CROWNED RIDGE WIND II – POST-CONSTRUCTION NOISE COMPLIANCE

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Report Title:

Crowned Ridge Wind II – Post-Construction Noise Compliance

Report Prepared by:

RSG

Report Prepared for:

Xcel Energy

For additional information regarding this report, or for questions about permissions or use of findings contained therein, please contact:

RSG (Headquarters)
55 Railroad Row
White River Junction, VT 05001
(802) 295-4999
www.rsginc.com

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EXECUTIVE SUMMARY

A post-construction noise compliance assessment for Crowned Ridge II (the "Project") in Codington, Deuel, and Grant Counties in South Dakota was performed pursuant to the construction and operating permit conditions.

The assessment includes:

- Monitoring at seven sites within the Project area for at least 18 days in May and June 2021;
- Consideration of turbine operation, meteorology, and sound levels over the entire monitoring period;
- Analysis focused on nighttime periods surrounding wind turbine shutdowns; and
- A comparison of the modeled sound levels from the pre-construction noise assessment.

For the compliance analysis, wind turbine-only sound levels were evaluated through a deterministic shutdown method at each monitor: the background sound level (sound levels without wind turbines operating) was assessed directly by shutting down nearby wind turbines for 10 to 20 minutes four times per night. Turbine-only levels (10-minute L_{eq}) were assessed during the hour prior and hour after each shutdown.

Seventy-nine (79) shutdowns were performed over the course of two monitoring periods for the 55 turbines within 1.75 miles of all monitors (including four turbines from the adjacent Crowned Ridge I project). An additional forty (40) shutdowns at thirteen (13) Project wind turbines were necessitated for a third monitoring period due to a power failure at one of the monitors (LT3) in the second monitoring period.

A total of 59 evaluation periods were initially calculated to have wind turbine-only levels above 45 dBA. Inspection of these periods found them to be contaminated with biogenic sound, vehicles/tractors, excessive wind in the trees aloft, and dogs. Upon removing transient and anomalous events, wind turbine-only sound levels at all locations were below 45 dBA. Maximum calculated wind-turbine levels at four monitors were within 0.7 dB of the 45 dBA limit, though all of these periods contained anomalous sources that were not excluded from the analysis because the exclusion of anomalous events ceased at compliance levels. Average wind turbine-only sound levels for the target evaluation periods for each monitor were at least 1 dB below the modeled sound level from Pre-Construction. This post-construction compliance assessment concludes that the Project complies with the noise limits in the Project permit.

1.0 INTRODUCTION

This report describes a sound level and meteorological monitoring campaign deployed in May and June 2021 at the Crowned Ridge II Wind Farm (the "Project" or "CRWII") to determine the Project's compliance with noise limits defined in the Project's operation permit[1] (the "Permit") issued by the SD PUC and additional SD PUC guidance.

1.1 BACKGROUND AND PROJECT DESCRIPTION

The Crowned Ridge II Wind Farm in Codington, Deuel, and Grant Counties in South Dakota was permitted for construction and operation in April 2020. Originally designed and permitted as a 300 MW project, a 200 MW portion of the project is currently built and operating. The 200 MW portion of the Project commenced commercial operation in December 2020.

The built and operating 200 MW project consists of eighty-eight (88) wind turbines: nine (9) GE 2.1 and seventy-nine (79) GE 2.3 wind turbines. The hub height of the GE 2.1 is 80 meters above ground level while the hubs of the GE 2.3 models are 90 meters above ground level. Both wind turbine models have 116-meter rotor diameters. All wind turbines have low noise trailing edges (LNTE) installed on the blades.

The region surrounding the Project is a working landscape, composed primarily of grain and beef cattle operations, residential homesteads, and other wind projects. The Project spans an area about 7 to 20 kilometers (4.4 to 12.4 miles) east of Watertown, SD around the towns of Waverly, Kranzburg, and Goodwin. It is bordered on the east by a string of lakes including Crooked Lake, Round Lake, and Wigdale Lake. Most of the project is located north of US Highway 212, which bisects the Project east to west. Other wind turbine projects operating in the area include Crowned Ridge I, to the north, and Deuel Harvest wind, to the east. A map[2] of the Project and surrounding area, including the locations[3] of other wind turbines operating in the area, is provided in Figure 1.

A pre-construction study[4] (the "Pre-Con Study") was completed as part of the permitting process for the Project. The original array was amended to a final proposed array, which is enumerated in additional testimony in the docket.[5] Prior to deploying this study, a Post-Construction Protocol[6] (the "Protocol") was submitted that directed the monitoring in accordance with the Permit. This report is the Noise Compliance Assessment that evaluates the Project's adherence to applicable noise limits per the Protocol.

[1] Wind energy permit EL19-027, South Dakota Public Utility Commission
[2] All maps in this report are oriented such that geographic north is "up" and were generated with ggmap: D. Kahle and H. Wickham. ggmap: Spatial Visualization with ggplot2. The R Journal, 5(1), 144-161. http://journal.r-project.org/archive/2013-1/kahle-wickham.pdf
[3] Source: https://eerscmap.usgs.gov/uswtdb/
[4] EL19-027. Jay Haley's Supplemental Testimony - Exhibit JH-S-1 - Final Report Crowned Ridge II Wind Farm Sound Study Codington, Deuel and Grant Counties, SD
[5] EL19-027. Rebuttal Testimony of Jay Haley - Corrected Exhibit JH-R-1 - 01/24/20"
[6] EL19-027: RSG - 05/14/21 - Revised Facility Post Construction Sound Monitoring Protocol

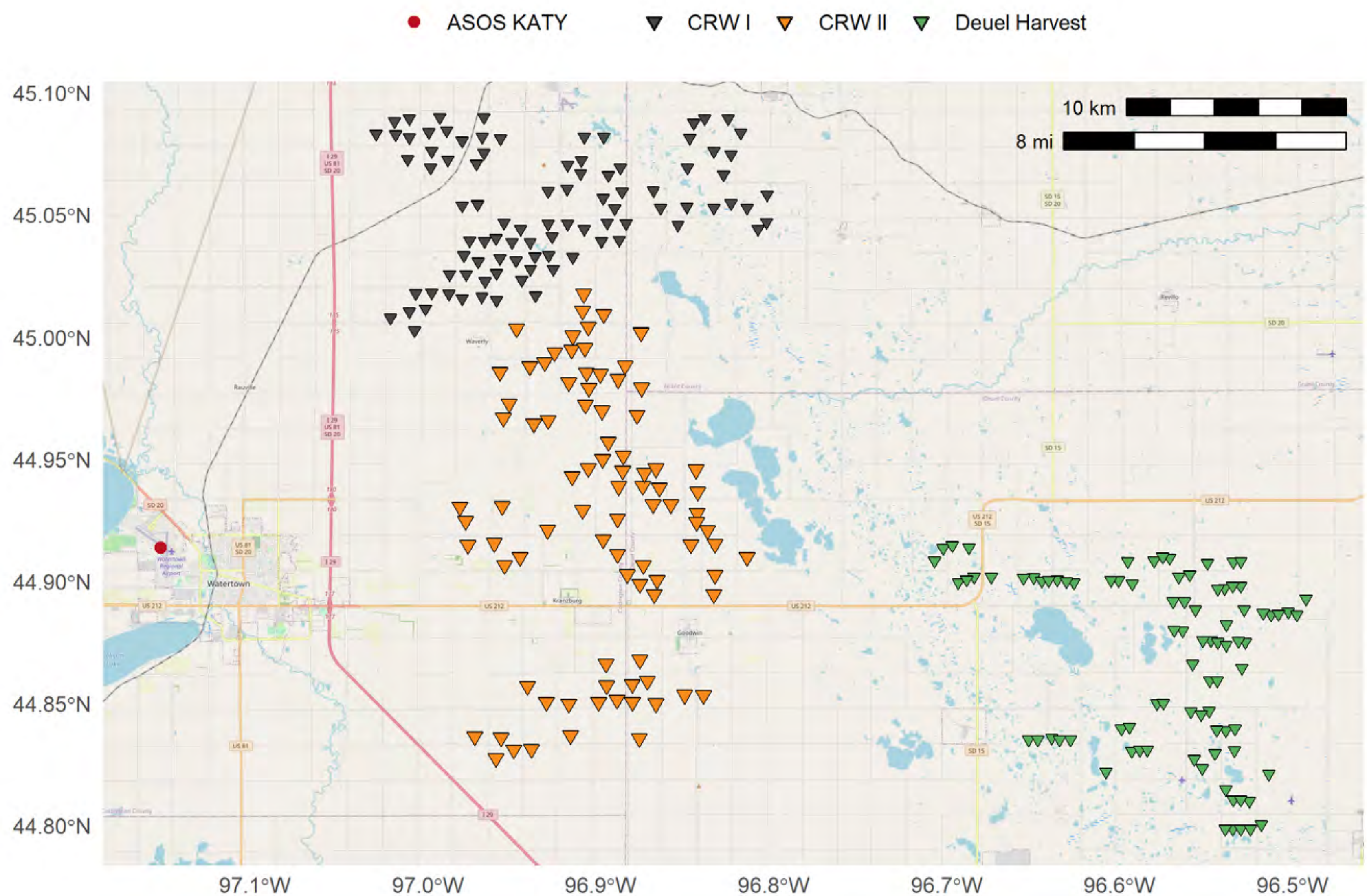

FIGURE 1: MAP OF THE CROWNED RIDGE II WIND FARM, THE SURROUNDING AREA, AND OTHER NEARBY WIND PROJECTS

1.2 NOISE COMPLIANCE

Permit Conditions

The South Dakota counties of Codington, Deuel, and Grant each have their own specific ordinances regulating the sound generated by wind turbines. The most stringent limit (Grant County) of 45 dBA at 25 feet from the structure was adopted as a condition in the Permit; sound levels for participating residences up to 50 dBA are permitted. The Permit specifically dictates that the 10-minute equivalent average sound level ($L_{eq10min}$) be used to evaluate the wind turbine-only contribution to sound level at the assessment location.

A primer on acoustics and the terminology used in this report is provided in Appendix A, including a section specifically about wind turbine noise.

Compliance Assessment

Methodology

Wind turbine shutdowns provide an in-situ measurement of background sound that allow for the turbine only sound to be calculated from the total (turbine + background) sound by quantifying the background sound immediately before or after a period of turbine operation at the same location. The primary purpose of establishing background sound levels for each turbine operation period is to separate total sound (wind turbine + background) into its constituent components (turbine-only sound and background sound). The background sound level measured during a turbine shutdown is utilized to represent the background sound level of all other sources of sound during turbine operation. To determine the sound contributed by only the wind turbine, background sound levels are logarithmically subtracted from total sound levels on a 1/3 octave band basis, as described in ANSI S12.9 Part 3 Section 7.

Approach

All wind turbines within 2.8 kilometers (1.75 miles) of a monitor location were shutdown (so that the blades ceased rotating) four times each night for about 20 minutes. Shutdowns were performed at night because nighttime periods are most likely to have lower background sound level and favorable conditions for sound propagation.

Wind turbine shutdown and operation periods were assigned according to the observable sound level and production data. Within each identified time interval, measured 1-second L_{eq} sound levels were aggregated for acoustically valid periods (i.e., no precipitation, ground level windspeeds below 5 m/s, no anomalous activity) and the 10-minute equivalent sound level (L_{eq}) is reported. Six 10-minute periods before and after each shutdown were analyzed independently to determine the L_{eq} for each discrete turbine operation period on a 1/3 octave band basis. The middle 10-minutes of the turbine-off period was classified as the background sound level (L_{eq}) corresponding to the surrounding turbine operation periods.

Target Evaluation Periods

The Permit stipulates the following two conditions for a period to qualify for a compliance assessment:

1) The closest five wind turbines are operating.
2) The closet wind turbine is operating within 1 dB of maximum sound power emission.

According to manufacturer documentation, both wind turbines reach maximum power production at 11 m/s hub-height wind speed. Maximum sound output is achieved at 10 m/s hub-height wind speed. At 85% of maximum power, corresponding to 9 m/s hub height wind speed, both wind turbine models are at least 1 dB below maximum sound power level. At 33% of maximum power production, the GE wind turbines are about 10 dB below their maximum sound power level.

As such, evaluation periods for noise compliance considered in this study consist of:

- 10-minute periods in the hour before and hour after a turbine shutdown
- the closest five turbines operating at 33% maximum power production or more, and
- the closest turbine operating at 85% of its maximum power production or more.

2.0 MONITOR LOCATIONS

Post-construction monitoring was completed at the seven monitoring sites listed in this section from May 24 to June 14th, 2021. The monitoring was extended an additional ten days (until June 24th) at one site (LT3) due to a power failure in the data acquisition system.

The Permit prescribed a sound level monitoring study with at least six on-site monitors for at least 14 days. The Protocol specified seven to obtain a geographically distributed sample of the highest modeled wind turbine sound levels and to include all three residences that had registered formal noise complaints.

The seven monitor locations described in this report are referred to as LT1 through LT7 and are referenced with the modeling receptor ID assigned in the Pre-Con Study. The Protocol specified Primary and Alternative locations for most monitors. All monitors were deployed at their Primary location except the Primary LT5 monitor location (CR2-D85-NP); permission to monitor at a suitable location (within 25 feet of the residence) was denied.[7]

The monitor locations associated with formal noise complaints are LT2, LT3, and LT6. LT7 is the only participating residence included in the study, all other monitor locations are on non-participating parcels.

The Permit specified that wind turbine noise should be assessed within 25 feet of the corresponding residence. This distance was realized at each monitor, with the exceptions of LT1 and LT7; the reasons for the deviations are explained in the respective sections.

The geographic locations of the monitor locations used in this study, as well the modeled sound levels for the residence closest to each monitoring location, as reported in the Pre-Con Study, [8] are provided in Table 1. The table provides predicted wind turbine-only sound levels for the Project, as well as for the cumulative impact of the Project and the surrounding wind projects.

Figure 2 shows a map of the area surrounding the Project and the locations of the monitoring locations throughout the Project. Coordinates for the operating wind turbines associated with Crowned Ridge I (to the north of the Project) were retrieved from the FAA's Obstruction Evaluation / Airport Airspace Analysis database.[9] As-built coordinates for wind turbines associated with the Project were retrieved from the docket.[10]

The following sections in this chapter detail each monitor location, with physical and soundscape descriptions of the sites, maps of the surrounding area, and pictures of the monitor locations from this study. Two maps are provided for each monitor: one maps showing at least the five closest wind turbines and a second map of aerial imagery clearly showing the monitor location in the context of the surrounding homestead and residence.

[7] The LT5 monitor location in this report is the "LT5 Alternate" in the Protocol

[8] EL19-027. Rebuttal Testimony of Jay Haley - Corrected Exhibit JH-R-1 - 01/24/20. "Proposed Array""

[9] https://oeaaa.faa.gov/

[10] EL19-027. Attachment A - As-built Location of the Structures and Facilities – 03/17/21.

TABLE 1: MONITOR LOCATIONS AND PRE-CON MODELED TURBINE-ONLY SOUND LEVELS (WGS 84)

MONITOR	RECEPTOR ID	PROJECT PARTICIPANT?	MODELED SOUND LEVEL (dBA)	LONGITUDE	LATITUDE
LT1	CR1-C13-NP	No	43.5	-96.92107	45.00672
LT2	CR2-C132-NP	No	42.4	-96.88294	44.99927
LT3	CR2-C79-NP	No	41.4	-96.88289	44.99577
LT4	CR2-C97-NP	No	42.4	-96.97168	44.91927
LT5	CR2-D21-NP	No	43.8	-96.85166	44.93577
LT6	CR2-D221-NP	No	41.7	-96.84228	44.89483
LT7	CR2-D212-P	Yes	45.8	-96.88314	44.86203

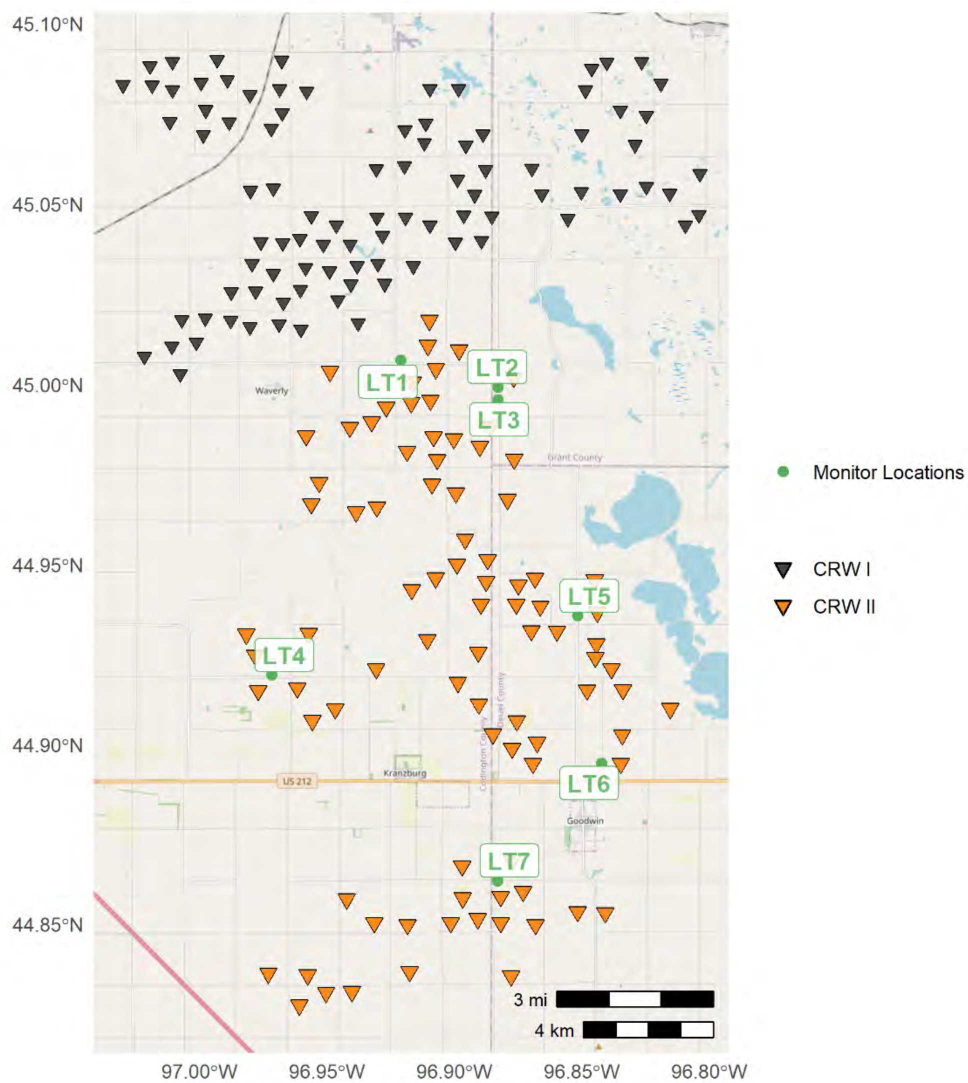

FIGURE 2: CROWNED RIDGE II PROJECT AREA AND SOUND MONITOR MAP

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2.1 LT1 MONITOR (CR1-C13-NP)

The LT1 monitoring location is in the northern portion of the Project on the property northeast of the intersection between 164th Street and 464th Ave. A map of the area surrounding the monitoring location, including nearby operating wind turbines, is provided in Figure 3. Note that all Project wind turbines are identified by their Turbine ID (e.g., “T-83”); wind turbines from the neighboring Crowned Ridge I project are identified as “T-CRW1”

The closest wind turbine to the LT1 monitoring location is T-83 to the south-southeast. The LT1 monitor location has four operating wind turbines from Crowned Ridge I within 1.75 miles to the northwest; all these turbines were shut down in conjunction with the Project to evaluate turbine-only sound levels.

Aerial imagery depicting the monitoring location is provided in Figure 4. The monitor was placed 16.5 meters (54 feet) northeast of the residence to maintain direct line-of-sight to the nearest wind turbine to the south-southeast. Most locations within 7.6 meters (25 feet) of the residence were shielded from the nearest turbine and were not satisfactory monitoring locations. The monitoring location is 80 meters (260 feet) from 164th Street and 180 meters (590 feet) from 464th Avenue. Pictures of the monitor setup are provided in Figure 5 and Figure 6.

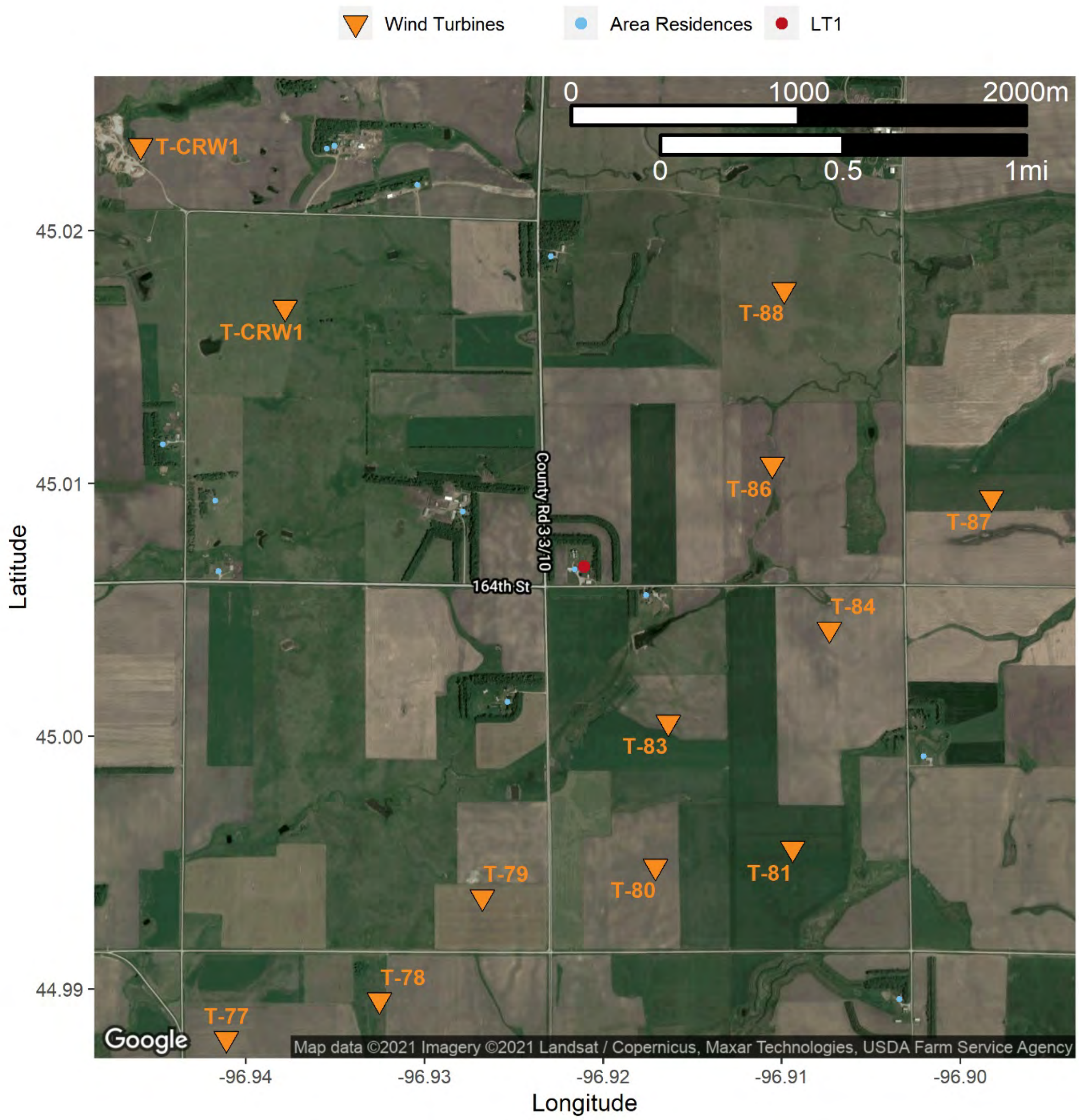


FIGURE 3: MAP OF LT1 AND SURROUNDING AREA

FIGURE 4: MAP OF LT1 MONITOR LOCATION

FIGURE 5: PICTURE OF LT1 DURING POST CONSTRUCTION MONITORING, FACING SOUTHEAST

FIGURE 6: PICTURE OF LT1 DURING POST CONSTRUCTION MONITORING, FACING WEST

2.2 LT2 MONITOR (CR2-C132-NP)

The LT2 monitoring location is adjacent to a residence on 466th Avenue in the northeastern portion of the project. Formal complaints related to wind turbine noise were registered by the residence adjacent to the monitor, particularly related to the nearest turbine, T-85, which is located 560 meters (1840 feet) to the northeast of the monitoring location. A map showing the monitoring location with respect to nearby turbines and local roads is provided in Figure 7.

As shown in Figure 8, the sound monitor was placed 7.6 meters (25 feet) northeast of the residence and 17 meters (56 feet) from 466th Avenue. Photographs of the monitor setup are shown in Figure 9 and Figure 10. T-85 is visible behind the clump of trees in Figure 10.

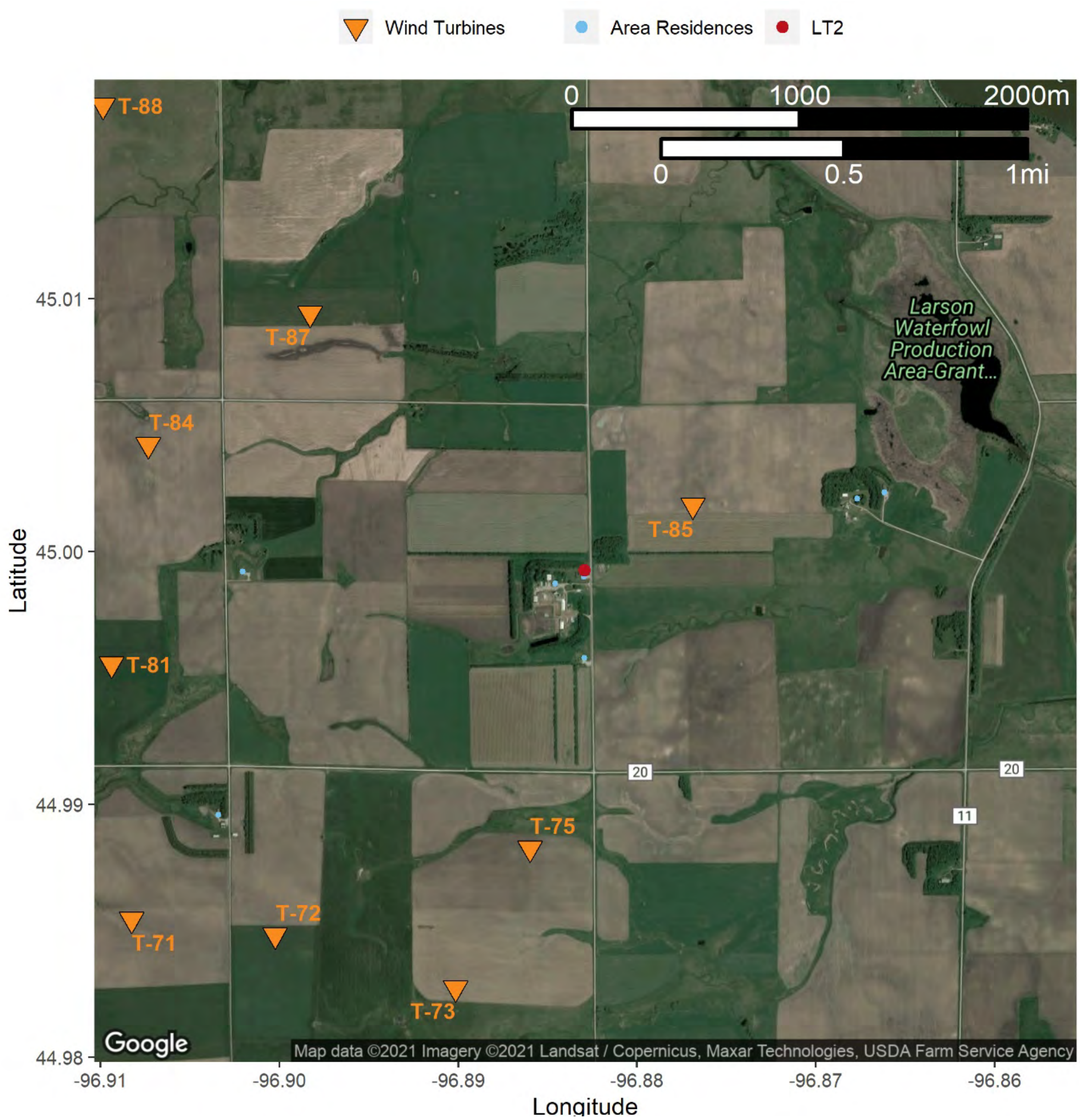


FIGURE 7: MAP OF LT2 AND SURROUNDING AREA

FIGURE 8: MAP OF LT2 MONITORING LOCATION

FIGURE 9: PICTURE OF LT2 DURING POST-CONSTRUCTION MONITORING, FACING SOUTH

FIGURE 10: PICTURE OF LT2 DURING POST-CONSTRUCTION MONITORING, FACING EAST

2.3 LT3 MONITOR (CR2-C79-NP)

The LT3 monitoring location is in the northeast portion of the Project, approximately 390 meters (1280 feet) south of LT2 along 466th Avenue. The LT3 monitor corresponded to a residence associated with formal complaints. Noise observations were recorded in a Turbine Noise Log by a resident at the LT3 monitoring location. No other complainant provided a log. The log provided by the resident is reproduced in Table 2. All text included are direct quotes. Due to the lack of shutdowns during the timeframes that were logged and the lack of time detail in the noise observations, turbine-only sound levels could not be assessed during the timeframes provided.

The closest wind turbine to LT3 is T-85 to the northeast. T-75 to the south-southwest is about 40 meters farther than T-85 from the LT3 monitoring location. A map of the area surrounding LT3 is provided in Figure 11. Aerial imagery depicting the monitor location is provided in Figure 12. The monitor was placed 7.6 meters (25 feet) east of the residence. Photographs of the monitor setup are shown in Figure 13 and Figure 14. T-85 is visible in Figure 13.

Distortion in the sound level data at LT3 after a prolonged rain event on 5/26 and 5/27 resulted in about 11 hours of data loss. The malfunction was most likely the result of moisture associated with the preceding storm system. Excessively high sound levels were recorded during this period, which were characterized by sporadic bursts of impulsive sound with no apparent physical stimulus. These periods were excluded from the rest of the sound level data as an anomaly.

The sound level meter at LT3 lost power shortly after being re-deployed for the second monitoring period, which was not found until field staff attempted to retrieve the monitoring equipment on June 14th. As such, the monitor was left out for an additional ten days and shutdowns at wind turbines within 1.75 miles continued for the third monitoring period.

TABLE 2: NOISE OBSERVATIONS FROM A RESIDENT AT THE LT3 MONITORING LOCATION

DATE	TIME	TURBINE OF CONCERN	DESCRIPTION OF NOISE	DESCRIPTION OF WEATHER
5/25	a.m.	#85	Whoosh	Winds S/SW/W
5/26	a.m.	#85	Whoosh	N winds
			Was off a lot this week!	
5/31		#85	Whoosh, / high pitch scream	N winds
6/2	a.m.	#85	LOUD whoosh then like an airplane flying overhead	
6/3	a.m.	#85	Whoosh	West wind
6/4		#85	LOUD	SW winds
6/5			Whoosh	Loud when wind
6/7		#85	Loud high pitch + whoosh	NE winds
6/10	a.m.	#85	Loud whoosh	SW winds
			None of these sounds compare to winter months with ice and north/NE winds...and when there are NO leaves on the trees!!	

