Varying Roughness Lengths of Waves for Wind Energy Modeling Predictions

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Resource Assessment and Correlation

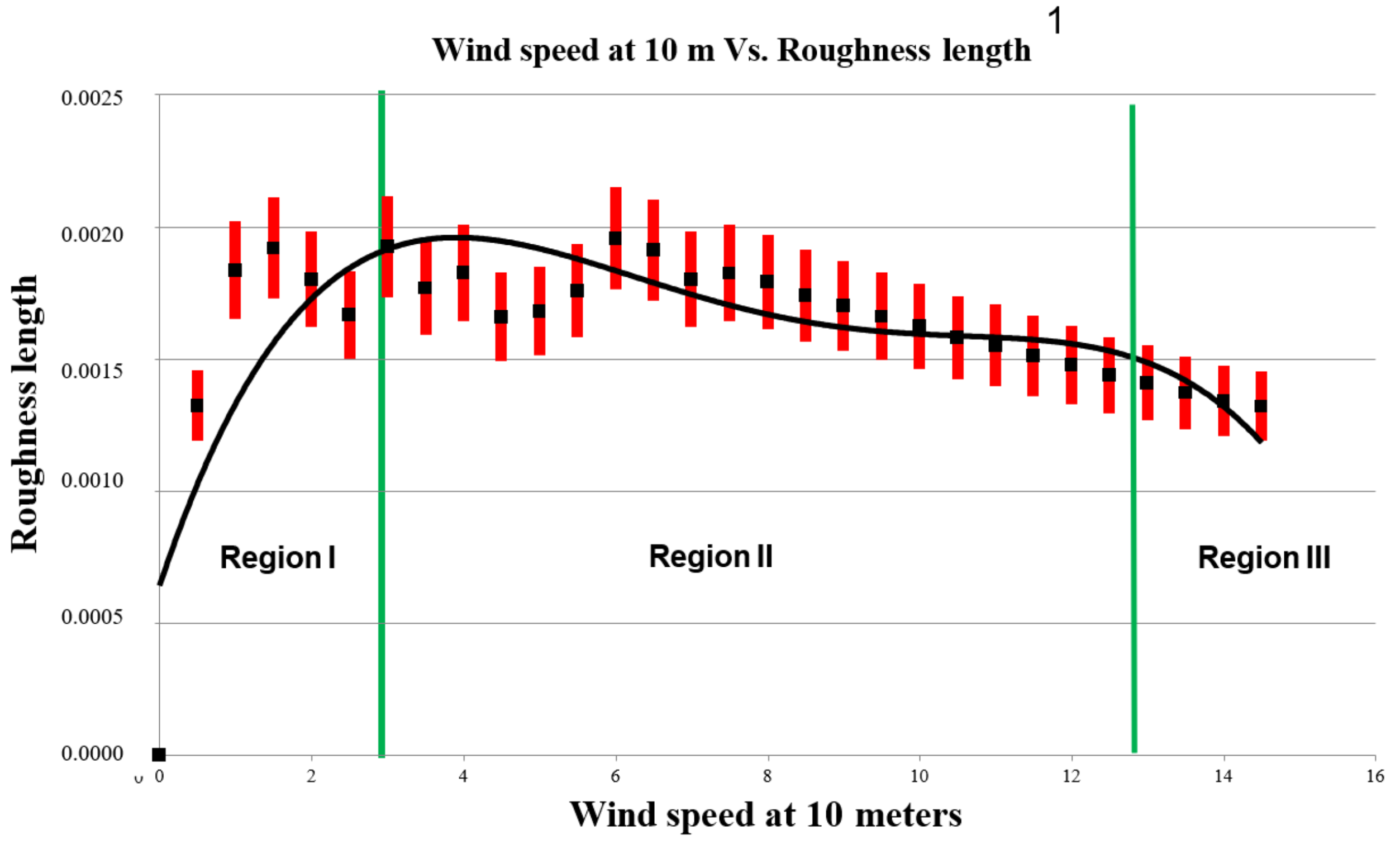

Figure 1 is showing mean wind speed averages and the corresponding surface roughness length of that wind speed. The data points are shown with error bars of 7% to illustrate the trend line of best fit.

