Vaisala 3TIER Services Wind Energy Due Diligence

PROJECT

La Cumbre : Las Animas and Huerfano Counties, Colorado

using 22 GE 2.5-127 wind turbines at 88.6 m
and 2 GE 2.3-116 wind turbines at 80 m

FOR

Black Hills Corp.

DATE

6 December, 2017

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VAISALA

Process Versioning

Employed Version	6.12
Most Recent Validated Version	6.5
Process Updates Since Validation	• Extreme Cold Temperature Derating Algorithm • Topographic Data Improvement in United States • Turbulence Intensity Loss Algorithm • Turbine Specific Wind Energy Sensitivity • Climate Variability Uncertainty Algorithm

Report Creation

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Report Specifications

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Contents

1 EXECUTIVE SUMMARY

Vaisala has conducted a wind resource assessment of the La Cumbre project, located in Las Animas and Huerfano Counties, Colorado. This project consists of 22 GE 2.5-127 and 2 GE 2.3-116 wind turbines at 88.6 m and 80 m respectively, for a total capacity of 59.6 MW. The project is located in rangeland approximately 20 km southeast of Walsenburg.

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. Table 2 shows the probability of exceedance levels associated with the P50 project estimate. The long-term reference period used in this analysis extends over 37 years (January, 1980 – September, 2017). The wind resource assessment yields a gross project-average long-term wind speed estimate, at hub height, of **8.05 m/s**. The long-term mean gross generation estimate is **254.8 GWh**, with a corresponding gross capacity factor of 48.8 %. Loss factors are considered, leading to a net energy estimate of **212.9 GWh**, with a corresponding net capacity factor of 40.8 %.

Maps of the long-term mean wind speed values at 88.6 m and 80 m hub heights across the La Cumbre project area are displayed in Wind Speed Maps.

Project Size	59.6 MW
Number of Turbines	24
Turbine Types	GE 2.5-127 and GE 2.3-116
Hub Heights	88.6 m and 80 m
Project-Average Wind Speed	8.05 m/s
Project-Average Density	0.978 kg/m^3
Gross Generation	254.8 GWh
Net Generation	212.9 GWh
Gross Capacity Factor	48.8 %
Net Capacity Factor	40.8 %
Aggregate Loss Factor	83.6 %
Standard Error of 20-year Estimate	6.5 %

Table 1: Project Overview

	1-year	10-year	20-year
Gross-P50	254.8	254.8	254.8
Net-P50	212.9	212.9	212.9
Net-P75	202.5	203.6	203.6
Net-P90	193.1	195.1	195.3
Net-P95	187.5	190.1	190.3
Net-P99	176.9	180.6	180.9

Table 2: Probability of Exceedance Values (GWh)

1.1 Wind Speed Maps

This section contains maps of MOS-corrected long-term mean wind speed values at hub height (88.6 m and 80 m) across the La Cumbre project area.

1.1.1 88.6 m Hub Height

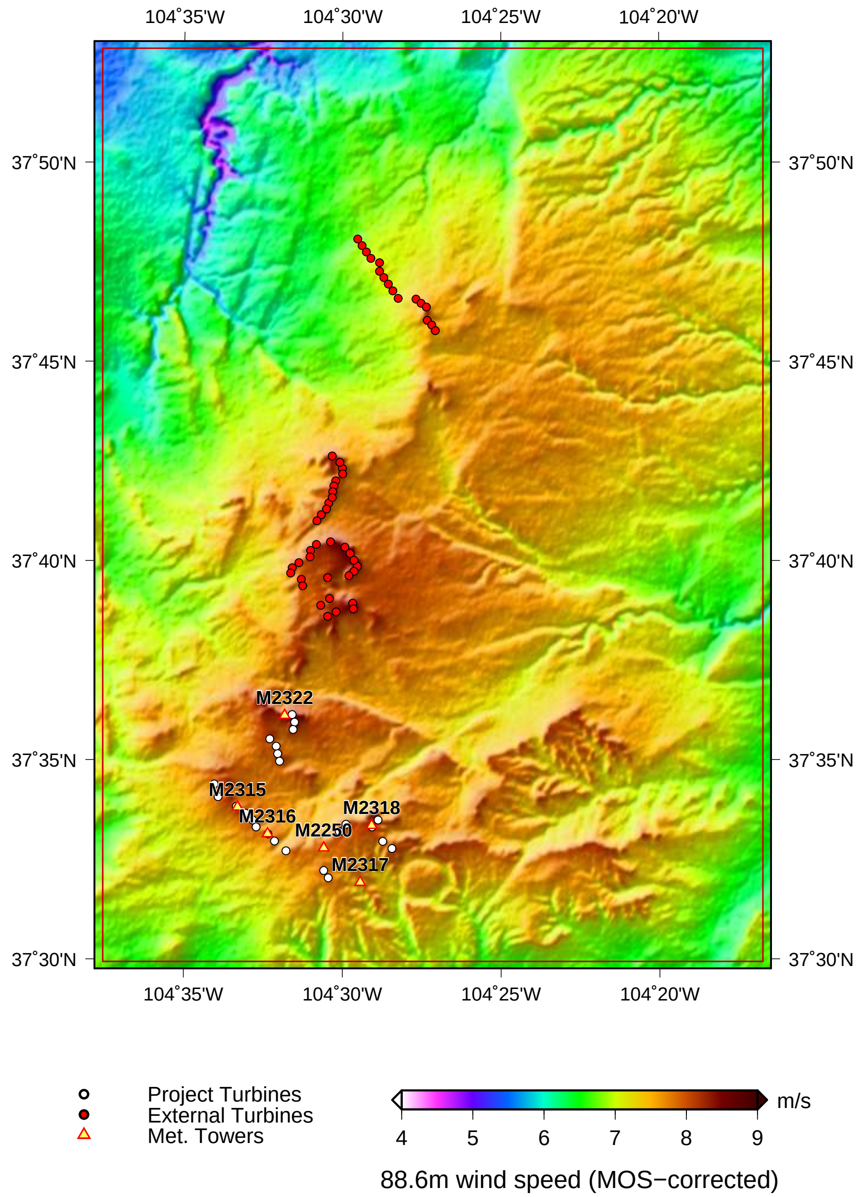

Figure 1: 37-year (January, 1980 – September, 2017) mean wind speed at 88.6 m.

1.1.2 80 m Hub Height

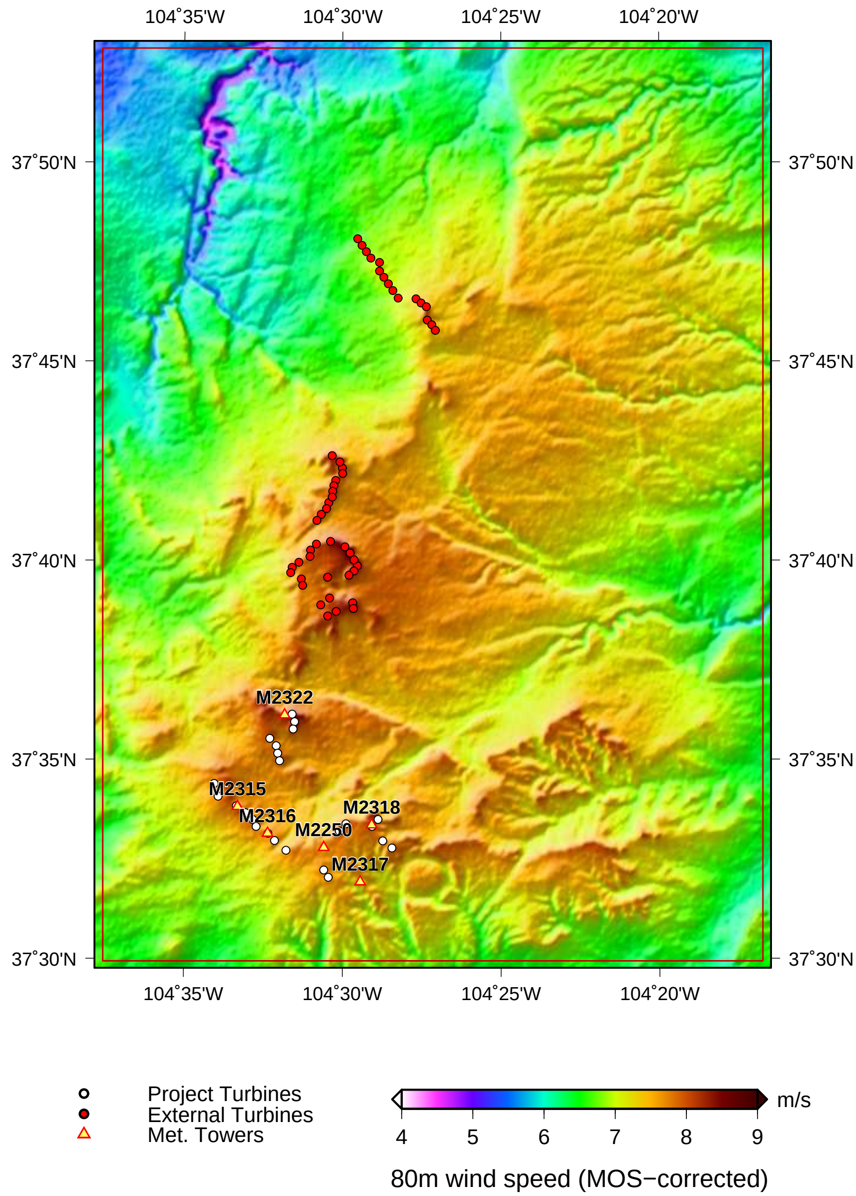

Figure 2: 37-year (January, 1980 – September, 2017) mean wind speed at 80 m.

2 METHODOLOGY

Vaisala's wind resource assessments are conducted using the 3TIER Services' NWP 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, and for continuous assimilation of gridded analysis into the simulations. 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 [1]. Topographic data are sourced from the Shuttle Radar Topography Mission (SRTM) data set at 3 arc-second (approximately $90\,m$) resolution [2]. 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 3TIER Services Time-Varying Microscale (TVM) Model enables high-resolution mapping of meteorological fields without the computational cost of running an NWP model, such as the WRF model, at such fine spatial resolution. TVM uses several techniques to analyze microscale winds. Terrain effects that are unresolved by the mesoscale NWP model are estimated by considering both the variability of the elevation and the depth of the atmospheric mixed layer [3]. This is followed by a divergence minimization that enforces conservation of mass and further redistributed the wind velocity field. 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 La Cumbre wind project, the following procedure was implemented:

1. For the ERA-I [4], NCAR/NCEP [5], and MERRA-2 [6] reanalysis data sets, simulate 37 years at $4.5\,km$ resolution using WRF to understand the long-term temporal variability of weather over the project site.
2. When on-site observational data are available, validate time series data collected from each measurement location, and then perform correlation analysis between observations and $4.5\,km$ model results to determine primary reanalysis data set for NWP modeling.
3. Simulate 1 year at $500\,m$ resolution using WRF to understand the spatial variability of the wind resource at the site.
4. Run TVM to downscale $500\,m$ WRF simulation to $90\,m$ spatial resolution.
5. Perform ensemble analysis to integrate effects of each long-term data set including consistency checks to determine usefulness of entire 37 year period for each data set.
6. Combine the high-resolution spatial model data with the ensemble-adjusted coarser resolution long-term data, creating the final $90\,m$ resolution long-term data set.
7. When on-site observational data are available, compute and apply MOS to eliminate temporal bias and mitigate spatial bias of WRF/TVM model output.
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 data, yielding the expected (P50) net capacity factor.
11. Perform uncertainty analysis using the 3TIER Services' Energy Risk Framework.
12. Calculate probability of exceedance levels for the net capacity factor data using the results of the uncertainty analysis.

The following sections provide detail regarding the process outlined above as applied to the La Cumbre wind project.

3 OBSERVATIONAL DATA

Black Hills Corp. provided observational data from the following towers at the proposed La Cumbre site:

- Tower M2250
- Tower M2315
- Tower M2316
- Tower M2317
- Tower M2318
- Tower M2322

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 3 and Table 4. Vaisala did not perform a site visit of the La Cumbre wind project. Quality control of the observed data for each tower are described in detail within the following sections.

	M2250	**M2315**	**M2316**
Latitude	37.54650°	37.56359°	37.55243°
Longitude	-104.50980°	-104.55513°	-104.53930°
Time Series Start	2009-Mar-03	2010-May-27	2010-May-30
Time Series End	2012-Jan-31	2012-Jan-26	2011-Jul-28
Observed 20 m Wind Speed	–	7.11	6.84
Observed 21 m Wind Speed	6.76	–	–
Observed 22 m Wind Speed	6.81	–	–
Observed 40 m Wind Speed	7.38	7.76	7.49
Observed 59 m Wind Speed	7.50	–	–
Observed 60 m Wind Speed	–	8.05	7.79
Observed 61 m Wind Speed	–	–	–
Average Shear	0.13	0.12	0.14
Hub Height 80 m Wind Speed	7.81	8.34	8.11
Hub Height 88.6 m Wind Speed	7.92	8.46	8.23
Long-term 80 m Wind Speed	7.71	7.96	7.75
Long-term 88.6 m Wind Speed	7.82	8.06	7.87
Long-term 88.6 m Adjustment Factor	98.7 %	95.3 %	95.7 %
Mean Turbulence Intensity (TI) 80 m	7.1 %	7.5 %	7.9 %
Characteristic TI 80 m	10.8 %	10.8 %	11.5 %
Mean TI 88.6 m	7.1 %	7.3 %	7.7 %
Characteristic TI 88.6 m	10.8 %	10.6 %	11.3 %

Table 3: 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.

	M2317	M2318	M2322
Latitude	37.53212°	37.55595°	37.60197°
Longitude	-104.49060°	-104.48466°	-104.53034°
Time Series Start	2010-Jun-10	2010-Jun-08	2010-Jun-12
Time Series End	2011-Aug-02	2011-Oct-24	2011-Mar-09
Observed 20 m Wind Speed	5.52	6.07	6.86
Observed 21 m Wind Speed	–	–	–
Observed 22 m Wind Speed	–	–	–
Observed 40 m Wind Speed	6.88	7.04	7.70
Observed 59 m Wind Speed	–	–	–
Observed 60 m Wind Speed	7.50	–	8.15
Observed 61 m Wind Speed	–	7.70	–
Average Shear	0.21	0.21	0.15
Hub Height 80 m Wind Speed	7.97	8.18	8.53
Hub Height 88.6 m Wind Speed	8.15	8.37	8.68
Long-term 80 m Wind Speed	7.55	7.97	8.26
Long-term 88.6 m Wind Speed	7.72	8.13	8.39
Long-term 88.6 m Adjustment Factor	94.7 %	97.1 %	96.7 %
Mean Turbulence Intensity (TI) 80 m	7.9 %	8.4 %	7.8 %
Characteristic TI 80 m	13.3 %	11.2 %	–
Mean TI 88.6 m	8.4 %	7.6 %	–
Characteristic TI 88.6 m	13.2 %	11.0 %	–

Table 4: 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.

3.1 Tower M2250

The M2250 Tower is located at $37.5465° N$, $104.5098° W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located in the south-central project area. The tower has instrumentation up to $59.4\,m$, with anemometers at four heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 5 and Table 6 for each configuration.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	59.4	166°	49.1 %
Anemometer	59.2	350°	92.8 %
Anemometer	40.1	170°	49.4 %
Anemometer	40.0	352°	93.1 %
Anemometer	22.1	173°	93.0 %
Anemometer	22.0	355°	87.7 %
Wind Vane	58.5	164°	–
Wind Vane	20.5	164°	–

Table 5: M2250 Tower instrumentation (1st configuration).

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	59.4	164°	71.9 %
Anemometer	59.2	344°	72.8 %
Anemometer	40.0	164°	24.3 %
Anemometer	39.9	344°	72.6 %
Anemometer	21.1	164°	7.6 %
Anemometer	21.6	344°	72.7 %
Wind Vane	57.5	164°	79.5 %
Wind Vane	20.3	164°	79.5 %

Table 6: M2250 Tower instrumentation (2nd configuration).

3.1.1 Quality Control

The observed data at the M2250 Tower were quality controlled to check for instrument malfunction and tower shadow. The data record provided extended from 4 March 2009 to 31 January 2012. The tower was originally commissioned with WindSensor P2546A and SecondWind C3 anemometers (approximately) at the $59\,m$, $40\,m$ and $22\,m$ levels. On 7 December 2009, maintenance was performed on the tower and the SecondWind C3 anemometers were replaced with Thies 4.3350.10.000 anemometers and the $22.1\,m$ WindSensor P2546A anemometer was moved to $21.1\,m$. There were noted oddities in the wind direction data during the first tower configuration relative to regional expectations, so the wind direction data before 7 December 2009 were not included in the analysis. There were a number of logger failures throughout the data record, with a notable failure occurring from 4 July to 1 October 2010. The south oriented $59.4\,m$ and $40.1\,m$ anemometers failed from 30 July 2009 to 7 December 2009. The south oriented $40.0\,m$ also failed from 25 October 2010 to 31 January 2012. The $21.1\,m$ anemometer failed from 23 February 2010 to 31 January 2012.

3.1.2 Shear Extrapolation

Observed anemometer data from M2250 were used for extrapolating top sensor level wind speed data to 88.6 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 88.6 m and 80 m.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	0.19	0.16	0.16	0.17	0.18	0.19	0.17	0.18	0.12	0.16	0.18	0.16	0.17
1	0.19	0.17	0.16	0.17	0.17	0.19	0.18	0.18	0.12	0.16	0.16	0.16	0.17
2	0.19	0.17	0.16	0.17	0.17	0.19	0.17	0.17	0.12	0.16	0.16	0.17	0.17
3	0.19	0.16	0.17	0.17	0.18	0.18	0.17	0.16	0.14	0.17	0.16	0.17	0.17
4	0.18	0.16	0.18	0.17	0.18	0.18	0.16	0.15	0.16	0.18	0.17	0.17	0.17
5	0.18	0.16	0.18	0.16	0.17	0.16	0.14	0.16	0.17	0.19	0.17	0.17	0.17
6	0.18	0.15	0.17	0.14	0.12	0.13	0.11	0.16	0.16	0.18	0.17	0.17	0.15
7	0.18	0.14	0.15	0.10	0.07	0.09	0.08	0.12	0.11	0.15	0.16	0.16	0.13
8	0.16	0.13	0.12	0.07	0.05	0.06	0.06	0.07	0.07	0.11	0.13	0.15	0.10
9	0.12	0.12	0.08	0.06	0.04	0.05	0.06	0.05	0.05	0.07	0.09	0.13	0.08
10	0.08	0.11	0.06	0.05	0.04	0.04	0.05	0.04	0.04	0.06	0.07	0.11	0.06
11	0.07	0.10	0.05	0.05	0.04	0.05	0.04	0.05	0.04	0.05	0.07	0.10	0.06
12	0.06	0.08	0.05	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.06	0.09	0.06
13	0.06	0.07	0.05	0.05	0.05	0.05	0.05	0.06	0.04	0.05	0.06	0.09	0.06
14	0.07	0.07	0.06	0.05	0.05	0.05	0.06	0.06	0.05	0.06	0.07	0.10	0.06
15	0.10	0.09	0.06	0.06	0.06	0.06	0.07	0.07	0.05	0.08	0.10	0.11	0.08
16	0.13	0.11	0.09	0.08	0.07	0.07	0.09	0.08	0.08	0.13	0.14	0.14	0.10
17	0.16	0.15	0.13	0.10	0.09	0.10	0.10	0.11	0.12	0.17	0.17	0.16	0.13
18	0.18	0.18	0.17	0.14	0.13	0.14	0.13	0.16	0.18	0.20	0.19	0.16	0.16
19	0.18	0.19	0.19	0.16	0.17	0.18	0.15	0.19	0.20	0.20	0.20	0.15	0.18
20	0.17	0.19	0.19	0.17	0.19	0.20	0.17	0.20	0.20	0.19	0.19	0.15	0.19
21	0.17	0.18	0.19	0.17	0.19	0.21	0.18	0.20	0.19	0.18	0.19	0.15	0.18
22	0.18	0.17	0.19	0.16	0.19	0.21	0.18	0.20	0.17	0.18	0.19	0.15	0.18
23	0.19	0.17	0.18	0.16	0.18	0.20	0.17	0.19	0.13	0.17	0.18	0.15	0.17
Avg	0.15	0.14	0.13	0.12	0.12	0.13	0.12	0.13	0.12	0.14	0.14	0.14	0.13

Figure 3: Shear exponent values for the M2250 Tower.

3.2 Tower M2315

The M2315 Tower is located at $37.56359°\,N$, $104.55513°\,W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located on the western edge of the project area. The tower has instrumentation up to $60.4\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 7.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	60.2	319°	74.2 %
Anemometer	60.4	139°	74.4 %
Anemometer	40.1	319°	70.8 %
Anemometer	40.3	139°	71.2 %
Anemometer	19.9	319°	71.9 %
Anemometer	20.0	139°	71.4 %
Wind Vane	58.5	319°	79.3 %
Wind Vane	18.5	319°	79.2 %

Table 7: M2315 Tower instrumentation.

3.2.1 Quality Control

The observed data at the M2315 Tower were quality controlled to check for instrument malfunction and tower shadow. The data record provided extended from 27 May 2010 to 26 January 2012. The tower was commissioned with WindSensor P2546A and Thies 4.3350.10.000 anemometers (approximately) at the $60\,m$, $40\,m$ and $20\,m$ levels. Offsets were applied to the wind direction data to align with expected regions of tower shadow. There were a number of periods of missing data throughout the data record, resulting in over 15% of total data loss. There were no significant periods of anemometer failure, with the rest of the data loss the result of icing (approximately 4%) and tower shadow (approximately 5%).

3.2.2 Shear Extrapolation

Observed anemometer data from M2315 were used for extrapolating top sensor level wind speed data to 88.6 m hub height level. A 12-by-24 table, see Figure 4 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 88.6 m and 80 m.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	0.19	0.17	0.15	0.15	0.15	0.16	0.14	0.14	0.12	0.13	0.15	0.14	0.15
1	0.19	0.17	0.15	0.15	0.14	0.15	0.13	0.14	0.12	0.14	0.15	0.14	0.15
2	0.19	0.17	0.16	0.15	0.14	0.13	0.13	0.14	0.12	0.14	0.15	0.14	0.15
3	0.19	0.17	0.18	0.16	0.14	0.13	0.13	0.13	0.13	0.15	0.15	0.14	0.15
4	0.19	0.17	0.18	0.17	0.14	0.13	0.14	0.13	0.14	0.15	0.15	0.14	0.15
5	0.18	0.17	0.17	0.15	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.14	0.15
6	0.18	0.17	0.16	0.13	0.11	0.12	0.12	0.15	0.14	0.15	0.15	0.14	0.14
7	0.17	0.16	0.14	0.10	0.08	0.09	0.09	0.12	0.11	0.14	0.14	0.14	0.12
8	0.16	0.15	0.11	0.08	0.05	0.06	0.07	0.08	0.07	0.10	0.12	0.13	0.10
9	0.13	0.14	0.08	0.06	0.05	0.05	0.06	0.06	0.05	0.07	0.09	0.12	0.08
10	0.09	0.12	0.06	0.06	0.04	0.05	0.06	0.05	0.05	0.06	0.07	0.11	0.07
11	0.07	0.11	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.06	0.09	0.06
12	0.07	0.11	0.05	0.05	0.04	0.05	0.05	0.06	0.05	0.05	0.06	0.09	0.06
13	0.07	0.10	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.09	0.06
14	0.08	0.10	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.06	0.07	0.10	0.06
15	0.10	0.10	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.08	0.09	0.12	0.07
16	0.13	0.12	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.11	0.12	0.14	0.09
17	0.16	0.14	0.11	0.09	0.08	0.09	0.08	0.10	0.11	0.15	0.15	0.16	0.12
18	0.17	0.17	0.15	0.12	0.12	0.12	0.11	0.13	0.15	0.17	0.17	0.17	0.15
19	0.17	0.19	0.18	0.14	0.15	0.16	0.14	0.16	0.19	0.18	0.17	0.16	0.17
20	0.17	0.20	0.18	0.15	0.18	0.18	0.16	0.17	0.19	0.17	0.16	0.15	0.17
21	0.16	0.20	0.18	0.15	0.18	0.19	0.16	0.17	0.18	0.16	0.15	0.14	0.17
22	0.17	0.20	0.17	0.15	0.18	0.17	0.15	0.17	0.15	0.14	0.15	0.14	0.16
23	0.18	0.18	0.16	0.15	0.16	0.16	0.14	0.15	0.13	0.13	0.15	0.13	0.15
Avg	0.15	0.15	0.13	0.11	0.11	0.11	0.10	0.11	0.11	0.12	0.13	0.13	0.12

Figure 4: Shear exponent values for the M2315 Tower.

3.3 Tower M2316

The M2316 Tower is located at $37.55243° N$, $104.5393° W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located on the western edge of the project area. The tower has instrumentation up to $60.4\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 8.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	60.4	325°	81.4 %
Anemometer	60.1	139°	83.2 %
Anemometer	40.3	322°	75.1 %
Anemometer	40.3	139°	80.3 %
Anemometer	20.4	319°	78.8 %
Anemometer	20.5	139°	–
Wind Vane	58.5	325°	89.3 %
Wind Vane	18.8	319°	89.0 %

Table 8: M2316 Tower instrumentation.

3.3.1 Quality Control

The observed data at the M2316 Tower were quality controlled to check for instrument malfunction and tower shadow. The data record provided extended from 30 May 2010 to 28 July 2011. The tower was commissioned with WindSensor P2546A and Thies 4.3350.10.000 anemometers (approximately) at the $60\,m$, $40\,m$ and $20\,m$ levels. Offsets were applied to the wind direction data to align with expected regions of tower shadow. The southeast oriented $20.5\,m$ anemometer exhibited suspicious behavior relative to the other anemometers for the entire data record and was not included in the analysis. There were no other significant periods of anemometer failure, with the rest of the data loss the result of icing (approximately 4%) and tower shadow (approximately 8%).

3.3.2 Shear Extrapolation

Observed anemometer data from M2316 were used for extrapolating top sensor level wind speed data to 88.6 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 88.6 m and 80 m.

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

Jan Feb Mar Apr May Jun Jly Aug Sep Oct Nov Dec Avg

Figure 5: Shear exponent values for the M2316 Tower.

3.4 Tower M2317

The M2317 Tower is located at $37.53212° N$, $104.4906° W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located on the southern edge of the project area. The tower has instrumentation up to $60.3\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 9.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	60.3	336°	69.0 %
Anemometer	60.3	155°	71.1 %
Anemometer	40.0	336°	71.3 %
Anemometer	40.0	155°	71.2 %
Anemometer	20.0	336°	71.2 %
Anemometer	20.1	155°	69.9 %
Wind Vane	58.5	336°	78.0 %
Wind Vane	18.5	336°	78.0 %

Table 9: M2317 Tower instrumentation.

3.4.1 Quality Control

The observed data at the M2317 Tower were quality controlled to check for instrument malfunction and tower shadow. The data record provided extended from 10 June 2010 to 2 August 2011. The tower was commissioned with WindSensor P2546A and Thies 4.3350.10.000 anemometers at the $60.3\,m$, $40.0\,m$ and $20\,m$ levels. Offsets were applied to the wind direction data to align with expected regions of tower shadow. There were several periods of missing data throughout the data record, with the most notable missing period from 26 August 2010 to 16 October 2010. There were no other significant periods of anemometer failure, with the rest of the data loss the result of icing (approximately 3%) and tower shadow (approximately 9%).

3.4.2 Shear Extrapolation

Observed anemometer data from M2317 were used for extrapolating top sensor level wind speed data to 88.6 m hub height level. A 12-by-24 table, see Figure 6 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 88.6 m and 80 m.

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

Figure 6: Shear exponent values for the M2317 Tower.

3.5 Tower M2318

The M2318 Tower is located at $37.55595° N$, $104.48466° W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located in the southeastern project area. The tower has instrumentation up to $60.5\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 10.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	60.5	342°	54.3 %
Anemometer	60.5	164°	56.1 %
Anemometer	40.3	338°	52.7 %
Anemometer	40.3	158°	54.7 %
Anemometer	20.1	335°	53.1 %
Anemometer	20.1	155°	54.2 %
Wind Vane	58.8	342°	51.2 %
Wind Vane	18.6	335°	59.4 %

Table 10: M2318 Tower instrumentation.

3.5.1 Quality Control

The observed data at the M2318 Tower were quality controlled to check for instrument malfunction and tower shadow. The data record provided extended from 8 June 2010 to 24 October 2011. The tower was commissioned with WindSensor P2546A and Thies 4.3350.10.000 anemometers at the $60.5\,m$, $40.3\,m$ and $20.1\,m$ levels. Offsets were applied to the wind direction data to align with expected regions of tower shadow. Data were missing for the period of 1 April 2011 to 30 September 2011. Because of the data gap, the calendar months of April and May were missing from the dataset. Measure-Correlate-Predict (MCP) was completed with M2250 as a reference tower to fill in these missing months in order to mitigate the potential for seasonal bias during MOS correction. The $58.8\,m$ wind vane malfunctioned from 2-20 August 2010 and from 30 September 2011 to 24 October 2011. There were no significant periods of anemometer failure.

3.5.2 Shear Extrapolation

Observed anemometer data from M2318 were used for extrapolating top sensor level wind speed data to 88.6 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 88.6 m and 80 m.

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

Figure 7: Shear exponent values for the M2318 Tower.

3.6 Tower M2322

The M2322 Tower is located at $37.60197^\circ N$, $104.53034^\circ W$. The location of the tower and the turbine locations are shown in Wind Speed Maps. The tower is located on the northern edge of the project area. The tower has instrumentation up to $60.1\,m$, with anemometers at three heights and wind vanes at two heights. A summary of instruments installed on the tower is shown in Table 11.

Instrument	Height (m)	Boom Orientation	Recovery Rate
Anemometer	60.1	335°	85.7 %
Anemometer	60.1	155°	87.7 %
Anemometer	40.0	335°	85.7 %
Anemometer	40.0	155°	83.7 %
Anemometer	20.1	335°	84.2 %
Anemometer	20.1	155°	82.6 %
Wind Vane	58.6	335°	93.2 %
Wind Vane	18.5	335°	93.2 %

Table 11: M2322 Tower instrumentation.

3.6.1 Quality Control

The observed data at the M2322 Tower were quality controlled to check for instrument malfunction and tower shadow. The data record provided extended from 12 June 2010 to 9 March 2011. The tower was commissioned with WindSensor P2546A and Thies 4.3350.10.000 anemometers at the $60.1\,m$, $40.0\,m$ and $20.1\,m$ levels. Offsets were applied to the wind direction data to align with expected regions of tower shadow. Because of the short data record, the calendar months of April and May were missing from the dataset. Measure-Correlate-Predict (MCP) was completed with M2315 as a reference tower to fill in these missing months in order to mitigate the potential for seasonal bias during MOS correction. There were no significant periods of anemometer failure.

3.6.2 Shear Extrapolation

Observed anemometer data from M2322 were used for extrapolating top sensor level wind speed data to 88.6 m hub height level. A 12-by-24 table, see Figure 8 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 88.6 m and 80 m.

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

Figure 8: Shear exponent values for the M2322 Tower.

4 LONG-TERM REFERENCE

In order to put the short-term observational data into the climatological context, Vaisala performed a review of several long term climate data sources. Vaisala 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.

Vaisala 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 Vaisala 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 12, including the daily-mean explained variance, long-term climate adjustment, and considered start year statistics. Figure 9 shows the annual-mean wind speed values extracted from each reanalysis data set across the period of record. Each time series shown in Figure 9 has been MOS-corrected using the observed data at Tower M2322.

Tower	Data Set	Explained Variance (R^2)	Climate Adjustment	Start Year
M2250	ECMWF ERA-I	74.6%	99.7%	1980
M2250	MERRA2	73.6%	99.2%	1980
M2250	NCEP/NCAR	61.4%	98.3%	1980
M2315	ECMWF ERA-I	75.3%	95.3%	1980
M2315	MERRA2	74.1%	96.5%	1980
M2315	NCEP/NCAR	63.1%	95.3%	1983
M2316	ECMWF ERA-I	72.8%	94.6%	1980
M2316	MERRA2	72.7%	94.9%	1980
M2316	NCEP/NCAR	57.5%	95.2%	1983
M2317	ECMWF ERA-I	71.8%	96.6%	1980
M2317	MERRA2	71.5%	96.8%	1980
M2317	NCEP/NCAR	55.7%	96.1%	1983
M2318	ECMWF ERA-I	75.3%	96.3%	1980
M2318	MERRA2	74.5%	96.6%	1980
M2318	NCEP/NCAR	58.7%	96.0%	1983
M2322	ECMWF ERA-I	77.6%	94.5%	1980
M2322	MERRA2	75.6%	94.7%	1980
M2322	NCEP/NCAR	64.0%	94.7%	1983

Table 12: Daily explained variance and long-term climate adjustment values for the considered reanalysis data sets.

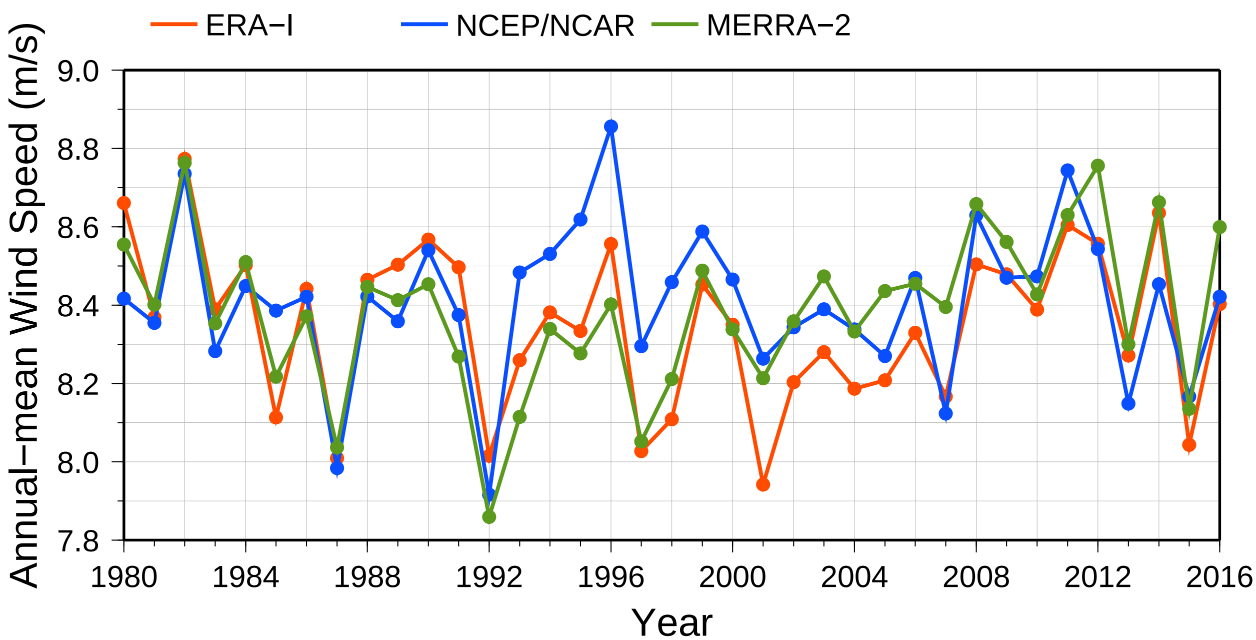

Figure 9: Time series of annual-mean wind speed data for each considered reanalysis data set.

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 ($88.6\,m$ or $80\,m$) and then averaged across all 24 turbine locations.

Based on the results of the 3TIER Services' Energy Risk Framework, the last 37 years (January, 1980 – September, 2017) of data have been utilized for estimating the expected future generation at La Cumbre. The long-term mean project-average wind speed at hub height is $\mathbf{8.05\,m/s}$. Maps of the 37-year average wind speed values at $88.6\,m$ and $80\,m$ hub heights are displayed in Wind Speed Maps. Gross wind speed values and average density values at each of the 24 turbine locations are provided in Appendix Turbine Means. The project-average density value at hub height is $0.978\,kg/m^3$.

The distribution of hourly MOS-corrected project-average wind speed values is shown below in Figure 10. The distribution is based on the 37 years of modeled data. The annual wind rose is shown in Figure 11. Figure 12 displays the time series of gross project-average annual-mean wind speed values. Tables 13 and 14 shown on the following pages contain tabular-formatted month-hour and monthly-mean wind speed values, respectively. Table 13, often referred to as a '12x24' table, shows the average diurnal profile of wind speed values for each month of the calendar year. Table 14 shows the monthly-mean wind speed value for each month of the 37-year analysis period. Annual-mean wind speed values are also displayed in the right-most column of data in Table 14. Additional analysis of the long-term variability is available in Project-average Long-term Wind Resource Assessment.

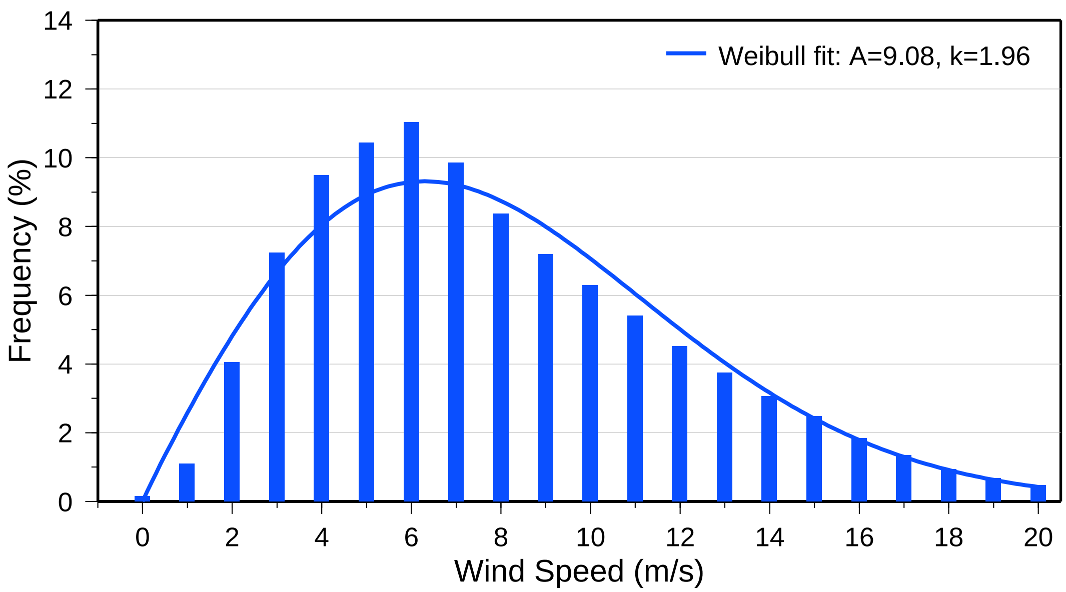

Figure 10: Hourly distribution of simulated project-average wind speed using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5.) Weibull distribution is also shown with the scale (A) and shape (k) parameters listed in the legend.

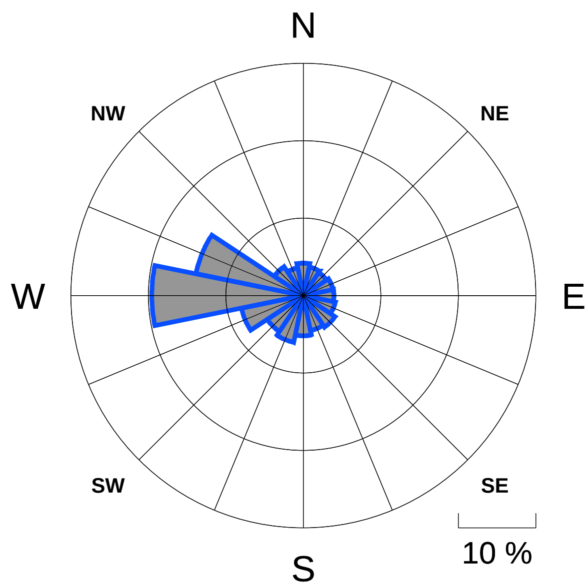

Figure 11: Annual wind rose of the hourly-mean project-average wind direction time series. Directional bins are 22.5° wide, and the radial contour interval is 10%.

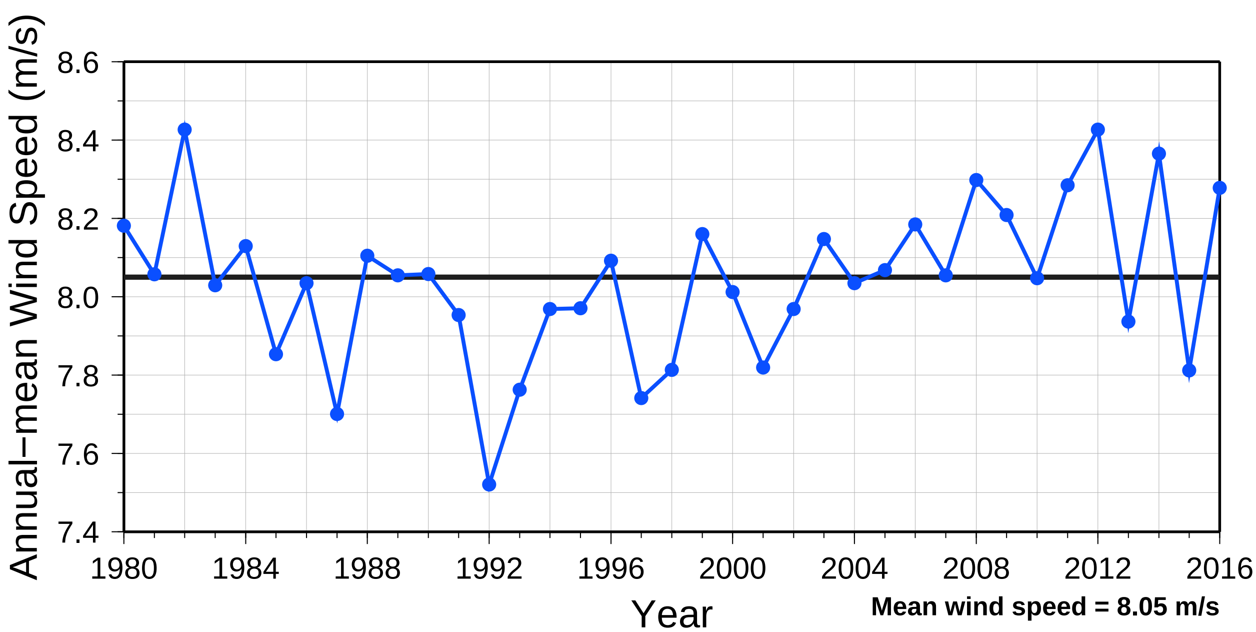

Figure 12: Time series of annual-mean project-average wind speed. Black line denotes the long-term mean.

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	10.33	8.85	7.70	7.57	7.21	8.19	8.23	7.58	7.93	8.80	9.29	9.73	8.44
1	10.63	9.00	7.72	7.85	7.11	7.98	7.70	7.45	8.01	8.83	9.56	10.17	8.49
2	10.71	9.60	8.21	8.55	7.54	8.06	7.37	7.45	8.26	8.65	9.51	10.10	8.66
3	10.94	10.13	8.33	9.03	7.80	7.97	7.52	7.31	8.15	8.66	9.80	10.53	8.83
4	11.20	10.32	8.83	8.39	7.55	7.78	7.66	7.24	8.04	8.86	10.00	11.05	8.90
5	11.19	9.85	8.82	8.44	7.41	7.47	7.86	7.12	7.69	8.79	9.63	10.82	8.75
6	10.74	9.75	8.55	8.47	7.29	6.84	7.49	7.06	7.71	8.23	8.94	10.18	8.43
7	10.59	9.82	8.48	8.28	6.77	5.91	6.33	6.54	7.38	7.71	8.95	9.68	8.02
8	10.56	9.69	8.42	8.11	6.53	5.19	5.03	5.52	6.56	6.96	8.76	9.45	7.55
9	10.01	9.34	8.06	8.11	6.52	5.04	4.82	5.19	5.75	6.35	8.25	8.80	7.17
10	8.96	8.58	7.75	8.11	6.83	5.07	4.63	4.87	5.31	6.02	7.49	7.86	6.78
11	8.58	8.83	7.88	8.21	6.97	5.40	4.66	4.77	5.28	6.14	7.14	7.29	6.75
12	8.41	8.68	7.64	7.66	7.04	5.72	4.67	4.85	5.58	6.51	7.49	7.48	6.80
13	8.02	8.16	7.85	7.69	7.69	6.58	5.03	5.37	5.91	6.45	7.78	7.46	6.99
14	7.82	8.32	8.29	8.26	8.35	7.92	5.94	5.67	6.18	6.51	7.76	7.42	7.36
15	8.23	8.75	8.59	8.93	8.79	7.94	6.84	6.26	6.51	6.84	8.07	7.50	7.76
16	8.49	8.83	8.51	8.89	9.30	8.06	7.14	6.60	7.05	6.90	7.83	7.75	7.94
17	9.32	8.32	8.62	9.09	9.71	9.04	8.25	6.92	7.27	7.09	8.05	8.34	8.34
18	9.60	8.73	8.41	8.87	10.00	9.58	9.06	7.25	7.98	7.63	8.15	8.60	8.66
19	8.98	8.53	8.27	9.32	9.24	9.08	8.97	7.94	8.59	7.78	8.64	8.34	8.64
20	8.37	8.02	7.96	8.96	8.64	9.00	8.37	7.76	8.30	7.69	9.15	8.88	8.42
21	8.35	7.85	7.97	8.77	8.45	9.12	8.54	7.89	8.38	8.05	9.27	8.88	8.46
22	8.96	8.31	7.98	8.50	7.91	8.29	8.25	7.72	8.39	8.47	9.27	9.41	8.45
23	9.60	8.95	7.52	7.80	7.70	8.23	8.31	7.44	8.45	8.69	9.39	9.66	8.47
Avg	9.52	8.97	8.18	8.41	7.85	7.48	7.03	6.66	7.28	7.61	8.67	8.97	8.05

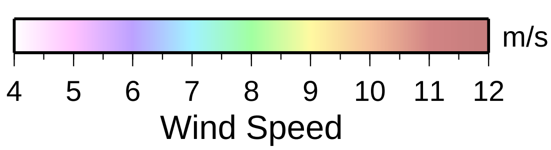

Figure 13: Hourly-mean values of simulated project-average wind speed. Vertical axis is local time.

Year	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
1980	9.86	9.40	9.06	7.48	7.75	7.87	7.50	7.95	7.84	7.37	7.76	8.35	8.18
1981	7.70	8.78	7.98	8.62	8.43	7.68	6.91	6.36	6.94	8.13	9.24	9.99	8.06
1982	12.28	8.81	8.98	9.61	7.23	7.03	7.52	6.44	7.37	7.54	8.92	9.40	8.43
1983	8.79	8.96	8.00	7.89	7.93	7.34	7.79	6.47	8.16	7.22	9.30	8.62	8.03
1984	8.29	9.01	7.80	8.94	8.17	7.93	7.03	6.26	7.58	7.57	9.95	9.13	8.13
1985	7.73	8.58	9.18	7.91	7.40	7.02	6.91	7.34	7.82	7.72	8.88	7.83	7.85
1986	9.98	10.40	7.64	8.86	7.53	6.93	7.81	6.68	7.98	7.13	9.12	6.60	8.03
1987	9.71	8.38	7.60	7.88	7.30	6.89	8.37	6.60	6.34	6.81	7.93	8.60	7.70
1988	9.85	8.29	7.79	8.50	8.87	7.38	6.93	7.17	7.80	6.72	9.27	8.71	8.10
1989	10.77	7.70	8.80	7.94	8.21	6.90	7.44	7.01	7.26	7.68	9.17	7.71	8.05
1990	10.75	8.58	6.86	7.66	8.69	8.27	6.60	6.92	6.97	7.87	9.08	8.49	8.06
1991	8.42	7.99	9.91	8.23	8.58	8.15	6.83	6.26	7.16	7.41	8.30	8.23	7.95
1992	8.50	8.39	7.27	7.53	6.91	6.54	6.87	6.43	7.95	7.09	7.15	9.65	7.52
1993	8.70	8.37	6.91	7.73	6.87	7.99	7.84	6.45	7.02	6.90	8.97	9.48	7.76
1994	9.11	9.55	7.65	8.45	7.55	7.65	6.76	6.49	6.85	7.76	9.37	8.59	7.97
1995	9.06	8.73	8.23	8.57	7.79	7.44	7.18	6.55	6.91	7.82	9.62	7.83	7.97
1996	10.30	8.74	7.44	8.72	8.11	6.78	6.44	6.25	7.12	7.88	7.81	11.49	8.09
1997	10.08	7.66	7.98	7.79	6.86	7.15	7.32	6.43	6.63	8.68	7.88	8.39	7.74
1998	9.81	7.84	7.11	7.75	8.32	8.58	6.55	6.12	7.05	7.73	8.72	8.23	7.81
1999	10.16	10.20	8.10	9.38	8.18	7.86	7.21	6.77	6.74	7.02	8.05	8.44	8.16
2000	9.54	9.77	7.58	8.42	8.39	7.74	6.98	6.80	7.66	7.13	7.57	8.64	8.01
2001	8.40	8.97	6.90	9.07	7.24	7.52	7.10	6.54	6.85	8.58	8.07	8.70	7.82
2002	8.91	8.76	8.36	9.06	8.21	7.51	6.23	7.04	7.39	7.02	8.18	9.04	7.97
2003	9.07	7.88	8.84	9.77	7.85	6.81	7.45	6.74	7.09	7.48	9.01	9.76	8.15
2004	9.10	8.14	7.82	8.09	8.52	7.05	6.72	6.89	7.59	8.59	8.00	9.88	8.03
2005	9.14	7.87	8.22	8.43	7.52	7.89	7.27	6.25	7.78	7.07	9.88	9.54	8.07
2006	12.10	9.12	9.25	9.27	7.00	7.20	6.33	5.90	6.67	7.96	8.47	9.01	8.18
2007	8.86	10.50	7.69	7.91	7.40	7.07	6.12	6.75	7.96	8.23	8.42	9.96	8.05
2008	11.32	9.70	8.82	8.26	8.35	7.36	6.85	6.89	6.82	7.40	7.79	10.01	8.30
2009	10.12	10.59	9.04	9.02	7.74	7.47	6.81	6.87	6.90	8.02	7.59	8.50	8.21
2010	8.73	7.08	7.53	9.33	8.74	7.77	7.18	7.01	7.80	7.92	8.67	8.77	8.05
2011	9.29	9.68	8.86	9.34	8.42	8.36	7.25	6.72	6.64	7.34	9.65	8.04	8.28
2012	10.09	9.64	9.36	8.40	8.12	8.59	6.73	6.89	6.43	7.76	9.20	9.95	8.43
2013	8.61	8.68	7.86	7.36	7.79	7.61	6.77	6.38	8.23	7.89	8.51	9.62	7.94
2014	10.46	10.41	9.15	8.47	7.82	8.14	6.88	6.98	7.33	7.18	9.85	7.91	8.37
2015	8.58	8.83	6.96	7.88	7.36	6.70	6.84	6.67	6.98	7.52	9.38	10.13	7.81
2016	9.39	9.43	9.17	7.63	7.83	6.61	7.53	6.53	7.80	8.40	8.20	10.81	8.28
2017	10.33	11.24	9.23	8.44	7.21	7.37	6.24	6.11	7.15				--
Avg	9.52	8.97	8.18	8.41	7.85	7.48	7.03	6.66	7.28	7.61	8.67	8.97	8.05

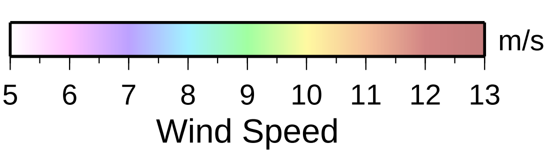

Figure 14: Monthly-mean values of simulated project-average wind speed.

5.2 Gross Generation Variability

Following WRF/TVM modeling and MOS correction, 37 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 37 years.

Computing the nameplate capacity factor at each turbine and then averaging across all 24 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. Summing these across all 24 turbines yields the project-average gross energy estimate.

Based on the results of the 3TIER Services' Energy Risk Framework, the last 37 years (January, 1980 – September, 2017) of data have been utilized for estimating the expected future generation at La Cumbre. The 37-year long-term mean gross energy estimate at the proposed La Cumbre project is $\mathbf{254.8}\,\boldsymbol{GWh}$. Figure 15 below shows the time series of gross project-average annual-mean energy values. Gross energy values at each of the 24 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.

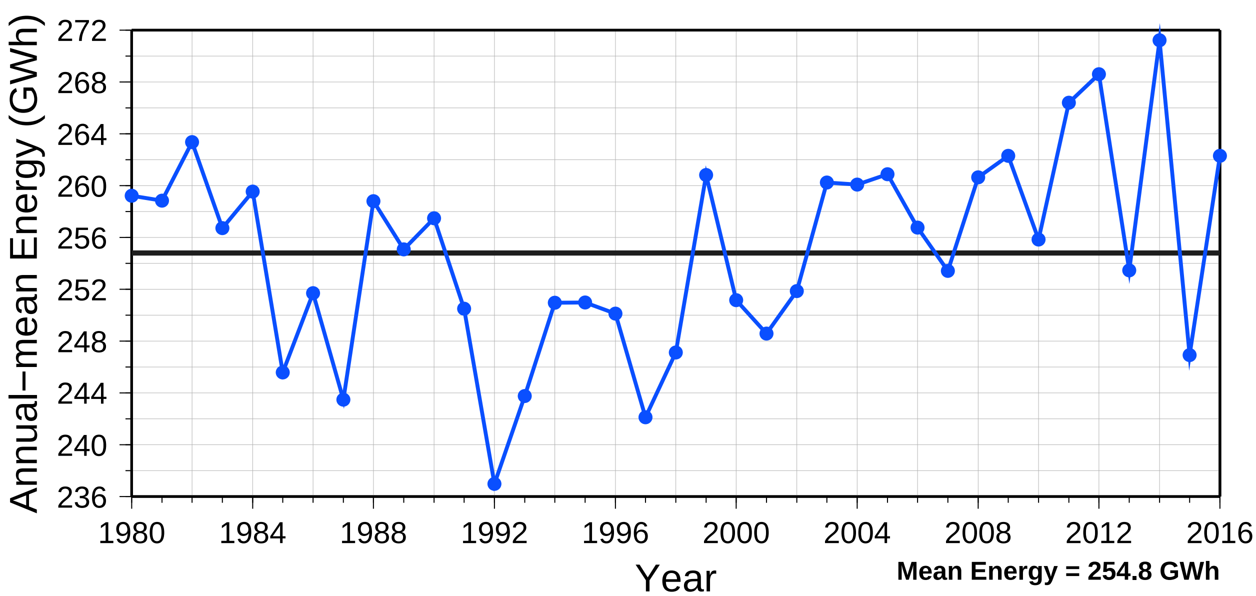

Figure 15: Time series of annual-mean project-average gross energy. Black line denotes the long-term mean.

5.3 Power Curves

It is expected that GE 2.5-127 wind turbines at a hub height of 88.6 m and GE 2.3-116 wind turbines at a hub height of 80 m will be erected at the site. The GE 2.5-127 power curve is shown in Figure 16 and Table 13. The GE 2.3-116 power curve is shown in Figure 17 and Table 14. The reference density for each power curve is shown in the caption of each respective Figure and Table below.

