New York State Offshore Wind Master Plan

Preliminary Offshore Wind Resource Assessment

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New York State Offshore Wind Master Plan Preliminary Offshore Wind Resource Assessment

Final Report

Prepared for:

New York State Energy Research and Development Authority

Prepared by:

AWS Truepower, LLC, a UL Company

Albany, New York

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Acronyms and Abbreviations

AoA	Area of Analysis
AWST	AWS Truepower
BOEM	Bureau of Ocean Energy Management
GIS	geographic information system
IEC	International Electrotechnical Commission
kg/m^3	kilograms per cubic meter
km	kilometers
m	meters
Master Plan	New York State Offshore Wind Master Plan
metocean	meteorological and ocean
MSL	above mean sea level
NWP	numerical weather prediction
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OSA	offshore study area
rms	root mean square
Study	Preliminary Offshore Wind Resource Assessment
TI	turbulence intensity
TMY	Typical Meteorological Year
WRF	Weather Research and Forecasting

Executive Summary

This Preliminary Offshore Wind Resource Assessment (Study) provides preliminary, model-based estimates of the long-term wind resource and atmosphere characteristics of the New York Offshore Study Area (OSA) out to a water depth of at least 60 meters (m) (referred to as the Area of Analysis [AoA] throughout this Study). The modeled wind conditions are derived from AWS Truepower's validated national wind map and dedicated numerical weather prediction (NWP) model runs. The purpose of this work is to advance the New York State Offshore Wind Master Plan by providing long-term wind and atmosphere information that can be used to inform the preliminary identification of potential wind energy areas that the State believes should be considered by the U.S. Bureau of Ocean Energy Management for offshore wind energy projects in the OSA and to estimate future offshore wind project costs and energy production. The resource assessment evaluated conditions across the AoA at a hub height of 110 m above mean sea level, out to a water depth of at least 60 m. Time series of relevant wind parameters at multiple elevations were developed for five locations within the AoA.

The results of the preliminary wind resource assessment indicate that the range of modeled long-term wind speeds at 110 m above mean sea level is approximately 7.9 meters per second near the coast to approximately 9.7 meters per second at the 60 m depth contour. Prevailing wind directions are modeled to be southwest and west-northwest and, similar to average wind speeds, vary by season. Consistent with other offshore environments, distance from coastline is the most influential factor defining the spatial distribution of the wind resource across the AoA, with wind speeds generally increasing with distance from shore. The range of long-term conditions predicted for areas under additional analysis is comparable with active regional offshore wind development areas in Rhode Island and Massachusetts, as well as previously constructed projects in Europe. This Study indicates that in general, modeled wind speeds within the OSA appear to be viable for commercial-scale offshore wind development.

1 Introduction

1.1 New York State Offshore Wind Master Plan

This Preliminary Offshore Wind Resource Assessment (Study) is one of a collection of studies prepared on behalf of New York State in support of the New York State Offshore Wind Master Plan (Master Plan). These studies provide information on a variety of potential environmental, social, economic, regulatory, and infrastructure-related issues associated with the planning for future offshore wind energy development off the coast of the State. When the State embarked on these studies, it began by looking at a study area identified by the New York State Department of State in its two-year Offshore Atlantic Ocean Study (NYS Department of State 2013). This study area, referred to as the "offshore study area (OSA)," is a 16,740-square-mile (43,356-square-kilometer) area of the Atlantic Ocean extending from New York City and the south shore of Long Island to beyond the continental shelf break and slope into oceanic waters to an approximate maximum depth of 2,500 meters (m) (Figure 1). The OSA was a starting point for examining where turbines may best be located, and the area potentially impacted. Each of the State's individual studies ultimately focused on a geographic Area of Analysis (AoA) that was unique to that respective study. The AoA for this Study is described in Section 1.2.

The State envisions that its collection of studies will form a knowledge base for the area off the coast of New York that will serve a number of purposes, including (1) informing the preliminary identification of an area for the potential locating of offshore wind energy areas that was submitted to the Bureau of Ocean Energy Management (BOEM) on October 2, 2017, for consideration and further analysis; (2) providing current information about potential environmental and social sensitivities, economic and practical considerations, and regulatory requirements associated with any future offshore wind energy development; (3) identifying measures that could be considered or implemented with offshore wind projects to avoid or mitigate potential risks involving other uses and/or resources; and (4) informing the preparation of a Master Plan to articulate New York State's vision of future offshore wind development. The Master Plan identifies the potential future wind energy areas that have been submitted for BOEM's consideration, discusses the State's goal of encouraging the development of 2,400 megawatts of wind energy off the New York coast by 2030, and sets forth suggested guidelines and best management practices that the State will encourage to be incorporated into future offshore wind energy development.

Each of the studies was prepared in support of the larger effort and was shared for comment with federal and State agencies, indigenous nations, and relevant stakeholders, including nongovernmental organizations and commercial entities, as appropriate. The State addressed comments and incorporated feedback received into the studies. Feedback from these entities helped to strengthen the quality of the studies and helped to ensure that these work products will be of assistance to developers of proposed offshore wind projects in the future. A summary of the comments and issues identified by these external parties is included in the Outreach Engagement Summary, which is appended to the Master Plan.

The Energy Policy Act of 2005 amended Section 8 of the Outer Continental Shelf Lands Act (OCSLA) to give BOEM the authority to identify offshore wind development sites within the Outer Continental Shelf (OCS) and to issue leases on the OCS for activities that are not otherwise authorized by the OCSLA, including wind farms. The State recognizes that all development in the OCS is subject to review processes and decision-making by BOEM and other federal and State agencies. Neither this collection of studies nor the State's Master Plan commit the State or any other agency or entity to any specific course of action with respect to offshore wind energy development. Rather, the State's intent is to facilitate the principled planning of future offshore development off the New York coast, provide a resource for the various stakeholders, and encourage the achievement of the State's offshore wind energy goals.

1.2 Preliminary Wind Resource Assessment Study Introduction

This Study provides preliminary, model-based estimates of the long-term wind resource and atmosphere characteristics of the OSA, out to water depths of at least 60 m, which is referred to herein as the AoA. The objective of this Study is to support the State's Master Plan by providing data and analyses to characterize the atmospheric conditions relevant to offshore wind development. Specifically, this Study is intended to help to inform the preliminary identification of areas that BOEM should consider for offshore wind energy projects within the OSA. This Study is additionally intended to help estimate future offshore wind project costs and energy production projections, and to support initial project design and any bid processes for future candidate projects. The results of this effort provide preliminary definition of high-level meteorological parameters that may be used to inform future project siting, design, assessment, and costs. The information also provides a baseline understanding of the OSA region, from which more detailed analyses may be conducted in the future.

Existing validated data sets and industry-standard tools were employed to characterize the wind resource across the AoA. Wind and other relevant atmosphere conditions were derived from AWS Truepower's (AWST's) validated national wind map and dedicated numerical weather prediction (NWP) model runs. The resource assessment evaluated conditions across the AoA at a hub height of 110 m above mean sea level (MSL), out to a water depth of at least 60 m. The depth limit of 60 m was employed as the near-term threshold for cost effective, bottom-fixed, offshore wind turbine foundations. Time series of relevant parameters at multiple elevations, including 100, 110, and 140 m MSL, were developed for five locations to support additional analysis of regions within the AoA. The elevations were identified to represent the range of current and potential future offshore wind turbine hub heights and to facilitate comparison with legacy offshore wind analyses. The 110 m MSL elevation was employed as a reference hub height across a number of the State's related studies.

This Study presents a narrative discussion of the preliminary offshore wind resource and atmosphere conditions assessed across the AoA. It identifies the implications of those conditions for potential future offshore wind project development in the AoA and presents the methods employed to derive these conditions. The Study focuses on the modeled parameters in the context of deriving long-term energy production estimates; findings relevant to project development and design are also identified where appropriate. Relevant findings are presented in various plots, tables, and parameter summaries in the following sections. More detailed statistical summaries of modeled conditions at each of the evaluation areas are provided in Appendices A through E.

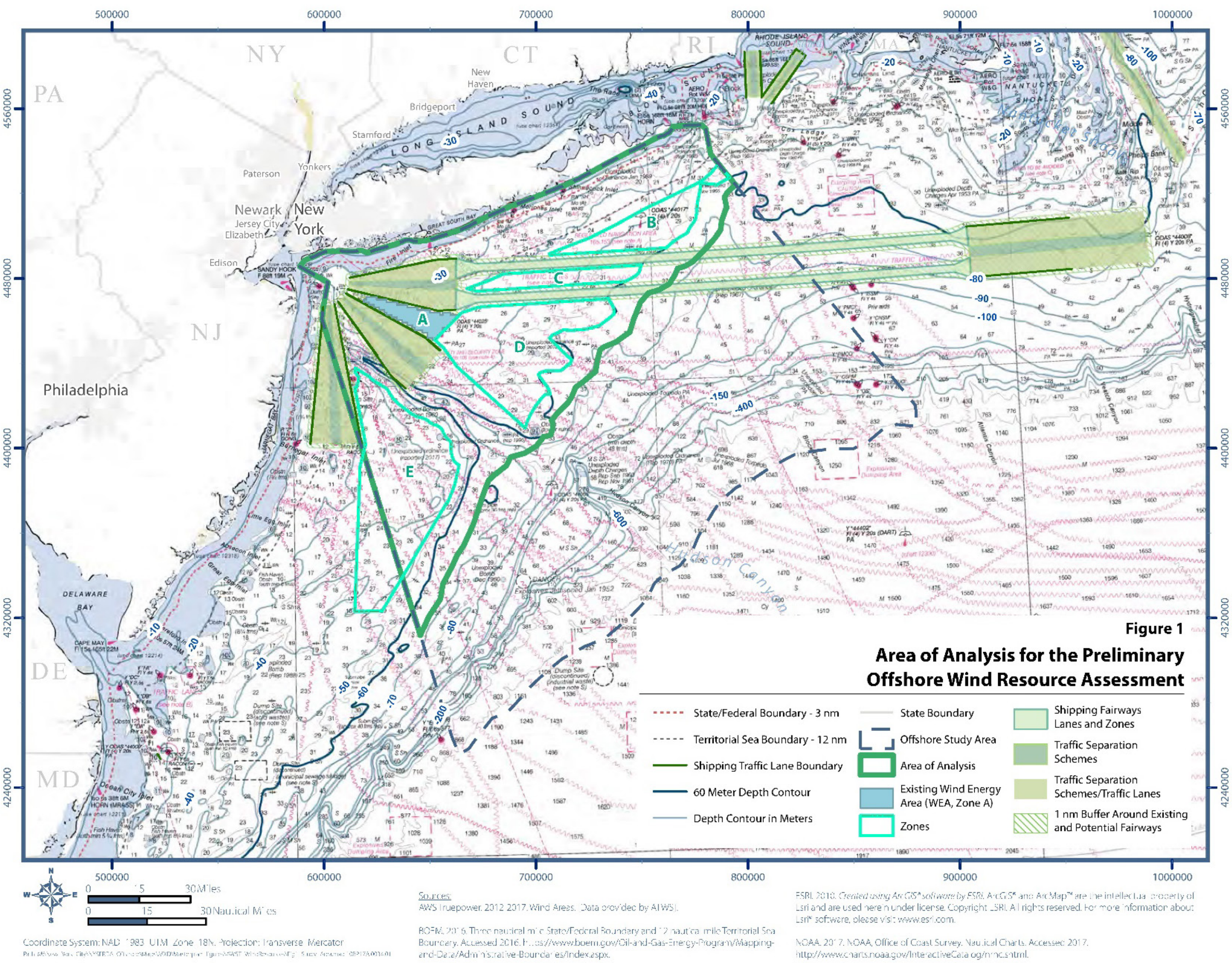
2 Site Description

The OSA is defined in the Blueprint for the New York State Offshore Wind Master Plan (NYSERDA n.d.) and matches the New York State Department of State's 2013 "Offshore Planning Area" boundary (NYS Department of State 2013). The full area comprises 16,740 square miles of the ocean, extending from the south shore of Long Island and New York City offshore to the continental shelf break. The preliminary wind resource assessment analyses in this Study focus on waters in the OSA up to 60 m deep. This depth is commonly used to represent the near-term limit of bottom-fixed, offshore wind turbine structures and thus functions as an effective physical development boundary for this analysis.

The State identified basic constraints to offshore wind energy development, including navigation and shipping traffic separation schemes and areas precluded by the U.S. Department of Defense. This resulted in the identification of four zones that limit potential conflicts and merit further examination, identified from east to west as B, C, D, A, and E (Zone A comprises the area that is now the Statoil Lease Area). The AoA and Sites A through E are illustrated below in Figure 1. This preliminary wind resource assessment covers the AoA out to at least the 60 m depth contour, and specific data sets were developed for each of the evaluation areas.

Figure 1. Area of Analysis for the Preliminary Offshore Wind Resource Assessment

Source: AWST (2017)



3 Wind Modeling

Model-based wind characteristics, derived from NWP and/or other flow simulation tools, are commonly employed for preliminary offshore resource assessment when observational data are scarce. In many cases, modeled offshore data serve as the basis for preliminary energy production estimates and design inputs prior to the deployment of dedicated meteorological and ocean (metocean) measurements within a specific area of interest. Several model-based data products were part of the preliminary wind resource assessment for the AoA. These data products and the derivation methods are described in the following sections. All wind and atmosphere conditions presented in this Study were modeled at the New York State Energy Research and Development Authority—designated hub height of 110 m MSL, which was considered a representative height for near-term turbines and was employed across a number of related offshore wind studies.

3.1 National Wind Map

A geographic information system (GIS) wind map of long-term wind speeds at 110 m MSL was provided for the AoA, out to a depth of at least 60 m. The wind resource characteristics for this Study were partly derived from AWST's validated national wind map. The map was developed with the MesoMap system (AWS Truepower 2012), which employed a numerical weather prediction model to simulate long-term wind and weather conditions throughout the AoA at a spatial resolution of 200 m.

The standard MesoMap system configuration, noted above, was used to produce the national wind map. The mesoscale model (Mesoscale Atmospheric Simulations System) simulated regional weather patterns with a grid spacing of 2.5 kilometers (km). The microscale model (WindMap) simulated the localized effects of topography and surface roughness on a grid spacing of 200 m. The source of topographic data was the National Elevation Dataset, a digital terrain model produced on a 30 m grid by the U.S. Geological Survey (USGS). The source of land cover data was the 30 m resolution National Land Cover Dataset, which is produced by the USGS and derived from Landsat imagery. Both data sets are of very high quality and are among industry standard inputs for modeling of this type. The onshore land cover characteristics were converted into regionally representative roughness length values, which are numerical approximations of surface conditions employed in flow modeling to capture the effects of varying land cover types on wind condition. The offshore roughness length values are typical for open ocean locations.

The predicted long-term average free wind speed across the AoA at 110 m MSL is expected to range between approximately 7.9 meters per second (m/s) near the coast to approximately 9.7 m/s at the 60 m depth contour. The overall estimated long-term average free wind speed in the AoA is 9.3 m/s. In offshore environments, distance from coastline is typically the most influential factor defining the spatial distribution of wind in the AoA, with wind speeds generally increasing with distance from shore. The modeled wind resource characteristics are described further in Section 4.

The accuracy of the national wind map data has been verified by comparing map predictions with independent observations for over 1,600 stations across the country, including numerous coastal and offshore data sets within and adjacent to the AoA. The National Renewable Energy Laboratory has been closely involved to ensure the objectivity of the national wind map validation process. As part of the process, the root mean square (rms) error was calculated for all of the validation points. This metric represents the average error between modeled and measured speeds at a measurement point. In simple wind regimes (such as open plains or well offshore), the rms error has typically been found to be 5% or less, meaning that the modeled speeds were within 5% of the observed speeds, on average. In complex wind regimes such as Wyoming and coastal Brazil, the rms error (after accounting for uncertainty in the measurements) is typically 0.3 to 0.5 m/s, or 5% to 7% of the mean speed. It should be stressed that the mean wind speed at any particular location may depart substantially from the predicted values, especially where the elevation, exposure, or surface roughness differs from that assumed by the model, or where observed data are scarce.

3.2 Time Series

Long-term 10-minute time series of wind speed, wind direction, air temperature, relative humidity, air density, and turbulence intensity (TI) were developed at the centroid of each of the five sites in the OSA. The State selected these five centroids as geographically representative of Sites A through E and used the data developed at these locations across other related analyses. The period of record modeled included 1980 through 2016, though the wind resource assessment focused on the 20-year period of 1997 through 2016.[1] The time series were developed at three[2] heights that reflect the range

[1] The full period of record was developed to support specific analyses with concurrent metocean data. Due to a known discontinuity in one of the model input data sets, AWST's procedures constrain the long-term time series used for resource assessment to 1997 and later. This 20-year data set is stable and verified.

[2] Time series at a fourth height—10 m MSL—were also developed for each location to support correlation with concurrent metocean hindcast data sets. Since the metocean analyses were not executed, data at the elevation were archived.

of current and near-term offshore wind turbine hub heights. The three heights, which are considered throughout the Study, were selected based partly on the following:

- 100 m MSL, to compare with legacy wind data in the region (e.g., National Renewable Energy Laboratory).
- 110 m MSL, the defined hub height.
- 140 m MSL, to represent potential future hub heights and to provide an additional data point within an offshore turbine's rotor swept area from which additional site characteristics can be calculated (e.g., wind shear).

The mesoscale model used to develop these time series was the open-source Weather Research and Forecasting (WRF) model. WRF is a state-of-the-art NWP model designed to simulate synoptic and mesoscale atmospheric circulations (Skamarock, William C. 2004). WRF was developed by several organizations, including the National Center for Atmospheric Research, the National Centers for Environmental Prediction, the Air Force Weather Agency, the Naval Research Lab, the University of Oklahoma, and the Federal Aviation Administration in the early 2000s. The WRF model is updated frequently, with new versions released twice annually, and can use analysis or reanalysis datasets for initialization.

The WRF simulations were initialized by the ERA-Interim (Dee, D. P., et al. 2011) reanalysis dataset. Several studies by AWST (Brower, Michael C., et al. 2013) and others (Lileo, Sonia and Olga Petrik. 2011; Decker, Mark 2012) show that the third-generation reanalysis datasets, such as ERA-Interim, have superior accuracy in terms of their correlation to meteorological mast data. AWST uses a dynamical downscaling approach with nested grids of 27 km, 9 km, 3 km, and 1 km resolution. The 1 km resolution WRF model outputs were then coupled with WindMap—a microscale mass-conserving model—which was run on a grid scale of 200 m.[3] Finally, the output of WindMap was adjusted to the AWST validated national wind map speed at the modeled location to ensure representativeness of the long-term average speed. A map of the long-term wind speeds and time series data points across the AoA is presented below in Figure 2.

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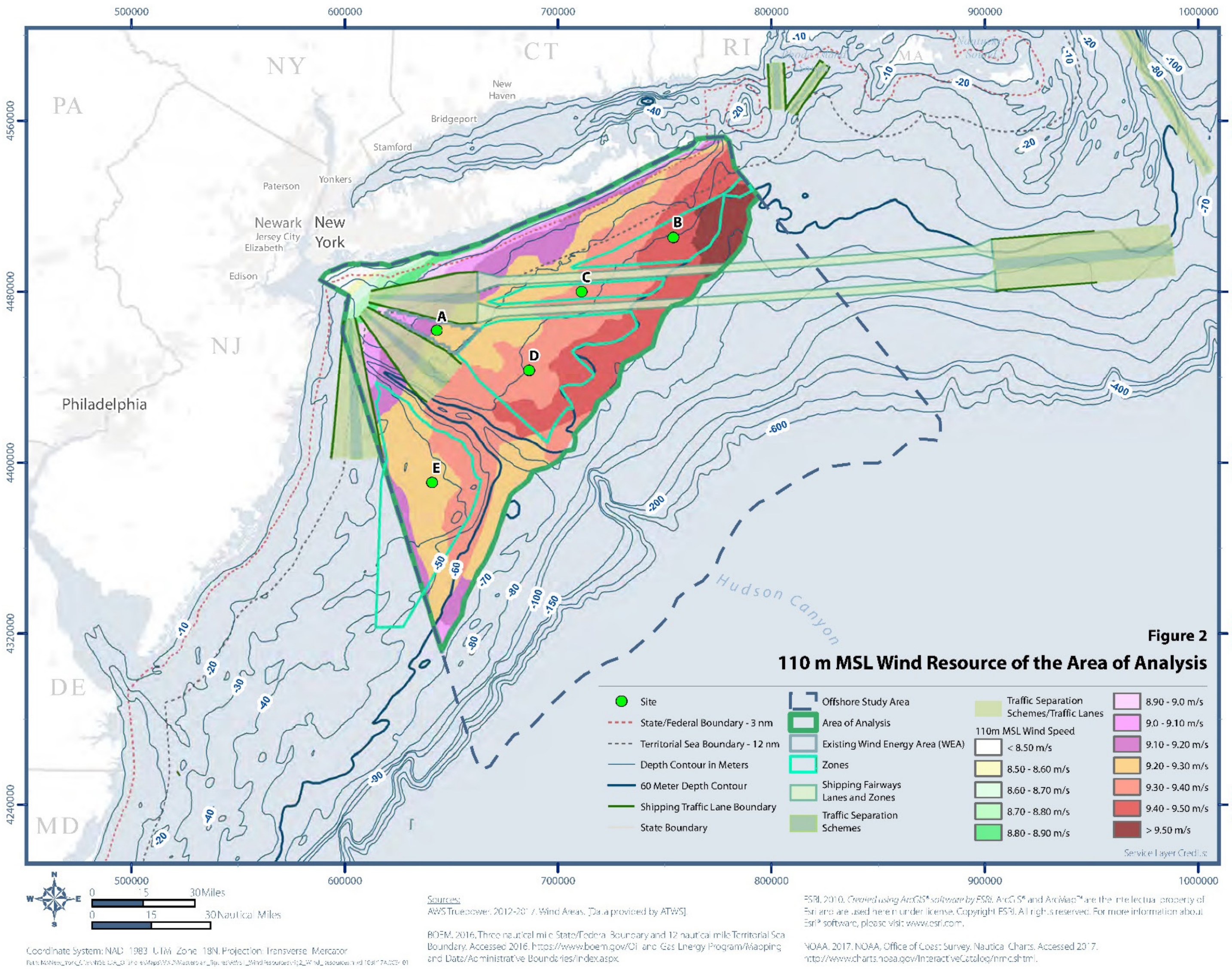
3 WindMap, developed by AWST, is a mass-conserving model that adjusts an initial wind field, here supplied by WRF, in response to local variations in topography and surface roughness. See, e.g., Michael Brower, "Validation of the WindMap Model," Proceedings of WindPower 1999, American Wind Energy Association, June 1999.

In addition to the long-term 10-minute time series, Typical Meteorological Year (TMY) data files of wind speed, wind direction, and temperature at three heights were developed for each of the area centroids. TMYs are single year, hourly time series constructed to be representative of both long-term average conditions and a location's temporal variability. They are commonly leveraged to support ancillary, energy-related analyses such as seasonal or monthly load correlation assessment.

