place a strict limitation on the freestream wind speed of conventional wind tunnels. In this work, the Penn State Compressed Air Wind Tunnel will be used to achieve low kinematic fluid viscosities and full-scale relevant Reynolds numbers (order $x10^6$) using scale models. Two different rotor geometries will be tested, including the NREL Phase VI and a wake-scaled Low Induction Rotor concept. Comparisons will be made with existing experimental data sets and with numerical methods to assess scaling behavior.

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The influence of wind speed and direction shear on rotor aerodynamics

Storm Mata, Michael Howland
Massachusetts Institute of Technology, Cambridge, MA, USA

Introductory Summary

Wind speed and direction shear across the rotor area affect power production. Conventional parametric turbine power modeling techniques, like those prescribed by the IEC for wind resource assessment, do not consider the influence of the incident wind on efficiency or the velocity induced at the rotor. Subsequently, these models are limited in their ability to account for the aerodynamic effects of shear that modify turbine power production. We investigate an actuator disc in large eddy simulations to resolve the aerodynamic interactions between the turbine and sheared inflow wind profiles. These simulations demonstrate that induction increases monotonically as the magnitude of shear over the rotor increases. This subsequently lowers the disc velocity and power production of the turbine. We compare the results from the LES simulations to the predictions from the common rotor-equivalent wind speed (REWS) and cosine power models. Both the REWS and cosine models systematically over-predict power production by as much as 4.3%. These results demonstrate that the REWS and cosine models neglect nonlinear aerodynamic interactions that affect power production, pointing to future avenues of research.

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Weathering the Storm: Strategies to Better Model Extreme Wind Loads on Idling Wind Turbines

Mayank Chetan, Georgios Deskos, Shreyas Bidadi, Jason Jonkman
NREL, Golden, CO, USA

Introductory Summary

Offshore wind turbines offer high potential but face challenges from extreme weather events like hurricanes. Current modeling techniques struggle with accurately modeling on idling turbines when subjected to extreme wind scenarios. This study proposes improvements in modeling the inflow conditions, unsteady airfoil aerodynamics in deep stall, and nacelle drag modeling. Initial results show reduction in load uncertainty with updated airfoil polars over 360-deg angles of attack using computational fluid dynamics simulation simulations. Further research aims to refine the modeling techniques and explore passive solutions to reduce extreme wind loads.

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Bruce LeBlanc, Scott Johnson
Siemens Gamesa Renewable Energy, Boulder, CO, USA

Introductory Summary

This work presents an overview of the challenge of standstill and idling vibrations for modern utility scale wind turbines with moderate yaw errors and a process for modeling these instabilities. As wind turbines have continued to scale in size, the dynamics which they exhibit have become increasingly non-linear and difficult to model. Aeroelastic modeling has had to account for these dynamics during operation, analyzing and avoiding phenomena such as harmonic excitation and flutter. In modern turbines, these vibrations have extended to cases during idling or standstill, where an unstable turbine can put technicians in harm's way and do severe damage to equipment. This paper presents a method to model these vibrations using time domain aeroelastic tools combined with operational modal analysis methods. These phenomena are described to elicit the insights of the broader research community.

Final category: Smart Materials, Structures, and Systems

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A Study of Morphing Wind Turbine Blade with Piezocomposite Trailing Edge

Mohammad Katibeh, Onur Bilgen
Rutgers University, Piscataway, NJ, USA

Introductory Summary

The aim of this research is to explore a morphing blade concept with a piezocomposite trailing-edge for wind turbines, develop an analysis framework for this concept, and investigate potential improvements in power and fatigue. The piezocomposite blades employ the Macro-Fiber Composite actuators to modify the shape of the blade, and control the aerodynamic characteristics of the blades. The analysis presented in this research indicates that piezoelectric material-induced shape modifications can improve the power coefficient. However, enhancing the power coefficient without careful design can increase the mass of and the loads on the blade. Therefore, optimizing the design is essential to balance increase in power generation, reducing fatigue, and consequently improving the Levelized Cost of Electricity of the overall system.

111

Concrete Additive Manufacturing for Ultra-Tall Wind Turbine Towers and Foundations: A Life Cycle Environmental Assessment

Kathryn Jones, Mo Li
University of California Irvine, Irvine, CA, USA

Introductory Summary

Concrete additive manufacturing, also known as concrete 3D printing, is an emerging technology with the potential to enhance the construction and design of tall wind turbine towers and foundations by using locally sourced materials and circumventing onshore transportation constraints. A life cycle environmental assessment (LCA) is conducted to quantify and compare the greenhouse gas emissions of four 140 m-tall 7.5 MW wind turbine towers: a steel tower, a 3D printed concrete (3DPC) tower with standard-strength concrete, a 3DPC tower with high-strength concrete, and a 3D cast tower that combines normal and high strength concrete via a printed cast-in-place design. The results revealed

was performed with the goal of minimizing the life cycle emissions of printed concrete by incorporating coarse and recycled aggregate and reducing cement content. Furthermore, the tower LCA is expanded to include four concrete foundation designs including two conventional designs and two novel 3DPC designs. This study provides a life cycle perspective on the potential environmental impacts, and the paths for improvement, of adopting concrete additive manufacturing in the wind industry.

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Feather-inspired Flight Control for Airborne Energy Harvesting Kites

Diaa Zekry, Hannah Wiswell, Aimy Wissa
Princeton University, Princeton, NJ, USA

Introductory Summary

In this study, we examine the role of covert feather-inspired flaps and slotted primary-inspired wingtips as flight control devices for airborne energy harvesting applications. Creating engineering analogies for covert and slotted primary feathers and collecting wind tunnel and time-resolved flow field measurements allows us to capture underlying flow physics. System ID is also implemented to derive statistically significant models that describe the effectiveness of the coverts as flight control devices.

166

Strength prediction of wind turbine towers by numerical simulation

Xi Peng[1], Dehui Lin[2], Sandor Adany[1], Andrew Myers[2], Benjamin Schafer[1]
[1]Johns Hopkins University, Baltimore, Maryland, USA. [2]Northeastern University, Boston, Massachusetts, USA

Introductory Summary

The objective of this research is to illustrate the application of advanced numerical analysis to predict the strength of wind turbine towers. Nonlinear shell finite element analyses were performed with carefully controlled geometries, material, and analyses parameters. To validate the numerical results, the studied specimens were taken from a recent experimental campaign in which large steel tubes were investigated experimentally, representing (1:4 downscaled) typical segments of wind turbine towers. Since the imperfections of cylindrical shells have crucial role in the strength, special attention was paid to geometric imperfections, both in the experimental program and the numerical simulations. The numerical results show reasonable agreement with the test results, proving that while an advanced analysis might be challenging, if carefully completed, it is able to reliably predict the static behavior of wind turbine towers.

