3TIER by Vaisala

Due Diligence Analysis

PROJECT

Rush Creek II : Colorado, USA

using 126 Vestas V110-2.0 wind turbines at 80 m

FOR

Xcel Energy

DATE

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Contents

1 EXECUTIVE SUMMARY

3TIER has conducted a wind resource assessment of the Rush Creek II project, located in Colorado, USA. This project consists of 126 Vestas V110-2.0 wind turbines at 80 m, for a total capacity of 252.0 MW. The project is located approximately 40 km southeast of the town of Limon in a mixture of farmland and shrub-steppe terrain.

A summary of the major results is provided here. Table 1 provides configuration details of the project as well as primary wind speed, generation and uncertainty results. The long-term reference period used in this analysis extends over 36 years (January, 1980 – December, 2015). The wind resource assessment yields a gross project-average long-term wind speed estimate, at hub height, of **8.83 m/s**. The long-term mean gross generation estimate is **1321.0 GWh**, with a corresponding gross capacity factor of 59.8 %. Loss factors are considered, leading to a net energy estimate of **1024.9 GWh**, with a corresponding net capacity factor of 46.4 %.

The micro-sited turbine layout for the Rush Creek II project has not yet been finalized. The final target nameplate capacity for this project is planned to be 200MW and consist of 100 turbine locations. For planning purposes, until the turbine layout is finalized, the results presented in this report as energy (MWh) can be scaled to the target capacity. A ratio of $\frac{200}{252}$, applied to the net energy values will provide reasonably representative approximations of the energy output for the final project size. Relevant values for this scaled 200MW project are also given in Table 1.

A map of the hub height long-term mean wind speed values across the Rush Creek II project area is displayed in Wind Speed Maps.

Project Size	252.0 MW	200.0 MW
Number of Turbines	126	100
Turbine Type	V110-2.0	V110-2.0
Hub Height	80 m	80 m
Project-Average Wind Speed	8.83 m/s	-
Project-Average Density	1.019 kg/m^3	-
Gross Generation	1321.0 GWh	1048.4 GWh
Net Generation	1024.9 GWh	813.4 GWh
Gross Capacity Factor	59.8 %	59.8 %
Net Capacity Factor	46.4 %	46.4 %
Aggregate Loss Factor	77.6 %	77.6 %
Standard Error of 20-year Estimate	5.7 %	5.7 %
Net-P10 20-year Generation	1099.7 GWh	872.8 GWh
Net-P25 20-year Generation	1064.3 GWh	844.7 GWh
Net-P75 20-year Generation	985.6 GWh	782.2 GWh
Net-P90 20-year Generation	950.1 GWh	754.0 GWh
Net-P10 20-year Capacity Factor	49.8 %	49.8 %
Net-P25 20-year Capacity Factor	48.2 %	48.2 %
Net-P75 20-year Capacity Factor	44.6 %	44.6 %
Net-P90 20-year Capacity Factor	43.0 %	43.0 %

Table 1: Project Overview

1.1 Wind Speed Maps

This section contains a map of MOS-corrected long-term mean wind speed values at hub height ($80\,m$) across the Rush Creek II project area.

1.1.1 80 m Hub Height

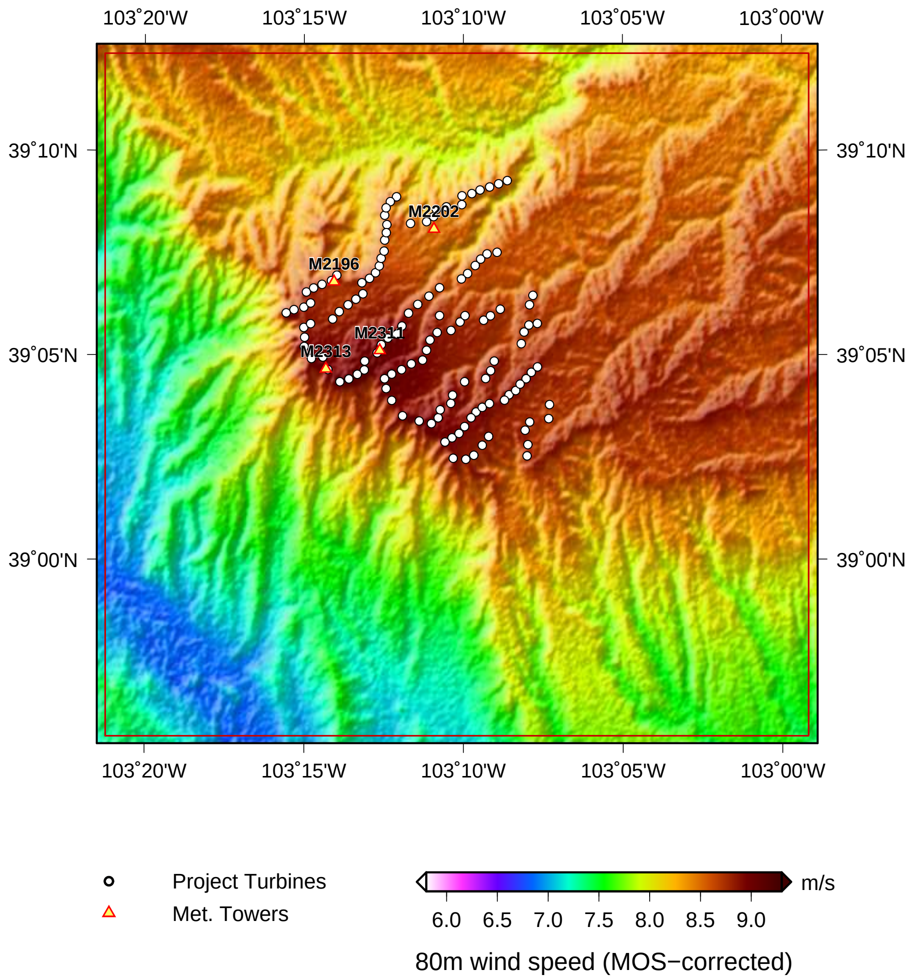

Figure 1: 36-year (January, 1980 – December, 2015) mean wind speed at $80\,m$.

2 METHODOLOGY

Wind resource assessments are conducted using 3TIER's modeling platform that combines on-site observations with mesoscale and microscale weather simulation models. The output from the modeling system is a four-dimensional data set of modeled historical weather for each meteorological (met) tower and wind turbine location. Model output is statistically calibrated using observed data from met towers. The resulting data sets are the basis for analysis of the wind resource.

The core of this modeling system is the Weather Research and Forecasting (WRF) Numerical Weather Prediction (NWP) model, developed in a partnership between U.S. federal agencies and universities. WRF is suitable for a broad spectrum of applications including air quality plume modeling, wind resource assessment, and climate modeling. WRF provides a flexible and computationally efficient framework that allows the worldwide academic, government, and private research communities to contribute advancements in physics, numerical methods, and data assimilation.

The WRF model uses reanalysis data for initial and boundary conditions. A reanalysis data set is a coarse resolution, observational-based data set that exists for the past several decades. WRF relies on the reanalysis data set to provide an accurate representation of the large-scale (hundreds of kilometers) historic flow patterns throughout the atmosphere (e.g. the location of high and low pressure centers, the position of the jet stream, etc). In addition, WRF requires as input high-resolution topographic and land-use data in order to accurately represent surface conditions. Land surface characteristics are derived from the 10 arc second (approximately $300\,m$) resolution European Space Agency (ESA) GlobCover data set [2]. Topographic data are sourced from the Shuttle Radar Topography Mission (SRTM) data set at 3 arc-second (approximately $90\,m$) resolution [4]. With these primary inputs, WRF then solves the dynamical and physical equations that describe the processes of the atmosphere. A nested grid configuration is used to simulate the fine-resolution, local-scale flow conditions given the large-scale state of the atmosphere (as described by the reanalysis data).

The Time-Varying Microscale (TVM) Model enables high-resolution mapping (tens of meters to a few hundred meters) of meteorological fields without the computational cost of running a high-resolution NWP model, such as the WRF model. TVM uses several techniques to analyze microscale winds. Kinematic terrain effects are applied to the wind field allowing TVM to resolve the effects of microscale terrain features, effects that are unresolved by a mesoscale NWP model [7]. A Froude number adjustment is applied [1], which incorporates terrain blocking effects on the wind flow (i.e., determine whether the wind flows over or around specific terrain features). A log-profile surface roughness adjustment is also calculated to adjust the near-surface wind fields for the effects of roughness features that could not be resolved on the coarser WRF model grid. These effects are computed at each time step in the study period and are based not only on wind speed and elevation, but also on other quantities, including wind direction and the thermodynamic properties of the lower atmosphere. This enables a sophisticated time-varying spatial analysis at high-resolution.

On-site observational data are incorporated into the analysis to validate and correct the raw model data from WRF and TVM using a process of Model Output Statistics (MOS) correction. MOS uses multi-linear regression equations to remove bias and adjust the variance of the raw model output to improve the match with observational data at met tower locations. The MOS equation for each met tower is fit to the observational period of record. The MOS equation is then applied over the entire data set, correcting the historical period during which direct observational data are unavailable. MOS corrections are distributed across the model domain using a weighting scheme that depends on horizontal and vertical distance from the met tower.

A detailed analysis of the data set from each met tower ensures the integrity of the observational data before MOS-correction. Data are reviewed to ensure that:

- The functions to convert anemometer output to wind speed are appropriate, assuming raw data logger files and conversion functions are provided.
- Periods of icing affecting the accuracy of wind speed and direction measurement are excluded.
- Sensor data affected by the tower structures may be properly accounted for.
- Periods of anemometer dragging and/or malfunction are excluded.

During wind project development, met tower sensors are usually placed lower than the hub height of the proposed wind turbines. The analysis process must extrapolate the sensor data to hub height using a wind shear coefficient. Wind shear is a meteorological phenomenon in which wind speed values generally increase with height above ground level (AGL); the surrounding ground cover, trees, and topographic features such as hills and valleys can significantly affect the measured wind shear. The analysis calculates the shear coefficient from the observed data and then applies the coefficient to highest observed wind speed data to estimate wind speed values at hub height.

Long-term time series at each proposed turbine location are extracted from the MOS-corrected data set. These hourly time series are then combined with the manufacturer's specified power curve to compute gross capacity factor values. Applying site-specific loss factor estimates to the mean P50 gross capacity factor yields the P50 net capacity factor. Uncertainty of the measured data and modeling data is then estimated to calculate the final net capacity factors at various probabilities of exceedance.

2.1 Wind Resource Assessment Steps

To determine the energy production potential of the proposed Rush Creek II wind project, the following procedure was implemented:

1. For the ECMWF ERA-I [3], NCAR/NCEP [5], and MERRA [8] reanalysis data sets, simulate 36 years at $4.5\,km$ resolution using WRF to understand the long-term temporal variability of weather over the project site.
2. Validate time series data collected from each met tower.
3. Perform correlation analysis between observations and $4.5\,km$ models to determine primary reanalysis data set for NWP modeling.
4. Simulate 1 year at $500\,m$ resolution using WRF to understand the spatial variability of the wind resource at the site.
5. Run TVM to downscale $500\,m$ WRF simulation to $90\,m$ spatial resolution.
6. Perform ensemble analysis to integrate effects of each long term data set including consistency checks to determine usefulness of entire 36 year period for each data set
7. Run MOS to eliminate temporal bias and mitigate spatial bias of WRF/TVM model output. Compute MOS corrections at each met tower. Combine the high-resolution spatial model data with the ensemble adjusted coarser resolution long-term data, creating the final MOS-corrected $90\,m$ resolution long term data set.
8. Calculate the expected (P50) gross capacity factor using modeled long-term time series at each turbine location in combination with the appropriate power curve.
9. Perform numerical wake and turbulence modeling.
10. Apply wake deficit as well as other site-specific loss factor estimates to the gross capacity factor, yielding the expected (P50) net capacity factor.
11. Calculate probability of exceedance levels for the net capacity factor data based on year-to-year wind resource variation, measurement uncertainty, and modeling uncertainty.

The following sections provide detail regarding the process outlined above as applied to the Rush Creek II wind project.

3 OBSERVATIONAL DATA

Xcel Energy provided observational data from the following towers at the proposed Rush Creek II site:

- Tower M2196
- Tower M2202
- Tower M2311
- Tower M2313

The location of each tower and the proposed turbine locations are shown in Wind Speed Maps, and a summary of each tower is presented in Table 2. 3TIER performed a site visit of the Rush Creek II wind project, and the data were inspected for quality control purposes following the visit. Site visit information and quality control of the observed data for each tower are described in detail within the following sections.

	M2196	**M2202**	**M2311**	**M2313**
Latitude	39.11318°	39.13467°	39.08518°	39.07764°
Longitude	-103.23440°	-103.18216°	-103.21049°	-103.23864°
Time Series Start	2008-Jun-03	2008-Jun-03	2010-Oct-05	2010-Oct-07
Time Series End	2013-May-09*	2013-May-28*	2013-May-18	2013-Jan-09
Observed 20 m Wind Speed	6.91	6.84	6.91	7.05
Observed 40 m Wind Speed	7.88	7.81	7.90	7.95
Observed 59 m Wind Speed	8.51	8.23	–	–
Observed 60 m Wind Speed	–	–	8.53	8.54
Average Shear	0.18	0.17	0.19	0.17
Hub Height 80 m Wind Speed	9.01	8.68	9.03	8.99
Long-term 80 m Wind Speed	8.78	8.51	9.08	9.00
Long-term 80 m Adjustment Factor	97.4 %	98.0 %	100.6 %	100.1 %
Mean Turbulence Intensity (TI) 80 m	6.1 %	6.3 %	6.3 %	5.9 %
Characteristic TI 80 m	9.1 %	9.2 %	9.6 %	9.0 %

Table 2: On-site met tower summary. Hub height wind speeds are extrapolated unless there is a sensor at the hub height. Wind speed values shown above are in units of m/s. Mean and characteristic turbulence intensity are at $15\,m/s$.

* Summary statistics for M2196 and M2202 use time series end dates of 2010-Sep-22 and 2010-Sep-23, respectively, due to issues with data processing. Further details can be found in the quality control section for each met tower.

3.1 Tower M2196

The M2196 Tower is located at $39.11318^\circ\ N$, $103.2344^\circ\ W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located in the northwest part of the project area in a grassy field. The tower has instrumentation up to $59\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 3. An image of the terrain surrounding the M2196 Tower is shown in Figure 2.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	59	223°	85.9 %
Anemometer	59	42°	44.0 %
Anemometer	40	222°	86.0 %
Anemometer	40	40°	84.1 %
Anemometer	20	222°	85.8 %
Anemometer	20	43°	84.3 %
Wind Vane	57	223°	96.0 %
Wind Vane	18	222°	96.0 %

Table 3: M2196 Tower instrumentation.

Figure 2: Panoramic view from the base of the M2196 Tower.

3.1.1 Quality Control

The observed data at the M2196 Tower were quality controlled to check for instrument malfunction and tower shadow. The period of data for the tower spans from June 3, 2008 - May 9, 2013. A 40° offset was applied to the wind direction data to align with expected tower shadow regions. The sensors were replaced on March 19, 2009 and on September 22, 1010. The first two tower configurations utilized Second Wind C3 anemometers, while the last configuration after September 22, 2010 utilized a combination of Thies First Class anemometers and NRG #40C anemometers. There was not adequate documentation to determine the correct calibration transfer functions that should be applied for the configuration after September 22, 2010. Because of this, there were consistency issues with the processed Thies and NRG anemometer data during this period that could not be resolved. Therefore, data after September 22, 2010 were not used in the analysis. The $59\,m$ anemometer oriented at 42° failed from August 17, 2009 - September 23, 2010 and from May 27, 2012 through the end of the data record. The $20\,m$ anemometer oriented at 222° failed from May 25, 2012 through the end of the data record. There were a number of intermittent periods of icing affecting the anemometer data throughout the data record, leading to approximately 5% data loss. The selectively averaged wind speed data recovery rate at $59\,m$ was 90.9%.

3.1.2 Shear Extrapolation

Observed anemometer data from M2196 were used for extrapolating top sensor level wind speed data to 80 m hub height level. A 12-by-24 table, see Figure 3 below, was developed based on observed data from the anemometers at all of the available sensor levels. These shear exponent values were then applied to the observed data using the power law extrapolation method to calculate wind speed values at 80 m.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	0.30	0.27	0.24	0.23	0.23	0.27	0.27	0.26	0.26	0.20	0.24	0.21	0.25
1	0.30	0.27	0.24	0.23	0.24	0.26	0.27	0.25	0.26	0.20	0.24	0.21	0.25
2	0.30	0.26	0.24	0.23	0.25	0.26	0.27	0.25	0.26	0.19	0.24	0.22	0.25
3	0.30	0.26	0.24	0.24	0.25	0.25	0.26	0.24	0.25	0.19	0.24	0.23	0.25
4	0.30	0.26	0.24	0.24	0.23	0.24	0.25	0.24	0.24	0.19	0.24	0.23	0.24
5	0.29	0.26	0.24	0.22	0.21	0.21	0.23	0.23	0.23	0.19	0.24	0.24	0.23
6	0.29	0.26	0.23	0.19	0.16	0.15	0.18	0.19	0.20	0.19	0.24	0.25	0.21
7	0.26	0.24	0.20	0.14	0.11	0.10	0.12	0.13	0.14	0.17	0.22	0.24	0.17
8	0.21	0.18	0.15	0.10	0.08	0.08	0.08	0.09	0.10	0.13	0.18	0.21	0.13
9	0.15	0.12	0.11	0.09	0.08	0.07	0.07	0.07	0.08	0.10	0.12	0.16	0.10
10	0.11	0.08	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.08	0.09	0.11	0.08
11	0.09	0.07	0.08	0.08	0.08	0.07	0.07	0.07	0.08	0.08	0.07	0.09	0.08
12	0.08	0.07	0.08	0.08	0.08	0.08	0.07	0.07	0.08	0.07	0.07	0.08	0.08
13	0.08	0.07	0.08	0.09	0.08	0.08	0.08	0.07	0.08	0.08	0.08	0.09	0.08
14	0.09	0.08	0.08	0.09	0.08	0.09	0.08	0.08	0.08	0.09	0.10	0.11	0.09
15	0.12	0.11	0.09	0.10	0.09	0.10	0.10	0.10	0.10	0.11	0.13	0.15	0.11
16	0.16	0.16	0.13	0.12	0.11	0.12	0.12	0.12	0.14	0.15	0.17	0.19	0.14
17	0.19	0.22	0.18	0.15	0.14	0.15	0.15	0.17	0.19	0.19	0.20	0.22	0.18
18	0.22	0.26	0.23	0.20	0.18	0.20	0.20	0.21	0.25	0.22	0.22	0.23	0.22
19	0.24	0.27	0.25	0.23	0.22	0.25	0.24	0.25	0.28	0.23	0.23	0.24	0.24
20	0.25	0.27	0.26	0.24	0.23	0.28	0.26	0.26	0.29	0.23	0.24	0.24	0.25
21	0.27	0.26	0.25	0.24	0.23	0.29	0.27	0.26	0.28	0.23	0.25	0.24	0.26
22	0.28	0.26	0.25	0.23	0.23	0.28	0.27	0.26	0.28	0.22	0.25	0.24	0.25
23	0.29	0.27	0.24	0.23	0.23	0.27	0.27	0.26	0.27	0.21	0.25	0.22	0.25
Avg	0.21	0.20	0.18	0.17	0.16	0.18	0.18	0.18	0.19	0.16	0.19	0.19	0.18

Figure 3: Shear exponent values for the M2196 Tower.

3.2 Tower M2202

The M2202 Tower is located at $39.13467° N$, $103.18216° W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located in the northern part of the project area in a grassy field. The tower has instrumentation up to $59\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 4. An image of the terrain surrounding the M2202 Tower is shown in Figure 4.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	59	222°	46.1 %
Anemometer	59	43°	70.1 %
Anemometer	40	222°	75.4 %
Anemometer	40	43°	54.4 %
Anemometer	20	222°	87.5 %
Anemometer	20	44°	85.6 %
Wind Vane	57	222	95.7 %
Wind Vane	18	222	95.7 %

Table 4: M2202 Tower instrumentation.

Figure 4: Panoramic view from the base of the M2202 Tower.

3.2.1 Quality Control

The observed data at the M2202 Tower were quality controlled to check for instrument malfunction and tower shadow. The period of data for the tower spans from June 3, 2008 - May 28, 2013. A 40° offset was applied to the wind direction data to align with expected tower shadow regions. The sensors were replaced on June 10, 2009 and on September 23, 1010. The first two tower configurations utilized Second Wind C3 anemometers, while the last configuration after September 23, 2010 utilized a combination of Thies First Class anemometers and NRG #40C anemometers. There was not adequate documentation to determine the correct calibration transfer functions that should be applied for the configuration after September 23, 2010. Because of this, there were consistency issues with the processed Thies and NRG anemometer data during this period that could not be resolved. Therefore, data after September 23, 2010 were not used in the analysis. There were numerous anemometer failures affecting the data recovery rate. The $59\,m$ anemometer oriented at 222° failed from July 8, 2008 - July 11, 2009 and from July 1, 2010 - September 23, 2010. The $59\,m$ anemometer oriented at 43° failed from May 10, 2010 - September 23, 2010 and from May 1, 2010 - May 28, 2013. The $40\,m$ anemometer oriented at 43° failed from August 4, 2008 - June 11, 2009. The $40\,m$ anemometer oriented at 222° failed from June 1, 2010 - September 23, 2013. There were a number of intermittent periods of icing affecting the anemometer data throughout the data record, leading to approximately 4% data loss. The selectively averaged wind speed data recovery rate at $59\,m$ was 83.4%.

3.2.2 Shear Extrapolation

Observed anemometer data from M2202 were used for extrapolating top sensor level wind speed data to $80\,m$ hub height level. A 12-by-24 table, see Figure 5 below, was developed based on observed data from the anemometers at all of the available sensor levels. These shear exponent values were then applied to the observed data using the power law extrapolation method to calculate wind speed values at $80\,m$.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	0.26	0.25	0.22	0.22	0.21	0.27	0.29	0.25	0.28	0.20	0.23	0.18	0.24
1	0.26	0.24	0.22	0.21	0.22	0.27	0.29	0.25	0.27	0.19	0.22	0.17	0.23
2	0.26	0.24	0.22	0.21	0.22	0.26	0.28	0.25	0.26	0.19	0.21	0.17	0.23
3	0.25	0.24	0.22	0.22	0.22	0.26	0.27	0.24	0.26	0.19	0.22	0.18	0.23
4	0.25	0.24	0.21	0.22	0.21	0.24	0.26	0.24	0.25	0.19	0.22	0.19	0.23
5	0.25	0.25	0.20	0.20	0.17	0.20	0.22	0.22	0.24	0.20	0.22	0.20	0.21
6	0.25	0.25	0.18	0.16	0.12	0.14	0.16	0.17	0.20	0.19	0.21	0.22	0.19
7	0.23	0.23	0.16	0.11	0.08	0.09	0.09	0.11	0.14	0.16	0.19	0.21	0.15
8	0.18	0.17	0.12	0.07	0.06	0.07	0.06	0.07	0.09	0.12	0.16	0.18	0.11
9	0.13	0.11	0.08	0.06	0.05	0.06	0.05	0.06	0.07	0.10	0.11	0.12	0.08
10	0.09	0.07	0.07	0.06	0.05	0.06	0.05	0.06	0.07	0.08	0.08	0.09	0.07
11	0.07	0.06	0.06	0.06	0.05	0.06	0.05	0.06	0.07	0.07	0.07	0.07	0.06
12	0.07	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.06
13	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.08	0.08	0.07
14	0.08	0.07	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.08	0.10	0.10	0.07
15	0.11	0.10	0.07	0.07	0.07	0.08	0.07	0.08	0.09	0.11	0.14	0.14	0.09
16	0.15	0.15	0.11	0.08	0.08	0.10	0.09	0.11	0.14	0.16	0.19	0.18	0.13
17	0.19	0.22	0.16	0.12	0.12	0.13	0.13	0.15	0.21	0.21	0.22	0.21	0.17
18	0.22	0.26	0.21	0.17	0.16	0.19	0.18	0.21	0.28	0.24	0.24	0.22	0.22
19	0.23	0.28	0.24	0.21	0.20	0.25	0.24	0.25	0.31	0.26	0.25	0.23	0.24
20	0.23	0.27	0.25	0.22	0.21	0.28	0.27	0.27	0.32	0.26	0.25	0.23	0.26
21	0.24	0.26	0.24	0.23	0.22	0.29	0.28	0.26	0.32	0.25	0.25	0.23	0.26
22	0.24	0.26	0.24	0.22	0.22	0.28	0.28	0.26	0.31	0.23	0.24	0.22	0.25
23	0.25	0.26	0.23	0.22	0.22	0.27	0.28	0.25	0.30	0.21	0.23	0.20	0.24
Avg	0.19	0.19	0.16	0.15	0.14	0.17	0.17	0.17	0.19	0.17	0.18	0.17	0.17

Figure 5: Shear exponent values for the M2202 Tower.

3.3 Tower M2311

The M2311 Tower is located at $39.08518° N$, $103.21049° W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located in a grassy field within the proposed turbine array. The tower has instrumentation up to $60\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 5. An image of the terrain surrounding the M2311 Tower is shown in Figure 6.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	60	215°	61.8 %
Anemometer	60	37°	59.4 %
Anemometer	40	216°	61.8 %
Anemometer	40	36°	59.3 %
Anemometer	20	216°	61.8 %
Anemometer	20	38°	59.9 %
Wind Vane	58	215°	67.9 %
Wind Vane	19	216°	67.9 %

Table 5: M2311 Tower instrumentation.

Figure 6: Panoramic view from the base of the M2311 Tower.

3.3.1 Quality Control

The observed data at the M2311 Tower were quality controlled to check for instrument malfunction and tower shadow. The period of data for the tower spans from October 6, 2010 - May 18, 2013. Data were processed using provided calibrated transfer functions. A 30° offset was applied to the wind direction data to align with expected tower shadow regions. The logger had failures from June 23 - 27, 2011, July 4 - 24, 2011 and from June 3, 2012 - January 9, 2013. There were a number of intermittent periods of icing affecting the anemometer data throughout the data record, leading to approximately 5% data loss. The selectively averaged wind speed data recovery rate at $60\,m$ was 68.3%.

3.3.2 Shear Extrapolation

Observed anemometer data from M2311 were used for extrapolating top sensor level wind speed data to 80 m hub height level. A 12-by-24 table, see Figure 7 below, was developed based on observed data from the anemometers at all of the available sensor levels. These shear exponent values were then applied to the observed data using the power law extrapolation method to calculate wind speed values at 80 m.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	0.25	0.26	0.27	0.24	0.25	0.27	0.27	0.23	0.23	0.27	0.25	0.25	0.25
1	0.25	0.25	0.27	0.24	0.24	0.25	0.27	0.22	0.22	0.26	0.25	0.27	0.25
2	0.25	0.24	0.26	0.24	0.23	0.24	0.25	0.22	0.22	0.25	0.25	0.27	0.24
3	0.24	0.24	0.26	0.24	0.23	0.24	0.22	0.22	0.24	0.25	0.24	0.27	0.24
4	0.24	0.23	0.27	0.23	0.21	0.23	0.19	0.22	0.25	0.25	0.24	0.25	0.23
5	0.24	0.23	0.26	0.20	0.17	0.19	0.15	0.19	0.23	0.24	0.24	0.24	0.22
6	0.24	0.21	0.22	0.15	0.12	0.13	0.10	0.14	0.17	0.20	0.23	0.23	0.18
7	0.22	0.18	0.16	0.10	0.09	0.10	0.08	0.10	0.12	0.15	0.19	0.22	0.14
8	0.17	0.13	0.11	0.08	0.08	0.08	0.07	0.08	0.09	0.10	0.14	0.17	0.11
9	0.13	0.10	0.08	0.08	0.08	0.08	0.07	0.07	0.08	0.09	0.10	0.13	0.09
10	0.10	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.08	0.09	0.09	0.10	0.09
11	0.09	0.09	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.09	0.09	0.09	0.08
12	0.09	0.09	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.10	0.10	0.10	0.09
13	0.10	0.09	0.09	0.09	0.09	0.10	0.08	0.08	0.08	0.11	0.11	0.12	0.09
14	0.13	0.11	0.10	0.09	0.09	0.11	0.09	0.09	0.09	0.13	0.15	0.16	0.11
15	0.17	0.15	0.13	0.11	0.11	0.13	0.11	0.11	0.12	0.18	0.21	0.20	0.14
16	0.20	0.20	0.18	0.15	0.14	0.17	0.15	0.16	0.18	0.23	0.25	0.23	0.19
17	0.22	0.24	0.24	0.19	0.19	0.21	0.21	0.23	0.23	0.27	0.27	0.25	0.23
18	0.23	0.27	0.28	0.23	0.23	0.25	0.27	0.29	0.27	0.29	0.27	0.25	0.26
19	0.23	0.27	0.30	0.25	0.26	0.28	0.29	0.31	0.29	0.29	0.26	0.24	0.27
20	0.23	0.27	0.30	0.25	0.27	0.28	0.30	0.32	0.29	0.29	0.26	0.23	0.27
21	0.23	0.27	0.28	0.25	0.26	0.28	0.31	0.31	0.28	0.29	0.26	0.22	0.27
22	0.24	0.27	0.27	0.25	0.26	0.28	0.30	0.29	0.27	0.28	0.26	0.23	0.27
23	0.24	0.26	0.27	0.24	0.26	0.28	0.28	0.26	0.25	0.27	0.25	0.24	0.26
Avg	0.20	0.20	0.20	0.17	0.17	0.19	0.18	0.18	0.19	0.21	0.21	0.21	0.19

Figure 7: Shear exponent values for the M2311 Tower.

3.4 Tower M2313

The M2313 Tower is located at $39.07764° N$, $103.23864° W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located in a grassy field on the western border of the project area. The tower has instrumentation up to $60\,m$, with anemometers at three heights and wind vanes at one heights. A summary of instruments installed on the tower is shown in Table 6. An image of the terrain surrounding the M2313 Tower is shown in Figure 8.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	60	217°	57.0 %
Anemometer	60	37°	55.1 %
Anemometer	40	217°	56.5 %
Anemometer	40	36°	54.2 %
Anemometer	20	217°	55.5 %
Anemometer	20	37°	51.2 %
Wind Vane	58	217°	63.4 %

Table 6: M2313 Tower instrumentation.

Figure 8: Panoramic view from the base of the M2313 Tower.

3.4.1 Quality Control

The observed data at the M2313 Tower were quality controlled to check for instrument malfunction and tower shadow. The period of data for the tower spans from October 7, 2010 - January 9, 2013. Data were processed using provided calibrated transfer functions. A $35°$ offset was applied to the wind direction data to align with expected tower shadow regions. Provided documentation indicates a wind vane at $18.5\,m$. However, measurements for this wind vane are not present in the provided raw data. Raw data for the period of November 27, 2010 - August 23, 2011 were not provided by the client. There were a number of intermittent periods of icing affecting the anemometer data throughout the data record, leading to approximately 3.5% data loss. The selectively averaged wind speed data recovery rate at $60\,m$ was 63.4%.

3.4.2 Shear Extrapolation

Observed anemometer data from M2313 were used for extrapolating top sensor level wind speed data to 80 m hub height level. A 12-by-24 table, see Figure 9 below, was developed based on observed data from the anemometers at all of the available sensor levels. These shear exponent values were then applied to the observed data using the power law extrapolation method to calculate wind speed values at 80 m.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	0.26	0.26	0.27	0.22	0.23	0.26	0.25	0.25	0.20	0.24	0.25	0.26	0.25
1	0.25	0.27	0.26	0.21	0.21	0.25	0.23	0.23	0.20	0.24	0.25	0.26	0.24
2	0.24	0.27	0.26	0.20	0.20	0.23	0.22	0.23	0.20	0.24	0.24	0.25	0.23
3	0.23	0.26	0.26	0.20	0.19	0.21	0.19	0.24	0.20	0.24	0.24	0.24	0.23
4	0.23	0.25	0.26	0.20	0.18	0.19	0.17	0.23	0.20	0.23	0.25	0.23	0.22
5	0.24	0.23	0.25	0.17	0.14	0.15	0.13	0.19	0.19	0.21	0.24	0.23	0.20
6	0.23	0.20	0.21	0.13	0.10	0.11	0.08	0.13	0.15	0.17	0.23	0.22	0.16
7	0.21	0.15	0.14	0.09	0.07	0.08	0.05	0.08	0.10	0.12	0.18	0.20	0.12
8	0.16	0.11	0.09	0.07	0.06	0.07	0.05	0.06	0.07	0.08	0.12	0.17	0.09
9	0.11	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.06	0.07	0.08	0.12	0.07
10	0.08	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.09	0.07
11	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06
12	0.07	0.07	0.07	0.07	0.06	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.07
13	0.08	0.07	0.07	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.08	0.09	0.07
14	0.11	0.09	0.08	0.08	0.07	0.08	0.07	0.07	0.08	0.10	0.12	0.12	0.09
15	0.15	0.12	0.10	0.10	0.08	0.10	0.09	0.09	0.10	0.14	0.17	0.17	0.12
16	0.19	0.16	0.16	0.14	0.11	0.12	0.11	0.13	0.15	0.18	0.22	0.21	0.16
17	0.22	0.20	0.23	0.19	0.16	0.17	0.16	0.19	0.20	0.22	0.24	0.23	0.20
18	0.23	0.23	0.28	0.23	0.21	0.21	0.21	0.23	0.23	0.24	0.26	0.24	0.23
19	0.24	0.25	0.30	0.25	0.24	0.24	0.24	0.25	0.23	0.25	0.26	0.23	0.25
20	0.25	0.26	0.31	0.25	0.24	0.25	0.26	0.27	0.23	0.24	0.26	0.23	0.25
21	0.25	0.27	0.30	0.24	0.23	0.25	0.26	0.27	0.23	0.23	0.26	0.24	0.25
22	0.25	0.27	0.28	0.24	0.23	0.25	0.26	0.27	0.22	0.23	0.26	0.24	0.25
23	0.26	0.27	0.28	0.23	0.23	0.26	0.25	0.26	0.21	0.23	0.25	0.25	0.25
Avg	0.19	0.19	0.19	0.16	0.15	0.16	0.15	0.17	0.15	0.17	0.19	0.19	0.17

Figure 9: Shear exponent values for the M2313 Tower.

4 LONG-TERM REFERENCE

In order to put the short-term observational data into the climatological context, 3TIER performed a review of several long term climate data sources. 3TIER primarily relies on global reanalysis data sets for understanding long-term climate variability. The reanalysis data sets are derived from thousands of global observations, including ground based weather stations, ocean surface buoys, satellites, and weather balloons.

3TIER analyzed three major reanalysis data sets that are each produced independently by various institutions. Each data set offers an independent view of the climate, and 3TIER will consider each in determining the most appropriate data set. The statistics relating each met tower to the reanalysis data sets reviewed are shown below in Table 7, including the daily-mean explained variance, long-term climate adjustment, and considered start year statistics. Figure 10 shows the annual-mean wind speed values extracted from each reanalysis data set across the period of record. Each time series shown in Figure 10 has been MOS-corrected using the observed data at Tower M2313.

Tower	Data Set	Explained Variance (R^2)	Climate Adjustment	Start Year
M2196	MERRA	77.7%	97.0%	1999
M2196	NCEP/NCAR	54.9%	97.8%	1980
M2196	ECMWF ERA-I	78.8%	97.3%	1980
M2202	MERRA	79.1%	97.7%	1999
M2202	NCEP/NCAR	59.1%	98.3%	1980
M2202	ECMWF ERA-I	78.9%	98.2%	1980
M2311	MERRA	78.0%	101.0%	2002
M2311	NCEP/NCAR	55.6%	100.1%	1980
M2311	ECMWF ERA-I	77.9%	100.3%	1980
M2313	MERRA	80.1%	99.6%	1999
M2313	NCEP/NCAR	59.4%	100.1%	1980
M2313	ECMWF ERA-I	80.0%	99.9%	1980

Table 7: Daily explained variance and long-term climate adjustment values for the considered reanalysis data sets.

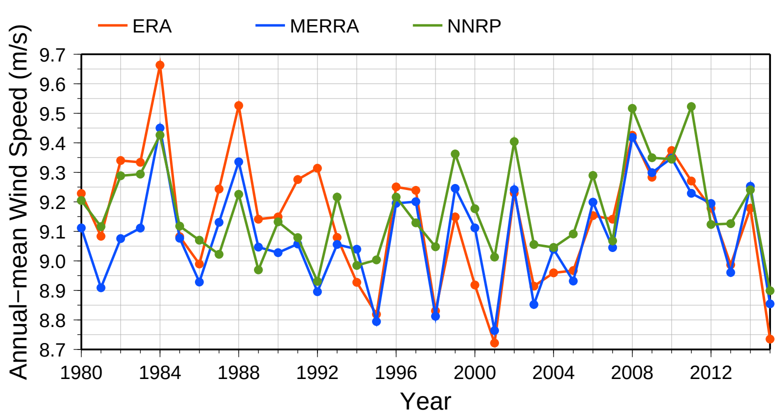

Figure 10: Time series of annual-mean wind speed data for each considered reanalysis data set.

5 GROSS GENERATION

5.1 Wind Resource Variability

This section provides an analysis of the MOS-corrected model-simulated project-average wind resource at hub height. To generate the project-average wind resource time series, MOS-corrected wind resource time series data are extracted at each turbine location at the appropriate height ($80\,m$) and then averaged across all 126 turbine locations.

Based on the results of 3TIER's Energy Risk Framework, the last 36 years (January, 1980 – December, 2015) of data have been utilized for estimating the expected future generation at Rush Creek II. The long-term mean project-average wind speed at hub height is $\mathbf{8.83}\,\boldsymbol{m/s}$. A map of the 36-year average wind speed values at $80\,m$ is displayed in Figure 1. Gross wind speed values and average density values at each of the 126 turbine locations are provided in Appendix Turbine Means. The project-average density value at hub height is $1.019\,kg/m^3$.

The distribution of hourly MOS-corrected project-average wind speed values is shown below in Figure 11. The distribution is based on the 36 years of modeled data. The annual wind rose is shown in Figure 12. Figure 13 displays the time series of gross project-average annual-mean wind speed values. Tables 14 and 15 shown on the following pages contain tabular-formatted month-hour and monthly-mean wind speed values, respectively. Table 14, often referred to as a '12x24' table, shows the average diurnal profile of wind speed values for each month of the calendar year. Table 15 shows the monthly-mean wind speed value for each month of the 36-year analysis period. Annual-mean wind speed values are also displayed in the right-most column of data in Table 15. Additional analysis of the long-term variability is available in Project-average Long-term Wind Resource Assessment.

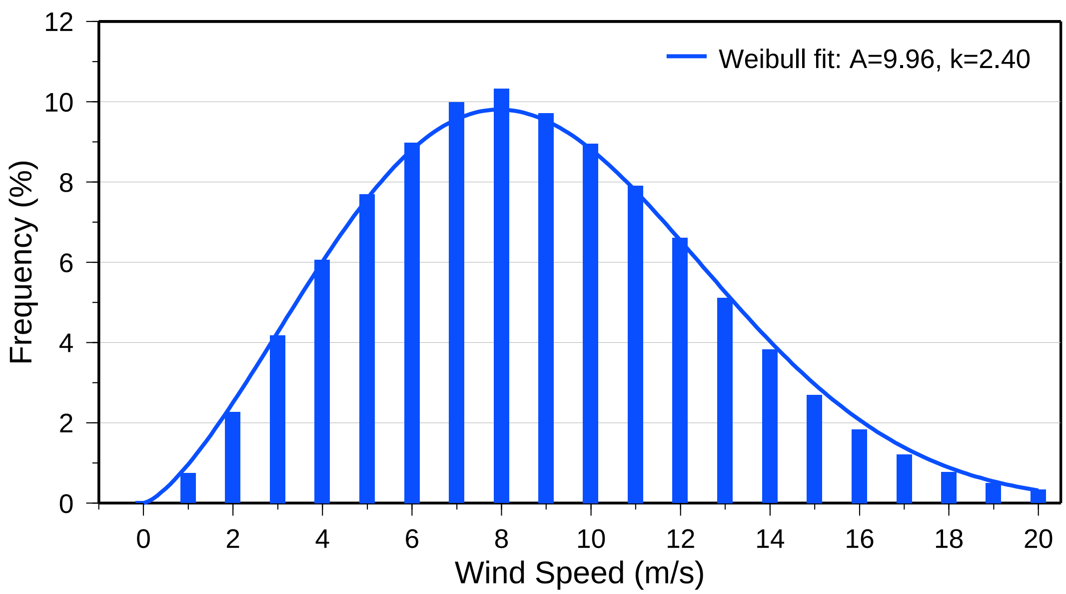

Figure 11: Hourly distribution of simulated project-average wind speed using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5.) Weibull distribution is also shown with the scale (A) and shape (k) parameters listed in the legend.

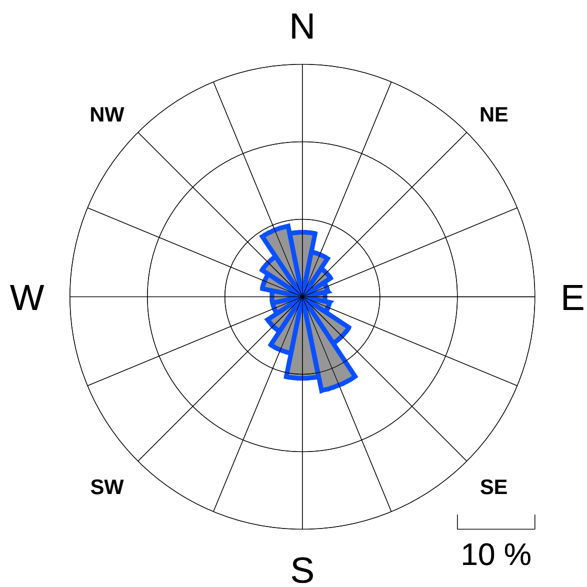

Figure 12: Annual wind rose of the hourly-mean project-average wind direction time series. Directional bins are 22.5° wide, and the radial contour interval is 10%.

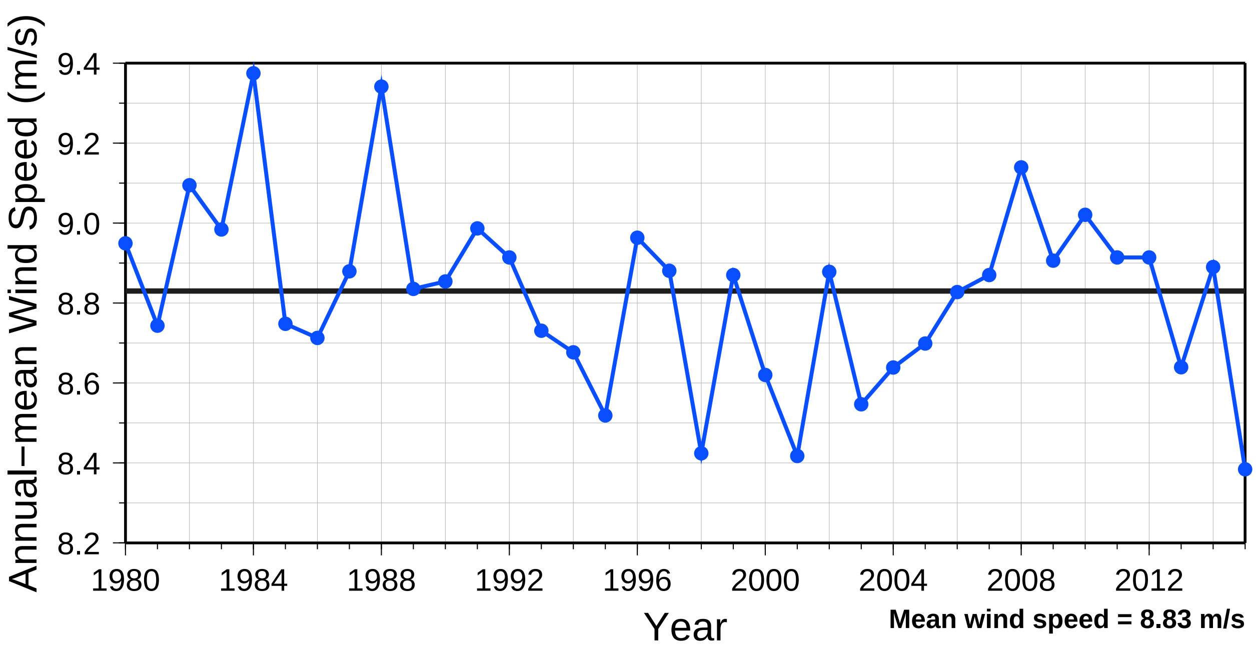

Figure 13: Time series of annual-mean project-average wind speed. Black line denotes the long-term mean.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.65	9.39	9.58	10.18	9.75	9.92	9.61	8.89	9.58	9.46	9.60	9.17	9.56
1	9.52	9.30	9.58	10.22	9.57	9.72	9.38	8.61	9.30	9.49	9.62	9.15	9.45
2	9.34	9.22	9.77	10.50	9.36	9.39	9.01	8.28	9.07	9.41	9.46	9.17	9.33
3	9.31	9.11	9.78	10.34	9.09	8.98	8.56	8.13	8.89	9.23	9.30	9.20	9.16
4	9.29	8.92	9.56	9.91	8.80	8.66	8.08	8.04	8.89	9.22	9.10	9.13	8.97
5	9.34	8.97	9.58	9.65	8.53	8.23	7.77	7.67	8.62	8.85	8.96	9.32	8.79
6	9.58	9.00	9.53	9.63	7.80	7.54	7.08	7.23	8.39	8.55	8.94	9.50	8.56
7	9.52	8.90	9.22	9.15	7.34	7.17	6.22	6.42	7.40	8.12	8.79	9.66	8.15
8	9.06	8.59	8.78	8.82	7.57	7.28	6.18	6.26	6.90	7.72	8.38	9.19	7.89
9	8.48	8.20	8.82	9.06	7.88	7.31	6.31	6.39	6.99	7.63	8.06	8.35	7.79
10	8.46	8.34	8.92	9.12	7.99	7.34	6.30	6.52	7.01	7.90	7.94	8.28	7.84
11	8.43	8.34	8.93	9.14	8.16	7.27	6.25	6.46	6.87	7.96	7.93	8.23	7.83
12	8.16	8.18	8.95	9.29	8.26	7.22	6.17	6.40	6.96	7.98	7.93	8.11	7.80
13	7.82	8.02	8.93	9.33	8.25	7.37	6.35	6.46	6.92	8.02	8.06	7.97	7.79
14	7.95	8.20	8.97	9.60	8.59	7.70	6.82	6.64	7.03	8.12	8.15	7.83	7.96
15	7.98	8.36	9.14	9.87	9.50	8.56	7.24	7.18	7.39	8.31	8.16	7.77	8.29
16	8.07	8.34	9.14	10.18	9.70	9.25	8.10	7.86	7.99	8.71	8.53	8.13	8.67
17	8.52	8.54	9.37	10.21	10.30	9.32	8.77	8.87	8.56	9.05	9.37	8.88	9.15
18	9.12	9.12	9.90	10.05	10.36	9.90	9.36	9.50	9.49	9.36	9.64	9.23	9.59
19	9.16	9.43	10.17	10.47	10.61	10.18	9.86	10.19	10.16	9.70	9.76	9.35	9.92
20	9.06	9.29	10.23	10.63	10.40	10.57	10.03	10.21	10.25	9.63	9.68	9.31	9.94
21	9.26	9.21	10.24	10.40	10.13	10.33	10.31	10.15	10.27	9.44	9.64	9.48	9.91
22	9.54	9.28	10.02	10.39	10.13	10.38	10.14	9.65	10.08	9.53	9.55	9.51	9.85
23	9.59	9.38	9.86	10.32	9.85	10.26	9.84	9.19	9.75	9.38	9.50	9.33	9.69
Avg	8.93	8.82	9.46	9.85	9.08	8.74	8.07	7.97	8.45	8.78	8.92	8.89	8.83

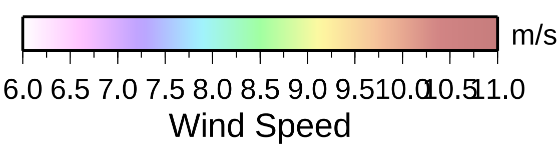

Figure 14: Hourly-mean values of simulated project-average wind speed. Vertical axis is local time.

