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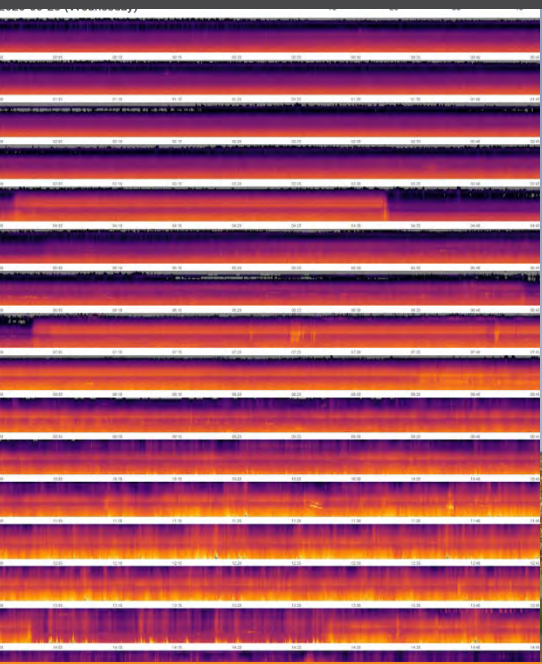
BSW NOISE COMPLAINT RESPONSE - WEVERKA RESIDENCE (OUTDOOR)

Report | November 23, 2020



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1.0 INTRODUCTION

This report details the sound level monitoring performed at the Weverka residence to determine compliance of Blazing Star Wind with Minnesota noise regulations. The report describes the methods utilized to acquire and analyze the data and presents results.

A noise primer and specific issues relating to wind turbine acoustics are provided in Appendix A.

1.1 BACKGROUND

Blazing Star Wind ("BSW") was commissioned in April 2020. Noise complaints from some nearby residences began shortly after commissioning in the spring of 2020. RSG was retained to perform sound level monitoring to assess sound levels at two complainant homesites relative to permitted levels. Sound level and meteorological monitoring was conducted pursuant to Minnesota Rules Chapter 7030.

Noise Standards

Per the site permit, BSW is required to comply with the noise standards set forth in Minnesota Rules Chapter 7030.

Minnesota Rules Chapter 7030 provides sound level limits for a variety of land uses. A residence falls under Noise Area Classification ("NAC") 1, which is considered the most sensitive land use, and has a median 1-hour daytime limit of 60 dBA (L_{50}) and nighttime limit of 50 dBA (L_{50}). The limits for the 90th percentile levels (L_{10}, which is the level exceeded only 10% of the time over one hour) are 5 dB higher, as shown in Table 1. In regard to where to apply the standard, Measurement Methodology (7030.0060), Subpart 1 states that "measurements of sound must be made at or within the applicable NAC at the point of human activity which is nearest to the noise source. All measurements shall be made outdoors."

The noise standards in Minnesota Rules 7030 "describe the limiting levels of sound," yet do not explicitly specify if the regulation applies to total sound (source sound level + background sound level) or just the source in question, in this case wind turbines. When the pre-construction noise study was completed and when BSW was permitted, the guiding document for the noise study was "Guidance for Large Wind Energy Conversion Systems Noise Study Protocol and Report" ("2012 Guidance").[1] Appendix A of the 2012 Guidance provides comments from the Minnesota Pollution Control Agency that state the following with regard to compliance:

> *b) Compliance. Although the noise rules apply to total noise measured at a wind farm, the culpability of the wind turbine depends on attribution. If noise exceedances are*

[1] "Guidance for Large Wind Energy Conversion Systems Noise Study Protocol and Report, October 2012, MN Department of Commerce, Energy Facilities Permitting.

recorded, it is necessary to determine the increment due to the turbine noise. Background noise information is very important to this effort. This is where background data might be "subtracted". Compliance is based on the inclusion of background in total noise, whereas attribution depends on the use of the background information to adjust the measured noise to the source (turbines).

Under the 2012 Guidance, the process of compliance determination is a two-part test. First, there must be a determination of whether the total measured sound level is above or below the limits set forth in Minnesota Rules 7030. If the total sound level is above the limits, then the level is out of compliance with the limits, and the second part of the test, attribution, applies. Attribution, that is, whether the exceedance the limit is due to the wind turbines, is determined by subtracting background sound levels from the total sound level.

Since BSW's site permitting process, the Commission's application of the Noise standards has changed to better accommodate the MPCA's stance on noise compliance. The Department of Commerce's 2019 Guidance document on the subject[2] states that the overall sound level includes the combination of background noise plus the contribution made by wind turbines. This is very similar to the compliance discussion in Appendix A of the 2012 Guidance. Thus, under the 2019 Guidance, the total overall sound level (wind turbine with other background sounds) should not exceed 50 dBA (L_{50}) at night. If background sound levels at night are at least 10 dB below the noise standard, Minnesota Rule 7030 would allow for 1-hour L_{50} wind turbine up to nearly 50 dBA (see Appendix A for information regarding decibel addition and subtraction).

Other recent guidance[3] from the DOC provides the following guidance of the interplay between background sound levels and turbine-only contribution relative to their interpretation of the limit being a "total noise standard":

If background sound levels are equal to or greater than the applicable state standard at nearby receptors, the wind farm should not contribute more than 47 dB(A) to total sound levels at nearby receptors. Therefore, for example, when nighttime background sound levels are at 50 dB(A), a maximum turbine-only contribution of 47 dB(A) would result in a non-significant increase in total sound of 3 dB(A).[4]

This guidance, which was published after the BSW pre-construction noise assessment was completed and after BSW received a permit, allows for an exceedance of 50 dBA by up to 3 dB under some circumstances, and characterizes it as a "non-significant increase".

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[2] "LWECS Guidance for Noise Study Protocol and Report", July 2019, MN Department of Commerce.
[3] "Application Guidance for Site Permitting of Large Wind Energy Conversion Systems in Minnesota," July 2019, MN Department of Commerce.
[4] We believe that the guidance meant to state "...*a non-significant increase in total sound of* **less than** *3 dB(A)" because 50 dBA + 47 dBA = 51.8 dBA.*

Given this information, this report provides two sets of data, the total sound level measured, and the turbine-only sound level, which is the sound level attributable to BSW.

TABLE 1: MINNESOTA NOISE POLLUTION CONTROL 7030.0050 NOISE STANDARDS FOR LIMITING LEVELS OF SOUND OVER A ONE HOUR SURVEY

	L_{50}	L_{10}
Daytime	60 dBA	65 dBA
Nighttime	50 dBA	55 dBA

1.2 WEVERKA RESIDENCE

The Weverka Residence ("Residence") is located at 2948 160th Avenue W in Hendricks, MN. As shown in Figure 1, six wind turbines are located within 2.4 km (1.5 miles)[5] of the Weverka residence. These six "nearby" turbines BSW are the only wind turbines considered in this analysis. Table 2 lists the locations of the six nearby wind turbines relative to the Residence. T-90 is the closest turbine to the Weverka Residence. It is located approximately 370 meters to the north-northwest of the residence (at an angle of 20 degrees west of north). All nearby turbines are Vestas V120 at a hub height of 80 meters with a 120-meter rotor diameter.

[5] Wind turbines more than 1.5 miles away from a receiver do not contribute appreciably to the overall wind turbine sound level at the residence when there are other wind turbines within 1 mile.

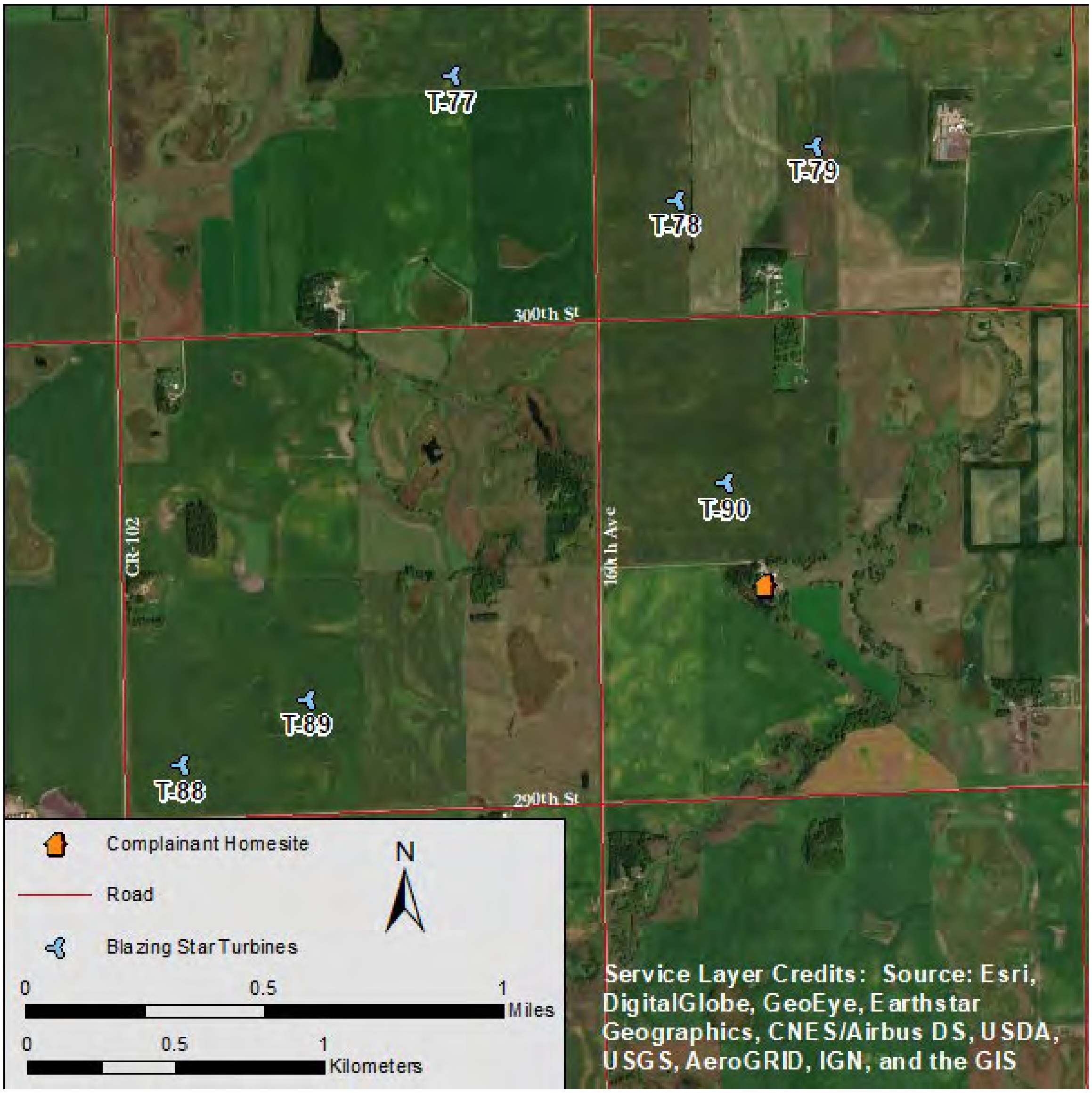

FIGURE 1: WEVERKA RESIDENCE WITH ALL NEARBY TURBINES

TABLE 2: BLAZING STAR WIND TURBINES WITHIN 1.5 MILES OF THE WEVERKA RESIDENCE

TURBINE	TURBINE GROUP	DISTANCE (m)	DISTANCE (ft)	DIRECTION TO TURBINE FROM RESIDENCE (DEG)
T-77	Other Nearby Turbines	2016	6610	330
T-78	Other Nearby Turbines	1335	4380	350
T-79	Other Nearby Turbines	1493	4900	8
T-88	Other Nearby Turbines	2059	6760	225
T-89	Other Nearby Turbines	1587	5210	258
T-90	Closest Turbine	373	1220	340

2.0 SOUND LEVEL MONITORING CAMPAIGN

2.1 MONITOR LOCATION DETAIL

Outdoor sound levels were monitored at two outdoor locations near the Weverka Residence. The monitoring began on Tuesday, September 8, 2020 and continued through Tuesday, September 29, 2020. The position of both monitoring locations is described below and shown in the map on Figure 2. A comparison of the modeled turbine-only sound levels for the Residence and the monitoring location is provided in Table 3; T-90 is the main contributor to wind turbine sound levels at the Residence.

For the first monitoring period, the monitor was placed 45 meters to the west-southwest of the Residence, within the homestead's windbreak at Monitor Location 1. The monitor was about 375 m (1230 ft) from T-90. A photo of this monitoring location is provided in Figure 3. This monitoring location was secluded from the home and the daily activities on the homestead, while maintaining approximately the same distance to the residence from T-90. This location was chosen because the modeled wind turbine sound levels were nearly identical to the Residence, and the location was protected from direct wind exposure by the windbreaks planted for the homestead. Note that T-90 did not operate at night during this period.

On September 17, 2020, at the request of the residents, the sound level meter was physically moved to the north of the house and closer to T-90 for the second monitoring period to Location 2. Location 2 was 65 meters from the Residence and about 305 meters from T-90. T-90 was operated at night during this period.

TABLE 3: MODELED SOUND LEVELS (L_{50}) FOR THE RESIDENCE AND THE TWO MONITORING LOCATIONS

LOCATION	ALL TURBINES	T-90 ONLY	OTHER NEARBY TURBINES
Residence	47.7 dBA	47.0 dBA	38.3 dBA
Monitor Location 1	47.7 dBA	47.0 dBA	38.4 dBA
Monitor Location 2	49.4 dBA	48.9 dBA	38.4 dBA

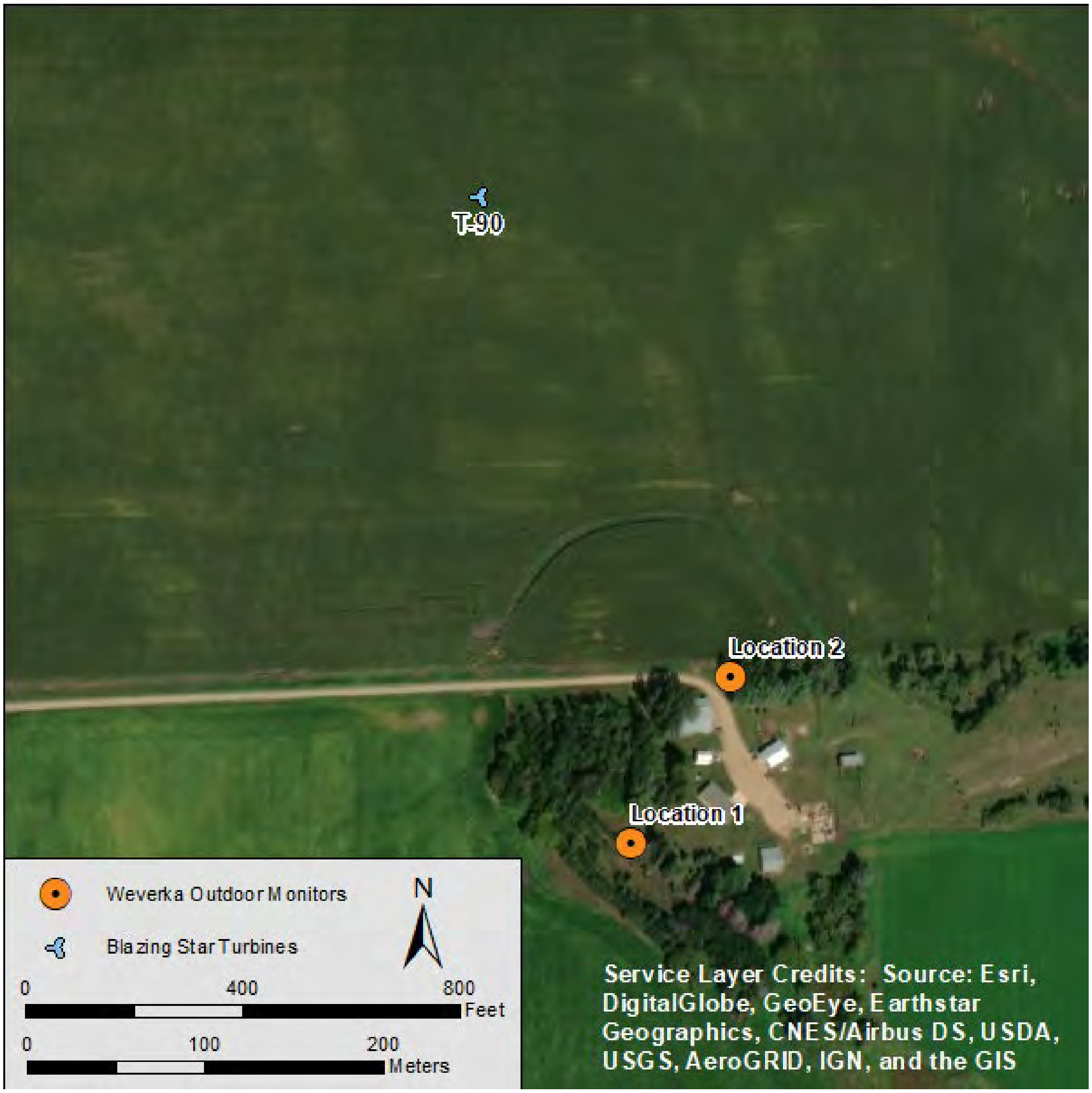

FIGURE 2: WEVERKA HOMESTEAD WITH BOTH OUTDOOR MONITORING LOCATIONS. THE SOUTHERN CORNER OF THE RESIDENCE IS SLIGHTLY COVERED BY THE “n” IN “Location 1”

Monitor Location 1

FIGURE 3: PHOTOGRAPH OF THE INITIAL MONITOR SETUP AT THE WEVERKA RESIDENCE (LOCATION 1), LOOKING WEST.

Monitor Location 2

FIGURE 4: PHOTOGRAPH OF THE SECOND WEVERKA OUTDOOR MONITOR (LOCATION 2), WITH T-90 IN THE BACKGROUND, LOOKING NORTH

2.2 DATA COLLECTION

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

Sound Level Monitoring Station Detail

Under the direction of RSG. the sound level monitoring stations were deployed by ESI Engineering. Sound level data were collected using a Svantek SV 979 sound level meter ("SLM"). The Type 1 SLM continuously logged overall and 1/3-octave band sound levels once each second and recorded continuous audio files in 24-bit *.wav format at 12 kHz sample rate internally. The sound level meter's microphone 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 Cesva CB-5 calibrator.

Along with the sound level meter, ground-level wind speed and precipitation were measured adjacent to the monitor with a HOBO Onset Microstation. Precipitation rate, average wind speed, and gust wind speed were logged every minute.

Data were excluded from the analysis under the following conditions:

- Wind gust speeds above 5 m/s (11.2 mph);
- Rain and thunderstorm events identified by the adjacent precipitation gauge or through data inspection; and
- During site setup and microphone calibration.

Meteorological Data

Beyond the site-specific meteorological data described above, the Automated Surface Observation Station ("ASOS") at Myers Field Airport (KCNB) in Canby, MN provided regional meteorological data. The airport is about 17.5 miles north of the Residence. Temperature and relative humidity from these data are used throughout the report.

Additionally, Xcel provided SCADA that included hub height wind speed, hub height wind direction, and power production by turbine at one-minute intervals. Yaw direction (that is, the direction of the nacelle) was also provided for most of the period but was not utilized directly in this analysis.

2.3 MONITORING PERIOD DETAIL

The monitoring period spanned 21 days, from September 8th to September 29th, which was mostly prior to harvest season in the region. The transition between monitoring periods (when the monitor was relocated from Location 1 to Location 2) was on September 17th.

Regional Weather

The regional meteorology over the course of the monitoring period is plotted in Figure 5 (Monitoring Period 1) and Figure 6 (Monitoring Period 2). The hourly plots of each monitoring period show three panes of data from the ASOS meteorological station at Myers Field Airport (KCNB) in Canby, MN. The top pane displays temperature (in red); the second pane displays relatively humidity (in purple) as well as rain rate in millimeters per hour (light blue). The third pane shows average wind speed and direction measured at 10 m above ground level (in mph). To represent wind direction, the arrow points in the direction that the wind was blowing, (e.g., ">" would represent winds out of the west blowing to the east).

Regional winds were generally calm until the end of the first period. Precipitation was recorded in Canby, MN on 9/11, 9/12, 9/27, and 9/28. The maximum temperature in Canby, MN during the full monitoring period was 31˚C (88 ˚F) and the minimum temperature was 2˚C (36˚F).

Hub Height Wind Speeds

Hub height wind speed for the first monitoring period is plotted in Figure 7 for all six turbines within 2.4 km (1.5 miles) of the Residence; the same plot for the second monitoring period is provided in Figure 8. The minimum, maximum, mean, and median hourly wind speeds for all nearby turbines are represented in the plot on an hourly basis. The 1-minute wind speed and wind direction data collected by the SCADA system was aggregated into one-hour period for each turbine. The wind direction is plotted as the value of mean wind speed, with the arrow pointing in the direction that the wind was blowing (as described above). Comparing the hub-height winds to 10-meter ASOS data, the same periods of strong winds are evident (e.g., midday 9/14 to 9/17, 9/19 to midday 9/21, and after 9/27).