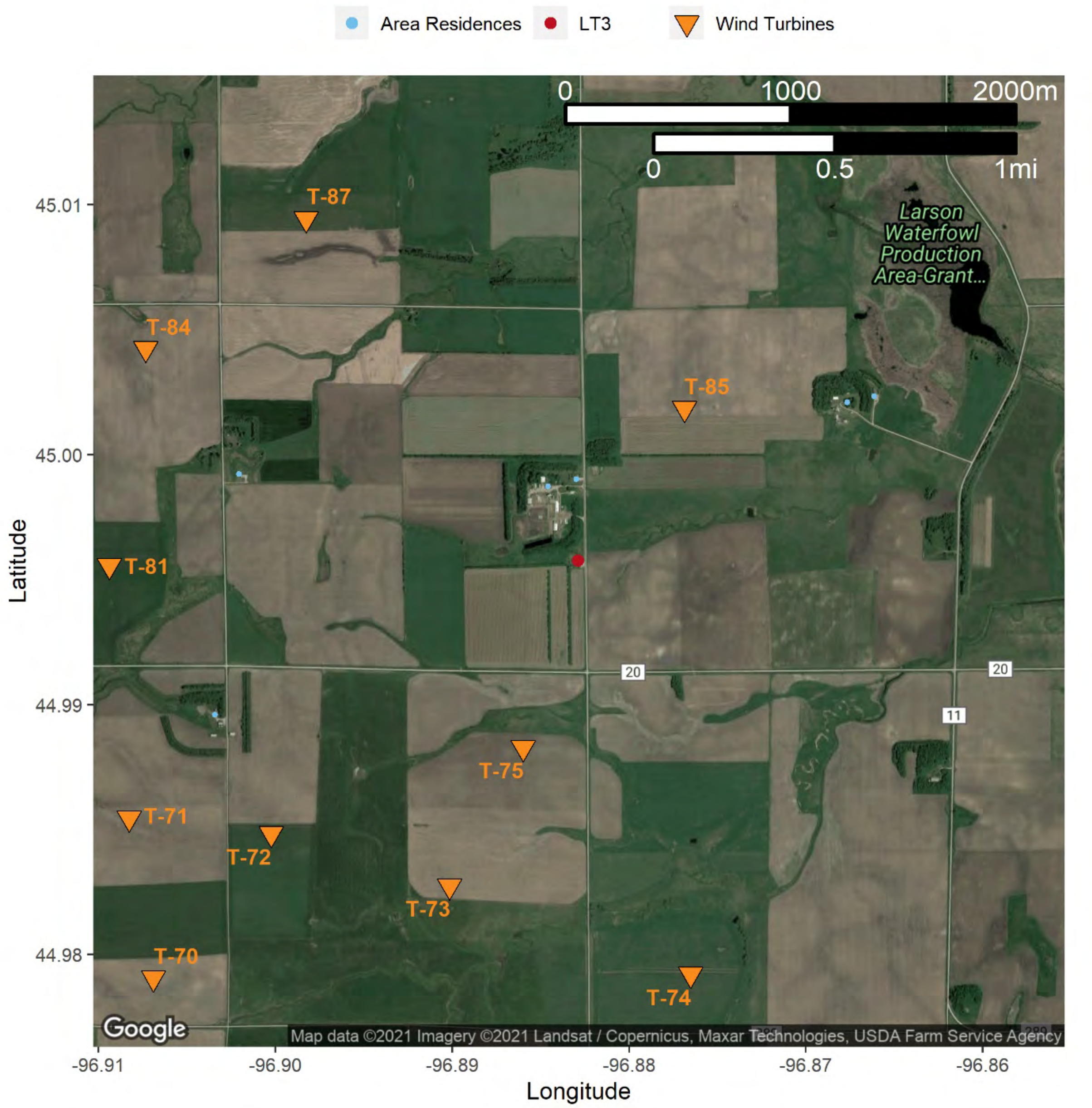


FIGURE 11: MAP OF LT3 AND SURROUNDING AREA

FIGURE 12: MAP OF LT3 MONITORING LOCATION

FIGURE 13: PHOTOGRAPH OF LT3 DURING POST-CONSTRUCTION MONITORING, FACING NORTHEAST

FIGURE 14: PHOTOGRAPH OF LT3 DURING POST-CONSTRUCTION MONITORING, FACING WEST

2.4 LT4 MONITOR (CR2-C97-NP)

The LT4 monitoring location is in the western central portion of the Project. The monitoring location is 23 meters (75 feet) north of 170th Street and about 460 meters (1510 feet) west of 462nd Avenue. An active cattle operation on the parcel is located north of the residence.

The map in Figure 15 shows the area surrounding the monitor location and homestead. T-34, to the southwest, is the closest wind turbine to the monitoring location. As shown in Figure 16, the monitor was placed 7.6 meters (25 feet) southwest of the residence between the associated residence, a vegetative wind break to the south, and a garden. Pictures of the deployed LT4 monitor are provided in Figure 17 and Figure 18. The closest wind turbine, T-34, is visible in Figure 18.

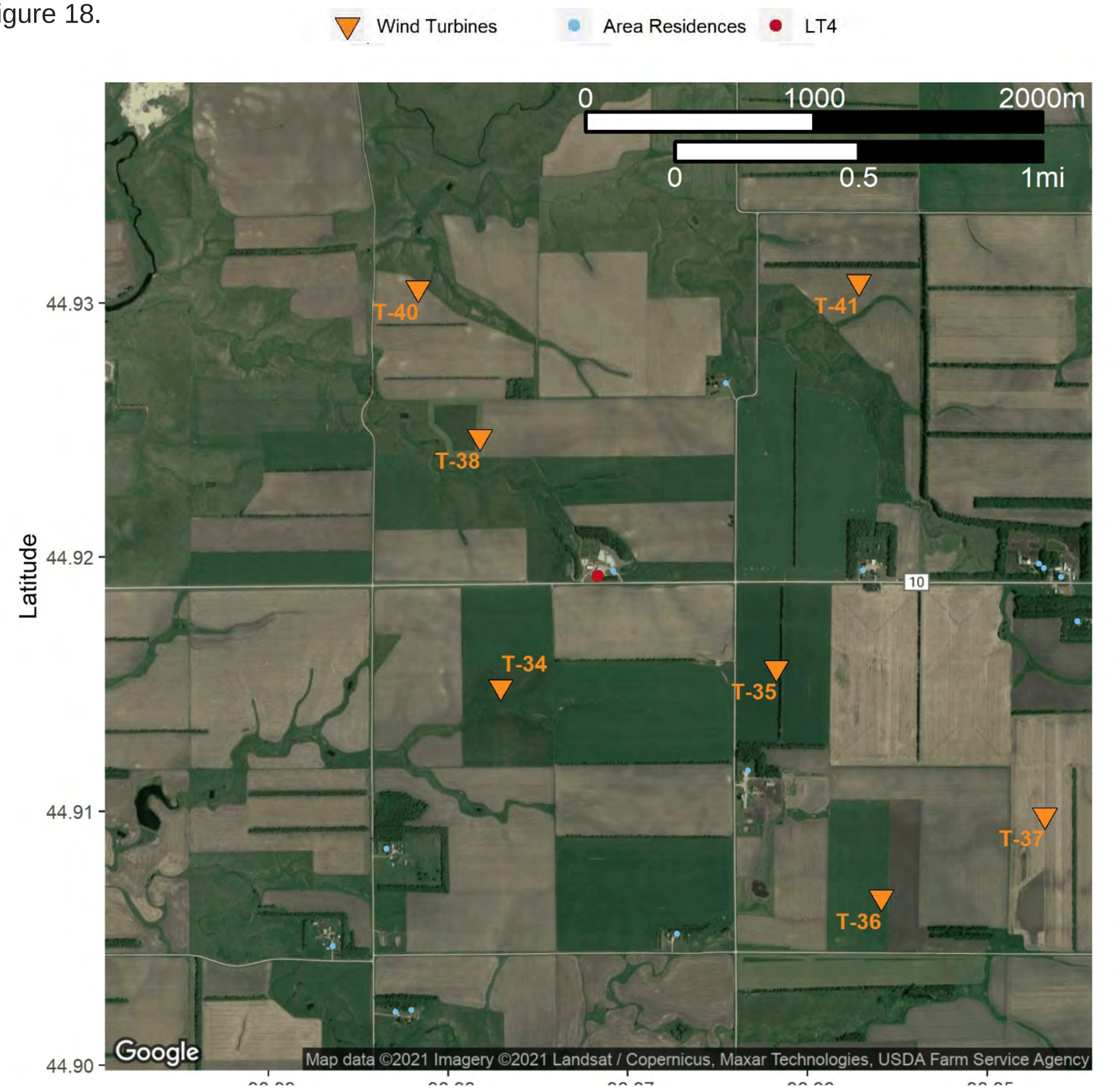


FIGURE 15: MAP OF THE AREA SURROUNDING LT4

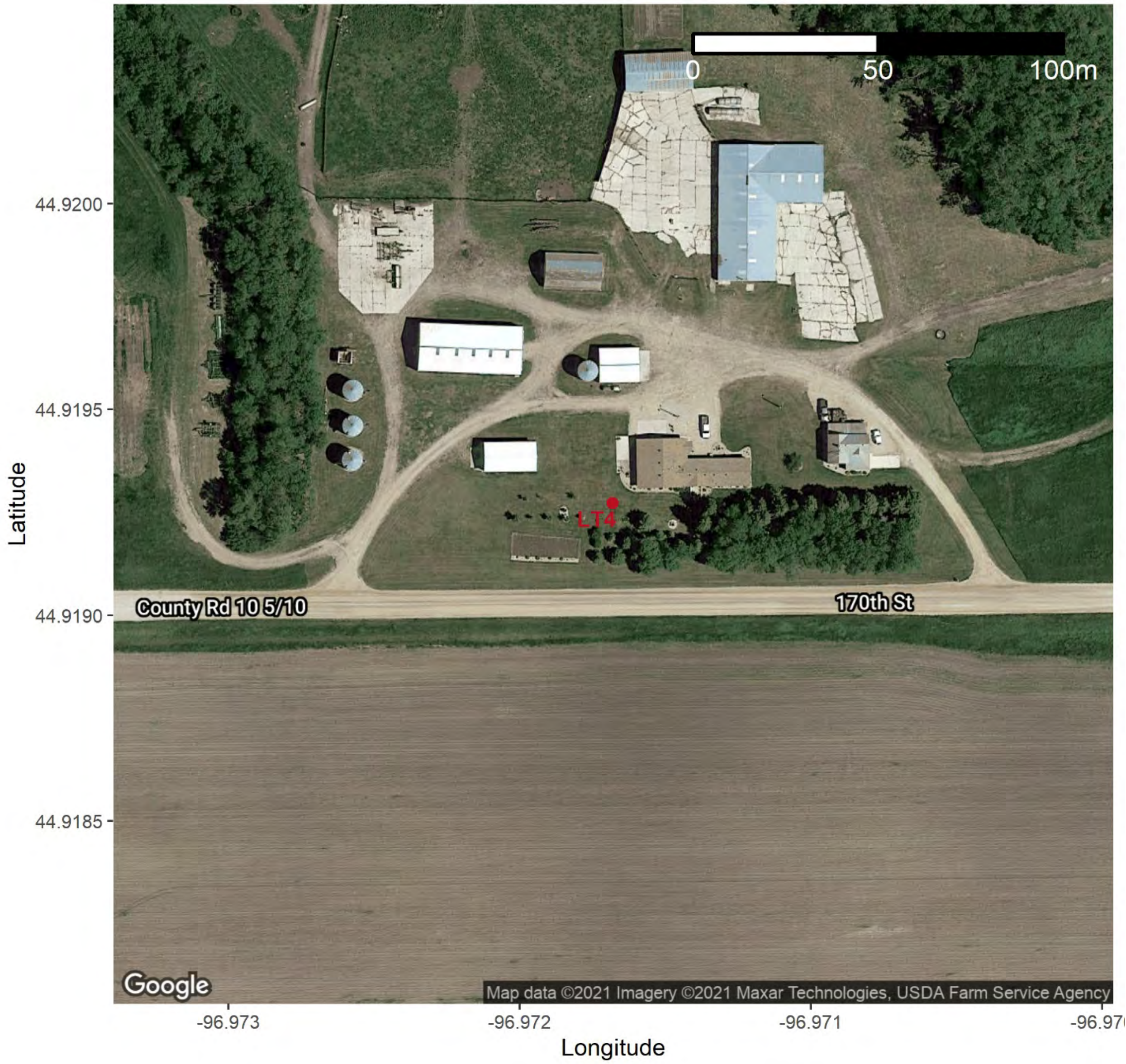


FIGURE 16: MAP OF THE LT4 MONITORING LOCATION

FIGURE 17: PICTURE OF LT4 DURING POST-CONSTRUCTION MONITORING, FACING NORTHEAST

FIGURE 18: PICTURE OF LT4 DURING POST-CONSTRUCTION MONITORING, FACING SOUTHWEST

2.5 LT5 MONITOR (CR2-D21-NP)

The location of the LT5 monitor is in the eastern central part of the Project Area. The monitor was placed 21 meters (69 feet) east of 467th Avenue and 250 meters (820 feet) north of 169th Street on a parcel with a residence and active cattle operation. A map of the monitoring area, including the wind turbines closest to the monitor, is provided in Figure 19. T-52 is the closest wind turbine to the monitoring location at 610 meters (2000 feet) to the east-northeast.

A map of the immediate area surrounding the monitoring location in Figure 20 shows that the monitoring location is 7.62 meters (25 feet) northwest of the residence. Figure 20 also demonstrates that the monitor location it is well protected from ground level winds on nearly all sides.

The photographs of the monitoring location in Figure 21 shows the monitor's placement with respect to the residence. Figure 22 shows the view of the monitoring setup looking in the opposite direction, illustrating the mature trees directly adjacent the monitoring location to the north.

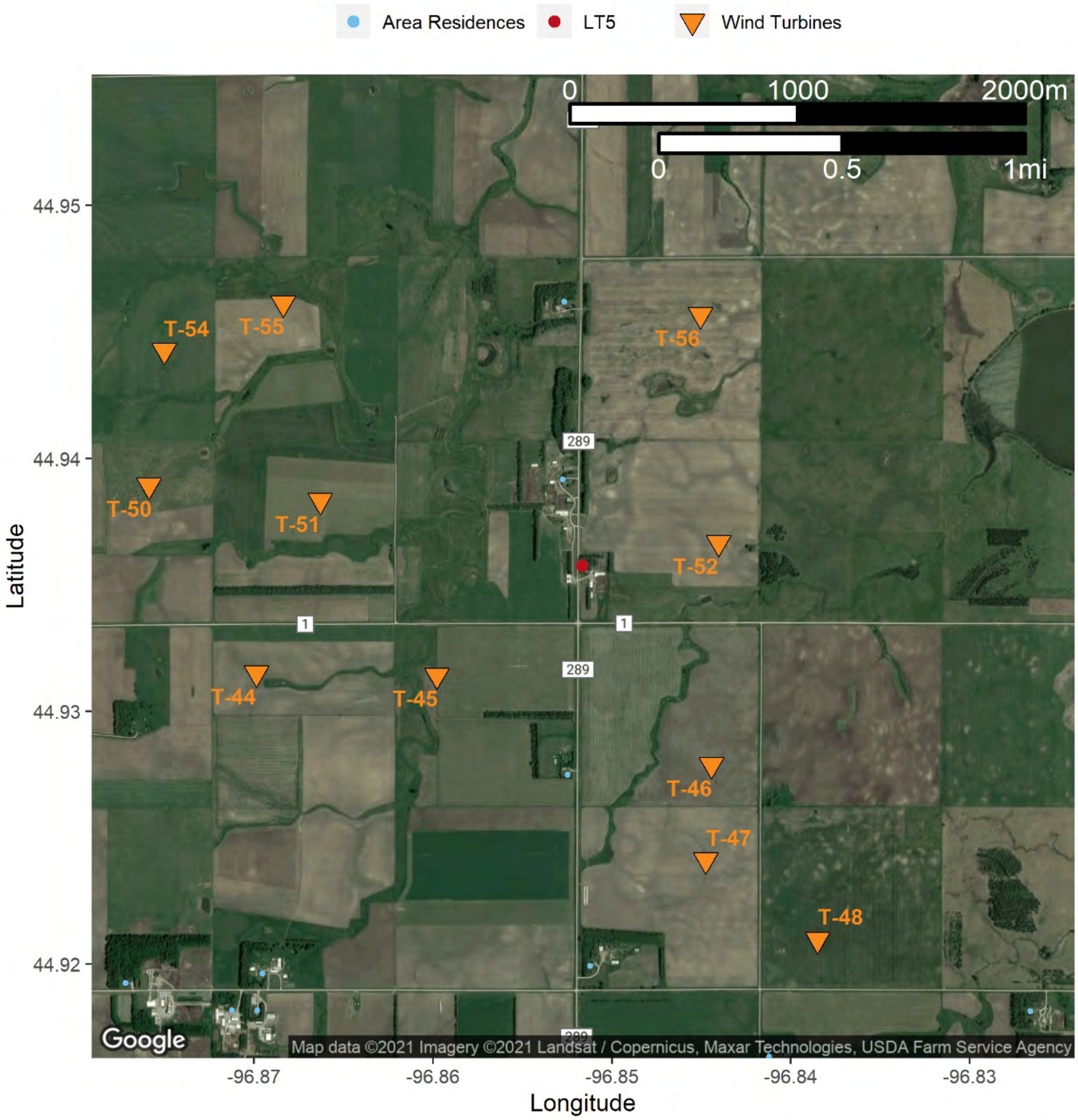


FIGURE 19: MAP OF THE AREA SURROUNDING LT5

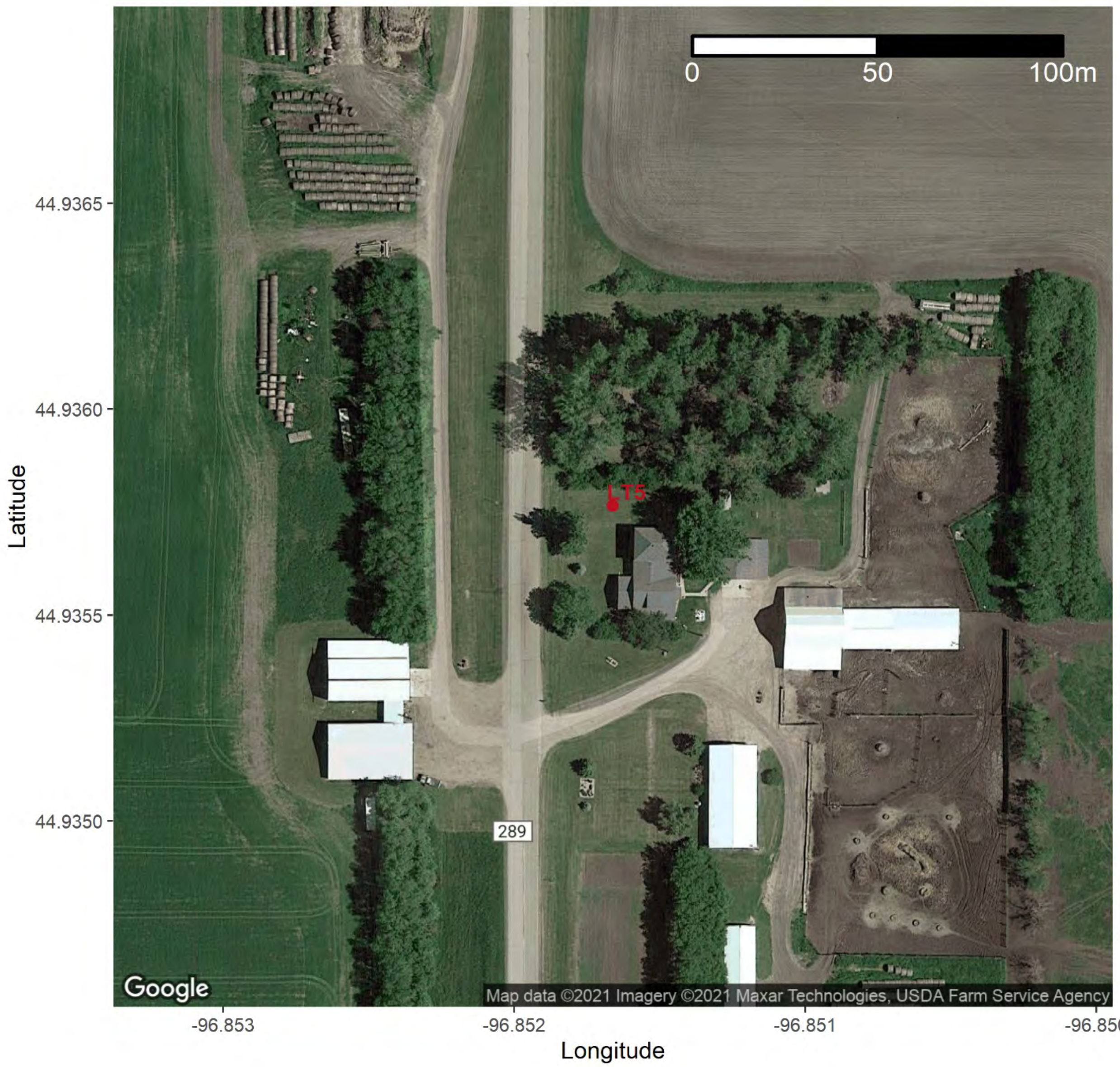


FIGURE 20: MAP OF LT5 MONITORING LOCATION

FIGURE 21: PHOTOGRAPH OF LT5 DURING POST CONSTRUCTION MONITORING, FACING SOUTHEAST

FIGURE 22: PHOTOGRAPH OF LT5 DURING POST CONSTRUCTION MONITORING, FACING NORTH

2.6 LT6 MONITOR (CR2-D221-NP)

The LT6 monitor location is in the front yard of a residence on 468th Avenue in the southwestern portion of the project. The residents at this location have registered formal wind turbine noise complaints associated with the Project's operation. The monitor was placed about 28 meters (92 feet) west of 468th Avenue, 530 meters (1,740 feet) north of US Highway 212, and about 1 km (0.63 miles) north-northeast of Goodwin. A map of the area is shown in Figure 23. The closest wind turbine, T-23 is 600 meters (1,969 feet) to the east of the monitoring location.

The immediate area around the monitoring location is shown in Figure 24. The microphone was placed 7.6 meters (25 feet) east-southeast of the residence. Figure 24 shows the mature vegetative wind breaks surrounding the homestead on the north, south, and west.

Photographs of the monitoring setup are provided in Figure 25 and Figure 26. A view of T-23 from the monitor is shown on the cover of this report.

FIGURE 23: MAP OF THE AREA SURROUNDING LT6

The road adjacent to the LT6 monitor (running north-south) is 468th Avenue.

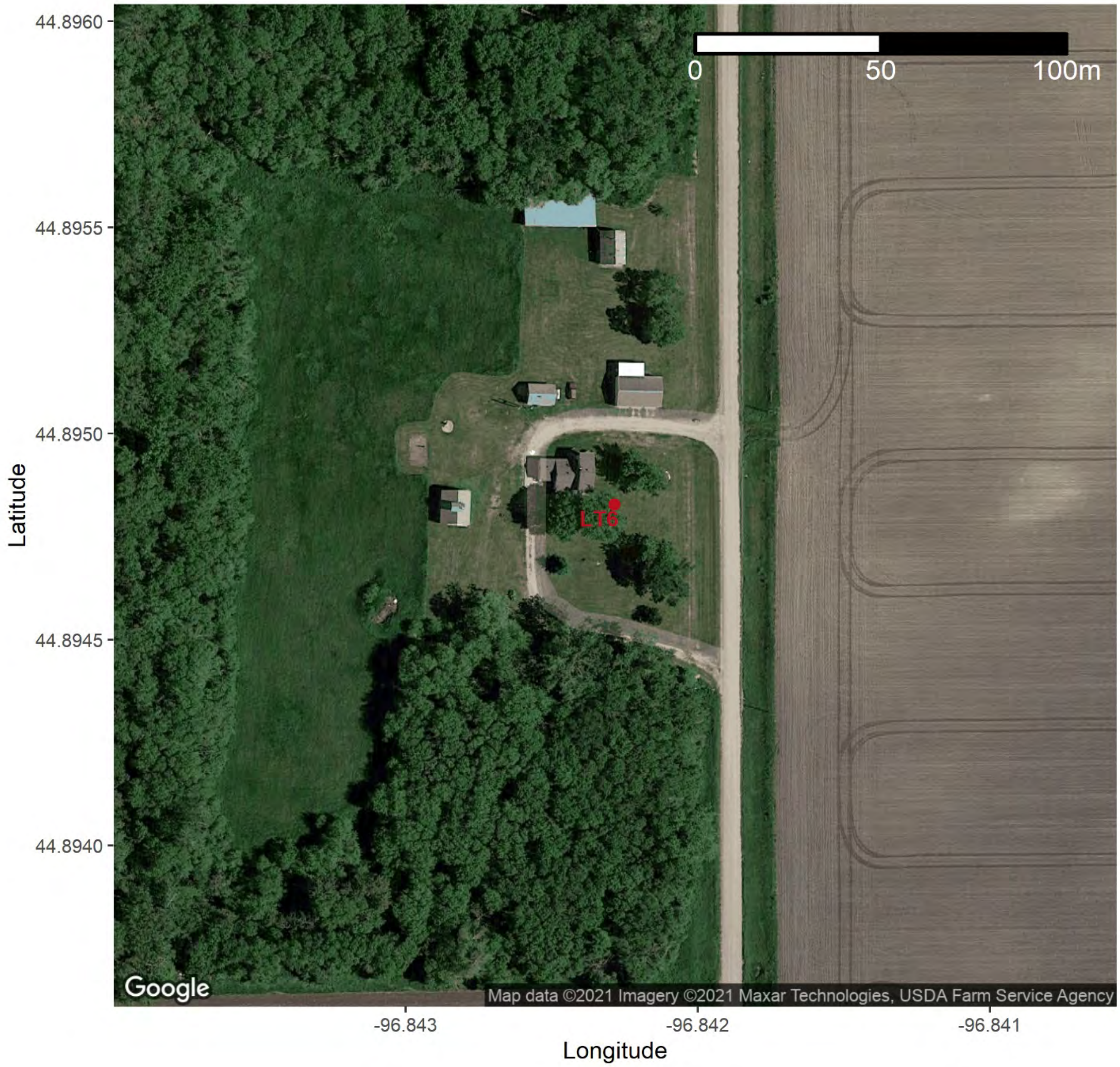


FIGURE 24: MAP OF THE LT6 MONITORING LOCATION

The road adjacent to the LT6 monitor (running north-south) is 468th Avenue.

FIGURE 25: PHOTOGRAPH OF LT6 DURING POST CONSTRUCTION MONITORING, FACING NORTHWEST

FIGURE 26: PHOTOGRAPH OF LT6 DURING POST CONSTRUCTION MONITORING, FACING SOUTHEAST

2.7 LT7 MONITOR (CR2-D212-P)

The LT7 monitor location is at a participating residence in the southern portion of the Project.

The intended location for monitor setup on the south side of the home was avoided due to a gable attic fan that was audible from the intended monitor location. No locations with direct line-of-sight to the nearest turbine were encountered within 7.6 meters (25 feet) of the residence. To maintain line of sight to the closest turbines surrounding the homestead, a location across the main driveway was selected. The location where the monitor was ultimately set up is about 12 meters (38 feet) west of the implement shed and about 32 meters (104 feet) east of the residence.

The monitoring location is 100 meters (330 feet) east of 466th Avenue and 55 meters (180 feet) south of 174th Street. A map of the surrounding area is shown in Figure 27. The closest wind turbine, T-18, is 500 meters (1,640 feet) south of the monitoring location. The map in Figure 28 shows the farm buildings surrounding the homestead with respect to the monitoring location and associated residence.

A photograph of the monitoring setup and the nearby residence is shown in Figure 29. Figure 30 is a picture of the monitor facing south with T-18 in view.

Audible sources during the monitoring period included wind turbines, farm related sounds (including machinery and cattle), intermittent barking dogs, wind rustling the leaves in nearby trees, and occasional vehicle passbys.

Distortion in the sound level data at LT7 occurred between 5/27 and 5/29 because of moisture associated with the prolonged rain event on 5/26 and 5/27. Excessively high sound levels were recorded during this period, which were characterized by sporadic bursts of impulsive sound with no apparent physical stimulus. As a result, these periods were excluded from the data analysis as an anomaly.

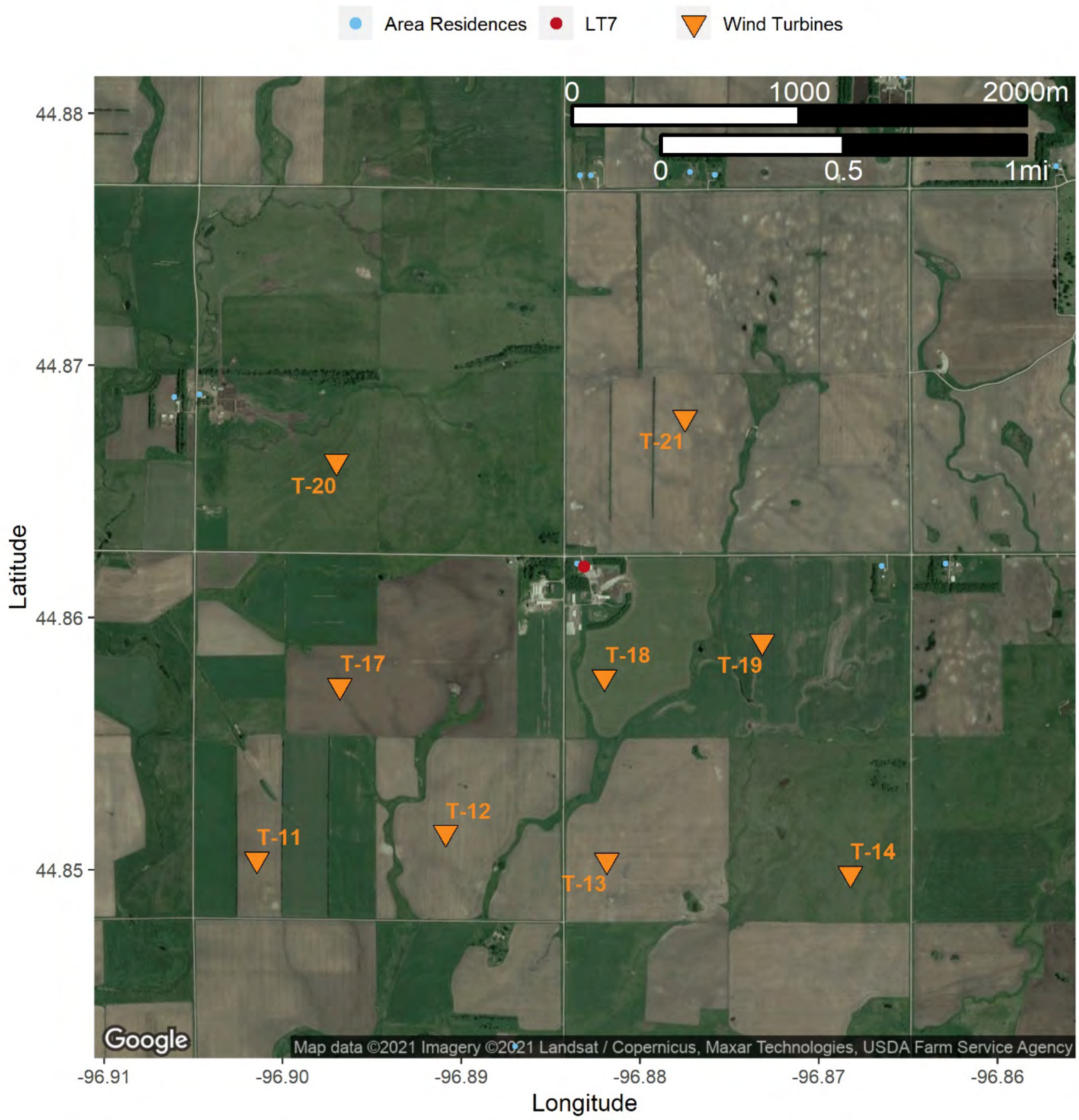


FIGURE 27: MAP OF THE AREA SURROUNDING LT7

FIGURE 28: MAP OF THE LT7 MONITORING LOCATION

FIGURE 29: PHOTOGRAPH OF LT7 DURING POST CONSTRUCTION MONITORING, FACING NORTHWEST

FIGURE 30: PHOTOGRAPH OF LT7 DURING POST CONSTRUCTION MONITORING, FACING SOUTH

3.0 DATA COLLECTION AND PROCESSING

3.1 DATA ACQUISITION

Several sources of data were leveraged for this study, including 1/3 octave band sound levels, ground-level wind speed and temperature, hub-height wind speed and direction, and meteorological data for the region.

Sound Level Monitoring Station Detail

Under the direction of RSG, the sound level monitoring stations were deployed by ESI Engineering on May 24, 2021. Sound level data were collected using ANSI/IEC Type 1 Cesva SC310 and Svantek SV979 sound level meters ("SLM"). The SLMs continuously logged overall and 1/3-octave band sound levels once each second. The Cesva SC310 meters were connected to Edirol R-09HR or R-05 audio recorders, recording audio data at a 128 kbps in *.mp3 format. The Svantek SV979 sound level meters internally recorded continuous audio files in 24-bit *.wav format at a 12 kHz sample rate.

The microphone of each sound level meter was mounted on a wooden stake at a height of approximately 1.2 m (4 ft) and protected by an ACO-Pacific hydrophobic windscreen 17 cm (7 in) in diameter. Before and after measurement periods, sound level meters were calibrated with a Larson Davis CAL200 calibrator. All equipment was lab-calibrated within 1 year of the measurement campaign.

At each monitor site, an Onset HOBO anemometer was deployed in conjunction with the sound level monitoring equipment. The average wind speed and maximum gust speed was logged once per minute. Additionally, a wind vane that measured ground-level wind direction was placed at LT2 and LT4 and a rain gauge was placed at LT7. Precipitation data from the rain gauge at LT7 are used throughout the time history results in this report.

Calibration drift for each monitor was tracked and applied to the data in conformance with ANSI 12.18 between monitor checkups. The most calibration drift between checkups was -0.6 dB;[11] the average (absolute value) drift between calibrations was 0.2 dB.

Table 3 lists the models and spectral specifications of each sound level meter. Inclusive of all equipment deployed, this report considers frequencies between 20 Hz and 10 kHz.

[11] For LT1, the sound level meter calibrated 0.6 dB below the initial field calibration at setup after the first monitoring period. As specified in ANSI 12.18, data from the First Monitoring Period were offset 0.3 dB higher than recorded by the sound level meter at LT1.