5.3.1 GE 2.5-127

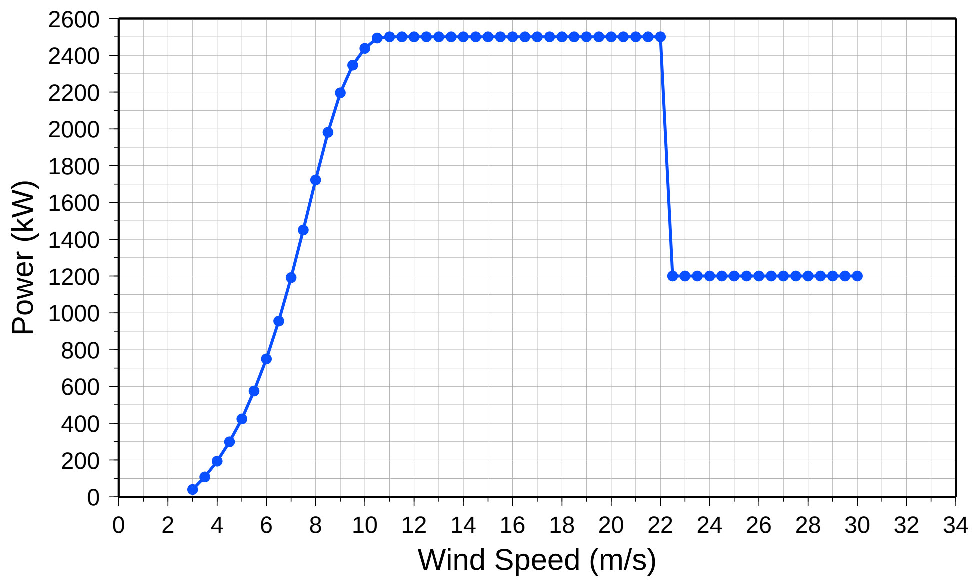

Figure 16: Power curve values for a GE 2.5-127 turbine with a reference density of 1.225 kg/m^3.

Wind Speed ($\frac{m}{s}$)	Power (kW)	Wind Speed ($\frac{m}{s}$)	Power (kW)	Wind Speed ($\frac{m}{s}$)	Power (kW)	Wind Speed ($\frac{m}{s}$)	Power (kW)
3.0	40.0	10.0	2438.0	17.0	2500.0	24.0	1200.0
3.5	108.0	10.5	2494.0	17.5	2500.0	24.5	1200.0
4.0	194.0	11.0	2500.0	18.0	2500.0	25.0	1200.0
4.5	299.0	11.5	2500.0	18.5	2500.0	25.5	1200.0
5.0	424.0	12.0	2500.0	19.0	2500.0	26.0	1200.0
5.5	575.0	12.5	2500.0	19.5	2500.0	26.5	1200.0
6.0	750.0	13.0	2500.0	20.0	2500.0	27.0	1200.0
6.5	955.0	13.5	2500.0	20.5	2500.0	27.5	1200.0
7.0	1192.0	14.0	2500.0	21.0	2500.0	28.0	1200.0
7.5	1451.0	14.5	2500.0	21.5	2500.0	28.5	1200.0
8.0	1722.0	15.0	2500.0	22.0	2500.0	29.0	1200.0
8.5	1981.0	15.5	2500.0	22.5	1200.0	29.5	1200.0
9.0	2196.0	16.0	2500.0	23.0	1200.0	30.0	1200.0
9.5	2346.0	16.5	2500.0	23.5	1200.0		

Table 13: Power curve values for a GE 2.5-127 turbine with a reference density of 1.225 kg/m^3.

5.3.2 GE 2.3-116

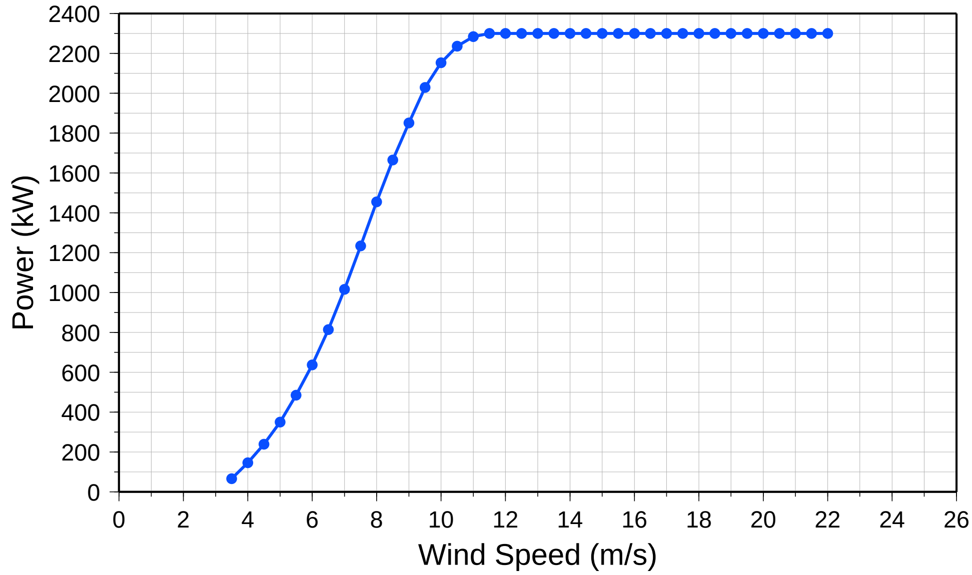

Figure 17: Power curve values for a GE 2.3-116 turbine with a reference density of 1.225 kg/m^3.

Wind Speed ($\frac{m}{s}$)	Power (kW)	Wind Speed ($\frac{m}{s}$)	Power (kW)	Wind Speed ($\frac{m}{s}$)	Power (kW)
3.5	66.0	10.0	2153.0	16.5	2300.0
4.0	146.0	10.5	2236.0	17.0	2300.0
4.5	239.0	11.0	2284.0	17.5	2300.0
5.0	350.0	11.5	2300.0	18.0	2300.0
5.5	485.0	12.0	2300.0	18.5	2300.0
6.0	637.0	12.5	2300.0	19.0	2300.0
6.5	814.0	13.0	2300.0	19.5	2300.0
7.0	1016.0	13.5	2300.0	20.0	2300.0
7.5	1234.0	14.0	2300.0	20.5	2300.0
8.0	1455.0	14.5	2300.0	21.0	2300.0
8.5	1665.0	15.0	2300.0	21.5	2300.0
9.0	1851.0	15.5	2300.0	22.0	2300.0
9.5	2029.0	16.0	2300.0		

Table 14: Power curve values for a GE 2.3-116 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

Vaisala 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. Vaisala has assumed a regional grid availability loss factor of **99.5%** for the La Cumbre 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 some 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 37 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 **99.8%**.

6.2.3 Extreme Temperature

The GE 2.5-127 and GE 2.3-116 turbines have an assumed maximum operating temperature between -15° and $40^{\circ}C$. 37 years of MOS-corrected temperature data were analyzed to determine the production losses due to the temperature constraint. Based on the potential power production during periods with temperatures above the operating limits, and a total wind farm shutdown during these times, the extreme temperature loss factor is estimated to be **99.7%**.

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

The 3TIER Services' time-varying 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. Vaisala 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). [7] Vaisala's internal research has shown that the low bias associated with other Larsen-derived wake models [8] 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 **97.3%**.

6.3.2 External Wakes

External wakes represent additional wakes caused by turbines from surrounding wind farms. An additional 16 Vestas V100-1.8MW turbines and 34 GE 1.79-100 turbines have been included as external turbines in the wake model. The location of all the external turbines are shown in Wind Speed Maps. The effect of wake deficit on energy output due to external turbines is **99.8%**.

6.3.3 Future Wakes

Future wakes represent wakes caused by turbines that will be built in the future, not related to this project. Vaisala performed a review of the potential impact of future wakes due to nearby developments using the FAA's Obstruction Evaluation / Airport Airspace Analysis (OEAAA) website [9]. At this time Vaisala is unaware of any planned wind farms in the region, therefore this loss factor is **100%**.

6.3.4 Total Wakes

The total wake loss factor, including the project (i.e. internal) turbines, and external turbines, is **97.1%**. 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. Vaisala assumes the wind farm will be metered on the high side of the substation power transformer. Given this assumption, the electrical system efficiency is expected to be **97.5%**.

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. These losses are inherent in the electrical system efficiency loss factor.

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. Vaisala assumes the plant will be metered at the high side of the substation transformer; therefore, substation power transformer losses are applicable.

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. Vaisala assumes the plant will be metered at the high side of the substation transformer; therefore, high voltage transmission line losses are applicable.

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. Vaisala assumes that consumptive power of the wind farm will be metered separately from the export power generated by the wind turbines, i.e. net metering is not applicable. Based on this assumption, consumptive power will not lead to a reduction in the export power; thus, a loss factor of **100.0%** is applied 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

Based on Vaisala's experience with operating wind farms, 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. It is suggested 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, which are often accompanied by low turbulence intensity and high vertical wind shear. 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. Vaisala analyzes the potential for both of these effects using the measured turbulence intensity and has calculated a loss factor of **98.4%**.

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. Vaisala has analyzed projects in similar terrain and has calculated a standard loss factor for 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. Vaisala has analyzed projects in similar terrain and has calculated a standard loss factor for shrub-steppe conditions. A loss factor of **99.5%** is applied for blade degradation.

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

Additional environmental losses such as thunderstorms and tree growth have not been evaluated, but are expected to be negligible.

6.7 Aggregate Loss Factor

Table 15 below shows the individual loss factors for all considered categories and the aggregate loss factor. The product of all considered losses is **83.6%**. The expected gross P50 generation is $254.8\,GWh$; therefore, the net P50 generation is the product of 83.6% and $254.8\,GWh$, which equals $\mathbf{212.9\,GWh}$. Table 16 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 %
Environmental Curtailment	
Sector Management	–
High Wind Hysteresis	99.8 %
Icing	99.0 %
Extreme Temperature	99.7 %
Wake Deficit	
Total Wakes	97.1 %
Electrical Efficiency	
Total Electrical Efficiency	97.5 %
Consumptive Power	100.0 %
Turbine Efficiency	
Turbine Performance	98.0 %
Turbulence Intensity	98.4 %
Inflow Angle	100.0 %
Environmental	
Blade Soiling	98.5 %
Blade Degradation	99.5 %
Soft Icing	99.5 %
Aggregate Loss Factor	**83.6 %**

Table 15: 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	10.3 %
February	8.8 %
March	8.8 %
April	8.9 %
May	8.4 %
June	7.5 %
July	6.9 %
August	6.4 %
September	7.3 %
October	8.0 %
November	9.0 %
December	9.7 %

Table 16: 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, Vaisala has utilized the 3TIER Services' 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 the 3TIER Services' 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. Vaisala 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 other categories of uncertainty are within acceptable ranges for a quality due diligence analysis. The measurement uncertainty is slightly elevated because Vaisala was unable to complete a site visit to verify the configurations because the towers have all been decommissioned. There is good spatial coverage through the met tower campaign, leading to low spatial uncertainty. The project uncertainty also benefits from a low wind energy sensitivity by which changes in wind speed do not greatly affect the the overall project energy estimates.

7.2.1 Met Tower Uncertainty

Uncertainty values for each met tower are presented as a function of wind speed below in Table 17 and Table 18.

	M2250	M2315	M2316	M2317	M2318	M2322
Measurement	2.5	2.1	2.2	3.2	3.4	3.1
Vertical Extrapolation	2.1	2.0	2.0	2.0	1.9	2.0
MOS Correction	0.7	1.8	2.3	2.6	2.3	3.1
Climate Variability	1.4	1.3	1.3	1.4	1.3	1.3
Combined Uncertainty	**3.7**	**3.6**	**4.0**	**4.8**	**4.7**	**4.9**

Table 17: Standard error of wind speed estimation at each met tower (%) at 88.6 m

	M2250	M2315	M2316	M2317	M2318	M2322
Measurement	2.3	1.9	2.0	2.7	2.8	2.6
Vertical Extrapolation	1.5	1.4	1.4	1.4	1.4	1.4
MOS Correction	0.7	1.8	2.3	2.6	2.3	3.1
Climate Variability	1.4	1.3	1.3	1.4	1.5	1.3
Combined Uncertainty	**3.2**	**3.3**	**3.6**	**4.2**	**4.1**	**4.4**

Table 18: Standard error of wind speed estimation at each met tower (%) at 80 m

7.2.2 Combined Project Uncertainties

The total project uncertainties, represented as a percent of the P50 estimate are presented in Table 19 as a function of energy.

	1-year	10-year	20-year
Measurement	2.5	2.5	2.5
Vertical Extrapolation	2.3	2.3	2.3
MOS Correction	2.4	2.4	2.4
Climate Variability	3.7	1.8	1.6
Spatial Modeling	1.5	1.5	1.5
Power Modeling	4.4	4.4	4.4
Total Uncertainty	**7.3**	**6.5**	**6.5**

Table 19: Standard error of wind energy estimation (%)

8 PROBABILITY OF EXCEEDANCES

Based on the estimated total project uncertainties, Tables 20 and 21 present the probability of exceedance levels associated with the P50 project estimate. Table 20 provides results in terms of GWh, while Table 21 shows results in terms of project-average capacity factor (%). Table 22 shows the net P50, P75, and P90 values for each calendar month.

	1-year	10-year	20-year
Gross-P50	254.8	254.8	254.8
Net-P50	212.9	212.9	212.9
Net-P75	202.5	203.6	203.6
Net-P90	193.1	195.1	195.3
Net-P95	187.5	190.1	190.3
Net-P99	176.9	180.6	180.9

Table 20: Probability of Exceedance Values (GWh)

	1-year	10-year	20-year
Gross-P50	48.8	48.8	48.8
Net-P50	40.8	40.8	40.8
Net-P75	38.8	39.0	39.0
Net-P90	37.0	37.4	37.4
Net-P95	35.9	36.4	36.4
Net-P99	33.9	34.6	34.6

Table 21: Probability of Exceedance Values (%)

	Net P50	20-year Net P75	20-year Net P90
January	21.8	20.8	20.0
February	18.7	17.9	17.1
March	18.8	17.9	17.1
April	18.9	18.0	17.2
May	18.0	17.1	16.3
June	16.0	15.2	14.4
July	14.7	13.9	13.2
August	13.7	12.9	12.2
September	15.5	14.7	13.9
October	17.0	16.2	15.4
November	19.2	18.4	17.6
December	20.6	19.7	18.9

Table 22: 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.

9 CONCLUSION

Vaisala has conducted a wind resource assessment of the La Cumbre project. The assessment is based on a wind turbine layout consisting of 22 GE 2.5-127 wind turbines at $88.6\,m$ and 2 GE 2.3-116 wind turbines at $80\,m$. The wind resource assessment yields a gross energy value of $254.8\,GWh$. Loss factors were considered, leading to a net energy estimate of $212.9\,GWh$. 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 $203.6\,GWh$ and $195.3\,GWh$, 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 24 turbines at the La Cumbre project.

10.1 GE 2.5-127 wind turbines at 88.6 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 :: %)
T01	37.60222	-104.52640	1966	8.62	0.977	11633 :: 53.1	97.4	9748 :: 44.5
T02	37.59912	-104.52514	1963	8.67	0.977	11703 :: 53.4	96.6	9726 :: 44.4
T03	37.59604	-104.52589	1946	8.44	0.979	11381 :: 51.9	97.2	9522 :: 43.5
T04	37.59212	-104.53816	1944	8.07	0.980	10829 :: 49.4	97.5	9074 :: 41.4
T05	37.58905	-104.53479	1935	8.03	0.980	10780 :: 49.2	96.4	8941 :: 40.8
T06	37.58590	-104.53395	1932	8.03	0.981	10782 :: 49.2	96.2	8926 :: 40.7
T07	37.58276	-104.53299	1921	7.95	0.982	10658 :: 48.6	97.2	8918 :: 40.7
T08	37.57325	-104.56738	1972	7.84	0.977	10426 :: 47.6	98.5	8808 :: 40.2
T09	37.56786	-104.56527	1975	7.87	0.977	10472 :: 47.8	98.5	8848 :: 40.4
T10	37.56391	-104.55570	1973	8.05	0.977	10794 :: 49.3	97.5	9014 :: 41.1
T11	37.56102	-104.55080	1967	8.08	0.977	10842 :: 49.5	96.9	9009 :: 41.1
T12	37.55817	-104.54710	1963	8.04	0.977	10770 :: 49.1	96.5	8926 :: 40.7
T13	37.55527	-104.54533	1958	7.95	0.978	10593 :: 48.3	97.2	8852 :: 40.4
T15	37.54937	-104.53558	1954	7.90	0.978	10492 :: 47.9	97.7	8823 :: 40.3
T16	37.54534	-104.52965	1961	7.82	0.978	10357 :: 47.3	98.2	8761 :: 40.0
T17	37.53710	-104.50980	1966	7.87	0.977	10372 :: 47.3	97.7	8759 :: 40.0
T18	37.53399	-104.50736	1963	7.81	0.977	10259 :: 46.8	97.6	8662 :: 39.5
T19	37.55337	-104.50154	1967	8.08	0.977	10748 :: 49.0	96.9	8993 :: 41.0
T20	37.55640	-104.49813	1971	8.12	0.977	10829 :: 49.4	96.4	9013 :: 41.1
T21	37.55527	-104.48445	1970	8.08	0.977	10732 :: 49.0	96.1	8928 :: 40.7
T22	37.55822	-104.48126	1967	8.24	0.977	10994 :: 50.2	96.4	9165 :: 41.8
T24	37.54624	-104.47394	1957	8.06	0.978	10694 :: 48.8	96.5	8924 :: 40.7

Table 23: Turbine-specific 37-year mean values for 22 GE 2.5-127 wind turbines at 88.6 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 :: %)
T01	9748 :: 44.5	9299 :: 42.4	8894 :: 40.6	8652 :: 39.5	8198 :: 37.4
T02	9726 :: 44.4	9282 :: 42.4	8883 :: 40.5	8644 :: 39.4	8195 :: 37.4
T03	9522 :: 43.5	9075 :: 41.4	8673 :: 39.6	8432 :: 38.5	7980 :: 36.4
T04	9074 :: 41.4	8655 :: 39.5	8277 :: 37.8	8052 :: 36.7	7628 :: 34.8
T05	8941 :: 40.8	8534 :: 38.9	8168 :: 37.3	7950 :: 36.3	7539 :: 34.4
T06	8926 :: 40.7	8533 :: 38.9	8180 :: 37.3	7968 :: 36.4	7571 :: 34.5
T07	8918 :: 40.7	8529 :: 38.9	8179 :: 37.3	7970 :: 36.4	7578 :: 34.6
T08	8808 :: 40.2	8423 :: 38.4	8077 :: 36.9	7870 :: 35.9	7481 :: 34.1
T09	8848 :: 40.4	8466 :: 38.6	8122 :: 37.1	7916 :: 36.1	7530 :: 34.4
T10	9014 :: 41.1	8629 :: 39.4	8283 :: 37.8	8075 :: 36.8	7686 :: 35.1
T11	9009 :: 41.1	8629 :: 39.4	8287 :: 37.8	8082 :: 36.9	7699 :: 35.1
T12	8926 :: 40.7	8558 :: 39.0	8226 :: 37.5	8027 :: 36.6	7655 :: 34.9
T13	8852 :: 40.4	8478 :: 38.7	8142 :: 37.2	7941 :: 36.2	7564 :: 34.5
T15	8823 :: 40.3	8444 :: 38.5	8102 :: 37.0	7898 :: 36.0	7514 :: 34.3
T16	8761 :: 40.0	8395 :: 38.3	8065 :: 36.8	7868 :: 35.9	7498 :: 34.2
T17	8759 :: 40.0	8394 :: 38.3	8065 :: 36.8	7868 :: 35.9	7499 :: 34.2
T18	8662 :: 39.5	8296 :: 37.9	7967 :: 36.4	7770 :: 35.5	7400 :: 33.8
T19	8993 :: 41.0	8627 :: 39.4	8297 :: 37.9	8100 :: 37.0	7730 :: 35.3
T20	9013 :: 41.1	8638 :: 39.4	8300 :: 37.9	8099 :: 37.0	7720 :: 35.2
T21	8928 :: 40.7	8488 :: 38.7	8091 :: 36.9	7854 :: 35.8	7409 :: 33.8
T22	9165 :: 41.8	8736 :: 39.9	8349 :: 38.1	8118 :: 37.0	7684 :: 35.1
T24	8924 :: 40.7	8534 :: 38.9	8183 :: 37.3	7973 :: 36.4	7579 :: 34.6

Table 24: Turbine-specific 20-year generation probability of exceedance values (P-values) for 22 GE 2.5-127 wind turbines at 88.6 m.

10.2 GE 2.3-116 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 :: %)
T14	37.55235	-104.53913	1952	7.75	0.980	8914 :: 44.2	96.7	7350 :: 36.5
T23	37.54925	-104.47879	1955	7.72	0.979	8793 :: 43.6	96.0	7234 :: 35.9

Table 25: Turbine-specific 37-year mean values for 2 GE 2.3-116 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 :: %)
T14	7350 :: 36.5	7035 :: 34.9	6751 :: 33.5	6581 :: 32.6	6263 :: 31.1
T23	7234 :: 35.9	6921 :: 34.3	6639 :: 32.9	6470 :: 32.1	6154 :: 30.5

Table 26: Turbine-specific 20-year generation probability of exceedance values (P-values) for 2 GE 2.3-116 wind turbines at 80 m.

11 APPENDIX GROSS LONG-TERM VARIABILITY

11.1 Summary

This section provides a retrospective analysis of the past 37 years of wind speed and power at the La Cumbre 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 M2250, M2315, M2316, M2317, M2318 and M2322). 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 the 3TIER Services' Energy Risk Framework, the last 37 years (January, 1980 – September, 2017) of data have been utilized for estimating the expected future generation at La Cumbre. The average MOS-corrected simulated wind speed at hub height ($88.6\,m$ or $80\,m$) during the past 37 years of record (January, 1980 – September, 2017) across all 24 turbines is $\mathbf{8.05\,m/s}$. The average MOS-corrected simulated gross power capacity at hub height during the past 37 years across all 24 turbines is **48.8%**. Maps of average MOS-corrected gross power capacity values across the La Cumbre project area using the power curve for each of the GE 2.5-127 and GE 2.3-116 wind turbines are displayed in Power Capacity Maps.

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

11.2 Power Capacity Maps

This section contains maps of MOS-corrected long-term mean gross power capacity values across the La Cumbre project area for each turbine model and hub height.

11.2.1 GE 2.5-127 at 88.6 m

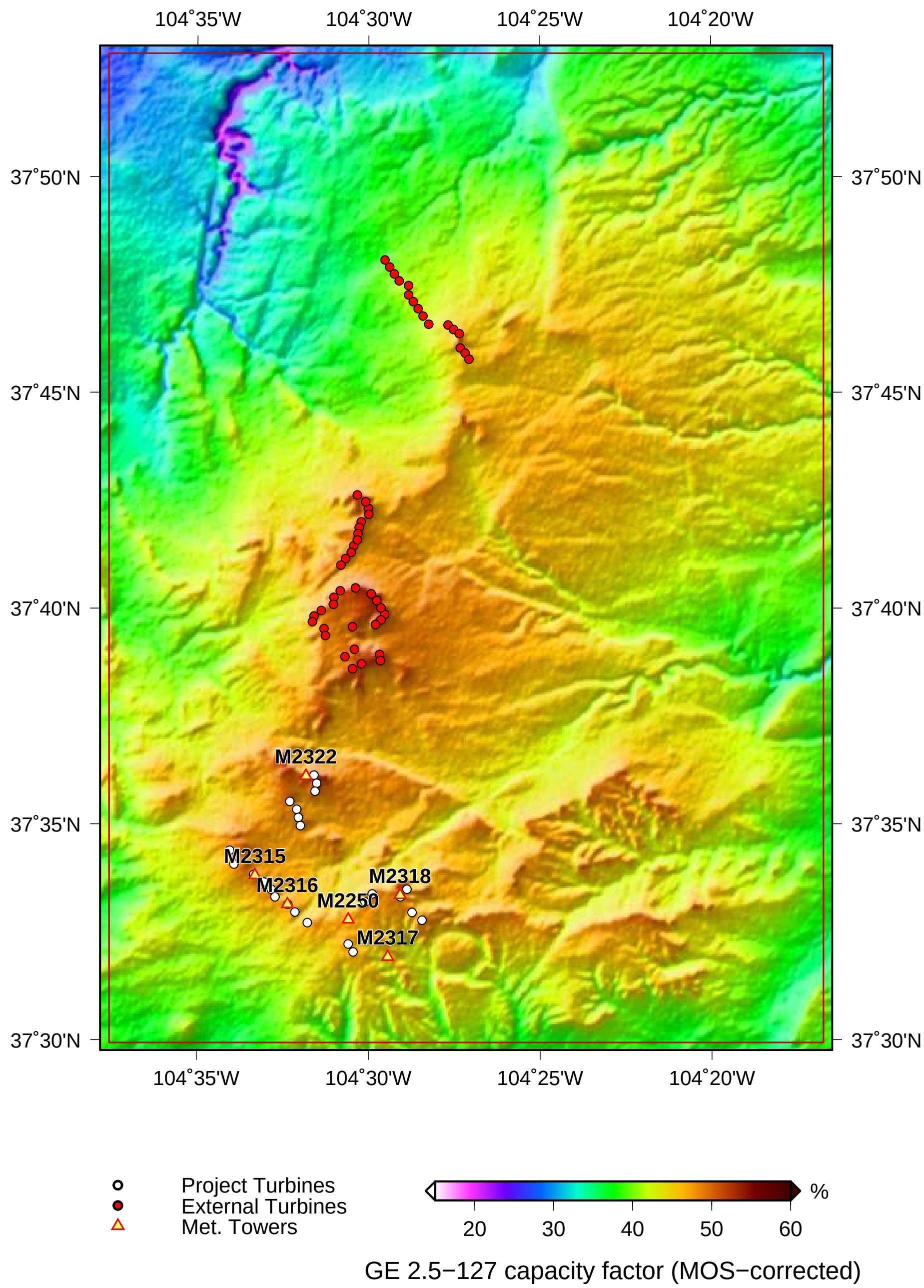

Figure 18: 37-year mean capacity factor at 88.6 m.

11.2.2 GE 2.3-116 at 80 m

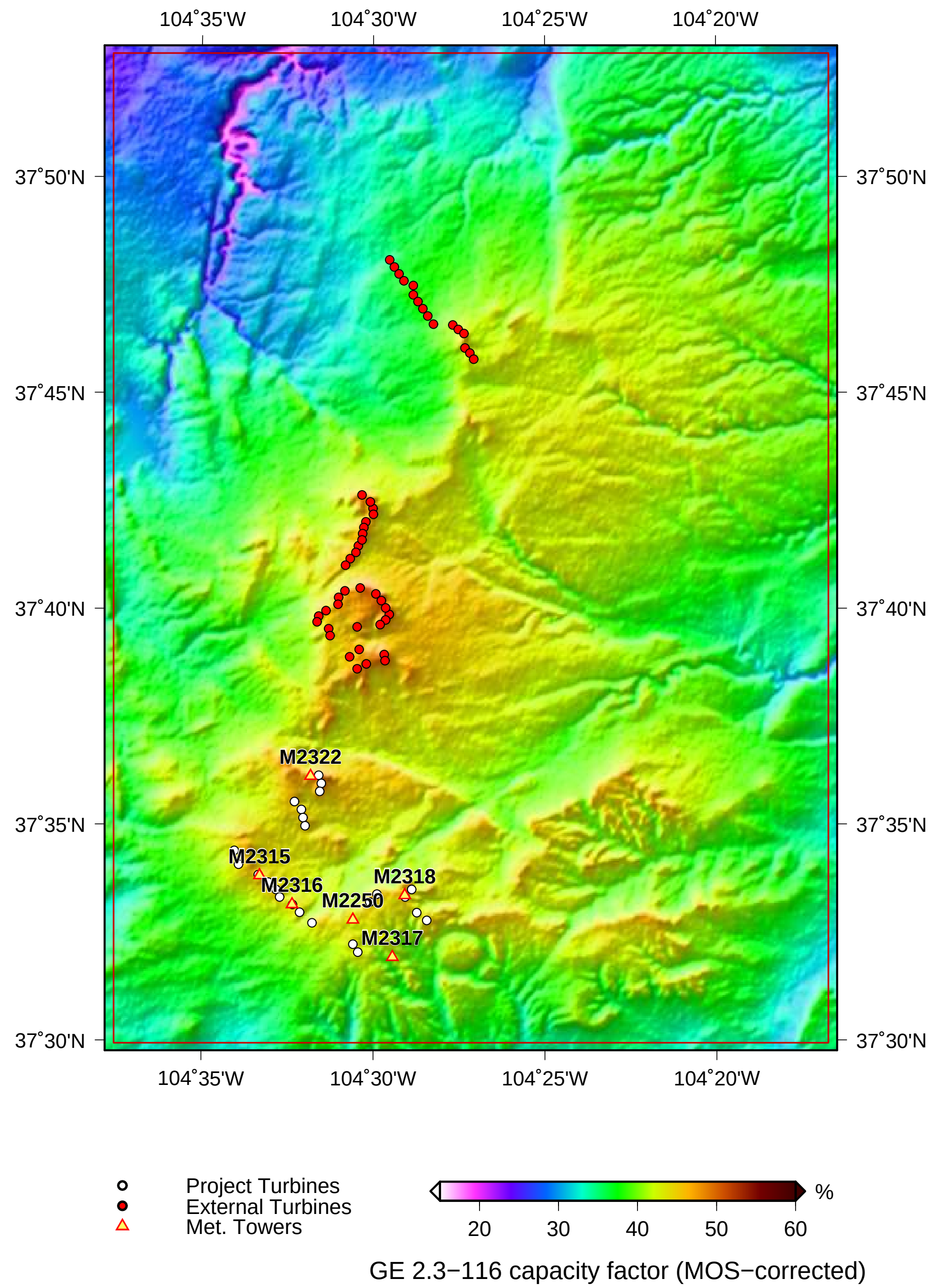

Figure 19: 37-year mean capacity factor at 80 m.

11.3 Model Simulations By Vaisala

The assessment of the wind resource across the La Cumbre project presented in this section is based on 37 years of simulated data (January, 1980 – September, 2017) using a numerical weather prediction (NWP) model of the atmosphere.

The 37-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 (2007 – 2016)), and
2. a 37-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.

Vaisala configured the NWP model using nested grids to simulate the wind resource over the La Cumbre region. Some details of the NWP configuration are shown below in Table 27. 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 20.

Based on a comparison of the NWP output with observations from each meteorological tower for which data were provided (Towers M2250, M2315, M2316, M2317, M2318 and M2322), 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	1 second NLCD01
Surface parameterization	Monin-Obukhov similarity model
Boundary layer parameterization	Mellor-Yamada-Janjic TKE
Land surface scheme	5-layer soil diffusivity model

Table 27: Numerical weather prediction model configuration

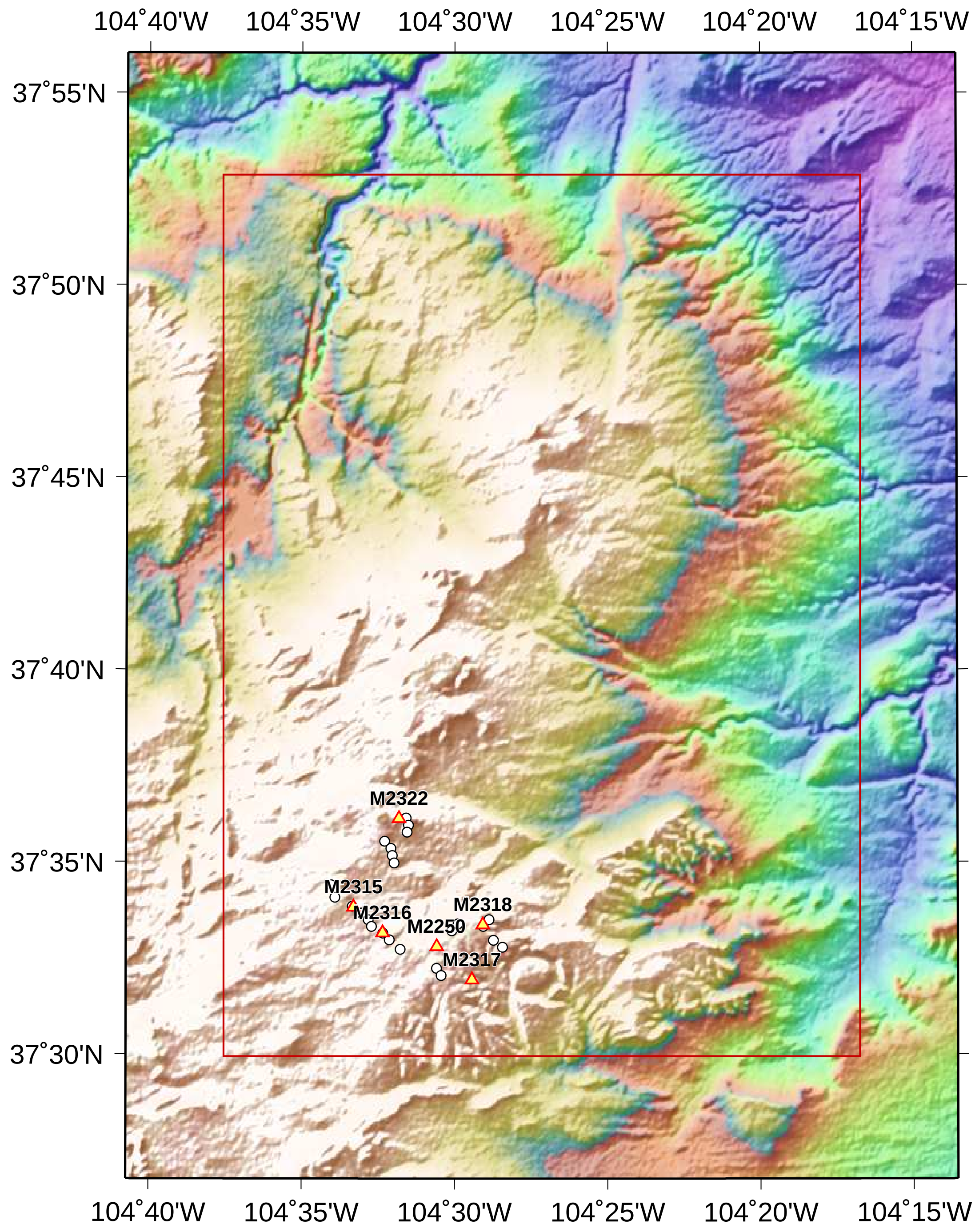

Figure 20: Map of the 90 m resolution NWP model domain. The bold red box marks the boundary of the valid study area. The yellow triangles denote locations of meteorological towers and white dots indicate wind turbines.

11.4 Project-average Long-term Wind Resource Assessment

11.4.1 Monthly-mean Variability of Wind Speed

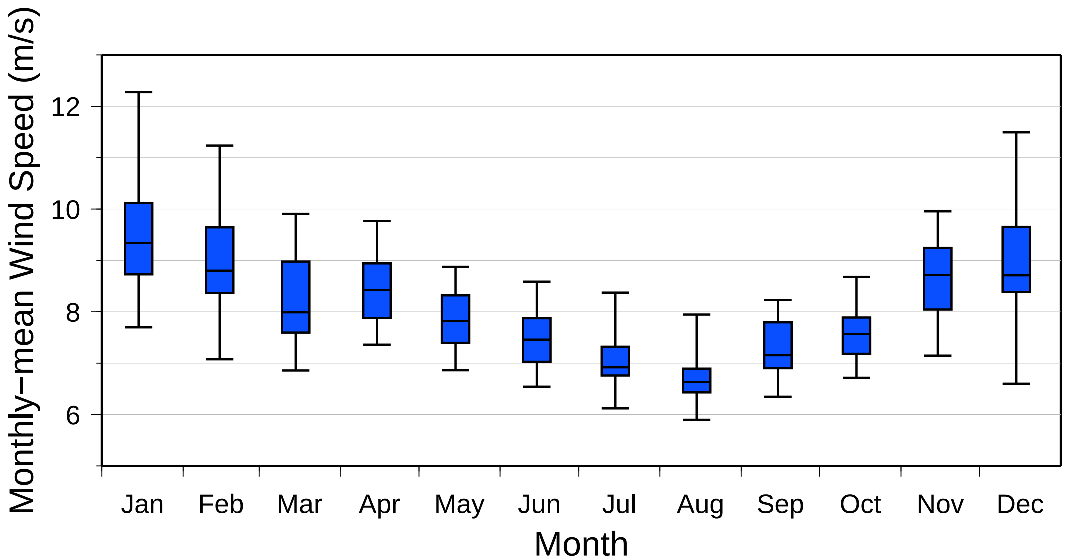

Figure 21: Box-and-whisker plot of monthly-mean project-average wind speed. This figure displays the expected variability of monthly-mean project-average wind speeds. Median wind speed denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond to the 75% and 25% quartiles, while the whiskers denote the maximum and minimum monthly-mean wind speeds.

11.4.2 Annual-mean Variability of Wind Speed

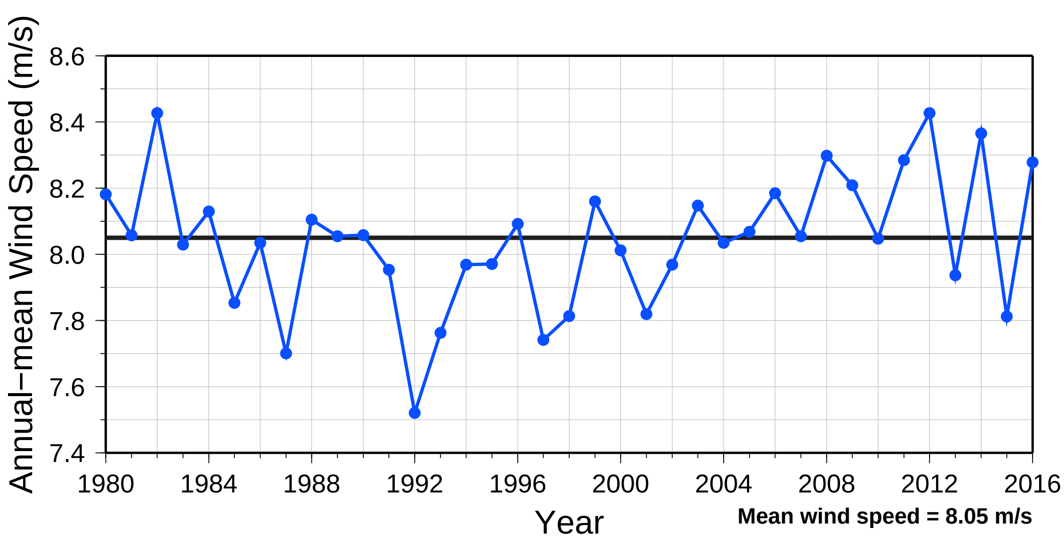

Figure 22: Time series of annual-mean project-average wind speed. Black line denotes the long-term mean.

11.4.3 Wind Speed Distribution

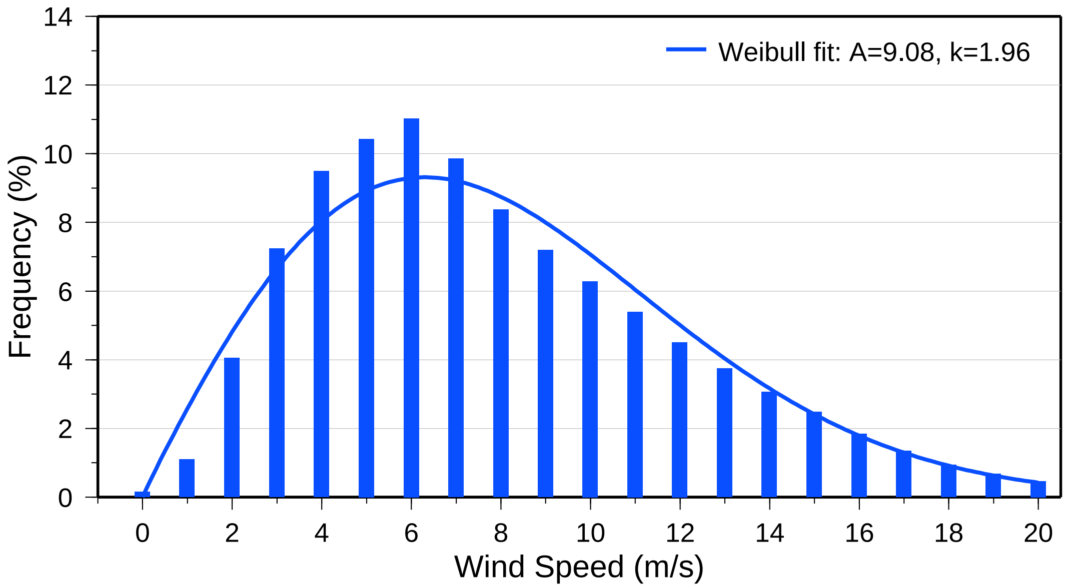

Figure 23: Hourly distribution of simulated project-average wind speed using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5.) Weibull distribution is also shown with the scale (A) and shape (k) parameters listed in the legend.

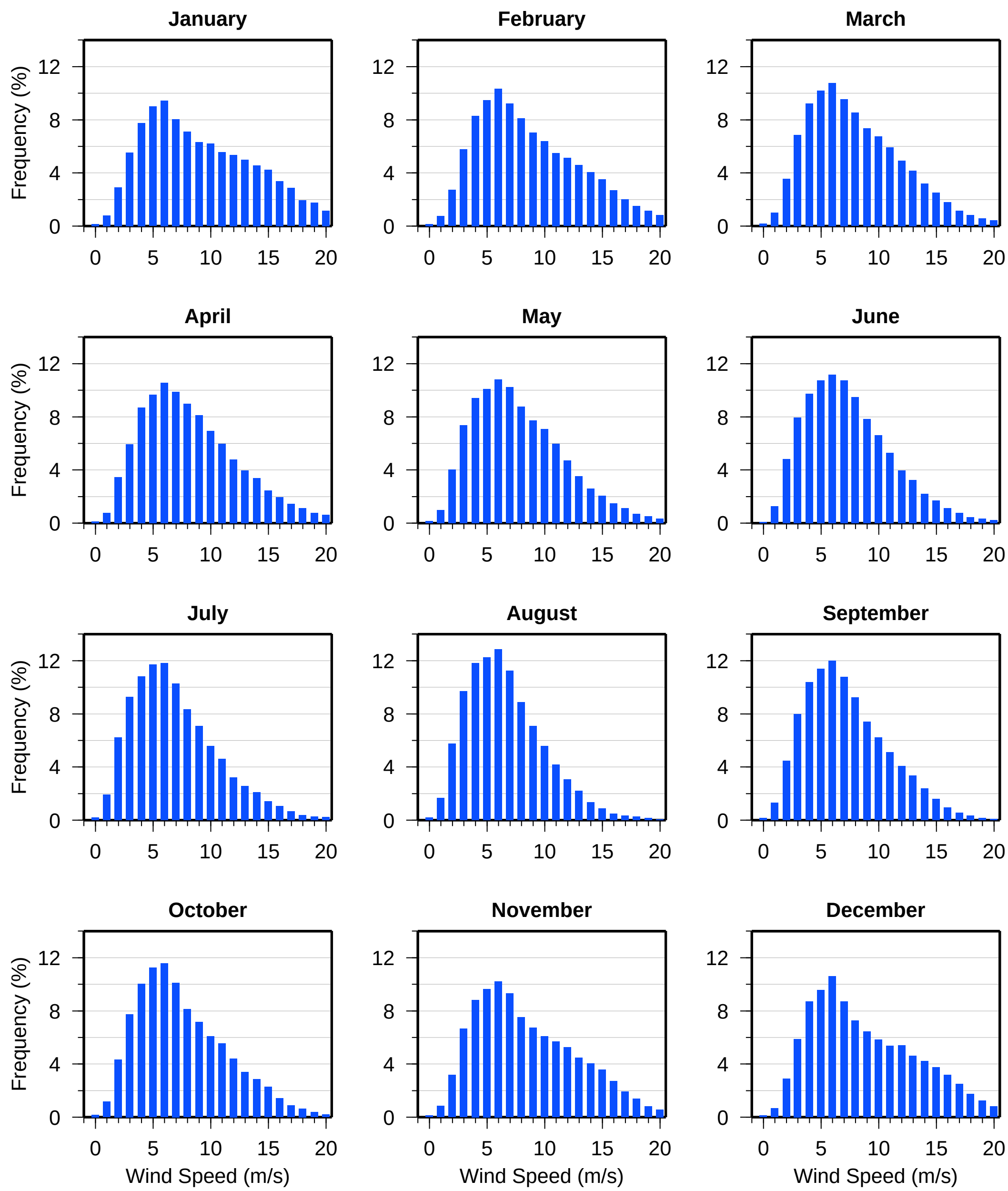

Figure 24: Hourly distribution of simulated project-average wind speed using $1\,m/s$ bins for each calendar month. ($0\,m/s$ bin contains only values ≤ 0.5.)

11.4.4 Wind Direction Distribution

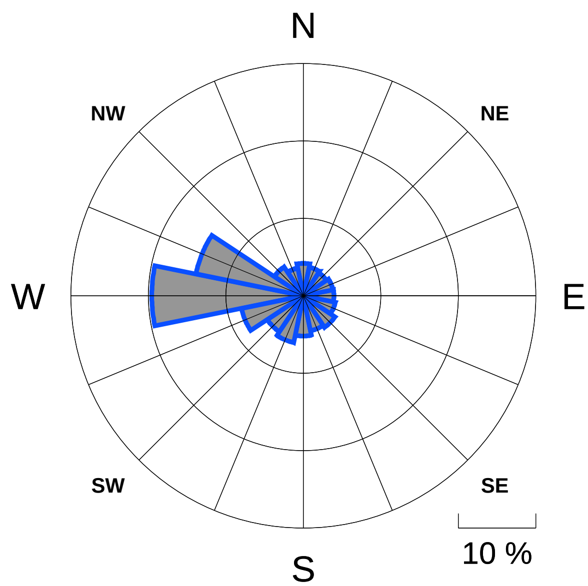

Figure 25: Annual wind rose of the hourly-mean project-average wind direction time series. Directional bins are 22.5° wide, and the radial contour interval is 10%.

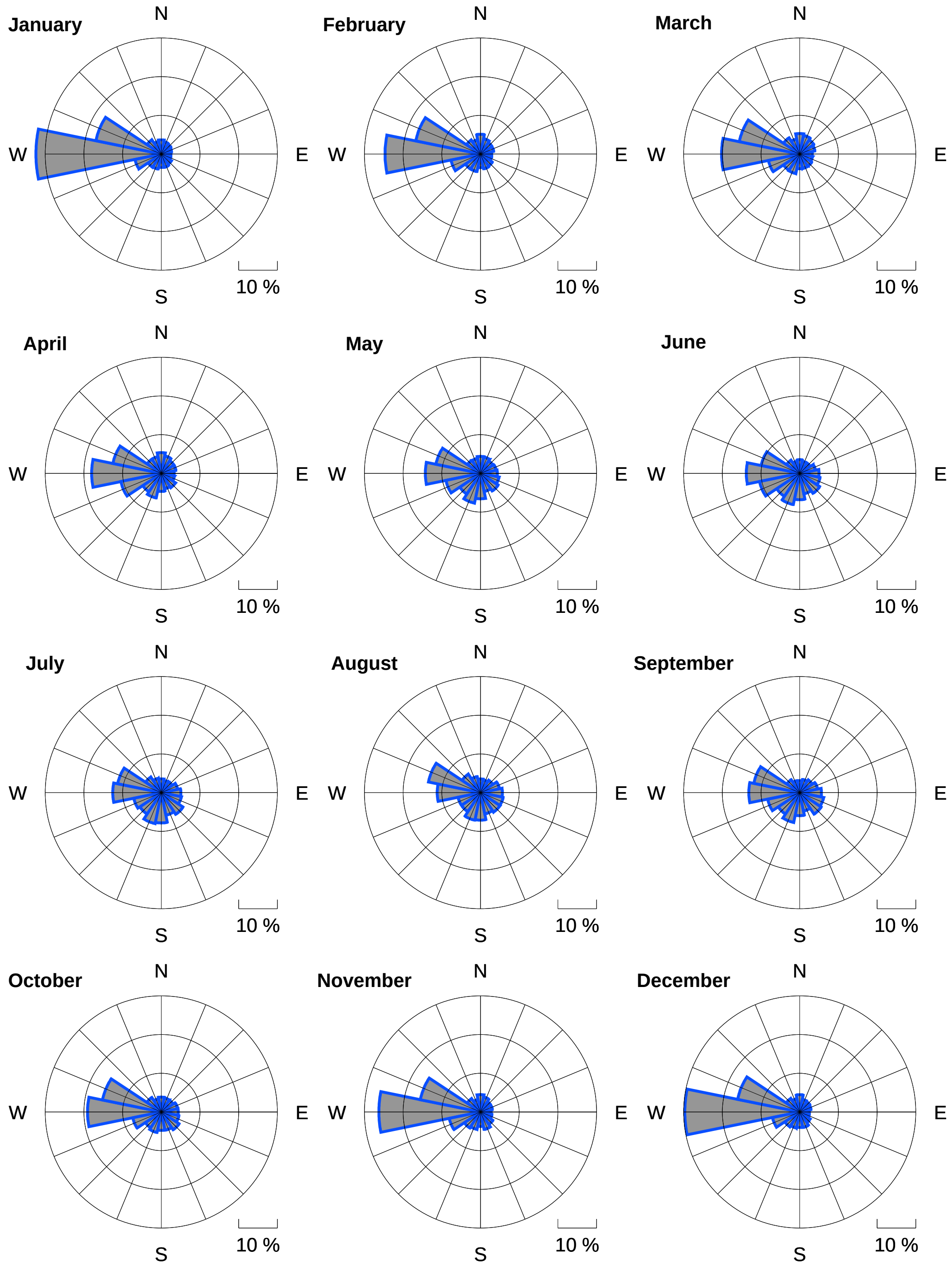

Figure 26: Wind roses of the hourly-mean project-average wind direction time series for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%.

11.4.5 Diurnal Variability of Wind Speed

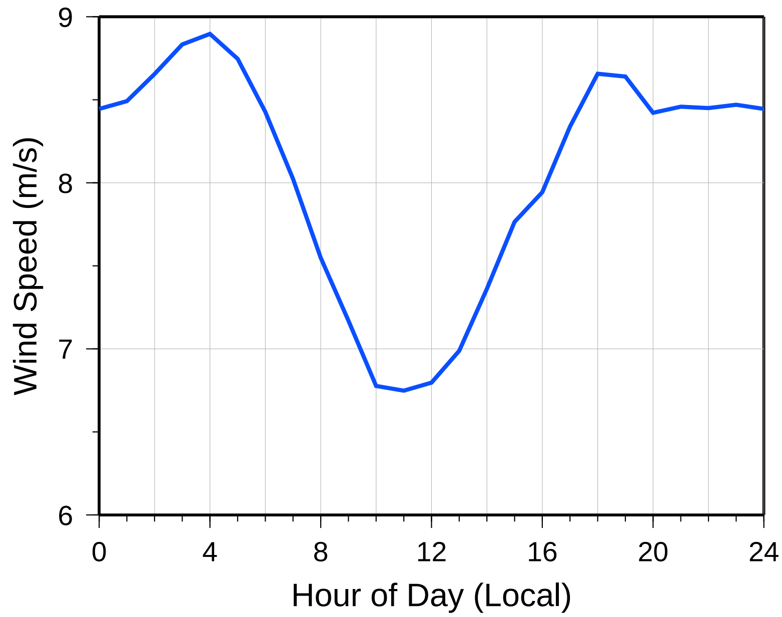

Figure 27: Diurnal cycle of simulated project-average wind speed. The horizontal axis is Mountain Time Zone.

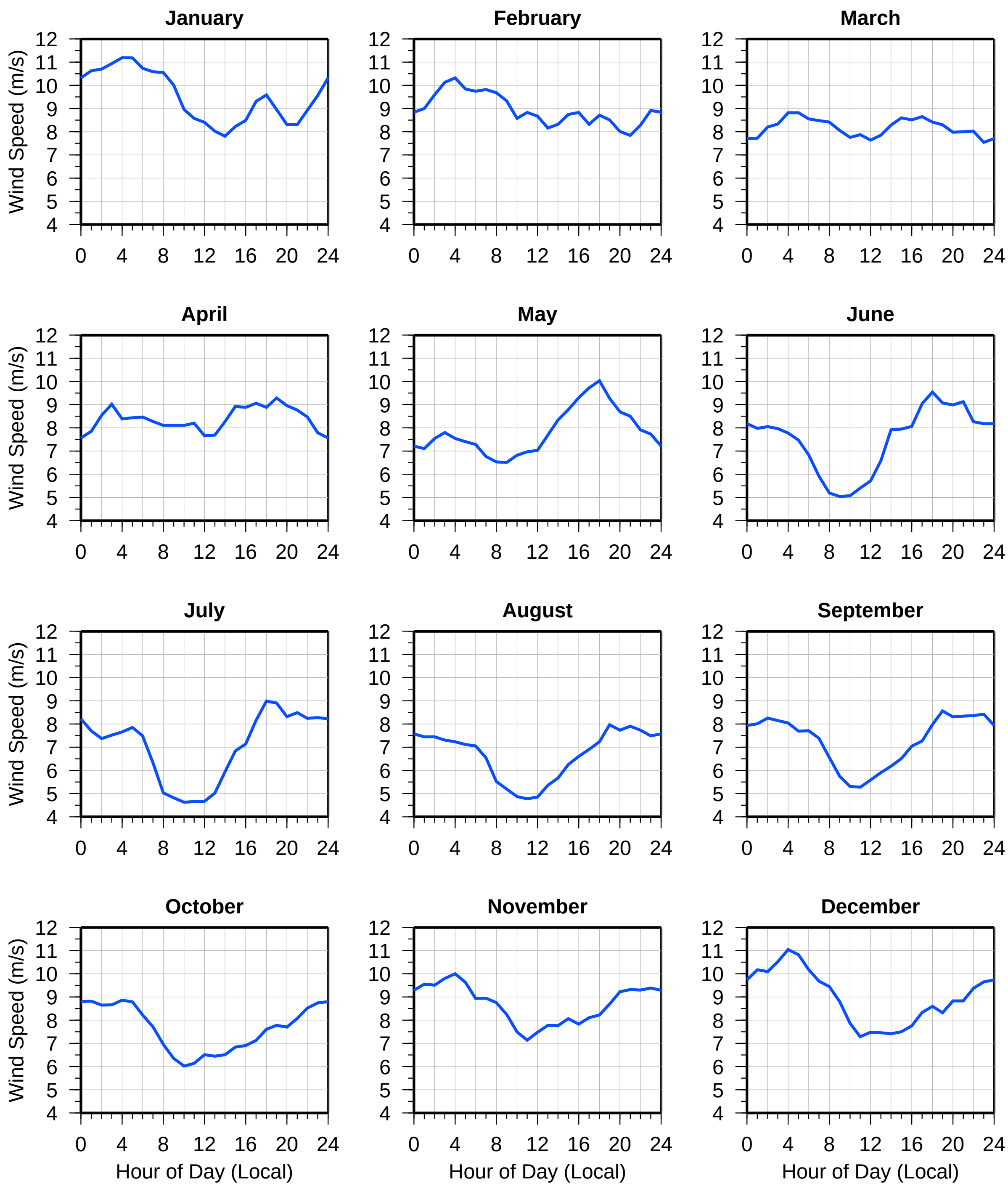

Figure 28: Diurnal cycle of simulated project-average wind speed for each calendar month. The horizontal axis is Mountain Time Zone.

