New York State Energy Research and Development Authority

Wind Turbine-Related Noise in Western New York

Final Report

January 2013

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Wind Turbine-Related Noise in Western New York

Final Report

Prepared for the

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Notice

Abstract

Wind turbine-related noise can be an important issue when siting new projects, as well as with operational facilities. This project addresses a number of knowledge gaps related to this topic, including (1) little available data on wind turbine noise from operating wind parks; (2) sparse literature regarding complaints or reported annoyance due to wind turbine noise; and (3) lack of understanding of the potential health effects related to wind turbine noise.

The objective of this study was to increase the understanding of potential noise issues related to wind turbine operation in New York State. We studied a 126 MW wind park located in Wethersfield, New York. The facility consists of 84 1.5 MW General Electric model 1.5sle turbines spanning approximately 19 square miles of rural farmland. To provide oversight and technical feedback, both an Industry Advisory Committee as well as a Scientific Advisory Committee was established.

Noise monitoring was conducted at five locations within the wind park, as well as two locations outside the wind park, which were intended to serve as background locations. Monitoring was conducted over three campaigns (August 2011, October 2011, and February 2012), each consisting of continuous monitoring over a four-day period. A cross-sectional survey among individuals living in and around the wind park was conducted to assess attitudes towards wind turbines and concerns regarding health effects. Short-term outdoor and indoor sound level measurements were also performed at each dwelling in which a questionnaire was administered.

Measured sound levels during all campaigns were higher than background measurements. The winter campaign had the highest wind speeds and monitored sound levels. There was no apparent exposure-response relationship between an individual's level of annoyance and the short duration sound measurements collected at the time of the survey. There was a correlation between an individual's concern regarding health effects and the prevalence of sleep disturbance and stress among the study population.

Keywords: wind turbine, environmental noise, sound level measurement, noise annoyance, wind turbine noise, infrasound, wind turbine health effects, wind turbine annoyance

Definitions

°C – degrees Celsius

dB – Decibels

dBA – Decibels on the A weighting scale

Hz – Hertz

IRB – institutional review board

L90 – 90th percentile sound pressure level. The sound pressure level exceeded during 90 percent of the measurement duration.

LAS90 – 90th percentile A-weighted slow time constant sound pressure level. The L90 value obtained with the sound level meter set for an A-weighting frequency response and the "slow" time response.

LEQ – equivalent (energy-average) sound pressure level. The sound pressure level that, if constant over the measurement duration, would have had the same sound energy as the actual measured time-varying sound pressure level.

LAEQ – A-weighted equivalent (energy-average) sound pressure level. The LEQ value obtained with the sound level meter set for an A-weighting frequency response.

m/s – meters per second

mV/Pa – milliVolts per Pascal

MW – Megawatt

sd – standard deviation

SLM – Sound level meter

SPL – Sound pressure level. The decibel value of sound pressure referenced to 20 microPascals.

Study Designated Frequency Ranges

Infra, 6.3 – 16 Hz

Low, 20 – 250 Hz

Overall, 6.3 – 3150 Hz

Acknowledgements

The authors would like to acknowledge the participation of the Wethersfield, NY residents and the survey group. We are especially grateful to those residents who allowed us to place the monitors on their property throughout the year. We would also like to acknowledge EPRI for providing funding for this project. We would also like to thank the Project Advisory Committee members along with the Industry Advisory Committee members for their input throughout the project. Lastly, we would like to thank Dr. Don Cibula for his statistical review.

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1.0 INTRODUCTION

As the boundaries of harvesting wind energy expand to meet the ever-increasing societal energy demands, the number and size of wind turbines being constructed continues to rise. Geographical locations with favorable characteristics for wind turbines are sought after by energy companies to optimize energy output from each turbine. Though the site location may be favorable for optimum energy output, private landowners and residents may not have the same perception. Colden Corporation ("Colden") and Lally Acoustical Consulting were retained by the Electric Power Research Institute ("EPRI") under a contract with the New York State Energy Research and Development Authority ("NYSERDA") to assess the level of noise produced by a new generation of wind turbines and to characterize the perception, level of annoyance and health impacts held by nearby landowners and residents.

The project directly addresses the following three Policy Questions as outlined in the original NYSERDA Request for Proposals (RFP):

1. How much sound and at what frequencies do operating wind turbines produce in New York State (NYS) compared to ambient, pre-development conditions?

2. What are the background sound levels and what is the nature of these sounds in NYS regions where wind development is most feasible?

3. To what extent are wind turbine noise complaints associated with factors other than the level and/or frequency of sounds emitted from wind turbines?

To our knowledge, this project is the first comprehensive evaluation of wind turbine-related sound in NYS. Our project results are expected to help State and local officials in understanding how turbine noise may affect communities; further, the evaluation of community perceptions, in conjunction with noise levels and other features, will provide data that will allow officials to better understand the nature and origin of noise complaints, and as a result work more effectively with landowners and residents to minimize negative impacts.