The horizontal light dotted line at about 20 miles per hour (9 meters per second) represents the hub height wind speed at which rated maximum sound power is nearly achieved (within 0.3 dB, according to manufacturer specifications). Figure 7 shows that the turbines were not operating at full sound power for most of the period. During the first monitoring period, the only time when hub height wind speed exceeded this threshold was during the strong wind period surrounding September 15th. During the second monitoring period (Figure 8), higher winds were more common and hub height wind speeds suitable for maximum sound power emission were achieved on several occasions throughout the period.

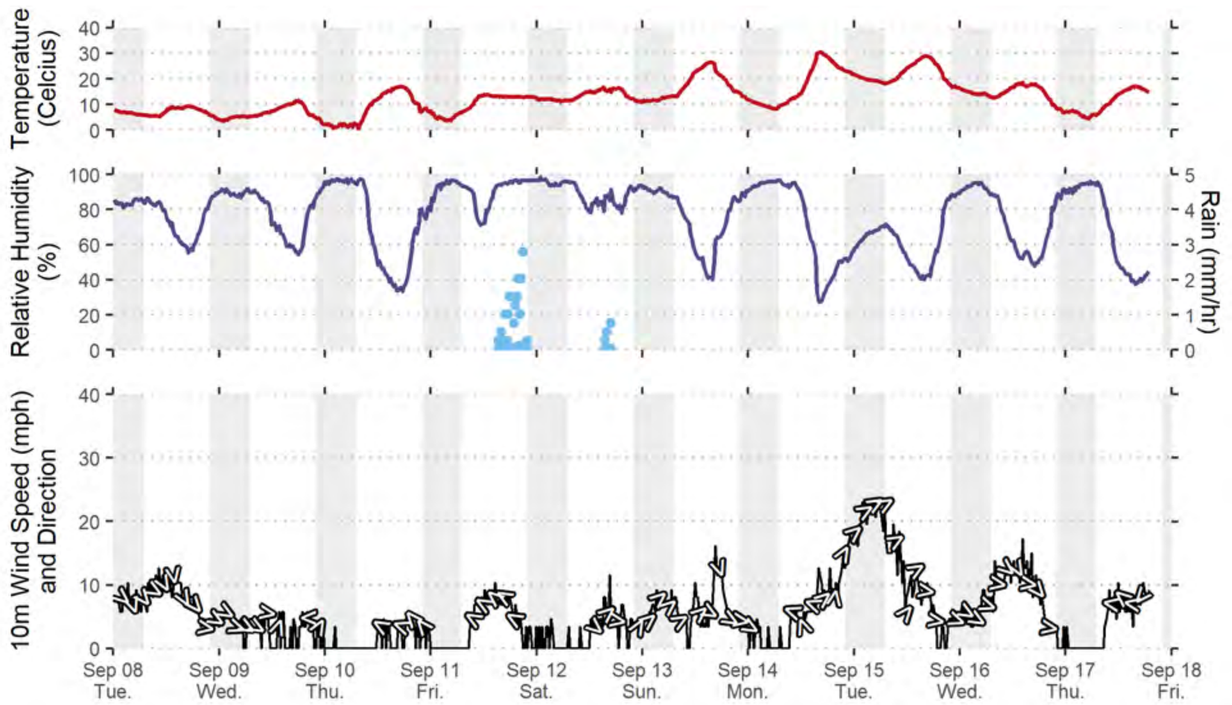

FIGURE 5: REGIONAL METEOROLOGY FOR THE FIRST MONITORING PERIOD

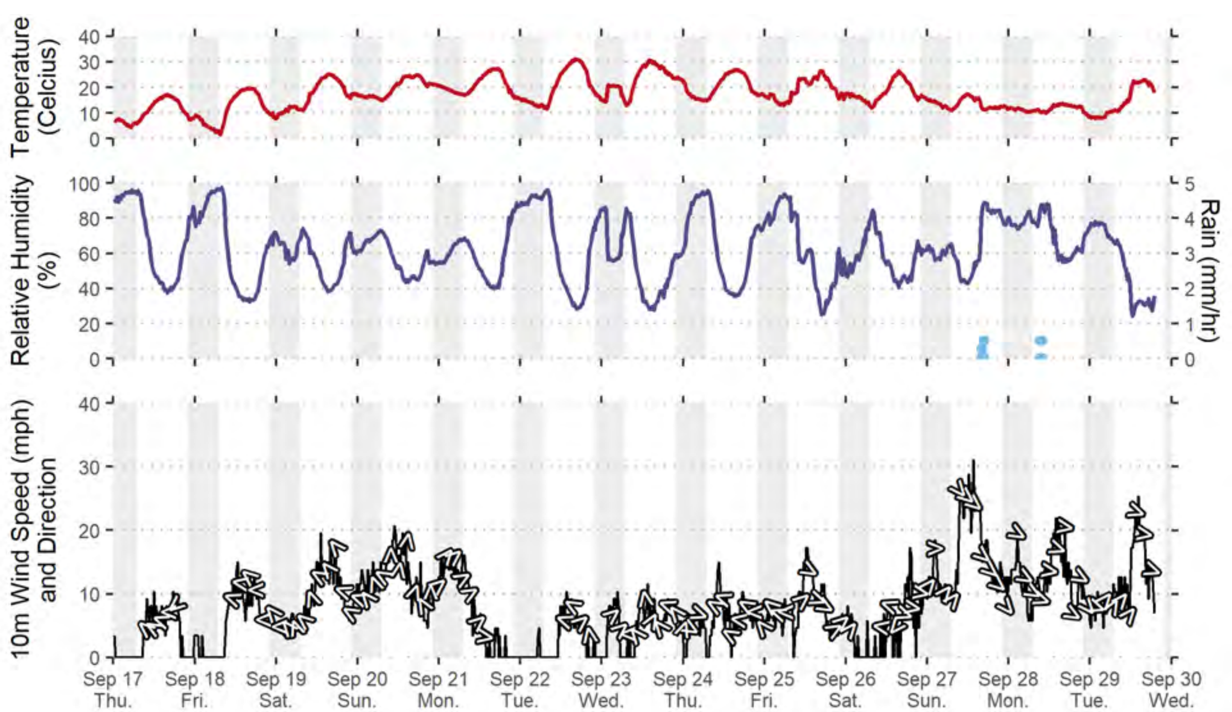

FIGURE 6: REGIONAL METEOROLOGY FOR THE SECOND MONITORING PERIOD

Source: Canby Minnesota ASOS station (CNB) [Year: 2020]

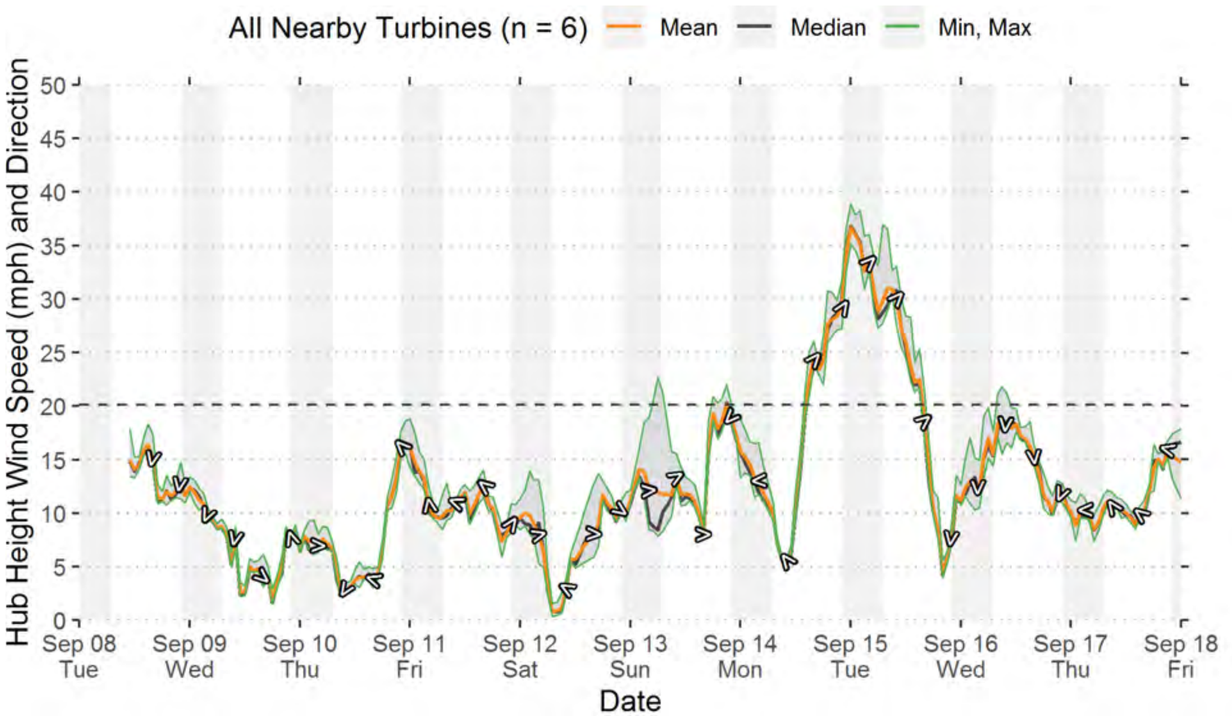

FIGURE 7: HUB HEIGHT WIND SPEEDS FOR THE FIRST MONITORING PERIOD

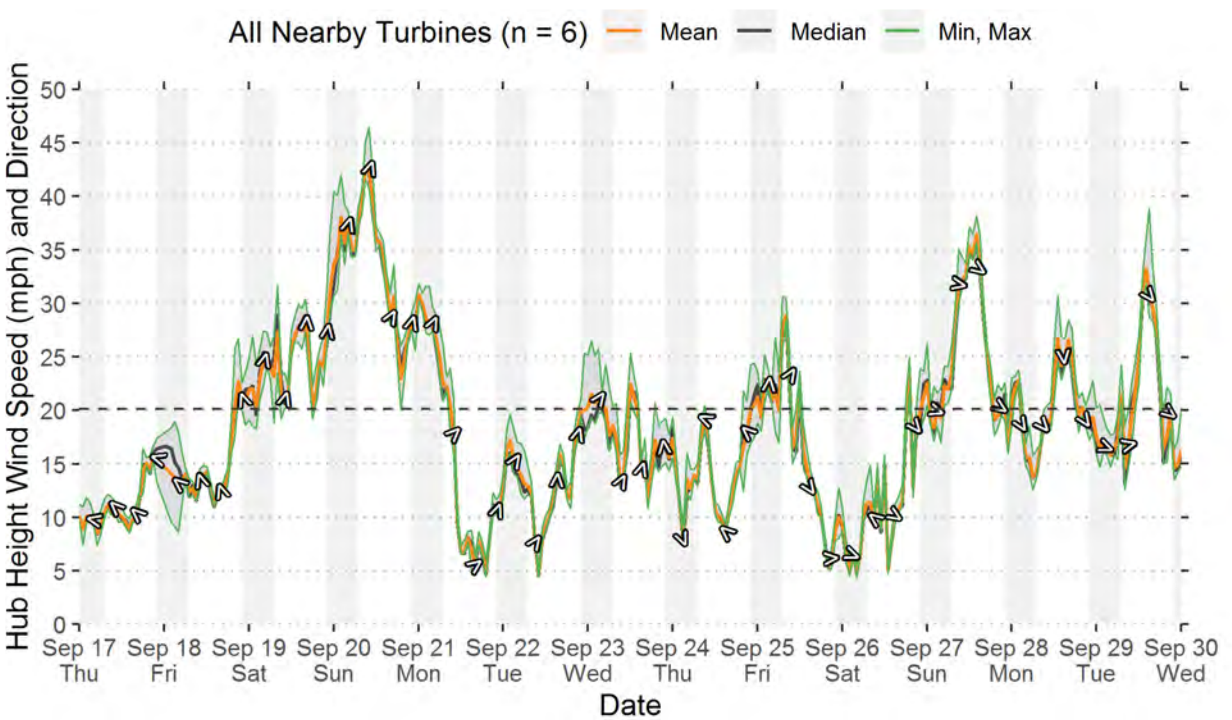

FIGURE 8: HUB HEIGHT WIND SPEEDS FOR THE SECOND MONITORING PERIOD

Hub Height Wind Pattern

A summary of the wind pattern during the full monitoring period (Period 1 and Period 2 combined) is provided in the wind rose in Figure 9. The wind rose collects wind speed and wind direction from each sample and the distribution of wind speed and cardinal direction are plotted. Wind speed and direction for all nearby turbines were averaged for each one-hour period to produce the wind rose. Wind direction on a wind rose plot represents the cardinal direction from which the wind is blowing.

The most consistent and strongest winds came out of the southwest during the monitoring period. This was consistent with expected patterns according to historical data from NREL's Wind Integration National Dataset ("WIND") Toolkit[6] for the month of September. According to the WIND Toolkit, winds from the south are common between July and November, while wind direction is more variable at the site between October and January.

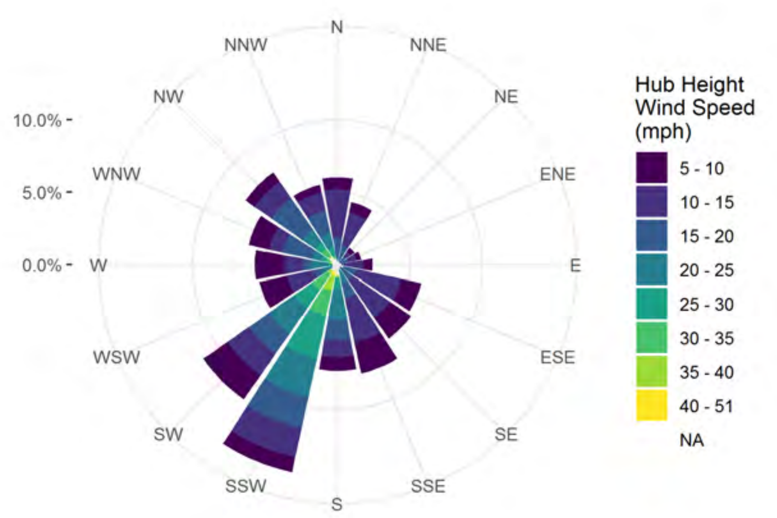

FIGURE 9: WIND ROSE DURING THE MONITORING PERIOD FOR ALL TURBINES NEARBY THE WEVERKA RESIDENCE

[6] https://www.nrel.gov/grid/wind-toolkit.html

Excluded Periods

Data were excluded from the analysis for anomalous activity at the monitor, high ground level gust wind speeds, and precipitation. In this case, sound levels were only marked as anomalous when a technician was onsite, that is, specific interfering events were not identified nor removed from the data. High wind periods were removed according to the measurements of ground-level wind gust speed data by an adjacent anemometer. Sustained rain was removed according to precipitation measured with an onsite rain gauge and manual inspection of the corresponding audio files. Measured rain periods within 30 minutes of one another were concatenated to account for dripping and excessive humidity. If more than half of samples were excluded from a given aggregation period (regardless of the exclusion type), the data for that 1-hour period was discarded.

A summary of the excluded periods for each monitoring period is provided in Table 4. The influence of stronger winds is evident in Monitoring Period 2, with nearly 30 hours of ground level wind speed exclusions triggered by periods above 5 m/s (11.2 mph); Less than one hour of data was excluded in Monitoring Period 1 due to high winds. In Table 4, the "Total Excluded" value does not equal the sum of all exclusions due to overlapping exclusion periods (e.g. concurrent high winds and precipitation).

TABLE 4: SUMMARY TABLE FOR EACH TYPE OF DATA EXCLUSION

MONITORING PERIOD 1			MONITORING PERIOD 2		
Exclusion	**Hours**	**Days**	**Exclusion**	**Hours**	**Days**
Anomaly	0.5	0.02	Anomaly	4.7	0.19
Precipitation	12.7	0.53	Precipitation	2	0.08
Wind Gust	0.9	0.04	Wind Gust	29.1	1.21
Total Excluded	9.4	0.39	Total Excluded	33.8	1.41
SLM Runtime	209	8.7	SLM Runtime	285	11.9
Valid Periods	199.6	8.3	Valid Periods	251.2	10.5

2.4 DATA PROCESSING METHODS

Results in the next chapter are presented for three distinct sets of analyses, described below.

Overall Sound Levels

Sound levels were aggregated in 1-hour periods for each monitoring period in accordance with Minnesota Rules Chapter 7030 methods and related guidance from the MN Department of Commerce. The measured sound levels for each period are assessed for compliance with state regulations. These results are presented in Section 3.1. However, it is important to note that the limiting metric for compliance is most often the nighttime limit of 50 dBA L_{50}. T-90, the dominant turbine at the Residence, was normally shutdown at night due to resident reported disturbance and sleep interference. Thus, surveying the overall sound level on a strictly hourly basis is insufficient to determine compliance during the critical nighttime period. It is for this reason that discrete wind turbine startups and shutdowns were employed, as discussed below.

Biogenic sounds (particularly insects and birds) were present during the monitoring period but were not a significant factor in overall sound levels: the overall L_{50} for both monitoring periods differed by less than 1 dB when ANS frequency-weighting was applied to all logged data for which tonal biogenic sound was found. A description of the methodology, “smart-ANS” frequency weighting network, and overall results are provided in Appendix B for reference.

Residence Trigger Complaint

An indoor monitor that was concurrently deployed in the Weverka’s residence included a “trigger” button for the residents to press when the turbine noise was notable.[7] The trigger provided direct, time-stamped resident feedback. Residents were instructed to initiate the trigger when sound levels were particularly noticeable or disturbing. A representative 1-hour period surrounding the trigger feedback was manually identified to calculate total 1-hour L_{50}, average wind turbine production, and average wind speed/direction with each trigger push. Trigger feedback was provided a total of 2 times during the first monitoring period and 13 times during the second monitoring period, which generally correlates with the higher wind speeds and increased wind turbine production in the second monitoring period. These results are presented in Section 3.2.

[7] Indoor monitoring results are discussed in a separate report

Shutdown analysis

Methodology Overview

Wind turbine shutdowns are the most effective method at our disposal to determine the contribution of wind turbine noise to total sound. They provide an in-situ measurement of background sound that allows 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.

A typical shutdown protocol is as follows: wind turbines operated normally for 1 hour, followed by a 20-minute shutdown, which was then followed by another 1-hour period of normal turbine operation (if possible). The 1-hour operation period provides a direct measurement of the total sound at the monitor (turbine + background) pursuant to Minnesota Rule 7030 that regulates total sound in 1-hour periods. Due to operational constraints (i.e., nighttime curtailment of T-90), some turbine shutdowns were only one-sided, that is, the analysis considers a single 1-hour operating period in conjunction with a 20-minute shutdown period.

Methodology Execution

RSG provided a daily schedule of specified wind turbine shutdowns (or startups) throughout the monitoring period for the Blazing Star Wind operators to employ. Due to a lack of data from the first period and the importance of making these measurements at night, nighttime startups and shutdowns of T-90 were executed in the second period. Nighttime periods generally have lower background sound level, favorable conditions for sound propagation, and the most stringent sound level regulation limits. At the end of both monitoring periods, 120 wind turbine shutdown periods were identified and processed.

For each shutdown, wind turbine production data and sound level data were leveraged to identify time intervals for shutdowns and turbine operations. Wind turbine operation periods were assigned according the turbines represented in the shutdown. The three groups included “All Nearby Turbines,” “Closest Turbine,” and “Other Nearby Turbines,” as identified in Table 2.

Measured 1-second L_{eq} sound levels for each identified time interval were aggregated for acoustically valid periods (i.e. no precipitation, ground level windspeeds below 5 m/s) and the median sound level (L_{50}) is reported. When turbine operation occurred on both sides of the shutdown, these periods were averaged together to determine the L_{50} for the turbine operation period. The background sound level was then logarithmically subtracted from the turbine operation level to determine the turbine-only sound level. The results of this analysis are presented in Section 3.3

3.0 MONITORING RESULTS

Results of the monitoring are presented in this section for the overall hourly time histories, discrete trigger feedback periods, and the shutdown analysis.

3.1 OVERALL SOUND LEVEL RESULTS

Time History Plot Description

Time history plots for the complete monitoring period at each monitor location are provided in Figure 10 (Location 1) and Figure 11 (Location 2). Each figure combines three panes of relevant data, including wind turbine power production, sound levels, and meteorology. The contents of the plots are described below.

For all plots, 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. Each plot displays data that has been aggregated into 1-hour periods. The vertical dashed lines ("Trigger Complaint") in the top two panes indicate instances when the residents registered a direct complaint regarding the noise. These periods are discussed in Section 3.2; they are provided on the time history plots to provide context.

The top pane shows the average hourly wind turbine power production in kilowatts (kW). Production from the nearest turbine (T-90) is displayed in red, while the range, median, and mean of the other nearby turbines are identified by color in the legend. The shaded area between the green lines (min/max) represents the range of other nearby turbine operation.

The middle pane provides the aggregated sound level data results as hourly values for A- and C-weighted data, which is plotted along with data exclusions, sound level limits, and trigger-initiated complaints. The L_{50} is plotted as a solid line, while the L_{10} and L_{90} are bound by the color shading. Periods when the L_{50} line is blank are excluded periods. The cause of the exclusion is denoted by the colored points (yellow, red, blue) corresponding to the type of exclusion (anomaly, wind gust, rain). Note that the L_{10} and L_{90} range are still plotted during excluded periods for context and continuity. Lastly, the sound level limits according to Minnesota Rule 7030 are represented as horizontal dotted orange lines.