Year	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
1980	9.64	8.23	10.76	9.53	9.18	9.05	7.96	8.79	8.92	8.33	8.05	8.91	8.95
1981	8.31	9.03	9.27	9.20	9.77	8.59	8.46	7.58	8.11	8.87	9.02	8.75	8.74
1982	9.92	8.82	9.61	10.41	8.60	8.89	8.26	7.60	8.52	9.74	8.78	9.97	9.09
1983	9.40	8.82	9.65	9.86	9.29	7.68	8.87	7.78	8.90	8.32	9.92	9.32	8.98
1984	8.91	10.93	10.01	11.56	9.23	9.26	8.53	8.18	8.51	8.91	9.76	8.86	9.37
1985	8.72	8.16	9.97	9.44	8.57	8.42	7.84	8.43	9.16	8.64	8.46	9.13	8.75
1986	9.03	8.29	9.03	10.23	8.68	8.55	8.42	8.52	8.79	8.78	8.66	7.56	8.71
1987	9.96	8.70	10.96	9.62	8.43	8.95	9.19	8.10	6.79	7.84	8.95	9.00	8.88
1988	9.86	8.82	10.65	9.79	11.39	8.73	8.28	8.84	8.87	8.24	9.65	8.94	9.34
1989	8.74	8.00	9.54	8.92	9.42	9.17	8.93	8.47	8.71	8.77	8.72	8.56	8.84
1990	9.67	8.78	8.64	9.33	9.45	9.55	7.92	7.73	8.51	8.62	9.24	8.85	8.85
1991	8.44	8.66	10.25	9.14	10.71	10.09	7.64	8.24	8.67	8.35	9.18	8.46	8.99
1992	10.25	8.65	8.80	9.08	9.35	8.47	7.93	7.96	9.07	8.53	9.38	9.49	8.91
1993	8.71	8.06	9.73	9.76	8.25	9.05	8.82	7.80	8.26	8.03	8.75	9.50	8.73
1994	8.89	9.05	8.93	9.03	9.11	8.22	7.79	8.09	8.16	8.77	9.93	8.20	8.68
1995	8.30	8.63	9.20	8.80	9.37	8.70	8.01	7.60	8.00	9.26	8.43	7.91	8.52
1996	9.43	9.06	9.82	10.11	9.18	8.19	7.65	7.69	8.60	9.26	9.02	9.54	8.96
1997	8.89	9.14	9.36	9.46	8.48	8.80	8.54	6.88	7.87	10.43	9.11	9.63	8.88
1998	7.99	8.68	9.18	9.09	8.57	9.10	7.28	7.57	8.52	8.54	8.40	8.23	8.42
1999	8.93	9.83	9.78	10.53	9.38	8.81	8.11	7.42	7.74	8.51	7.84	9.63	8.87
2000	7.98	8.74	8.88	10.35	9.00	9.00	7.84	7.13	8.56	8.43	8.58	9.02	8.62
2001	8.83	8.16	7.84	10.05	8.37	8.34	7.56	7.99	8.21	8.62	8.46	8.60	8.42
2002	8.89	9.86	9.05	9.49	9.38	9.14	8.57	9.07	8.97	8.43	8.43	7.37	8.88
2003	8.47	7.60	8.97	10.31	8.47	7.94	7.92	8.05	8.31	8.37	8.81	9.28	8.55
2004	7.76	9.16	9.37	9.05	8.99	8.38	7.21	7.73	9.50	9.24	9.14	8.22	8.64
2005	8.29	7.31	9.17	10.59	8.43	8.90	9.01	7.35	8.32	8.29	10.15	8.54	8.70
2006	9.42	9.02	10.54	10.14	8.01	8.44	7.75	7.86	7.76	8.79	8.59	9.60	8.83
2007	8.82	8.77	9.06	9.38	8.60	9.10	7.87	8.01	9.31	9.89	8.26	9.39	8.87
2008	9.19	9.11	8.84	10.68	10.33	8.16	8.06	8.74	8.44	9.26	9.33	9.54	9.14
2009	9.78	8.87	9.86	10.48	8.58	7.69	7.44	8.29	8.63	9.45	8.44	9.34	8.91
2010	7.52	7.70	9.87	10.78	10.46	9.23	8.35	8.60	8.97	8.88	9.33	8.50	9.02
2011	8.44	10.06	9.41	10.29	9.55	9.37	7.96	7.57	7.58	8.69	9.30	8.88	8.91
2012	9.23	9.77	9.40	10.23	8.73	9.68	8.08	8.53	7.88	8.63	8.10	8.77	8.91
2013	8.28	9.50	9.14	9.62	8.29	8.73	7.83	7.41	8.90	9.11	8.63	8.36	8.64
2014	9.56	8.72	9.63	11.06	8.82	8.98	7.58	7.14	8.53	8.66	9.55	8.52	8.89
2015	8.85	8.69	8.27	9.36	8.42	7.39	7.12	8.08	7.64	8.66	8.69	9.57	8.38
Avg	8.93	8.82	9.46	9.85	9.08	8.74	8.07	7.97	8.45	8.78	8.92	8.89	8.83

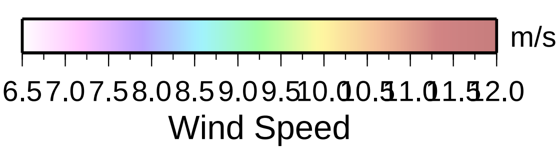

Figure 15: Monthly-mean values of simulated project-average wind speed.

5.2 Gross Generation Variability

Following WRF/TVM modeling and MOS correction, 36 years of hourly wind speed, wind direction, temperature, and pressure time series data were extracted for each proposed turbine location at hub height. The simulated temperature and pressure data are used to normalize simulated wind speed data to the power curve's reference density with the equation

$$V_{norm} = V\left(\left(\frac{\rho}{\rho_0}\right)^{1/3}\right)$$

where V_{norm} is normalized hourly wind speed at hub height, V is simulated hourly wind speed at hub height, ρ is density calculated from simulated hourly temperature and pressure at hub height using the Ideal Gas Law, and ρ_0 is the reference density of the power curve.

The turbine power curve is then applied to the normalized wind speed data using piecewise linear interpolation between the power curve points supplied by the manufacturer. Turbine specific cut-in and cut-out limits on wind speed are also applied. This allows the manufacturer's power curve to be applied to the wind speed time series to calculate gross expected energy for all proposed turbine locations for each hour over the past 36 years.

Computing the nameplate capacity factor at each turbine and then averaging across all 126 turbines yields the project-wide gross capacity factor value. A turbine-by-turbine gross energy estimate is calculated by multiplying the nameplate capacity factor at each turbine by the turbine-specific nameplate capacity, and by 8766 hours. Averaging these across all 126 turbines yields the project-average gross energy estimate.

Based on the results of 3TIER's Energy Risk Framework, the last 36 years (January, 1980 – December, 2015) of data have been utilized for estimating the expected future generation at Rush Creek II. The 36-year long-term mean gross energy estimate at the proposed Rush Creek II project is **1321.0 GWh**. Figure 16 below shows the time series of gross project-average annual-mean energy values. Gross energy values at each of the 126 turbine locations are provided in Appendix Turbine Means. Additional analysis of the long-term variability is available in Project-average Long-term Gross Power Capacity Assessment.

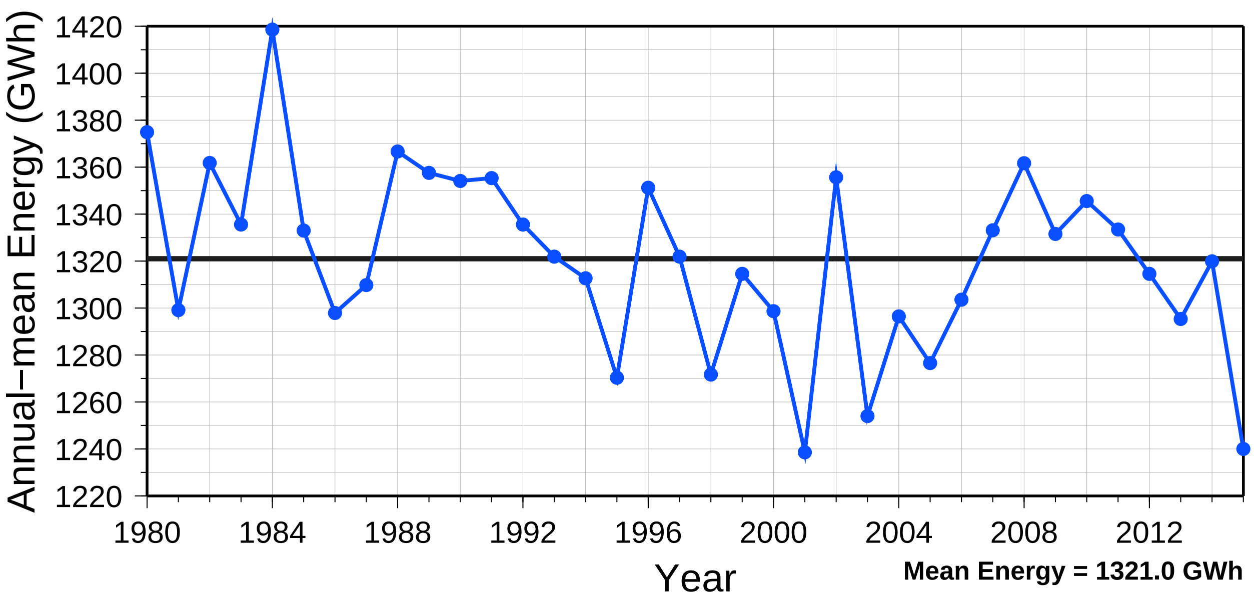

Figure 16: Time series of annual-mean project-average gross energy. Black line denotes the long-term mean.

5.3 Power Curves

It is expected that Vestas V110-2.0 wind turbines at a hub height of 80 m will be erected at the site. The Vestas V110-2.0 power curve is shown in Figure 17 and Table 8. The reference density for each power curve is shown in the caption of each respective Figure and Table below.

5.3.1 Vestas V110-2.0

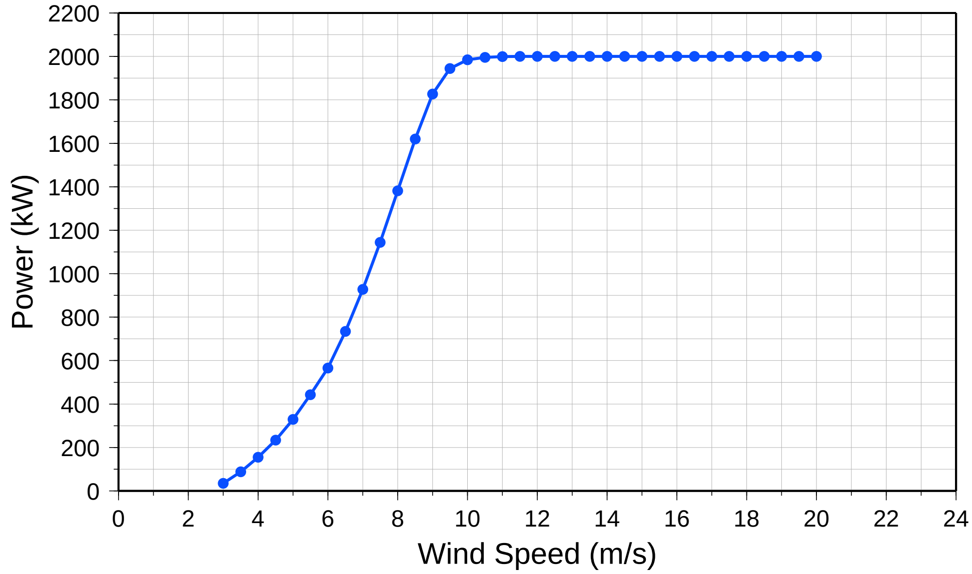

Figure 17: Power curve values for a Vestas V110-2.0 turbine with a reference density of 1.225 kg/m^3.

Wind Speed ($\frac{m}{s}$)	Power (kW)	Wind Speed ($\frac{m}{s}$)	Power (kW)	Wind Speed ($\frac{m}{s}$)	Power (kW)
3.0	35.0	9.0	1827.0	15.0	2000.0
3.5	88.0	9.5	1944.0	15.5	2000.0
4.0	155.0	10.0	1985.0	16.0	2000.0
4.5	234.0	10.5	1996.0	16.5	2000.0
5.0	329.0	11.0	1999.0	17.0	2000.0
5.5	443.0	11.5	2000.0	17.5	2000.0
6.0	566.0	12.0	2000.0	18.0	2000.0
6.5	734.0	12.5	2000.0	18.5	2000.0
7.0	928.0	13.0	2000.0	19.0	2000.0
7.5	1144.0	13.5	2000.0	19.5	2000.0
8.0	1381.0	14.0	2000.0	20.0	2000.0
8.5	1620.0	14.5	2000.0		

Table 8: Power curve values for a Vestas V110-2.0 turbine with a reference density of 1.225 kg/m^3.

6 LOSS FACTORS

To convert from expected gross generation to expected net generation, the following loss factor categories are considered: availability, curtailment, wake deficit, electrical efficiency, turbine efficiency, and environmental. Details for each loss factor are discussed below.

6.1 Availability

Availability losses include losses driven by turbine and transmission shutdowns caused by planned and unexpected faults.

6.1.1 Turbine Availability

3TIER has observed that turbine availability at newly constructed wind farms achieve 96.0% or higher availability when averaged over an entire calendar year. Therefore, the turbine availability loss factor is estimated to be **96.0%**.

6.1.2 Grid Availability

The ability of the electric grid to receive and transmit wind power to load centers varies by year, season and location. Issues with grid availability are very dynamic and may actually be worsened as wind penetration levels increase. Grid availability is expected to be high across the United States. 3TIER has assumed a regional grid availability loss factor of **99.5%** for the Rush Creek II wind energy project.

6.1.3 Balance of Plant Availability

The balance of the plant availability is based on a total of 24 hours of outage time per year per turbine for transformer inspections and maintenance. Therefore, the balance of plant availability loss factor is estimated to be **99.7%**.

6.2 Curtailment

Curtailment losses are based on forced wind plant shutdowns resulting from environmental conditions that can adversely effect the turbines. These curtailments include wind driven sector management, high wind hysteresis, extreme icing events, and extreme temperatures.

6.2.1 Sector Management

Standard minimum turbine spacing of three rotor diameters perpendicular to the dominant wind direction and five rotor diameters parallel to the dominant wind direction was tested against the layout. Turbine spacing perpendicular to the prevailing wind direction is less than three rotor diameters for a significant number of turbines. Due to the tight spacing, a sector management curtailment loss factor may apply, and the layout should be verified by the turbine manufacturer to ensure sector management is properly considered. A quantitative sector management loss calculation may be performed, once details of a sector loss algorithm (if required) are provided by the turbine manufacturer.

6.2.2 High Wind Hysteresis

High wind speed hysteresis loss potentially occurs after a turbine has shut down because of a high wind speed cut-out event. Before the turbine can re-start, the wind speed must slow down to the hysteresis cut-in wind speed. If wind speed values reduce to below the cut-out wind speed, but remain above the hysteresis cut-in wind speed, then hysteresis loss will occur. Based on 36 years of modeled hourly wind speed data, cut-out wind speed events are expected to periodically occur. The hysteresis loss factor associated with cut-out events is estimated to be **98.5%**.

6.2.3 Extreme Temperature

The Vestas V110-2.0 has an assumed operating temperature between $-20°C$ and $40°C$ without an additional cold weather package. 36 years of MOS-corrected temperature data were analyzed to determine the production losses due to the temperature constraints. Based on the potential power production during periods with temperatures outside the operating limits, and a total wind farm shutdown during these times, the extreme temperature loss factor is estimated to be **99.9%** due to extreme temperatures below $-20°C$.

6.2.4 Icing Shutdown

Observational data were inspected for significant icing events that may lead an operator to shutdown the wind farm. The observational data suggest a curtailment associated with icing events of **99.0%**.

6.3 Wake Deficit

3TIER's wake model is used to determine the expected wake deficit for the turbine layout. The magnitude of the losses at any given time is a combination of the gross wind field and ambient turbulence intensity across the park, the turbine layout, and physical characteristics of the installed turbines. 3TIER analyzes wakes using a proprietary time-varying wake model that analyzes the wake at every individual time within the simulated record, rather than relying on bulk statistical descriptions of the wind field. Wakes for each turbine are computed individually and interact in a physically consistent way, eliminating the need for posterior models to combine wakes from multiple turbines or add in deep-array effects. The single turbine wake model is based on concepts originally presented by Larsen et al. (1996). [6] 3TIER's internal research has shown that the low bias associated with other Larsen-derived wake models [9] is a result of poorly handled wake addition rather than the underlying model. The full system has been calibrated using production numbers from permanently installed turbines under a wide range of environmental conditions, including a broad span of turbulence intensities and stability regimes. The outputs from the model are wake-induced velocity deficit and turbulence intensity at all turbine locations, and can include additional reference locations.

6.3.1 Internal Wakes

Internal wakes represent wakes caused by turbines within the project. The effect of wake deficit on energy output for the layout leads to an internal wake loss factor of **92.7%**.

6.3.2 External Wakes

External wakes represent additional wakes caused by turbines from surrounding wind farms. Cedar Point and Limon (Phases 1, 2 and 3) Wind Farms are over 20 km to the northwest of the nearest Rush Creek II project wind turbine. 3TIER considered the distances between and positions of project turbines and surrounding turbines within the context of the local wind rose and determined the surrounding wind farms to be inconsequential.

6.3.3 Future Wakes

Future wakes represent wakes caused by turbines that will be built in the future, not related to this project. 3TIER utilized the Federal Aviation Administration's (FAA) Wind Turbine Build Out web tool to identify possible future developments in the region. 3TIER also directly searched the FAA's Obstruction Evaluation online database for relevant records of Determination of No Hazard to Air Navigation. The closest possible future project filed with the FAA is EDPR's Crossing Trails project in Kit Carson County, but it is over 20 km to the east and would have no impacts on the Rush Creek II Wind Farm. The terrain and expected wind resource immediately north and east, and to some extent to the south, are similar to that of Rush Creek II and could potentially be developed in the future. Such developments would have future wake impacts. However, because 3TIER is unaware of any future developments in the immediate area at this time, the future wakes loss factor is assumed to be **100%**.

6.3.4 Total Wakes

The total wake loss factor, including the project (i.e. internal) turbines, is **92.7%**. Waked generation values for each individual turbine are shown in Appendix Turbine Means.

6.4 Electrical Efficiency

Electrical efficiency considers losses associated with the electrical systems connecting the turbines to the metering point. These systems include the on-site collection system, the substation power transformer, and the transmission line depending on the meter location. 3TIER assumes the wind farm will be metered on the low side of the substation power transformer. Given this assumption, the electrical system efficiency is expected to be **98.0%**.

6.4.1 Collection System Efficiency

The collection system efficiency covers the efficiency of all components from the turbines to the pooling substation, including the medium voltage transformer efficiency that steps up the turbine voltage to the collection system voltage.

6.4.2 Substation Power Transformer Efficiency

The substation power transformer converts the voltage of the collection system to the voltage of the high voltage transmission line. This analysis ends at the low side of the substation transformer and does not consider substation power transformer losses. The client is undertaking a study to determine the full substation loss.

6.4.3 High Voltage Transmission Line Efficiency

Transmission line efficiency is dependent on the cable type, voltage, load, and the distance from the pooling substation to the plant metering point. The client has indicated that the export power will be delivered to a substation that is approximately 90 miles away which would incur additional high voltage transmission line losses. The client is undertaking a study to determine these added losses. 3TIER has not included an assumption for additional high voltage transmission line losses in this analysis.

6.4.4 Consumptive Power

Consumptive power considers the fact that a wind farm consumes electrical power when generation levels are very low. This is primarily due to power required to keep generators and transformers active and ready for operations. When the plant is operating, consumptive power is inherent to the turbine power curve and electrical efficiency assumptions. The client has specified that the wind farm will have a bidirectional meter and has requested that consumptive power of the wind farm be accounted for as an additional loss factor. 3TIER has assumed a loss factor of **99.5%** for consumptive power.

6.5 Turbine Efficiency

Turbine efficiency is based on the ability of the turbines to perform at a level relative to the manufacturer's suggested performance rating. This can be affected by many factors, including the manufacturer's warranted performance level, the turbulence, and inflow angle.

6.5.1 Turbine Performance

3TIER's experience with operating wind farms suggests a loss factor should be applied for turbine performance. This loss factor is related to turbines not performing at the manufacturer's rated power curve. The Vestas V110-2.0 is a relatively new turbine. Within the United States, there are 5 projects currently under construction with this model and a limited number of operating turbines. This turbine model is based on the Vestas V100-2.0, with a longer blade and new gear box. According to a database of installed turbines created by the American Wind Energy Association, there are 2,288 V100-2.0 turbines installed in the United States. Based on the lack operational history for the Vestas V110-2.0, 3TIER suggests that a turbine performance loss factor of **98.0%** be applied to account for the risk that the turbines do not perform exactly at the manufacturer's rated power curve.

6.5.2 Turbulence Intensity

Research has linked turbine under performance to stable atmospheric conditions. These conditions are often identified by low turbulence intensity. In addition, periods of low or high turbulence intensity can affect the specified power curve by creating a statistical averaging effect. The statistical averaging effect is assessed by comparing the average of the instantaneous wind speeds using a theoretical zero turbulence power curve against the manufacturer's power curve at given turbulence level. 3TIER analyzes the potential for both of these effects using the measured turbulence intensity and has calculated a loss factor of **96.9%**.

6.5.3 Inflow Angle

Reduced efficiency associated with extreme inflow angles is expected to be negligible; therefore, an inflow angle loss factor of **100.0%** is applied.

6.6 Environmental

Potential environmental losses include turbine under-performance caused by turbine blade soiling and degradation, extreme weather conditions such as icing and thunderstorms, and changes to the surrounding environment such as tree growth.

6.6.1 Blade Soiling

In locations where the ground is dry and the soil is loose, turbine blades can build up substantial amounts of soil, leading to a power curve derating. 3TIER has analyzed projects in similar terrain and has calculated a standard loss factor for cultivated farmland and shrub-steppe conditions. A loss factor of **98.5%** is applied for blade soiling.

6.6.2 Blade Degradation

Blade degradation, unlike blade soiling, is permanent damage caused to the turbine blades by material in hitting the blades. This can include corrosive material, such as sodium chloride (sea salt), and larger diameter soil and dirt particles. 3TIER has analyzed projects in similar terrain and has calculated a standard loss factor for cultivated farmland and shrub steppe conditions. A loss factor of **99.5%** is applied for blade degradation. While this elevated risk of hail applies to the general region, the probability of hail damage at the project or at an individual turbine location is relatively small. No additional loss factor has been applied for blade degradation due to hail.

6.6.3 Soft Icing

Soft icing occurs when ice builds up on the turbine blades and affects the ability of the turbine to operate optimally. Soft icing is often found as shoulder events to hard ice in which loads are exceeded and turbine shutdown occurs. A loss factor of **99.5%** is applied for soft icing.

6.6.4 Other Environmental Losses

3TIER has considered the effects from additional environmental losses. Average lightning density for the project is expected to be moderate relative to the state of Colorado as a whole. Local lightning density is expected to be lower than high risk lightning areas in the Midwestern and Southeastern United States. Additional losses such thunderstorms and tree growth, are expected to be negligible.

6.7 Aggregate Loss Factor

Table 9 below shows the individual loss factors for all considered categories and the aggregate loss factor. The product of all considered losses is **77.6%**. The expected gross P50 generation is $1321.0\,GWh$; therefore, the net P50 generation is the product of 77.6% and $1321.0\,GWh$, which equals $\mathbf{1024.9\,GWh}$. Table 10 displays the monthly-mean net values as a percent of the expected annual-mean generation value (GWh).

Loss Factor	Percent Loss
Project Availability	
Turbine Availability	96.0 %
Balance Of Plant Availability	99.7 %
Grid Availability	99.5 %
Curtailment	
Sector Management	–
High Wind Hysteresis	98.5 %
Icing	99.0 %
Extreme Temperature	99.9 %
Wake Deficit	
Total Wakes	92.7 %
Electrical Efficiency	
Total Electrical Efficiency	98.0 %
Consumptive Power	99.5 %
Turbine Efficiency	
Turbine Performance	98.0 %
Turbulence Intensity	96.9 %
Inflow Angle	100.0 %
Environmental	
Blade Soiling	98.5 %
Blade Degradation	99.5 %
Soft Icing	99.5 %
Aggregate Loss Factor	**77.6 %**

Table 9: Summary of loss factors. Sector management loss has not been considered, but a calculation could be made with additional data from the turbine manufacturer.

Month	GWh (%)
January	8.6 %
February	7.7 %
March	9.2 %
April	9.3 %
May	8.8 %
June	8.3 %
July	7.6 %
August	7.5 %
September	8.0 %
October	8.4 %
November	8.2 %
December	8.4 %

Table 10: Monthly-mean net values as a percent of the total annual-mean generation.

7 UNCERTAINTY ANALYSIS

To calculate uncertainty and estimates of probabilities of exceedance, 3TIER has utilized its Energy Risk Framework. This framework is based on theoretical propagation of error theory and models hundreds of sources of uncertainty and their relationships throughout the modeling process. Each source of uncertainty is treated in a separate model that interacts with the framework through overlying covariance models. The analysis considers the following sources of uncertainty: measurement, vertical extrapolation, MOS correction, climate variability, spatial modeling, and power modeling.

7.1 Uncertainty Methodology

7.1.1 Measurement Uncertainty

Measurement uncertainty captures the uncertainties related to the on-site measured data utilized in the energy assessment. It is a measure of the confidence that the recorded data, which are presumed to represent the truth, actually do represent the truth. Individual components of measurement uncertainty include the following: anemometer uncertainty, benefits of utilizing redundant sensors, measurement height uncertainty, and the statistical propagation of these uncertainties through the wind shear and extrapolation calculations to estimate hub height wind speed values. Uncertainty is separately estimated for each measurement sensor, and the sensor uncertainties are aggregated together to represent the total measurement uncertainty at hub height level for each met tower. Measurement uncertainty estimates at each met tower are considered to be independent when predicting measurement uncertainty at each turbine location.

7.1.2 Vertical Extrapolation Uncertainty

If on-site measurements are not directly recorded at hub height, an uncertainty exists that the true vertical wind speed profile may differ from the assumed power law profile. A vertical extrapolation uncertainty is required to account for this uncertainty. Remote sensing and/or hub height measurements can reduce and potentially eliminate this uncertainty.

Vertical extrapolation uncertainty is estimated at each met tower individually and, met tower estimates are combined assuming partial dependency on the mast and turbine heights when estimating vertical extrapolation uncertainty at the turbine locations. For example, if met towers are located in meteorologically similar environments, risk is increased that common errors are present in the vertical extrapolation process.

7.1.3 MOS Correction Uncertainty

A MOS Correction uncertainty is applied at each met tower that accounts for the probability that the statistical correction applied to the long term climate signal will accurately capture the true historic climate variability. The uncertainty associated with 3TIER's MOS correction algorithm decreases as the training period increases. The uncertainty depends on the length of data available at the met tower and the quality of the relationship between the met tower and the long term data set.

MOS correction uncertainty is estimated at each met tower, and then individual uncertainties are combined to predict the uncertainty at each turbine location assuming partial dependence between each met tower. This dependence is a function of the concurrency of measurements between the met towers, since the uncertainty of this relationship will depend on common errors in the climate signal used as the reference.

7.1.4 Climate Variability Uncertainty

Climate variability uncertainty is comprised of the following individual component uncertainties: historic climate, future climate, climate change, and climate signal consistency. Historic and future climate uncertainties represent the uncertainty associated with the natural variability of the climate and whether the climate reference period or future prediction period will capture the true climate. These uncertainties are a function of the inter-annual variability and auto-correlation of the climate signal. Climate change and climate signal consistency uncertainties represent the probability of error of the future prediction because the climate of the future may not be accurately represented by the climate of the past. These uncertainties are higher if the past few years show potential trends that may point towards a changing pattern.

Climate variability uncertainty is considered common across all met towers and is modeled with complete dependence in the uncertainty framework.

7.1.5 Spatial Modeling Uncertainty

Spatial modeling uncertainty is estimated by calibrating a spatial model for each met tower that applies the MOS correction derived at that met tower to all the turbine locations. The individual spatial models are combined at each turbine location using weights that are a function of the total uncertainty at each met tower considering dependence and independence of each component uncertainty. Spatial uncertainties are a function of the geographic covariance between each met tower and turbine location. 3TIER applies two spatial modeling uncertainties: micro spatial uncertainty and macro spatial uncertainty. Micro spatial uncertainty represents the uncertainty associated with the grid resolution of the spatial model and whether the model is capturing micro scale effects. Macro spatial uncertainty represents the risk that a spatial model calibration at the location of a met tower is applicable at distances away from that met tower.

This complex uncertainty is a function of all the prior uncertainties and relative proximity and complexity of each geospatial relationship. The dependence on prior uncertainties is driven by the weighting scheme of each met tower, which has uncertainty dependence. Spatial covariance is also considered when aggregating each individual turbine uncertainty into a project average uncertainty.

7.1.6 Power Modeling Uncertainty

Power modeling uncertainty considers each step in converting wind speed estimates into energy estimates. In this step, wind speed uncertainties are expanded by the wind speed to energy relationship and then the following is considered: representativeness of the modeled frequency distribution when applying the specified power curve, wakes, availabilities, electrical losses, and all other losses considered in the loss evaluation process. Power modeling uncertainties are considered to be dependent between each turbine location.

7.2 Uncertainty Framework Results

All uncertainty categories for the Rush Creek II project fall within acceptable ranges for a quality pre-construction due diligence analysis. The project benefits from multiple met towers with redundant anemometry all collecting over a year of data. Although the vertical extrapolation uncertainty is relatively low, the project could benefit by collecting wind speed measurements at or near hub height to further reduce the vertical extrapolation uncertainty. This can be achieved by installing additional met towers with hub height measurements, or by utilizing a wind profiler device such as a Triton SODAR (Sonic Detection and Ranging) or LIDAR (Light Detection and Ranging). 3TIER can provide further recommendations regarding wind profiler options at the clients request.

7.2.1 Met Tower Uncertainty

Uncertainty values for each met tower are presented as a function of wind speed below in Table 11.

	M2196	M2202	M2311	M2313
Measurement	1.1	1.5	1.2	1.1
Vertical Extrapolation	1.5	1.5	1.4	1.4
MOS Correction	1.0	1.1	1.2	1.6
Climate Variability	1.2	1.2	1.2	1.2
Combined Uncertainty	**2.4**	**2.7**	**2.6**	**2.8**

Table 11: Standard error of wind speed estimation at each met tower (%)

7.2.2 Combined Project Uncertainties

The total project uncertainties, represented as a percent of the P50 estimate are presented in Table 12 as a function of energy.

	1-year	10-year	20-year
Measurement	0.9	0.9	0.9
Vertical Extrapolation	1.5	1.5	1.5
MOS Correction	1.0	1.0	1.0
Climate Variability	3.2	1.4	1.3
Spatial Modeling	2.7	2.7	2.7
Power Modeling	4.4	4.4	4.4
Total Uncertainty	**6.4**	**5.7**	**5.7**

Table 12: Standard error of wind energy estimation (%)

8 PROBABILITY OF EXCEEDANCES

Based on the estimated total project uncertainties, Tables 13 and 14 present the probability of exceedance levels associated with the P50 project estimate. Table 13 provides results in terms of GWh, while Table 14 shows results in terms of project-average capacity factor (%). Table 15 shows the net P50, P75, and P90 values for each calendar month.

	1-year	10-year	20-year
Gross-P50	1321.0	1321.0	1321.0
Net-P50	1024.9	1024.9	1024.9
Net-P10	1109.2	1100.2	1099.7
Net-P25	1069.3	1064.6	1064.3
Net-P65	999.6	1002.3	1002.4
Net-P75	980.6	985.3	985.6
Net-P90	940.7	949.6	950.1
Net-P95	916.8	928.3	928.9
Net-P99	872.0	888.2	889.2

Table 13: Probability of Exceedance Values (GWh)

	1-year	10-year	20-year
Gross-P50	59.8	59.8	59.8
Net-P50	46.4	46.4	46.4
Net-P10	50.2	49.8	49.8
Net-P25	48.4	48.2	48.2
Net-P65	45.3	45.4	45.4
Net-P75	44.4	44.6	44.6
Net-P90	42.6	43.0	43.0
Net-P95	41.5	42.0	42.1
Net-P99	39.5	40.2	40.3

Table 14: Probability of Exceedance Values (%)

	Net P50	20-year Net P75	20-year Net P90
January	87.5	84.0	80.8
February	78.8	75.6	72.7
March	94.1	90.6	87.5
April	95.5	92.2	89.2
May	90.4	86.7	83.4
June	85.0	81.5	78.3
July	78.1	74.5	71.3
August	77.1	73.5	70.2
September	81.7	78.2	75.0
October	86.1	82.6	79.4
November	84.0	80.6	77.5
December	86.6	83.2	80.0

Table 15: Monthly Probability of Exceedance Values (GWh). The monthly P75 and P90 values are not expected to sum to the annual values, since the variability of the monthly-means is greater than the variability of the annual-mean.

8.1 Alternative Project Size

The micro-sited turbine layout for the Rush Creek II project has not yet been finalized. The final target nameplate capacity for this project is planned to be 200MW and consist of 100 turbine locations. For planning purposes, until the turbine layout is finalized, the results presented in this report as energy (MWh) can be scaled to the target capacity. A ratio of $\frac{200}{252}$, applied to the net energy values will provide reasonably representative approximations of the energy output for the final project size. Table 16 provides the results of this reduced size project in terms of GWh. The project average capacity factor (%) for this scaled down project remains unchanged.

	1-year	**10-year**	**20-year**
Gross-P50	1048.4	1048.4	1048.4
Net-P50	813.4	813.4	813.4
Net-P10	880.3	873.2	872.8
Net-P25	848.7	844.9	844.7
Net-P65	793.3	795.5	795.6
Net-P75	778.3	782.0	782.2
Net-P90	746.6	753.7	754.0
Net-P95	727.6	736.7	737.2
Net-P99	692.1	704.9	705.7

Table 16: Probability of Exceedance Values (GWh)

9 CONCLUSION

3TIER has conducted a wind resource assessment of the Rush Creek II project. The assessment is based on a wind turbine layout consisting of 126 Vestas V110-2.0 wind turbines at $80\,m$. The wind resource assessment yields a gross energy value of $1321.0\,GWh$. Loss factors were considered, leading to a net energy estimate of $1024.9\,GWh$. Turbine-wise values of gross energy, wake loss, and net energy are available in Appendix Turbine Means. Following the uncertainty assessment of wind speed measurement and energy modeling analysis, net probabilities of exceedance were calculated. 20-year P75 and P90 cases are $985.6\,GWh$ and $950.1\,GWh$, respectively.

The micro-sited turbine layout for the Rush Creek II project has not yet been finalized. The final target nameplate capacity for this project is planned to be 200MW and consist of 100 turbine locations. For planning purposes, until the turbine layout is finalized, the results presented in this report as energy (MWh) can be scaled to the target capacity. A ratio of $\frac{200}{252}$, applied to the net energy values will provide reasonably representative approximations of the energy output for the final project size. Under this scenario the 200MW project has a gross energy value of $1048.4\,GWh$. The 200MW project has a net energy estimate of $813.4\,GWh$, and a 20-year P75 and P90 values of $782.2\,GWh$ and $754.0\,GWh$, respectively.

10 APPENDIX TURBINE MEANS

This section contains turbine-specific elevation, wind speed, and air density, along with gross energy values, wake loss, and net energy values for each of the 126 turbines at the Rush Creek II project.

10.1 Vestas V110-2.0 wind turbines at 80 m

ID	Latitude ($degrees$)	Longitude ($degrees$)	Elevation (m)	Wind Speed ($\frac{m}{s}$)	Air Density ($\frac{kg}{m^3}$)	Gross Generation (MWh :: %)	Wake Loss (%)	Net Generation (MWh :: %)
A1	39.10894	-103.24881	1635	8.85	1.017	10387 :: 59.2	92.6	8016 :: 45.7
A2	39.10279	-103.25022	1637	8.84	1.016	10350 :: 59.0	93.1	8030 :: 45.8
A3	39.10181	-103.25533	1637	8.90	1.016	10385 :: 59.2	94.7	8184 :: 46.7
A4	39.10046	-103.25943	1635	9.02	1.017	10493 :: 59.9	96.7	8424 :: 48.0
A5	39.09055	-103.24974	1637	8.91	1.016	10374 :: 59.2	92.1	7955 :: 45.4
A6	39.08679	-103.24998	1640	9.05	1.016	10499 :: 59.9	95.0	8284 :: 47.3
A7	39.08191	-103.24618	1637	8.99	1.016	10410 :: 59.4	95.9	8290 :: 47.3
A8	39.07240	-103.23134	1633	9.09	1.017	10559 :: 60.2	96.0	8408 :: 48.0
A9	39.11360	-103.23573	1626	8.78	1.017	10371 :: 59.2	92.8	8050 :: 45.9
A10	39.11212	-103.24065	1631	8.81	1.017	10381 :: 59.2	93.0	8054 :: 45.9
A11	39.11062	-103.24504	1633	8.82	1.017	10367 :: 59.1	92.6	8006 :: 45.7
A12	39.09455	-103.25023	1635	8.84	1.017	10321 :: 58.9	92.1	7922 :: 45.2
A13	39.14265	-103.18085	1583	8.52	1.022	10010 :: 57.1	92.1	7762 :: 44.3
A14	39.05017	-103.15351	1601	8.84	1.020	10454 :: 59.6	93.8	8209 :: 46.8
A15	39.08243	-103.24021	1634	9.00	1.017	10442 :: 59.6	93.9	8138 :: 46.4
A16	39.14779	-103.20166	1586	8.61	1.021	10157 :: 57.9	92.6	7877 :: 44.9
A17	39.13970	-103.18226	1587	8.53	1.021	10010 :: 57.1	92.3	7778 :: 44.4
A18	39.13769	-103.18600	1591	8.55	1.021	10038 :: 57.3	93.1	7868 :: 44.9
A19	39.13642	-103.20676	1604	8.61	1.020	10161 :: 58.0	90.0	7656 :: 43.7
A20	39.14579	-103.20492	1593	8.63	1.021	10180 :: 58.1	91.6	7810 :: 44.5
A21	39.08080	-103.15059	1598	8.88	1.020	10697 :: 61.0	91.5	8219 :: 46.9
A22	39.08085	-103.21836	1634	9.08	1.016	10783 :: 61.5	91.8	8234 :: 47.0
A23	39.07724	-103.21853	1634	9.10	1.016	10773 :: 61.4	94.0	8427 :: 48.1
A24	39.07544	-103.22218	1636	9.11	1.016	10714 :: 61.1	94.6	8420 :: 48.0
A25	39.07356	-103.22657	1637	9.14	1.016	10670 :: 60.9	95.1	8419 :: 48.0
A26	39.11458	-103.21578	1616	8.81	1.018	10488 :: 59.8	91.4	8010 :: 45.7
A27	39.11682	-103.21271	1613	8.76	1.019	10425 :: 59.5	91.7	7989 :: 45.6
A28	39.11960	-103.21072	1611	8.70	1.019	10349 :: 59.0	91.1	7889 :: 45.0
A29	39.12273	-103.20978	1610	8.69	1.019	10327 :: 58.9	89.9	7770 :: 44.3
A30	39.12563	-103.20822	1608	8.66	1.019	10268 :: 58.6	90.9	7811 :: 44.6
A31	39.13012	-103.20791	1607	8.63	1.019	10219 :: 58.3	90.8	7770 :: 44.3
A32	39.13316	-103.20704	1607	8.64	1.019	10206 :: 58.2	90.4	7723 :: 44.1
A33	39.05269	-103.13447	1590	8.79	1.021	10458 :: 59.6	93.1	8158 :: 46.5
A34	39.08413	-103.21181	1629	9.07	1.017	10854 :: 61.9	92.4	8356 :: 47.7
A35	39.08755	-103.20961	1628	9.08	1.017	10887 :: 62.1	91.4	8292 :: 47.3
A36	39.09616	-103.12798	1579	8.73	1.022	10525 :: 60.0	93.3	8251 :: 47.1

Table 17: Turbine-specific 36-year mean values for 126 Vestas V110-2.0 wind turbines at 80 m. Generation values are provided in terms of energy and capacity factor. (continued on next page)

ID	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Wind Speed ($\frac{m}{s}$)	Air Density ($\frac{kg}{m^3}$)	Gross Generation (MWh :: %)	Wake Loss (%)	Net Generation (MWh :: %)
A37	39.04659	-103.15681	1602	8.83	1.020	10392 :: 59.3	93.8	8156 :: 46.5
A38	39.05604	-103.13203	1588	8.79	1.021	10491 :: 59.8	93.1	8191 :: 46.7
A39	39.06006	-103.16007	1612	8.95	1.019	10672 :: 60.9	91.5	8180 :: 46.7
A40	39.07732	-103.19909	1623	9.02	1.017	10801 :: 61.6	92.6	8346 :: 47.6
A41	39.05740	-103.12206	1578	8.70	1.022	10401 :: 59.3	95.1	8303 :: 47.4
A42	39.04218	-103.13338	1590	8.80	1.021	10382 :: 59.2	96.0	8345 :: 47.6
A43	39.09182	-103.20148	1621	9.02	1.018	10851 :: 61.9	91.5	8290 :: 47.3
A44	39.09022	-103.20613	1625	9.08	1.017	10903 :: 62.2	92.0	8357 :: 47.7
A45	39.06713	-103.14281	1600	8.89	1.020	10675 :: 60.9	91.5	8192 :: 46.7
A46	39.10396	-103.19059	1604	8.79	1.019	10556 :: 60.2	92.1	8177 :: 46.6
A47	39.14910	-103.16230	1571	8.56	1.023	10114 :: 57.7	93.8	7977 :: 45.5
A48	39.07694	-103.15248	1600	8.88	1.020	10692 :: 61.0	90.4	8114 :: 46.3
A49	39.15058	-103.15799	1567	8.56	1.023	10130 :: 57.8	94.6	8061 :: 46.0
A50	39.15176	-103.15297	1568	8.60	1.023	10200 :: 58.2	95.1	8148 :: 46.5
A51	39.15312	-103.14819	1565	8.60	1.024	10212 :: 58.3	95.4	8183 :: 46.7
A52	39.15436	-103.14373	1559	8.58	1.024	10194 :: 58.1	96.2	8238 :: 47.0
A53	39.07360	-103.20796	1632	9.11	1.017	10830 :: 61.8	91.5	8239 :: 47.0
A54	39.04678	-103.13298	1590	8.79	1.021	10412 :: 59.4	94.2	8217 :: 46.9
A55	39.06881	-103.13939	1597	8.88	1.020	10665 :: 60.8	92.5	8277 :: 47.2
A56	39.07553	-103.20420	1629	9.08	1.017	10830 :: 61.8	91.8	8277 :: 47.2
A57	39.06482	-103.20415	1623	8.99	1.018	10623 :: 60.6	94.3	8342 :: 47.6
A58	39.05853	-103.19849	1620	9.02	1.018	10628 :: 60.6	95.7	8468 :: 48.3
A59	39.06968	-103.20709	1628	9.05	1.017	10724 :: 61.2	92.7	8278 :: 47.2
A60	39.08943	-103.18413	1612	8.91	1.019	10741 :: 61.3	90.7	8195 :: 46.7
A61	39.10762	-103.13030	1577	8.73	1.022	10505 :: 59.9	93.8	8275 :: 47.2
A62	39.11649	-103.16447	1589	8.64	1.021	10309 :: 58.8	91.9	7978 :: 45.5
A63	39.12238	-103.15766	1589	8.71	1.021	10375 :: 59.2	92.0	8022 :: 45.8
A64	39.09335	-103.17321	1604	8.81	1.019	10618 :: 60.6	91.9	8216 :: 46.9
A65	39.09676	-103.16850	1601	8.79	1.020	10590 :: 60.4	91.4	8145 :: 46.5
A66	39.12455	-103.15435	1585	8.66	1.022	10317 :: 58.8	92.9	8053 :: 45.9
A67	39.14457	-103.16752	1575	8.49	1.023	10006 :: 57.1	92.8	7817 :: 44.6
A68	39.11979	-103.16047	1588	8.67	1.021	10330 :: 58.9	92.1	7999 :: 45.6
A69	39.08790	-103.13643	1584	8.75	1.022	10546 :: 60.2	92.1	8157 :: 46.5
A70	39.10374	-103.13213	1582	8.80	1.022	10601 :: 60.5	93.0	8280 :: 47.2
A71	39.07627	-103.13113	1594	8.88	1.021	10693 :: 61.0	92.9	8335 :: 47.5
A72	39.11277	-103.21987	1618	8.82	1.018	10495 :: 59.9	91.1	7987 :: 45.6
A73	39.07367	-103.13394	1595	8.88	1.020	10691 :: 61.0	92.8	8319 :: 47.4
A74	39.09747	-103.15611	1593	8.77	1.021	10565 :: 60.3	92.3	8197 :: 46.8
A75	39.07143	-103.13701	1595	8.87	1.020	10666 :: 60.8	92.3	8257 :: 47.1
A76	39.10037	-103.19542	1609	8.85	1.019	10642 :: 60.7	91.6	8177 :: 46.6
A77	39.07965	-103.19395	1620	9.02	1.018	10821 :: 61.7	92.6	8388 :: 47.8
A78	39.13693	-103.19437	1597	8.62	1.020	10136 :: 57.8	93.2	7932 :: 45.2
A79	39.07842	-103.12794	1592	8.87	1.021	10689 :: 61.0	94.1	8439 :: 48.1
A80	39.04955	-103.17267	1618	8.95	1.018	10533 :: 60.1	92.7	8167 :: 46.6
A81	39.08521	-103.18596	1613	8.93	1.018	10757 :: 61.4	90.9	8217 :: 46.9
A82	39.10729	-103.18466	1598	8.71	1.020	10441 :: 59.6	91.9	8088 :: 46.1

Table 17: Turbine-specific 36-year mean values for 126 Vestas V110-2.0 wind turbines at 80 m. Generation values are provided in terms of energy and capacity factor. (continued on next page)

ID	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Wind Speed ($\frac{m}{s}$)	Air Density ($\frac{kg}{m^3}$)	Gross Generation (MWh :: %)	Wake Loss (%)	Net Generation (MWh :: %)
A83	39.09514	-103.19880	1616	8.96	1.018	10782 :: 61.5	91.0	8212 :: 46.8
A84	39.05639	-103.18984	1623	9.07	1.018	10696 :: 61.0	95.0	8471 :: 48.3
A85	39.05539	-103.18345	1623	9.02	1.018	10646 :: 60.7	93.6	8328 :: 47.5
A86	39.05775	-103.17986	1621	8.99	1.018	10651 :: 60.8	91.5	8151 :: 46.5
A87	39.04784	-103.17635	1619	8.99	1.018	10552 :: 60.2	94.4	8318 :: 47.4
A88	39.06357	-103.17329	1616	8.96	1.018	10696 :: 61.0	91.1	8167 :: 46.6
A89	39.05770	-103.16267	1613	8.94	1.018	10627 :: 60.6	91.3	8127 :: 46.4
A90	39.04127	-103.17198	1611	8.92	1.019	10409 :: 59.4	95.7	8319 :: 47.4
A91	39.04086	-103.16542	1604	8.82	1.019	10297 :: 58.7	94.9	8175 :: 46.6
A92	39.05138	-103.16895	1616	8.92	1.018	10535 :: 60.1	92.3	8141 :: 46.4
A93	39.07370	-103.15501	1602	8.88	1.020	10676 :: 60.9	91.1	8165 :: 46.6
A94	39.09249	-103.18045	1610	8.88	1.019	10701 :: 61.0	91.2	8213 :: 46.8
A95	39.06314	-103.12166	1580	8.74	1.022	10487 :: 59.8	94.1	8279 :: 47.2
A96	39.08128	-103.18806	1614	8.95	1.018	10764 :: 61.4	92.3	8343 :: 47.6
A97	39.06694	-103.17238	1616	9.00	1.018	10774 :: 61.5	90.1	8139 :: 46.4
A98	39.06200	-103.15685	1609	8.92	1.019	10660 :: 60.8	92.0	8219 :: 46.9
A99	39.04250	-103.16126	1603	8.83	1.019	10345 :: 59.0	94.5	8176 :: 46.6
A100	39.09933	-103.16582	1598	8.76	1.020	10551 :: 60.2	91.5	8131 :: 46.4
A101	39.09605	-103.24666	1634	8.83	1.017	10339 :: 59.0	92.0	7924 :: 45.2
A102	39.09796	-103.23505	1625	8.79	1.017	10369 :: 59.1	93.1	8064 :: 46.0
A103	39.10102	-103.23161	1623	8.75	1.018	10352 :: 59.0	92.2	7986 :: 45.6
A104	39.10376	-103.22707	1621	8.74	1.018	10369 :: 59.1	92.4	8018 :: 45.7
A105	39.10602	-103.22290	1619	8.74	1.018	10391 :: 59.3	92.3	8025 :: 45.8
A106	39.14369	-103.17557	1579	8.51	1.022	10005 :: 57.1	93.6	7883 :: 45.0
A107	39.12513	-103.14912	1579	8.59	1.022	10239 :: 58.4	93.6	8057 :: 46.0
A108	39.10448	-103.24665	1636	8.82	1.016	10357 :: 59.1	92.5	7985 :: 45.5
A109	39.11587	-103.23292	1623	8.77	1.018	10370 :: 59.1	92.8	8056 :: 45.9
A110	39.14025	-103.20793	1598	8.60	1.020	10149 :: 57.9	90.7	7710 :: 44.0
A111	39.06349	-103.15304	1608	8.93	1.019	10684 :: 60.9	92.5	8279 :: 47.2
A112	39.11429	-103.16775	1589	8.63	1.021	10311 :: 58.8	92.3	8020 :: 45.7
A113	39.11071	-103.17916	1594	8.65	1.020	10343 :: 59.0	92.1	8038 :: 45.8
A114	39.07247	-103.16609	1607	8.93	1.019	10733 :: 61.2	91.6	8258 :: 47.1
A115	39.05415	-103.16601	1615	8.93	1.018	10573 :: 60.3	91.4	8089 :: 46.1
A116	39.06487	-103.14522	1601	8.89	1.020	10656 :: 60.8	92.9	8301 :: 47.3
A117	39.09264	-103.13493	1582	8.75	1.022	10545 :: 60.1	91.3	8085 :: 46.1
A118	39.09550	-103.13246	1580	8.73	1.022	10523 :: 60.0	91.9	8130 :: 46.4
A119	39.10828	-103.21924	1616	8.74	1.018	10406 :: 59.4	92.0	8013 :: 45.7
A120	39.14330	-103.20715	1595	8.58	1.021	10123 :: 57.7	91.4	7743 :: 44.2
A121	39.14820	-103.16742	1571	8.50	1.023	10026 :: 57.2	93.2	7867 :: 44.9
A122	39.07742	-103.23760	1632	9.01	1.017	10427 :: 59.5	95.2	8243 :: 47.0
A123	39.06101	-103.17883	1620	8.98	1.018	10683 :: 60.9	90.2	8065 :: 46.0
A124	39.09930	-103.15254	1590	8.78	1.021	10565 :: 60.3	92.1	8182 :: 46.7
A125	39.10200	-103.14741	1584	8.73	1.022	10502 :: 59.9	93.0	8214 :: 46.9
A126	39.09939	-103.17914	1606	8.83	1.019	10626 :: 60.6	91.1	8160 :: 46.5

Table 17: Turbine-specific 36-year mean values for 126 Vestas V110-2.0 wind turbines at 80 m. Generation values are provided in terms of energy and capacity factor.