The primary project goal is to increase the understanding of potential noise issues related to wind turbine operation in NYS. The specific project objectives are to:

1. Determine background/baseline sound levels and frequencies at a representative site for potential wind development in Central NYS.

2. Determine sound levels and frequencies at different distances from operating wind turbines in Central NYS, under different meteorological and seasonal conditions.

3. Evaluate public perceptions of operating wind turbines at residences and/or workplaces in the vicinity of wind projects in NYS, and determine if these perceptions are correlated with noise and/or non-noise factors.

4. Translate scientific findings into a policy-relevant paper.

This project addresses a number of knowledge gaps identified in the literature related to wind turbine noise. First, little published measurement data on wind turbine-related noise exists. This study characterized both sound pressure level and frequency of noise at an operating wind facility in NYS. Importantly, we investigated low frequency sound and a portion of the infrasound frequencies that have been hypothesized to play a role in noise-related complaints and certain health effects. The influence of environmental conditions on noise was evaluated, and a weather station was deployed concurrently with the noise monitoring equipment to enable such analyses.

Second, the literature regarding complaints or reported annoyance due to wind turbine noise is also sparse. Several cross-sectional Scandinavian studies have been conducted to attempt to correlate turbine noise to complaints or level of annoyance (Pedersen and Waye, 2004, 2007; Pedersen *et al.,* 2009); however, these have suffered from a lack of measured data and instead utilized manufacturer specifications in concert with modeling methodologies to estimate noise exposure at receptor locations. Our study included short-term sound measurements collected at residences to enable evaluation of any correlation between annoyance and sound levels. This direct measurement approach is a significant improvement over previous studies. Although these short-term measurements were brief in comparison to the four-day logging campaigns, this study did not include the very fine time resolution (less than one second) needed to characterize amplitude modulation, “thumping”, or other time-domain characteristics that are sometimes associated with wind turbine noise.

Additionally, this study investigated the concerns and experiences of the health effects of residents living in close proximity to wind turbines. A comprehensive review written by a panel of experts published in 2009 by the American Wind Energy Association and the Canadian Wind Energy Association (Colby *et al.,* 2009) indicates conflicting evidence in the existing literature regarding the purported health effects associated with wind turbines, including sleep disturbance, chronic stress, hypertension and heart disease. Infrasound and low frequency sound have been further associated with increased anxiety, depression, dizziness, nausea, headache, weakness, difficulty concentrating and gastrointestinal health effects. Furthermore, Francis *et al.,* (2012) determined there was no evidence present for the effect of calculated actual or non-specific symptoms. This study aimed to analyze the correlation between actual sound measurements collected inside and outside the residents’ homes with their self-reported health effects.

By studying an existing wind project in NYS, and individuals living in proximity to this project, coupled with the unique terrain and weather patterns, the project has generated results that are highly specific for this region of the country. Gaining an understanding of the factor(s) that may influence public perception near wind projects is the first step in developing strategies to mitigate these factors.

2.0 BACKGROUND AND OVERVIEW

A large, recently constructed wind turbine park in Western NYS was selected for the study. The utility operator did not elect to participate, so data on the wind park are limited to publically available information. The 126 megawatt (MW) wind park, located in Wethersfield, New York employs 84, 1.5 MW General Electric model 1.5sle turbines spanning approximately 19 square miles of rural farmland; the project began commercial operation in March 2009. Each turbine has a hub height of 80 meters (m) and a rotor diameter of 77 m. This model of turbine has a published maximum sound power wind speed of 9 meters per second (m/s) at hub height, above which noise output does not increase. According to the manufacturer (GE Wind Energy GmbH, 2005), this is equivalent to a maximum sound power wind speed of approximately seven m/s at a standardized ten m height (assuming a logarithmic wind profile with characteristic roughness of 0.03 m).

Extended noise monitoring was conducted at five receptor locations within the wind park, as well as at two locations removed from the wind park to provide comparison "no turbine" measurements. Each receptor location was on a residential property without a wind turbine or related infrastructure. This monitoring was conducted over three monitoring campaigns (August 2011, October 2011, and February 2012), each consisting of four days of continuous monitoring. Noise data were logged over contiguous ten-minute periods, with meteorological data (including wind speed and direction at ten meter height) logged over concurrent periods at one of the central receptor locations.

In addition to the noise monitoring, a cross-sectional survey among individuals living in the wind park was conducted. During the October 2011 campaign and a separate period in November 2011, questionnaires were administered to residents living within the wind park to assess the perception and prevalence of annoyance associated with living in close proximity to wind turbines. A limited set of questions was also administered regarding health effects related to the wind turbines. Lastly, short-term outdoor and indoor sound level measurements were performed at each dwelling in which a questionnaire was administered. Statistical analyses were performed to determine the nature of the association between the noise monitoring, short-term measurements, and questionnaire results.