TABLE 3: SOUND LEVEL METER SPECIFICATIONS

Monitor	Manufacturer	Model	SN	1/3 Octave Band Frequency Range
LT1	Cesva	SC310	T235260	10 Hz to 20 kHz
LT2	Cesva	SC310	T224253	10 Hz to 20 kHz
LT3[12]	Cesva	SC310	T231914	20 Hz to 10 kHz
LT4	Svantek	SV979	34091	5 Hz to 20 kHz
LT5	Svantek	SV979	35868	5 Hz to 20 kHz
LT6	Cesva	SC310	T220294	20 Hz to 10 kHz
LT7	Svantek	SV979	35869	5 Hz to 20 kHz

Meteorological Data

Automated Surface Observation Station

Beyond the site-specific meteorological data described in the previous section, the Automated Surface Observation Station ("ASOS") at the Watertown Regional Airport (KATY) in Watertown, SD provided regional meteorological data. The KATY ASOS station[13] is located about 14 km (8.75 mi) west of the nearest Project wind turbine.

Wind Turbine Operation Data

Xcel Energy provided SCADA that included hub-height wind speed, nacelle direction, and power production by turbine at ten-minute intervals. NextEra Energy Resources, the operator of the Crowned Ridge I project directly to the north, also provided hub-height wind speed, nacelle direction, and power production for the four turbines in that project within 1.75 miles of LT1. Power production was provided in 10-minute intervals. This study utilizes the hub-height wind speed and power production for each turbine. Hub-height wind direction from Project SCADA data was inaccurate. Thus, hub-height wind direction from Crowned Ridge I was applied to Crowned Ridge II. When this data was not available (e.g., the third monitoring period for LT3), regional wind direction, collected at 10 meters above ground level, was utilized. For the first two monitoring periods, the regional wind direction was in basic agreement with the wind direction provided by Crowned Ridge I, as well as the ground-level direction data measured.

Project met tower data was also provided but was not directly incorporated into this study because the wind direction data was similarly inaccurate.

[12] The LT3 monitor did not operate during the second monitoring period. Thus, monitoring at this site was extended to a third monitoring period in which a different Cesva SC310 (T220294) was deployed at LT3.

[13] Latitude/Longitude: 44.913972 N, 97.154722 W

3.2 SOUND LEVEL DATA PROCESSING

All logged one-second L_{eq} sound levels were imported into R[14], an Open-Source computing language, for processing and data analysis. The outputs from this analysis are provided as plots and tables throughout this report.

Data were aggregated in 10-minute periods and the equivalent continuous sound levels were calculated from the valid (non-excluded) data from the measured 1-second sound level data. If more than half of samples in an aggregation period were excluded (regardless of the exclusion type), the given period was not analyzed.[15]

Data Exclusions

For each monitoring location, pre-processing of the data was carried out to exclude acoustically invalid periods during which any of the following occurred:

- Wind gusts: ground-level wind gust speeds above 5 m/s (11.2 mph)
    - Periods were excluded according to the measurements of ground-level wind gust speed collected by an anemometer at each respective monitoring location (all monitoring locations included an anemometer)
- Precipitation: rain and thunderstorm events
    - Periods with precipitation were found through data collected from a rain gauge installed at LT7 and regional data. Specific time periods of precipitation were pinpointed through inspection of acoustic data (including digital audio recordings).[16]
- Anomaly: outliers in the sound level data
    - Site setup and microphone calibration
    - Periods of microphone malfunction at LT3 and LT7, which were both related to moisture-induced distortion caused by a preceding heavy rain event
    - “Additional anomalous sounds” [17] that interfered with the measurement of wind turbine noise during evaluation periods, as discussed in Section 5.1.

[14] https://www.r-project.org/about.html

[15] ANSI S12.9 Part 3: Quantities and Procedures for Description and Measurement of Environmental Sound - Part 3: Short-Term Measurements with an Observer Present

[16]Note that data are excluded for any period of precipitation, regardless of the rain rate, because of the self-noise induced on the microphone windscreen by droplets or hailstone.

[17] Transient noise sources that occurred during the turbine-on period that were not present in the turbine off period (or the opposite – sounds in a turbine-off period that were not present in turbine-on period)

ANS-weighting

Since monitoring took place in the summer, all soundscapes consisted of considerable biogenic sound (particularly insects and birds). Biogenic sounds are typically tonal, that is, concentrated in narrow ranges of frequency. At times, biogenic sounds had a pronounced effect on overall A-weighted sound levels.

To mitigate the influence of biogenic sounds, the “ANS” frequency-weighting network can be applied to the spectral data.[18] All analyses in this report utilize a “Smart” ANS weight, in that ANS weighting is only applied when prominent discrete tones above the 1.25 kHz 1/3 octave band are detected.[19] When prominent discrete tones are found, then the overall A-weighted sound level is recalculated by summing 1/3 octave bands from 20 Hz to 1.25 kHz (18 Hz to 1,414 kHz). The “Smart” ANS sound level (denoted dB-ANS) was calculated for every 1-second sample of sound level data collected.

Note that the contribution of wind turbine sound above the 1 kHz octave band (the portion of the sound spectrum that is removed to obtain the ANS-weighted level when high frequency tonality is detected in the sample) is typically at least 10 dB below the turbine-only sound level at residences. As such, ANS weighting “focuses” the spectral range in the low to mid frequency range where wind turbine sound emissions are expected.

[18] ANSI S12.100, “Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas”

[19] Sounds considered tonal that get the ANS weight applied are those for which a prominent discrete high frequency (>1.25 kHz 1/3 octave band) tone is found using either of the two methods:

1. If a 1/3 octave band exceeds the neighboring 1/3 octave band on either side by more than 5 dB (as in ANSI S12.9 Part 4 Annex C), or
2. If a 1/3 octave band exceeds the average of the two neighboring lower and two neighboring upper 1/3 octave bands on each side by more than 5 dB.

The latter method is used to capture complex bird harmonic sounds that would not be considered tonal under the first method.

4.0 MONITORING PERIOD RESULTS

This section provides the results from the full post-construction monitoring period, including regional weather patterns, wind turbine operational characteristics, and sound levels.

4.1 REGIONAL WEATHER

Regional meteorological conditions over the course of the post-construction monitoring period are plotted in Figure 31. The vertical lines on the figure delineate the three monitoring periods. The third monitoring period is only applicable to LT3.

The charts are presented with three panes of approximately hourly data from the ASOS meteorological station at Watertown Regional Airport (KATY) in Watertown, SD. Nighttime periods (10 PM to 7 AM) are indicated with the vertical gray shading.

The top pane displays temperature (in red); the second pane displays relatively humidity (in purple) and rain rate in millimeters per hour (light blue). The third pane shows average wind speed (in miles per hour) and direction measured at 10 m (33 ft) above ground level.

Regional wind direction is represented in two different ways in the bottom pane. First, the arrows are overlaid on the mean wind speed to indicate the direction that the wind was blowing: the convention is that the arrow at the mean wind speed points in the direction that the wind was blowing, (e.g., “>” would represent winds out of the west blowing to the east). Second, the orange points correspond to the cardinal direction on the y-axis to represent the wind direction.[20]

Precipitation was recorded during the monitoring period in Watertown, SD on 5/26, 5/27, 5/29, 5/30, 6/9, 6/11, and 6/20. The extended rain period and excessive humidity from the storm system on 5/26 and 5/27 likely contributed to some data loss at LT3 and LT7 between 5/27 and 5/29.

[20] The point-based representation provides a finer resolution than the arrows but the point-based method suffers from the inherent discontinuity of North (0 degrees) at the bottom of the plot and North (360 degrees) at the top of the plot.

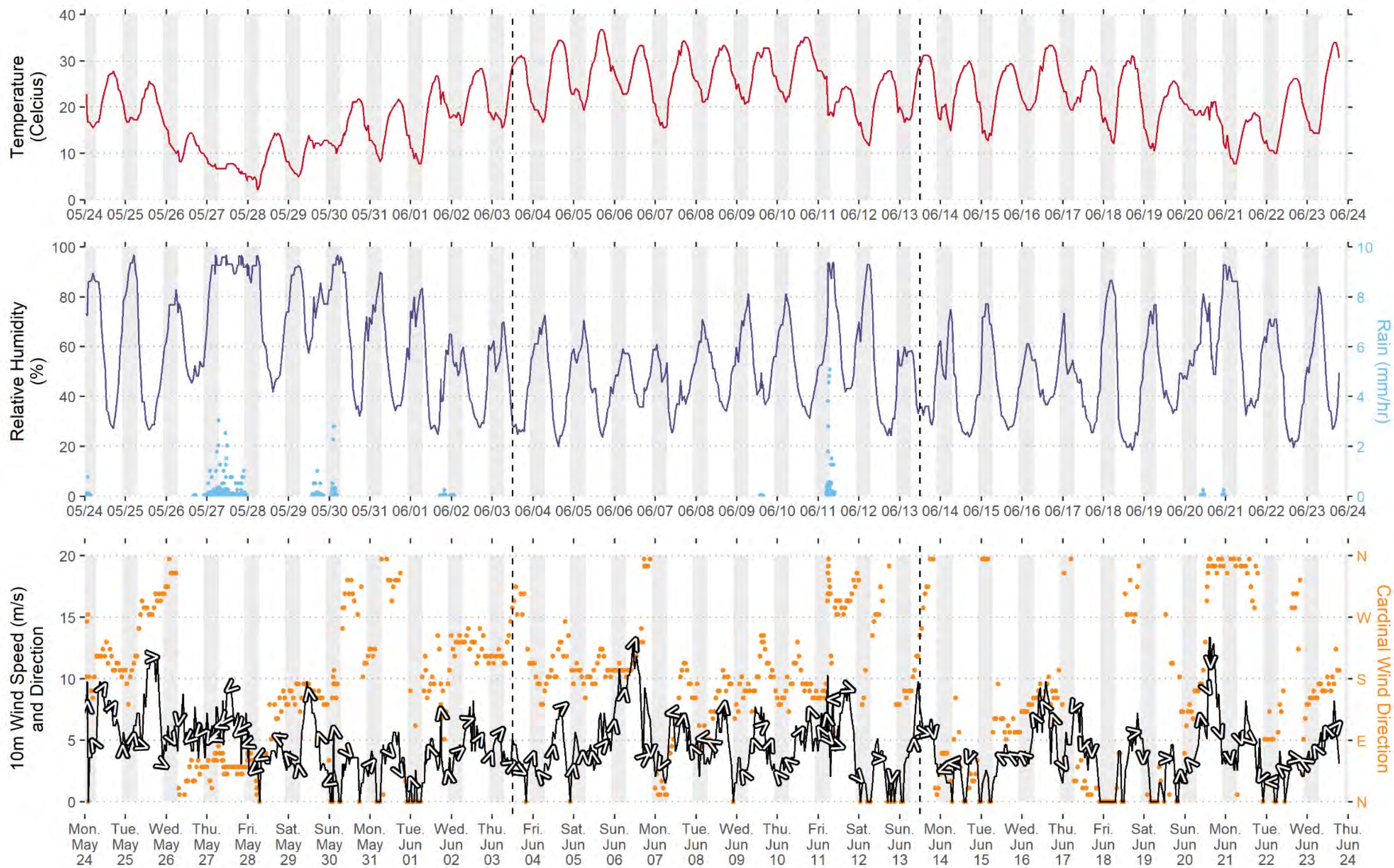


FIGURE 31: TIME HISTORY OF REGIONAL METEOROLOGY FOR THE ENTIRE MONITORING STUDY.

Source: Watertown Regional Airport, South Dakota ASOS station (ATY) [Year: 2021]

The three monitoring periods are delineated by the vertical dotted lines. The third monitoring period is only applicable to LT3.

4.2 HUB HEIGHT WIND AND POWER PRODUCTION

The average wind turbine power production and hub-height wind speed and for all three monitoring periods is plotted in Figure 32 for all 55 turbines within 2.8 km (1.75 miles) of the monitoring locations.

Wind turbine power production and hub-height wind speed are separated into parallel panes in each figure. Nighttime periods (10 PM to 7 AM) are indicated with the vertical gray shading. The vertical dashed lines delineate the three distinct monitoring periods.

The first pane of the plot shows wind turbine power production. The 10-minute power production data collected by the Project's SCADA system was scaled to the percentage of its maximum power output. In this way, the GE 2.1 (with a maximum power output of 2.1 MW) and the GE 2.3 (with a maximum power output of 2.3 MW) can be aggregated together on the same scale. The scaled 10-minute data power production data was then aggregated into one-hour averages for each turbine. These hourly values were than averaged across all 55 wind turbines included in the study. The horizontal dotted line at 85% of maximum power production represents the wind turbine power production associated with sound emissions within 1 dB of maximum sound power output: the target compliance condition (see Section 1.2).

The second pane of the plot shows hub height wind speed and wind direction for the complete monitoring study. Wind speed is shown as the mean of all 55 study turbines; the range of measured values at the 55 turbines is represented by the light gray shading that follows the wind speed line. The wind direction data are plotted in an identical manner to those of Figure 31: using arrows pointing in the direction that the wind was blowing overlaid on the mean hourly wind speed and the orange dots (corresponding to the y-axis on the right) that represent the cardinal direction of the wind for that hour. The SCADA data available from the Project did not include reliable wind direction data. All hub height wind direction for the first two weeks is from the neighboring Crowned Ridge I project. Wind direction for the third monitoring period uses the ASOS data from KATY (see Figure 31). The horizontal dotted line at 9 m/s (20.1 mph) represents the hub-height wind speed at which rated maximum sound power is achieved (according to manufacturer specifications).

Periods with power production and wind speeds above the target thresholds (horizontal dashed lines) in Figure 32 are in general agreement with each other. That is, when the power production is above 85% of maximum output, hub height wind speeds were measured above 9 m/s.

Figure 32 shows that the first monitoring period experienced considerable power production over the first few days, on May 29, and over the last day of the monitoring period. The mean power production did not reach the 85% threshold for maximum sound power production between May 30 and June 2. The second monitoring period experienced more robust production until the final day, with mean hub height winds hovering around the 9 m/s threshold. The third monitoring period oscillated between days of strong winds and calm periods.

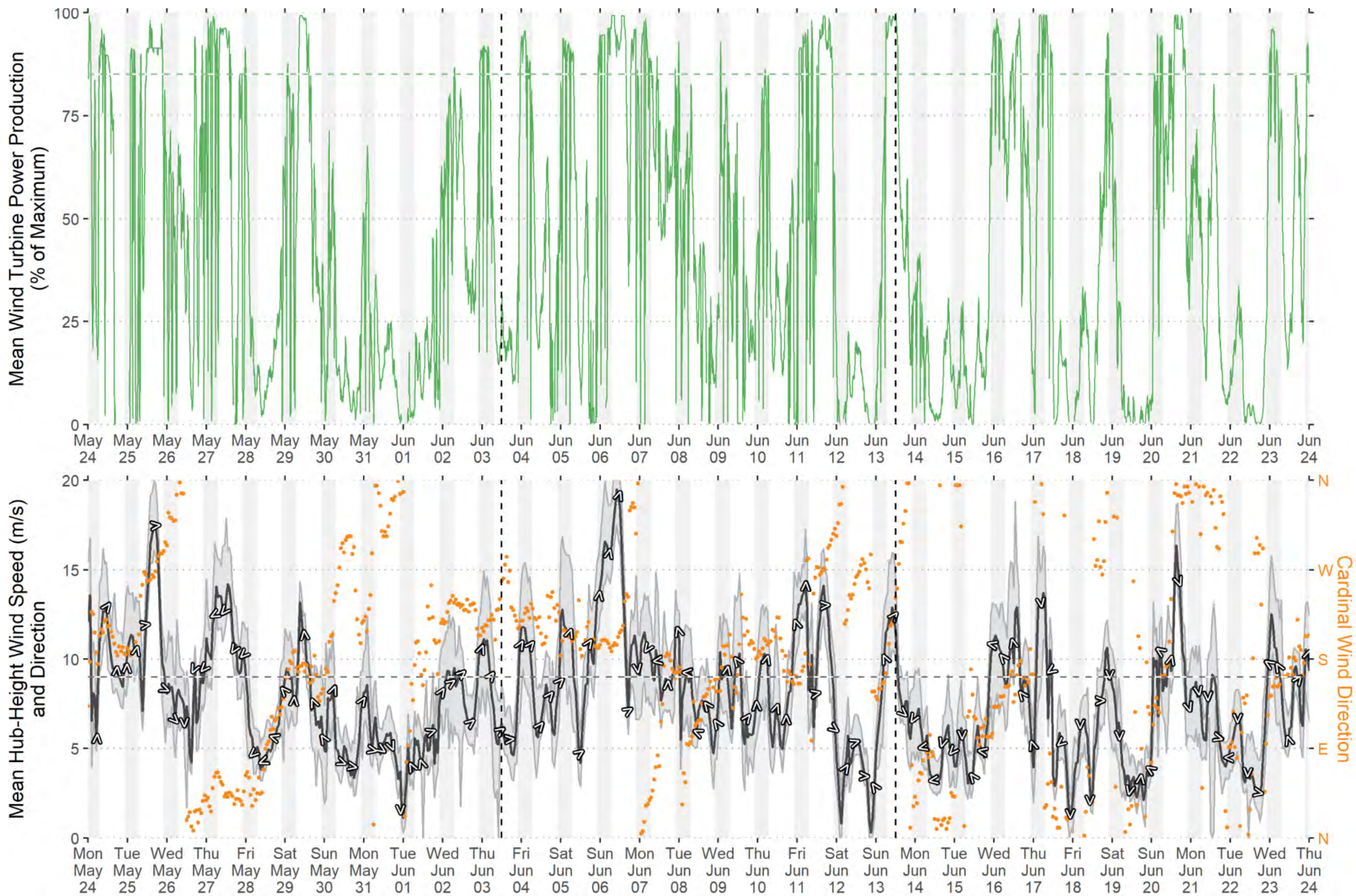


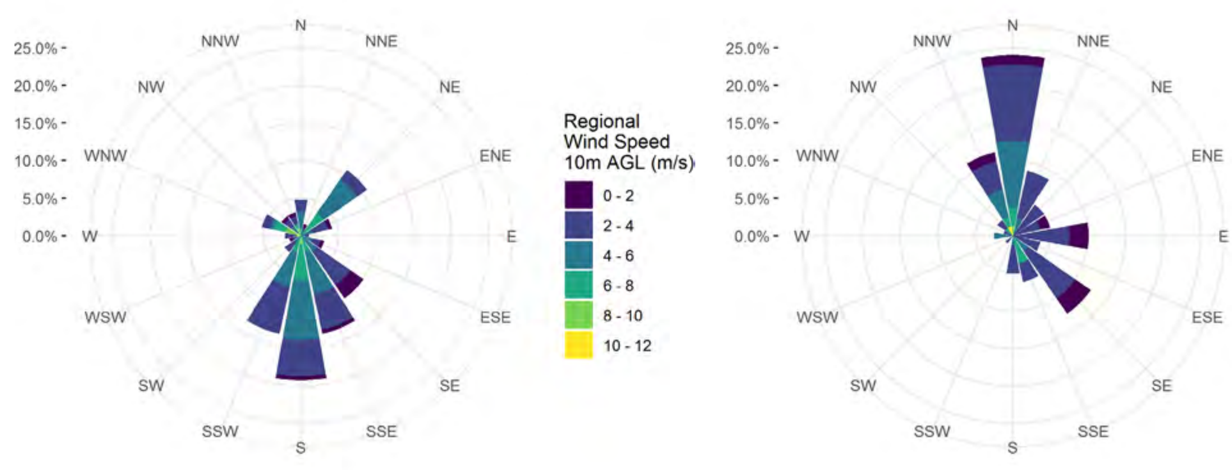
FIGURE 32: WIND TURBINE POWER PRODUCTION AND HUB HEIGHT WIND SPEED AND DIRECTION FOR POST-CONSTRUCTION MONITORING

The three monitoring periods are delineated by the vertical dotted lines. The last monitoring period is only applicable to LT3.

Wind Direction Pattern

A summary of the wind pattern from the ASOS station in Watertown, SD[21] during nighttime hours (10 AM to 7AM) is provided in the wind roses in in Figure 33. A wind rose plot collects wind speed and wind direction and displays the distribution of wind speeds by cardinal direction. Wind direction on a wind rose plot represents the cardinal direction from which the wind is blowing. Only nighttime hours are shown to portray the wind conditions for which turbine-only noise levels were assessed. The ASOS wind speed data is collected 10 meters above ground level (AGL).

Figure 33(A) summarizes the wind rose for the first two monitoring periods (5/24 through 6/13) and Figure 33(B) displays the wind rose for third monitoring period (6/13 through 6/24, which is only applicable to LT3). Figure 33(A) shows that that winds at night were consistently out of the south for the first two monitoring periods. A similar plot using hub height wind data (not shown) presents a very similar pattern to that shown in Figure 33(A) but it indicates that winds were most prominent from the south-southwest at hub height (as opposed to the south, as shown in Figure 33(A)). The distribution of wind direction in Figure 33(A) is generally consistent with the historical wind patterns in the region for the early summer months, according NREL's Wind Integration National Dataset ("WIND") Toolkit[22]. In contrast, Figure 33(B) exhibits a drastically different wind pattern than was observed in the first two monitoring periods, with wind primarily out of the north for about 20% of the nighttime periods. According to the WIND Toolkit, winds from due north are not common in the region. The colder months typically bring winds from the Northwest. Winds from the east are uncommon in the region.



(A) **(B)**

FIGURE 33: REGIONAL WIND ROSE DURING NIGHTTIME HOURS FOR (A) THE FIRST AND SECOND MONITORING PERIOD AND (B) THE THIRD MONITORING PERIOD

Source: Watertown Regional Airport, South Dakota ASOS station (ATY)

[21] The plots do not use hub height winds due the lack of hub height wind direction data for the third period
[22] https://www.nrel.gov/grid/wind-toolkit.html

4.3 MONITORING STATION RESULTS

This section provides an overview of the monitoring results. Comparing meteorological data at each monitor provides an objective comparison of the influence of ground level wind speeds at each monitor. The time history plots portray the results of the full monitoring period, leveraging all available data (wind turbine power production, sound, and wind), lending context to the compliance results.

Overview of Meteorological Conditions

The first monitoring period spanned from May 24 to June 3. The second monitoring period spanned from June 3 and until June 14. Some monitors lost power or filled up their memory a day or two prior to checkup or pickup. A power failure of the sound level meter at LT3 during the second monitoring period necessitated the extension of monitoring at LT3 and the continuation of nighttime shutdowns at wind turbines within 1.75 miles of LT3 through June 24, 2021. LT3 was the only sound level monitoring station that collected data during the third monitoring period, which lasted from June 14 to June 24.

Precipitation exclusions for each monitor were similar, with an average of 40 hours of data of data removed for precipitation over the first two monitoring periods. The third monitoring period had 2.5 hours of precipitation excluded at LT3.

Ground level wind speeds have a profound influence on outdoor sound levels. As shown in Table 4, ground-level winds varied considerably between monitor locations. LT5 had the lowest wind speeds and the fewest hours excluded due to ground-level wind gusts above 5 m/s. In contrast, LT2 and LT4 experienced the strongest ground-level wind, with over one hundred hours of wind gust exclusions. The average wind speed at LT2 and LT4 was about four times that of LT5, which contributed to an order of magnitude more wind gust exclusions over the full monitoring study at LT2 and LT4 compared to LT5. These results demonstrate that LT5 was the monitoring location most sheltered from ground-level wind speeds.

Overall, between 450 and 500 hours of sound level data were collected at each monitor, resulting in at least 320 hours of acoustically valid data at each monitor (380 hours on average).

TABLE 4: GROUND-LEVEL WIND SPEED SUMMARY AT EACH MONITORING LOCATION

MONITORING LOCATION	PERIOD AVERAGE WIND SPEED		MAXIMUM 1-MINUTE AVERAGE WIND SPEED		MAXIMUM WIND GUST SPEED		WIND GUST EXCLUSIONS
	m/s	mph	m/s	mph	m/s	mph	hours
LT1	1.2	2.6	5.9	13.3	11.6	25.9	52.9
LT2	1.8	4.0	7.5	16.8	12.6	28.2	101.5
LT3	1.5	3.4	7.1	15.8	12.8	28.8	83.7
LT4	1.9	4.2	9.6	21.4	16.1	36.1	124.8
LT5	0.5	1.1	4.0	8.9	9.6	21.4	9.5
LT6	1.0	2.3	9.4	21.0	14.6	32.7	47.9
LT7	0.9	2.1	7.4	16.6	12.9	29.0	51.5

Time History Plots

Description

Each figure combines three panes of relevant data, including wind turbine power production, sound levels, and meteorology. Time runs consecutively along the x-axis (from left to right). The labeled dates represent the beginning of each day; dotted vertical lines through each plot delineate midnight and noon. Nighttime periods (10 PM to 7 AM) are indicated in each pane by vertical grey shading. Results are presented for two monitoring periods for each monitor, each about 10 days each, totaling up to 20 days.

The top pane shows the 10-minute wind turbine power production in percentage of maximum output, which allows wind turbine models with different maximum power outputs (2100 kW and 2300 kW) to be compared on the same scale. Production from the closest turbine is displayed in red and the mean of the five nearest turbines (including the closest) is shown in green. The light-yellow shaded area between the traces if minimum and maximum power production represents the range of turbine operation for the nearest five wind turbines. Turbine shutdowns on nights with full power production are visible as nearly vertical red lines.

The middle pane provides the aggregated sound level data results as overall $L_{eq10min}$. The solid orange line is the smart-ANS weighted level and the dashed orange line shows the A-weighted level. Periods when the dashed line is visible above the solid line indicate periods when biogenic sound was prominent. Often the lines are indistinguishable because the values are the same.

The orange shading surrounding the A-weighted values represents the range of statistical sound levels for each hourly period (L_{10} to L_{90}). Periods when the L_{eq} lines are blank indicate exclusions. The cause of the exclusion is denoted by the colored points (yellow, blue, red) corresponding to the type of exclusion (anomaly, precipitation, wind gust). Note that the “raw” L_{10} and L_{90} range are still plotted during excluded periods for context and continuity. Additional anomaly exclusions around wind turbine shutdown periods (described in Section 5.1) are included on the plots.

The third pane provides ground height gust speed, hub height wind speed, and precipitation. To match the aggregation period of sound levels, the maximum ground-level wind gust speed for each hour is plotted in red, while the average wind speed over the hour is displayed in pink. Hub height wind speed (in green) and direction (arrows) are averaged over the hour for all nearby turbines; light green shading provides the range of hourly windspeeds at all nearby turbines. The horizontal red dot-dash line corresponds to wind speed exclusion threshold of 5 m/s (11.2 mph), while the horizontal green dot-dash line at 9 m/s (20.1 mph) represents the hub height wind speed at which the wind turbines reach their full rated sound power output. The green shading shows the rate of precipitation, with darker shading indicating a higher precipitation rate.

LT1

Time history results for the first monitoring period at LT1 are plotted in Figure 34; a similar plot for the second monitoring period is provided Figure 35.

Shutdown periods are apparent in the wind turbine production data and sound level on most nights with acoustically valid data, that is, the measured sound level data is often correlated with wind turbine operation. Note that ground level wind speeds are often correlated, as well. Robust wind turbine production with valid acoustical data was limited to the nights ending on May 25, May 29, and June 2 in the first monitoring period. The second monitoring period had production in the target compliance range on most nights.

LT2

The time history plot for the first monitoring period at LT2 are provided in Figure 36. Figure 37 shows the time history for the second monitoring period. Due to the monitor's exposure to ground level winds, substantial exclusions resulting from high-ground level wind speeds accompanied this monitor, though the strong ground level winds generally occurred during the daytime. Nighttime wind turbine shutdowns are most evident in the sound level data on the nights ending on 5/26, 5/27, 5/29, 6/2, and 6/7 through 6/10.

LT3

The time history plot for the first monitoring period at LT3 are provided in Figure 38. The chart shows the malfunction of the sound level meter on 5/27 coincides with the rain event that began on 5/26; distortion caused by the moisture fixed itself on the morning of 5/28. All data during this period were excluded from the analysis. Also, the LT3 monitor external power system failed shortly after deployment for the second monitoring period and was not running for any turbine shutdowns during that period. Thus, instead of removing the monitoring station on 6/14, a different sound level meter with a fresh battery was deployed for another ten days to collect sufficient data. Figure 39 is a plot of the time history results for the third monitoring period.

Shutdown periods were apparent on most nights at LT3. The nights ending on 5/29, 5/31, 6/2, 6/3 from the first monitoring period, and 6/16, 6/19, 6/21, and 6/23 from the third monitoring were particularly evident. Although the closest turbine (T-85) did not operate for about 24-hours starting in the afternoon of 6/22 during the third monitoring period, the shutdown on the night ending on 6/23 are still evident in the data.

LT4

Time history charts for LT4 are provided in Figure 40 and Figure 41. Substantial wind gust exclusions were necessitated at LT4. These wind gust exclusions were most common during the daytime. Shutdown periods at the monitor were evident in the data on the nights ending on 5/26, 5/29, 6/3, 6/4, 6/5, 6/9, 6/10, and 6/13. Nighttime $L_{eq10min}$ were typically below 40 dBA throughout both monitoring periods.

LT5

Time history results at LT5 are plotted in Figure 42 and Figure 43. Compared to the time history plots for the other monitors, the wind turbine shutdowns at LT5 were generally less evident, which is a result of higher background sound levels. Wind in the trees was the significant common driver of nighttime sound levels. The monitoring location was sheltered from direct winds and thus necessitated the fewest exclusions among all monitors. The shutdowns that are most apparent in the time history data at LT5 were on the nights ending on 5/26, 5/29, 5/31, 6/7, and 6/8.

LT6

The time history results for LT6 are provided in Figure 44 and Figure 45. Traffic on US Highway 212 is evident as a major source at the monitor due to the consistent difference of about 10 dB between the L10 and L90; large differences in these two metrics indicates that sporadic (i.e., transient) sources of sound are common on the soundscape. Due to traffic noise, shutdowns are not particularly evident in the 10-minute time history data, though the drop in sound levels associated with the shutdowns can be observed on 5/26, 5/31, 6/7, and 6/8.

LT7

Time history results for LT7 are presented in Figure 46 and Figure 47. The malfunction of the sound level meter at LT7 is evident in Figure 46 on 5/27, which was caused by the rain event that began on 5/26. Data from the monitor returned to expected function early in the morning on 5/29. Data during this period of elevated sound levels was excluded from the analysis. Shutdowns are clearly observable on many nights during the monitoring period, including, 5/25, 5/26, 5,29, 6/2, 6/3, 6/5, 6/9, and 6/10.