ID	Net P50 (MWh :: %)	Net P75 (MWh :: %)	Net P90 (MWh :: %)	Net P95 (MWh :: %)	Net P99 (MWh :: %)
A1	8016 :: 45.7	7719 :: 44.0	7452 :: 42.5	7292 :: 41.6	6992 :: 39.9
A2	8030 :: 45.8	7732 :: 44.1	7463 :: 42.6	7302 :: 41.6	7000 :: 39.9
A3	8184 :: 46.7	7878 :: 44.9	7602 :: 43.4	7436 :: 42.4	7126 :: 40.6
A4	8424 :: 48.0	8107 :: 46.2	7821 :: 44.6	7651 :: 43.6	7330 :: 41.8
A5	7955 :: 45.4	7657 :: 43.7	7389 :: 42.1	7229 :: 41.2	6929 :: 39.5
A6	8284 :: 47.3	7972 :: 45.5	7692 :: 43.9	7524 :: 42.9	7209 :: 41.1
A7	8290 :: 47.3	7984 :: 45.5	7708 :: 44.0	7543 :: 43.0	7234 :: 41.3
A8	8408 :: 48.0	8100 :: 46.2	7823 :: 44.6	7657 :: 43.7	7345 :: 41.9
A9	8050 :: 45.9	7773 :: 44.3	7523 :: 42.9	7373 :: 42.1	7093 :: 40.5
A10	8054 :: 45.9	7768 :: 44.3	7511 :: 42.8	7358 :: 42.0	7069 :: 40.3
A11	8006 :: 45.7	7715 :: 44.0	7452 :: 42.5	7295 :: 41.6	7001 :: 39.9
A12	7922 :: 45.2	7627 :: 43.5	7361 :: 42.0	7202 :: 41.1	6904 :: 39.4
A13	7762 :: 44.3	7435 :: 42.4	7141 :: 40.7	6965 :: 39.7	6635 :: 37.8
A14	8209 :: 46.8	7879 :: 44.9	7582 :: 43.2	7404 :: 42.2	7070 :: 40.3
A15	8138 :: 46.4	7843 :: 44.7	7577 :: 43.2	7419 :: 42.3	7121 :: 40.6
A16	7877 :: 44.9	7563 :: 43.1	7280 :: 41.5	7111 :: 40.6	6794 :: 38.7
A17	7778 :: 44.4	7454 :: 42.5	7161 :: 40.8	6986 :: 39.8	6658 :: 38.0
A18	7868 :: 44.9	7544 :: 43.0	7253 :: 41.4	7079 :: 40.4	6752 :: 38.5
A19	7656 :: 43.7	7362 :: 42.0	7098 :: 40.5	6940 :: 39.6	6644 :: 37.9
A20	7810 :: 44.5	7503 :: 42.8	7227 :: 41.2	7061 :: 40.3	6751 :: 38.5
A21	8219 :: 46.9	7897 :: 45.0	7608 :: 43.4	7435 :: 42.4	7110 :: 40.6
A22	8234 :: 47.0	7938 :: 45.3	7671 :: 43.8	7512 :: 42.8	7212 :: 41.1
A23	8427 :: 48.1	8120 :: 46.3	7844 :: 44.7	7678 :: 43.8	7368 :: 42.0
A24	8420 :: 48.0	8111 :: 46.3	7832 :: 44.7	7666 :: 43.7	7353 :: 41.9
A25	8419 :: 48.0	8108 :: 46.2	7828 :: 44.6	7660 :: 43.7	7346 :: 41.9
A26	8010 :: 45.7	7716 :: 44.0	7451 :: 42.5	7293 :: 41.6	6996 :: 39.9
A27	7989 :: 45.6	7694 :: 43.9	7429 :: 42.4	7270 :: 41.5	6972 :: 39.8
A28	7889 :: 45.0	7597 :: 43.3	7334 :: 41.8	7176 :: 40.9	6881 :: 39.2
A29	7770 :: 44.3	7480 :: 42.7	7220 :: 41.2	7065 :: 40.3	6773 :: 38.6
A30	7811 :: 44.6	7519 :: 42.9	7256 :: 41.4	7099 :: 40.5	6804 :: 38.8
A31	7770 :: 44.3	7477 :: 42.6	7213 :: 41.1	7055 :: 40.2	6759 :: 38.6
A32	7723 :: 44.1	7430 :: 42.4	7165 :: 40.9	7007 :: 40.0	6711 :: 38.3
A33	8158 :: 46.5	7822 :: 44.6	7521 :: 42.9	7340 :: 41.9	7001 :: 39.9
A34	8356 :: 47.7	8064 :: 46.0	7802 :: 44.5	7645 :: 43.6	7350 :: 41.9
A35	8292 :: 47.3	8002 :: 45.6	7740 :: 44.2	7584 :: 43.3	7291 :: 41.6
A36	8251 :: 47.1	7920 :: 45.2	7622 :: 43.5	7444 :: 42.5	7110 :: 40.6
A37	8156 :: 46.5	7827 :: 44.6	7532 :: 43.0	7355 :: 42.0	7023 :: 40.1
A38	8191 :: 46.7	7855 :: 44.8	7552 :: 43.1	7371 :: 42.0	7031 :: 40.1
A39	8180 :: 46.7	7858 :: 44.8	7567 :: 43.2	7394 :: 42.2	7068 :: 40.3
A40	8346 :: 47.6	8036 :: 45.8	7756 :: 44.2	7589 :: 43.3	7275 :: 41.5
A41	8303 :: 47.4	7957 :: 45.4	7645 :: 43.6	7459 :: 42.5	7109 :: 40.5
A42	8345 :: 47.6	7996 :: 45.6	7682 :: 43.8	7495 :: 42.7	7142 :: 40.7
A43	8290 :: 47.3	7987 :: 45.6	7714 :: 44.0	7550 :: 43.1	7244 :: 41.3
A44	8357 :: 47.7	8059 :: 46.0	7791 :: 44.4	7630 :: 43.5	7329 :: 41.8
A45	8192 :: 46.7	7866 :: 44.9	7571 :: 43.2	7395 :: 42.2	7065 :: 40.3
A46	8177 :: 46.6	7871 :: 44.9	7596 :: 43.3	7431 :: 42.4	7122 :: 40.6
A47	7977 :: 45.5	7645 :: 43.6	7347 :: 41.9	7169 :: 40.9	6834 :: 39.0
A48	8114 :: 46.3	7796 :: 44.5	7511 :: 42.8	7339 :: 41.9	7019 :: 40.0

Table 18: Turbine-specific 20-year generation probability of exceedance values (P-values) for 126 Vestas V110-2.0 wind turbines at $80\,m$. (continued on next page)

ID	Net P50 (MWh :: %)	Net P75 (MWh :: %)	Net P90 (MWh :: %)	Net P95 (MWh :: %)	Net P99 (MWh :: %)
A49	8061 :: 46.0	7728 :: 44.1	7428 :: 42.4	7249 :: 41.3	6912 :: 39.4
A50	8148 :: 46.5	7813 :: 44.6	7512 :: 42.8	7332 :: 41.8	6994 :: 39.9
A51	8183 :: 46.7	7848 :: 44.8	7546 :: 43.0	7365 :: 42.0	7026 :: 40.1
A52	8238 :: 47.0	7899 :: 45.1	7594 :: 43.3	7412 :: 42.3	7070 :: 40.3
A53	8239 :: 47.0	7933 :: 45.3	7658 :: 43.7	7494 :: 42.7	7185 :: 41.0
A54	8217 :: 46.9	7876 :: 44.9	7569 :: 43.2	7385 :: 42.1	7041 :: 40.2
A55	8277 :: 47.2	7946 :: 45.3	7647 :: 43.6	7469 :: 42.6	7134 :: 40.7
A56	8277 :: 47.2	7971 :: 45.5	7697 :: 43.9	7532 :: 43.0	7224 :: 41.2
A57	8342 :: 47.6	8022 :: 45.8	7734 :: 44.1	7562 :: 43.1	7239 :: 41.3
A58	8468 :: 48.3	8140 :: 46.4	7844 :: 44.7	7667 :: 43.7	7335 :: 41.8
A59	8278 :: 47.2	7966 :: 45.4	7685 :: 43.8	7517 :: 42.9	7201 :: 41.1
A60	8195 :: 46.7	7883 :: 45.0	7602 :: 43.4	7433 :: 42.4	7117 :: 40.6
A61	8275 :: 47.2	7945 :: 45.3	7648 :: 43.6	7470 :: 42.6	7136 :: 40.7
A62	7978 :: 45.5	7665 :: 43.7	7382 :: 42.1	7213 :: 41.1	6896 :: 39.3
A63	8022 :: 45.8	7702 :: 43.9	7414 :: 42.3	7242 :: 41.3	6919 :: 39.5
A64	8216 :: 46.9	7902 :: 45.1	7621 :: 43.5	7452 :: 42.5	7136 :: 40.7
A65	8145 :: 46.5	7834 :: 44.7	7555 :: 43.1	7388 :: 42.1	7074 :: 40.3
A66	8053 :: 45.9	7731 :: 44.1	7440 :: 42.4	7266 :: 41.4	6940 :: 39.6
A67	7817 :: 44.6	7488 :: 42.7	7192 :: 41.0	7015 :: 40.0	6683 :: 38.1
A68	7999 :: 45.6	7681 :: 43.8	7395 :: 42.2	7224 :: 41.2	6904 :: 39.4
A69	8157 :: 46.5	7833 :: 44.7	7541 :: 43.0	7367 :: 42.0	7040 :: 40.2
A70	8280 :: 47.2	7951 :: 45.3	7654 :: 43.7	7477 :: 42.6	7144 :: 40.8
A71	8335 :: 47.5	7999 :: 45.6	7698 :: 43.9	7517 :: 42.9	7178 :: 40.9
A72	7987 :: 45.6	7698 :: 43.9	7437 :: 42.4	7281 :: 41.5	6988 :: 39.9
A73	8319 :: 47.4	7985 :: 45.5	7684 :: 43.8	7504 :: 42.8	7167 :: 40.9
A74	8197 :: 46.8	7881 :: 45.0	7597 :: 43.3	7426 :: 42.4	7107 :: 40.5
A75	8257 :: 47.1	7926 :: 45.2	7629 :: 43.5	7450 :: 42.5	7116 :: 40.6
A76	8177 :: 46.6	7871 :: 44.9	7595 :: 43.3	7430 :: 42.4	7121 :: 40.6
A77	8388 :: 47.8	8072 :: 46.0	7787 :: 44.4	7617 :: 43.4	7297 :: 41.6
A78	7932 :: 45.2	7616 :: 43.4	7332 :: 41.8	7162 :: 40.9	6843 :: 39.0
A79	8439 :: 48.1	8098 :: 46.2	7792 :: 44.4	7608 :: 43.4	7264 :: 41.4
A80	8167 :: 46.6	7844 :: 44.7	7554 :: 43.1	7380 :: 42.1	7054 :: 40.2
A81	8217 :: 46.9	7903 :: 45.1	7620 :: 43.5	7451 :: 42.5	7133 :: 40.7
A82	8088 :: 46.1	7784 :: 44.4	7510 :: 42.8	7347 :: 41.9	7039 :: 40.2
A83	8212 :: 46.8	7906 :: 45.1	7631 :: 43.5	7466 :: 42.6	7157 :: 40.8
A84	8471 :: 48.3	8141 :: 46.4	7844 :: 44.7	7667 :: 43.7	7333 :: 41.8
A85	8328 :: 47.5	8003 :: 45.6	7710 :: 44.0	7535 :: 43.0	7206 :: 41.1
A86	8151 :: 46.5	7833 :: 44.7	7547 :: 43.0	7375 :: 42.1	7053 :: 40.2
A87	8318 :: 47.4	7990 :: 45.6	7694 :: 43.9	7517 :: 42.9	7185 :: 41.0
A88	8167 :: 46.6	7849 :: 44.8	7562 :: 43.1	7391 :: 42.2	7069 :: 40.3
A89	8127 :: 46.4	7806 :: 44.5	7518 :: 42.9	7345 :: 41.9	7021 :: 40.0
A90	8319 :: 47.4	7986 :: 45.6	7687 :: 43.8	7508 :: 42.8	7171 :: 40.9
A91	8175 :: 46.6	7846 :: 44.8	7550 :: 43.1	7372 :: 42.1	7040 :: 40.2
A92	8141 :: 46.4	7819 :: 44.6	7529 :: 42.9	7356 :: 42.0	7031 :: 40.1
A93	8165 :: 46.6	7845 :: 44.7	7557 :: 43.1	7385 :: 42.1	7062 :: 40.3
A94	8213 :: 46.8	7900 :: 45.1	7619 :: 43.5	7450 :: 42.5	7135 :: 40.7
A95	8279 :: 47.2	7936 :: 45.3	7628 :: 43.5	7443 :: 42.5	7096 :: 40.5
A96	8343 :: 47.6	8023 :: 45.8	7736 :: 44.1	7564 :: 43.1	7241 :: 41.3

Table 18: Turbine-specific 20-year generation probability of exceedance values (P-values) for 126 Vestas V110-2.0 wind turbines at $80\,m$. (continued on next page)

ID	Net P50 (MWh :: %)	Net P75 (MWh :: %)	Net P90 (MWh :: %)	Net P95 (MWh :: %)	Net P99 (MWh :: %)
A97	8139 :: 46.4	7822 :: 44.6	7537 :: 43.0	7367 :: 42.0	7047 :: 40.2
A98	8219 :: 46.9	7894 :: 45.0	7602 :: 43.4	7428 :: 42.4	7100 :: 40.5
A99	8176 :: 46.6	7846 :: 44.8	7550 :: 43.1	7372 :: 42.0	7039 :: 40.1
A100	8131 :: 46.4	7821 :: 44.6	7542 :: 43.0	7374 :: 42.1	7061 :: 40.3
A101	7924 :: 45.2	7631 :: 43.5	7368 :: 42.0	7210 :: 41.1	6914 :: 39.4
A102	8064 :: 46.0	7772 :: 44.3	7508 :: 42.8	7350 :: 41.9	7054 :: 40.2
A103	7986 :: 45.6	7698 :: 43.9	7439 :: 42.4	7284 :: 41.5	6993 :: 39.9
A104	8018 :: 45.7	7730 :: 44.1	7471 :: 42.6	7316 :: 41.7	7025 :: 40.1
A105	8025 :: 45.8	7736 :: 44.1	7475 :: 42.6	7319 :: 41.7	7027 :: 40.1
A106	7883 :: 45.0	7549 :: 43.1	7249 :: 41.3	7069 :: 40.3	6732 :: 38.4
A107	8057 :: 46.0	7734 :: 44.1	7443 :: 42.5	7269 :: 41.5	6943 :: 39.6
A108	7985 :: 45.5	7690 :: 43.9	7424 :: 42.3	7265 :: 41.4	6967 :: 39.7
A109	8056 :: 45.9	7777 :: 44.4	7526 :: 42.9	7376 :: 42.1	7094 :: 40.5
A110	7710 :: 44.0	7412 :: 42.3	7144 :: 40.7	6983 :: 39.8	6682 :: 38.1
A111	8279 :: 47.2	7952 :: 45.4	7657 :: 43.7	7480 :: 42.7	7149 :: 40.8
A112	8020 :: 45.7	7707 :: 44.0	7426 :: 42.4	7257 :: 41.4	6941 :: 39.6
A113	8038 :: 45.8	7732 :: 44.1	7456 :: 42.5	7291 :: 41.6	6982 :: 39.8
A114	8258 :: 47.1	7937 :: 45.3	7648 :: 43.6	7475 :: 42.6	7150 :: 40.8
A115	8089 :: 46.1	7769 :: 44.3	7482 :: 42.7	7310 :: 41.7	6987 :: 39.9
A116	8301 :: 47.3	7970 :: 45.5	7672 :: 43.8	7494 :: 42.7	7159 :: 40.8
A117	8085 :: 46.1	7764 :: 44.3	7475 :: 42.6	7302 :: 41.7	6978 :: 39.8
A118	8130 :: 46.4	7806 :: 44.5	7515 :: 42.9	7340 :: 41.9	7013 :: 40.0
A119	8013 :: 45.7	7722 :: 44.0	7460 :: 42.6	7303 :: 41.7	7009 :: 40.0
A120	7743 :: 44.2	7442 :: 42.4	7170 :: 40.9	7008 :: 40.0	6703 :: 38.2
A121	7867 :: 44.9	7537 :: 43.0	7240 :: 41.3	7063 :: 40.3	6730 :: 38.4
A122	8243 :: 47.0	7949 :: 45.3	7684 :: 43.8	7525 :: 42.9	7228 :: 41.2
A123	8065 :: 46.0	7751 :: 44.2	7468 :: 42.6	7298 :: 41.6	6981 :: 39.8
A124	8182 :: 46.7	7865 :: 44.9	7580 :: 43.2	7410 :: 42.3	7089 :: 40.4
A125	8214 :: 46.9	7894 :: 45.0	7605 :: 43.4	7433 :: 42.4	7109 :: 40.5
A126	8160 :: 46.5	7851 :: 44.8	7574 :: 43.2	7408 :: 42.3	7097 :: 40.5

Table 18: Turbine-specific 20-year generation probability of exceedance values (P-values) for 126 Vestas V110-2.0 wind turbines at $80\,m$.

11 APPENDIX GROSS LONG-TERM VARIABILITY

11.1 Summary

This section provides a retrospective analysis of the past 36 years of wind speed and power at the Rush Creek II location. These data were derived from a mesoscale Numerical Weather Prediction (NWP) model that has been statistically calibrated to match the observed data during the measurement period at each meteorological tower for which data were provided (Towers M2196, M2202, M2311 and M2313). Due to long-term climate variability and/or change the historic distributions of wind and power capacity described here may not be indicative of future conditions.

Based on the results of 3TIER's Energy Risk Framework, the last 36 years (January, 1980 – December, 2015) of data have been utilized for estimating the expected future generation at Rush Creek II. The average MOS-corrected simulated wind speed at hub height ($80\,m$) during the past 36 years of record (January, 1980 – December, 2015) across all 126 turbines is $\mathbf{8.83}\,\boldsymbol{m/s}$. The average MOS-corrected simulated gross power capacity at hub height during the past 36 years across all 126 turbines is $\mathbf{59.8\%}$. A map of average MOS-corrected gross power capacity values across the Rush Creek II project area using the power curve for the Vestas V110-2.0 wind turbines is displayed in Power Capacity Maps.

All power capacities presented in this section are gross power capacities.

11.2 Power Capacity Maps

This section contains a map of MOS-corrected long-term mean gross power capacity values across the Rush Creek II project area for each turbine model and hub height.

11.2.1 Vestas V110-2.0 at 80 m

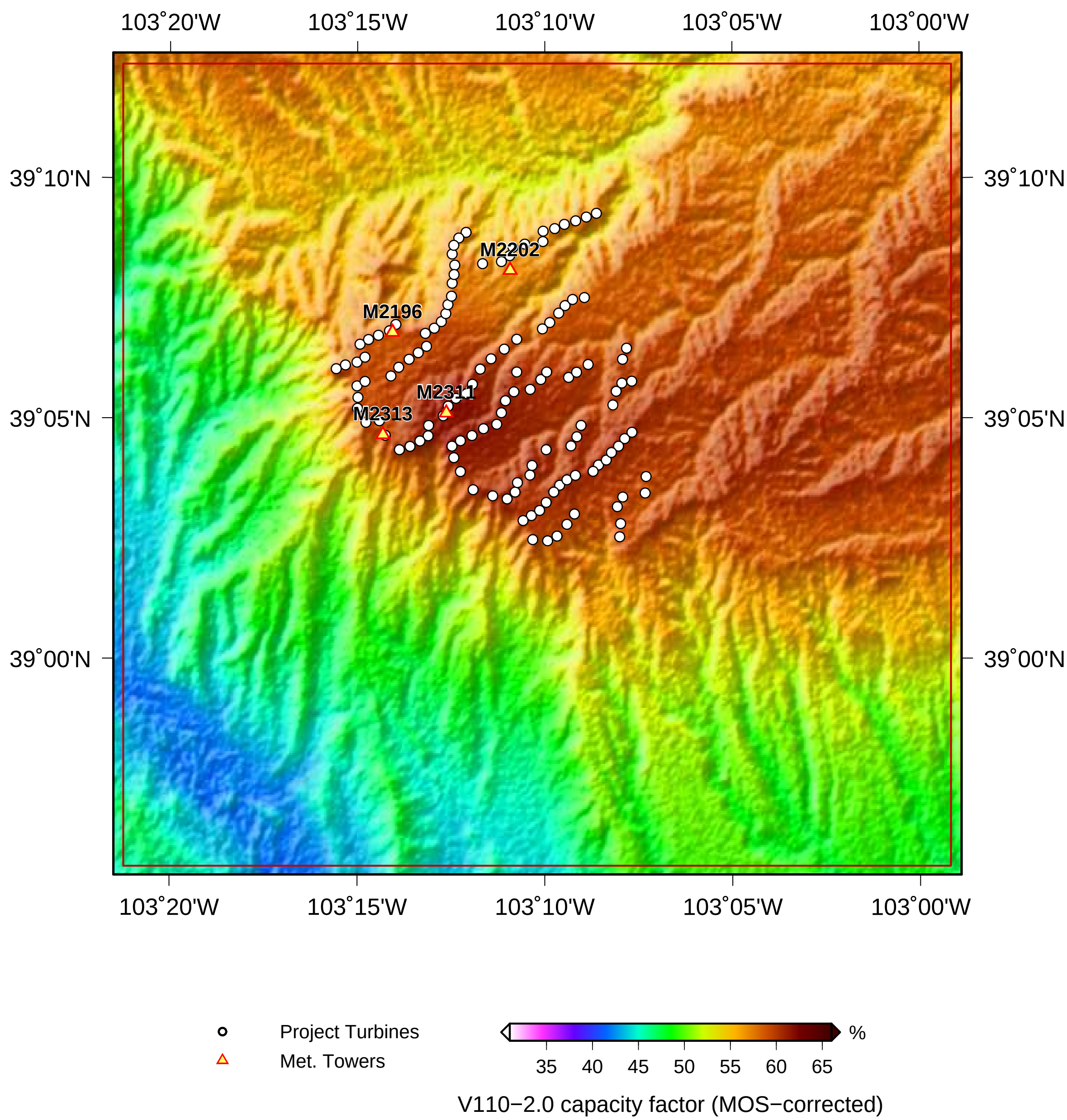

Figure 18: 36-year mean capacity factor at $80\,m$.

11.3 Model Simulations By 3TIER

The assessment of the wind resource across the Rush Creek II project presented in this section is based on 36 years of simulated data (January, 1980 – December, 2015) using a numerical weather prediction (NWP) model of the atmosphere.

The 36-year simulated data set is constructed from two separate model runs:

1. a 1-year, $500\,m$ resolution simulation (where the year of each calendar day is chosen sequentially from the last 10 years (2006 – 2015)), and
2. a 36-year continuous $4.5\,km$ resolution simulation.

The NWP model represents atmospheric processes in the boundary layer, including the roughness of the underlying terrain or water, stability within the boundary layer, heat and moisture fluxes into the atmosphere, wind shear, and turbulence within the boundary layer. The model outputs winds at fixed vertical levels, and there are 6 such levels in the lowest $600\,m$ of the atmosphere. To determine winds at specific hub heights, model data are interpolated between fixed vertical levels using "power-law interpolation". This process essentially uses the standard power-law shear formula, where the shear exponent is determined exactly from the winds at the two bracketing levels, rather than assuming a fixed shear exponent.

3TIER configured the NWP model using nested grids to simulate the wind resource over the Rush Creek II region. Some details of the NWP configuration are shown below in Table 19. The extent of the coarsest grid was selected to capture the effect of synoptic weather events on the wind resource at the site, as well as to allow the model to develop regional, thermally-driven circulations. The increasingly fine $40.5\,km$, $13.5\,km$, $4.5\,km$, $1.5\,km$ and $500\,m$ grids were selected to model the effect of local terrain and local scale atmospheric circulations.

After the NWP model simulations finished, a Time-Varying Microscale (TVM) model was employed to downscale the $500\,m$ horizontal resolution NWP model output to the final $90\,m$ horizontal resolution. All deliverables and model data shown in this section are derived from the $90\,m$ resolution model grids. A map of the $90\,m$ TVM grid is shown in Figure 19.

Based on a comparison of the NWP output with observations from each meteorological tower for which data were provided (Towers M2196, M2202, M2311 and M2313), a linear statistical model was constructed to remove the bias and adjust the variance of the raw NWP simulated winds.

Parameter	**Value**
Mesoscale numerical weather prediction model	WRF
Horizontal resolution of valid study area	$500\,m$
Final downscaled horizontal resolution	$90\,m$
Number of vertical levels	31
Elevation database	3 second SRTM
Vegetation database	10 second ESA Globcover
Surface parameterization	Monin-Obukhov similarity model
Boundary layer parameterization	YSU model (MRF with entrainment)
Land surface scheme	4-layer Noah-Land Surface Model

Table 19: Numerical weather prediction model configuration

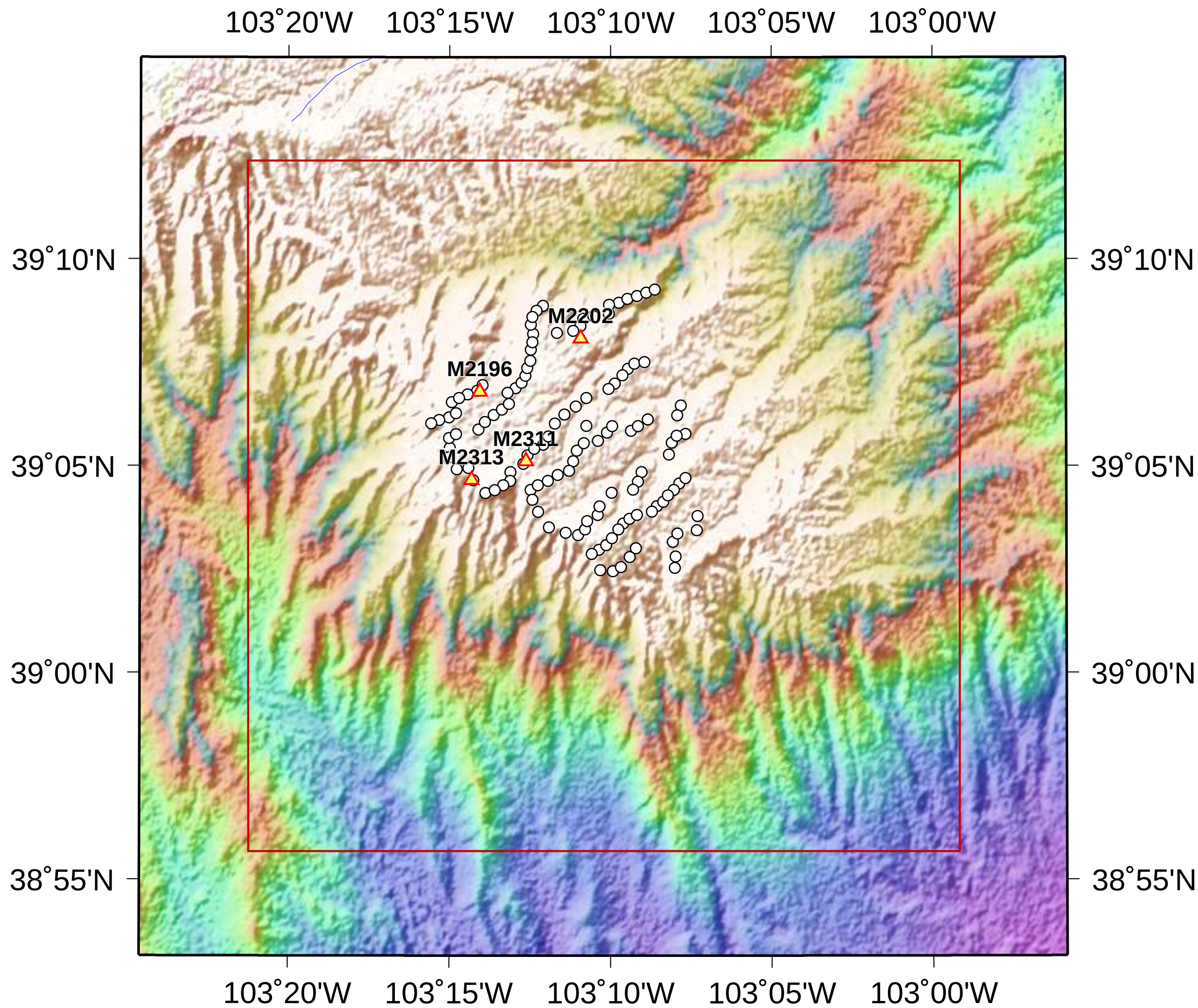

Figure 19: Map of the $90\,m$ resolution NWP model domain. The bold red box marks the boundary of the valid study area. The yellow triangles denote locations of meteorological towers and white dots indicate wind turbines.

11.4 Project-average Long-term Wind Resource Assessment

11.4.1 Monthly-mean Variability of Wind Speed

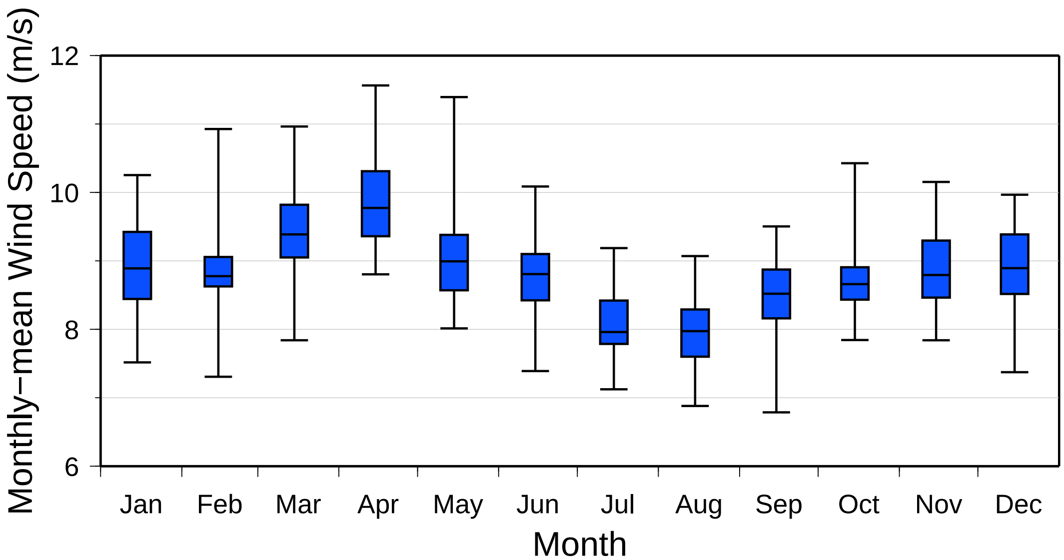

Figure 20: Box-and-whisker plot of monthly-mean project-average wind speed. This figure displays the expected variability of monthly-mean project-average wind speeds. Median wind speed denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond to the 75% and 25% quartiles, while the whiskers denote the maximum and minimum monthly-mean wind speeds.

11.4.2 Annual-mean Variability of Wind Speed

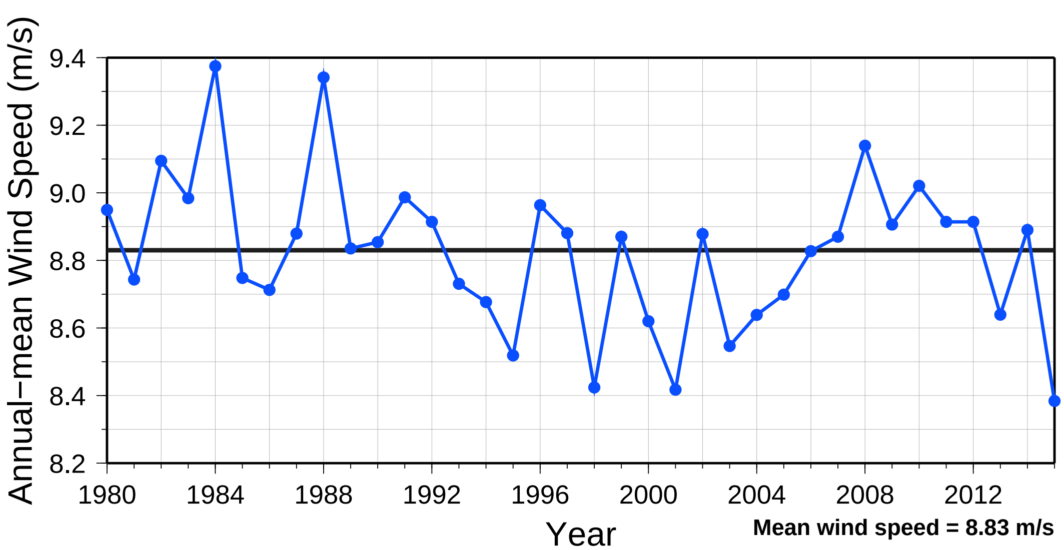

Figure 21: Time series of annual-mean project-average wind speed. Black line denotes the long-term mean.

11.4.3 Wind Speed Distribution

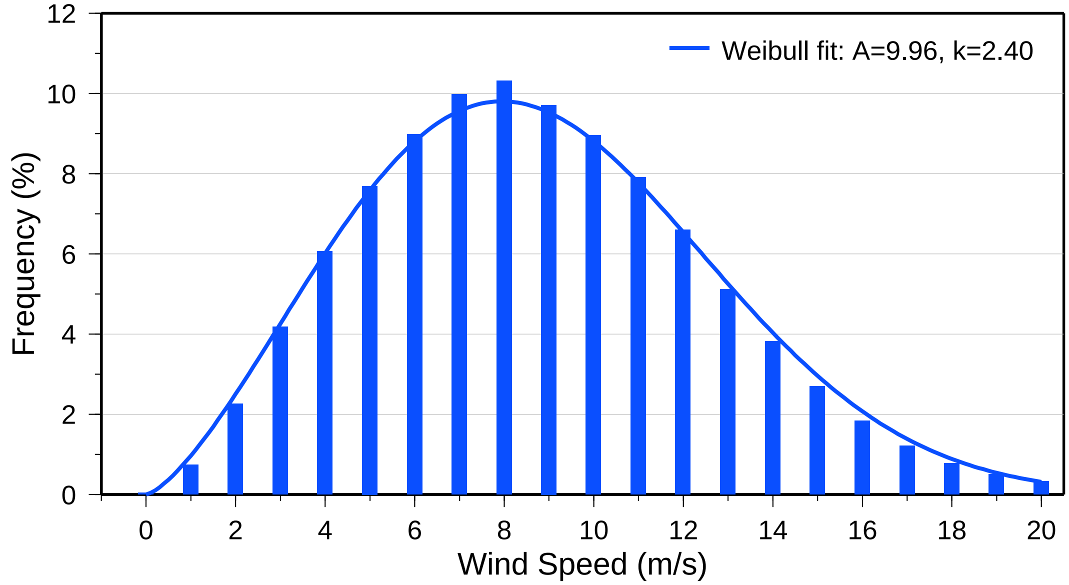

Figure 22: Hourly distribution of simulated project-average wind speed using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5.) Weibull distribution is also shown with the scale (A) and shape (k) parameters listed in the legend.

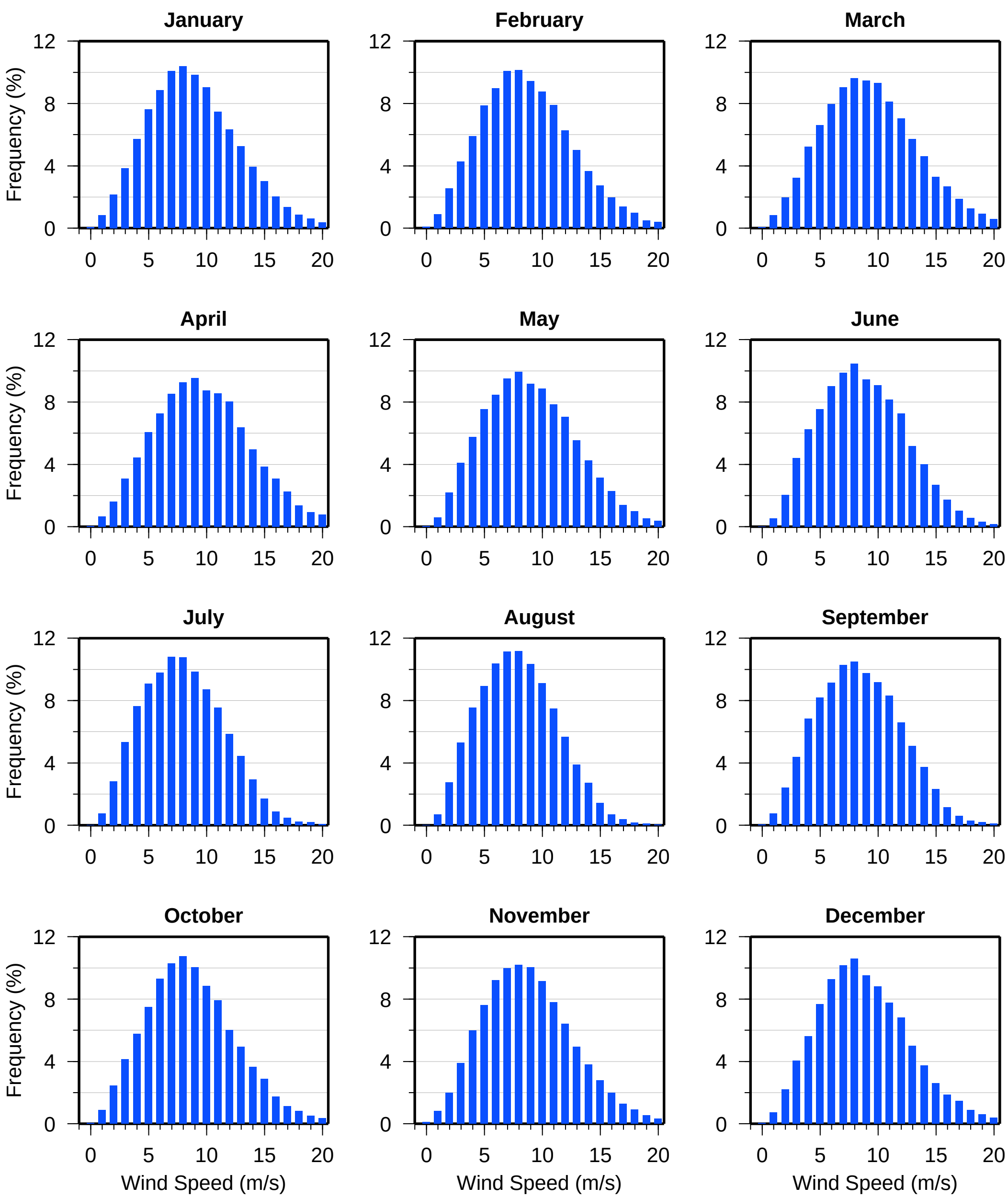

Figure 23: Hourly distribution of simulated project-average wind speed using $1\,m/s$ bins for each calendar month. ($0\,m/s$ bin contains only values ≤ 0.5.)

11.4.4 Wind Direction Distribution

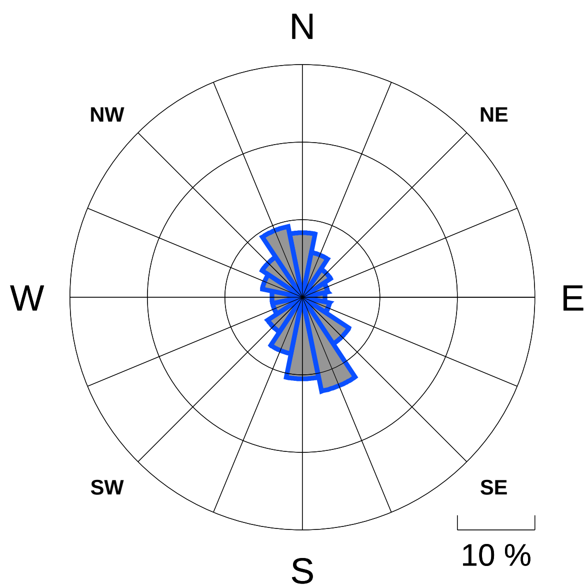

Figure 24: Annual wind rose of the hourly-mean project-average wind direction time series. Directional bins are 22.5° wide, and the radial contour interval is 10%.

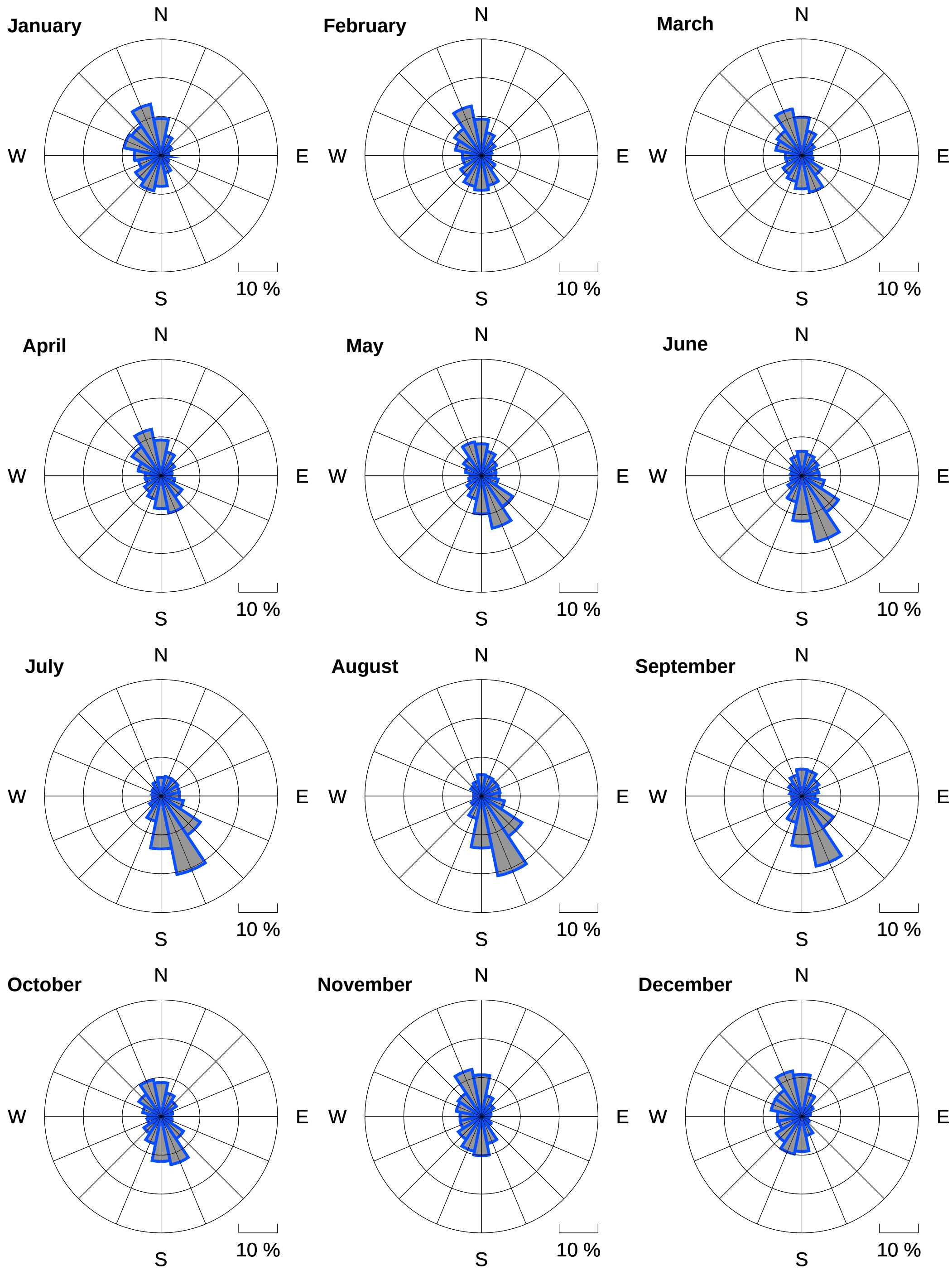

Figure 25: Wind roses of the hourly-mean project-average wind direction time series for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%.

11.4.5 Diurnal Variability of Wind Speed

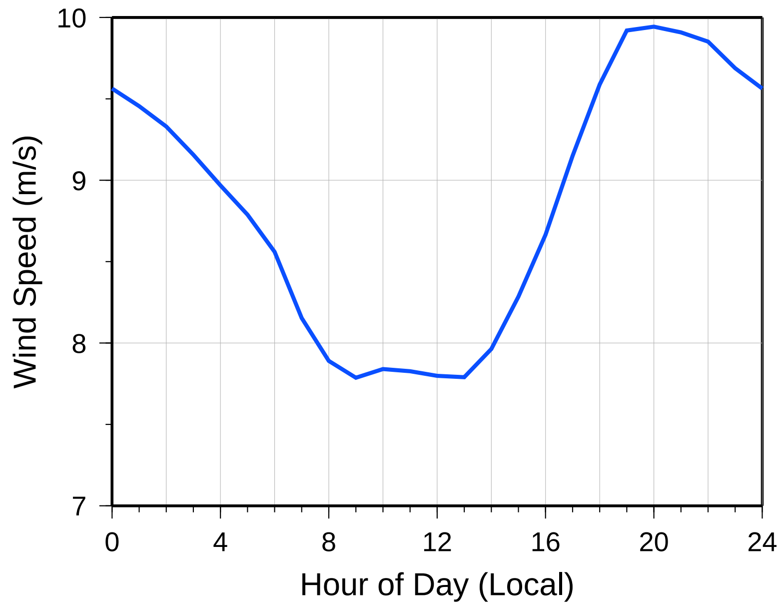

Figure 26: Diurnal cycle of simulated project-average wind speed. The horizontal axis is Mountain Standard Time (MST).

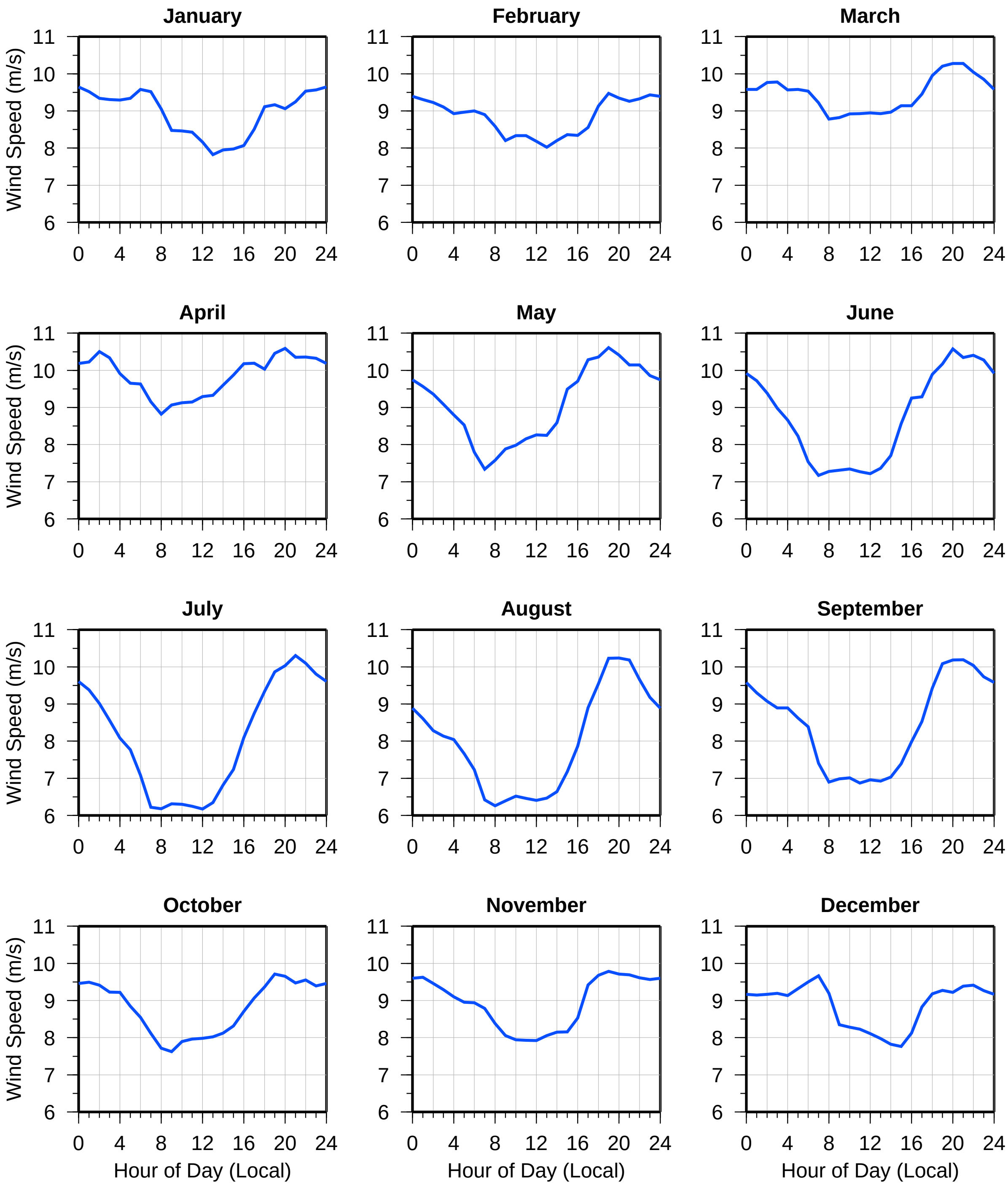

Figure 27: Diurnal cycle of simulated project-average wind speed for each calendar month. The horizontal axis is Mountain Standard Time (MST).