The modeled time series—both the long-term 10-minute and the hourly TMY files—facilitate detailed examination of the wind resource across the AoA. For example, the wind and atmosphere parameters can be assessed by height, month, time of day, and other metrics. Coupled with the 110 m validated wind map, the time series allow the spatial and temporal characteristics of the AoA's modeled wind resource to be well described. These data and their associated effects on potential offshore wind energy production and future project design are anticipated to support the State's broader assessment of the OSA.

Figure 2. 110 m MSL Wind Resource of the Area of Analysis

Source: AWST (2012-2017)



4 Wind Resource Characteristics

This section presents summary statistics and discussions of preliminary modeled wind resource and atmosphere characteristics relevant to potential offshore wind energy production estimation and future project design. Tabular information is presented for each of the centroids. Graphical summaries are presented for Location D as representative examples of the AoA geography and wind resource characteristics. Detailed statistics for each time series are provided in Appendices A through E.

4.1 Wind Speed

4.1.1 Long-term Average

Long-term average wind speed is one of the primary characteristics employed to assess the viability of a location for commercial offshore wind development. Modeled annual average speeds for each of the centroids' three elevations are presented in Table 1. The 110 m speeds across the region are comparable with modeled conditions in neighboring wind energy areas under development,[4] as well as modeled speeds at operating projects in Europe.[5]

Table 1. Modeled Long-term Average Speeds

Height (m MSL)	Location A (m/s)	Location B (m/s)	Location C (m/s)	Location D (m/s)	Location E (m/s)
100	9.1	9.3	9.2	9.2	9.1
110	9.2	9.4	9.3	9.4	9.3
140	9.5	9.8	9.6	9.7	9.6

4.1.2 Weibull Parameters

The Weibull function is an analytical curve that describes the wind speed frequency distribution, or number of observations in specific wind speed ranges. Its two adjustable parameters allow a reasonably good fit to a wide range of actual distributions. A is a scale parameter related to the mean wind speed, while k controls the width of the distribution. Values of k typically range from 1 to 3.5, the higher values indicating a narrower distribution. The annual k values at 110 m, which ranged from 2.02 to 2.06 across

4 The range of AWST's national wind map speeds across the Rhode Island/Massachusetts Wind Energy Area is approximately of 9.1 m/s to 9.6 m/s at 110 m MSL.

5 AWST modeled wind speed at the operating London Array project in the United Kingdom is approximately 9.5 m/s at hub height (87 m).

Sites A through E, indicate a moderately consistent wind resource. These values also align closely with the value of 2.0 that the International Electrotechnical Commission (IEC) assumes for turbine design (International Electrotechnical Commission 2009). Figure 3 shows the observed annual frequency distribution and fitted Weibull curve for 110 m MSL wind speeds at Location D. Table 2 summarizes the 110 m MSL Weibull parameters for all locations.

Figure 3. 110 m MSL Wind Speed Frequency Distribution – Location D

Source: AWST (2017)

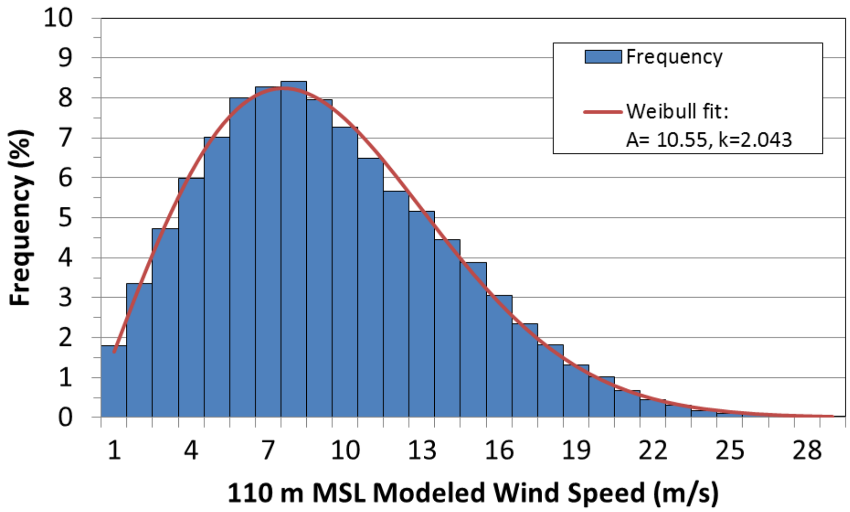


Table 2. 110 m MSL Wind Speed Frequency Distribution – Weibull Parameters

	Location A (m/s)	Location B (m/s)	Location C (m/s)	Location D (m/s)	Location E (m/s)
A (m/s)	10.4	10.7	10.5	10.6	10.5
k (-)	2.02	2.06	2.05	2.04	2.04
Mean (m/s)	9.2	9.4	9.3	9.4	9.3
Fit - R^2	1.00	1.00	1.00	1.00	1.00

4.1.3 Monthly Variation

Monthly patterns of variation are also useful indicators of the wind resource. The observed pattern of monthly mean wind speeds at Location D is presented in Figure 4 and is generally representative of the region. The modeled long-term record at this location indicates that the strongest winds normally occur in winter and the weakest winds in summer. The range of variation in the observed monthly average wind speeds at Location D is about 3.9 m/s. Table 3 presents a summary of the monthly mean wind speeds at 110 m MSL for each of the locations.

Figure 4. Monthly Mean Wind Speeds – Location D

Source: AWST (2017)

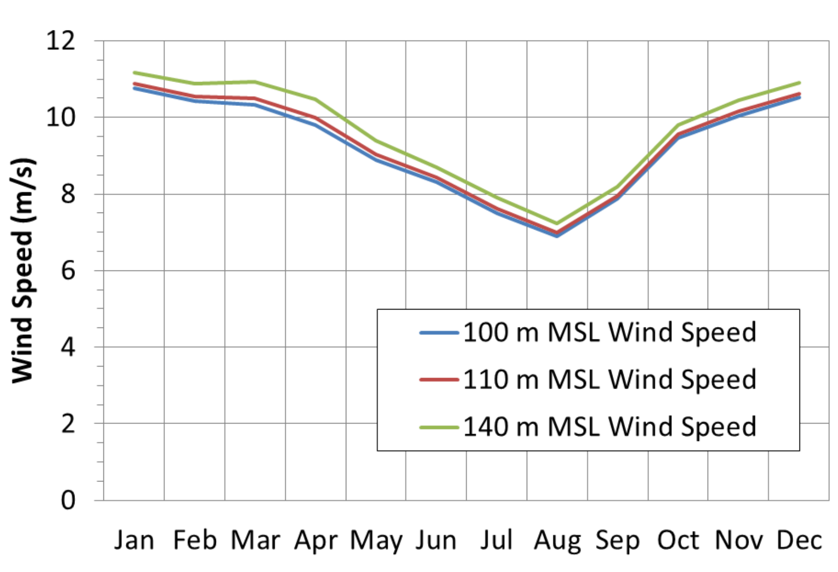


Table 3. 110 m MSL Monthly Mean Wind Speeds

Month	Location A (m/s)	Location B (m/s)	Location C (m/s)	Location D (m/s)	Location E (m/s)
January	10.6	10.9	10.8	10.9	10.7
February	10.3	10.6	10.5	10.5	10.5
March	10.2	10.5	10.4	10.5	10.4
April	9.7	9.9	9.8	10.0	10.1
May	8.7	9.1	8.9	9.0	8.9
June	8.1	8.5	8.3	8.4	8.3
July	7.5	7.8	7.6	7.6	7.5
August	7.0	7.1	7.0	7.0	6.9
September	8.0	8.1	8.0	8.0	7.9
October	9.6	9.7	9.6	9.6	9.4
November	10.1	10.3	10.2	10.2	10.0
December	10.5	10.8	10.6	10.6	10.5
All	**9.2**	**9.4**	**9.3**	**9.4**	**9.3**

4.1.4 Diurnal Variation

Figure 5 depicts the variation in average wind speed with time of day (in Eastern Standard Time) at Location D. The data set indicates that the average wind speed is highest during the evening and lowest around midday. This diurnal pattern of wind speed is anticipated to support a load-matching benefit for offshore wind, as generation is expected to align more closely with diurnal energy use profiles than some other renewables.[6] Table 4 presents the 110 m MSL average diurnal wind speeds for all locations.

Figure 5. 110 m MSL Mean Diurnal Profile (Eastern Standard Time) – Location D

Source: AWST (2017)

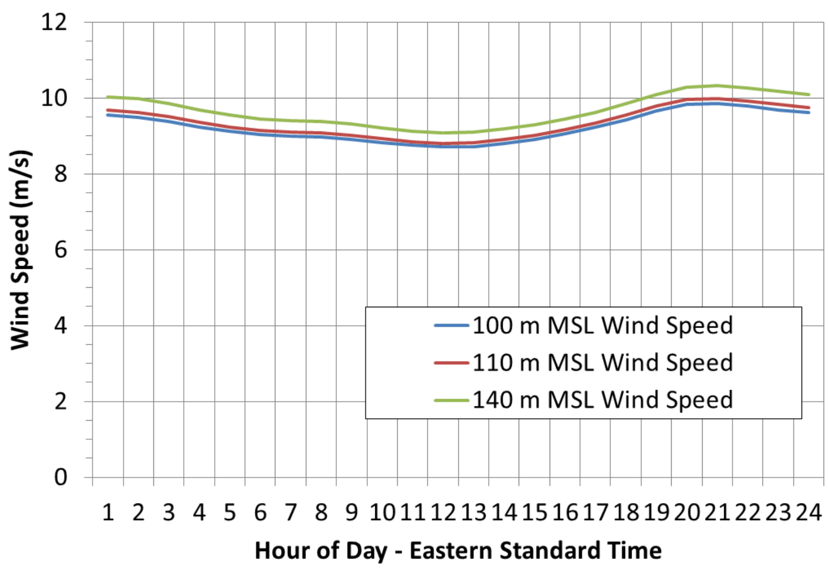


Table 4. 110 m MSL Mean Diurnal Wind Speeds (Eastern Standard Time)

Hour of Day (EST)	Location A (m/s)	Location B (m/s)	Location C (m/s)	Location D (m/s)	Location E (m/s)
0:00	9.5	9.7	9.6	9.7	9.6
1:00	9.4	9.7	9.6	9.6	9.6
2:00	9.3	9.6	9.4	9.5	9.5
3:00	9.1	9.4	9.3	9.4	9.4
4:00	9.0	9.3	9.2	9.2	9.2

6 Onshore wind projects in the New York and New England regions will typically have peak production during overnight hours.

Table 4 continued

Hour of Day (EST)	Location A (m/s)	Location B (m/s)	Location C (m/s)	Location D (m/s)	Location E (m/s)
5:00	8.9	9.2	9.1	9.1	9.1
6:00	8.9	9.2	9.1	9.1	9.1
7:00	8.8	9.1	9.0	9.1	9.0
8:00	8.7	9.1	8.9	9.0	9.0
9:00	8.6	9.0	8.8	8.9	8.9
10:00	8.5	8.9	8.7	8.9	8.8
11:00	8.4	8.9	8.7	8.8	8.7
12:00	8.5	8.9	8.7	8.8	8.7
13:00	8.6	9.1	8.9	8.9	8.8
14:00	8.9	9.2	9.0	9.0	8.9
15:00	9.1	9.4	9.2	9.2	9.0
16:00	9.4	9.5	9.4	9.3	9.2
17:00	9.7	9.7	9.6	9.6	9.5
18:00	9.9	9.9	9.8	9.8	9.7
19:00	10.0	10.0	9.9	10.0	9.8
20:00	10.0	10.0	9.9	10.0	9.9
21:00	9.9	9.9	9.9	9.9	9.8
22:00	9.7	9.8	9.8	9.8	9.7
23:00	9.6	9.8	9.7	9.7	9.7
All	9.2	9.4	9.3	9.4	9.3

4.2 Wind Direction

The directional distribution of the wind resource across the AoA is an important factor to consider when designing any future wind project, to minimize the wake interference between turbines. The 110 m MSL annual wind frequency by direction and energy plots (wind rose) for Location D is presented in Figure 6. The wind roses indicate that the prevailing wind directions are from the southwest and west-northwest. Tables 5 and 6 present summaries of the 110 m MSL frequency- and energy-weight wind roses, respectively, for each location.

Figure 6. 110 m MSL Wind Direction Frequency Distribution – Location D

Source: AWST (2017)

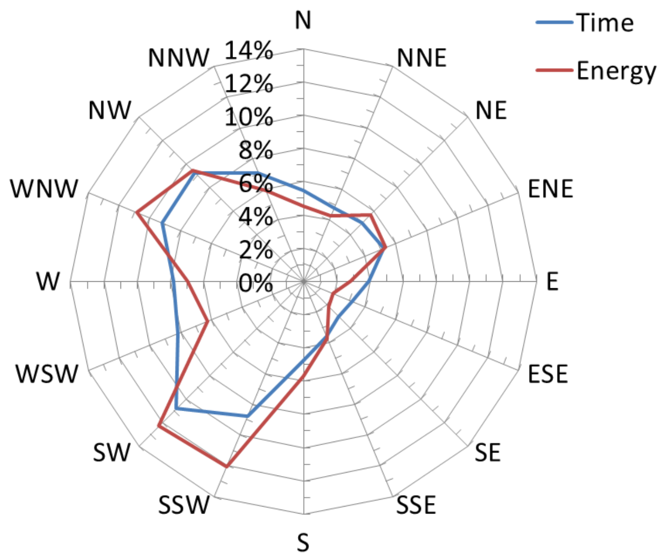


Table 5. 110 m MSL Wind Direction Frequency Distribution

Direction Sector (True North)	Location A (%)	Location B (%)	Location C (%)	Location D (%)	Location E (%)
348.75°–11.25°	5.6	5.3	5.5	5.5	5.4
11.25°–33.75°	4.7	4.6	4.6	4.8	5.0
33.75°–56.25°	4.6	5.0	4.7	5.0	5.3
56.25°–78.75°	4.8	5.0	5.1	5.2	5.3
78.75°–101.25°	3.9	3.9	4.1	3.9	3.9
101.25°–123.75°	3.3	3.0	3.1	3.2	3.1
123.75°–146.25°	3.2	2.9	3.0	3.0	3.0
146.25°–168.75°	3.8	3.3	3.4	3.6	3.7
168.75°–191.25°	5.3	4.6	4.6	4.8	4.8
191.25°–213.75°	9.5	8.2	8.2	8.8	8.9
213.75°–236.25°	9.7	11.0	10.6	10.8	10.6
236.25°–258.75°	7.5	9.2	8.9	8.2	7.9
258.75°–281.25°	8.1	7.6	7.8	7.8	7.3
281.25°–303.75°	9.6	10.1	9.6	9.2	9.8
303.75°–326.25°	9.2	9.3	9.5	9.2	9.3
326.25°–348.75°	7.1	7.2	7.5	7.1	6.8
All data	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 6. 110 m MSL Energy-weighted Wind Direction Frequency Distribution

Direction Sector (True North)	Location A (%)	Location B (%)	Location C (%)	Location D (%)	Location E (%)
348.75°–11.25°	4.28	4.4	4.6	4.6	4.7
11.25°–33.75°	4.34	4.2	4.1	4.3	4.4
33.75°–56.25°	5.59	6.1	5.7	5.7	5.8
56.25°–78.75°	5.45	5.2	5.6	5.4	5.3
78.75°–101.25°	3.06	3.0	3.1	2.8	2.7
101.25°–123.75°	1.98	2.0	2.0	1.9	1.7
123.75°–146.25°	2.19	2.3	2.1	2.2	1.9
146.25°–168.75°	3.88	3.6	3.4	3.7	3.6
168.75°–191.25°	5.95	5.5	5.1	5.7	5.5
191.25°–213.75°	13.72	11.0	10.9	12.1	12.0
213.75°–236.25°	11.12	12.5	12.2	12.3	12.4
236.25°–258.75°	5.00	7.8	7.4	6.2	6.3
258.75°–281.25°	7.68	6.9	7.5	7.0	6.2
281.25°–303.75°	10.96	11.1	11.1	10.8	11.5
303.75°–326.25°	9.27	9.2	9.2	9.5	9.9
326.25°–348.75°	5.54	5.5	6.1	5.9	6.1
All data	**100.00**	**100.0**	**100.0**	**100.0**	**100.0**

4.3 Air Temperature and Air Density

Ambient air temperatures affect turbine power production, primarily through variations in air density but also through some turbine-specific controls features. Temperatures also influence turbine suitability and design. Figure 7 presents the 110 m MSL average minimum and maximum modeled air temperatures at Location D by month. Table 7 summarizes average minimum and maximum temperature values at 110 m MSL for each location. Based on typical IEC turbine design parameters, the temperatures on site are not expected to present a suitability risk. However, some turbine models may require a cold temperature package[7] to limit potential energy loss due to low-temperature shut down.

[7] Many wind turbines are designed to operate in ambient temperatures between -10 and +40°C. To support operations at sites where temperatures are expected to be outside that range, turbine manufacturers may develop and deploy supplemental equipment and/or controls packages. These packages allow the turbines to run at temperature above or below the standard limits (e.g., -20 to +40°C for common cold temperature packages), thereby limiting potential energy production losses due to conditions outside of temperature limits. For example, a "cold temperature package" may include different lubrication specifications, supplemental component heaters, and specific start-up strategies for cold temperatures.

Air density directly affects energy production: the greater the density, the greater the power output of a wind turbine for the same speed distribution. Table 8 summarizes average, minimum, and maximum modeled air density values at 110 m MSL for each location.

Figure 7. 110 m MSL Monthly Air Temperatures – Location D

Source: AWST (2017)

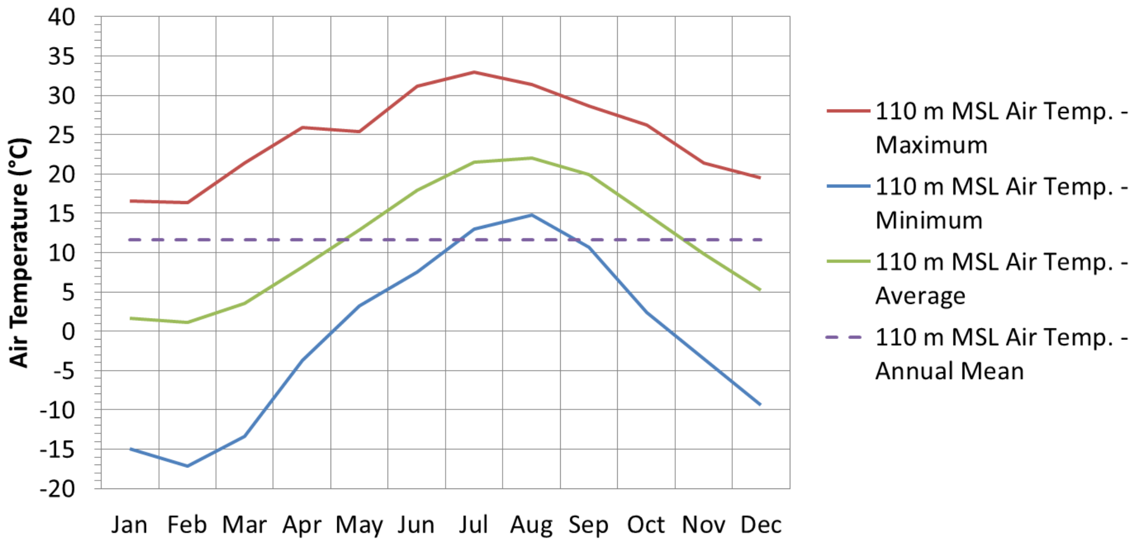


Table 7. 110 m MSL Air Temperatures

	Location A (°C)	Location B (°C)	Location C (°C)	Location D (°C)	Location E (°C)
Maximum	33.5	32.6	32.6	32.9	32.9
Average	11.3	10.9	11.2	11.6	12.0
Minimum	-18.8	-19.7	-19.0	-17.5	-15.4

Table 8. 110 m MSL Air Densities

	Location A (kg/m^3)	Location B (kg/m^3)	Location C (kg/m^3)	Location D (kg/m^3)	Location E (kg/m^3)
Maximum	1.37	1.37	1.39	1.38	1.37
Average	1.22	1.22	1.22	1.22	1.21
Minimum	1.12	1.12	1.10	1.10	1.09

4.4 Wind Shear

Variation in wind speed with height is commonly estimated using the power law equation:

Equation 1. $$U = UO(Z/ZO)\alpha$$

where

U = the unknown wind speed at height Z above ground;
U0 = the known speed at a reference height Z0; and
α = the shear exponent.

This equation is an empirical relationship that is widely employed in wind resource assessment and turbine suitability assessments. The variations in wind speeds represented by the shear exponent would affect the energy production of future turbines, as well as loading on the rotor. The estimated long-term average shear profile for Location D is illustrated in Figure 8. Table 9 summarizes average shear exponents defined between each modeled elevation, and for all modeled elevations, for each location.

Similar to wind speeds, the monthly and diurnal shear variations are relevant to energy production and suitability. Figure 9 illustrates the monthly variation in average wind shear at Location D. Table 10 summarizes monthly variation in average shear exponent for all locations. Figure 10 illustrates the diurnal variation in average shear exponent for Location D. Table 11 summarizes diurnal variation in average shear exponent for all locations.

The shear conditions across the AoA are generally in line with IEC offshore assumptions and with other U.S. and European locations.

Figure 8. Average Wind Shear Profile – Location D

Source: AWST (2017)

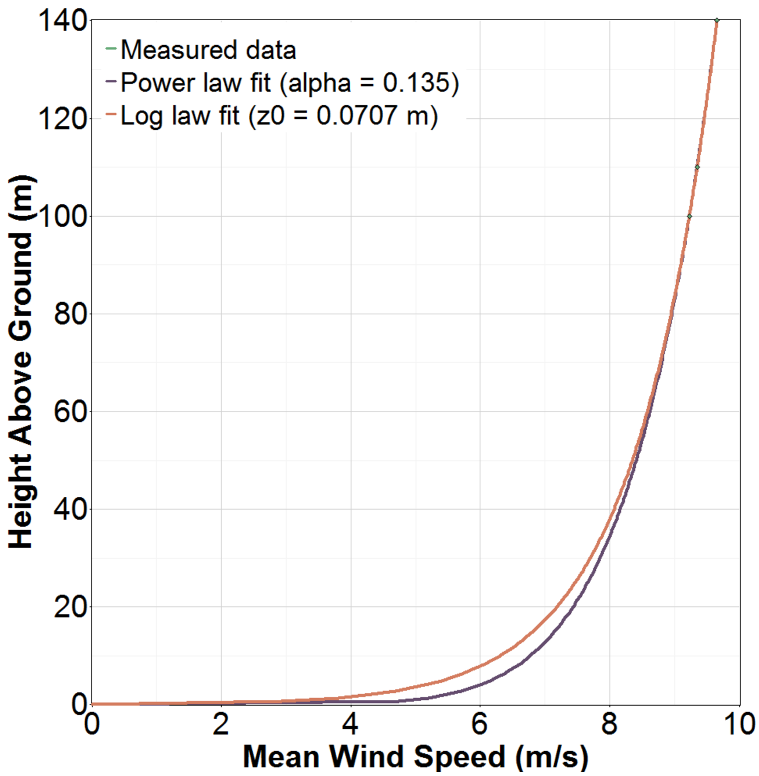


Table 9. Average Power Law Wind Shear Exponents

Elevations[a] (m MSL)	Location A (α)	Location B (α)	Location C (α)	Location D (α)	Location E (α)
All Heights (100, 110, and 140)	0.126	0.136	0.130	0.135	0.141
140/100	0.126	0.136	0.130	0.135	0.141
140/110	0.126	0.136	0.130	0.135	0.141
110/100	0.128	0.137	0.130	0.134	0.142

Note

[a] Power Law shear exponents are calculated based on speeds at two or more elevations above the surface.