3.0 METHODS

3.1 Measurement Procedures and Layout

Procedures for extended noise logging at the receptor locations were guided by the International Energy Agency Wind recommended practices for noise receptor immission measurements from operating wind turbines (Ljunggren, 1997). Certain aspects of the recommended practice, including direct measurement and subtraction of background noise with turbines parked, could not be followed due to lack of participation by the utility operator.

At each location, broadband sound pressure levels and one-third-octave band spectra from 6.3 Hertz (Hz) upward, including Leq (average sound pressure level) and statistical distribution were collected in ten-minute periods using a Class I sound level meter with a tripod-mounted microphone and hydrophobically treated 175 millimeter (mm) diameter foam windscreen. The large windscreen was chosen to provide greater immunity to wind-induced "pseudo-noise" or "self-noise" at high wind speeds and at low frequencies; published spectra for insertion loss and self-noise at various wind speeds (Hessler *et al.,* 2008; Hessler *et al.*, 2011) were incorporated into the data analysis.

Five noise-monitoring locations ("A" – "E") were selected by identifying parcels of residential property near one or more wind turbines, but without a turbine or infrastructure on the property itself. Individuals were given a $50 gift card to Wal-Mart to thank them for allowing us to use their land for monitoring. Figures 1−6 show the location of the monitoring locations. The distances from each monitoring location to the nearest wind turbine ranged from 219 m (720 feet) to 663 m (2,174 feet). The terrain surrounding the wind turbines is rural and used primarily for agricultural purposes with sparse stands of woods and small shrub growth.

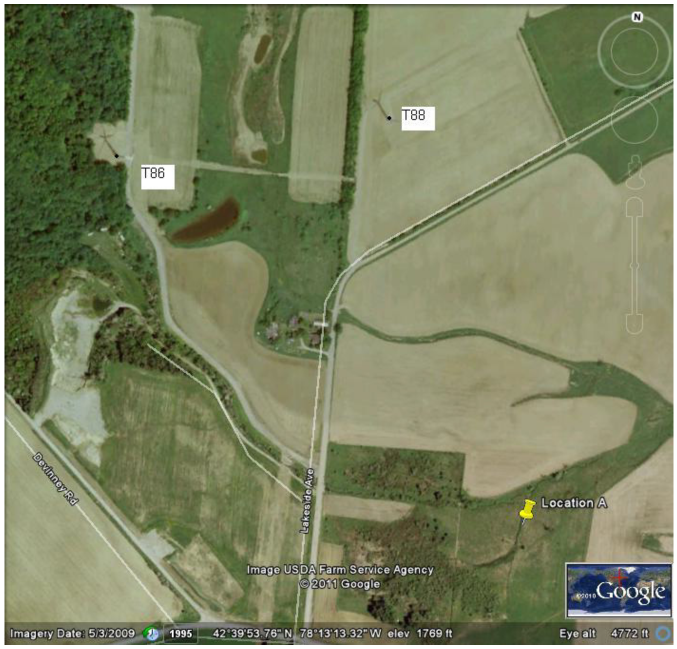

Figure 1. Monitoring Location A with respect to the nearest wind turbines.

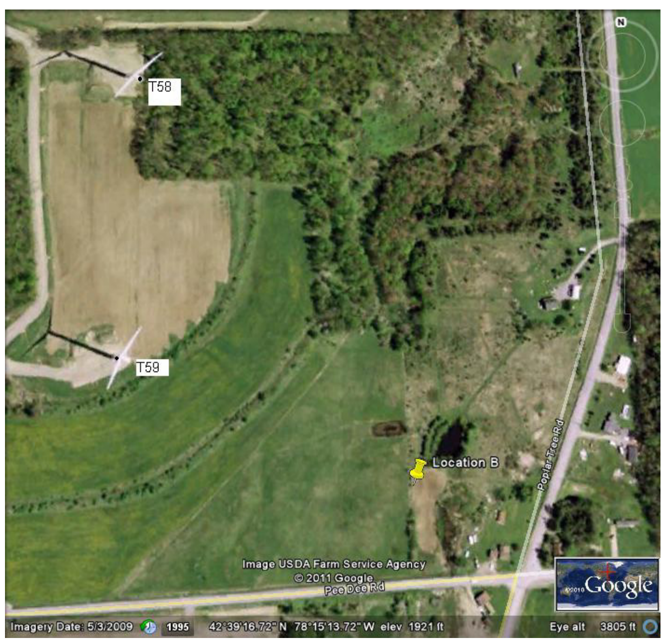

Figure 2. Monitoring Location B with respect to the nearest wind turbines.