The third pane provides ground height gust speed, hub height wind speed, relative humidity, and precipitation. 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) is averaged over the hour for all nearby turbines; light green shading provides the range of hourly windspeeds at all nearby turbines. The horizontal red dotted line corresponds to wind speed exclusion threshold of 11.2 mph (5 m/s), while the horizontal green dotted line at about 20 mph (9 m/s) represents the hub height wind speed at which the wind turbines reach their full rated sound power output. The blue shading shows the rate of precipitation, with darker shading indicating a higher precipitation rate. Note that one additional precipitation period beyond what was measured at the rain gauge was identified in the sound level data; regional precipitation on the same day (9/12) confirms the identification.

Discussion of Time History Results

Monitoring Period 1 (Figure 10)

Windspeeds were relatively low for the first five days of monitoring. As a result, sound levels generally remained below 40 dBA L_{50} until September 13th, when increased ground level wind speeds and turbine production increased daytime sound levels to around 45 dBA L_{50}.

Sound emissions from T-90 are often evident in the sound level data when the shape of the trace of overall sound levels is correlated to T-90's production. For example, on September 11th, T-90 was not curtailed at night and hourly sound levels mirrored wind turbine production. In this case, ground level wind speeds remained calm while hub-height wind speeds increased (representing a high wind shear[8] condition). Further, sound levels from T-90 measured at the monitor are particularly evident on the afternoon of September 13th, when winds aloft (at hub height) increased sharply but ground level wind remained relatively consistent (a high wind shear condition). The nightly shutdown of T-90 was apparent with the sharp decrease in levels at around 10 PM.

The stronger winds starting on September 14th increased nighttime sound levels above the nighttime limits (L_{50} and L_{10}). Elevated sound levels were caused by sustained high ground level wind speeds in the absence of T-90 operation; ground level windspeeds only occasionally rose above the 5 m/s (11.2 mph) during these periods and thus did not warrant the exclusion of the whole period. In fact, sound levels were above the set limits during a background periods with all nearby wind turbines shutdown.[9] Thus, wind turbine sound emissions did not contribute to elevating the total sound level above the limits in those cases. However, the total 1-hour L_{50} was above 50 dBA during the day on September 14th and September 15th while T-90 was producing maximum power. A wind turbine shutdown in the early afternoon on September 14th confirms that the contribution of the wind turbines caused total sound levels to reach 50.9 dBA. As discussed in Section 3.3, the background for this period was 46.8 dBA and the calculated turbine-only level of 48.7 dBA[10]. On September 15th, a shutdown in the early afternoon revealed that the background L_{50} was over 50 dBA (51.3 dB); an increase to 53 dBA during turbine operation yielded a calculated T-90 only sound level of 48.1 dBA.[11]

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[8] Wind shear is a measure of the difference between ground level wind speed and wind speeds aloft. High wind shear conditions often lead to improved measurements of wind turbine noise due to the lack of interfering ground level wind speed yet with sufficient wind at hub height wind speed to produce power.
[9] Shutdown #21 and #22 (see Tables in Appendix D)
[10] Shutdown #16
[11] Shutdown #25

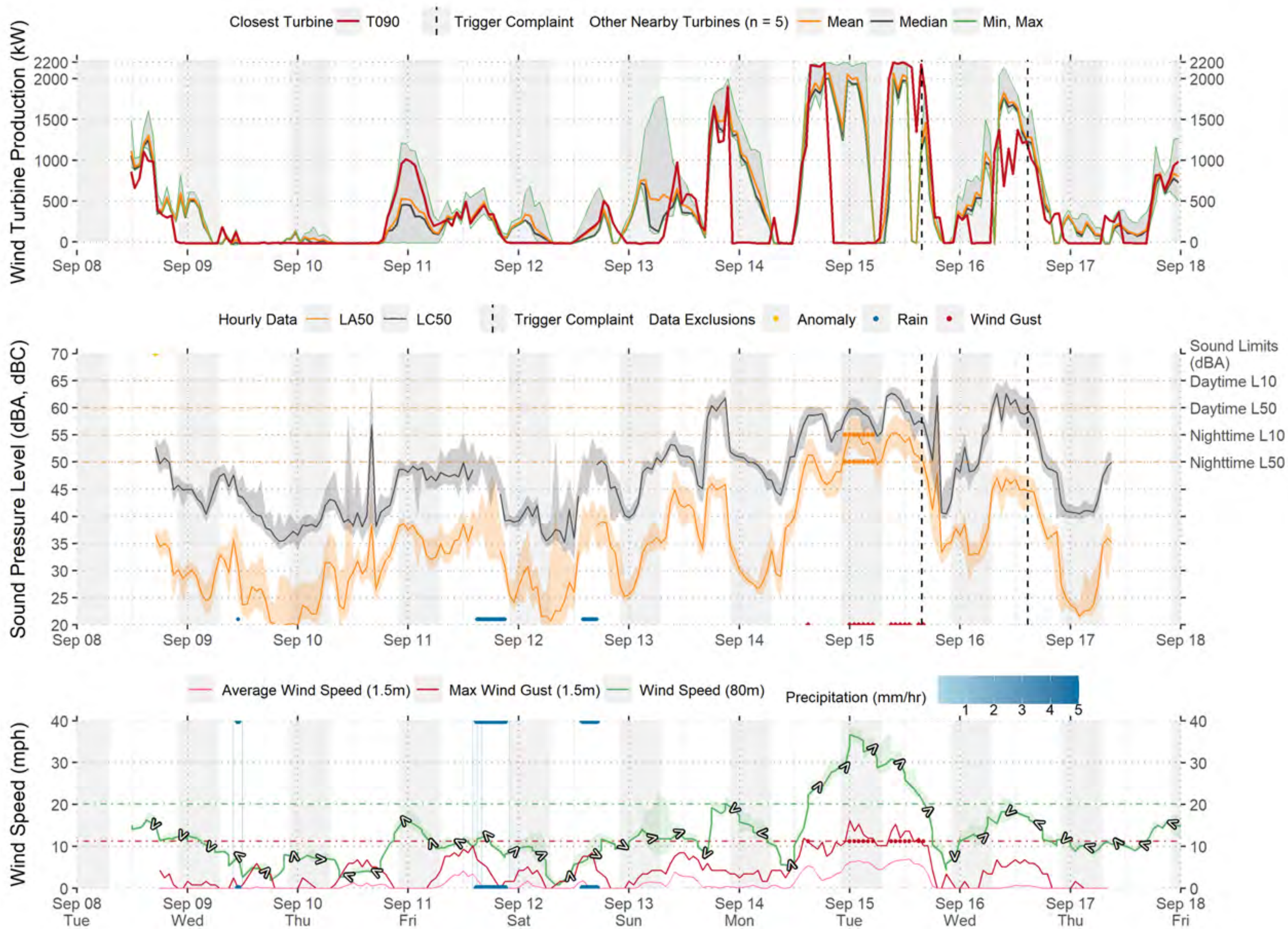

FIGURE 10: TIME HISTORY PLOT FOR MONITORING LOCATION 1 (2020)

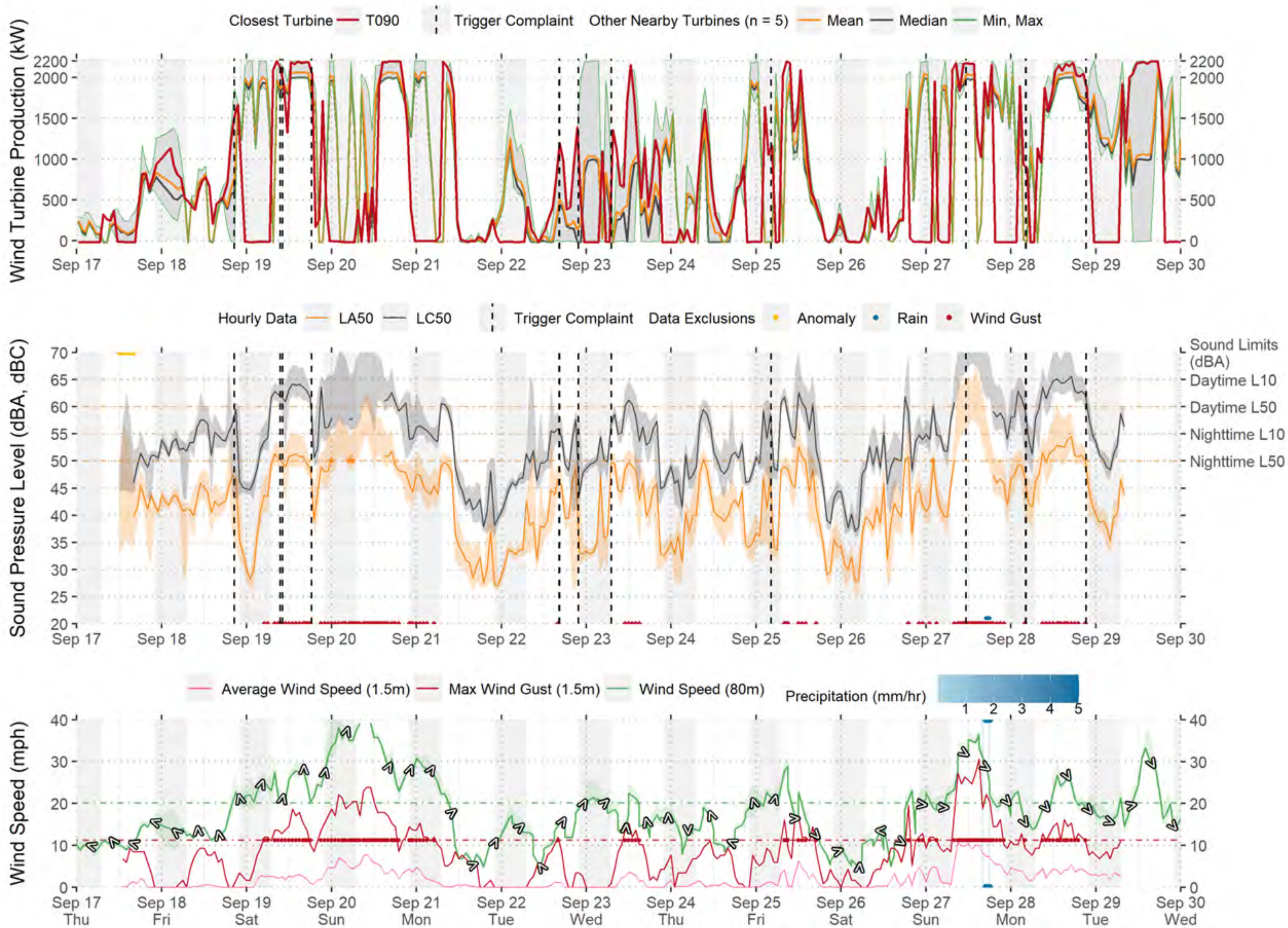

FIGURE 11: TIME HISTORY PLOT FOR MONITORING LOCATION 2 (2020)

Monitoring Period 2 (Figure 11)

Windspeeds and sound levels during the second monitoring period were generally higher than the first. The overall increase in sound levels at Monitor Location 2 is due to several factors, including notably different meteorological conditions (more wind), more exposure to wind and resident activities, and slightly higher expected turbine-only sound levels (see Table 3) due to its closer proximity to the T-90. The quietest nighttime L_{50} was 6 dB louder at Location 2 than Location 1, which was unrelated to T-90 operation.

The second monitoring period provided several periods of full sound power and energy production. The periods when T-90 was operating in earnest are apparent in the overall data, suggesting that the sound emissions from T-90 are a dominant contributor to the soundscape at this location.

T-90 operated through most of the night from September 17th to September 18th, albeit below maximum sound power and at about 50% overall power production. For this nighttime period, the range of nighttime sound levels ranged between 40 and 45 dBA (10th through 90th percentile levels) with little to no ground level wind to contribute additional sound. On the following night, T-90 did not operate, hub height wind speeds increased and ground level windspeeds were slightly higher, yet the L_{50} dropped below 30 dBA. This suggests that T-90 on September 18th predominantly contributed to the total sound levels (40 to 45 dBA). Spectrograms and turbine shutdowns on each end[12] of the night confirm this assessment.

During the day on September 19th, high yet intermittent ground level wind gust speeds were recorded and hub-height wind speeds persisted above 20 mph. Sound levels exceed 50 dBA L_{50} and dropped below 40 dBA when winds subsided for a couple hours before picking up again. Excessive ground-level wind speed on September 20th did not produce valid sound level data (in the absence of T-90). A few nighttime periods that were not excluded, exceeded 50 dBA L_{50} as a result of the background sound levels due to high winds; T-90 was not operating during these times and is thus not responsible for the exceedance. Valid sound levels returned that afternoon with total levels varying between 47 dBA and 52 dBA with T-90 at full power production. Sound levels remained above 45 dBA L_{50} through the night on September 21st due to high winds and in the absence of T-90 operation. The startup of T-90 the following day was apparent with the changes observed in sound level data mirroring the morning startup of T-90.

Following this, intermittent operation of T-90 occurred for several days, with several daytime periods on from September 23rd to 26th approaching or exceeding 50 dBA hourly L_{50} during episodes of robust T-90 operation. High wind shear conditions at night permitted several turbine shutdowns with full sound power emission of T-90. One shutdown period is apparent in the early morning hours of September 27th in Figure 11. The startup of the turbine caused total sound levels to increase above 50 dBA hourly L_{50} at night. This was the only hourly period (i.e. 07:00 to 07:59) that exceeded the state limit in our analysis. As discussed in Section 3.3, turbine

[12] Shutdown # 40 and # 41

shutdowns provided more precise assessments. Including the shutdown associated with this exceedance, the state limit was exceeded at night at the monitoring location on four occasions.

A storm system that brought high wind speeds and precipitation on September 27th elicited substantial exclusion periods. The last full day of monitoring on September 28th saw intermittent ground-level gust wind speeds and resulting exclusions, full sound power emissions for most of the day, and southerly winds. The hourly L_{50} ranged between 50 and 55 dBA. After a trigger feedback period in the evening, sound levels decreased to below 40 dBA until T-90 operation began the following morning.

3.2 TRIGGER FEEDBACK PERIOD RESULTS

A total of 15 trigger feedback complaints were received from the Weverkas. Most of the trigger timestamps correspond with a shutdown period and are thus also dually accounted for in the next section. A summary of the trigger periods, including dates, times, overall sound levels, turbine and wind conditions, and any shutdowns that occurred in close proximity to the trigger feedback period are provided in Table 5. The hub height wind direction lists the cardinal angle (0 to 360, with north at 0 degrees) that the wind is coming from. Time history detail plots of each trigger period are provided in Appendix C.

T-90 was typically the dominant feature of the soundscape during trigger feedback periods. On two occasions, the residents appear to have been awakened by a T-90 turbine startup in the middle of the night during the second week; they responded appropriately by activating the trigger. One trigger complaint (#12) was excluded from the summary because the period was acoustically invalid due to excessive ground-level winds.

Most trigger feedback periods coincided with T-90 operating at or near maximum rated sound power and power production. The trigger feedback periods with lower average wind speeds and production levels featured gusty winds, variable power production, and fluctuating turbine sound level emissions (e.g. Trigger Periods #2, #7, and #8 - see Appendix C).

Three trigger periods exceeded 50 dBA 1-hour L_{50} total sound, with a maximum of 51 dBA; all three occurred during the day. The highest nighttime total sound trigger period was 49 dBA L_{50}. Total sound exceeded 50 dBA L_{50} during the first hour of the day on 9/23 (Trigger Period #10) when T-90 was restarted from its nighttime curtailment shutdown. The background level prior to T-90 starting up (with no nearby turbine operation) was below 35 dBA.

In some cases, we observed that measured wind turbine sound levels may not have been at their maximum sound emission level with higher hub-height wind speeds as suggested by manufacturer specifications for the V120. Rather, on several occasions, wind turbine sound emissions appear to be at a maximum between 8 and 9 m/s (18 to 20 mph) before settling to lower sound emissions as hub height wind speeds increased. One explicit example is for Trigger Period #9. A time history graph of the wind turbine production, overall sound levels, and wind characteristics is provided for this trigger feedback period in Figure 12. The trigger period was initiated at the time when the highest sound output from the turbine was apparent. The period saw little to no ground level wind with wind turbine production steadily increasing after a prescribed shutdown. The L_{eq1min} sound levels (plotted) exceed 50 dBA at the monitor during this period of apparent heightened sound emissions (between about 21:30 and 21:45). The background level prior to T-90 starting up (with no nearby turbine operation) was below 30 dBA. The sound emissions of T-90 are within a couple tenths of a dB adjacent to the nighttime regulatory limit.

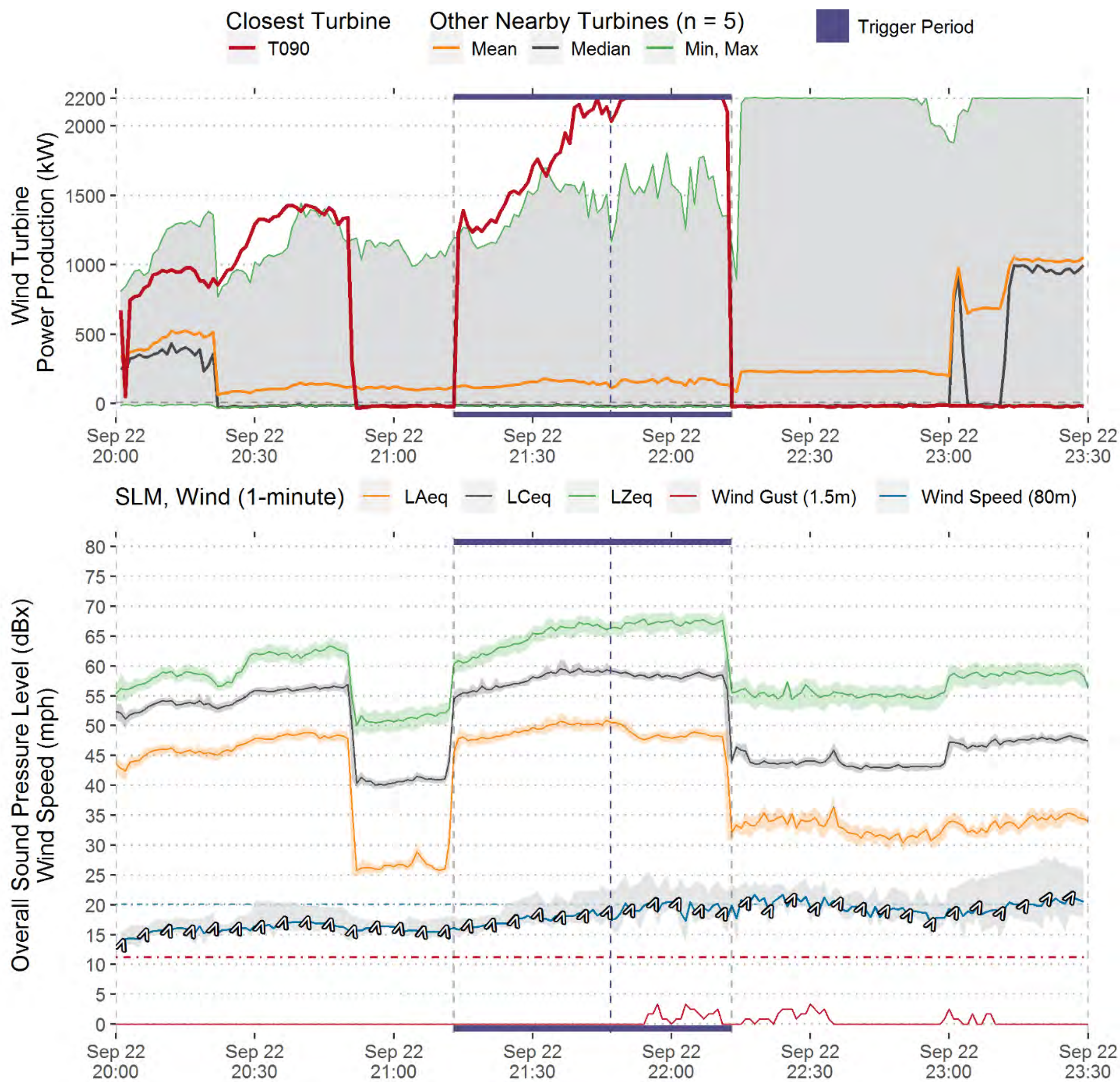

FIGURE 12: TIME HISTORY PLOT FOR TRIGGER FEEDBACK PERIOD #9

TABLE 5: RESULTS AND CHARACTERISTICS FROM TRIGGER FEEDBACK PERIODS

			PERIOD L_{50}		HUB HEIGHT WIND		GROUND LEVEL WIND		AVERAGE POWER		
Trigger Period	Date	Time	Total Sound		Average Speed	Direction	Max Gust	Average Speed	T-90	Other Nearby Turbines	Corresponding Shutdown
(#)			(dBA)	(dBC)	(mph)	(degrees)	(mph)	(mph)	(kW)	(kW)	
1	2020-09-15	15:43	51	57	21	237	12	6	2142	1441	SD #25
2	2020-09-16	14:43	45	58	15	360	7	1	1120	1043	
3	2020-09-18	20:29	47	56	20	149	0	0	1652	853	SD #44
4	2020-09-19	9:31	50	62	21	205	14	2	2123	1808	SD #48
5	2020-09-19	10:12	50	61	20	197	14	3	1977	1841	SD #49
6	2020-09-19	18:23	48	61	20	175	12	1	2045	1655	
7	2020-09-22	16:19	46	55	15	206	12	1	1128	444	
8	2020-09-22	16:26	46	55	15	206	12	1	1165	476	
9	2020-09-22	21:46	49	58	18	201	3	0	1833	148	SD #67
10	2020-09-23	7:08	50	57	18	217	1	0	1445	-16	SD #70
11	2020-09-25	4:15	48	60	21	189	9	1	2078	-15	SD #85
13	2020-09-28	4:10	49	61	16	333	13	3	1539	-15	SD #112
14	2020-09-28	4:17	49	61	16	333	13	3	1463	-15	SD #112
15	2020-09-28	21:15	51	63	20	324	12	4	2099	1880	SD #119

Note that results from Trigger Feedback Period #12 at 11:14 AM on September 27th is not reported because it was not an acoustically valid period

3.3 WIND TURBINE SHUTDOWN / STARTUP RESULTS

Wind turbine startups or shutdowns provide a robust method for determining the contribution of wind turbine sound to total sound. Appendix D includes summary data for each shutdown while Appendix E provides detailed time history plots of each shutdown, indicating the periods utilized for the calculations. This section summarizes the results of the shutdowns.