Figure 9. Monthly Mean Power Law Wind Shear Exponents – Location D

Source: AWST (2017)

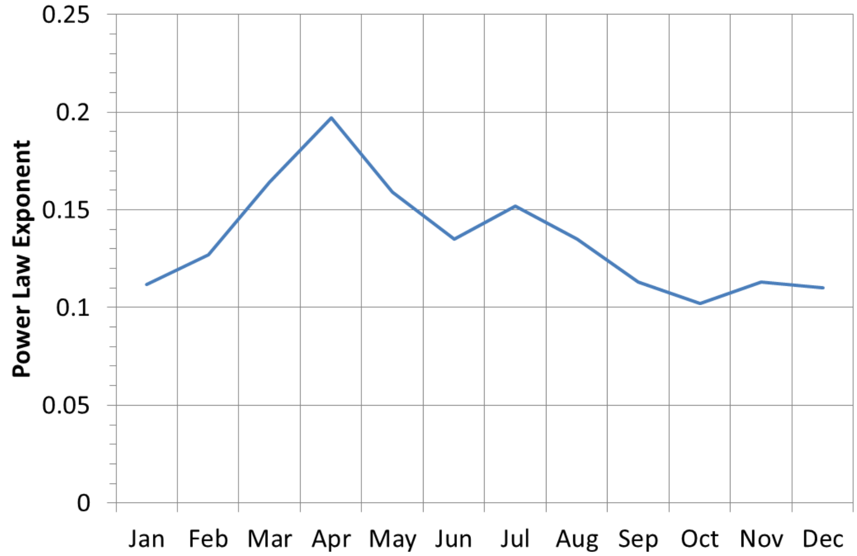


Table 10. Monthly Mean Power Law Wind Shear Exponents – All Heights

Month	Location A (α)	Location B (α)	Location C (α)	Location D (α)	Location E (α)
January	0.110	0.105	0.103	0.112	0.121
February	0.127	0.117	0.117	0.127	0.141
March	0.156	0.161	0.157	0.164	0.177
April	0.182	0.198	0.192	0.197	0.205
May	0.147	0.172	0.163	0.159	0.162
June	0.116	0.161	0.146	0.135	0.140
July	0.133	0.164	0.155	0.152	0.152
August	0.125	0.145	0.135	0.135	0.134
September	0.108	0.117	0.111	0.113	0.116
October	0.097	0.098	0.094	0.102	0.106
November	0.109	0.107	0.104	0.113	0.120
December	0.105	0.102	0.100	0.110	0.120
All	**0.126**	**0.136**	**0.130**	**0.135**	**0.141**

Figure 10. Diurnal Mean Power Law Wind Shear Exponents (Eastern Standard Time) – Location D.

Source: AWST (2017)

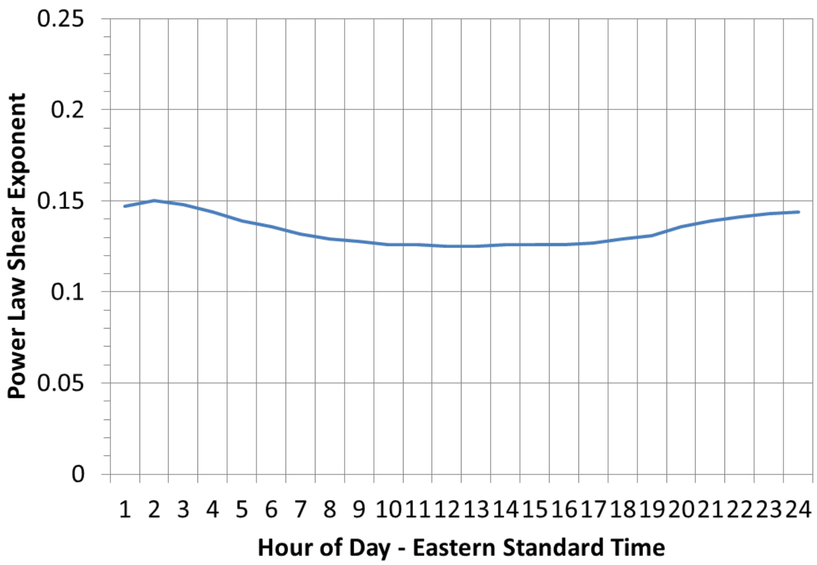


Table 11. Diurnal Mean Power Law Wind Shear Exponents (Eastern Standard Time) – All Heights

Hour of Day (EST)	Location A (α)	Location B (α)	Location C (α)	Location D (α)	Location E (α)
0:00	0.144	0.153	0.144	0.147	0.155
1:00	0.147	0.155	0.146	0.150	0.159
2:00	0.146	0.151	0.144	0.148	0.156
3:00	0.142	0.146	0.141	0.144	0.153
4:00	0.139	0.142	0.136	0.139	0.149
5:00	0.135	0.137	0.132	0.136	0.145
6:00	0.132	0.133	0.128	0.132	0.141
7:00	0.131	0.131	0.128	0.129	0.139
8:00	0.127	0.128	0.124	0.128	0.136
9:00	0.124	0.126	0.122	0.126	0.135
10:00	0.121	0.126	0.121	0.126	0.134
11:00	0.116	0.124	0.118	0.125	0.132
12:00	0.109	0.123	0.117	0.125	0.131
13:00	0.106	0.123	0.117	0.126	0.132
14:00	0.106	0.122	0.116	0.126	0.130
15:00	0.106	0.122	0.117	0.126	0.129

Table 11 continued

Hour of Day (EST)	Location A (α)	Location B (α)	Location C (α)	Location D (α)	Location E (α)
16:00	0.109	0.124	0.120	0.127	0.129
17:00	0.112	0.127	0.125	0.129	0.132
18:00	0.116	0.132	0.129	0.131	0.135
19:00	0.120	0.138	0.134	0.136	0.141
20:00	0.125	0.144	0.137	0.139	0.143
21:00	0.131	0.147	0.139	0.141	0.147
22:00	0.137	0.150	0.143	0.143	0.150
23:00	0.140	0.151	0.143	0.144	0.152
All	**0.126**	**0.136**	**0.130**	**0.135**	**0.141**

4.5 Turbulence Intensity

TI, defined in measured data as the standard deviation of the 10-minute average wind speed divided by the 10-minute average wind speed value, is an important parameter for assessing energy production, estimating plant wake losses, and evaluating turbine suitability and fatigue life. Ambient turbulence intensity is typically evaluated by wind speed bin, with sites classified by the IEC based on the 15 m/s value. Modeled TI is derived from a separate parameter in the NWP tool—turbulent kinetic energy—and may vary from observed conditions depending on the environment and model configuration.

A plot of 110 m MSL modeled TI versus wind speed at Location D is presented in Figure 11. This figure also illustrates the IEC classification curves. Most offshore turbines are certified to operate in Category B or C turbulence conditions. The WRF model has been shown to perform well in characterizing ambient TI conditions in simple terrain (Beaucage, P. and M. Brower. 2017). These modeled TI characteristics generally align with typical offshore project areas in that the ambient conditions are well within Category C. Modeled TI by wind speed at 110 m MSL is summarized for each site in Table 12. More thorough characterization of TI on site requires additional analysis and, ideally, incorporation of on-site measurements.

Figure 11. 110 m MSL Modeled Ambient Turbulence Intensity by Wind Speed – Location D

Source: AWST (2017), IEC (2005)

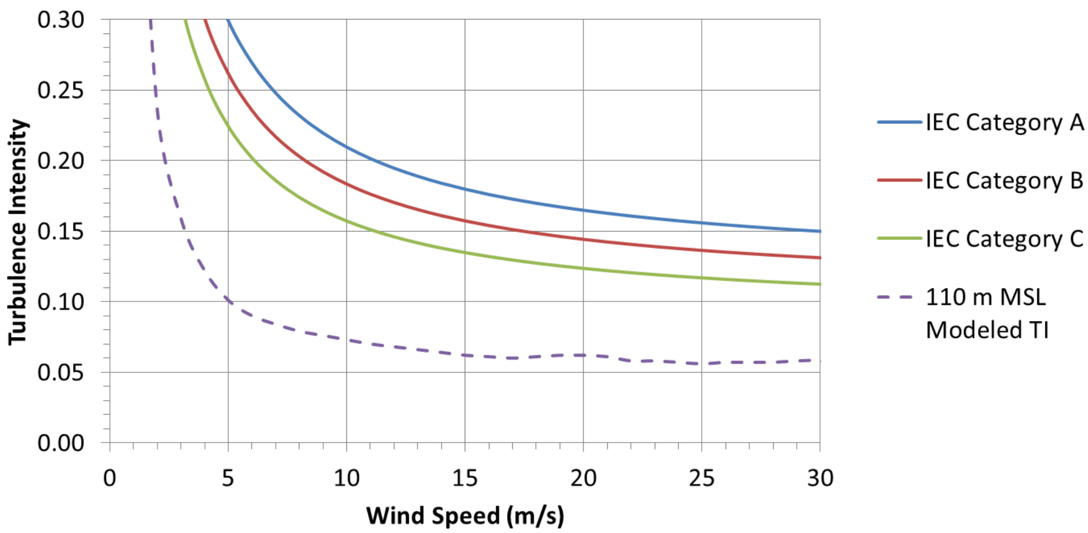


Table 12. 110 m MSL Modeled Ambient Turbulence Intensity by Wind Speed

Wind Speed (m/s)	Location A (-)	Location B (-)	Location C (-)	Location D (-)	Location E (-)
1	1.10	1.09	1.12	1.10	1.07
2	0.35	0.34	0.34	0.34	0.34
3	0.18	0.18	0.18	0.18	0.18
4	0.12	0.12	0.12	0.12	0.12
5	0.09	0.09	0.09	0.09	0.09
6	0.08	0.07	0.07	0.07	0.07
7	0.07	0.06	0.06	0.06	0.06
8	0.06	0.06	0.06	0.06	0.06
9	0.06	0.05	0.05	0.05	0.05
10	0.05	0.05	0.05	0.05	0.05
11	0.05	0.05	0.05	0.05	0.05
12	0.05	0.05	0.05	0.05	0.05
13	0.05	0.05	0.05	0.05	0.05
14	0.05	0.05	0.05	0.05	0.05
15	0.05	0.04	0.05	0.05	0.05
16	0.05	0.04	0.04	0.04	0.04
17	0.04	0.04	0.04	0.04	0.04
18	0.04	0.04	0.04	0.04	0.04

Table 12 continued

Wind Speed (m/s)	Location A (-)	Location B (-)	Location C (-)	Location D (-)	Location E (-)
19	0.04	0.04	0.04	0.04	0.04
20	0.04	0.05	0.04	0.04	0.04
21	0.05	0.05	0.05	0.05	0.05
22	0.05	0.05	0.05	0.05	0.05
23	0.05	0.05	0.05	0.05	0.05
24	0.05	0.05	0.05	0.05	0.05
25	0.05	0.05	0.05	0.05	0.05
26	0.05	0.05	0.05	0.05	0.05
27	0.05	0.05	0.05	0.05	0.05
28	0.05	0.05	0.05	0.05	0.05
29	0.05	0.05	0.05	0.05	0.05
30	0.05	0.05	0.05	0.05	0.05

5 Summary and Recommendations

The results of the preliminary wind resource assessment of the AoA indicate that the range of modeled long-term wind speeds at 110 m MSL is approximately 7.9 m/s near the coast to approximately 9.7 m/s at the 60 m depth contour. Prevailing wind directions are modeled to be southwest and west-northwest. Consistent with other offshore environments, distance from coastline is the most influential factor defining the spatial distribution of the wind resource across the AoA, where wind speeds generally increase with distance from shore. The range of long-term conditions predicted for areas under additional analysis are comparable with active regional offshore wind development areas in Rhode Island and Massachusetts, as well as previously constructed projects in Europe. In general, modeled wind speeds within the AoA appear to be viable for commercial scale offshore wind development.

As BOEM and/or developers of future offshore wind projects continue investigating the OSA for wind development, the following is recommended:

- Continue efforts defined under the offshore Blueprint (NYSERDA, n.d.) and pending Master Plan.
- Develop and implement a comprehensive metocean assessment campaign to collect high-quality wind speed and direction data within the OSA.
- Validate and adjust the wind map using on-site measurements.
- Run and validate comprehensive ocean models to fully characterize metocean conditions.

6 References

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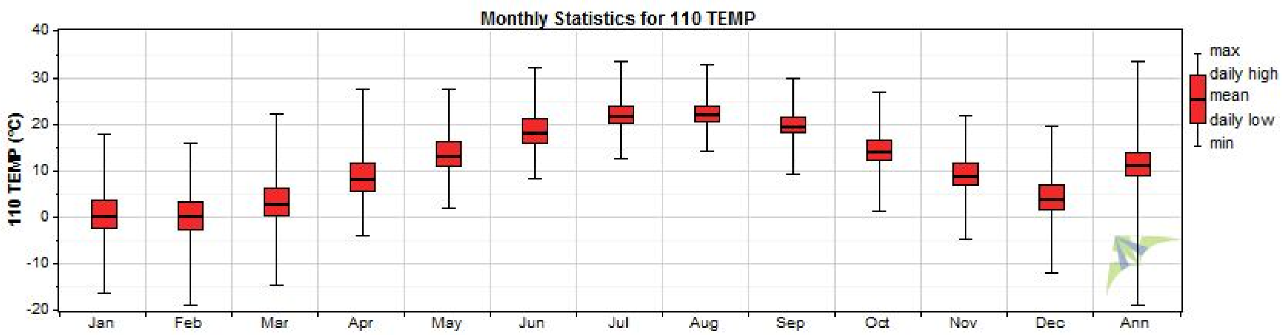
Appendix A. Extended Statistical Summary Report – Location A

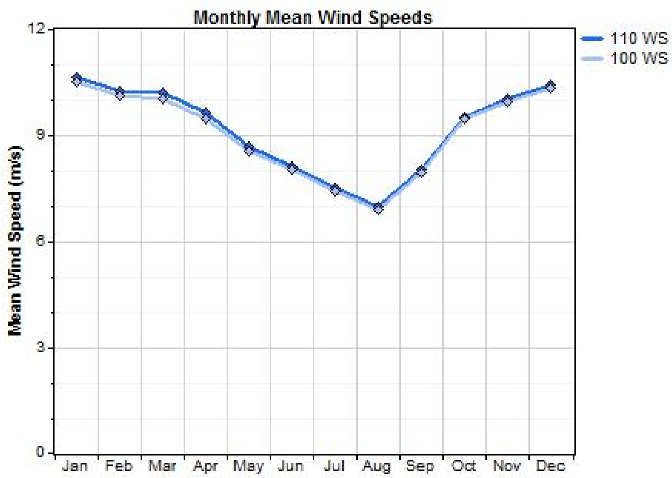
Data Set Properties

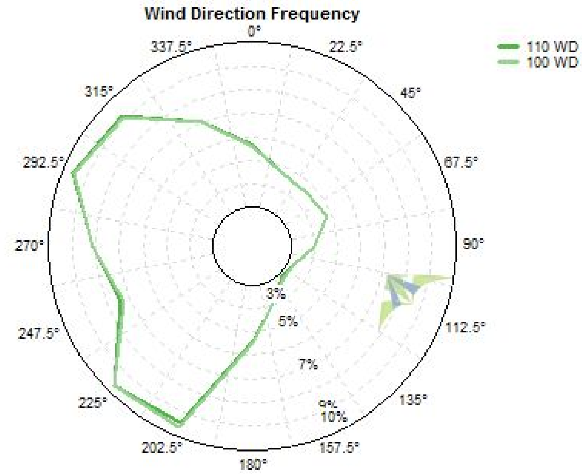
Report Created: 9/22/2017 14:50 using Windographer 4.1 beta
Filter Settings: <Unflagged data>

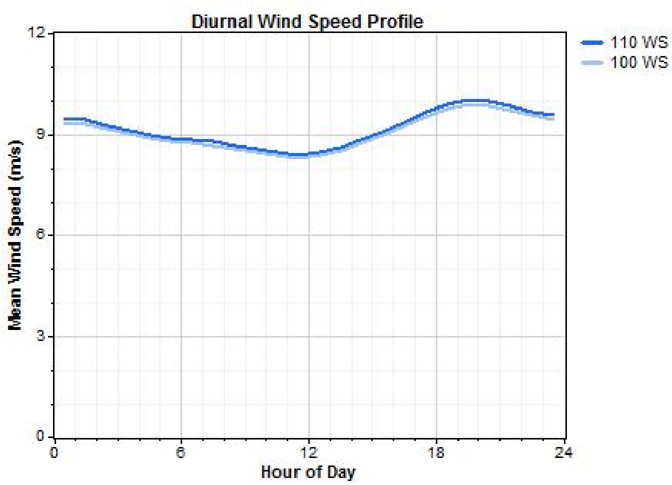
Variable	Value
Latitude	N 40.295400
Longitude	W 70.314700
Elevation	0 m
Start date	1/1/1997 00:00
End date	12/31/2016 19:00
Duration	20 years
Length of time step	10 minutes
Calm threshold	0 m/s
MoMM temperature	11.3 °C
MoMM pressure	
MoMM air density	1.221 kg/m3
Power density at 50m	628 W/m²
Wind power class	6 (Outstanding)
Power law exponent	0.128
Surface roughness	0.0418 m
Roughness class	1.28