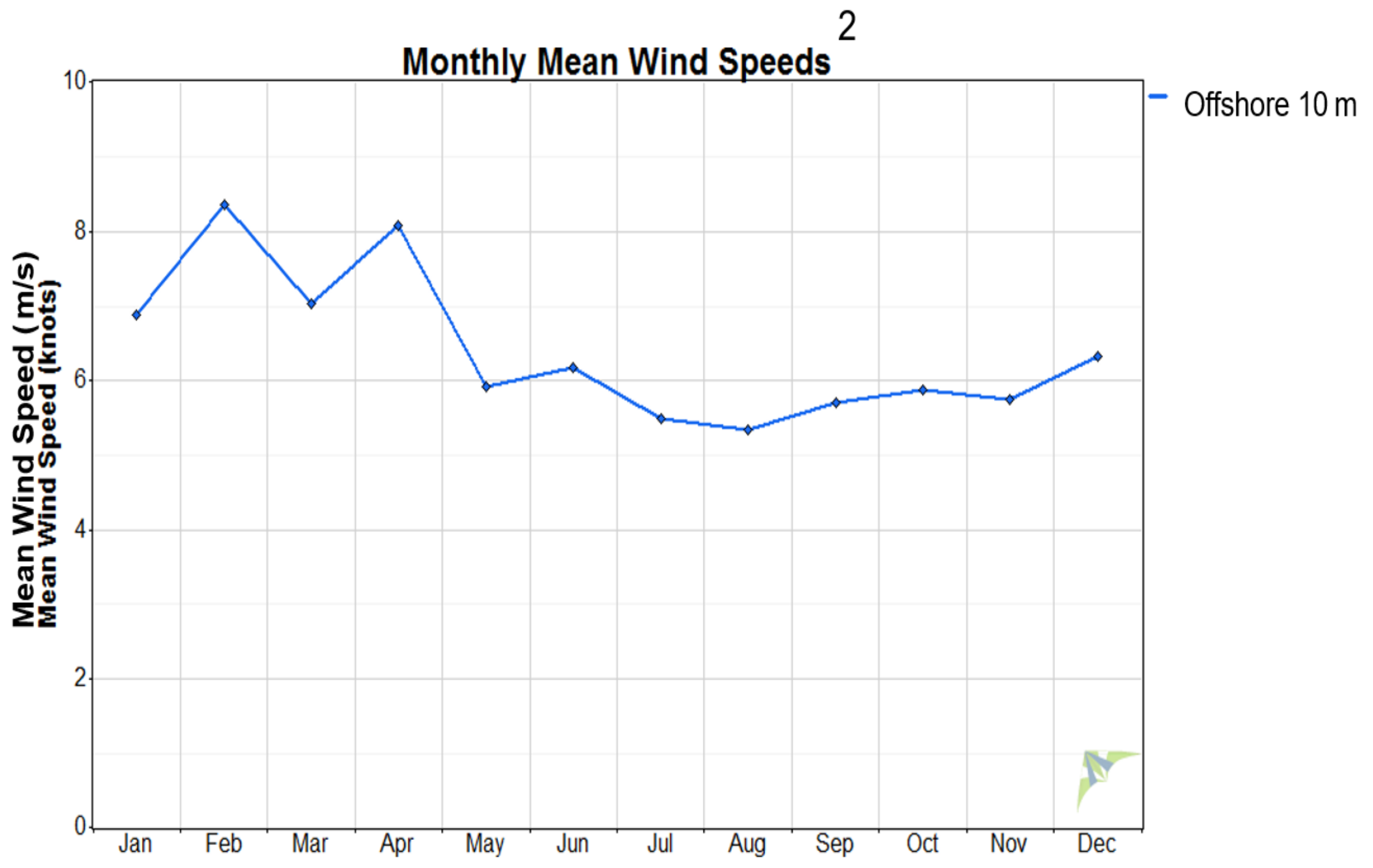

Figure 2 is showing the monthly means of wind speeds in meters per second at a height of 10 meters; this is 24 months of continuous data shown above.

