EPJ Web of Conferences **119**, 14004 (2016) DOI: 10.1051/epjconf/201611914004
ILRC 27

IMPROVING MARYLAND'S OFFSHORE WIND ENERGY RESOURCE ESTIMATE USING DOPPLER WIND LIDAR TECHNOLOGY TO ASSESS MICROTMETEOROLOGY CONTROLS

Alexandra St.Pé [1]*, Daniel Wesloh[1], Graham Antoszewski[1], Farrah Daham[1], Navid Goudarzi[2], Scott Rabenhorst[3], Ruben Delgado[4]

[1]*University of Maryland, Baltimore County, Baltimore, MD 21250, USA, *Email: astpe@umbc.edu*

[2]*University of Maryland, College Park, MD 20742, USA*

[3]*Naval Research Laboratory, Washington D.C., 20375, USA*

[4]*Joint Center for Earth Systems Technology, Baltimore, MD, 21250, USA*

ABSTRACT

There is enormous potential to harness the kinetic energy of offshore wind and produce power. However significant uncertainties are introduced in the offshore wind resource assessment process, due in part to limited observational networks and a poor understanding of the marine atmosphere's complexity. Given the cubic relationship between a turbine's power output and wind speed, a relatively small error in the wind speed estimate translates to a significant error in expected power production. The University of Maryland Baltimore County (UMBC) collected in-situ measurements offshore, within Maryland's Wind Energy Area (WEA) from July-August 2013. This research demonstrates the ability of Doppler wind lidar technology to reduce uncertainty in estimating an offshore wind resource, compared to traditional resource assessment techniques, by providing a more accurate representation of the wind profile and associated hub-height wind speed variability. The second objective of this research is to elucidate the impact of offshore micrometeorology controls (stability, wind shear, turbulence) on a turbine's ability to produce power.

Compared to lidar measurements, power law extrapolation estimates and operational National Weather Service models *underestimated* hub-height wind speeds in the WEA. In addition, lidar observations suggest the frequent development of a low-level wind maximum (LLWM), with high turbine-layer wind shear and low turbulence intensity within a turbine's rotor layer (40m-160m). Results elucidate the advantages of using Doppler wind lidar technology to improve offshore wind resource estimates and its ability to monitor under-sampled offshore meteorological controls impact on a potential turbine's ability to produce power.

1. INTRODUCTION

Offshore wind energy promises to be a significant domestic renewable energy source for coastal electricity loads. Maryland is engaging in groundbreaking work to inform the planning and development of a utility-scale offshore wind farm. In 2013, the Offshore Wind Energy Act was passed and outlined Maryland's plan to lead in United States offshore wind energy development, incentivizing the development of 500 MW of offshore wind capacity at least 10 nautical miles (NM) off the coast of Ocean City, MD. Although there is enormous potential to produce offshore wind energy in Maryland, significant uncertainties, and associated high costs, exist when developing offshore wind energy projects.

In part, wind project uncertainties exist due to the natural intermittency of wind. Unlike traditional energy resources, the wind resource, and therefore its power output is highly variable, making it particularly challenging to compete and integrate with traditional power sources, which supply a relatively steady flow of power. The variability wind is driven by local meteorological conditions. Monitoring and predicting the relationship between micrometeorology controls (stability, wind shear, turbulence) and a wind turbine's power curve performance at a distinct location, is critical for reducing project uncertainties, in particular, uncertainties that arise during an offshore wind resource assessment [1].