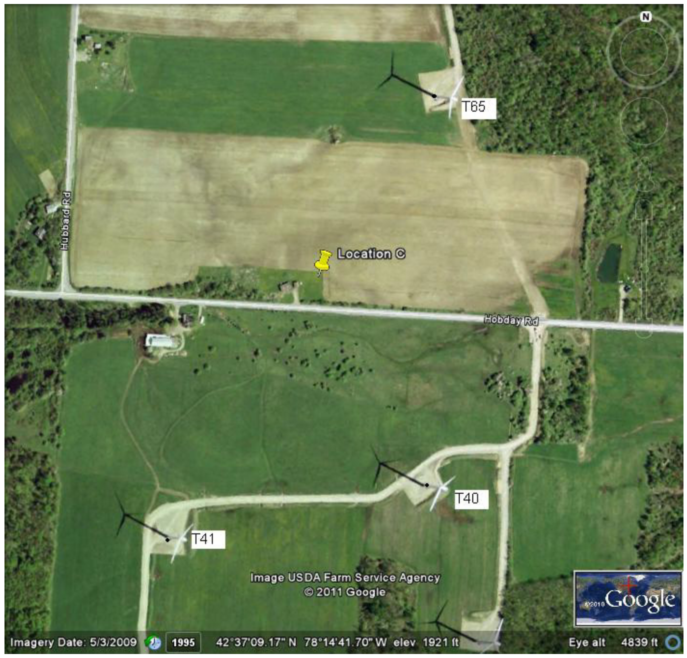

Figure 3. Monitoring Location C with respect to the nearest wind turbines.

Figure 4. Monitoring Location D with respect to the nearest wind turbines.

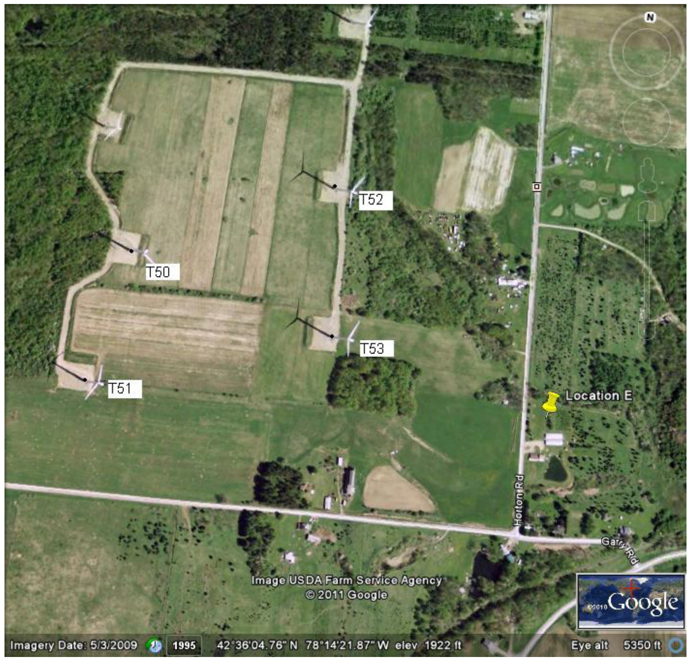

Figure 5. Monitoring Location E with respect to the nearest wind turbines.

Since background ambient noise monitoring could not be conducted within the wind park while the turbines were parked, two alternative locations were selected outside of the area. These "background" locations were selected with consideration for similar elevation, terrain, and proximity to roadways as the operational locations, with a minimum distance of 4.6 km (2.9 miles) from the nearest wind turbine. Figure 6 shows the location of the background monitoring locations compared to the turbine monitoring locations.

The selection and use of background location sites and data unintentionally varied slightly from campaign to campaign. After measurements had already been conducted during the summer campaign, the Background 2 location was deemed too close to a major roadway and was not representative of the other monitoring locations. Therefore, those measurements were not included as part of the analysis and an alternate background location was chosen for the fall and winter campaigns. During the winter campaign, equipment malfunction prohibited the use of the data from Background 1 in the analysis.