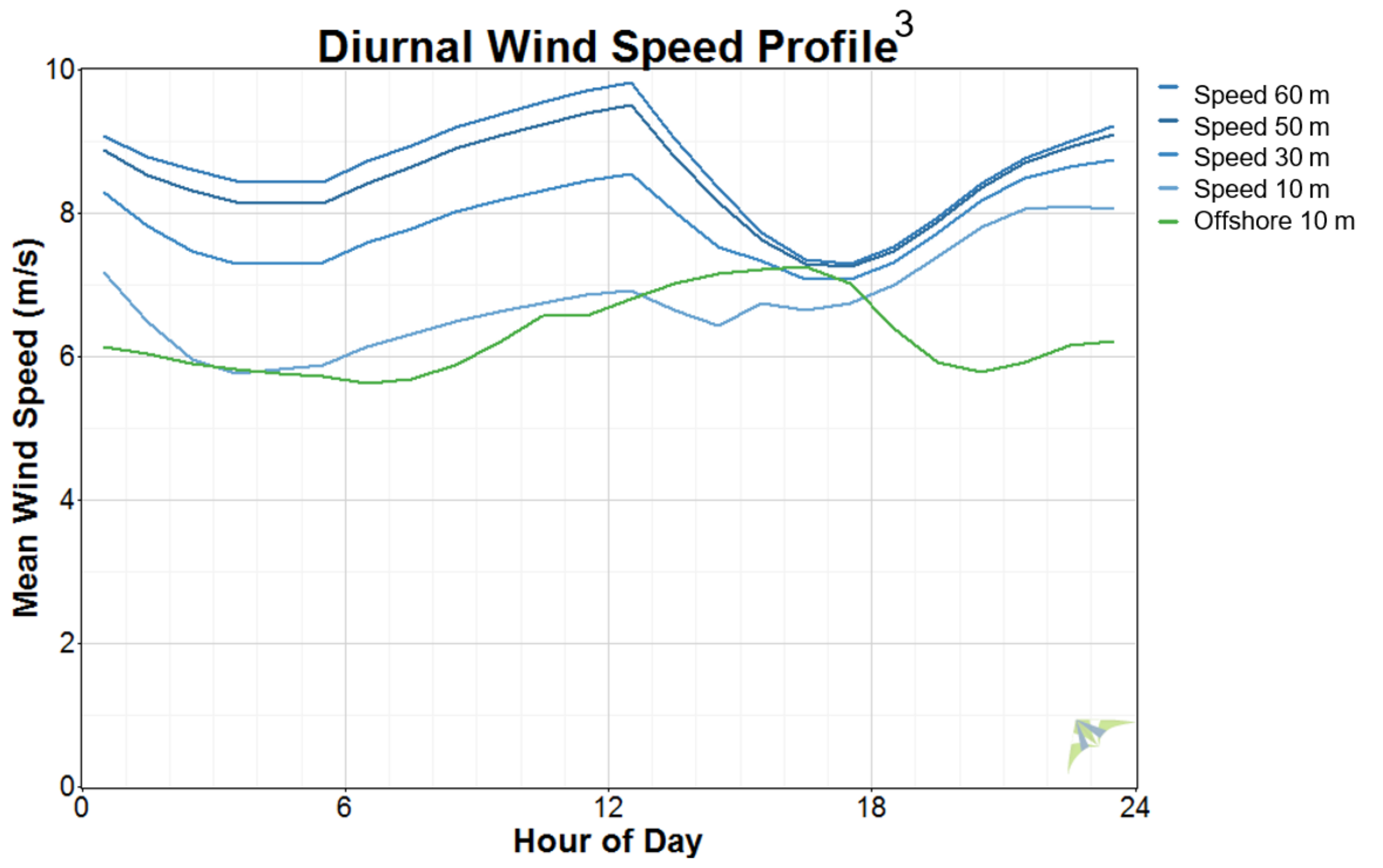

Figure 3 is showing the correlation of the offshore meteorological data to the onshore meteorological tower with all sensor heights shown. The offshore data shows a strong correlation to the onshore data at the same height.