Final category: Social Science

112

Offshore Wind Influencers: A Communication Network Analysis of an

Introductory Summary

This paper presents the preliminary results of a communication network analysis of the community of practice involved in planning for the Vineyard Wind I and South Fork Wind Farm projects in southern New England.

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Offshore Transmission for Wind, Reliability, and Public Acceptance: Coordinating Institutional Innovation

Tyler Hansen[1], Abraham Silverman[2], Stephanie Lenhart[3], Helen Deng[1], Elizabeth Wilson[1]
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Introductory Summary

Coordinated transmission planning and infrastructure along the U.S. Eastern Seaboard has the potential to enable a rapid expansion of offshore wind power near densely populated coastal communities while potentially improving grid reliability and reducing overall system costs. We review and summarize literature on offshore transmission topologies in the U.S. and internationally, assess current U.S. policy, and propose paths forward to realize the potential of coordinated transmission.

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Large Language Models in Social Science Research: Approaches forAnalyzing Environmental Review of Atlantic Offshore Wind Projects

Stephanie Lenhart[1], Elizabeth Wilson[2], Soroush Vosoughi[2], Weicheng Ma[2], Tyler Hansen[2], Michael Bornstein[2], Andrew Shi[2]
[1]Boise State University, Boise, ID, USA. [2]Dartmouth, Hanover, NH, USA

Introductory Summary

Achieving federal and state goals for offshore wind (OSW) deployment hinges on the creation of partnerships and alignment of complex regulatory and planning processes that span Federal, Tribal, state, and local jurisdictional boundaries. This paper explores the potential for generative artificial intelligence (GenAI) and large language models (LLM) to inform and accelerate efforts to align planning, siting, and permitting of OSW projects. To do so, it demonstrates different research methodologies for understanding the evolution of the environmental review process for OSW project leases located adjacent to four different states and in various stages of development.

143

Do Turbines Make Good Neighbors? Understanding the Role of Local Benefit Agreements in Offshore Wind Development

Introductory Summary

This study utilizes semi-structured interviews to investigate offshore wind developer experiences and perspectives of negotiating and executing local benefit agreements in the context of offshore wind development. It is part of a larger DOE-funded study that aims to examine these benefit agreements and offshore wind from diverse perspectives. Our goal is to gain insight into an understudied set of perspectives relating to important decision-making processes of offshore wind development with the framework of energy justice. Our results will advance the growing field of energy and environmental justice relating to offshore wind energy development. We intend to make meaningful policy recommendations to contribute to goals around a just transition.

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Are the Laws Enough? Opposition to Offshore Wind Energy in New Jersey and Solutions Through Comparative Law Analysis

Kevin Leach, Steve Gold
Rutgers Law, Newark, NJ, USA

Introductory Summary

The environmental laws of the federal and New Jersey state governments were created to ensure offshore wind projects are environmentally safe, economically feasible, and effective at easing the state's reliance on fossil fuels. However, opponents to offshore wind can take advantage of these laws and file lawsuits challenging the projects every step along the way. Federal laws like the Marine Mammal Protection Act, the National Environmental Policy Act, the Outer Continental Shelf Lands Act, the Coastal Zone Management Act, and the Endangered Species Act, as well as state procedures like permitting and zoning all provide abundant legal avenues for opponents to attempt to block the offshore wind projects. The offshore wind industry will face inevitable legal challenges that, without preparation, can lead to injunctions, heavy fines, or extensive delays that will drive up the costs of the projects and potentially deter developers from continuing their projects. To move on from an overreliance on executive orders from President Biden and the Governor Murphy, offshore wind proponents should push for new legislative laws promoting offshore wind that cannot as easily be overturned after the November 2024 and 2025 elections. Proponents must also continue to spread accurate and understandable scientific information about the projects. While greater scientific communication will not block the flood of lawsuits, it may create a better sense of trust between the public and the government.

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Justice dimensions of offshore wind development

David Bidwell[1], Jeremy Firestone[2], Kelsey Leonard[3], Tiffany Smythe[1], Emma Korein[2], Shannon Howley[1], Sara Swett[2]
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energy development. This presentation summarizes findings from a multimethod study of perceptions of the justice dimensions of offshore wind energy development in five communities in the Northeast U.S. Taken together, these data paint a picture of industry successes and failures and provide insights for future development.

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Analysis of the wind turbine performance during weather events

Rebeca Marini, Kayacan Kestel, Konstantinos Vratsinis, Jonathan Sterckx, Jens Matthys, Pieter-Jan Daems, Jan Helsen
Vrije Universiteit Brussel, Brussels, Brussels, Belgium

Introductory Summary

As wind turbines grow and wind farms become denser, addressing weather events is essential for operational efficiency. LiDAR technology, which eliminates the need for meteorology masts, has garnered significant attention in the literature. However, it indirectly measures wind parameters, relying on assumptions and built-in algorithms. Wind field reconstruction (WFR) methods offer users greater control over LiDAR measurements, enabling customised flow assumptions and parameter estimation. During the measurement campaign, this methodology detected weather events, such as low-level jets (LLJs). These events are linked to on-site conditions using Meetnet Vlaasme Banken open-source environmental data. Additionally, these events are compared with vibration measurements obtained from accelerometers in wind turbines to assess their impact on the machine. This comprehensive analysis completes the loop between measurements, weather events, and their effect on the wind turbine's behaviour.

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Community Attitudes Regarding the Energy Justice Dimensions of Mid-Atlantic Offshore Wind Development

Emma Korein, Lorren Ruscetta, Zoē Ketola, Eva Pumo, Nina David, Jeremy Firestone
University of Delaware, Newark, Delaware, USA

Introductory Summary

The aim of this NOAA/Delaware Sea Grant-funded study is to understand community perceptions of the justice dimensions of offshore wind energy development. Surveys will be distributed to ocean-adjacent communities in Delaware, New Jersey, and Maryland, including focus communities that host fish processing facilities and coal generation plants. In doing so, we aim to understand participants' perceptions of offshore wind development processes and outcomes, as well as their perceptions of related energy justice issues. Study results will have implications for how decision-makers and communities can facilitate a just renewable energy transition.

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Wind Energy in a Decarbonized Future: Findings from an International

Coloardo, USA

Introductory Summary

In this research, we evaluate how design and operations, siting choices, and manufacturing practices may change for land-based wind energy in a deep decarbonization future. The survey will be distributed to leading wind energy experts during summer 2024 with questions about current and anticipated siting constraints, policy considerations, new wind energy applications (e.g., storage, hydrogen) and opportunities for value creation. We anticipate that these considerations will become increasingly important as the energy system evolves toward economy-wide decarbonization.