Summary of Hub Height Wind Characteristics

The distribution of hub-height wind speeds during turbine shutdowns is summarized in the wind rose provided in Figure 13. Although the overall wind pattern is not exemplary of the entire year, the wind patterns during the prescribed shutdown periods are representative of the monitoring period (compare to Figure 9). The most common wind condition during shutdowns included winds from the south-southwest, putting the Residence between crosswind and upwind of the turbine. Higher sound levels would be expected under the opposite condition: if the wind turbine was upwind (i.e. winds were out of the north).

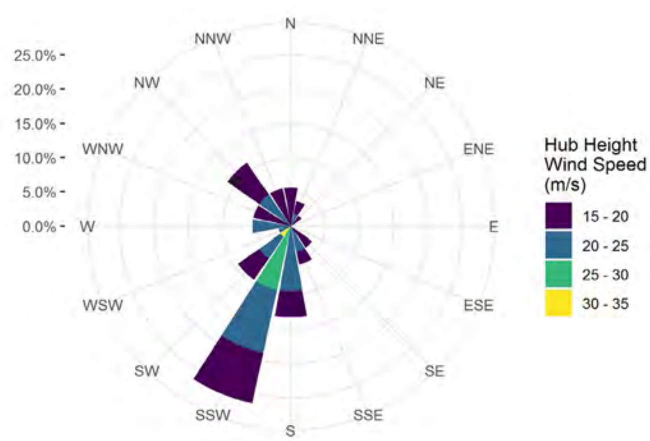

FIGURE 13: WIND ROSE FOR ALL SHUTDOWN PERIODS

Summary of Shutdowns

A total of 92 discrete shutdown or startup periods were identified for analysis at the Weverka Residence. Shutdown periods in the first monitoring period provided 9 periods with nearby wind turbines operating at or near maximum sound power level; 42 periods were acquired in the second monitoring period. To summarize the data acquired from the shutdown and startup, shutdowns were classified relating to which turbines were started up and/or shutdown and could have their sound level contributions quantified: the closest turbine (T90), other nearby turbines, or all turbines. Shutdown periods were considered for summarization if hub-height wind speeds averaged above 7 m/s and background sound levels were less than 50 dBA.[13]

The maximum aggregated values for the shutdown period and the turbine operation period are provided in Table 6 for Monitor Location 1 and Table 7 for Monitor Location 2. Several measured and calculated parameters are summarized in the tables, including:

- overall L_{50} sound levels (background, turbine only, and total sound)
- period average hub height wind speed for all nearby turbines
- period average power production for closest turbine
- period average power production for other nearby turbines

Considering only the periods described above, Table 6 shows that Monitoring Location 1 experienced the highest wind turbine-only and total sound levels related to a shutdown T-90 only. The maximum sound levels for Monitor Location 1 (Table 6) were all measured around Shutdown #16, which is discussed in the following section. This was the only shutdown period with the given criteria at Monitoring Location 1 that exceeded 50 dBA total sound. Sound levels from other turbines remained below 40 dBA for turbine-only and total sound levels. Note that some shutdown periods concentrating on the closest turbine allowed the nearby turbines to continue operating during the shutdown period, which is why the average power for the nearby turbines is above 2000 kW for the closest turbine shutdown group classification.

Table 7 shows the maximum aggregated parameters measured or calculated at Monitoring Location 2. The highest total sound level and turbine-only sound level was measured around a T-90 only shutdown. The highest turbine-only calculated sound level was 49.8 dBA L_{50} during shutdown #97; the next highest turbine-only period (49.3 dBA) was measured during Shutdown #118. Both turbine operation periods exceeded 50 dBA total sound (50.2 dBA). The same situation occurred for one other shutdown period (#98) at Monitor Location 2. Sound levels from the other nearby turbines have only a minimal effect on the total wind turbine contribution at the monitoring locations relative to T-90.

[13] Note that a few of the prescribed shutdowns included the shutdowns of other nearby turbines while T-90 (the closest turbine) continued operating. The signal to noise ratio between the background and the turbine operation was very poor because T-90 was dominant during both the “background” and “turbine operation” periods. Thus, these periods were not considered in the summary of shutdown levels though they remain in the tables and plots in the Appendices.

TABLE 6: MAXIMUM MEASURED VALUES FROM TURBINE SHUTDOWN PERIODS AT MONITOR LOCATION 1

SHUTDOWN TYPE	(n)[14]	SOUND LEVEL (L_{50}) Turbine Only (dBA)	SOUND LEVEL (L_{50}) Total Sound (dBA)	HUB HEIGHT WIND SPEED Shutdown Period (mph)	HUB HEIGHT WIND SPEED Turbine Operation (mph)	CLOSEST TURBINE POWER Shutdown Period (kW)	CLOSEST TURBINE POWER Turbine Operation (kW)	NEARBY TURBINES POWER Shutdown Period (kW)	NEARBY TURBINES POWER Turbine Operation (kW)
All Turbines	3	46.4	46.6	19	20	187	2107	332	1905
Closest Turbines	4	48.7	50.9	27	26	14	2194	2064	2048
Other Turbines	2	36.2	38.2	17	18	-17	-14	186	1571

TABLE 7: MAXIMUM MEASURED VALUES FROM TURBINE SHUTDOWN PERIODS AT MONITOR LOCATION 2

SHUTDOWN TYPE	(n)[13]	SOUND LEVEL (L_{50}) Turbine Only (dBA)	SOUND LEVEL (L_{50}) Total Sound (dBA)	HUB HEIGHT WIND SPEED Shutdown Period (mph)	HUB HEIGHT WIND SPEED Turbine Operation (mph)	CLOSEST TURBINE POWER Shutdown Period (kW)	CLOSEST TURBINE POWER Turbine Operation (kW)	NEARBY TURBINES POWER Shutdown Period (kW)	NEARBY TURBINES POWER Turbine Operation (kW)
All Turbines	11	49.3	50.2	26	27	-16	2199	-16	2067
Closest Turbines	17	49.8	50.2	26	28	83	2200	1765	1863
Other Turbines	14	38	47.7	26	28	51	-2	-12	2065

[14] Number of shutdowns in each grouping

Shutdown Case Studies

While all shutdown results are provided in Appendix D and Appendix E, one shutdown for each monitoring location are described in narrative and graphical form in this section. The green points and green bars on the plots 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.

Monitoring Location 1 (Figure 14)

At Monitoring Location 1, the highest turbine-only sound level of 48.7 dBA was calculated from a total sound level of 50.9 dBA and a background sound level of 46.8 dBA for Shutdown #16. This shutdown occurred on September 14th from about 2:09 PM to 2:28 PM (14:09 to 14:28) local time. The 1/3 octave bands and overall levels for the turbine operation and shutdown periods are provided in Figure 14. The background sound level during the shutdown period is relatively high as a result of gusty ground level wind speeds, though less than 5% of the turbine operation period was excluded due to high winds at the microphone. Nonetheless, turbine operation increased the relatively high background sound levels above 50 dBA.

This was the only period at Monitoring Location 1 during for which total sound above 50 dBA was attributable to the wind turbine. These sound levels comply with daytime sound level limits (which is when the shutdown took place) but may not comply if the same conditions were to occur at night. No nighttime shutdowns of T-90 were performed when the monitor was in this location to assess the nighttime limit directly.

Monitor Location 2 (Figure 15)

At Monitoring Location 2, the maximum turbine only sound level of 49.8 dBA was calculated around Shutdown #97, which occurred on September 27th between about 01:31 AM and 02:03 AM. A total sound level of 50.2 dBA during the turbine operation period following the shutdown period. This shutdown occurred at night and pushed the total sound level over 50 dBA. The one-third octave band and overall levels plotted in Figure 15 reveal that the wind turbine-only sound level was nearly 10 dB above background, signifying that it was the dominant source of sound in the soundscape. The largest increase over background sound levels was observed between 125 Hz and 1 kHz, which is typically the spectral range of wind turbines that is most notable outdoors. The small amount of orange bars (total 1/3 octave band sound levels) visible above the dark grey turbine only levels signifies that the background sound provided a small increase in levels above the turbine-only level. Note that this shutdown occurred during a crosswind to upwind wind regime. If downwind conditions were present at the time, it may have resulted in higher turbine-only sound levels.

A total of three nighttime periods of T-90 operation in temporal proximity to shutdowns exceeded the total nighttime L_{50} limit.

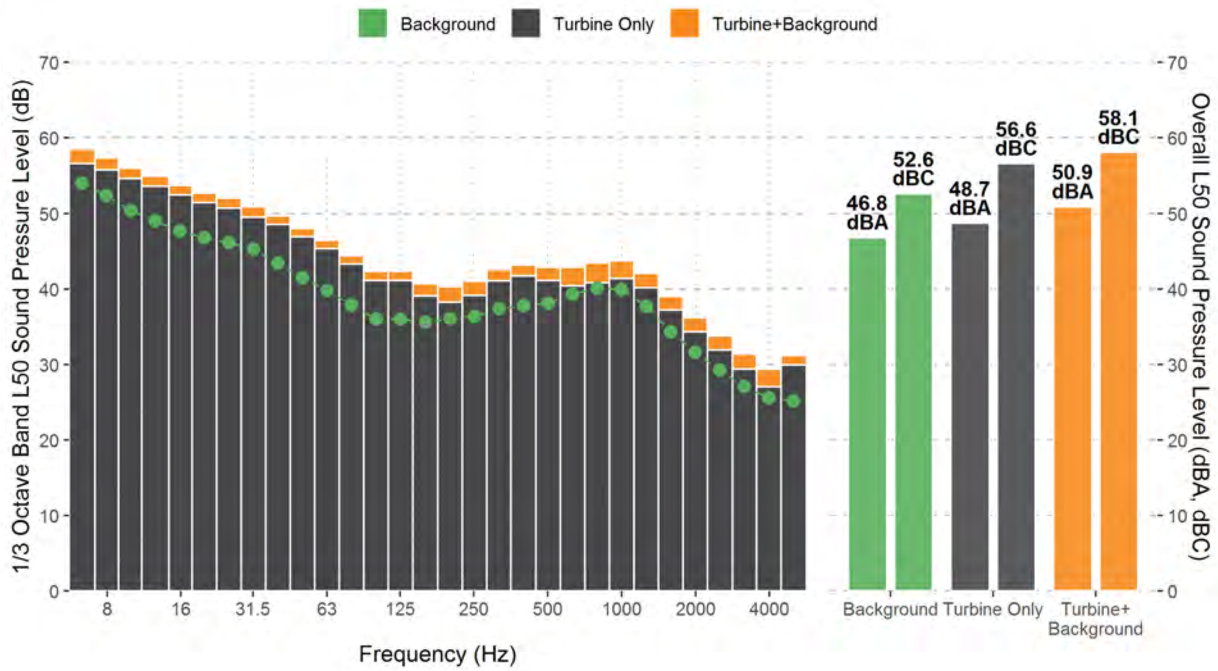

FIGURE 14: ONE-THIRD OCTAVE BAND RESULTS OF MAXIMUM SOUND LEVEL MEASURED AT MONITOR LOCATION 1 (SHUTDOWN #16)

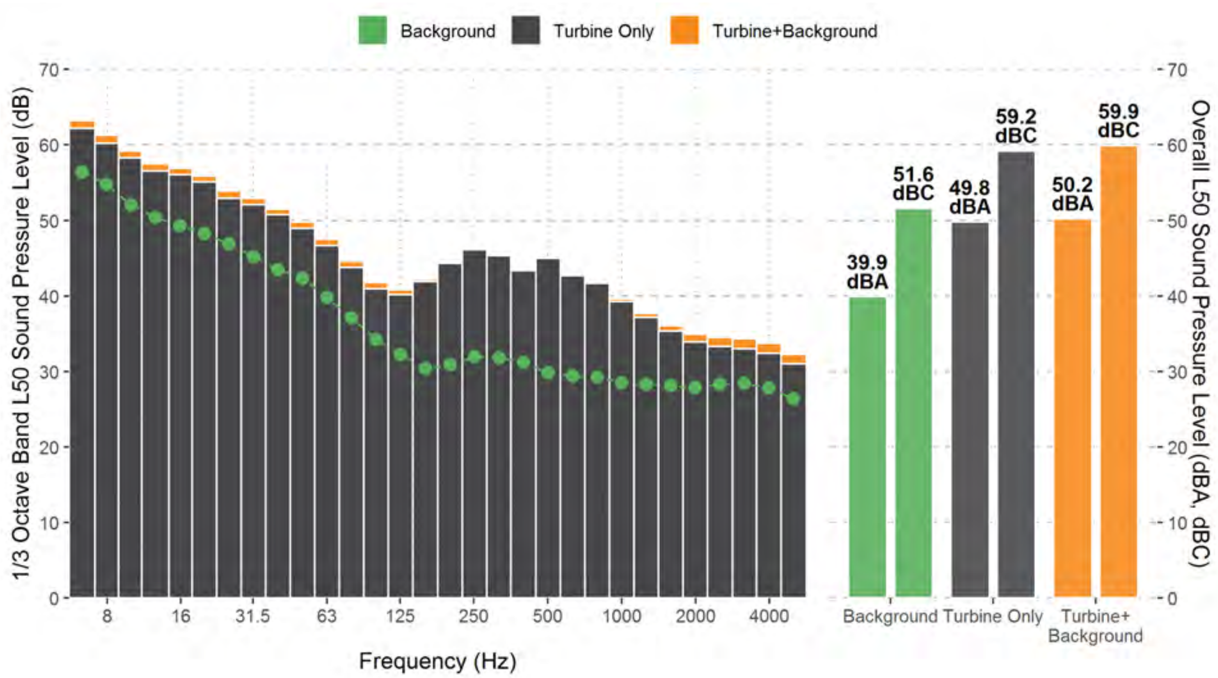

FIGURE 15: ONE-THIRD OCTAVE BAND RESULTS OF SOUND LEVELS MEASURED AND CALCULATED AT MONITOR LOCATION 2 FOR SHUTDOWN #97

4.0 CONCLUSIONS

Twenty days of monitoring wind turbine sound levels at the Weverka Residence demonstrated that the current operation of the wind turbines did not result in any exceedances of the daytime limits in Minnesota Rule 7030 but nighttime limits (50 dBA L_{50}) were exceeded at both monitoring locations.

Monitoring Location 1 is a representative approximation of the sound levels experienced at the Weverka Residence. Sound levels measured at Monitor Location 2 represent one of the closest points on the Weverka property to T-90, about 65 meters closer to T-90 from the Residence.

No operation of T-90 (the turbine closest to the Residence) occurred at night during Monitoring Period 1. Thus, compliance with nighttime sound level limits could not be assessed directly at Monitor Location 1. However, there were daytime periods where wind turbine sound emissions caused total sound levels to increase above 50 dBA L_{50} (e.g. Shutdown #16). If the same conditions occurred at night, an exceedance of the nighttime limit would result.

Considering nighttime shutdown periods at Monitoring Location 2 with background sound levels below 50 dBA L_{50}, there were four instances where the startup of nearby wind turbines caused total nighttime sound levels to exceed the nighttime L_{50} limits in Minnesota Rule 7030. In other words, in these cases, wind turbines from BSW caused the total hourly L_{50} to exceed 50 dBA when the background sound level would have otherwise been below 50 dBA. During four these instances, the shutdowns revealed sound levels attributable to the wind farm were up to 49.8 dBA.

The highest turbine-only level of T-90 alone was calculated from measurements to be 49.8 dBA, which suggests that with all turbines operating, BSW could generate over 50 dBA turbine-only sound at Monitoring Location 2. Turbine-only sound levels from T-90 were measured to be about 1 to 2 dB higher than predicted by the sound propagation model.

APPENDIX A. PRIMER ON SOUND

Expressing Sound in Decibel Levels

The varying air pressure that constitutes sound can be characterized in many different 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”).[15] 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 final 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 16.

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.

[15] 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.

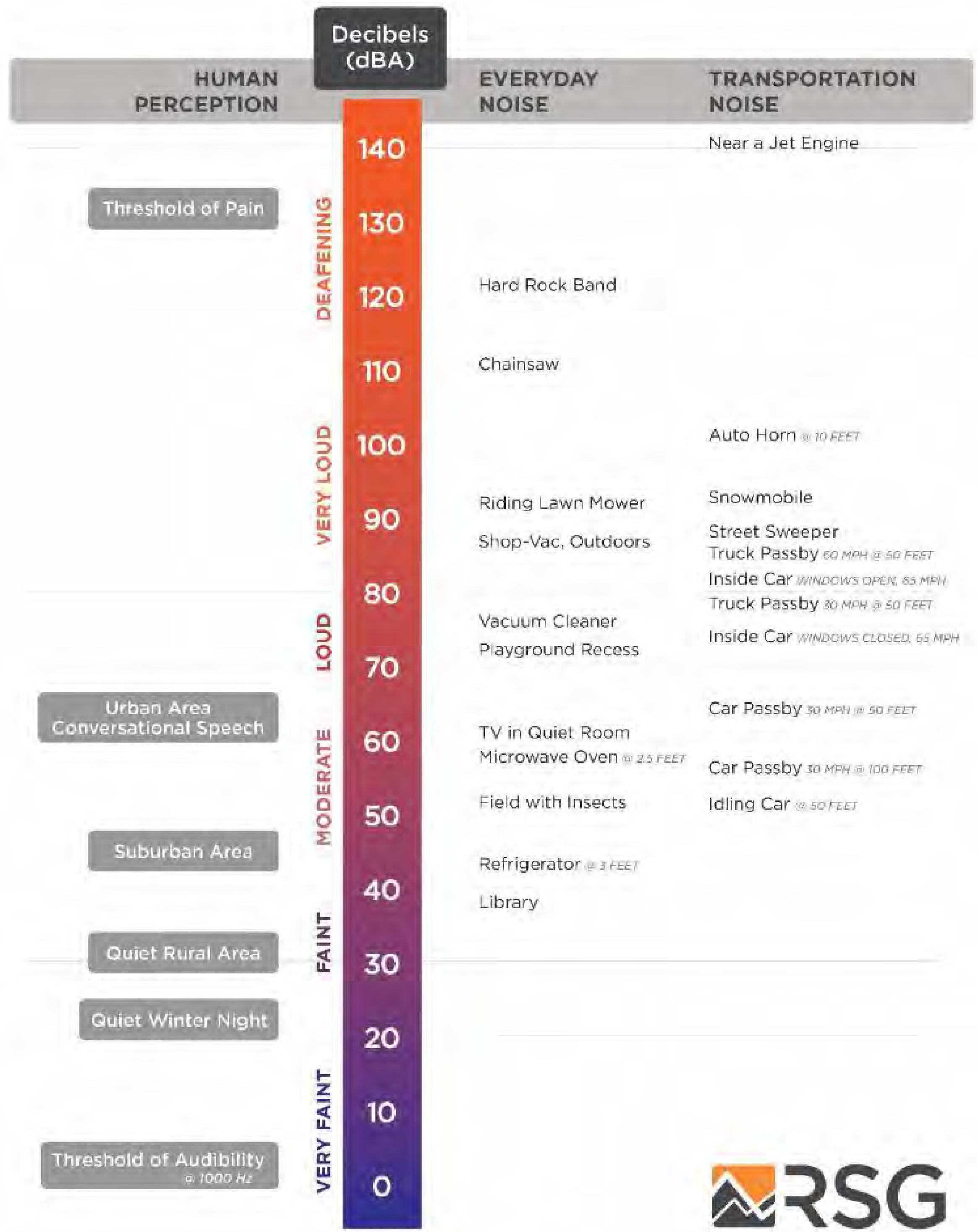

FIGURE 16: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

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.[16] 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_{EQmax}.