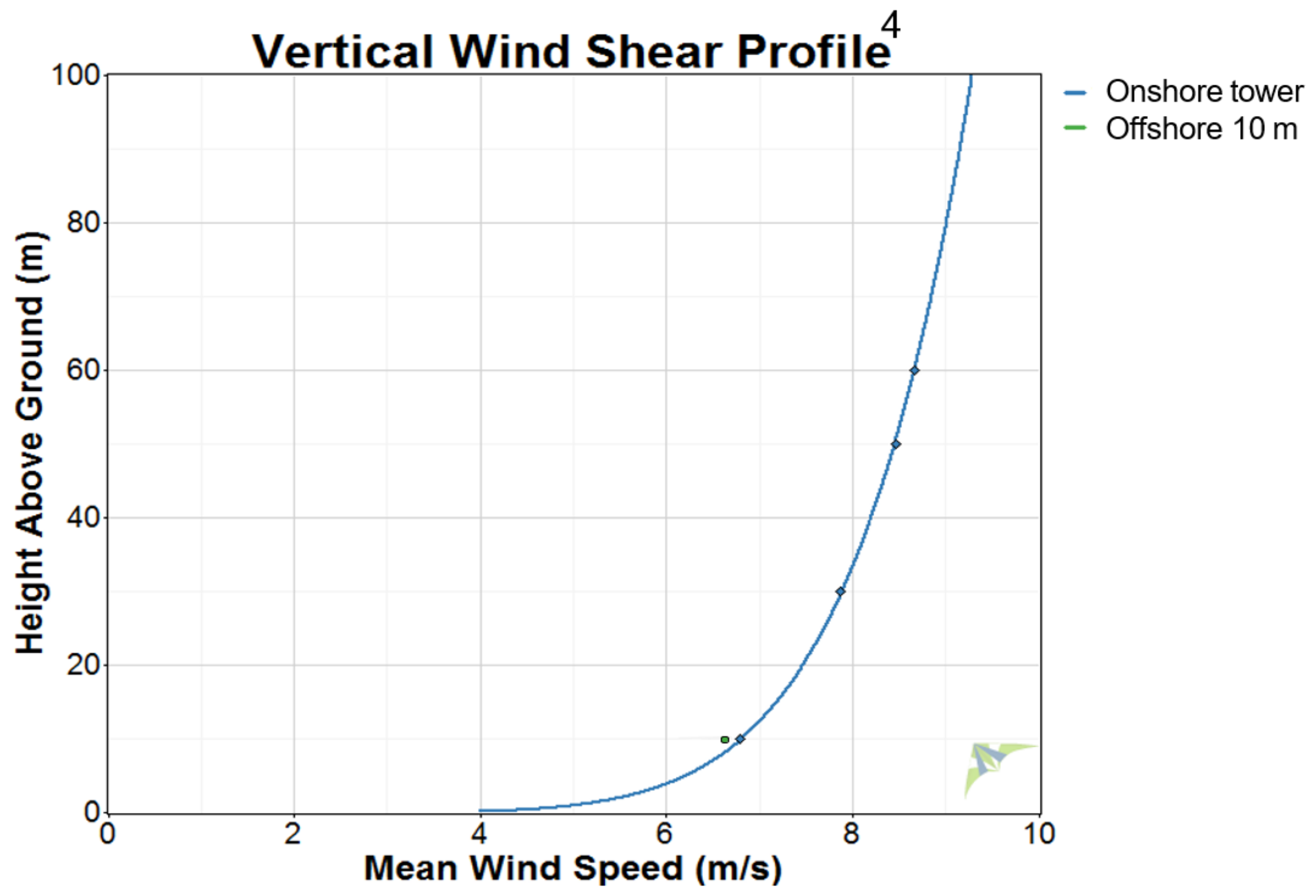

Figure 4 is showing the vertical wind profile of the onshore meteorological tower at all heights along with the offshore data point at 10 meters height.