11.4.6 Wind Speed Variability and ENSO

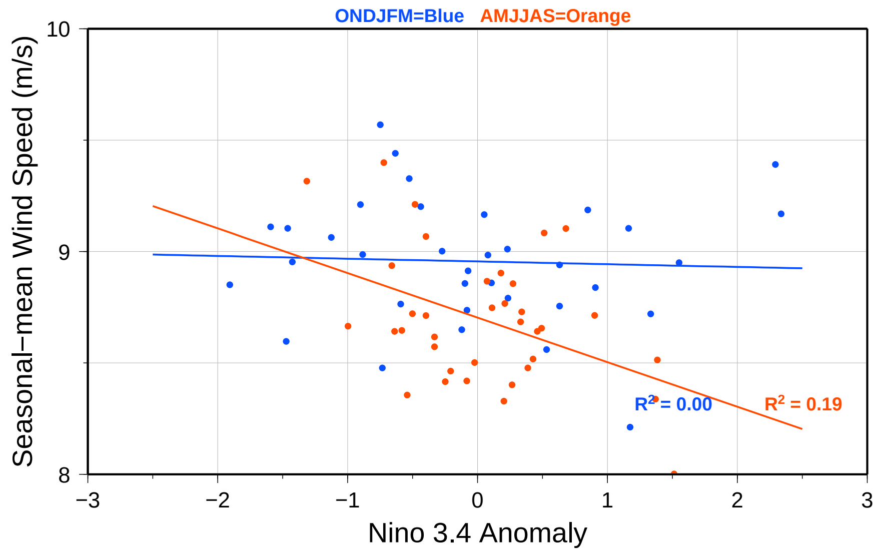

Figure 28: Scatter plot of Niño 3.4 anomalies vs. 6-month seasonal-mean project-average wind speed. Blue dots denote the mean during ONDJFM (October, November, December, January, February, and March); orange dots denote the mean during AMJJAS (April, May, June, July, August and September).

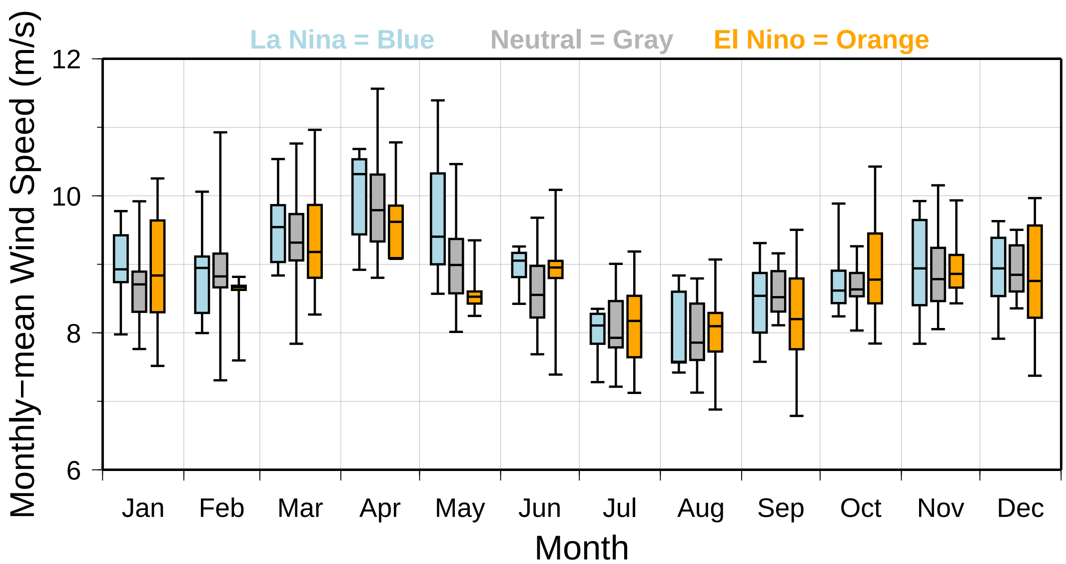

Figure 29: Box-and-whisker plot of monthly-mean project-average wind speed for La Niña (blue), neutral (gray), and El Niño (orange) phases of ENSO. Median wind speed denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond to the 75% and 25% quartiles, while the whiskers denote the maximum and minimum wind speeds.

11.4.7 Tabular Data

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.65	9.39	9.58	10.18	9.75	9.92	9.61	8.89	9.58	9.46	9.60	9.17	9.56
1	9.52	9.30	9.58	10.22	9.57	9.72	9.38	8.61	9.30	9.49	9.62	9.15	9.45
2	9.34	9.22	9.77	10.50	9.36	9.39	9.01	8.28	9.07	9.41	9.46	9.17	9.33
3	9.31	9.11	9.78	10.34	9.09	8.98	8.56	8.13	8.89	9.23	9.30	9.20	9.16
4	9.29	8.92	9.56	9.91	8.80	8.66	8.08	8.04	8.89	9.22	9.10	9.13	8.97
5	9.34	8.97	9.58	9.65	8.53	8.23	7.77	7.67	8.62	8.85	8.96	9.32	8.79
6	9.58	9.00	9.53	9.63	7.80	7.54	7.08	7.23	8.39	8.55	8.94	9.50	8.56
7	9.52	8.90	9.22	9.15	7.34	7.17	6.22	6.42	7.40	8.12	8.79	9.66	8.15
8	9.06	8.59	8.78	8.82	7.57	7.28	6.18	6.26	6.90	7.72	8.38	9.19	7.89
9	8.48	8.20	8.82	9.06	7.88	7.31	6.31	6.39	6.99	7.63	8.06	8.35	7.79
10	8.46	8.34	8.92	9.12	7.99	7.34	6.30	6.52	7.01	7.90	7.94	8.28	7.84
11	8.43	8.34	8.93	9.14	8.16	7.27	6.25	6.46	6.87	7.96	7.93	8.23	7.83
12	8.16	8.18	8.95	9.29	8.26	7.22	6.17	6.40	6.96	7.98	7.93	8.11	7.80
13	7.82	8.02	8.93	9.33	8.25	7.37	6.35	6.46	6.92	8.02	8.06	7.97	7.79
14	7.95	8.20	8.97	9.60	8.59	7.70	6.82	6.64	7.03	8.12	8.15	7.83	7.96
15	7.98	8.36	9.14	9.87	9.50	8.56	7.24	7.18	7.39	8.31	8.16	7.77	8.29
16	8.07	8.34	9.14	10.18	9.70	9.25	8.10	7.86	7.99	8.71	8.53	8.13	8.67
17	8.52	8.54	9.37	10.21	10.30	9.32	8.77	8.87	8.56	9.05	9.37	8.88	9.15
18	9.12	9.12	9.90	10.05	10.36	9.90	9.36	9.50	9.49	9.36	9.64	9.23	9.59
19	9.16	9.43	10.17	10.47	10.61	10.18	9.86	10.19	10.16	9.70	9.76	9.35	9.92
20	9.06	9.29	10.23	10.63	10.40	10.57	10.03	10.21	10.25	9.63	9.68	9.31	9.94
21	9.26	9.21	10.24	10.40	10.13	10.33	10.31	10.15	10.27	9.44	9.64	9.48	9.91
22	9.54	9.28	10.02	10.39	10.13	10.38	10.14	9.65	10.08	9.53	9.55	9.51	9.85
23	9.59	9.38	9.86	10.32	9.85	10.26	9.84	9.19	9.75	9.38	9.50	9.33	9.69
Avg	8.93	8.82	9.46	9.85	9.08	8.74	8.07	7.97	8.45	8.78	8.92	8.89	8.83

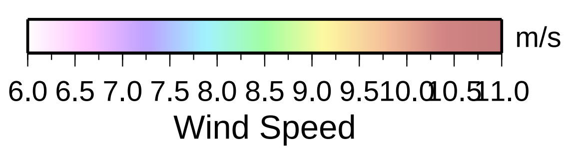

Figure 30: Hourly-mean values of simulated project-average wind speed. Vertical axis is local time.

Year	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
1980	9.64	8.23	10.76	9.53	9.18	9.05	7.96	8.79	8.92	8.33	8.05	8.91	8.95
1981	8.31	9.03	9.27	9.20	9.77	8.59	8.46	7.58	8.11	8.87	9.02	8.75	8.74
1982	9.92	8.82	9.61	10.41	8.60	8.89	8.26	7.60	8.52	9.74	8.78	9.97	9.09
1983	9.40	8.82	9.65	9.86	9.29	7.68	8.87	7.78	8.90	8.32	9.92	9.32	8.98
1984	8.91	10.93	10.01	11.56	9.23	9.26	8.53	8.18	8.51	8.91	9.76	8.86	9.37
1985	8.72	8.16	9.97	9.44	8.57	8.42	7.84	8.43	9.16	8.64	8.46	9.13	8.75
1986	9.03	8.29	9.03	10.23	8.68	8.55	8.42	8.52	8.79	8.78	8.66	7.56	8.71
1987	9.96	8.70	10.96	9.62	8.43	8.95	9.19	8.10	6.79	7.84	8.95	9.00	8.88
1988	9.86	8.82	10.65	9.79	11.39	8.73	8.28	8.84	8.87	8.24	9.65	8.94	9.34
1989	8.74	8.00	9.54	8.92	9.42	9.17	8.93	8.47	8.71	8.77	8.72	8.56	8.84
1990	9.67	8.78	8.64	9.33	9.45	9.55	7.92	7.73	8.51	8.62	9.24	8.85	8.85
1991	8.44	8.66	10.25	9.14	10.71	10.09	7.64	8.24	8.67	8.35	9.18	8.46	8.99
1992	10.25	8.65	8.80	9.08	9.35	8.47	7.93	7.96	9.07	8.53	9.38	9.49	8.91
1993	8.71	8.06	9.73	9.76	8.25	9.05	8.82	7.80	8.26	8.03	8.75	9.50	8.73
1994	8.89	9.05	8.93	9.03	9.11	8.22	7.79	8.09	8.16	8.77	9.93	8.20	8.68
1995	8.30	8.63	9.20	8.80	9.37	8.70	8.01	7.60	8.00	9.26	8.43	7.91	8.52
1996	9.43	9.06	9.82	10.11	9.18	8.19	7.65	7.69	8.60	9.26	9.02	9.54	8.96
1997	8.89	9.14	9.36	9.46	8.48	8.80	8.54	6.88	7.87	10.43	9.11	9.63	8.88
1998	7.99	8.68	9.18	9.09	8.57	9.10	7.28	7.57	8.52	8.54	8.40	8.23	8.42
1999	8.93	9.83	9.78	10.53	9.38	8.81	8.11	7.42	7.74	8.51	7.84	9.63	8.87
2000	7.98	8.74	8.88	10.35	9.00	9.00	7.84	7.13	8.56	8.43	8.58	9.02	8.62
2001	8.83	8.16	7.84	10.05	8.37	8.34	7.56	7.99	8.21	8.62	8.46	8.60	8.42
2002	8.89	9.86	9.05	9.49	9.38	9.14	8.57	9.07	8.97	8.43	8.43	7.37	8.88
2003	8.47	7.60	8.97	10.31	8.47	7.94	7.92	8.05	8.31	8.37	8.81	9.28	8.55
2004	7.76	9.16	9.37	9.05	8.99	8.38	7.21	7.73	9.50	9.24	9.14	8.22	8.64
2005	8.29	7.31	9.17	10.59	8.43	8.90	9.01	7.35	8.32	8.29	10.15	8.54	8.70
2006	9.42	9.02	10.54	10.14	8.01	8.44	7.75	7.86	7.76	8.79	8.59	9.60	8.83
2007	8.82	8.77	9.06	9.38	8.60	9.10	7.87	8.01	9.31	9.89	8.26	9.39	8.87
2008	9.19	9.11	8.84	10.68	10.33	8.16	8.06	8.74	8.44	9.26	9.33	9.54	9.14
2009	9.78	8.87	9.86	10.48	8.58	7.69	7.44	8.29	8.63	9.45	8.44	9.34	8.91
2010	7.52	7.70	9.87	10.78	10.46	9.23	8.35	8.60	8.97	8.88	9.33	8.50	9.02
2011	8.44	10.06	9.41	10.29	9.55	9.37	7.96	7.57	7.58	8.69	9.30	8.88	8.91
2012	9.23	9.77	9.40	10.23	8.73	9.68	8.08	8.53	7.88	8.63	8.10	8.77	8.91
2013	8.28	9.50	9.14	9.62	8.29	8.73	7.83	7.41	8.90	9.11	8.63	8.36	8.64
2014	9.56	8.72	9.63	11.06	8.82	8.98	7.58	7.14	8.53	8.66	9.55	8.52	8.89
2015	8.85	8.69	8.27	9.36	8.42	7.39	7.12	8.08	7.64	8.66	8.69	9.57	8.38
Avg	8.93	8.82	9.46	9.85	9.08	8.74	8.07	7.97	8.45	8.78	8.92	8.89	8.83

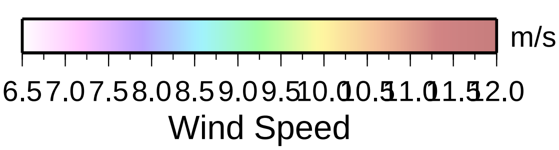

Figure 31: Monthly-mean values of simulated project-average wind speed.

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	9.89	11.14	2.61	8.32
NNE	8.49	9.56	2.59	5.90
NE	7.49	8.45	2.43	4.36
ENE	6.92	7.80	2.35	3.34
E	6.93	7.83	2.20	2.93
ESE	7.74	8.74	2.18	3.58
SE	9.63	10.85	2.57	7.21
SSE	9.95	11.15	2.93	12.35
S	8.67	9.74	2.79	10.52
SSW	7.71	8.68	2.65	7.42
SW	7.42	8.37	2.34	5.36
WSW	7.00	7.91	2.21	3.92
W	7.47	8.42	2.41	3.94
WNW	8.85	9.96	2.58	5.28
NW	9.59	10.82	2.47	6.24
NNW	11.01	12.41	2.47	9.31
ALL	**8.83**	**9.96**	**2.40**	**100.00**

Table 20: Simulated project-average mean wind speed, Weibull parameters, and frequency. Blank values correspond to times with less than 10 data points.

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
0.5 - 1.5	0.03	0.04	0.04	0.06	0.06	0.07	0.05	0.06	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.74
1.5 - 2.5	0.13	0.13	0.17	0.15	0.17	0.15	0.16	0.14	0.14	0.14	0.14	0.13	0.12	0.13	0.12	0.13	2.26
2.5 - 3.5	0.23	0.26	0.28	0.28	0.24	0.23	0.23	0.26	0.30	0.32	0.31	0.28	0.26	0.24	0.21	0.23	4.16
3.5 - 4.5	0.35	0.39	0.36	0.34	0.30	0.30	0.34	0.42	0.51	0.54	0.50	0.42	0.34	0.30	0.30	0.31	6.03
4.5 - 5.5	0.49	0.46	0.45	0.37	0.32	0.34	0.43	0.59	0.73	0.71	0.64	0.56	0.45	0.38	0.35	0.40	7.65
5.5 - 6.5	0.59	0.54	0.49	0.38	0.31	0.34	0.51	0.76	0.96	0.93	0.71	0.58	0.47	0.41	0.44	0.51	8.93
6.5 - 7.5	0.68	0.60	0.52	0.42	0.32	0.35	0.61	0.99	1.17	1.02	0.72	0.51	0.45	0.45	0.52	0.61	9.94
7.5 - 8.5	0.74	0.65	0.51	0.36	0.30	0.34	0.63	1.15	1.34	1.00	0.63	0.38	0.42	0.51	0.58	0.72	10.27
8.5 - 9.5	0.77	0.60	0.40	0.29	0.26	0.31	0.60	1.24	1.35	0.87	0.47	0.27	0.36	0.50	0.62	0.77	9.66
9.5 - 10.5	0.76	0.57	0.34	0.24	0.21	0.28	0.61	1.27	1.17	0.65	0.37	0.19	0.30	0.56	0.59	0.80	8.92
10.5 - 11.5	0.70	0.49	0.28	0.19	0.16	0.26	0.61	1.25	0.95	0.43	0.27	0.15	0.25	0.49	0.59	0.79	7.87
11.5 - 12.5	0.66	0.40	0.21	0.12	0.12	0.20	0.59	1.17	0.66	0.29	0.17	0.12	0.18	0.43	0.50	0.76	6.57
12.5 - 13.5	0.62	0.28	0.13	0.07	0.07	0.13	0.53	0.98	0.41	0.18	0.12	0.09	0.13	0.32	0.39	0.64	5.09
13.5 - 14.5	0.45	0.19	0.08	0.03	0.04	0.10	0.44	0.80	0.30	0.11	0.09	0.07	0.07	0.22	0.27	0.56	3.81
14.5 - 15.5	0.34	0.14	0.05	0.02	0.02	0.06	0.32	0.52	0.19	0.07	0.06	0.05	0.05	0.13	0.21	0.47	2.69
15.5 - 16.5	0.28	0.08	0.03	0.01	0.01	0.04	0.22	0.30	0.10	0.05	0.04	0.03	0.02	0.08	0.15	0.37	1.83
16.5 - 17.5	0.21	0.04	0.01	0.01	0.01	0.02	0.12	0.18	0.05	0.03	0.03	0.02	0.01	0.04	0.10	0.33	1.21
17.5 - 18.5	0.11	0.02	0.01	0.00	0.00	0.01	0.08	0.10	0.05	0.02	0.02	0.02	0.01	0.02	0.07	0.24	0.77
18.5 - 19.5	0.07	0.01	0.01	0.00	0.00	0.01	0.05	0.06	0.03	0.01	0.01	0.01	0.00	0.01	0.04	0.17	0.50
19.5 - 20.5	0.05	0.01	0.00	0.00	0.00	0.01	0.03	0.04	0.01	0.01	0.01	0.01	0.00	0.01	0.04	0.12	0.33
20.5 - 21.5	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.02	0.09	0.23
21.5 - 22.5	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.07	0.17
22.5 - 23.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.11
23.5 - 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.08
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.12

Table 21: Distribution of simulated project-average wind speed by direction.

11.5 Project-average Long-term Gross Power Capacity Assessment

11.5.1 Monthly-mean Variability of Power Capacity

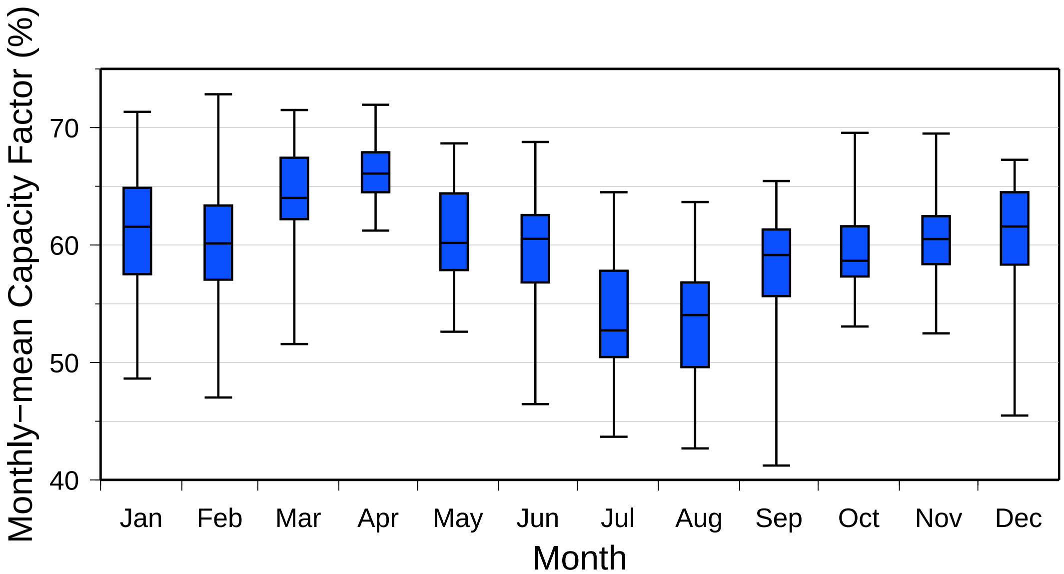

Figure 32: Box-and-whisker plot of monthly-mean project-average gross power capacity. This figure displays the expected variability of monthly-mean project-average gross power capacities. Median power capacity denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond to the 75% and 25% quartiles, while the whiskers denote the maximum and minimum monthly-mean power capacities.

11.5.2 Annual-mean Variability of Power Capacity

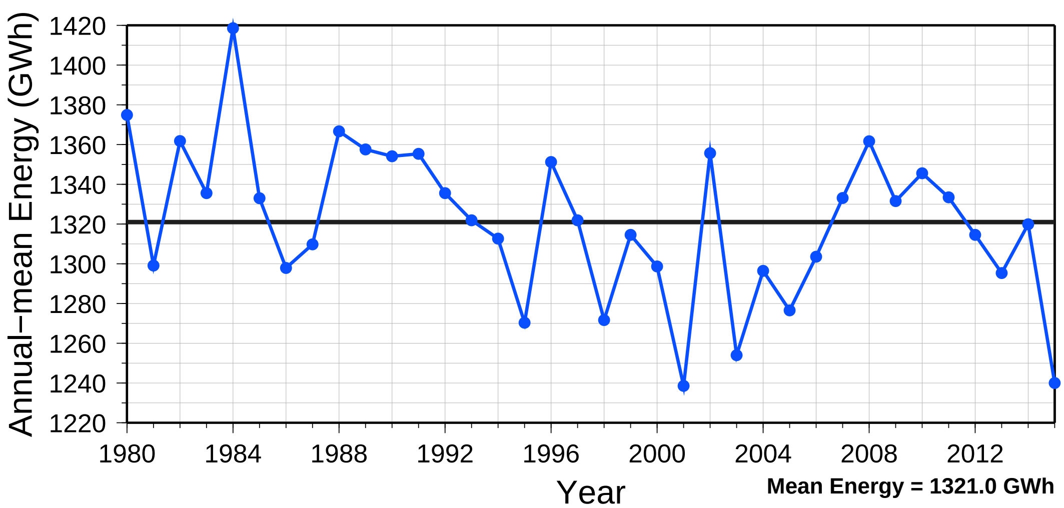

Figure 33: Time series of annual-mean project-average gross energy. Black line denotes the long-term mean.

11.5.3 Power Direction Distribution

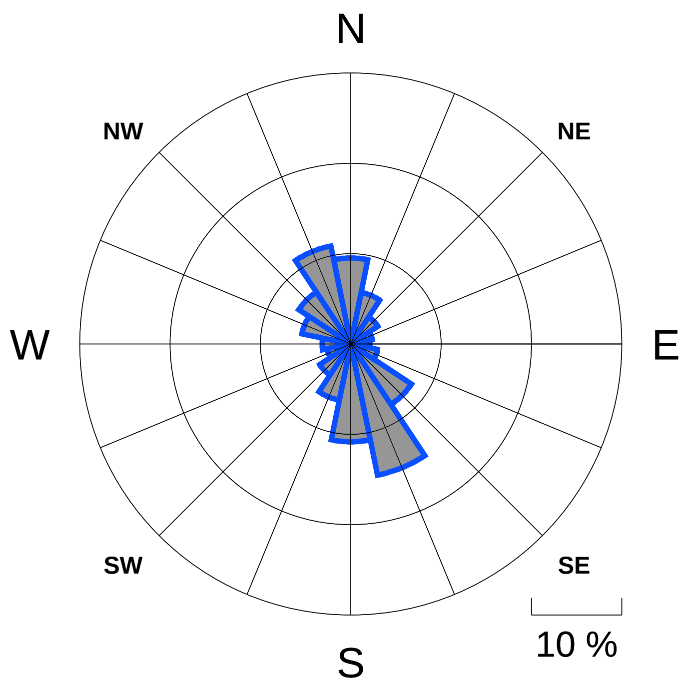

Figure 34: Annual power rose of the hourly-mean project-average gross capacity factor time series. Power rose shows the percent of total power within each sector. Directional bins are 22.5° wide, and the radial contour interval is 10%.

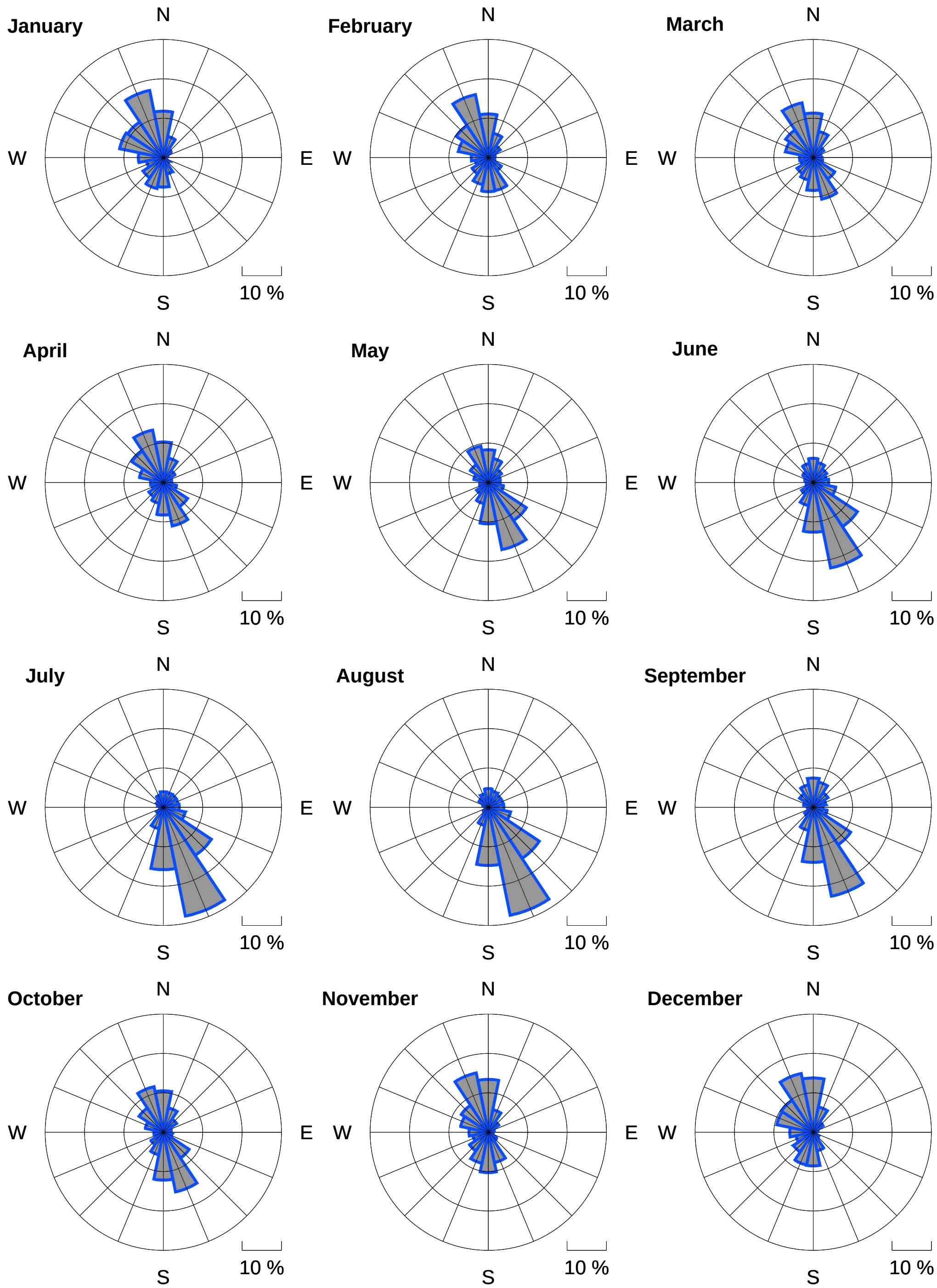

Figure 35: Power roses of the hourly-mean project-average gross capacity factor time series for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%.

11.5.4 Diurnal Variability of Power Capacity

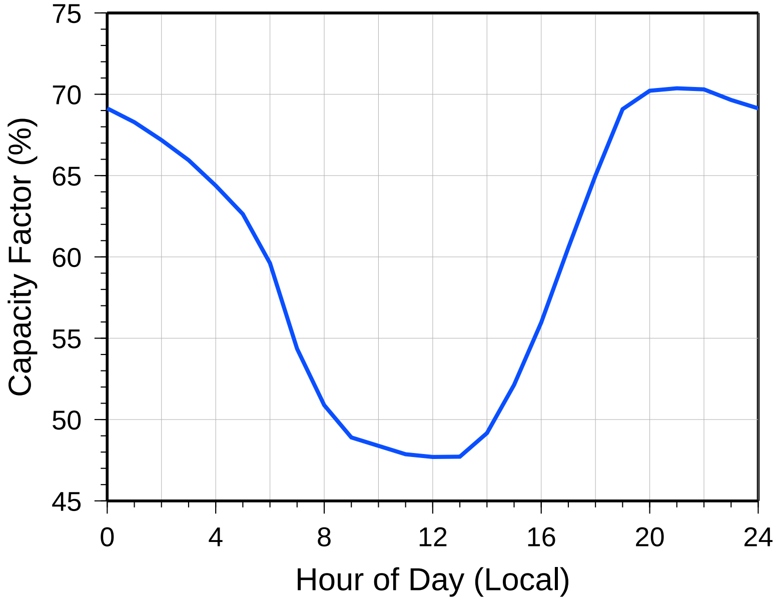

Figure 36: Diurnal cycle of simulated project-average gross power capacity. The horizontal axis is Mountain Standard Time (MST).

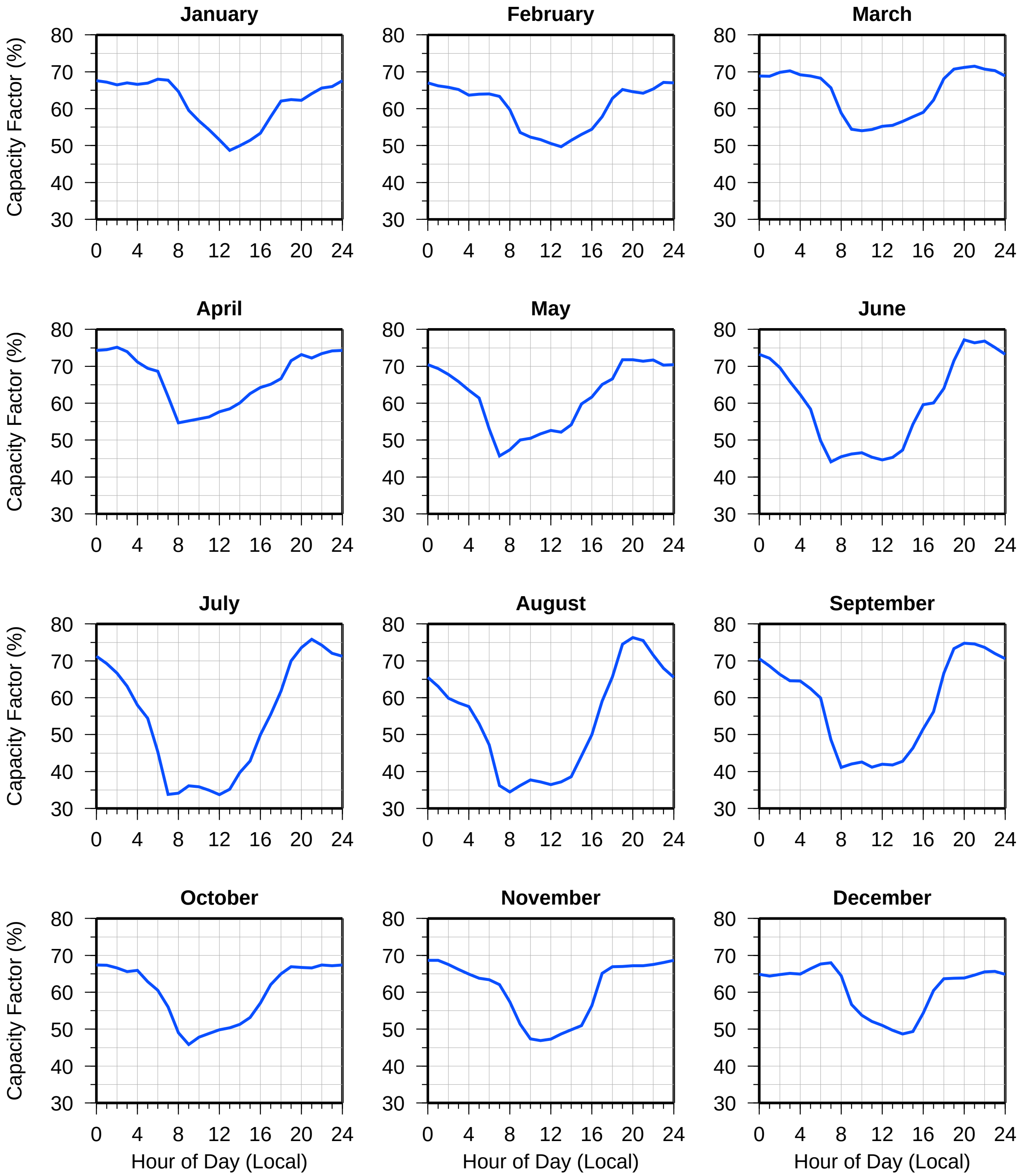

Figure 37: Diurnal cycle of simulated project-average gross power capacity for each calendar month. The horizontal axis is Mountain Standard Time (MST).

11.5.5 Power Capacity Variability and ENSO

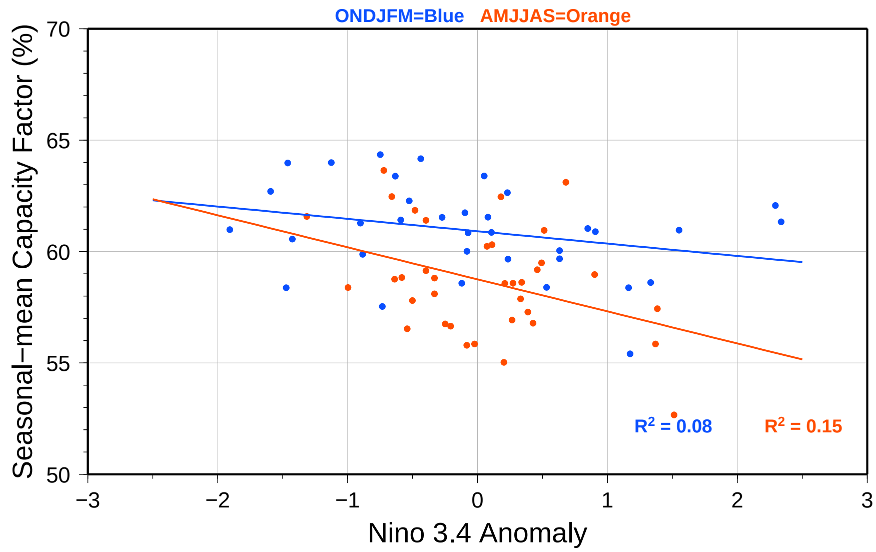

Figure 38: Scatter plot of Niño 3.4 anomalies vs. 6-month seasonal-mean gross power capacity. Blue dots denote the mean during ONDJFM (October, November, December, January, February, and March); orange dots denote the mean during AMJJAS (April, May, June, July, August and September).

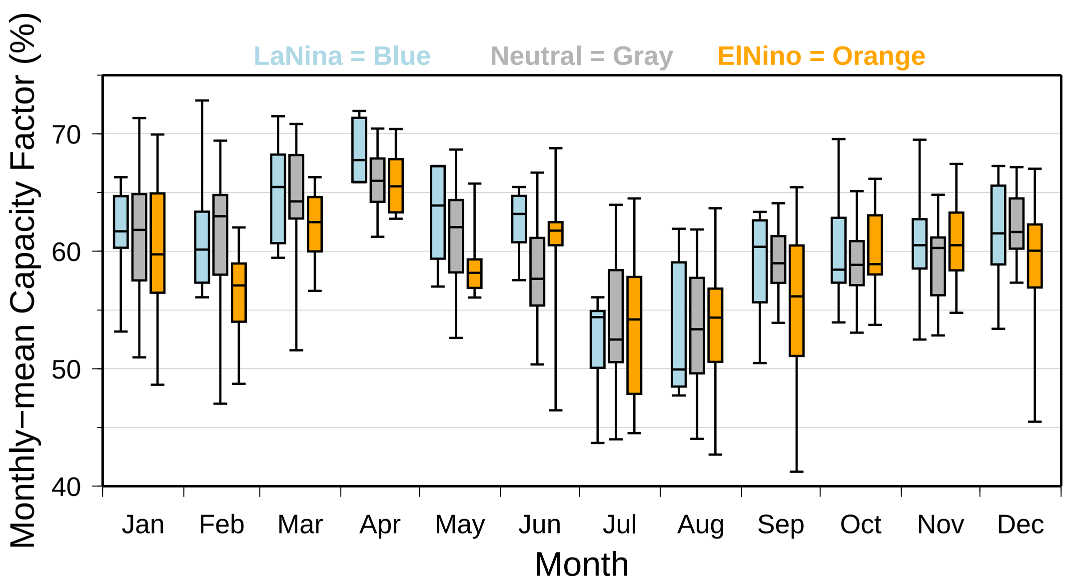

Figure 39: Box-and-whisker plot of monthly-mean project-average gross power capacity for La Niña (blue), neutral (gray), and El Niño (orange) phases of ENSO. Median power capacity denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond to the 75% and 25% quartiles, while the whiskers denote the maximum and minimum power capacities.

11.5.6 Tabular Data

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	67.6	67.0	68.8	74.3	70.5	73.2	71.2	65.5	70.6	67.4	68.6	64.9	69.1
1	67.2	66.2	68.8	74.5	69.4	72.2	69.2	63.0	68.6	67.3	68.7	64.4	68.3
2	66.5	65.8	69.8	75.2	67.8	69.6	66.7	59.8	66.3	66.6	67.5	64.8	67.2
3	67.0	65.2	70.3	74.0	65.9	65.8	63.1	58.6	64.6	65.6	66.2	65.2	65.9
4	66.6	63.7	69.2	71.2	63.5	62.4	58.0	57.6	64.5	66.0	64.9	65.0	64.4
5	66.9	64.0	68.8	69.4	61.4	58.4	54.4	52.9	62.5	62.9	63.8	66.4	62.6
6	68.0	64.0	68.3	68.7	53.0	49.8	45.4	47.2	59.9	60.6	63.4	67.6	59.6
7	67.7	63.3	65.7	61.8	45.7	44.1	33.8	36.2	48.6	56.0	62.1	68.0	54.3
8	64.7	59.7	58.8	54.7	47.4	45.5	34.1	34.5	41.1	49.0	57.4	64.5	50.9
9	59.6	53.5	54.4	55.2	50.0	46.3	36.2	36.2	42.0	45.8	51.3	56.7	48.9
10	56.7	52.3	54.0	55.8	50.5	46.6	35.9	37.7	42.6	47.8	47.4	53.8	48.4
11	54.3	51.6	54.4	56.3	51.7	45.4	34.9	37.2	41.2	48.8	46.9	52.1	47.9
12	51.6	50.6	55.2	57.7	52.6	44.6	33.7	36.5	42.0	49.8	47.3	51.0	47.7
13	48.7	49.7	55.5	58.5	52.2	45.3	35.2	37.2	41.8	50.4	48.7	49.7	47.7
14	50.0	51.4	56.6	60.1	54.2	47.3	39.7	38.6	42.8	51.3	49.8	48.7	49.2
15	51.4	53.0	57.8	62.6	59.8	54.3	42.8	44.3	46.4	53.1	50.9	49.4	52.1
16	53.4	54.4	59.0	64.3	61.7	59.6	50.0	49.9	51.6	57.1	56.4	54.3	56.0
17	57.9	57.9	61.5	65.6	65.0	60.3	55.8	58.8	56.6	61.7	65.0	60.6	60.6
18	62.1	62.8	67.5	67.0	66.7	64.2	61.8	65.3	67.3	64.8	66.8	63.8	65.0
19	62.4	65.0	70.3	71.7	71.7	71.6	70.0	74.2	74.1	66.8	67.1	64.1	69.1
20	62.2	64.3	70.9	73.2	71.7	76.9	73.6	76.1	75.4	66.7	67.3	64.2	70.2
21	64.1	63.9	71.4	72.4	71.2	76.2	76.0	75.2	75.2	66.4	67.1	65.0	70.4
22	65.7	65.0	70.5	73.5	71.6	76.8	74.4	71.5	74.1	67.3	67.3	66.0	70.3
23	66.2	66.7	70.4	74.1	70.2	75.0	72.3	68.0	72.3	67.1	67.8	66.0	69.7
Avg	61.2	60.0	64.1	66.3	61.0	59.6	53.7	53.4	58.0	59.4	60.4	60.7	59.8

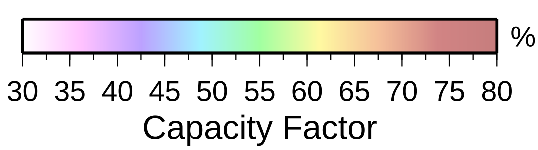

Figure 40: Hourly-mean values of simulated project-average gross capacity factor. Vertical axis is local time.

Year	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
1980	66.4	58.0	70.8	67.5	64.3	65.6	52.9	61.0	63.5	57.1	55.1	64.5	62.2
1981	57.5	60.0	57.2	66.0	65.2	58.5	59.3	49.9	53.9	62.9	56.3	59.0	58.8
1982	71.3	64.4	66.5	68.4	59.7	61.8	55.8	48.3	59.8	63.1	58.8	62.3	61.6
1983	64.9	57.0	66.3	66.6	59.3	50.2	62.4	53.0	60.2	57.3	60.5	67.3	60.5
1984	63.4	69.4	68.2	70.2	63.3	63.8	58.4	56.6	58.8	63.9	69.5	65.6	64.2
1985	60.3	56.1	68.6	67.2	57.0	57.5	50.1	57.7	63.1	60.9	60.6	65.0	60.3
1986	64.7	56.7	60.7	69.9	57.9	57.7	58.1	58.4	59.5	58.9	57.3	45.5	58.8
1987	69.9	54.0	64.6	65.5	57.6	61.6	64.5	54.1	41.2	53.7	62.1	61.8	59.3
1988	56.6	62.5	69.4	63.6	65.0	60.2	56.1	61.9	62.6	57.8	64.4	62.4	61.9
1989	61.8	57.3	62.2	65.9	62.8	62.6	64.0	58.6	61.0	58.3	60.6	62.2	61.5
1990	66.5	62.9	60.0	66.7	65.7	66.2	52.2	51.9	59.2	58.1	64.8	62.0	61.3
1991	60.7	60.0	70.3	64.8	65.5	68.8	47.8	56.8	61.9	55.0	66.7	58.3	61.4
1992	68.7	57.1	60.0	62.8	65.8	55.4	53.0	54.1	64.1	57.3	60.0	67.2	60.5
1993	62.7	52.8	69.3	67.8	56.9	62.5	61.4	51.1	57.3	53.1	61.2	61.6	59.8
1994	61.8	63.0	64.4	64.2	62.9	56.0	48.0	54.0	56.4	58.7	66.3	57.8	59.4
1995	58.0	60.6	64.0	61.2	64.9	57.1	52.0	49.6	55.7	53.9	60.1	53.4	57.5
1996	61.0	63.4	67.4	69.3	64.4	54.1	50.6	51.7	58.6	65.1	63.9	64.7	61.2
1997	61.7	64.9	64.6	65.1	56.2	60.5	57.8	42.7	52.8	62.0	63.3	67.0	59.8
1998	54.2	59.0	62.5	64.0	58.7	64.9	43.7	48.5	59.4	59.7	58.5	58.3	57.6
1999	61.4	59.9	65.5	68.4	67.2	60.8	54.4	47.7	51.8	58.6	52.5	65.8	59.5
2000	53.2	60.2	59.9	71.4	59.4	64.7	52.2	44.0	61.3	58.2	60.6	61.1	58.8
2001	57.5	56.1	51.6	66.2	56.5	55.1	46.6	54.8	55.6	60.0	52.8	60.2	56.1
2002	64.9	64.5	62.7	66.6	60.7	61.9	61.2	63.7	64.6	59.3	60.2	46.8	61.4
2003	56.4	48.7	61.1	65.2	58.2	51.4	49.8	54.5	55.9	57.9	61.0	60.5	56.8
2004	51.0	64.8	62.8	61.8	62.7	59.1	44.0	50.6	65.5	65.1	60.8	56.9	58.7
2005	56.5	47.0	64.0	64.6	58.2	60.5	63.3	46.7	58.1	56.2	59.5	58.1	57.8
2006	66.3	62.0	71.5	67.9	52.6	56.8	50.7	53.4	48.7	58.0	58.4	61.9	59.0
2007	61.5	55.0	63.3	64.0	58.9	61.4	53.5	54.2	62.9	69.6	58.1	61.5	60.3
2008	63.0	64.5	59.4	71.9	67.3	55.7	53.9	61.9	57.8	55.3	62.5	66.7	61.6
2009	65.9	61.7	68.2	66.7	58.9	50.4	47.9	56.4	60.5	66.2	57.6	63.0	60.3
2010	48.6	53.2	63.1	70.4	68.7	65.5	54.9	59.1	63.4	62.8	62.3	58.9	60.9
2011	59.2	72.8	67.8	65.9	64.4	64.2	52.5	49.4	50.5	56.6	62.7	59.6	60.4
2012	61.2	64.0	63.5	64.5	56.0	66.7	52.6	60.3	51.3	59.4	53.5	61.3	59.5
2013	56.6	65.5	63.7	61.5	56.8	61.1	51.9	47.3	61.3	61.6	59.9	57.3	58.6
2014	65.5	59.8	65.1	70.4	62.1	60.5	50.5	44.6	59.1	59.4	67.4	53.2	59.8
2015	61.6	62.0	56.6	63.3	56.1	46.5	44.5	54.6	51.1	58.3	54.8	65.5	56.1
Avg	61.2	60.0	64.1	66.3	61.0	59.6	53.7	53.4	58.0	59.4	60.4	60.7	59.8

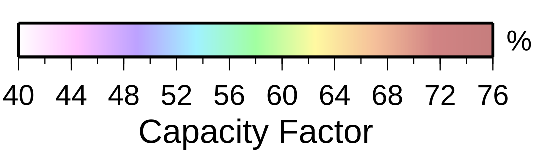

Figure 41: Monthly-mean values of simulated project-average gross capacity factor.

Sector	Mean Capacity Factor(%)	Percent Total Power(%)
N	68.3	9.5
NNE	59.1	5.8
NE	49.0	3.6
ENE	43.1	2.4
E	43.3	2.1
ESE	50.7	3.0
SE	66.7	8.0
SSE	71.8	14.8
S	61.5	10.8
SSW	51.2	6.4
SW	46.1	4.1
WSW	40.8	2.7
W	48.2	3.2
WNW	62.6	5.5
NW	66.1	6.9
NNW	71.1	11.1
ALL	**59.8**	**100.0**

Table 22: Simulated project-average gross mean power capacity factor and percent of total power. Blank values correspond to times with less than 10 data points.

Power Capacity (%)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 5%	0.52	0.53	0.57	0.57	0.55	0.54	0.54	0.60	0.66	0.66	0.63	0.55	0.50	0.48	0.52	0.73	9.14
5% - 15%	0.56	0.55	0.54	0.47	0.42	0.44	0.53	0.68	0.82	0.82	0.75	0.66	0.52	0.46	0.43	0.50	9.16
15% - 25%	0.52	0.47	0.45	0.35	0.29	0.32	0.46	0.65	0.81	0.78	0.63	0.53	0.44	0.37	0.36	0.44	7.89
25% - 35%	0.45	0.40	0.35	0.29	0.22	0.24	0.39	0.63	0.76	0.70	0.49	0.41	0.33	0.30	0.34	0.40	6.71
35% - 45%	0.39	0.34	0.29	0.26	0.19	0.21	0.36	0.59	0.69	0.59	0.44	0.30	0.27	0.26	0.32	0.38	5.87
45% - 55%	0.40	0.33	0.28	0.19	0.17	0.17	0.35	0.59	0.65	0.51	0.33	0.22	0.23	0.25	0.29	0.39	5.35
55% - 65%	0.37	0.32	0.27	0.17	0.15	0.17	0.31	0.56	0.67	0.49	0.32	0.19	0.20	0.27	0.30	0.38	5.15
65% - 75%	0.40	0.33	0.23	0.17	0.14	0.17	0.32	0.59	0.67	0.48	0.29	0.15	0.19	0.24	0.31	0.40	5.08
75% - 85%	0.48	0.37	0.24	0.17	0.16	0.18	0.35	0.68	0.75	0.49	0.27	0.17	0.20	0.29	0.35	0.48	5.64
85% - 95%	0.70	0.56	0.33	0.22	0.20	0.26	0.54	1.07	1.04	0.64	0.38	0.21	0.31	0.47	0.52	0.74	8.17
95% - 100%	3.53	1.70	0.83	0.48	0.45	0.86	3.06	5.71	3.01	1.27	0.83	0.53	0.74	1.89	2.49	4.47	31.84

Table 23: Distribution of simulated project-average gross power capacity by direction.

11.6 Long-term Wind Resource Assessment for Tower M2196 at 80 m

11.6.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	9.91	11.17	2.47	8.74
NNE	8.33	9.39	2.47	5.92
NE	7.51	8.47	2.41	4.54
ENE	6.85	7.73	2.39	3.53
E	6.77	7.64	2.24	2.93
ESE	7.44	8.40	2.05	3.14
SE	9.61	10.84	2.30	5.81
SSE	10.52	11.81	2.79	11.59
S	9.14	10.27	2.76	11.58
SSW	7.87	8.86	2.64	8.44
SW	7.19	8.12	2.26	5.95
WSW	6.65	7.51	2.20	4.20
W	7.19	8.11	2.36	4.19
WNW	8.56	9.65	2.44	5.18
NW	9.31	10.50	2.31	5.67
NNW	10.83	12.22	2.36	8.59
ALL	**8.78**	**9.91**	**2.29**	**100.00**

Table 24: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2196 at 80 m. Blank values correspond to times with less than 10 data points.