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Building the Offshore Wind Workforce: Local and Regional Assessments

Bailey Pons, Brinn McDowell, Jeremy Stefek, Adam Kanter
National Renewable Energy Laboratory, Golden, CO, USA

Introductory Summary

To further understand workforce development needed to operate offshore wind supply chain facilities, the National Renewable Energy Laboratory (NREL) developed a methodology and framework to assess a multitude of workforce-related factors on a local community and regional level. The framework was developed initially for the American-Made FLoating Offshore Wind ReadINess (FLOWIN) prize and was expanded for the Southeast and Mid-Atlantic Regional Transformative Partnership for Offshore Wind Energy Resources (SMART-POWER) supply chain project. The framework included leveraging publicly available data from the U.S. Department of Labor Bureau of Labor Statistics (BLS) and U.S. Census as well as internally developed occupational maps to inform key takeaways regarding workforce development. This presentation will include how the methodology and internal datasets were developed, results and key takeaways from applications of the framework, and potential next steps to expand the methodology for future uses.

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Community Benefits and Impacts from Offshore Wind

Greg Stelmach[1], Hilary Boudet[1], Shawn Hazboun[1], Jeremy Firestone[2], Shana Hirsch[3], Arne Jacobson[4], Teresa Johnson[5], Caroline Noblet[5]
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Introductory Summary

We are submitting the following abstract to present an overview of our planned research activities for a recently awarded research grant from the Department of Energy Wind Energy Technology Office, as well as preliminary findings that we expect to have by the time of the conference. Our research will explore community perspectives of offshore wind, with a particular focus on community benefits arrangements around development, by focusing on six coastal communities across four states where floating offshore wind projects have been, or are likely to be, proposed. The research will use both quantitative and qualitative research methods to explore the types of community benefits potentially available to coastal communities impacted by offshore wind development and understand the needs,

Communication and Engagement Strategies in Offshore Wind: A Mixed Methods Investigation of an Offshore Wind Community of Practice

Shannon Howley, Tiffany Smythe, Emily Diamond, David Bidwell
University of Rhode Island, Kingston, RI, USA

Introductory Summary

This research investigates the communications and engagement surrounding the Vineyard Wind 1 (VW1) and South Fork Wind (SFW) offshore wind projects by conducting qualitative interviews and a quantitative survey with an offshore community of practice. Results from a thematic analysis are reported and elucidate characteristics of offshore wind communication practices, experiences of false information, and perspectives on public engagement forums. Preliminary survey results will also be presented. This research addresses a gap in the literature regarding the experience of practitioners and stakeholders with offshore wind communications and will provide insights for future communication strategies and public engagement approaches.

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Leadership Development and Institutional Capabilities for the United States' Emerging Offshore Wind Energy Industry

Tolulope Omodara
Rutgers, Camden, New Jersey, USA

Introductory Summary

The objective of this research is to gain insights into the impact of leadership development, upon the quality of institutions, in an emerging Offshore Wind Energy Industry. Consequently, the main research question being explored is: What can be the impact of leadership development upon the ability of the United States' emerging Offshore Wind Energy Industry to grow critical institutional capabilities in the short- to medium-term; and upon the long-term success-cum-sustainability of the industry? In other words, a question being considered in this study is: What can be the impact of leadership development on the ability of evolving (sub)sectors, such as the United States' emerging Offshore Wind Energy Industry, to grow critical institutional capabilities?

According to McGonagill & Reinelt (2011), "The value of investing in leadership has been well established in all sectors," and, "a comprehensive review of leadership development found that investing in leadership development adds value, giving the organization a competitive advantage." While this & other such works share the benefits of building leaders across sectors, the impact of leadership development on the institutional capabilities of an emerging industry, particularly, appears yet to be explored, therefore, it is an area which this study chooses to concentrate on.

The Independent Variable of the study would be, "Effective & Intentional Leadership Development-cum-Pipelining," and the Dependent Variables will be as follows:

- Adequacy, Timeliness & Quality of Policies, Processes & Rules designed for the industry;
- Degree & Promptness of Policy & Strategy Implementation in the industry; and
- Level of Global Innovative Adaptation of Good Practices created in precursor industries.

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Greg Stelmach, Hilary Boudet
Oregon State University, Corvallis, OR, USA

Introductory Summary

This abstract presents analysis from a 2023 survey of public attitudes to offshore wind development. With siting efforts just getting underway on the West Coast, we set out to understand how the general public views hypothetical development of offshore wind at this early stage. We use cluster analysis to identify the main perspectives to proposed development, then explore a variety of factors that significantly influence the likelihood of cluster membership by using multinomial logistic regression modeling.

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Home price premiums in school districts with high levels of wind energy development

Ben Hoen[1], Eric Brunner[2], David Schwegman[3]
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Introductory Summary

Concerns over the possible impacts of wind energy projects on nearby residential property values are a top concern of prospective host communities and one of the leading causes of opposition. Over the last decade, literature has emerged that examines the impact of wind turbines on residential property values, with mixed results. European-based studies largely find declines in value following the construction and operation of turbines, and US results largely do not find statistically significant effects. The methods used by most of these studies, only examine home values within close proximity to wind projects. In so doing, local fiscal and amenity benefits of wind energy development, brought about by increases in the local tax base, which might be capitalized into home values, have not been investigated. In this novel analysis, we first find that school district per-pupil revenues and expenditures increase significantly after wind project operations begin, particularly in districts with greater installed capacity. The number of students per teacher also decreases at higher installed capacities. Correspondingly, we find significant increases in home values in school districts with installed wind energy that mirror the increases in school district revenues and expenditures in terms of timing. We find heterogeneous results for districts above the median installed capacity per pupil (20 MW per pupil) vs. below, indicating a strong positive relationship between our outcomes and installed capacity.

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Procedural Justice and Offshore Wind's Landfall in Southern New England

Samuel Ayivi, Carol Atkinson-Palombo, Oksan Bayulgen, Robert Downes, Syma Ebbin, Vanessa Heigel, Lyle Scruggs, Nathaniel Trumbull
University of Connecticut, Storrs, Connecticut, USA

Introductory Summary

The rapid growth of offshore wind (OSW) energy along the East Coast of the United States has raised questions about the onshore impacts of these large-scale renewable energy projects

necessitate careful planning of offshore wind within lease areas, transmission cable landfalls, onshore and offshore cable routes, and onshore POIs." (DOE, 2021, p. 5) The present study investigates community acceptance levels towards the landfall sites, cable routes, and substations referred to hereafter as CABLANS (CABle LANdfall, Substations, and POIs to the grid) that are necessary in the development of these projects in host communities in Southern New England. Our study focuses on four New England communities—Falmouth, MA; Barnstable, MA; Somerset, MA; and Portsmouth, RI, all of which are in discussions to host some of the first large OSW projects in the US. Some projects are proceeding smoothly while others are facing opposition. It is essential for the successful rollout of OSW in the United States to understand what factors shape community attitudes towards CABLANS and how and why those vary across geographic settings.