Flow Model Results vs. Control Flow Model

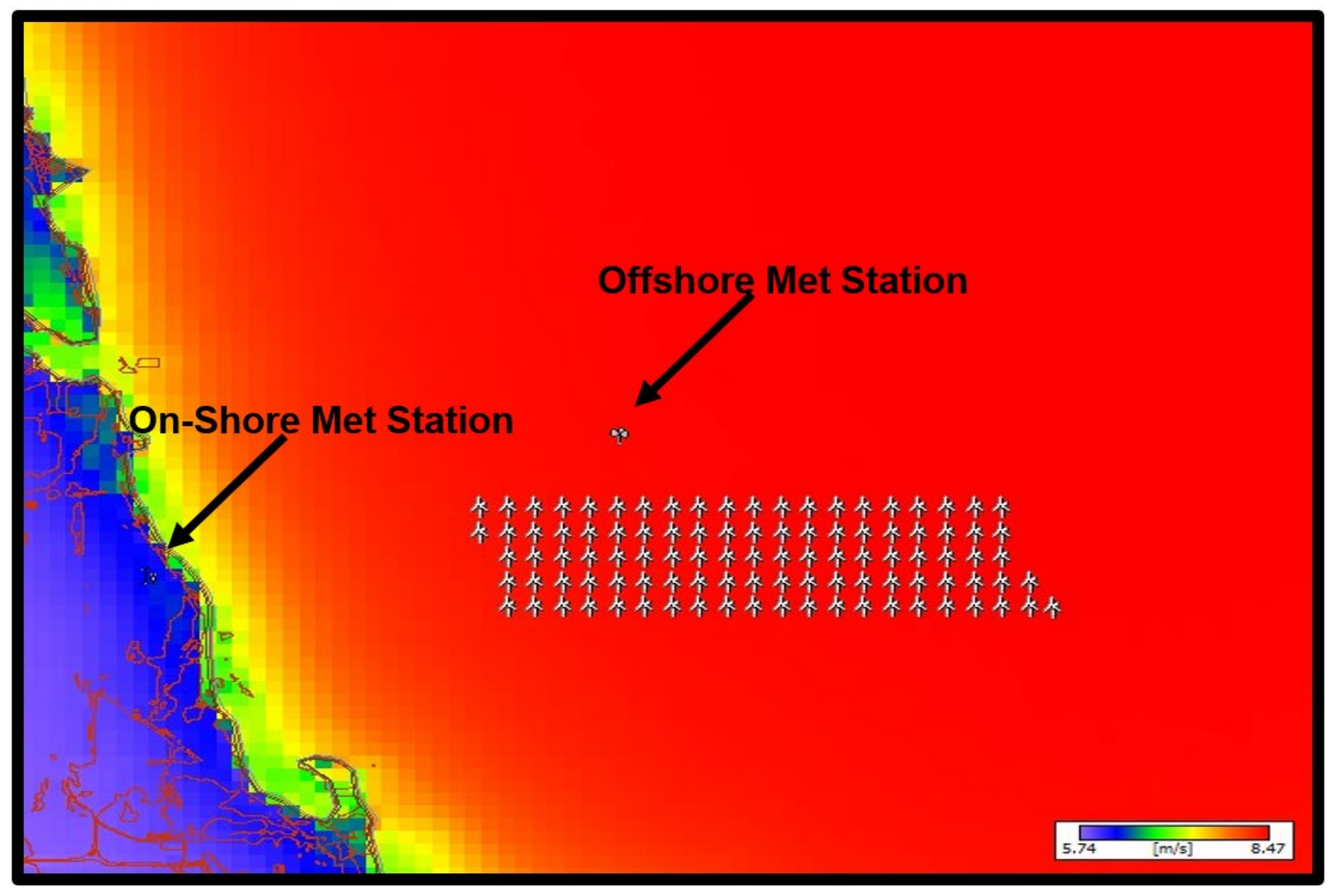

Figure 5 is showing the layout of the proposed 100 turbine layout project along with showing a resource grid calculated at hub height for the Siemens SWT 3.6. Turbine placement was not changed in the experiment to illustrate the difference in production just based on varying surface roughness lengths.