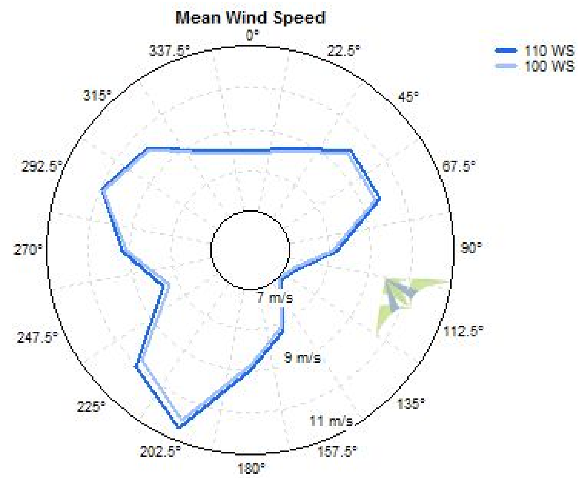


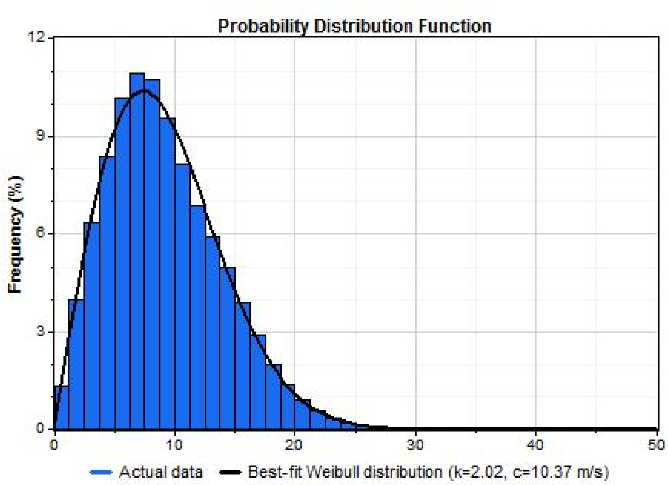
Wind Speed and Direction

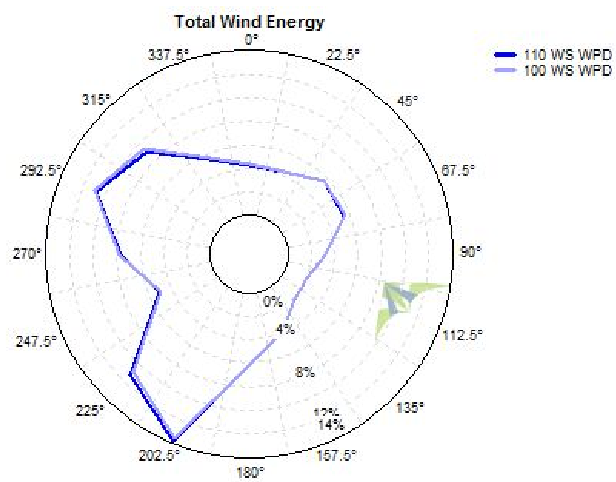




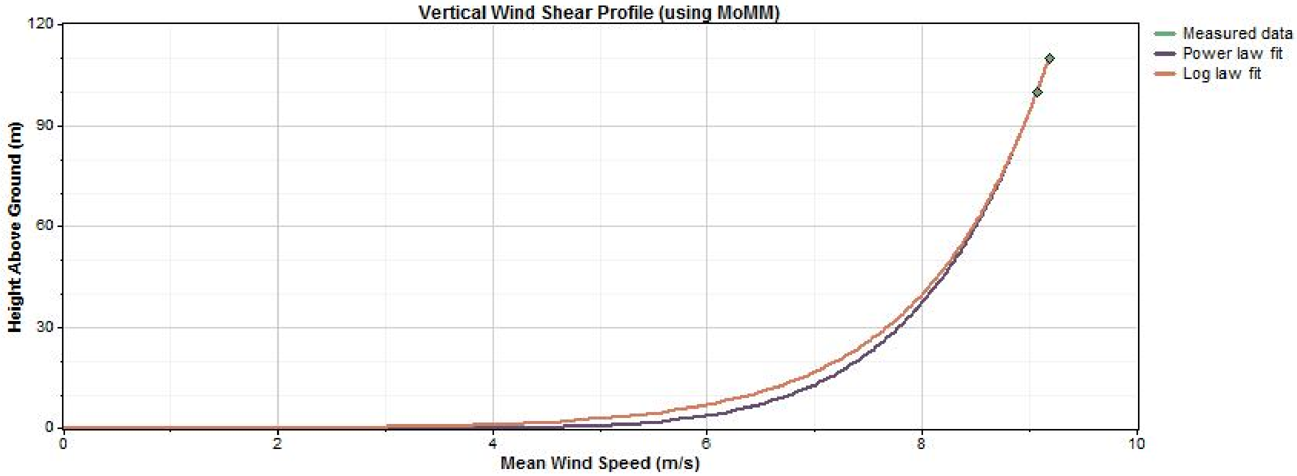


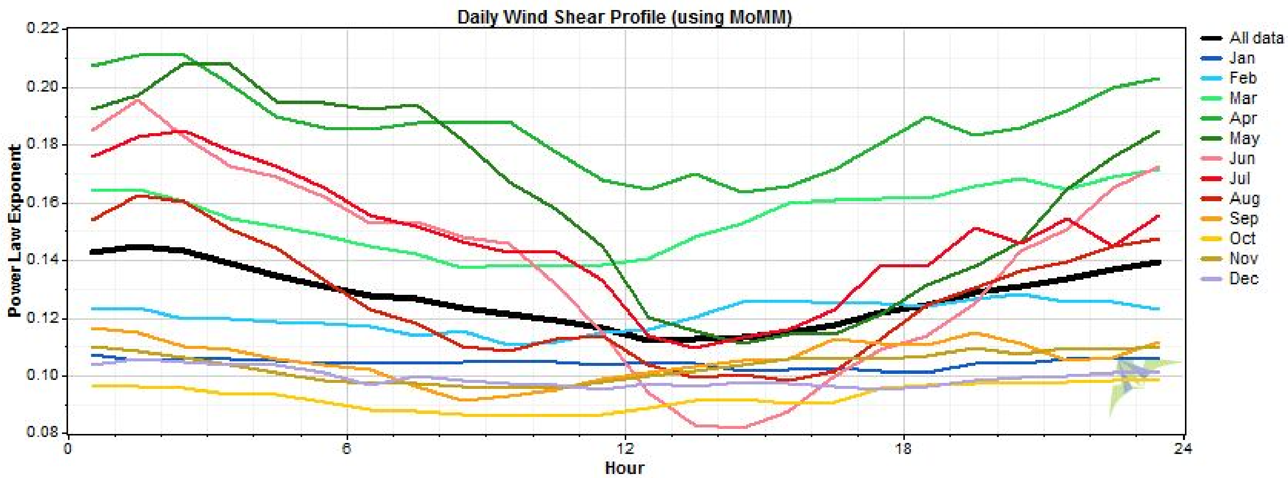


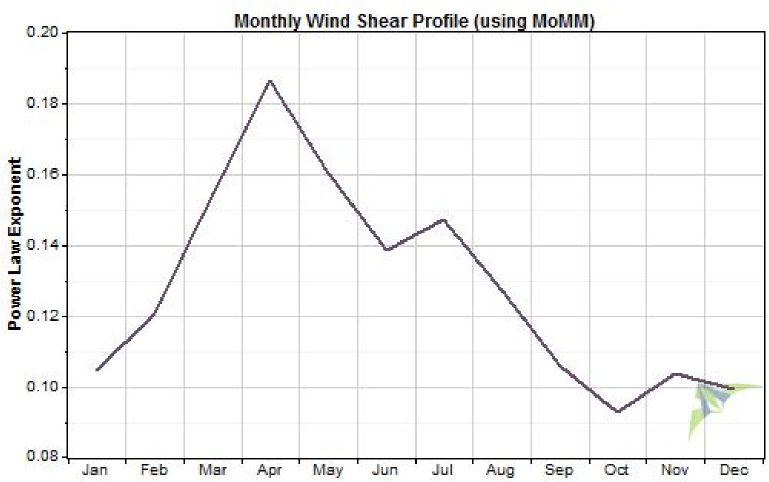


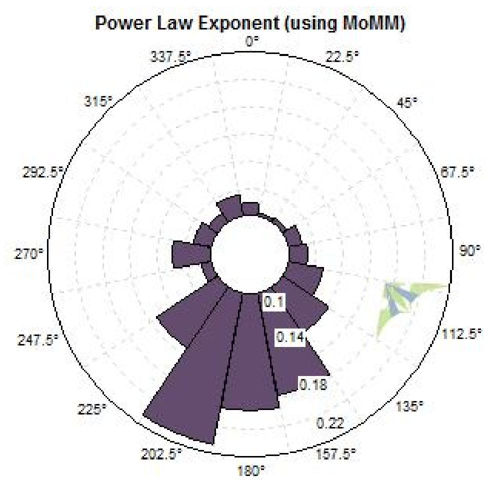


Wind Shear

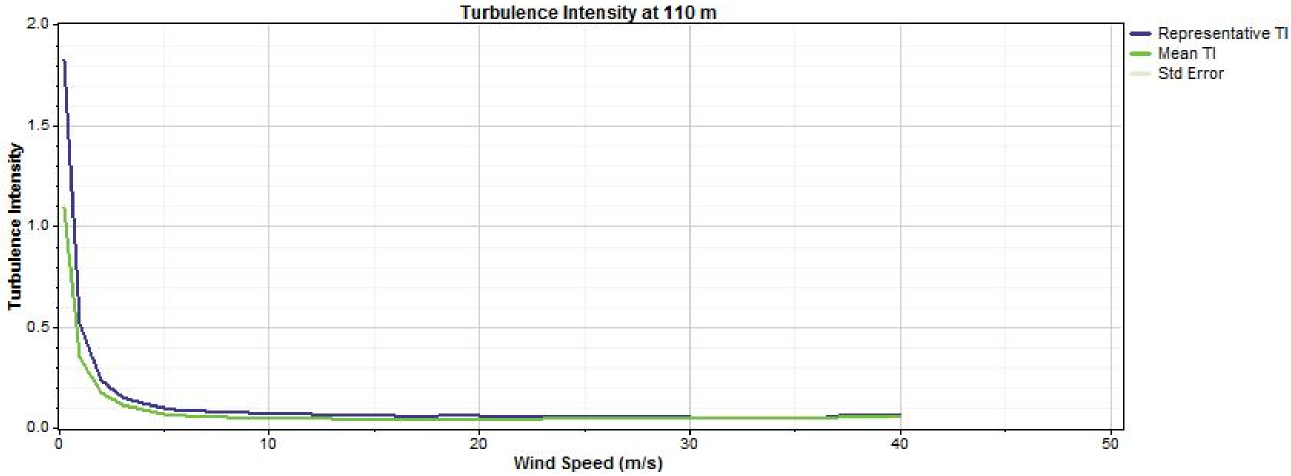

Vertical Wind Shear Profile (using MoMM)
Measured data
Power law fit
Log law fit
Height Above Ground (m)
Mean Wind Speed (m/s)

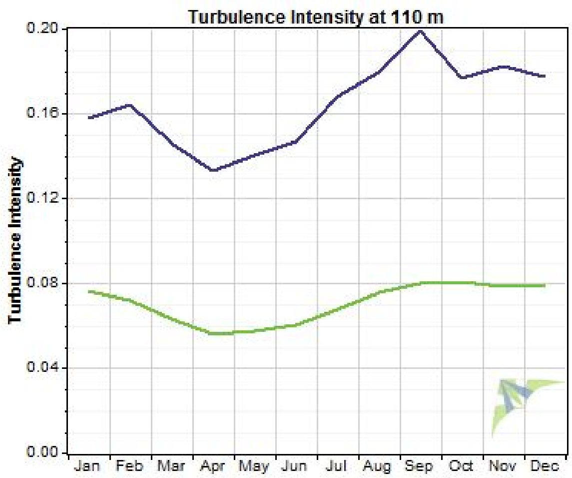

Daily Wind Shear Profile (using MoMM)
All data
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Power Law Exponent
Hour

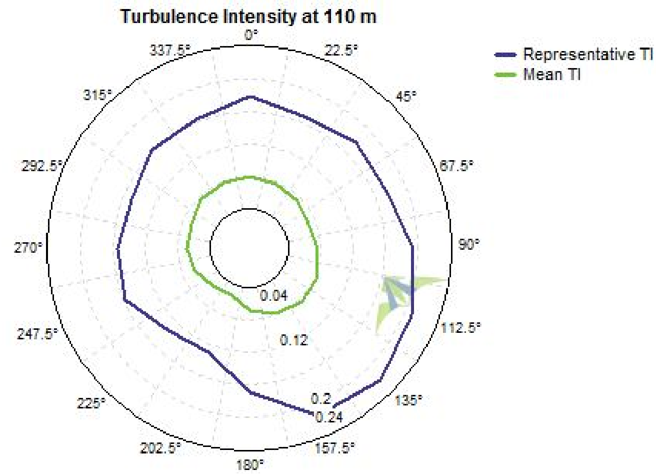

Monthly Wind Shear Profile (using MoMM)
Power Law Exponent
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

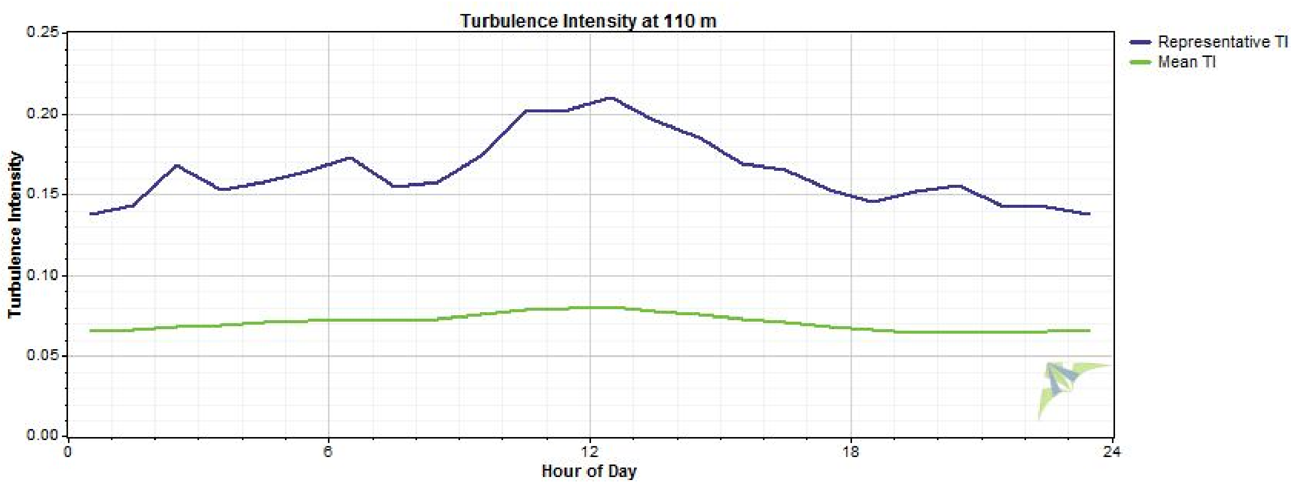

Power Law Exponent (using MoMM)

Turbulence Intensity









Environmental Summary

Variable	Mean	MoMM	Min	Max
Temperature (°C)	11.3	11.3	-18.8	33.5
Pressure (kPa)				
Air Density (kg/m3)	1.221	1.221	1.123	1.369
Energy-Weighted Air Density (kg/m3)	1.230	1.230	0.000	50.125

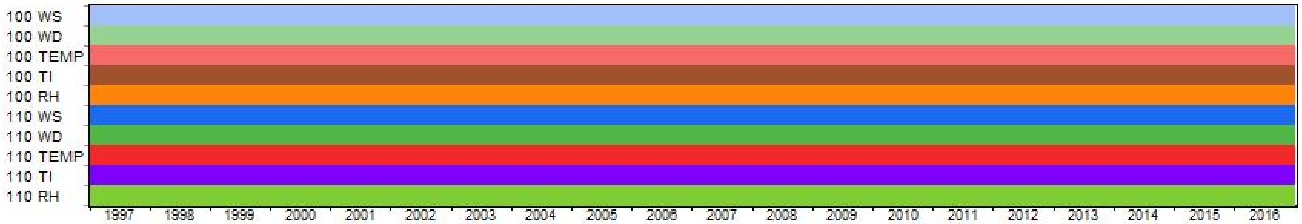
Wind Speed Sensor Summary

Variable	110 WS	100 WS
Measurement height (m)	110	100
Mean wind speed (m/s)	9.184	9.073
MoMM wind speed (m/s)	9.184	9.073
Median wind speed (m/s)	8.522	8.438
Min wind speed (m/s)	0.053	0.048
Max wind speed (m/s)	40.013	39.468
CRMC wind speed (m/s)	11.375	11.207
Weibull k	2.016	2.030
Weibull c (m/s)	10.366	10.242
Mean power density (W/m²)	0	0
MoMM power density (W/m²)	904	865
Mean energy content (kWh/m²/yr)	0	0
MoMM energy content (kWh/m²/yr)	7,918	7,576
Energy pattern factor	1.900	1.885
Frequency of calms (%)	0.00	0.00
Possible data points	1,051,890	1,051,890
Valid data points	1,051,890	1,051,890
Missing data points	0	0
Data recovery rate (%)	100.00	100.00

Flag Statistics

	Data Column	Time Steps Flagged As <Unflagged data>
1	100 WS	1,051,890
2	100 WD	1,051,890
3	100 TEMP	1,051,890
4	100 TI	1,051,890
5	100 RH	1,051,890
6	110 WS	1,051,890
7	110 WD	1,051,890
8	110 TEMP	1,051,890
9	110 TI	1,051,890
10	110 RH	1,051,890
11	Air Density	1,051,890
12	100 WS WPD	1,051,890
13	110 WS WPD	1,051,890

Data Coverage



Data Column Properties

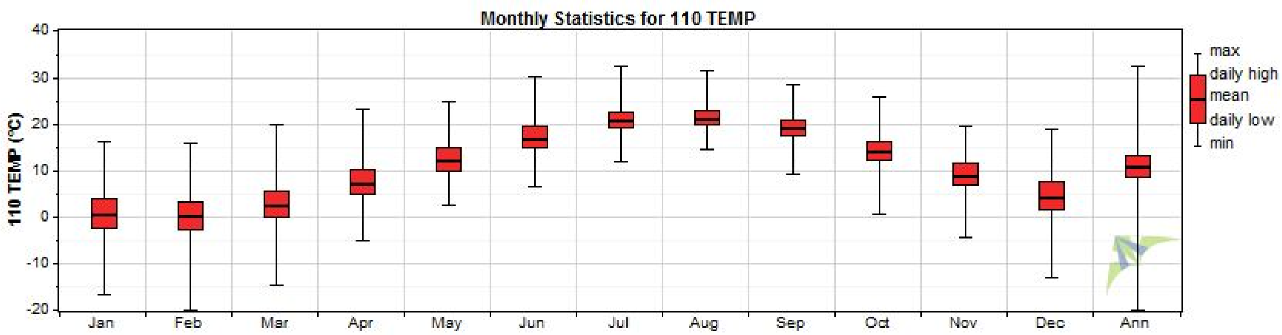
# #	Label	Units	Height	Possible Data Points	Valid Data Points	DRR (%)	Mean	MoMM	Median	Min	Max	Std. Dev
1	100 WS	m/s	100 m	1,051,890	1,051,890	100.00	9.073	9.073	8.438	0.048	39.468	4.685
2	100 WD	°	100 m	1,051,890	1,051,890	100.00	270.5	206.3	222.1	0.0	360.0	87.4
3	100 TEMP	°C	100 m	1,051,890	1,051,890	100.00	11.3	11.3	11.8	-18.6	33.5	8.9
4	100 TI		100 m	1,051,890	1,051,890	100.00	0.07	0.07	0.06	0.02	7.49	0.07
5	100 RH	%		1,051,890	1,051,890	100.00	75.5	75.5	75.9	5.9	100.9	16.8
6	110 WS	m/s	110 m	1,051,890	1,051,890	100.00	9.184	9.184	8.522	0.053	40.013	4.773
7	110 WD	°	110 m	1,051,890	1,051,890	100.00	270.7	206.6	222.9	0.0	360.0	87.2
8	110 TEMP	°C	110 m	1,051,890	1,051,890	100.00	11.3	11.3	11.8	-18.8	33.5	8.9
9	110 TI		110 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.01	6.73	0.07
10	110 RH	%		1,051,890	1,051,890	100.00	75.3	75.3	75.7	4.5	100.9	17.0
11	Air Density	kg/m3		1,051,890	1,051,890	100.00	1.221	1.221	1.218	1.123	1.369	0.041
12	100 WS WPD	W/m²		1,051,890	1,051,890	100.00	865	865	366	0	36,553	1,315
13	110 WS WPD	W/m²		1,051,890	1,051,890	100.00	904	904	378	0	38,088	1,389

Appendix B. Extended Statistical Summary Report – Location B

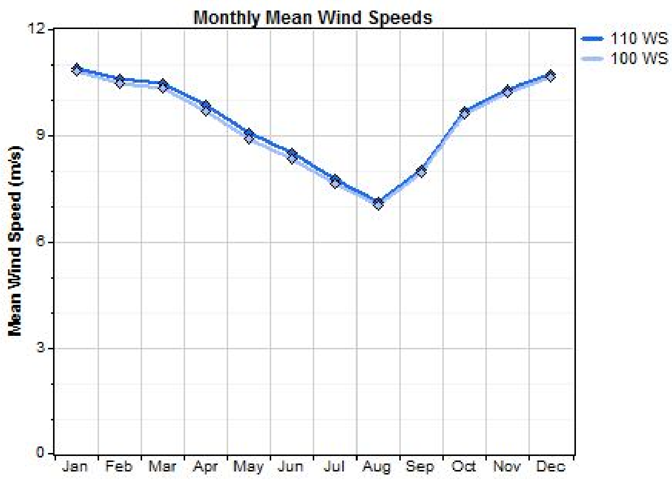
Data Set Properties

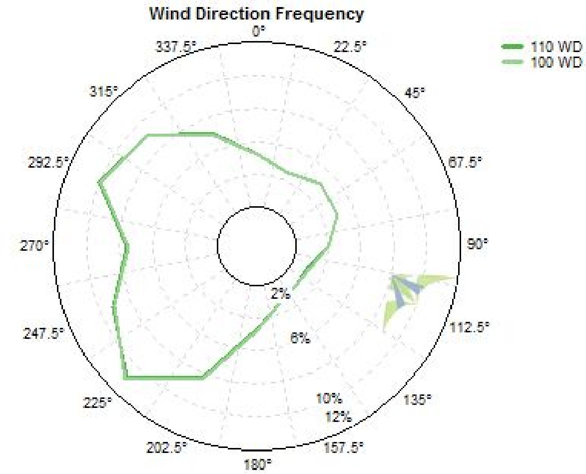
Report Created: 9/22/2017 14:59 using Windographer 4.1 beta
Filter Settings: <Unflagged data>

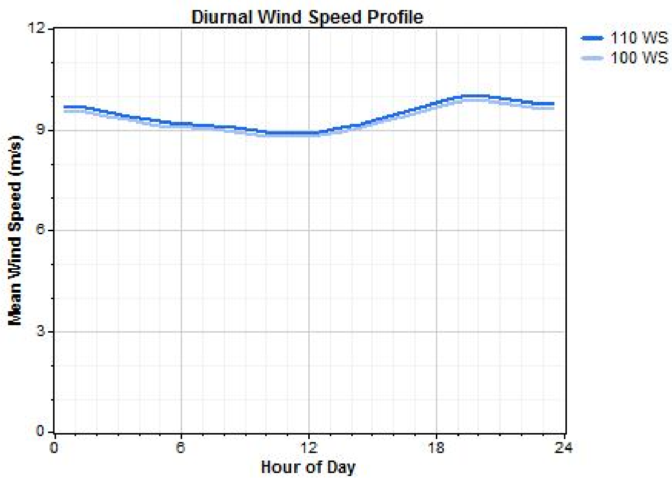
Variable	Value
Latitude	N 40.664300
Longitude	W 71.997100
Elevation	0 m
Start date	1/1/1997 00:00
End date	12/31/2016 19:00
Duration	20 years
Length of time step	10 minutes
Calm threshold	0 m/s
MoMM temperature	10.9 °C
MoMM pressure	
MoMM air density	1.223 kg/m3
Power density at 50m	653 W/m²
Wind power class	6 (Outstanding)
Power law exponent	0.136
Surface roughness	0.0684 m
Roughness class	1.68