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"Navigating the Winds of Change: Digital Governance and Sustainability in Offshore Wind Energy Expansion in the North Sea"

Helena Solman
Wageningen University, Wageningen, Gelderland, Netherlands

Introductory Summary

In response to the urgent need for clean energy amidst climate change, offshore wind farms have emerged as pivotal components of the renewable energy landscape, particularly in regions like the North Sea basin. However, the expansion of this industry presents a complex interplay of socio-economic and environmental considerations. This paper explores the challenges in sustainable expansion of offshore wind farms and the visions for digitally-enabled governance of the North Sea region. This paper zooms into how digital solutions are designed and used for monitoring and managing offshore wind farms and their impact on biodiversity. Through an examination of current policy frameworks in the North Sea Region and in-depth expert and stakeholder interviews, the paper illuminates the efforts and hurdles involved in incorporating digital monitoring into decision-making processes for sustainable offshore wind development. It shows that digital technologies offer essential tools for assessing and mitigating these impacts, providing valuable insights for informed decision-making. However, the paper also shows that the implementation of digital monitoring is not without controversy. Debates arise regarding acceptable levels of environmental impact, the inclusion of diverse ecological knowledge, and the involvement of various stakeholders in design and implementation of digital technologies for offshore wind. The paper ends with reflections about how to design and implement digital technologies in a way that is inclusive of different kinds of expert, stakeholder and lay knowledge and about the governance conundrums related to environmental protection and upscaling offshore wind energy infrastructure.

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A Comparative Analysis of Governance Mechanisms for Managing Competing Ocean Uses

Victoria Ramenzoni, Rachael Shwom, Rion Hunter
Rutgers University, New Brunswick, NJ, USA

Introductory Summary

competing coastal ocean uses and the interactions between different resource governance use. Using the case of the area of the New York Bight, this analysis will identify key exogenous variables along with actors and their formal and informal decision rules for decisions about coastal real estate development, recreational boating, ocean conservation, fisheries, oil and gas, and offshore wind. Particular attention will be given to where the governance processes provide opportunities for public input, how they account for competing ocean resource uses, and interactions and connections between different decision-making arenas for ocean uses. Results will provide basis for detailing institutional challenges for managing competing uses in ocean areas and making recommendations for potential improvements in coordination and design for sustainable use of ocean areas.

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Floating Offshore Wind in Maine Fishing Communities: Visioning Fair Futures and Virtual Environments

Alison Bates
Colby College, Waterville, ME, USA

Introductory Summary

Recent advances in offshore wind technology have expanded focus beyond near-shore development in southern New England and the mid-Atlantic to a geographically broader area including deeper waters which now include the Gulf of Maine and beyond. What was once considered cost-prohibitive and technologically nascent, floating wind farms have been successfully deployed in Europe and is now an emerging market in the U.S. The larger spatial footprint and associated mooring lines create a unique conflict for fishermen and will be highly limiting for some types of fishing vessels. In addition to potential exclusion zones, there are also coastal community-related concerns including a lack of direct community benefits, local workforce impacts, equitable distribution of benefits and costs. Beyond the media narratives, there remains a considerable opportunity to better understand the complex analyses that drive acceptance, such as place-based values, benefits and impacts, risk perception, social acceptance, the role of institutions and governance, and fairness. Dynamic, multisensory visualizations offer a significant advancement in attitudinal research of offshore wind and offer a progressive approach to stakeholder engagement with fishing communities. This presentation will describe new findings from a study where the research team implemented virtual reality as an immersive tool to understand nuanced attitudes towards offshore wind. With additional data and more complex analyses, we present attitudinal change with access to information and compare "reality" with preconceived ideas about offshore wind aesthetics, and understand mental models of fishermen and fisheries managers towards fairness in a future with offshore wind.

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The Whales in the Room: The Discursive Politics of Whales and Wind Farms

Syma Ebbin, Nathaniel Trumbull
University of Connecticut, Groton, CT, USA

Introductory Summary

Whales have long been an iconic species; large and intelligent, valued for their bodies, baleen, bones and oil, and more recently for being charismatic mammals, the heart and song of the environmental movement, and now adopted by opponents of offshore wind. Humans have moved from killing whales, to watching them in awe, coupled with

energy, domesticating the wilderness with names like “Empire” and “Revolution”. As part of a new political discourse, whales are contributing to shaping policy outcomes and defining the realm of economic possibilities as discussion and publicity surrounding them have been strategically brought into offshore wind debates. The discourse surrounding whales and wind energy provides insights into changing human-ocean relationships.

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Evaluating Offshore Wind Potential in New Jersey Using SWOT-AHP Analysis

Faith Monesteri, Meghann Smith
Montclair State University, Montclair, NJ, USA

Introductory Summary

This research applies SWOT-AHP (strengths, weaknesses, opportunities, and threats - analytical hierarchy process) methodology, a mixed-methods approach combining expert interviews and stakeholder survey results to better understand the opinions towards offshore wind (OSW) development within New Jersey coastal waters.

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Local government experiences with wind energy planning: results from an eight-state survey

Salma Elmallah[1], Emma Uridge[2], Ben Hoen[1], Roberta Nilson[1], Joe Rand[1]
[1]Lawrence Berkeley National Laboratory, Berkeley, CA, USA. [2]Kansas Health Institutue, Topeka, KS, USA

Introductory Summary

This presentation shares results from a survey of 260 elected county officials in eight states that have experience with wind energy planning. Motivated by both the critical role of local officials in facilitating wind energy planning and realizing the benefits of wind energy development to communities, as well as the relative lack of empirical scholarship on the experiences of local officials involved in wind energy planning in the US, this survey characterizes the capacity of local government officials to undertake centralized renewable energy planning, negotiate with developers, and facilitate public participation.

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Fishing Communities in Transition: Evaluating Vulnerability and Environmental Justice Amid Offshore Wind Growth

Leonardo Calzada[1], Kevin St. Martin[1], Rebecca L. Selden[2], Zoë Kitchel[3], Kaycee E. Coleman[1]

Introductory Summary

This poster highlights the need for a deeper understanding of the social, economic, and ecological dynamics of fishing communities amid the expansion of offshore wind energy. Traditionally, fisheries management has focused on maximizing economic gains and sustainable yields, often overlooking the unique challenges faced by marginalized communities. As offshore wind development gains momentum, it introduces new tensions between economic growth and the preservation of cultural and ecological values. By analyzing spatial and temporal changes in fishing efforts, this initiative aims to render visible the experiences of fishing communities in a more nuanced and comprehensive manner, reflecting their dynamics and interactions with marine environments.