11.4.6 Wind Speed Variability and ENSO

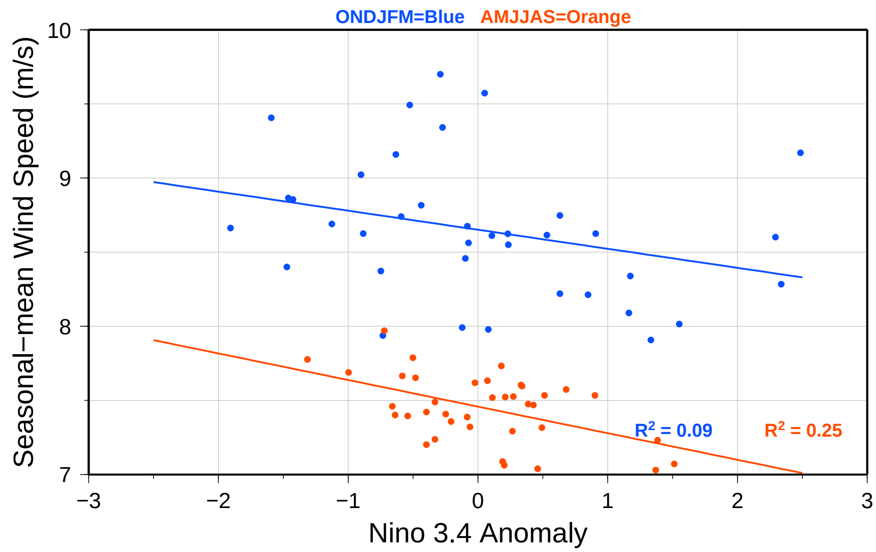

Figure 29: Scatter plot of Niño 3.4 anomalies vs. 6-month seasonal-mean project-average wind speed. Blue dots denote the mean during ONDJFM (October, November, December, January, February, and March); orange dots denote the mean during AMJJAS (April, May, June, July, August and September).

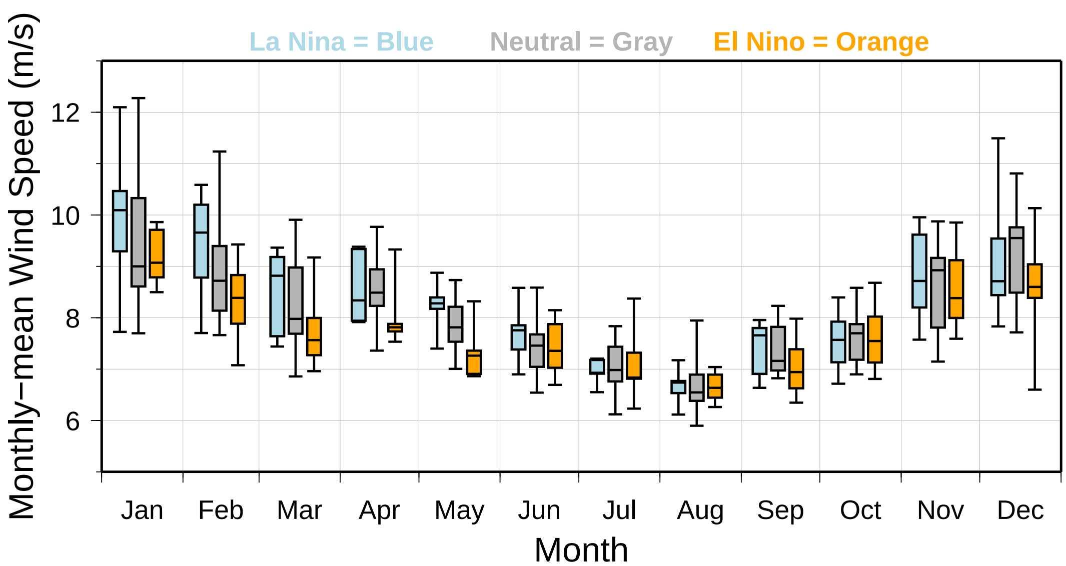

Figure 30: Box-and-whisker plot of monthly-mean project-average wind speed for La Niña (blue), neutral (gray), and El Niño (orange) phases of ENSO. Median wind speed denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond to the 75% and 25% quartiles, while 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	10.33	8.85	7.70	7.57	7.21	8.19	8.23	7.58	7.93	8.80	9.29	9.73	8.44
1	10.63	9.00	7.72	7.85	7.11	7.98	7.70	7.45	8.01	8.83	9.56	10.17	8.49
2	10.71	9.60	8.21	8.55	7.54	8.06	7.37	7.45	8.26	8.65	9.51	10.10	8.66
3	10.94	10.13	8.33	9.03	7.80	7.97	7.52	7.31	8.15	8.66	9.80	10.53	8.83
4	11.20	10.32	8.83	8.39	7.55	7.78	7.66	7.24	8.04	8.86	10.00	11.05	8.90
5	11.19	9.85	8.82	8.44	7.41	7.47	7.86	7.12	7.69	8.79	9.63	10.82	8.75
6	10.74	9.75	8.55	8.47	7.29	6.84	7.49	7.06	7.71	8.23	8.94	10.18	8.43
7	10.59	9.82	8.48	8.28	6.77	5.91	6.33	6.54	7.38	7.71	8.95	9.68	8.02
8	10.56	9.69	8.42	8.11	6.53	5.19	5.03	5.52	6.56	6.96	8.76	9.45	7.55
9	10.01	9.34	8.06	8.11	6.52	5.04	4.82	5.19	5.75	6.35	8.25	8.80	7.17
10	8.96	8.58	7.75	8.11	6.83	5.07	4.63	4.87	5.31	6.02	7.49	7.86	6.78
11	8.58	8.83	7.88	8.21	6.97	5.40	4.66	4.77	5.28	6.14	7.14	7.29	6.75
12	8.41	8.68	7.64	7.66	7.04	5.72	4.67	4.85	5.58	6.51	7.49	7.48	6.80
13	8.02	8.16	7.85	7.69	7.69	6.58	5.03	5.37	5.91	6.45	7.78	7.46	6.99
14	7.82	8.32	8.29	8.26	8.35	7.92	5.94	5.67	6.18	6.51	7.76	7.42	7.36
15	8.23	8.75	8.59	8.93	8.79	7.94	6.84	6.26	6.51	6.84	8.07	7.50	7.76
16	8.49	8.83	8.51	8.89	9.30	8.06	7.14	6.60	7.05	6.90	7.83	7.75	7.94
17	9.32	8.32	8.62	9.09	9.71	9.04	8.25	6.92	7.27	7.09	8.05	8.34	8.34
18	9.60	8.73	8.41	8.87	10.00	9.58	9.06	7.25	7.98	7.63	8.15	8.60	8.66
19	8.98	8.53	8.27	9.32	9.24	9.08	8.97	7.94	8.59	7.78	8.64	8.34	8.64
20	8.37	8.02	7.96	8.96	8.64	9.00	8.37	7.76	8.30	7.69	9.15	8.88	8.42
21	8.35	7.85	7.97	8.77	8.45	9.12	8.54	7.89	8.38	8.05	9.27	8.88	8.46
22	8.96	8.31	7.98	8.50	7.91	8.29	8.25	7.72	8.39	8.47	9.27	9.41	8.45
23	9.60	8.95	7.52	7.80	7.70	8.23	8.31	7.44	8.45	8.69	9.39	9.66	8.47
Avg	9.52	8.97	8.18	8.41	7.85	7.48	7.03	6.66	7.28	7.61	8.67	8.97	8.05

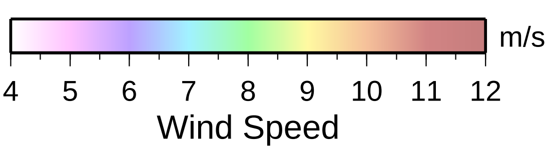

Figure 31: Hourly-mean values of simulated project-average wind speed. Vertical axis is local time.

Year	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
1980	9.86	9.40	9.06	7.48	7.75	7.87	7.50	7.95	7.84	7.37	7.76	8.35	8.18
1981	7.70	8.78	7.98	8.62	8.43	7.68	6.91	6.36	6.94	8.13	9.24	9.99	8.06
1982	12.28	8.81	8.98	9.61	7.23	7.03	7.52	6.44	7.37	7.54	8.92	9.40	8.43
1983	8.79	8.96	8.00	7.89	7.93	7.34	7.79	6.47	8.16	7.22	9.30	8.62	8.03
1984	8.29	9.01	7.80	8.94	8.17	7.93	7.03	6.26	7.58	7.57	9.95	9.13	8.13
1985	7.73	8.58	9.18	7.91	7.40	7.02	6.91	7.34	7.82	7.72	8.88	7.83	7.85
1986	9.98	10.40	7.64	8.86	7.53	6.93	7.81	6.68	7.98	7.13	9.12	6.60	8.03
1987	9.71	8.38	7.60	7.88	7.30	6.89	8.37	6.60	6.34	6.81	7.93	8.60	7.70
1988	9.85	8.29	7.79	8.50	8.87	7.38	6.93	7.17	7.80	6.72	9.27	8.71	8.10
1989	10.77	7.70	8.80	7.94	8.21	6.90	7.44	7.01	7.26	7.68	9.17	7.71	8.05
1990	10.75	8.58	6.86	7.66	8.69	8.27	6.60	6.92	6.97	7.87	9.08	8.49	8.06
1991	8.42	7.99	9.91	8.23	8.58	8.15	6.83	6.26	7.16	7.41	8.30	8.23	7.95
1992	8.50	8.39	7.27	7.53	6.91	6.54	6.87	6.43	7.95	7.09	7.15	9.65	7.52
1993	8.70	8.37	6.91	7.73	6.87	7.99	7.84	6.45	7.02	6.90	8.97	9.48	7.76
1994	9.11	9.55	7.65	8.45	7.55	7.65	6.76	6.49	6.85	7.76	9.37	8.59	7.97
1995	9.06	8.73	8.23	8.57	7.79	7.44	7.18	6.55	6.91	7.82	9.62	7.83	7.97
1996	10.30	8.74	7.44	8.72	8.11	6.78	6.44	6.25	7.12	7.88	7.81	11.49	8.09
1997	10.08	7.66	7.98	7.79	6.86	7.15	7.32	6.43	6.63	8.68	7.88	8.39	7.74
1998	9.81	7.84	7.11	7.75	8.32	8.58	6.55	6.12	7.05	7.73	8.72	8.23	7.81
1999	10.16	10.20	8.10	9.38	8.18	7.86	7.21	6.77	6.74	7.02	8.05	8.44	8.16
2000	9.54	9.77	7.58	8.42	8.39	7.74	6.98	6.80	7.66	7.13	7.57	8.64	8.01
2001	8.40	8.97	6.90	9.07	7.24	7.52	7.10	6.54	6.85	8.58	8.07	8.70	7.82
2002	8.91	8.76	8.36	9.06	8.21	7.51	6.23	7.04	7.39	7.02	8.18	9.04	7.97
2003	9.07	7.88	8.84	9.77	7.85	6.81	7.45	6.74	7.09	7.48	9.01	9.76	8.15
2004	9.10	8.14	7.82	8.09	8.52	7.05	6.72	6.89	7.59	8.59	8.00	9.88	8.03
2005	9.14	7.87	8.22	8.43	7.52	7.89	7.27	6.25	7.78	7.07	9.88	9.54	8.07
2006	12.10	9.12	9.25	9.27	7.00	7.20	6.33	5.90	6.67	7.96	8.47	9.01	8.18
2007	8.86	10.50	7.69	7.91	7.40	7.07	6.12	6.75	7.96	8.23	8.42	9.96	8.05
2008	11.32	9.70	8.82	8.26	8.35	7.36	6.85	6.89	6.82	7.40	7.79	10.01	8.30
2009	10.12	10.59	9.04	9.02	7.74	7.47	6.81	6.87	6.90	8.02	7.59	8.50	8.21
2010	8.73	7.08	7.53	9.33	8.74	7.77	7.18	7.01	7.80	7.92	8.67	8.77	8.05
2011	9.29	9.68	8.86	9.34	8.42	8.36	7.25	6.72	6.64	7.34	9.65	8.04	8.28
2012	10.09	9.64	9.36	8.40	8.12	8.59	6.73	6.89	6.43	7.76	9.20	9.95	8.43
2013	8.61	8.68	7.86	7.36	7.79	7.61	6.77	6.38	8.23	7.89	8.51	9.62	7.94
2014	10.46	10.41	9.15	8.47	7.82	8.14	6.88	6.98	7.33	7.18	9.85	7.91	8.37
2015	8.58	8.83	6.96	7.88	7.36	6.70	6.84	6.67	6.98	7.52	9.38	10.13	7.81
2016	9.39	9.43	9.17	7.63	7.83	6.61	7.53	6.53	7.80	8.40	8.20	10.81	8.28
2017	10.33	11.24	9.23	8.44	7.21	7.37	6.24	6.11	7.15				−−
Avg	9.52	8.97	8.18	8.41	7.85	7.48	7.03	6.66	7.28	7.61	8.67	8.97	**8.05**

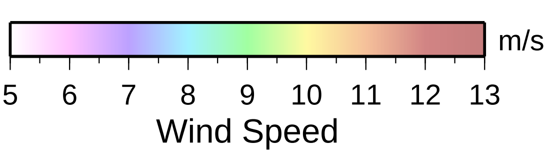

Figure 32: Monthly-mean values of simulated project-average wind speed.

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	7.04	7.94	2.09	4.19
NNE	6.14	6.93	2.14	3.77
NE	5.43	6.13	2.13	3.60
ENE	5.19	5.86	2.04	3.89
E	4.82	5.44	1.98	3.95
ESE	4.97	5.61	1.92	4.20
SE	5.46	6.16	2.04	4.90
SSE	5.75	6.49	2.03	4.61
S	7.34	8.27	1.92	5.20
SSW	8.44	9.53	2.13	6.16
SW	7.53	8.50	2.33	5.57
WSW	9.28	10.48	2.06	8.14
W	11.29	12.70	2.67	19.55
WNW	9.70	10.91	2.71	14.15
NW	6.62	7.47	2.37	4.48
NNW	6.46	7.30	2.20	3.65
ALL	**8.05**	**9.08**	**1.96**	**100.00**

Table 28: 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	0.01	0.04	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
0.5 - 1.5	0.01	0.02	0.05	0.17	0.21	0.23	0.18	0.11	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	1.10
1.5 - 2.5	0.16	0.22	0.35	0.38	0.43	0.43	0.44	0.38	0.28	0.19	0.14	0.13	0.12	0.12	0.12	0.13	4.02
2.5 - 3.5	0.39	0.45	0.50	0.54	0.59	0.57	0.58	0.56	0.53	0.46	0.39	0.32	0.32	0.31	0.33	0.35	7.19
3.5 - 4.5	0.53	0.55	0.60	0.61	0.65	0.67	0.70	0.65	0.59	0.58	0.56	0.55	0.53	0.57	0.55	0.53	9.42
4.5 - 5.5	0.53	0.58	0.54	0.59	0.64	0.64	0.76	0.68	0.60	0.59	0.62	0.72	0.79	0.82	0.68	0.57	10.35
5.5 - 6.5	0.54	0.54	0.52	0.57	0.54	0.58	0.72	0.70	0.58	0.53	0.70	0.86	1.08	1.13	0.76	0.58	10.94
6.5 - 7.5	0.47	0.42	0.40	0.39	0.35	0.39	0.57	0.52	0.50	0.51	0.67	0.82	1.27	1.38	0.66	0.46	9.77
7.5 - 8.5	0.38	0.31	0.23	0.24	0.20	0.26	0.35	0.35	0.41	0.49	0.59	0.78	1.45	1.47	0.48	0.32	8.30
8.5 - 9.5	0.31	0.22	0.15	0.15	0.12	0.15	0.22	0.21	0.35	0.46	0.50	0.68	1.58	1.48	0.34	0.23	7.14
9.5 - 10.5	0.23	0.15	0.09	0.09	0.07	0.09	0.13	0.15	0.30	0.45	0.41	0.60	1.72	1.41	0.19	0.14	6.23
10.5 - 11.5	0.17	0.10	0.06	0.05	0.04	0.05	0.08	0.09	0.23	0.42	0.30	0.52	1.73	1.28	0.11	0.11	5.35
11.5 - 12.5	0.13	0.07	0.03	0.04	0.02	0.02	0.05	0.06	0.18	0.35	0.22	0.43	1.69	1.06	0.07	0.06	4.48
12.5 - 13.5	0.09	0.05	0.03	0.02	0.01	0.02	0.03	0.04	0.15	0.30	0.16	0.37	1.53	0.84	0.05	0.05	3.72
13.5 - 14.5	0.06	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.12	0.23	0.10	0.29	1.38	0.67	0.04	0.03	3.04
14.5 - 15.5	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.09	0.18	0.07	0.25	1.14	0.55	0.02	0.03	2.46
15.5 - 16.5	0.04	0.02	0.00	0.01	0.00	0.01	0.01	0.02	0.07	0.12	0.05	0.18	0.88	0.37	0.02	0.02	1.83
16.5 - 17.5	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.06	0.10	0.03	0.14	0.67	0.25	0.01	0.01	1.34
17.5 - 18.5	0.02	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.04	0.06	0.02	0.10	0.47	0.16	0.01	0.01	0.93
18.5 - 19.5	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.01	0.08	0.35	0.11	0.01	0.01	0.67
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.07	0.23	0.07	0.00	0.01	0.46
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.05	0.17	0.04	0.00	0.00	0.32
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.05	0.12	0.02	0.00	0.00	0.22
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.02	0.00	0.00	0.16
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.01	0.00	0.00	0.12
$>$ 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.09	0.16	0.01	0.00	0.00	0.29

Table 29: 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

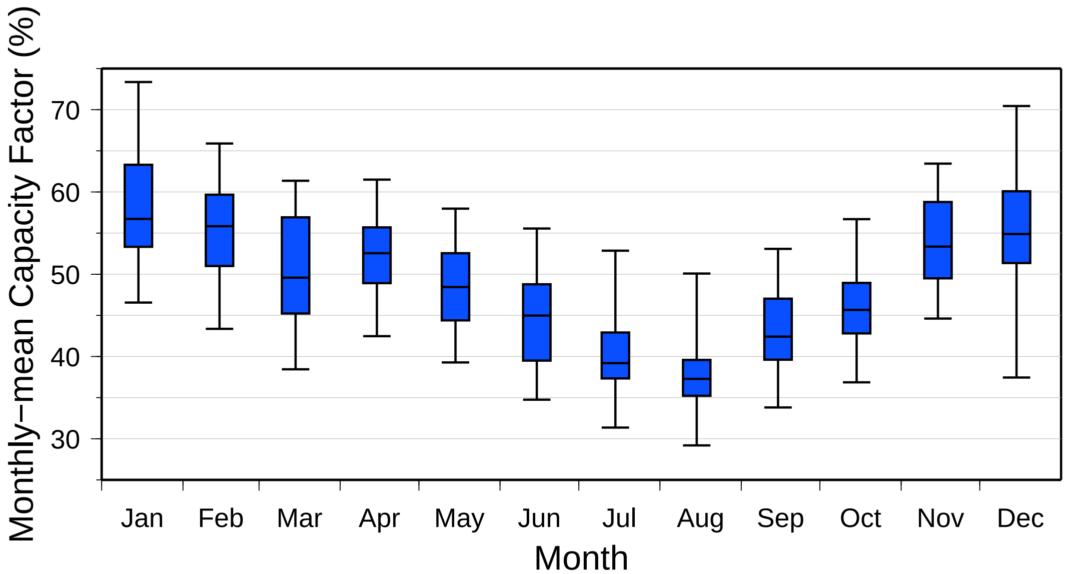

Figure 33: Box-and-whisker plot of monthly-mean project-average gross power capacity. This figure displays the expected variability of monthly-mean project-average gross power capacities. Median power capacity denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond 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

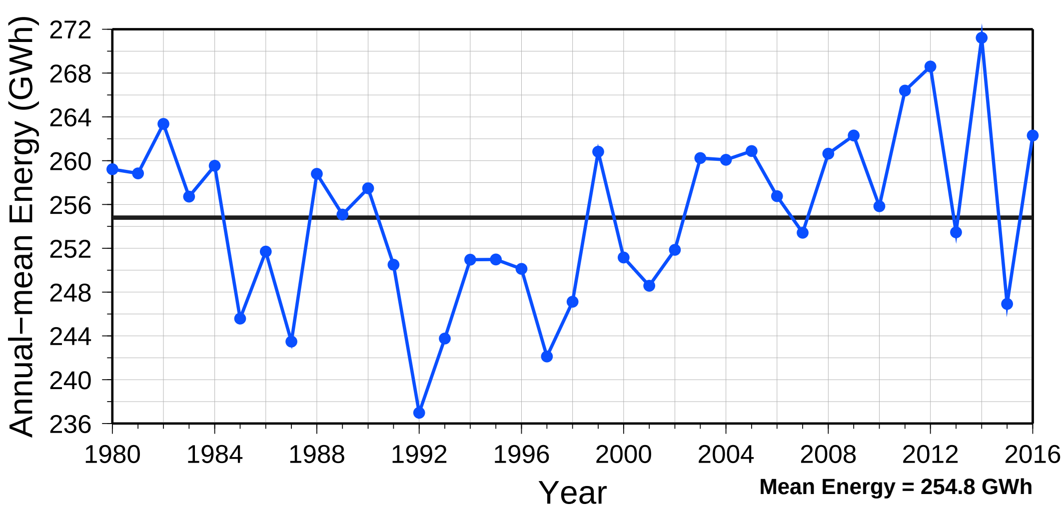

Figure 34: Time series of annual-mean project-average gross energy. Black line denotes the long-term mean.

11.5.3 Power Direction Distribution

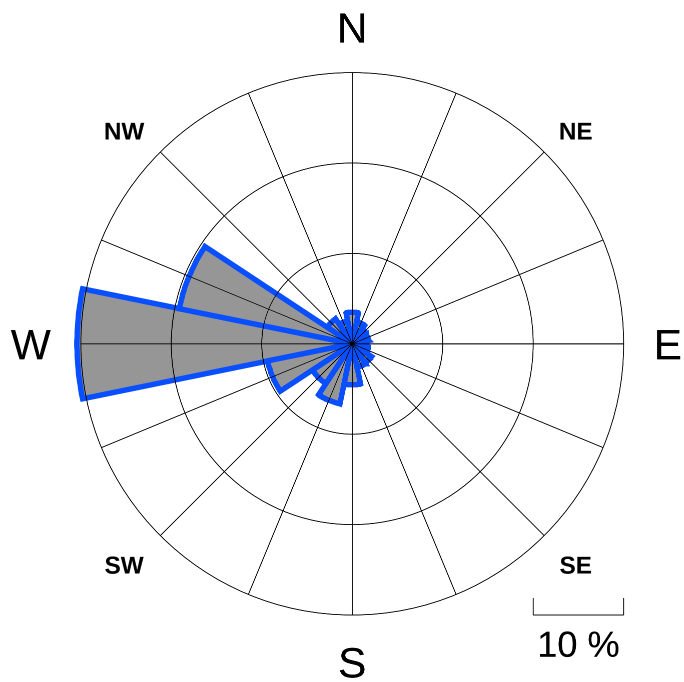

Figure 35: Annual power rose of the hourly-mean project-average gross capacity factor time series. Power rose shows the percent of total power within each sector. Directional bins are 22.5° wide, and the radial contour interval is 10%.

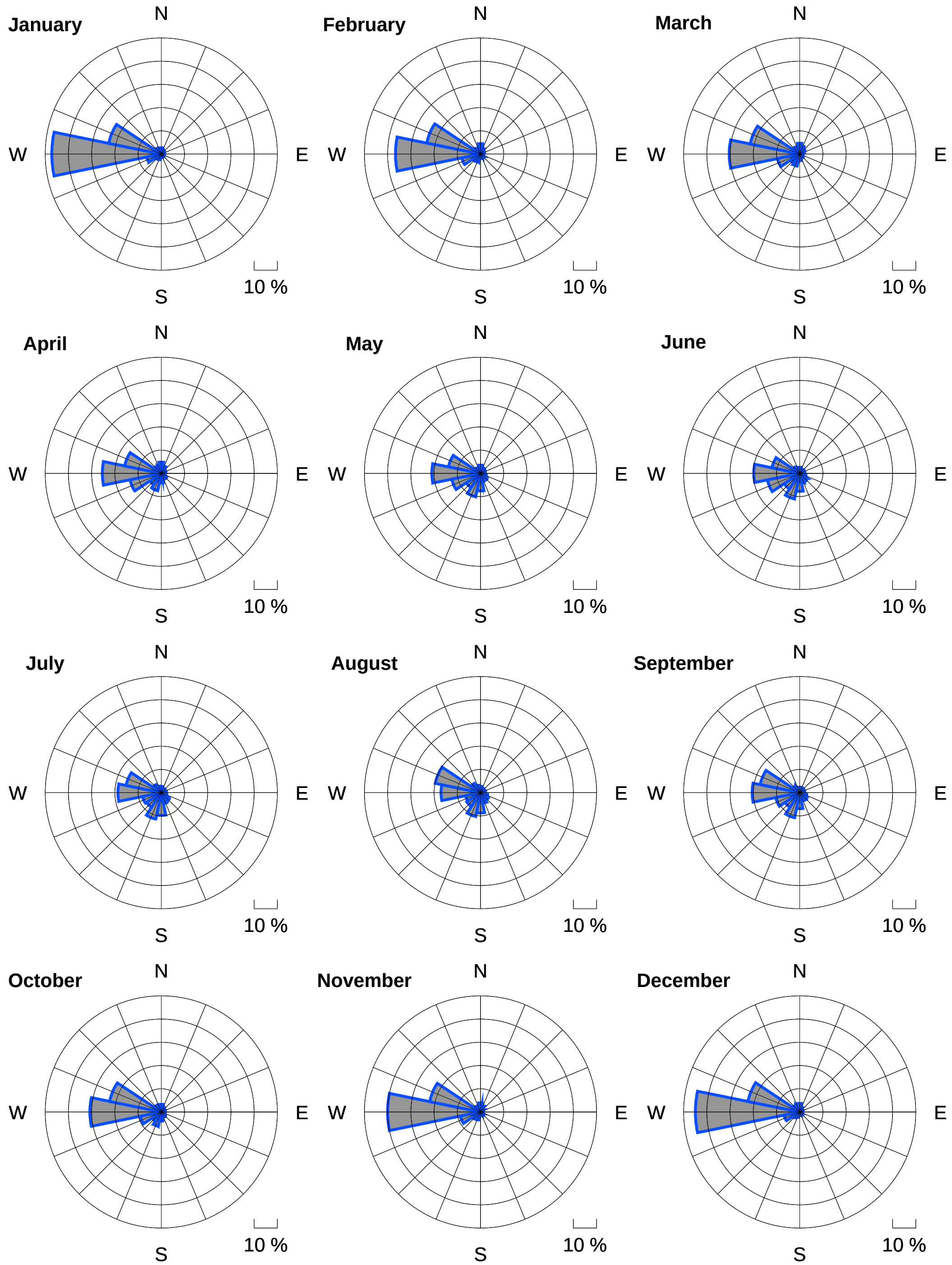

Figure 36: Power roses of the hourly-mean project-average gross capacity factor time series for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%.

11.5.4 Diurnal Variability of Power Capacity

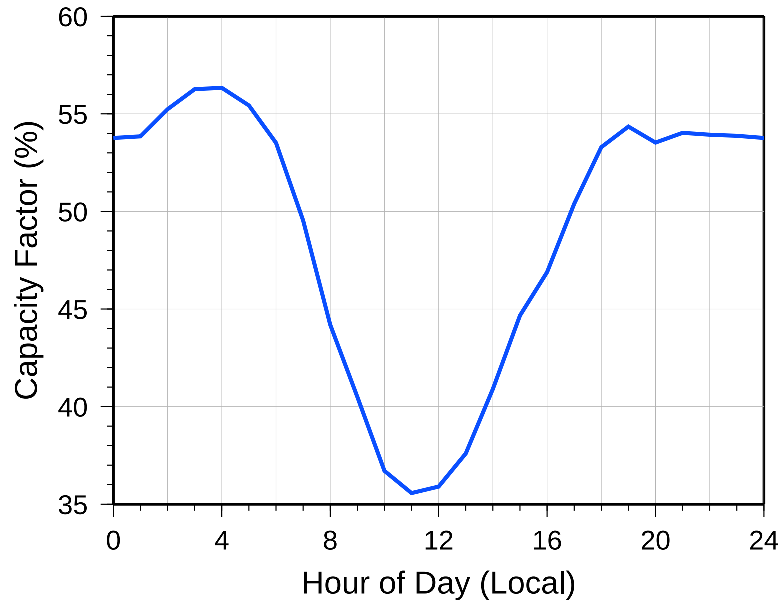

Figure 37: Diurnal cycle of simulated project-average gross power capacity. The horizontal axis is Mountain Time Zone.

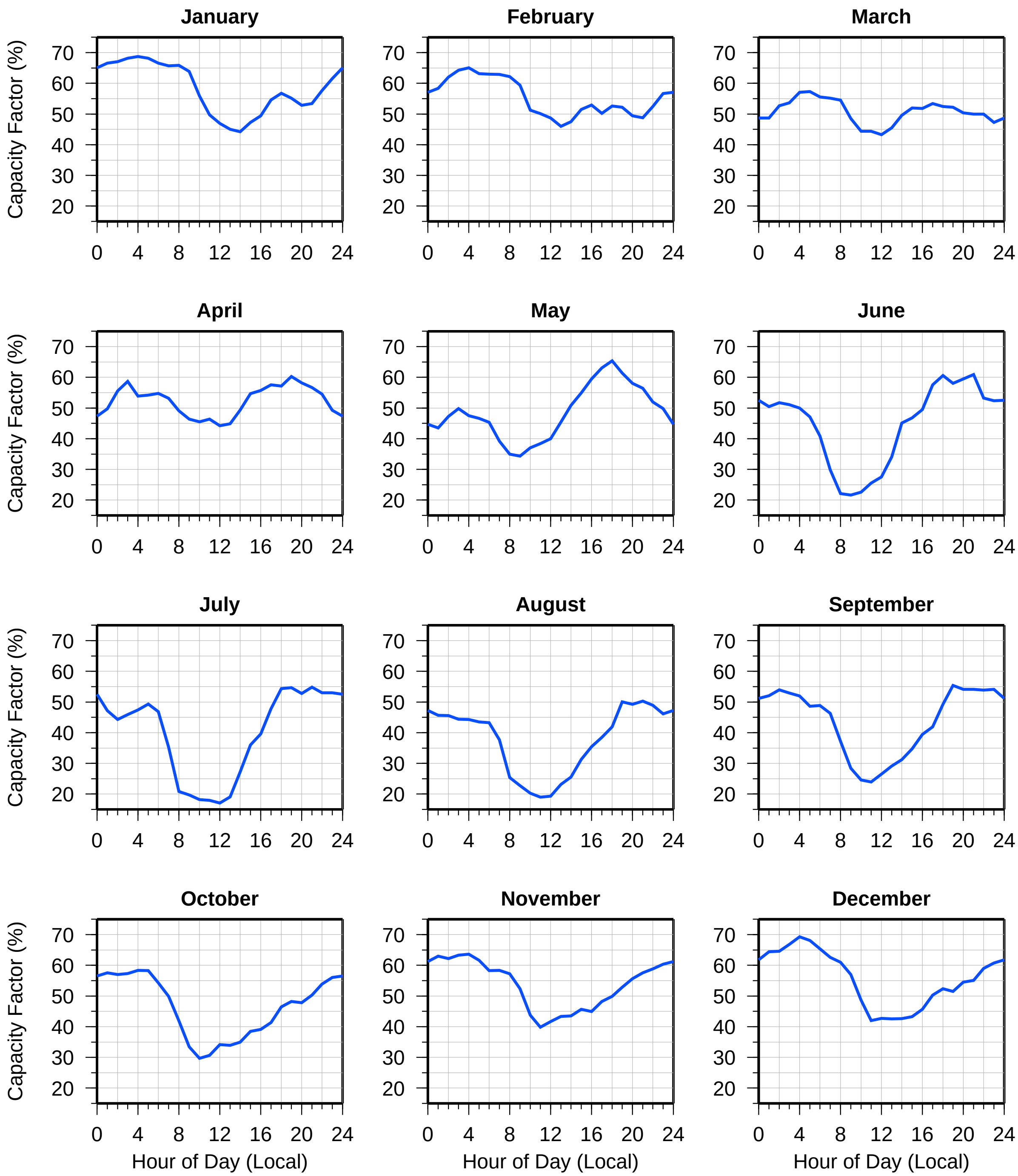

Figure 38: Diurnal cycle of simulated project-average gross power capacity for each calendar month. The horizontal axis is Mountain Time Zone.

11.5.5 Power Capacity Variability and ENSO

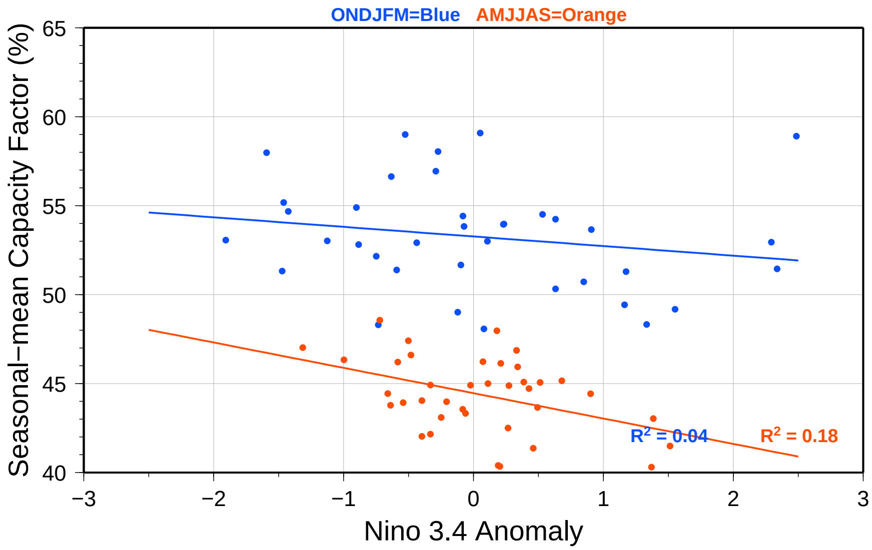

Figure 39: Scatter plot of Niño 3.4 anomalies vs. 6-month seasonal-mean gross power capacity. Blue dots denote the mean during ONDJFM (October, November, December, January, February, and March); orange dots denote the mean during AMJJAS (April, May, June, July, August and September).

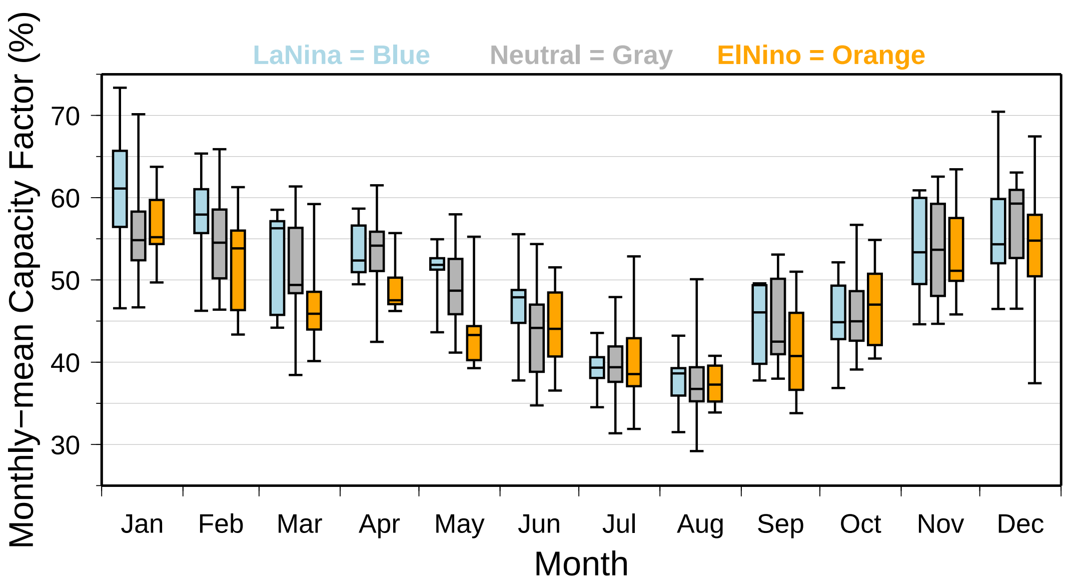

Figure 40: Box-and-whisker plot of monthly-mean project-average gross power capacity for La Niña (blue), neutral (gray), and El Niño (orange) phases of ENSO. Median power capacity denoted by solid line within the shaded box. Upper and lower boundaries of the shaded box correspond to the 75% and 25% quartiles, 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	65.1	57.1	48.7	47.3	44.7	52.5	52.5	47.3	51.2	56.5	61.2	61.8	53.8
1	66.6	58.3	48.7	49.8	43.5	50.5	47.2	45.6	52.1	57.6	63.0	64.4	53.9
2	67.0	62.0	52.7	55.6	47.3	51.7	44.3	45.6	54.0	57.0	62.2	64.6	55.2
3	68.2	64.3	53.7	58.7	49.8	51.0	45.9	44.4	52.9	57.3	63.3	66.8	56.3
4	68.8	65.0	57.1	53.9	47.5	50.0	47.4	44.3	51.9	58.4	63.6	69.3	56.3
5	68.1	63.2	57.4	54.2	46.6	47.1	49.3	43.5	48.6	58.3	61.6	68.1	55.4
6	66.6	63.0	55.6	54.8	45.3	40.9	46.9	43.3	48.8	54.3	58.3	65.4	53.5
7	65.7	62.9	55.2	53.1	39.2	29.8	35.3	37.7	46.3	49.9	58.4	62.6	49.5
8	65.9	62.2	54.5	49.1	35.0	22.1	20.8	25.4	37.2	41.9	57.2	61.0	44.2
9	63.8	59.4	48.6	46.4	34.3	21.6	19.7	22.8	28.4	33.4	52.4	57.0	40.5
10	55.9	51.2	44.4	45.5	37.0	22.6	18.2	20.2	24.6	29.7	43.7	48.6	36.7
11	49.8	50.1	44.3	46.4	38.4	25.6	18.0	19.0	24.0	30.7	39.8	42.0	35.6
12	47.0	48.7	43.3	44.3	40.0	27.5	17.1	19.3	26.5	34.2	41.7	42.7	35.9
13	45.0	46.0	45.5	44.9	45.4	34.1	19.1	23.1	29.1	33.9	43.3	42.6	37.6
14	44.2	47.5	49.5	49.3	50.8	45.1	27.2	25.5	31.2	34.9	43.5	42.6	40.9
15	47.3	51.5	52.0	54.7	54.9	46.7	36.0	31.3	34.7	38.5	45.7	43.3	44.7
16	49.4	52.9	51.8	55.7	59.5	49.5	39.6	35.4	39.4	39.1	45.0	45.6	46.9
17	54.7	50.2	53.4	57.3	62.9	57.7	48.6	38.5	41.9	41.1	47.7	50.4	50.4
18	56.9	52.7	52.4	56.8	65.2	61.0	54.9	41.9	49.3	46.4	49.3	52.5	53.3
19	55.3	52.4	51.9	60.4	61.0	58.2	55.3	49.6	55.6	48.1	52.4	51.7	54.4
20	53.3	49.4	50.1	58.1	57.7	59.6	53.1	49.4	54.1	47.6	55.2	54.8	53.5
21	53.7	48.8	49.8	56.8	55.7	61.0	55.1	50.2	54.3	49.9	57.5	55.3	54.0
22	58.0	52.6	49.8	54.6	51.7	53.7	52.9	48.7	54.2	53.3	59.0	59.0	53.9
23	61.9	56.8	47.2	49.4	49.3	52.9	53.2	45.6	54.4	55.4	60.6	60.6	53.9
Avg	58.3	55.3	50.7	52.4	48.4	44.7	39.9	37.4	43.5	46.1	53.6	55.5	48.8

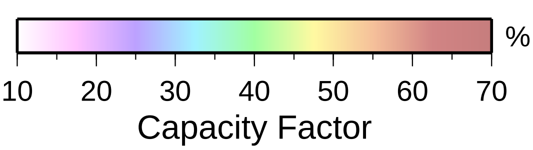

Figure 41: Hourly-mean values of simulated project-average gross capacity factor. Vertical axis is local time.

Year	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
1980	55.2	53.9	56.9	45.1	47.4	51.5	43.5	50.1	50.1	42.6	46.4	52.7	49.6
1981	46.7	57.3	48.4	55.9	52.7	46.7	40.0	33.2	41.0	53.4	59.9	60.2	49.5
1982	68.0	56.7	56.3	55.6	43.1	40.8	45.9	35.2	46.0	45.7	54.2	57.9	50.4
1983	54.8	56.5	48.6	48.0	47.8	44.9	47.9	35.4	51.6	43.3	59.7	52.0	49.1
1984	50.2	58.5	49.1	58.5	52.6	50.2	38.6	32.7	47.0	44.9	60.0	54.9	49.7
1985	46.6	55.5	56.3	49.5	43.6	39.9	39.3	43.9	46.4	46.7	50.6	46.5	47.0
1986	63.1	55.7	45.7	55.6	45.8	38.7	47.7	38.6	51.0	42.1	57.7	37.4	48.2
1987	61.0	51.7	46.6	50.7	44.4	38.9	52.9	36.9	34.5	40.4	49.0	52.4	46.6
1988	63.5	49.0	50.0	54.3	55.0	44.8	38.1	43.2	46.8	36.9	60.9	52.2	49.5
1989	67.6	46.3	54.5	51.0	51.7	37.8	43.5	40.2	42.5	46.2	56.5	47.8	48.8
1990	70.1	51.0	38.5	46.6	54.5	53.5	35.4	39.4	40.7	49.9	60.9	51.3	49.3
1991	52.9	50.2	58.5	52.1	55.2	48.5	38.4	33.9	42.4	43.3	50.3	50.1	47.9
1992	53.3	54.1	44.0	47.0	40.2	34.8	39.4	35.5	51.3	41.5	44.7	58.9	45.4
1993	53.6	47.5	42.2	47.1	40.2	50.6	47.3	35.3	41.4	39.1	53.9	61.9	46.7
1994	58.3	59.7	45.0	51.1	46.6	45.2	37.3	35.2	39.6	47.1	57.5	54.9	48.0
1995	55.6	53.8	52.9	53.0	45.7	43.3	40.2	36.6	39.8	49.3	60.5	46.5	48.0
1996	60.9	55.5	44.2	54.8	52.6	36.8	34.1	32.1	42.5	43.8	46.9	70.5	47.9
1997	60.6	46.4	49.4	46.7	39.3	40.7	42.9	35.5	36.6	53.1	49.9	54.6	46.3
1998	63.7	44.4	43.0	46.4	55.3	55.6	34.5	31.5	40.3	48.1	53.4	51.4	47.3
1999	60.0	65.4	49.8	56.6	52.6	48.0	43.6	39.3	37.9	41.7	49.5	56.0	49.9
2000	56.4	60.1	44.2	52.1	52.0	47.8	39.1	40.3	46.1	42.8	44.6	52.1	48.1
2001	51.3	58.1	40.9	56.0	42.8	45.9	41.7	36.9	38.0	56.7	50.0	53.7	47.6
2002	56.2	55.2	51.2	58.5	50.7	45.1	31.9	40.8	44.0	41.4	46.4	57.9	48.2
2003	57.0	46.3	58.7	61.5	48.2	37.5	41.9	38.5	41.9	45.3	57.5	63.0	49.8
2004	56.1	53.5	48.4	49.8	58.0	39.5	38.6	37.9	46.8	54.9	50.9	63.0	49.8
2005	54.6	49.2	54.5	54.7	45.8	51.2	40.7	34.3	50.1	42.0	62.5	60.1	49.9
2006	73.4	57.8	58.3	58.4	41.2	42.0	33.7	29.2	37.7	49.0	51.4	58.5	49.1
2007	52.3	65.9	48.4	48.9	44.5	38.8	31.4	39.0	49.5	50.3	51.9	62.6	48.5
2008	65.7	61.0	56.3	52.6	51.3	43.3	38.9	39.1	39.0	43.7	48.0	59.8	49.9
2009	66.6	64.6	57.0	58.9	46.8	47.0	36.7	39.6	39.3	50.8	45.8	50.4	50.2
2010	54.4	43.4	45.2	55.7	54.9	48.8	40.6	41.8	49.6	47.0	51.8	54.3	49.0
2011	61.1	59.7	57.1	58.7	54.7	53.8	41.2	38.3	37.8	44.6	55.3	50.5	51.0
2012	63.3	57.2	58.5	53.1	51.0	54.4	37.1	40.0	33.8	48.6	59.2	61.0	51.4
2013	52.4	56.1	49.2	42.5	50.3	45.0	37.6	35.4	53.1	48.3	53.4	59.6	48.5
2014	65.5	62.5	58.9	54.0	49.2	52.0	38.7	42.1	45.3	43.6	63.4	49.1	51.9
2015	49.7	56.0	40.1	50.3	43.6	36.6	38.7	37.7	42.2	47.0	58.8	67.4	47.3
2016	59.7	61.3	59.2	46.2	48.7	35.5	44.2	36.0	49.4	52.1	48.7	61.5	50.2
2017	52.3	65.7	61.4	52.5	41.3	43.2	32.8	31.4	41.1				--
Avg	58.3	55.3	50.7	52.4	48.4	44.7	39.9	37.4	43.5	46.1	53.6	55.5	48.8

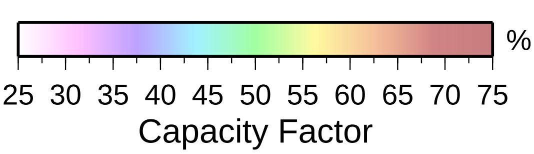

Figure 42: Monthly-mean values of simulated project-average gross capacity factor.

Sector	Mean Capacity Factor(%)	Percent Total Power(%)
N	40.6	3.5
NNE	31.7	2.5
NE	24.7	1.8
ENE	22.8	1.8
E	19.2	1.6
ESE	21.1	1.8
SE	25.2	2.5
SSE	27.7	2.6
S	42.6	4.5
SSW	53.6	6.8
SW	46.2	5.3
WSW	57.1	9.5
W	75.9	30.4
WNW	67.2	19.5
NW	35.9	3.3
NNW	34.1	2.6
ALL	**48.8**	**100.0**

Table 30: 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%	0.75	0.86	1.11	1.31	1.50	1.54	1.46	1.26	1.04	0.83	0.68	0.62	0.62	0.60	0.62	0.65	15.44
5% - 15%	0.69	0.74	0.74	0.77	0.84	0.85	0.95	0.87	0.76	0.78	0.76	0.81	0.85	0.91	0.80	0.72	12.83
15% - 25%	0.47	0.50	0.48	0.52	0.55	0.55	0.68	0.64	0.57	0.50	0.63	0.75	0.86	0.90	0.68	0.54	9.81
25% - 35%	0.38	0.36	0.34	0.38	0.33	0.38	0.49	0.47	0.39	0.41	0.49	0.62	0.85	0.92	0.53	0.38	7.72
35% - 45%	0.28	0.24	0.24	0.22	0.20	0.22	0.33	0.31	0.31	0.32	0.44	0.56	0.84	0.84	0.41	0.28	6.05
45% - 55%	0.24	0.20	0.15	0.15	0.13	0.16	0.23	0.23	0.26	0.28	0.37	0.52	0.86	0.81	0.29	0.21	5.10
55% - 65%	0.19	0.16	0.12	0.12	0.09	0.13	0.17	0.18	0.22	0.29	0.34	0.47	0.88	0.81	0.25	0.16	4.56
65% - 75%	0.20	0.13	0.09	0.10	0.08	0.10	0.15	0.14	0.22	0.29	0.34	0.47	0.99	0.87	0.22	0.15	4.55
75% - 85%	0.18	0.13	0.08	0.08	0.07	0.09	0.12	0.13	0.24	0.33	0.33	0.53	1.21	0.99	0.19	0.13	4.83
85% - 95%	0.23	0.15	0.10	0.09	0.07	0.09	0.13	0.15	0.31	0.50	0.38	0.71	2.01	1.51	0.18	0.14	6.75
95% - 100%	0.58	0.29	0.15	0.13	0.08	0.10	0.17	0.23	0.89	1.64	0.81	2.08	9.59	5.00	0.31	0.30	22.35

Table 31: Distribution of simulated project-average gross power capacity by direction.

11.6 Long-term Wind Resource Assessment for Tower M2250 at 88.6 m

11.6.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.90	7.79	2.08	4.46
NNE	5.90	6.66	2.14	4.03
NE	5.29	5.97	2.17	4.09
ENE	4.85	5.48	2.05	4.23
E	4.41	4.98	1.93	4.20
ESE	4.60	5.19	1.90	4.73
SE	5.00	5.65	1.98	5.02
SSE	5.34	6.02	1.96	4.29
S	7.08	7.99	1.96	5.01
SSW	8.12	9.17	2.21	5.99
SW	7.60	8.57	2.38	5.27
WSW	8.54	9.64	2.10	6.40
W	11.24	12.67	2.47	15.48
WNW	10.31	11.57	2.80	17.35
NW	7.06	7.96	2.42	5.30
NNW	6.79	7.67	2.13	4.14
ALL	**7.82**	**8.82**	**1.90**	**100.00**

Table 32: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2250 at 88.6 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	0.01	0.06	0.09	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21
0.5 - 1.5	0.03	0.04	0.09	0.22	0.30	0.32	0.25	0.12	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	1.55
1.5 - 2.5	0.18	0.25	0.38	0.46	0.54	0.56	0.51	0.41	0.26	0.17	0.13	0.12	0.11	0.12	0.13	0.14	4.47
2.5 - 3.5	0.44	0.52	0.59	0.65	0.73	0.74	0.73	0.67	0.55	0.45	0.35	0.30	0.30	0.30	0.31	0.37	8.00
3.5 - 4.5	0.51	0.60	0.64	0.69	0.68	0.73	0.72	0.65	0.58	0.51	0.44	0.44	0.44	0.44	0.46	0.49	9.02
4.5 - 5.5	0.62	0.68	0.70	0.76	0.72	0.76	0.88	0.71	0.64	0.61	0.60	0.68	0.74	0.82	0.76	0.63	11.30
5.5 - 6.5	0.56	0.54	0.59	0.57	0.49	0.61	0.71	0.55	0.55	0.54	0.62	0.75	0.94	1.13	0.82	0.61	10.57
6.5 - 7.5	0.52	0.45	0.44	0.38	0.31	0.42	0.48	0.41	0.46	0.58	0.64	0.77	1.11	1.47	0.81	0.53	9.79
7.5 - 8.5	0.44	0.33	0.27	0.22	0.18	0.23	0.31	0.29	0.44	0.59	0.65	0.71	1.25	1.80	0.66	0.41	8.77
8.5 - 9.5	0.31	0.22	0.14	0.11	0.09	0.12	0.16	0.16	0.36	0.54	0.53	0.54	1.23	1.80	0.46	0.27	7.06
9.5 - 10.5	0.23	0.14	0.10	0.06	0.05	0.06	0.08	0.10	0.28	0.48	0.39	0.45	1.27	1.73	0.30	0.19	5.92
10.5 - 11.5	0.15	0.08	0.05	0.04	0.02	0.03	0.05	0.06	0.20	0.38	0.28	0.33	1.20	1.50	0.19	0.12	4.66
11.5 - 12.5	0.11	0.05	0.03	0.02	0.01	0.02	0.03	0.04	0.17	0.32	0.20	0.30	1.20	1.50	0.12	0.10	4.23
12.5 - 13.5	0.08	0.04	0.02	0.02	0.01	0.01	0.02	0.02	0.12	0.21	0.13	0.20	1.02	1.13	0.08	0.06	3.16
13.5 - 14.5	0.07	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.10	0.18	0.10	0.18	1.02	1.04	0.06	0.06	2.89
14.5 - 15.5	0.05	0.02	0.01	0.01	0.00	0.01	0.01	0.02	0.08	0.13	0.07	0.14	0.89	0.82	0.04	0.04	2.33
15.5 - 16.5	0.04	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.06	0.09	0.04	0.11	0.70	0.59	0.03	0.03	1.74
16.5 - 17.5	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.04	0.07	0.03	0.08	0.55	0.40	0.02	0.02	1.28
17.5 - 18.5	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.02	0.06	0.36	0.25	0.01	0.02	0.83
18.5 - 19.5	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.05	0.32	0.19	0.01	0.02	0.68
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.05	0.23	0.13	0.01	0.01	0.49
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.13	0.07	0.00	0.00	0.26
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.13	0.04	0.00	0.00	0.22
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.10	0.04	0.00	0.00	0.19
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.01	0.00	0.00	0.09
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.18	0.03	0.00	0.00	0.27

Table 33: Distribution of simulated wind speed by direction for Tower M2250 at $88.6\,m$.