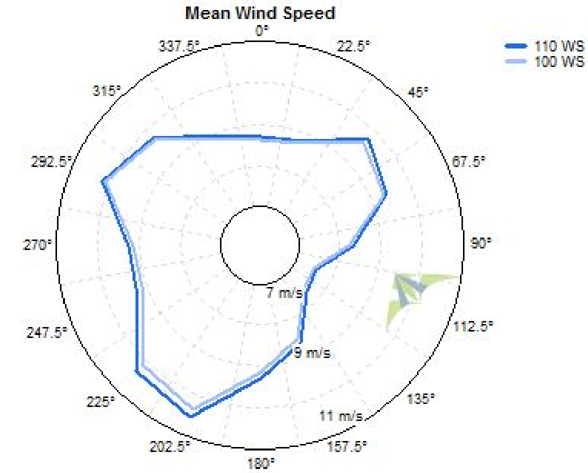


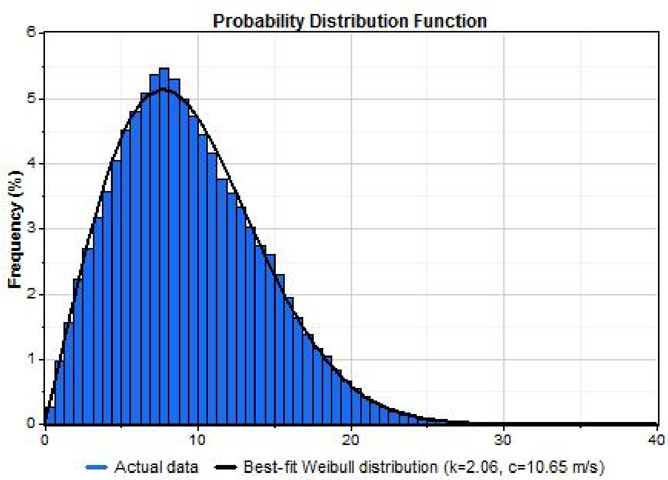
Wind Speed and Direction

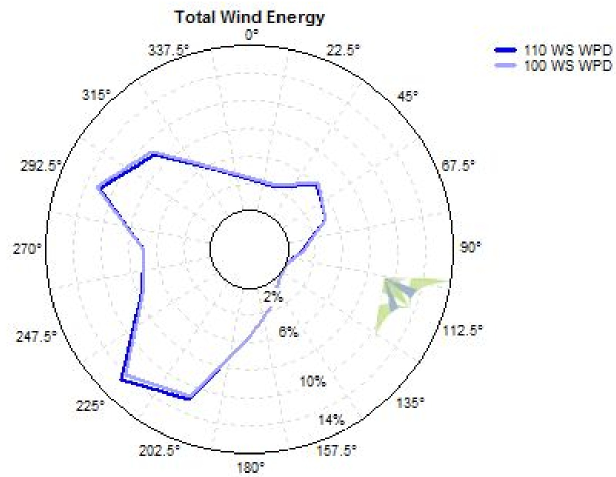




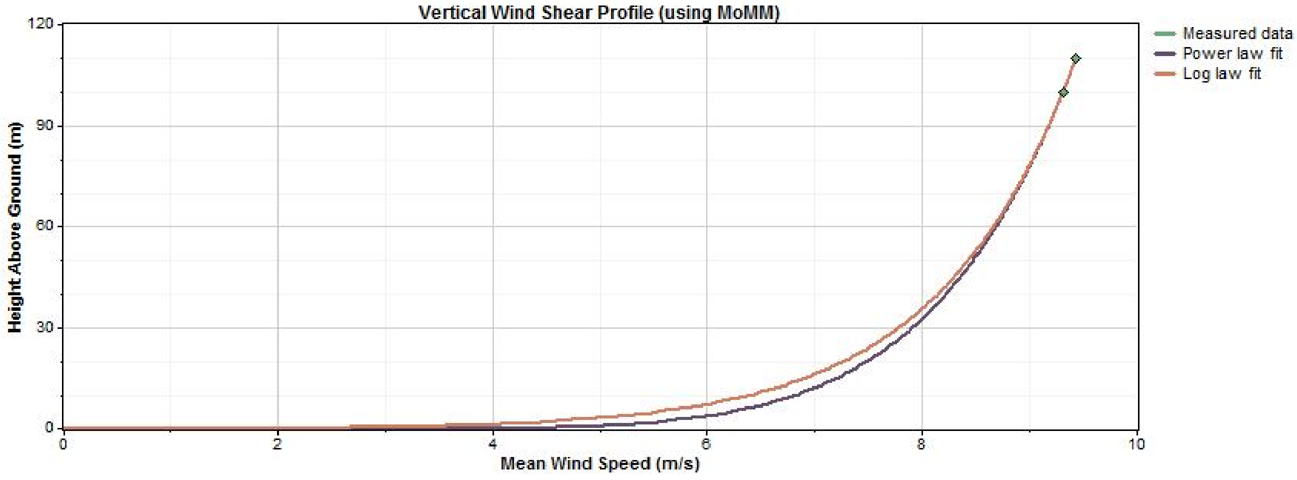


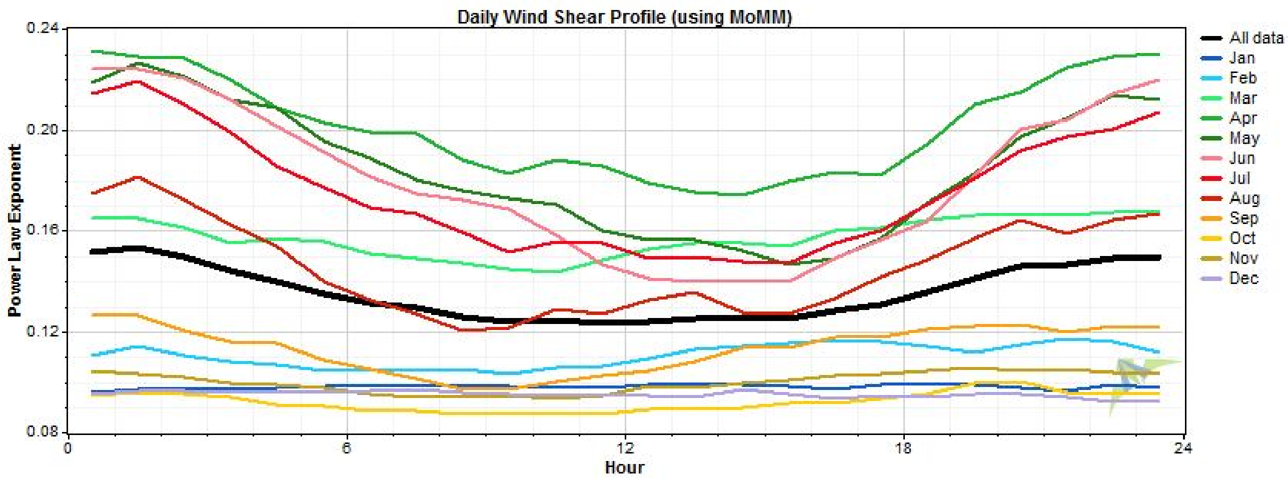


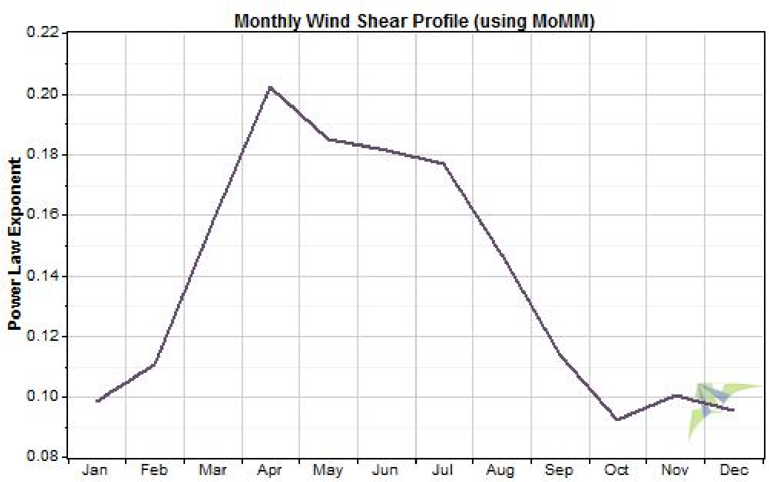


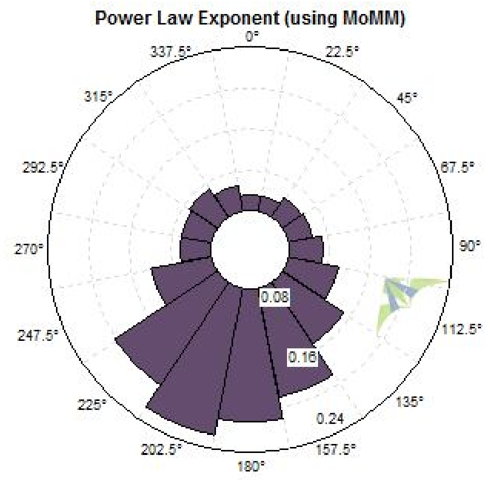


Wind Shear

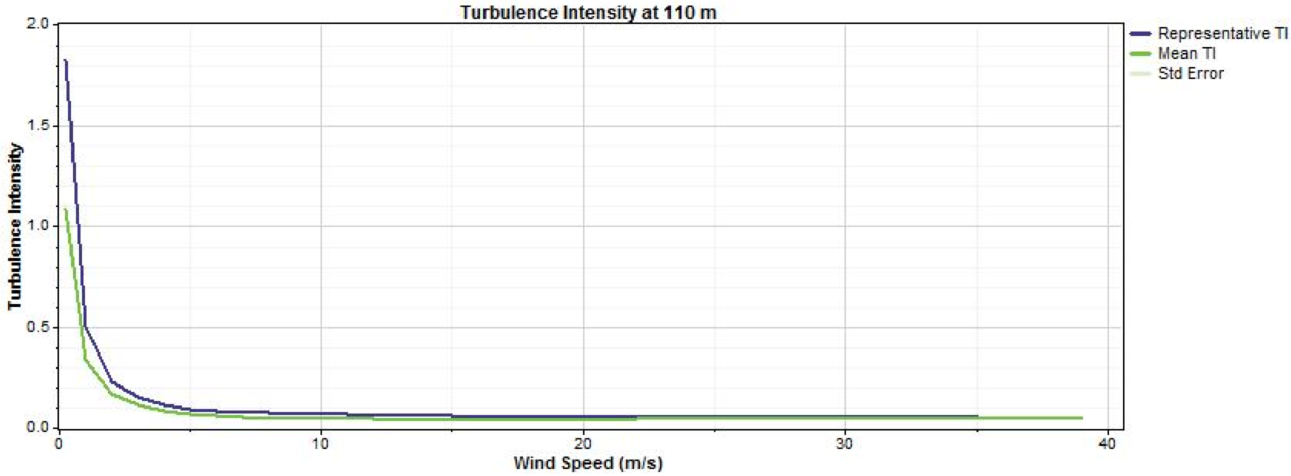

Vertical Wind Shear Profile (using MoMM)
Measured data
Power law fit
Log law fit
Height Above Ground (m)
Mean Wind Speed (m/s)

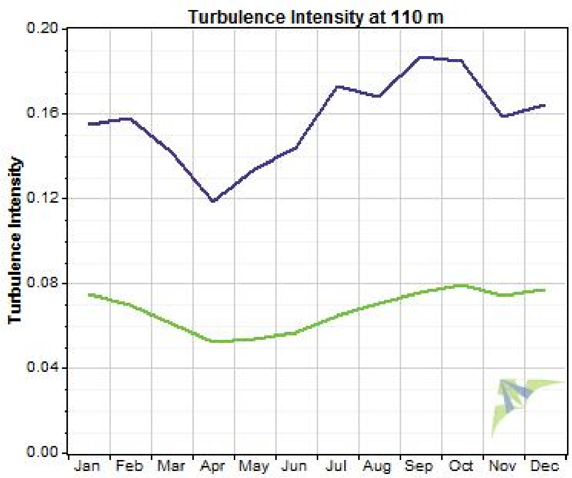

Daily Wind Shear Profile (using MoMM)
All data
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Power Law Exponent
Hour

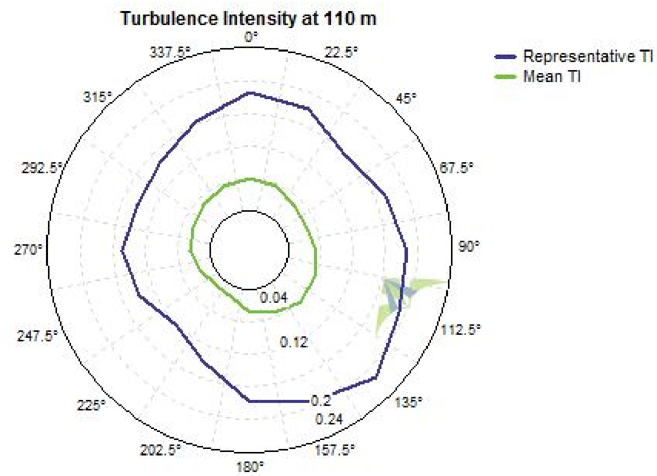

Monthly Wind Shear Profile (using MoMM)
Power Law Exponent
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

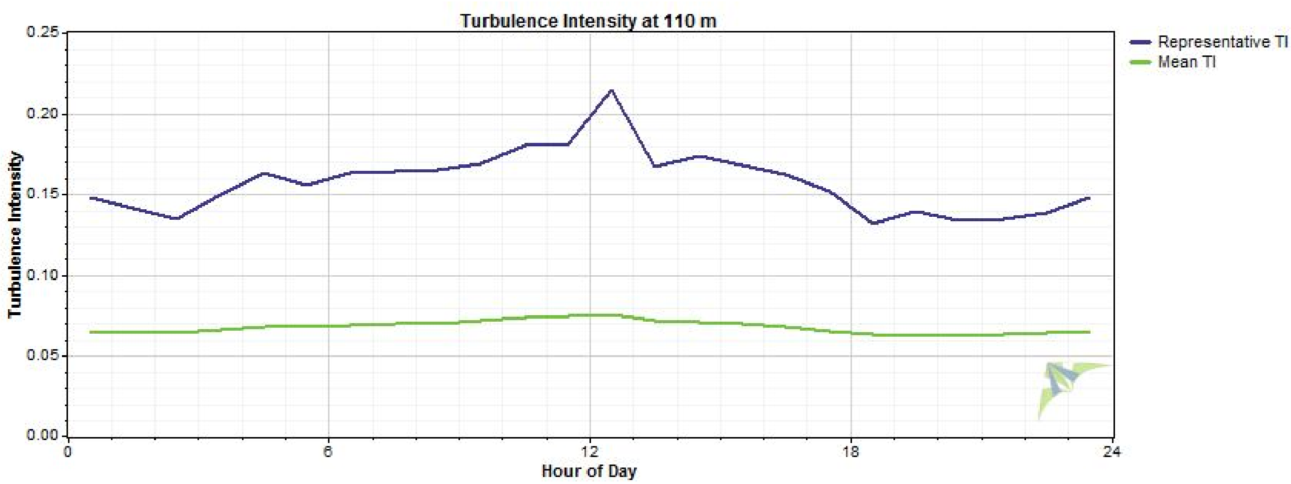

Power Law Exponent (using MoMM)
0°
22.5°
45°
67.5°
90°
112.5°
135°
157.5°
180°
202.5°
225°
247.5°
270°
292.5°
315°
337.5°
0.08
0.16
0.24

Turbulence Intensity









Environmental Summary

Variable	Mean	MoMM	Min	Max
Temperature (°C)	10.9	10.9	-19.7	32.6
Pressure (kPa)				
Air Density (kg/m3)	1.223	1.223	1.128	1.374
Energy-Weighted Air Density (kg/m3)	1.231	1.231	0.000	43.623

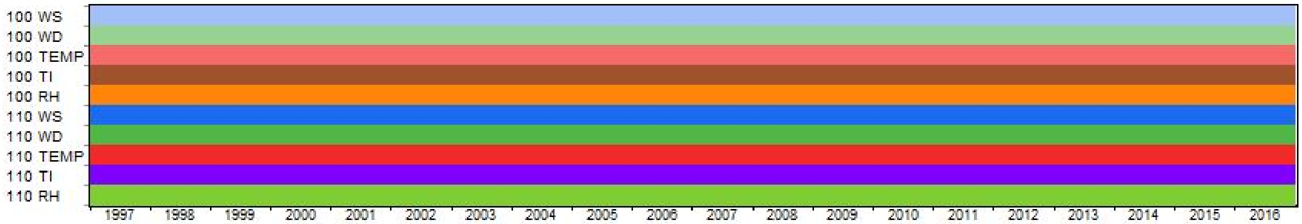
Wind Speed Sensor Summary

Variable	110 WS	100 WS
Measurement height (m)	110	100
Mean wind speed (m/s)	9.437	9.315
MoMM wind speed (m/s)	9.437	9.315
Median wind speed (m/s)	8.852	8.765
Min wind speed (m/s)	0.067	0.057
Max wind speed (m/s)	38.979	38.460
CRMC wind speed (m/s)	11.583	11.404
Weibull k	2.063	2.079
Weibull c (m/s)	10.651	10.514
Mean power density (W/m²)	0	0
MoMM power density (W/m²)	956	913
Mean energy content (kWh/m²/yr)	0	0
MoMM energy content (kWh/m²/yr)	8,371	7,994
Energy pattern factor	1.849	1.835
Frequency of calms (%)	0.00	0.00
Possible data points	1,051,890	1,051,890
Valid data points	1,051,890	1,051,890
Missing data points	0	0
Data recovery rate (%)	100.00	100.00

Flag Statistics

	Data Column	Time Steps Flagged As <Unflagged data>
1	100 WS	1,051,890
2	100 WD	1,051,890
3	100 TEMP	1,051,890
4	100 TI	1,051,890
5	100 RH	1,051,890
6	110 WS	1,051,890
7	110 WD	1,051,890
8	110 TEMP	1,051,890
9	110 TI	1,051,890
10	110 RH	1,051,890
11	Air Density	1,051,890
12	100 WS WPD	1,051,890
13	110 WS WPD	1,051,890

Data Coverage



Data Column Properties

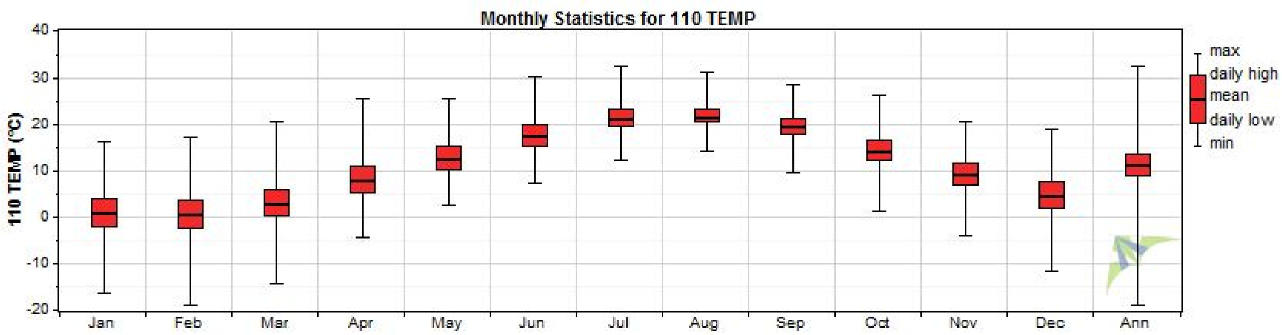
# #	Label	Units	Height	Possible Data Points	Valid Data Points	DRR (%)	Mean	MoMM	Median	Min	Max	Std. Dev
1	100 WS	m/s	100 m	1,051,890	1,051,890	100.00	9.315	9.315	8.765	0.057	38.460	4.699
2	100 WD	°	100 m	1,051,890	1,051,890	100.00	272.7	207.6	227.4	0.0	360.0	85.7
3	100 TEMP	°C	100 m	1,051,890	1,051,890	100.00	10.9	10.9	11.4	-19.6	32.5	8.5
4	100 TI		100 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.02	6.07	0.07
5	100 RH	%		1,051,890	1,051,890	100.00	78.0	78.0	78.5	8.7	100.9	15.9
6	110 WS	m/s	110 m	1,051,890	1,051,890	100.00	9.437	9.437	8.852	0.067	38.979	4.792
7	110 WD	°	110 m	1,051,890	1,051,890	100.00	272.6	207.9	228.1	0.0	360.0	85.5
8	110 TEMP	°C	110 m	1,051,890	1,051,890	100.00	10.9	10.9	11.4	-19.7	32.6	8.5
9	110 TI		110 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.02	5.82	0.07
10	110 RH	%		1,051,890	1,051,890	100.00	77.8	77.8	78.4	8.4	100.9	16.1
11	Air Density	kg/m3		1,051,890	1,051,890	100.00	1.223	1.223	1.220	1.128	1.374	0.040
12	100 WS WPD	W/m²		1,051,890	1,051,890	100.00	913	913	411	0	33,742	1,351
13	110 WS WPD	W/m²		1,051,890	1,051,890	100.00	956	956	424	0	35,127	1,425

Appendix C. Extended Statistical Summary Report – Location C

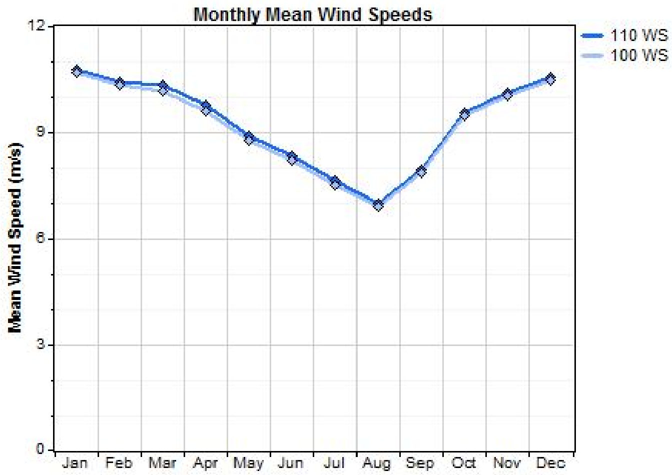
Data Set Properties

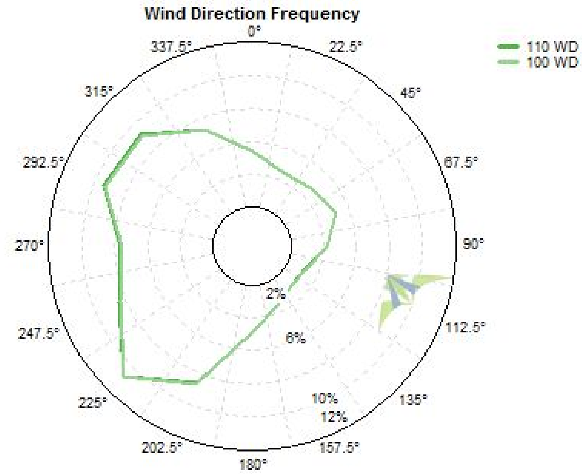
Report Created: 9/22/2017 15:05 using Windographer 4.1 beta
Filter Settings: <Unflagged data>

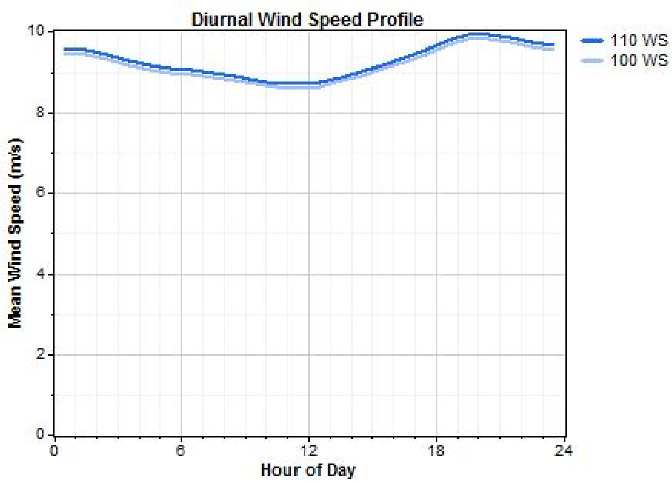
Variable	Value
Latitude	N 40.445400
Longitude	W 72.510300
Elevation	0 m
Start date	1/1/1997 00:00
End date	12/31/2016 19:00
Duration	20 years
Length of time step	10 minutes
Calm threshold	0 m/s
MoMM temperature	11.2 °C
MoMM pressure	
MoMM air density	1.221 kg/m3
Power density at 50m	635 W/m²
Wind power class	6 (Outstanding)
Power law exponent	0.13
Surface roughness	0.0488 m
Roughness class	1.40