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 17. 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.

[16] 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 - Leq

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 commonly used 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 17, even though the sound levels spends 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.

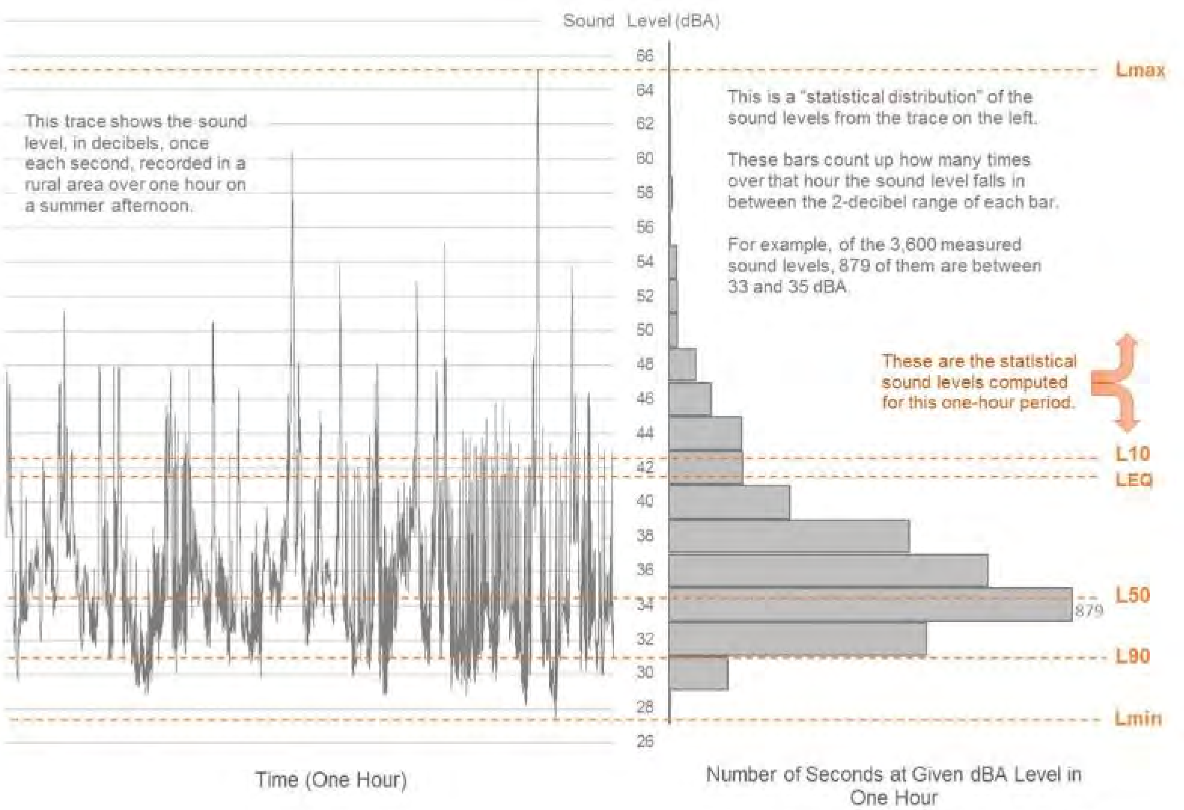

FIGURE 17: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

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. (the “median level”) is exceeded 50% of the time: half of the time the sound is louder than , and half the time it is quieter than . Note that (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 of the 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 Acoustics

Wind Turbine Acoustics

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, the majority of 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 18):

- 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.

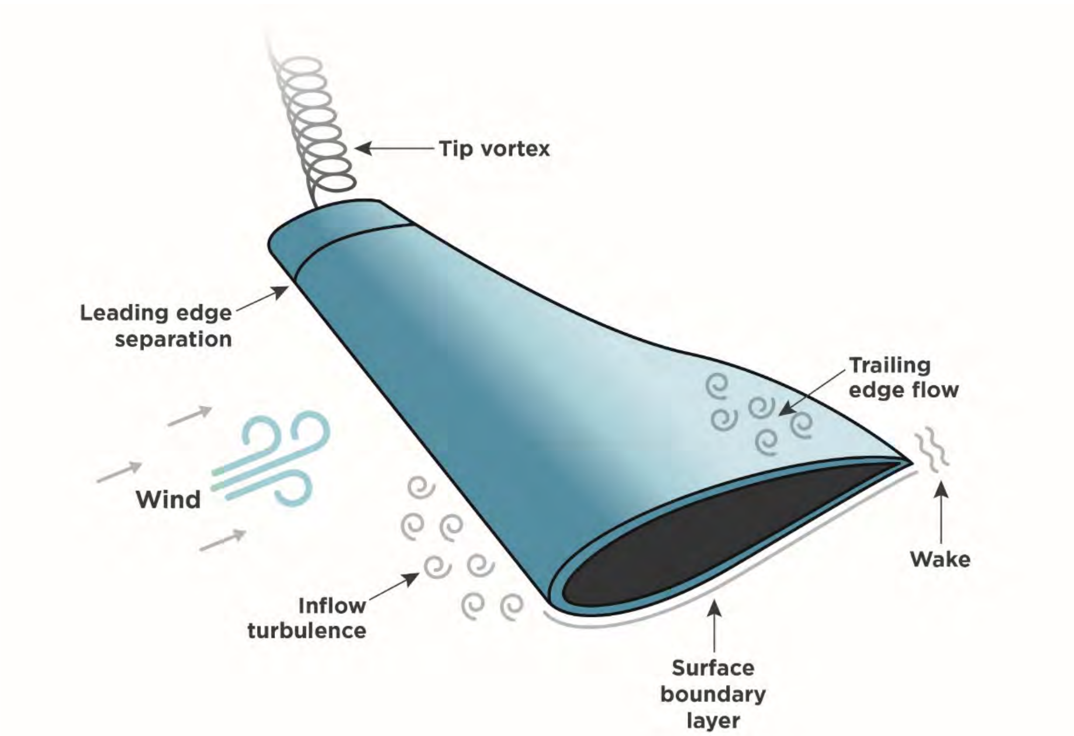

FIGURE 18: AIRFLOW AROUND A ROTOR BLADE

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.[17] Most amplitude modulation is in the mid frequencies and most overall A-weighted AM is less than 4.5 dB in depth.[18]

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.[19] 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 19).

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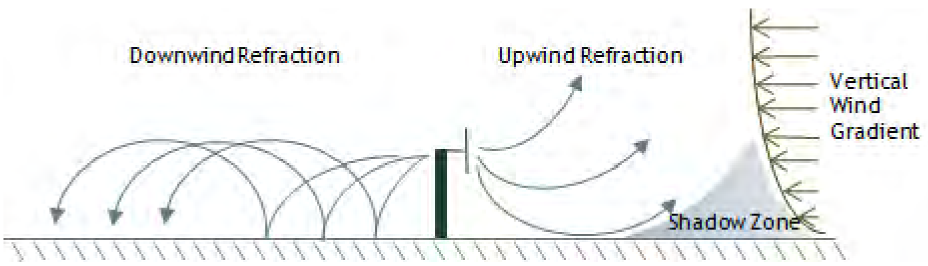
[17] McCunney, Robert, et al. "Wind Turbines and Health: A Critical Review of the Scientific Literature." *Journal of Occupational and Environmental Medicine.* 56(11) November 2014: pp. e108-e130.
[18] RSG, et al., "Massachusetts Study on Wind Turbine Acoustics," Massachusetts Clean Energy Center and Massachusetts Department of Environmental Protection, 2016
[19] "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 19: 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 20 compares the shape of the sound spectrum measured during a 5 m/s wind event to that of the GE 2.8-127 LNTE 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.

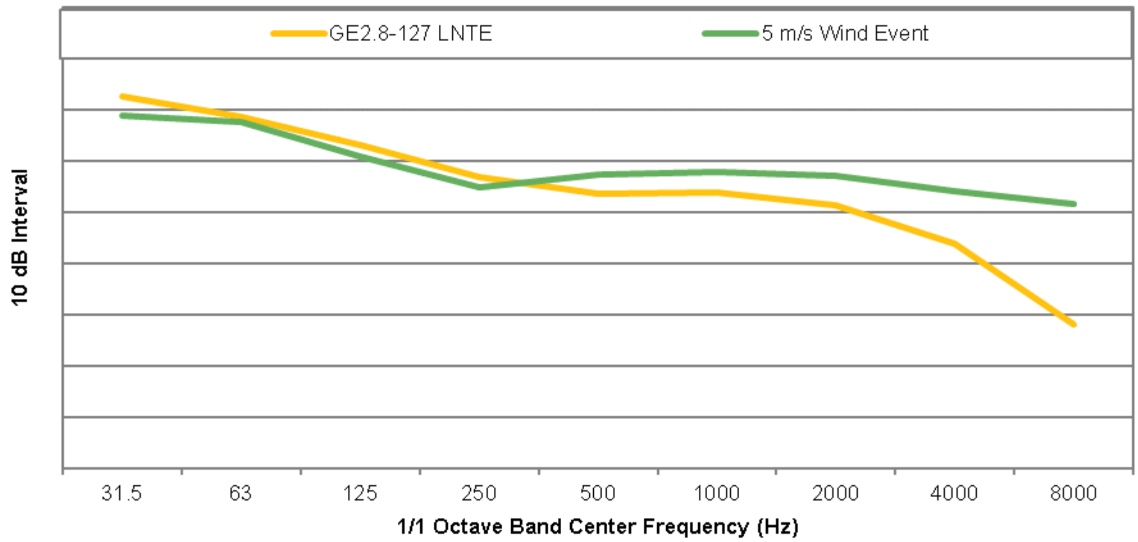


FIGURE 20: COMPARISON OF NORMALIZED FREQUENCY SPECTRA MEASURED FROM A 5 M/S WIND EVENT AND THE SOUND POWER SPECTRA FROM THE GE 2.8-127 LNTE[20]

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.

[20] The purpose of this Figure is to show the shapes to two spectra relative to one another and not the actual sound level of the two sources of sound. The level of each source was normalized independently.

APPENDIX B. ADDITIONAL OVERALL RESULTS

This appendix considers the overall contribution of tonal biogenic noise for the monitoring period.

The method for calculating ANS weighted data is such that if tones above 1.25 kHz were detected, then the A-weighted sound level was recalculated by summing 1/3 octave bands from 20 Hz to 1.25 kHz.[21] It is worth considering that the contribution to the overall A-weighted sound levels of wind turbine sound above the 1 kHz octave band (the portion of the sound spectrum that is removed when tonality is detected in the sample) is at least 10 dB below the overall sound level and is thus negligible with respect to the source. As such, ANS weighting could help "focus" the spectral range in the low to mid frequency range where wind turbine sound emissions are expected in the sound level spectrum.

The overall sound levels for all acoustically valid periods are provided as A-weighted values in Table 8 and ANS-weighted in Table 9. The comparison in tables shows the minimal difference between A-weighted and ANS-weighting (generally 1 dB or less), which suggests minimal additional total sound from biogenic sources, supporting the use of the standard A-weighting network throughout the report. The increase in sound levels due to higher winds in the second period is evident in the L_{50} and L_{90} metrics.

TABLE 8: OVERALL SOUND LEVELS AGGREGATED FOR EACH MONITORING – A-WEIGHTED

	Monitoring Period 1 (dBA)				Monitoring Period 2 (dBA)			
Time Period	L_{eq}	L_{10}	L_{50}	L_{90}	L_{eq}	L_{10}	L_{50}	L_{90}
Day	47	50	37	25	48	52	45	34
Night	44	47	30	22	43	48	39	30
Overall	46	49	34	23	47	51	42	32

TABLE 9: OVERALL SOUND LEVELS AGGREGATED FOR EACH MONITORING – ANS-WEIGHTED

	Monitoring Period 1 (dB-ANS)				Monitoring Period 2 (dB-ANS)			
Time Period	L_{eq}	L_{10}	L_{50}	L_{90}	L_{eq}	L_{10}	L_{50}	L_{90}
Day	46	49	36	22	48	52	45	34
Night	43	47	30	22	43	48	39	30
Overall	45	49	33	22	47	51	42	32

[21] Sounds considered tonal that get the ANS weight applied are those for which a prominent discrete high frequency (>1.25 kHz) 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.

APPENDIX C. TRIGGER FEEDBACK PERIODS

This section provides time history results for each complaint period provided by the residents. Each trigger feedback period is represented by a 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 stacks vertically through all three panes.

The first pane charts 1-minute wind turbine power production for the closest turbine (T-90) and the other five nearby turbines. The aggregation periods for each wind turbine operating classification are indicated: turbine operation (purple) or turbine shutdown (light blue).

The second pane plots 1-minute equivalent A-, C-, and Z-weighted values sound level. The plot also contains ground-level gust wind speed and hub height wind speed and direction, measured and plotted on a 1-minute basis. The trigger feedback period is also identified in the pane.

The third pane is the 1/3 octave band spectrogram representation of the study period surrounding the trigger feedback timestamp. On the spectrogram plot, the y-axis represents frequency, which increases as the y-axis increases. The color of the shading represents the magnitude of the level of sound. Brighter colors represent higher sound levels while darker colors represent lower sound levels. 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 with 1-second sound level data, essentially representing the “raw” data acquired by the sound level meter down through the 12.5 Hz 1/3 octave band.