11.7 Long-term Wind Resource Assessment for Tower M2315 at 88.6 m

11.7.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	7.25	8.19	2.10	4.11
NNE	6.24	7.05	2.12	3.43
NE	5.59	6.31	2.08	3.33
ENE	5.45	6.15	2.02	3.67
E	5.02	5.66	1.91	3.86
ESE	5.17	5.81	1.80	4.23
SE	5.58	6.29	1.92	4.98
SSE	5.90	6.65	1.95	5.02
S	7.48	8.43	1.91	5.72
SSW	8.25	9.32	2.12	6.36
SW	7.28	8.22	2.25	5.46
WSW	10.15	11.46	2.08	10.20
W	11.11	12.48	2.76	20.51
WNW	8.89	10.00	2.59	11.26
NW	6.46	7.29	2.33	4.24
NNW	6.52	7.36	2.15	3.61
ALL	**8.06**	**9.09**	**1.95**	**100.00**

Table 34: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2315 at 88.6 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	0.02	0.06	0.13	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29
0.5 - 1.5	0.02	0.03	0.06	0.14	0.22	0.27	0.28	0.14	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.02	1.30
1.5 - 2.5	0.15	0.19	0.29	0.35	0.40	0.40	0.44	0.47	0.34	0.20	0.15	0.14	0.14	0.11	0.12	0.14	4.04
2.5 - 3.5	0.33	0.36	0.45	0.44	0.49	0.46	0.49	0.54	0.53	0.47	0.40	0.36	0.32	0.33	0.32	0.32	6.60
3.5 - 4.5	0.49	0.51	0.52	0.52	0.59	0.59	0.62	0.67	0.60	0.65	0.60	0.59	0.60	0.60	0.56	0.51	9.20
4.5 - 5.5	0.46	0.48	0.45	0.52	0.56	0.57	0.65	0.62	0.60	0.56	0.61	0.68	0.76	0.78	0.66	0.55	9.53
5.5 - 6.5	0.57	0.52	0.51	0.59	0.56	0.62	0.75	0.76	0.66	0.63	0.79	0.89	1.09	1.18	0.80	0.59	11.50
6.5 - 7.5	0.50	0.42	0.39	0.42	0.40	0.45	0.61	0.62	0.58	0.57	0.70	0.91	1.37	1.36	0.65	0.46	10.41
7.5 - 8.5	0.39	0.28	0.23	0.24	0.22	0.28	0.40	0.39	0.44	0.52	0.56	0.84	1.55	1.32	0.39	0.31	8.36
8.5 - 9.5	0.32	0.20	0.15	0.16	0.15	0.18	0.25	0.26	0.40	0.51	0.46	0.89	1.80	1.28	0.25	0.22	7.48
9.5 - 10.5	0.22	0.14	0.09	0.10	0.08	0.10	0.15	0.16	0.32	0.44	0.32	0.76	1.85	1.06	0.16	0.13	6.09
10.5 - 11.5	0.18	0.09	0.06	0.06	0.05	0.07	0.10	0.12	0.26	0.41	0.26	0.71	1.90	0.86	0.10	0.11	5.33
11.5 - 12.5	0.13	0.07	0.04	0.04	0.03	0.03	0.05	0.07	0.22	0.35	0.17	0.60	1.86	0.66	0.06	0.07	4.45
12.5 - 13.5	0.10	0.04	0.03	0.03	0.02	0.02	0.04	0.05	0.16	0.27	0.12	0.53	1.63	0.49	0.04	0.05	3.62
13.5 - 14.5	0.07	0.03	0.02	0.02	0.01	0.02	0.02	0.04	0.14	0.21	0.09	0.46	1.38	0.36	0.04	0.04	2.94
14.5 - 15.5	0.05	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.10	0.16	0.06	0.37	1.15	0.29	0.02	0.03	2.34
15.5 - 16.5	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.10	0.13	0.04	0.32	0.98	0.21	0.02	0.02	1.95
16.5 - 17.5	0.03	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.07	0.10	0.03	0.25	0.71	0.14	0.01	0.02	1.42
17.5 - 18.5	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.05	0.06	0.02	0.17	0.41	0.08	0.01	0.01	0.87
18.5 - 19.5	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.04	0.02	0.16	0.33	0.06	0.01	0.01	0.69
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.01	0.12	0.21	0.03	0.00	0.00	0.46
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.09	0.15	0.02	0.00	0.00	0.32
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.10	0.12	0.02	0.00	0.01	0.28
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.05	0.01	0.00	0.00	0.12
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.00	0.00	0.00	0.09
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.17	0.11	0.01	0.00	0.00	0.33

Table 35: Distribution of simulated wind speed by direction for Tower M2315 at $88.6\,m$.

11.8 Long-term Wind Resource Assessment for Tower M2316 at 88.6 m

11.8.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	7.02	7.93	2.05	3.91
NNE	6.29	7.10	2.07	3.75
NE	5.45	6.15	2.05	3.58
ENE	5.14	5.79	1.91	3.81
E	4.66	5.24	1.76	3.94
ESE	4.73	5.28	1.62	4.32
SE	5.16	5.80	1.77	5.31
SSE	5.51	6.21	1.87	5.09
S	7.09	7.97	1.80	5.53
SSW	8.33	9.40	2.02	6.50
SW	7.37	8.32	2.16	5.67
WSW	8.97	10.12	2.00	7.88
W	11.00	12.40	2.53	18.29
WNW	9.83	11.05	2.71	14.60
NW	6.79	7.67	2.32	4.49
NNW	6.36	7.18	2.14	3.34
ALL	**7.87**	**8.86**	**1.87**	**100.00**

Table 36: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2316 at 88.6 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	0.02	0.10	0.20	0.10	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
0.5 - 1.5	0.01	0.02	0.05	0.16	0.25	0.30	0.33	0.18	0.06	0.02	0.02	0.02	0.01	0.02	0.01	0.01	1.47
1.5 - 2.5	0.15	0.20	0.36	0.44	0.50	0.50	0.58	0.57	0.42	0.26	0.19	0.16	0.15	0.12	0.11	0.12	4.84
2.5 - 3.5	0.41	0.46	0.54	0.56	0.62	0.61	0.66	0.66	0.66	0.58	0.48	0.44	0.38	0.33	0.33	0.36	8.06
3.5 - 4.5	0.48	0.55	0.59	0.59	0.61	0.64	0.73	0.72	0.64	0.64	0.62	0.63	0.61	0.58	0.54	0.49	9.68
4.5 - 5.5	0.49	0.53	0.52	0.54	0.57	0.56	0.74	0.67	0.60	0.57	0.66	0.76	0.83	0.81	0.64	0.53	10.04
5.5 - 6.5	0.52	0.53	0.50	0.53	0.50	0.52	0.71	0.72	0.60	0.57	0.72	0.84	1.14	1.18	0.78	0.54	10.92
6.5 - 7.5	0.44	0.40	0.38	0.34	0.31	0.35	0.53	0.52	0.50	0.53	0.64	0.79	1.28	1.37	0.63	0.41	9.42
7.5 - 8.5	0.32	0.27	0.21	0.20	0.16	0.22	0.31	0.32	0.36	0.46	0.52	0.61	1.29	1.33	0.41	0.26	7.22
8.5 - 9.5	0.28	0.24	0.15	0.16	0.12	0.16	0.23	0.23	0.35	0.49	0.45	0.66	1.53	1.57	0.34	0.20	7.17
9.5 - 10.5	0.20	0.16	0.09	0.08	0.07	0.09	0.12	0.14	0.26	0.41	0.34	0.51	1.54	1.35	0.22	0.12	5.71
10.5 - 11.5	0.16	0.12	0.07	0.06	0.05	0.06	0.10	0.11	0.25	0.44	0.29	0.50	1.69	1.39	0.16	0.09	5.53
11.5 - 12.5	0.12	0.08	0.04	0.03	0.03	0.03	0.05	0.07	0.19	0.34	0.21	0.39	1.50	1.12	0.09	0.06	4.35
12.5 - 13.5	0.09	0.06	0.03	0.03	0.02	0.02	0.03	0.04	0.15	0.30	0.16	0.31	1.39	0.92	0.06	0.04	3.65
13.5 - 14.5	0.05	0.03	0.02	0.02	0.01	0.02	0.02	0.03	0.10	0.21	0.10	0.25	1.07	0.67	0.05	0.02	2.67
14.5 - 15.5	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.11	0.21	0.09	0.25	1.03	0.61	0.04	0.02	2.52
15.5 - 16.5	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.07	0.15	0.05	0.18	0.78	0.43	0.03	0.02	1.82
16.5 - 17.5	0.03	0.02	0.01	0.00	0.00	0.01	0.01	0.01	0.07	0.11	0.04	0.15	0.60	0.30	0.02	0.01	1.39
17.5 - 18.5	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.08	0.03	0.09	0.41	0.19	0.01	0.01	0.93
18.5 - 19.5	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.02	0.08	0.28	0.12	0.01	0.01	0.63
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.03	0.01	0.07	0.22	0.08	0.01	0.01	0.49
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.04	0.14	0.04	0.00	0.00	0.30
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.04	0.11	0.02	0.00	0.00	0.21
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.02	0.00	0.00	0.14
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.09	0.01	0.00	0.00	0.15
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.06	0.14	0.02	0.00	0.00	0.25

Table 37: Distribution of simulated wind speed by direction for Tower M2316 at 88.6 m.

11.9 Long-term Wind Resource Assessment for Tower M2317 at 88.6 m

11.9.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.78	7.66	2.14	4.13
NNE	5.98	6.75	2.24	4.16
NE	5.28	5.95	2.28	4.26
ENE	4.76	5.37	2.16	4.23
E	4.28	4.83	2.02	4.02
ESE	4.39	4.96	1.93	4.54
SE	4.68	5.28	2.02	4.99
SSE	4.97	5.60	2.01	4.32
S	6.46	7.28	1.94	4.95
SSW	7.64	8.63	2.16	6.20
SW	7.60	8.58	2.37	6.32
WSW	7.96	8.98	2.10	6.67
W	10.95	12.35	2.35	14.87
WNW	10.81	12.15	2.74	17.78
NW	7.14	8.05	2.40	4.91
NNW	6.56	7.40	2.20	3.68
ALL	**7.72**	**8.70**	**1.87**	**100.00**

Table 38: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2317 at 88.6 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	0.01	0.04	0.09	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
0.5 - 1.5	0.01	0.02	0.03	0.09	0.22	0.27	0.20	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	1.03
1.5 - 2.5	0.14	0.18	0.32	0.50	0.58	0.59	0.61	0.47	0.29	0.17	0.14	0.13	0.11	0.11	0.10	0.12	4.53
2.5 - 3.5	0.42	0.53	0.69	0.75	0.78	0.80	0.86	0.82	0.69	0.57	0.44	0.37	0.34	0.33	0.30	0.34	9.05
3.5 - 4.5	0.54	0.66	0.76	0.81	0.76	0.83	0.89	0.79	0.70	0.67	0.63	0.58	0.54	0.51	0.49	0.50	10.65
4.5 - 5.5	0.56	0.68	0.72	0.73	0.64	0.70	0.79	0.72	0.63	0.64	0.66	0.73	0.80	0.75	0.64	0.54	10.94
5.5 - 6.5	0.55	0.61	0.66	0.56	0.44	0.52	0.67	0.53	0.58	0.63	0.71	0.90	0.99	1.03	0.73	0.56	10.69
6.5 - 7.5	0.50	0.49	0.44	0.34	0.27	0.35	0.42	0.35	0.47	0.62	0.74	0.89	1.16	1.32	0.72	0.48	9.56
7.5 - 8.5	0.41	0.37	0.27	0.20	0.14	0.19	0.22	0.23	0.40	0.62	0.75	0.78	1.24	1.53	0.60	0.36	8.31
8.5 - 9.5	0.29	0.21	0.15	0.09	0.06	0.08	0.12	0.12	0.30	0.50	0.60	0.54	1.20	1.59	0.42	0.25	6.52
9.5 - 10.5	0.22	0.16	0.09	0.05	0.04	0.05	0.06	0.07	0.24	0.50	0.51	0.44	1.26	1.71	0.30	0.18	5.88
10.5 - 11.5	0.14	0.09	0.05	0.03	0.02	0.02	0.04	0.04	0.18	0.36	0.35	0.32	1.21	1.65	0.20	0.11	4.80
11.5 - 12.5	0.10	0.06	0.03	0.02	0.01	0.01	0.02	0.03	0.13	0.26	0.25	0.22	1.05	1.48	0.13	0.06	3.86
12.5 - 13.5	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.08	0.20	0.18	0.19	1.00	1.39	0.08	0.04	3.36
13.5 - 14.5	0.04	0.02	0.01	0.01	0.00	0.00	0.01	0.01	0.05	0.11	0.10	0.10	0.65	0.87	0.04	0.02	2.04
14.5 - 15.5	0.04	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.05	0.10	0.10	0.09	0.74	0.96	0.04	0.03	2.21
15.5 - 16.5	0.03	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.05	0.08	0.06	0.09	0.68	0.87	0.03	0.02	1.96
16.5 - 17.5	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.03	0.05	0.42	0.49	0.02	0.01	1.14
17.5 - 18.5	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.02	0.05	0.38	0.40	0.02	0.01	0.97
18.5 - 19.5	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.03	0.21	0.20	0.01	0.01	0.52
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.03	0.19	0.19	0.01	0.01	0.48
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.18	0.16	0.01	0.00	0.42
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.04	0.00	0.00	0.14
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.07	0.00	0.00	0.25
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.13	0.06	0.00	0.00	0.24
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.18	0.04	0.01	0.00	0.27

Table 39: Distribution of simulated wind speed by direction for Tower M2317 at $88.6\,m$.

11.10 Long-term Wind Resource Assessment for Tower M2318 at 88.6 m

11.10.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.97	7.87	2.14	3.94
NNE	6.14	6.93	2.23	3.67
NE	5.51	6.22	2.26	3.69
ENE	5.18	5.85	2.20	3.96
E	4.75	5.37	2.09	4.02
ESE	4.78	5.39	2.02	4.36
SE	5.30	5.99	2.06	5.33
SSE	5.60	6.32	2.04	4.81
S	7.41	8.35	1.90	5.46
SSW	8.53	9.63	2.19	6.52
SW	7.93	8.95	2.36	5.80
WSW	9.09	10.26	2.07	7.43
W	11.54	13.00	2.57	17.84
WNW	10.36	11.64	2.76	15.15
NW	6.93	7.82	2.37	4.41
NNW	6.74	7.61	2.21	3.62
ALL	**8.13**	**9.17**	**1.94**	**100.00**

Table 40: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2318 at 88.6 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	0.01	0.04	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
0.5 - 1.5	0.01	0.01	0.03	0.09	0.16	0.20	0.18	0.08	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.84
1.5 - 2.5	0.11	0.16	0.28	0.35	0.42	0.49	0.47	0.40	0.25	0.16	0.12	0.11	0.09	0.09	0.09	0.10	3.67
2.5 - 3.5	0.35	0.42	0.47	0.54	0.66	0.63	0.68	0.65	0.56	0.43	0.34	0.31	0.27	0.28	0.27	0.31	7.15
3.5 - 4.5	0.52	0.57	0.65	0.72	0.75	0.79	0.85	0.79	0.65	0.61	0.54	0.48	0.47	0.47	0.49	0.50	9.84
4.5 - 5.5	0.52	0.56	0.59	0.67	0.66	0.69	0.84	0.72	0.64	0.59	0.58	0.63	0.68	0.71	0.61	0.52	10.21
5.5 - 6.5	0.56	0.55	0.61	0.64	0.58	0.61	0.84	0.73	0.62	0.61	0.66	0.83	1.01	1.02	0.75	0.56	11.19
6.5 - 7.5	0.45	0.42	0.42	0.39	0.33	0.37	0.57	0.51	0.52	0.57	0.62	0.84	1.14	1.27	0.67	0.45	9.55
7.5 - 8.5	0.39	0.33	0.26	0.24	0.18	0.23	0.36	0.33	0.45	0.56	0.65	0.82	1.37	1.46	0.55	0.37	8.54
8.5 - 9.5	0.30	0.22	0.15	0.12	0.10	0.12	0.19	0.21	0.37	0.54	0.56	0.67	1.43	1.48	0.34	0.24	7.04
9.5 - 10.5	0.20	0.14	0.09	0.07	0.05	0.07	0.11	0.13	0.29	0.50	0.47	0.54	1.48	1.49	0.23	0.18	6.05
10.5 - 11.5	0.15	0.09	0.06	0.05	0.03	0.04	0.06	0.09	0.23	0.46	0.40	0.46	1.61	1.43	0.14	0.12	5.41
11.5 - 12.5	0.09	0.06	0.03	0.02	0.02	0.01	0.04	0.05	0.17	0.36	0.24	0.34	1.33	1.15	0.07	0.08	4.06
12.5 - 13.5	0.08	0.04	0.02	0.02	0.01	0.01	0.03	0.03	0.17	0.32	0.21	0.32	1.47	1.17	0.06	0.05	4.01
13.5 - 14.5	0.05	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.12	0.24	0.14	0.23	1.21	0.87	0.04	0.04	3.07
14.5 - 15.5	0.04	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.10	0.19	0.10	0.19	1.05	0.71	0.03	0.02	2.49
15.5 - 16.5	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.06	0.11	0.05	0.13	0.75	0.46	0.02	0.02	1.68
16.5 - 17.5	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.07	0.09	0.04	0.11	0.67	0.39	0.02	0.02	1.46
17.5 - 18.5	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.06	0.03	0.08	0.46	0.23	0.01	0.01	0.97
18.5 - 19.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.02	0.07	0.37	0.16	0.01	0.01	0.75
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.03	0.18	0.08	0.00	0.00	0.37
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.04	0.18	0.07	0.01	0.00	0.36
21.5 - 22.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.06	0.21	0.07	0.01	0.00	0.42
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.04	0.14	0.04	0.00	0.00	0.25
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.01	0.00	0.00	0.08
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.08	0.23	0.03	0.01	0.00	0.40

Table 41: Distribution of simulated wind speed by direction for Tower M2318 at 88.6 m.

11.11 Long-term Wind Resource Assessment for Tower M2322 at 88.6 m

11.11.1 Tabular Data

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	7.06	7.96	1.98	4.27
NNE	6.30	7.11	1.99	3.96
NE	5.42	6.10	1.88	3.53
ENE	5.27	5.92	1.80	3.74
E	4.98	5.59	1.77	4.32
ESE	5.09	5.72	1.80	4.28
SE	5.85	6.60	1.97	4.83
SSE	6.32	7.13	2.02	4.51
S	8.01	9.02	1.90	4.78
SSW	9.38	10.59	2.07	5.52
SW	7.93	8.96	2.18	4.68
WSW	10.18	11.48	2.03	8.46
W	11.50	12.94	2.66	21.71
WNW	9.69	10.91	2.54	13.55
NW	6.47	7.31	2.27	4.25
NNW	6.42	7.25	2.06	3.60
ALL	**8.39**	**9.46**	**1.89**	**100.00**

Table 42: Simulated mean wind speed, Weibull parameters, and frequency for Tower M2322 at 88.6 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	0.01	0.03	0.10	0.18	0.14	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54
0.5 - 1.5	0.03	0.04	0.11	0.19	0.20	0.21	0.16	0.07	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.02	1.12
1.5 - 2.5	0.20	0.27	0.38	0.38	0.45	0.42	0.39	0.33	0.22	0.17	0.13	0.13	0.14	0.14	0.14	0.15	4.05
2.5 - 3.5	0.46	0.49	0.52	0.49	0.60	0.58	0.51	0.45	0.44	0.38	0.35	0.36	0.40	0.39	0.38	0.41	7.22
3.5 - 4.5	0.52	0.52	0.49	0.51	0.61	0.60	0.58	0.54	0.45	0.43	0.42	0.50	0.56	0.61	0.55	0.50	8.39
4.5 - 5.5	0.48	0.54	0.47	0.49	0.59	0.59	0.67	0.57	0.46	0.44	0.47	0.61	0.83	0.81	0.64	0.53	9.16
5.5 - 6.5	0.51	0.49	0.45	0.47	0.55	0.54	0.68	0.63	0.48	0.41	0.50	0.70	1.02	1.09	0.70	0.54	9.75
6.5 - 7.5	0.47	0.43	0.38	0.40	0.47	0.43	0.61	0.60	0.50	0.42	0.52	0.77	1.38	1.35	0.62	0.44	9.81
7.5 - 8.5	0.37	0.33	0.23	0.25	0.25	0.28	0.42	0.41	0.40	0.36	0.47	0.69	1.53	1.35	0.43	0.30	8.05
8.5 - 9.5	0.31	0.26	0.16	0.17	0.17	0.19	0.28	0.30	0.34	0.39	0.41	0.67	1.77	1.39	0.28	0.22	7.29
9.5 - 10.5	0.23	0.16	0.09	0.10	0.10	0.11	0.16	0.18	0.28	0.37	0.31	0.57	1.80	1.22	0.17	0.13	5.99
10.5 - 11.5	0.19	0.13	0.07	0.07	0.06	0.07	0.12	0.14	0.25	0.38	0.32	0.57	2.06	1.17	0.11	0.10	5.82
11.5 - 12.5	0.13	0.09	0.04	0.04	0.03	0.03	0.07	0.09	0.19	0.33	0.22	0.52	1.91	0.95	0.07	0.06	4.78
12.5 - 13.5	0.09	0.05	0.02	0.03	0.02	0.02	0.04	0.05	0.14	0.26	0.14	0.39	1.47	0.65	0.04	0.04	3.42
13.5 - 14.5	0.07	0.04	0.02	0.02	0.01	0.02	0.03	0.04	0.14	0.28	0.12	0.39	1.54	0.65	0.03	0.03	3.42
14.5 - 15.5	0.06	0.03	0.01	0.01	0.01	0.01	0.02	0.03	0.11	0.24	0.09	0.33	1.35	0.51	0.02	0.03	2.87
15.5 - 16.5	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.09	0.17	0.06	0.23	0.94	0.36	0.02	0.02	2.02
16.5 - 17.5	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.07	0.15	0.05	0.21	0.81	0.30	0.02	0.01	1.72
17.5 - 18.5	0.03	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.06	0.12	0.03	0.18	0.65	0.21	0.01	0.01	1.35
18.5 - 19.5	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.09	0.02	0.15	0.54	0.16	0.01	0.01	1.09
19.5 - 20.5	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.01	0.10	0.30	0.08	0.00	0.01	0.61
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.01	0.09	0.21	0.06	0.00	0.01	0.45
21.5 - 22.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.06	0.14	0.03	0.00	0.00	0.31
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.03	0.05	0.01	0.00	0.00	0.12
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.08	0.14	0.02	0.00	0.00	0.30
> 24.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.14	0.16	0.02	0.00	0.00	0.37

Table 43: Distribution of simulated wind speed by direction for Tower M2322 at 88.6 m.

12 APPENDIX VALIDATION OF MODEL RESULTS

12.1 Validation of Model Results at Tower M2250

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 M2250 (latitude 37.5465, longitude -104.5098).

The average observed wind speed (for all valid observational times) at $59\,m$ during the 35 months of the period of record (March, 2009 to January, 2012) is $7.50\,m/s$ with an hourly standard deviation of $4.12\,m/s$ at Tower M2250. This compares to a modeled $59\,m$ wind speed of $7.59\,m/s$ with a $3.94\,m/s$ 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 M2250 results in a MOS-corrected mean value of $7.49\,m/s$ and an hourly standard deviation of $4.12\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2250). 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 35 months of wind speed data at 59 *meters* and wind direction data at 58 *meters* (March, 2009 to January, 2012) from a meteorological tower (Tower M2250) at La Cumbre 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 Vaisala are not allowed to influence the raw model simulations.

12.1.2 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	0.94
RMS error of monthly-mean simulated wind speed	0.32 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.97
RMS error of monthly-mean MOS-corrected wind speed	0.22 m/s
Correlation of daily-mean simulated wind speed to observed	0.85
RMS error of daily-mean simulated wind speed	1.48 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.86
RMS error of daily-mean MOS-corrected wind speed	1.38 m/s

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

12.1.3 Monthly Mean Wind Speed

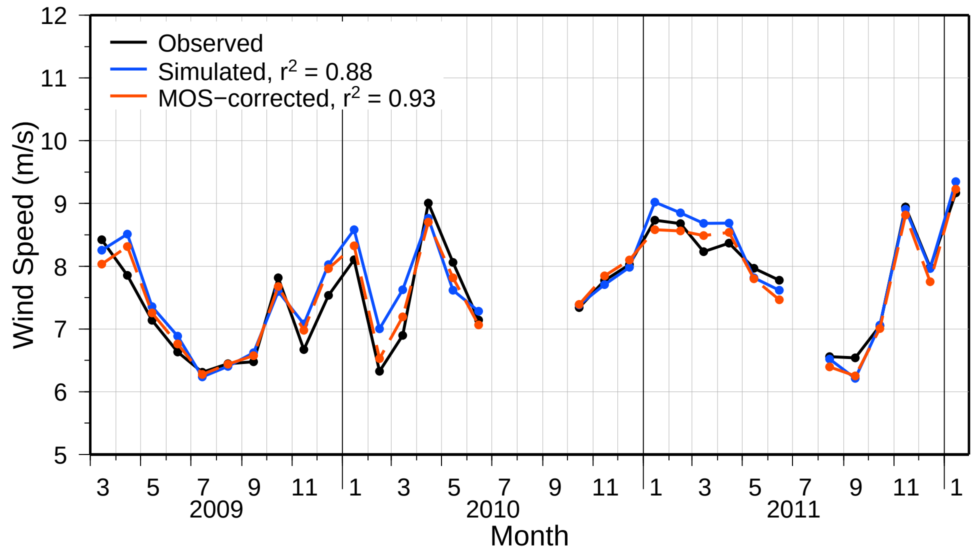

Figure 43: A comparison of the observed, simulated, and MOS-corrected monthly-mean 59 m wind speed at Tower M2250. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 45 (p. 94).

12.1.4 Wind Speed Distribution

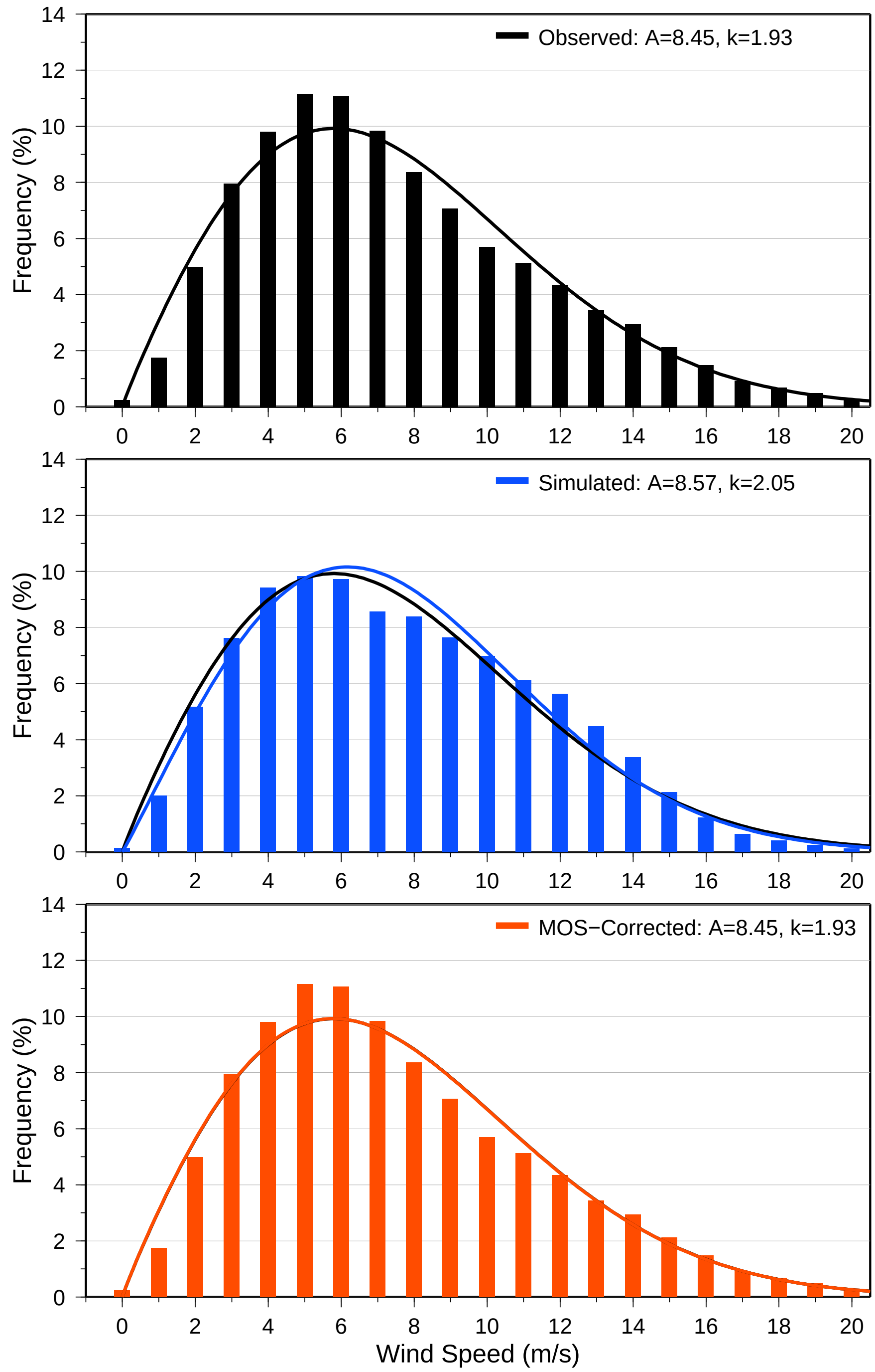

Figure 44: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $59\,m$ at Tower M2250 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend. Tabular formatted data are available in Tables 46 and 47 (p. 97 and 98).

12.1.5 Wind Direction Distribution

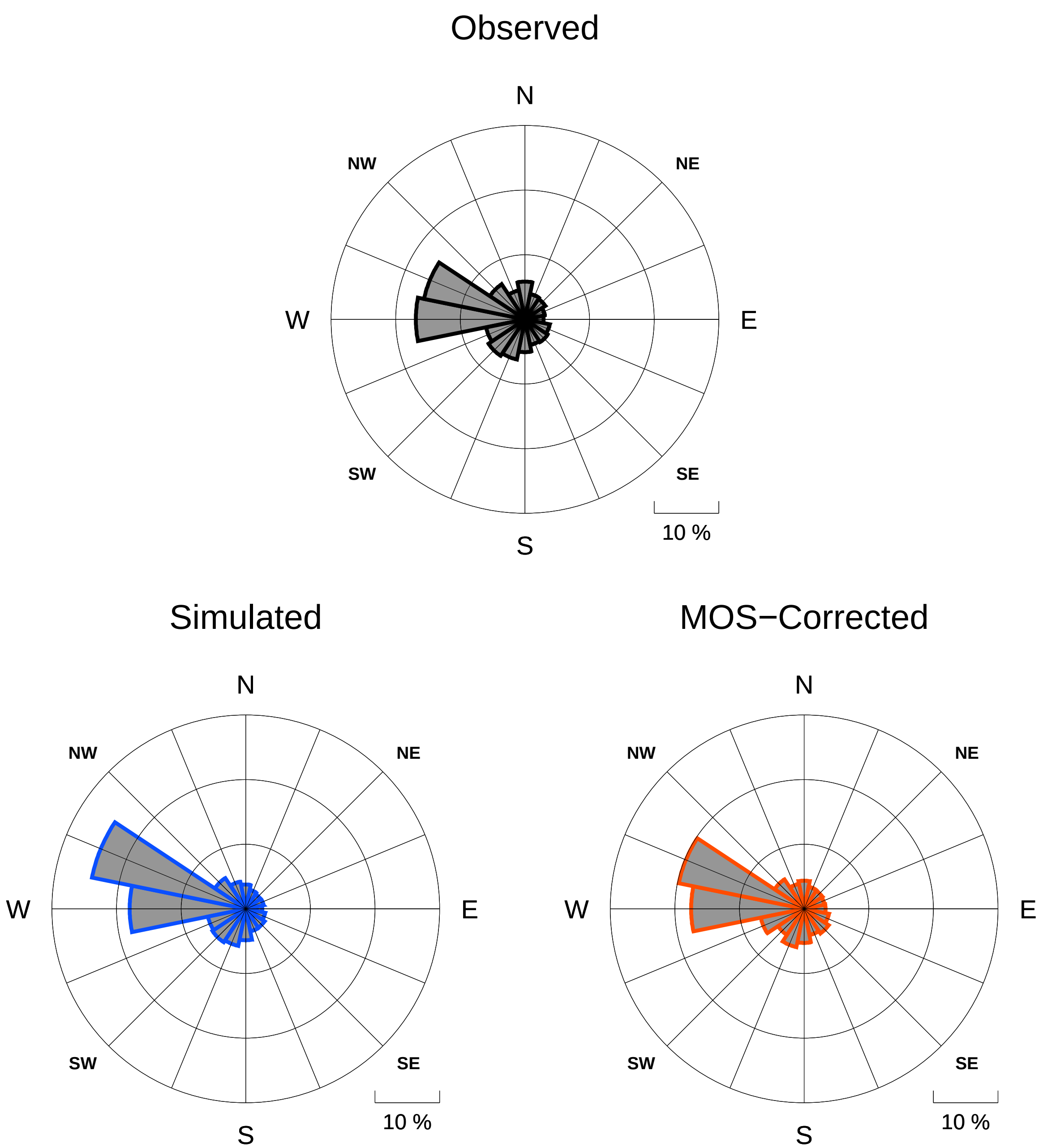

Figure 45: Wind roses at 58 m at Tower M2250 for observational data and simulated model data, averaged over the period of record (March, 2009–January, 2012). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 48 and 49 (p. 99).

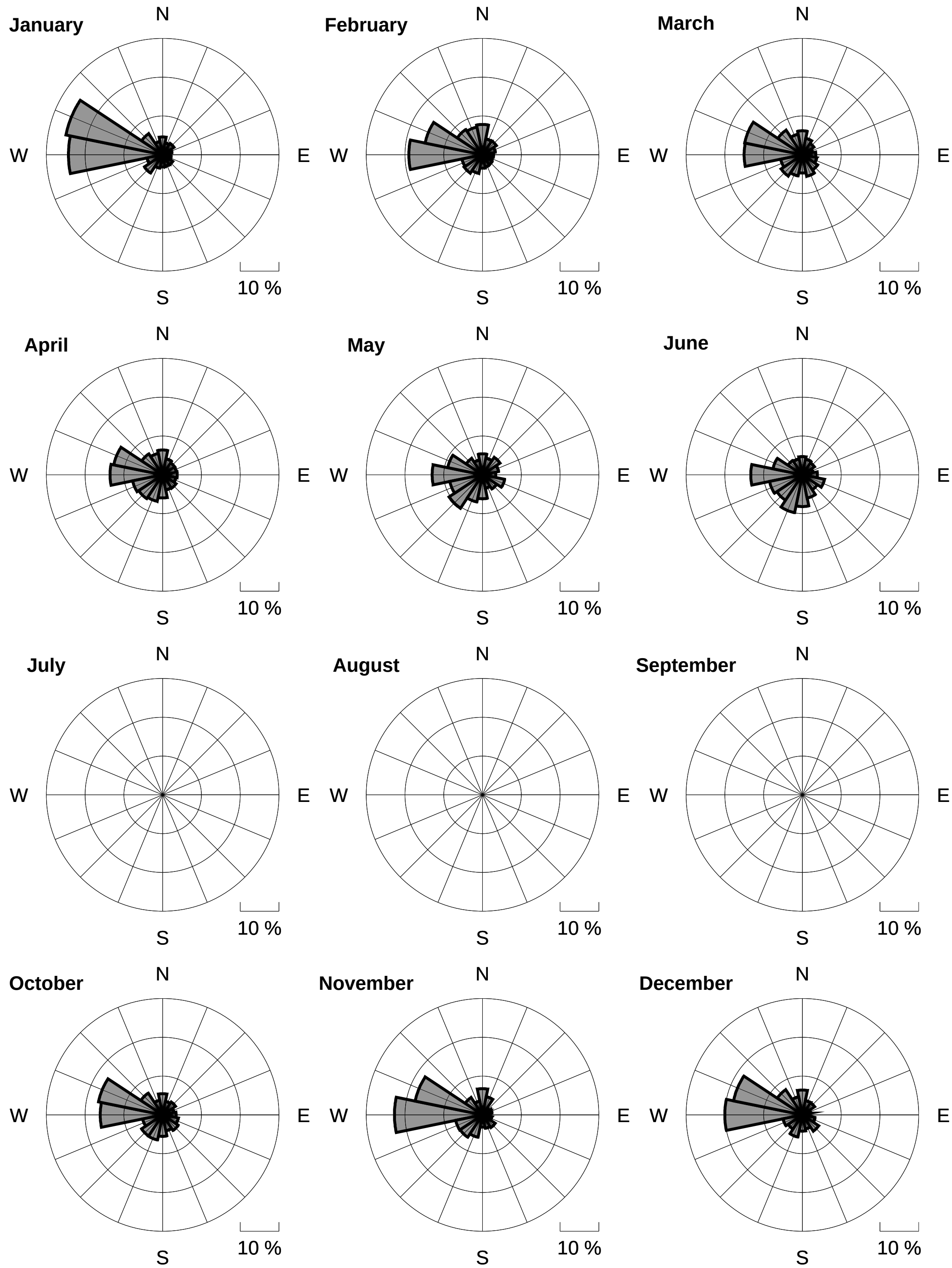

Figure 46: Wind rose of observed wind direction at 58 m at Tower M2250 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

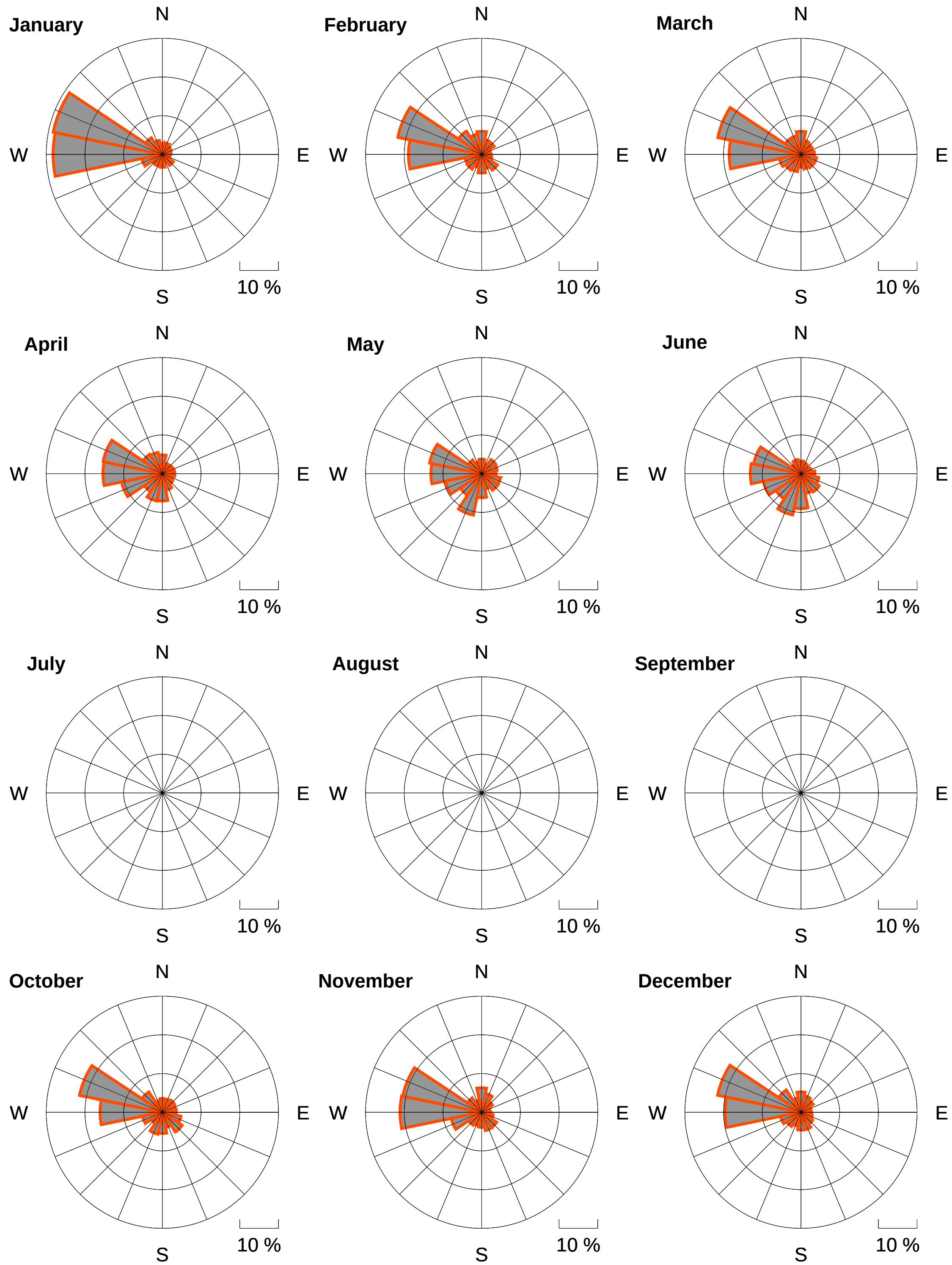

Figure 47: Wind rose of MOS-corrected wind direction at 58 m at Tower M2250 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.1.6 Diurnal Variability of Wind Speed

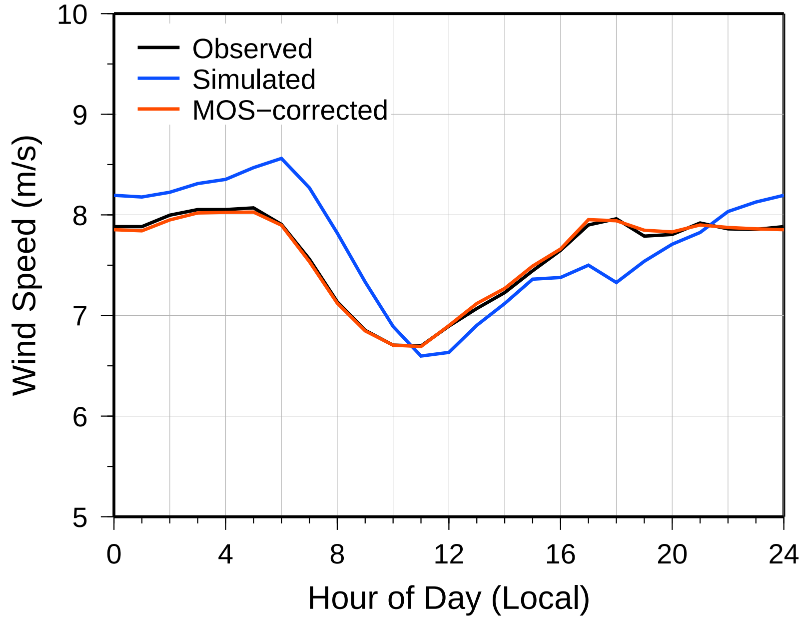

Figure 48: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 59 m wind speed at Tower M2250. Data are averaged over the period of record (March, 2009–January, 2012). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data are available in Figures 50 and 51 (p. 95 and 96).

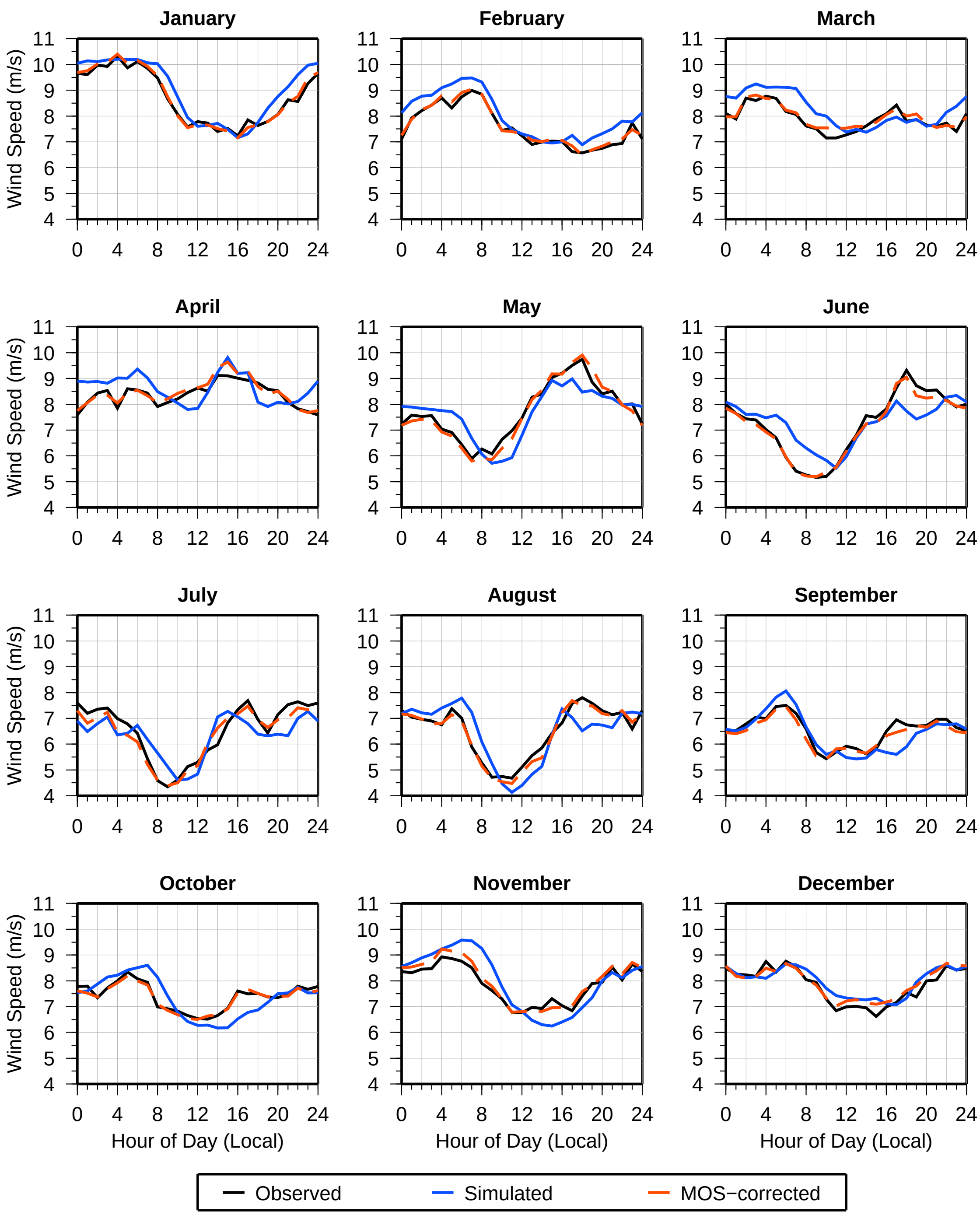

Figure 49: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 59 m wind speed for each calendar month at Tower M2250. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data available in Figures 50 and 51 (p. 95 and 96).

12.1.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
03/2009	8.42	8.25	-0.17	8.03	74.1
04/2009	7.85	8.51	0.66	8.31	93.6
05/2009	7.14	7.35	0.21	7.25	98.0
06/2009	6.63	6.89	0.25	6.76	100.0
07/2009	6.31	6.24	-0.08	6.27	90.3
08/2009	6.45	6.40	-0.04	6.44	100.0
09/2009	6.48	6.62	0.15	6.57	100.0
10/2009	7.82	7.60	-0.22	7.67	82.0
11/2009	6.67	7.08	0.41	6.98	89.9
12/2009	7.53	8.03	0.49	7.96	94.1
01/2010	8.10	8.58	0.48	8.33	80.6
02/2010	6.32	7.00	0.68	6.53	79.9
03/2010	6.90	7.63	0.73	7.19	79.3
04/2010	9.01	8.76	-0.24	8.70	96.5
05/2010	8.06	7.62	-0.44	7.82	95.0
06/2010	7.14	7.28	0.14	7.06	99.7
07/2010	9.80	8.83	-0.97	9.03	9.7
08/2010	–	–	–	–	0.0
09/2010	–	–	–	–	0.0
10/2010	7.34	7.38	0.04	7.39	98.5
11/2010	7.77	7.71	-0.07	7.85	92.9
12/2010	8.03	7.98	-0.05	8.10	90.9
01/2011	8.73	9.02	0.29	8.58	87.9
02/2011	8.68	8.85	0.17	8.56	87.2
03/2011	8.23	8.68	0.45	8.49	92.2
04/2011	8.37	8.69	0.32	8.54	98.5
05/2011	7.97	7.82	-0.15	7.80	98.4
06/2011	7.78	7.62	-0.16	7.46	86.5
07/2011	6.25	6.04	-0.21	6.15	35.5
08/2011	6.56	6.52	-0.04	6.40	99.2
09/2011	6.54	6.21	-0.33	6.25	99.7
10/2011	7.05	7.06	0.01	7.01	91.5
11/2011	8.94	8.91	-0.04	8.81	96.7
12/2011	7.98	7.96	-0.02	7.75	92.7
01/2012	9.17	9.35	0.18	9.23	84.3
All	**7.50**	**7.59**	**0.10**	**7.49**	**82.7**

Table 45: Monthly-mean $59\,m$ wind speeds (m/s) at Tower M2250. Time series graph of data is available in Figure 43 (p. 87). 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 (Local)

	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.65	7.11	8.10	7.58	7.24	8.00	7.59	7.31	6.52	7.78	8.36	8.48	7.88
1	9.61	7.92	7.88	8.08	7.58	7.64	7.20	7.05	6.53	7.79	8.31	8.26	7.88
2	9.97	8.21	8.70	8.44	7.53	7.43	7.36	6.96	6.78	7.34	8.45	8.23	8.00
3	9.92	8.42	8.60	8.54	7.55	7.39	7.40	6.90	7.05	7.73	8.48	8.17	8.05
4	10.32	8.70	8.77	7.85	7.04	7.02	6.99	6.74	6.99	8.00	8.93	8.75	8.05
5	9.87	8.32	8.69	8.60	6.91	6.70	6.79	7.37	7.45	8.34	8.86	8.34	8.07
6	10.11	8.74	8.17	8.56	6.44	5.93	6.42	7.00	7.50	8.08	8.76	8.76	7.90
7	9.85	9.00	8.06	8.44	5.89	5.41	5.43	5.89	7.20	7.94	8.51	8.55	7.56
8	9.48	8.85	7.61	7.91	6.26	5.25	4.58	5.27	6.59	6.99	7.90	8.04	7.14
9	8.66	8.11	7.50	8.07	6.08	5.16	4.35	4.72	5.67	6.91	7.62	7.94	6.85
10	8.06	7.43	7.15	8.21	6.63	5.20	4.61	4.74	5.43	6.82	7.30	7.29	6.71
11	7.57	7.54	7.15	8.45	6.97	5.58	5.13	4.68	5.70	6.65	6.79	6.84	6.70
12	7.78	7.23	7.27	8.63	7.46	6.23	5.29	5.11	5.92	6.54	6.77	6.99	6.89
13	7.73	6.89	7.40	8.51	8.27	6.80	5.77	5.55	5.83	6.51	6.97	7.01	7.07
14	7.40	6.99	7.61	9.12	8.40	7.55	5.98	5.86	5.62	6.65	6.93	6.96	7.23
15	7.52	7.02	7.89	9.10	9.04	7.49	6.82	6.43	5.83	6.93	7.31	6.62	7.44
16	7.23	7.01	8.09	9.01	9.21	7.82	7.33	6.82	6.49	7.60	7.04	6.99	7.65
17	7.90	6.60	8.34	8.95	9.45	8.60	7.80	7.73	6.75	7.62	6.82	7.12	7.90
18	7.69	6.57	7.70	8.74	9.80	9.25	7.14	7.84	6.67	7.61	7.22	7.68	7.96
19	7.77	6.73	7.77	8.52	8.97	8.58	6.73	7.52	6.75	7.39	7.65	7.61	7.79
20	8.04	6.78	7.58	8.61	8.39	8.36	7.38	7.31	6.70	7.32	7.79	8.20	7.80
21	8.57	6.94	7.46	8.27	8.38	8.43	7.62	7.23	6.92	7.40	8.45	8.24	7.92
22	8.55	6.98	7.65	7.89	7.93	8.06	7.86	7.24	6.82	7.78	8.02	8.71	7.86
23	9.25	7.60	7.43	7.78	7.89	7.84	7.53	6.71	6.50	7.67	8.63	8.56	7.86
Avg	8.68	7.55	7.86	8.42	7.72	7.16	6.55	6.50	6.51	7.39	7.82	7.85	7.50

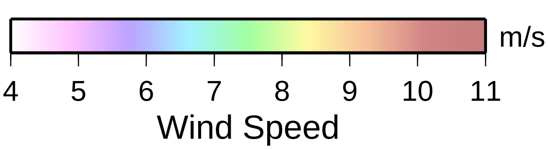

Figure 50: Hourly-mean values of observed $59\,m$ wind speed at Tower M2250. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 48 and 49 (p. 92 and 93).

MOS−Corrected

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.68	7.25	7.97	7.76	7.19	7.84	7.29	7.17	6.45	7.61	8.51	8.57	7.85
1	9.75	7.88	7.97	8.06	7.35	7.64	6.81	7.11	6.41	7.52	8.53	8.19	7.84
2	10.01	8.25	8.73	8.36	7.42	7.33	7.02	6.97	6.52	7.38	8.64	8.09	7.95
3	10.09	8.42	8.82	8.35	7.38	7.21	7.23	6.79	6.81	7.69	8.73	8.16	8.02
4	10.40	8.79	8.67	8.05	6.92	6.92	6.46	6.81	6.94	7.93	9.23	8.49	8.02
5	10.03	8.55	8.64	8.44	6.77	6.66	6.34	7.14	7.37	8.19	9.15	8.36	8.03
6	10.15	8.91	8.23	8.54	6.30	5.96	6.09	6.90	7.46	8.00	9.10	8.67	7.90
7	9.93	9.04	8.13	8.33	5.80	5.35	5.21	5.95	6.95	7.84	8.76	8.49	7.54
8	9.56	8.83	7.68	8.06	5.91	5.22	4.60	5.15	6.19	7.09	8.10	8.08	7.12
9	8.75	8.10	7.54	8.21	5.85	5.20	4.39	4.67	5.54	6.85	7.79	7.84	6.85
10	8.01	7.42	7.54	8.43	6.29	5.37	4.51	4.54	5.41	6.68	7.29	7.32	6.71
11	7.55	7.40	7.52	8.57	6.66	5.56	4.98	4.48	5.81	6.54	6.78	7.03	6.69
12	7.66	7.30	7.53	8.64	7.45	6.17	5.17	4.91	5.84	6.51	6.80	7.22	6.90
13	7.65	7.07	7.60	8.78	8.19	6.76	6.06	5.32	5.73	6.64	6.84	7.27	7.12
14	7.51	7.01	7.61	9.43	8.54	7.24	6.63	5.48	5.65	6.70	6.81	7.14	7.27
15	7.42	7.09	7.76	9.63	9.18	7.25	7.01	6.31	5.94	6.91	6.95	7.10	7.49
16	7.16	7.05	8.06	9.19	9.17	7.72	7.18	7.22	6.33	7.54	6.97	7.18	7.66
17	7.60	6.92	8.10	9.45	9.59	8.67	7.60	7.91	6.40	7.72	6.77	7.40	7.95
18	7.66	6.58	7.79	8.92	9.74	8.94	7.26	7.49	6.67	7.53	7.32	7.76	7.94
19	7.82	6.73	7.89	8.59	9.17	8.31	7.11	7.30	6.80	7.45	7.59	7.96	7.85
20	8.10	6.87	7.64	8.55	8.53	8.18	7.25	7.24	6.65	7.40	7.97	8.31	7.83
21	8.56	6.94	7.59	8.23	8.34	8.21	7.41	7.06	6.88	7.44	8.42	8.49	7.90
22	8.84	6.96	7.71	7.93	7.72	8.19	7.54	7.24	6.72	7.75	8.11	8.75	7.87
23	9.52	7.27	7.67	7.83	7.54	7.97	7.40	6.78	6.49	7.57	8.61	8.66	7.86
Avg	8.71	7.59	7.93	8.52	7.62	7.08	6.44	6.42	6.41	7.35	7.90	7.94	7.49

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

Figure 51: Hourly-mean values of MOS-corrected 59 m wind speed at Tower M2250. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 48 and 49 (p. 92 and 93).