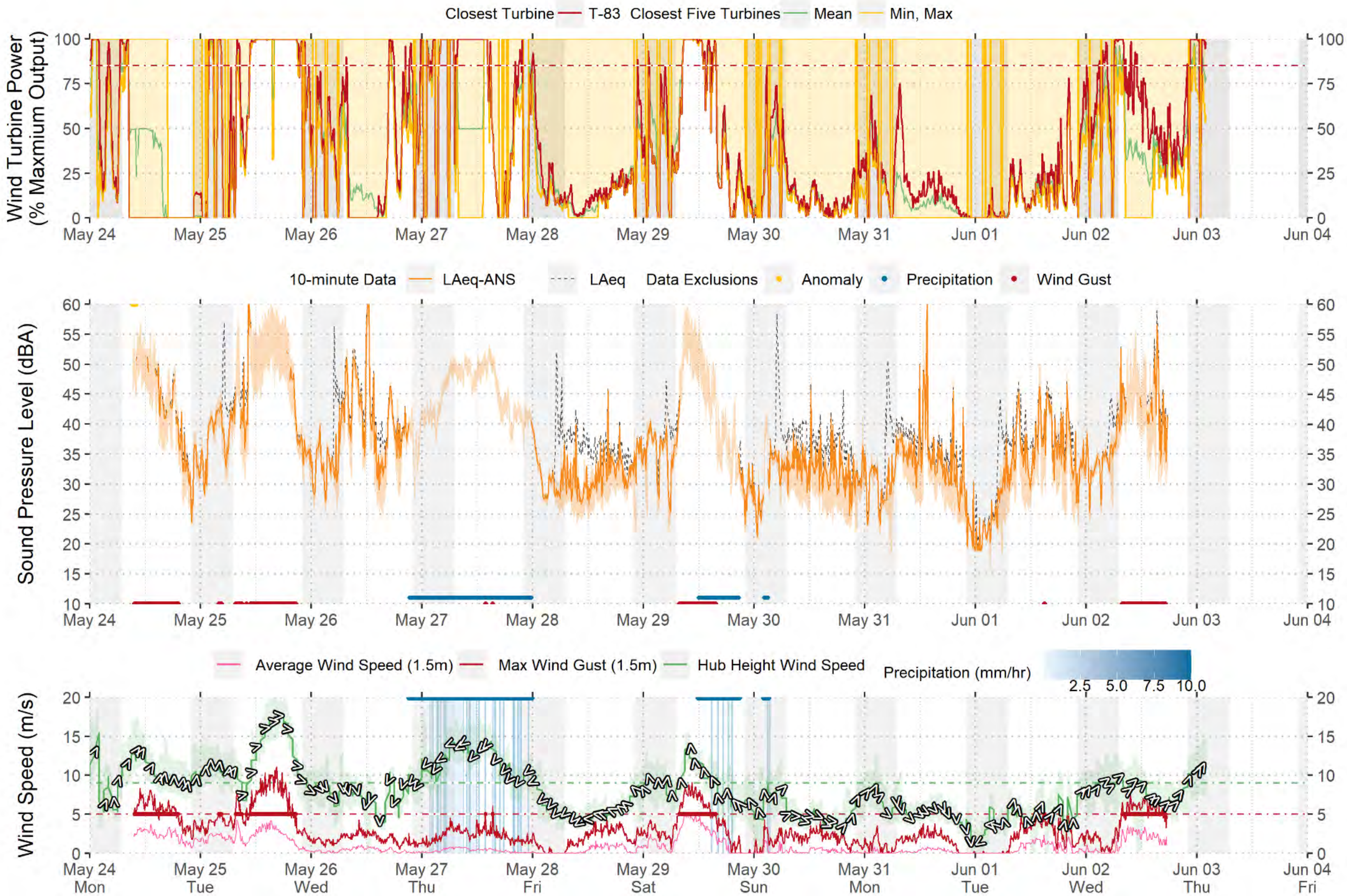


FIGURE 34: LT1 MONITOR – MONITORING PERIOD 1 – TIME HISTORY PLOT – 2021

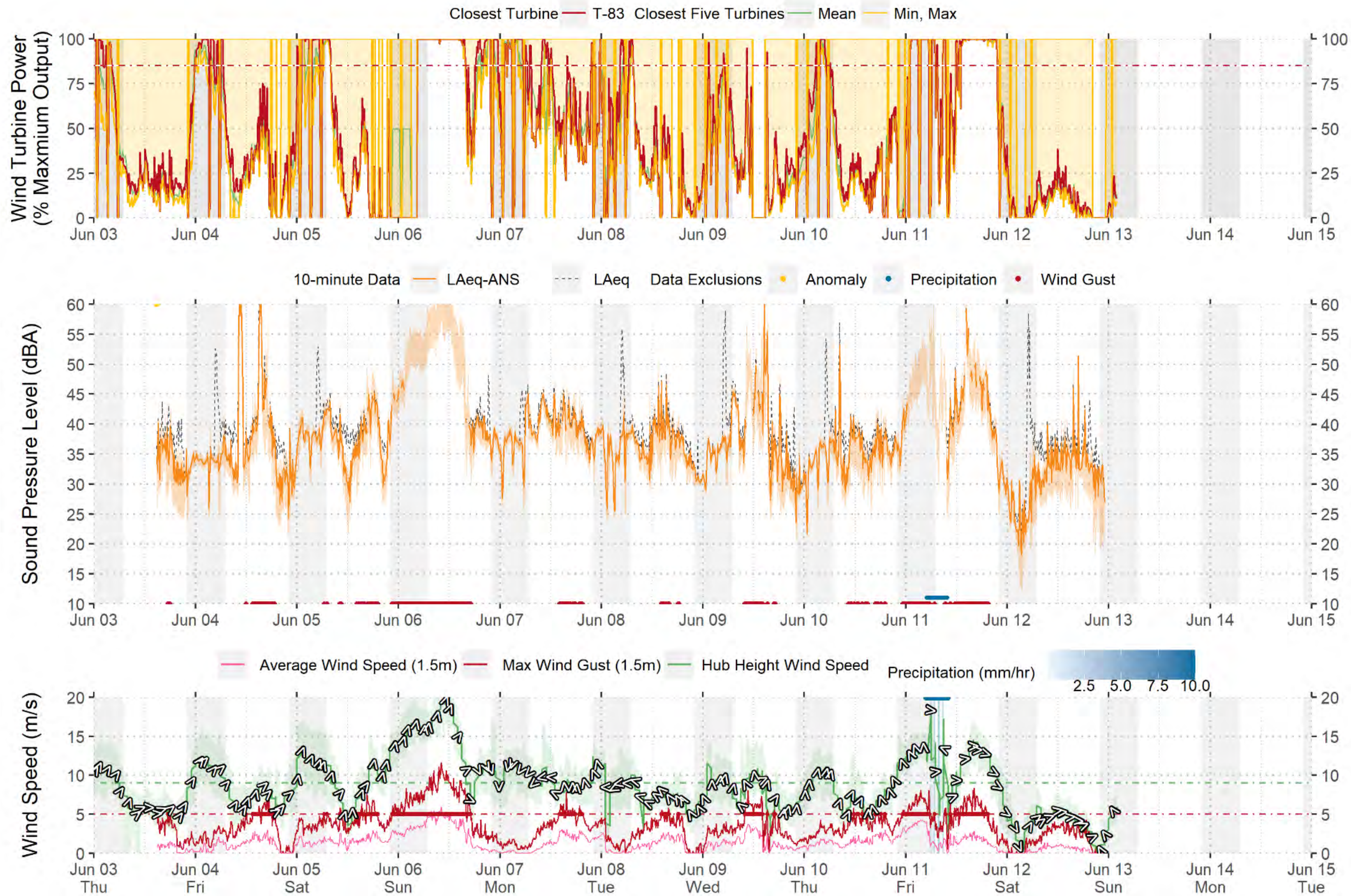


FIGURE 35: LT1 MONITOR – MONITORING PERIOD 2 – TIME HISTORY PLOT – 2021

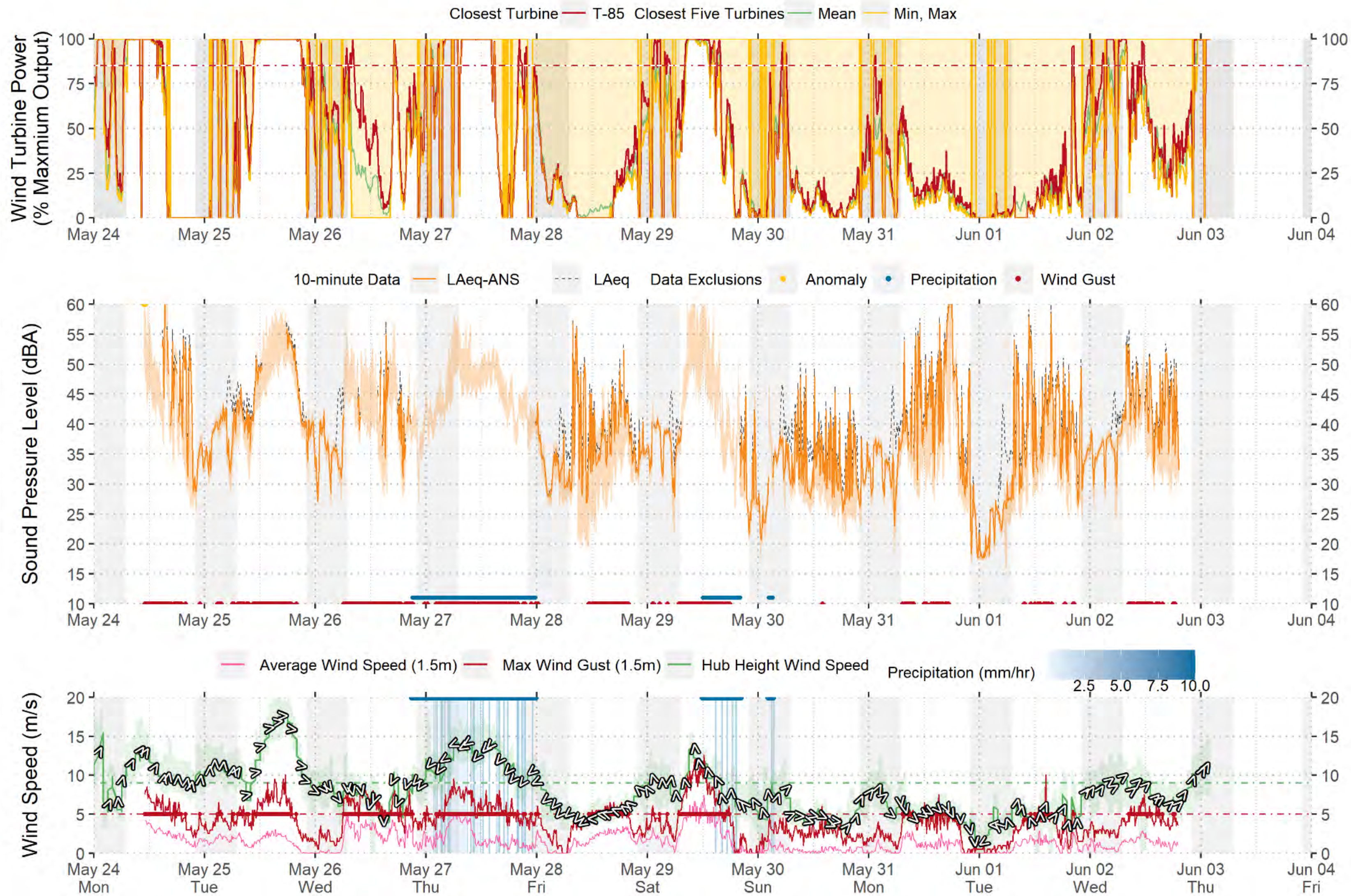


FIGURE 36: LT2 MONITOR – MONITORING PERIOD 1 – TIME HISTORY PLOT – 2021

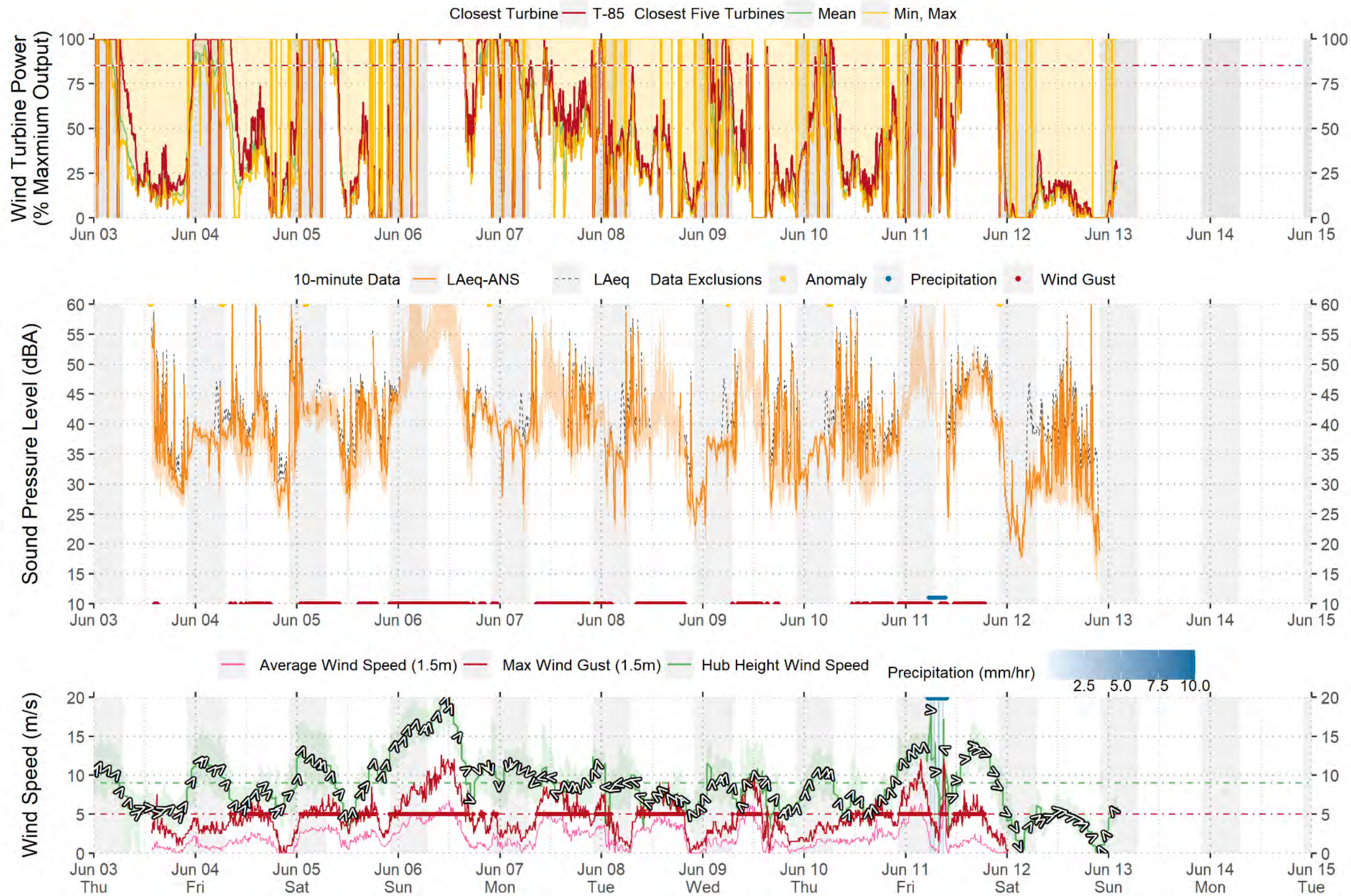


FIGURE 37: LT2 MONITOR – MONITORING PERIOD 2 – TIME HISTORY PLOT – 2021

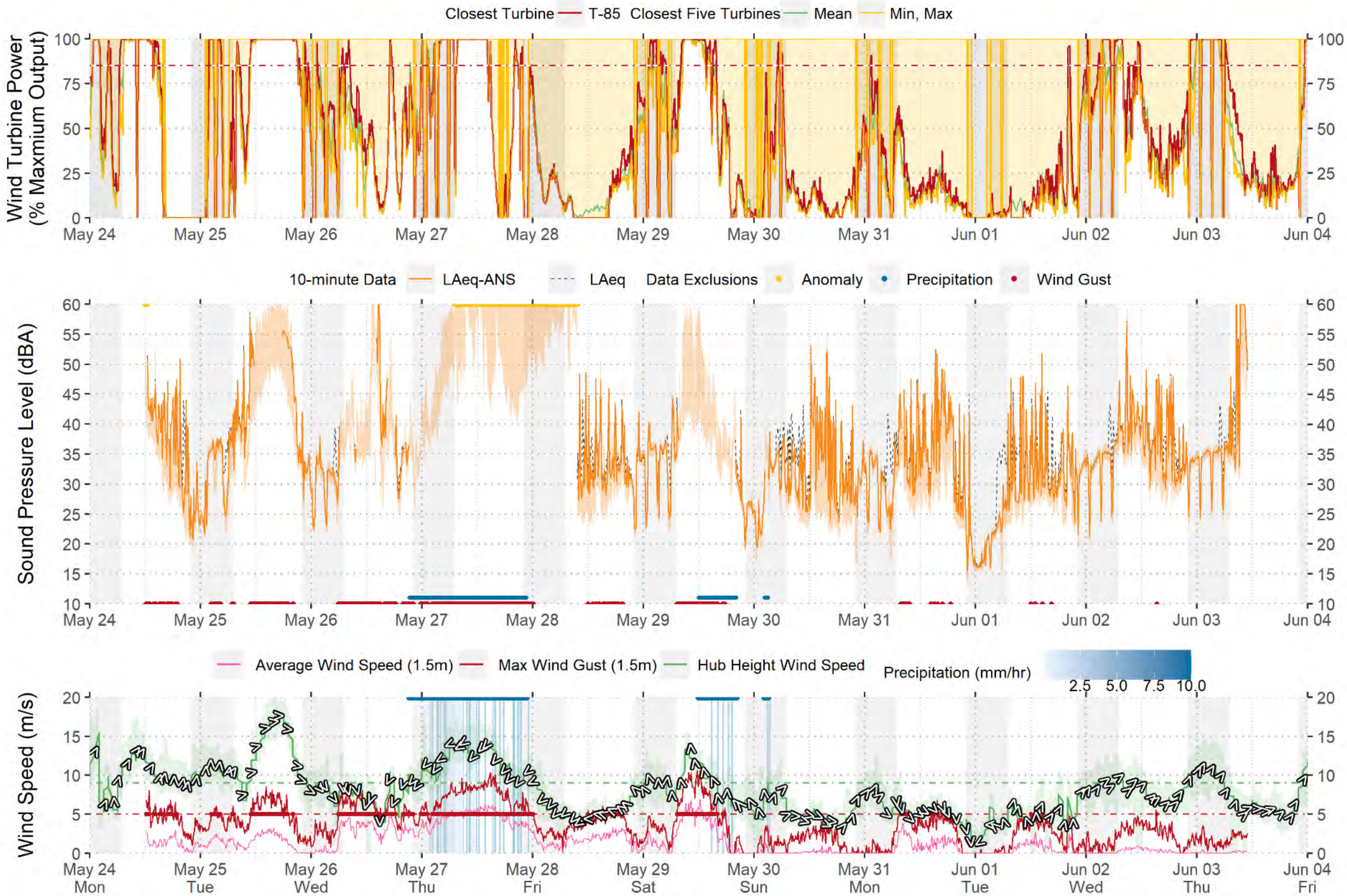


FIGURE 38: LT3 MONITOR – MONITORING PERIOD 1 – TIME HISTORY PLOT – 2021

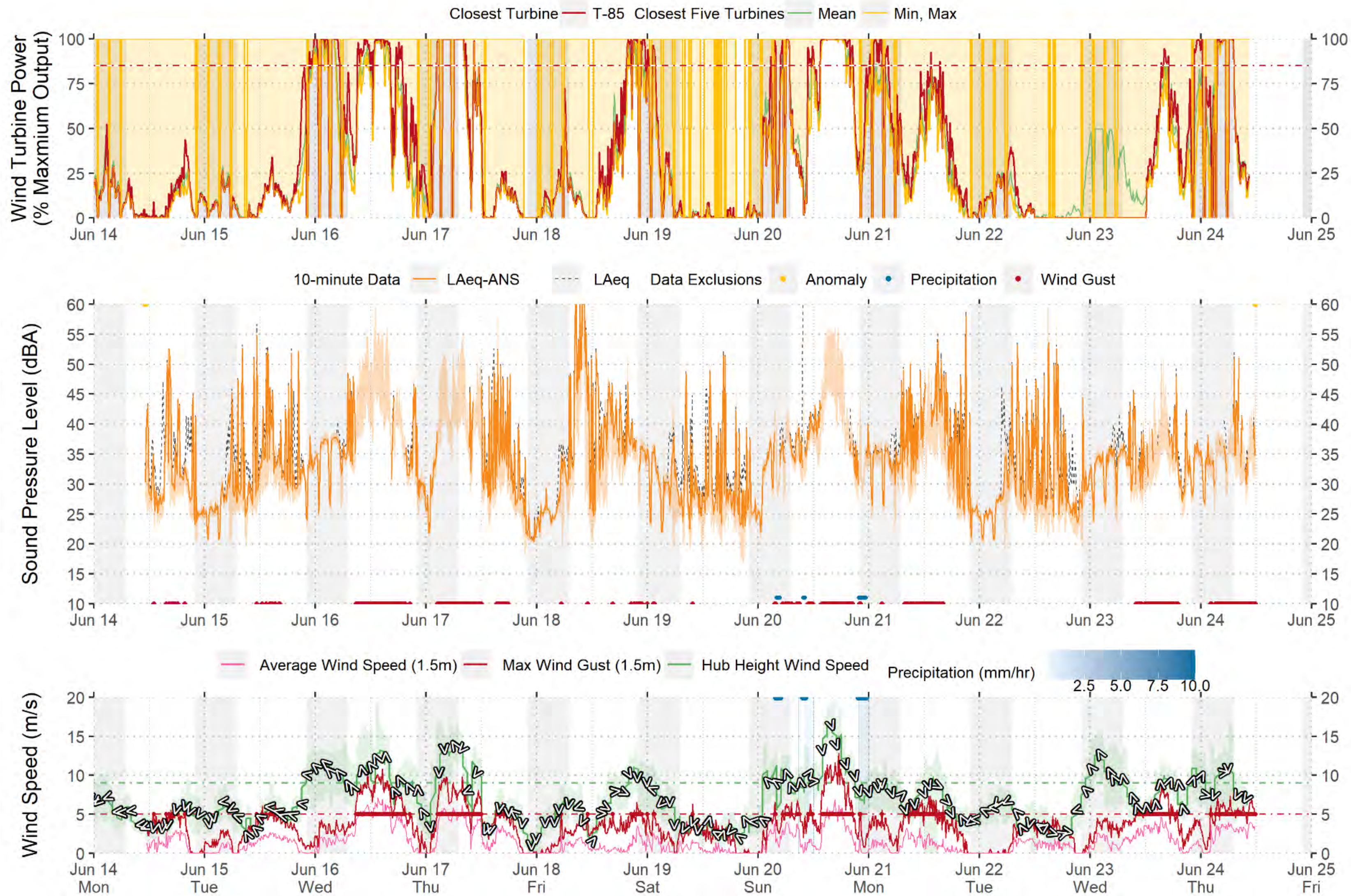


FIGURE 39: LT3 MONITOR – MONITORING PERIOD 3 – TIME HISTORY PLOT – 2021

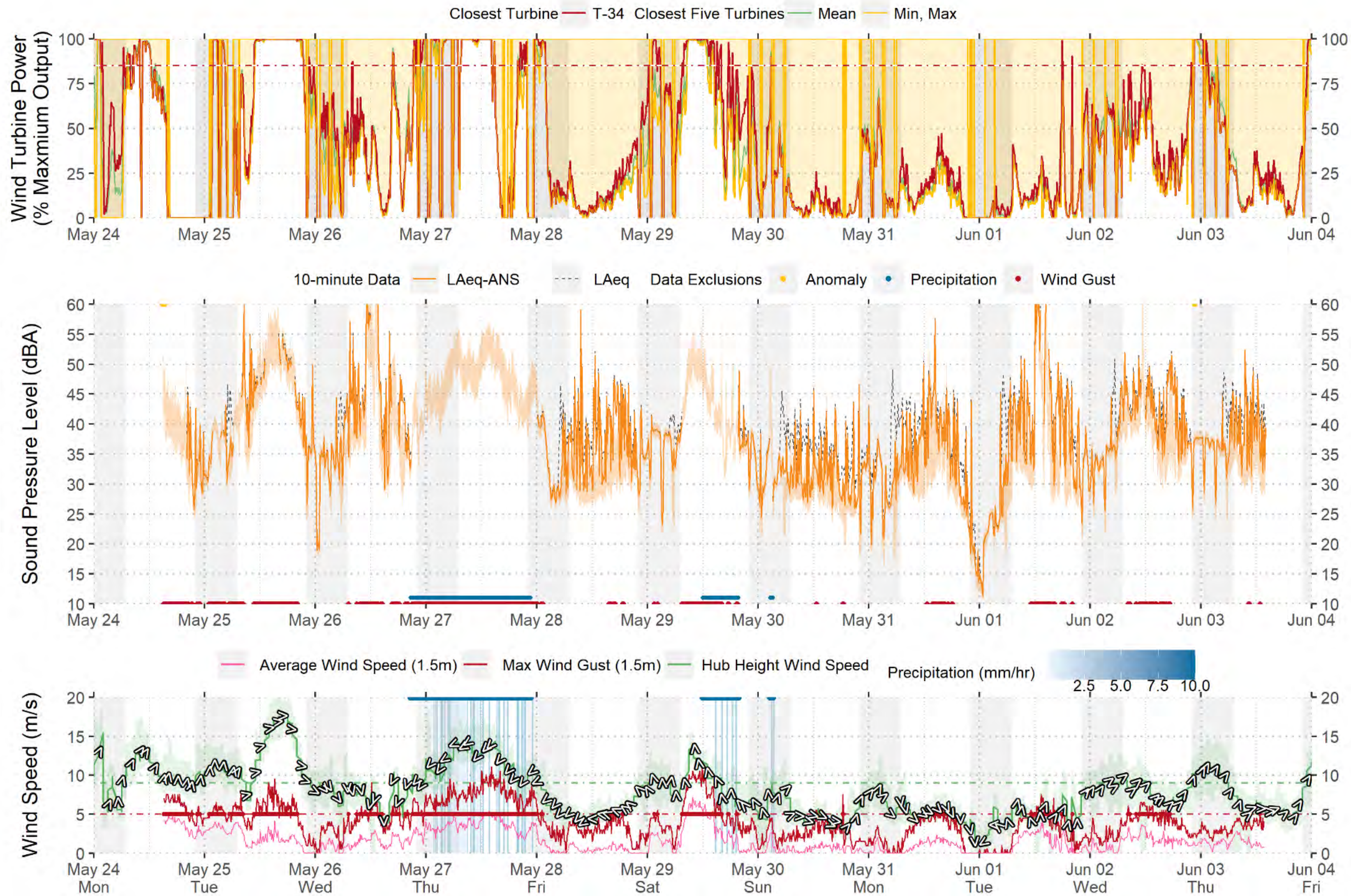


FIGURE 40: LT4 MONITOR – MONITORING PERIOD 1 – TIME HISTORY PLOT – 2021

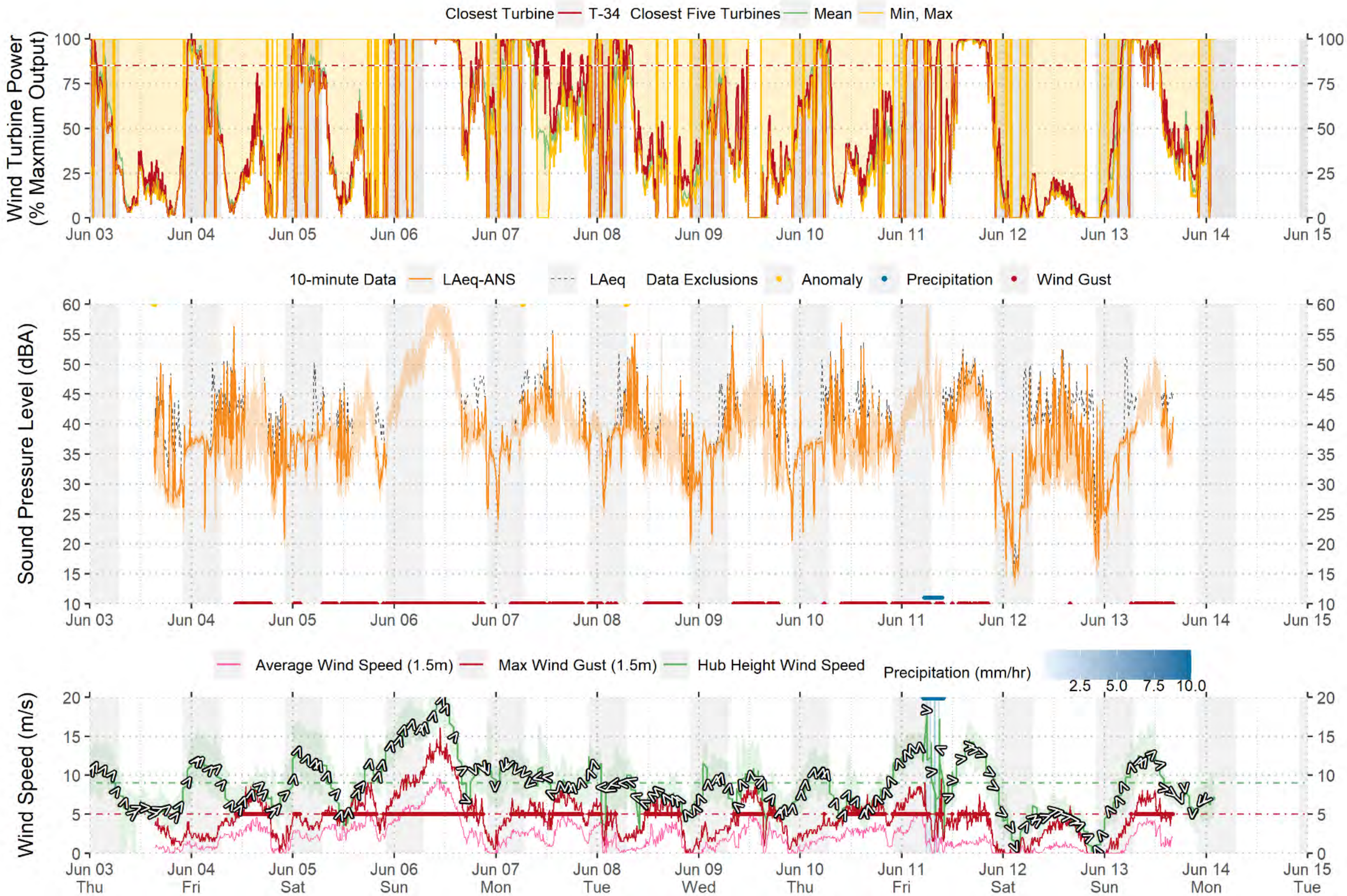


FIGURE 41: LT4 MONITOR – MONITORING PERIOD 2 – TIME HISTORY PLOT – 2021

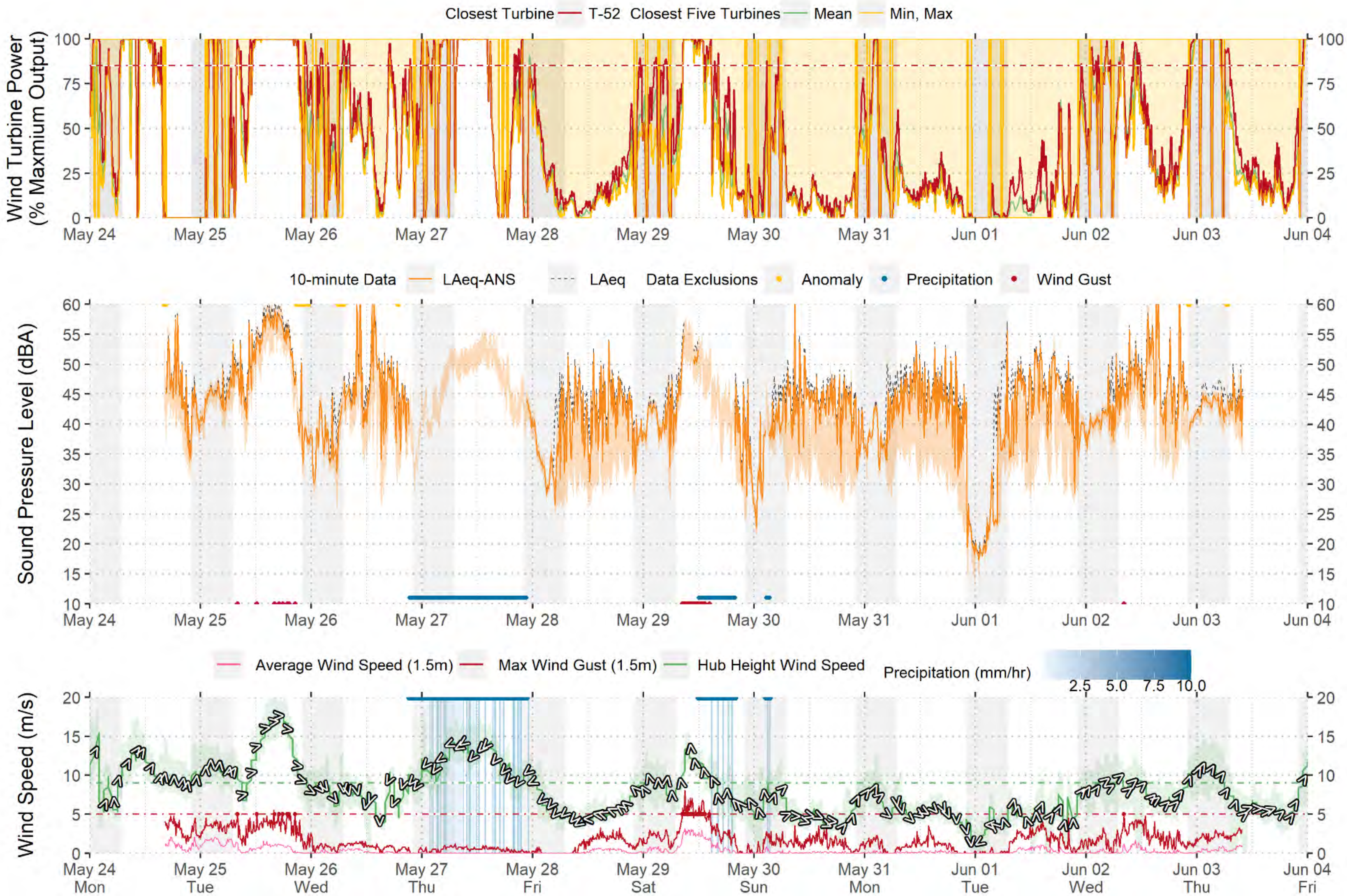


FIGURE 42: LT5 MONITOR – MONITORING PERIOD 1 – TIME HISTORY PLOT – 2021

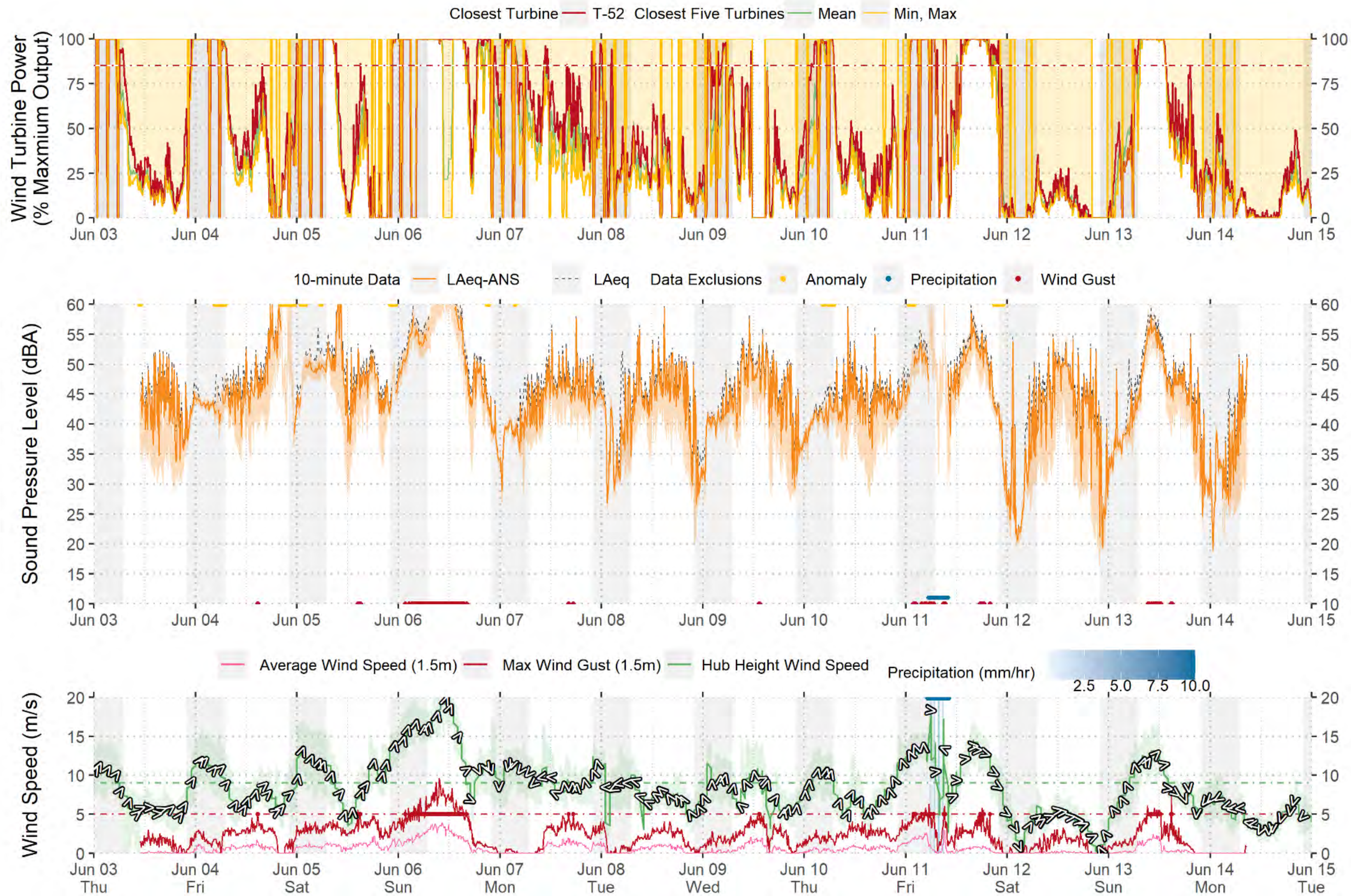


FIGURE 43: LT5 MONITOR – MONITORING PERIOD 2 – TIME HISTORY PLOT – 2021

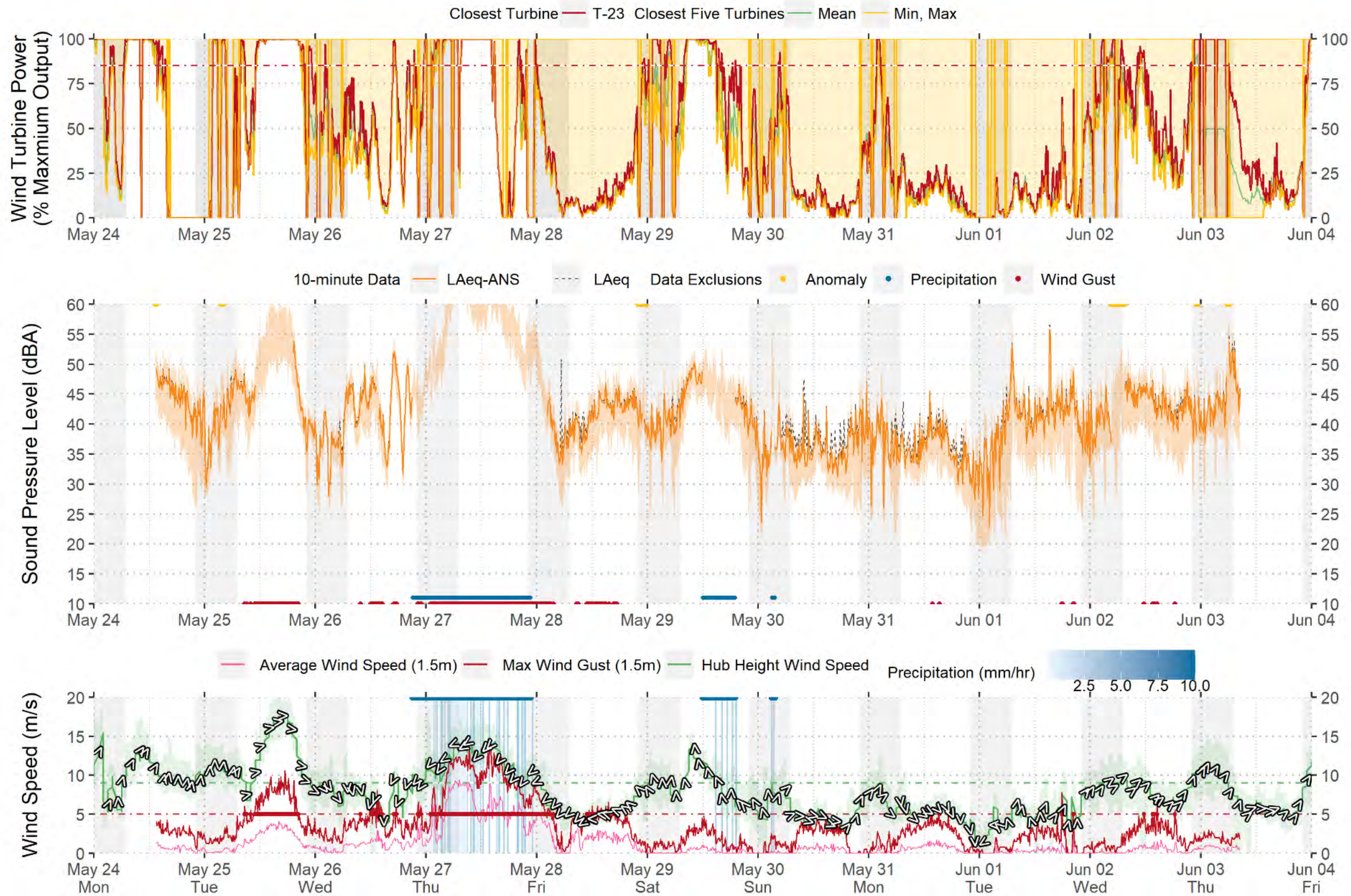


FIGURE 44: LT6 MONITOR – MONITORING PERIOD 1 – TIME HISTORY PLOT - 2021

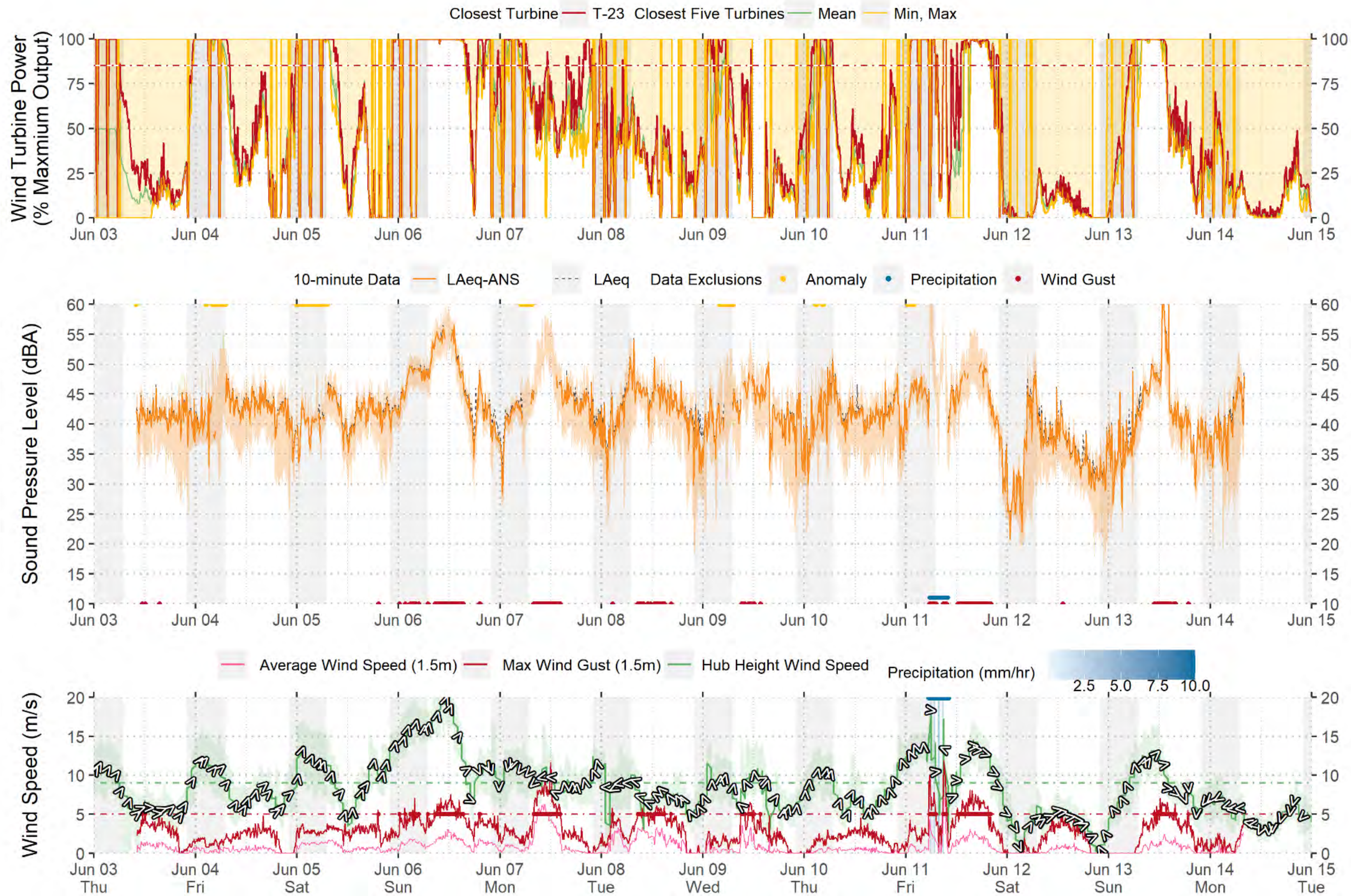


FIGURE 45: LT6 MONITOR– MONITORING PERIOD 2 – TIME HISTORY PLOT – 2021

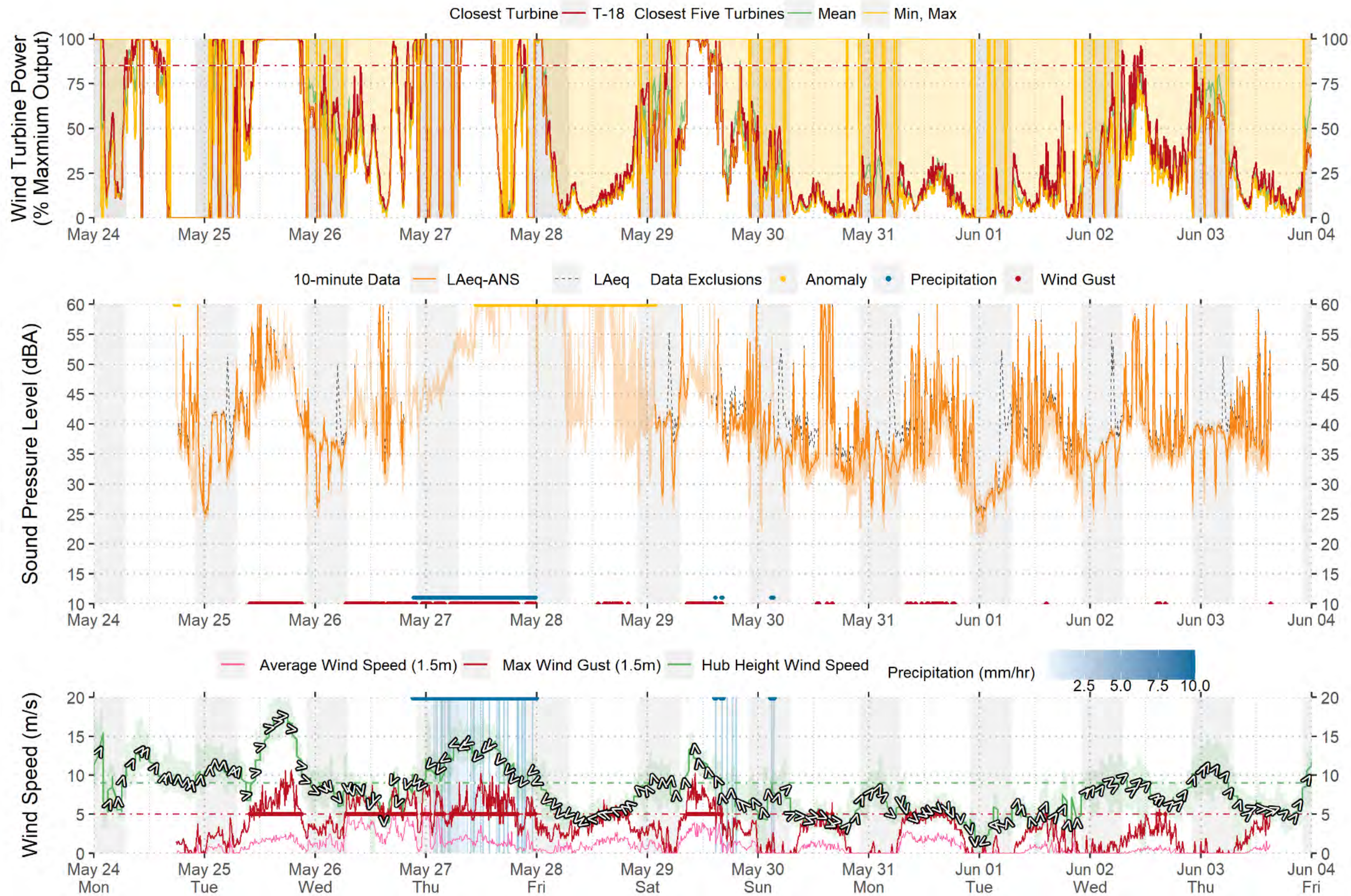


FIGURE 46: LT7 MONITOR– MONITORING PERIOD 1 – TIME HISTORY PLOT – 2021

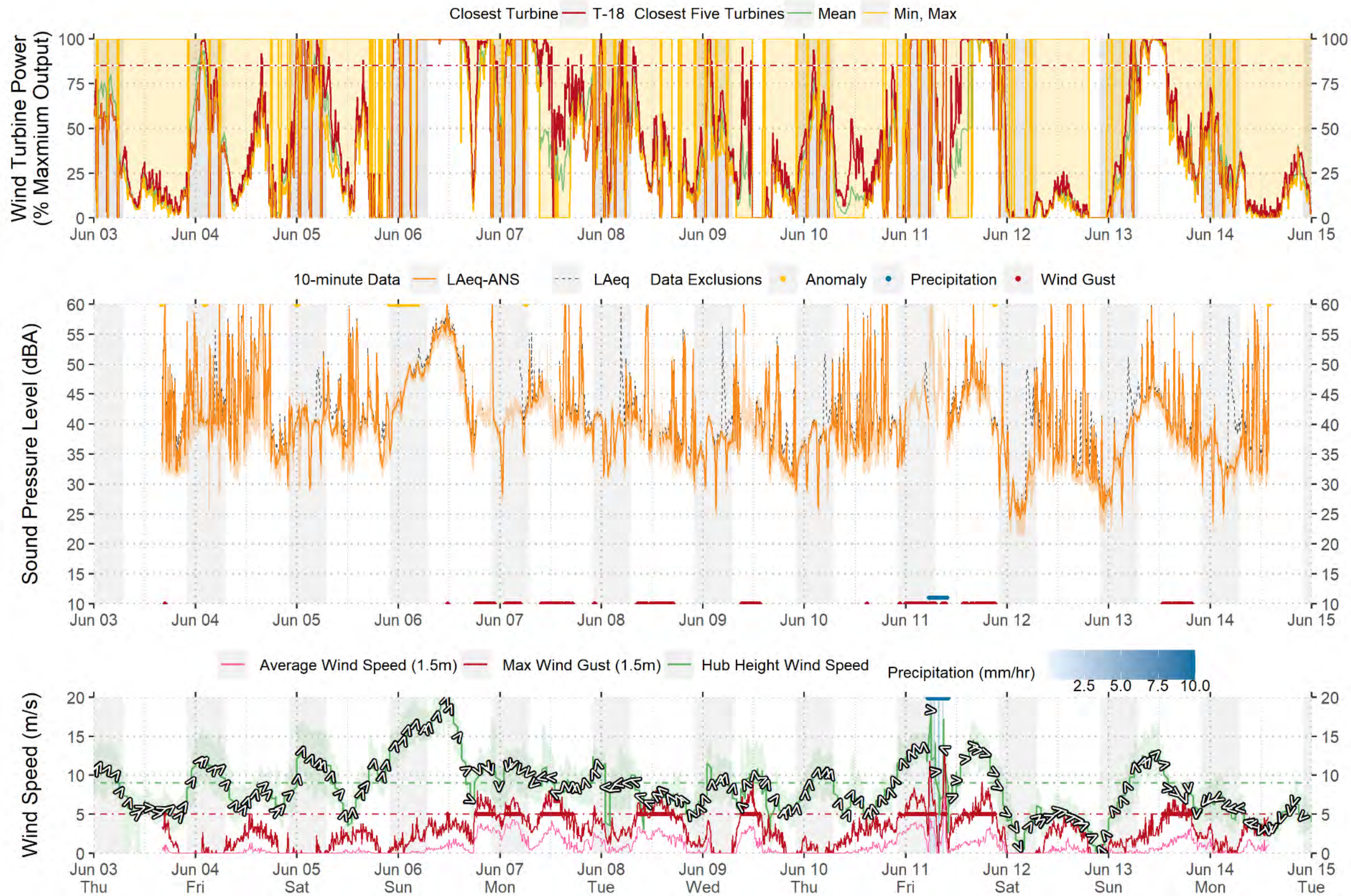


FIGURE 47: LT7 MONITOR– MONITORING PERIOD 2 – TIME HISTORY PLOT – 2021

5.0 NOISE COMPLIANCE ASSESSMENT

5.1 SHUTDOWN OVERVIEW

As noted in the previous sections, wind turbines were shut down periodically to obtain an accurate measure of background sound levels to help calculate wind turbine only contributions to the total sound levels. Four shutdowns per night occurred. The exception to this schedule occurred on the morning of May 28 and for the 5:30 AM shutdown on June 6 because of wind turbine control issues.

One hour of wind turbine operation before and after each shutdown were analyzed, resulting in twelve 10-minute turbine operation periods at each monitor for each shutdown. A diagram of an example overall sound level time history plot in Figure 48 defines the convention given for referring to each evaluation period.

Evaluation periods were only included in the analysis if sufficient valid data were collected, i.e., half of samples in the evaluation periods were not excluded due to high ground-level wind, precipitation, or anomalous events. Further, the shutdown analysis was narrowed down to periods meeting the target evaluation conditions. Lastly, periods within the target conditions were subset to only consider those with an acceptable signal-to-noise ratio between background and total (total + background) sound level to allow for the calculation of turbine-only sound level.[23] The biggest contributors to a low signal-to-noise ratio were ground level winds and wind blowing through nearby trees.

Between all monitors, 6,408 evaluation periods were collected; 5,414 of these periods possessed valid acoustical conditions. The target conditions for compliance, as defined in the Permit, includes the closest five wind turbines operating and the closest wind turbine to the monitor operating at within 1 dB of its maximum sound power output. A total of 1,092 10-minute periods with valid acoustical conditions under the target wind turbine operating conditions were assessed; at least 109 10-minute periods were collected at each monitor. Of this sample, 795 evaluation periods had a signal-to-noise ratio that allowed the calculation of wind turbine-only sound levels. A summary of the number of evaluation periods at each monitor is provided in Table 5.

[23] The signal-to-noise ratio refers to the arithmetic difference between the total sound level and the background sound. A low signal-to-noise ratio means that the received sound of a source (wind turbines in this case) is masked by background sound and an accurate assessment of wind turbine-only sound level cannot be made. The minimum signal-to-noise ratio for a valid calculation is 3 dB (per ANSI S12.9 Part 3).

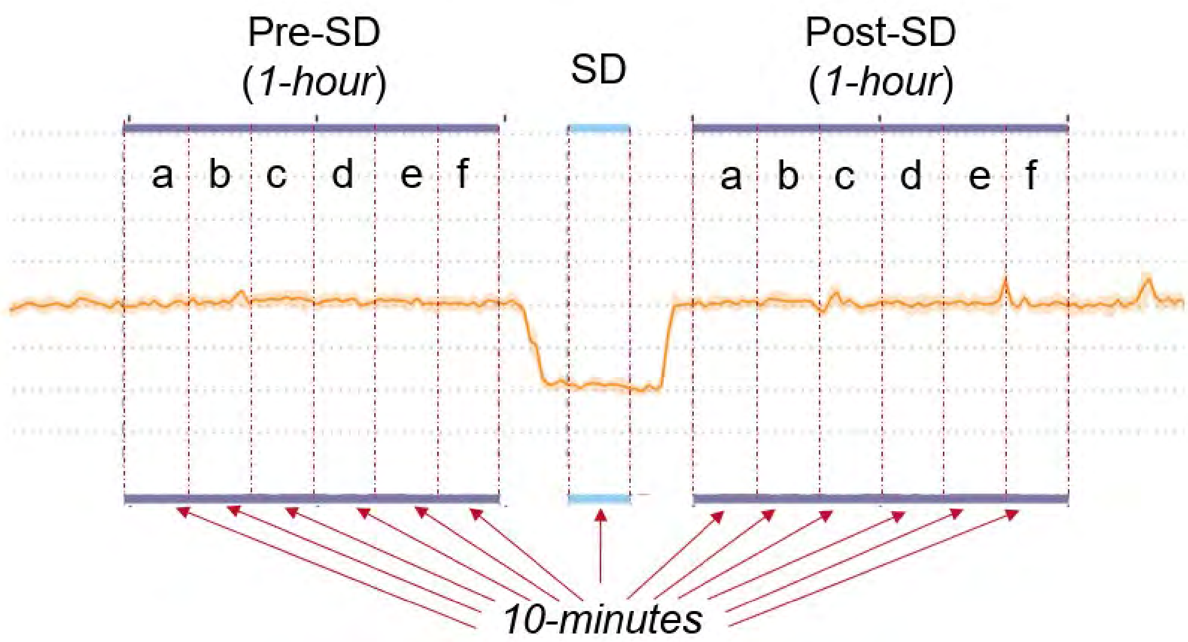


FIGURE 48: DIAGRAM OF A SOUND LEVEL TIME HISTORY DEMONSTRATING THE CONVENTION FOR IDENTIFYING EVALUATION PERIODS SURROUNDING A TURBINE SHUTDOWN ("SD").

TABLE 5: TALLY OF 10-MINUTE EVALUATION PERIODS AT EACH MONITOR

MONITOR	SHUTDOWN (BACKGROUND) PERIODS		TURBINE OPERATION PERIODS		
	Total	Acoustically Valid	Acoustically Valid	Within Target Conditions: Total	Within Target Conditions: With Acceptable Signal-to-Noise Ratio
LT1	73	60	705	153	114
LT2	72	55	658	144	126
LT3	77	68	805	192	170
LT4	75	63	736	121	108
LT5	79	71	853	201	74
LT6	79	66	835	172	101
LT7	79	67	822	109	102

Exclusions for Additional Anomalous Sounds

Upon initial processing of the target evaluation periods, ninety-eight (98) 10-minute evaluation periods resulted in calculated wind-turbine only levels above 45 dBA during the target conditions. Subsequently, these periods were investigated for anomalous (i.e., non-wind turbine) sound sources. Anomalous sources present included distinct variations in insect/bird activity between the shutdown and turbine operation periods, vehicle passbys, mobile farm equipment, cows, dogs, and excessive wind gusts aloft resulting in sporadic foliage rustle sounds

Biogenic noise was excluded only when it was detected, using the "Smart" ANS-weighting, as described in Section 3.2. For evaluation periods with dB-ANS at least 1 dB greater than the dBA sound level, the wind turbine sound level was calculated using only the ANS frequencies. Recalculating the target evaluation periods with the smart-ANS weighting left fifty-nine (59) total evaluation periods above 45 dBA at LT2, LT4, LT5, LT6, and LT7. Nearly half of these periods (26/59) were at LT5.

To address transient sources, all periods with apparent wind turbine sound levels at or above 45 dBA were reviewed in detail using spectrogram representations of the 1-second sound level data and/or digital audio recordings. Transient sources were removed when they were not equally present in the operational period and shutdown period, that is, they were present in the one period but not the other. Transient sources during background periods being reviewed were also excluded.

The type and total duration of anomalous sound excluded from evaluation periods for each monitor are listed in Table 6. LT6 necessitated the greatest amount of additional anomalous exclusions because of traffic on US Highway 212.

TABLE 6: ADDITIONAL ANOMALY EXCLUSION TYPES BY MONITOR FOR EVALUATION PERIODS

MONITORING LOCATION	ANOMALY EXCLUSIONS	MINUTES EXCLUDED
LT1	n/a	0
LT2	Dog barking, truck, vehicle idling, vehicle passbys, variable wind gusts	60
LT3	n/a	0
LT4	Vehicle passbys	7
LT5	Vehicle passbys, Mourning Doves[24], excessive wind gusts aloft through the trees	481
LT6	Vehicle passbys	827
LT7	Mobile farm equipment, cows, dog barking	101

[24] The vocalization of the Mourning Dove (*Zenaida macroura)* falls outside of the frequency range of the ANS method. Some periods with Mourning Dove calls were identified for exclusion manually.

5.2 SHUTDOWN ANALYSIS RESULTS

This section provides the maximum apparent wind turbine-only levels calculated at each monitor and the average wind turbine-only sound levels calculated at each monitor.

Maximum calculated wind turbine-only sound levels