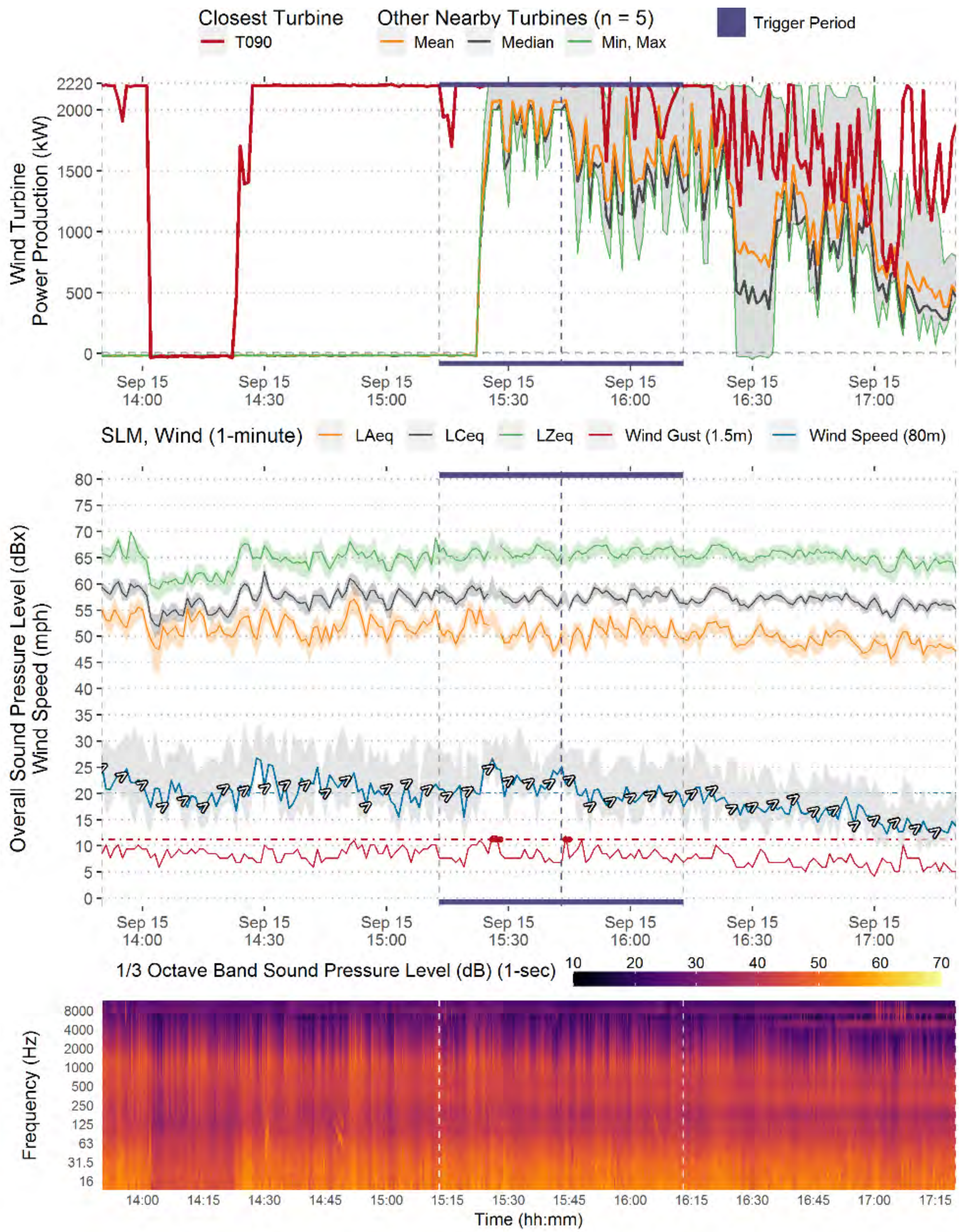


FIGURE C1: TIME HISTORY PLOT FOR TRIGGER PERIOD #01

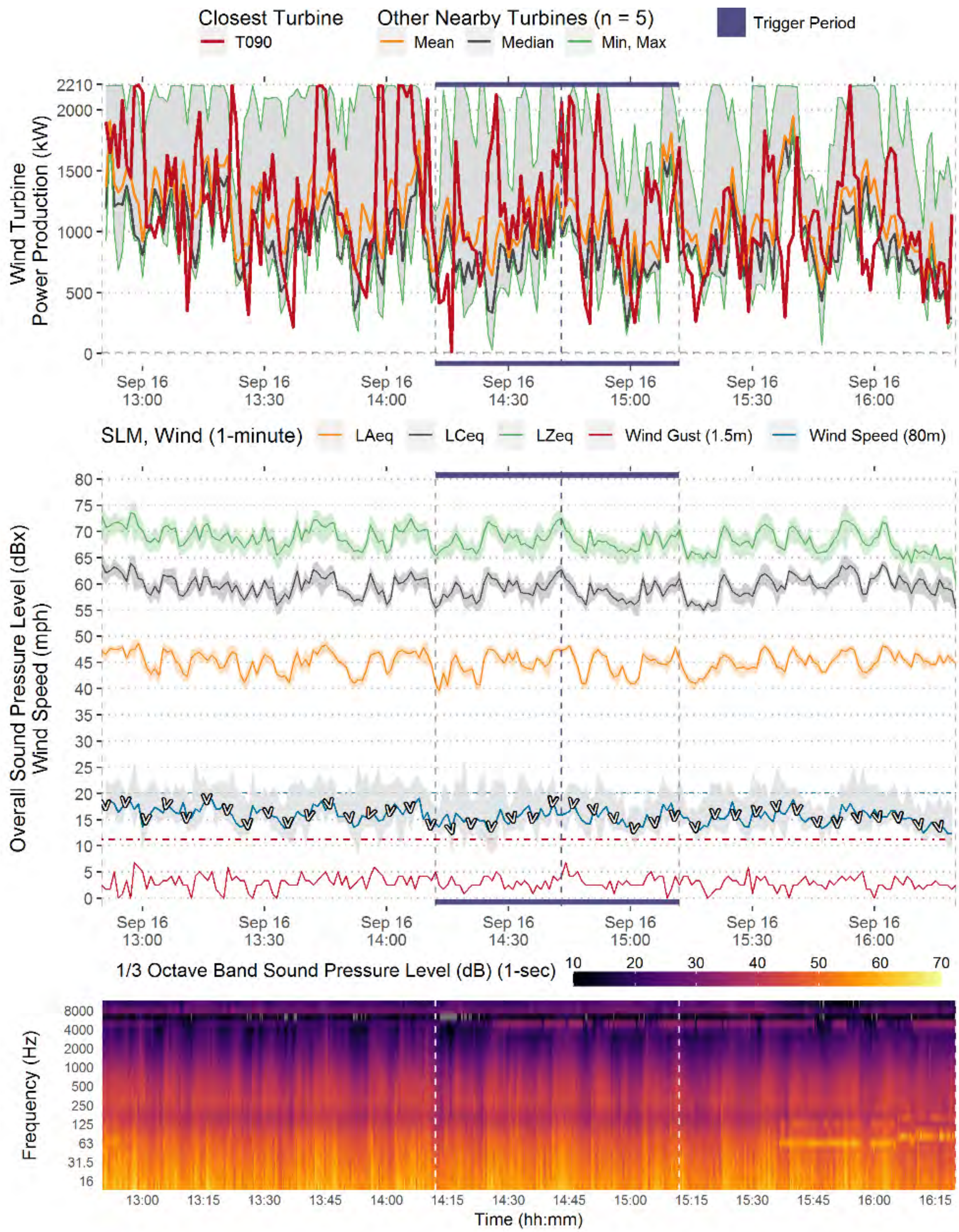


FIGURE C2: TIME HISTORY PLOT FOR TRIGGER PERIOD #02

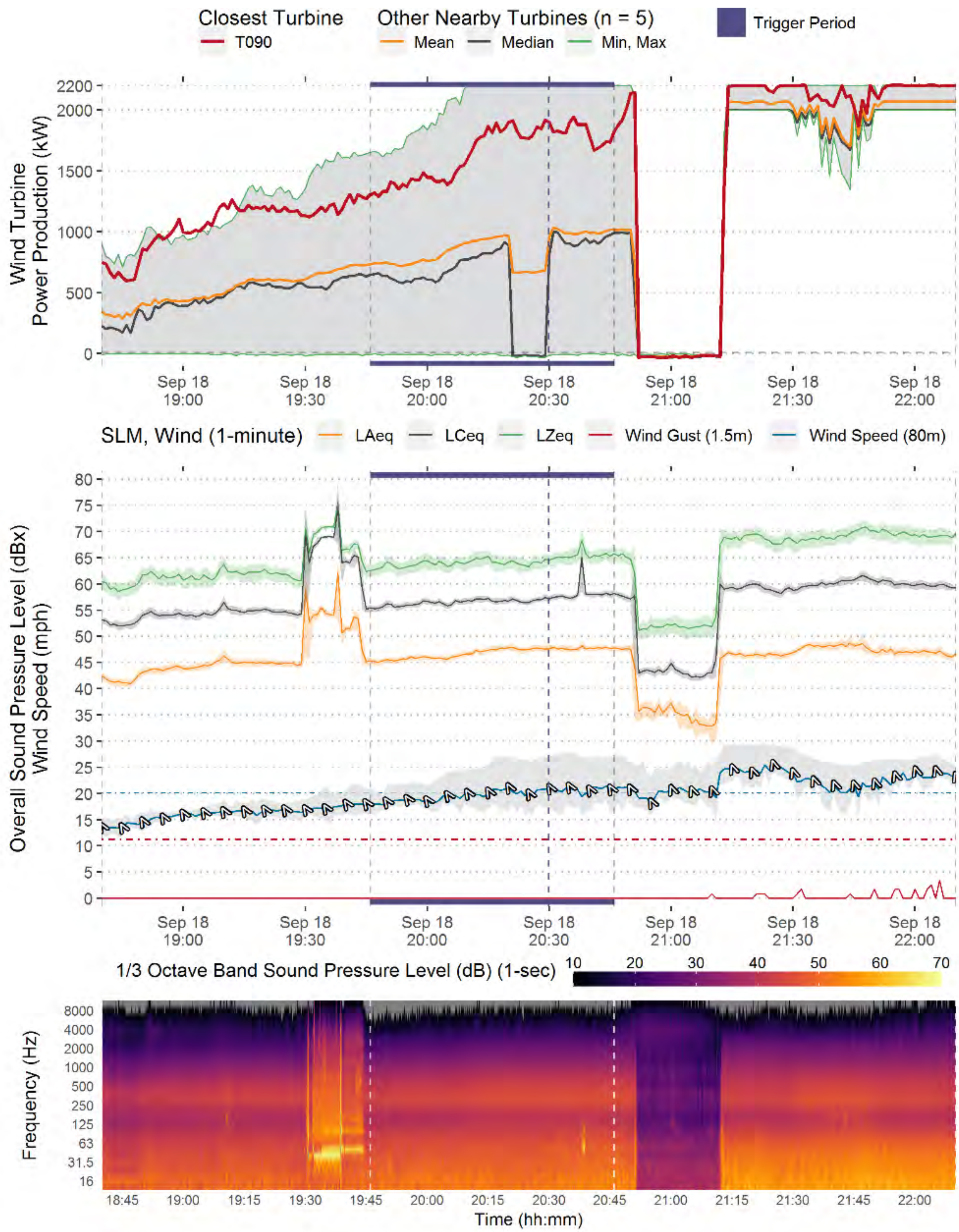


FIGURE C3: TIME HISTORY PLOT FOR TRIGGER PERIOD #03

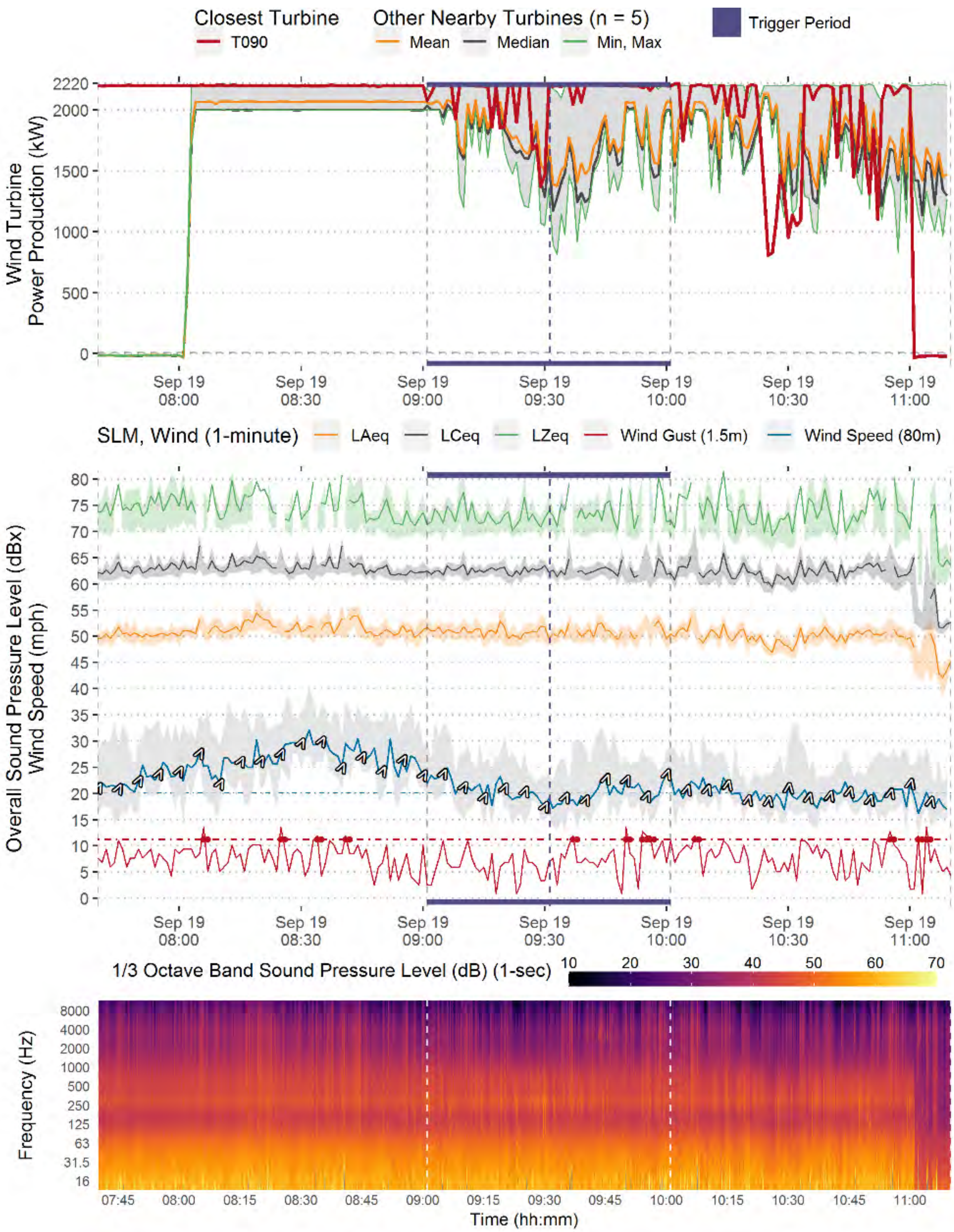


FIGURE C4: TIME HISTORY PLOT FOR TRIGGER PERIOD #04

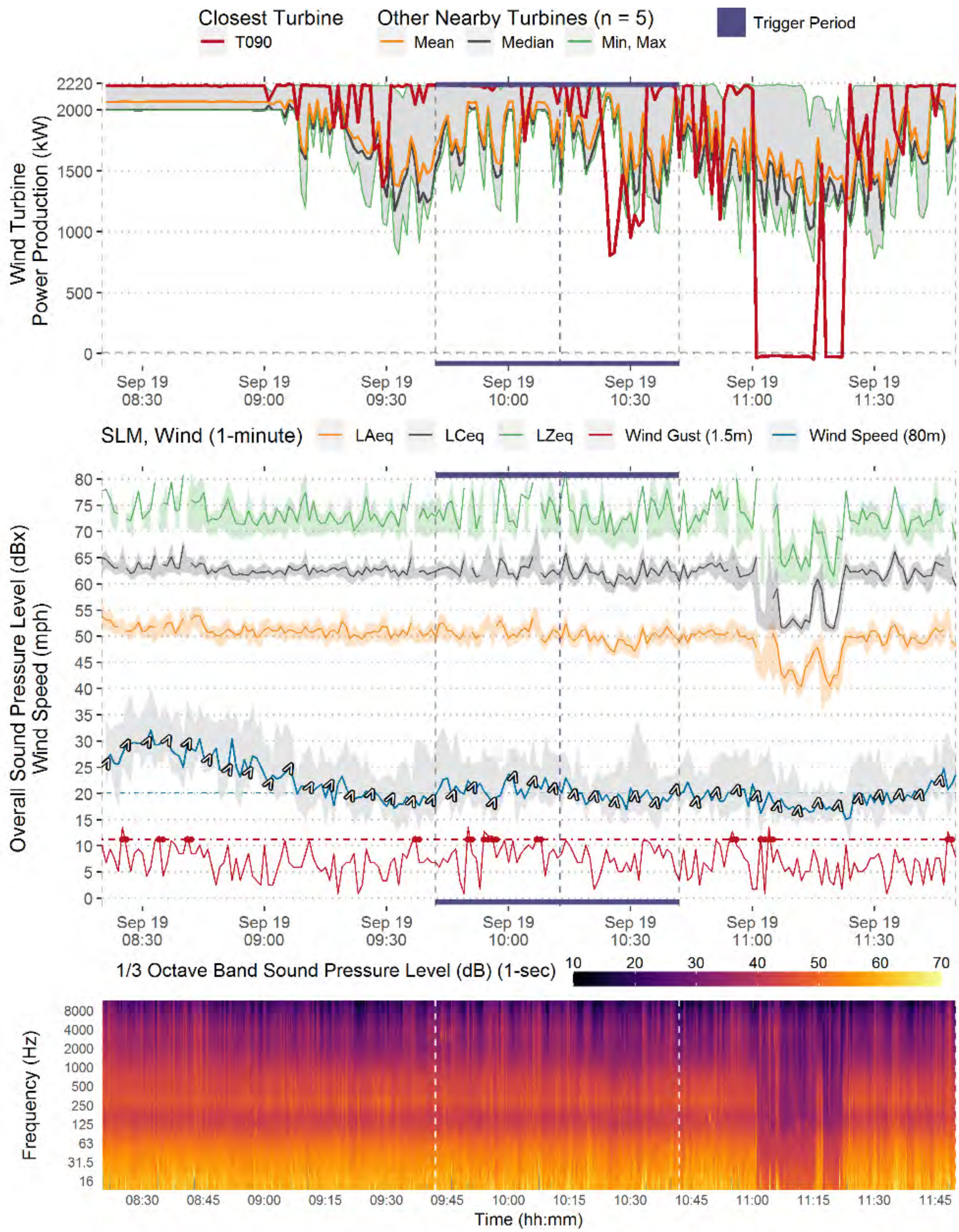


FIGURE C5: TIME HISTORY PLOT FOR TRIGGER PERIOD #05

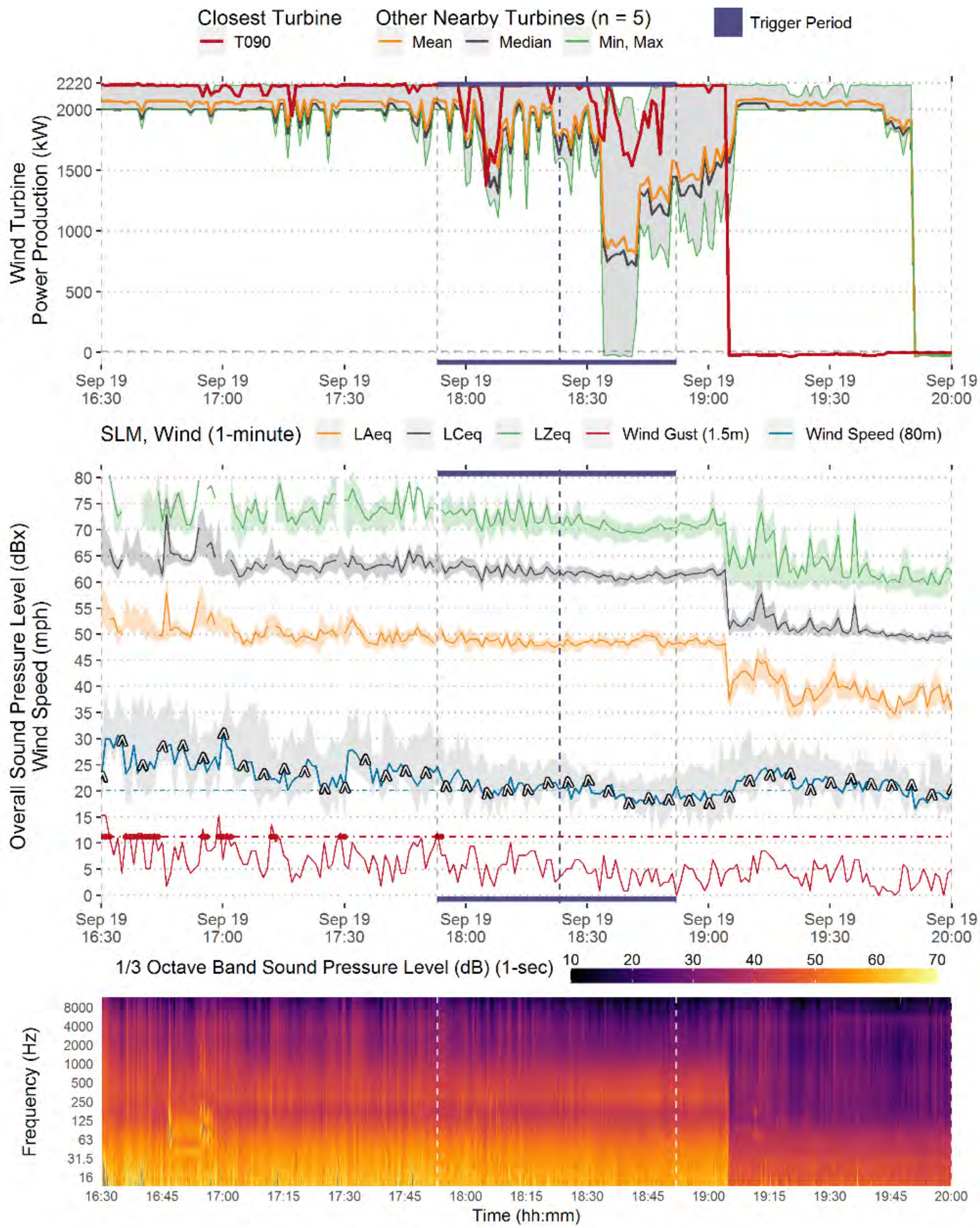


FIGURE C6: TIME HISTORY PLOT FOR TRIGGER PERIOD #06

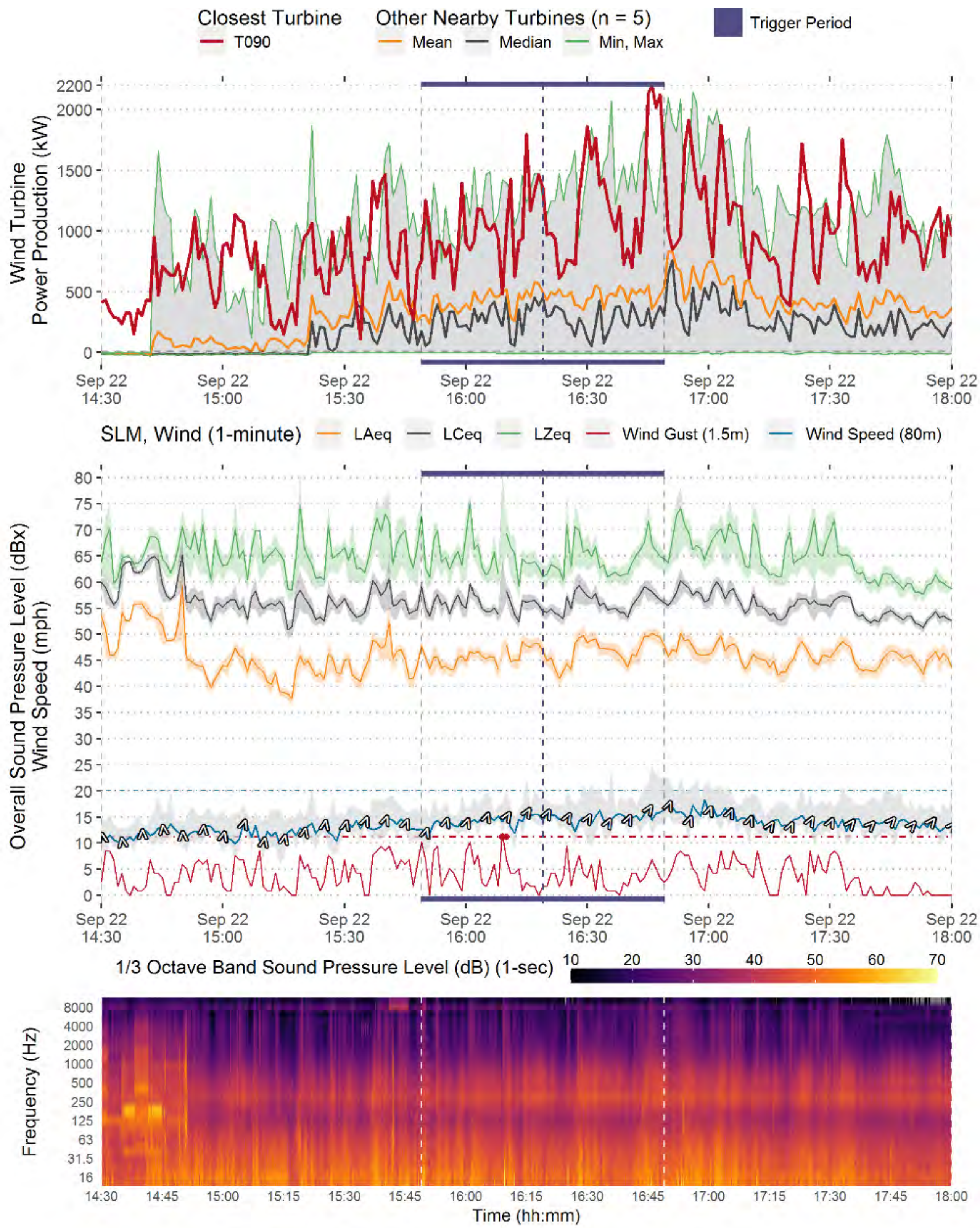


FIGURE C7: TIME HISTORY PLOT FOR TRIGGER PERIOD #07

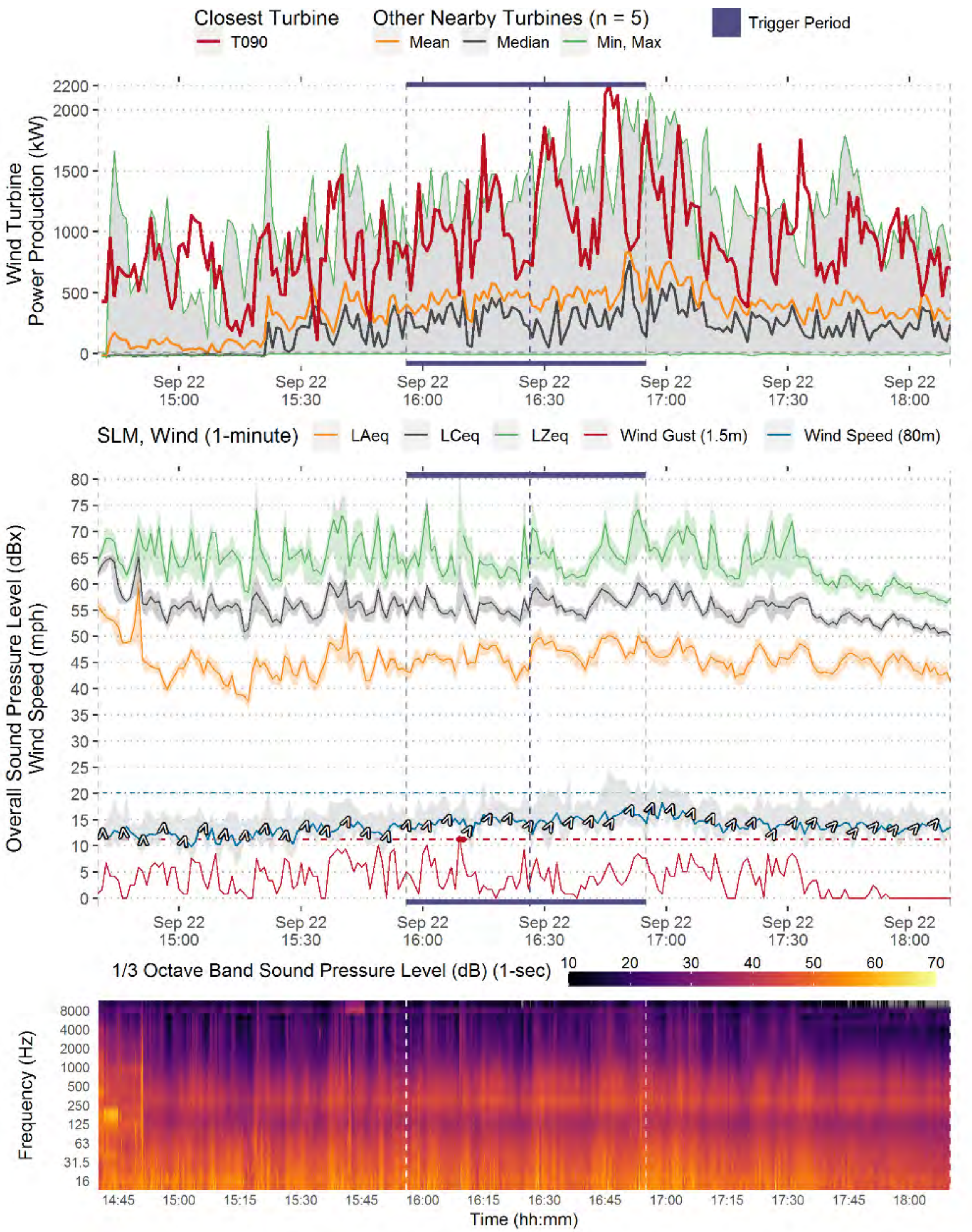


FIGURE C8: TIME HISTORY PLOT FOR TRIGGER PERIOD #08

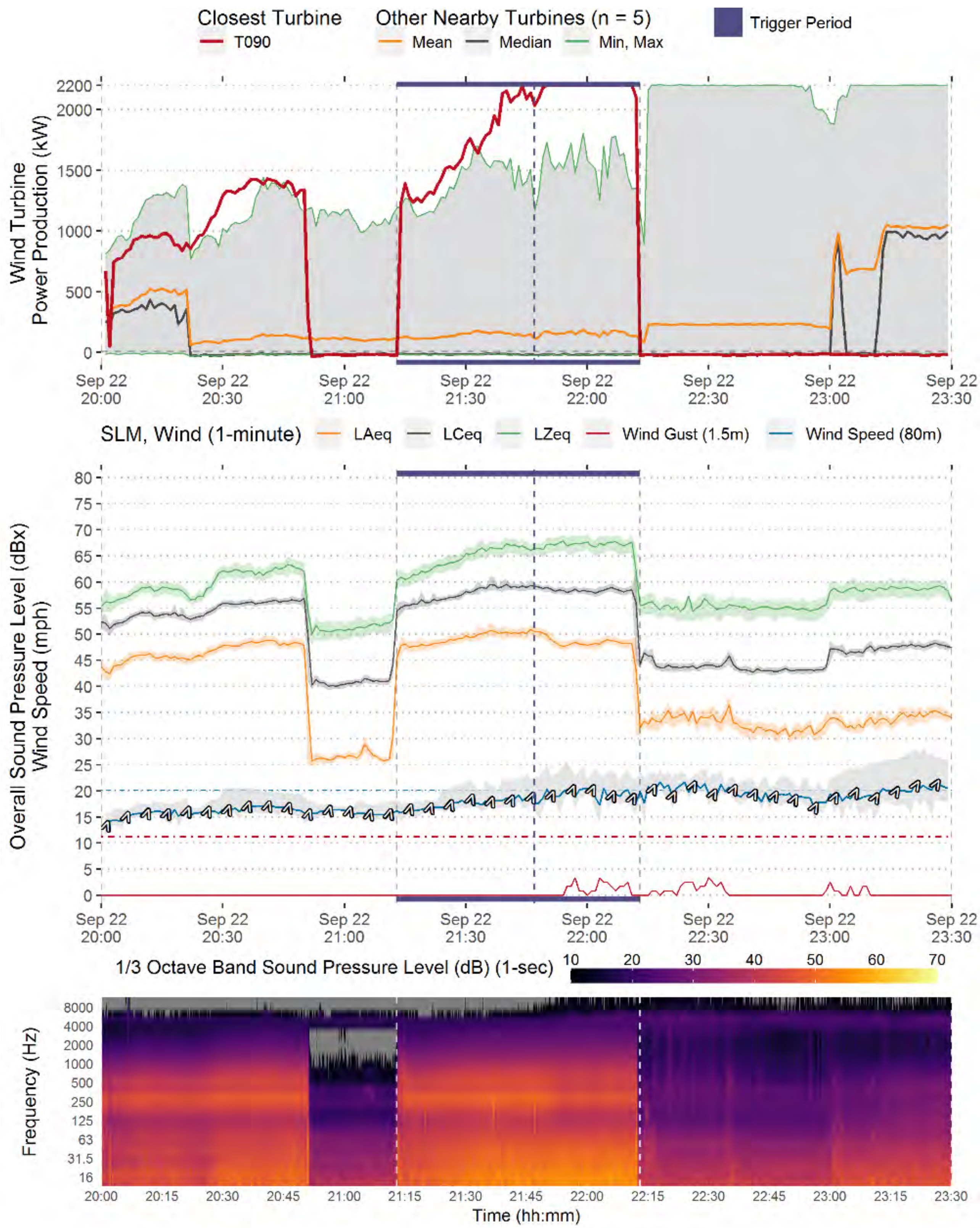


FIGURE C9: TIME HISTORY PLOT FOR TRIGGER PERIOD #09

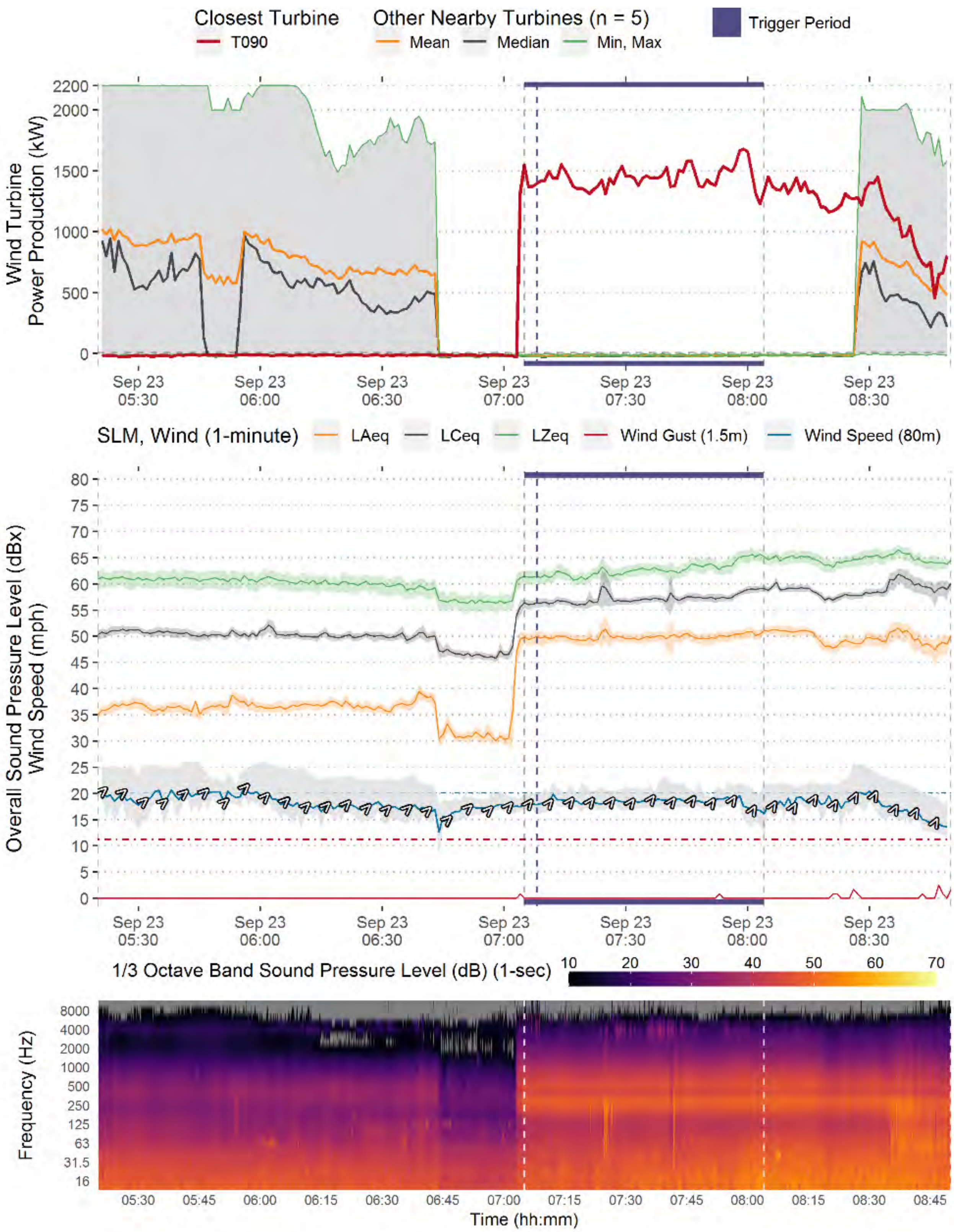


FIGURE C10: TIME HISTORY PLOT FOR TRIGGER PERIOD #10

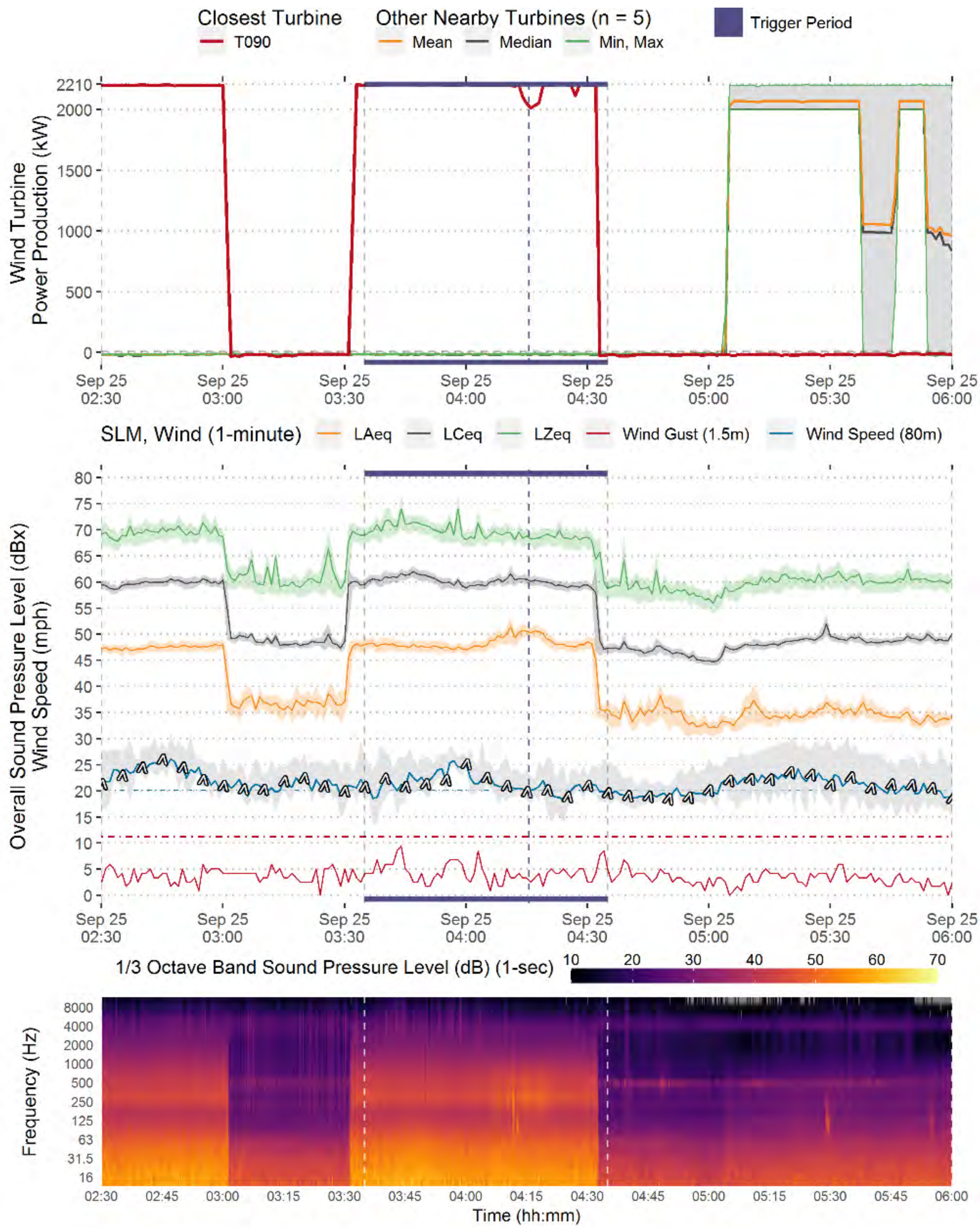


FIGURE C11: TIME HISTORY PLOT FOR TRIGGER PERIOD #11

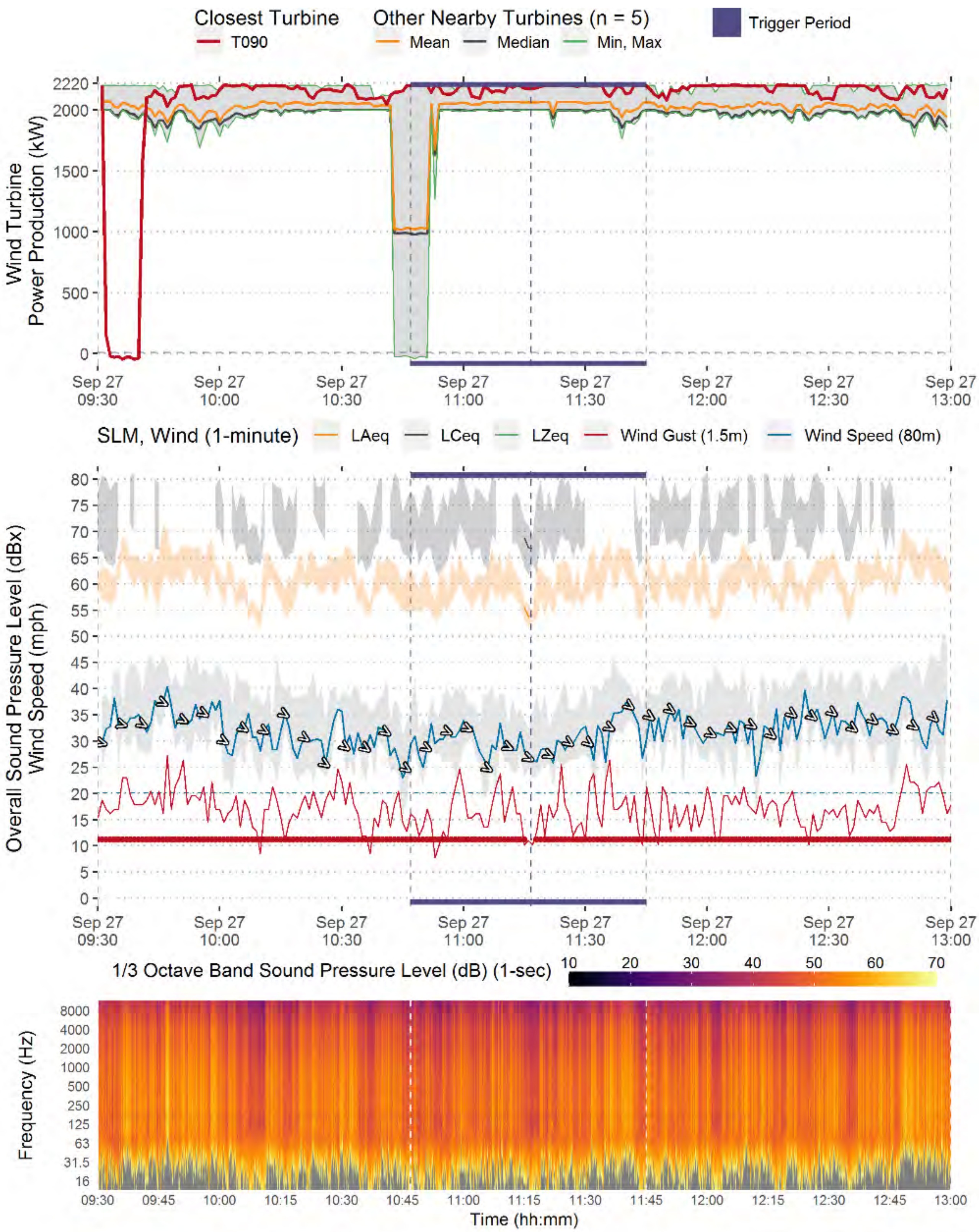


FIGURE C12: TIME HISTORY PLOT FOR TRIGGER PERIOD #13

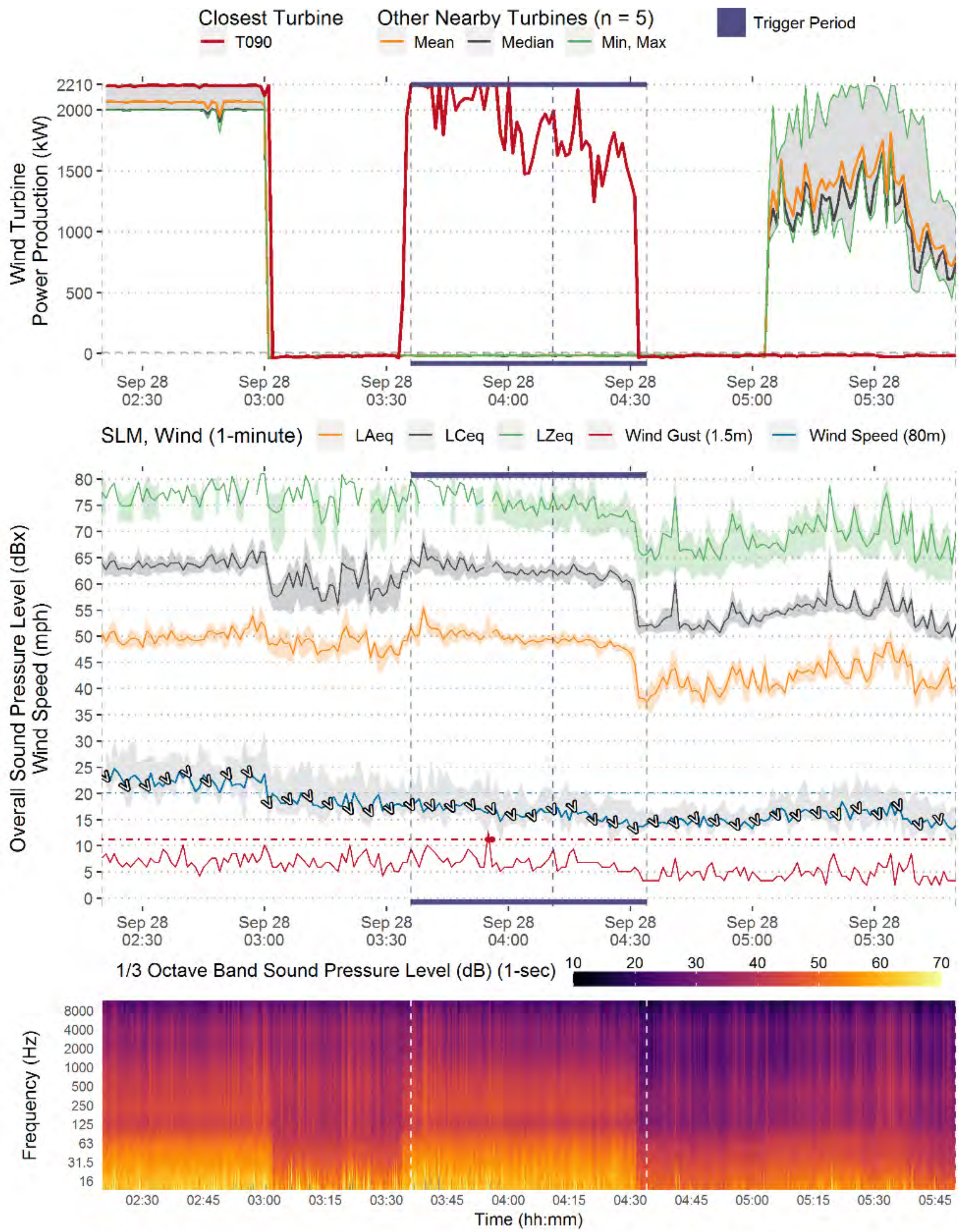


FIGURE C13: TIME HISTORY PLOT FOR TRIGGER PERIOD #14

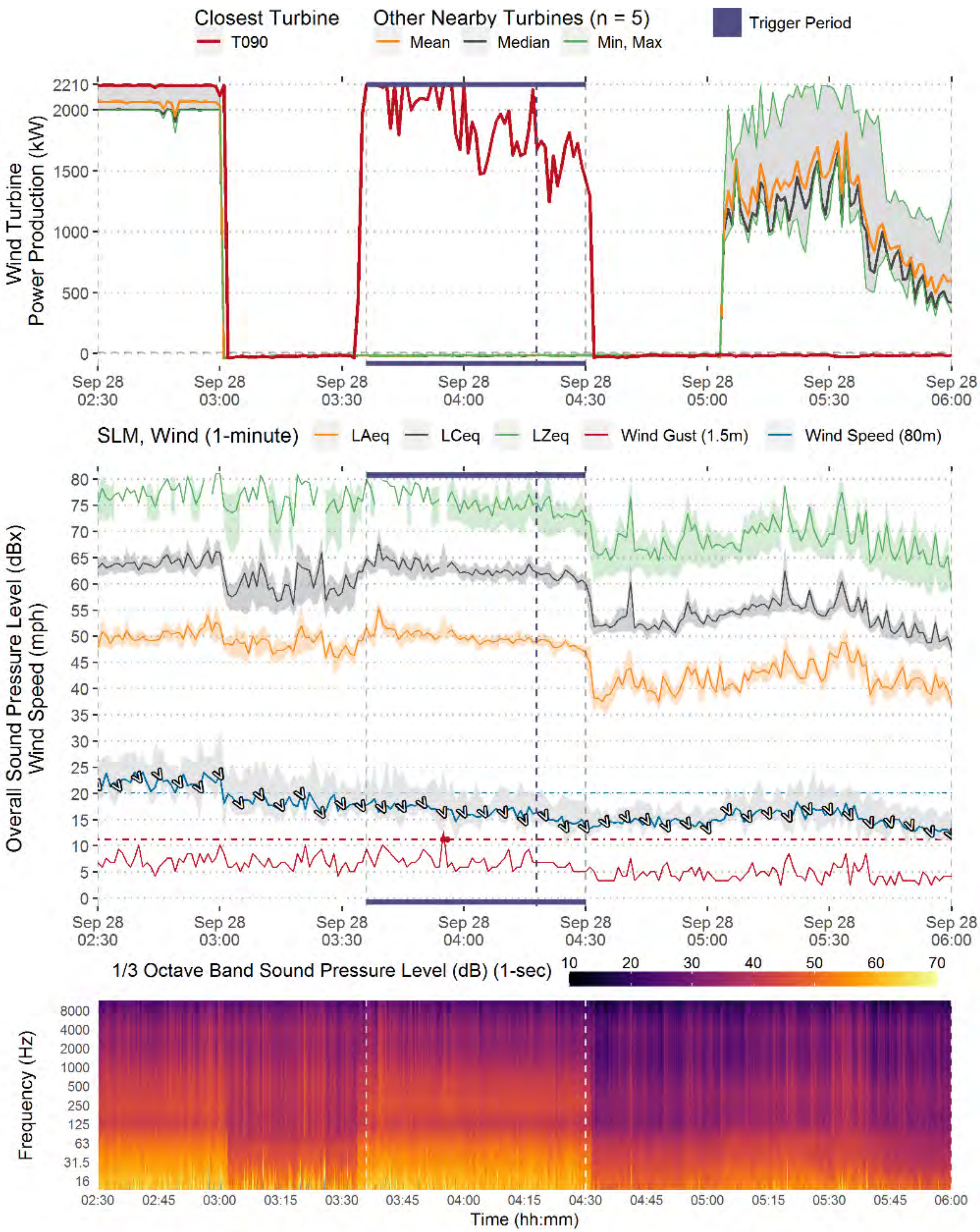


FIGURE C14: TIME HISTORY PLOT FOR TRIGGER PERIOD #15

APPENDIX D. SHUTDOWN RESULTS TABLES

This section provides tabular results of each shutdown period analyzed for Monitoring Location 1 (Table 10) and Monitoring Location 2 (Table 11).

In the tables, the “SD #” is the Shutdown reference number. Some shutdown IDs are skipped because they were not applicable to the Weverka Residence. Similar monitoring was occurring concurrently at another nearby residence and some shutdown periods were not applicable for both locations.

The date and time of each shutdown is provided, along with the turbines represented for that shutdown. Median (L_{50}) background, turbine-only, total sound levels, and hub height wind speed and direction are provided for each period considered. Further, power production at T-90 and at other nearby turbines are provided for each shutdown and corresponding turbine operation period.

TABLE 10: MEASUREMENTS AND CALCULATIONS FROM SHUTDOWNS AND SURROUNDING PERIODS AT LOCATION 1

Monitoring Location 1												
				SOUND PRESSURE LEVEL (L_{50})			HUB HEIGHT WIND		CLOSEST TURBINE POWER		OTHER NEARBY TURBINES POWER	
SD #	DATE	TIME	TURBINE SHUTDOWN TYPE	Back-ground (dBA)	Turbine Only (dBA)	Total Sound (dBA)	Average Speed (mph)	Average Direction (deg)	Shutdown Period (kW)	Turbine Operation (kW)	Shutdown Period (kW)	Turbine Operation (kW)
2	9/8	21:13	Other	25.8	28.7	30.5	12	7	-16	-15	-17	594
3	9/8	23:32	Other	24.8	27.9	29.6	12	18	-13	-14	-16	519
5	9/9	3:00	Other	24.6	24.5	27.5	11	23	-18	-17	-17	370
6	9/11	11:02	All	34.1	33.6	36.7	11	117	-15	448	-17	391
7	9/12	19:53	Other	35.5	36.9	39.2	11	313	275	483	-16	289
8	9/12	20:53	Closest	25.9	34.3	34.8	10	321	-16	256	-14	-15
9	9/12	22:15	Other	25.9	20.1	26.2	10	300	-15	-15	-15	184
10	9/13	20:53	All	36.2	45.2	45.7	19	31	187	1673	332	1684
11	9/13	21:55	All	33.3	45.9	46.1	19	36	-25	2107	186	1905
12	9/13	21:55	Other	33.3	29.4	34.7	18	41	-25	-16	186	1571
13	9/14	6:42	Other	29.6	21.1	29.6	11	90	-15	-16	-16	325
14	9/14	6:42	Closest	29.6	30.7	33.2	10	89	-15	324	-16	-17
15	9/14	8:01	Closest	28.9	31.2	33.2	9	88	-17	313	-17	-17
16	9/14	14:09	Closest	46.8	48.7	50.9	19	224	-17	2146	1339	1699
17	9/14	19:32	Closest	44.9	40.6	46.2	26	207	-22	2194	2064	2048
18	9/14	20:54	Other	45.1	43.7	47.5	27	210	-17	-15	225	1975
19	9/14	22:14	Other	47.1	47.2	50.1	29	217	-10	-13	224	2055
21	9/15	3:10	Other	52.3	48.8	53.9	32	229	-16	-15	222	1957
22	9/15	4:22	Other	54.1	30.5	53.5	32	230	-16	-15	-24	2065