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	0.02
0.5 - 1.5	0.09	0.09	0.06	0.07	0.07	0.06	0.07	0.05	0.06	0.09	0.11	0.07	0.04	0.07	0.09	0.08	1.14
1.5 - 2.5	0.30	0.23	0.17	0.20	0.14	0.23	0.22	0.26	0.26	0.19	0.26	0.22	0.18	0.23	0.28	0.18	3.55
2.5 - 3.5	0.41	0.35	0.38	0.24	0.28	0.34	0.42	0.42	0.41	0.40	0.35	0.33	0.37	0.28	0.27	0.31	5.56
3.5 - 4.5	0.44	0.43	0.37	0.34	0.34	0.48	0.50	0.48	0.47	0.43	0.42	0.46	0.47	0.40	0.51	0.37	6.91
4.5 - 5.5	0.48	0.39	0.39	0.40	0.38	0.50	0.59	0.55	0.42	0.48	0.45	0.49	0.65	0.46	0.55	0.44	7.61
5.5 - 6.5	0.54	0.36	0.41	0.36	0.34	0.45	0.41	0.34	0.28	0.31	0.41	0.43	0.74	0.72	0.68	0.54	7.31
6.5 - 7.5	0.44	0.25	0.26	0.25	0.26	0.33	0.35	0.26	0.35	0.40	0.38	0.44	0.77	0.72	0.59	0.47	6.52
7.5 - 8.5	0.39	0.22	0.19	0.17	0.12	0.22	0.17	0.18	0.26	0.37	0.42	0.35	0.85	0.78	0.51	0.30	5.49
8.5 - 9.5	0.28	0.18	0.16	0.11	0.09	0.09	0.09	0.10	0.20	0.33	0.46	0.26	0.83	0.86	0.37	0.21	4.62
9.5 - 10.5	0.25	0.11	0.13	0.04	0.01	0.03	0.07	0.07	0.21	0.36	0.30	0.17	0.92	0.95	0.23	0.14	3.99
10.5 - 11.5	0.12	0.07	0.06	0.01	0.00	0.01	0.05	0.08	0.17	0.31	0.25	0.24	1.03	0.95	0.18	0.07	3.60
11.5 - 12.5	0.15	0.03	0.05	0.00	0.00	0.01	0.02	0.03	0.19	0.31	0.25	0.13	0.93	1.02	0.10	0.05	3.28
12.5 - 13.5	0.09	0.04	0.01	0.00	0.00	0.00	0.00	0.02	0.13	0.15	0.15	0.12	0.80	0.96	0.09	0.03	2.58
13.5 - 14.5	0.07	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.10	0.13	0.12	0.76	0.96	0.07	0.00	2.32
14.5 - 15.5	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.11	0.11	0.69	0.68	0.03	0.00	1.80
15.5 - 16.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.11	0.08	0.48	0.45	0.01	0.00	1.24
16.5 - 17.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.04	0.05	0.37	0.22	0.01	0.01	0.75
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.05	0.23	0.22	0.01	0.00	0.60
18.5 - 19.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.05	0.19	0.12	0.00	0.00	0.46
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.17	0.04	0.00	0.00	0.27
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.12	0.03	0.00	0.00	0.20
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.12	0.04	0.00	0.00	0.18
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.02	0.00	0.00	0.10
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.00	0.00	0.07
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.01	0.00	0.00	0.13

Table 46: Distribution of observed 59 m wind speed by direction at Tower M2250. Histogram of data is available in Figure 44 (p. 88).

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	0.03	0.06	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
0.5 - 1.5	0.03	0.00	0.06	0.18	0.23	0.19	0.28	0.09	0.06	0.04	0.03	0.01	0.01	0.01	0.01	0.02	1.27
1.5 - 2.5	0.17	0.15	0.36	0.33	0.28	0.37	0.44	0.38	0.28	0.14	0.09	0.08	0.07	0.09	0.09	0.13	3.42
2.5 - 3.5	0.37	0.38	0.40	0.27	0.40	0.46	0.51	0.41	0.49	0.41	0.30	0.23	0.25	0.20	0.19	0.28	5.56
3.5 - 4.5	0.41	0.44	0.42	0.40	0.40	0.53	0.55	0.65	0.46	0.37	0.35	0.34	0.32	0.34	0.36	0.40	6.72
4.5 - 5.5	0.40	0.41	0.43	0.37	0.39	0.43	0.42	0.42	0.40	0.41	0.36	0.54	0.65	0.62	0.59	0.44	7.26
5.5 - 6.5	0.36	0.31	0.23	0.25	0.31	0.24	0.41	0.32	0.43	0.34	0.47	0.68	0.73	1.07	0.70	0.46	7.32
6.5 - 7.5	0.36	0.23	0.17	0.20	0.16	0.22	0.25	0.25	0.27	0.35	0.37	0.48	0.93	1.36	0.58	0.31	6.50
7.5 - 8.5	0.28	0.16	0.13	0.09	0.09	0.17	0.13	0.10	0.22	0.37	0.33	0.48	1.00	1.54	0.40	0.23	5.70
8.5 - 9.5	0.22	0.11	0.06	0.08	0.01	0.04	0.06	0.09	0.22	0.35	0.33	0.32	1.16	1.46	0.32	0.13	4.96
9.5 - 10.5	0.15	0.09	0.05	0.01	0.01	0.01	0.03	0.04	0.20	0.30	0.19	0.28	1.00	1.40	0.24	0.11	4.13
10.5 - 11.5	0.10	0.07	0.03	0.03	0.00	0.02	0.00	0.05	0.17	0.24	0.13	0.26	1.11	1.37	0.16	0.07	3.84
11.5 - 12.5	0.08	0.03	0.01	0.01	0.01	0.00	0.02	0.02	0.11	0.21	0.16	0.22	0.92	1.27	0.07	0.05	3.20
12.5 - 13.5	0.04	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.09	0.15	0.08	0.17	0.88	1.03	0.05	0.04	2.58
13.5 - 14.5	0.02	0.02	0.02	0.00	0.00	0.01	0.01	0.02	0.06	0.13	0.09	0.15	0.97	0.77	0.01	0.03	2.32
14.5 - 15.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.10	0.06	0.09	0.69	0.58	0.03	0.02	1.70
15.5 - 16.5	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.14	0.04	0.13	0.45	0.30	0.02	0.00	1.17
16.5 - 17.5	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.09	0.02	0.09	0.25	0.11	0.00	0.02	0.67
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.06	0.28	0.16	0.00	0.01	0.58
18.5 - 19.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.01	0.02	0.15	0.10	0.01	0.01	0.39
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.11	0.07	0.00	0.00	0.26
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.11	0.01	0.01	0.00	0.18
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.05	0.02	0.00	0.01	0.15
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.01	0.00	0.00	0.09
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	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	0.01	0.09	0.01	0.00	0.00	0.12

Table 47: Distribution of MOS-corrected 59 m wind speed by direction at Tower M2250. All model values are computed only for times with valid observations. Histogram of data is available in Figure 44 (p. 88).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.53	7.37	2.12	5.85
NNE	5.78	6.52	2.06	4.01
NE	5.74	6.48	2.26	3.78
ENE	5.16	5.82	2.55	3.12
E	5.00	5.61	2.77	2.88
ESE	5.11	5.75	2.61	3.92
SE	5.17	5.83	2.47	4.23
SSE	5.29	5.98	2.24	4.03
S	6.82	7.69	1.95	5.07
SSW	7.66	8.65	2.09	6.30
SW	7.99	9.01	1.93	6.78
WSW	8.04	9.02	1.72	6.14
W	10.79	12.18	2.39	16.85
WNW	10.48	11.78	2.73	15.94
NW	6.67	7.53	2.29	6.52
NNW	6.00	6.76	2.45	4.58
ALL	**7.50**	**8.45**	**1.93**	**100.00**

Table 48: Observed 59 m mean wind speed, Weibull parameters, and frequency at Tower M2250. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 45 (p. 89).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.35	7.17	2.14	4.36
NNE	5.69	6.43	2.13	3.47
NE	4.78	5.40	2.04	3.39
ENE	4.61	5.20	1.93	3.22
E	4.16	4.70	2.02	3.31
ESE	4.32	4.87	1.92	3.91
SE	4.36	4.90	1.81	4.55
SSE	4.89	5.51	1.95	4.10
S	6.86	7.72	1.80	5.27
SSW	8.20	9.25	2.04	6.03
SW	7.38	8.34	2.23	4.86
WSW	8.76	9.89	2.04	6.84
W	10.85	12.21	2.59	17.47
WNW	9.93	11.13	3.00	19.80
NW	6.92	7.80	2.52	5.48
NNW	6.31	7.12	2.09	3.94
ALL	**7.49**	**8.45**	**1.93**	**100.00**

Table 49: MOS-corrected 59 m mean wind speed, Weibull parameters, and frequency at Tower M2250. 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 45 (p. 89).

12.2 Validation of Model Results at Tower M2315

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 M2315 (latitude 37.56359, longitude -104.55513).

The average observed wind speed (for all valid observational times) at $60\,m$ during the 21 months of the period of record (May, 2010 to January, 2012) is $8.05\,m/s$ with an hourly standard deviation of $4.35\,m/s$ at Tower M2315. This compares to a modeled $60\,m$ wind speed of $7.91\,m/s$ with a $4.06\,m/s$ 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 M2315 results in a MOS-corrected mean value of $8.06\,m/s$ and an hourly standard deviation of $4.35\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2315). 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 21 months of wind speed data at 60 *meters* and wind direction data at 59 *meters* (May, 2010 to January, 2012) from a meteorological tower (Tower M2315) at La Cumbre 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 Vaisala are not allowed to influence the raw model simulations.

12.2.2 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	0.96
RMS error of monthly-mean simulated wind speed	0.33 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.99
RMS error of monthly-mean MOS-corrected wind speed	0.20 m/s
Correlation of daily-mean simulated wind speed to observed	0.84
RMS error of daily-mean simulated wind speed	1.60 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.87
RMS error of daily-mean MOS-corrected wind speed	1.47 m/s

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

12.2.3 Monthly Mean Wind Speed

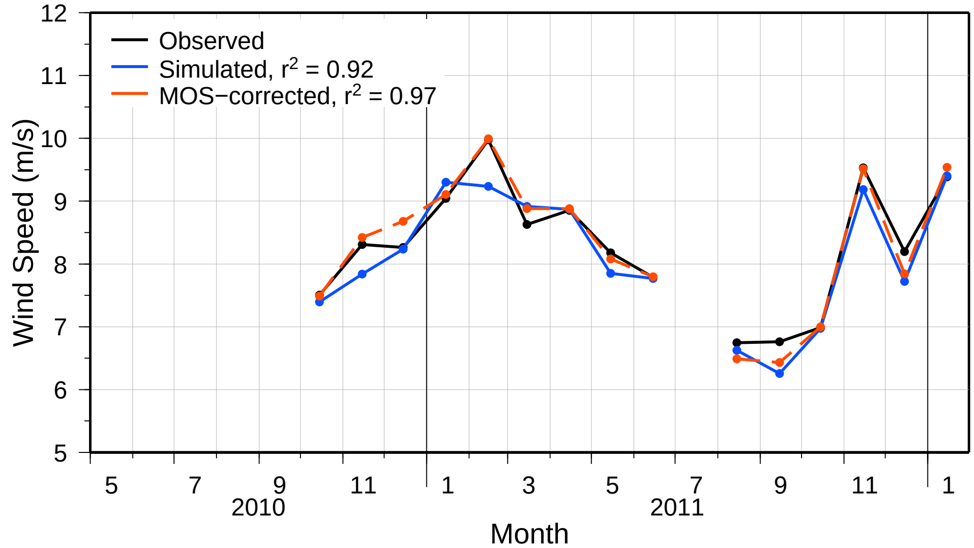

Figure 52: A comparison of the observed, simulated, and MOS-corrected monthly-mean $60\,m$ wind speed at Tower M2315. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 51 (p. 109).

12.2.4 Wind Speed Distribution

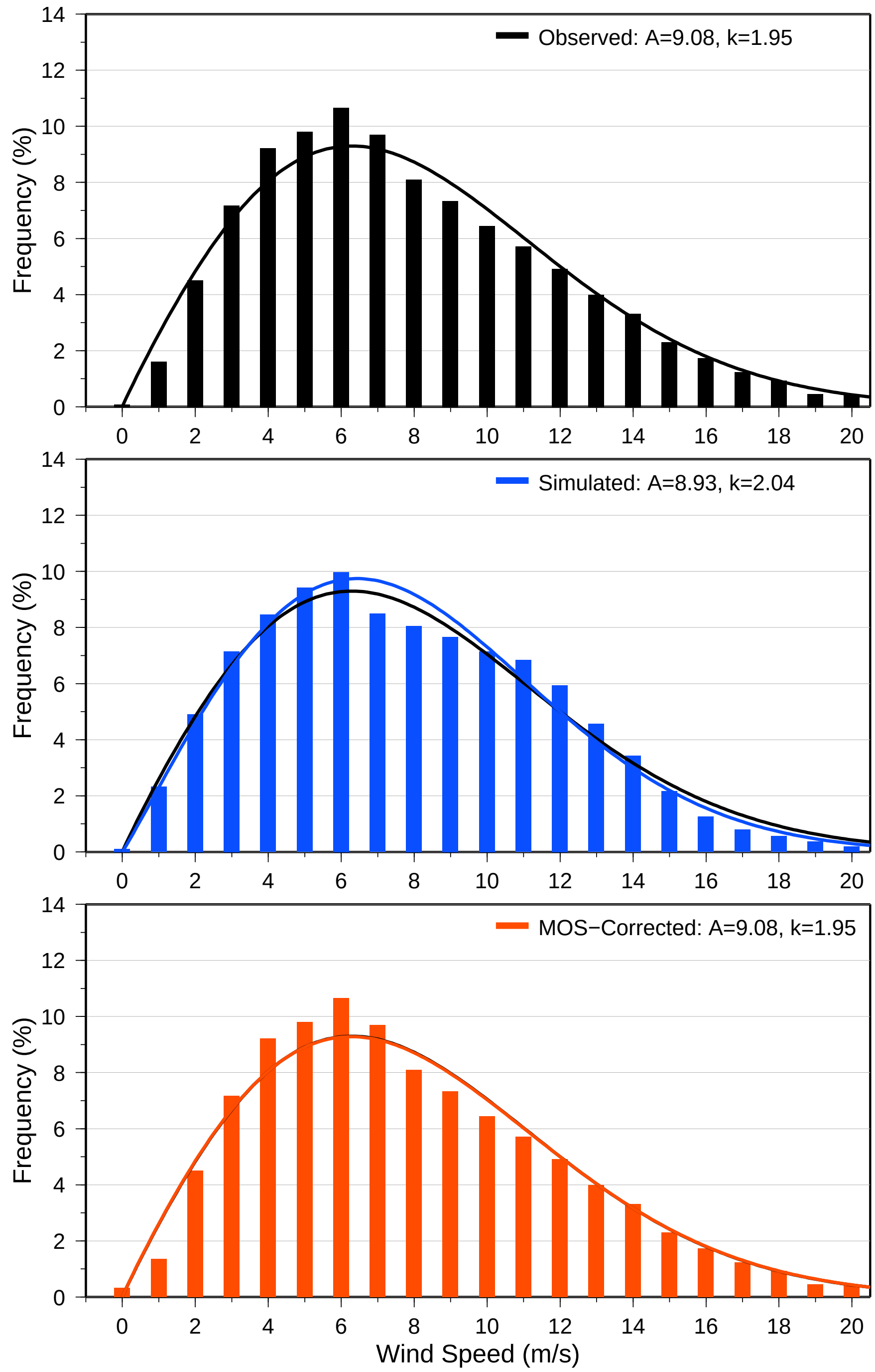

Figure 53: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $60\,m$ at Tower M2315 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend. Tabular formatted data are available in Tables 52 and 53 (p. 112 and 113).

12.2.5 Wind Direction Distribution

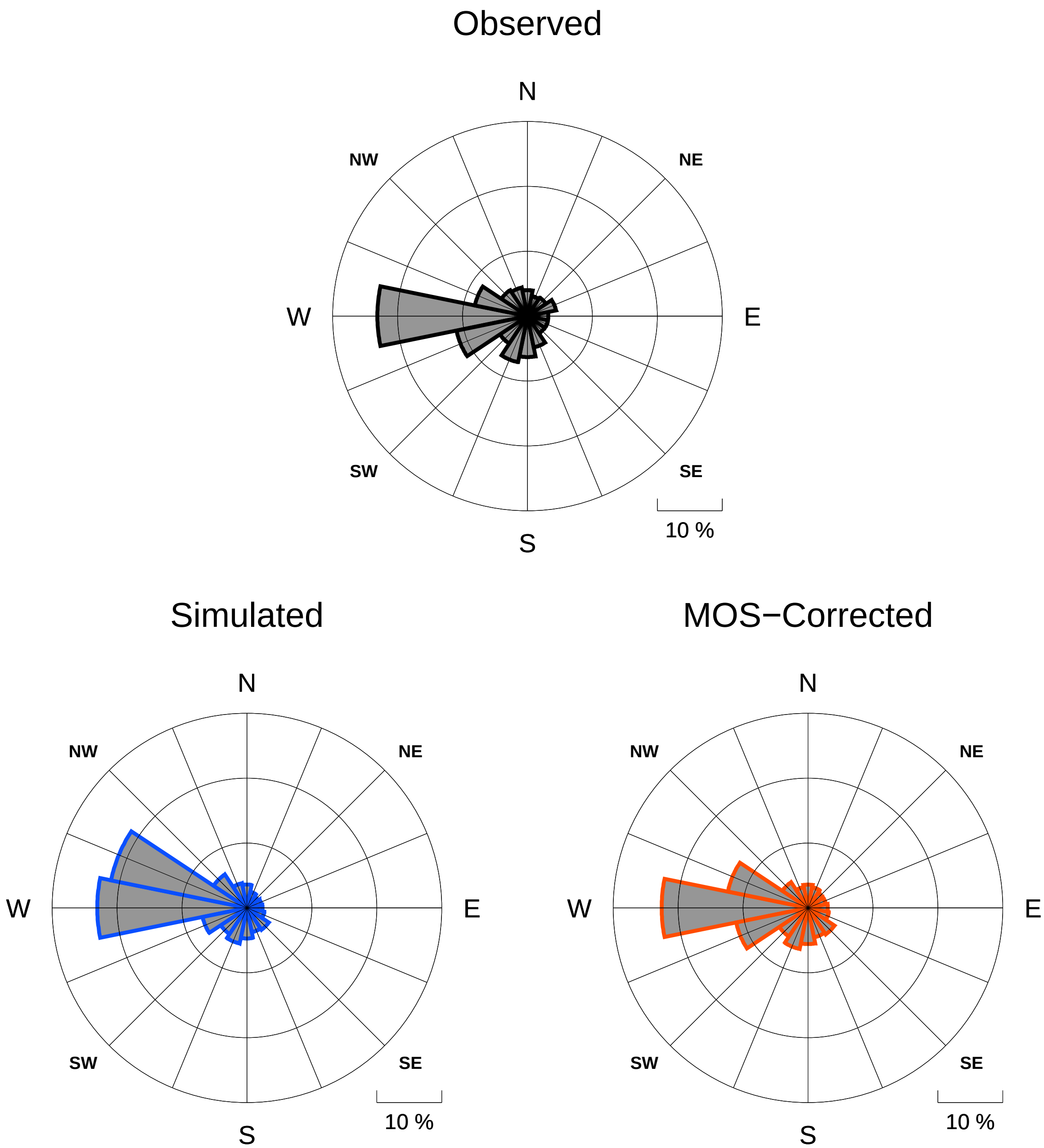

Figure 54: Wind roses at 59 m at Tower M2315 for observational data and simulated model data, averaged over the period of record (May, 2010–January, 2012). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 54 and 55 (p. 114).

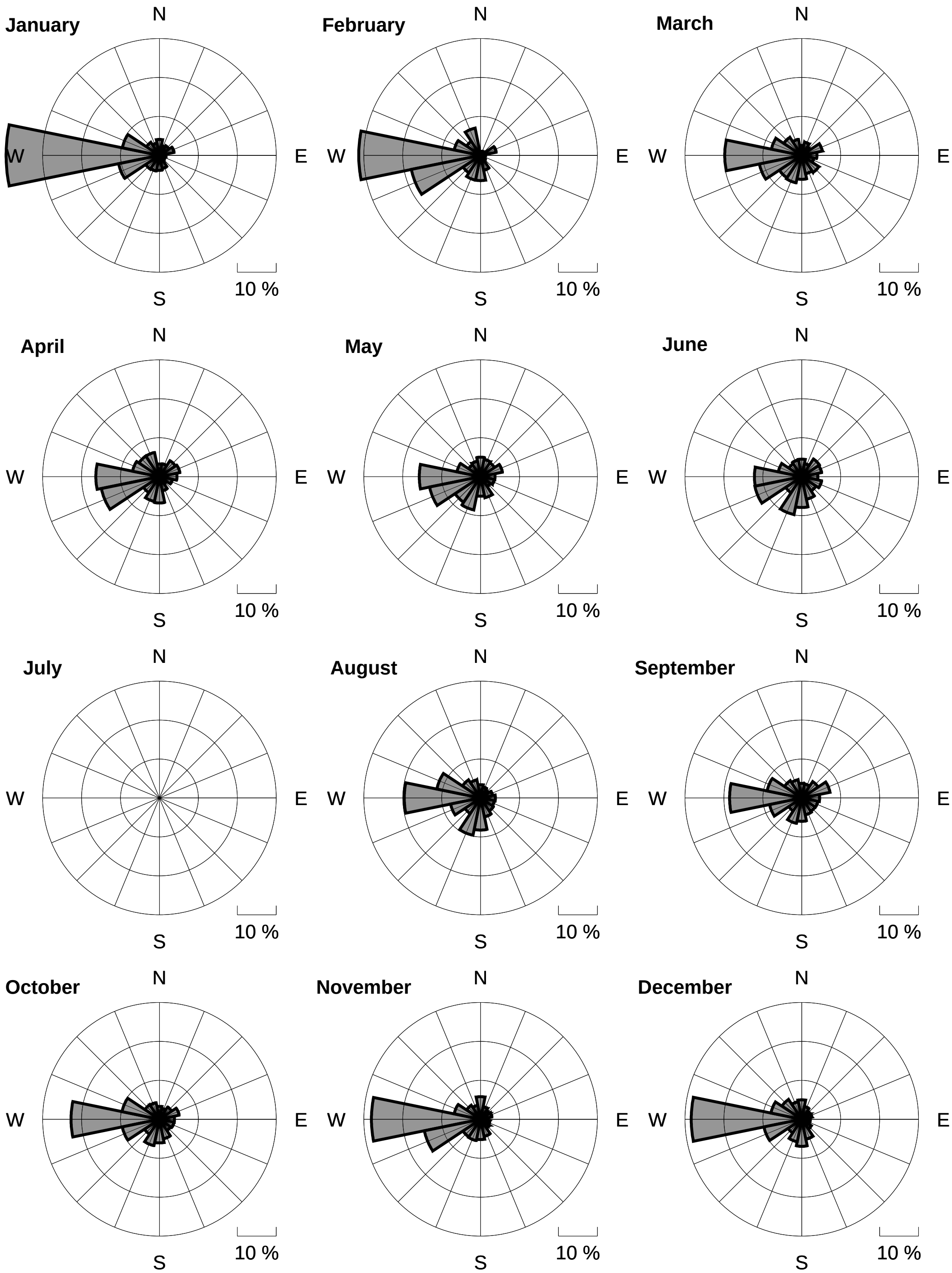

Figure 55: Wind rose of observed wind direction at 59 m at Tower M2315 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

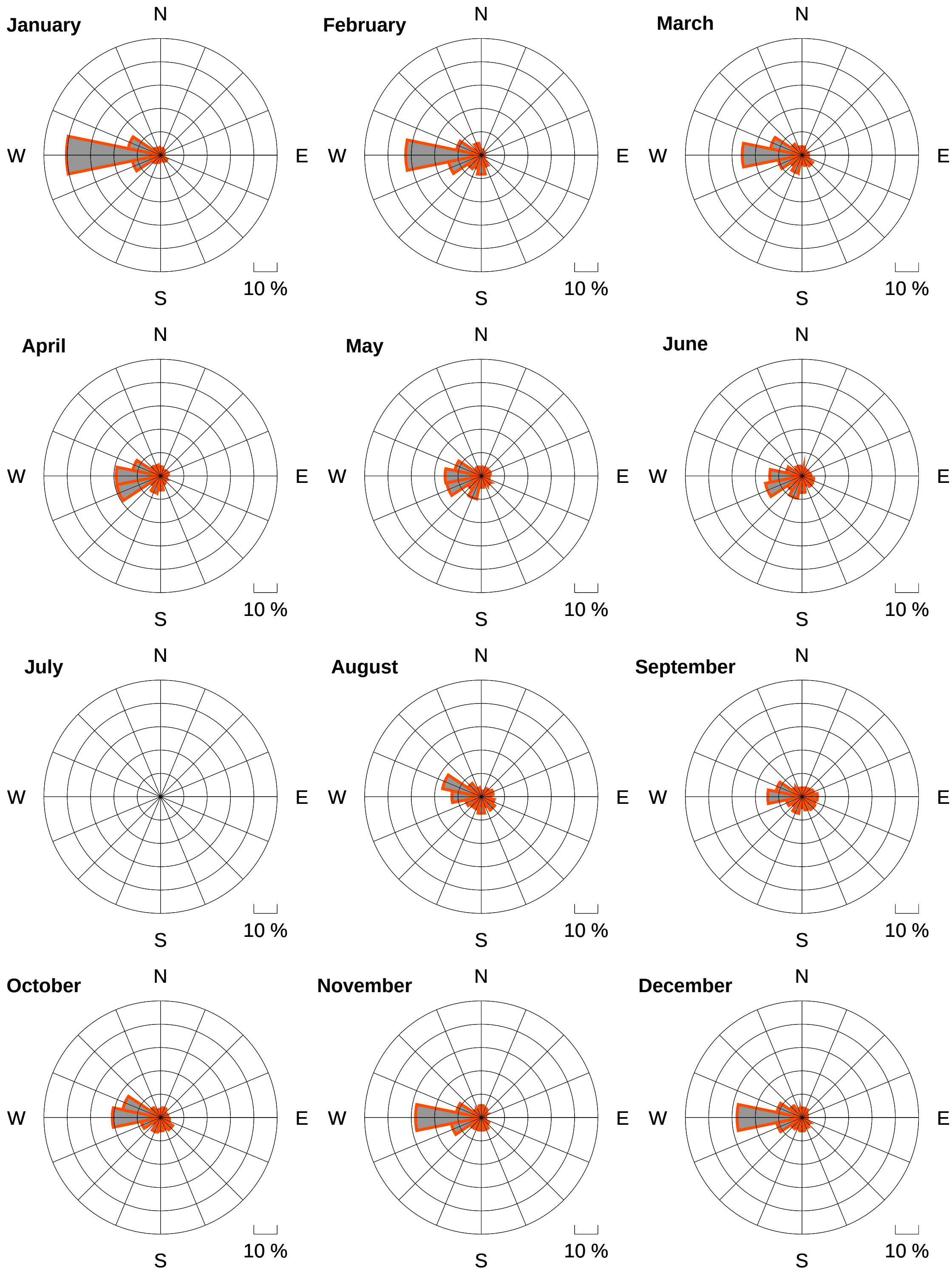

Figure 56: Wind rose of MOS-corrected wind direction at 59 m at Tower M2315 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.2.6 Diurnal Variability of Wind Speed

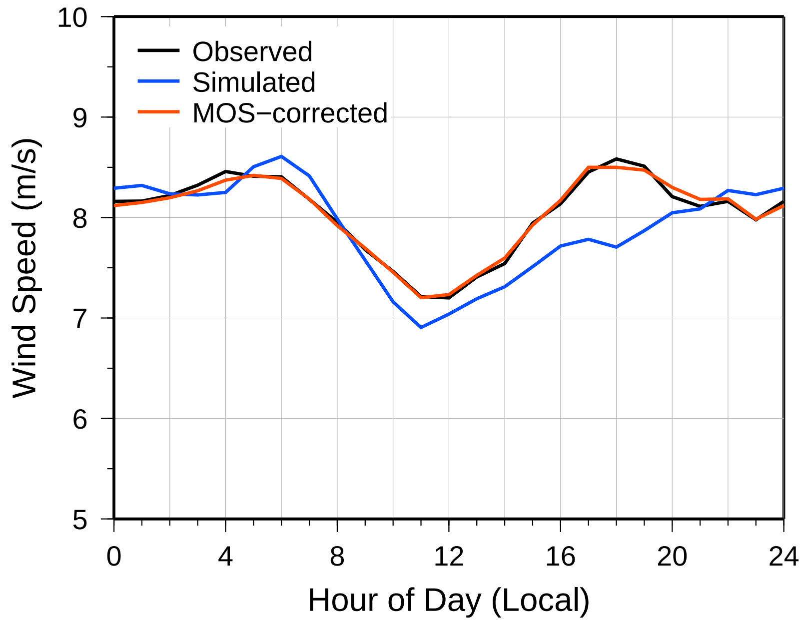

Figure 57: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed at Tower M2315. Data are averaged over the period of record (May, 2010–January, 2012). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data are available in Figures 59 and 60 (p. 110 and 111).

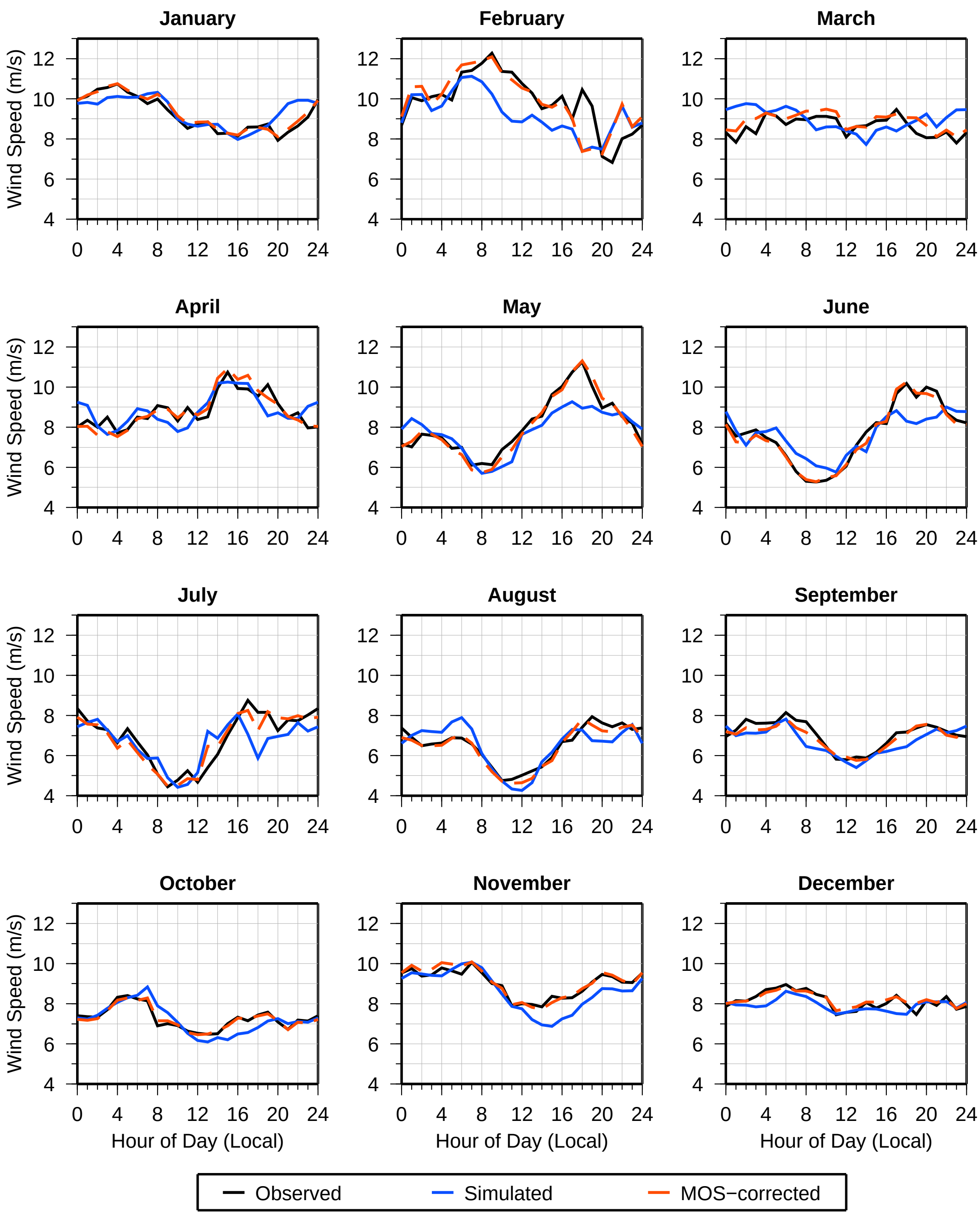

Figure 58: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed for each calendar month at Tower M2315. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data available in Figures 59 and 60 (p. 110 and 111).

12.2.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
05/2010	7.42	6.98	-0.44	7.36	12.8
06/2010	7.26	7.30	0.04	7.06	46.7
07/2010	7.31	7.16	-0.15	7.34	45.2
08/2010	5.90	6.21	0.31	6.23	41.9
09/2010	7.63	7.58	-0.06	7.86	49.9
10/2010	7.51	7.40	-0.11	7.49	99.7
11/2010	8.31	7.84	-0.47	8.42	92.5
12/2010	8.26	8.23	-0.03	8.68	91.0
01/2011	9.04	9.30	0.26	9.11	82.1
02/2011	9.98	9.24	-0.74	10.00	68.9
03/2011	8.63	8.92	0.29	8.88	89.5
04/2011	8.86	8.87	0.02	8.88	98.6
05/2011	8.18	7.85	-0.32	8.08	100.0
06/2011	7.79	7.77	-0.02	7.79	70.8
07/2011	6.56	6.13	-0.42	6.27	35.5
08/2011	6.75	6.62	-0.12	6.49	100.0
09/2011	6.76	6.26	-0.51	6.43	98.8
10/2011	6.99	6.98	-0.01	7.00	95.6
11/2011	9.53	9.19	-0.35	9.51	94.6
12/2011	8.20	7.72	-0.47	7.84	87.0
01/2012	9.39	9.40	0.01	9.54	82.5
All	**8.05**	**7.91**	**-0.14**	**8.06**	**75.4**

Table 51: Monthly-mean $60\,m$ wind speeds (m/s) at Tower M2315. Time series graph of data is available in Figure 52 (p. 102). 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 (Local)

	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.97	8.69	8.33	8.01	7.16	8.22	8.35	7.38	6.95	7.40	9.53	7.86	8.16
1	10.13	10.06	7.84	8.35	7.02	7.56	7.73	6.91	7.27	7.35	9.75	8.15	8.16
2	10.47	9.90	8.61	8.01	7.65	7.71	7.37	6.49	7.80	7.33	9.38	8.13	8.22
3	10.56	10.10	8.27	8.50	7.59	7.86	7.29	6.57	7.61	7.70	9.44	8.36	8.32
4	10.74	10.22	9.31	7.71	7.48	7.48	6.65	6.62	7.62	8.32	9.78	8.70	8.46
5	10.34	9.94	9.15	7.88	6.95	7.24	7.34	6.88	7.65	8.40	9.64	8.78	8.41
6	10.12	11.33	8.72	8.51	6.99	6.59	6.68	6.87	8.14	8.24	9.47	8.96	8.41
7	9.76	11.41	8.99	8.44	6.10	5.80	6.03	6.57	7.76	8.14	10.06	8.65	8.18
8	9.99	11.77	8.96	9.08	6.19	5.30	5.08	6.07	7.69	6.89	9.55	8.77	7.95
9	9.45	12.28	9.13	8.97	6.13	5.27	4.45	5.42	7.08	7.01	9.00	8.46	7.68
10	8.99	11.37	9.13	8.31	6.89	5.35	4.78	4.75	6.45	6.91	8.90	8.33	7.46
11	8.53	11.33	9.02	8.98	7.29	5.62	5.25	4.82	5.82	6.64	7.90	7.45	7.21
12	8.74	10.76	8.10	8.38	7.82	6.06	4.67	5.01	5.80	6.53	8.01	7.57	7.20
13	8.85	10.29	8.62	8.51	8.41	7.10	5.41	5.23	5.93	6.48	7.96	7.62	7.41
14	8.26	9.51	8.66	9.95	8.55	7.75	6.07	5.44	5.88	6.50	7.84	8.06	7.54
15	8.29	9.68	8.91	10.74	9.63	8.23	7.03	5.91	6.17	7.01	8.37	7.79	7.95
16	8.14	10.13	8.94	9.93	10.04	8.18	7.88	6.70	6.61	7.33	8.28	8.01	8.14
17	8.64	8.98	9.39	10.04	10.67	9.54	8.81	6.93	7.14	7.15	8.08	8.55	8.45
18	8.62	10.34	8.89	9.29	11.45	9.97	8.45	7.55	7.22	7.43	8.29	8.25	8.58
19	8.66	9.76	8.26	9.87	10.13	9.32	8.71	7.96	7.45	7.51	8.78	7.83	8.51
20	7.84	7.37	7.87	9.28	8.88	9.68	7.97	7.55	7.67	6.93	9.28	8.48	8.21
21	8.20	7.13	7.86	8.63	8.97	9.53	8.48	7.53	7.28	6.64	9.26	8.19	8.11
22	8.53	7.96	8.37	8.84	8.31	8.49	8.36	7.64	7.15	7.16	8.93	8.61	8.16
23	8.99	8.11	7.89	8.15	7.95	8.06	8.71	7.10	7.18	7.09	8.93	7.94	7.98
Avg	9.22	9.98	8.63	8.86	8.09	7.58	6.98	6.50	7.05	7.25	8.93	8.23	8.05

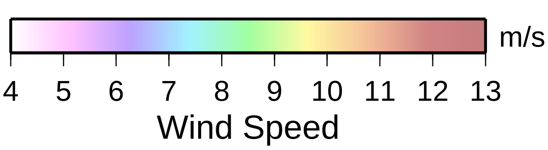

Figure 59: Hourly-mean values of observed $60\,m$ wind speed at Tower M2315. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 57 and 58 (p. 107 and 108).

MOS−Corrected

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.91	9.11	8.46	8.04	7.05	8.14	7.92	6.90	7.20	7.22	9.55	8.02	8.12
1	10.19	10.60	8.39	8.04	7.29	7.27	7.57	6.77	7.06	7.18	9.91	8.10	8.15
2	10.36	10.62	8.99	7.60	7.80	7.22	7.53	6.51	7.39	7.26	9.62	8.13	8.20
3	10.62	9.71	9.02	7.77	7.65	7.61	7.12	6.50	7.28	7.66	9.72	8.26	8.27
4	10.75	10.23	9.29	7.53	7.38	7.33	6.38	6.52	7.30	8.18	10.04	8.56	8.37
5	10.43	11.10	9.14	7.85	6.89	7.22	6.77	6.87	7.46	8.29	9.97	8.67	8.42
6	10.16	11.69	9.01	8.42	6.63	6.53	6.15	7.00	7.84	8.17	9.87	8.88	8.39
7	9.99	11.78	9.19	8.54	5.86	5.78	5.55	6.62	7.39	8.29	10.09	8.63	8.18
8	10.23	11.90	9.39	8.86	5.74	5.39	5.08	5.79	7.16	7.15	9.63	8.64	7.92
9	9.85	12.10	9.39	8.89	5.90	5.28	4.48	5.20	6.82	7.15	9.08	8.47	7.70
10	9.15	11.29	9.48	8.47	6.53	5.50	4.51	4.72	6.40	6.95	8.76	8.31	7.46
11	8.76	10.95	9.37	8.86	6.89	5.58	4.85	4.62	6.00	6.57	7.96	7.66	7.20
12	8.84	10.54	8.47	8.61	7.67	6.14	4.80	4.65	5.93	6.46	8.05	7.76	7.23
13	8.86	10.35	8.62	8.93	8.22	6.88	6.46	4.86	5.76	6.49	7.82	7.84	7.42
14	8.47	9.72	8.58	10.44	8.73	7.19	6.45	5.46	5.81	6.65	7.73	8.09	7.60
15	8.29	9.58	9.11	10.93	9.54	8.15	7.27	5.75	6.09	6.90	8.06	8.09	7.92
16	8.19	9.87	9.09	10.39	9.87	8.29	8.09	6.64	6.46	7.28	8.30	8.19	8.17
17	8.51	9.17	9.13	10.62	10.64	9.84	8.33	7.45	6.85	7.19	8.08	8.65	8.50
18	8.62	7.49	8.89	9.86	11.22	9.88	7.94	8.02	7.05	7.39	8.47	8.26	8.50
19	8.53	7.81	8.62	9.62	10.43	9.39	8.74	7.72	7.42	7.51	8.75	8.21	8.47
20	8.15	7.48	8.49	9.26	9.25	9.40	8.34	7.44	7.53	7.12	9.27	8.41	8.30
21	8.48	8.54	8.08	8.65	8.98	9.22	8.33	7.33	7.37	6.79	9.16	8.24	8.18
22	8.83	9.42	8.68	8.49	8.29	8.68	8.20	7.31	7.18	7.14	8.84	8.45	8.19
23	9.20	8.23	8.37	8.25	7.63	8.19	8.06	7.22	7.18	7.04	8.80	7.97	7.98
Avg	9.32	10.00	8.88	8.88	8.00	7.50	6.87	6.41	6.91	7.25	8.97	8.27	8.06

Wind Speed (m/s): 4 5 6 7 8 9 10 11 12 13

Figure 60: Hourly-mean values of MOS-corrected 60 m wind speed at Tower M2315. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 57 and 58 (p. 107 and 108).

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	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.09
0.5 - 1.5	0.14	0.10	0.09	0.06	0.11	0.12	0.06	0.06	0.12	0.09	0.10	0.13	0.11	0.07	0.13	0.08	1.58
1.5 - 2.5	0.22	0.28	0.25	0.28	0.31	0.33	0.33	0.30	0.27	0.32	0.30	0.25	0.29	0.22	0.19	0.30	4.46
2.5 - 3.5	0.40	0.47	0.36	0.43	0.35	0.41	0.35	0.64	0.57	0.56	0.48	0.43	0.44	0.42	0.41	0.35	7.09
3.5 - 4.5	0.43	0.27	0.48	0.77	0.61	0.38	0.46	0.75	0.82	0.62	0.60	0.61	0.62	0.64	0.51	0.52	9.09
4.5 - 5.5	0.37	0.48	0.39	0.60	0.63	0.54	0.40	0.71	0.81	0.79	0.66	0.74	0.75	0.66	0.66	0.51	9.71
5.5 - 6.5	0.47	0.37	0.47	0.66	0.48	0.54	0.53	0.81	0.65	0.65	0.71	0.78	1.17	0.90	0.84	0.53	10.57
6.5 - 7.5	0.47	0.22	0.41	0.64	0.35	0.43	0.42	0.47	0.58	0.69	0.49	0.91	1.40	0.90	0.70	0.53	9.61
7.5 - 8.5	0.30	0.27	0.25	0.40	0.20	0.24	0.36	0.33	0.43	0.55	0.38	0.77	1.78	0.79	0.49	0.50	8.04
8.5 - 9.5	0.28	0.22	0.28	0.22	0.09	0.16	0.12	0.22	0.38	0.64	0.23	0.88	2.00	0.83	0.37	0.34	7.27
9.5 - 10.5	0.21	0.19	0.16	0.21	0.03	0.03	0.06	0.16	0.37	0.51	0.19	0.75	2.16	0.81	0.23	0.32	6.39
10.5 - 11.5	0.22	0.08	0.09	0.10	0.00	0.01	0.04	0.12	0.29	0.41	0.12	0.82	2.34	0.65	0.11	0.28	5.68
11.5 - 12.5	0.11	0.08	0.08	0.04	0.00	0.02	0.01	0.15	0.24	0.32	0.14	0.66	2.42	0.47	0.03	0.10	4.88
12.5 - 13.5	0.07	0.05	0.02	0.01	0.00	0.01	0.03	0.07	0.33	0.30	0.15	0.64	1.89	0.28	0.07	0.05	3.96
13.5 - 14.5	0.17	0.01	0.03	0.01	0.00	0.00	0.01	0.05	0.10	0.22	0.13	0.58	1.67	0.26	0.03	0.02	3.28
14.5 - 15.5	0.03	0.03	0.03	0.01	0.00	0.00	0.00	0.04	0.10	0.16	0.06	0.38	1.28	0.16	0.03	0.00	2.29
15.5 - 16.5	0.03	0.00	0.01	0.02	0.00	0.00	0.01	0.01	0.10	0.17	0.08	0.33	0.86	0.07	0.01	0.02	1.72
16.5 - 17.5	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.07	0.09	0.08	0.28	0.59	0.03	0.00	0.02	1.22
17.5 - 18.5	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.07	0.30	0.40	0.03	0.00	0.00	0.92
18.5 - 19.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.15	0.26	0.02	0.00	0.00	0.46
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.19	0.16	0.02	0.00	0.00	0.44
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.16	0.16	0.01	0.00	0.00	0.35
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.10	0.09	0.00	0.00	0.00	0.22
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.00	0.00	0.00	0.11
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.05	0.00	0.00	0.00	0.10
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.11	0.00	0.00	0.00	0.33

Table 52: Distribution of observed 60 m wind speed by direction at Tower M2315. Histogram of data is available in Figure 53 (p. 103).

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	0.00	0.03	0.07	0.10	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
0.5 - 1.5	0.00	0.02	0.10	0.11	0.17	0.20	0.26	0.25	0.10	0.04	0.01	0.02	0.00	0.02	0.02	0.02	1.34
1.5 - 2.5	0.18	0.24	0.34	0.33	0.29	0.41	0.51	0.47	0.49	0.19	0.16	0.16	0.16	0.18	0.16	0.17	4.46
2.5 - 3.5	0.48	0.46	0.51	0.41	0.41	0.39	0.53	0.63	0.64	0.66	0.42	0.28	0.29	0.30	0.40	0.31	7.11
3.5 - 4.5	0.34	0.55	0.45	0.45	0.44	0.53	0.75	0.61	0.60	0.78	0.68	0.66	0.61	0.57	0.64	0.48	9.15
4.5 - 5.5	0.47	0.44	0.38	0.35	0.50	0.51	0.71	0.77	0.60	0.55	0.72	0.72	0.86	0.70	0.82	0.62	9.72
5.5 - 6.5	0.57	0.44	0.32	0.40	0.32	0.43	0.71	0.48	0.50	0.68	0.72	0.88	1.22	1.56	0.83	0.47	10.54
6.5 - 7.5	0.33	0.40	0.16	0.33	0.36	0.26	0.56	0.42	0.41	0.47	0.58	0.96	1.78	1.49	0.73	0.36	9.60
7.5 - 8.5	0.28	0.19	0.13	0.08	0.24	0.14	0.42	0.28	0.41	0.47	0.55	0.78	1.84	1.62	0.34	0.26	8.03
8.5 - 9.5	0.23	0.16	0.09	0.10	0.11	0.15	0.15	0.21	0.32	0.46	0.41	0.96	2.07	1.37	0.31	0.19	7.27
9.5 - 10.5	0.24	0.12	0.09	0.06	0.04	0.08	0.10	0.16	0.34	0.38	0.27	0.91	2.26	1.10	0.16	0.08	6.38
10.5 - 11.5	0.15	0.07	0.08	0.07	0.02	0.03	0.03	0.08	0.25	0.35	0.21	0.66	2.22	1.28	0.08	0.10	5.67
11.5 - 12.5	0.13	0.07	0.07	0.03	0.03	0.03	0.01	0.09	0.18	0.22	0.10	0.84	2.16	0.77	0.09	0.05	4.87
12.5 - 13.5	0.08	0.05	0.02	0.03	0.02	0.01	0.02	0.02	0.19	0.29	0.12	0.72	1.72	0.61	0.04	0.02	3.96
13.5 - 14.5	0.02	0.02	0.01	0.02	0.00	0.00	0.01	0.03	0.14	0.24	0.09	0.53	1.67	0.46	0.03	0.02	3.28
14.5 - 15.5	0.02	0.02	0.02	0.00	0.01	0.00	0.00	0.03	0.10	0.10	0.09	0.54	1.09	0.25	0.01	0.01	2.28
15.5 - 16.5	0.04	0.00	0.03	0.00	0.00	0.01	0.03	0.03	0.09	0.21	0.05	0.38	0.73	0.07	0.01	0.04	1.72
16.5 - 17.5	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.12	0.16	0.05	0.37	0.45	0.03	0.02	0.02	1.22
17.5 - 18.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.09	0.03	0.26	0.44	0.05	0.02	0.01	0.92
18.5 - 19.5	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.09	0.22	0.04	0.01	0.02	0.46
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.15	0.22	0.03	0.00	0.00	0.44
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.03	0.01	0.12	0.13	0.01	0.02	0.01	0.35
21.5 - 22.5	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.13	0.02	0.00	0.01	0.22
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.02	0.00	0.00	0.11
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	0.05	0.03	0.02	0.00	0.00	0.10
> 24.5	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.16	0.14	0.02	0.00	0.00	0.33

Table 53: Distribution of MOS-corrected $60\,m$ wind speed by direction at Tower M2315. All model values are computed only for times with valid observations. Histogram of data is available in Figure 53 (p. 103).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.86	7.74	1.96	4.01
NNE	5.99	6.75	1.96	3.15
NE	6.07	6.85	2.07	3.43
ENE	5.83	6.58	2.42	4.47
E	4.87	5.48	2.62	3.19
ESE	5.15	5.81	2.47	3.23
SE	5.49	6.20	2.37	3.19
SSE	5.94	6.71	2.16	4.90
S	7.24	8.17	2.00	6.31
SSW	7.98	9.00	2.03	7.24
SW	7.11	7.99	1.77	5.08
WSW	10.33	11.65	2.00	11.15
W	10.87	12.21	2.76	23.11
WNW	8.08	9.11	2.48	8.24
NW	6.27	7.06	2.51	4.82
NNW	6.56	7.41	2.35	4.47
ALL	**8.05**	**9.08**	**1.95**	**100.00**

Table 54: Observed 60 m mean wind speed, Weibull parameters, and frequency at Tower M2315. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 54 (p. 104).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.66	7.52	2.20	3.59
NNE	5.77	6.51	2.01	3.25
NE	5.21	5.86	1.81	2.80
ENE	5.12	5.78	1.90	2.81
E	4.95	5.58	1.97	3.05
ESE	4.75	5.35	1.88	3.27
SE	5.06	5.71	1.97	4.90
SSE	5.40	6.08	1.86	4.60
S	7.12	8.00	1.78	5.58
SSW	8.11	9.14	1.96	6.44
SW	7.10	8.02	2.17	5.30
WSW	10.42	11.77	2.22	11.28
W	10.81	12.14	2.76	22.53
WNW	8.78	9.87	2.73	12.60
NW	6.30	7.11	2.33	4.73
NNW	6.28	7.08	2.05	3.27
ALL	**8.06**	**9.08**	**1.95**	**100.00**

Table 55: MOS-corrected 60 m mean wind speed, Weibull parameters, and frequency at Tower M2315. 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 54 (p. 104).

12.3 Validation of Model Results at Tower M2316

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 M2316 (latitude 37.55243, longitude -104.5393).

The average observed wind speed (for all valid observational times) at $60\,m$ during the 15 months of the period of record (May, 2010 to July, 2011) is $7.79\,m/s$ with an hourly standard deviation of $4.18\,m/s$ at Tower M2316. This compares to a modeled $60\,m$ wind speed of $7.76\,m/s$ with a $3.80\,m/s$ 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 M2316 results in a MOS-corrected mean value of $7.80\,m/s$ and an hourly standard deviation of $4.19\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2316). 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 15 months of wind speed data at 60 $meters$ and wind direction data at 59 $meters$ (May, 2010 to July, 2011) from a meteorological tower (Tower M2316) at La Cumbre 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 Vaisala are not allowed to influence the raw model simulations.

12.3.2 Model Validation Statistics

Table 56 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	0.96
RMS error of monthly-mean simulated wind speed	0.25 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.99
RMS error of monthly-mean MOS-corrected wind speed	0.12 m/s
Correlation of daily-mean simulated wind speed to observed	0.81
RMS error of daily-mean simulated wind speed	1.59 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.84
RMS error of daily-mean MOS-corrected wind speed	1.42 m/s

Table 56: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.3.3 Monthly Mean Wind Speed

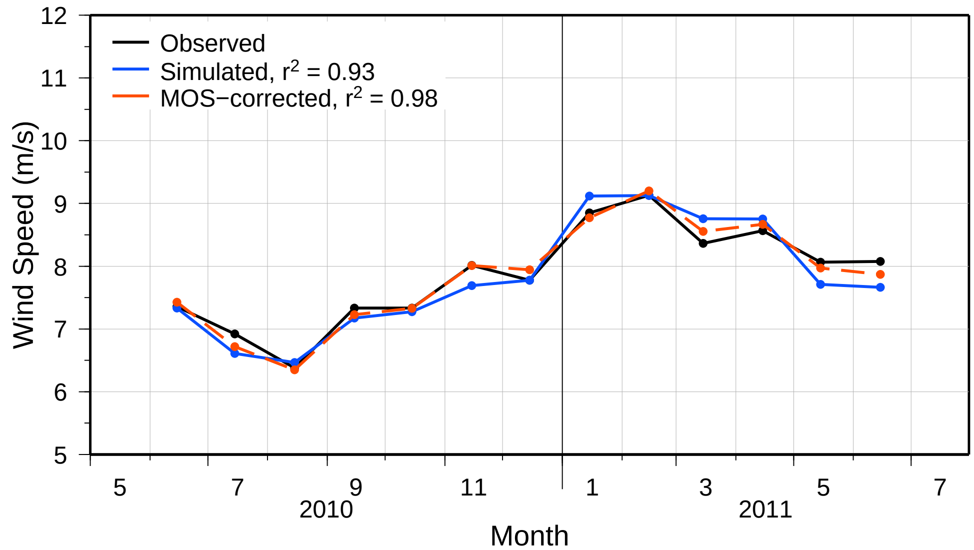

Figure 61: A comparison of the observed, simulated, and MOS-corrected monthly-mean $60\,m$ wind speed at Tower M2316. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 57 (p. 124).