Unfortunately, due to limited high spatial and temporal offshore met-ocean measurements at a proposed offshore wind farm location, characterizing, with a high degree of certainty, the meteorological conditions that impact a potential wind turbine's performance, thus the wind resource, is challenging. To overcome data limitations, available offshore surface wind data is often extrapolated, using the power law equation (1) to estimate the wind speed at hub-height:

$$\frac{u(z_2)}{u(z_1)} = \left(\frac{z_2}{z_1}\right)^{\alpha} \qquad (1)$$

where z_1 and z_2 are the measurement height and the desired height to estimate the wind speed, respectively. The theoretical shear exponent, α, varies by site, and is estimated to be 0.11 for an offshore environments [2]. Although the power law method provides a first estimate, the technique is limited as it assumes a logarithmic or neutral stability wind profile. Similarly, turbine manufacturer estimates of expected power curves, known as the Manufacturers' Power Curve (MPC), also assume neutral stability and only mechanical turbulence [2]. In reality, depending on local meteorological conditions, offshore wind deviates from convective, neutral, and stable profiles. The ramifications of not accounting for 'non-standard' turbine inflow conditions during an initial offshore wind resource estimate is significant, since expected power output is proportional to the cube of wind speed at hub-height. Therefore, a relatively small wind speed error introduced from a non-neutral conditions, translates to significant error in expected power production. Many efforts have been made to quantify the error introduced from the inherent atmospheric assumptions within traditional wind resource assessment techniques [3-6]. The objective of this research is to use the results of a two-month (July 17-August 17, 2013) offshore measurement campaign to demonstrate the advantages of deploying remote sensing technologies to quantify the uncertainty introduced from traditional wind resource assessment techniques and elucidate the impact of micrometeorology on a turbine's ability to produce power. A case study is presented to illustrate the impact of atmospheric stability on a turbine's power output and demonstrate the importance of high spatial and temporal measurements to accurately estimate the potential capacity of an offshore wind farm.

2. METHODOLOGY

The University of Maryland Baltimore County (UMBC) deployed Doppler wind lidar technology and other in-situ instruments within Maryland's offshore Wind Energy Area (WEA) during the State's sponsored geophysical survey (July-August 2013). Elastic and Doppler wind lidars (Leosphere ALS-450 355 nm and Windcube V2 Offshore) collected vertical profiles of aerosols and wind (speed and direction) on board the *Scarlet Isabella* research vessel. The group also launched weather balloons equipped with radiosonde instruments that measured vertical profiles of temperature, moisture, and wind speed and direction. Since the ship was in motion during most of the campaign, the translational motion was accounted for during data post-processing.

Buoy wind speed data were obtained from the closest the station to Maryland's WEA (38.461°N, 74.703°W). The anemometer height of Buoy 44009 data is 5m above the site elevation (sea level) [7]. Surface wind data are converted to wind speed at hub height (100m) using the Power Law extrapolation technique (1).

3. RESULTS

The July-August 2013 offshore Doppler wind Lidar data set was compared to available[1] buoy data to assess the relationship between empirically measured hub-height winds and power law extrapolated[2] estimates. Overall, both datasets suggest greatest wind speeds occurred during late day or overnight (between 06:00 pm - 06:00 am local time). However, compared to lidar measurements, the buoy power law extrapolations significantly *underestimated* hub-height (100 m) wind speeds. Hub-height mean wind speed values are 4.723 m/s and 8.143 m/s from buoy and Doppler wind data, respectively. Similar results were found when comparing offshore lidar measurements to operational Numerical Weather Prediction (NWP) models. Using a suite of NWP models, results indicate an *underestimation* of the offshore wind speed from 1.63-3.15 m/s, depending on model spatial resolution. Large model error in wind direction is also demonstrated, ranging from 26.9 -72.9 degrees. Finally, offshore lidar measurements were compared to the Department of Energy's National Renewable Energy Laboratory (NREL) estimate of the offshore wind resource within Maryland's WEA. The average July-August 2013 lidar hub-height wind speed is 7.4 m/s, while the NREL *annual* estimate is 8.2 m/s. Given the Mid-Atlantic wind resource is climatologically weakest during the summer season [8], results suggest that the *annual* mean wind speeds within Maryland's WEA may be higher than the initial NREL estimate.

Collectively, the results suggest significant differences between empirical hub-height wind measurements and power law/model estimates. The discrepancies are the result of 'non-standard' (neutral) turbine inflow conditions offshore. For example, the mean diurnal

[1]Due to buoy data availability, buoy-Doppler wind Lidar comparison was calculated from July 17-August 17, 2013.