Final category: Systems Engineering

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Informed decision-making for investment in robotics-driven inspection of floating offshore wind farms: A real options approach

Omer Khalid[1,2,3], Guangbo Hao[3], Hamish Macdonald[4], Cian Desmond[1]
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Introductory Summary

The inspection and maintenance of floating offshore wind farms presents significant challenges due to their remote locations and harsh environments. Utilizing robotics can be an effective solution for enhancing the efficiency and safety of these operations. There is an increased focus on the deployment of autonomous robotic systems for inspecting the critical components of floating offshore wind farms, such as the turbine blades, mooring lines, and export cables. However, the integration of robotic systems for offshore inspection involves significant upfront investments, extended deployment timelines, and uncertainties arising from the technology readiness levels of such systems. An informed investment approach based on the insights derived from extensive cost assessment can allay these concerns. This research focuses on the devising of an informed investment decision-making process, leveraging real options analysis as the basis. Four different scenarios ranging from no autonomy to full-scale autonomy have been simulated in a cost model and the option values associated with various decision paths have been calculated. The model aims to determine the optimal investment approach and timing for the deployment of robotic inspection systems in a way to lower the incurred costs for each decision path. Results show that the transition to full-scale autonomy earlier in the project's lifecycle can save upto 21% in the operational expenditure.

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Design for Repowering of Wind Turbines Through Future-Proof Structural Engineering: Case Study of Tower Repowering

Daniel Bouzolin, D. Todd Griffith
The University of Texas at Dallas, Richardson, TX, USA

options, specifically regarding repowering. While most repowering action is decided upon near EOL, a new approach called Design for Repowering (DFR) has the potential to revolutionize the way wind farms are designed, installed, and maintained. In this paper, we focus on applying a major aspect of the DFR framework (i.e., Novel Component Designs) to one of the most crucial components of a turbine: the tower. Preliminary results show the potential of the DFR approach to lower long-term wind farm costs when repowering action is taken, relative to a baseline (unplanned) repowering case.

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Co-Optimizing Layout and Joint Yaw-Thrust Control to Design Cost-Effective and Profitable Wind Farms

Ilan Upfal, Michael Howland
Massachusetts Institute of Technology, Cambridge, MA, USA

Introductory Summary

We perform wind farm control co-design with thrust, yaw, and joint yaw-thrust control using power per unit cost and lifetime farm profit as design objectives. The high dimensional optimization problem (~ 10,000 parameters) is efficiently handled by using gradient-based optimization with automatic differentiation. Control co-design is performed by simultaneously optimizing the wind farm layout with thrust, yaw or joint yaw-thrust control. Layout optimization without collective control yields baseline layouts to which thrust, yaw and joint yaw-thrust control are then applied. We quantify how co-design with each control strategy changes optimal turbine spacing, power per unit cost, lifetime farm profit and capacity factor. We then compare the control co-design results with the wind farms designed using separate layout and control optimization to isolate the impact of co-design.

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Model Validation for Power Curve Certification

Julian Quick, Juan Pablo Murcia Leon, Nikolay Dimitrov, Pierre-Elouan Réthoré, Taeseong Kim
Technical University of Denmark, Roskilde, Denmark, Denmark

Introductory Summary

We apply a model validation framework to quantify the agreement between a model that predicts power curves when compared to power curve measurements. This framework quantifies the agreement between the model and experiment and what this implies about model agreement with future potential experiments. This can allow analysts to certify power curves predicted by the model, without conducting the expensive power curve measurements, by interpolating or extrapolating the recorded agreement of the model and previous power curve experiments.

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to Neighboring Wind Farms.

Julian Quick, Mikkel Friis-Møller, Juan Pablo Murcia Leon, Pierre-Elouan Réthoré
Technical University of Denmark, Roskilde, Denmark, Denmark

Introductory Summary

Wakes from neighboring wind farms can significantly affect power production. This must be taken into account during the land lease bidding process. In this study, we examine a wind farm in the center of the Danish energy island wind cluster in a pre-consruction setting, considering uncertainty in the neighboring wind farms' turbine types, turbine layouts, and date of construction.

Final category: Wind Plant and Wakes Modeling

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Experimentally Driven Sensitivity Analysis of Operational Parameters for Wake-induced Power Loss in the Block Island Offshore Wind Farm

Sina Shid-Moosavi[1], Fabrizio Di Cioccio[2], Rad Haghi[2], Eleonora Maria Tronci[1], Babak Moaveni[2], Sauro Liberatore[2], Eric Hines[2]
[1]Department of Civil and Environmental Engineering, Northeastern University, Boston, MA, USA. [2]Department of Civil and Environmental Engineering, Tufts University, Medford, MA, USA

Introductory Summary

Large-scale wind farms, comprising multiple turbines arranged in a linear configuration, encounter operational challenges due to the wake effects of upstream turbines on downstream ones, leading to power loss and heightened fatigue loads. This study conducts a comprehensive sensitivity analysis on several operational parameters, such as turbulence intensity, power and thrust coefficients, and yaw misalignment, to evaluate their individual and collective impact on power loss in downstream turbines. Utilizing a numerical 6MW offshore wind turbine model within the FLORIS software platform, these parameters are analyzed against operational data from Block Island Wind Farm. Specifically, scenarios, where two turbines are aligned, are focused on, allowing for the detailed observation and quantification of wake effects on the downstream turbine's performance. This analysis aims to identify and prioritize the most influential parameters affecting power loss, thereby enhancing the selection of values for accurate turbine modeling based on experimental data.

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An International Benchmark on Wind Plant Wakes from the American Wake Experiment (AWAKEN)

Nicola Bodini[1], Aliza Abraham[1], Bruno Carmo[2], Lawrence Cheung[3], William Corrêa Radünz[2], Paula Doubrawa[1],

Solari[5], Regis Thedin[1], Sonia Wharton[11]
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Introductory Summary

This presentation will introduce the preliminary results of the inaugural benchmark study under the International Energy Agency Wind Task 57 for the Joint Assessment of Models (JAM) framework, focusing on wind plant wakes. Utilizing open-source data from the American WAKE ExperimeNt (AWAKEN), the benchmark aims to evaluate the accuracy of simulation tools in representing wind plant wakes and their downwind flow impacts under various inflow conditions. The AWAKEN field campaign, conducted in Oklahoma from 2022 to 2024, offers unprecedented insights into wind plant-atmosphere interactions, providing a substantial data set to validate numerical models of varying complexities. The benchmark comprises three phases—baseline, model improvement with inflow observations, and model improvement with both inflow and wake observations—enabling participants to refine their numerical models based on the results of the benchmark. In this presentation, we will delineate the benchmark case study chosen from observations, presenting atmospheric conditions, wake phenomena, and wind turbine operations in detail. Additionally, the results of the first phase of the benchmark will be presented, showing the public a first view of the results from this collaborative endeavor to improve the accuracy of wind plant wake simulations, thereby enhancing estimates for wind energy production in regions with multiple wind plants.

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Data-driven wake model parameter estimation to analyze effects of wake superposition

Michael LoCascio[1], Michael Howland[2], Catherine Gorlé[1]
[1]Stanford University, Stanford, CA, USA. [2]Massachusetts Institute of Technology, Cambridge, MA, USA

Introductory Summary

Analytical wake models parameterize the effects of atmospheric boundary layer and wake-added turbulence with an unknown wake spreading coefficient. Traditional approaches to estimate this wake spreading parameter are based on deterministic, empirically-tuned correlations with key physical variables, namely streamwise turbulence intensity. We develop a data-driven, Bayesian parameter estimation approach that estimates the wake model parameter for each turbine in a wind farm with quantified uncertainty based on data at the site of interest. In this work, we use this parameter estimation framework to analyze the effects of approximate wake superposition methods on the parameter estimates. We also test the accuracy of our parameter estimates compared with the baseline approach for predicting turbine power production.