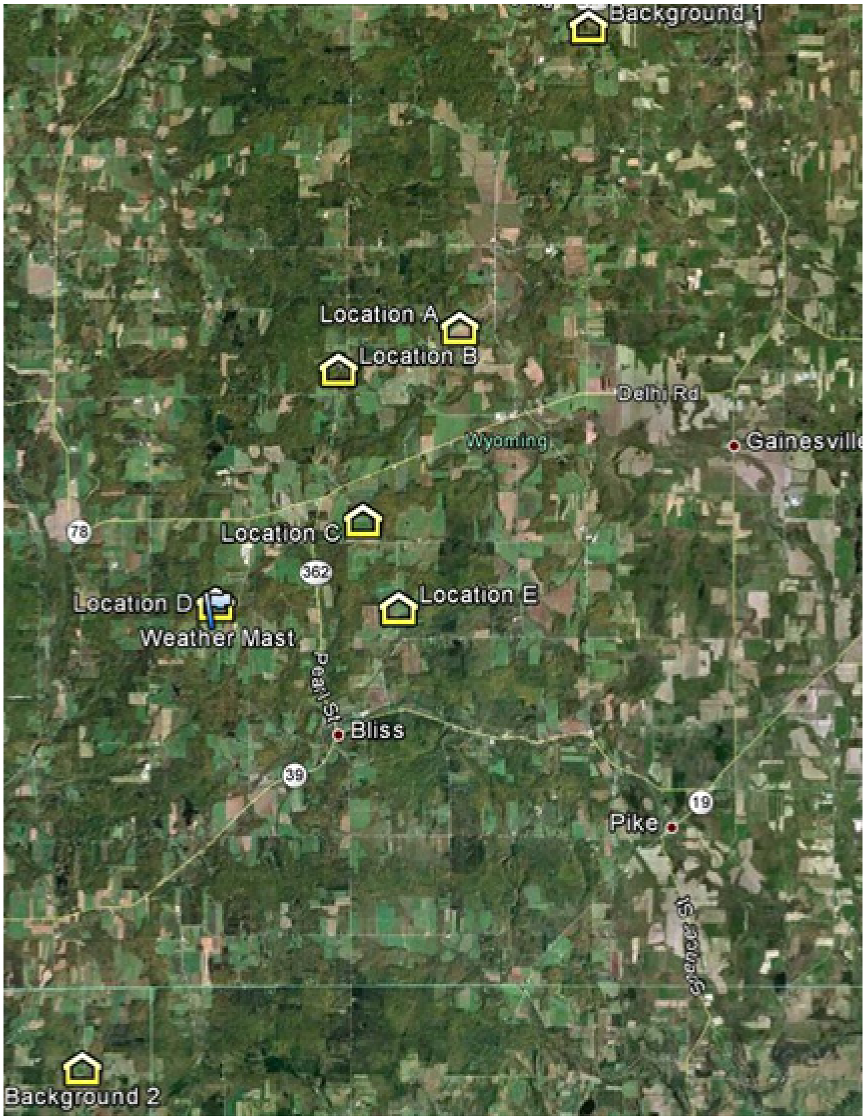

Figure 6. Turbine noise monitoring and weather station locations in the Wethersfield, NY area.

The monitoring locations along with the distance to the three closest turbines are summarized in Table 1 below.

Table 1. Distance to three nearest wind turbines from each of the five monitoring locations.

Monitoring Location ID	Distance to Nearest Three Turbines in Meters (feet)	Compass Direction From Monitoring Location
A	663 (2,174)	NW
	813 (2,666)	N
	856 (2,810)	WNW
B	305 (1,000)	WNW
	506 (1,660)	NW
	770 (2,527)	SSE
C	317 (1,041)	NNE
	345 (1,132)	SSE
	449 (1,472)	SSW
D	219 (720)	NW
	427 (1,400)	N
	666 (2,184)	W
E	421 (1,380)	WNW
	549 (1,800)	NNW
	789 (2,590)	W

Average wind speed, direction, and other weather conditions were logged in concurrent ten-minute intervals during the noise monitoring. A ten m tall wind mast was deployed for this purpose on the same property as monitoring Location D. Hand-held wind speed measurements at the microphone height were conducted intermittently at all monitoring locations for comparison with the wind speeds measured at the wind mast.

3.1.2 Instrumentation

Sound pressure level (SPL), logged on a ten-minute interval continuously for four days, was measured using the Larson Davis Model 831 Sound Level Meter (SLM) with Class-1 random incidence pre-polarized condenser microphone (50 milliVolts per Pascal (mV/Pa) nominal sensitivity) and preamplifier (PRM831). Monitoring parameters also included a one-third-octave band analyzer filter set and exceedance based logging analysis with the event, interval, and daily history. ACO Pacific Inc. seven-inch hydrophobic windscreens, Model WS7-80T, were positioned on all microphones atop an eight-foot tall tripod. The tripod unit stood adjacent to a weatherproof environmental enclosure, which housed the SLM and battery.

As an additional measure, the sound level meters at each monitoring location were programmed to trigger sound recording when a sound level of 60 decibels on the A weighted scale (dBA) occurred for three seconds or longer. Recording lasted until the sound level decreased below the 60 dBA threshold. The sound recordings were used to identify prominent extraneous noise sources outdoors in the monitoring area.

Sound recording was only performed during the October and February campaigns, as its importance had not been discovered until after the first campaign.

Average wind speed, wind direction, and other weather conditions were continuously logged on a ten-minute interval during the noise monitoring. A Davis Weather Station Wireless Vantage Pro2™ was deployed to a height of ten meters (30 feet) at monitoring Location D. Hand-held wind speed measurements with a Kestrel 4000 Weather Meter at microphone height (2.4 m) were conducted as described above.