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.02	0.02	0.01	0.02	0.02	0.03	0.04	0.05	0.03	0.02	0.01	0.02	0.02	0.03	0.02	0.03	0.40
0.5 - 1.5	0.07	0.06	0.05	0.06	0.06	0.07	0.08	0.06	0.07	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.94
1.5 - 2.5	0.14	0.14	0.16	0.13	0.14	0.15	0.14	0.14	0.16	0.16	0.15	0.13	0.14	0.13	0.14	0.13	2.29
2.5 - 3.5	0.26	0.30	0.28	0.27	0.25	0.25	0.22	0.24	0.30	0.35	0.39	0.31	0.29	0.24	0.21	0.23	4.36
3.5 - 4.5	0.41	0.42	0.39	0.38	0.33	0.30	0.29	0.38	0.49	0.60	0.62	0.54	0.41	0.33	0.29	0.32	6.49
4.5 - 5.5	0.46	0.44	0.43	0.38	0.33	0.28	0.32	0.46	0.65	0.73	0.73	0.62	0.47	0.35	0.34	0.36	7.36
5.5 - 6.5	0.60	0.54	0.47	0.43	0.33	0.29	0.42	0.60	0.87	0.96	0.83	0.65	0.49	0.43	0.40	0.48	8.77
6.5 - 7.5	0.72	0.64	0.57	0.45	0.34	0.30	0.47	0.83	1.18	1.14	0.84	0.58	0.53	0.49	0.54	0.60	10.22
7.5 - 8.5	0.77	0.63	0.50	0.39	0.31	0.30	0.49	0.93	1.33	1.08	0.63	0.38	0.46	0.52	0.52	0.69	9.92
8.5 - 9.5	0.77	0.59	0.44	0.31	0.25	0.25	0.46	1.00	1.34	0.97	0.47	0.25	0.40	0.52	0.54	0.70	9.27
9.5 - 10.5	0.83	0.58	0.39	0.28	0.21	0.25	0.48	1.12	1.35	0.85	0.37	0.21	0.32	0.57	0.54	0.81	9.17
10.5 - 11.5	0.73	0.45	0.29	0.17	0.15	0.22	0.43	1.03	1.11	0.55	0.26	0.14	0.23	0.46	0.48	0.68	7.37
11.5 - 12.5	0.67	0.38	0.21	0.13	0.10	0.16	0.44	1.07	0.92	0.37	0.18	0.11	0.15	0.40	0.43	0.66	6.38
12.5 - 13.5	0.57	0.25	0.13	0.06	0.05	0.10	0.38	0.94	0.60	0.23	0.12	0.07	0.09	0.25	0.31	0.52	4.66
13.5 - 14.5	0.44	0.18	0.08	0.03	0.03	0.07	0.29	0.79	0.39	0.13	0.08	0.05	0.05	0.15	0.21	0.41	3.40
14.5 - 15.5	0.35	0.13	0.06	0.02	0.02	0.05	0.24	0.65	0.30	0.07	0.05	0.03	0.03	0.10	0.17	0.40	2.67
15.5 - 16.5	0.31	0.10	0.03	0.01	0.01	0.03	0.23	0.53	0.21	0.06	0.05	0.03	0.02	0.07	0.15	0.37	2.19
16.5 - 17.5	0.23	0.05	0.02	0.00	0.01	0.02	0.16	0.35	0.11	0.04	0.04	0.02	0.01	0.04	0.11	0.33	1.54
17.5 - 18.5	0.15	0.02	0.01	0.00	0.00	0.01	0.09	0.18	0.06	0.02	0.02	0.01	0.01	0.02	0.06	0.22	0.90
18.5 - 19.5	0.08	0.01	0.00	0.00	0.00	0.01	0.05	0.09	0.04	0.01	0.01	0.01	0.00	0.01	0.04	0.15	0.51
19.5 - 20.5	0.07	0.01	0.00	0.00	0.00	0.00	0.04	0.08	0.03	0.01	0.01	0.01	0.00	0.01	0.03	0.14	0.45
20.5 - 21.5	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.02	0.08	0.22
21.5 - 22.5	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.07	0.20
22.5 - 23.5	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.13
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05
> 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.13

Table 25: Distribution of simulated wind speed by direction for Tower M2196 at $80\,m$.

11.7 Long-term Wind Resource Assessment for Tower M2202 at 80 m

11.7.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	8.72	9.84	2.38	8.02
NNE	7.35	8.29	2.34	5.56
NE	6.59	7.44	2.19	4.22
ENE	6.07	6.85	2.07	3.38
E	5.98	6.74	1.90	3.04
ESE	6.65	7.49	1.88	3.53
SE	8.95	10.11	2.21	6.80
SSE	10.10	11.36	2.70	12.48
S	9.14	10.28	2.68	10.65
SSW	8.13	9.16	2.56	7.26
SW	7.68	8.67	2.29	5.35
WSW	7.05	7.96	2.20	4.04
W	7.49	8.46	2.26	3.99
WNW	8.54	9.64	2.36	4.93
NW	9.34	10.54	2.29	6.66
NNW	10.28	11.61	2.30	10.10
ALL	**8.51**	**9.61**	**2.22**	**100.00**

Table 26: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2202 at 80 m. Blank values correspond to times with less than 10 data points.

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.02	0.03	0.04	0.05	0.05	0.06	0.05	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.48
0.5 - 1.5	0.08	0.09	0.10	0.10	0.13	0.14	0.10	0.08	0.07	0.05	0.05	0.06	0.06	0.06	0.06	0.08	1.31
1.5 - 2.5	0.20	0.24	0.25	0.24	0.25	0.25	0.21	0.17	0.17	0.15	0.15	0.14	0.16	0.17	0.18	0.20	3.12
2.5 - 3.5	0.31	0.33	0.32	0.33	0.31	0.29	0.26	0.27	0.27	0.27	0.27	0.25	0.24	0.23	0.25	0.29	4.49
3.5 - 4.5	0.51	0.46	0.44	0.37	0.34	0.35	0.37	0.42	0.45	0.44	0.43	0.41	0.35	0.31	0.35	0.40	6.40
4.5 - 5.5	0.62	0.58	0.52	0.45	0.38	0.38	0.54	0.66	0.67	0.66	0.60	0.57	0.45	0.37	0.43	0.56	8.43
5.5 - 6.5	0.72	0.61	0.52	0.46	0.32	0.38	0.57	0.80	0.88	0.83	0.68	0.59	0.44	0.39	0.49	0.67	9.35
6.5 - 7.5	0.80	0.66	0.54	0.39	0.34	0.34	0.61	0.96	1.06	0.89	0.70	0.52	0.43	0.43	0.57	0.76	10.00
7.5 - 8.5	0.82	0.61	0.42	0.31	0.27	0.30	0.59	1.09	1.19	0.89	0.59	0.40	0.39	0.46	0.61	0.88	9.81
8.5 - 9.5	0.74	0.52	0.35	0.22	0.21	0.26	0.55	1.13	1.18	0.80	0.47	0.27	0.34	0.47	0.61	0.87	9.00
9.5 - 10.5	0.72	0.47	0.26	0.18	0.16	0.24	0.58	1.18	1.15	0.71	0.41	0.22	0.33	0.51	0.64	0.94	8.71
10.5 - 11.5	0.65	0.35	0.18	0.12	0.11	0.20	0.51	1.17	1.03	0.54	0.30	0.18	0.26	0.43	0.61	0.82	7.45
11.5 - 12.5	0.52	0.25	0.11	0.07	0.07	0.13	0.47	1.09	0.79	0.34	0.22	0.14	0.21	0.36	0.48	0.73	5.96
12.5 - 13.5	0.36	0.15	0.07	0.04	0.04	0.08	0.36	0.90	0.55	0.24	0.14	0.10	0.11	0.25	0.33	0.57	4.28
13.5 - 14.5	0.26	0.08	0.04	0.02	0.02	0.04	0.29	0.72	0.36	0.16	0.09	0.06	0.08	0.16	0.24	0.45	3.09
14.5 - 15.5	0.24	0.06	0.03	0.01	0.02	0.03	0.25	0.66	0.32	0.10	0.08	0.05	0.06	0.12	0.21	0.46	2.70
15.5 - 16.5	0.18	0.03	0.02	0.01	0.01	0.02	0.18	0.48	0.20	0.06	0.06	0.02	0.03	0.08	0.17	0.36	1.92
16.5 - 17.5	0.10	0.02	0.01	0.01	0.01	0.02	0.12	0.27	0.12	0.04	0.04	0.02	0.01	0.04	0.12	0.27	1.21
17.5 - 18.5	0.06	0.01	0.00	0.00	0.00	0.01	0.08	0.16	0.06	0.03	0.02	0.01	0.01	0.02	0.08	0.21	0.78
18.5 - 19.5	0.04	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.05	0.02	0.02	0.01	0.01	0.01	0.06	0.16	0.54
19.5 - 20.5	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.02	0.01	0.01	0.01	0.00	0.01	0.04	0.10	0.29
20.5 - 21.5	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.06	0.17
21.5 - 22.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.03	0.07	0.20
22.5 - 23.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.14
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.12

Table 27: Distribution of simulated wind speed by direction for Tower M2202 at $80\,m$.

11.8 Long-term Wind Resource Assessment for Tower M2311 at 80 m

11.8.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	10.48	11.79	2.70	8.33
NNE	9.11	10.26	2.63	6.04
NE	8.19	9.23	2.48	4.59
ENE	7.47	8.43	2.38	3.49
E	7.48	8.45	2.24	3.06
ESE	8.37	9.45	2.21	3.89
SE	10.25	11.53	2.68	8.18
SSE	10.04	11.25	2.96	12.66
S	8.61	9.67	2.74	10.08
SSW	7.61	8.56	2.61	6.96
SW	7.26	8.19	2.28	4.94
WSW	6.86	7.75	2.22	3.69
W	7.34	8.27	2.49	3.84
WNW	8.90	10.02	2.67	5.41
NW	9.74	10.97	2.55	6.09
NNW	11.34	12.78	2.53	8.75
ALL	**9.08**	**10.24**	**2.42**	**100.00**

Table 28: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2311 at 80 m. Blank values correspond to times with less than 10 data points.

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
0.5 - 1.5	0.02	0.03	0.03	0.03	0.03	0.05	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.41
1.5 - 2.5	0.11	0.10	0.12	0.13	0.16	0.17	0.16	0.16	0.16	0.12	0.12	0.10	0.10	0.11	0.10	0.11	2.04
2.5 - 3.5	0.21	0.22	0.25	0.25	0.25	0.23	0.24	0.28	0.33	0.35	0.32	0.29	0.26	0.23	0.21	0.22	4.15
3.5 - 4.5	0.30	0.36	0.36	0.34	0.30	0.29	0.31	0.42	0.53	0.60	0.54	0.46	0.38	0.33	0.29	0.29	6.11
4.5 - 5.5	0.38	0.40	0.36	0.32	0.27	0.28	0.39	0.53	0.66	0.70	0.61	0.54	0.43	0.34	0.31	0.32	6.86
5.5 - 6.5	0.52	0.50	0.46	0.38	0.30	0.35	0.48	0.76	0.95	0.90	0.72	0.59	0.51	0.44	0.40	0.43	8.70
6.5 - 7.5	0.57	0.51	0.46	0.36	0.30	0.34	0.54	0.92	1.10	0.92	0.64	0.48	0.46	0.48	0.47	0.52	9.06
7.5 - 8.5	0.68	0.57	0.49	0.39	0.30	0.35	0.64	1.17	1.23	0.90	0.51	0.31	0.43	0.53	0.55	0.61	9.67
8.5 - 9.5	0.72	0.62	0.49	0.33	0.29	0.34	0.69	1.32	1.30	0.77	0.40	0.26	0.36	0.56	0.63	0.71	9.78
9.5 - 10.5	0.74	0.59	0.40	0.27	0.26	0.32	0.71	1.33	1.12	0.56	0.31	0.17	0.29	0.58	0.63	0.74	9.02
10.5 - 11.5	0.72	0.52	0.34	0.22	0.20	0.29	0.69	1.34	0.92	0.41	0.21	0.13	0.22	0.50	0.57	0.73	8.03
11.5 - 12.5	0.70	0.47	0.29	0.18	0.17	0.26	0.74	1.26	0.64	0.27	0.16	0.10	0.17	0.46	0.53	0.72	7.11
12.5 - 13.5	0.64	0.37	0.19	0.12	0.10	0.20	0.64	1.01	0.41	0.16	0.10	0.08	0.10	0.34	0.41	0.65	5.53
13.5 - 14.5	0.61	0.29	0.15	0.08	0.06	0.15	0.64	0.86	0.27	0.10	0.09	0.06	0.06	0.23	0.32	0.63	4.56
14.5 - 15.5	0.42	0.19	0.08	0.03	0.04	0.10	0.46	0.51	0.15	0.06	0.05	0.03	0.03	0.12	0.20	0.48	2.96
15.5 - 16.5	0.34	0.12	0.05	0.02	0.02	0.07	0.31	0.30	0.08	0.03	0.04	0.02	0.01	0.06	0.14	0.37	1.99
16.5 - 17.5	0.23	0.08	0.03	0.01	0.01	0.04	0.21	0.17	0.05	0.03	0.03	0.02	0.01	0.03	0.10	0.33	1.37
17.5 - 18.5	0.16	0.04	0.02	0.01	0.01	0.03	0.12	0.11	0.04	0.02	0.02	0.01	0.01	0.02	0.06	0.26	0.93
18.5 - 19.5	0.08	0.02	0.01	0.00	0.00	0.01	0.06	0.06	0.02	0.01	0.01	0.01	0.00	0.01	0.04	0.16	0.51
19.5 - 20.5	0.05	0.01	0.01	0.00	0.00	0.01	0.04	0.03	0.01	0.01	0.01	0.01	0.00	0.01	0.03	0.10	0.32
20.5 - 21.5	0.05	0.01	0.01	0.00	0.00	0.00	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.03	0.11	0.30
21.5 - 22.5	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.06	0.16
22.5 - 23.5	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.06	0.16
23.5 - 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.10
> 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.09	0.16

Table 29: Distribution of simulated wind speed by direction for Tower M2311 at $80\,m$.

11.9 Long-term Wind Resource Assessment for Tower M2313 at 80 m

11.9.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	10.84	12.20	2.63	8.38
NNE	9.63	10.84	2.56	6.14
NE	8.86	9.99	2.45	4.66
ENE	8.09	9.13	2.36	3.39
E	8.10	9.14	2.22	2.91
ESE	9.18	10.36	2.27	3.74
SE	10.62	11.94	2.77	8.49
SSE	9.64	10.82	2.86	12.38
S	7.93	8.93	2.57	10.22
SSW	6.98	7.87	2.38	6.87
SW	6.72	7.58	2.07	4.70
WSW	6.30	7.12	2.03	3.52
W	6.60	7.45	2.30	3.75
WNW	8.45	9.52	2.52	5.79
NW	9.53	10.75	2.47	6.58
NNW	11.21	12.64	2.40	8.49
ALL	**9.00**	**10.16**	**2.31**	**100.00**

Table 30: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2313 at 80 m. Blank values correspond to times with less than 10 data points.

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
0.5 - 1.5	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.35
1.5 - 2.5	0.09	0.10	0.10	0.10	0.12	0.13	0.13	0.15	0.17	0.16	0.14	0.13	0.13	0.13	0.12	0.13	2.05
2.5 - 3.5	0.19	0.20	0.20	0.21	0.20	0.16	0.19	0.27	0.43	0.49	0.43	0.40	0.36	0.29	0.25	0.21	4.49
3.5 - 4.5	0.26	0.28	0.26	0.25	0.22	0.20	0.25	0.38	0.64	0.73	0.67	0.56	0.44	0.36	0.29	0.26	6.03
4.5 - 5.5	0.40	0.41	0.36	0.31	0.26	0.27	0.39	0.64	0.98	0.98	0.82	0.67	0.58	0.48	0.37	0.38	8.29
5.5 - 6.5	0.54	0.46	0.43	0.35	0.26	0.30	0.47	0.86	1.24	1.04	0.67	0.53	0.53	0.55	0.49	0.48	9.21
6.5 - 7.5	0.61	0.55	0.50	0.38	0.30	0.35	0.60	1.16	1.43	0.96	0.51	0.35	0.48	0.64	0.62	0.59	10.04
7.5 - 8.5	0.68	0.59	0.49	0.37	0.28	0.34	0.67	1.35	1.41	0.77	0.39	0.23	0.37	0.63	0.67	0.67	9.93
8.5 - 9.5	0.72	0.59	0.46	0.32	0.26	0.32	0.71	1.44	1.22	0.58	0.27	0.16	0.27	0.60	0.69	0.75	9.38
9.5 - 10.5	0.65	0.51	0.37	0.25	0.22	0.30	0.68	1.32	0.86	0.38	0.18	0.11	0.18	0.51	0.59	0.67	7.78
10.5 - 11.5	0.59	0.44	0.31	0.20	0.17	0.24	0.69	1.08	0.57	0.23	0.14	0.08	0.12	0.42	0.51	0.58	6.38
11.5 - 12.5	0.61	0.44	0.27	0.17	0.16	0.23	0.67	1.01	0.39	0.15	0.10	0.07	0.08	0.35	0.47	0.56	5.74
12.5 - 13.5	0.62	0.40	0.26	0.16	0.14	0.23	0.73	0.94	0.29	0.11	0.10	0.06	0.06	0.30	0.43	0.58	5.41
13.5 - 14.5	0.66	0.37	0.22	0.13	0.11	0.21	0.77	0.73	0.20	0.09	0.08	0.05	0.05	0.23	0.35	0.58	4.83
14.5 - 15.5	0.50	0.27	0.16	0.07	0.06	0.14	0.54	0.40	0.11	0.07	0.05	0.03	0.02	0.12	0.22	0.48	3.25
15.5 - 16.5	0.35	0.17	0.08	0.04	0.04	0.09	0.34	0.19	0.06	0.04	0.03	0.02	0.02	0.06	0.14	0.32	1.99
16.5 - 17.5	0.25	0.13	0.06	0.02	0.02	0.06	0.20	0.14	0.03	0.02	0.03	0.01	0.01	0.03	0.09	0.25	1.36
17.5 - 18.5	0.22	0.08	0.05	0.01	0.02	0.05	0.15	0.10	0.04	0.02	0.02	0.02	0.01	0.02	0.08	0.26	1.14
18.5 - 19.5	0.18	0.06	0.03	0.01	0.01	0.04	0.11	0.07	0.03	0.02	0.02	0.01	0.01	0.01	0.06	0.22	0.88
19.5 - 20.5	0.09	0.03	0.01	0.01	0.01	0.02	0.05	0.04	0.02	0.01	0.01	0.00	0.00	0.01	0.03	0.13	0.46
20.5 - 21.5	0.05	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.23
21.5 - 22.5	0.04	0.01	0.01	0.00	0.00	0.01	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.03	0.10	0.30
22.5 - 23.5	0.04	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.09	0.23
23.5 - 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06
> 24.5	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.11	0.20

Table 31: Distribution of simulated wind speed by direction for Tower M2313 at $80\,m$.

12 APPENDIX VALIDATION OF MODEL RESULTS

12.1 Validation of Model Results at Tower M2196

This section examines the quality of the NWP simulations used at a single point within the study area. For this section, the observations were taken at Tower M2196 (latitude 39.11318, longitude -103.2344).

The average observed wind speed (for all valid observational times) at $59.0\,m$ during the 28 months of the period of record (June, 2008 to September, 2010) is $8.51\,m/s$ with an hourly standard deviation of $3.86\,m/s$ at Tower M2196. This compares to a modeled $59\,m$ wind speed of $7.44\,m/s$ with a $3.47\,m/s$ standard deviation for these same times.

Based on a comparison of the NWP model output with observations from each of the meteorological towers for which data were provided, Model Output Statistics (MOS) was constructed. MOS uses a multilinear regression model designed to remove the bias and adjust the variance of the raw NWP simulated wind speed and direction. Applying this statistical model to the simulated data at Tower M2196 results in a MOS-corrected mean value of $8.51\,m/s$ and an hourly standard deviation of $3.86\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2196). The focus of the verification is on the model's ability to reproduce the observed variability of the wind resource at daily and monthly time scales, while preserving the distribution of hourly wind speeds and the diurnal characteristics of the wind.

12.1.1 Observational Data

Approximately 28 months of wind speed data at $59.0\,meters$ and wind direction data at $57.0\,meters$ (June, 2008 to September, 2010) from a meteorological tower (Tower M2196) at Rush Creek II were used in this analysis. This tower will be referred to as the reference tower throughout this section. The data at $59\,m$ were used to assess the quality of the model simulations at $59\,m$.

It should be noted that meteorological observations provided to 3TIER are not allowed to influence the raw model simulations.

12.1.2 Model Validation Statistics

Table 32 presents some basic statistical measures of the model performance relative to the measured winds at the reference tower during the observational period. Also shown are values (labeled "MOS-corrected") for model data with the statistical model applied. For reference, the correlation of the reference tower data to itself is perfect and hence the explained variance (r^2) value is 1.0.

The observed and modeled winds in this section represent the mean of all times during the month for which a valid wind speed or direction observation was available. Therefore they should not be interpreted as estimates of the true winds at the site, but rather a verification of the model's ability to reproduce the available observations. Any month or hour missing greater than 50% of the available observations is omitted from the following figures, tables, and statistics.

Comparison	Value
Correlation of monthly-mean simulated wind speed to observed	0.95
RMS error of monthly-mean simulated wind speed	1.10 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.98
RMS error of monthly-mean MOS-corrected wind speed	0.18 m/s
Correlation of daily-mean simulated wind speed to observed	0.88
RMS error of daily-mean simulated wind speed	1.62 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.90
RMS error of daily-mean MOS-corrected wind speed	1.15 m/s

Table 32: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.1.3 Monthly Mean Wind Speed

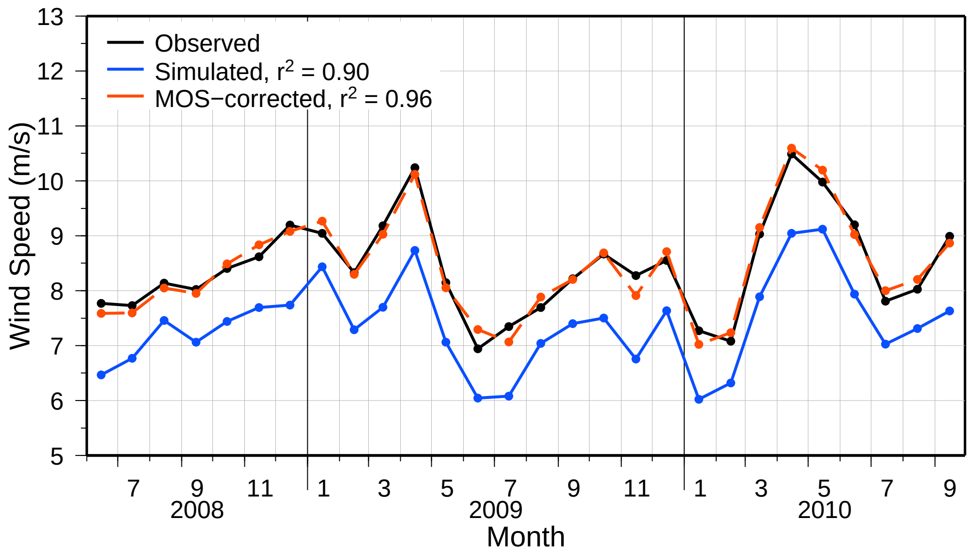

Figure 42: A comparison of the observed, simulated, and MOS-corrected monthly-mean $59\,m$ wind speed at Tower M2196. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 33 (p. 85).

12.1.4 Wind Speed Distribution

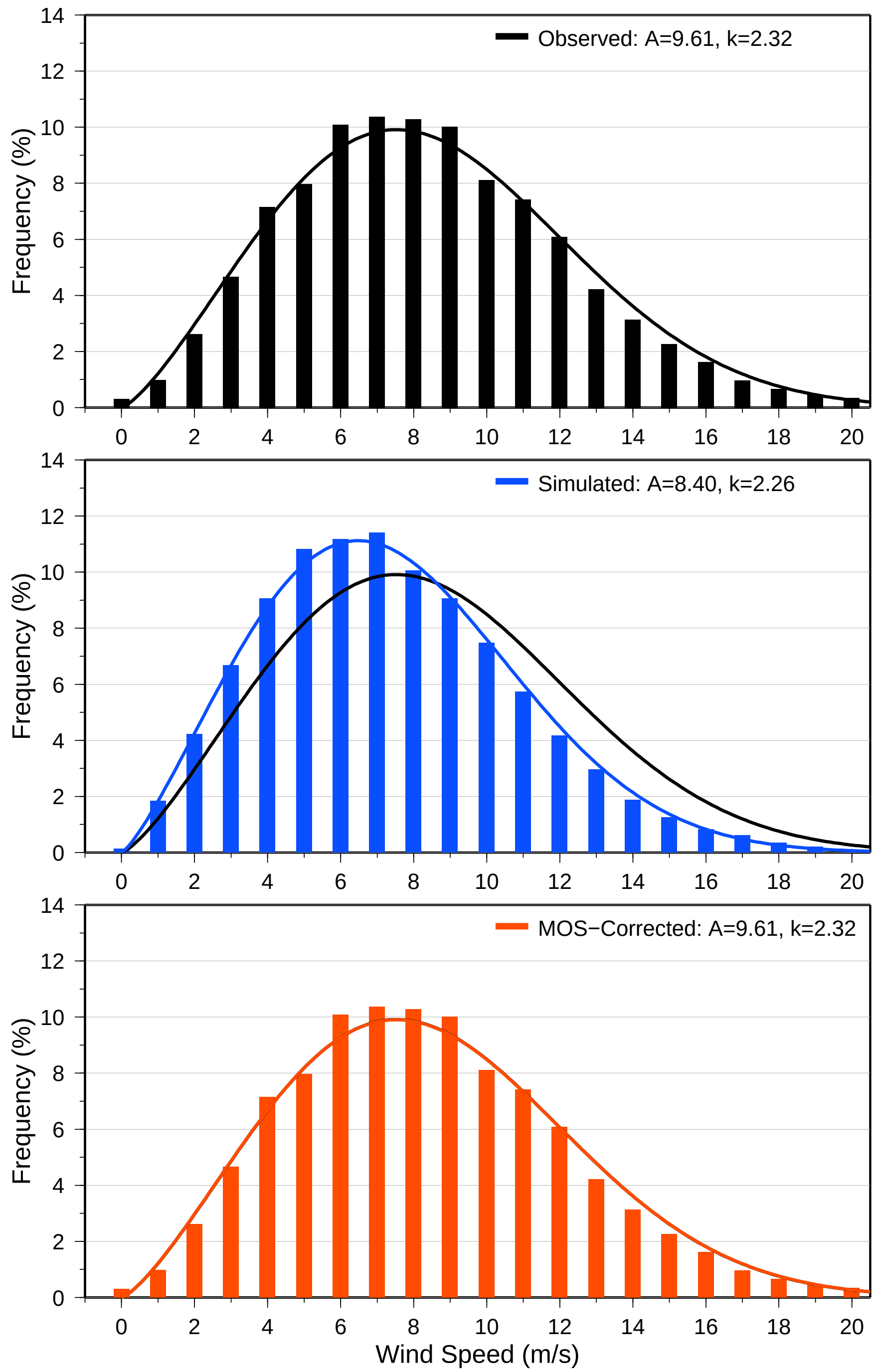

Figure 43: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $59\,m$ at Tower M2196 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend.

12.1.5 Wind Direction Distribution

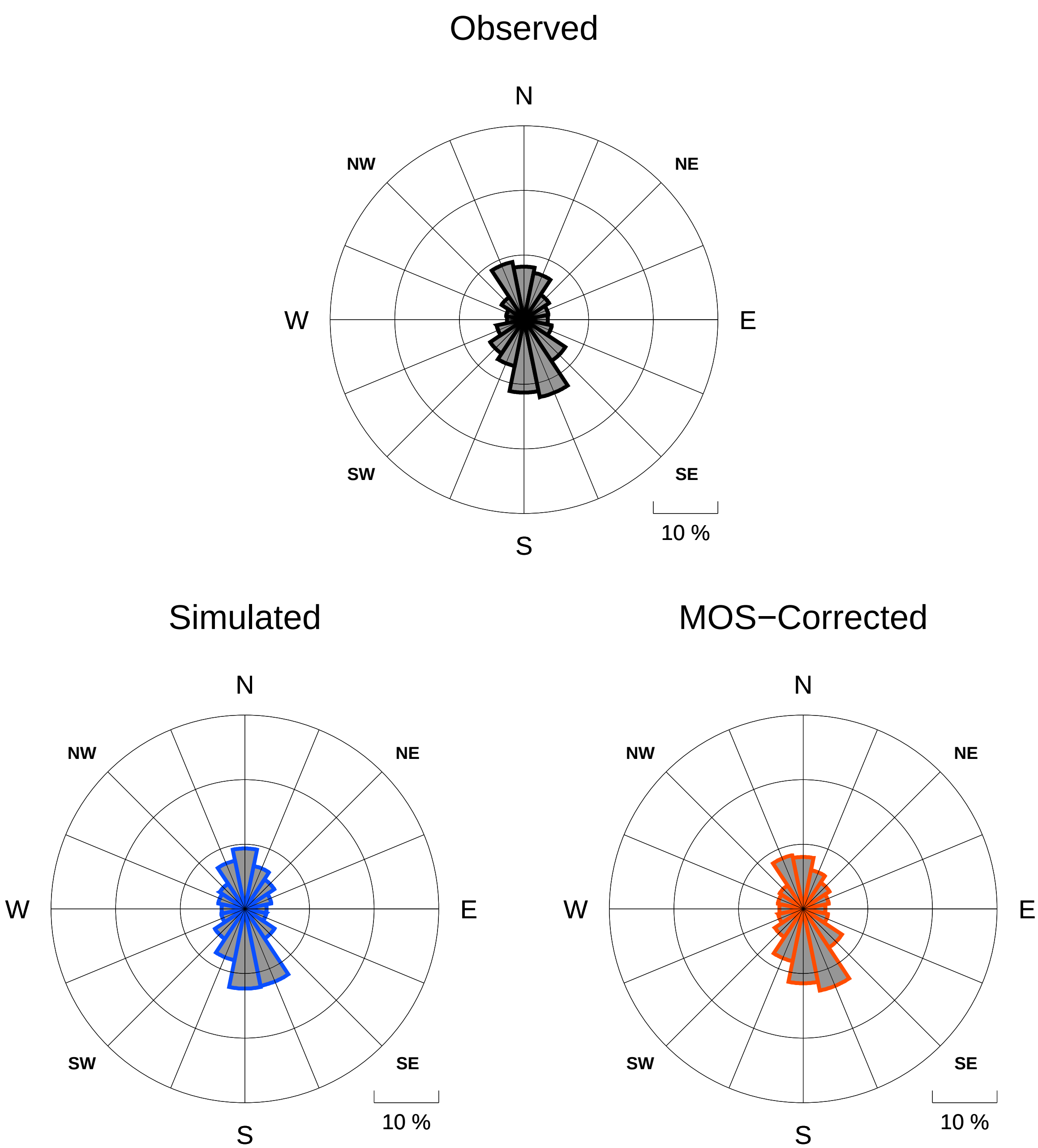

Figure 44: Wind roses at 57 m at Tower M2196 for observational data and simulated model data, averaged over the period of record (June, 2008–September, 2010). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 36 and 37 (p. 90).

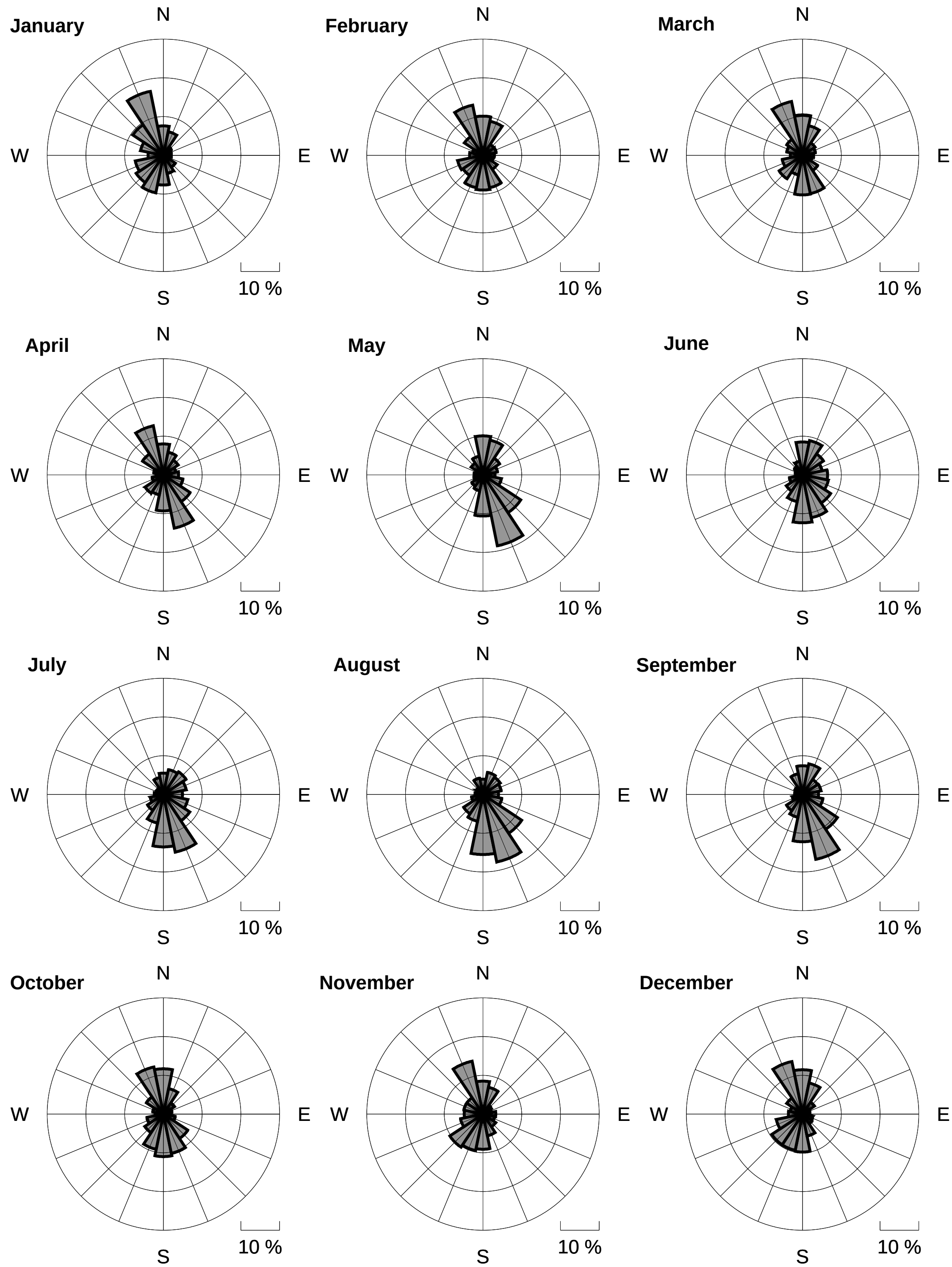

Figure 45: Wind rose of observed wind direction at $57\,m$ at Tower M2196 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

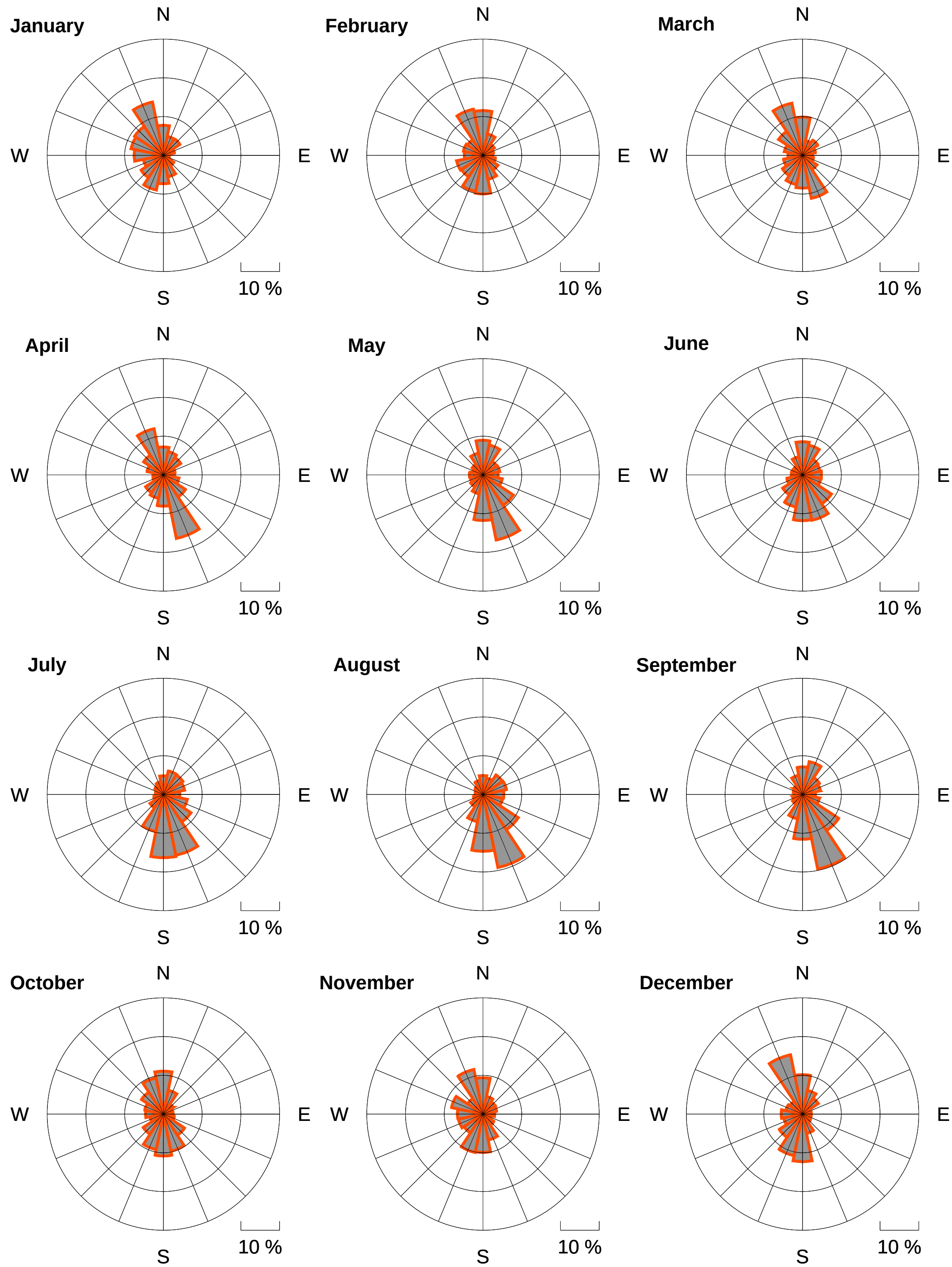

Figure 46: Wind rose of MOS-corrected wind direction at $57\,m$ at Tower M2196 for each calendar month. Directional bins are $22.5°$ wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.1.6 Diurnal Variability of Wind Speed

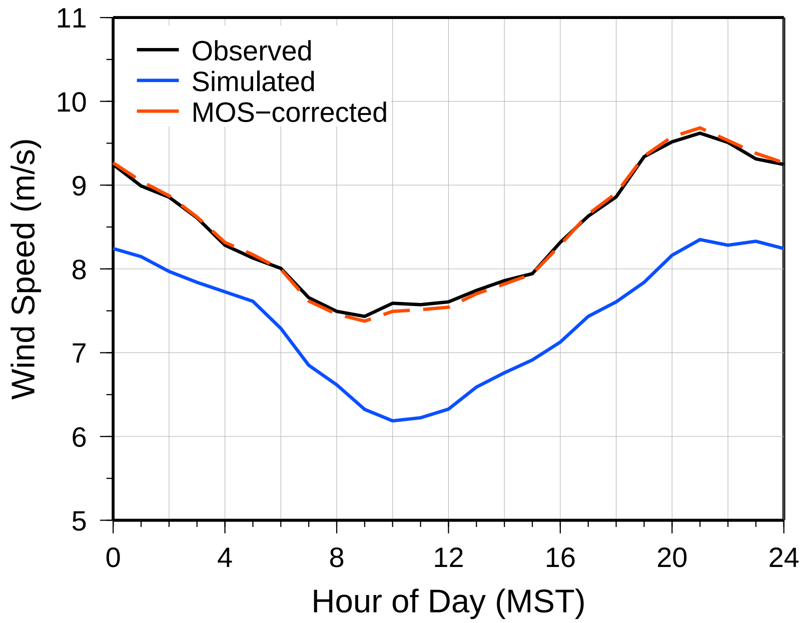

Figure 47: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 59 m wind speed at Tower M2196. Data are averaged over the period of record (June, 2008–September, 2010). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data are available in Figures 49 and 50 (p. 86 and 87).

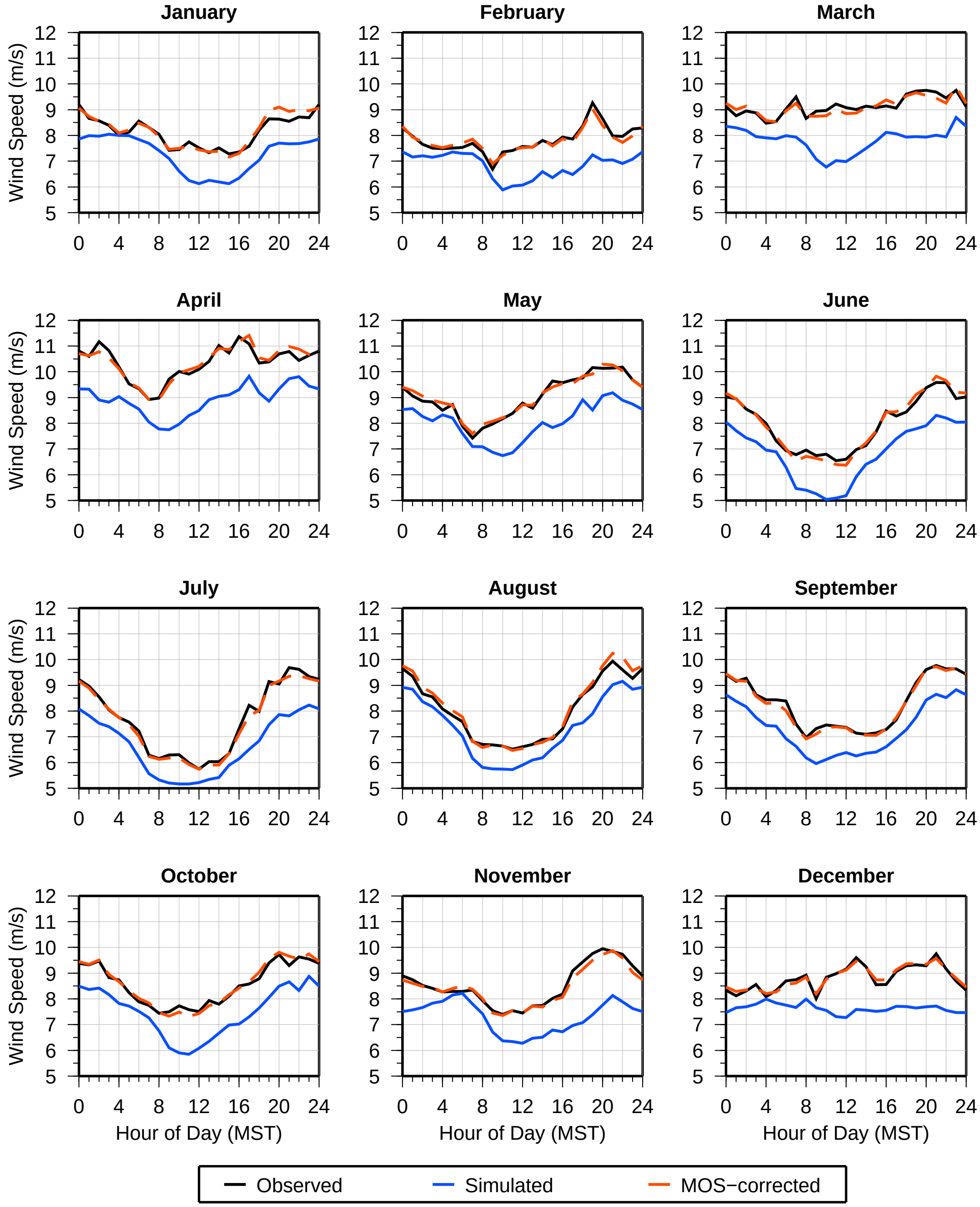

Figure 48: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected $59\,m$ wind speed for each calendar month at Tower M2196. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data available in Figures 49 and 50 (p. 86 and 87).

12.1.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
06/2008	7.77	6.47	-1.31	7.59	90.7
07/2008	7.73	6.77	-0.96	7.59	99.6
08/2008	8.14	7.46	-0.68	8.05	99.9
09/2008	8.02	7.06	-0.96	7.95	100.0
10/2008	8.41	7.44	-0.96	8.49	97.8
11/2008	8.62	7.69	-0.93	8.83	96.4
12/2008	9.20	7.74	-1.46	9.08	85.1
01/2009	9.04	8.44	-0.61	9.27	88.3
02/2009	8.33	7.29	-1.04	8.30	95.1
03/2009	9.18	7.70	-1.48	9.03	84.5
04/2009	10.24	8.74	-1.50	10.12	92.9
05/2009	8.15	7.06	-1.08	8.06	99.9
06/2009	6.94	6.04	-0.90	7.29	100.0
07/2009	7.35	6.08	-1.27	7.07	99.6
08/2009	7.69	7.04	-0.65	7.88	94.0
09/2009	8.22	7.40	-0.82	8.20	94.0
10/2009	8.67	7.50	-1.17	8.69	70.7
11/2009	8.28	6.76	-1.52	7.91	87.5
12/2009	8.55	7.63	-0.92	8.71	91.7
01/2010	7.27	6.02	-1.25	7.02	88.8
02/2010	7.08	6.32	-0.76	7.24	65.9
03/2010	9.03	7.89	-1.14	9.15	82.9
04/2010	10.49	9.05	-1.44	10.60	85.8
05/2010	9.98	9.12	-0.86	10.19	89.0
06/2010	9.20	7.94	-1.26	9.02	87.8
07/2010	7.81	7.03	-0.78	8.00	87.5
08/2010	8.03	7.31	-0.72	8.21	89.2
09/2010	8.99	7.63	-1.36	8.86	56.3
All	**8.51**	**7.44**	**-1.08**	**8.51**	**89.3**

Table 33: Monthly-mean $59\,m$ wind speeds (m/s) at Tower M2196. Time series graph of data is available in Figure 42 (p. 78). The average values shown at the bottom of the table, labeled 'All', are computed as the mean of monthly means.

Observed = mean of all available wind speed observations
Simulated = mean of simulated model output for times with observations
Bias = Simulated − Observed
MOS-corrected = mean of MOS-corrected output for times with observations

Observations

Hour of Day (MST)

	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.20	8.29	9.12	10.81	9.39	9.02	9.23	9.65	9.42	9.38	8.89	8.34	9.25
1	8.66	7.97	8.76	10.60	9.06	8.95	8.97	9.35	9.15	9.32	8.74	8.12	8.99
2	8.57	7.66	8.95	11.17	8.86	8.55	8.55	8.67	9.28	9.47	8.53	8.31	8.86
3	8.39	7.51	8.87	10.82	8.83	8.35	8.04	8.55	8.64	8.83	8.41	8.55	8.61
4	8.00	7.48	8.47	10.18	8.50	7.99	7.75	8.09	8.44	8.74	8.27	8.08	8.28
5	8.13	7.51	8.54	9.53	8.72	7.31	7.57	7.82	8.43	8.24	8.29	8.32	8.13
6	8.55	7.53	9.02	9.34	7.89	6.94	7.23	7.59	8.39	7.88	8.28	8.70	8.01
7	8.31	7.69	9.50	8.92	7.42	6.78	6.28	6.82	7.50	7.75	8.34	8.75	7.66
8	8.04	7.37	8.66	8.97	7.80	6.96	6.16	6.71	6.96	7.44	7.93	8.92	7.49
9	7.42	6.69	8.94	9.72	7.97	6.74	6.29	6.69	7.32	7.50	7.55	8.01	7.43
10	7.45	7.36	8.96	10.01	8.18	6.80	6.30	6.64	7.46	7.73	7.40	8.84	7.59
11	7.75	7.41	9.22	9.91	8.38	6.55	5.98	6.52	7.41	7.58	7.54	8.98	7.57
12	7.51	7.57	9.08	10.10	8.78	6.60	5.74	6.61	7.37	7.51	7.45	9.16	7.61
13	7.33	7.54	9.01	10.40	8.59	6.98	6.03	6.71	7.14	7.94	7.73	9.60	7.74
14	7.52	7.80	9.13	11.02	9.12	7.13	6.03	6.90	7.09	7.80	7.74	9.25	7.86
15	7.28	7.64	9.08	10.73	9.64	7.66	6.34	6.92	7.15	8.10	8.02	8.55	7.94
16	7.36	7.93	9.14	11.37	9.57	8.47	7.31	7.31	7.28	8.50	8.19	8.56	8.32
17	7.64	7.92	8.91	11.13	9.88	8.14	8.15	8.08	7.85	8.58	8.88	9.27	8.63
18	8.14	8.57	9.48	10.38	9.79	8.33	8.09	8.47	8.55	8.82	9.23	9.50	8.86
19	8.69	9.41	9.57	10.49	10.04	8.81	9.23	8.89	9.15	9.41	9.53	9.51	9.34
20	8.81	8.70	9.64	10.79	10.06	9.26	9.08	9.46	9.86	9.57	9.72	9.45	9.52
21	8.75	8.01	9.58	10.79	10.12	9.48	9.66	9.93	9.97	9.19	9.65	9.88	9.62
22	9.04	7.89	9.31	10.53	10.10	9.46	9.56	9.63	9.88	9.47	9.55	9.24	9.51
23	8.94	8.21	9.65	10.74	9.50	9.00	9.27	9.27	9.81	9.43	9.07	8.81	9.31
Avg	8.15	7.82	9.11	10.36	9.01	7.92	7.62	7.96	8.31	8.52	8.46	8.86	8.51

Wind Speed (m/s): 5 6 7 8 9 10 11 12

Figure 49: Hourly-mean values of observed 59 m wind speed at Tower M2196. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 47 and 48 (p. 83 and 84).