25	9/15	14:03	Closest	51.3	48.1	53	20	238	-22	2156	-16	-17
27	9/16	2:02	All	28.8	38.1	38.6	13	5	-17	386	-17	470
28	9/16	2:02	Other	28.8	32.5	34	13	4	-17	-17	-17	657
29	9/16	6:41	Other	33.9	36.2	38.2	16	354	-17	-14	-24	1486
30	9/16	6:41	Closest	33.9	44.8	45.1	15	352	-17	1164	-24	-16
31	9/16	6:41	All	33.9	46.4	46.6	16	351	-17	1377	-24	1444

Monitoring Location 1												
SD #	DATE	TIME	TURBINE SHUTDOWN TYPE	SOUND PRESSURE LEVEL (L_{50})			HUB HEIGHT WIND		CLOSEST TURBINE POWER		OTHER NEARBY TURBINES POWER	
				Back-ground (dBA)	Turbine Only (dBA)	Total Sound (dBA)	Average Speed (mph)	Average Direction (deg)	Shutdown Period (kW)	Turbine Operation (kW)	Shutdown Period (kW)	Turbine Operation (kW)
32	9/16	9:18	Closest	41	46.1	47.2	17	1	14	1432	1604	1620
33	9/16	11:01	Closest	45.2	43.7	46.8	17	6	-19	1338	1621	1530
34	9/16	20:58	All	25.7	33.7	34.3	11	9	-16	183	-14	287
35	9/16	20:58	Closest	25.7	36.8	37.1	11	15	-16	417	-14	-16
36	9/16	22:13	Closest	23.5	37.2	37.4	11	27	-15	462	-16	-15
37	9/16	22:13	Other	23.5	24.3	26.9	11	35	-15	-14	-16	412
38	9/17	6:42	Other	26.9	NA	25.5	9	129	-17	-17	-15	120
39	9/17	8:01	Closest	28.9	34.4	35.5	11	135	-16	348	-16	-17

TABLE 11: MEASUREMENTS AND CALCULATIONS FROM SHUTDOWNS AND SURROUNDING PERIODS AT LOCATION 2

Monitoring Location 2												
				SOUND PRESSURE LEVEL (L_{50})			HUB HEIGHT WIND		CLOSEST TURBINE POWER		OTHER NEARBY TURBINES POWER	
SD #	DATE	TIME	TURBINE SHUTDOWN TYPE	Back-ground (dBA)	Turbine Only (dBA)	Total Sound (dBA)	Average Speed (mph)	Average Direction (deg)	Shutdown Period (kW)	Turbine Operation (kW)	Shutdown Period (kW)	Turbine Operation (kW)
40	9/17	20:53	All	32	42.2	42.6	15	103	-16	858	-17	819
41	9/18	6:49	All	26.8	41.1	41.2	13	148	-17	653	-18	716
42	9/18	6:49	Closest	26.8	41.3	41.4	12	157	-17	586	-18	-16
43	9/18	14:02	Closest	38.5	40.8	42.8	11	170	-16	506	-17	-17
44	9/18	20:53	All	35.1	46.9	47.2	21	156	-25	1905	-23	1423
45	9/18	22:16	All	32.7	47	47.1	21	163	-28	2161	-26	2013
46	9/19	2:16	Other	26	30.1	31.5	20	186	-16	-14	-26	1938
47	9/19	6:45	Other	44.6	22.9	43	23	206	-14	-15	-26	2065
48	9/19	6:45	Closest	44.6	47.7	49.3	23	207	-14	2200	-26	-17
49	9/19	11:02	Closest	42.8	49	49.9	19	192	83	2013	1483	1863
52	9/19	22:14	Closest	47.3	46	49.2	24	189	-23	2172	-12	-13
53	9/19	22:14	Other	47.3	37.1	47.7	27	194	-23	-2	-12	1902
61	9/20	20:52	All	44.1	46.3	48.2	25	200	-22	1999	-22	2049
62	9/20	22:13	All	45.8	45.1	48.2	26	200	-18	1825	-22	2061
63	9/20	22:13	All	45.8	20.6	44.7	27	203	-18	-5	-22	2067
67	9/22	20:53	Closest	26.6	47.4	47.4	16	199	-19	1399	110	203
68	9/23	4:34	Closest	29.9	48.7	48.8	20	222	-18	2174	-18	15
69	9/23	6:45	Other	30.8	35.5	36.7	18	227	-12	-12	-20	740
70	9/23	6:45	Closest	30.8	49.8	49.9	18	222	-12	1445	-20	-16
73	9/23	15:34	All	35.7	46.6	47	14	200	-21	1239	-20	738
74	9/23	20:51	All	29.8	46.2	46.3	15	173	-19	1291	-20	659
75	9/23	20:51	Other	29.8	30.1	32.9	15	170	-19	-17	-20	1320
76	9/24	1:32	Other	28.8	33.9	35.1	14	229	-15	-16	-19	1210

Monitoring Location 2													
				SOUND PRESSURE LEVEL (L_{50})			HUB HEIGHT WIND		CLOSEST TURBINE POWER		OTHER NEARBY TURBINES POWER		
SD #	DATE	TIME	TURBINE SHUTDOWN TYPE	Back-ground (dBA)	Turbine Only (dBA)	Total Sound (dBA)	Average Speed (mph)	Average Direction (deg)	Shutdown Period (kW)	Turbine Operation (kW)	Shutdown Period (kW)	Turbine Operation (kW)
77	9/24	1:32	Closest	28.8	36.4	37	11	283	-15	269	-19	-16
79	9/24	6:45	Other	40.6	24.4	37.9	14	40	-14	-14	-17	641
80	9/24	6:45	Closest	40.6	35.4	41.5	14	64	-14	903	-17	-12
81	9/24	20:56	All	35.5	44	44.5	17	129	-16	970	-20	964
82	9/24	20:56	Other	35.5	20	34.1	18	138	-16	-15	-20	1648
83	9/25	1:34	Other	35.5	30	36.5	20	175	-16	-14	-20	1930
84	9/25	1:34	Closest	35.5	47.1	47.4	21	183	-16	2198	-20	-18
85	9/25	3:03	Closest	36.4	47.3	47.6	22	188	-20	2197	-14	-16