3.2 Extended Noise Measurement Analysis

Analysis methods for the logged noise data were guided by the International Energy Agency (IEA) Wind recommended practice for immission measurements (Ljunggren, 1997). This method outlines a procedure where A-weighted Leq values (and optionally spectral values) are plotted against the concurrent wind speeds, with a best-fit line then applied to the resulting data scatter. However, in this case, direct subtraction of background values (to determine a turbine-only noise level) was not attempted, since direct background measurement at each receptor location was not possible. Values from the remote background sites are therefore presented only as a basis for comparison.

In this case, the raw data points were first examined for extraneous noises; where loud noise interference (such as thunder, gunshot, or immediate farm activity) was apparent in the data and could be positively identified through recorded audio samples, these data points were censored from further analysis. For consistency, an objective criterion was utilized for performing the data censorship. During the August monitoring campaign, ten-minute SPL averages were censored from the data set if the LAeq exceeded the LAS90 in the same ten-minute period by more than ten dBA. For the fall and winter monitoring campaign, ten-minute averages were excluded on the basis of extraneous noises recorded using the sound recording feature of the sound level meter. Comparison of LAeq and LAS90 values over the full monitoring period of August 2011 at Location B is illustrated in Figure 7. For reference purposes, the same plot for Background 1 during that campaign is provided in Figure 8.

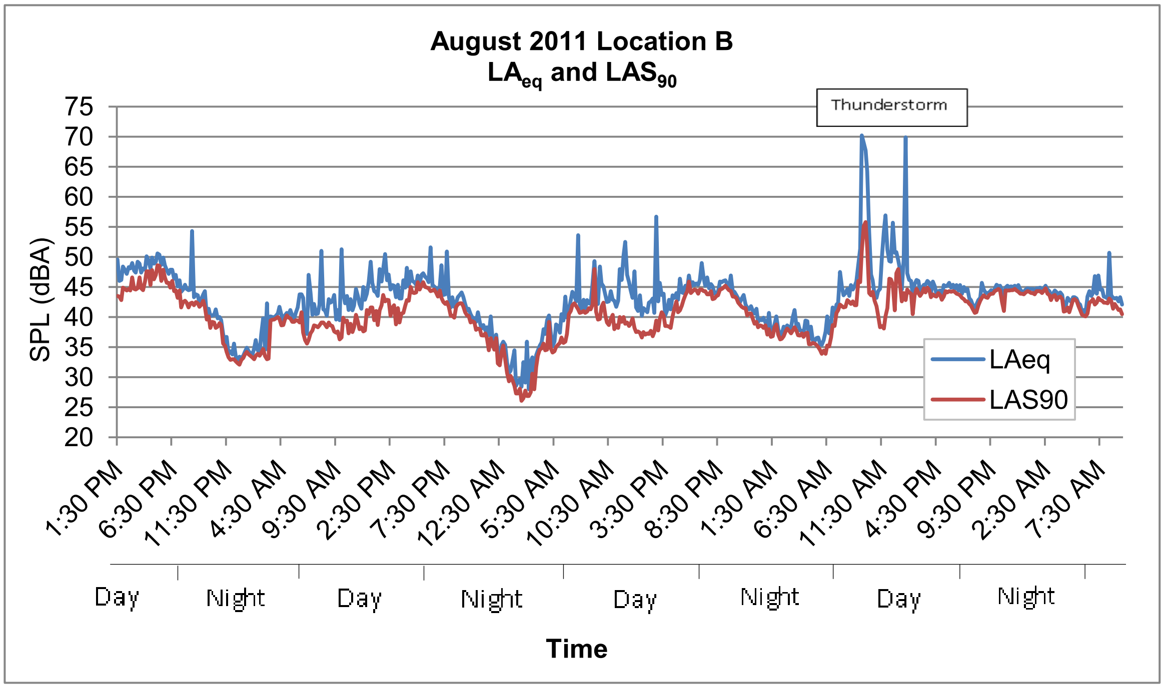

Figure 7. An example plot showing the LAeq and LAS90 measured levels for the continuous four-day monitoring period during the August 2011 campaign at Location B.