12.3.4 Wind Speed Distribution

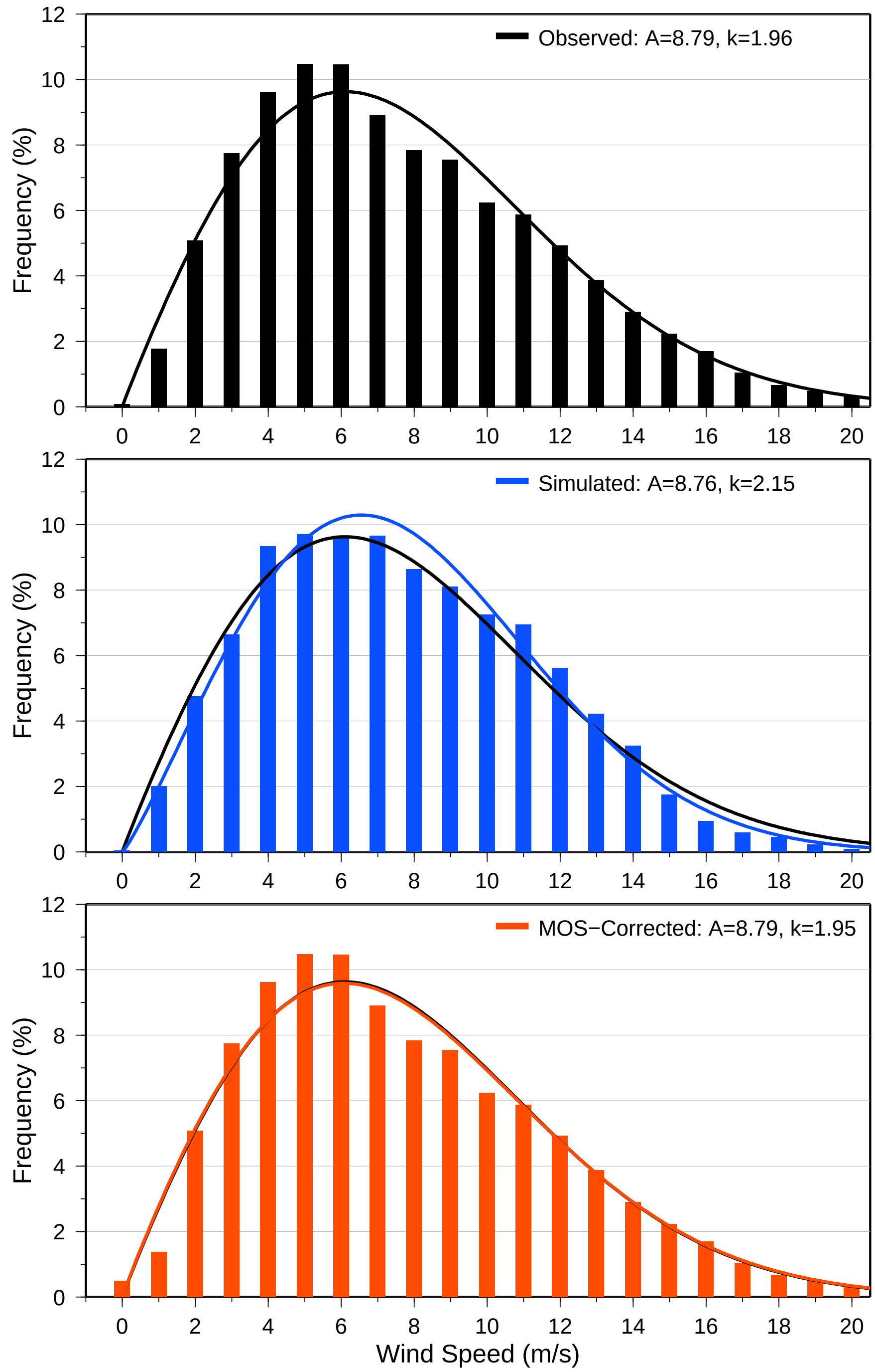

Figure 62: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $60\,m$ at Tower M2316 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend. Tabular formatted data are available in Tables 58 and 59 (p. 127 and 128).

12.3.5 Wind Direction Distribution

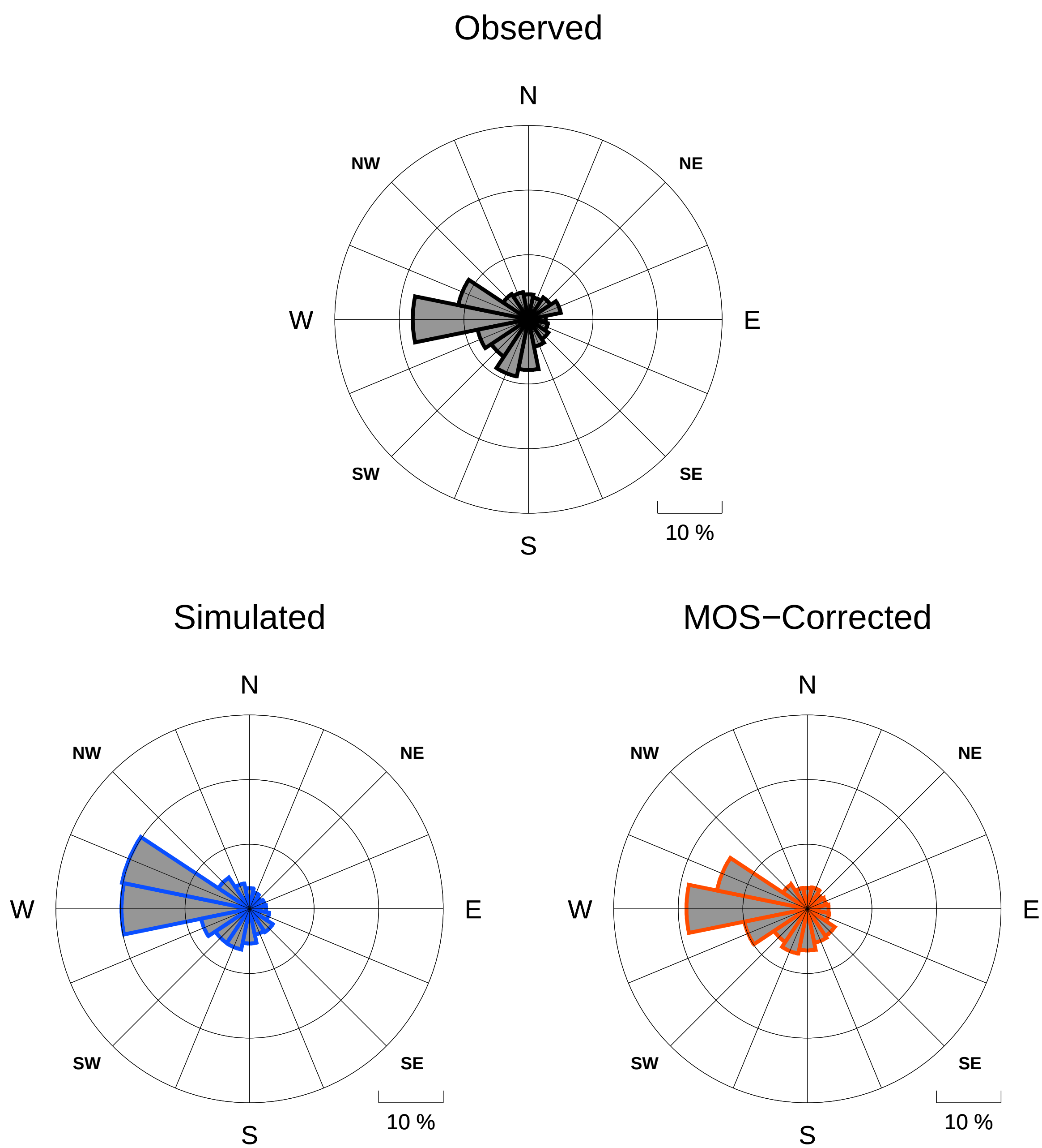

Figure 63: Wind roses at 59 m at Tower M2316 for observational data and simulated model data, averaged over the period of record (May, 2010–July, 2011). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 60 and 61 (p. 129).

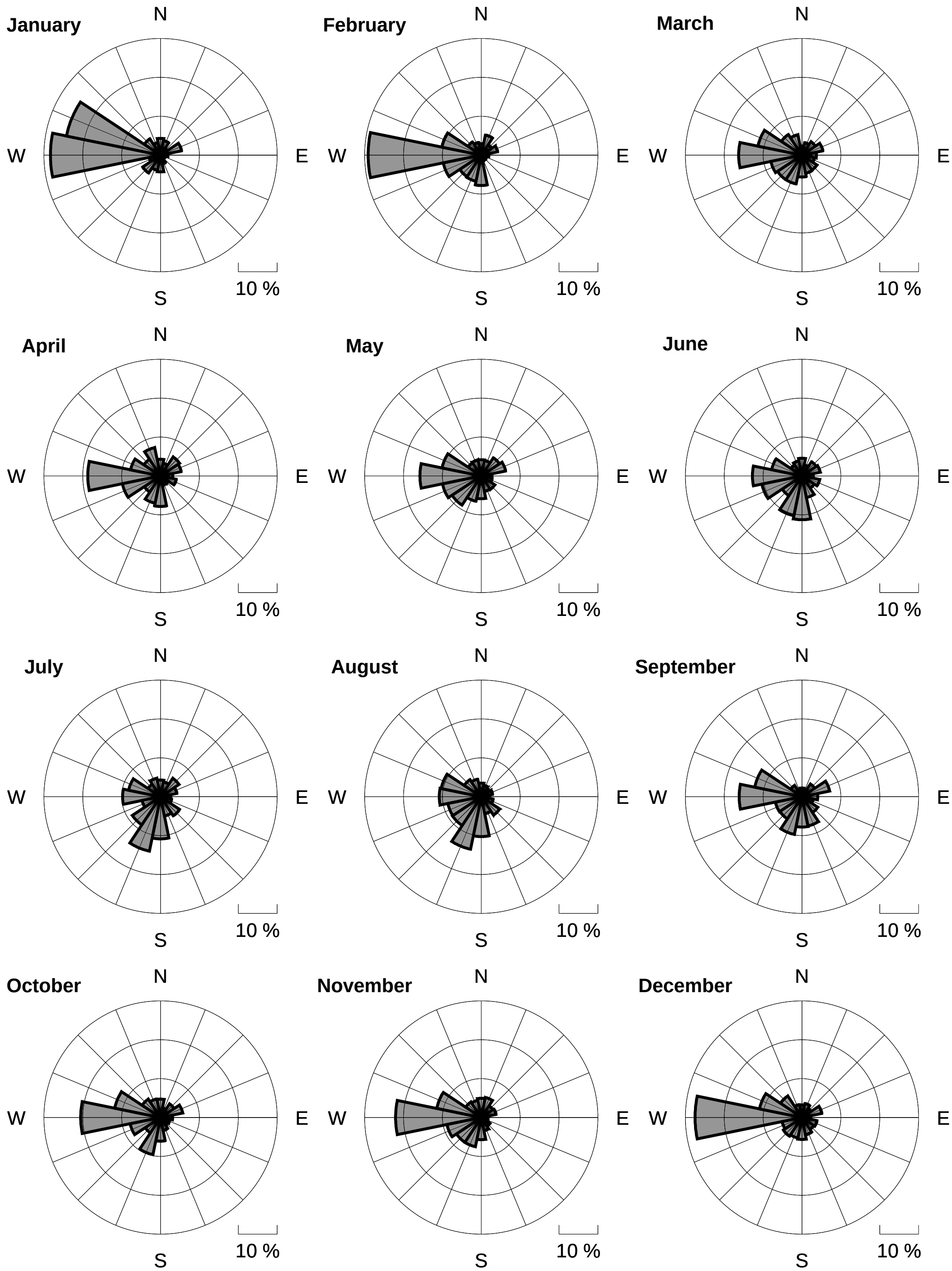

Figure 64: Wind rose of observed wind direction at 59 m at Tower M2316 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

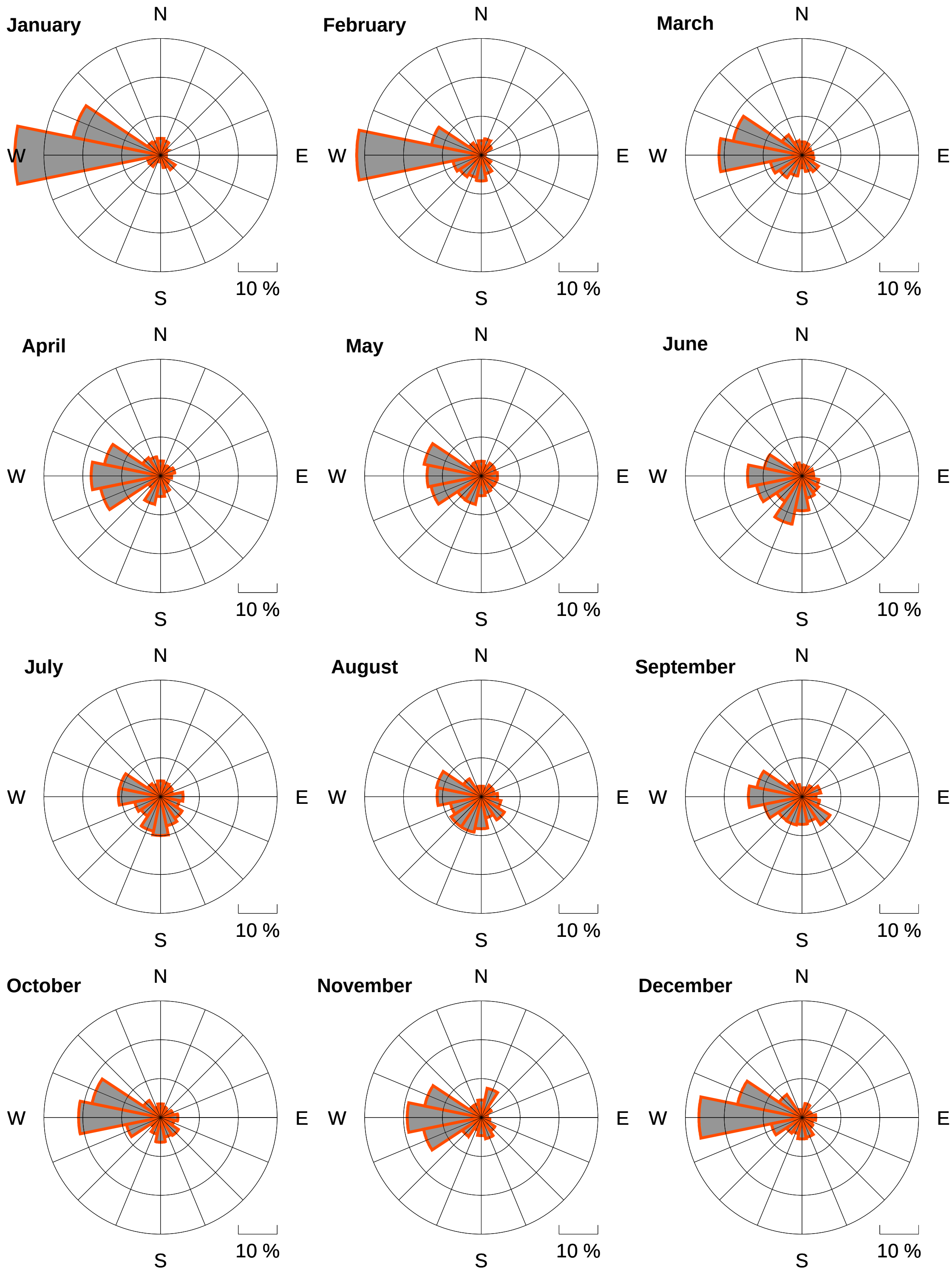

Figure 65: Wind rose of MOS-corrected wind direction at 59 m at Tower M2316 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.3.6 Diurnal Variability of Wind Speed

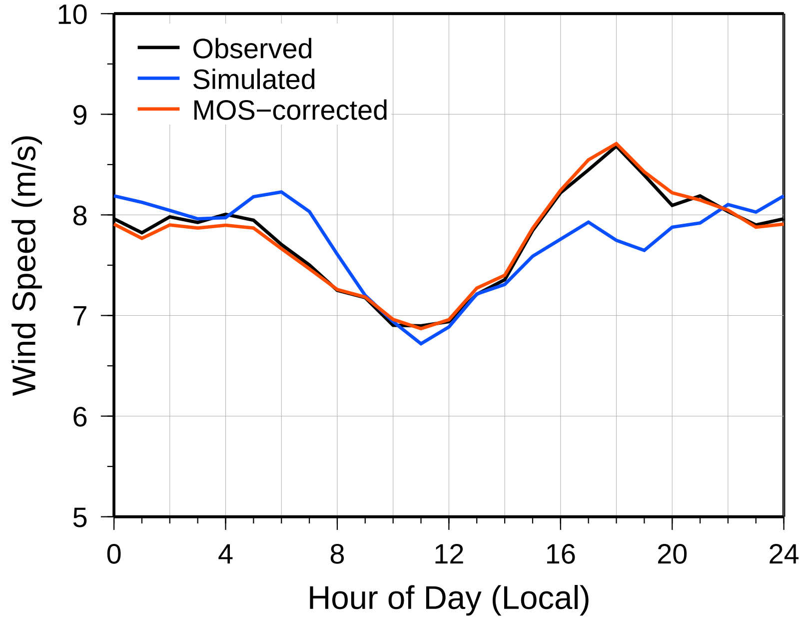

Figure 66: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed at Tower M2316. Data are averaged over the period of record (May, 2010–July, 2011). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data are available in Figures 68 and 69 (p. 125 and 126).

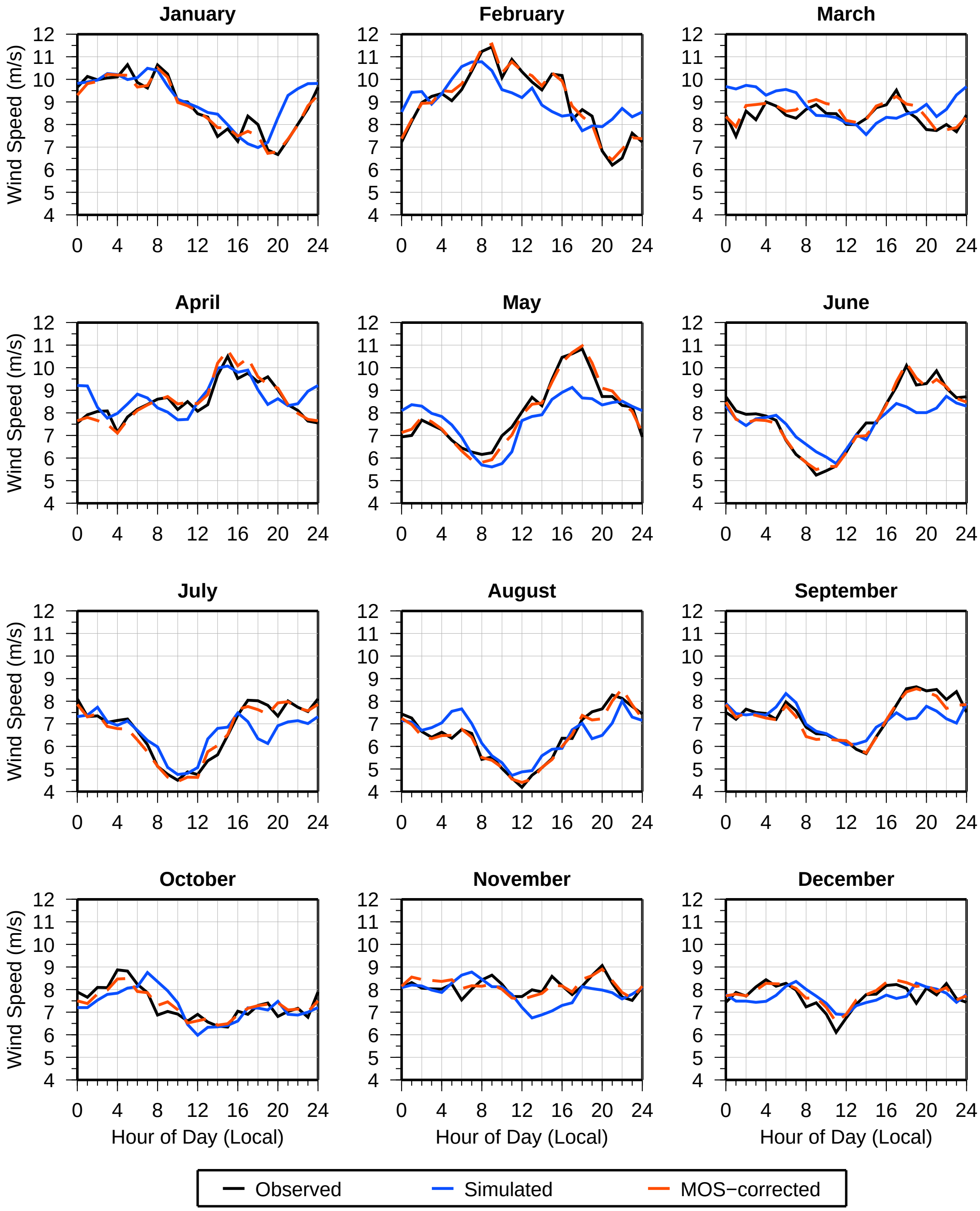

Figure 67: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed for each calendar month at Tower M2316. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data available in Figures 68 and 69 (p. 125 and 126).

12.3.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
05/2010	6.46	6.61	0.15	6.86	3.1
06/2010	7.36	7.33	-0.02	7.43	99.9
07/2010	6.92	6.61	-0.31	6.72	99.9
08/2010	6.38	6.47	0.08	6.35	99.6
09/2010	7.33	7.17	-0.16	7.23	99.7
10/2010	7.33	7.28	-0.06	7.33	99.6
11/2010	8.02	7.69	-0.32	8.01	92.6
12/2010	7.78	7.77	-0.00	7.94	95.3
01/2011	8.85	9.12	0.27	8.77	78.1
02/2011	9.13	9.13	-0.00	9.20	76.3
03/2011	8.36	8.76	0.40	8.56	90.7
04/2011	8.57	8.75	0.19	8.67	97.2
05/2011	8.07	7.71	-0.36	7.97	99.9
06/2011	8.08	7.67	-0.41	7.87	86.4
07/2011	6.32	6.69	0.37	6.65	25.4
All	**7.79**	**7.76**	**-0.03**	**7.80**	**82.9**

Table 57: Monthly-mean 60 m wind speeds (m/s) at Tower M2316. Time series graph of data is available in Figure 61 (p. 117). 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 (Local)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.66	7.22	8.43	7.56	6.94	8.71	8.11	7.44	7.51	7.90	8.11	7.44	7.96
1	10.14	8.14	7.49	7.92	7.00	8.08	7.32	7.25	7.21	7.66	8.31	7.87	7.82
2	9.99	8.97	8.59	8.07	7.68	7.94	7.35	6.66	7.65	8.10	8.06	7.71	7.98
3	10.06	9.25	8.22	8.09	7.47	7.96	7.06	6.41	7.50	8.08	8.04	8.11	7.93
4	10.11	9.37	9.01	7.14	7.26	7.87	7.15	6.62	7.46	8.87	8.02	8.44	8.01
5	10.65	9.06	8.83	7.82	6.79	7.67	7.21	6.37	7.21	8.83	8.25	8.15	7.95
6	9.86	9.54	8.42	8.16	6.45	6.79	6.68	6.74	7.97	8.24	7.55	8.28	7.70
7	9.62	10.37	8.28	8.37	6.26	6.17	6.08	6.58	7.59	7.87	8.02	7.98	7.50
8	10.64	11.24	8.67	8.61	6.16	5.81	5.12	5.43	6.85	6.88	8.43	7.24	7.25
9	10.23	11.44	8.89	8.69	6.24	5.25	4.77	5.53	6.57	7.03	8.64	7.42	7.18
10	9.05	10.08	8.49	8.15	6.99	5.43	4.50	5.02	6.53	6.92	8.24	6.92	6.90
11	9.00	10.89	8.49	8.51	7.38	5.65	4.87	4.60	6.29	6.60	7.69	6.10	6.90
12	8.48	10.35	8.02	8.08	8.04	6.27	4.76	4.19	6.23	6.91	7.69	6.74	6.94
13	8.33	9.88	8.00	8.37	8.70	7.02	5.36	4.72	5.87	6.57	7.99	7.36	7.21
14	7.47	9.54	8.26	9.67	8.32	7.56	5.63	5.05	5.68	6.39	7.89	7.78	7.35
15	7.81	10.24	8.75	10.50	9.48	7.55	6.49	5.45	6.43	6.34	8.58	7.80	7.85
16	7.26	10.17	8.87	9.52	10.47	8.40	7.38	6.36	7.08	7.05	8.18	8.19	8.22
17	8.37	8.19	9.47	9.88	10.51	9.05	8.36	6.30	7.84	6.99	7.48	8.43	8.45
18	8.01	8.62	8.57	9.13	11.11	9.91	8.46	7.14	8.57	7.28	7.82	8.33	8.68
19	6.87	8.49	8.22	9.39	9.95	9.12	8.25	7.50	8.64	7.32	8.31	7.72	8.39
20	6.68	6.98	7.64	9.11	8.70	9.09	7.85	7.57	8.39	6.79	8.71	8.36	8.09
21	7.33	6.34	7.58	8.51	8.53	9.70	8.46	8.28	8.35	7.13	7.99	7.97	8.19
22	8.01	6.65	7.84	8.23	8.07	8.99	8.09	8.21	7.93	7.28	7.28	8.49	8.03
23	8.71	7.49	7.77	7.75	7.99	8.60	7.87	7.58	8.56	6.96	7.06	7.83	7.90
Avg	8.85	9.13	8.36	8.57	8.02	7.69	6.80	6.38	7.33	7.33	8.02	7.78	7.79

m/s

3 4 5 6 7 8 9 10 11 12

Wind Speed

Figure 68: Hourly-mean values of observed 60 m wind speed at Tower M2316. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 66 and 67 (p. 122 and 123).

MOS−Corrected

Hour of Day (Local)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.30	7.38	8.35	7.65	7.13	8.49	7.86	7.25	7.85	7.50	8.15	7.73	7.91
1	9.81	8.22	7.91	7.80	7.28	7.72	7.31	6.97	7.29	7.39	8.56	7.80	7.77
2	9.91	8.94	8.84	7.67	7.81	7.56	7.45	6.46	7.47	7.81	8.45	7.72	7.90
3	10.23	8.96	8.89	7.49	7.61	7.69	6.88	6.35	7.37	7.98	8.41	7.97	7.87
4	10.19	9.50	8.94	7.11	7.29	7.66	6.79	6.48	7.26	8.47	8.37	8.28	7.90
5	10.19	9.46	8.83	7.70	6.79	7.55	6.77	6.49	7.18	8.49	8.44	8.26	7.87
6	9.67	9.80	8.58	8.10	6.32	6.82	6.29	6.77	7.81	7.92	8.05	8.24	7.66
7	9.73	10.48	8.65	8.35	5.92	6.19	5.75	6.41	7.32	7.87	8.17	8.06	7.47
8	10.50	11.37	8.98	8.57	5.81	5.79	5.13	5.51	6.44	7.30	8.16	7.62	7.26
9	10.10	11.57	9.11	8.72	5.92	5.49	4.64	5.39	6.31	7.46	8.24	7.65	7.18
10	8.99	10.29	8.93	8.40	6.55	5.63	4.44	5.07	6.34	7.11	8.01	7.21	6.96
11	8.84	10.78	8.86	8.47	7.03	5.63	4.64	4.56	6.27	6.53	7.63	6.57	6.87
12	8.58	10.37	8.18	8.41	7.92	6.23	4.63	4.40	6.26	6.62	7.57	6.90	6.96
13	8.27	10.17	8.10	8.81	8.38	6.96	5.77	4.56	5.93	6.71	7.71	7.54	7.27
14	7.86	9.72	8.22	10.21	8.44	6.99	6.04	5.06	5.71	6.43	7.83	7.78	7.40
15	7.85	10.29	8.82	10.78	9.36	7.59	6.52	5.42	6.39	6.49	8.21	7.96	7.87
16	7.50	9.93	9.00	10.09	10.24	8.36	7.64	6.00	7.17	6.88	8.16	8.32	8.25
17	7.70	8.94	9.15	10.46	10.53	9.28	8.19	6.64	7.68	7.29	7.36	8.75	8.55
18	7.50	8.50	8.76	9.67	10.82	9.99	8.06	7.65	8.22	7.38	8.00	8.64	8.71
19	6.72	8.27	8.61	9.29	10.05	9.35	7.95	7.38	8.38	7.41	8.18	8.47	8.43
20	6.80	6.99	8.10	9.23	8.84	9.01	8.30	7.40	8.38	7.39	8.40	8.58	8.22
21	7.35	6.50	7.65	8.49	8.70	9.34	8.34	8.11	8.27	7.15	7.86	8.28	8.15
22	7.98	6.74	7.86	8.12	8.12	9.20	7.86	8.41	7.91	7.22	7.27	8.47	8.05
23	8.84	7.10	8.09	7.91	7.75	8.68	7.73	7.51	8.16	7.08	7.10	7.89	7.88
Avg	8.77	9.20	8.56	8.67	7.94	7.63	6.71	6.35	7.23	7.33	8.01	7.94	7.80

Wind Speed (m/s): 3 4 5 6 7 8 9 10 11 12

Figure 69: Hourly-mean values of MOS-corrected 60 m wind speed at Tower M2316. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 66 and 67 (p. 122 and 123).

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	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.02	0.09
0.5 - 1.5	0.10	0.14	0.12	0.19	0.15	0.12	0.08	0.11	0.09	0.09	0.08	0.09	0.10	0.11	0.10	0.11	1.77
1.5 - 2.5	0.28	0.35	0.26	0.24	0.22	0.30	0.34	0.41	0.41	0.46	0.35	0.36	0.35	0.22	0.24	0.24	5.04
2.5 - 3.5	0.39	0.42	0.57	0.72	0.34	0.28	0.45	0.59	0.68	0.54	0.59	0.44	0.55	0.44	0.30	0.37	7.67
3.5 - 4.5	0.44	0.45	0.58	0.73	0.36	0.48	0.48	0.78	0.87	0.79	0.74	0.67	0.68	0.44	0.50	0.54	9.54
4.5 - 5.5	0.51	0.47	0.51	0.92	0.54	0.48	0.46	0.45	0.87	0.76	0.73	0.77	0.94	0.69	0.67	0.62	10.39
5.5 - 6.5	0.47	0.39	0.54	0.75	0.34	0.46	0.58	0.62	0.88	0.90	0.81	0.73	1.06	0.78	0.65	0.43	10.39
6.5 - 7.5	0.55	0.34	0.47	0.51	0.29	0.42	0.40	0.37	0.44	0.55	0.74	0.78	1.10	0.81	0.55	0.52	8.84
7.5 - 8.5	0.28	0.30	0.29	0.40	0.30	0.31	0.36	0.31	0.59	0.54	0.48	0.54	1.13	1.05	0.47	0.45	7.79
8.5 - 9.5	0.28	0.24	0.33	0.29	0.13	0.13	0.24	0.29	0.53	0.85	0.55	0.55	1.51	1.09	0.17	0.34	7.51
9.5 - 10.5	0.20	0.20	0.11	0.17	0.00	0.04	0.13	0.08	0.57	0.77	0.34	0.46	1.55	1.03	0.39	0.17	6.21
10.5 - 11.5	0.19	0.08	0.11	0.11	0.00	0.01	0.07	0.15	0.56	0.69	0.34	0.41	1.65	1.08	0.14	0.25	5.85
11.5 - 12.5	0.09	0.01	0.03	0.03	0.00	0.02	0.02	0.09	0.37	0.58	0.21	0.37	1.72	1.07	0.20	0.09	4.91
12.5 - 13.5	0.06	0.02	0.07	0.01	0.00	0.00	0.03	0.04	0.42	0.40	0.26	0.35	1.38	0.62	0.12	0.08	3.85
13.5 - 14.5	0.02	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.19	0.31	0.11	0.29	1.13	0.67	0.09	0.03	2.90
14.5 - 15.5	0.01	0.00	0.02	0.03	0.01	0.00	0.01	0.00	0.15	0.29	0.20	0.20	0.87	0.34	0.08	0.00	2.21
15.5 - 16.5	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.11	0.20	0.15	0.24	0.63	0.30	0.02	0.00	1.70
16.5 - 17.5	0.02	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.04	0.07	0.09	0.18	0.45	0.15	0.00	0.01	1.03
17.5 - 18.5	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.03	0.14	0.29	0.07	0.01	0.00	0.66
18.5 - 19.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.02	0.06	0.28	0.06	0.00	0.00	0.47
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.10	0.14	0.01	0.00	0.00	0.33
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.07	0.02	0.00	0.00	0.17
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.13	0.00	0.00	0.00	0.17
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.07	0.00	0.00	0.00	0.10
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.00	0.00	0.00	0.08
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.07	0.00	0.00	0.00	0.17

Table 58: Distribution of observed 60 m wind speed by direction at Tower M2316. Histogram of data is available in Figure 62 (p. 118).

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	0.00	0.01	0.06	0.08	0.08	0.15	0.09	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.50
0.5 - 1.5	0.02	0.02	0.07	0.14	0.21	0.21	0.17	0.21	0.11	0.06	0.03	0.03	0.01	0.04	0.03	0.00	1.37
1.5 - 2.5	0.15	0.30	0.36	0.35	0.40	0.39	0.54	0.72	0.58	0.26	0.23	0.22	0.17	0.13	0.11	0.13	5.04
2.5 - 3.5	0.45	0.39	0.50	0.47	0.59	0.46	0.65	0.65	0.58	0.57	0.64	0.47	0.40	0.35	0.25	0.28	7.71
3.5 - 4.5	0.37	0.56	0.36	0.51	0.58	0.79	0.89	0.89	0.69	0.66	0.61	0.65	0.64	0.54	0.41	0.42	9.58
4.5 - 5.5	0.53	0.50	0.33	0.47	0.45	0.57	0.73	0.61	0.70	0.62	0.59	0.91	1.07	0.90	0.76	0.66	10.40
5.5 - 6.5	0.44	0.39	0.33	0.32	0.44	0.31	0.70	0.53	0.61	0.66	0.72	0.97	1.27	1.53	0.65	0.55	10.40
6.5 - 7.5	0.21	0.35	0.23	0.19	0.15	0.18	0.54	0.52	0.55	0.43	0.72	0.96	1.52	1.37	0.58	0.36	8.85
7.5 - 8.5	0.36	0.28	0.18	0.20	0.14	0.25	0.25	0.33	0.32	0.44	0.58	0.91	1.43	1.44	0.43	0.23	7.78
8.5 - 9.5	0.22	0.21	0.09	0.04	0.12	0.12	0.18	0.33	0.48	0.50	0.63	0.73	1.82	1.42	0.44	0.18	7.50
9.5 - 10.5	0.13	0.18	0.07	0.06	0.03	0.02	0.10	0.17	0.40	0.66	0.30	0.52	1.72	1.41	0.31	0.13	6.19
10.5 - 11.5	0.10	0.10	0.02	0.09	0.02	0.03	0.06	0.12	0.32	0.45	0.35	0.72	1.74	1.38	0.23	0.11	5.83
11.5 - 12.5	0.04	0.07	0.04	0.02	0.02	0.01	0.03	0.02	0.30	0.37	0.23	0.63	1.66	1.18	0.19	0.06	4.88
12.5 - 13.5	0.09	0.01	0.08	0.01	0.02	0.00	0.02	0.04	0.23	0.32	0.12	0.55	1.34	0.90	0.06	0.06	3.85
13.5 - 14.5	0.01	0.02	0.03	0.02	0.01	0.00	0.00	0.03	0.13	0.24	0.14	0.52	1.09	0.58	0.02	0.02	2.88
14.5 - 15.5	0.03	0.02	0.01	0.00	0.00	0.01	0.03	0.03	0.12	0.17	0.12	0.30	0.83	0.52	0.01	0.01	2.21
15.5 - 16.5	0.02	0.00	0.01	0.00	0.01	0.02	0.01	0.03	0.12	0.25	0.08	0.28	0.58	0.22	0.02	0.03	1.70
16.5 - 17.5	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.06	0.22	0.02	0.22	0.40	0.07	0.00	0.01	1.03
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	0.01	0.09	0.31	0.09	0.02	0.02	0.66
18.5 - 19.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.06	0.00	0.08	0.22	0.06	0.00	0.03	0.47
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.01	0.04	0.17	0.06	0.00	0.02	0.33
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.11	0.01	0.00	0.01	0.17
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.07	0.04	0.02	0.01	0.00	0.17
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.00	0.00	0.10
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.02	0.00	0.00	0.08
> 24.5	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.10	0.02	0.00	0.00	0.17

Table 59: Distribution of MOS-corrected $60\,m$ wind speed by direction at Tower M2316. All model values are computed only for times with valid observations. Histogram of data is available in Figure 62 (p. 118).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.25	7.06	2.14	3.88
NNE	5.47	6.18	2.06	3.46
NE	5.92	6.68	2.05	4.10
ENE	5.52	6.23	2.34	5.09
E	5.03	5.67	2.41	2.69
ESE	5.26	5.93	2.53	3.07
SE	5.66	6.39	2.22	3.70
SSE	5.51	6.22	2.13	4.32
S	7.47	8.44	2.11	7.82
SSW	8.35	9.42	2.15	9.00
SW	7.49	8.45	1.98	6.89
WSW	8.95	10.07	1.81	8.01
W	10.46	11.79	2.50	17.91
WNW	9.36	10.53	2.67	11.08
NW	6.84	7.72	2.22	4.70
NNW	6.33	7.15	2.27	4.28
ALL	**7.79**	**8.79**	**1.96**	**100.00**

Table 60: Observed 60 m mean wind speed, Weibull parameters, and frequency at Tower M2316. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 63 (p. 119).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.27	7.08	2.11	3.23
NNE	5.90	6.66	2.05	3.40
NE	5.36	6.04	1.83	2.73
ENE	4.77	5.38	1.87	2.96
E	4.50	5.06	1.83	3.30
ESE	4.63	5.21	1.82	3.47
SE	4.96	5.58	1.88	5.07
SSE	5.32	5.97	1.74	5.36
S	7.24	8.15	1.84	6.44
SSW	8.49	9.58	2.08	7.05
SW	7.26	8.19	2.18	6.16
WSW	9.07	10.25	2.22	9.95
W	10.37	11.68	2.60	18.72
WNW	9.31	10.46	2.73	14.29
NW	7.02	7.91	2.51	4.54
NNW	6.65	7.51	2.05	3.33
ALL	**7.80**	**8.79**	**1.95**	**100.00**

Table 61: MOS-corrected 60 m mean wind speed, Weibull parameters, and frequency at Tower M2316. 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 63 (p. 119).

12.4 Validation of Model Results at Tower M2317

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 M2317 (latitude 37.53212, longitude -104.4906).

The average observed wind speed (for all valid observational times) at $60\,m$ during the 15 months of the period of record (June, 2010 to August, 2011) is $7.50\,m/s$ with an hourly standard deviation of $4.04\,m/s$ at Tower M2317. This compares to a modeled $60\,m$ wind speed of $7.79\,m/s$ with a $3.92\,m/s$ 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 M2317 results in a MOS-corrected mean value of $7.51\,m/s$ and an hourly standard deviation of $4.04\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2317). 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 15 months of wind speed data at 60 $meters$ and wind direction data at 59 $meters$ (June, 2010 to August, 2011) from a meteorological tower (Tower M2317) at La Cumbre 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 Vaisala are not allowed to influence the raw model simulations.

12.4.2 Model Validation Statistics

Table 62 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	0.96
RMS error of monthly-mean simulated wind speed	0.37 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	1.00
RMS error of monthly-mean MOS-corrected wind speed	0.11 m/s
Correlation of daily-mean simulated wind speed to observed	0.82
RMS error of daily-mean simulated wind speed	1.54 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.85
RMS error of daily-mean MOS-corrected wind speed	1.34 m/s

Table 62: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.4.3 Monthly Mean Wind Speed

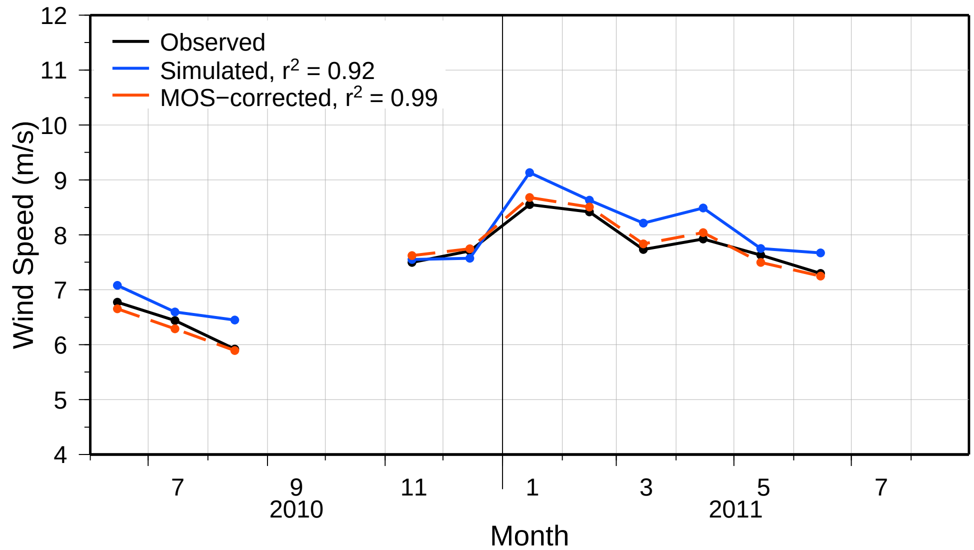

Figure 70: A comparison of the observed, simulated, and MOS-corrected monthly-mean $60\,m$ wind speed at Tower M2317. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 63 (p. 139).

12.4.4 Wind Speed Distribution

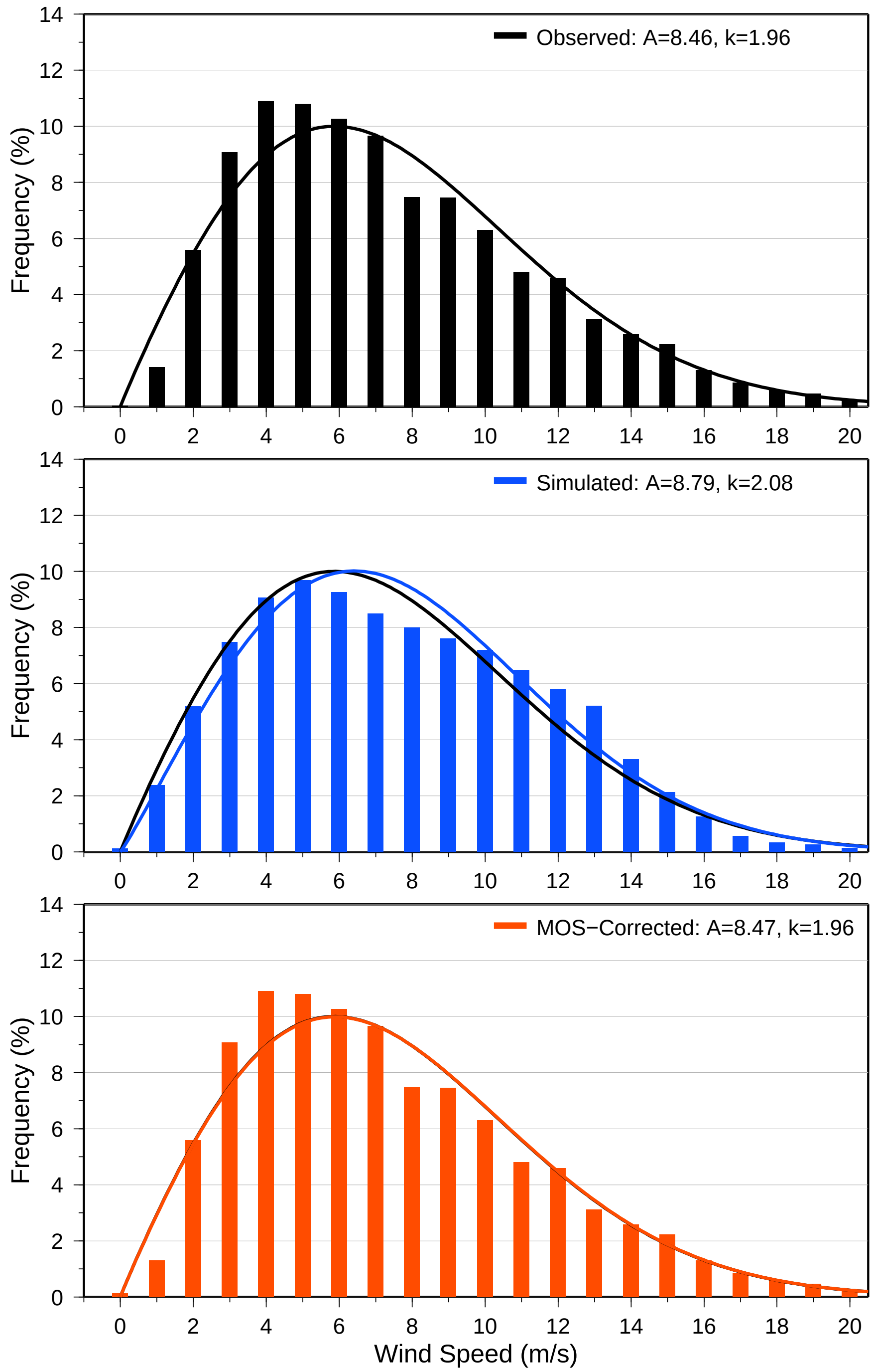

Figure 71: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $60\,m$ at Tower M2317 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend. Tabular formatted data are available in Tables 64 and 65 (p. 142 and 143).

12.4.5 Wind Direction Distribution

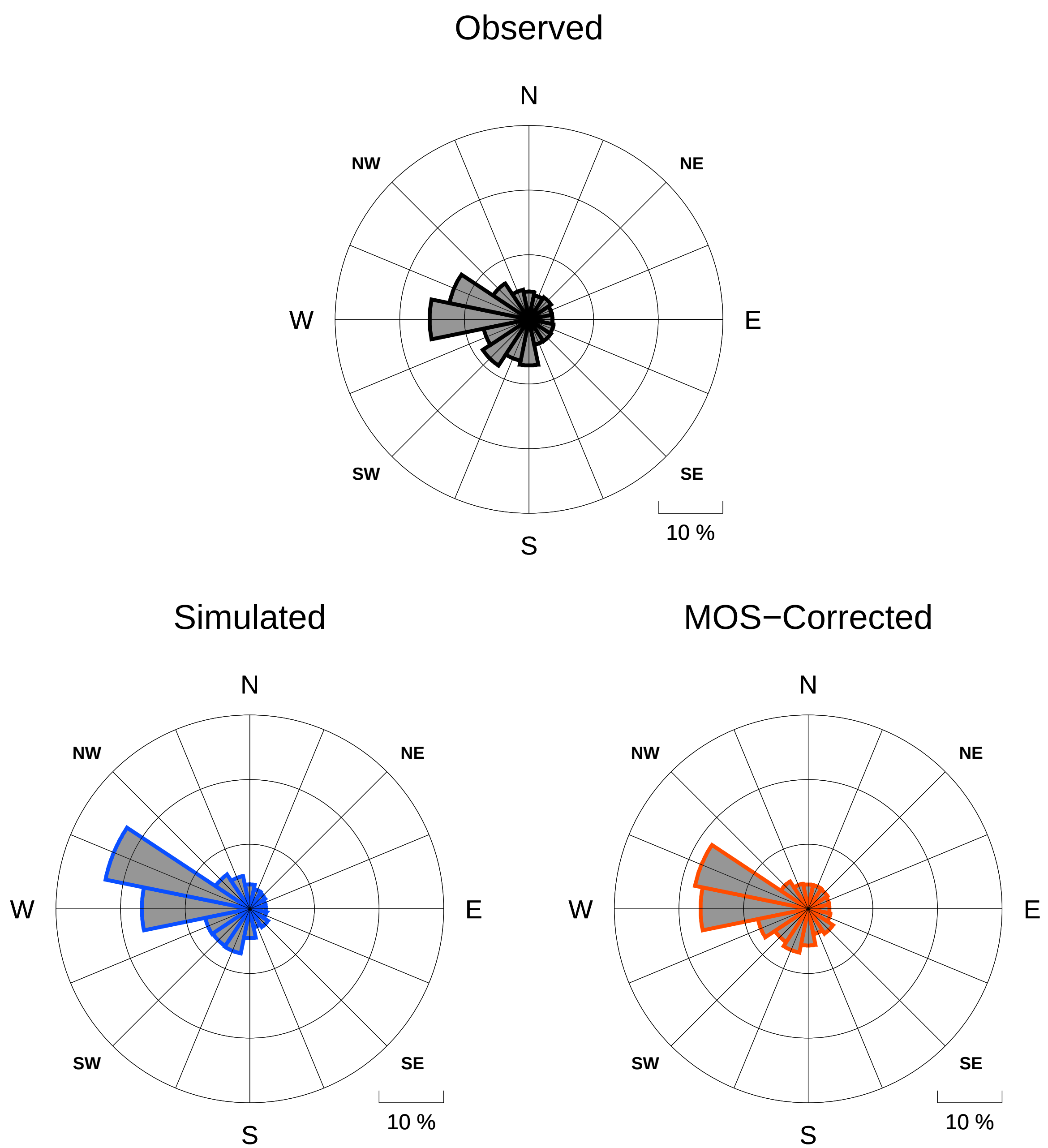

Figure 72: Wind roses at $59\,m$ at Tower M2317 for observational data and simulated model data, averaged over the period of record (June, 2010–August, 2011). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 66 and 67 (p. 144).

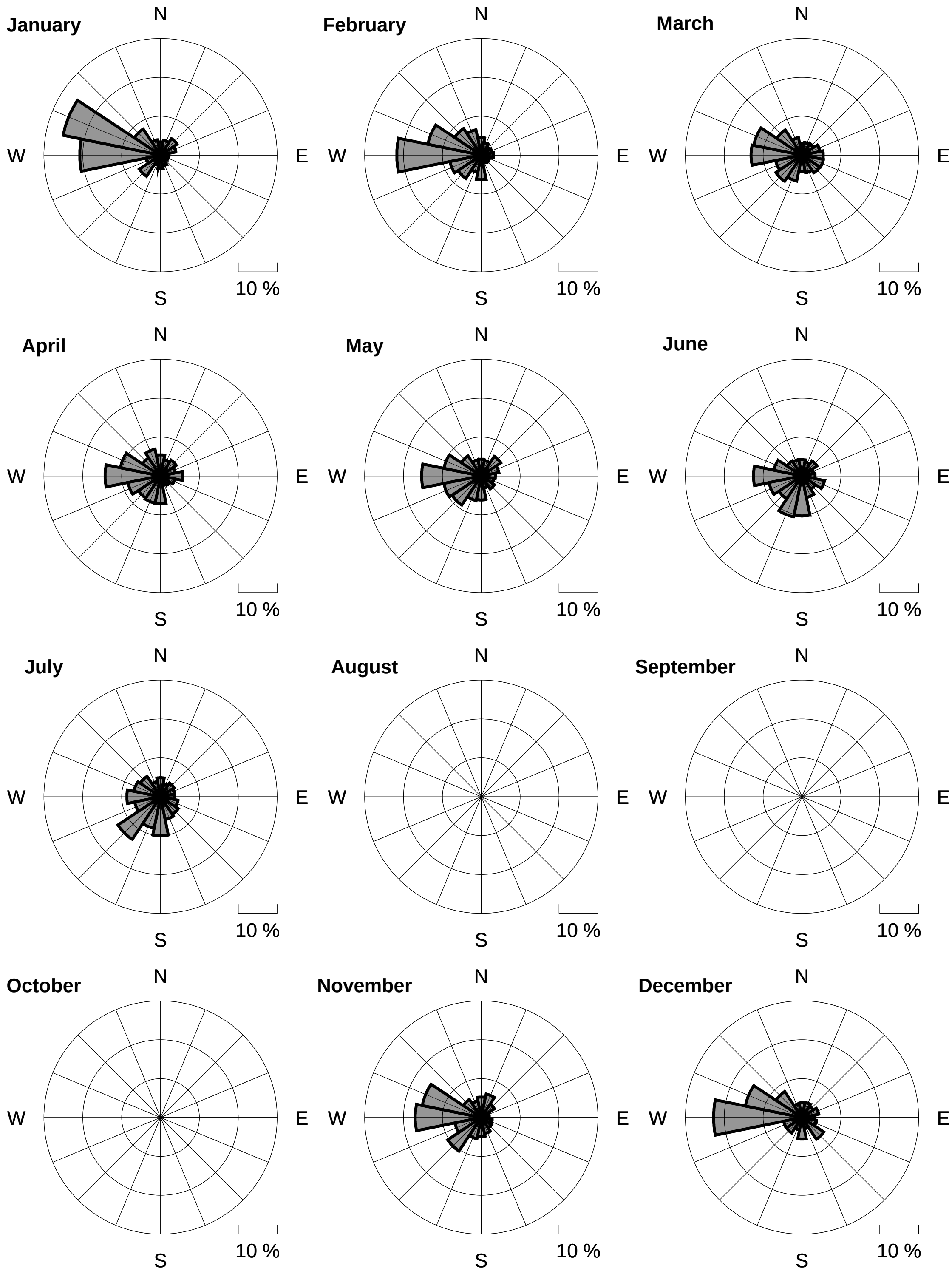

Figure 73: Wind rose of observed wind direction at 59 m at Tower M2317 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

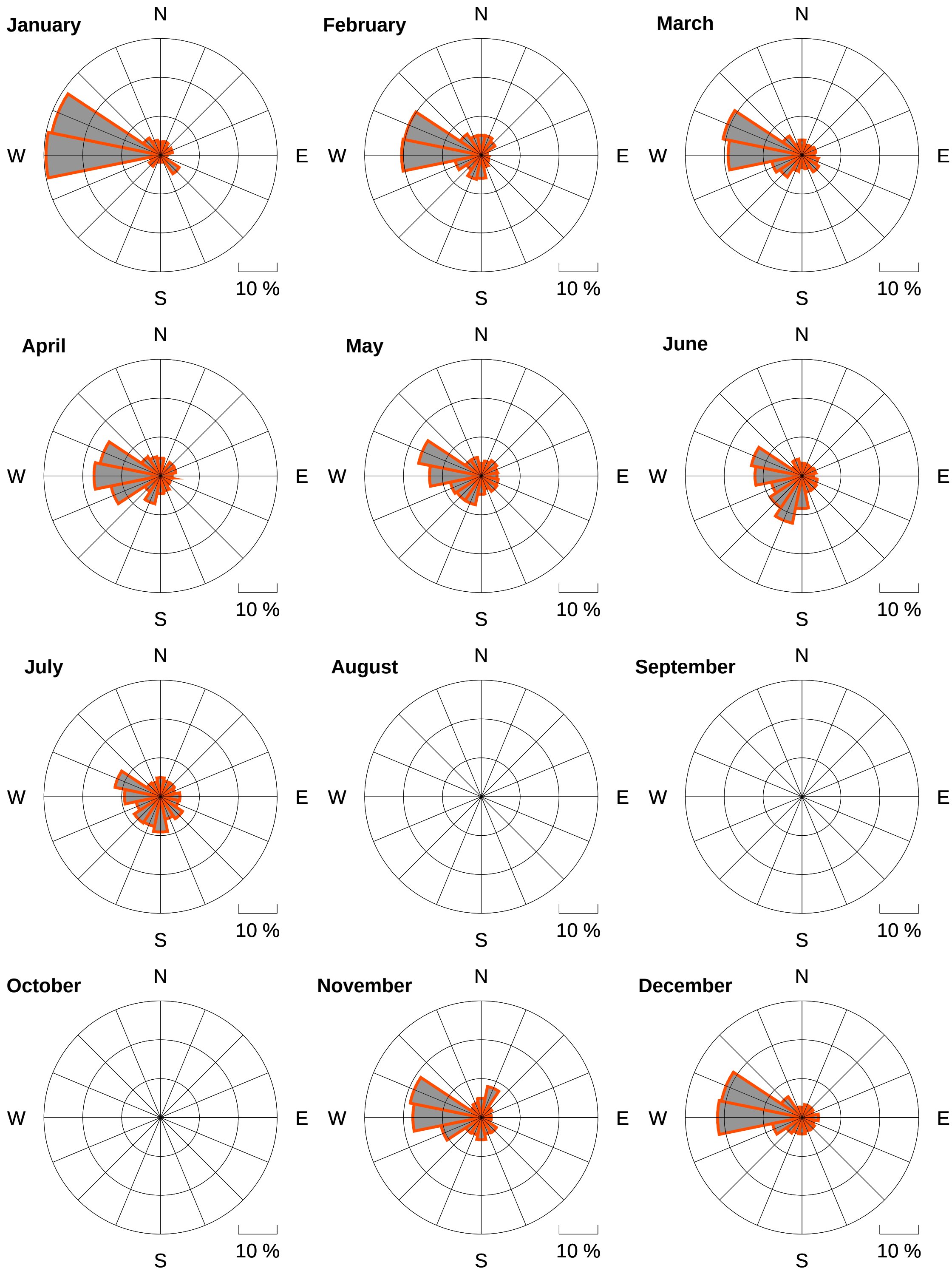

Figure 74: Wind rose of MOS-corrected wind direction at 59 m at Tower M2317 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.4.6 Diurnal Variability of Wind Speed

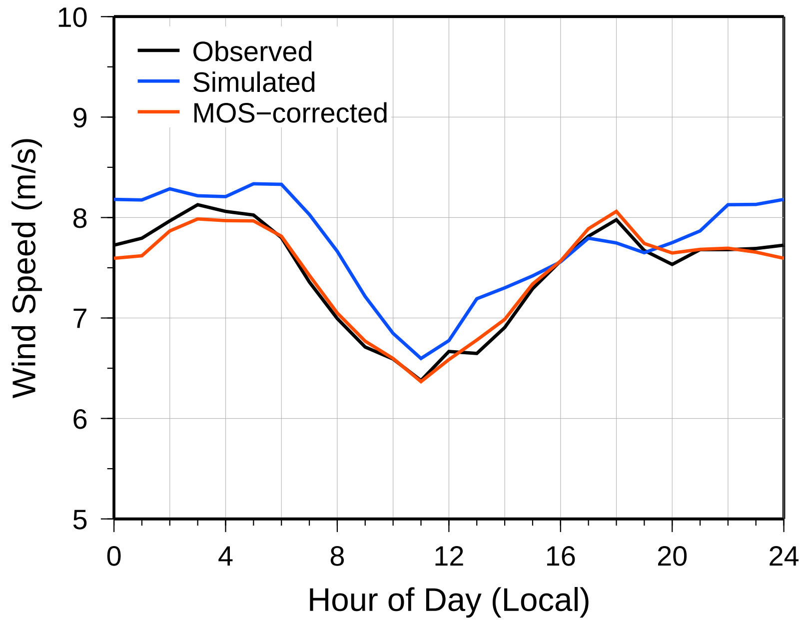

Figure 75: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed at Tower M2317. Data are averaged over the period of record (June, 2010–August, 2011). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data are available in Figures 77 and 78 (p. 140 and 141).