Table 7 lists the modeled wind turbine-only sound levels at the monitor location (from the Pre-Con Study) alongside the maximum wind-turbine only level calculated for each monitor. The measured background $L_{eq10min}$, measured total $L_{eq10min}$, and shutdown reference number associated with the highest calculated turbine-only level for each monitor are also provided. Shutdown reference numbers follow the convention established in Figure 48. Detailed time history charts and 1/3 octave band results for the maximum turbine-only sound level for each evaluation period listed in Table 7 are provided in Appendix B.

Table 7 suggests that four monitor locations were within 0.7 dB of the 45 dBA limit. The detailed time history charts in Appendix B reveal that in most cases, anomalous sources of sound are still included in the aggregated data: anomalous sources were only investigated and excluded for wind turbine operation periods with calculated apparent wind turbine sound levels of 45 dBA and above. The maximum wind turbine-only sound level for LT3 was 1.1 dB below the sound level modeled in the Pre-Con Study.

TABLE 7: MODELED PROJECT-ONLY WIND TURBINE-ONLY SOUND LEVEL (dBA) COMPARED TO THE MAXIMUM WIND TURBINE-ONLY $L_{eq10min}$ FROM THE TURBINE SHUTDOWN ANALYSIS AT EACH MONITOR. TOTAL AND BACKGROUND SOUND LEVELS, AS WELL AS THE CORRESPONDING THE EVALUATION PERIOD IDENTIFICATION NUMBER ARE LISTED.

MONITOR	MODELED (Pre-Con)	MAXIMUM CALCULATED L_{eq}	MEASURED L_{eq}		EVALUATION PERIOD ID
	Turbine-Only	Turbine-Only	Back-ground	Total	
LT1	43.5	44.8	42.8	46.9	SD065_PostSD-a
LT2	42.4	42.6	40.9	45	SD045_PostSD-e
LT3	41.4	40.3	24.1	40.4	SD015_PostSD-c
LT4	42.4	44.9	41	46	SD055_PostSD-e
LT5	43.8	44	42.9	46.5	SD053_PreSD-c
LT6	41.7	44.3	32.8	44.6	SD039_PostSD-c
LT7	45.8	44.9	40.2	46.1	SD051_PostSD-f

Average wind turbine only levels at each monitor

The energy averages of all valid wind turbine-only evaluation periods meeting the target compliance conditions with an acceptable signal-to-noise ratio were calculated for each monitor. The overall A-weighted values computed from these averages are provided in Table 8.The "Overall Average" was calculated with each overall wind turbine-only level from each evaluation period; the "1/3 Octave Band Average" was computed by taking the energy average for all 1/3 octave bands below 1.6 kHz and calculating the overall sound level for each. The results between these two methods are 0.6 dB or less at each monitor. The "Overall Average" result is always slightly higher because ANS weighting was only used when biogenic sound was detected. The "1/3 Octave Band Average" for "Turbine Operation Periods with Biogenic Sound Included" is included in the table for reference, in which all 1/3 octave bands (20 Hz to 10 kHz) were summed to compute the overall sound level. This final column is not indicative of wind turbine-only sound levels. Rather, it shows that biogenic sound was most prevalent in turbine-operation periods as compared to background (turbine shutdown) periods at LT1 and LT6. The 45.2 dBA mean value at LT7 for turbine operation periods with biogenic sound included is not a result of wind turbine noise. The range of wind turbine-only levels, including 1/3 octave band levels, are provided in Appendix C.

Table 8 demonstrates that the equivalent average sound levels for the target periods were at least 1 dB below the modeled sound level at each monitoring location.

TABLE 8: MODELED PROJECT-ONLY WIND TURBINE-ONLY SOUND LEVEL (dBA) COMPARED TO THE ENERGY AVERAGE WIND TURBINE-ONLY L_{eq} FROM THE TURBINE SHUTDOWN ANALYSIS AT EACH MONITOR.

MONITOR	MODELED (FROM PRE-CON)	MEAN $L_{eq10min}$ (FROM POST-CON STUDY)		
	Turbine-Only	Turbine-Only		Turbine Operation Periods with Biogenic Sound included
		Overall Average	1/3 Octave Band Average (ANS)	1/3 Octave Band Average
LT1	43.5	37.3	36.9	43.6
LT2	42.4	37.5	36.9	39.0
LT3	41.4	35.6	35.2	36.2
LT4	42.4	38.7	38.4	41.3
LT5	43.8	41.0	40.4	42.2
LT6	41.7	40.2	39.8	40.7
LT7	45.8	40.9	40.6	45.2

6.0 CONCLUSIONS

In conformance with the Project permit, this post-construction noise assessment was completed to determine whether the as-built Project complies with the wind turbine only limit of 45 dBA $L_{eq10min}$ at nearby residences.

Monitoring was completed at seven sites throughout the Project area, three of which had registered formal complaints about noise from the Project.

Wind turbines were shut down periodically to obtain an accurate measure of background sound levels. Background sound levels provide context to the total noise on-site, which includes turbine operations and background sounds. Four shutdowns per night occurred. To assess compliance, calculated wind turbine-only sound levels were evaluated when target conditions were observed: all five nearest wind turbines operating and the closest wind turbine operating within 1 dB of maximum sound power emission.

The maximum wind turbine-only sound levels calculated during for periods with the target operating conditions were below 45 dBA $L_{eq10min}$ at all monitoring locations. The equivalent average wind turbine-only sound level for evaluation periods with the target compliance conditions were at least 1 dB below the modeled sound level from the Pre-Construction Study.

Thus, we conclude that the Project complies with the noise limits set forth in the Permit.

APPENDIX A. NOISE PRIMER

Expressing Sound in Decibel Levels

The varying air pressure that constitutes sound can be characterized in many ways. The human ear is the basis for the metrics that are used in acoustics. Normal human hearing is sensitive to sound fluctuations over an enormous range of pressures, from about 20 micropascals (the “threshold of audibility”) to about 20 pascals (the “threshold of pain”).[25] This factor of one million in sound pressure difference is challenging to convey in engineering units. Instead, sound pressure is converted to sound “levels” in units of “decibels” (dB, named after Alexander Graham Bell). Once a measured sound is converted to dB, it is denoted as a level with the letter “L”.

The conversion from sound pressure in pascals to sound level in dB is a four-step process. First, the sound wave’s measured amplitude is squared and the mean is taken. Second, a ratio is taken between the mean square sound pressure and the square of the threshold of audibility (20 micropascals). Third, using the logarithm function, the ratio is converted to factors of 10. The result is multiplied by 10 to give the decibel level. By this decibel scale, sound levels range from 0 dB at the threshold of audibility to 120 dB at the threshold of pain.

Typical sound sources, and their sound pressure levels, are listed on the scale in Figure 49.

Human Response to Sound Levels: Apparent Loudness

For every 20 dB increase in sound level, the sound pressure increases by a *factor* of 10; the sound *level* range from 0 dB to 120 dB covers 6 factors of 10, or one million, in sound *pressure*. However, for an increase of 10 dB in sound *level* as measured by a meter, humans perceive an approximate doubling of apparent loudness: to the human ear, a sound level of 70 dB sounds about “twice as loud” as a sound level of 60 dB. Smaller changes in sound level, less than 3 dB up or down, are generally not perceptible.

[25] The pascal is a measure of pressure in the metric system. In Imperial units, they are themselves very small: one pascal is only 145 millionths of a pound per square inch (psi). The sound pressure at the threshold of audibility is only 3 one-billionths of one psi: at the threshold of pain, it is about 3 one-thousandths of one psi.