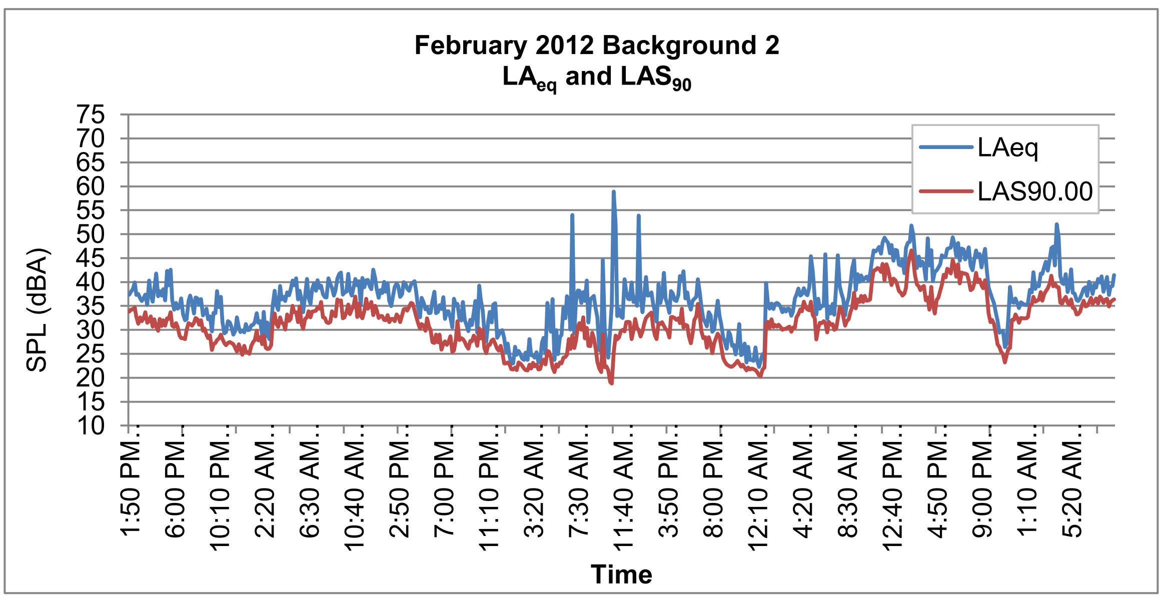

Figure 8. An example plot showing the LAeq and LAS90 measured levels for the continuous four-day monitoring period during the February 2012 campaign at Background 2.

The L90 is a conservative value for the background noise. For that reason, it is commonly used to designate background noise levels during turbine siting process and compliance purposes, as described in 2001 by the NYS Department of Environmental Conservation (DEC). For example, if during a ten-minute measurement there is gusty wind for nine of the minutes and one minute is calm and quiet, that single quiet minute will determine the L90 noise level. However, the ten-minute average wind speed and average (Leq) noise level will be almost totally determined by the more active nine minutes. Commonly, the L90 measure is used specifically for background noise monitoring because it is the quietest one-minute-in-ten when people are more apt to notice abnormal ambient noises. The LAeq is used predominantly in this study, as it is more representative of the entire sound profile over each ten-minute period.

One-third-octave band spectral Leq values for each period were then corrected for windscreen attenuation (Hessler *et al.*, 2008) and summed into three wide bands: an un-weighted Leq including 6.3 Hertz (Hz) through 16 Hz (representing an infrasound range), an un-weighted Leq including 20 Hz through 250 Hz (representing a low-frequency range), and an A-weighted LAeq including 6.3 Hz through 3150 Hz (a broadband A-weighted range). The highest frequencies were truncated from the LAeq frequency range to avoid substantial insect noise contribution during the summer campaign at 4 kHz and higher; the exclusion did not substantially affect the results in the remaining campaigns, when insect noise was not present. For the "infrasound" and "low frequency" wide bands, sound pressure levels were analyzed without A-weighting, as this weighting would discount their contribution to the sound profile. An example of an instantaneous, un-weighted, one-third-octave band spectra for frequencies between 6.3 Hz and 3150 Hz is shown in Figure 9. The sound pressure level peak centered at 125 Hz at the turbine location was audible and unquestionably was produced by the turbines present.