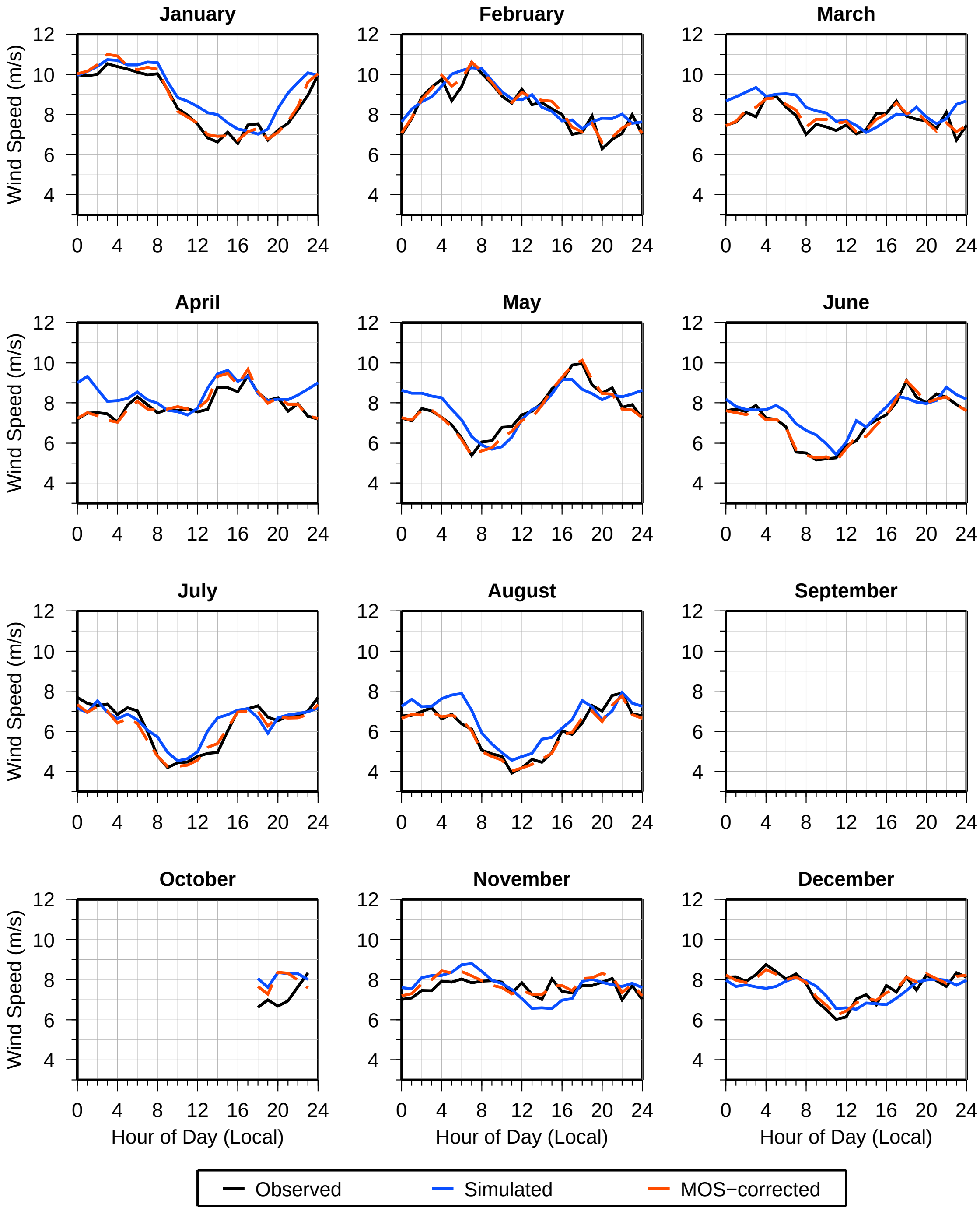

Figure 76: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed for each calendar month at Tower M2317. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data available in Figures 77 and 78 (p. 140 and 141).

12.4.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
06/2010	6.77	7.08	0.31	6.65	66.4
07/2010	6.44	6.59	0.15	6.29	99.9
08/2010	5.92	6.45	0.53	5.89	83.2
09/2010	–	–	–	–	0.0
10/2010	8.20	8.47	0.27	8.13	47.6
11/2010	7.50	7.55	0.05	7.62	92.9
12/2010	7.71	7.57	-0.13	7.75	93.1
01/2011	8.55	9.13	0.59	8.68	87.4
02/2011	8.42	8.63	0.22	8.51	85.6
03/2011	7.73	8.21	0.48	7.84	93.8
04/2011	7.93	8.49	0.56	8.04	97.2
05/2011	7.63	7.75	0.12	7.50	100.0
06/2011	7.30	7.67	0.37	7.25	86.4
07/2011	6.01	6.02	0.01	5.87	35.5
08/2011	8.05	8.48	0.43	7.52	6.2
All	**7.50**	**7.79**	**0.28**	**7.51**	**71.7**

Table 63: Monthly-mean 60 m wind speeds (m/s) at Tower M2317. Time series graph of data is available in Figure 70 (p. 132). 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 (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.98	6.99	7.46	7.19	7.24	7.62	7.70	6.77	--	--	7.01	8.13	7.73
1	9.93	7.79	7.62	7.49	7.11	7.69	7.39	6.80	--	--	7.08	8.14	7.80
2	10.01	8.87	8.11	7.52	7.72	7.57	7.29	6.99	--	--	7.45	7.91	7.97
3	10.54	9.36	7.89	7.46	7.60	7.87	7.36	7.18	--	--	7.44	8.24	8.13
4	10.39	9.76	8.87	7.04	7.27	7.24	6.84	6.63	--	--	7.92	8.75	8.06
5	10.27	8.68	8.92	7.89	6.91	7.18	7.18	6.85	--	--	7.88	8.40	8.02
6	10.11	9.40	8.37	8.30	6.25	6.81	7.03	6.38	--	--	8.03	8.03	7.80
7	9.98	10.62	7.94	7.92	5.39	5.55	5.99	6.10	--	--	7.84	8.28	7.36
8	10.03	10.04	7.01	7.50	6.05	5.50	4.77	5.06	--	--	7.93	7.81	6.99
9	9.24	9.52	7.52	7.69	6.11	5.16	4.20	4.88	--	--	7.95	6.92	6.71
10	8.29	8.92	7.38	7.63	6.79	5.22	4.44	4.75	--	--	7.88	6.49	6.59
11	7.97	8.57	7.20	7.71	6.82	5.27	4.47	3.93	--	--	7.33	6.02	6.38
12	7.51	9.26	7.48	7.55	7.40	5.86	4.75	4.18	--	--	7.84	6.14	6.67
13	6.83	8.49	7.03	7.68	7.59	6.11	4.91	4.61	--	--	7.27	7.04	6.65
14	6.63	8.60	7.25	8.78	7.99	6.84	4.95	4.47	--	--	7.01	7.26	6.91
15	7.12	8.28	8.04	8.76	8.70	7.14	6.02	4.95	--	--	8.03	6.73	7.29
16	6.56	8.00	8.07	8.56	9.12	7.41	7.03	6.02	--	--	7.41	7.71	7.57
17	7.48	6.98	8.60	9.43	9.71	7.98	7.21	6.15	--	--	7.00	7.62	7.81
18	7.54	7.16	7.84	8.31	10.02	9.04	7.57	6.40	--	--	7.32	8.41	7.98
19	6.72	7.98	7.77	7.94	9.03	8.24	6.93	7.12	--	--	7.32	7.81	7.67
20	7.22	6.40	7.56	8.34	8.36	7.98	6.73	6.91	--	--	7.46	8.49	7.53
21	7.56	6.92	7.15	7.72	8.55	8.41	6.96	7.66	--	--	7.75	8.09	7.68
22	8.24	7.32	7.88	8.10	7.67	8.19	6.95	7.78	--	--	6.58	7.88	7.68
23	8.96	8.03	6.74	7.46	7.73	7.89	7.18	6.83	--	--	7.23	8.60	7.69
Avg	8.55	8.42	7.73	7.93	7.63	7.07	6.33	6.07	--	--	7.50	7.71	7.50

Wind Speed (m/s): 3 4 5 6 7 8 9 10 11 12

Figure 77: Hourly-mean values of observed 60 *m* wind speed at Tower M2317. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 75 and 76 (p. 137 and 138).

MOS−Corrected

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	10.04	7.07	7.44	7.23	7.27	7.61	7.34	6.65	--	--	7.19	8.23	7.59
1	10.16	7.83	7.66	7.52	7.14	7.51	6.95	6.85	--	--	7.30	7.97	7.62
2	10.48	8.76	8.21	7.36	7.64	7.42	7.25	6.80	--	--	7.80	7.85	7.87
3	11.00	9.27	8.37	7.15	7.64	7.57	7.01	6.96	--	--	7.99	8.06	7.99
4	10.91	9.96	8.79	7.04	7.26	7.16	6.42	6.73	--	--	8.44	8.50	7.97
5	10.41	9.42	8.84	7.67	6.78	7.19	6.63	6.80	--	--	8.33	8.27	7.97
6	10.23	9.76	8.51	8.08	6.17	6.76	6.40	6.59	--	--	8.40	8.00	7.81
7	10.35	10.61	8.22	7.69	5.37	5.68	5.54	6.02	--	--	8.19	8.12	7.42
8	10.26	10.16	7.38	7.62	5.61	5.39	4.76	4.99	--	--	7.94	7.87	7.05
9	9.19	9.60	7.77	7.69	5.77	5.26	4.24	4.75	--	--	7.72	7.15	6.77
10	8.17	8.96	7.76	7.82	6.27	5.31	4.25	4.57	--	--	7.60	6.72	6.60
11	7.87	8.60	7.56	7.69	6.58	5.10	4.32	4.03	--	--	7.28	6.21	6.37
12	7.57	9.11	7.64	7.71	7.13	5.73	4.56	4.18	--	--	7.46	6.43	6.59
13	6.99	8.84	7.13	8.15	7.25	6.31	5.21	4.35	--	--	7.27	6.84	6.78
14	6.92	8.72	7.23	9.32	7.89	6.33	5.39	4.62	--	--	7.24	7.06	6.98
15	6.94	8.66	7.76	9.46	8.65	6.89	6.17	4.92	--	--	7.67	6.96	7.34
16	6.71	8.12	8.03	8.91	9.28	7.36	6.97	5.84	--	--	7.70	7.34	7.57
17	7.15	7.38	8.55	9.73	9.68	8.10	7.28	6.01	--	--	6.89	7.92	7.89
18	7.31	7.16	8.00	8.68	9.88	8.91	7.34	6.78	--	--	7.53	8.50	8.06
19	6.78	7.63	7.98	8.12	9.04	8.30	6.68	7.06	--	--	7.59	8.25	7.74
20	7.11	6.76	7.48	8.37	8.30	7.81	6.97	6.63	--	--	7.76	8.67	7.65
21	7.65	6.95	7.09	8.03	8.31	8.00	6.94	7.30	--	--	7.60	8.40	7.68
22	8.40	7.36	7.56	8.05	7.58	8.28	6.73	7.74	--	--	6.81	8.13	7.70
23	9.62	7.47	7.27	7.55	7.49	7.87	6.96	6.75	--	--	7.23	8.49	7.65
Avg	8.68	8.51	7.84	8.04	7.50	6.99	6.18	6.01	--	--	7.62	7.75	7.51

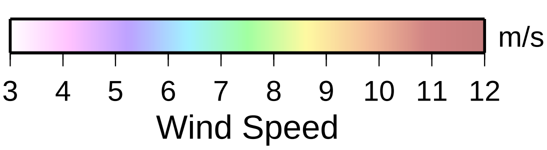

Figure 78: Hourly-mean values of MOS-corrected 60 m wind speed at Tower M2317. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 75 and 76 (p. 137 and 138).

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	0.01	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	0.00	0.04
0.5 - 1.5	0.06	0.06	0.11	0.09	0.10	0.14	0.10	0.08	0.06	0.08	0.11	0.14	0.09	0.01	0.09	0.08	1.41
1.5 - 2.5	0.24	0.24	0.37	0.31	0.37	0.53	0.51	0.42	0.52	0.28	0.36	0.41	0.19	0.27	0.27	0.28	5.56
2.5 - 3.5	0.33	0.32	0.57	0.52	0.66	0.65	0.73	0.70	1.02	0.65	0.57	0.42	0.61	0.42	0.50	0.32	8.99
3.5 - 4.5	0.50	0.51	0.66	0.61	0.76	0.59	0.66	0.98	1.03	0.74	0.69	0.55	0.70	0.57	0.57	0.57	10.69
4.5 - 5.5	0.51	0.51	0.50	0.73	0.70	0.66	0.87	0.64	0.67	0.61	0.80	0.71	0.80	0.61	0.80	0.52	10.64
5.5 - 6.5	0.57	0.71	0.45	0.55	0.29	0.47	0.53	0.48	0.75	0.59	0.84	0.76	0.67	0.94	0.87	0.71	10.20
6.5 - 7.5	0.60	0.45	0.42	0.46	0.38	0.42	0.38	0.32	0.74	0.65	0.81	0.64	0.89	0.90	0.83	0.73	9.61
7.5 - 8.5	0.43	0.37	0.48	0.17	0.22	0.23	0.09	0.14	0.57	0.56	0.90	0.43	0.88	0.88	0.73	0.36	7.43
8.5 - 9.5	0.36	0.25	0.23	0.08	0.10	0.14	0.11	0.08	0.51	0.75	1.06	0.79	1.12	0.87	0.65	0.32	7.41
9.5 - 10.5	0.29	0.10	0.11	0.10	0.00	0.04	0.01	0.08	0.48	0.57	0.89	0.55	1.45	0.79	0.53	0.28	6.29
10.5 - 11.5	0.15	0.08	0.04	0.01	0.00	0.01	0.01	0.06	0.31	0.45	0.47	0.38	1.22	1.07	0.31	0.23	4.80
11.5 - 12.5	0.13	0.08	0.05	0.00	0.01	0.00	0.00	0.01	0.19	0.24	0.27	0.28	1.54	1.41	0.22	0.14	4.57
12.5 - 13.5	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.14	0.23	0.24	1.06	1.01	0.13	0.06	3.11
13.5 - 14.5	0.03	0.03	0.05	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.18	0.23	1.15	0.70	0.10	0.01	2.57
14.5 - 15.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.06	0.03	0.10	0.15	0.92	0.92	0.00	0.01	2.22
15.5 - 16.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.13	0.10	0.48	0.50	0.03	0.00	1.30
16.5 - 17.5	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.05	0.43	0.22	0.01	0.01	0.87
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.34	0.17	0.01	0.00	0.59
18.5 - 19.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10	0.23	0.10	0.01	0.00	0.47
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.06	0.01	0.00	0.24
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.15	0.03	0.00	0.00	0.19
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.04	0.00	0.00	0.11
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	0.03	0.00	0.00	0.14
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.04
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.00	0.00	0.06

Table 64: Distribution of observed 60 m wind speed by direction at Tower M2317. Histogram of data is available in Figure 71 (p. 133).

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	0.05	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.14
0.5 - 1.5	0.01	0.01	0.04	0.13	0.23	0.15	0.33	0.09	0.13	0.06	0.03	0.03	0.00	0.03	0.01	0.04	1.31
1.5 - 2.5	0.17	0.29	0.50	0.65	0.51	0.47	0.70	0.67	0.47	0.18	0.20	0.17	0.11	0.15	0.10	0.17	5.51
2.5 - 3.5	0.59	0.57	0.70	0.70	0.65	0.69	0.67	0.76	0.74	0.56	0.42	0.48	0.37	0.43	0.34	0.32	9.00
3.5 - 4.5	0.51	0.67	0.62	0.56	0.79	0.87	0.88	0.64	0.69	0.75	0.66	0.78	0.69	0.53	0.57	0.60	10.81
4.5 - 5.5	0.66	0.48	0.67	0.42	0.51	0.50	0.65	0.52	0.67	0.65	0.74	0.87	0.97	1.07	0.66	0.61	10.66
5.5 - 6.5	0.50	0.52	0.27	0.34	0.27	0.29	0.62	0.39	0.75	0.67	0.76	0.99	1.13	1.22	0.71	0.71	10.17
6.5 - 7.5	0.37	0.39	0.34	0.28	0.17	0.32	0.34	0.47	0.57	0.76	0.56	1.06	1.32	1.53	0.61	0.50	9.60
7.5 - 8.5	0.33	0.23	0.13	0.09	0.09	0.09	0.10	0.13	0.34	0.57	0.61	0.84	1.32	1.53	0.71	0.29	7.41
8.5 - 9.5	0.25	0.29	0.09	0.08	0.00	0.01	0.08	0.08	0.36	0.66	0.73	0.65	1.77	1.85	0.31	0.20	7.40
9.5 - 10.5	0.15	0.08	0.05	0.03	0.04	0.01	0.04	0.05	0.27	0.50	0.45	0.57	1.58	1.85	0.45	0.19	6.29
10.5 - 11.5	0.09	0.08	0.04	0.03	0.00	0.00	0.05	0.06	0.17	0.29	0.28	0.36	1.41	1.62	0.23	0.09	4.79
11.5 - 12.5	0.05	0.05	0.04	0.00	0.00	0.01	0.01	0.06	0.18	0.23	0.20	0.33	1.45	1.81	0.10	0.04	4.57
12.5 - 13.5	0.00	0.01	0.06	0.00	0.00	0.03	0.01	0.00	0.06	0.19	0.25	0.13	0.98	1.22	0.08	0.08	3.11
13.5 - 14.5	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.04	0.20	0.11	0.15	0.99	0.93	0.04	0.04	2.57
14.5 - 15.5	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.08	0.25	0.09	0.09	0.78	0.83	0.03	0.03	2.22
15.5 - 16.5	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.09	0.04	0.10	0.59	0.39	0.01	0.01	1.30
16.5 - 17.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.00	0.14	0.34	0.28	0.00	0.00	0.87
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.06	0.25	0.18	0.00	0.03	0.59
18.5 - 19.5	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.00	0.01	0.18	0.15	0.03	0.01	0.47
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.08	0.01	0.01	0.24
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.04	0.00	0.03	0.04	0.04	0.03	0.00	0.19
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.08	0.03	0.00	0.00	0.11
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.05	0.04	0.01	0.00	0.14
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	0.01	0.00	0.01	0.00	0.04
> 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	0.03	0.04	0.00	0.00	0.06

Table 65: Distribution of MOS-corrected $60\,m$ wind speed by direction at Tower M2317. All model values are computed only for times with valid observations. Histogram of data is available in Figure 71 (p. 133).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.53	7.37	2.35	4.31
NNE	6.01	6.77	2.42	3.80
NE	5.54	6.26	2.09	4.09
ENE	4.96	5.58	2.60	3.63
E	4.60	5.18	2.51	3.63
ESE	4.66	5.26	2.36	3.90
SE	4.57	5.15	2.43	4.04
SSE	4.72	5.33	2.31	4.02
S	6.23	7.04	2.14	7.14
SSW	7.08	7.99	2.35	6.50
SW	7.64	8.63	2.34	8.58
WSW	7.99	9.01	1.94	7.10
W	10.67	12.02	2.51	15.37
WNW	10.17	11.44	2.65	12.56
NW	7.01	7.91	2.40	6.69
NNW	6.49	7.32	2.43	4.65
ALL	**7.50**	**8.46**	**1.96**	**100.00**

Table 66: Observed 60 m mean wind speed, Weibull parameters, and frequency at Tower M2317. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 72 (p. 134).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	5.92	6.69	2.21	3.76
NNE	5.52	6.23	2.23	3.73
NE	4.86	5.48	2.08	3.58
ENE	4.24	4.79	2.10	3.32
E	3.96	4.48	2.23	3.27
ESE	4.22	4.77	1.97	3.52
SE	4.33	4.89	1.96	4.59
SSE	4.64	5.24	2.05	3.98
S	6.24	7.02	1.86	5.68
SSW	7.85	8.86	2.11	6.88
SW	7.34	8.28	2.42	6.18
WSW	7.76	8.76	2.21	7.93
W	10.17	11.44	2.69	16.62
WNW	9.94	11.17	2.78	17.89
NW	7.12	8.03	2.27	5.09
NNW	6.35	7.18	2.19	3.98
ALL	**7.51**	**8.47**	**1.96**	**100.00**

Table 67: MOS-corrected 60 m mean wind speed, Weibull parameters, and frequency at Tower M2317. 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 72 (p. 134).

12.5 Validation of Model Results at Tower M2318

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 M2318 (latitude 37.55595, longitude -104.48466). Because the calendar months of April and May were missing from the dataset, Measure-Correlate-Predict (MCP) was completed with M2250 as a reference tower to fill in these missing months in order to mitigate the potential for seasonal bias in the MOS correction. Statistics presented in this section include both observed and MCP data.

The average observed wind speed (for all valid observational times) at $61\,m$ during the 17 months of the period of record (June, 2010 to October, 2011) is $7.76\,m/s$ with an hourly standard deviation of $3.99\,m/s$ at Tower M2318. This compares to a modeled $61\,m$ wind speed of $8.13\,m/s$ with a $4.03\,m/s$ 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 M2318 results in a MOS-corrected mean value of $7.77\,m/s$ and an hourly standard deviation of $3.99\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2318). 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.

12.5.1 Observational Data

Approximately 17 months of wind speed data at 61 $meters$ and wind direction data at 59 $meters$ (June, 2010 to October, 2011) from a meteorological tower (Tower M2318) at La Cumbre were used in this analysis. This tower will be referred to as the reference tower throughout this section. The data at 61 m were used to assess the quality of the model simulations at 61 m.

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

12.5.2 Model Validation Statistics

Table 68 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	0.98
RMS error of monthly-mean simulated wind speed	0.42 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.99
RMS error of monthly-mean MOS-corrected wind speed	0.13 m/s
Correlation of daily-mean simulated wind speed to observed	0.83
RMS error of daily-mean simulated wind speed	1.54 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.86
RMS error of daily-mean MOS-corrected wind speed	1.31 m/s

Table 68: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.5.3 Monthly Mean Wind Speed

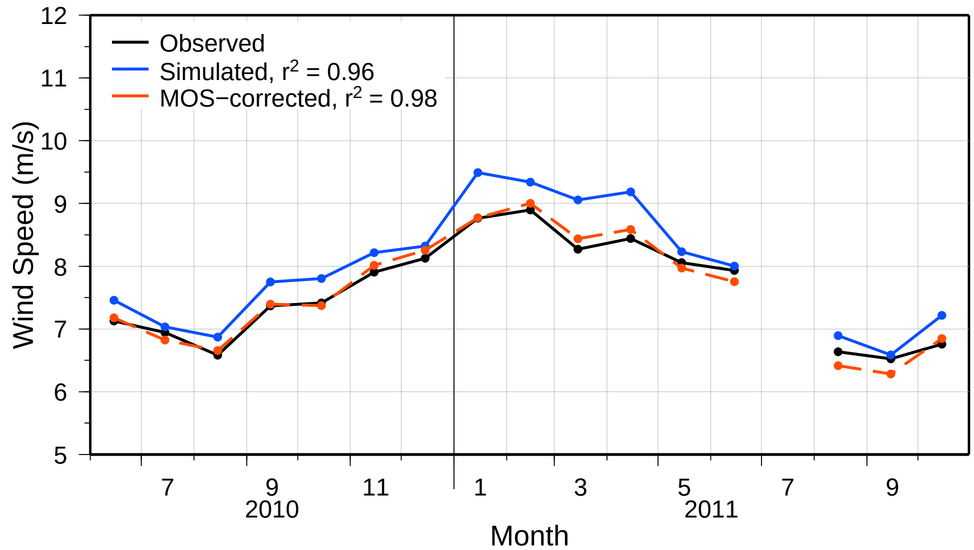

Figure 79: A comparison of the observed, simulated, and MOS-corrected monthly-mean 61 m wind speed at Tower M2318. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 69 (p. 154).

12.5.4 Wind Speed Distribution

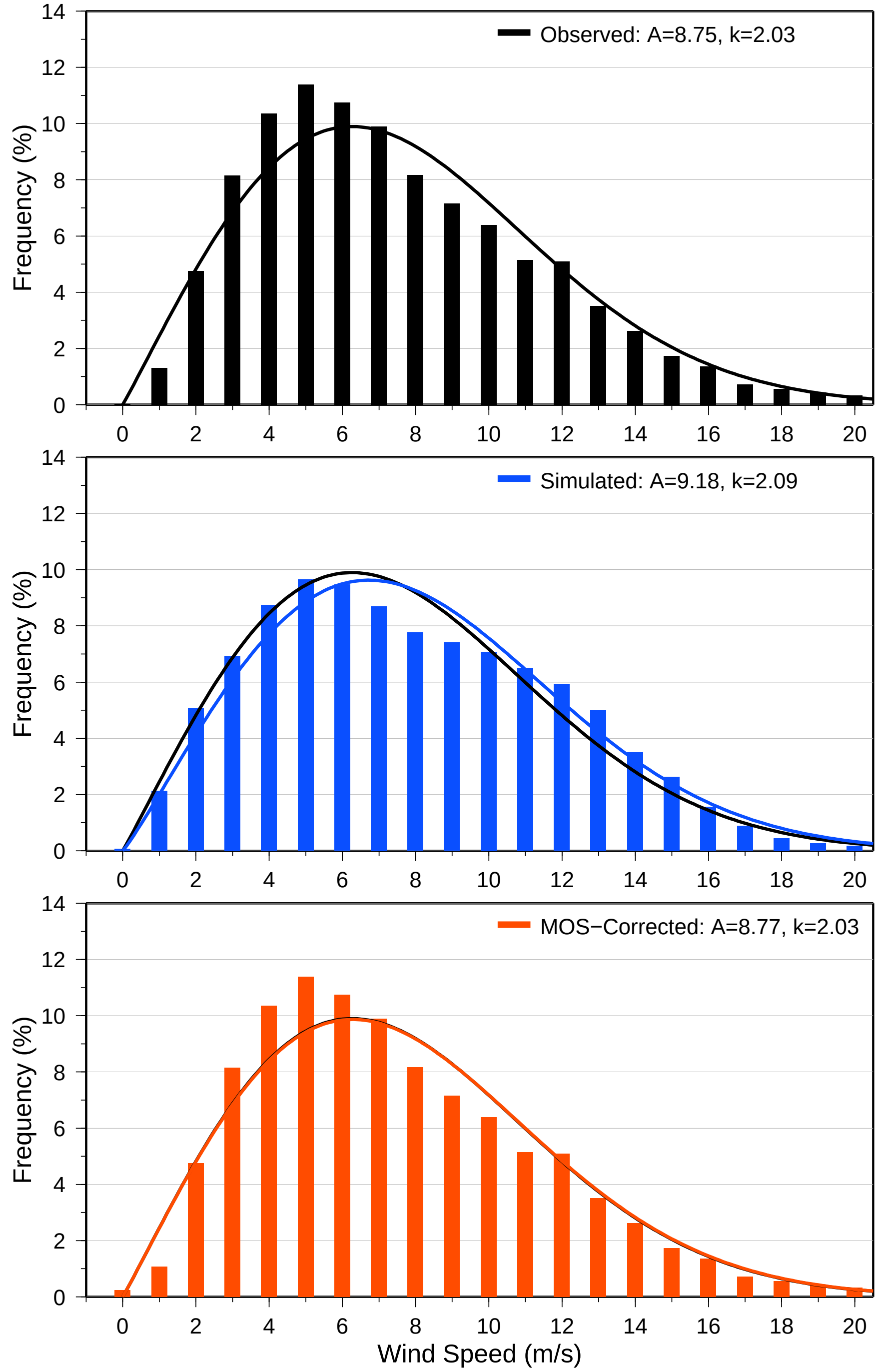

Figure 80: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at 61 m at Tower M2318 during the period of record, using 1 m/s bins. (0 m/s bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend. Tabular formatted data are available in Tables 70 and 71 (p. 157 and 158).

12.5.5 Wind Direction Distribution

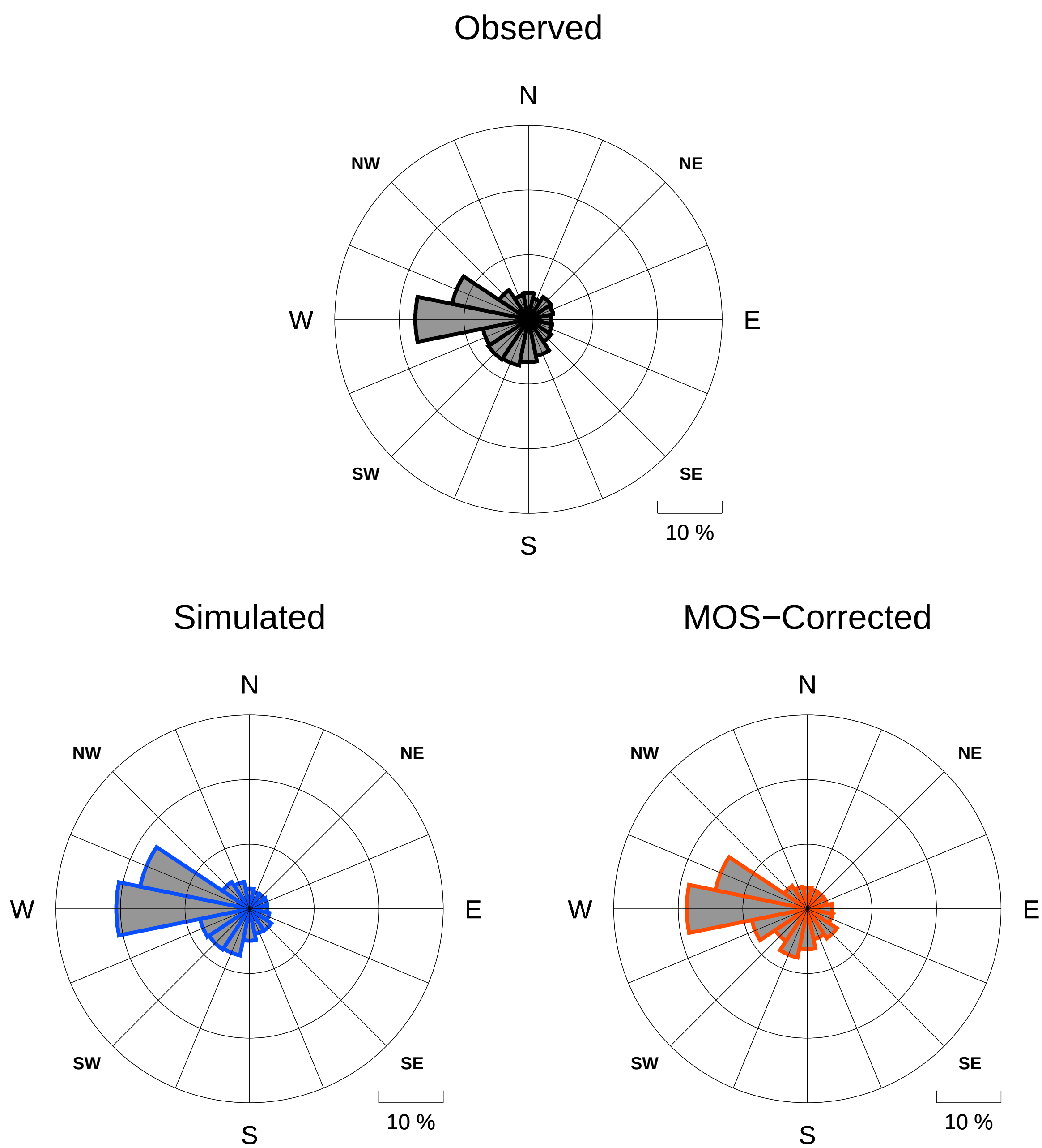

Figure 81: Wind roses at 59 m at Tower M2318 for observational data and simulated model data, averaged over the period of record (June, 2010–October, 2011). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 72 and 73 (p. 159).

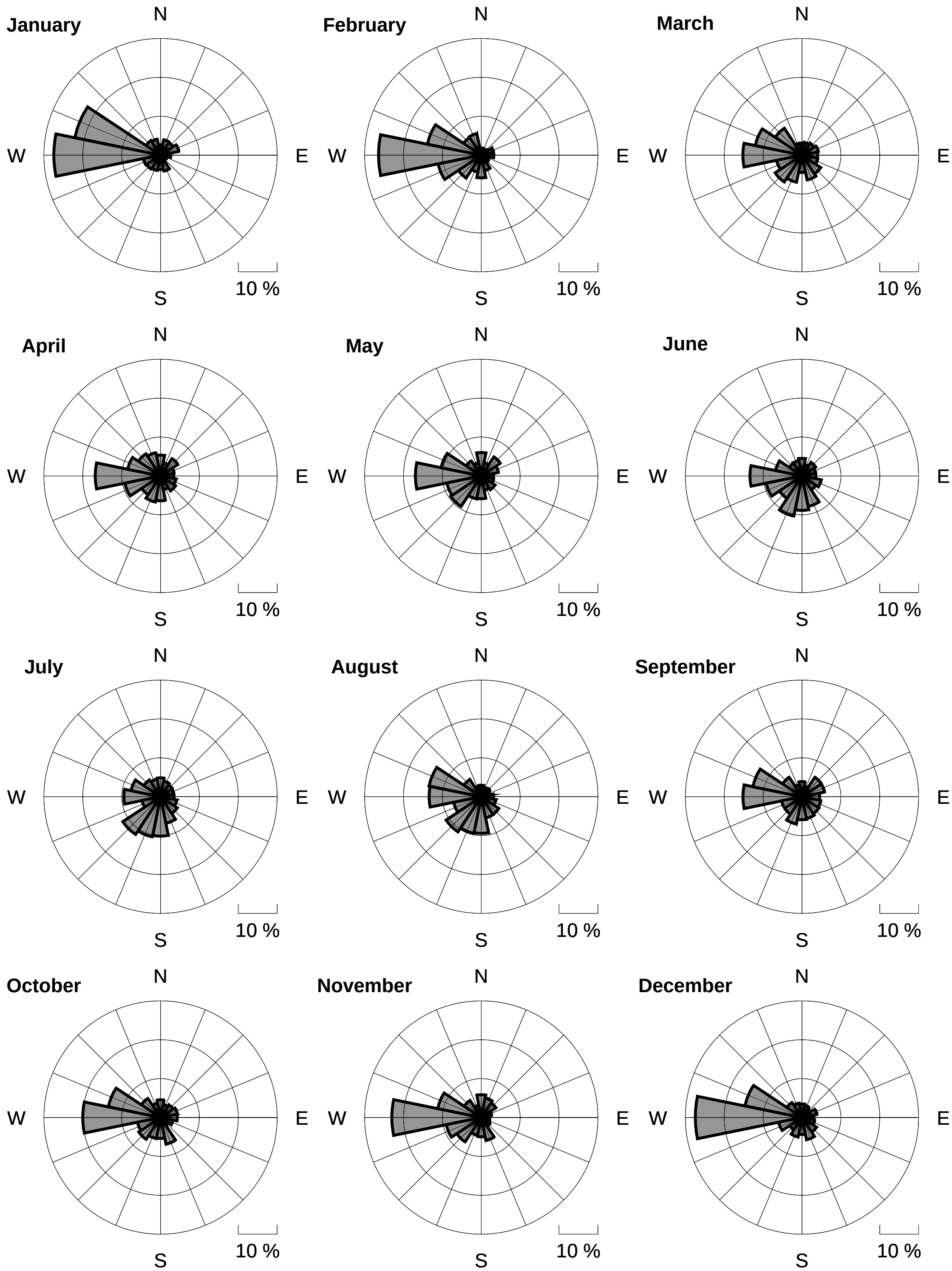

Figure 82: Wind rose of observed wind direction at 59 m at Tower M2318 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

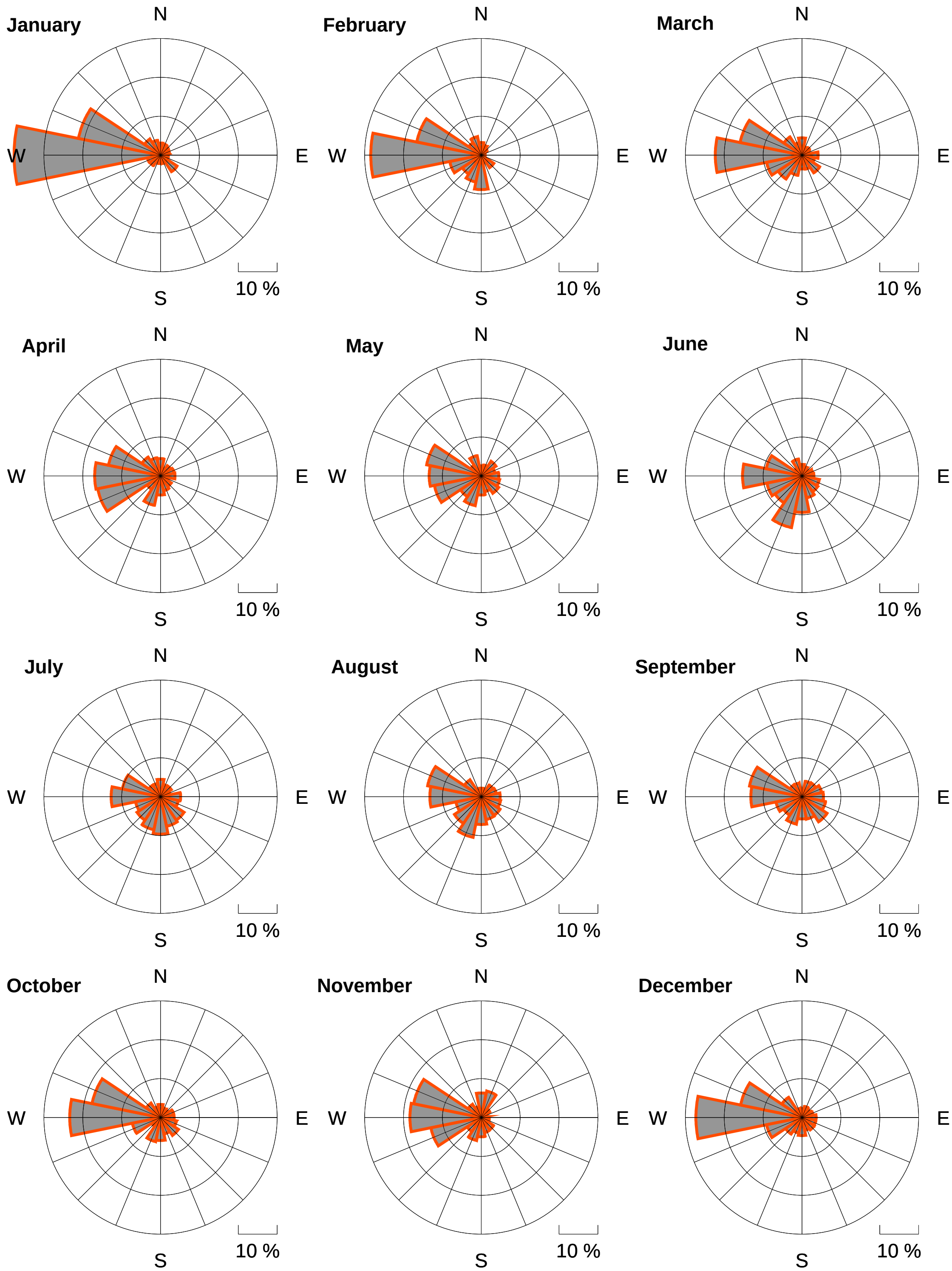

Figure 83: Wind rose of MOS-corrected wind direction at 59 m at Tower M2318 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.5.6 Diurnal Variability of Wind Speed

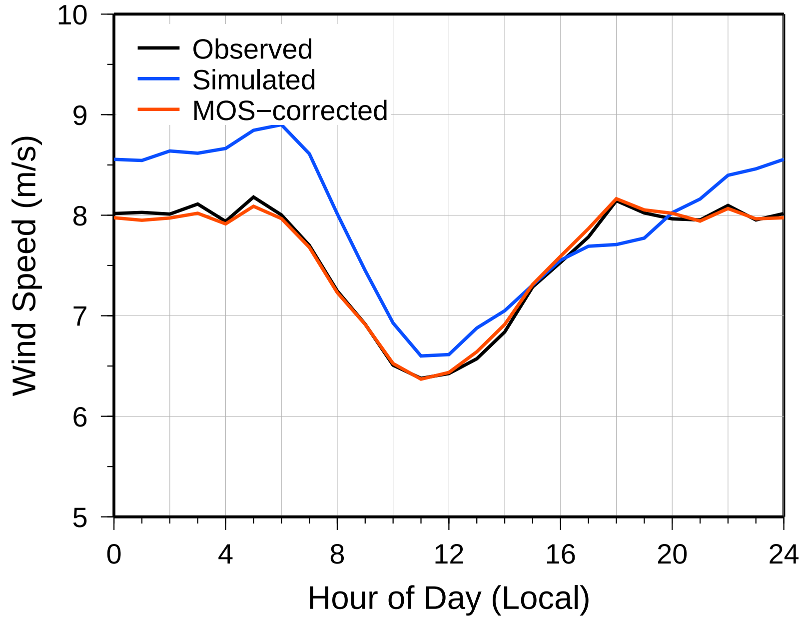

Figure 84: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 61 m wind speed at Tower M2318. Data are averaged over the period of record (June, 2010–October, 2011). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data are available in Figures 86 and 87 (p. 155 and 156).

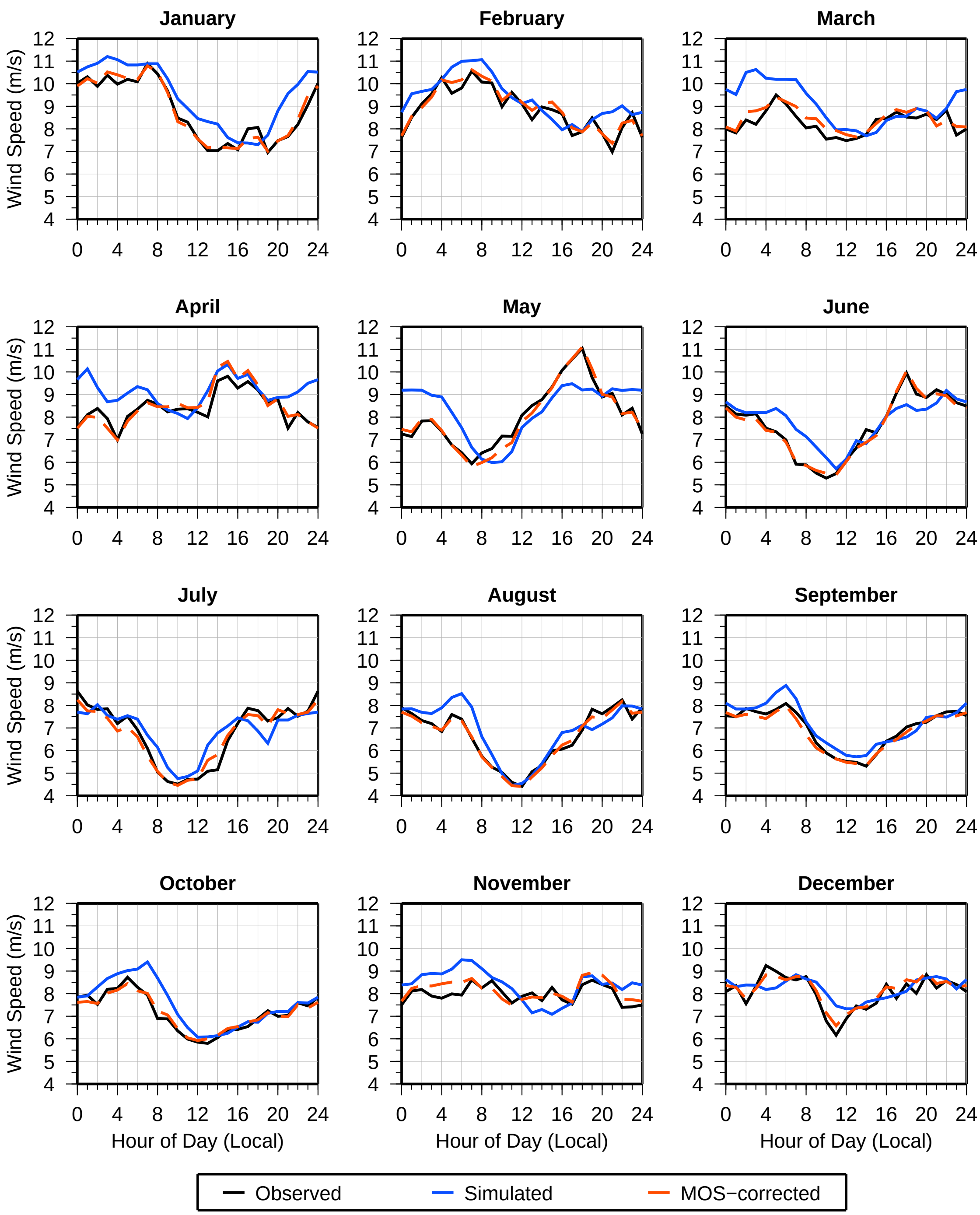

Figure 85: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 61 m wind speed for each calendar month at Tower M2318. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data available in Figures 86 and 87 (p. 155 and 156).

12.5.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
06/2010	7.13	7.46	0.33	7.18	74.0
07/2010	6.94	7.04	0.09	6.82	99.9
08/2010	6.58	6.87	0.29	6.66	99.9
09/2010	7.37	7.75	0.38	7.39	99.9
10/2010	7.42	7.80	0.39	7.37	100.0
11/2010	7.91	8.22	0.31	8.01	93.1
12/2010	8.13	8.32	0.19	8.25	93.7
01/2011	8.76	9.49	0.73	8.77	88.2
02/2011	8.90	9.34	0.45	9.00	87.8
03/2011	8.27	9.06	0.79	8.44	92.3
04/2011	8.44	9.18	0.74	8.58	98.5
05/2011	8.06	8.23	0.18	7.97	98.4
06/2011	7.93	8.00	0.07	7.75	86.5
07/2011	6.34	6.49	0.16	6.43	35.5
08/2011	6.64	6.89	0.26	6.41	99.2
09/2011	6.53	6.59	0.06	6.28	99.7
10/2011	6.76	7.22	0.46	6.85	76.5
All	**7.76**	**8.13**	**0.38**	**7.77**	**89.6**

Table 69: Monthly-mean $61\,m$ wind speeds (m/s) at Tower M2318. Time series graph of data is available in Figure 79 (p. 147). 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 (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	10.03	7.62	8.00	7.55	7.26	8.50	8.63	7.90	7.55	7.85	7.50	8.09	8.02
1	10.31	8.52	7.82	8.11	7.14	8.14	8.02	7.65	7.50	7.93	8.12	8.35	8.03
2	9.89	9.11	8.40	8.39	7.83	8.08	7.82	7.33	7.86	7.52	8.18	7.55	8.01
3	10.38	9.55	8.20	7.94	7.84	8.15	7.85	7.19	7.73	8.19	7.90	8.32	8.11
4	9.98	10.27	8.80	6.99	7.38	7.52	7.19	6.84	7.62	8.23	7.81	9.24	7.94
5	10.20	9.58	9.50	8.03	6.77	7.35	7.52	7.60	7.82	8.73	8.00	8.99	8.18
6	10.09	9.81	9.11	8.35	6.42	6.99	6.93	7.40	8.09	8.29	7.94	8.72	8.00
7	10.90	10.56	8.55	8.75	5.94	5.92	6.10	6.55	7.70	7.94	8.61	8.60	7.70
8	10.44	10.08	8.05	8.58	6.42	5.88	5.05	5.76	7.18	6.90	8.25	8.75	7.25
9	9.69	10.04	8.12	8.23	6.61	5.52	4.63	5.27	6.35	6.89	8.58	7.95	6.92
10	8.48	8.99	7.55	8.35	7.16	5.29	4.51	5.03	5.89	6.35	8.08	6.79	6.51
11	8.30	9.62	7.62	8.37	7.15	5.50	4.72	4.59	5.62	5.99	7.59	6.16	6.38
12	7.58	9.11	7.48	8.22	8.08	6.12	4.73	4.42	5.52	5.86	7.88	6.88	6.42
13	7.03	8.41	7.58	8.01	8.51	6.64	5.08	5.06	5.48	5.80	8.03	7.46	6.57
14	7.03	8.97	7.74	9.61	8.78	7.45	5.15	5.34	5.31	6.05	7.70	7.31	6.84
15	7.35	8.85	8.43	9.81	9.33	7.32	6.44	5.99	5.82	6.41	8.27	7.58	7.29
16	7.07	8.68	8.46	9.29	10.07	8.04	7.21	6.06	6.42	6.42	7.73	8.41	7.53
17	8.00	7.66	8.71	9.69	10.26	9.03	8.00	6.39	6.63	6.57	7.20	8.05	7.78
18	8.07	7.87	8.52	8.98	11.03	9.89	8.04	6.96	7.08	6.87	8.01	8.75	8.14
19	6.96	8.51	8.54	8.35	9.90	8.89	7.63	7.81	7.26	7.18	8.22	8.34	8.02
20	7.48	7.78	8.64	8.95	8.64	8.75	7.78	7.64	7.31	6.91	8.07	9.09	7.96
21	7.66	7.06	8.31	7.64	8.84	9.10	8.12	8.03	7.53	7.00	7.98	8.38	7.95
22	8.19	8.32	8.58	8.37	7.86	8.88	7.75	8.35	7.66	7.62	7.08	8.73	8.10
23	9.06	8.63	7.84	7.93	8.15	8.52	7.93	7.38	7.80	7.54	7.06	8.59	7.95
Avg	8.76	8.90	8.27	8.44	8.06	7.56	6.78	6.61	6.95	7.13	7.91	8.13	7.76

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

Figure 86: Hourly-mean values of observed 61 m wind speed at Tower M2318. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 84 and 85 (p. 152 and 153).

MOS−Corrected

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.89	7.70	8.08	7.51	7.46	8.41	8.25	7.70	7.69	7.62	7.67	8.37	7.98
1	10.22	8.56	7.90	8.04	7.35	8.00	7.76	7.52	7.50	7.65	8.24	8.28	7.95
2	10.03	8.95	8.76	7.99	7.93	7.88	7.74	7.24	7.61	7.57	8.36	7.78	7.97
3	10.52	9.41	8.80	7.51	7.91	7.91	7.44	7.08	7.52	8.02	8.35	8.23	8.02
4	10.40	10.17	8.95	6.99	7.40	7.42	6.87	6.90	7.42	8.16	8.44	8.83	7.91
5	10.24	10.05	9.41	7.82	6.77	7.33	7.04	7.42	7.73	8.45	8.52	8.78	8.09
6	10.19	10.18	9.20	8.27	6.32	6.89	6.62	7.32	7.98	8.13	8.50	8.61	7.97
7	10.79	10.62	8.99	8.64	5.81	6.03	5.76	6.61	7.42	8.01	8.67	8.75	7.68
8	10.52	10.33	8.48	8.46	5.99	5.85	5.08	5.72	6.70	7.24	8.25	8.78	7.23
9	9.61	10.13	8.45	8.46	6.21	5.64	4.60	5.25	6.12	7.05	8.24	8.14	6.91
10	8.32	9.26	8.00	8.61	6.61	5.51	4.46	4.86	5.84	6.45	7.77	7.15	6.52
11	8.11	9.63	7.93	8.42	6.88	5.44	4.68	4.45	5.63	6.04	7.49	6.58	6.37
12	7.55	9.18	7.75	8.43	7.81	6.03	4.75	4.40	5.48	5.93	7.74	7.06	6.44
13	7.16	8.82	7.64	8.69	8.19	6.63	5.58	4.83	5.42	6.00	7.85	7.36	6.64
14	7.22	9.11	7.84	10.20	8.73	6.88	5.82	5.23	5.33	6.16	7.82	7.41	6.91
15	7.16	9.19	8.23	10.47	9.30	7.18	6.67	5.78	5.85	6.46	8.03	7.80	7.31
16	7.13	8.73	8.62	9.70	10.11	8.02	7.23	6.24	6.23	6.55	7.89	8.30	7.59
17	7.57	8.07	8.83	10.09	10.38	9.03	7.99	6.54	6.41	6.75	7.16	8.57	7.87
18	7.63	7.90	8.71	9.54	10.83	9.85	7.88	7.17	6.89	6.80	8.31	8.98	8.16
19	7.01	8.35	8.71	8.67	9.96	8.97	7.56	7.53	7.16	7.19	8.46	8.87	8.05
20	7.47	7.95	8.63	8.93	8.78	8.62	8.07	7.52	7.36	7.01	8.31	9.28	8.02
21	7.70	7.39	8.08	8.14	8.72	8.82	7.94	7.88	7.47	7.10	7.92	8.77	7.94
22	8.42	8.22	8.39	8.26	7.99	8.91	7.67	8.14	7.63	7.58	7.20	8.85	8.07
23	9.49	8.15	8.30	7.99	8.00	8.50	7.82	7.45	7.72	7.46	7.24	8.56	7.96
Avg	8.77	9.00	8.44	8.58	7.97	7.49	6.72	6.54	6.84	7.14	8.01	8.25	7.77

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

Figure 87: Hourly-mean values of MOS-corrected 61 m wind speed at Tower M2318. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 84 and 85 (p. 152 and 153).