MOS−Corrected

Hour of Day (MST)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.06	8.35	9.24	10.70	9.40	9.17	9.16	9.76	9.45	9.45	8.74	8.46	9.27
1	8.73	7.94	9.00	10.62	9.27	8.94	8.89	9.55	9.19	9.35	8.61	8.28	9.05
2	8.55	7.74	9.14	10.77	9.05	8.57	8.45	8.92	9.15	9.51	8.49	8.35	8.87
3	8.42	7.60	8.92	10.55	8.89	8.32	8.07	8.70	8.58	8.95	8.44	8.41	8.62
4	8.09	7.52	8.58	10.12	8.79	7.85	7.75	8.31	8.30	8.67	8.27	8.20	8.32
5	8.21	7.62	8.53	9.57	8.70	7.48	7.48	8.02	8.31	8.30	8.40	8.27	8.17
6	8.47	7.70	8.95	9.37	7.98	7.01	7.02	7.78	8.02	8.02	8.50	8.56	8.00
7	8.32	7.85	9.24	8.92	7.60	6.53	6.24	6.82	7.39	7.84	8.37	8.61	7.62
8	7.96	7.49	8.75	8.92	7.96	6.71	6.12	6.58	6.92	7.47	8.01	8.85	7.46
9	7.46	6.90	8.74	9.53	8.08	6.64	6.17	6.68	7.10	7.33	7.45	8.20	7.38
10	7.50	7.23	8.77	9.96	8.21	6.54	6.19	6.64	7.36	7.48	7.36	8.75	7.49
11	7.58	7.46	9.01	10.08	8.36	6.40	5.92	6.47	7.39	7.32	7.54	8.99	7.51
12	7.44	7.53	8.85	10.21	8.71	6.37	5.75	6.55	7.34	7.43	7.46	9.11	7.54
13	7.37	7.54	8.87	10.54	8.70	6.91	5.90	6.69	7.09	7.74	7.72	9.46	7.70
14	7.39	7.86	9.08	10.90	9.17	7.23	5.90	6.79	7.07	7.83	7.68	9.22	7.82
15	7.16	7.59	9.14	10.86	9.41	7.69	6.34	6.98	7.06	8.16	7.94	8.73	7.94
16	7.30	7.87	9.37	11.18	9.54	8.42	7.12	7.39	7.30	8.42	8.06	8.73	8.29
17	7.68	7.84	9.11	11.23	9.76	8.43	7.85	8.18	7.83	8.80	8.60	9.42	8.65
18	8.16	8.54	9.39	10.47	9.97	8.61	8.01	8.49	8.52	9.13	8.94	9.59	8.90
19	8.83	9.22	9.65	10.45	9.90	9.02	9.02	9.00	9.15	9.64	9.30	9.57	9.35
20	8.85	8.66	9.59	10.79	10.21	9.28	9.22	9.61	9.87	9.82	9.54	9.59	9.58
21	8.80	8.23	9.43	10.94	10.21	9.68	9.44	10.08	10.00	9.60	9.69	9.74	9.68
22	8.90	8.09	9.06	10.87	9.98	9.56	9.45	9.94	9.83	9.50	9.45	9.31	9.53
23	8.93	8.30	9.71	10.63	9.64	9.09	9.30	9.47	9.86	9.72	8.94	8.88	9.38
Avg	8.14	7.86	9.09	10.35	9.06	7.93	7.53	8.04	8.25	8.57	8.40	8.89	8.51

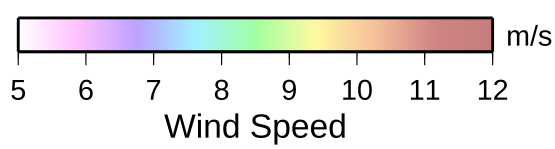

Figure 50: Hourly-mean values of MOS-corrected $59\,m$ wind speed at Tower M2196. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 47 and 48 (p. 83 and 84).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.01	0.04	0.03	0.02	0.01	0.01	0.02	0.03	0.01	0.04	0.00	0.03	0.02	0.01	0.01	0.02	0.31
0.5 - 1.5	0.10	0.05	0.04	0.08	0.03	0.03	0.09	0.07	0.09	0.06	0.07	0.08	0.04	0.06	0.04	0.08	0.98
1.5 - 2.5	0.19	0.17	0.09	0.08	0.16	0.20	0.18	0.14	0.17	0.14	0.21	0.21	0.17	0.18	0.17	0.16	2.62
2.5 - 3.5	0.36	0.32	0.20	0.27	0.25	0.29	0.31	0.25	0.33	0.28	0.31	0.37	0.27	0.29	0.28	0.27	4.65
3.5 - 4.5	0.51	0.37	0.32	0.41	0.50	0.37	0.37	0.48	0.62	0.64	0.51	0.48	0.38	0.32	0.35	0.49	7.13
4.5 - 5.5	0.53	0.54	0.30	0.40	0.37	0.53	0.56	0.57	0.83	0.69	0.58	0.44	0.40	0.36	0.32	0.53	7.94
5.5 - 6.5	0.76	0.72	0.40	0.54	0.54	0.40	0.69	0.83	0.95	1.07	0.76	0.48	0.31	0.41	0.56	0.62	10.05
6.5 - 7.5	0.79	0.56	0.35	0.38	0.51	0.53	0.75	0.97	1.12	1.00	0.85	0.55	0.35	0.35	0.56	0.71	10.34
7.5 - 8.5	0.86	0.66	0.26	0.34	0.40	0.47	0.82	0.94	1.24	1.00	0.74	0.61	0.33	0.28	0.48	0.79	10.23
8.5 - 9.5	0.83	0.71	0.25	0.30	0.34	0.50	0.71	1.18	1.42	0.79	0.80	0.55	0.22	0.22	0.45	0.71	9.99
9.5 - 10.5	0.79	0.64	0.14	0.14	0.24	0.37	0.66	1.20	1.21	0.63	0.54	0.30	0.12	0.15	0.31	0.63	8.08
10.5 - 11.5	0.69	0.53	0.08	0.07	0.19	0.30	0.70	1.32	1.16	0.52	0.44	0.15	0.06	0.11	0.26	0.81	7.39
11.5 - 12.5	0.56	0.36	0.06	0.11	0.13	0.30	0.57	1.29	0.88	0.37	0.27	0.10	0.04	0.08	0.24	0.71	6.06
12.5 - 13.5	0.55	0.24	0.02	0.02	0.05	0.13	0.40	1.09	0.59	0.15	0.15	0.04	0.01	0.05	0.13	0.59	4.20
13.5 - 14.5	0.37	0.16	0.02	0.02	0.02	0.04	0.38	0.84	0.45	0.12	0.09	0.04	0.02	0.04	0.03	0.48	3.12
14.5 - 15.5	0.31	0.10	0.00	0.00	0.03	0.04	0.28	0.67	0.30	0.07	0.06	0.02	0.01	0.02	0.06	0.31	2.25
15.5 - 16.5	0.19	0.04	0.00	0.00	0.01	0.02	0.25	0.38	0.16	0.03	0.07	0.03	0.01	0.01	0.04	0.40	1.62
16.5 - 17.5	0.09	0.03	0.01	0.00	0.01	0.02	0.14	0.20	0.08	0.03	0.04	0.02	0.00	0.01	0.03	0.26	0.96
17.5 - 18.5	0.03	0.02	0.01	0.00	0.01	0.00	0.06	0.12	0.03	0.02	0.04	0.02	0.01	0.01	0.02	0.28	0.67
18.5 - 19.5	0.04	0.01	0.00	0.00	0.01	0.01	0.03	0.08	0.01	0.01	0.02	0.00	0.00	0.01	0.01	0.23	0.45
19.5 - 20.5	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.04	0.00	0.01	0.01	0.00	0.01	0.01	0.16	0.35
20.5 - 21.5	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.13	0.22
21.5 - 22.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.08	0.16
22.5 - 23.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.04	0.08
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03

Table 34: Distribution of observed $59\,m$ wind speed by direction at Tower M2196. Histogram of data is available in Figure 43 (p. 79).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.03	0.02	0.01	0.01	0.01	0.01	0.04	0.03	0.02	0.01	0.01	0.03	0.00	0.02	0.03	0.02	0.31
0.5 - 1.5	0.08	0.07	0.07	0.06	0.05	0.07	0.04	0.07	0.08	0.03	0.04	0.04	0.07	0.08	0.05	0.09	0.98
1.5 - 2.5	0.19	0.24	0.16	0.18	0.15	0.15	0.18	0.15	0.17	0.15	0.18	0.15	0.16	0.13	0.15	0.14	2.62
2.5 - 3.5	0.28	0.21	0.34	0.36	0.32	0.27	0.36	0.25	0.31	0.30	0.33	0.38	0.30	0.27	0.16	0.22	4.65
3.5 - 4.5	0.34	0.43	0.37	0.38	0.42	0.43	0.40	0.40	0.52	0.57	0.66	0.64	0.51	0.41	0.33	0.30	7.13
4.5 - 5.5	0.37	0.29	0.30	0.50	0.29	0.38	0.44	0.49	0.71	0.89	0.84	0.68	0.49	0.45	0.39	0.43	7.94
5.5 - 6.5	0.59	0.50	0.46	0.56	0.44	0.38	0.60	0.68	1.09	1.27	0.90	0.66	0.50	0.50	0.32	0.61	10.05
6.5 - 7.5	0.76	0.53	0.43	0.37	0.42	0.41	0.53	1.00	1.36	1.44	0.71	0.40	0.50	0.46	0.44	0.59	10.34
7.5 - 8.5	0.72	0.55	0.37	0.38	0.43	0.42	0.73	1.14	1.44	1.22	0.47	0.34	0.43	0.40	0.54	0.68	10.25
8.5 - 9.5	0.82	0.56	0.39	0.33	0.25	0.40	0.67	1.43	1.54	0.92	0.38	0.20	0.26	0.41	0.54	0.88	9.99
9.5 - 10.5	0.72	0.52	0.32	0.18	0.25	0.29	0.66	1.25	1.21	0.54	0.19	0.15	0.27	0.40	0.39	0.73	8.08
10.5 - 11.5	0.82	0.42	0.20	0.10	0.13	0.31	0.69	1.31	1.16	0.45	0.20	0.11	0.13	0.27	0.41	0.68	7.38
11.5 - 12.5	0.61	0.43	0.19	0.09	0.07	0.20	0.55	1.36	0.88	0.29	0.14	0.08	0.09	0.20	0.33	0.55	6.06
12.5 - 13.5	0.45	0.30	0.05	0.03	0.05	0.11	0.50	1.17	0.51	0.19	0.14	0.04	0.05	0.06	0.14	0.42	4.20
13.5 - 14.5	0.40	0.23	0.04	0.00	0.04	0.05	0.38	0.79	0.38	0.08	0.10	0.08	0.03	0.04	0.08	0.41	3.12
14.5 - 15.5	0.31	0.11	0.03	0.01	0.02	0.02	0.19	0.67	0.27	0.07	0.04	0.02	0.03	0.02	0.07	0.39	2.25
15.5 - 16.5	0.16	0.07	0.01	0.00	0.01	0.02	0.21	0.43	0.08	0.06	0.04	0.04	0.01	0.01	0.04	0.44	1.62
16.5 - 17.5	0.15	0.02	0.02	0.00	0.01	0.01	0.08	0.21	0.04	0.01	0.02	0.03	0.00	0.01	0.01	0.36	0.96
17.5 - 18.5	0.05	0.01	0.02	0.00	0.00	0.00	0.07	0.15	0.02	0.02	0.02	0.01	0.00	0.01	0.02	0.28	0.67
18.5 - 19.5	0.08	0.01	0.00	0.00	0.00	0.01	0.01	0.11	0.02	0.01	0.03	0.01	0.01	0.00	0.01	0.16	0.45
19.5 - 20.5	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.08	0.02	0.02	0.03	0.01	0.00	0.00	0.01	0.14	0.35
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.01	0.02	0.01	0.00	0.01	0.00	0.02	0.09	0.22
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.00	0.06	0.16
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.06	0.08
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03

Table 35: Distribution of MOS-corrected 59 m wind speed by direction at Tower M2196. All model values are computed only for times with valid observations. Histogram of data is available in Figure 43 (p. 79).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	8.90	10.03	2.49	8.60
NNE	8.05	9.07	2.55	6.27
NE	6.43	7.25	2.42	2.58
ENE	6.31	7.11	2.51	3.18
E	6.82	7.69	2.42	3.80
ESE	7.48	8.44	2.46	4.55
SE	9.10	10.26	2.48	8.00
SSE	10.17	11.41	2.85	12.79
S	8.93	10.04	2.74	11.74
SSW	7.60	8.55	2.69	7.64
SW	7.78	8.78	2.41	6.61
WSW	6.88	7.77	2.23	4.55
W	6.04	6.82	2.22	2.78
WNW	6.52	7.36	2.08	2.98
NW	7.65	8.64	2.27	4.38
NNW	10.52	11.87	2.25	9.56
ALL	**8.51**	**9.61**	**2.32**	**100.00**

Table 36: Observed 59 m mean wind speed, Weibull parameters, and frequency at Tower M2196. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 44 (p. 80).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	9.35	10.53	2.57	7.95
NNE	8.34	9.40	2.50	5.51
NE	7.06	7.97	2.31	3.78
ENE	6.18	6.96	2.49	3.53
E	6.59	7.44	2.38	3.34
ESE	7.31	8.25	2.31	3.95
SE	9.09	10.25	2.47	7.37
SSE	10.31	11.56	2.91	13.25
S	8.76	9.83	2.82	11.88
SSW	7.58	8.53	2.62	8.58
SW	6.98	7.88	2.15	5.47
WSW	6.35	7.17	2.06	4.12
W	6.62	7.47	2.27	3.85
WNW	7.17	8.09	2.39	4.15
NW	8.17	9.22	2.39	4.49
NNW	10.68	12.05	2.33	8.78
ALL	**8.51**	**9.61**	**2.32**	**100.00**

Table 37: MOS-corrected 59 m mean wind speed, Weibull parameters, and frequency at Tower M2196. All MOS-corrected model values are computed only for times with valid observations; blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 44 (p. 80).

12.2 Validation of Model Results at Tower M2202

This section examines the quality of the NWP simulations used at a single point within the study area. For this section, the observations were taken at Tower M2202 (latitude 39.13467, longitude -103.18216).

The average observed wind speed (for all valid observational times) at $59.0\,m$ during the 27 months of the period of record (June, 2008 to August, 2010) is $8.23\,m/s$ with an hourly standard deviation of $3.90\,m/s$ at Tower M2202. This compares to a modeled $59\,m$ wind speed of $7.23\,m/s$ with a $3.34\,m/s$ standard deviation for these same times.

Based on a comparison of the NWP model output with observations from each of the meteorological towers for which data were provided, Model Output Statistics (MOS) was constructed. MOS uses a multilinear regression model designed to remove the bias and adjust the variance of the raw NWP simulated wind speed and direction. Applying this statistical model to the simulated data at Tower M2202 results in a MOS-corrected mean value of $8.24\,m/s$ and an hourly standard deviation of $3.90\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2202). The focus of the verification is on the model's ability to reproduce the observed variability of the wind resource at daily and monthly time scales, while preserving the distribution of hourly wind speeds and the diurnal characteristics of the wind.

12.2.1 Observational Data

Approximately 27 months of wind speed data at $59.0\,meters$ and wind direction data at $57.0\,meters$ (June, 2008 to August, 2010) from a meteorological tower (Tower M2202) at Rush Creek II were used in this analysis. This tower will be referred to as the reference tower throughout this section. The data at $59\,m$ were used to assess the quality of the model simulations at $59\,m$.

It should be noted that meteorological observations provided to 3TIER are not allowed to influence the raw model simulations.

12.2.2 Model Validation Statistics

Table 38 presents some basic statistical measures of the model performance relative to the measured winds at the reference tower during the observational period. Also shown are values (labeled "MOS-corrected") for model data with the statistical model applied. For reference, the correlation of the reference tower data to itself is perfect and hence the explained variance (r^2) value is 1.0.

The observed and modeled winds in this section represent the mean of all times during the month for which a valid wind speed or direction observation was available. Therefore they should not be interpreted as estimates of the true winds at the site, but rather a verification of the model's ability to reproduce the available observations. Any month or hour missing greater than 50% of the available observations is omitted from the following figures, tables, and statistics.

Comparison	Value
Correlation of monthly-mean simulated wind speed to observed	0.95
RMS error of monthly-mean simulated wind speed	1.04 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.98
RMS error of monthly-mean MOS-corrected wind speed	0.20 m/s
Correlation of daily-mean simulated wind speed to observed	0.88
RMS error of daily-mean simulated wind speed	1.62 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.90
RMS error of daily-mean MOS-corrected wind speed	1.20 m/s

Table 38: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.2.3 Monthly Mean Wind Speed

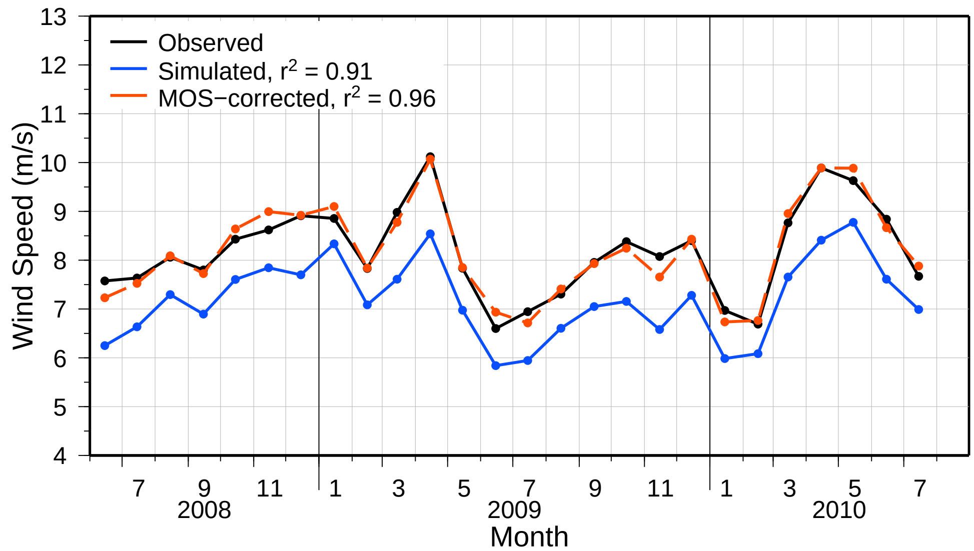

Figure 51: A comparison of the observed, simulated, and MOS-corrected monthly-mean $59\,m$ wind speed at Tower M2202. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 39 (p. 100).

12.2.4 Wind Speed Distribution

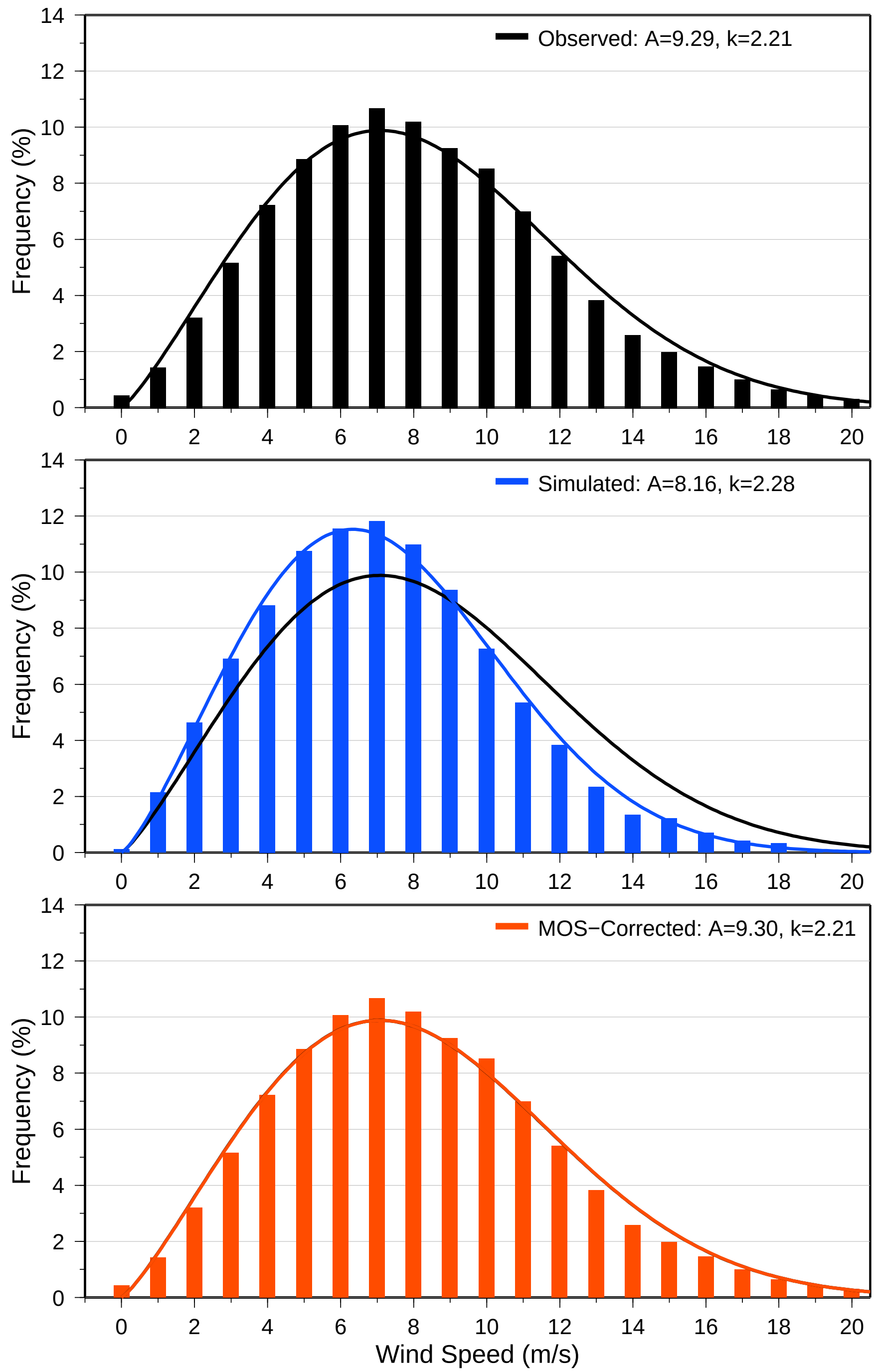

Figure 52: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at 59 m at Tower M2202 during the period of record, using 1 m/s bins. (0 m/s bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend.

12.2.5 Wind Direction Distribution

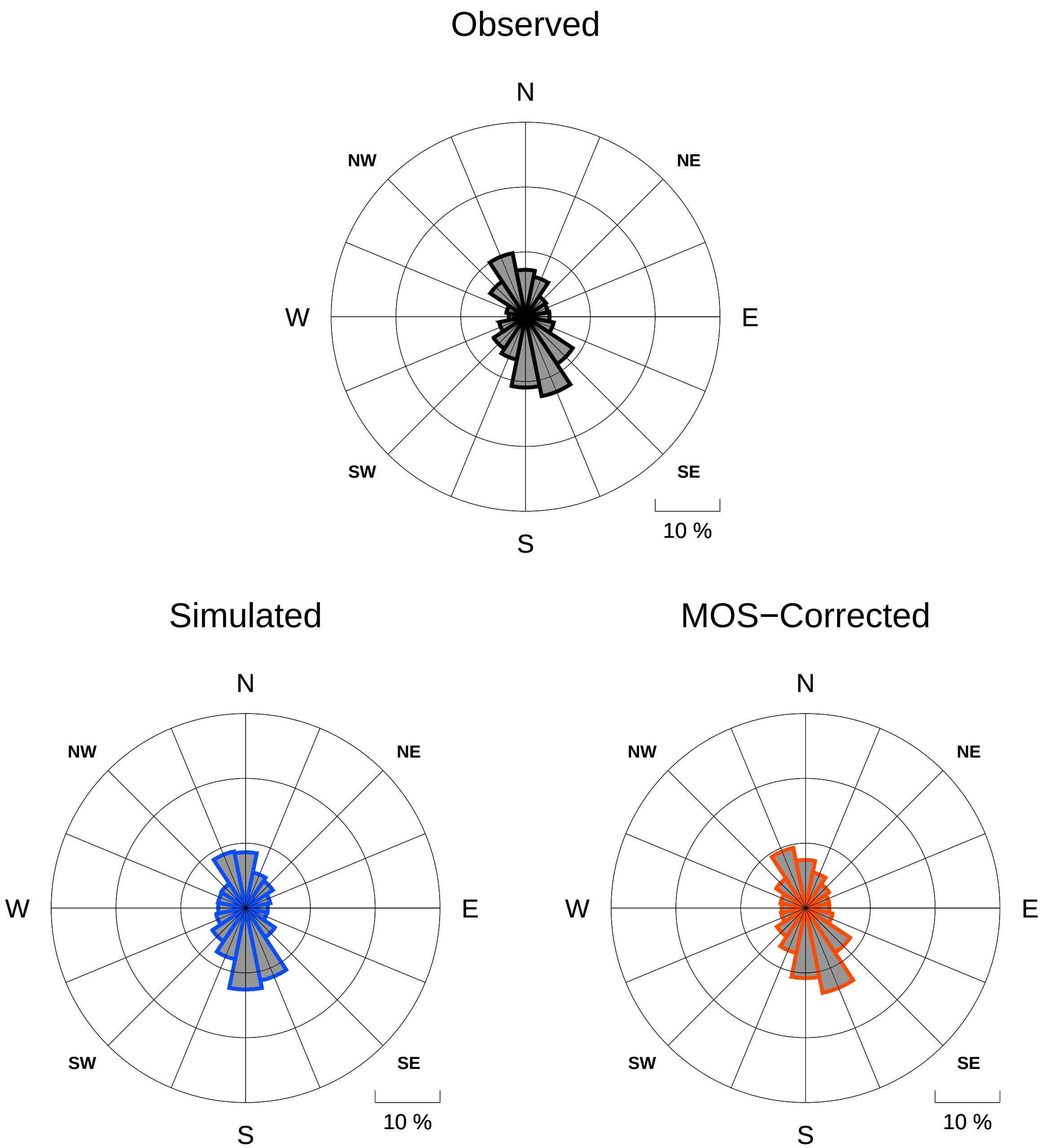

Figure 53: Wind roses at 57 m at Tower M2202 for observational data and simulated model data, averaged over the period of record (June, 2008–August, 2010). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 42 and 43 (p. 105).

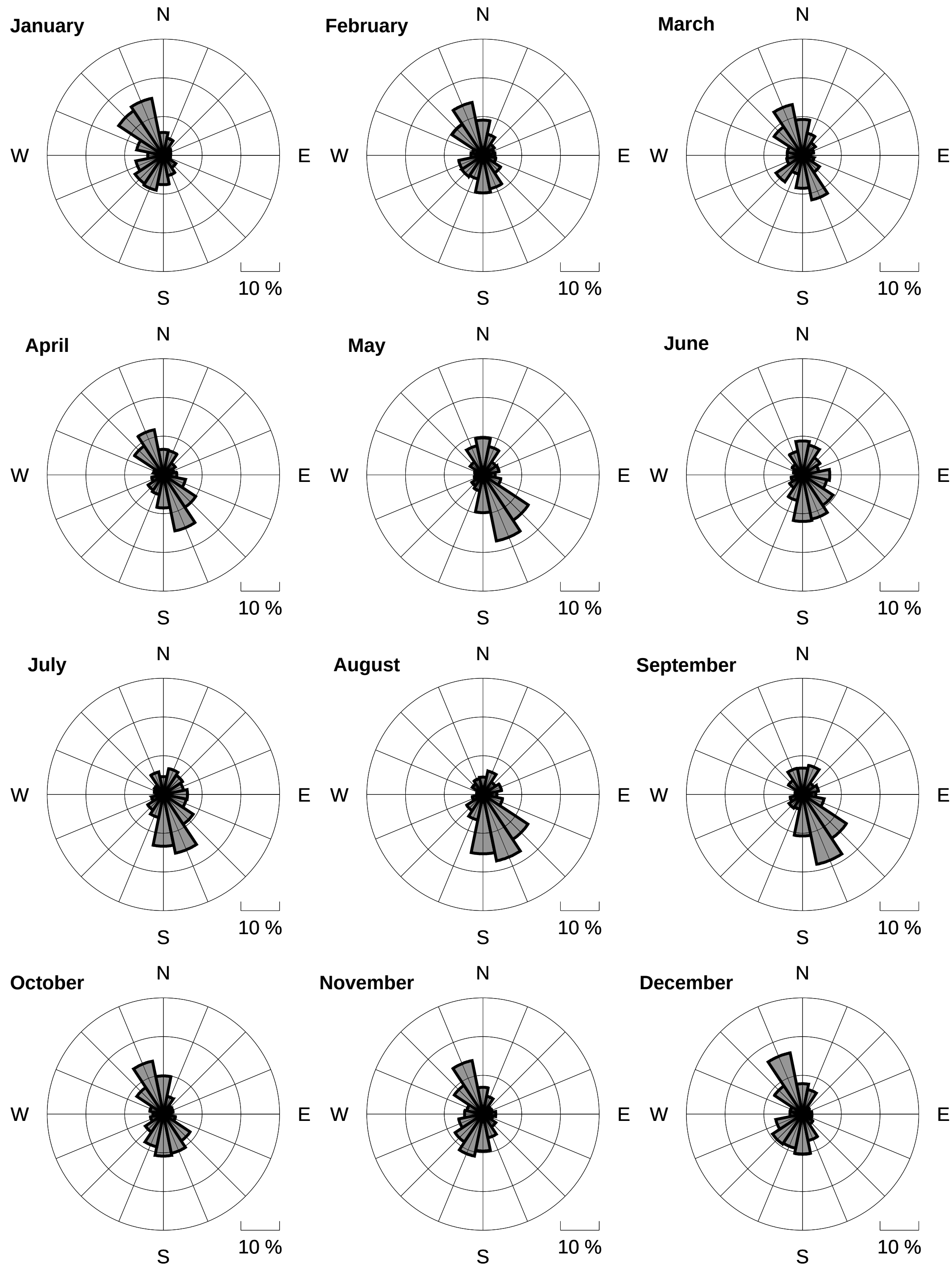

Figure 54: Wind rose of observed wind direction at $57\,m$ at Tower M2202 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

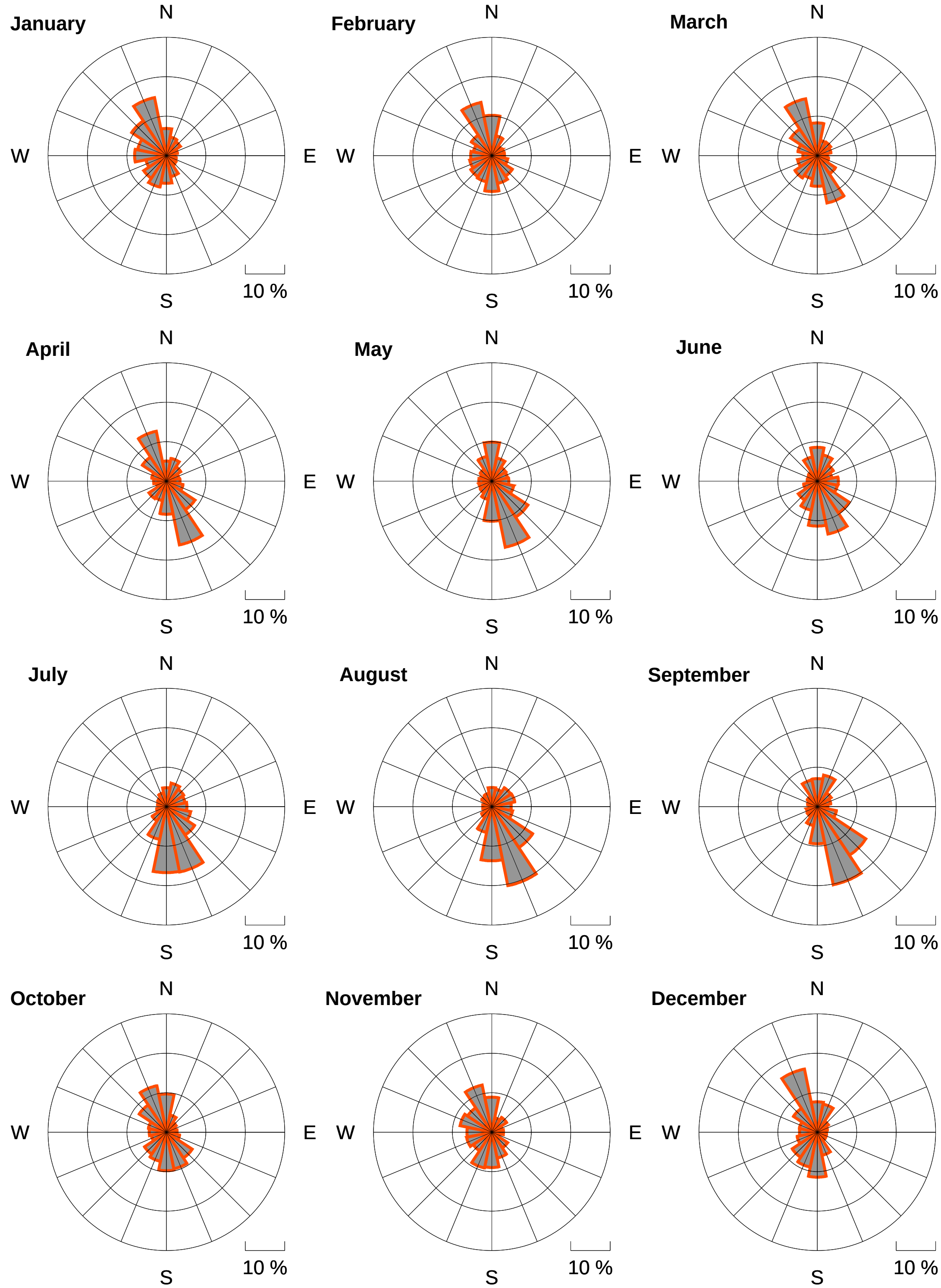

Figure 55: Wind rose of MOS-corrected wind direction at $57\,m$ at Tower M2202 for each calendar month. Directional bins are $22.5°$ wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.2.6 Diurnal Variability of Wind Speed

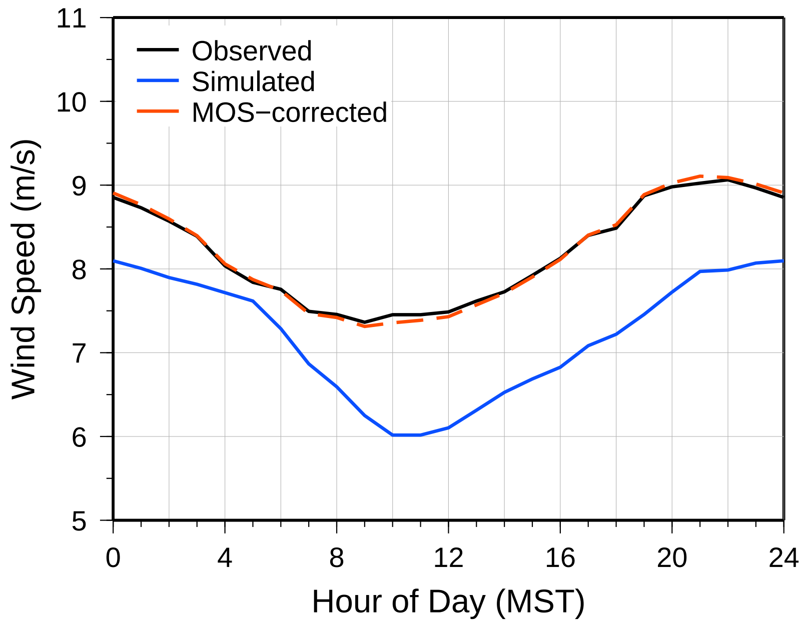

Figure 56: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 59 m wind speed at Tower M2202. Data are averaged over the period of record (June, 2008–August, 2010). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data are available in Figures 58 and 59 (p. 101 and 102).

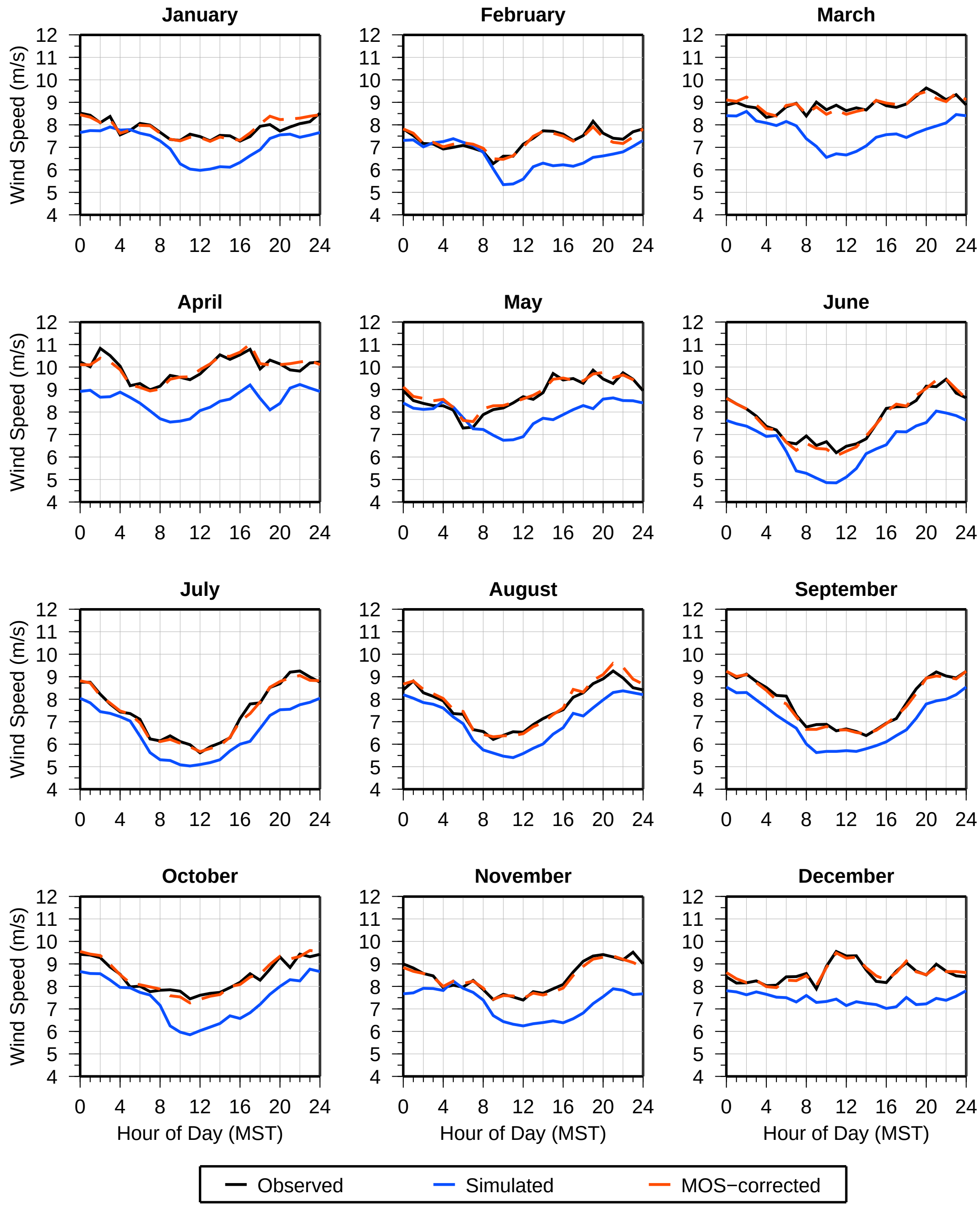

Figure 57: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 59 m wind speed for each calendar month at Tower M2202. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data available in Figures 58 and 59 (p. 101 and 102).

12.2.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
06/2008	7.58	6.25	-1.33	7.23	89.2
07/2008	7.63	6.64	-1.00	7.52	91.5
08/2008	8.06	7.29	-0.77	8.09	91.7
09/2008	7.80	6.89	-0.91	7.72	91.3
10/2008	8.43	7.60	-0.83	8.64	85.8
11/2008	8.62	7.85	-0.78	9.00	77.9
12/2008	8.91	7.70	-1.21	8.92	72.3
01/2009	8.86	8.33	-0.52	9.10	80.0
02/2009	7.83	7.09	-0.74	7.84	84.7
03/2009	8.98	7.61	-1.37	8.77	74.6
04/2009	10.12	8.54	-1.58	10.07	84.2
05/2009	7.83	6.98	-0.86	7.85	92.1
06/2009	6.60	5.84	-0.76	6.94	93.1
07/2009	6.94	5.94	-1.00	6.72	99.5
08/2009	7.31	6.61	-0.70	7.41	96.4
09/2009	7.96	7.05	-0.91	7.93	100.0
10/2009	8.38	7.15	-1.23	8.24	75.4
11/2009	8.07	6.58	-1.49	7.66	92.4
12/2009	8.40	7.28	-1.12	8.43	95.8
01/2010	6.97	5.98	-0.99	6.73	94.4
02/2010	6.69	6.09	-0.61	6.76	73.4
03/2010	8.77	7.65	-1.11	8.95	89.8
04/2010	9.89	8.41	-1.48	9.89	99.9
05/2010	9.63	8.77	-0.86	9.88	94.2
06/2010	8.84	7.61	-1.23	8.67	87.8
07/2010	7.67	6.99	-0.68	7.88	88.0
08/2010	10.94	8.77	-2.17	9.78	1.3
All	**8.23**	**7.23**	**-1.01**	**8.24**	**85.0**

Table 39: Monthly-mean $59\,m$ wind speeds (m/s) at Tower M2202. Time series graph of data is available in Figure 51 (p. 93). The average values shown at the bottom of the table, labeled 'All', are computed as the mean of monthly means.

Observed = mean of all available wind speed observations
Simulated = mean of simulated model output for times with observations
Bias = Simulated − Observed
MOS-corrected = mean of MOS-corrected output for times with observations

Observations

Hour of Day (MST)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	8.53	7.82	8.89	10.23	8.95	8.63	8.75	8.42	9.24	9.43	9.01	8.43	8.85
1	8.43	7.52	8.99	10.01	8.51	8.37	8.76	8.81	8.95	9.40	8.82	8.15	8.73
2	8.10	7.18	8.82	10.83	8.39	8.14	8.23	8.28	9.12	9.28	8.57	8.16	8.57
3	8.38	7.15	8.76	10.52	8.29	7.82	7.79	8.13	8.79	8.87	8.48	8.25	8.39
4	7.56	6.93	8.33	10.05	8.28	7.36	7.44	7.93	8.53	8.55	7.95	8.04	8.04
5	7.76	7.00	8.43	9.17	8.08	7.21	7.37	7.36	8.17	7.98	8.06	8.05	7.84
6	8.07	7.09	8.80	9.27	7.29	6.66	7.11	7.33	8.14	8.01	7.97	8.42	7.76
7	7.99	6.96	8.96	9.00	7.33	6.59	6.24	6.65	7.29	7.77	8.27	8.44	7.49
8	7.68	6.82	8.40	9.16	7.89	6.94	6.15	6.57	6.76	7.83	7.86	8.58	7.46
9	7.35	6.28	9.01	9.63	8.11	6.51	6.37	6.22	6.87	7.85	7.42	7.90	7.36
10	7.31	6.60	8.67	9.54	8.18	6.68	6.11	6.39	6.88	7.79	7.65	8.89	7.45
11	7.59	6.61	8.87	9.44	8.41	6.19	5.98	6.56	6.59	7.44	7.53	9.55	7.45
12	7.48	7.14	8.63	9.69	8.69	6.49	5.62	6.53	6.68	7.61	7.39	9.35	7.49
13	7.29	7.41	8.76	10.12	8.57	6.58	5.89	6.88	6.56	7.70	7.76	9.37	7.62
14	7.54	7.74	8.66	10.55	8.86	6.81	6.05	7.14	6.39	7.74	7.70	8.74	7.73
15	7.51	7.71	9.08	10.35	9.72	7.46	6.29	7.36	6.65	7.95	7.89	8.23	7.92
16	7.27	7.59	8.85	10.54	9.42	8.16	7.14	7.54	6.94	8.19	8.09	8.17	8.13
17	7.52	7.42	8.64	10.84	9.62	8.11	7.71	7.99	7.36	8.57	8.46	8.84	8.40
18	7.90	7.70	8.85	9.91	9.30	8.16	7.95	7.99	8.00	8.31	8.97	9.21	8.49
19	8.02	8.30	9.19	10.31	9.76	8.54	8.59	8.61	8.51	8.78	9.16	8.87	8.87
20	7.90	7.61	9.56	10.24	9.34	9.11	8.73	8.74	9.15	9.24	9.22	8.71	8.98
21	8.03	7.43	9.29	9.89	9.26	9.04	9.18	9.24	9.42	8.74	9.17	9.14	9.02
22	8.33	7.34	8.93	9.97	9.61	9.41	9.18	9.04	9.27	9.27	9.00	8.84	9.06
23	8.48	7.61	9.20	10.31	9.30	8.83	8.97	8.53	9.15	9.19	9.26	8.58	8.97
Avg	7.84	7.30	8.86	10.00	8.74	7.65	7.40	7.70	7.88	8.41	8.32	8.62	8.23

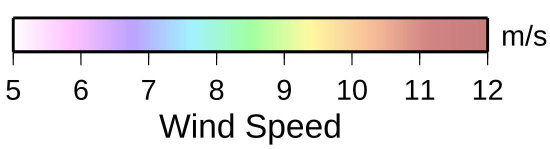

Figure 58: Hourly-mean values of observed 59 m wind speed at Tower M2202. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 56 and 57 (p. 98 and 99).