[2] α =0.11 (offshore)

variability of lidar wind speeds demonstrated the frequent development of a low-level wind maximum (LLWM), with associated high turbine-layer wind shear and low turbulence intensity. High wind shear exponents were observed across a turbine's typical rotor layer (40m-160m), and 21% of the time values were negative. A case study event on August 30-31, 2013 was analyzed to investigate possible drivers of measurement versus estimate discrepancies during the campaign. August 30-31 offshore radiosonde data indicated an increase in atmospheric stability led to the development of a late afternoon/nocturnal LLWM near 100m. Further, the onset of the LLWM was marked by a sharp change in wind direction (northeast to southwest). To determine whether offshore conditions were similar to onshore, August 30-31 offshore data sets were compared to the nearest Maryland Department of Environment wind profiler, in Cambridge, MD. Although the wind profiler suggests a nocturnal low-level jet developed on land overnight on August 31, the event superseded an initial increase in offshore stability, wind speed, and change in wind direction within Maryland's WEA. The physical processes driving August 30-31 offshore conditions may be related to a variety of factors, such as coastal upwelling in the WEA or the development of a sea-land breeze circulation. More measurements and investigation is needed to determine the cause of the 'non-standard' turbine inflow conditions observed on August 30-31 as well as throughout the measurement campaign within Maryland's WEA.

4. CONCLUSIONS

Significant uncertainties are introduced when estimating a turbine's ability to produce power, due in part to limited met-ocean data networks and atmospheric assumptions inherent in traditional offshore wind resource assessment techniques. More measurements of site-specific micrometeorology and investigation of its impact on a turbine's power curve performance are needed to reduce offshore wind resource uncertainties. Results from a two month offshore data collection campaign in Maryland's WEA demonstrate significant error between measured hub-height wind speeds and traditional techniques used to estimate these values. The results suggest 'non-standard' inflow conditions occurred within Maryland's WEA, and elucidate the advantages of Doppler wind lidar technology for accurately assessing the offshore wind resource, as well as quantifying micrometeorological controls that impact a turbine's power curve performance.

ACKNOWLEDGEMENT

Funding for this work was provided from the Maryland Energy Administration Clean Energy Program (Contract Number U00P3400325) and the Joint Center for Earth System Technology Fellowship Program. The authors would also like to acknowledge the DOD/Army Research Laboratory for their Partnership in Research Transition (PIRT) Program and NOAA-CREST funding. Finally, a special thank you to Leosphere/Renewable NRG System and CB&I/Coastal Planning and Engineering Environmental and Infrastructure for instrument and data post-processing support.

REFERENCES

[1] Archer, C. L., Colle, B. A., Monache, L., 2014: Meteorology for coastal/offshore wind energy in the United States: recommendations and research needs for the next 10 years. *Bulletin of the American Meteorological Society*.

[2] Emeis, S. 2013: Wind Energy Meteorology: Atmospheric Physics for Wind Power Generation. Springer. ISBN 978-3-642-30523-8, pp. 34.

[3] Wharton and Lundquist, 2012: Atmospheric stability affects wind turbine power collection. *Environmental Research Letters*, **7**, 014005, doi: 10.1088/1748-9326/7/1/01400

[4] Vanderwende and Lundquist 2012, The modification of wind turbine performance by statistically significant distinct atmospheric regimes, *Environmental Research Letters*, **7**,034035, doi:1088/1748-9326/7/3/034035

[5] Barthelmie et al. 2013, Meteorological controls on wind turbine wakes, Proceedings of the IEEE, Vol. **101**, No.4

[6] Honrubia et al. 2012: The influence of turbulence and vertical wind profile in wind turbine power curve, *Progress in Turbulence and Wind Energy IV*, SPPHY, **141**, pp.251-254

[7] Station 44009, available at : http://www.ndbc.noaa.gov/station_page.php?station=44009

[8] Zhang, D. L., Zhang, S., & Weaver, S. J. 2006: Low-level jets over the mid-Atlantic states: Warm-season climatology and a case study. *Journal of applied meteorology and climatology*, **45**(1), 194-209.