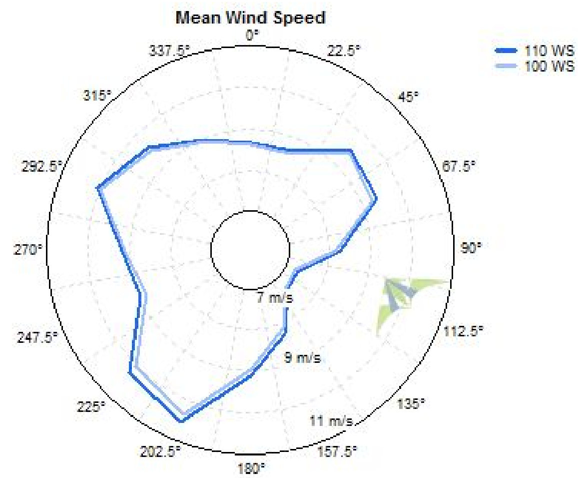


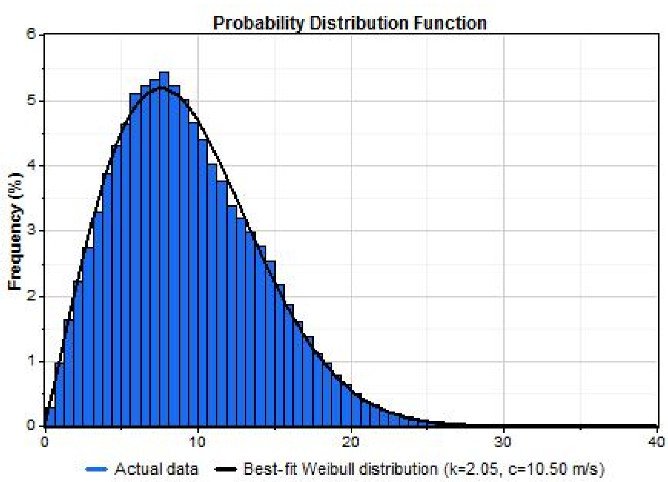
Wind Speed and Direction

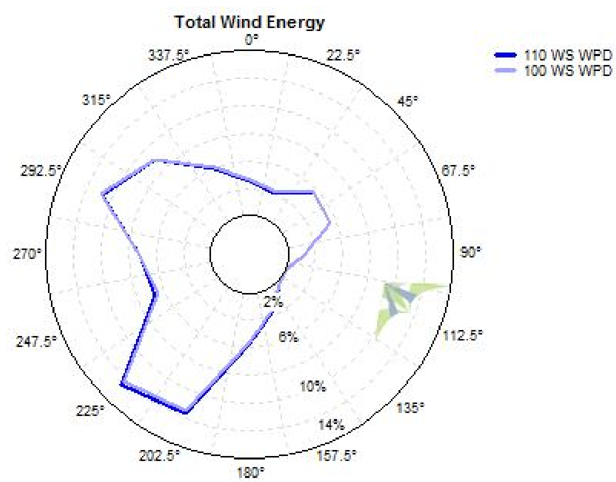




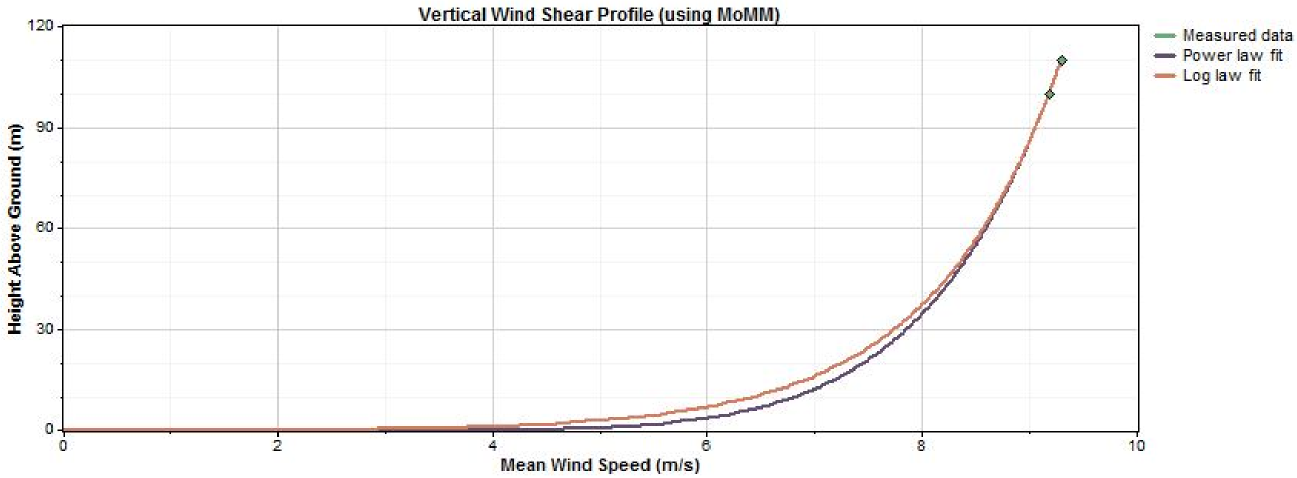


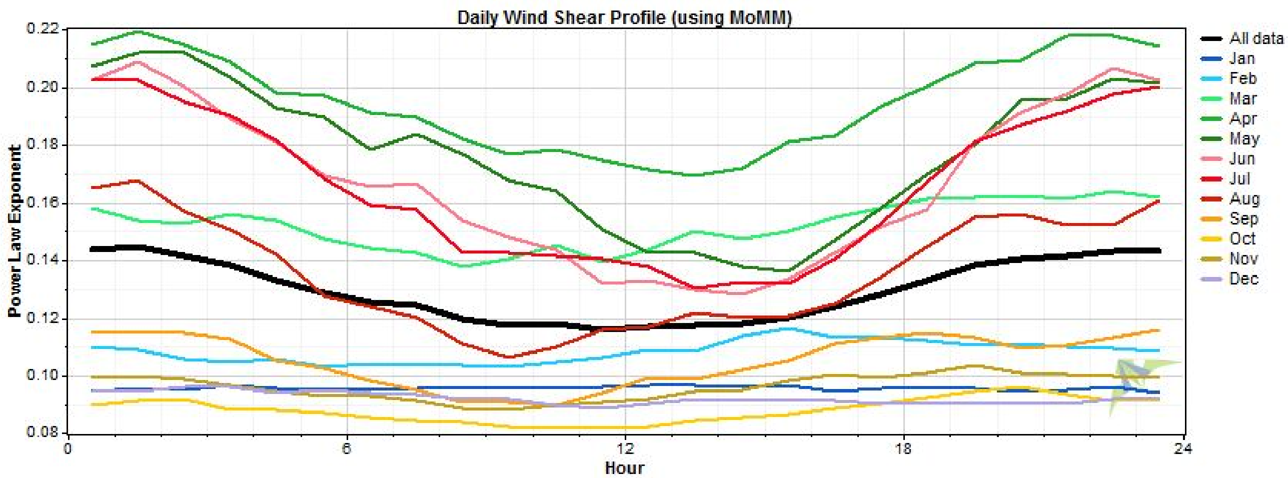


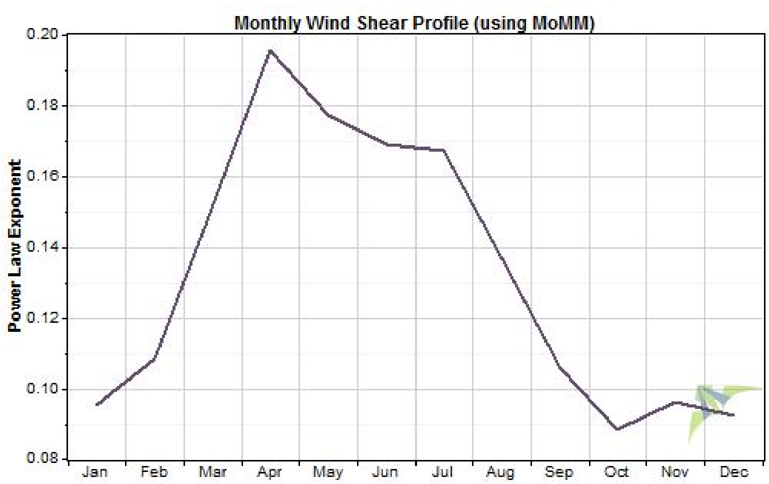


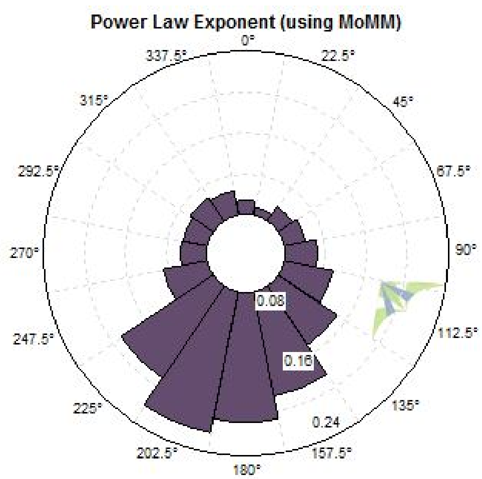


Wind Shear

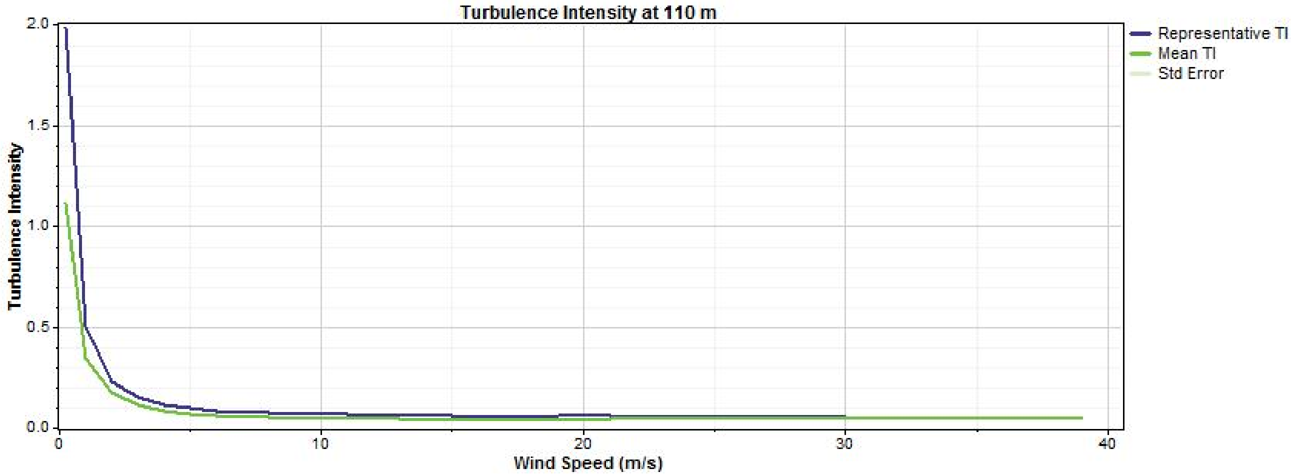

Vertical Wind Shear Profile (using MoMM)
Height Above Ground (m)
Mean Wind Speed (m/s)
Measured data
Power law fit
Log law fit
0
30
60
90
120
0
2
4
6
8
10

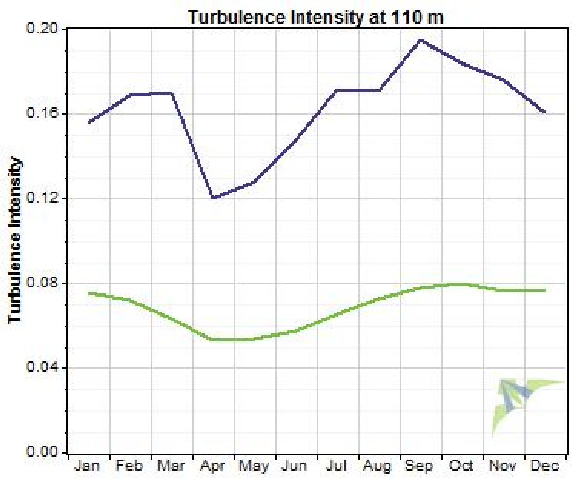

Daily Wind Shear Profile (using MoMM)
Power Law Exponent
Hour
All data
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0
6
12
18
24

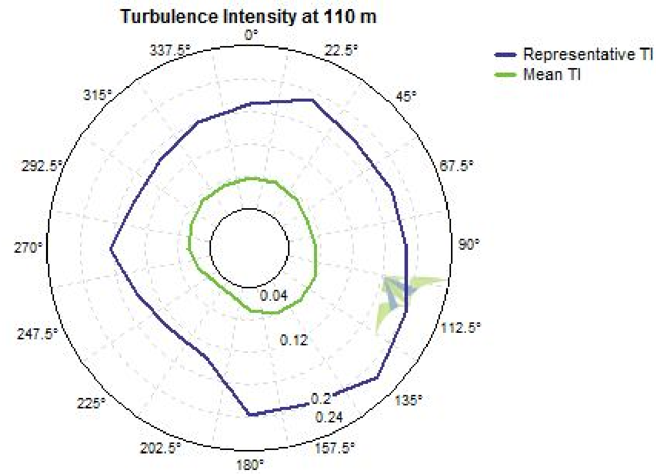

Monthly Wind Shear Profile (using MoMM)
Power Law Exponent
0.08
0.10
0.12
0.14
0.16
0.18
0.20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

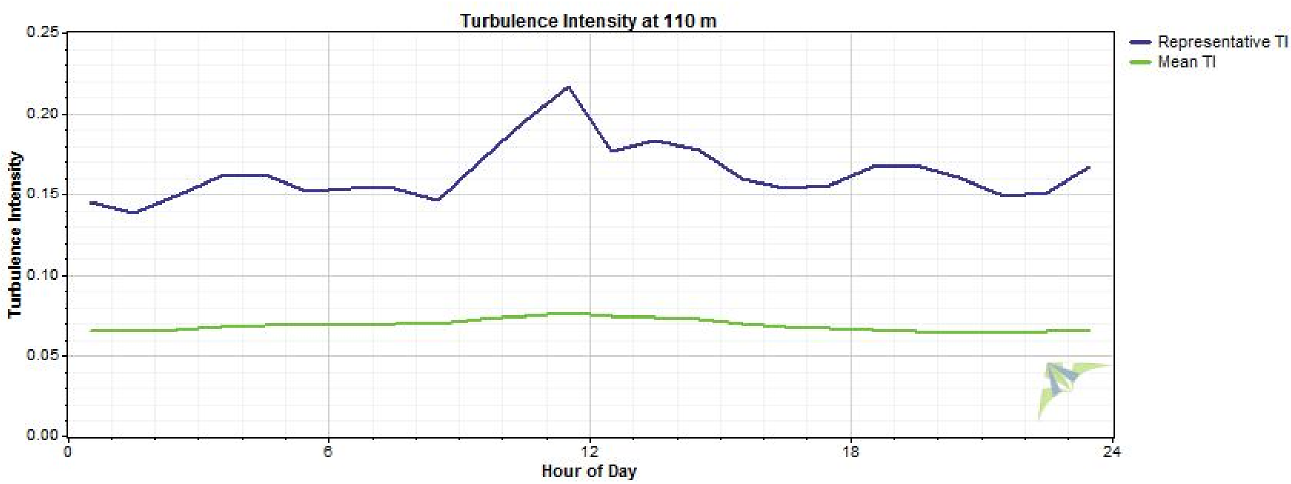

Power Law Exponent (using MoMM)
0°
22.5°
45°
67.5°
90°
112.5°
135°
157.5°
180°
202.5°
225°
247.5°
270°
292.5°
315°
337.5°
0.08
0.16
0.24

Turbulence Intensity









Environmental Summary

Variable	Mean	MoMM	Min	Max
Temperature (°C)	11.2	11.2	-19.0	32.6
Pressure (kPa)				
Air Density (kg/m3)	1.221	1.221	1.127	1.370
Energy-Weighted Air Density (kg/m3)	1.230	1.230	0.000	44.713

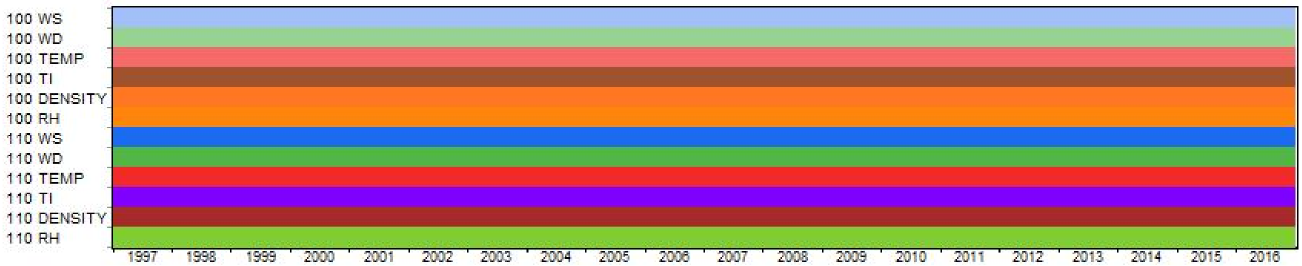
Wind Speed Sensor Summary

Variable	110 WS	100 WS
Measurement height (m)	110	100
Mean wind speed (m/s)	9.299	9.184
MoMM wind speed (m/s)	9.299	9.184
Median wind speed (m/s)	8.704	8.620
Min wind speed (m/s)	0.040	0.035
Max wind speed (m/s)	38.716	38.215
CRMC wind speed (m/s)	11.436	11.265
Weibull k	2.052	2.067
Weibull c (m/s)	10.496	10.366
Mean power density (W/m²)	0	0
MoMM power density (W/m²)	919	879
Mean energy content (kWh/m²/yr)	0	0
MoMM energy content (kWh/m²/yr)	8,048	7,696
Energy pattern factor	1.860	1.846
Frequency of calms (%)	0.00	0.00
Possible data points	1,051,890	1,051,890
Valid data points	1,051,890	1,051,890
Missing data points	0	0
Data recovery rate (%)	100.00	100.00

Flag Statistics

	Data Column	Time Steps Flagged As <Unflagged data>
1	100 WS	1,051,890
2	100 WD	1,051,890
3	100 TEMP	1,051,890
4	100 TI	1,051,890
5	100 DENSITY	1,051,890
6	100 RH	1,051,890
7	110 WS	1,051,890
8	110 WD	1,051,890
9	110 TEMP	1,051,890
10	110 TI	1,051,890
11	110 DENSITY	1,051,890
12	110 RH	1,051,890
13	Air Density	1,051,890
14	100 WS WPD	1,051,890
15	110 WS WPD	1,051,890

Data Coverage



Data Column Properties

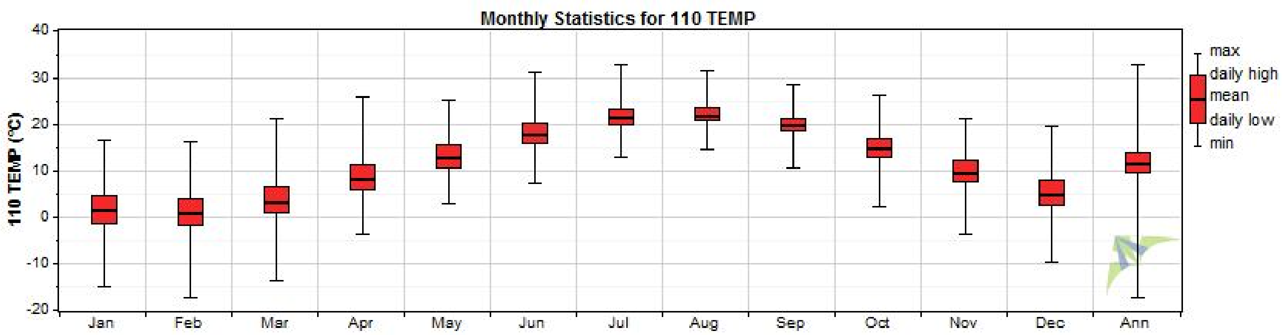
# #	Label	Units	Height	Possible Data Points	Valid Data Points	DRR (%)	Mean	MoMM	Median	Min	Max	Std. Dev
1	100 WS	m/s	100 m	1,051,890	1,051,890	100.00	9.184	9.184	8.620	0.035	38.215	4.659
2	100 WD	°	100 m	1,051,890	1,051,890	100.00	272.1	207.2	225.3	0.0	360.0	86.7
3	100 TEMP	°C	100 m	1,051,890	1,051,890	100.00	11.2	11.2	11.6	-18.9	32.5	8.5
4	100 TI		100 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.02	14.85	0.07
5	100 DENSITY			1,051,890	1,051,890	100.00	1.218	1.218	1.215	1.102	1.391	0.047
6	100 RH	%		1,051,890	1,051,890	100.00	77.3	77.3	77.8	9.7	100.9	16.1
7	110 WS	m/s	110 m	1,051,890	1,051,890	100.00	9.299	9.299	8.704	0.040	38.716	4.749
8	110 WD	°	110 m	1,051,890	1,051,890	100.00	272.0	207.4	226.0	0.0	360.0	86.5
9	110 TEMP	°C	110 m	1,051,890	1,051,890	100.00	11.2	11.2	11.7	-19.0	32.6	8.6
10	110 TI		110 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.01	12.96	0.07
11	110 DENSITY			1,051,890	1,051,890	100.00	1.217	1.217	1.213	1.101	1.390	0.047
12	110 RH	%		1,051,890	1,051,890	100.00	77.1	77.1	77.6	7.7	100.9	16.3
13	Air Density	kg/m3		1,051,890	1,051,890	100.00	1.221	1.221	1.218	1.127	1.370	0.040
14	100 WS WPD	W/m²		1,051,890	1,051,890	100.00	879	879	391	0	33,194	1,300
15	110 WS WPD	W/m²		1,051,890	1,051,890	100.00	919	919	402	0	34,517	1,370

Appendix D. Extended Statistical Summary Report – Location D

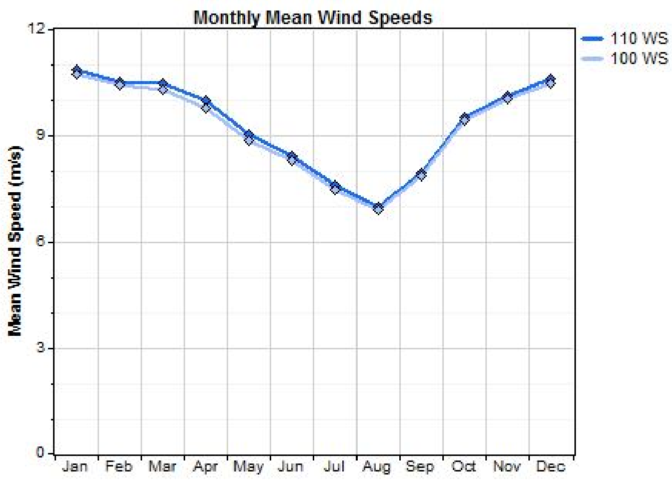
Data Set Properties

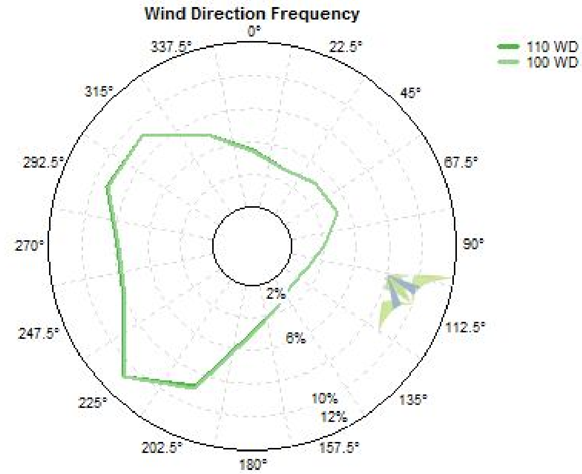
Report Created: 9/22/2017 15:11 using Windographer 4.1 beta
Filter Settings: <Unflagged data>

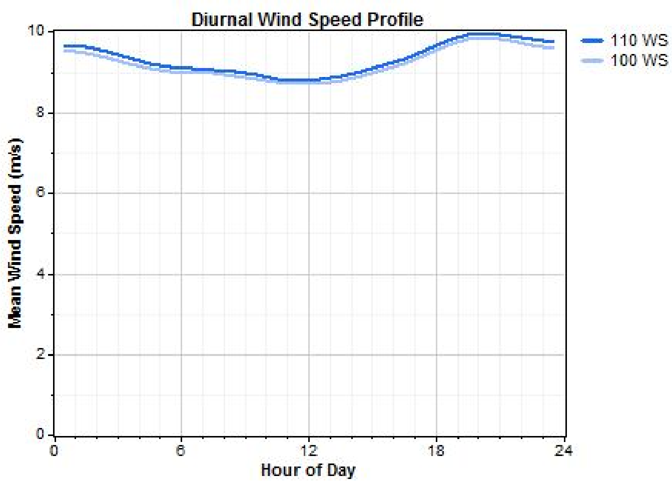
Variable	Value
Latitude	N 40.120600
Longitude	W 72.813500
Elevation	0 m
Start date	1/1/1997 00:00
End date	12/31/2016 19:00
Duration	20 years
Length of time step	10 minutes
Calm threshold	0 m/s
MoMM temperature	11.6 °C
MoMM pressure	
MoMM air density	1.219 kg/m3
Power density at 50m	638 W/m²
Wind power class	6 (Outstanding)
Power law exponent	0.134
Surface roughness	0.0595 m
Roughness class	1.57