MOS−Corrected

Hour of Day (MST)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	8.45	7.82	9.11	10.12	9.12	8.61	8.82	8.67	9.25	9.55	8.84	8.62	8.91
1	8.34	7.63	9.05	10.10	8.69	8.37	8.73	8.81	9.02	9.44	8.68	8.35	8.77
2	8.11	7.18	9.24	10.40	8.61	8.14	8.16	8.44	9.10	9.38	8.58	8.18	8.60
3	8.24	7.23	8.88	10.23	8.50	7.75	7.84	8.25	8.74	8.98	8.42	8.27	8.40
4	7.63	7.02	8.51	9.89	8.56	7.27	7.48	8.03	8.40	8.53	8.01	7.99	8.06
5	7.76	7.14	8.40	9.21	8.21	7.21	7.34	7.55	7.97	8.16	8.24	7.95	7.87
6	7.98	7.21	8.86	9.10	7.62	6.67	6.94	7.45	7.80	8.07	8.13	8.28	7.74
7	7.96	7.14	8.94	8.94	7.58	6.30	6.21	6.63	7.22	7.98	8.24	8.26	7.47
8	7.63	6.96	8.50	9.03	8.15	6.61	6.12	6.44	6.66	7.89	7.93	8.48	7.42
9	7.37	6.49	8.80	9.46	8.28	6.38	6.21	6.33	6.66	7.59	7.42	8.03	7.31
10	7.29	6.47	8.48	9.56	8.29	6.35	6.05	6.37	6.79	7.54	7.60	8.84	7.36
11	7.45	6.63	8.66	9.57	8.43	6.05	5.89	6.38	6.63	7.27	7.58	9.50	7.39
12	7.44	7.02	8.48	9.89	8.59	6.25	5.67	6.46	6.64	7.42	7.47	9.26	7.43
13	7.27	7.49	8.60	10.14	8.74	6.44	5.81	6.78	6.52	7.56	7.70	9.31	7.57
14	7.46	7.71	8.70	10.49	8.98	6.93	5.94	6.97	6.45	7.64	7.62	8.84	7.71
15	7.37	7.63	9.09	10.49	9.46	7.46	6.31	7.32	6.62	7.99	7.75	8.47	7.90
16	7.32	7.50	8.97	10.66	9.52	8.01	7.02	7.60	6.91	8.09	7.93	8.29	8.11
17	7.59	7.35	8.80	10.82	9.64	8.34	7.41	8.13	7.38	8.58	8.26	8.91	8.40
18	7.88	7.71	8.81	10.02	9.59	8.22	7.87	8.12	7.85	8.65	8.66	9.40	8.53
19	8.23	8.09	9.34	10.08	9.69	8.66	8.56	8.67	8.48	9.05	9.00	8.89	8.89
20	8.07	7.70	9.48	10.08	9.71	8.95	8.85	8.89	9.21	9.33	9.12	8.76	9.03
21	8.15	7.53	9.17	10.12	9.47	9.26	9.06	9.35	9.37	9.14	9.20	9.03	9.11
22	8.23	7.51	8.86	10.20	9.62	9.35	9.16	9.20	9.29	9.25	9.07	8.81	9.09
23	8.40	7.75	9.19	10.30	9.43	8.89	8.93	8.75	9.17	9.52	8.97	8.75	9.01
Avg	7.82	7.34	8.87	9.97	8.88	7.60	7.35	7.76	7.83	8.45	8.27	8.64	8.24

Wind Speed (m/s): 5 6 7 8 9 10 11 12

Figure 59: Hourly-mean values of MOS-corrected 59 m wind speed at Tower M2202. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 56 and 57 (p. 98 and 99).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.03	0.01	0.05	0.05	0.04	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.03	0.02	0.04	0.04	0.44
0.5 - 1.5	0.10	0.09	0.13	0.10	0.10	0.11	0.07	0.07	0.11	0.09	0.03	0.08	0.11	0.14	0.05	0.07	1.43
1.5 - 2.5	0.24	0.19	0.26	0.21	0.23	0.23	0.12	0.21	0.17	0.14	0.09	0.14	0.20	0.20	0.26	0.29	3.20
2.5 - 3.5	0.36	0.39	0.34	0.38	0.36	0.33	0.41	0.36	0.38	0.21	0.20	0.27	0.21	0.26	0.29	0.39	5.15
3.5 - 4.5	0.62	0.58	0.52	0.45	0.48	0.45	0.49	0.55	0.63	0.31	0.24	0.32	0.26	0.29	0.46	0.53	7.18
4.5 - 5.5	0.62	0.70	0.50	0.58	0.52	0.55	0.69	0.76	0.75	0.51	0.25	0.33	0.32	0.33	0.60	0.79	8.82
5.5 - 6.5	0.73	0.77	0.48	0.64	0.71	0.55	0.79	0.89	0.92	0.64	0.32	0.30	0.27	0.42	0.65	0.87	9.97
6.5 - 7.5	0.84	0.80	0.29	0.56	0.45	0.55	1.08	1.14	1.16	0.66	0.30	0.48	0.36	0.38	0.78	0.79	10.63
7.5 - 8.5	0.82	0.76	0.41	0.30	0.42	0.56	1.01	1.06	1.15	0.63	0.33	0.41	0.30	0.29	0.72	0.98	10.16
8.5 - 9.5	0.73	0.70	0.17	0.20	0.26	0.51	0.91	1.18	1.34	0.49	0.35	0.32	0.23	0.25	0.63	0.94	9.21
9.5 - 10.5	0.73	0.44	0.13	0.12	0.24	0.36	0.93	1.22	1.15	0.48	0.33	0.32	0.17	0.27	0.72	0.91	8.50
10.5 - 11.5	0.58	0.29	0.05	0.13	0.11	0.27	0.83	1.34	1.01	0.39	0.15	0.23	0.16	0.16	0.42	0.84	6.96
11.5 - 12.5	0.43	0.13	0.03	0.04	0.03	0.10	0.56	1.37	1.00	0.21	0.17	0.10	0.05	0.12	0.41	0.65	5.38
12.5 - 13.5	0.44	0.11	0.03	0.02	0.06	0.05	0.44	1.00	0.49	0.21	0.08	0.06	0.04	0.04	0.24	0.51	3.81
13.5 - 14.5	0.19	0.05	0.01	0.02	0.02	0.05	0.31	0.67	0.36	0.07	0.06	0.02	0.04	0.04	0.21	0.46	2.57
14.5 - 15.5	0.15	0.03	0.02	0.01	0.01	0.02	0.29	0.52	0.26	0.07	0.03	0.04	0.01	0.01	0.17	0.33	1.97
15.5 - 16.5	0.12	0.02	0.00	0.01	0.01	0.02	0.14	0.33	0.14	0.03	0.05	0.00	0.01	0.02	0.13	0.44	1.45
16.5 - 17.5	0.04	0.01	0.00	0.00	0.00	0.02	0.17	0.19	0.13	0.06	0.04	0.01	0.01	0.01	0.04	0.29	1.00
17.5 - 18.5	0.04	0.00	0.01	0.00	0.01	0.01	0.07	0.11	0.07	0.02	0.01	0.01	0.01	0.01	0.07	0.21	0.64
18.5 - 19.5	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.04	0.00	0.03	0.00	0.00	0.02	0.05	0.22	0.44
19.5 - 20.5	0.02	0.00	0.00	0.00	0.01	0.00	0.02	0.04	0.01	0.01	0.02	0.01	0.00	0.00	0.05	0.13	0.31
20.5 - 21.5	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.05	0.01	0.00	0.01	0.01	0.00	0.00	0.06	0.13	0.27
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.10	0.19
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.04	0.08
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.03	0.08
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04

Table 40: Distribution of observed $59\,m$ wind speed by direction at Tower M2202. Histogram of data is available in Figure 52 (p. 94).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.01	0.02	0.05	0.03	0.06	0.07	0.04	0.04	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.44
0.5 - 1.5	0.09	0.12	0.11	0.08	0.18	0.14	0.18	0.08	0.07	0.04	0.05	0.06	0.02	0.08	0.06	0.08	1.43
1.5 - 2.5	0.21	0.29	0.20	0.27	0.24	0.29	0.26	0.20	0.20	0.13	0.15	0.11	0.15	0.20	0.15	0.14	3.20
2.5 - 3.5	0.31	0.36	0.36	0.50	0.49	0.39	0.33	0.30	0.28	0.24	0.29	0.26	0.23	0.32	0.25	0.22	5.14
3.5 - 4.5	0.48	0.49	0.52	0.48	0.45	0.63	0.46	0.52	0.42	0.44	0.39	0.39	0.36	0.39	0.38	0.36	7.17
4.5 - 5.5	0.55	0.45	0.50	0.61	0.49	0.50	0.72	0.61	0.75	0.67	0.52	0.52	0.43	0.42	0.46	0.60	8.80
5.5 - 6.5	0.67	0.57	0.53	0.61	0.49	0.48	0.72	0.93	0.95	0.81	0.72	0.51	0.40	0.41	0.40	0.79	10.00
6.5 - 7.5	0.88	0.67	0.55	0.47	0.42	0.45	0.90	1.16	1.19	0.77	0.54	0.41	0.36	0.44	0.54	0.89	10.63
7.5 - 8.5	0.74	0.65	0.38	0.30	0.36	0.39	0.86	1.32	1.32	0.80	0.39	0.23	0.32	0.39	0.71	1.00	10.16
8.5 - 9.5	0.73	0.64	0.38	0.17	0.20	0.40	0.98	1.29	1.21	0.70	0.33	0.20	0.20	0.36	0.62	0.80	9.21
9.5 - 10.5	0.83	0.48	0.28	0.14	0.24	0.30	0.84	1.34	1.12	0.50	0.15	0.11	0.23	0.43	0.63	0.89	8.50
10.5 - 11.5	0.57	0.44	0.24	0.05	0.11	0.25	0.77	1.28	0.92	0.35	0.16	0.15	0.24	0.20	0.48	0.75	6.96
11.5 - 12.5	0.55	0.31	0.07	0.08	0.05	0.13	0.48	1.22	0.76	0.23	0.09	0.08	0.14	0.21	0.39	0.60	5.38
12.5 - 13.5	0.39	0.16	0.07	0.00	0.04	0.06	0.42	1.08	0.49	0.15	0.05	0.03	0.03	0.05	0.20	0.58	3.80
13.5 - 14.5	0.28	0.07	0.02	0.02	0.04	0.03	0.29	0.75	0.32	0.10	0.07	0.04	0.05	0.01	0.05	0.44	2.58
14.5 - 15.5	0.21	0.04	0.03	0.01	0.02	0.01	0.22	0.46	0.26	0.05	0.07	0.00	0.04	0.02	0.09	0.45	1.97
15.5 - 16.5	0.08	0.02	0.02	0.00	0.01	0.01	0.17	0.36	0.16	0.05	0.04	0.02	0.01	0.01	0.08	0.40	1.45
16.5 - 17.5	0.06	0.01	0.01	0.00	0.01	0.01	0.11	0.22	0.07	0.05	0.02	0.01	0.00	0.01	0.10	0.33	1.00
17.5 - 18.5	0.03	0.00	0.01	0.00	0.00	0.01	0.04	0.17	0.02	0.01	0.03	0.01	0.01	0.01	0.04	0.27	0.64
18.5 - 19.5	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.10	0.02	0.01	0.02	0.00	0.01	0.00	0.05	0.17	0.44
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.01	0.01	0.02	0.00	0.01	0.00	0.02	0.11	0.31
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.02	0.04	0.01	0.01	0.00	0.00	0.02	0.10	0.27
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.01	0.00	0.02	0.00	0.00	0.11	0.19
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.08
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.04	0.08
$>$ 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04

Table 41: Distribution of MOS-corrected 59 m wind speed by direction at Tower M2202. All model values are computed only for times with valid observations. Histogram of data is available in Figure 52 (p. 94).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	8.13	9.17	2.41	7.84
NNE	6.94	7.81	2.63	6.07
NE	5.60	6.32	2.12	3.43
ENE	5.79	6.54	2.33	3.82
E	6.12	6.91	2.22	4.06
ESE	6.85	7.73	2.35	4.78
SE	8.79	9.90	2.57	9.38
SSE	9.74	10.95	2.68	13.21
S	8.90	10.02	2.59	11.36
SSW	7.85	8.85	2.47	5.28
SW	8.12	9.16	2.21	3.12
WSW	7.06	7.97	2.30	3.47
W	6.49	7.33	2.07	2.79
WNW	6.64	7.50	2.02	3.28
NW	8.56	9.67	2.15	7.10
NNW	9.87	11.14	2.15	11.02
ALL	**8.23**	**9.29**	**2.21**	**100.00**

Table 42: Observed 59 m mean wind speed, Weibull parameters, and frequency at Tower M2202. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 53 (p. 95).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	8.49	9.57	2.53	7.72
NNE	7.37	8.32	2.43	5.79
NE	6.50	7.34	2.17	4.33
ENE	5.57	6.28	2.33	3.83
E	5.84	6.58	1.98	3.89
ESE	6.38	7.20	2.03	4.56
SE	8.55	9.64	2.37	8.87
SSE	9.87	11.10	2.68	13.62
S	8.81	9.91	2.69	10.66
SSW	7.77	8.76	2.48	6.17
SW	7.08	7.99	2.06	4.16
WSW	6.53	7.37	2.10	3.18
W	7.05	7.96	2.13	3.28
WNW	6.93	7.82	2.40	3.96
NW	8.58	9.69	2.32	5.77
NNW	10.35	11.68	2.33	10.22
ALL	**8.24**	**9.30**	**2.21**	**100.00**

Table 43: MOS-corrected 59 m mean wind speed, Weibull parameters, and frequency at Tower M2202. All MOS-corrected model values are computed only for times with valid observations; blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 53 (p. 95).

12.3 Validation of Model Results at Tower M2311

This section examines the quality of the NWP simulations used at a single point within the study area. For this section, the observations were taken at Tower M2311 (latitude 39.08518, longitude -103.21049).

The average observed wind speed (for all valid observational times) at $60.0\,m$ during the 32 months of the period of record (October, 2010 to May, 2013) is $8.53\,m/s$ with an hourly standard deviation of $3.91\,m/s$ at Tower M2311. This compares to a modeled $60\,m$ wind speed of $7.32\,m/s$ with a $3.54\,m/s$ standard deviation for these same times.

Based on a comparison of the NWP model output with observations from each of the meteorological towers for which data were provided, Model Output Statistics (MOS) was constructed. MOS uses a multilinear regression model designed to remove the bias and adjust the variance of the raw NWP simulated wind speed and direction. Applying this statistical model to the simulated data at Tower M2311 results in a MOS-corrected mean value of $8.54\,m/s$ and an hourly standard deviation of $3.91\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2311). The focus of the verification is on the model's ability to reproduce the observed variability of the wind resource at daily and monthly time scales, while preserving the distribution of hourly wind speeds and the diurnal characteristics of the wind.

12.3.1 Observational Data

Approximately 32 months of wind speed data at $60.0\,meters$ and wind direction data at $58.0\,meters$ (October, 2010 to May, 2013) from a meteorological tower (Tower M2311) at Rush Creek II were used in this analysis. This tower will be referred to as the reference tower throughout this section. The data at $60\,m$ were used to assess the quality of the model simulations at $60\,m$.

It should be noted that meteorological observations provided to 3TIER are not allowed to influence the raw model simulations.

12.3.2 Model Validation Statistics

Table 44 presents some basic statistical measures of the model performance relative to the measured winds at the reference tower during the observational period. Also shown are values (labeled "MOS-corrected") for model data with the statistical model applied. For reference, the correlation of the reference tower data to itself is perfect and hence the explained variance (r^2) value is 1.0.

The observed and modeled winds in this section represent the mean of all times during the month for which a valid wind speed or direction observation was available. Therefore they should not be interpreted as estimates of the true winds at the site, but rather a verification of the model's ability to reproduce the available observations. Any month or hour missing greater than 50% of the available observations is omitted from the following figures, tables, and statistics.

Comparison	Value
Correlation of monthly-mean simulated wind speed to observed	0.95
RMS error of monthly-mean simulated wind speed	1.25 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.98
RMS error of monthly-mean MOS-corrected wind speed	0.13 m/s
Correlation of daily-mean simulated wind speed to observed	0.89
RMS error of daily-mean simulated wind speed	1.69 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.90
RMS error of daily-mean MOS-corrected wind speed	1.18 m/s

Table 44: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.3.3 Monthly Mean Wind Speed

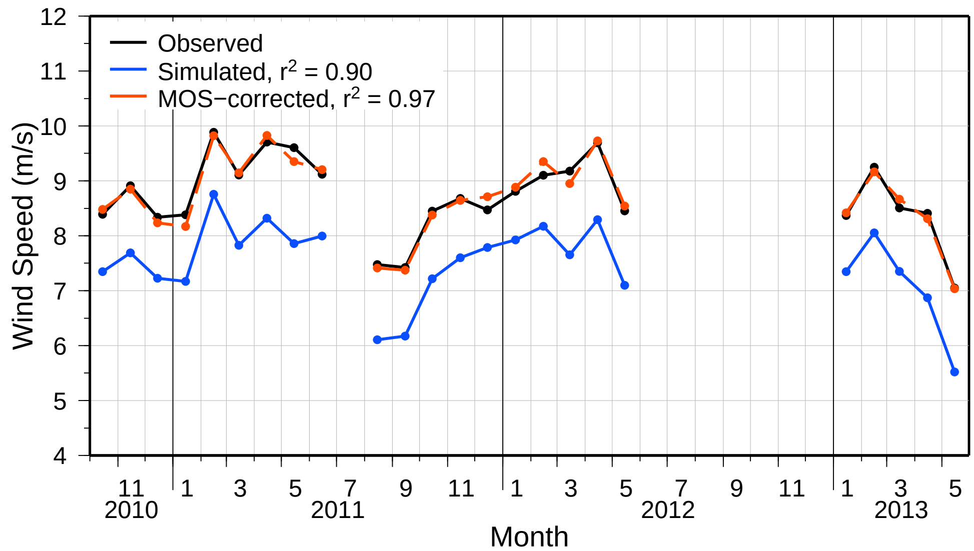

Figure 60: A comparison of the observed, simulated, and MOS-corrected monthly-mean $60\,m$ wind speed at Tower M2311. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 45 (p. 115).

12.3.4 Wind Speed Distribution

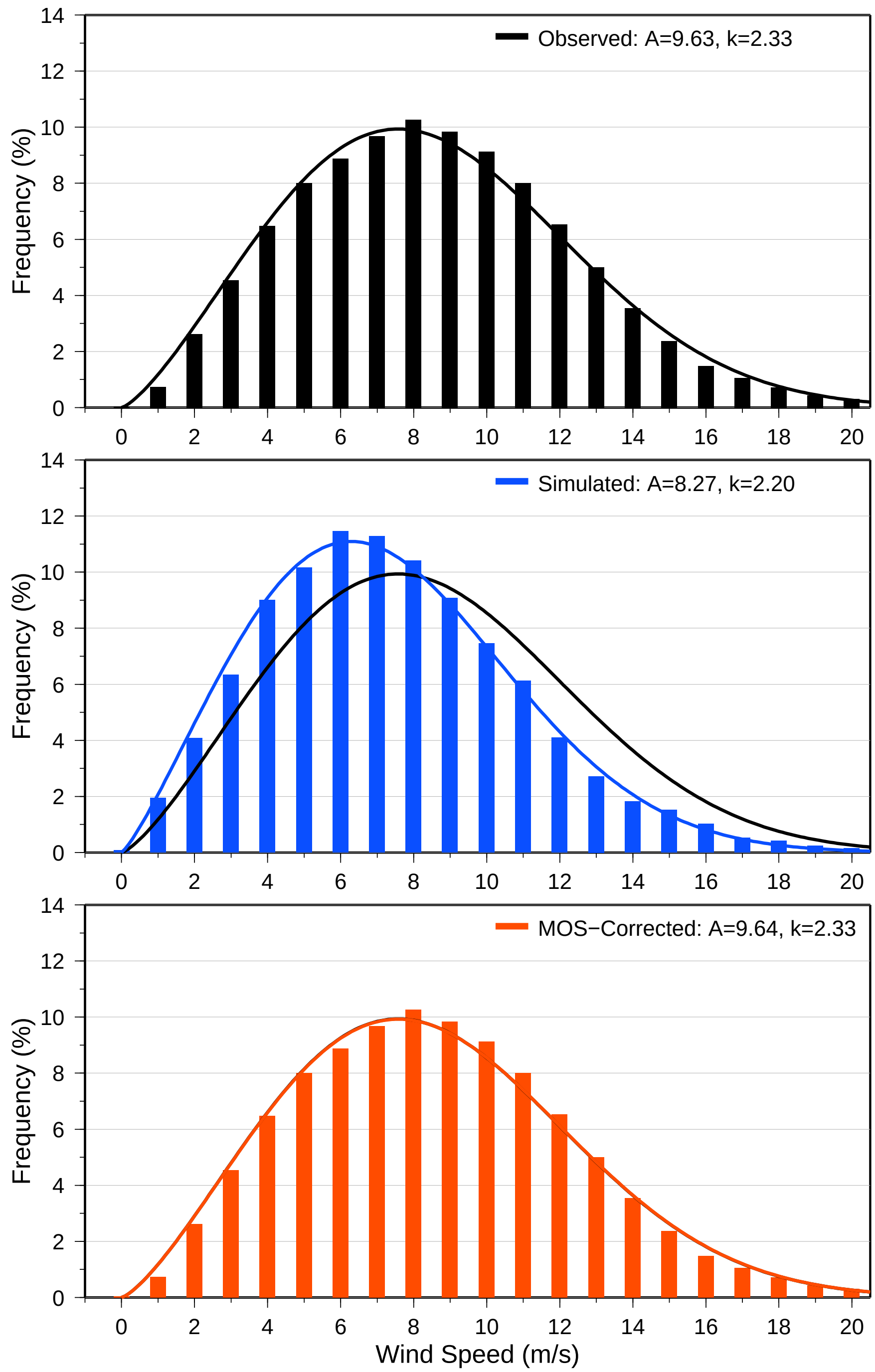

Figure 61: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $60\,m$ at Tower M2311 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend.

12.3.5 Wind Direction Distribution

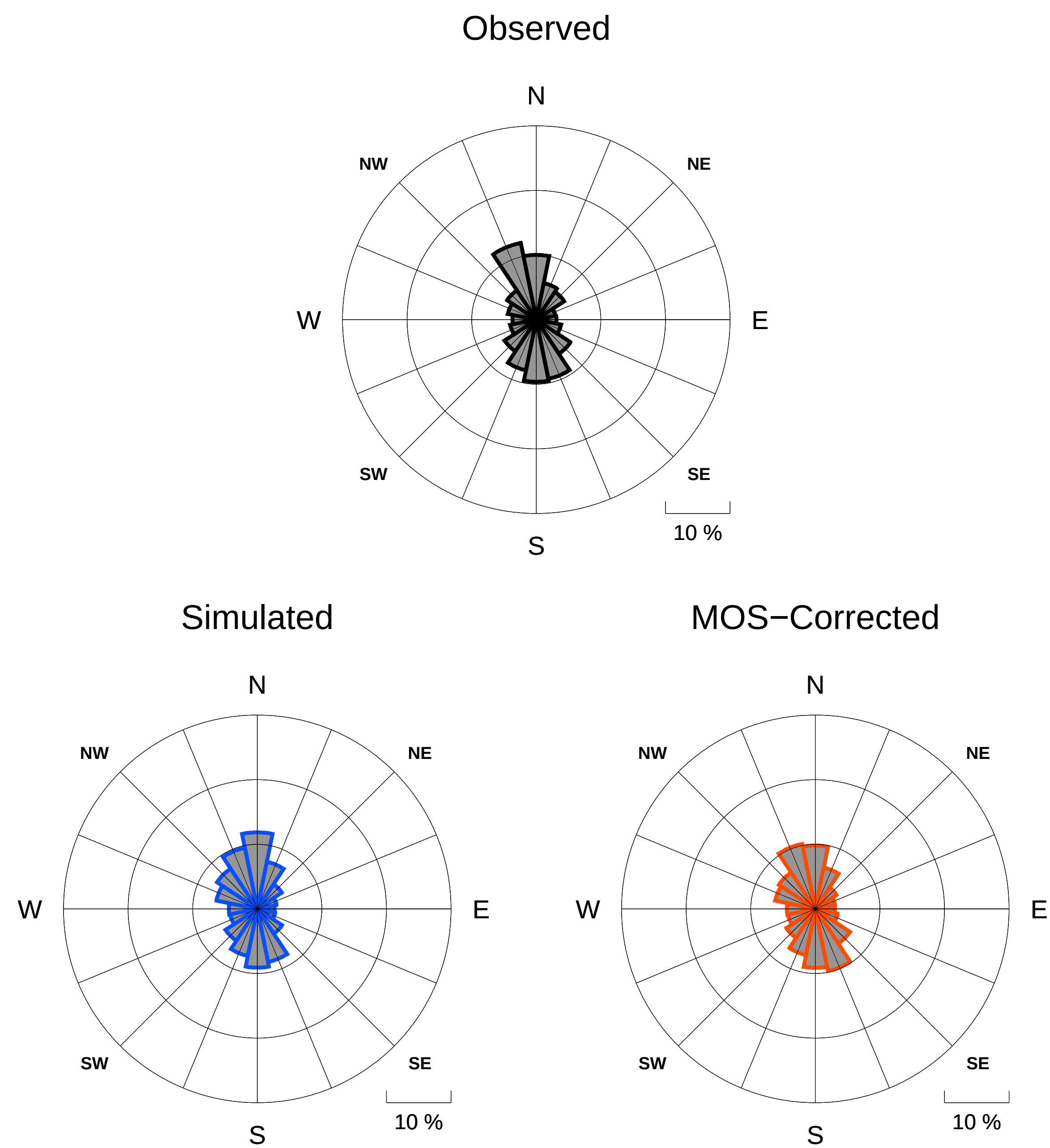

Figure 62: Wind roses at 58 m at Tower M2311 for observational data and simulated model data, averaged over the period of record (October, 2010–May, 2013). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 48 and 49 (p. 120).

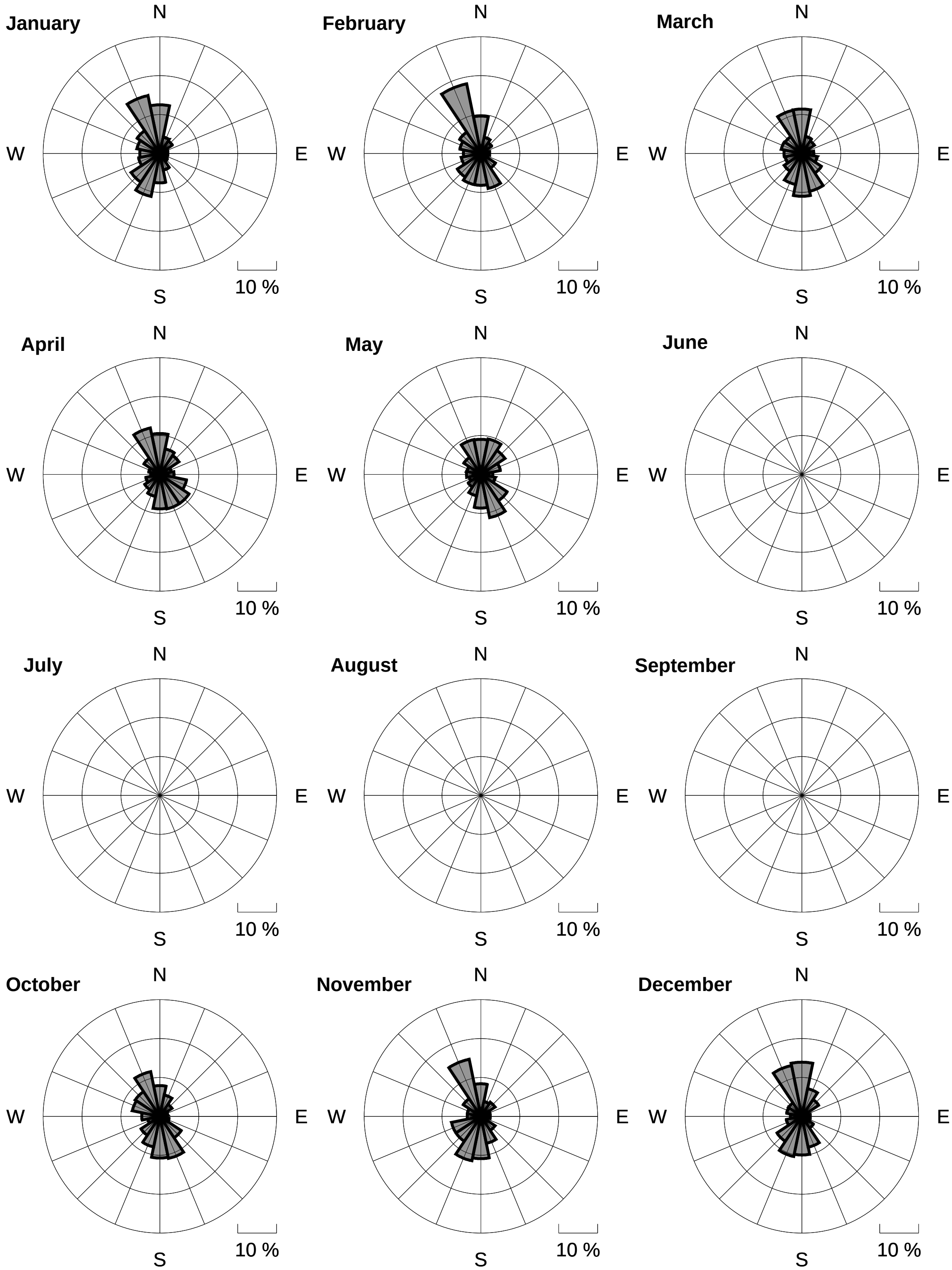

Figure 63: Wind rose of observed wind direction at 58 m at Tower M2311 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

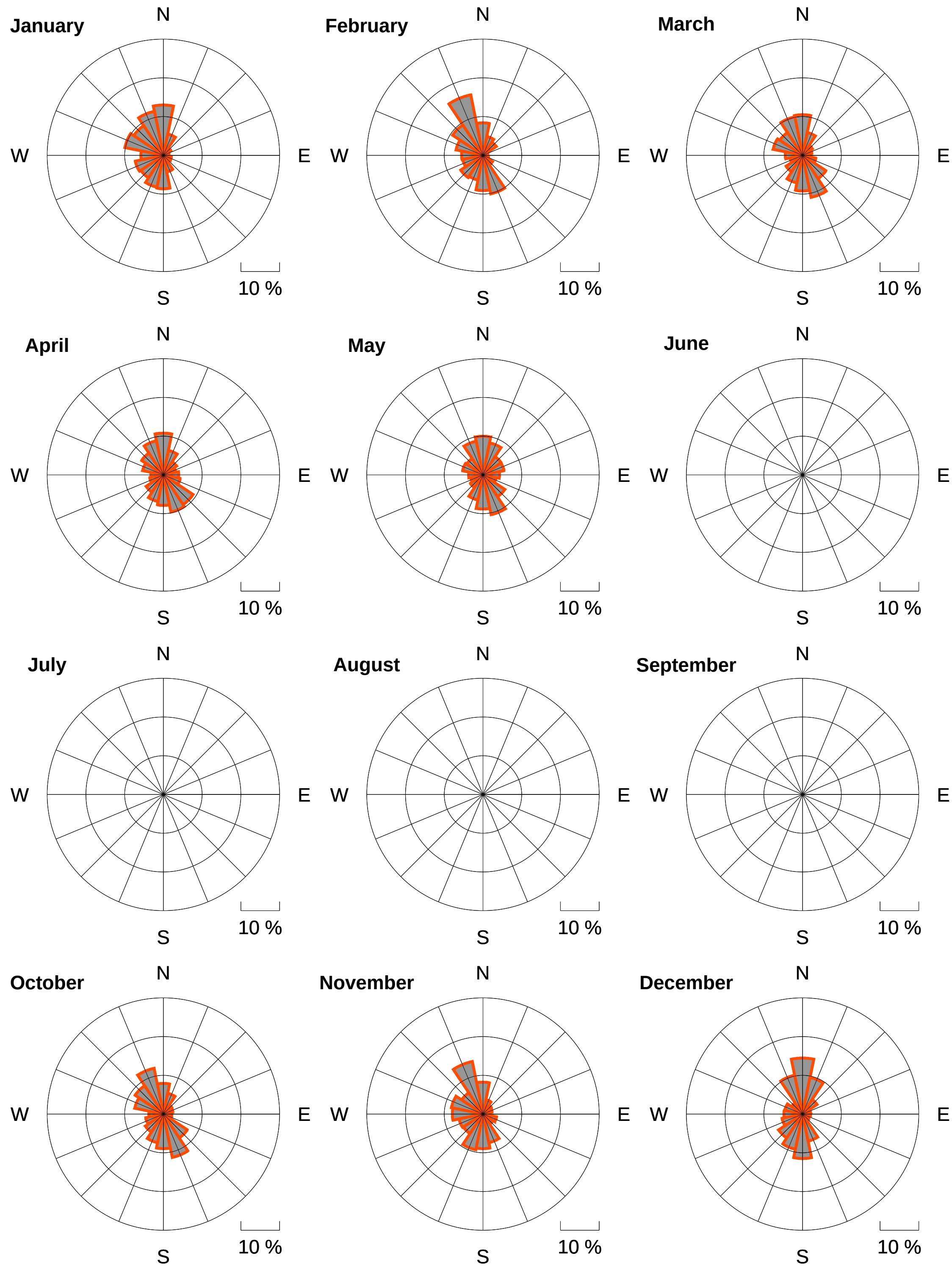

Figure 64: Wind rose of MOS-corrected wind direction at 58 m at Tower M2311 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.3.6 Diurnal Variability of Wind Speed

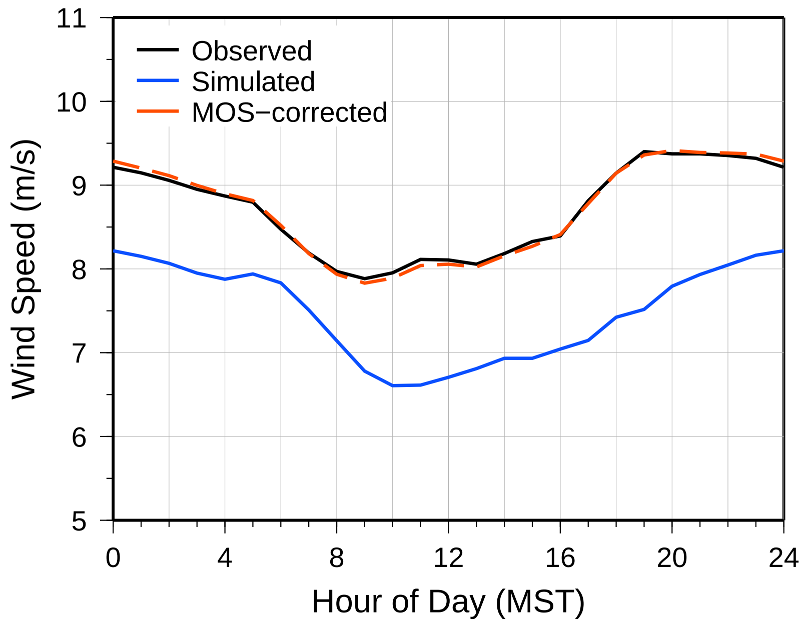

Figure 65: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed at Tower M2311. Data are averaged over the period of record (October, 2010–May, 2013). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data are available in Figures 67 and 68 (p. 116 and 117).

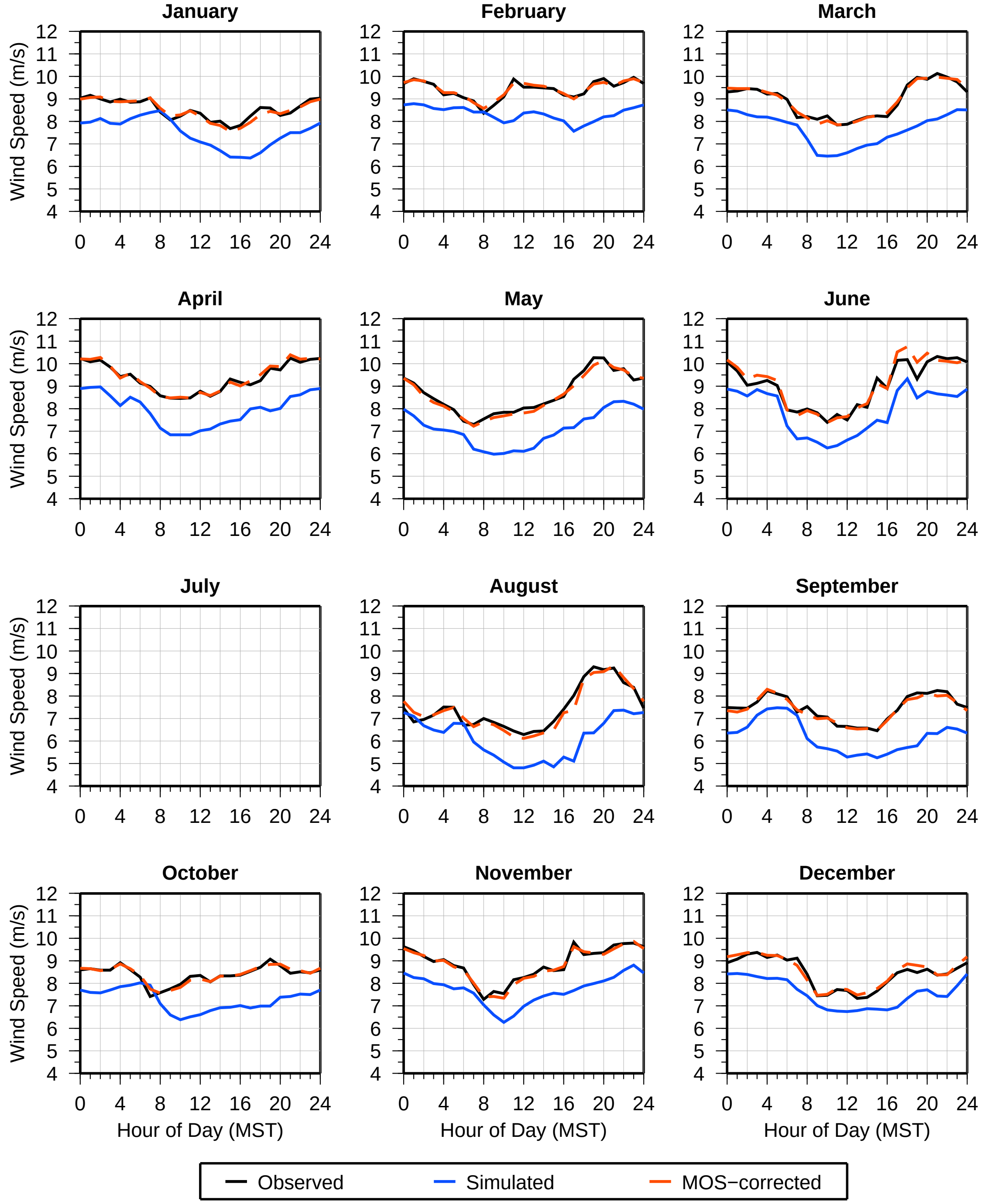

Figure 66: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed for each calendar month at Tower M2311. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data available in Figures 67 and 68 (p. 116 and 117).

12.3.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
10/2010	8.39	7.35	-1.05	8.48	78.6
11/2010	8.91	7.69	-1.23	8.85	89.2
12/2010	8.34	7.23	-1.11	8.24	97.6
01/2011	8.38	7.17	-1.21	8.17	88.0
02/2011	9.88	8.76	-1.13	9.82	76.0
03/2011	9.11	7.83	-1.28	9.15	85.8
04/2011	9.70	8.32	-1.38	9.83	96.5
05/2011	9.61	7.86	-1.75	9.35	100.0
06/2011	9.12	7.99	-1.13	9.20	85.7
07/2011	7.31	6.49	-0.83	7.77	35.3
08/2011	7.48	6.11	-1.37	7.41	99.1
09/2011	7.42	6.17	-1.25	7.37	99.7
10/2011	8.45	7.22	-1.23	8.38	95.0
11/2011	8.68	7.60	-1.08	8.64	91.7
12/2011	8.47	7.79	-0.69	8.71	85.8
01/2012	8.81	7.92	-0.89	8.88	100.0
02/2012	9.10	8.17	-0.93	9.35	76.0
03/2012	9.18	7.65	-1.52	8.95	97.8
04/2012	9.69	8.29	-1.40	9.73	95.7
05/2012	8.45	7.10	-1.35	8.54	100.0
06/2012	8.24	6.76	-1.48	8.10	10.0
07/2012	–	–	–	–	0.0
08/2012	–	–	–	–	0.0
09/2012	–	–	–	–	0.0
10/2012	–	–	–	–	0.0
11/2012	–	–	–	–	0.0
12/2012	–	–	–	–	0.0
01/2013	8.37	7.35	-1.03	8.42	64.7
02/2013	9.25	8.06	-1.19	9.17	76.3
03/2013	8.50	7.35	-1.15	8.67	92.6
04/2013	8.41	6.87	-1.54	8.31	76.5
05/2013	7.05	5.52	-1.53	7.04	51.9
All	**8.53**	**7.32**	**-1.21**	**8.54**	**67.0**

Table 45: Monthly-mean $60\,m$ wind speeds (m/s) at Tower M2311. Time series graph of data is available in Figure 60 (p. 108). The average values shown at the bottom of the table, labeled 'All', are computed as the mean of monthly means.

Observed = mean of all available wind speed observations
Simulated = mean of simulated model output for times with observations
Bias = Simulated – Observed
MOS-corrected = mean of MOS-corrected output for times with observations

Observations

Hour of Day (MST)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.03	9.68	9.31	10.24	9.36	10.07	--	7.46	7.50	8.60	9.63	8.92	9.21
1	9.17	9.89	9.35	10.09	9.14	9.69	--	6.85	7.47	8.65	9.45	9.07	9.15
2	9.01	9.78	9.46	10.16	8.71	9.05	--	6.96	7.46	8.59	9.19	9.31	9.06
3	8.86	9.65	9.43	9.85	8.45	9.13	--	7.15	7.74	8.59	8.98	9.38	8.95
4	8.99	9.18	9.22	9.43	8.20	9.26	--	7.52	8.24	8.92	9.06	9.15	8.87
5	8.86	9.25	9.25	9.54	7.96	9.04	--	7.50	8.09	8.60	8.79	9.25	8.80
6	8.87	9.05	8.98	9.14	7.44	7.95	--	6.70	7.97	8.27	8.68	9.04	8.47
7	9.05	8.91	8.17	9.00	7.30	7.85	--	6.73	7.29	7.42	7.95	9.12	8.19
8	8.42	8.37	8.21	8.57	7.54	7.99	--	7.00	7.54	7.59	7.29	8.41	7.97
9	8.06	8.72	8.10	8.47	7.78	7.82	--	6.83	7.11	7.75	7.64	7.45	7.88
10	8.24	9.09	8.24	8.46	7.84	7.40	--	6.66	7.07	7.96	7.54	7.47	7.95
11	8.49	9.89	7.84	8.48	7.85	7.74	--	6.44	6.67	8.31	8.17	7.72	8.11
12	8.37	9.53	7.87	8.78	8.03	7.50	--	6.29	6.66	8.36	8.26	7.68	8.11
13	7.96	9.52	8.06	8.56	8.05	8.18	--	6.43	6.57	8.07	8.41	7.33	8.06
14	8.01	9.50	8.20	8.77	8.21	8.07	--	6.45	6.58	8.34	8.73	7.38	8.18
15	7.69	9.46	8.24	9.32	8.37	9.36	--	6.88	6.46	8.33	8.56	7.66	8.33
16	7.82	9.17	8.21	9.17	8.55	8.91	--	7.42	6.98	8.37	8.60	8.07	8.39
17	8.32	9.00	8.88	8.87	9.32	10.13	--	8.07	7.33	8.61	9.83	8.37	8.81
18	8.69	9.18	9.71	9.12	9.68	10.27	--	8.87	7.93	8.88	9.22	8.54	9.14
19	8.70	9.77	9.97	9.71	10.27	9.76	--	9.48	7.90	9.24	9.29	8.35	9.40
20	8.37	9.90	9.79	9.75	10.23	10.24	--	9.29	7.95	8.95	9.22	8.56	9.37
21	8.47	9.61	9.99	10.32	9.64	10.40	--	9.35	8.12	8.57	9.60	8.29	9.37
22	8.73	9.75	9.90	10.07	9.71	10.38	--	8.75	8.02	8.62	9.63	8.41	9.35
23	8.92	9.96	9.75	10.14	9.27	10.46	--	8.48	7.56	8.54	9.64	8.81	9.32
Avg	8.55	9.41	8.93	9.33	8.62	9.03	--	7.48	7.42	8.42	8.79	8.40	8.53

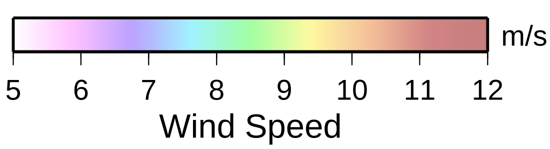

Figure 67: Hourly-mean values of observed 60 m wind speed at Tower M2311. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 65 and 66 (p. 113 and 114).

MOS−Corrected

Hour of Day (MST)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	8.99	9.73	9.48	10.22	9.36	10.17	--	7.76	7.35	8.67	9.55	9.18	9.29
1	9.07	9.85	9.46	10.20	9.07	9.84	--	7.28	7.29	8.65	9.36	9.27	9.20
2	9.08	9.81	9.46	10.28	8.55	9.33	--	7.09	7.42	8.57	9.24	9.37	9.11
3	8.89	9.62	9.43	9.90	8.28	9.49	--	7.16	7.83	8.62	8.99	9.38	9.00
4	8.88	9.28	9.29	9.37	8.12	9.43	--	7.35	8.30	8.86	9.02	9.25	8.90
5	8.89	9.28	9.17	9.58	7.86	9.26	--	7.49	8.13	8.65	8.74	9.23	8.82
6	8.92	9.14	8.88	9.21	7.54	7.95	--	7.02	7.86	8.36	8.60	9.07	8.52
7	9.04	8.83	8.42	8.92	7.23	7.69	--	6.64	7.39	7.74	8.01	8.80	8.18
8	8.59	8.58	8.16	8.54	7.44	7.92	--	6.84	7.19	7.57	7.39	8.15	7.94
9	8.25	8.85	7.88	8.48	7.60	7.76	--	6.73	6.99	7.69	7.41	7.47	7.83
10	8.29	9.19	8.03	8.51	7.68	7.39	--	6.47	7.03	7.82	7.34	7.51	7.89
11	8.47	9.71	7.86	8.48	7.77	7.60	--	6.18	6.79	8.15	7.94	7.77	8.04
12	8.24	9.69	7.86	8.72	7.81	7.65	--	6.12	6.58	8.19	8.23	7.72	8.06
13	7.92	9.61	8.02	8.59	7.89	8.05	--	6.23	6.53	8.08	8.32	7.48	8.02
14	7.82	9.57	8.18	8.79	8.16	8.23	--	6.36	6.55	8.33	8.55	7.59	8.16
15	7.55	9.43	8.26	9.18	8.39	9.12	--	6.49	6.48	8.33	8.59	7.77	8.27
16	7.70	9.23	8.39	9.02	8.65	8.90	--	7.25	6.92	8.39	8.75	8.10	8.41
17	8.17	8.98	8.78	9.24	9.04	10.18	--	7.53	7.42	8.72	9.52	8.41	8.78
18	8.43	9.37	9.46	9.45	9.50	10.67	--	8.99	7.71	8.92	9.35	8.67	9.14
19	8.56	9.79	9.85	9.78	9.97	9.99	--	9.13	7.85	9.05	9.28	8.60	9.36
20	8.46	9.84	9.88	9.76	10.16	10.36	--	9.13	8.07	8.92	9.30	8.58	9.41
21	8.55	9.63	9.94	10.27	9.88	10.38	--	9.32	7.97	8.71	9.45	8.36	9.39
22	8.67	9.78	9.91	10.07	9.82	10.38	--	8.93	7.89	8.68	9.59	8.45	9.38
23	8.88	9.89	9.83	10.14	9.49	10.30	--	8.51	7.48	8.58	9.66	8.92	9.37
Avg	8.52	9.44	8.92	9.36	8.55	9.09	--	7.41	7.37	8.43	8.74	8.46	8.54

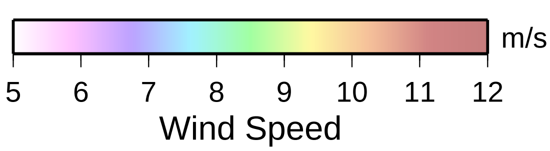

Figure 68: Hourly-mean values of MOS-corrected 60 m wind speed at Tower M2311. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 65 and 66 (p. 113 and 114).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.04
0.5 - 1.5	0.06	0.08	0.06	0.08	0.04	0.03	0.02	0.03	0.02	0.04	0.04	0.04	0.07	0.04	0.03	0.06	0.74
1.5 - 2.5	0.12	0.23	0.35	0.13	0.17	0.13	0.09	0.13	0.14	0.15	0.19	0.12	0.18	0.16	0.13	0.17	2.61
2.5 - 3.5	0.36	0.34	0.40	0.24	0.26	0.19	0.20	0.23	0.31	0.37	0.28	0.23	0.19	0.32	0.22	0.33	4.45
3.5 - 4.5	0.52	0.33	0.43	0.35	0.32	0.31	0.24	0.40	0.50	0.54	0.45	0.38	0.37	0.30	0.40	0.43	6.26
4.5 - 5.5	0.56	0.52	0.63	0.39	0.40	0.22	0.34	0.55	0.70	0.66	0.50	0.38	0.48	0.44	0.42	0.59	7.78
5.5 - 6.5	0.73	0.38	0.57	0.34	0.35	0.28	0.52	0.68	0.93	0.77	0.57	0.47	0.42	0.43	0.53	0.73	8.72
6.5 - 7.5	0.72	0.49	0.52	0.34	0.32	0.39	0.38	0.87	1.11	1.05	0.63	0.52	0.43	0.49	0.50	0.81	9.57
7.5 - 8.5	0.89	0.62	0.56	0.26	0.24	0.39	0.64	0.79	1.24	1.01	0.80	0.48	0.41	0.42	0.47	0.96	10.17
8.5 - 9.5	0.81	0.63	0.61	0.27	0.23	0.39	0.42	0.94	1.32	1.09	0.63	0.39	0.30	0.47	0.41	0.88	9.78
9.5 - 10.5	0.75	0.56	0.33	0.24	0.29	0.38	0.52	0.98	1.05	0.81	0.49	0.42	0.29	0.37	0.47	1.12	9.08
10.5 - 11.5	0.83	0.45	0.30	0.17	0.18	0.32	0.59	0.82	0.85	0.65	0.45	0.26	0.26	0.35	0.40	1.09	7.96
11.5 - 12.5	0.87	0.36	0.17	0.13	0.12	0.27	0.61	0.81	0.56	0.34	0.23	0.14	0.16	0.27	0.39	1.06	6.49
12.5 - 13.5	0.74	0.28	0.07	0.03	0.08	0.26	0.54	0.71	0.33	0.19	0.20	0.10	0.05	0.13	0.34	0.94	4.98
13.5 - 14.5	0.63	0.20	0.06	0.01	0.04	0.15	0.45	0.49	0.17	0.09	0.13	0.05	0.02	0.12	0.19	0.75	3.52
14.5 - 15.5	0.52	0.08	0.03	0.01	0.02	0.07	0.26	0.34	0.08	0.07	0.11	0.04	0.02	0.05	0.11	0.54	2.36
15.5 - 16.5	0.26	0.10	0.01	0.00	0.01	0.06	0.15	0.24	0.05	0.02	0.04	0.02	0.01	0.04	0.11	0.36	1.49
16.5 - 17.5	0.18	0.04	0.01	0.00	0.02	0.03	0.17	0.12	0.07	0.02	0.03	0.01	0.00	0.03	0.06	0.28	1.06
17.5 - 18.5	0.15	0.03	0.01	0.00	0.00	0.01	0.07	0.08	0.01	0.01	0.02	0.02	0.01	0.00	0.06	0.24	0.71
18.5 - 19.5	0.08	0.00	0.01	0.00	0.00	0.01	0.04	0.02	0.03	0.02	0.01	0.00	0.00	0.00	0.03	0.18	0.43
19.5 - 20.5	0.03	0.01	0.01	0.00	0.00	0.00	0.02	0.03	0.02	0.01	0.01	0.00	0.00	0.01	0.05	0.12	0.31
20.5 - 21.5	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.00	0.00	0.01	0.00	0.00	0.03	0.12	0.27
21.5 - 22.5	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.03	0.08	0.19
22.5 - 23.5	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.09	0.18
23.5 - 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.04	0.09
> 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.08

Table 46: Distribution of observed 60 m wind speed by direction at Tower M2311. Histogram of data is available in Figure 61 (p. 109).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.04
0.5 - 1.5	0.03	0.02	0.03	0.04	0.08	0.08	0.13	0.04	0.05	0.05	0.02	0.04	0.03	0.03	0.03	0.03	0.74
1.5 - 2.5	0.10	0.15	0.11	0.16	0.18	0.28	0.19	0.21	0.23	0.19	0.17	0.17	0.11	0.10	0.12	0.09	2.56
2.5 - 3.5	0.26	0.29	0.19	0.24	0.26	0.25	0.15	0.26	0.33	0.39	0.40	0.40	0.33	0.26	0.22	0.24	4.47
3.5 - 4.5	0.39	0.28	0.31	0.35	0.26	0.29	0.25	0.35	0.47	0.64	0.62	0.52	0.43	0.49	0.33	0.40	6.38
4.5 - 5.5	0.43	0.50	0.40	0.23	0.33	0.31	0.43	0.55	0.64	0.77	0.72	0.63	0.59	0.43	0.43	0.50	7.90
5.5 - 6.5	0.61	0.54	0.38	0.41	0.28	0.29	0.39	0.66	0.88	0.73	0.66	0.68	0.61	0.49	0.54	0.59	8.73
6.5 - 7.5	0.67	0.62	0.30	0.35	0.38	0.29	0.52	0.77	0.88	0.96	0.75	0.63	0.50	0.63	0.66	0.65	9.56
7.5 - 8.5	0.90	0.46	0.40	0.41	0.32	0.29	0.52	1.09	1.21	1.00	0.54	0.34	0.53	0.64	0.63	0.88	10.16
8.5 - 9.5	0.97	0.66	0.31	0.22	0.24	0.21	0.57	1.07	1.09	0.84	0.40	0.22	0.39	0.80	0.76	0.94	9.71
9.5 - 10.5	0.89	0.47	0.46	0.28	0.20	0.32	0.50	1.02	1.02	0.51	0.28	0.20	0.38	0.79	0.60	1.07	9.00
10.5 - 11.5	0.84	0.55	0.45	0.15	0.19	0.29	0.54	1.08	0.75	0.31	0.19	0.12	0.13	0.71	0.73	0.89	7.93
11.5 - 12.5	0.97	0.55	0.22	0.12	0.10	0.23	0.62	0.73	0.45	0.22	0.15	0.15	0.13	0.42	0.61	0.79	6.47
12.5 - 13.5	0.72	0.54	0.14	0.07	0.06	0.19	0.54	0.66	0.31	0.20	0.11	0.05	0.10	0.29	0.38	0.63	4.98
13.5 - 14.5	0.57	0.36	0.10	0.02	0.09	0.07	0.43	0.45	0.27	0.09	0.10	0.06	0.03	0.08	0.24	0.56	3.51
14.5 - 15.5	0.43	0.22	0.06	0.01	0.02	0.04	0.21	0.30	0.17	0.08	0.04	0.04	0.03	0.06	0.12	0.52	2.36
15.5 - 16.5	0.33	0.13	0.02	0.01	0.01	0.01	0.09	0.19	0.10	0.06	0.04	0.01	0.01	0.03	0.08	0.36	1.49
16.5 - 17.5	0.24	0.08	0.02	0.02	0.01	0.02	0.11	0.09	0.05	0.04	0.03	0.01	0.02	0.02	0.10	0.22	1.06
17.5 - 18.5	0.10	0.03	0.01	0.00	0.00	0.03	0.08	0.10	0.02	0.02	0.03	0.01	0.00	0.01	0.03	0.26	0.71
18.5 - 19.5	0.07	0.01	0.00	0.00	0.00	0.00	0.05	0.03	0.03	0.01	0.03	0.01	0.00	0.01	0.02	0.15	0.43
19.5 - 20.5	0.06	0.00	0.01	0.00	0.00	0.00	0.02	0.03	0.02	0.03	0.01	0.00	0.01	0.00	0.03	0.11	0.31
20.5 - 21.5	0.04	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.02	0.00	0.03	0.00	0.00	0.01	0.01	0.13	0.27
21.5 - 22.5	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.02	0.08	0.19
22.5 - 23.5	0.05	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.02	0.06	0.18
23.5 - 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.09
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.08

Table 47: Distribution of MOS-corrected $60\,m$ wind speed by direction at Tower M2311. All model values are computed only for times with valid observations. Histogram of data is available in Figure 61 (p. 109).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	9.90	11.15	2.51	10.02
NNE	8.23	9.29	2.39	5.77
NE	6.89	7.78	2.32	5.18
ENE	6.65	7.50	2.39	3.02
E	6.93	7.82	2.24	3.12
ESE	8.51	9.59	2.51	3.90
SE	9.98	11.22	2.74	6.34
SSE	9.58	10.77	2.79	9.36
S	8.49	9.55	2.71	9.62
SSW	7.91	8.89	2.69	7.99
SW	7.95	8.96	2.49	5.86
WSW	7.51	8.46	2.49	4.11
W	6.99	7.88	2.48	3.68
WNW	7.82	8.82	2.30	4.47
NW	9.00	10.17	2.22	5.43
NNW	10.62	11.97	2.49	12.12
ALL	**8.53**	**9.63**	**2.33**	**100.00**

Table 48: Observed 60 m mean wind speed, Weibull parameters, and frequency at Tower M2311. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 62 (p. 110).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	10.22	11.49	2.71	9.80
NNE	9.11	10.25	2.66	6.52
NE	8.12	9.14	2.56	3.95
ENE	6.97	7.86	2.40	3.12
E	6.95	7.84	2.24	3.03
ESE	7.61	8.59	2.02	3.53
SE	9.49	10.70	2.48	6.42
SSE	9.45	10.62	2.78	9.80
S	8.60	9.71	2.37	9.12
SSW	7.58	8.56	2.32	7.25
SW	7.17	8.10	2.15	5.37
WSW	6.54	7.38	2.26	4.34
W	6.94	7.82	2.49	4.40
WNW	8.39	9.41	2.86	6.33
NW	9.12	10.27	2.60	6.76
NNW	10.64	11.99	2.55	10.27
ALL	**8.54**	**9.64**	**2.33**	**100.00**

Table 49: MOS-corrected 60 m mean wind speed, Weibull parameters, and frequency at Tower M2311. All MOS-corrected model values are computed only for times with valid observations; blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 62 (p. 110).