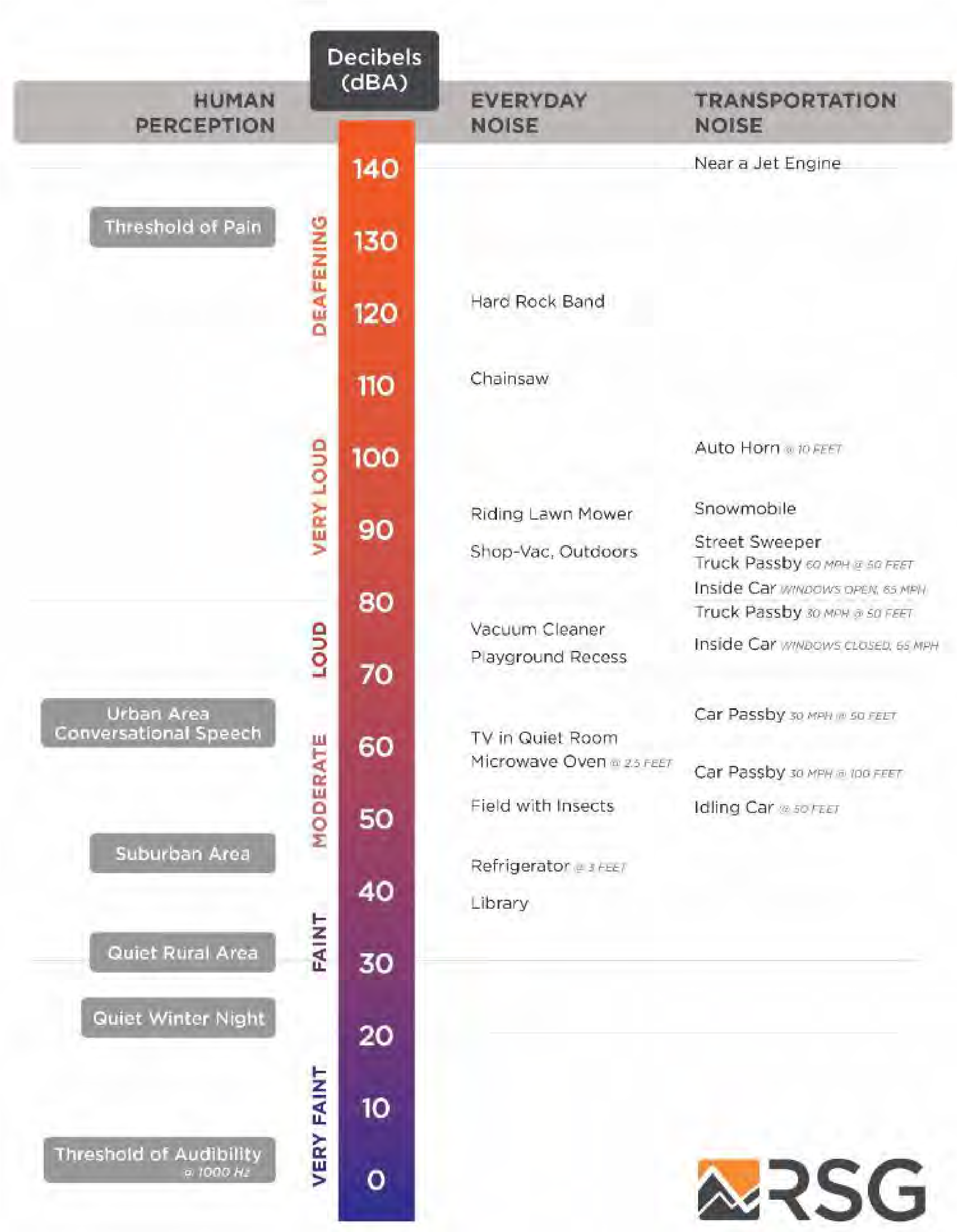


FIGURE 49: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

Frequency Spectrum of Sound

The “frequency” of a sound is the rate at which it fluctuates in time, expressed in Hertz (Hz), or cycles per second. Very few sounds occur at only one frequency: most sound contains energy at many different frequencies, and it can be broken down into different frequency divisions, or bands. These bands are similar to musical pitches, from low tones to high tones. The most common division is the standard octave band. An octave is the range of frequencies whose upper frequency limit is twice its lower frequency limit, exactly like an octave in music. An octave band is identified by its center frequency: each successive band’s center frequency is twice as high (one octave) as the previous band. For example, the 500 Hz octave band includes all sound whose frequencies range between 354 Hz (Hertz, or cycles per second) and 707 Hz. The next band is centered at 1,000 Hz with a range between 707 Hz and 1,414 Hz. The range of human hearing is divided into 10 standard octave bands: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, 8,000 Hz, and 16,000 Hz. For analyses that require finer frequency detail, each octave-band can be subdivided. A commonly used subdivision creates three smaller bands within each octave band, or so-called 1/3-octave bands.

Human Response to Frequency: Weighting of Sound Levels

The human ear is not equally sensitive to sounds of all frequencies. Sounds at some frequencies seem louder than others, despite having the same decibel level as measured by a sound level meter. In particular, human hearing is much more sensitive to medium pitches (from about 500 Hz to about 4,000 Hz) than to very low or very high pitches. For example, a tone measuring 80 dB at 500 Hz (a medium pitch) sounds quite a bit louder than a tone measuring 80 dB at 60 Hz (a very low pitch). The frequency response of normal human hearing ranges from 20 Hz to 20,000 Hz. Below 20 Hz, sound pressure fluctuations are not “heard”, but sometimes can be “felt”. This is known as “infrasound”. Likewise, above 20,000 Hz, sound can no longer be heard by humans; this is known as “ultrasound”. As humans age, they tend to lose the ability to hear higher frequencies first; many adults do not hear very well above about 16,000 Hz. Most natural and man-made sound occurs in the range from about 40 Hz to about 4,000 Hz. Some insects and birdsongs reach to about 8,000 Hz.

To adjust measured sound pressure levels so that they mimic human hearing response, sound level meters apply filters, known as “frequency weightings”, to the signals. There are several defined weighting scales, including “A”, “B”, “C”, “D”, “G”, and “Z”. The most common weighting scale used in environmental noise analysis and regulation is A-weighting. This weighting represents the sensitivity of the human ear to sounds of low to moderate level. It attenuates sounds with frequencies below 1000 Hz and above 4000 Hz; it amplifies very slightly sounds between 1000 Hz and 4000 Hz, where the human ear is particularly sensitive. The C-weighting scale is sometimes used to describe louder sounds. The B- and D- scales are seldom used. All of these frequency weighting scales are normalized to the average human hearing response at 1000 Hz: at this frequency, the filters neither attenuate nor amplify. G-weighting is a standardized weighting used to evaluate infrasound.

When a reported sound level has been filtered using a frequency weighting, the letter is appended to “dB”. For example, sound with A-weighting is usually denoted “dBA”. When no filtering is applied, the level is denoted “dB” or “dBZ”. The letter is also appended as a subscript to the level indicator “L”, for example “L_A” for A-weighted levels.

Time Response of Sound Level Meters

Because sound levels can vary greatly from one moment to the next, the time over which sound is measured can influence the value of the levels reported. Often, sound is measured in real time, as it fluctuates. In this case, acousticians apply a so-called “time response” to the sound level meter, and this time response is often part of regulations for measuring sound. If the sound level is varying slowly, over a few seconds, “Slow” time response is applied, with a time constant of one second. If the sound level is varying quickly (for example, if brief events are mixed into the overall sound), “Fast” time response can be applied, with a time constant of one-eighth of a second.[26] The time response setting for a sound level measurement is indicated with the subscript “S” for Slow and “F” for Fast: L_S or L_F. A sound level meter set to Fast time response will indicate higher sound levels than one set to Slow time response when brief events are mixed into the overall sound, because it can respond more quickly.

In some cases, the maximum sound level that can be generated by a source is of concern. Likewise, the minimum sound level occurring during a monitoring period may be required. To measure these, the sound level meter can be set to capture and hold the highest and lowest levels measured during a given monitoring period. This is represented by the subscript “max”, denoted as “L_{max}”. One can define a “max” level with Fast response L_{Fmax} (1/8-second time constant), Slow time response L_{Smax} (1-second time constant), or Continuous Equivalent level over a specified time period $L_{eq\ max}$.

Accounting for Changes in Sound Over Time

A sound level meter’s time response settings are useful for continuous monitoring. However, they are less useful in summarizing sound levels over longer periods. To do so, acousticians apply simple statistics to the measured sound levels, resulting in a set of defined types of sound level related to averages over time. An example is shown in Figure 50. The sound level at each instant of time is the grey trace going from left to right. Over the total time it was measured (1 hour in the figure), the sound energy spends certain fractions of time near various levels, ranging from the minimum (about 27 dB in the figure) to the maximum (about 65 dB in the figure). The simplest descriptor is the average sound level, known as the Equivalent Continuous Sound Level. Statistical levels are used to determine for what percentage of time the sound is louder than any given level. These levels are described in the following sections.

[26] There is a third time response defined by standards, the “Impulse” response. This response was defined to enable use of older, analog meters when measuring very brief sounds; it is no longer in common use.

Equivalent Continuous Sound Level - L_{eq}

One straightforward, common way of describing sound levels is in terms of the Continuous Equivalent Sound Level, or L_{eq}. The L_{eq} is the average sound pressure level over a defined period of time, such as one hour or one day. L_{eq} is the most common descriptor in noise standards and regulations. L_{eq} is representative of the overall sound to which a person is exposed. Because of the logarithmic calculation of decibels, L_{eq} tends to favor higher sound levels: loud and infrequent sources have a larger impact on the resulting average sound level than quieter but more frequent sounds. For example, in Figure 50, even though the sound levels spend most of the time near about 34 dBA, the L_{eq} is 41 dBA, having been "inflated" by the maximum level of 65 dBA and other occasional spikes over the course of the hour.

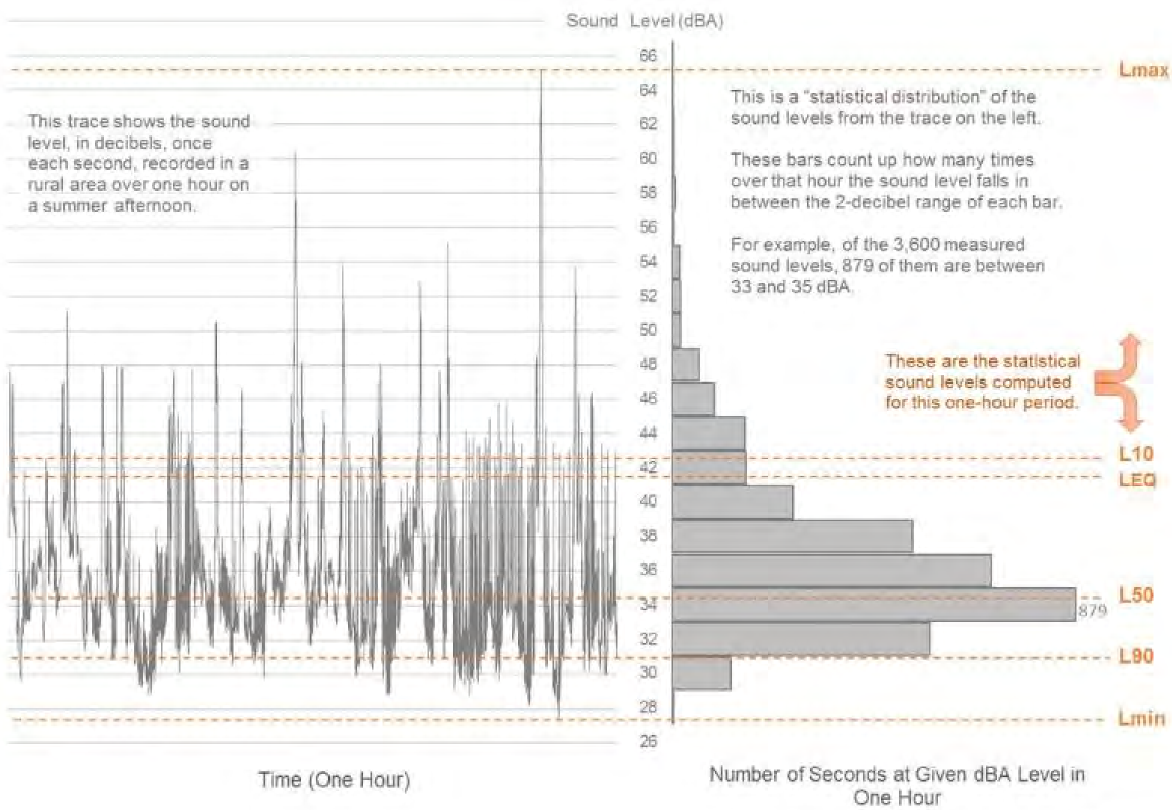


FIGURE 50: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

Percentile Sound Levels – Ln

Percentile sound levels describe the statistical distribution of sound levels over time. "L_N" is the level above which the sound spends "N" percent of the time. For example, L_{90} (sometimes called the "residual base level") is the sound level exceeded 90% of the time: the sound is louder than L_{90} most of the time. L_{10} is the sound level that is exceeded only 10% of the time. L_{50} (the "median level") is exceeded 50% of the time: half of the time the sound is louder than

L_{50}, and half the time it is quieter than L_{50}. Note that L_{50} (median) and L_{eq} (mean) are not always the same, for reasons described in the previous section.

L_{90} is often a good representation of the "ambient sound" in an area. This is the sound that persists for longer periods, and below which the overall sound level seldom falls. It tends to filter out other short-term environmental sounds that aren't part of the source being investigated. L_{10} represents the higher, but less frequent, sound levels. These could include such events as barking dogs, vehicles driving by and aircraft flying overhead, gusts of wind, and work operations. L_{90} represents the background sound that is present when these event sounds are excluded.

Note that if one sound source is very constant and dominates the soundscape in an area, all descriptive sound levels mentioned here tend toward the same value. It is when the sound is varying widely from one moment to the next that the statistical descriptors are useful

Wind Turbine Noise

Sources of Sound Generation by Wind Turbines

Wind turbines generate two principal types of noise: aerodynamic noise, produced from the flow of air around the blades, and mechanical noise, produced from mechanical and electrical components within the nacelle.

Aerodynamic noise is the primary source of noise associated with wind turbines. These acoustic emissions can be either tonal or broad band. Tonal noise occurs at discrete frequencies, whereas broadband noise is distributed with little peaking across the frequency spectrum.

While unusual, tonal noise can also originate from unstable air flows over holes, slits, or blunt trailing edges on blades. Most modern wind turbines have upwind rotors designed to prevent blade impulsive noise. Therefore, most of the audible aerodynamic noise from wind turbines is broadband at the middle frequencies, roughly between 200 Hz and 1,000 Hz.

Wind turbines emit aerodynamic broadband noise as the spinning blades interact with atmospheric turbulence and as air flows along their surfaces. This produces a characteristic "whooshing" sound through several mechanisms (Figure 51):

- Inflow turbulence noise occurs when the rotor blades encounter atmospheric turbulence as they pass through the air. Uneven pressure on a rotor blade causes variations in the local angle of attack, which affects the lift and drag forces, causing aerodynamic loading fluctuations. This generates noise that varies across a wide range of frequencies but is most significant at frequencies below 500 Hz.
- Trailing edge noise is produced as boundary-layer turbulence as the air passes into the wake, or trailing edge, of the blade. This noise is distributed across a wide frequency range but is most notable at high frequencies between 700 Hz and 2 kHz.

- Tip vortex noise occurs when tip turbulence interacts with the surface of the blade tip. While this is audible near the turbine, it tends to be a small component of the overall noise further away.
- Stall or separation noise occurs due to the interaction of turbulence with the blade surface.

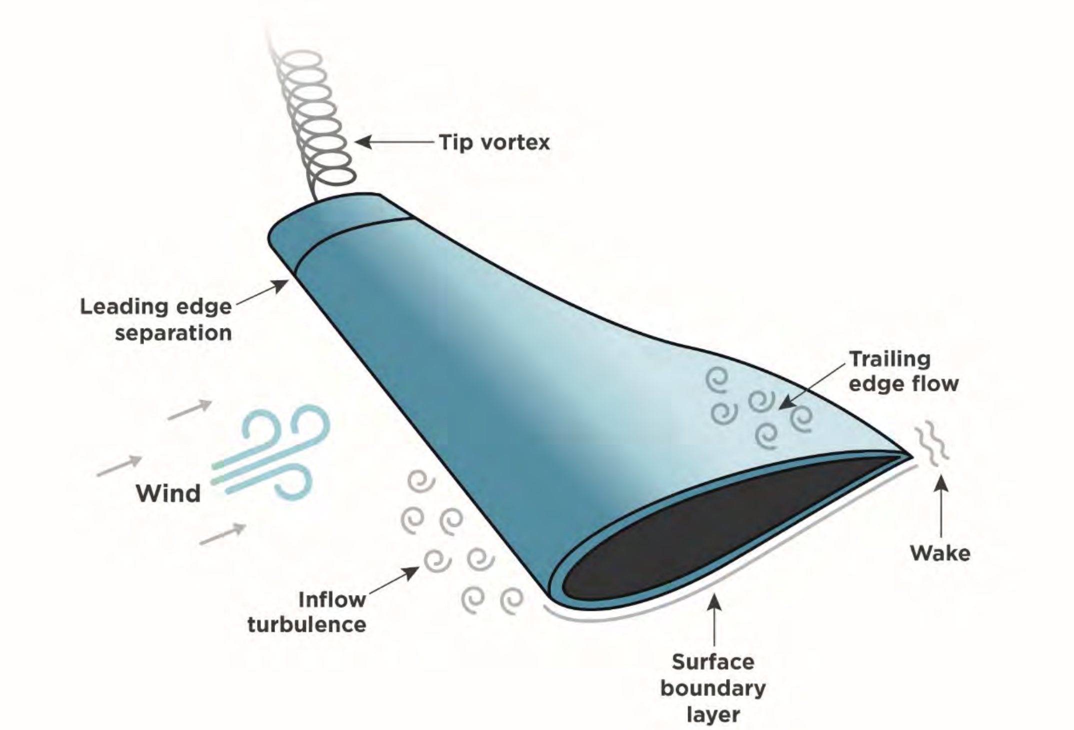


FIGURE 51: AIRFLOW AROUND A ROTOR BLADE

Mechanical sound from machinery inside the nacelle tends to be tonal in nature but can also have a broadband component. Potential sources of mechanical noise include the gearbox, generator, yaw drives, cooling fans, and auxiliary equipment. These components are housed within the nacelle, whose surfaces, if untreated, radiate the resulting noise. However modern wind turbines have nacelles that are designed to reduce internal noise, and rarely is the mechanical noise a significant portion of the total noise from a wind turbine.

Amplitude Modulation

Amplitude modulation (AM) is a fluctuation in sound level that occurs at the blade passage frequency. No consistent definition exists for how much of a sound level fluctuation is necessary for blade swish to be considered AM, however sound level fluctuations in A-weighted sound level can range up to 10 dB. Fluctuations in individual 1/3 octave bands are typically more and can exceed 15 dB. Fluctuations in individual 1/3 octave bands can sometimes synchronize and desynchronize over periods, leading to increases and decreases in magnitude of the A-weighted fluctuations. Similarly, in wind farms with multiple turbines, fluctuations can synchronize and desynchronize, leading to variations in AM depth.[27] Most amplitude modulation is in the mid frequencies and most overall A-weighted AM is less than 4.5 dB in depth.[28]

Many confirmed and hypothesized causes of AM exist, including blade passage in front of the tower, blade tip sound emission directivity, wind shear, inflow turbulence, and turbine blade yaw error. It has recently been noted that although wind shear can contribute to the extent of AM, wind shear does not contribute to the existence of AM in and of itself. Instead, there needs to be detachment of airflow from the blades for wind shear to contribute to AM.[29] While factors like the blade passing in front of the tower are intrinsic to wind turbine design, other factors vary with turbine design, local meteorology, topography, and turbine layout. Mountainous areas, for example, are more likely to have turbulent airflow, less likely to have high wind shear, and less likely to have turbine layouts that allow for blade passage synchronization for multiple turbines. AM extent varies with the relative location of a receiver to the turbine. AM is usually experienced most when the receiver is between 45 and 60 degrees from the downwind or upwind position and is experienced least directly with the receiver directly upwind or downwind of the turbines.

Meteorology

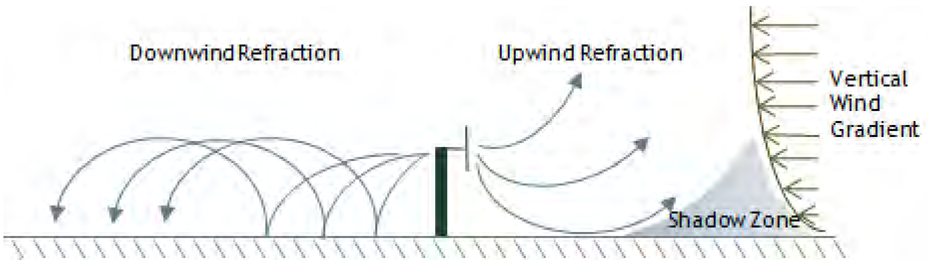
Meteorological conditions can significantly affect sound propagation. The two most important conditions to consider are wind shear and temperature lapse. Wind shear is the difference in wind speeds by elevation and temperature lapse rate is the temperature gradient by elevation. In conditions with high wind shear (large wind speed gradient), sound levels upwind from the source tend to decrease and sound levels downwind tend to increase due to the refraction, or bending, of the sound (Figure 52).

[27] McCunney, Robert, et al. “Wind Turbines and Health: A Critical Review of the Scientific Literature.” *Journal of Occupational and Environmental Medicine.* 56(11) November 2014: pp. e108-e130.
[28] RSG, et al., “Massachusetts Study on Wind Turbine Acoustics,” Massachusetts Clean Energy Center and Massachusetts Department of Environmental Protection, 2016
[29] “Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect.” *RenewableUK.* December 2013.

With temperature lapse, when ground surface temperatures are higher than those aloft, sound will tend to refract upwards, leading to lower sound levels near the ground. The opposite is true when ground temperatures are lower than those aloft (an inversion condition).

High winds and high solar radiation can create turbulence which tends to break up and dissipate sound energy. Highly stable atmospheres, which tend to occur on clear nights with low ground-level wind speeds, tend to minimize atmospheric turbulence and are generally more favorable to downwind propagation.

In general terms, sound propagates along the ground best under stable conditions with a strong temperature inversion. This tends to occur during the night and is characterized by low ground-level winds. As a result, worst-case conditions for wind turbines tend to occur downwind under moderate nighttime temperature inversions. Therefore, this is the default condition for modeling wind turbine sound.



Not to scale

FIGURE 52: SCHEMATIC OF THE REFRACTION OF SOUND DUE TO VERTICAL WIND GRADIENT (WIND SHEAR)

Masking

As mentioned above, sound levels from wind turbines are a function of wind speed. Background sound is also a function of wind speed, i.e., the stronger the winds, the louder the resulting background sound. This effect is amplified in areas covered by trees and other vegetation.

The sound from a wind turbine can often be masked by wind noise at downwind receivers because the frequency spectrum from wind is similar to the frequency spectrum from a wind turbine. Figure 53 compares the shape of the sound spectrum measured during a 5 m/s wind event to that of the Vestas V120-STE wind turbine. As shown, the shapes of the spectra are similar at lower frequencies. At higher frequencies, the sounds from the masking wind noise are higher than the wind turbine. As a result, the masking of turbine noise occurs at higher wind speeds for some meteorological conditions. Masking will occur most, when ground wind speeds are relatively high, creating wind-caused noise such as wind blowing through the trees and interaction of wind with structures.

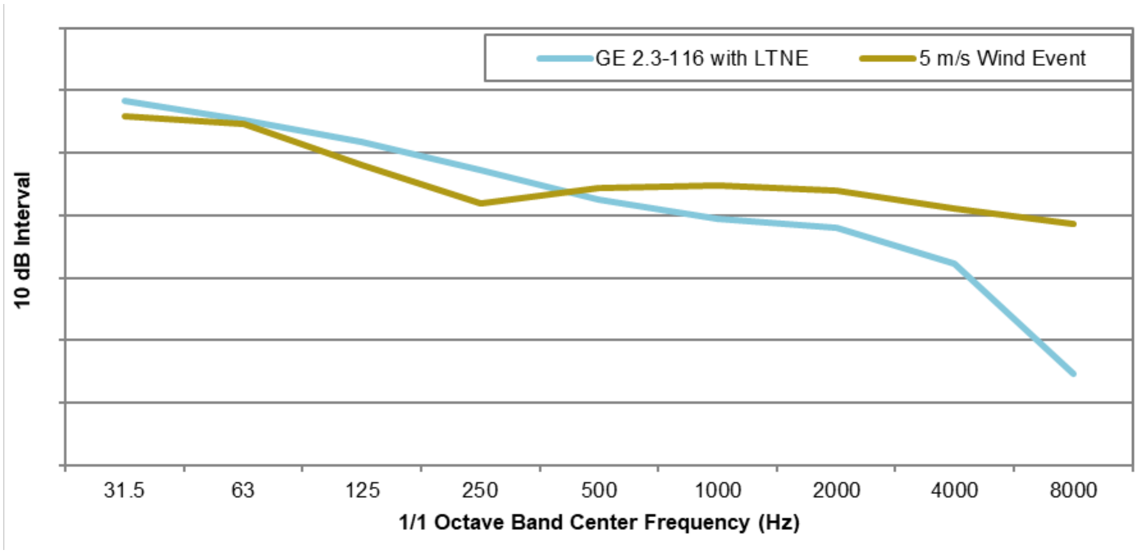


FIGURE 53: COMPARISON OF NORMALIZED FREQUENCY SPECTRA MEASURED FROM A 5 M/S WIND EVENT AND THE SOUND POWER SPECTRA FROM THE GE 2.3-116 WITH LNTE

It is important to note that while winds may be blowing at turbine height, there may be little to no wind at ground level. This is especially true during strong wind gradients (high wind shear), which mostly occur at night. This can also occur on the leeward side of ridges where the ridge blocks the wind.

APPENDIX B. SHUTDOWN ANALYSIS RESULTS

Data surrounding the maximum wind-turbine only sound level calculated for each monitor are compiled into detailed time history plots and a spectral summary for the evaluation period with the maximum wind turbine-only sound level.

Description of Detailed Time History Plots

The detailed time history plot with three panes.

1) wind turbine power production,
2) equivalent sound levels, wind speed/direction, and associated exclusions, and
3) a 1/3 octave band spectrogram representation of sound levels.

Time flows horizontally through all three panes.

The first pane charts the mean, maximum, and minimum 10-minute wind turbine power production for the closest five turbines. The red line depicts the power production of the closest turbine and the green line shows the mean of the closest five wind turbines. The shading represents the range of wind turbine power production for the closest five wind turbines. Wind turbine evaluation categories are indicated in the figures: turbine operation (purple) or turbine shutdown (light blue).

The second pane plots one-minute equivalent continuous A-weighted and ANS-weighted sound levels. The plot also contains hub-height wind speed and direction and ground-level gust wind speed (all in meters per second). The ground-level wind speed was measured and plotted on a one-minute basis, the hub-height wind speed measurement and plot intervals were ten-minutes.

The third pane is the 1/3 octave band spectrogram for the period. On the spectrogram plot, the y-axis represents frequency. The color intensity represents the magnitude of the level of sound. Grey shading is out of bounds of the colors bar, which spans from 10 to 70 dB. The spectral data are not weighted (i.e., dBZ). The spectrogram is plotted using one-second 1/3 octave band sound level data.

Description of Period Spectral Summary Plots

The summary plots for the evaluation period indicated contains a plot of the 1/3 octave band sound levels for background, total, and apparent wind turbine-only (left side), as well as the overall A-weighted sound level for each condition (right side). The green points and green bar report the background sound levels when the turbine was not operating. The lower the background sound level relative to the total sound level, the more the wind turbine-only sound contributed to the overall sound level. The total sound level is reported by the orange bars and the turbine-only sound level is presented as black bars.

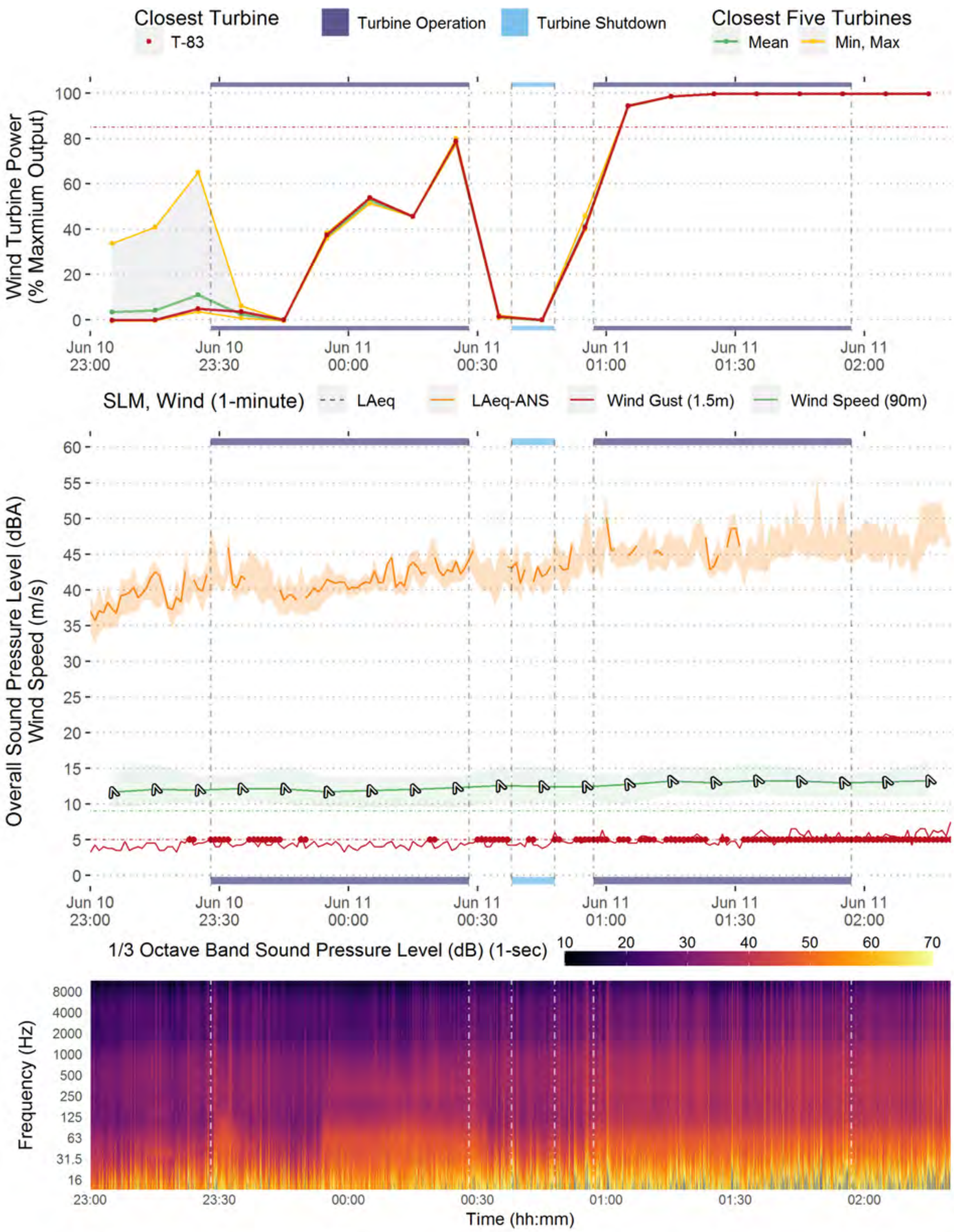


FIGURE 54: DETAILED TIME HISTORY PLOT FOR LT1 – SHUTDOWN #65

The periods following the shutdown are characterized by substantial wind gusts; most data after the shutdown were excluded due to ground-level gust speeds above 5 m/s. SD065-PostSD-a was valid acoustically (5 out of 10 1-minute periods were excluded) though gusty wind-induced sound dominates the data. Gusts are visible in the spectrogram as bright vertical striations.