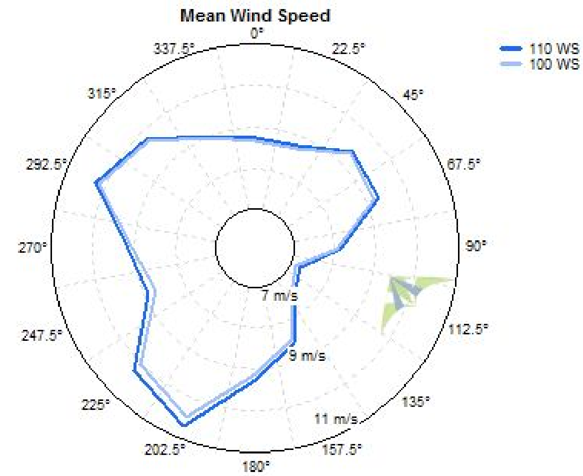


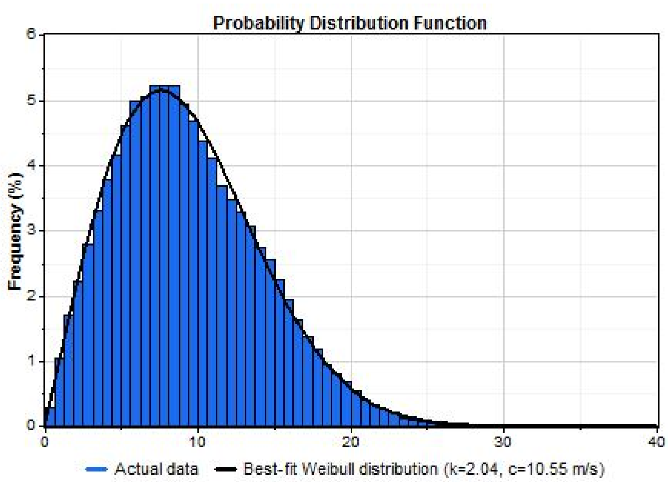
Wind Speed and Direction

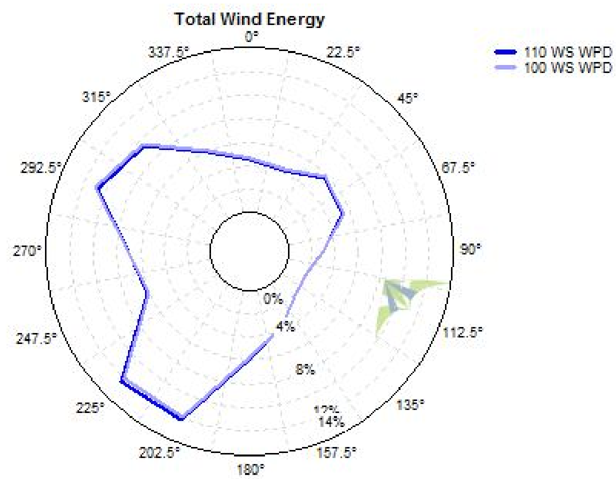




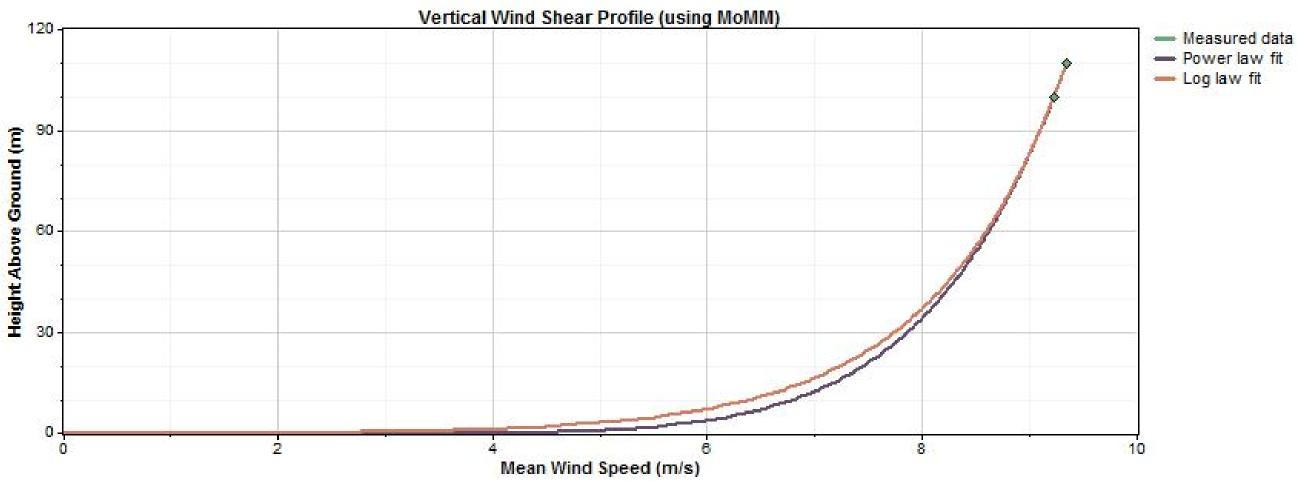


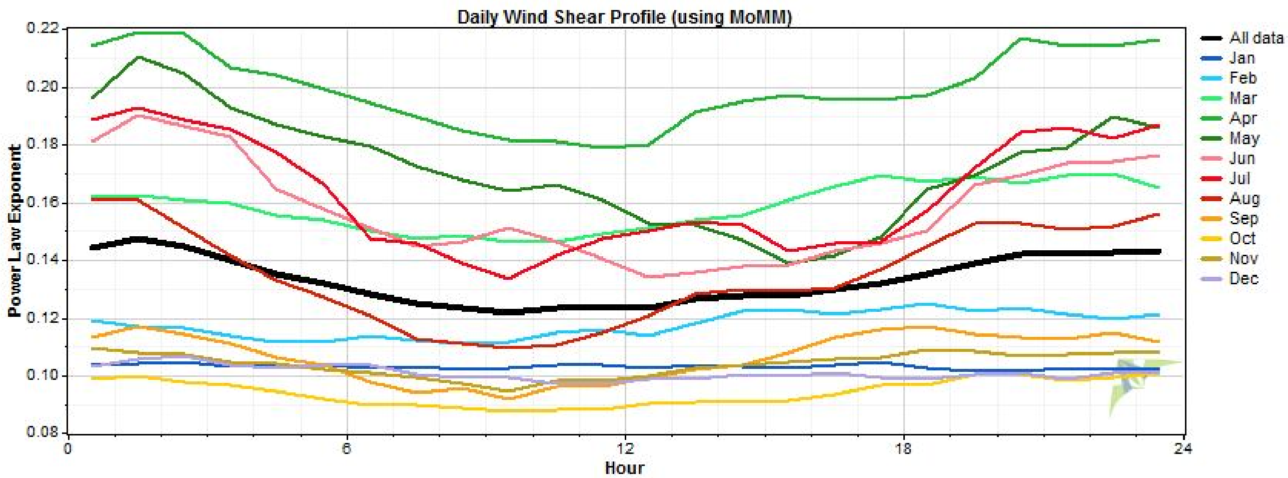


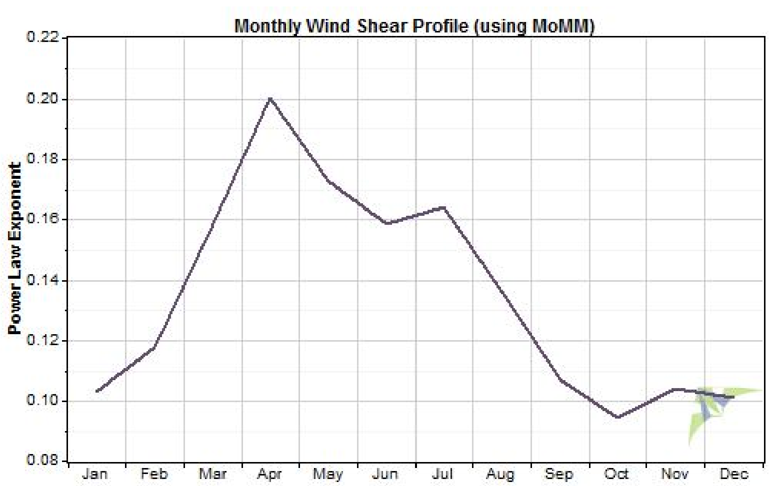


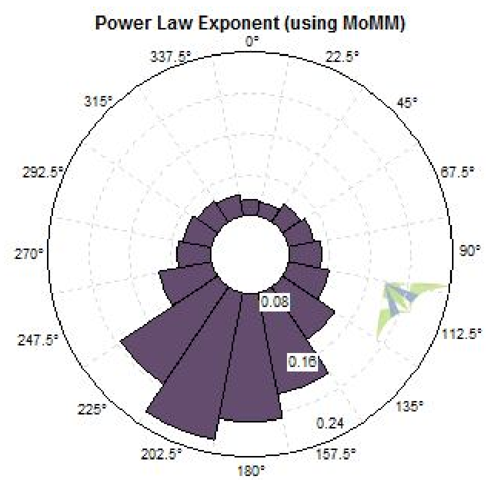


Wind Shear

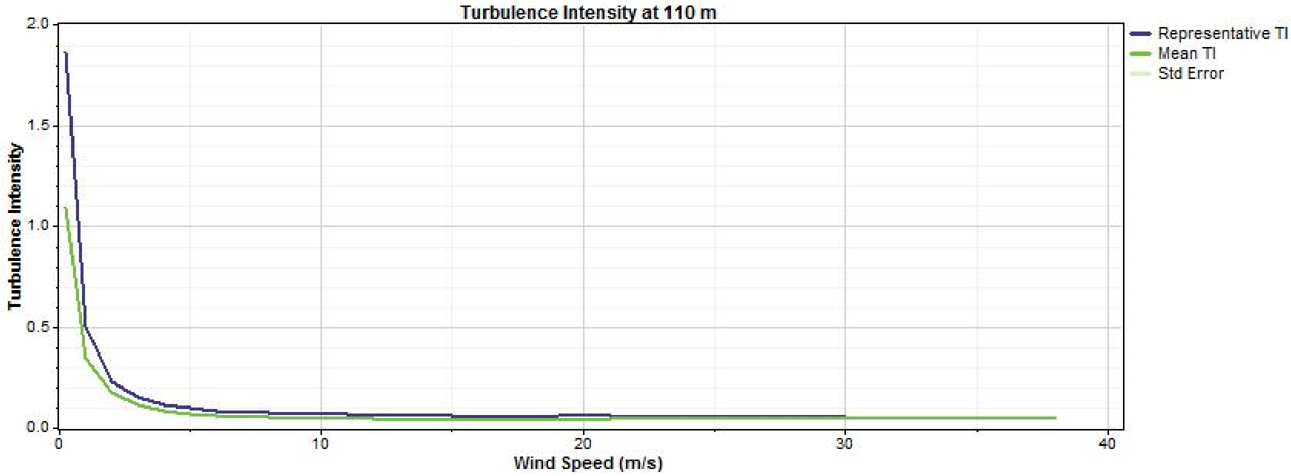

Vertical Wind Shear Profile (using MoMM)
Measured data
Power law fit
Log law fit
Height Above Ground (m)
Mean Wind Speed (m/s)

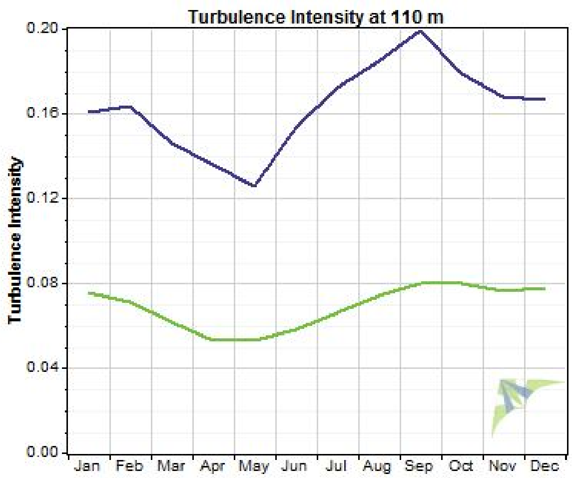

Daily Wind Shear Profile (using MoMM)
All data
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Power Law Exponent
Hour

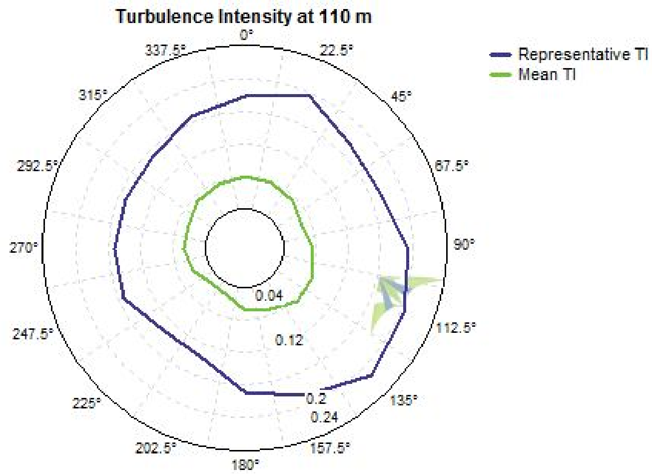

Monthly Wind Shear Profile (using MoMM)
Power Law Exponent
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

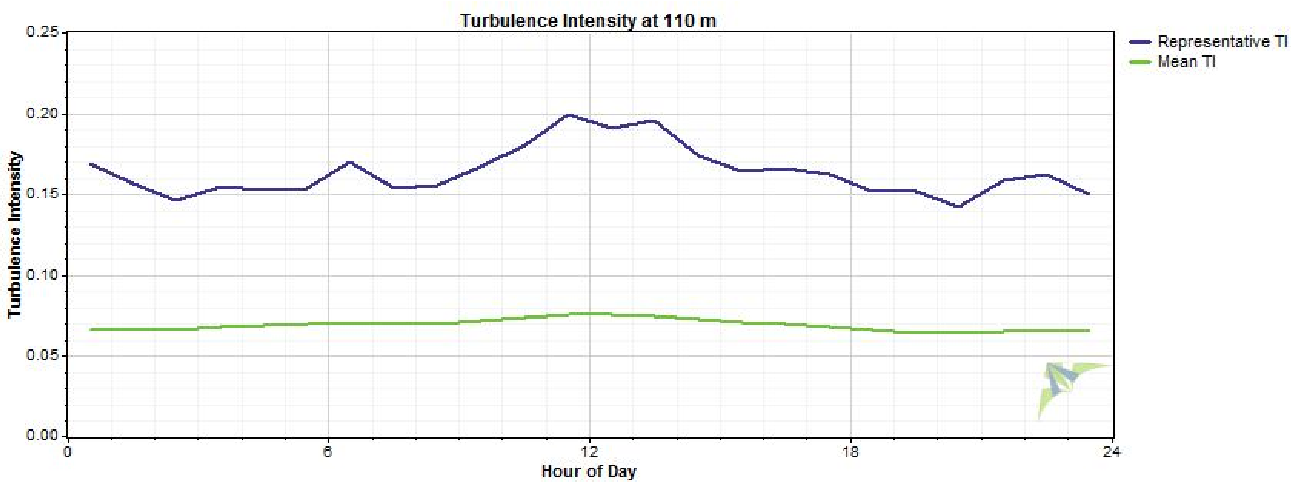

Power Law Exponent (using MoMM)
0°
22.5°
45°
67.5°
90°
112.5°
135°
157.5°
180°
202.5°
225°
247.5°
270°
292.5°
315°
337.5°
0.08
0.16
0.24

Turbulence Intensity









Environmental Summary

Variable	Mean	MoMM	Min	Max
Temperature (°C)	11.6	11.6	-17.1	32.9
Pressure (kPa)				
Air Density (kg/m3)	1.219	1.219	1.126	1.360
Energy-Weighted Air Density (kg/m3)	1.228	1.228	0.000	41.861

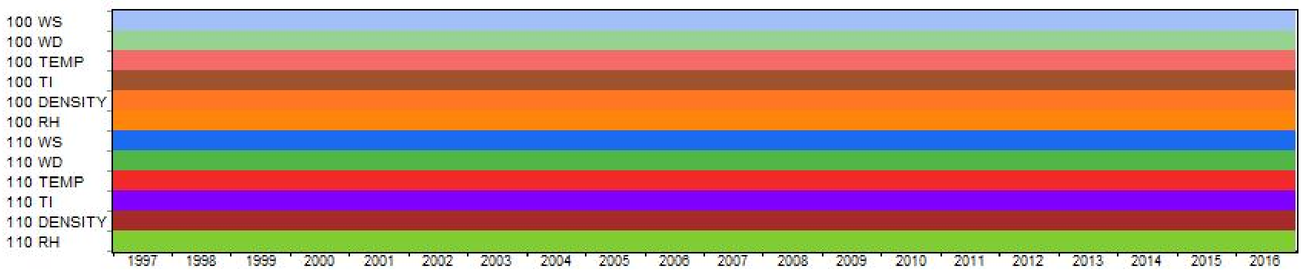
Wind Speed Sensor Summary

Variable	110 WS	100 WS
Measurement height (m)	110	100
Mean wind speed (m/s)	9.350	9.232
MoMM wind speed (m/s)	9.350	9.232
Median wind speed (m/s)	8.779	8.693
Min wind speed (m/s)	0.044	0.051
Max wind speed (m/s)	38.143	37.612
CRMC wind speed (m/s)	11.507	11.329
Weibull k	2.043	2.058
Weibull c (m/s)	10.552	10.417
Mean power density (W/m²)	0	0
MoMM power density (W/m²)	935	892
Mean energy content (kWh/m²/yr)	0	0
MoMM energy content (kWh/m²/yr)	8,187	7,818
Energy pattern factor	1.864	1.848
Frequency of calms (%)	0.00	0.00
Possible data points	1,051,890	1,051,890
Valid data points	1,051,890	1,051,890
Missing data points	0	0
Data recovery rate (%)	100.00	100.00

Flag Statistics

	Data Column	Time Steps Flagged As <Unflagged data>
1	100 WS	1,051,890
2	100 WD	1,051,890
3	100 TEMP	1,051,890
4	100 TI	1,051,890
5	100 DENSITY	1,051,890
6	100 RH	1,051,890
7	110 WS	1,051,890
8	110 WD	1,051,890
9	110 TEMP	1,051,890
10	110 TI	1,051,890
11	110 DENSITY	1,051,890
12	110 RH	1,051,890
13	Air Density	1,051,890
14	100 WS WPD	1,051,890
15	110 WS WPD	1,051,890

Data Coverage



Data Column Properties

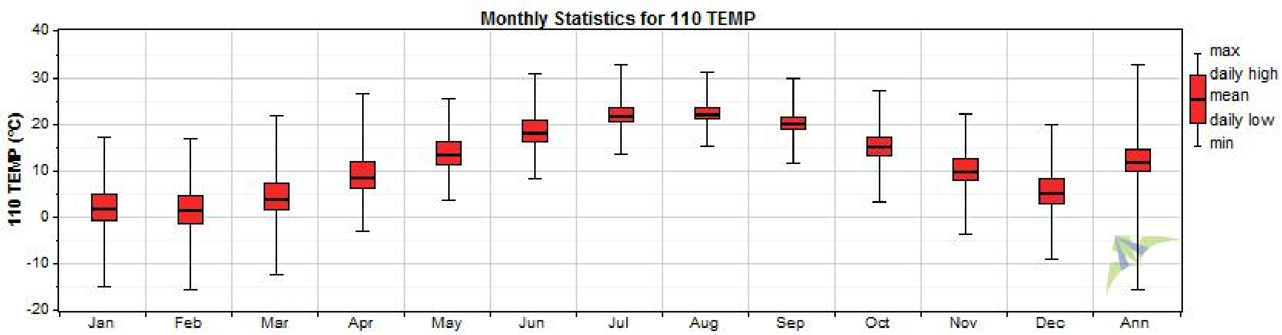
# #	Label	Units	Height	Possible Data Points	Valid Data Points	DRR (%)	Mean	MoMM	Median	Min	Max	Std. Dev
1	100 WS	m/s	100 m	1,051,890	1,051,890	100.00	9.232	9.232	8.693	0.051	37.612	4.698
2	100 WD	°	100 m	1,051,890	1,051,890	100.00	271.8	205.6	223.6	0.0	360.0	87.2
3	100 TEMP	°C	100 m	1,051,890	1,051,890	100.00	11.6	11.6	12.0	-17.0	32.7	8.4
4	100 TI		100 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.02	6.96	0.07
5	100 DENSITY			1,051,890	1,051,890	100.00	1.216	1.216	1.213	1.099	1.382	0.046
6	100 RH	%		1,051,890	1,051,890	100.00	77.5	77.5	78.0	9.8	100.9	15.9
7	110 WS	m/s	110 m	1,051,890	1,051,890	100.00	9.350	9.350	8.779	0.044	38.143	4.793
8	110 WD	°	110 m	1,051,890	1,051,890	100.00	271.7	205.9	224.4	0.0	360.0	87.0
9	110 TEMP	°C	110 m	1,051,890	1,051,890	100.00	11.6	11.6	12.1	-17.1	32.9	8.4
10	110 TI		110 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.02	8.20	0.07
11	110 DENSITY			1,051,890	1,051,890	100.00	1.215	1.215	1.211	1.098	1.381	0.046
12	110 RH	%		1,051,890	1,051,890	100.00	77.3	77.3	77.8	8.1	100.9	16.1
13	Air Density	kg/m3		1,051,890	1,051,890	100.00	1.219	1.219	1.216	1.126	1.360	0.039
14	100 WS WPD	W/m²		1,051,890	1,051,890	100.00	892	892	400	0	31,584	1,313
15	110 WS WPD	W/m²		1,051,890	1,051,890	100.00	935	935	412	0	32,941	1,386