Variable Flow model (Z_0 = changing every 10 minutes with data set)				
	Total	Mean	Min	Max
Total net AEP [GWh}	1409.773	14.098	13.874	14.171
Proportional wake loss [%]	6.98		2.76	8.92
Mean speed [m/s]		8.44	8.36	8.47
Control Flow Model (Z_0 = 0.000 m)				
	Total	Mean	Min	Max
Total net AEP [GWh}	1429.173	14.292	13.933	14.484
Proportional wake loss [%]	6.83		2.76	8.73
Mean speed [m/s]		8.52	8.38	8.59
Difference in Flow Models (100 turbine project)				
	Total	Mean	Min	Max
Total net AEP [GWh}	19.4	0.194	0.059	0.313
Proportional wake loss [%]	-0.15		0	-0.19
Mean speed [m/s]		0.08	0.02	0.12

Table 1 is showing the control experiment that was calculated with a near frictionless surface roughness length, as well as the varying roughness models annual energy predictions. The bottom of the table is showing the difference in estimated production, wake effect and wind speeds.

Physical z_0 [m]	Terrain Surface Characteristics	Roughness Class	Z_0 Specified in Flow Model [m]
1.5		**4** (1.5 m)	1.5
> 1	tall forest		> 1
1	city		1
0.8	forest		0.8
0.5	suburbs		0.5
0.4		**3** (0.40 m)	0.4
0.3	shelter belts		0.3
0.2	many trees and/or bushes		0.2
0.1	farmland with closed appearance	**2** (0.10 m)	0.1
0.05	farmland with open appearance		0.05
0.03	farmland with very few buildings/trees	**1** (0.03 m)	0.03
0.02	airport areas with buildings and trees		0.02
0.01	airport runway areas		0.01
0.008	mown grass		0.008
0.005	bare soil (smooth)		0.005
0.001	snow surfaces (smooth)		0.003
0.0003	sand surfaces (smooth)		0.003
0.0002	(used for water surfaces in the Atlas)	**0** (0.0002 m)	0
0.0001	water areas (lakes, fjords, open sea)		0

Table 2 is showing the current industry recommendations of surface roughness lengths to digitize maps for flow model energy predictions. Notice that, even though the roughness class of water is .0002 m, the flow model specified value is 0 to distinguish water from land.