Influence of atmospheric gravity waves on wind turbine wake dynamics: A measurement-driven large-eddy simulation study

Dachuan Feng, Simon Watson
Delft University of Technology, Delft, South Holland, Netherlands

Introductory Summary

We perform large-eddy simulation of wind turbine wake flow subjected to atmospheric gravity waves. The mesoscale forcing from atmospheric gravity waves is coupled to microscale turbine simulation using an indirect profile assimilation method. Our analysis will center on examining the effects of atmospheric gravity waves on wake meandering and wake-added turbulence, aiming to enhance understanding of the wake dynamics in the presence of atmospheric gravity waves. This study holds promise for guiding the development of wind farm models under realistic atmospheric conditions.

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Waves Effects on Wake and Power Generation of a Single Horizontal Axis Wind Turbine Using Coupled Level-Set Method and Large Eddy Simulation

Pharlin Médard, Umberto Ciri
University of Puerto Rico at Mayagüez, Mayagüez, Puerto Rico, Puerto Rico

Introductory Summary

Offshore wind energy is expected to triple by 2028 from its 2023 levels according to the Global Wind Energy Council. However, offshore wind energy projects face unique challenges during their initial phase like physical testing at scale. Hence, this investigation proposes a numerical model to understand the wave effects on power generation of offshore wind turbines using Large Eddy Simulations (LES) with rotating actuator-disk model coupled with the level-set method to a potential flow solution for the water waves.

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Effect of uncertainty and atmospheric stability on wake steering strategies

Diederik van Binsbergen[1,2], Pieter-Jan Daems[2], Timothy Verstraeten[2], Konstantinos Vratinis[2], Amir Nejad[1], Jan Helsen[2]
[1]Norwegian University of Science and Technology (NTNU), Trondheim, Trondelag, Norway. [2]Vrije Universiteit Brussel (VUB), Brussels, Brussels, Belgium

Introductory Summary

This work aims to optimize the yaw angles of wind turbines within the Belgian-Dutch offshore zone using calibrated wake models for maximum power production and compares the use of a probabilistic distribution for the tuning parameter with a deterministic approach. Additionally, results are analyzed for different atmospheric stability

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Effectiveness and Limitation of POD on Wind Flow from Mid-fidelity Simulations for Wind Farm Surrogate Modeling

Dexing Liu, Po Wen Cheng
Stuttgart Wind Energy (SWE), Institute of Aircraft Design, University of Stuttgart, Stuttgart, Baden württemberg, Germany

Introductory Summary

This study investigate the effectiveness of Proper Orthogonal Decomposition (POD) on obtaining low-order flow model for surrogate model training based on mid-fidelity simulation data. To do this, POD are applied to simulated free-streams and wake turbulence that based on Mann uniform shear model and dynamic wake meandering model, with various spatial sampling rates. As results, the uncertainty and limitations of the POD on mid-fidelity simulation data are evaluated and suggestions of mid-fidelity wind farm simulation are summarized for creating database for load surrogate model.

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Understanding the aerodynamic mechanisms of the Helix approach: insights from PIV experiments of a simplified porous disk helix model

Jonas Gutknecht, Daniel van den Berg, Daan van der Hoek, Brian de Vos, Bjorn Harder, Axelle Viré, Jan-Willem van Wingerden
TU Delft, Delft, Zuid Holland, Netherlands

Introductory Summary

Numerical and experimental studies have proven the potential of the helix approach to decrease power losses due to wakes in wind farms. However, its underlying aerodynamic mechanisms are not yet fully understood, in particular the different efficiencies of the clockwise and counterclockwise helix. Previous work presented a system of counter-rotating vortices in the clockwise helix wake and co-rotating vortices in the counterclockwise helix wake and identified them to govern the energy advection into the wake. This work focuses on the vortex generation mechanisms by investigating the wake of a simplified helix porous disk model with Particle Image Velocimetry experiments in a wind tunnel. The porous disk solely models the unsteady, non-uniform thrust distribution over the rotor plane induced by the helix approach and neglects blade-related phenomena like tip or hub vortices. Thus, it allows for investigating the effect of the helix thrust excitation on the velocity deficit in the wake, isolated from its effect on blade-related phenomena. We observe the same helical outer vortex structure in the porous disk wake as in the turbine wake, which implies that the increased energy advection into the wake is primarily triggered by the non-uniform, unsteady thrust distribution induced by the helix, whilst effects on tip vortices play a minor role. Additionally, we observe an oppositely oriented vortex in the wake center, which in the wake of a real turbine either enhances or destabilizes the hub vortex and thereby explains the differences between the vortex system in the clockwise and the counterclockwise helix wake.

Leonardo Alcayaga, Abdul Haseeb Syed, Jakob Mann, Gunner Larsen
Technical University of Denmark, Roskilde, Zealand, Denmark

Introductory Summary

Standard turbulence models are often unable to capture large-scale turbulence structures such as convective rolls and mesoscale turbulence. With a rapid increase in the size of offshore wind turbines and farms, it is imperative to analyze the effect of these structures on turbine and plant performance. We use a wake modeling framework called DYNAMIKS to investigate the impact of large-scale atmospheric structures on the wake dynamics and wind turbine loads inside a large reference wind farm. Preliminary results show that these structures significantly impact wake flow meandering, which should be expected, as wake dynamics are predominantly driven by large-scale atmospheric flow structures. Consequently, more elaborate control strategies are needed for wind farm operations in such conditions.

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Wind Resource Potentials using Multi-Criteria Decision-Making Model in South Korea

Jin-Young Kim, Hyun-Goo Kim, Changyeol Yun, Chang Ki Kim
Korea Institute of Energy Research, Daejeon, Daejeon, Korea, Republic of

Introductory Summary

In this study, wind resource potential was estimated using a multi-criteria decision-making model throughout South Korea. The model performs stepwise capacity and power generation calculation processes for theoretical, technical and market potential based on the wind resource map and available land information with the reference capacity density, power curve and cost model. This model has been updated to be able to decision-making analysis, setback distance scenarios were included as current decision-making issues for wind energy deployment. The market potential of 52 TWh/year (24 GW) under 100 m setback distance from the roads varied depending on the difference setback distances from roads and settlement-buildings, with a range from 33% to 8%. The results of this study suggest that setback distances from road and residences are critical factors for accelerating wind dissemination. The results will be useful in evaluating the sufficiency of and establishing government energy supply policies.