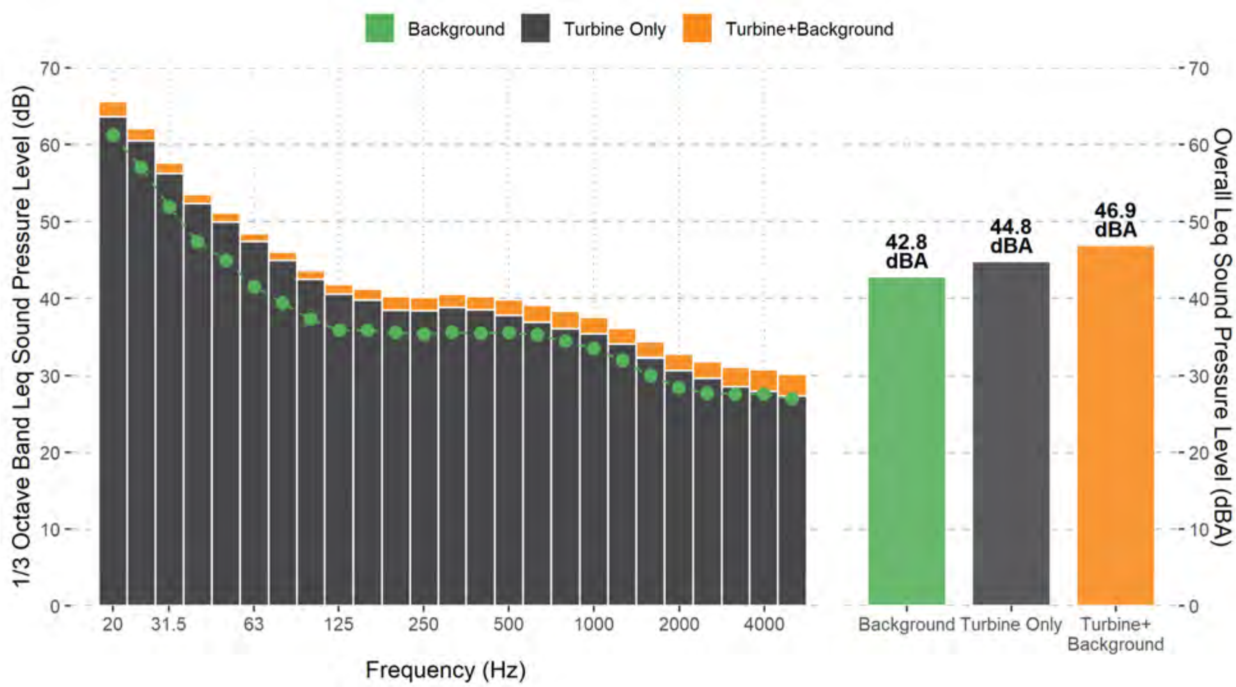


FIGURE 55: 1/3 OCTAVE BAND RESULTS FOR LT1 – SHUTDOWN #65 – POSTSD-A

SD065_PostSD-a: 2021-06-11 00:57 to 2021-06-11 01:07

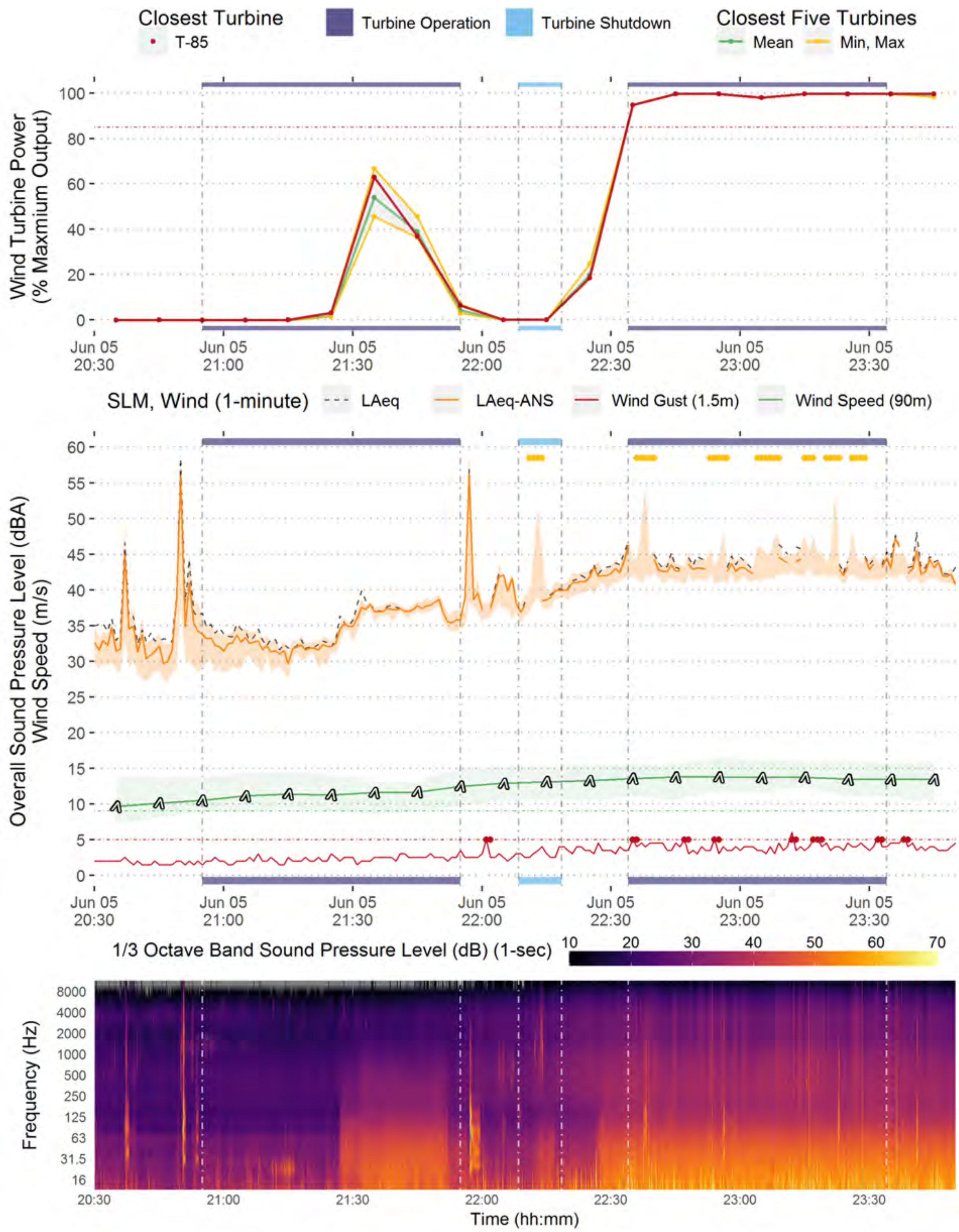


FIGURE 56: DETAILED TIME HISTORY PLOT FOR LT2 – SHUTDOWN #45

Ground-level wind speeds and hub-height wind speeds steadily increased through the Pre-Shutdown period and the background period when nearby wind turbines were shut down. Sound levels during the Post-Shutdown period were variable and required several exclusions for anomalously high sound levels due to variable wind gusts and vehicle passbys. The exclusion during the background period was nearby voices. Background levels were between 35 and 40 dBA, while total sound levels after the shutdown were generally between 40 and 45 dBA.

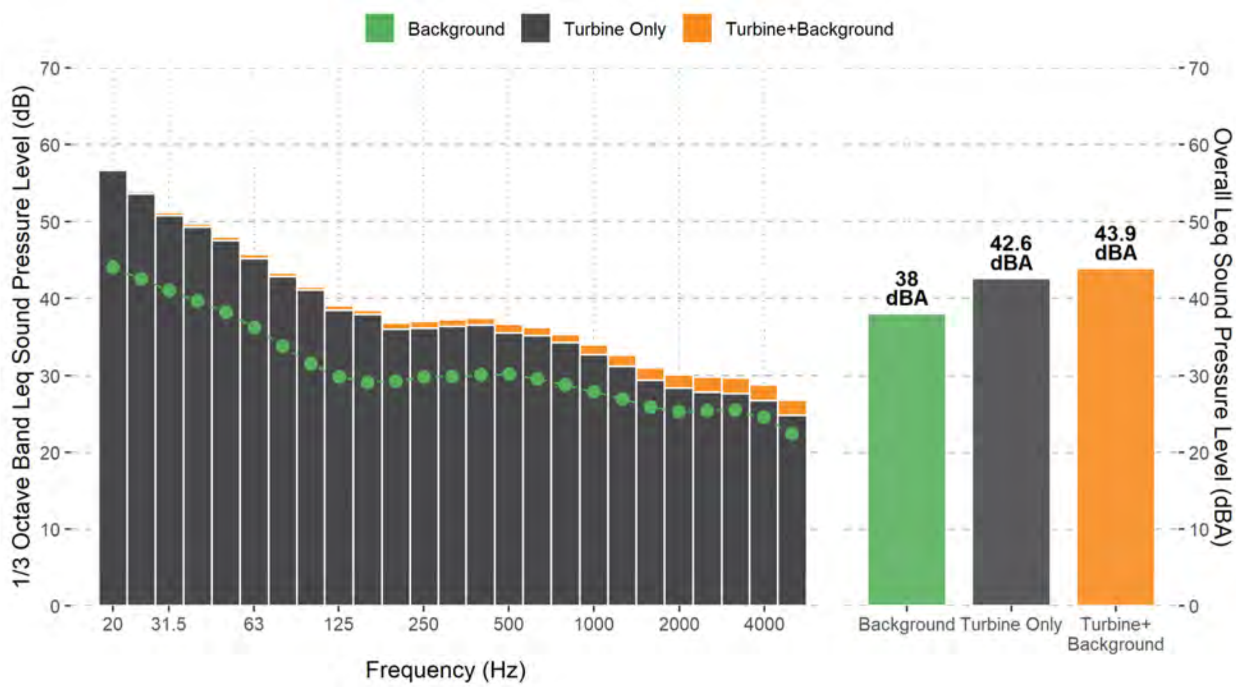


FIGURE 57: 1/3 OCTAVE BAND RESULTS FOR LT2 – SHUTDOWN #45 – POSTSD-A

SD045_PostSD-a: 2021-06-05 22:34 to 2021-06-05 22:44

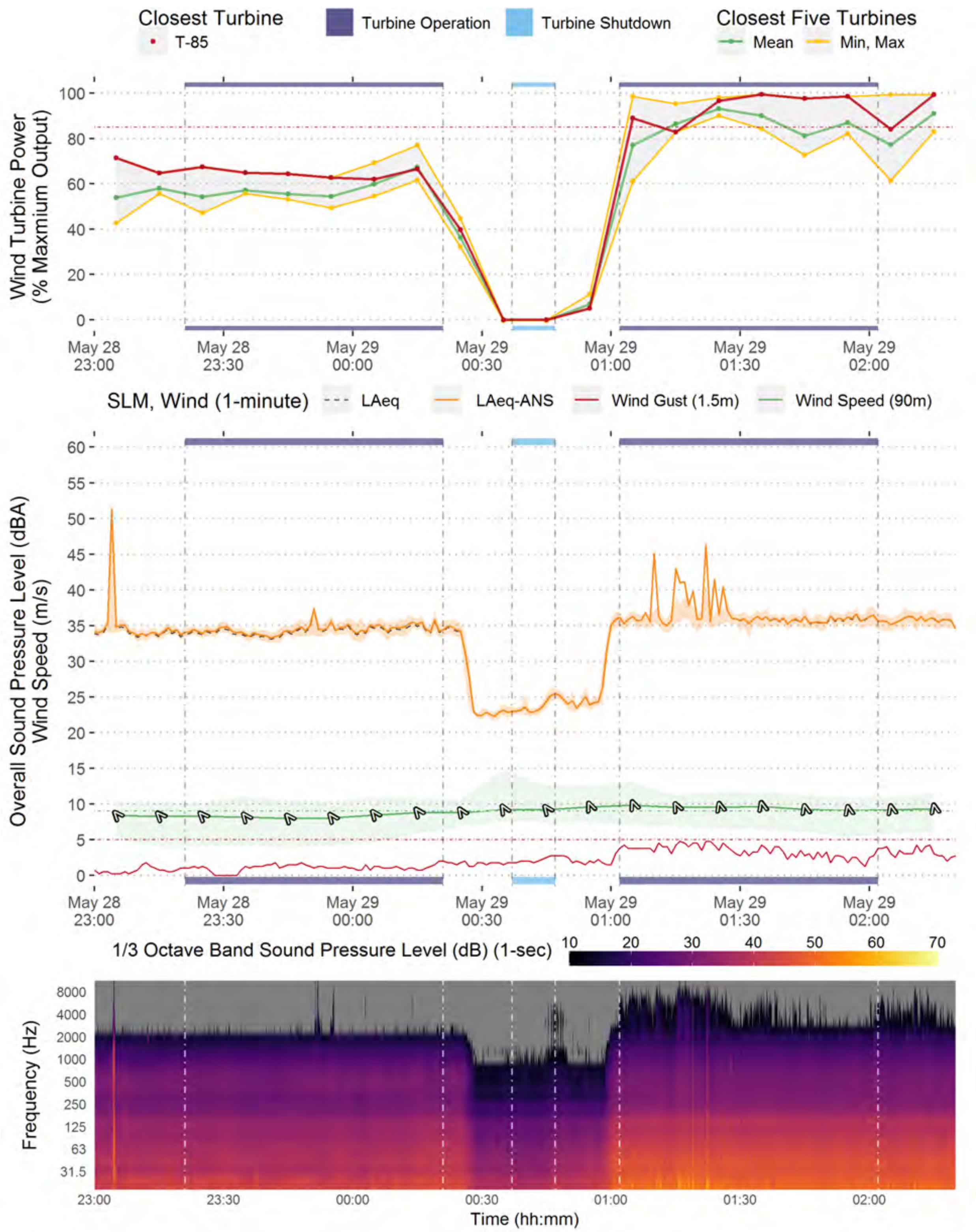


FIGURE 58: DETAILED TIME HISTORY PLOT FOR LT3 – SHUTDOWN #15

Background sound levels with nearby wind turbines shut down were generally below 25 dBA. Ground-level wind gusts increased after the background period and gustiness contributed to the spikes that caused the elevated sound levels. Otherwise, the total sound level (background + turbine) before and after the shutdown was consistently between 34 and 36 dBA.

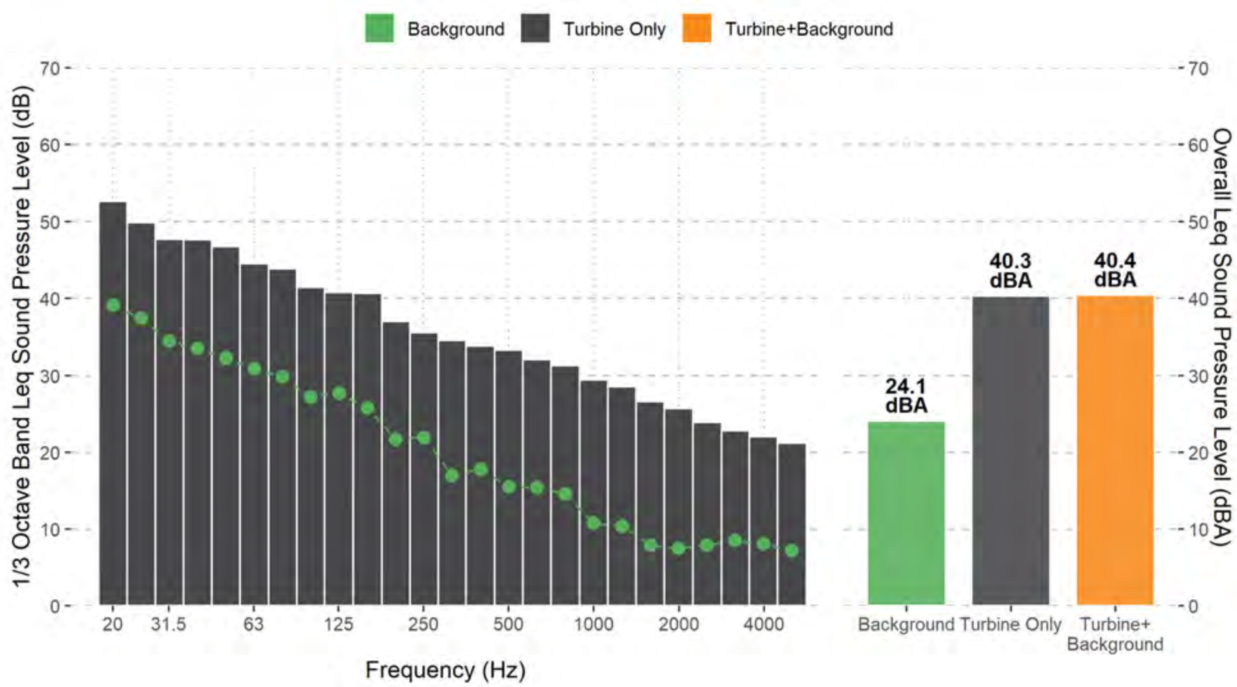


FIGURE 59: 1/3 OCTAVE BAND RESULTS FOR LT3 – SHUTDOWN #15 – POSTSD-C

SD015_PostSD-c: 2021-05-29 01:22 to 2021-05-29 01:32

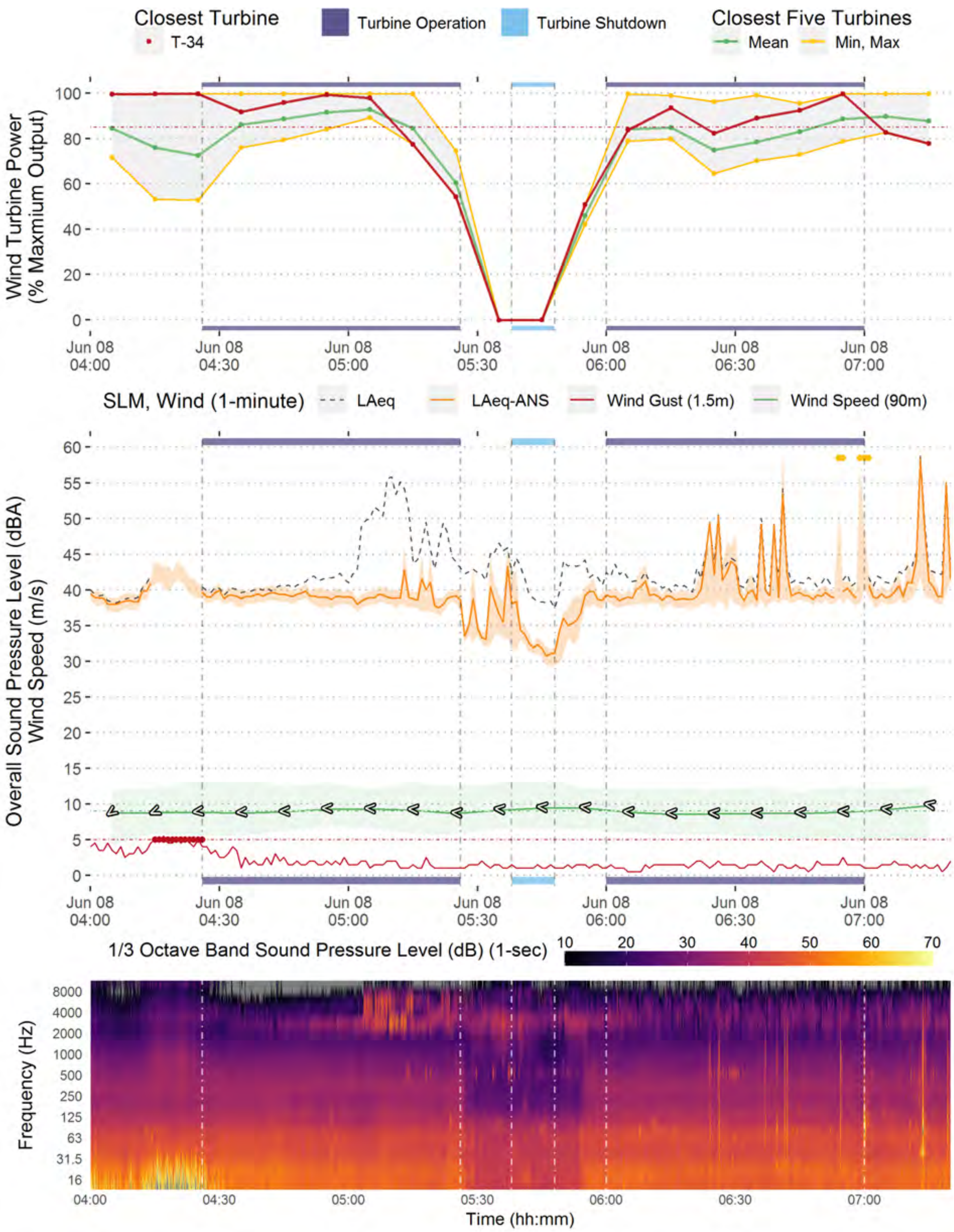


FIGURE 60: DETAILED TIME HISTORY PLOT FOR LT4 – SHUTDOWN #55

Total sound levels hovered consistently around 40 dB-ANS. Considerable biogenic sound is noticeable from 5 AM to 6 AM. Sound levels during the background period were between 30 and 35 dB-ANS. Several vehicle passbys in the Post-Shutdown periods generated spikes in 1-minute sound levels reaching between about 50 and 55 dBA.

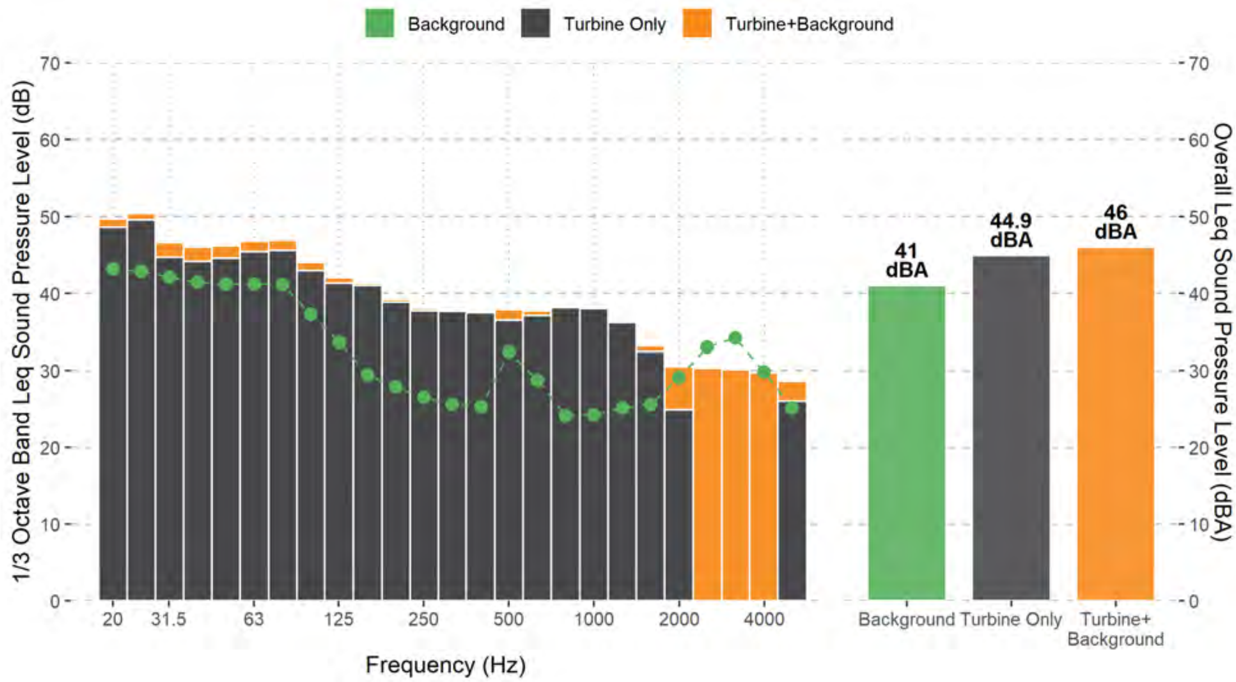


FIGURE 61: 1/3 OCTAVE BAND RESULTS FOR LT4 – SHUTDOWN #55 – POSTSD-E

SD055_PostSD-e: 2021-06-08 06:40 to 2021-06-08 06:50

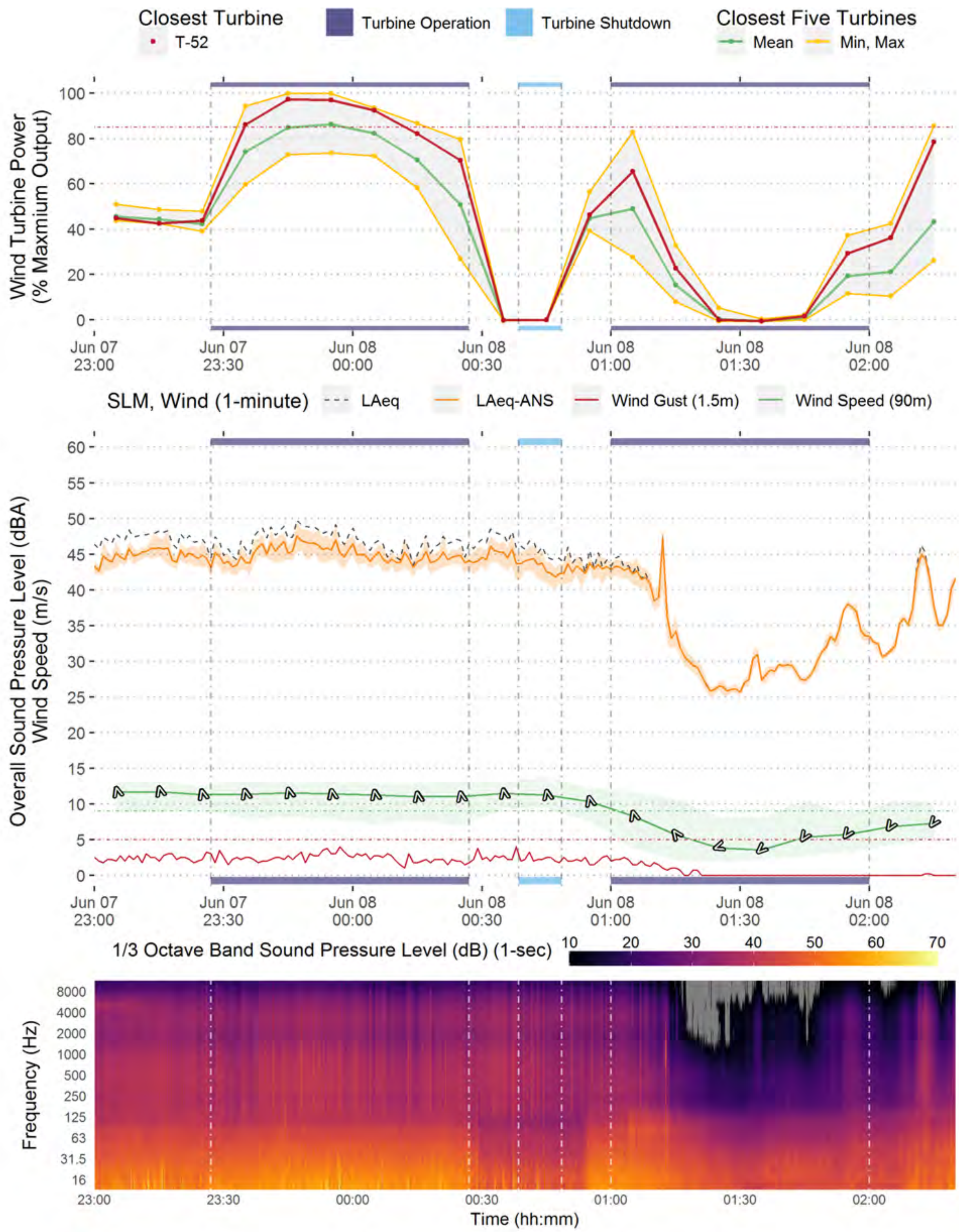


FIGURE 62: DETAILED TIME HISTORY PLOT FOR LT5 – SHUTDOWN #53

The Pre-Shutdown period and the Shutdown Period consisted of gusty winds, which is represented by variable sound levels and vertical striping in the spectrum. The change in sound levels with the shutdown is most noticeably below 125 Hz in the spectrogram. The Post-Shutdown periods saw a pronounced calming of winds, with a subsequent drop in wind turbine production, ground level wind speed, and sound levels.

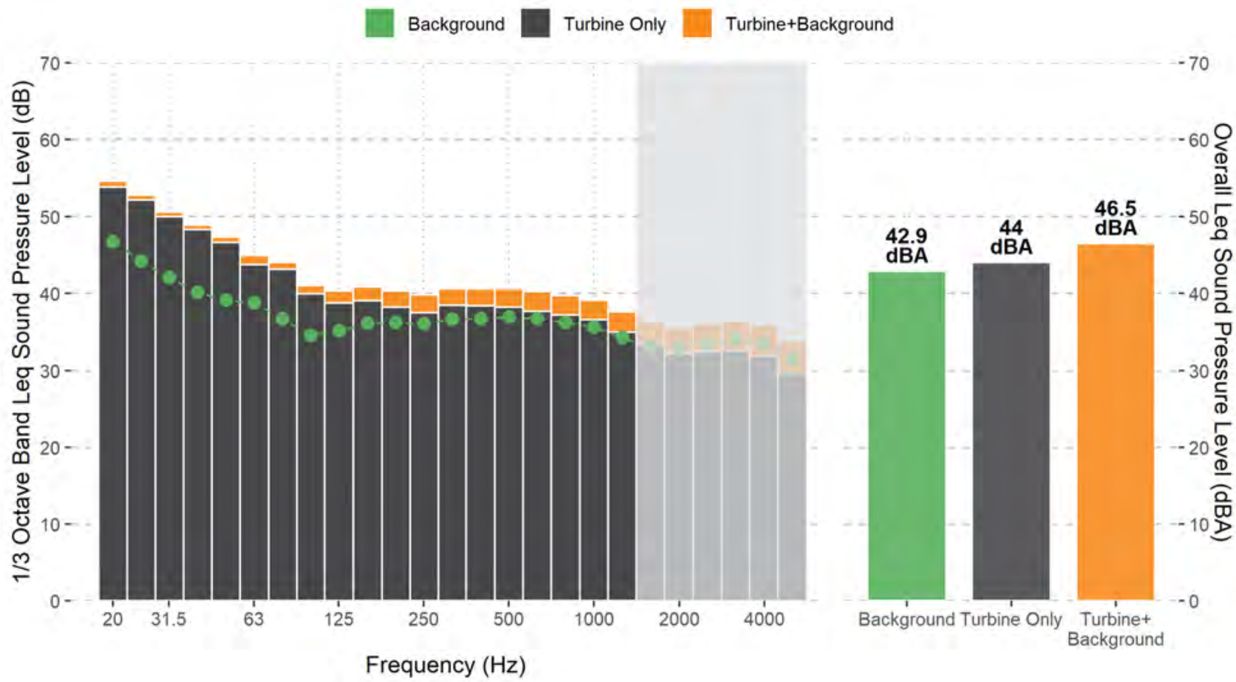


FIGURE 63: 1/3 OCTAVE BAND RESULTS FOR LT5 – SHUTDOWN #53 – PRESD-C

Overall sound levels were only calculated for 1/3 octave bands below 1.6 kHz

SD053_PreSD-c: 2021-06-07 23:47 to 2021-06-07 23:57

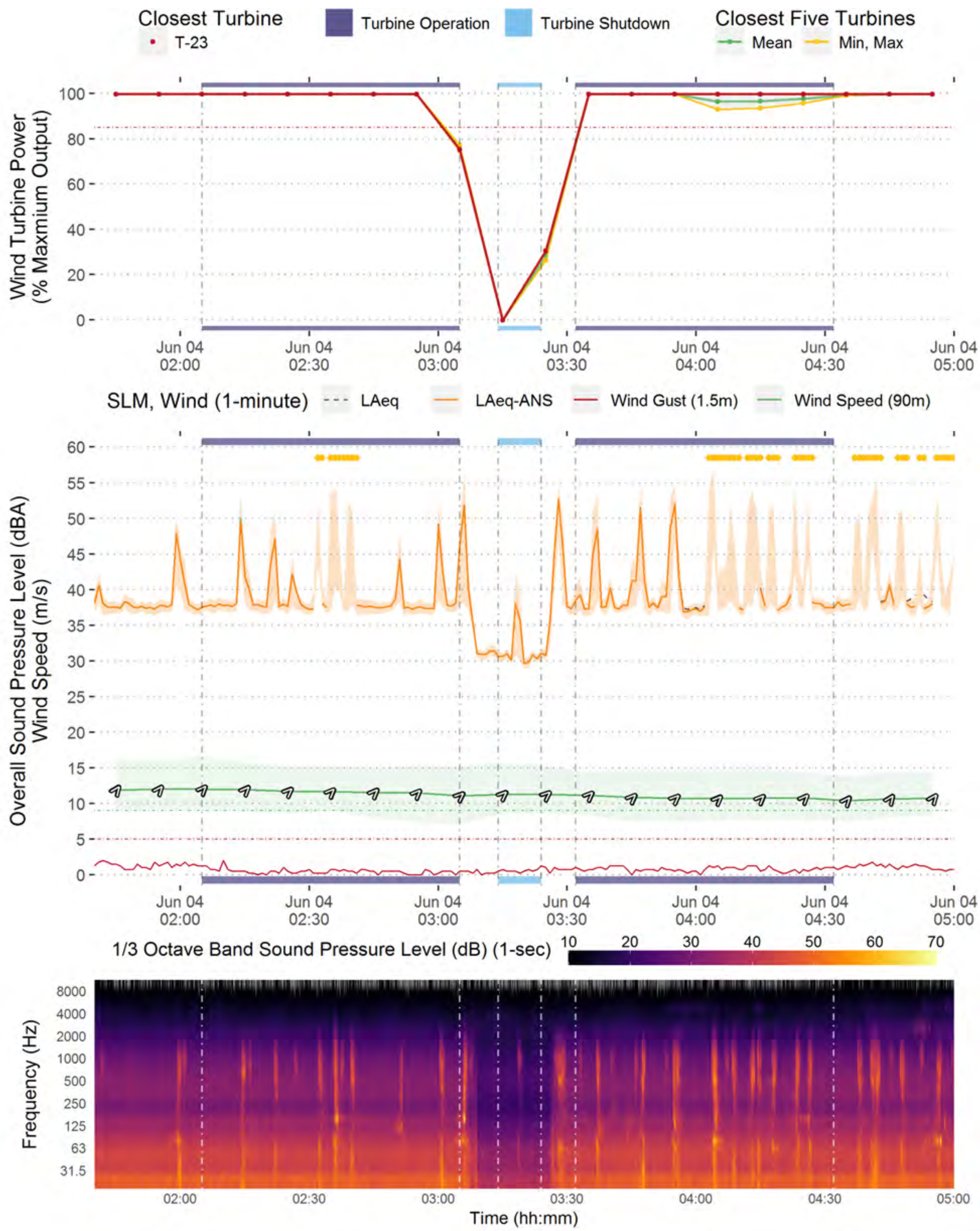


FIGURE 64: DETAILED TIME HISTORY PLOT FOR LT6 – SHUTDOWN #39

Vehicle passbys are consistent throughout the turbine operation periods and background period. In the absence of vehicle passbys, total sound levels (background + wind turbines) were below 40 dBA. Background sound levels approached 30 dBA during the background.