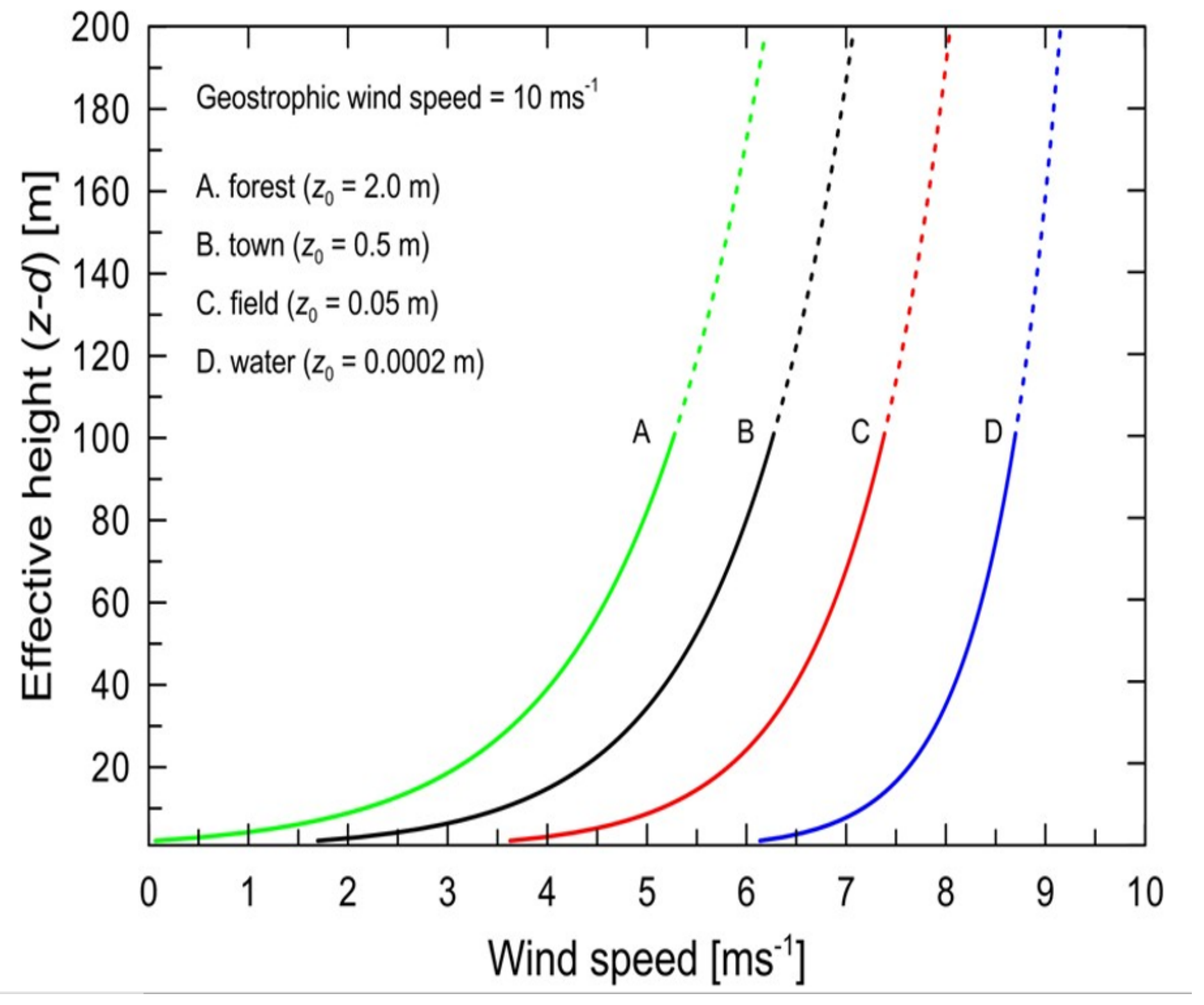

Figure 6 is showing different surface roughness lengths resulting in different vertical profiles of wind speed. The y-axis is height above surface and the x-axis is wind speed. For a range of surface roughness lengths.[IV]

Abstract

Current flow modeling prediction software does not account for seasonality with respect to surface roughness. This is mainly due to the lack of a proper way to measure surface roughness lengths of land. Current offshore meteorological stations allow us to have data that can calculate surface roughness of a wave given a wind speed, wave height, and wave period for every hour of the year. This poster argues that if meteorological data can be considered in flow models at 10-minute intervals, varying surface roughness lengths can be considered as well.

What would happen if we accounted for varying surface roughness lengths with respect to annual energy production? This is the question that this poster plans to answer and to prove that using a set surface roughness length for the duration of a meteorological data set will lead to an inappropriate estimation of wind energy production as it pertains to an off-shore wind energy project.

Introduction

Current land based meteorological towers do not have the necessary/proper instrumentation for measurement of surface roughness lengths with respect to seasonality. This poster will focus on offshore meteorological buoy data because surface roughness lengths can be derived from the data of wind speed, wave height, and wave period. This data will be correlated to a nearby land based meteorological tower (~ 5 Km).