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Modeling the Impact of Wind Farms on Surface Currents and Marine Atmospheric Boundary Layer Turbulence Structure

Mark A. Miller, John Wilkin, Qiuxuan Zheng, L. Fernando Pareja-Roman, Stephanie Braddock
Rutgers University, New Brunswick, NJ, USA

Introductory Summary

developed by the Rutgers Ocean Modeling Group (OMG), connects the Regional Ocean Modeling System (ROMS) ocean model and the Weather Research and Forecasting (WRF) atmospheric model using the Earth System Modeling Framework (ESMF) National Unified Operational Prediction Capability (NUOPC) layer that underpins all coupling application development in the Unified Forecast System (UFS) for the National Weather Service (NWS). The ROMS-WRF NUOPC interface supports coupling of high-resolution nested grids in both the ocean and atmosphere components.

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Ultra-efficient high-fidelity prediction of turbine wakes with machine learning

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Introductory Summary

A novel machine learning (ML) model is proposed for the efficient and cost-effective prediction of high-fidelity three-dimensional velocity fields in the wake of wind turbines. The ML model consists of an auto-encoder convolutional neural network with U-Net skipped connections. The model takes the low-fidelity velocity field of a wind farm generated from an analytical engineering wake model as input and produces the high-fidelity velocity fields. Large-eddy simulations (LES) of the Sandia National Lab scaled wind farm technology (SWiFT) facility at different wind speeds, wind directions, and yaw-misalignment of the wind turbines were used to generate the high-fidelity velocity fields for the training and validation of the ML model. The input to the ML model consists of the three-dimensional velocity field of the SWiFT facility obtained from the Gauss Curl Hybrid (GCH) model. The ML model results were compared against those of LES, the ML model was shown to reduce the error in the prediction from 20% obtained from the GCH model to less than 5%. In addition, the ML model captured the non-symmetric wake deflection observed for opposing yaw angles for wake steering cases, demonstrating a greater accuracy than the GCH model. The computational cost of the trained ML model is on par with that of the GCH model while generating numerical outcomes nearly as accurate as those of the high-fidelity LES.

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A Formulation of Wake Recovery Based on Local Turbulence Intensity

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atmospheric effects. However, these models often underpredict wake deficits in deep arrays of large wind farms. Current models typically account for ambient and "wake-added" turbulence, but they simplify wake recovery by assuming a linear relationship with the local ambient turbulence intensity, neglecting its downstream development. This paper aims to develop a model that better accounts for the streamwise decrease and lateral variations in turbulence when wakes partially overlap, offering a more realistic representation of wake recovery, as supported by large-eddy simulations (LES).

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A parameterization of turbulence added by wind farms for the WRF model: Preliminary results

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Introductory Summary

We develop a parameterization of the turbulent kinetic energy (TKE) added by wind turbines for use in numerical weather prediction models, like the Weather Research and Forecast (WRF) model, to improve the study of wake impacts on the environment and on other wind turbines and wind farms.

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Evaluation of wake simulations with North Sea observations, testing MYNN and 3DPBL schemes

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Introductory Summary

This work addresses the research gap on the sensitivity of simulated wind farm behavior to the choice of planetary boundary layer (PBL) scheme. This work extends a North Sea case study of the Fitch wind farm parameterization (WFP) and evaluates the impacts of replacing the 1D Mellor-Yamada-Nakanishi-Niino (MYNN) PBL scheme with a 3DPBL scheme via comparison to two sets of in-situ observations, one from a meteorological tower and the other from aircraft. 3DPBL simulations show smaller root-mean-square-error (RMSE) than MYNN wind speeds when compared to the tower observations in the wind turbine rotor region, but larger RMSE when compared to the aircraft observations collected at 250 m altitude above the turbines.

Keywords: *WRF, wind plant wake, wind farm wake, mesoscale modeling, 3DPBL, Fitch Wind Farm Parameterization, North Sea*

conditions

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Introductory Summary

This study investigates the wake dynamics of a turbine undergoing periodic surge motions in the direction of the incoming wind. A theoretical model predicts the formation and evolution of nonlinear traveling waves in the streamwise velocity and radius of the wake. Flow measurements in a towing tank demonstrate that these dynamics cause tip vortices to aggregate and the wake to recover faster than in the steady-flow case, suggesting that the unsteady turbine motions enhance the entrainment of momentum into the wake. Surge motions may therefore serve as a passive induction-control strategy for improving the power density of floating offshore wind farms.

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Impacts of peak shaving on wind farm energy production

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Introductory Summary

As wind turbines grow in size and become more flexible, peak shaving operation, where the axial thrust exerted by the turbine on the flow is reduced near the rated wind speed to lessen the peak structural loads, is becoming increasingly common. In reducing thrust, the power production of the wind turbine is also decreased. Moreover, the wind turbine's wake is made shallower due to the lower axial force exerted on the flow.

For a wind turbine operating in isolation, the reduction in structural loads achieved by peak shaving comes with a reduction in total energy capture. The extent of this reduction depends on how often the turbine is operating near rated wind conditions; the desired thrust reduction; and other possible conditions, such as turbulence intensity, that may be used to activate peak shaving. However, when wind turbines operate in a wind farm, the energy losses due to peak shaving may be partially recovered by the shallower wakes generated, which leave higher inflow (and therefore higher energy capture potential) for downstream turbines.

In this work, we investigate the wind farm-level impacts of peak shaving using actuator disk representations of the wind turbine and the wake modeling tool FLORIS. We find that the reduction in wake losses partially compensates for the loss in energy production due to peak shaving, especially in wind farms that have a high number of internal turbines (turbines that experience other turbines' wakes over much of the wind rose).

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Modal Characterization of the Swirling Wake

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Introductory Summary

This study investigates an axisymmetric wake flow using Proper Orthogonal Decomposition (POD) to characterize the

wake downstream of the wind turbines.

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Investigating wind-farm performance and backcasting AEP using a multi-pronged approach

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Introductory Summary

Wind farm performance is analyzed and compared with pre-construction assessments to understand the reasons for underperformance and improve the Energy Production Estimates. Various software tools are used along with resource measurement on-site to study different parameters affecting AEP and arrive at a realistic/corrected estimate.

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An engineering approach to modeling active wake mixing

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Introductory Summary

A relatively novel method of wind plant control, that is receiving an increasing amount of research attention, is called active wake control (AWC). In AWC, variations in pitch angles of an upstream turbine are used to enhance wake mixing, subsequently lowering the wake deficit and increasing power production for turbines situated in its wake. One such method is called the helix strategy. In this paper, an engineering model for applying the helix strategy on a wind plant is presented. This model is implemented in the well-known FLORIS wind farm simulation tool, which is focused on optimizing control strategies, thus enabling the possibility to quickly assess the effectiveness of the helix strategy for specific wind plant setups.