86	9/25	4:33	Closest	33.7	47.9	48	20	191	-20	2132	-14	-15
87	9/25	4:31	Other	33.8	27.2	34.1	20	195	51	-16	-14	1740
88	9/25	6:43	Other	34.7	17.5	33.3	20	195	-12	-12	-22	1710
89	9/25	6:43	Closest	34.7	48.3	48.5	24	197	-12	2194	-22	-18
90	9/25	15:50	All	37.9	47.1	47.6	11	320	-13	734	-16	558
91	9/26	6:42	All	33.1	33.1	36.1	10	141	-16	127	-18	119
92	9/26	6:42	Closest	33.1	38.5	39.6	11	125	-16	413	-18	-17
93	9/26	16:53	All	36.6	39.8	41.5	11	347	-15	503	-16	511
95	9/26	20:51	Other	36.9	43.6	44.5	15	314	-9	-11	-18	1556
96	9/27	1:31	Other	39.9	39.9	42.9	19	282	-14	-16	-24	2044
97	9/27	1:31	Closest	39.9	49.8	50.2	17	289	-14	2119	-24	-15
98	9/27	3:02	Closest	44.6	48.8	50.2	18	292	-24	2119	-12	-15
99	9/27	3:02	Other	44.6	30.2	42.8	19	294	-24	-16	-12	1796
100	9/27	6:43	Other	36.7	38	40.4	22	275	-16	-15	-24	2051
101	9/27	6:43	Closest	36.7	45.2	45.8	23	274	-16	2198	-24	149
108	9/27	20:56	Other	46.3	31.1	46.3	18	304	-13	-17	-26	1963
109	9/28	1:32	Other	47.8	21.2	46.9	21	321	-16	-16	-21	1916
110	9/28	1:32	All	47.8	45	49.5	21	325	-16	2199	-21	2060

Monitoring Location 2												
SD #	DATE	TIME	TURBINE SHUTDOWN TYPE	SOUND PRESSURE LEVEL (L_{50})			HUB HEIGHT WIND		CLOSEST TURBINE POWER		OTHER NEARBY TURBINES POWER	
				Back-ground (dBA)	Turbine Only (dBA)	Total Sound (dBA)	Average Speed (mph)	Average Direction (deg)	Shutdown Period (kW)	Turbine Operation (kW)	Shutdown Period (kW)	Turbine Operation (kW)
111	9/28	3:02	All	48.1	44.5	49.5	20	328	-22	2199	-21	2060
112	9/28	3:02	Closest	48.1	45.1	49.6	17	332	-22	1886	-21	-16
113	9/28	4:33	Closest	40.4	49	49.6	16	332	-19	1894	-15	-16
114	9/28	4:33	Other	40.4	37.2	42.1	15	333	-19	-17	-15	1125
115	9/28	6:44	Other	40.5	34.3	41.4	13	336	-16	-17	-17	821
116	9/28	6:44	Closest	40.5	44.9	46.2	13	330	-16	1186	-17	-15
117	9/28	8:03	Closest	43.1	43.5	46.2	14	322	-17	1194	-16	-16
118	9/28	8:03	All	43.1	49.3	50.2	16	321	-17	1715	-16	1414
119	9/28	22:32	Closest	41.3	48.6	49.4	18	320	-18	1704	1765	1413
120	9/29	6:02	Closest	40.2	44.9	46.1	19	275	-17	1947	1500	1736

APPENDIX E. SHUTDOWN RESULTS PLOTS

This section provides time history plots for each identified shutdown period. Each shutdown is represented by a 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.

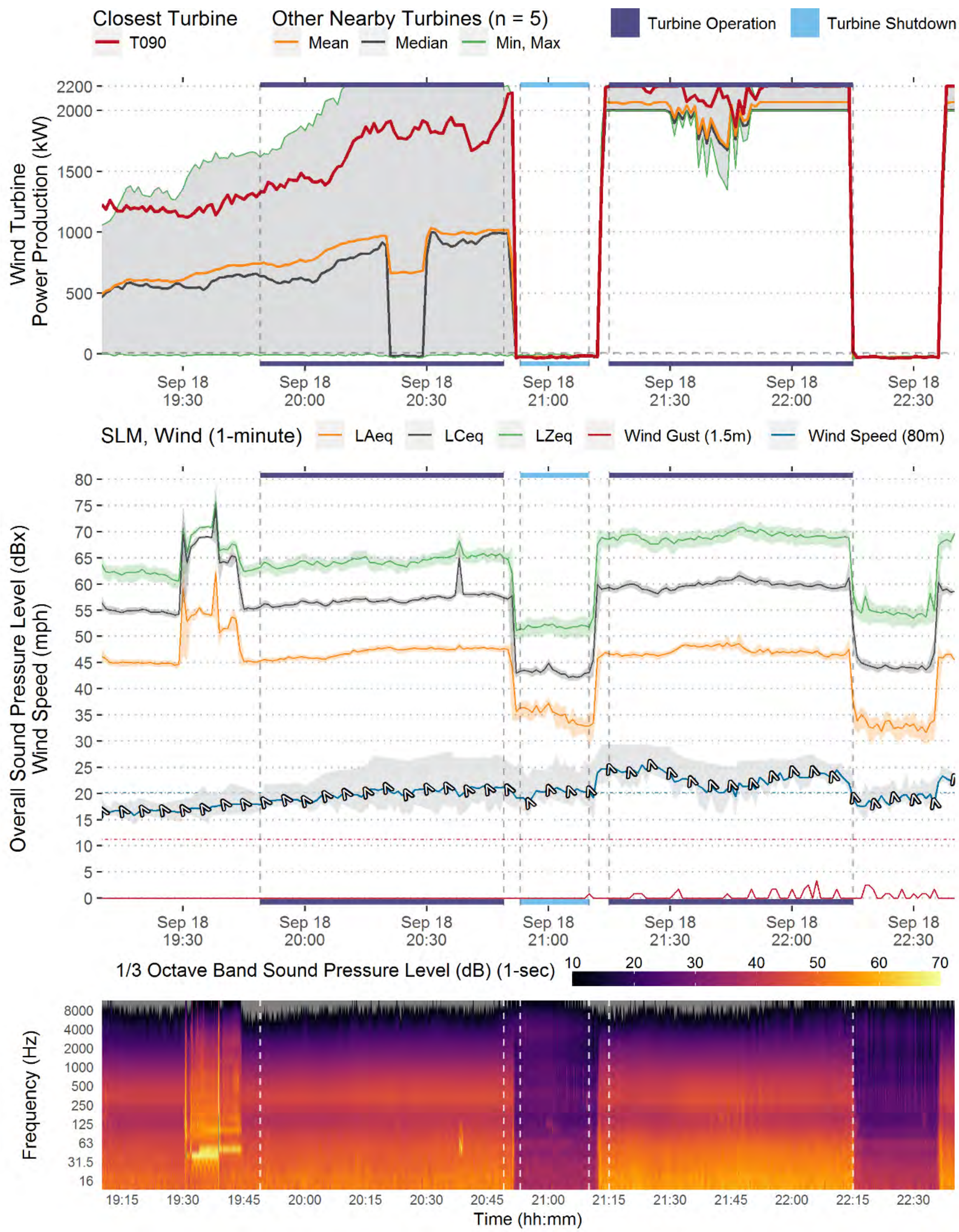
Time stacks vertically through all three panes.

The first pane charts 1-minute wind turbine power production for the closest turbine (T-90) and the five other “nearby” turbines. The aggregation periods for each wind turbine operating classification are indicated: turbine operation (purple) or turbine shutdown (light blue).

The second pane plots 1-minute equivalent A-, C-, and Z-weighted values sound level. The plot also contains ground-level gust wind speed and hub height wind speed and direction, measured and plotted on a 1-minute basis. The turbine operation periods are also identified in the pane.

The third pane is the 1/3 octave band spectrogram representation of the study period surrounding the shutdown. On the spectrogram plot, the y-axis represents frequency, which increases as the y-axis increases. The color of the shading represents the magnitude of the level of sound. Brighter colors represent higher sound levels while darker colors represent lower sound levels. 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 with 1-second sound level data, essentially representing the “raw” data acquired by the sound level meter down through the 12.5 Hz 1/3 octave band.

Note: Due to the size and quantify of the figures in this Appendix, it is provided as a separate document. A plot of Shutdown #44 is provided on the following page to exemplify the contents of the full Appendix.



APPENDIX E PLOT EXAMPLE: SHUTDOWN 44 (MONITORING LOCATION 2).

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