Current flow models assume water as frictionless even though industry admit this is a shortfall in the calculations. This frictionless coefficient of surface roughness leads to a "speed up" effect that is responsible for an over-estimation of production with respect to an offshore wind energy project.

Based on EWEA offshore wind industry key trends and statistics [I], the average size offshore wind energy project in Europe uses a Siemens SWT 3.6 wind turbine generator and the project has an average nameplate capacity of ~ 338 MW. Therefore, this poster will try to utilize these factors when making energy calculations.

Experiment

Data was obtained from a meteorological buoy that was classified as offshore (> 30 meters water depth) for a time period of 24 continuous months. Channels of data include mean wave height (1 hour), Wave Period (1 hour), wind direction (10 minutes), and wind speed (10 minutes) shown in Chart 2. Data was quality controlled for the purposes of correlation to a nearby meteorological tower that had channels at 10, 30, 50, and 60 meter heights for wind speed (10 minutes), as well as wind direction at 30 and 60 meters (10 minutes) shown in Charts 3 and 4.

Using the off-shore data, the phase velocity of the wave was determined knowing the wave period and wave height according to Kraaiennest [II]. Once wave height was determined, a roughness length could be calculated based on the wave height, phase velocity, and wind velocity using GAO, Z. [III]. A table was made with bin widths of 0.5 m/s to develop a bootstrap distribution of roughness length given wind speed, shown in Chart 1.

This distribution can now be processed in a flow model to determine the difference in annual energy production given the varying roughness lengths (changing every 10 minutes) of the offshore site in question. Using 100 Siemens SWT 3.6 MW–120 meter wind turbine generator for the simulation to stay as close as possible to the 338 MW average of the EWEA report. This distribution will be processed against a control flow model that has the exact same data set and turbine position with a surface roughness length of 0.000 meters.

Conclusions

1. Wave height and time period caused by a given wind speed has a unique roughness length value greater than the standard of 0.00 meters;
2. For this project with minimal roughness length additions (i.e. .0001 vs .0002), the estimated difference is 1.5% equating to ~19 GWhs per year equaling an estimated $1.2 M / year;
3. Minimal increases in proportional wake loss percentage was detected;
4. 1.5% difference using tools that are already available that require integration into each other;
5. Over a 20-year expected lifetime of a project, this could help explain an estimated $24.7M in over-estimated revenue

Future Work

1. Implement high fidelity wave data that is measured and averaged every 10 minutes;
2. Implement standardization of offshore metrological devices to measure wave height and wave period;
3. Develop ways to integrate offshore surface roughness length into flow models similar to that of wind speed and direction;
4. Develop a way to integrate seasonality (10 minutes, hourly, weekly, or monthly values) into existing flow models to take into consideration changing on-shore surface roughness lengths;
5. Collect additional data to identify trends that associate themselves with geographic location and climate;
6. Identify additional affects during stable and unstable atmospheric conditions beyond the neutral layer condition;
7. Utilize Texas Tech University Ka band radar trucks to measure high fidelity wind resource data from the coast, and integrate into SCADA systems;
8. Work with quality control software to ensure that extra variables such as wave height and wave period can be implemented, and that said software can calculate phase velocity as well as surface roughness lengths as a 10 minute variable data point

References:

I: Pineda, I., EWEA (Ed.). (n.d.). The European Offshore Wind Industry - key trends and statistics 2015. Retrieved November 15, 2016

II: $\lambda = \frac{gT^2}{2\pi}$ - formula provided by "Wave disp" by Kraaiennest

III: Gao, Z. Q. , Q. Wang, and M. Y. Zhou, 2009: Wave-dependence of friction velocity, roughness length, and drag coefficient over costal and open water surfaces by using three databases. *Adv. Atmos. Sci.,* **26** (5),

IV: Ib Troen, E. L. Petersen: *European Wind Atlas*. Published for the Commission of the European Communities, Directorate-General for Science, Research, and Development, Brussels, Belgium by Risø National Laboratory, 1989.