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Impact of Initial and Boundary Conditions on AWAKEN Benchmark Mesoscale Simulations

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Introductory Summary

This presentation builds on a related presentation of the inaugural benchmark study under the International Energy Agency Wind Task 57 framework, focusing on wind plant wakes. The case study, chosen from the American WAKE ExperimeNt (AWAKEN) dataset, incorporates a full diurnal cycle spanning daytime convective conditions to nighttime stably stratified conditions with a low-level jet. The benchmark case seeks to quantify the skill of various wake modeling approaches by comparison to the substantial AWAKEN observations, including wind profiling lidar, scanning lidar, and

initial and boundary condition datasets to investigate the sensitivity of the simulations to these basic choices for numerical modeling.

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A Modal Description of Wake Meandering

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Introductory Summary

Lidar scans from a nacelle-mounted measurement system provide time series of wake measurements during varied atmospheric inflow conditions, from which we describe the coherent turbulent structures that contribute to wake meandering through proper orthogonal decomposition. Subsets of modes are used to make low-order reconstructions in a combinatorial sense, yielding more than 30,000 estimates of meandering for each inflow case. A regression test using the range of reconstructed flow statistics identifies the modes that contribute most to wake meandering. Mode coefficient spectra highlight the dominant Strouhal number associated with each turbulent structure, suggesting that the lowest ranking modes do not necessarily contribute most to the accuracy of the reconstruction. Instead, some modes appear to have no influence on meandering dynamics, and still others consistently detract from wake meandering represented in low-dimensional flow reconstructions.

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Data generation workflow for meso/microscale coupled offshore wind farm simulations

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Introductory Summary

A robust, simple-to-use workflow is developed in this study which allows mesoscale information from the NOW-23 database to be easily incorporated into microscale wind farm simulations. This process will enable many different wind farm configurations to be simulated under realistic inflow conditions spanning a variety of atmospheric phenomena.

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Modeling the effects of AWC on wake behavior through large scale coherent structures

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Introductory Summary

A reduced order model is developed to capture the effect of active wake control strategies on the downstream wake evolution. This formulation is based on a coupled Reynolds-Averaged Navier-Stokes (RANS) and linear stability approach and models the development of large scale, coherent structures in the wind turbine wake.

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Influence of ocean waves on the sensitivity of offshore wind farms to atmospheric conditions

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Introductory Summary

Computationally efficient simulation tools are vital to simulating the flow field of full-scale offshore wind farms and predicting their power production. A key component of simulating offshore wind farms is understanding and representing the transfer of momentum between wind and ocean waves. In this work, a dynamic wave spectrum drag model is implemented within a Large Eddy Simulation modeling framework for a finite offshore wind farm with realistic atmospheric and oceanic conditions. The purpose of this study is to investigate how the sea state influences the sensitivity of the offshore wind farm's performance to the incoming flow.

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Optimization Approach To Analytical Modeling of Complex Wake Dynamics in Tilted Wind Turbines

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Introductory Summary

Floating offshore wind turbines can have a significant amount of platform tilt that deflects the wake vertically. However, current analytical wake models don't account for the effect of the ground on the growth and trajectory of the wake. In order for floating offshore wind energy to become more viable our approaches to analytical wake modeling need to be capable of modeling wake interactions with the ground.

In this study, we demonstrate an improved approach for characterizing deflected wakes and calibrating, through optimization, additions and modifications to the Bastankhah wake model. However, this approach is limited to tilt angles between -5° and 15° due to the Bastankhah wake model's inability to model complex structures beyond a simple Gaussian shape description.

Therefore, we also demonstrate a deep learning approach that can accurately model complex wake dynamics for any tilt angle.

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Assessing inter-array wake effects in the US East Coast offshore wind lease areas

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Introductory Summary

This study assesses the variability of wake effects over the 28 active wind lease areas in the U.S East Coast Outer Continental Shelf. To this end, we evaluate wake variability and power production over 50 climatic representative two-day periods using the Weather Research and Forecasting (WRF) [1]. A more realistic wind turbine layout is also proposed based on information available from the construction and operation plans (COP) provided by the Bureau of Ocean Energy Management (BOEM) [2]. Our analysis aims to provide insight into offshore wind inter-array wake effects in the U.S. East Coast, with a broader goal of understanding long-term power losses as well as seek potential solutions to future lease area planning.

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Realistic Floating Offshore Wind Farm Optimization

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Introductory Summary

Design decisions for wind farms often occur in iterations where each aspect of the design requires a separate process and objective. However, many of the design decisions are interdependent and therefore should be coupled in an overall optimization with an objective that reflects their relationships. In this study we demonstrate the importance of involving as many design decisions and constraints as possible in a wind farm's layout optimization in order to be able to design a more economically viable wind farm.

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Model Validation of the ABL, Turbine, and Wakes for AWAKEN Simulations under Neutral Stability Conditions

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Introductory Summary

This work aims to validate various ABL, turbine, wake quantities of interest for four wind farm models: AMR-Wind, Nalu-Wind, WRF-LES, and FLORIS using field data from the AWAKEN experiment under neutral stability conditions. Additional model tuning will be conducted to improve the accuracy of the modeled predictions.

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Impact of Wind Plants on Nocturnal Temperatures within and downwind of Wind Plants as seen in AWAKEN Observations and Simulations

Julie Lundquist[1,2,3], Stefano Letizia[2], Nicola Bodini[2], Aliza Abraham[2], Emina Maric[2], Geng Xia[2], David D. Turner[4]
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Introductory Summary

Mesoscale wind plant wakes are primarily understood to decrease wind speeds downwind, withMesoscale wind plant wakes are primarily understood to decrease wind speeds downwind, with subtle localized increases in temperature during nocturnal stably stratified conditions due to a redistribution of warmer air from the upper portion of turbine rotor disks down to the cold surface. Observations from temperature profilers deployed during the AWAKEN campaign also suggest this localized warming as well as distant cooling. To better understand the mechanisms leading these temperature impacts as well as to identify optimal modeling parameters, we carry out a set of mesoscale numerical weather prediction simulations with the Fitch wind farm parameterization, experimenting with the role of added turbulence, wind plant drag, and the planetary boundary layer scheme that allows the atmosphere to interact with the wind plant.atmosphere to interact with the wind plant

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Evaluating the Impact of Offshore Wind Farms on Wave Fields in New Jersey's Wind Energy Area

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Introductory Summary

Offshore wind energy holds significant promise for transforming the energy landscape in the United States. New Jersey is spearheading this transformation with plans to develop an 1100 MW offshore wind farm, aiming to triple its renewable energy production within the next decade. However, little is known about how the wind field will change after installing the wind turbines. Understanding these changes is critical for various sectors such as fisheries, water quality management, and shipping navigation, which rely on accurate information about waves and their

SWAN model results, this study simulates the interactions between wind turbines and wave fields in the New Jersey Wind Energy Area, assessing their environmental impacts. The research provides crucial insights not only for optimizing future offshore wind projects but also for understanding the modifications in wave fields due to the presence of wind turbines. These insights are essential for coastal management, marine navigation, and other related fields.