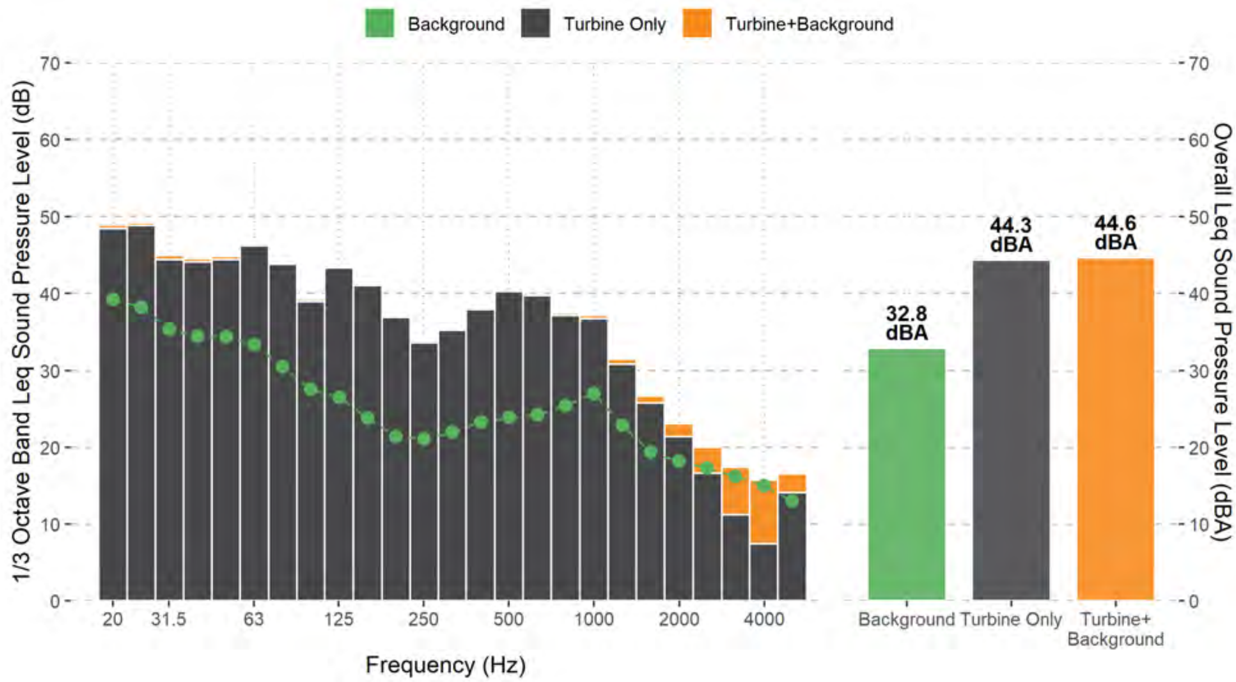


FIGURE 65: 1/3 OCTAVE BAND RESULTS FOR LT6 – SHUTDOWN #39 – POSTSD-C

SD039_PostSD-c: 2021-06-04 03:52 to 2021-06-04 04:02

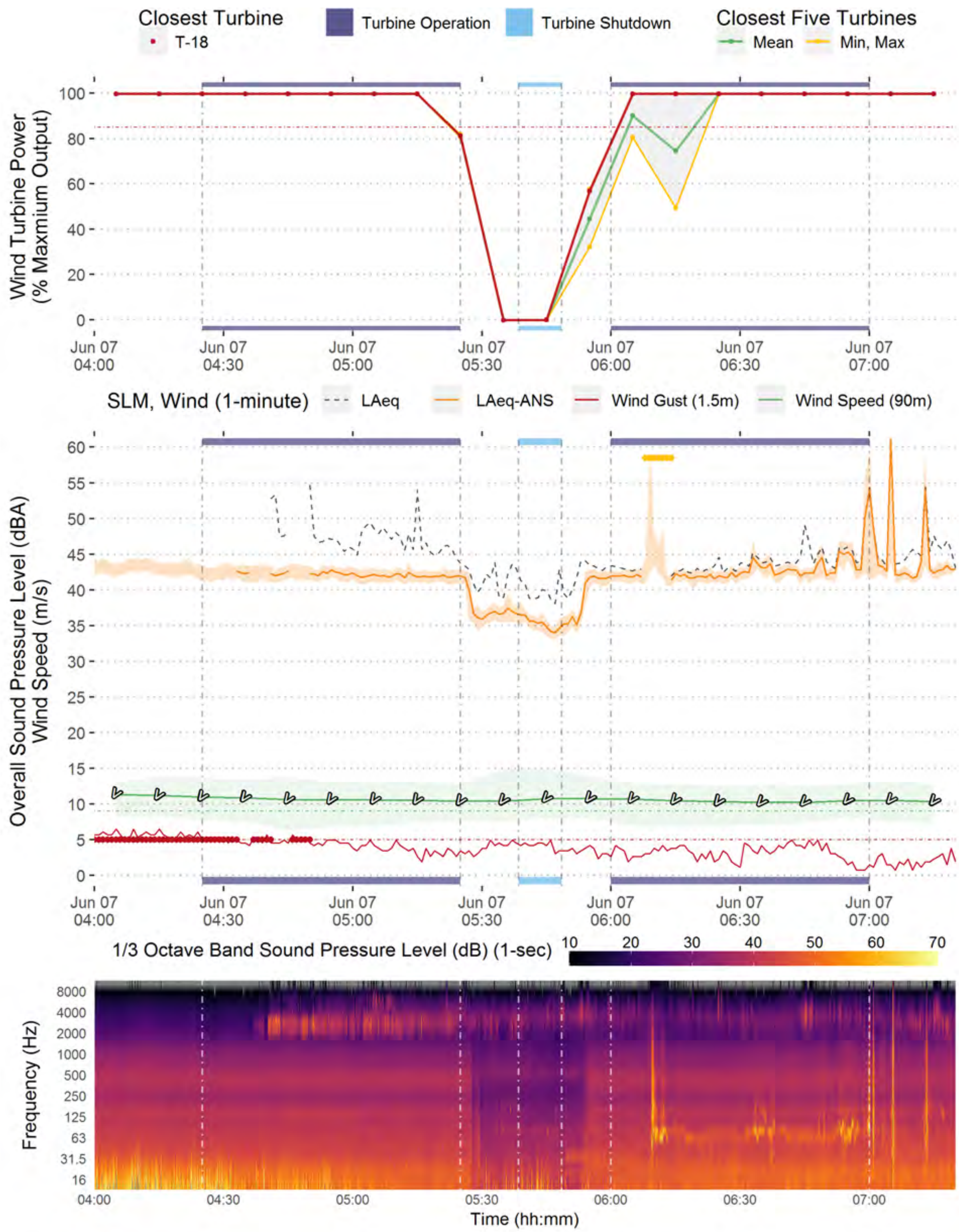


FIGURE 66: DETAILED TIME HISTORY PLOT FOR LT7 – SHUTDOWN #51

Total sound levels are consistently between about 42 and 43 dB-ANS during the turbine operation periods. Background sound levels while nearby wind turbines were shutdown averaged 35 dB-ANS. Ground level winds and biogenic sound was prevalent in the Pre-Shutdown periods. A farm vehicle raised sound levels during the Post-Shutdown periods. The change in sound levels with the wind turbine shutdown are clearly visible in the spectrogram, with all 1/3 octave bands from about 1 kHz and below becoming darker in color.

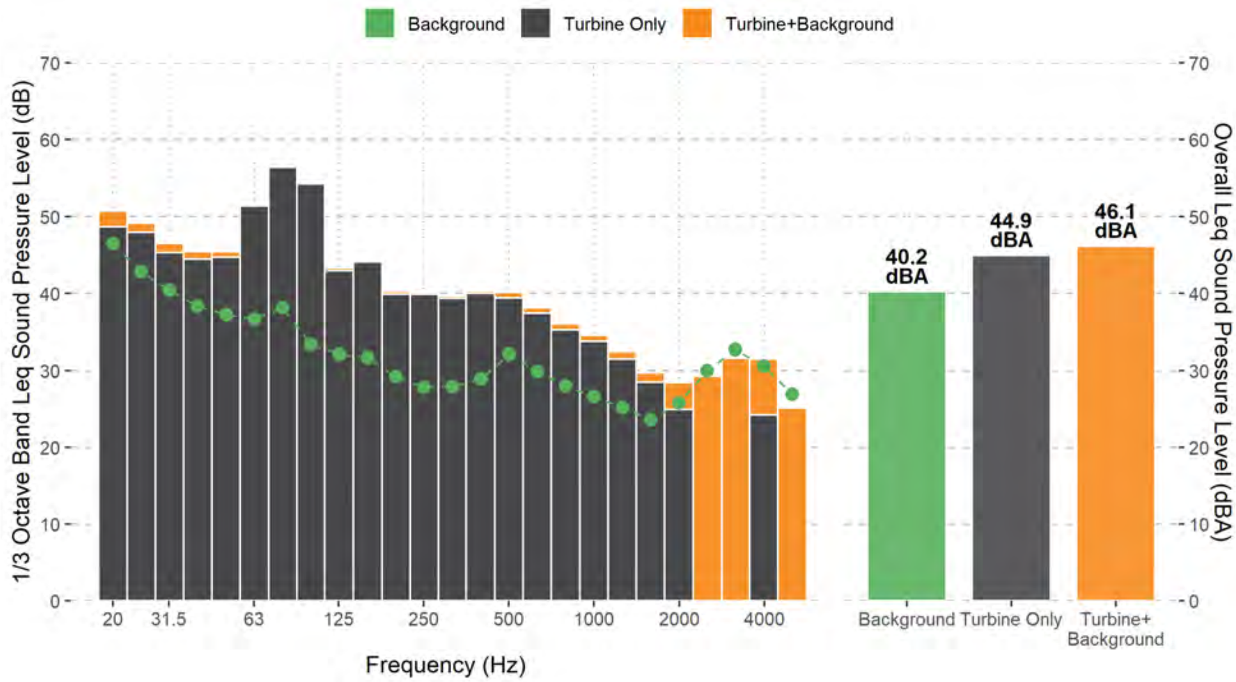


FIGURE 67: 1/3 OCTAVE BAND RESULTS FOR LT7 – SHUTDOWN #51 – POSTSD-F

SD051_PostSD-f: 2021-06-07 06:50 to 2021-06-07 07:00

APPENDIX C. TURBINE-ONLY SUMMARY

Appendix C presents summarizes the distribution of wind turbine-only sound levels collected and calculated for each monitor for acoustically valid evaluation periods under the target wind turbine operating conditions. The 1/3 octave band data (plot on the left) are unweighted (dBZ) and the overall sound levels (plot on the right) are A-weighted (dBA).

In each plot, wind turbine-only sounds levels for acoustically valid evaluation periods within the target conditions are represented by the following:

- Orange bars: the range of wind turbine-only 1/3 octave band sound levels for *any* evaluation period, i.e., they are not all from a single evaluation period.
- Green points/line and green bar: the minimum overall wind turbine-only sound level for a *single* evaluation period.
- Dark grey points/line and dark grey bar: the maximum overall wind turbine-only sound level for a *single* evaluation period.
- Red points/line: the energy average 1/3 octave band values of the turbine-only 1/3 octave band sound levels
- Red bar: energy average of the overall turbine-only levels.

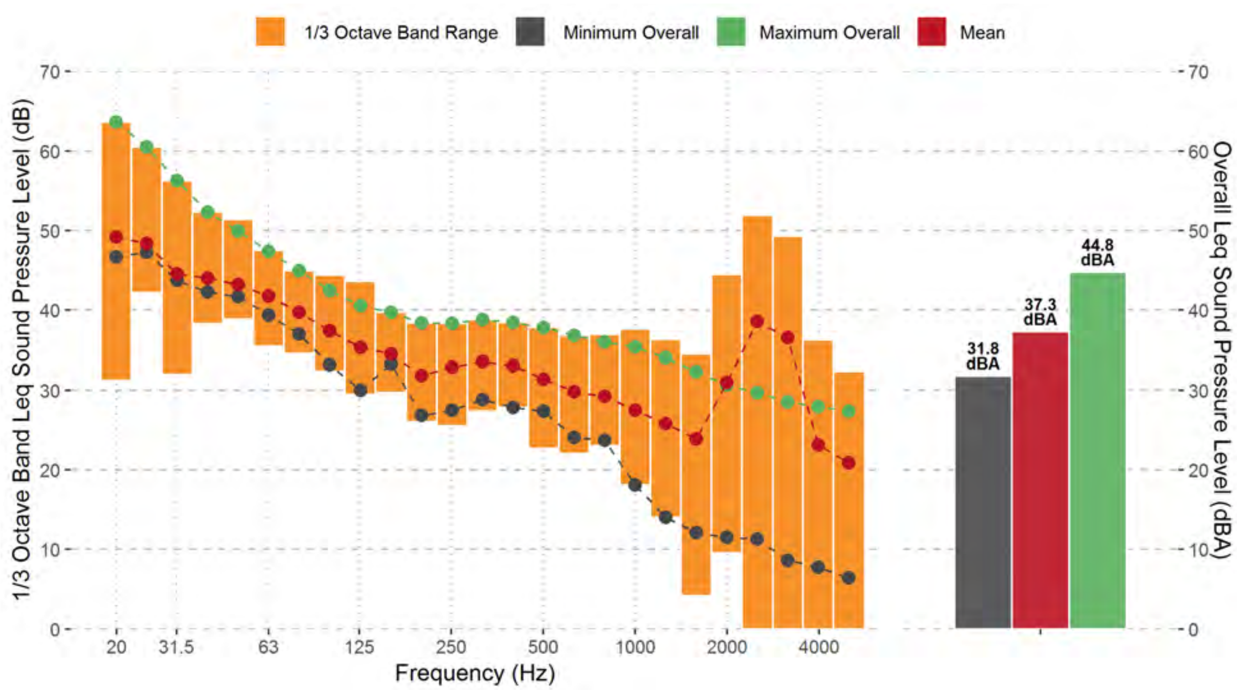


FIGURE 68: SUMMARY OF TURBINE-ONLY SOUND LEVELS AT LT1

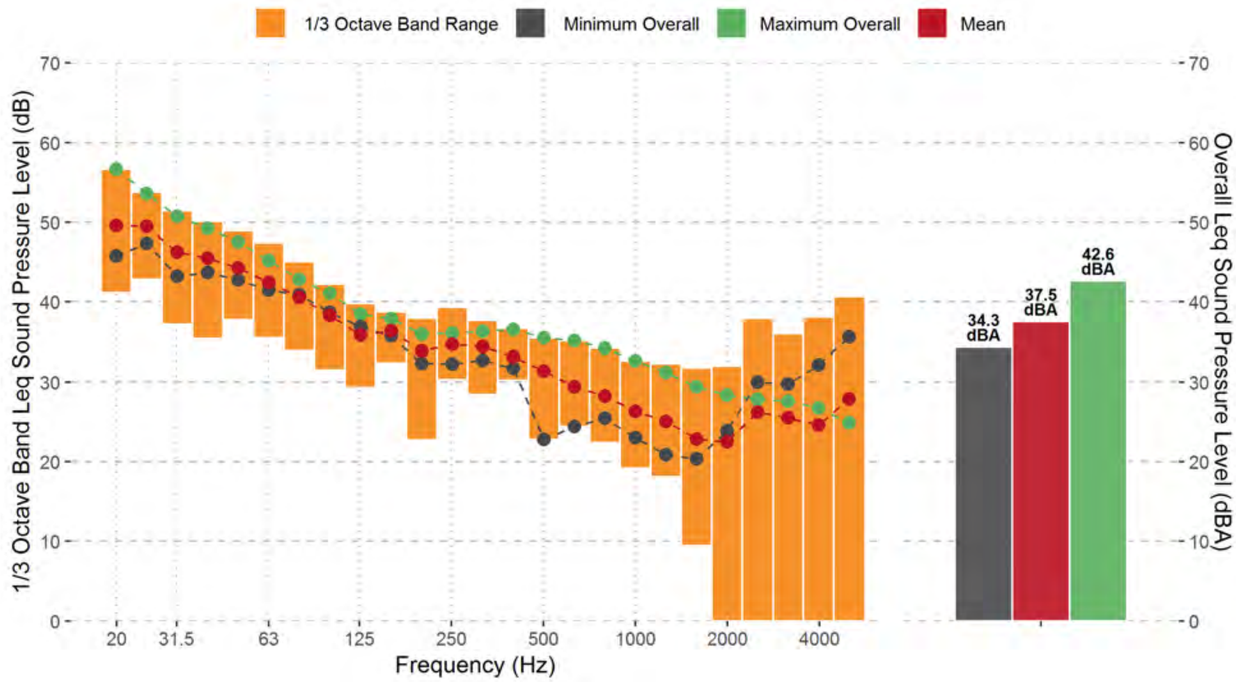


FIGURE 69: SUMMARY OF TURBINE-ONLY SOUND LEVELS AT LT2

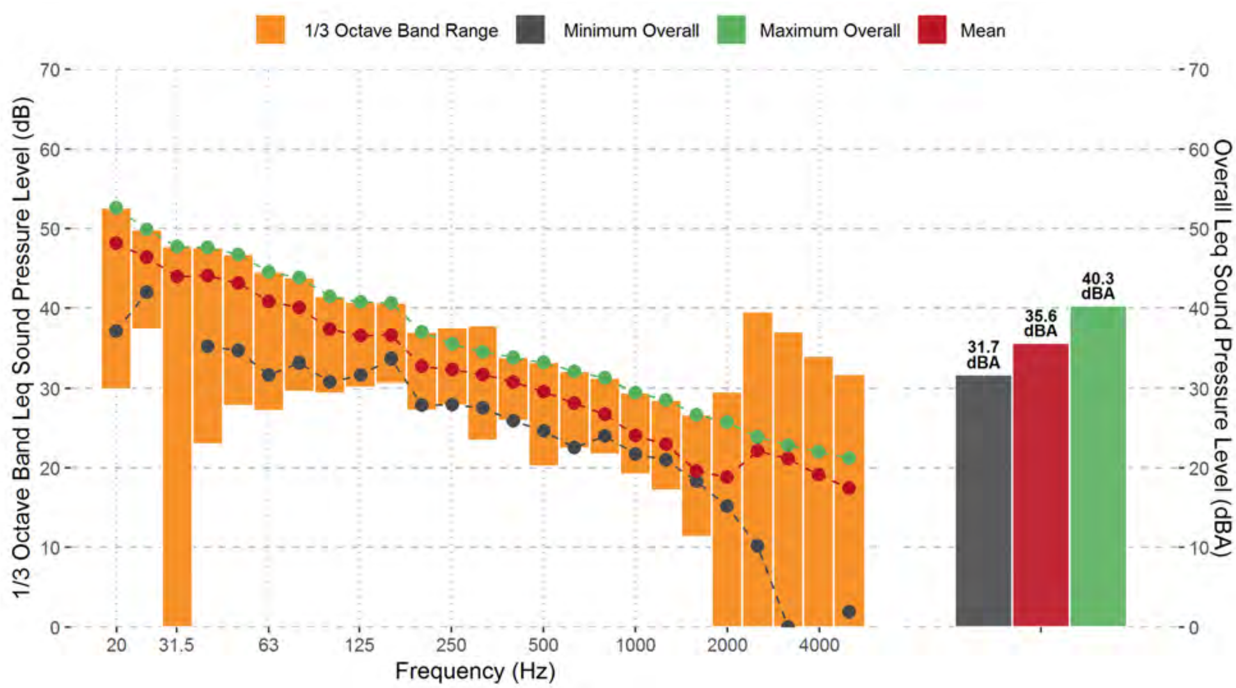


FIGURE 70: SUMMARY OF TURBINE-ONLY SOUND LEVELS AT LT3

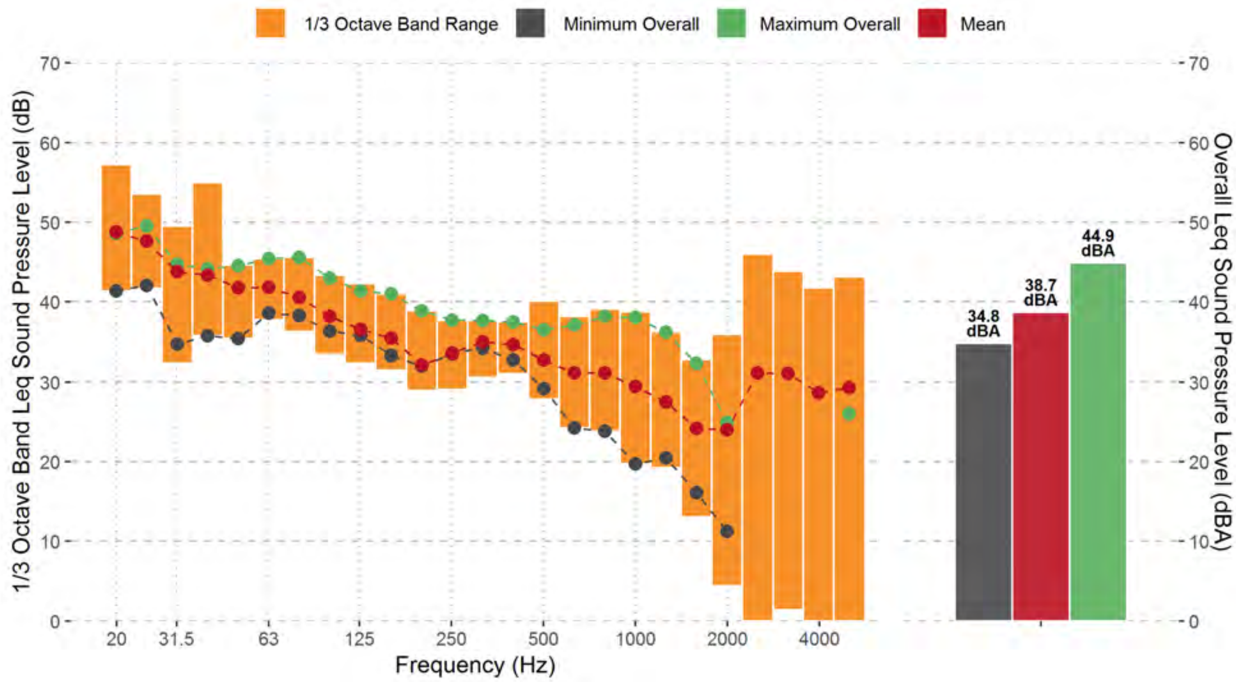


FIGURE 71: SUMMARY OF TURBINE-ONLY SOUND LEVELS AT LT4

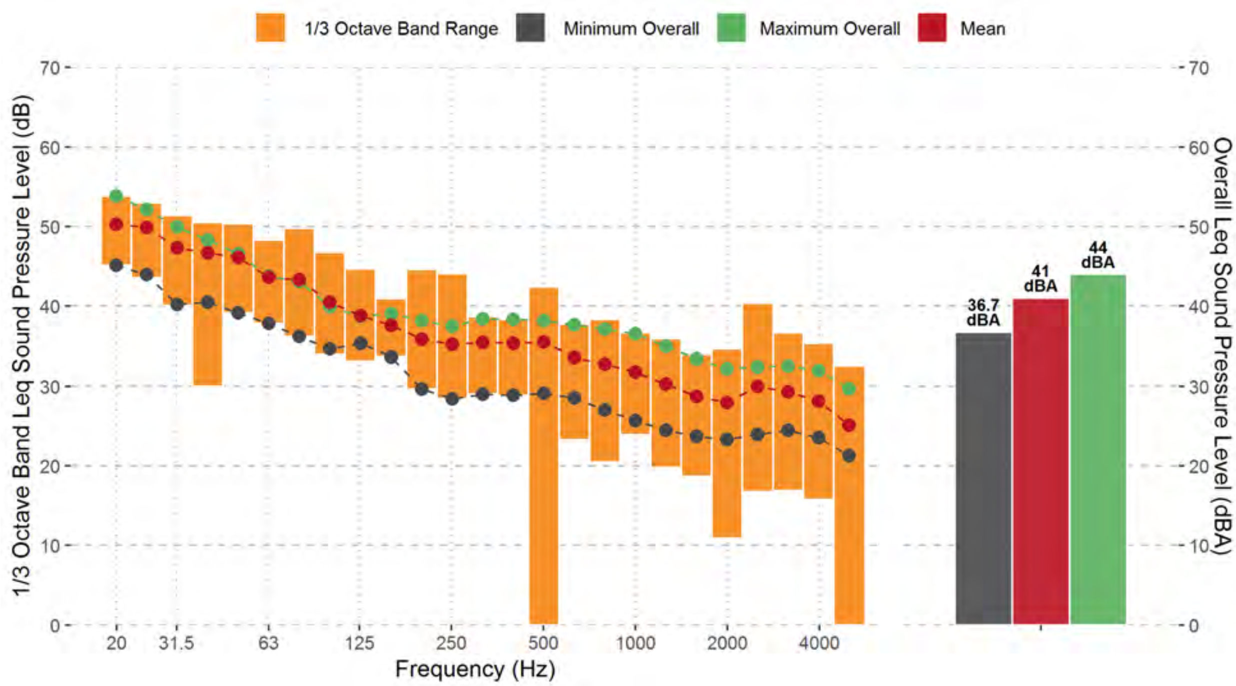


FIGURE 72: SUMMARY OF TURBINE-ONLY SOUND LEVELS AT LT5

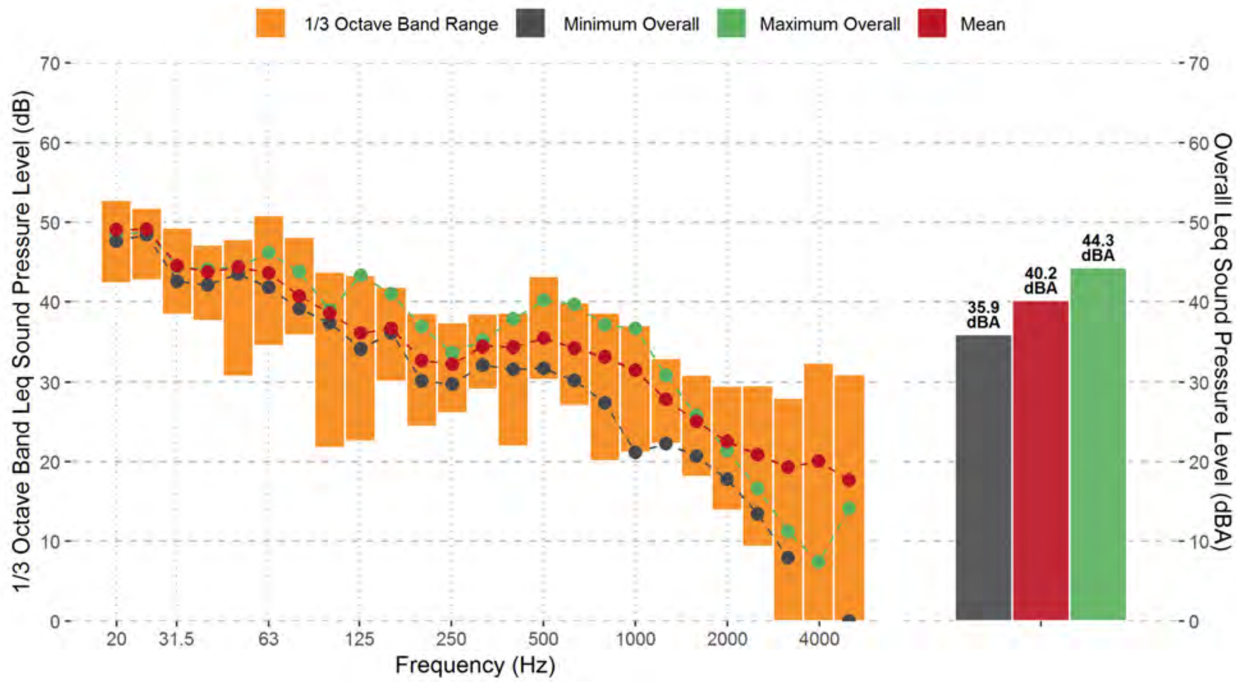


FIGURE 73: SUMMARY OF TURBINE-ONLY SOUND LEVELS AT LT6

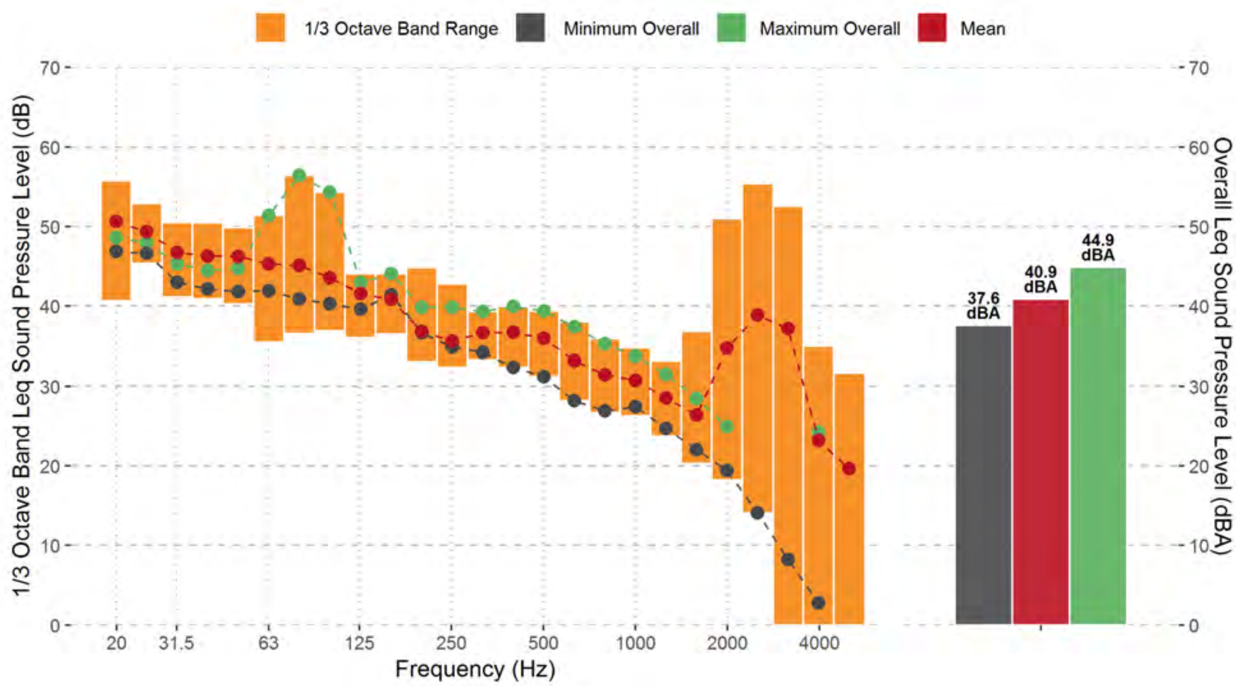


FIGURE 74: SUMMARY OF TURBINE-ONLY SOUND LEVELS AT LT7

CERTIFICATE OF SERVICE

I, Pamela Gibbs, hereby certify that I have this 6th day of August 2021 electronically served copies of the foregoing document on the attached list of persons,
(OFFICIAL SERVICE LIST):

Ms. Patricia Van Gerpen
Executive Director
Patty.vangerpen@state.sd.us

Ms. Kristen Edwards
Staff Attorney
Kristen.edwards@state.sd.us

Ms. Amanda Reiss
Staff Attorney
Amanda.reiss@state.sd.us

Mr. Darren Kearney
Staff Analyst
Darren.kearney@state.sd.us

Mr. Jon Thurber
Staff Analyst
Jon.thurber@state.sd.us

Mr. Eric Paulson
Staff Analyst
Eric.paulson@state.sd.us

Mr. Brian J. Murphy
Senior Attorney
NextEra Energy Resources, LLC
Brian.j.murphy@nee.com

Mr. Tyler Wilhelm
Associate Project Manager
NextEra Energy Resources, LLC
Tyler.Wilhelm@nexteraenergy.com

Ms. Cindy Brugman
Auditor
Codington County
cbrugman@codington.org

Ms. Karen Layher
Auditor
Grant County
Karen.layher@grantcountysd.us

Ms. Mary Korth
Auditor
Deuel County
Dcaudit1@itctel.com

Ms. Kristi Mogen
Silversagehomestead@gmail.com

Mr. Allen Robish
Allen.robish@gmail.com

Ms. Amber Christenson
amber@uniformoutlet.net

A.J. Swanson
Arvid J. Swanson, P.C.
aj@ajswanson.com

DOCKET NO. EL19-027 CROWNED RIDGE WIND II, LLC

Dated this 6th day of August 2021

/s/

____

Pamela Gibbs
Regulatory Case Specialist