12.4 Validation of Model Results at Tower M2313

This section examines the quality of the NWP simulations used at a single point within the study area. For this section, the observations were taken at Tower M2313 (latitude 39.07764, longitude -103.23864).

The average observed wind speed (for all valid observational times) at $60.0\,m$ during the 28 months of the period of record (October, 2010 to January, 2013) is $8.54\,m/s$ with an hourly standard deviation of $4.00\,m/s$ at Tower M2313. This compares to a modeled $60\,m$ wind speed of $7.23\,m/s$ with a $3.53\,m/s$ standard deviation for these same times.

Based on a comparison of the NWP model output with observations from each of the meteorological towers for which data were provided, Model Output Statistics (MOS) was constructed. MOS uses a multilinear regression model designed to remove the bias and adjust the variance of the raw NWP simulated wind speed and direction. Applying this statistical model to the simulated data at Tower M2313 results in a MOS-corrected mean value of $8.56\,m/s$ and an hourly standard deviation of $4.00\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2313). The focus of the verification is on the model's ability to reproduce the observed variability of the wind resource at daily and monthly time scales, while preserving the distribution of hourly wind speeds and the diurnal characteristics of the wind.

12.4.1 Observational Data

Approximately 28 months of wind speed data at $60.0\,meters$ and wind direction data at $58.0\,meters$ (October, 2010 to January, 2013) from a meteorological tower (Tower M2313) at Rush Creek II were used in this analysis. This tower will be referred to as the reference tower throughout this section. The data at $60\,m$ were used to assess the quality of the model simulations at $60\,m$.

It should be noted that meteorological observations provided to 3TIER are not allowed to influence the raw model simulations.

12.4.2 Model Validation Statistics

Table 50 presents some basic statistical measures of the model performance relative to the measured winds at the reference tower during the observational period. Also shown are values (labeled "MOS-corrected") for model data with the statistical model applied. For reference, the correlation of the reference tower data to itself is perfect and hence the explained variance (r^2) value is 1.0.

The observed and modeled winds in this section represent the mean of all times during the month for which a valid wind speed or direction observation was available. Therefore they should not be interpreted as estimates of the true winds at the site, but rather a verification of the model's ability to reproduce the available observations. Any month or hour missing greater than 50% of the available observations is omitted from the following figures, tables, and statistics.

Comparison	Value
Correlation of monthly-mean simulated wind speed to observed	0.94
RMS error of monthly-mean simulated wind speed	1.29 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.98
RMS error of monthly-mean MOS-corrected wind speed	0.13 m/s
Correlation of daily-mean simulated wind speed to observed	0.89
RMS error of daily-mean simulated wind speed	1.74 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.89
RMS error of daily-mean MOS-corrected wind speed	1.20 m/s

Table 50: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.4.3 Monthly Mean Wind Speed

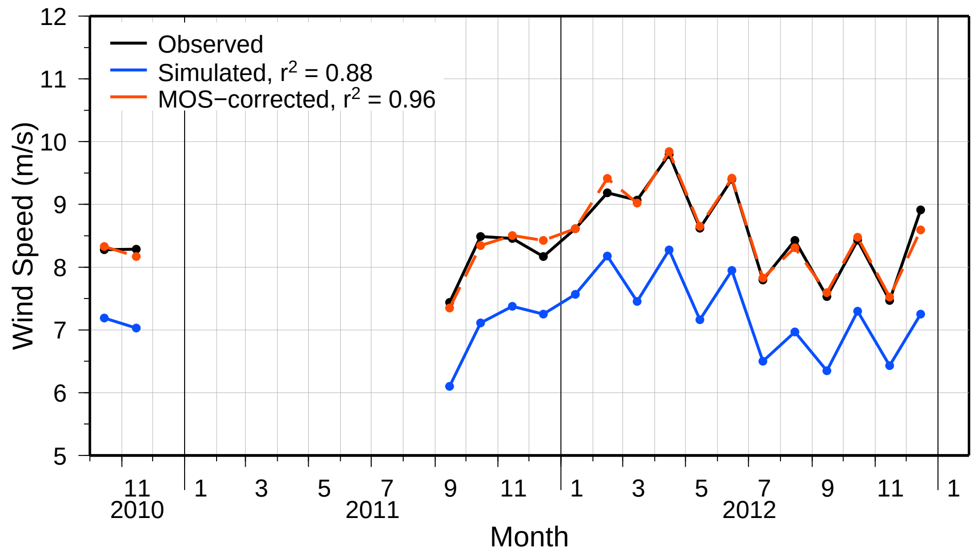

Figure 69: A comparison of the observed, simulated, and MOS-corrected monthly-mean $60\,m$ wind speed at Tower M2313. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 51 (p. 130).

12.4.4 Wind Speed Distribution

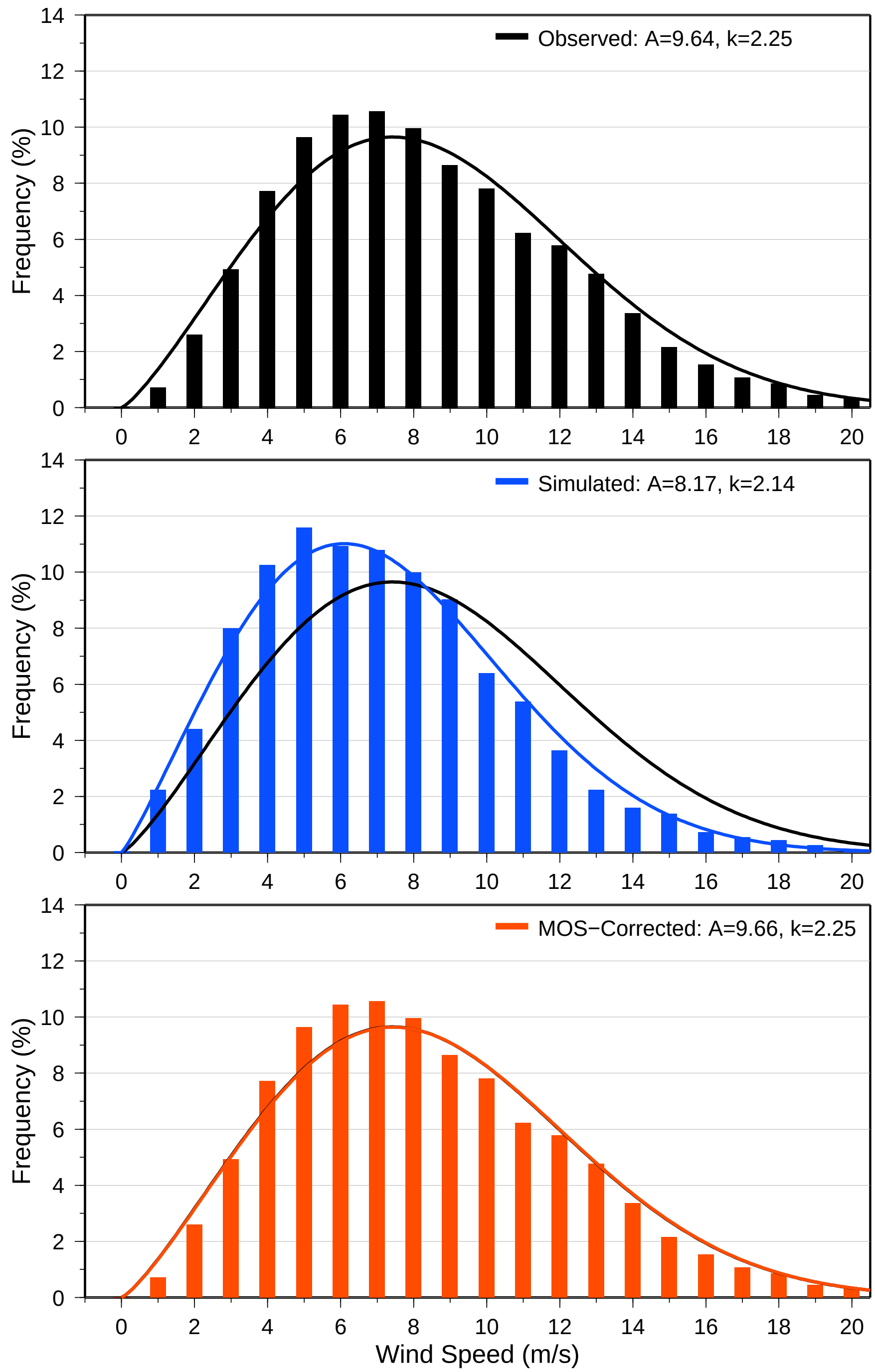

Figure 70: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $60\,m$ at Tower M2313 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend.

12.4.5 Wind Direction Distribution

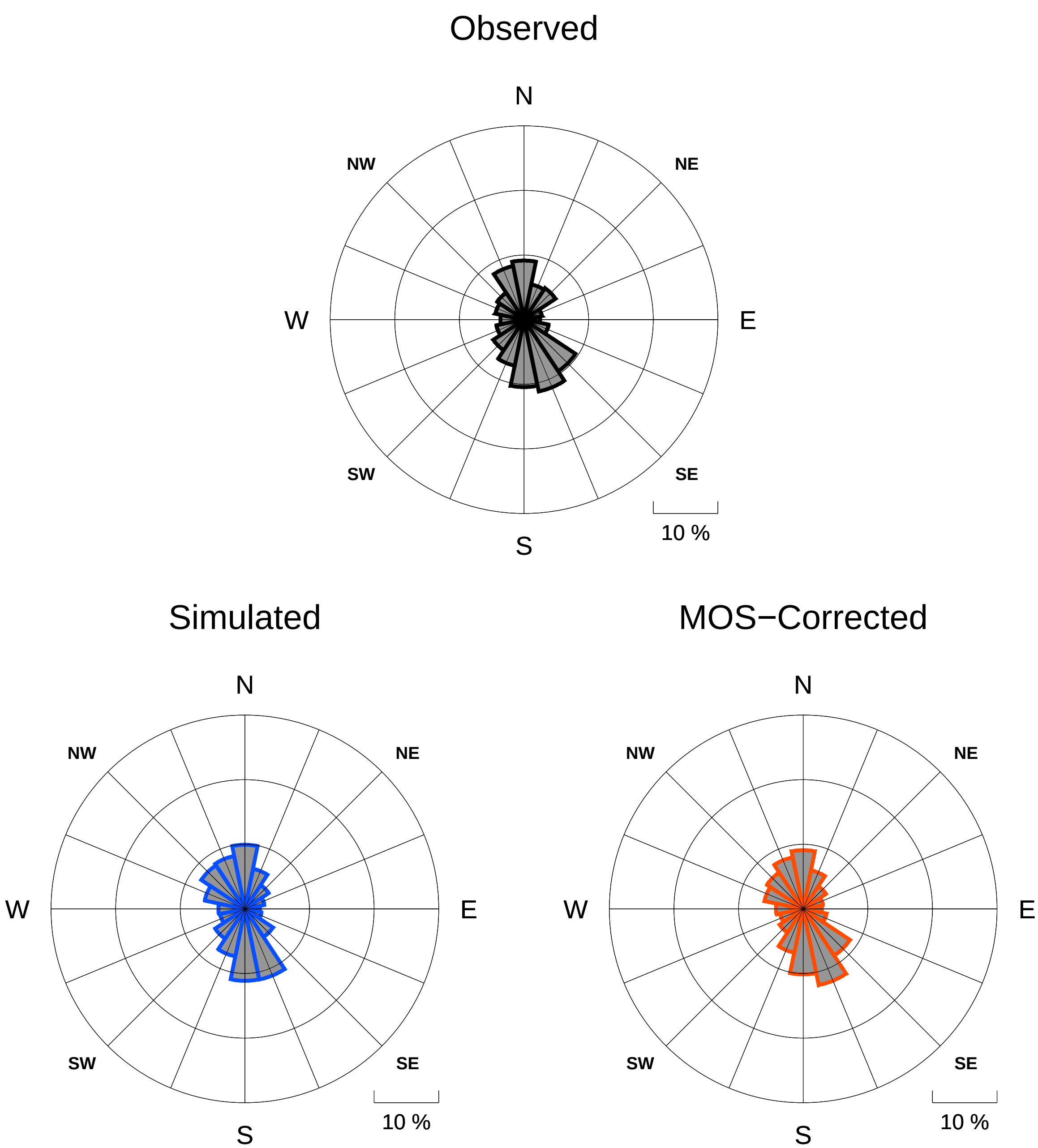

Figure 71: Wind roses at 58 m at Tower M2313 for observational data and simulated model data, averaged over the period of record (October, 2010–January, 2013). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 54 and 55 (p. 135).

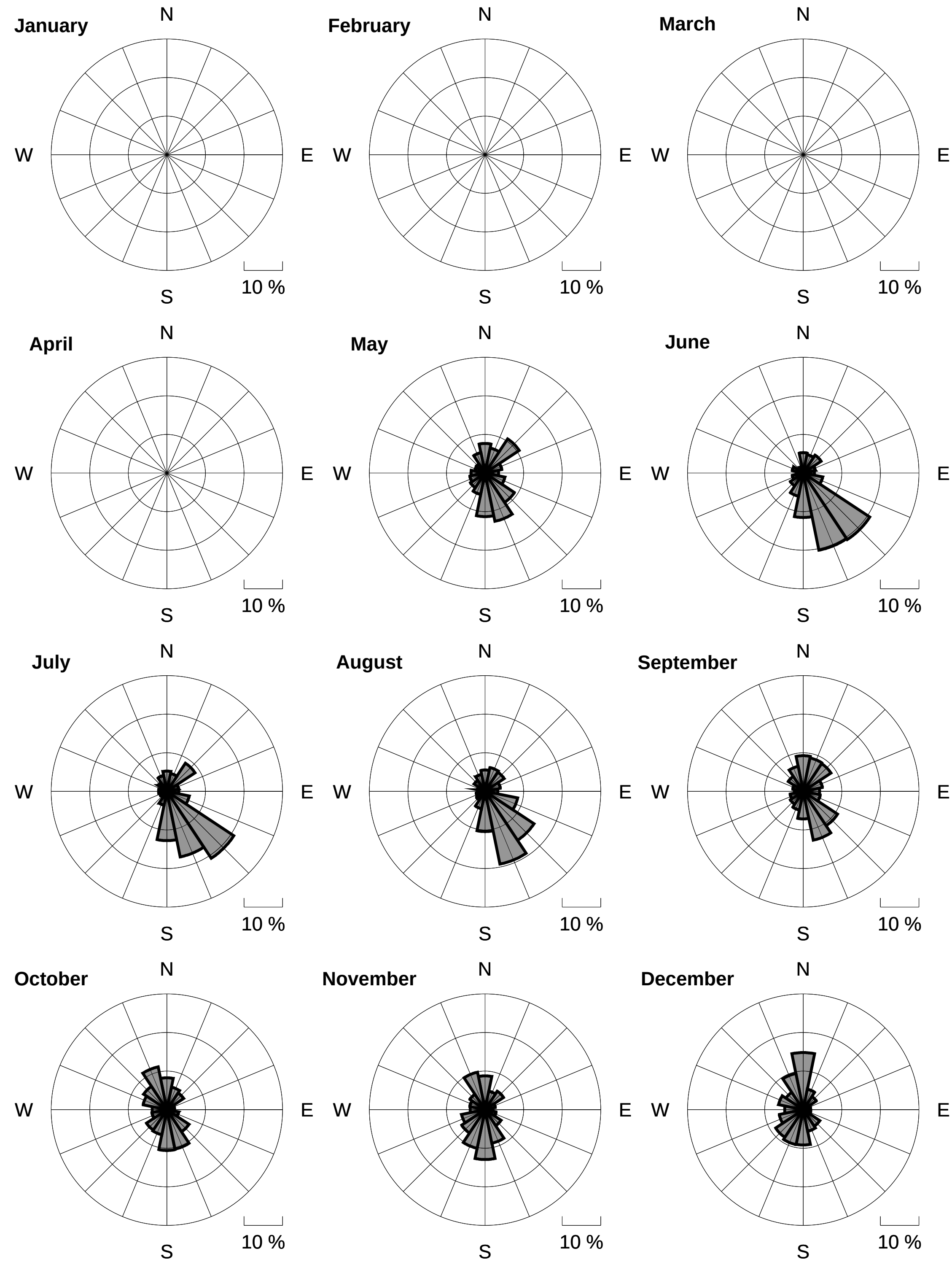

Figure 72: Wind rose of observed wind direction at $58\,m$ at Tower M2313 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

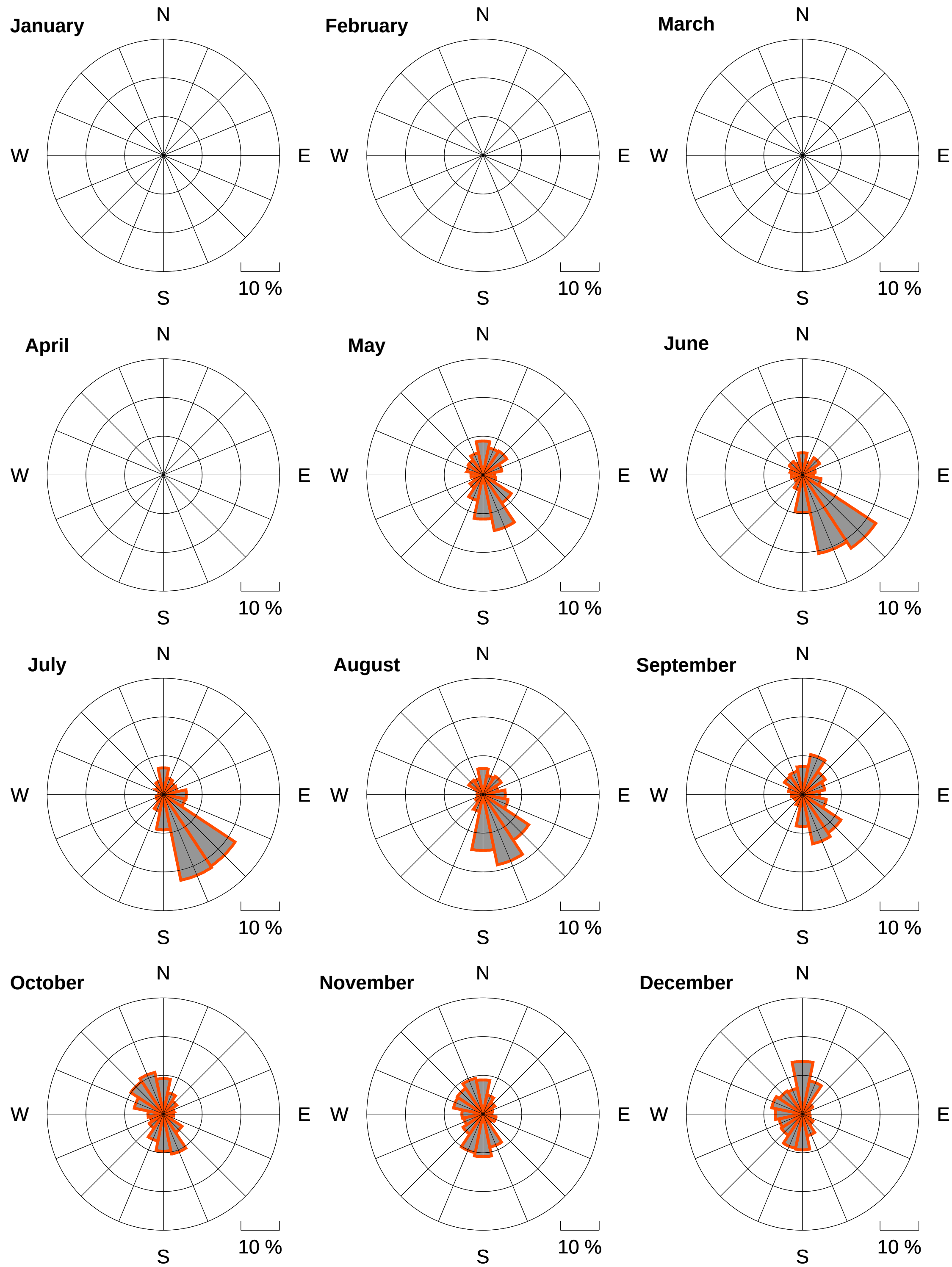

Figure 73: Wind rose of MOS-corrected wind direction at 58 m at Tower M2313 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.4.6 Diurnal Variability of Wind Speed

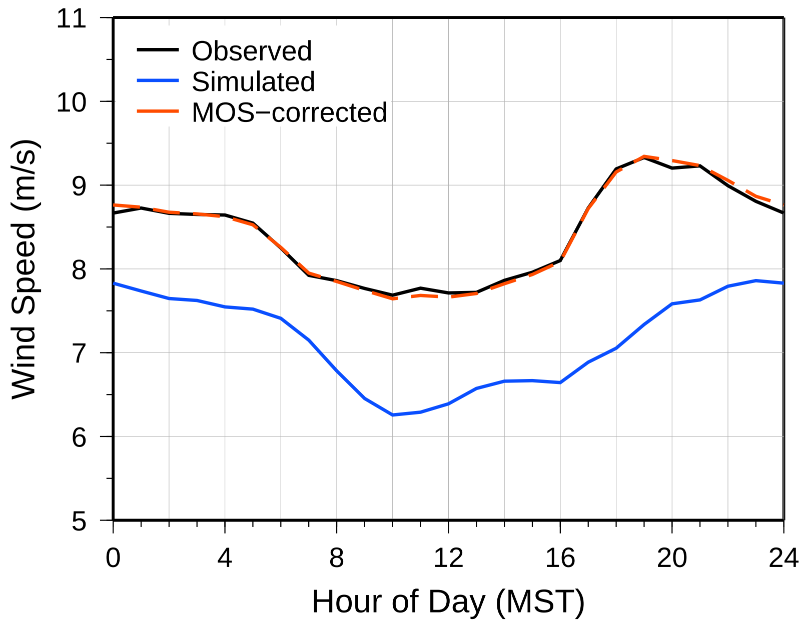

Figure 74: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed at Tower M2313. Data are averaged over the period of record (October, 2010–January, 2013). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data are available in Figures 76 and 77 (p. 131 and 132).

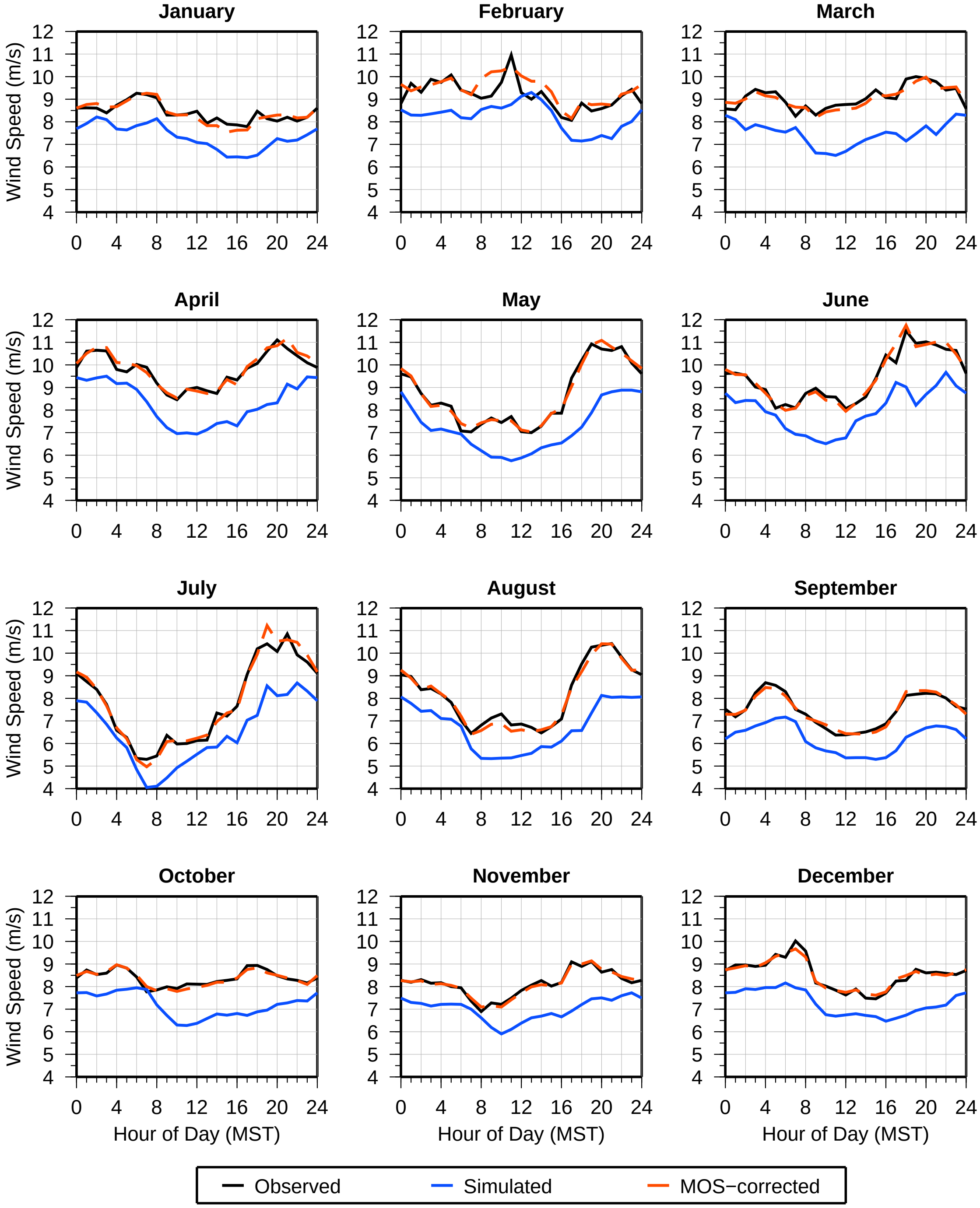

Figure 75: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected $60\,m$ wind speed for each calendar month at Tower M2313. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Standard Time (MST). Tabular formatted data available in Figures 76 and 77 (p. 131 and 132).

12.4.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
10/2010	8.28	7.19	-1.09	8.33	74.9
11/2010	8.29	7.03	-1.26	8.17	80.1
12/2010	–	–	–	–	0.0
01/2011	–	–	–	–	0.0
02/2011	–	–	–	–	0.0
03/2011	–	–	–	–	0.0
04/2011	–	–	–	–	0.0
05/2011	–	–	–	–	0.0
06/2011	–	–	–	–	0.0
07/2011	–	–	–	–	0.0
08/2011	6.79	5.53	-1.26	6.95	26.2
09/2011	7.44	6.10	-1.34	7.35	99.9
10/2011	8.49	7.11	-1.38	8.35	93.1
11/2011	8.46	7.38	-1.08	8.50	94.4
12/2011	8.17	7.25	-0.92	8.43	82.1
01/2012	8.61	7.57	-1.04	8.61	100.0
02/2012	9.18	8.18	-1.01	9.42	69.7
03/2012	9.07	7.45	-1.61	9.02	97.8
04/2012	9.80	8.28	-1.52	9.84	95.8
05/2012	8.62	7.16	-1.46	8.65	100.0
06/2012	9.40	7.95	-1.46	9.42	100.0
07/2012	7.80	6.50	-1.30	7.83	100.0
08/2012	8.42	6.97	-1.46	8.31	100.0
09/2012	7.53	6.35	-1.18	7.59	100.0
10/2012	8.43	7.30	-1.13	8.48	91.9
11/2012	7.47	6.43	-1.04	7.52	96.4
12/2012	8.91	7.25	-1.66	8.60	85.1
01/2013	7.78	6.69	-1.09	7.74	25.9
All	**8.54**	**7.23**	**-1.31**	**8.56**	**61.2**

Table 51: Monthly-mean $60\,m$ wind speeds (m/s) at Tower M2313. Time series graph of data is available in Figure 69 (p. 123). The average values shown at the bottom of the table, labeled 'All', are computed as the mean of monthly means.

Observed = mean of all available wind speed observations
Simulated = mean of simulated model output for times with observations
Bias = Simulated – Observed
MOS-corrected = mean of MOS-corrected output for times with observations

Observations

Hour of Day (MST)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	8.61	8.81	8.58	9.88	9.61	9.62	9.11	9.05	7.53	8.38	8.28	8.72	8.67
1	8.62	9.71	8.54	10.61	9.47	9.64	8.74	8.97	7.18	8.73	8.19	8.96	8.73
2	8.61	9.32	9.14	10.65	8.74	9.55	8.39	8.38	7.49	8.53	8.31	8.96	8.66
3	8.39	9.88	9.43	10.62	8.22	9.02	7.74	8.44	8.24	8.60	8.15	8.90	8.65
4	8.73	9.75	9.29	9.80	8.31	8.90	6.58	8.20	8.69	8.96	8.17	8.95	8.64
5	8.98	10.08	9.34	9.70	8.18	8.09	6.27	7.83	8.57	8.82	8.00	9.43	8.55
6	9.27	9.40	8.87	10.02	7.08	8.24	5.34	7.03	8.30	8.43	7.95	9.31	8.25
7	9.21	9.26	8.25	9.90	7.04	8.10	5.29	6.45	7.52	7.77	7.37	10.02	7.92
8	9.07	9.04	8.70	9.20	7.37	8.73	5.45	6.81	7.30	7.85	6.89	9.57	7.86
9	8.30	9.15	8.30	8.68	7.65	8.97	6.36	7.13	6.94	7.99	7.28	8.16	7.77
10	8.30	9.75	8.60	8.47	7.45	8.59	5.98	7.32	6.67	7.92	7.21	8.03	7.69
11	8.34	10.96	8.74	8.91	7.72	8.58	6.00	6.82	6.38	8.12	7.50	7.84	7.77
12	8.47	9.29	8.77	9.00	7.04	8.06	6.12	6.87	6.38	8.11	7.83	7.63	7.71
13	7.94	9.00	8.79	8.85	7.00	8.29	6.15	6.72	6.45	8.10	8.07	7.89	7.72
14	8.18	9.34	9.02	8.74	7.29	8.59	7.35	6.47	6.51	8.22	8.27	7.49	7.86
15	7.90	8.79	9.42	9.46	7.86	9.41	7.22	6.75	6.65	8.27	8.02	7.46	7.96
16	7.86	8.19	9.08	9.34	7.86	10.44	7.66	7.09	6.87	8.34	8.19	7.72	8.10
17	7.90	7.90	9.07	9.82	9.52	9.87	9.33	8.41	7.37	9.03	8.95	8.40	8.73
18	8.57	8.72	9.82	10.08	10.35	11.33	10.23	9.53	8.15	9.08	8.66	8.45	9.19
19	8.41	8.57	9.71	10.64	11.04	10.88	10.50	10.33	8.17	8.87	8.90	8.77	9.33
20	8.26	8.71	9.64	11.19	10.81	10.87	10.34	10.15	8.31	8.59	8.41	8.66	9.20
21	8.41	8.82	9.50	10.88	10.58	10.85	10.80	10.53	8.27	8.44	8.54	8.70	9.23
22	8.15	9.19	9.33	10.49	10.71	10.54	10.26	9.75	8.05	8.37	8.17	8.64	8.99
23	8.10	9.51	9.44	10.09	10.00	10.48	9.95	9.24	7.67	8.26	7.98	8.72	8.81
Avg	8.44	9.18	9.07	9.80	8.62	9.40	7.80	8.09	7.49	8.41	8.05	8.55	8.54

Wind Speed (m/s): 4 5 6 7 8 9 10 11 12

Figure 76: Hourly-mean values of observed 60 m wind speed at Tower M2313. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 74 and 75 (p. 128 and 129).

MOS−Corrected

Hour of Day (MST)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	8.61	9.66	8.87	10.07	9.85	9.80	9.18	9.26	7.30	8.49	8.27	8.74	8.76
1	8.77	9.37	8.83	10.51	9.51	9.57	8.94	8.90	7.29	8.67	8.21	8.83	8.74
2	8.81	9.55	9.01	10.78	8.73	9.57	8.42	8.40	7.49	8.55	8.25	8.93	8.68
3	8.65	9.65	9.33	10.77	8.16	9.20	7.68	8.55	8.10	8.67	8.10	8.85	8.66
4	8.68	9.78	9.15	10.11	8.21	8.75	6.69	8.21	8.49	8.97	8.13	9.05	8.62
5	8.92	9.94	9.08	10.07	7.95	8.28	6.22	7.89	8.43	8.82	8.05	9.34	8.53
6	9.19	9.41	8.80	9.97	7.41	7.99	5.28	7.22	8.11	8.51	7.92	9.48	8.26
7	9.27	9.21	8.66	9.66	7.20	8.08	4.97	6.41	7.57	8.00	7.49	9.67	7.95
8	9.21	9.92	8.63	9.15	7.44	8.64	5.31	6.58	7.15	7.82	7.10	9.32	7.85
9	8.43	10.21	8.19	8.76	7.58	8.81	6.09	6.86	7.00	7.91	7.15	8.22	7.74
10	8.30	10.26	8.44	8.54	7.54	8.43	6.14	6.88	6.83	7.78	7.10	7.93	7.64
11	8.31	10.44	8.52	8.93	7.53	8.41	6.12	6.55	6.61	7.90	7.42	7.84	7.68
12	8.15	10.04	8.56	8.84	7.12	7.94	6.23	6.61	6.43	7.97	7.73	7.75	7.66
13	7.83	9.80	8.61	8.73	7.03	8.31	6.38	6.53	6.43	8.05	7.99	7.85	7.71
14	7.83	9.80	8.82	8.83	7.31	8.75	6.97	6.61	6.42	8.20	8.08	7.67	7.82
15	7.54	9.33	9.20	9.35	7.85	9.32	7.35	6.75	6.51	8.19	8.05	7.62	7.93
16	7.63	8.48	9.15	9.12	8.05	10.25	7.49	7.25	6.74	8.39	8.16	7.77	8.09
17	7.92	8.11	9.14	9.97	9.16	10.59	9.30	8.37	7.39	8.92	8.80	8.33	8.72
18	8.35	8.73	9.52	10.33	10.13	11.38	10.23	9.17	8.24	8.99	8.80	8.48	9.16
19	8.42	8.74	9.68	10.82	10.96	10.78	11.04	10.05	8.31	8.81	8.92	8.65	9.34
20	8.49	8.79	9.84	10.87	11.17	10.97	10.47	10.32	8.36	8.62	8.63	8.49	9.29
21	8.45	8.82	9.32	11.18	10.81	10.88	10.84	10.23	8.39	8.48	8.50	8.56	9.23
22	8.29	9.18	9.45	10.43	10.69	10.94	10.53	9.81	8.04	8.38	8.30	8.50	9.06
23	8.31	9.33	9.47	10.32	10.19	10.38	9.95	9.44	7.67	8.23	8.17	8.64	8.87
Avg	8.43	9.42	9.02	9.84	8.65	9.42	7.83	8.03	7.47	8.39	8.06	8.51	8.56

Wind Speed (m/s): 4 5 6 7 8 9 10 11 12

Figure 77: Hourly-mean values of MOS-corrected 60 m wind speed at Tower M2313. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Standard Time (MST). Time series graphs of data are available in Figures 74 and 75 (p. 128 and 129).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
0.5 - 1.5	0.05	0.05	0.03	0.03	0.06	0.03	0.03	0.05	0.06	0.02	0.10	0.05	0.01	0.02	0.07	0.05	0.71
1.5 - 2.5	0.11	0.12	0.26	0.11	0.10	0.12	0.16	0.13	0.22	0.22	0.22	0.25	0.17	0.18	0.11	0.11	2.60
2.5 - 3.5	0.21	0.23	0.29	0.22	0.15	0.17	0.30	0.34	0.57	0.51	0.45	0.36	0.34	0.34	0.22	0.21	4.90
3.5 - 4.5	0.29	0.46	0.43	0.36	0.26	0.15	0.45	0.58	0.91	0.92	0.68	0.45	0.57	0.45	0.33	0.40	7.68
4.5 - 5.5	0.41	0.43	0.46	0.39	0.37	0.37	0.60	0.85	1.13	1.04	0.69	0.72	0.59	0.57	0.39	0.57	9.58
5.5 - 6.5	0.57	0.51	0.76	0.32	0.33	0.41	0.62	1.02	1.35	1.10	0.88	0.65	0.63	0.45	0.41	0.36	10.37
6.5 - 7.5	0.51	0.49	0.68	0.31	0.21	0.34	0.50	1.27	1.46	1.03	0.83	0.73	0.41	0.48	0.57	0.68	10.51
7.5 - 8.5	0.57	0.53	0.60	0.27	0.23	0.36	0.84	1.30	1.45	0.73	0.65	0.46	0.34	0.53	0.50	0.55	9.91
8.5 - 9.5	0.61	0.38	0.54	0.24	0.22	0.22	0.80	1.41	1.14	0.57	0.33	0.36	0.19	0.41	0.42	0.76	8.59
9.5 - 10.5	0.71	0.36	0.56	0.13	0.19	0.32	0.95	1.27	0.83	0.40	0.18	0.14	0.22	0.35	0.42	0.75	7.77
10.5 - 11.5	0.68	0.42	0.41	0.18	0.17	0.34	0.93	0.91	0.35	0.25	0.18	0.07	0.08	0.27	0.31	0.65	6.20
11.5 - 12.5	0.75	0.29	0.34	0.12	0.11	0.33	1.04	0.79	0.40	0.14	0.15	0.05	0.04	0.19	0.37	0.63	5.74
12.5 - 13.5	0.67	0.24	0.23	0.06	0.05	0.32	0.92	0.57	0.27	0.12	0.11	0.02	0.04	0.12	0.22	0.79	4.75
13.5 - 14.5	0.68	0.30	0.11	0.06	0.05	0.20	0.68	0.32	0.07	0.08	0.05	0.01	0.01	0.06	0.18	0.50	3.35
14.5 - 15.5	0.55	0.21	0.07	0.00	0.01	0.11	0.36	0.14	0.07	0.02	0.06	0.02	0.00	0.06	0.15	0.32	2.14
15.5 - 16.5	0.50	0.18	0.02	0.01	0.00	0.06	0.21	0.13	0.01	0.02	0.03	0.00	0.00	0.00	0.07	0.28	1.52
16.5 - 17.5	0.35	0.18	0.02	0.00	0.00	0.02	0.07	0.09	0.01	0.02	0.03	0.01	0.00	0.01	0.08	0.19	1.08
17.5 - 18.5	0.29	0.10	0.02	0.01	0.00	0.01	0.04	0.04	0.02	0.01	0.03	0.00	0.01	0.02	0.05	0.22	0.85
18.5 - 19.5	0.18	0.02	0.00	0.00	0.00	0.00	0.02	0.03	0.02	0.01	0.02	0.02	0.00	0.00	0.02	0.12	0.45
19.5 - 20.5	0.14	0.02	0.00	0.00	0.00	0.00	0.02	0.04	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.08	0.37
20.5 - 21.5	0.13	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.02	0.02	0.00	0.00	0.00	0.02	0.08	0.31
21.5 - 22.5	0.08	0.01	0.00	0.00	0.00	0.01	0.00	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.08	0.25
22.5 - 23.5	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.14
23.5 - 24.5	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.10
> 24.5	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.02	0.02	0.03	0.14

Table 52: Distribution of observed 60 m wind speed by direction at Tower M2313. Histogram of data is available in Figure 70 (p. 124).

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
0.5 - 1.5	0.03	0.03	0.04	0.02	0.04	0.06	0.07	0.10	0.07	0.02	0.07	0.02	0.05	0.02	0.02	0.05	0.71
1.5 - 2.5	0.11	0.10	0.14	0.14	0.14	0.24	0.13	0.22	0.29	0.17	0.15	0.14	0.18	0.14	0.17	0.14	2.60
2.5 - 3.5	0.20	0.22	0.20	0.22	0.26	0.25	0.23	0.37	0.56	0.64	0.36	0.42	0.37	0.22	0.19	0.19	4.90
3.5 - 4.5	0.27	0.35	0.34	0.37	0.22	0.27	0.27	0.53	0.81	1.02	0.83	0.64	0.59	0.42	0.44	0.30	7.68
4.5 - 5.5	0.43	0.47	0.41	0.31	0.38	0.32	0.37	0.68	1.13	0.96	0.92	0.87	0.66	0.68	0.51	0.47	9.58
5.5 - 6.5	0.69	0.49	0.62	0.23	0.34	0.34	0.55	0.91	1.22	1.15	0.63	0.58	0.73	0.68	0.60	0.60	10.37
6.5 - 7.5	0.66	0.56	0.37	0.41	0.38	0.37	0.69	1.18	1.43	0.94	0.42	0.33	0.64	0.73	0.70	0.68	10.51
7.5 - 8.5	0.71	0.49	0.46	0.42	0.34	0.28	0.75	1.49	1.33	0.54	0.30	0.18	0.28	0.74	0.84	0.75	9.91
8.5 - 9.5	0.82	0.44	0.30	0.29	0.24	0.30	0.68	1.38	0.99	0.42	0.11	0.10	0.25	0.72	0.80	0.75	8.59
9.5 - 10.5	0.79	0.51	0.29	0.20	0.19	0.26	0.69	1.23	0.74	0.38	0.11	0.06	0.20	0.61	0.61	0.88	7.77
10.5 - 11.5	0.53	0.49	0.26	0.20	0.10	0.27	0.82	0.98	0.48	0.18	0.08	0.06	0.10	0.45	0.53	0.67	6.20
11.5 - 12.5	0.74	0.37	0.25	0.14	0.10	0.19	0.92	1.00	0.39	0.11	0.09	0.09	0.06	0.26	0.44	0.60	5.74
12.5 - 13.5	0.62	0.38	0.17	0.08	0.06	0.23	0.97	0.83	0.18	0.11	0.06	0.03	0.09	0.16	0.33	0.45	4.75
13.5 - 14.5	0.57	0.34	0.13	0.04	0.04	0.15	0.68	0.39	0.12	0.09	0.06	0.07	0.02	0.12	0.18	0.35	3.35
14.5 - 15.5	0.47	0.29	0.09	0.01	0.01	0.07	0.38	0.25	0.10	0.02	0.03	0.01	0.01	0.05	0.10	0.25	2.14
15.5 - 16.5	0.39	0.25	0.04	0.00	0.01	0.02	0.22	0.15	0.07	0.02	0.02	0.01	0.00	0.04	0.09	0.22	1.52
16.5 - 17.5	0.25	0.12	0.10	0.01	0.01	0.01	0.10	0.12	0.02	0.02	0.01	0.02	0.01	0.03	0.05	0.22	1.08
17.5 - 18.5	0.32	0.10	0.01	0.00	0.01	0.01	0.09	0.10	0.02	0.05	0.02	0.01	0.00	0.00	0.01	0.11	0.85
18.5 - 19.5	0.14	0.04	0.00	0.00	0.02	0.00	0.02	0.05	0.01	0.02	0.01	0.00	0.00	0.00	0.02	0.14	0.45
19.5 - 20.5	0.12	0.03	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.01	0.03	0.00	0.00	0.01	0.02	0.10	0.37
20.5 - 21.5	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.02	0.02	0.00	0.00	0.00	0.03	0.11	0.31
21.5 - 22.5	0.08	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.02	0.03	0.00	0.00	0.00	0.02	0.07	0.25
22.5 - 23.5	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.03	0.03	0.14
23.5 - 24.5	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.10
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.14

Table 53: Distribution of MOS-corrected $60\,m$ wind speed by direction at Tower M2313. All model values are computed only for times with valid observations. Histogram of data is available in Figure 70 (p. 124).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	11.34	12.77	2.56	9.14
NNE	9.09	10.26	2.24	5.57
NE	7.75	8.73	2.55	5.84
ENE	6.85	7.73	2.36	2.80
E	6.95	7.83	2.42	2.50
ESE	8.81	9.93	2.53	3.89
SE	9.69	10.87	2.92	9.57
SSE	8.73	9.82	2.69	11.33
S	7.43	8.38	2.41	10.43
SSW	6.83	7.71	2.25	7.26
SW	6.72	7.59	2.15	5.69
WSW	6.13	6.90	2.53	4.37
W	6.03	6.79	2.57	3.64
WNW	7.28	8.22	2.25	4.51
NW	8.76	9.90	2.22	4.99
NNW	10.53	11.87	2.44	8.46
ALL	**8.54**	**9.64**	**2.25**	**100.00**

Table 54: Observed $60\,m$ mean wind speed, Weibull parameters, and frequency at Tower M2313. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 71 (p. 125).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	10.75	12.11	2.53	9.09
NNE	9.51	10.72	2.45	6.09
NE	7.98	9.00	2.35	4.21
ENE	7.07	7.97	2.51	3.11
E	6.86	7.75	2.30	2.89
ESE	7.72	8.71	2.20	3.66
SE	10.01	11.22	2.95	8.67
SSE	9.07	10.20	2.71	12.03
S	7.61	8.59	2.15	10.14
SSW	6.61	7.46	2.22	6.88
SW	6.37	7.17	1.81	4.39
WSW	5.85	6.60	2.11	3.64
W	6.14	6.92	2.51	4.22
WNW	7.86	8.84	2.64	6.11
NW	8.70	9.82	2.43	6.74
NNW	10.09	11.38	2.40	8.15
ALL	**8.56**	**9.66**	**2.25**	**100.00**

Table 55: MOS-corrected $60\,m$ mean wind speed, Weibull parameters, and frequency at Tower M2313. All MOS-corrected model values are computed only for times with valid observations; blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 71 (p. 125).

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