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	0.05	0.05	0.08	0.06	0.09	0.06	0.08	0.11	0.04	0.08	0.10	0.07	0.04	0.08	0.04	0.12	1.18
1.5 - 2.5	0.28	0.30	0.25	0.26	0.13	0.29	0.18	0.31	0.29	0.19	0.27	0.22	0.31	0.28	0.28	0.19	4.01
2.5 - 3.5	0.38	0.39	0.51	0.48	0.38	0.38	0.55	0.61	0.59	0.40	0.40	0.40	0.47	0.38	0.34	0.37	7.03
3.5 - 4.5	0.40	0.48	0.48	0.62	0.67	0.57	0.55	0.86	0.75	0.47	0.48	0.48	0.60	0.55	0.52	0.56	9.06
4.5 - 5.5	0.53	0.33	0.72	0.76	0.61	0.57	0.55	0.81	0.55	0.57	0.56	0.73	0.66	0.75	0.74	0.44	9.89
5.5 - 6.5	0.58	0.36	0.50	0.57	0.58	0.58	0.66	0.66	0.45	0.48	0.46	0.59	0.93	0.92	0.74	0.51	9.57
6.5 - 7.5	0.39	0.35	0.52	0.34	0.30	0.48	0.60	0.51	0.58	0.51	0.64	0.58	0.90	0.98	0.66	0.50	8.85
7.5 - 8.5	0.37	0.23	0.30	0.20	0.22	0.24	0.31	0.50	0.59	0.48	0.50	0.56	1.11	0.84	0.53	0.30	7.28
8.5 - 9.5	0.26	0.20	0.13	0.08	0.11	0.10	0.15	0.29	0.53	0.64	0.61	0.55	1.23	0.90	0.44	0.17	6.39
9.5 - 10.5	0.20	0.13	0.06	0.05	0.01	0.04	0.05	0.23	0.41	0.67	0.64	0.43	1.33	1.03	0.17	0.12	5.59
10.5 - 11.5	0.11	0.02	0.04	0.04	0.00	0.02	0.02	0.19	0.31	0.57	0.46	0.31	1.56	0.78	0.16	0.08	4.66
11.5 - 12.5	0.08	0.03	0.04	0.01	0.00	0.01	0.04	0.05	0.31	0.57	0.56	0.42	1.48	1.01	0.09	0.04	4.71
12.5 - 13.5	0.02	0.04	0.01	0.01	0.00	0.00	0.00	0.03	0.23	0.36	0.29	0.22	1.21	0.87	0.05	0.02	3.36
13.5 - 14.5	0.04	0.01	0.04	0.02	0.00	0.00	0.00	0.00	0.15	0.17	0.22	0.17	1.08	0.52	0.05	0.01	2.50
14.5 - 15.5	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.06	0.10	0.19	0.13	0.84	0.28	0.02	0.02	1.66
15.5 - 16.5	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.11	0.22	0.57	0.24	0.01	0.01	1.30
16.5 - 17.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.03	0.05	0.04	0.38	0.14	0.01	0.00	0.68
17.5 - 18.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.05	0.07	0.25	0.09	0.00	0.00	0.52
18.5 - 19.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.03	0.04	0.24	0.06	0.00	0.00	0.42
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.05	0.13	0.05	0.01	0.00	0.29
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.09	0.01	0.00	0.00	0.16
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.09	0.01	0.00	0.00	0.13
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.04
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.00	0.00	0.00	0.11
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.07	0.01	0.00	0.00	0.12

Table 70: Distribution of observed 61 m wind speed by direction at Tower M2318. Histogram of data is available in Figure 80 (p. 148).

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	0.02	0.04	0.05	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
0.5 - 1.5	0.01	0.01	0.04	0.06	0.20	0.14	0.28	0.07	0.06	0.01	0.02	0.00	0.02	0.01	0.00	0.01	0.94
1.5 - 2.5	0.07	0.22	0.35	0.37	0.33	0.50	0.45	0.48	0.38	0.18	0.13	0.06	0.10	0.10	0.14	0.11	3.97
2.5 - 3.5	0.47	0.39	0.43	0.41	0.62	0.53	0.68	0.62	0.58	0.48	0.36	0.26	0.32	0.36	0.22	0.26	7.00
3.5 - 4.5	0.46	0.38	0.50	0.57	0.75	0.72	0.94	0.75	0.60	0.55	0.56	0.41	0.52	0.45	0.51	0.50	9.18
4.5 - 5.5	0.59	0.43	0.40	0.46	0.49	0.63	0.81	0.60	0.75	0.62	0.56	0.79	0.92	0.76	0.67	0.54	10.02
5.5 - 6.5	0.34	0.33	0.34	0.45	0.48	0.31	0.74	0.48	0.56	0.67	0.62	0.95	1.13	1.16	0.65	0.49	9.71
6.5 - 7.5	0.33	0.40	0.26	0.16	0.27	0.29	0.44	0.41	0.60	0.53	0.62	0.93	1.30	1.23	0.48	0.35	8.60
7.5 - 8.5	0.22	0.20	0.18	0.08	0.13	0.18	0.23	0.29	0.35	0.61	0.59	0.72	1.57	1.25	0.40	0.25	7.26
8.5 - 9.5	0.16	0.18	0.07	0.06	0.07	0.07	0.10	0.13	0.40	0.61	0.58	0.68	1.63	1.26	0.23	0.18	6.44
9.5 - 10.5	0.09	0.08	0.02	0.06	0.03	0.03	0.04	0.13	0.29	0.63	0.47	0.63	1.46	1.50	0.21	0.17	5.83
10.5 - 11.5	0.09	0.05	0.03	0.01	0.02	0.01	0.03	0.07	0.20	0.54	0.24	0.61	1.47	1.13	0.10	0.05	4.65
11.5 - 12.5	0.01	0.02	0.01	0.02	0.00	0.02	0.03	0.03	0.24	0.46	0.19	0.49	1.51	1.41	0.04	0.07	4.54
12.5 - 13.5	0.01	0.02	0.03	0.01	0.01	0.02	0.02	0.04	0.16	0.19	0.17	0.31	1.38	0.84	0.03	0.05	3.28
13.5 - 14.5	0.04	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.10	0.29	0.10	0.17	1.10	0.61	0.01	0.02	2.46
14.5 - 15.5	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.06	0.06	0.18	0.09	0.13	0.65	0.42	0.03	0.02	1.66
15.5 - 16.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.13	0.04	0.17	0.55	0.24	0.00	0.03	1.30
16.5 - 17.5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.04	0.08	0.00	0.10	0.31	0.08	0.01	0.01	0.66
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.02	0.14	0.26	0.05	0.01	0.01	0.53
18.5 - 19.5	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.05	0.00	0.09	0.11	0.05	0.03	0.01	0.40
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.09	0.11	0.04	0.02	0.00	0.30
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.01	0.04	0.05	0.01	0.00	0.01	0.15
21.5 - 22.5	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.08	0.01	0.02	0.00	0.15
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.04
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	0.04	0.05	0.01	0.00	0.00	0.11
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.02	0.00	0.00	0.11

Table 71: Distribution of MOS-corrected 61 m wind speed by direction at Tower M2318. All model values are computed only for times with valid observations. Histogram of data is available in Figure 80 (p. 148).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.13	6.92	2.33	4.13
NNE	5.55	6.26	2.23	3.26
NE	5.50	6.21	2.32	4.15
ENE	5.08	5.72	2.50	3.91
E	5.03	5.63	3.04	3.45
ESE	5.17	5.81	2.80	3.75
SE	5.43	6.11	2.64	4.18
SSE	5.74	6.48	2.38	5.78
S	7.24	8.17	2.19	6.61
SSW	8.42	9.50	2.41	7.26
SW	8.42	9.51	2.26	7.44
WSW	8.57	9.66	1.97	7.19
W	10.64	11.99	2.53	17.53
WNW	9.25	10.42	2.53	12.05
NW	6.46	7.29	2.43	5.44
NNW	5.75	6.49	2.32	3.84
ALL	**7.76**	**8.75**	**2.03**	**100.00**

Table 72: Observed 61 m mean wind speed, Weibull parameters, and frequency at Tower M2318. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 81 (p. 149).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	5.84	6.60	2.23	3.25
NNE	5.65	6.37	2.31	3.02
NE	4.92	5.56	2.16	3.00
ENE	4.67	5.28	2.12	3.08
E	4.50	5.08	2.16	3.84
ESE	4.61	5.20	1.90	3.95
SE	4.66	5.26	2.22	5.45
SSE	5.35	6.03	1.93	4.75
S	7.04	7.93	1.94	6.24
SSW	8.39	9.47	2.32	7.67
SW	7.51	8.46	2.46	5.99
WSW	9.02	10.19	2.31	8.77
W	10.36	11.66	2.67	18.69
WNW	9.46	10.61	2.91	14.53
NW	6.57	7.41	2.24	4.25
NNW	6.45	7.29	2.21	3.51
ALL	**7.77**	**8.77**	**2.03**	**100.00**

Table 73: MOS-corrected 61 m mean wind speed, Weibull parameters, and frequency at Tower M2318. 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 81 (p. 149).

12.6 Validation of Model Results at Tower M2322

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 M2322 (latitude 37.60197, longitude -104.53034). Because M2322 did not have a full year of data, Measure-Correlate-Predict (MCP) was completed with M2315 as a reference tower to fill a full calendar year of data in order to mitigate the potential for seasonal bias in the MOS correction. Statistics presented in this section include both observed and MCP data.

The average observed wind speed (for all valid observational times) at $60\,m$ during the 13 months of the period of record (June, 2010 to June, 2011) is $8.34\,m/s$ with an hourly standard deviation of $4.47\,m/s$ at Tower M2322. This compares to a modeled $60\,m$ wind speed of $8.32\,m/s$ with a $4.10\,m/s$ 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 M2322 results in a MOS-corrected mean value of $8.33\,m/s$ and an hourly standard deviation of $4.48\,m/s$.

This section presents a comparison of the simulated winds with the observations at the reference tower (Tower M2322). 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.

12.6.1 Observational Data

Approximately 13 months of wind speed data at 60 *meters* and wind direction data at 59 *meters* (June, 2010 to June, 2011) from a meteorological tower (Tower M2322) at La Cumbre 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 Vaisala are not allowed to influence the raw model simulations.

12.6.2 Model Validation Statistics

Table 74 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	0.96
RMS error of monthly-mean simulated wind speed	0.25 m/s
Correlation of monthly-mean MOS-corrected wind speed to observed	0.99
RMS error of monthly-mean MOS-corrected wind speed	0.10 m/s
Correlation of daily-mean simulated wind speed to observed	0.84
RMS error of daily-mean simulated wind speed	1.65 m/s
Correlation of daily-mean MOS-corrected wind speed to observed	0.86
RMS error of daily-mean MOS-corrected wind speed	1.52 m/s

Table 74: Correlation and root mean square (RMS) error statistics of modeled wind speeds.

12.6.3 Monthly Mean Wind Speed

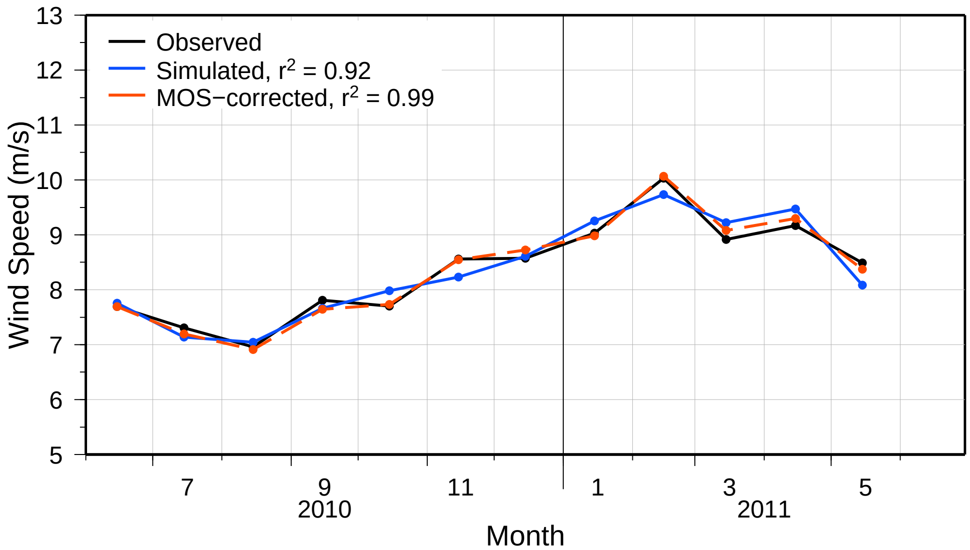

Figure 88: A comparison of the observed, simulated, and MOS-corrected monthly-mean $60\,m$ wind speed at Tower M2322. Explained variance(r^2) value of each data source relative to the monthly reference tower wind speeds are shown in the legend. Months missing greater than 50% of the available observations are not plotted. Tabular formatted data are available in Table 75 (p. 169).

12.6.4 Wind Speed Distribution

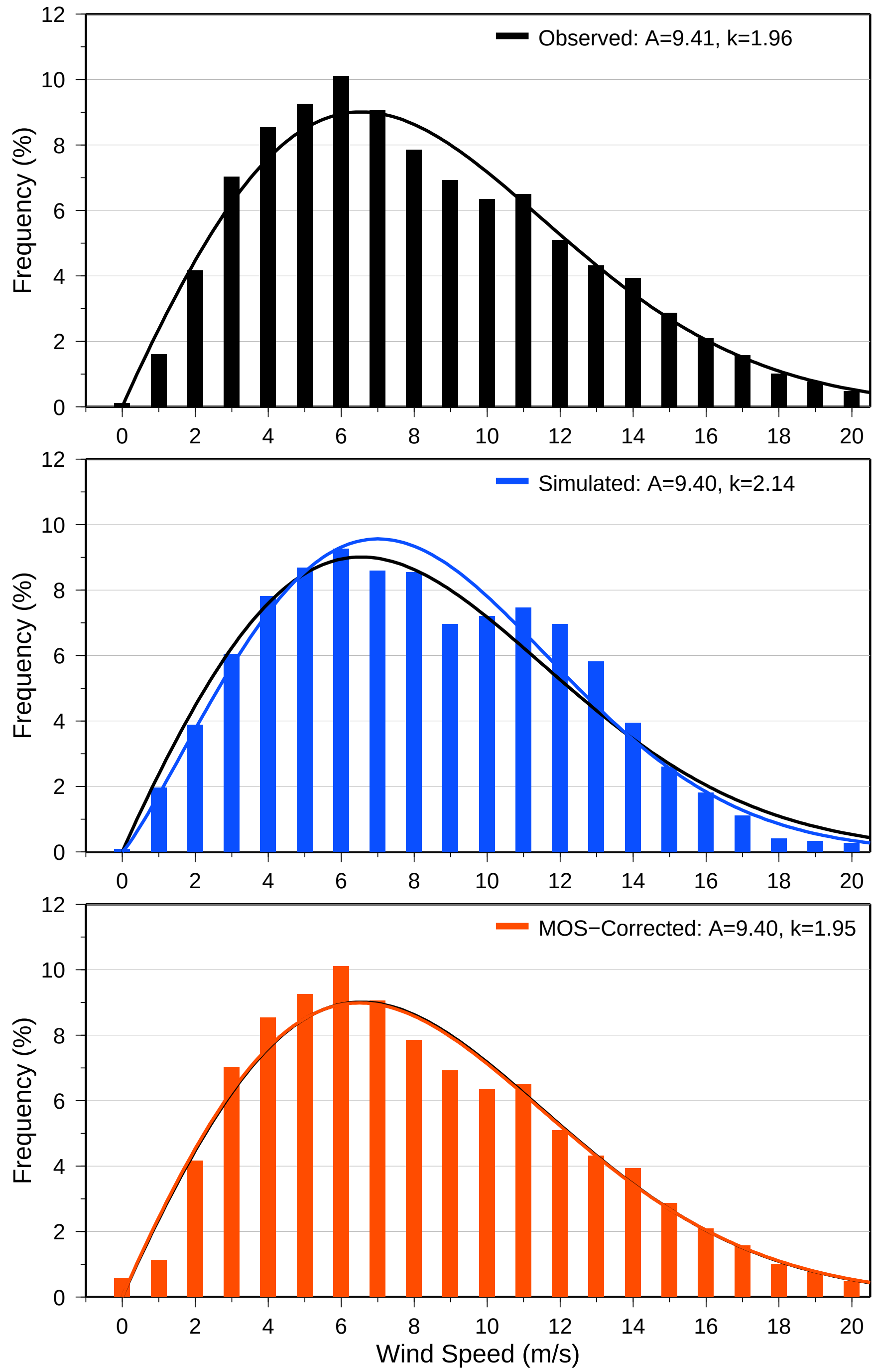

Figure 89: A comparison of the observed, simulated, and MOS-corrected hourly wind speed distributions at $60\,m$ at Tower M2322 during the period of record, using $1\,m/s$ bins. ($0\,m/s$ bin contains only values ≤ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend. Tabular formatted data are available in Tables 76 and 77 (p. 172 and 173).

12.6.5 Wind Direction Distribution

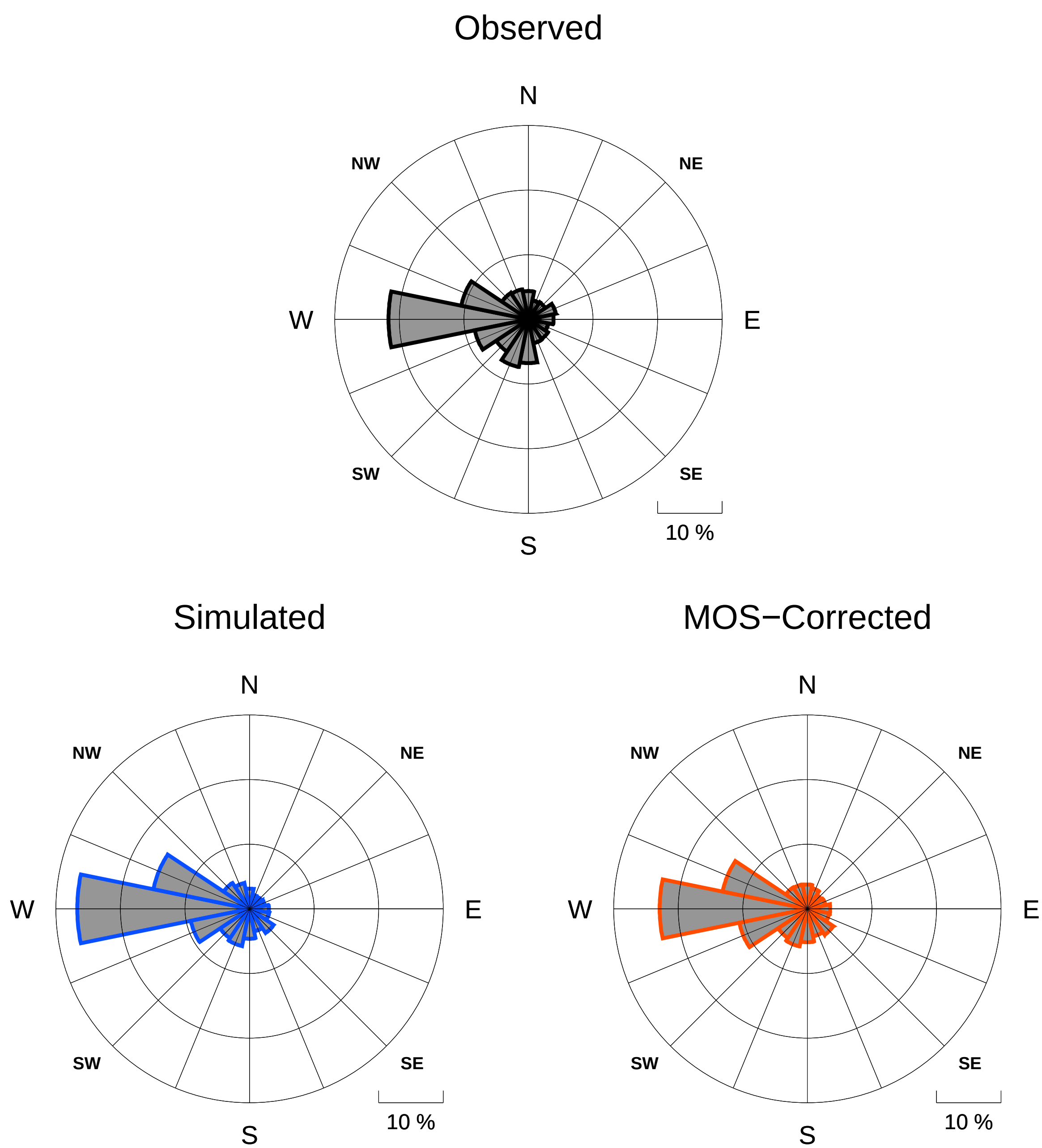

Figure 90: Wind roses at 59 m at Tower M2322 for observational data and simulated model data, averaged over the period of record (June, 2010–June, 2011). Directional bins are 22.5° wide, and the radial contour interval is 10%. Tabular formatted data, including mean wind speed values and Weibull parameters for each wind direction sector, are available in Tables 78 and 79 (p. 174).

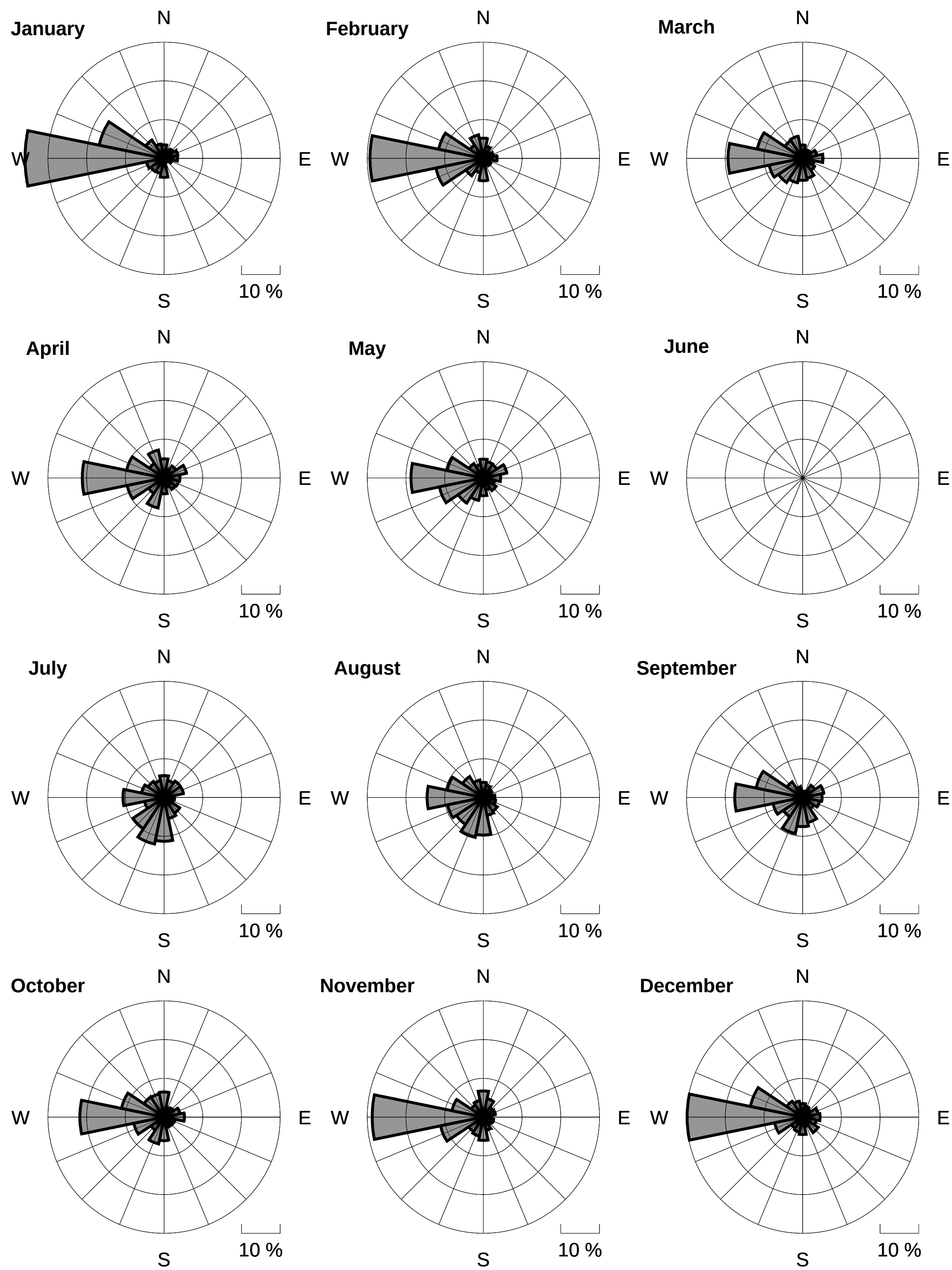

Figure 91: Wind rose of observed wind direction at 59 m at Tower M2322 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

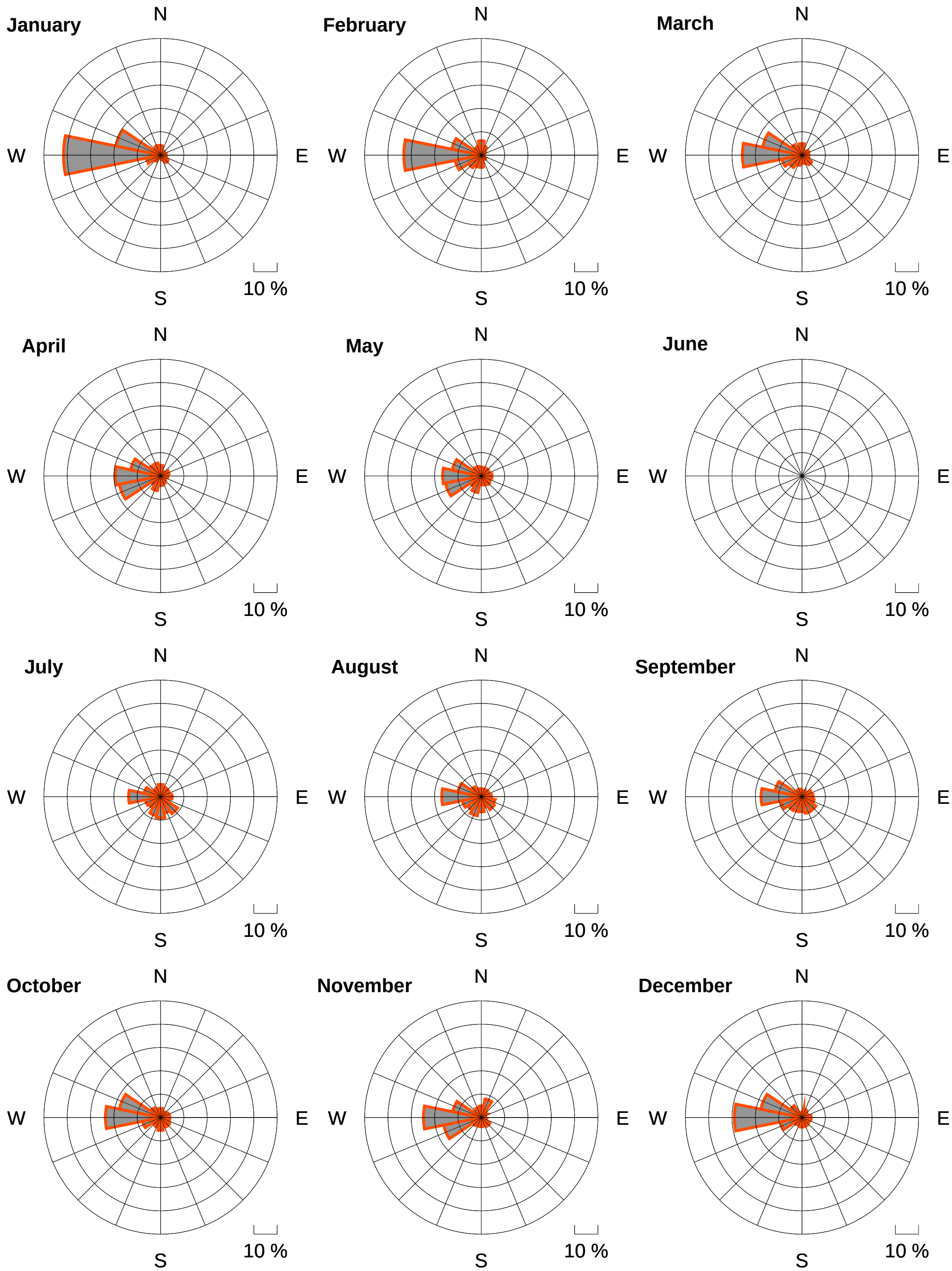

Figure 92: Wind rose of MOS-corrected wind direction at 59 m at Tower M2322 for each calendar month. Directional bins are 22.5° wide, and the radial contour interval is 10%. Months missing greater than 50% of the available observations are not plotted.

12.6.6 Diurnal Variability of Wind Speed

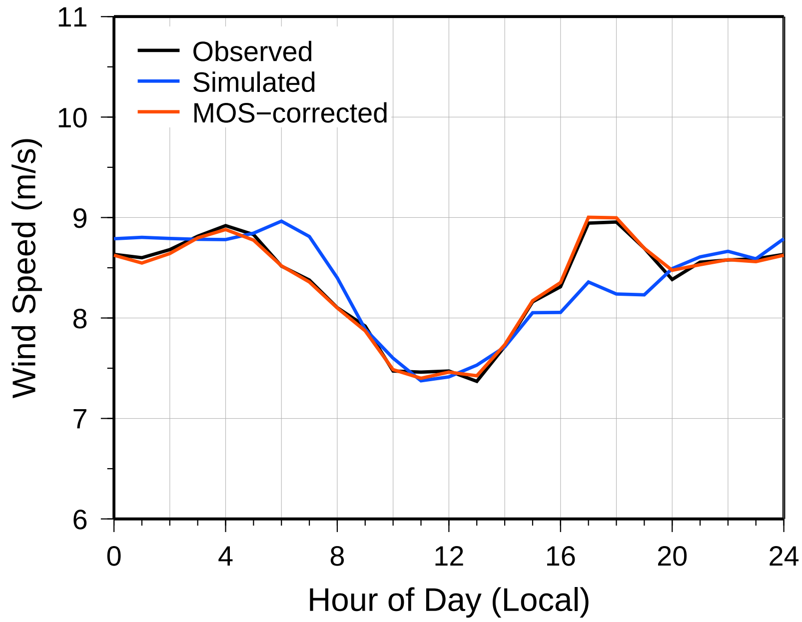

Figure 93: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed at Tower M2322. Data are averaged over the period of record (June, 2010–June, 2011). Hours missing greater than 15% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data are available in Figures 95 and 96 (p. 170 and 171).

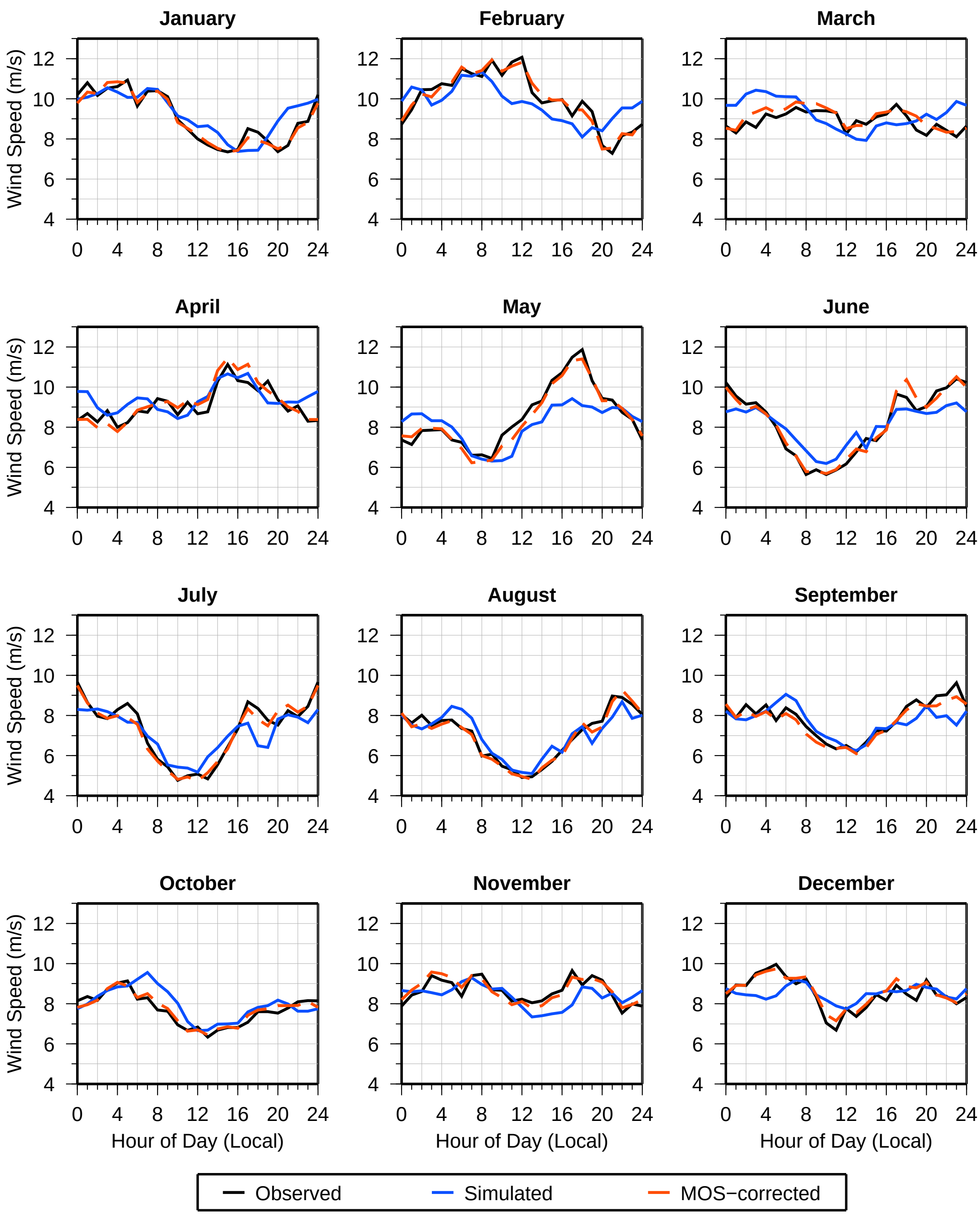

Figure 94: A comparison of the diurnal cycle of observed, simulated, and MOS-corrected 60 m wind speed for each calendar month at Tower M2322. Hours missing greater than 50% of the available observations are not plotted. The horizontal axis is Mountain Time Zone. Tabular formatted data available in Figures 95 and 96 (p. 170 and 171).

12.6.7 Tabular Data

Month	Observed	Simulated	Bias	MOS-corrected	Availability(%)
06/2010	7.69	7.76	0.06	7.70	59.4
07/2010	7.31	7.14	-0.17	7.20	100.0
08/2010	6.96	7.04	0.08	6.91	100.0
09/2010	7.81	7.66	-0.15	7.64	100.0
10/2010	7.70	7.98	0.28	7.73	100.0
11/2010	8.56	8.23	-0.33	8.55	92.8
12/2010	8.57	8.61	0.03	8.72	93.0
01/2011	9.03	9.25	0.22	8.98	87.5
02/2011	10.03	9.74	-0.30	10.07	80.5
03/2011	8.92	9.22	0.31	9.08	90.1
04/2011	9.17	9.47	0.30	9.30	98.6
05/2011	8.49	8.08	-0.41	8.37	99.9
06/2011	9.07	8.72	-0.35	9.05	24.3
All	**8.34**	**8.32**	**-0.02**	**8.33**	**86.6**

Table 75: Monthly-mean 60 m wind speeds (m/s) at Tower M2322. Time series graph of data is available in Figure 88 (p. 162). 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 (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	10.20	8.73	8.64	8.33	7.37	10.22	9.67	8.05	8.43	8.14	7.87	8.31	8.63
1	10.80	9.46	8.30	8.69	7.14	9.56	8.64	7.63	7.89	8.36	8.43	8.94	8.60
2	10.17	10.46	8.85	8.26	7.83	9.15	7.97	8.01	8.54	8.17	8.62	8.91	8.68
3	10.53	10.47	8.58	8.83	7.86	9.22	7.84	7.51	8.09	8.73	9.40	9.52	8.81
4	10.61	10.76	9.24	8.01	7.88	8.76	8.29	7.74	8.52	9.03	9.17	9.71	8.92
5	10.94	10.67	9.06	8.23	7.36	8.03	8.60	7.77	7.75	9.14	9.06	9.96	8.83
6	9.64	11.51	9.24	8.82	7.24	6.93	8.09	7.35	8.38	8.23	8.38	9.36	8.52
7	10.38	11.26	9.57	8.74	6.60	6.58	6.62	7.23	8.06	8.30	9.40	9.00	8.38
8	10.41	11.11	9.34	9.42	6.63	5.65	5.82	5.97	7.45	7.69	9.47	9.23	8.10
9	10.11	11.92	9.42	9.29	6.44	5.88	5.44	6.07	6.99	7.63	8.69	8.34	7.92
10	8.96	11.18	9.40	8.62	7.60	5.64	4.77	5.47	6.58	6.95	8.67	7.04	7.47
11	8.49	11.83	9.32	9.25	8.01	5.87	4.99	5.29	6.33	6.67	8.13	6.68	7.46
12	7.99	12.07	8.25	8.67	8.38	6.17	5.07	4.91	6.51	6.84	8.23	7.76	7.47
13	7.70	10.32	8.90	8.77	9.11	6.77	4.84	4.95	6.19	6.33	8.05	7.36	7.37
14	7.47	9.79	8.73	10.28	9.31	7.43	5.55	5.31	6.68	6.68	8.14	7.81	7.72
15	7.36	9.90	9.10	11.12	10.34	7.33	6.43	5.71	7.24	6.82	8.50	8.45	8.16
16	7.47	9.97	9.23	10.33	10.72	7.90	7.33	6.26	7.22	6.81	8.67	8.17	8.31
17	8.51	9.06	9.71	10.37	11.14	9.84	8.86	6.81	7.72	7.12	9.34	9.11	8.95
18	8.33	9.82	9.18	9.61	11.78	9.68	8.61	7.40	8.32	7.65	8.57	8.75	8.95
19	7.89	9.30	8.53	10.06	10.34	8.78	8.14	7.63	8.67	7.60	9.00	8.50	8.70
20	7.37	7.67	8.17	9.50	9.13	9.03	7.98	7.66	8.35	7.46	8.85	9.41	8.38
21	7.68	7.32	8.66	8.96	9.07	9.65	8.66	9.06	8.76	7.88	8.15	8.58	8.56
22	8.78	8.17	8.41	9.20	8.46	9.79	8.30	8.97	8.93	8.27	7.09	8.57	8.58
23	8.88	8.11	8.29	8.51	8.02	10.29	8.84	8.34	9.79	8.35	7.50	8.25	8.59
Avg	9.03	10.03	8.92	9.17	8.49	8.09	7.31	6.96	7.81	7.70	8.56	8.57	8.34

Wind Speed (m/s): 4 5 6 7 8 9 10 11 12 13

Figure 95: Hourly-mean values of observed 60 m wind speed at Tower M2322. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 93 and 94 (p. 167 and 168).

MOS−Corrected

Hour of Day (Local)	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Avg
0	9.79	8.90	8.54	8.39	7.57	9.99	9.50	8.11	8.56	7.82	8.21	8.51	8.63
1	10.33	9.69	8.43	8.40	7.52	9.39	8.62	7.43	7.90	7.95	8.68	8.91	8.55
2	10.26	10.24	9.16	7.98	7.94	8.86	8.12	7.59	8.21	8.18	9.02	8.92	8.64
3	10.82	10.10	9.34	8.16	7.95	9.04	7.85	7.35	7.95	8.75	9.58	9.43	8.80
4	10.85	10.65	9.56	7.79	7.92	8.66	7.98	7.57	8.19	9.06	9.50	9.62	8.88
5	10.79	10.83	9.30	8.25	7.40	8.10	7.90	7.74	7.80	8.89	9.30	9.74	8.77
6	9.81	11.58	9.51	8.85	6.94	7.21	7.56	7.40	8.10	8.31	8.81	9.27	8.52
7	10.30	11.25	9.84	9.02	6.23	6.57	6.33	7.05	7.79	8.50	9.40	9.27	8.36
8	10.39	11.41	9.76	9.18	6.29	5.79	5.73	5.99	7.08	8.04	9.24	9.35	8.10
9	9.98	11.94	9.76	9.28	6.36	5.80	5.24	5.82	6.67	7.76	8.60	8.45	7.87
10	8.82	11.37	9.54	8.97	7.06	5.69	4.82	5.48	6.41	7.15	8.30	7.45	7.49
11	8.52	11.63	9.29	9.33	7.37	5.89	4.93	5.09	6.36	6.63	7.96	7.15	7.40
12	8.19	11.82	8.52	9.12	8.05	6.39	4.75	4.95	6.40	6.69	8.11	7.74	7.46
13	7.82	10.78	8.68	9.38	8.63	6.90	5.14	4.81	6.09	6.44	7.77	7.54	7.42
14	7.54	10.20	8.66	10.82	9.22	6.78	5.70	5.39	6.40	6.75	7.90	7.98	7.73
15	7.36	9.94	9.26	11.45	10.16	7.47	6.34	5.78	7.06	6.85	8.30	8.50	8.17
16	7.43	9.94	9.34	10.88	10.57	7.86	7.44	5.99	7.26	6.78	8.45	8.63	8.35
17	8.06	9.55	9.41	11.09	11.16	9.86	8.65	6.99	7.52	7.56	8.84	9.54	9.00
18	7.93	9.53	9.27	10.29	11.26	10.23	8.01	7.91	8.07	7.78	8.79	9.14	9.00
19	7.76	9.12	8.77	10.02	10.33	9.26	7.75	7.38	8.39	7.80	8.85	9.07	8.69
20	7.51	7.60	8.54	9.59	9.13	8.89	8.38	7.61	8.45	7.85	8.63	9.39	8.47
21	7.74	7.50	8.51	9.17	9.12	9.26	8.71	8.79	8.54	7.93	8.12	8.75	8.53
22	8.55	8.02	8.53	8.96	8.69	9.82	8.38	9.26	8.89	7.98	7.25	8.60	8.58
23	8.82	8.00	8.52	8.59	8.06	10.30	8.85	8.37	9.31	8.16	7.48	8.38	8.56
Avg	8.98	10.07	9.08	9.30	8.37	8.09	7.20	6.91	7.64	7.73	8.55	8.72	8.33

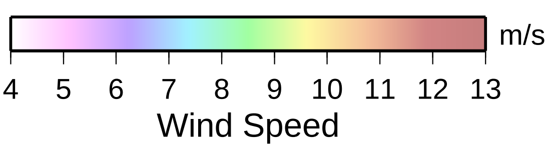

Figure 96: Hourly-mean values of MOS-corrected 60 m wind speed at Tower M2322. Hours missing greater than 50% of the available observations are not plotted. The vertical axis is Mountain Time Zone. Time series graphs of data are available in Figures 93 and 94 (p. 167 and 168).

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	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.11
0.5 - 1.5	0.11	0.11	0.10	0.09	0.07	0.09	0.12	0.10	0.15	0.07	0.11	0.11	0.16	0.06	0.07	0.07	1.58
1.5 - 2.5	0.26	0.33	0.16	0.28	0.26	0.26	0.40	0.19	0.29	0.23	0.27	0.22	0.17	0.19	0.29	0.34	4.13
2.5 - 3.5	0.46	0.45	0.39	0.52	0.47	0.41	0.41	0.32	0.56	0.46	0.35	0.44	0.40	0.40	0.43	0.43	6.90
3.5 - 4.5	0.39	0.34	0.43	0.68	0.66	0.70	0.49	0.61	0.74	0.55	0.41	0.49	0.58	0.39	0.34	0.57	8.36
4.5 - 5.5	0.49	0.28	0.52	0.60	0.78	0.57	0.46	0.57	0.89	0.49	0.52	0.61	0.64	0.56	0.64	0.51	9.13
5.5 - 6.5	0.52	0.39	0.38	0.74	0.61	0.45	0.62	0.55	0.78	0.57	0.61	0.57	1.04	0.84	0.62	0.68	9.96
6.5 - 7.5	0.62	0.29	0.34	0.43	0.45	0.32	0.55	0.51	0.67	0.46	0.57	0.75	1.09	0.83	0.55	0.56	8.98
7.5 - 8.5	0.43	0.33	0.28	0.36	0.24	0.19	0.29	0.29	0.41	0.50	0.57	0.69	1.24	0.84	0.57	0.52	7.76
8.5 - 9.5	0.29	0.16	0.22	0.28	0.23	0.07	0.16	0.22	0.45	0.41	0.50	0.62	1.52	0.91	0.38	0.45	6.87
9.5 - 10.5	0.24	0.15	0.10	0.17	0.06	0.02	0.02	0.16	0.36	0.57	0.41	0.43	1.81	1.17	0.43	0.17	6.27
10.5 - 11.5	0.21	0.07	0.06	0.06	0.01	0.00	0.06	0.06	0.40	0.50	0.38	0.63	2.38	1.20	0.22	0.19	6.44
11.5 - 12.5	0.09	0.05	0.06	0.04	0.00	0.00	0.01	0.07	0.22	0.49	0.32	0.43	2.09	0.84	0.22	0.11	5.02
12.5 - 13.5	0.06	0.02	0.01	0.00	0.02	0.00	0.01	0.06	0.23	0.56	0.10	0.46	1.85	0.75	0.06	0.06	4.26
13.5 - 14.5	0.06	0.01	0.01	0.02	0.01	0.00	0.00	0.02	0.23	0.52	0.28	0.41	1.68	0.57	0.04	0.02	3.90
14.5 - 15.5	0.04	0.01	0.02	0.02	0.00	0.00	0.01	0.01	0.10	0.34	0.17	0.26	1.36	0.46	0.04	0.01	2.86
15.5 - 16.5	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.15	0.19	0.13	0.24	1.01	0.29	0.01	0.00	2.08
16.5 - 17.5	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.06	0.21	0.15	0.33	0.63	0.13	0.00	0.01	1.57
17.5 - 18.5	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.05	0.18	0.04	0.17	0.49	0.06	0.00	0.00	1.01
18.5 - 19.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.04	0.17	0.41	0.06	0.00	0.00	0.77
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.11	0.29	0.00	0.00	0.00	0.47
20.5 - 21.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.19	0.00	0.00	0.00	0.30
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.15	0.00	0.00	0.00	0.21
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.12	0.00	0.00	0.00	0.19
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.07	0.00	0.00	0.00	0.10
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11	0.17	0.00	0.00	0.00	0.29

Table 76: Distribution of observed 60 m wind speed by direction at Tower M2322. Histogram of data is available in Figure 89 (p. 163).

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	0.02	0.12	0.09	0.13	0.07	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.57
0.5 - 1.5	0.02	0.05	0.12	0.13	0.15	0.11	0.23	0.12	0.06	0.01	0.00	0.02	0.02	0.02	0.01	0.01	1.11
1.5 - 2.5	0.21	0.34	0.35	0.30	0.30	0.29	0.51	0.28	0.28	0.23	0.17	0.18	0.07	0.10	0.18	0.28	4.08
2.5 - 3.5	0.56	0.41	0.35	0.47	0.52	0.50	0.46	0.43	0.34	0.44	0.49	0.51	0.47	0.19	0.35	0.44	6.94
3.5 - 4.5	0.41	0.38	0.40	0.49	0.61	0.72	0.69	0.70	0.49	0.35	0.62	0.49	0.58	0.58	0.50	0.45	8.46
4.5 - 5.5	0.62	0.49	0.33	0.35	0.46	0.56	0.73	0.60	0.51	0.43	0.58	0.63	0.94	0.64	0.64	0.64	9.15
5.5 - 6.5	0.55	0.27	0.32	0.39	0.56	0.30	0.84	0.55	0.55	0.38	0.56	0.83	1.46	1.29	0.55	0.58	9.95
6.5 - 7.5	0.32	0.39	0.26	0.21	0.36	0.28	0.47	0.43	0.52	0.23	0.61	0.95	1.54	1.39	0.55	0.45	8.94
7.5 - 8.5	0.24	0.36	0.12	0.11	0.22	0.29	0.28	0.38	0.45	0.28	0.41	0.89	1.93	1.15	0.41	0.21	7.74
8.5 - 9.5	0.29	0.18	0.10	0.07	0.15	0.11	0.18	0.16	0.21	0.43	0.45	0.73	1.88	1.39	0.29	0.22	6.83
9.5 - 10.5	0.12	0.15	0.01	0.04	0.06	0.07	0.13	0.24	0.38	0.41	0.35	0.79	1.86	1.39	0.16	0.11	6.27
10.5 - 11.5	0.13	0.07	0.09	0.05	0.04	0.01	0.07	0.19	0.26	0.43	0.29	0.73	2.53	1.36	0.11	0.09	6.44
11.5 - 12.5	0.07	0.04	0.06	0.02	0.01	0.02	0.04	0.06	0.18	0.45	0.18	0.63	2.22	0.86	0.06	0.11	5.03
12.5 - 13.5	0.06	0.05	0.02	0.04	0.00	0.00	0.04	0.00	0.23	0.44	0.22	0.55	1.64	0.86	0.07	0.06	4.28
13.5 - 14.5	0.06	0.02	0.02	0.00	0.00	0.01	0.01	0.05	0.16	0.23	0.10	0.58	1.68	0.89	0.02	0.06	3.90
14.5 - 15.5	0.02	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.11	0.27	0.17	0.51	1.17	0.51	0.01	0.02	2.86
15.5 - 16.5	0.02	0.01	0.00	0.01	0.00	0.02	0.00	0.01	0.12	0.27	0.10	0.38	0.77	0.34	0.01	0.01	2.08
16.5 - 17.5	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.10	0.26	0.06	0.30	0.62	0.17	0.01	0.01	1.57
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.07	0.18	0.01	0.26	0.39	0.06	0.01	0.01	1.01
18.5 - 19.5	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.12	0.00	0.24	0.28	0.05	0.00	0.01	0.75
19.5 - 20.5	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.06	0.04	0.01	0.06	0.24	0.01	0.00	0.02	0.47
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.09	0.13	0.04	0.00	0.01	0.30
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.11	0.00	0.00	0.00	0.21
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	0.09	0.06	0.01	0.00	0.01	0.19
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.02	0.00	0.00	0.00	0.10
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.12	0.15	0.01	0.00	0.00	0.29

Table 77: Distribution of MOS-corrected 60 m wind speed by direction at Tower M2322. All model values are computed only for times with valid observations. Histogram of data is available in Figure 89 (p. 163).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.64	7.49	2.04	4.38
NNE	5.66	6.39	2.07	3.00
NE	5.99	6.76	2.05	3.16
ENE	5.64	6.36	2.37	4.32
E	5.32	5.98	2.60	3.89
ESE	4.80	5.40	2.69	3.13
SE	5.29	5.96	2.36	3.64
SSE	5.95	6.72	2.37	3.76
S	7.30	8.24	2.02	6.76
SSW	9.47	10.69	2.18	7.52
SW	8.30	9.37	2.07	6.00
WSW	9.96	11.23	1.96	8.47
W	11.48	12.91	2.70	21.67
WNW	9.51	10.67	2.82	10.61
NW	6.81	7.68	2.39	4.92
NNW	6.29	7.10	2.34	4.75
ALL	**8.34**	**9.41**	**1.96**	**100.00**

Table 78: Observed 60 m mean wind speed, Weibull parameters, and frequency at Tower M2322. Blank values correspond to times with less than 10 data points. Wind rose of data is available in Figure 90 (p. 164).

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	6.23	7.04	2.05	3.77
NNE	5.82	6.57	2.09	3.26
NE	5.12	5.77	1.86	2.60
ENE	4.79	5.36	1.70	2.84
E	4.89	5.52	2.20	3.54
ESE	4.84	5.46	1.93	3.46
SE	5.27	5.94	1.99	4.82
SSE	6.02	6.78	1.93	4.33
S	8.04	9.07	1.90	5.16
SSW	9.84	11.11	2.16	5.91
SW	7.64	8.63	2.16	5.42
WSW	10.35	11.68	2.15	10.76
W	10.85	12.19	2.72	22.88
WNW	9.60	10.77	2.91	13.38
NW	6.36	7.18	2.38	3.99
NNW	6.36	7.17	1.93	3.86
ALL	**8.33**	**9.40**	**1.95**	**100.00**

Table 79: MOS-corrected 60 m mean wind speed, Weibull parameters, and frequency at Tower M2322. 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 90 (p. 164).

REFERENCES

[1] O. Arino, P. Bicheron, F. Achard, J. Latham, R. Witt, and J. Weber, "Globcover: The Most Detailed Portrait of Earth," *ESA Bulletin*, vol. 136, 2008.

[2] A. J. et al., "Hole-filled seamless SRTM data V4." International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org, 2008.

[3] M. Liu and M. Yocke, "Siting of Wind Turbine Generators in Complex Terrain," *Journal of Energy*, vol. 4, pp. 10–16, 1980.

[4] D. P. Dee, S. M. Uppala, A. J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, M. A. Balmaseda, G. Balsamo, P. Bauer, P. Bechtold, A. C. M. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, C. Delsol, R. Dragani, M. Fuentes, A. J. Geer, L. Haimberger, S. B. Healy, H. Hersbach, E. V. Hlm, L. Isaksen, P. Kllberg, M. Khler, M. Matricardi, A. P. McNally, B. M. Monge-Sanz, J.-J. Morcrette, B.-K. Park, C. Peubey, P. de Rosnay, C. Tavolato, J.-N. Thpaut, and F. Vitart, "The ERA-Interim Reanalysis: Configuration and Performance of the Data Assimilation System," *Quart. J. Roy. Meteor. Soc.*, vol. 137, pp. 553–597, 2011.

[5] E. Kalnay, M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W.Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph, "The NCEP/NCAR 40-year Reanalysis Project," *Bull. Amer. Meteor. Soc.*, vol. 77, pp. 437–470, 1996.

[6] R. D. Koster, M. G. Bosilovich, S. Akella, C. Lawrence, R. Cullather, C. Draper, R. Gelaro, R. Kovach, Q. Liu, A. Molod, *et al.*, "Technical Report Series on Global Modeling and Data Assimilation," *MERRA-2 Initial Evaluation of the Climate*, vol. 43, 2015.

[7] G. Larsen, J. Hjstrup, and H. A. Madsen, "Wind Fields in Wakes," in *Proceedings EWEC 1996*, (Göteborg, Sweden), pp. 764–768, 1996.

[8] T. Sorensen, P. Nielsen, and M. L. Thgersen, "Recalibrating Wind Turbine Wake Model Parameters - Validating the Wake Model Performance for Large Offshore Wind Farms," in *Proceedings EWEC 2006*, (Athens, Greece), 2006.

[9] "Obstruction Evaluation / Airport Airspace Analysis." https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp, 2017.