Appendix E. Extended Statistical Summary Report – Location E

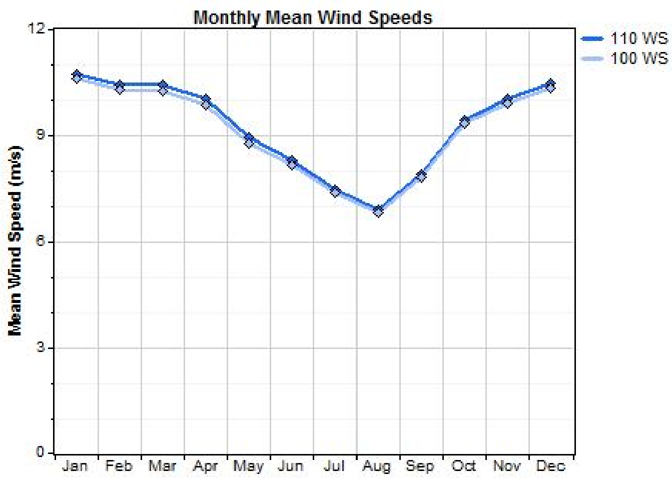
Data Set Properties

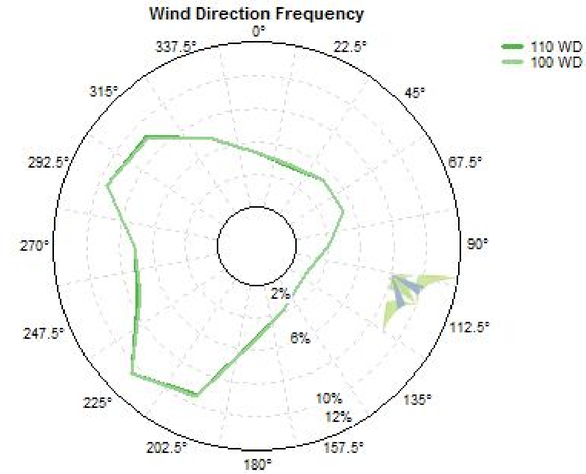
Report Created: 9/22/2017 15:23 using Windographer 4.1 beta
Filter Settings: <Unflagged data>

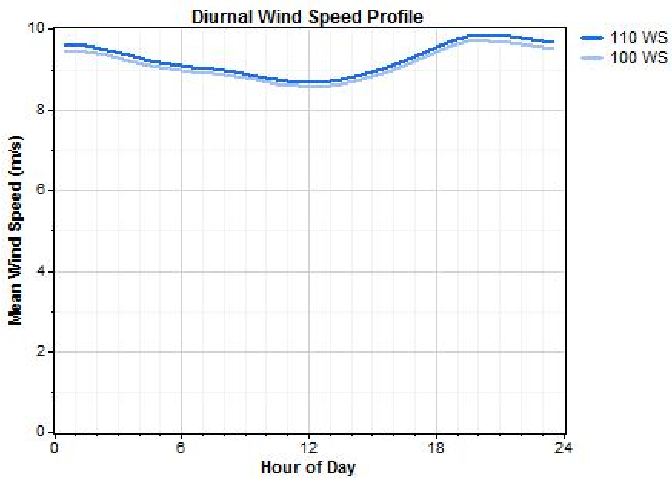
Variable	Value
Latitude	N 39.655900
Longitude	W 73.355600
Elevation	0 m
Start date	1/1/1997 00:00
End date	12/31/2016 19:00
Duration	20 years
Length of time step	10 minutes
Calm threshold	0 m/s
MoMM temperature	12.0 °C
MoMM pressure	
MoMM air density	1.217 kg/m3
Power density at 50m	609 W/m²
Wind power class	6 (Outstanding)
Power law exponent	0.142
Surface roughness	0.0902 m
Roughness class	1.91

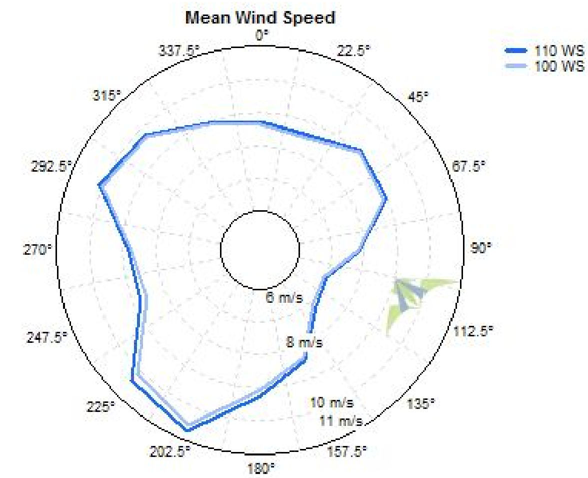


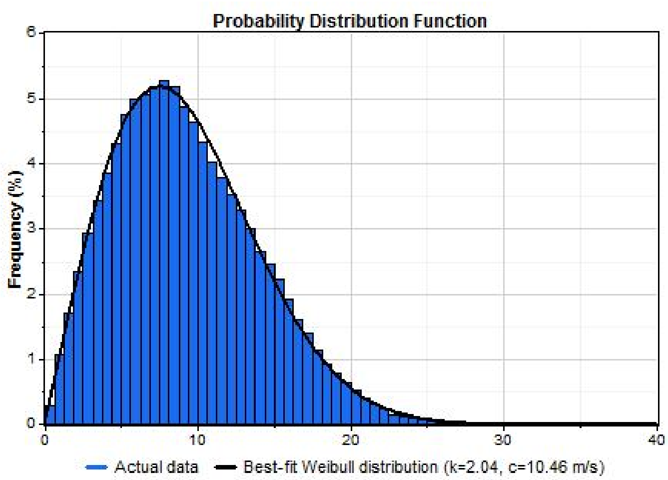
Wind Speed and Direction

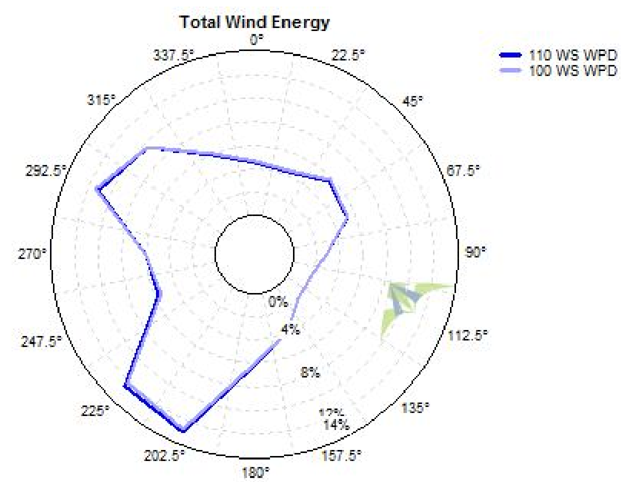




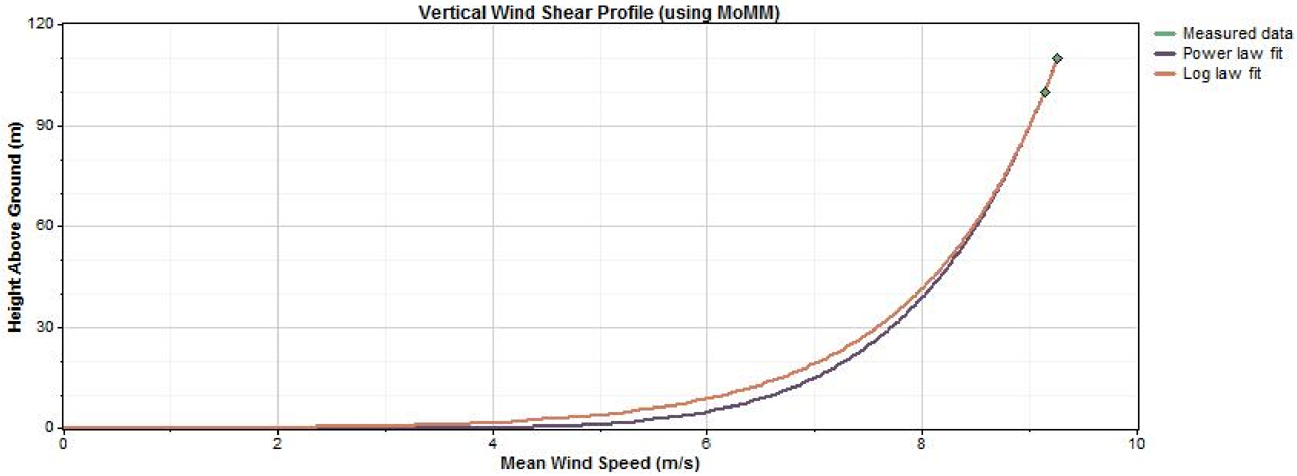


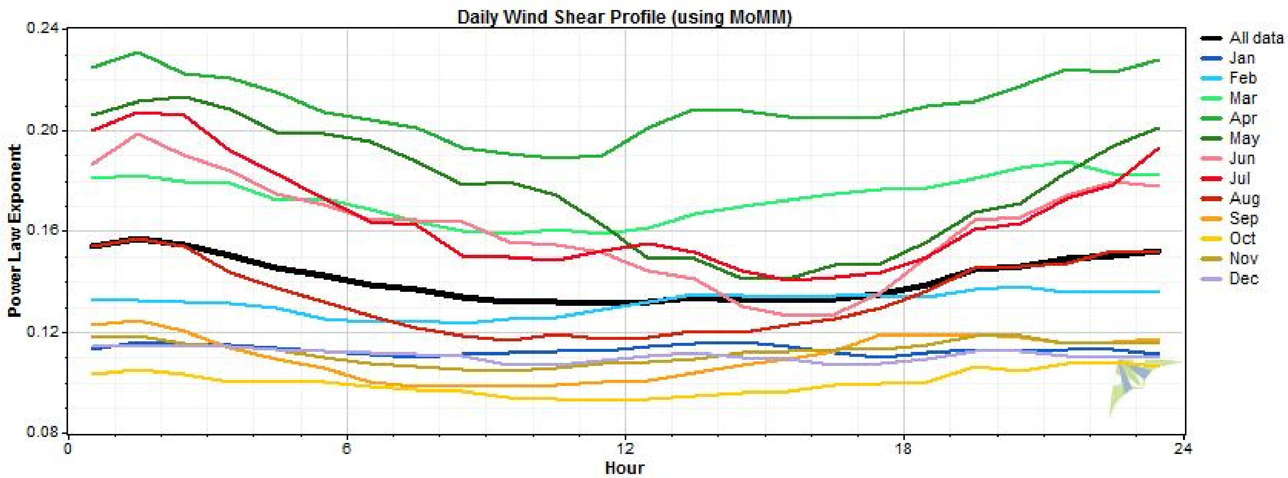


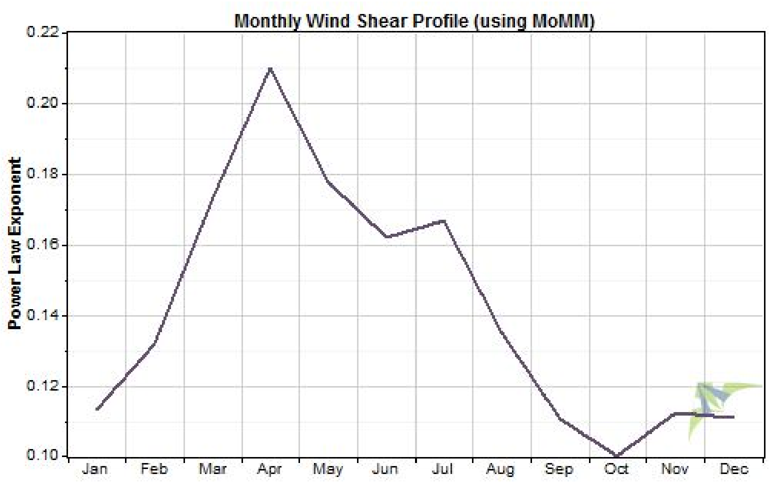


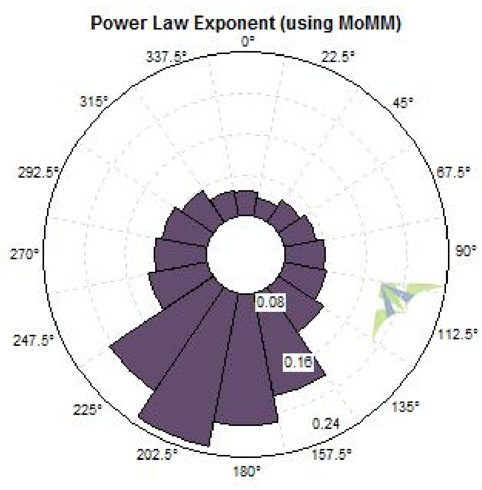


Wind Shear

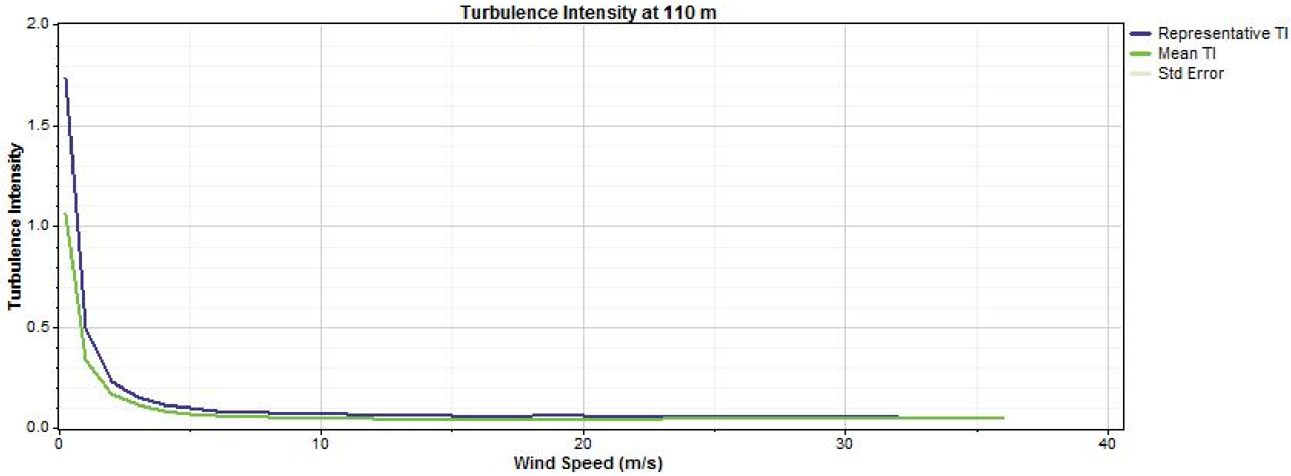

Vertical Wind Shear Profile (using MoMM)
Height Above Ground (m)
Mean Wind Speed (m/s)
Measured data
Power law fit
Log law fit

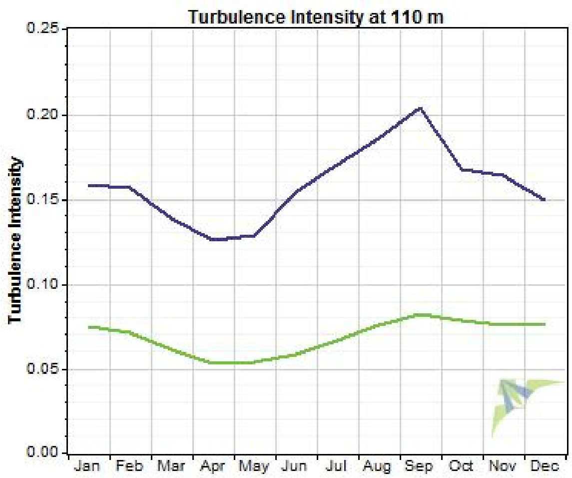

Daily Wind Shear Profile (using MoMM)
Power Law Exponent
Hour
All data
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

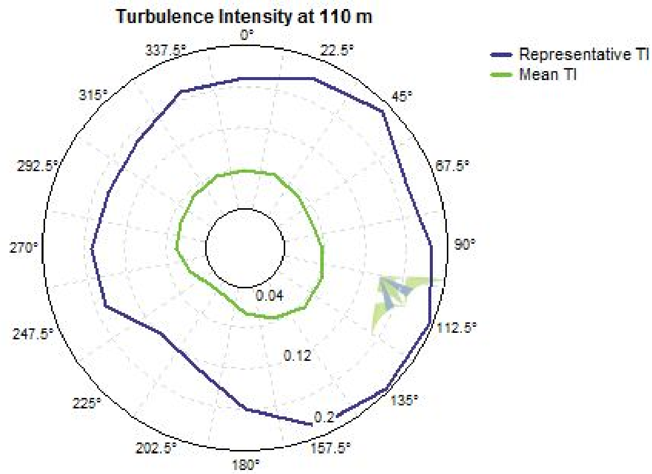

Monthly Wind Shear Profile (using MoMM)
Power Law Exponent
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

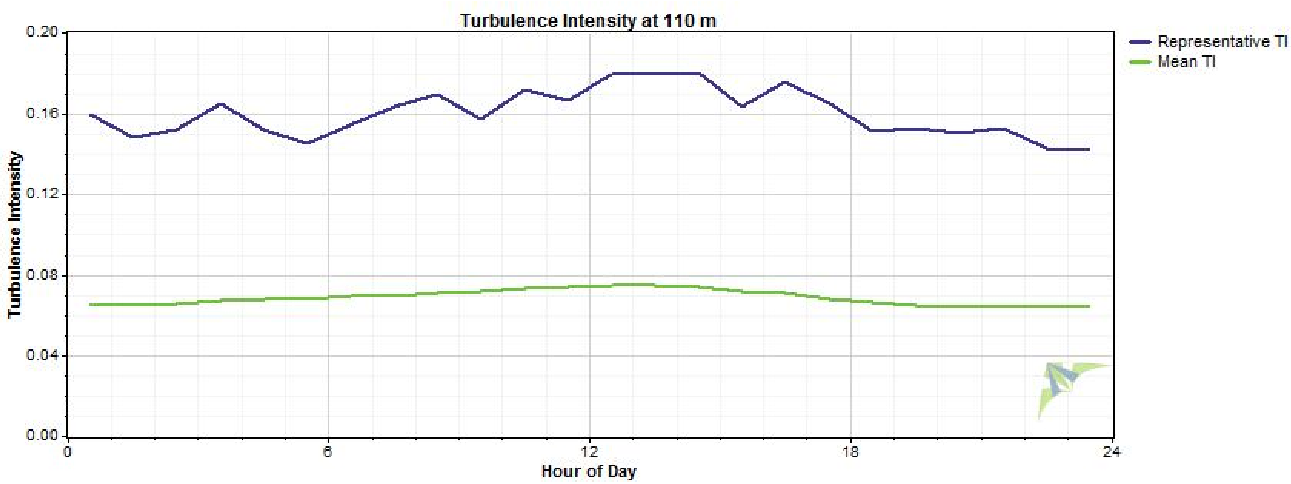

Power Law Exponent (using MoMM)

Turbulence Intensity









Environmental Summary

Variable	Mean	MoMM	Min	Max
Temperature (°C)	12.0	12.0	-15.4	32.9
Pressure (kPa)				
Air Density (kg/m3)	1.217	1.217	1.126	1.351
Energy-Weighted Air Density (kg/m3)	1.226	1.226	0.000	37.136

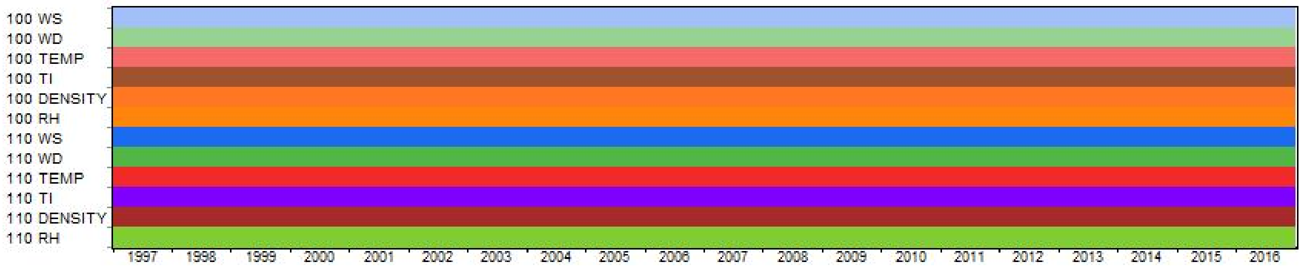
Wind Speed Sensor Summary

Variable	110 WS	100 WS
Measurement height (m)	110	100
Mean wind speed (m/s)	9.266	9.142
MoMM wind speed (m/s)	9.266	9.142
Median wind speed (m/s)	8.697	8.605
Min wind speed (m/s)	0.046	0.055
Max wind speed (m/s)	36.383	35.864
CRMC wind speed (m/s)	11.417	11.231
Weibull k	2.036	2.051
Weibull c (m/s)	10.459	10.317
Mean power density (W/m²)	0	0
MoMM power density (W/m²)	911	868
Mean energy content (kWh/m²/yr)	0	0
MoMM energy content (kWh/m²/yr)	7,984	7,605
Energy pattern factor	1.870	1.854
Frequency of calms (%)	0.00	0.00
Possible data points	1,051,890	1,051,890
Valid data points	1,051,890	1,051,890
Missing data points	0	0
Data recovery rate (%)	100.00	100.00

Flag Statistics

	Data Column	Time Steps Flagged As <Unflagged data>
1	100 WS	1,051,890
2	100 WD	1,051,890
3	100 TEMP	1,051,890
4	100 TI	1,051,890
5	100 DENSITY	1,051,890
6	100 RH	1,051,890
7	110 WS	1,051,890
8	110 WD	1,051,890
9	110 TEMP	1,051,890
10	110 TI	1,051,890
11	110 DENSITY	1,051,890
12	110 RH	1,051,890
13	Air Density	1,051,890
14	100 WS WPD	1,051,890
15	110 WS WPD	1,051,890

Data Coverage



Data Column Properties

# #	Label	Units	Height	Possible Data Points	Valid Data Points	DRR (%)	Mean	MoMM	Median	Min	Max	Std. Dev
1	100 WS	m/s	100 m	1,051,890	1,051,890	100.00	9.142	9.142	8.605	0.055	35.864	4.668
2	100 WD	°	100 m	1,051,890	1,051,890	100.00	270.3	203.5	220.5	0.0	360.0	88.4
3	100 TEMP	°C	100 m	1,051,890	1,051,890	100.00	12.1	12.1	12.6	-15.3	32.7	8.4
4	100 TI		100 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.02	5.57	0.07
5	100 DENSITY			1,051,890	1,051,890	100.00	1.214	1.214	1.210	1.089	1.372	0.046
6	100 RH	%		1,051,890	1,051,890	100.00	77.5	77.5	78.1	9.5	100.9	15.8
7	110 WS	m/s	110 m	1,051,890	1,051,890	100.00	9.266	9.266	8.697	0.046	36.383	4.767
8	110 WD	°	110 m	1,051,890	1,051,890	100.00	270.3	203.9	221.2	0.0	360.0	88.2
9	110 TEMP	°C	110 m	1,051,890	1,051,890	100.00	12.0	12.0	12.6	-15.4	32.9	8.4
10	110 TI		110 m	1,051,890	1,051,890	100.00	0.07	0.07	0.05	0.02	6.68	0.07
11	110 DENSITY			1,051,890	1,051,890	100.00	1.212	1.212	1.209	1.088	1.371	0.046
12	110 RH	%		1,051,890	1,051,890	100.00	77.3	77.3	77.9	8.4	100.9	16.1
13	Air Density	kg/m3		1,051,890	1,051,890	100.00	1.217	1.217	1.214	1.126	1.351	0.039
14	100 WS WPD	W/m²		1,051,890	1,051,890	100.00	868	868	388	0	27,339	1,280
15	110 WS WPD	W/m²		1,051,890	1,051,890	100.00	911	911	400	0	28,543	1,355

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New York State Energy Research and Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

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