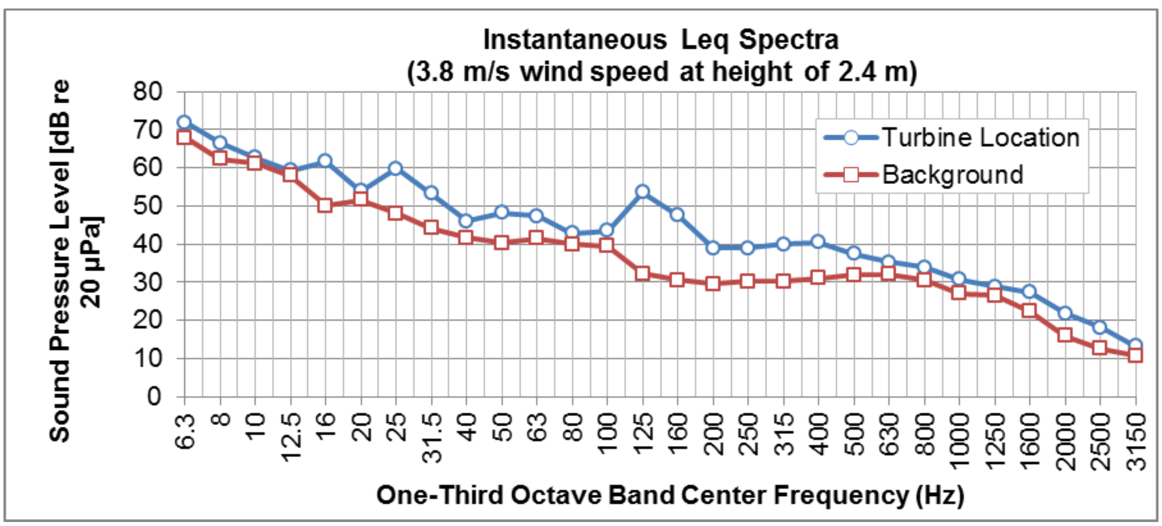

Figure 9. One-third-octave band spectra during winter campaign at Location D with a 3.8 m/s wind speed at 2.4 m.

For each data set, a best-fit first order line was plotted against the Leq versus wind speed scatter. A sample set is presented in Figure 10, for the A-weighted data set from Location D, Campaign 1.

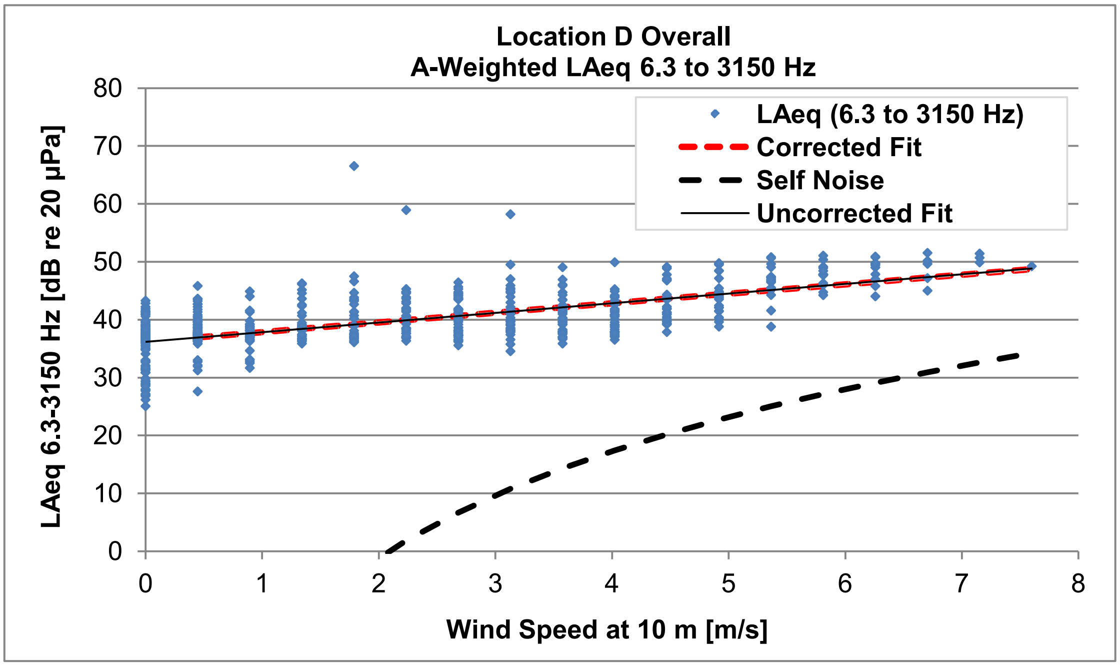

Figure 10. Location D, A-weighted data from Campaign 1, with best-fit line and best-fit line corrected for wind-induced self-noise.

These data are plotted along with the approximate wind-induced self-noise at the microphone, based on a logarithmic fit to the data of Hessler *et al.,* (2008) for the specific windscreen in use. Since self-noise is a function of wind speed at the microphone height (2.4 m), these microphone-height wind speed values are estimated from the measured wind speed at ten m using a logarithmic wind speed conversion (Ljunggren, 1997).

$$v_{2.4} = v_{10} \frac{\ln(2.4/z_0)}{\ln(10/z_0)}, \tag{1}$$

with the characteristic roughness z_0 taken as 0.05 m for farmland. The true wind profile may vary from the logarithmic approximation of equation (1), because local wind speed may vary with geographic distance from the single wind mast, and because the published self-noise values were obtained for steady airflow in a wind tunnel. Real wind may be variable or gusty, therefore the resulting self-noise values are approximate and likely represent a lower bound for the true contribution. Figure 8 also contains a "corrected fit" curve, which is the best-fit line corrected with a decibel subtraction of the corresponding self-noise values.

Following the above analysis methodology, Figure 11 presents the best-fit line to the same data (Location D, Campaign 1, A-weighted), compared with data from a background location (Background 1) during the same campaign. Both fit lines have been corrected for self-noise, as with most of the A-weighted data in this study, this self-noise correction was not substantial except at the very highest wind speeds.

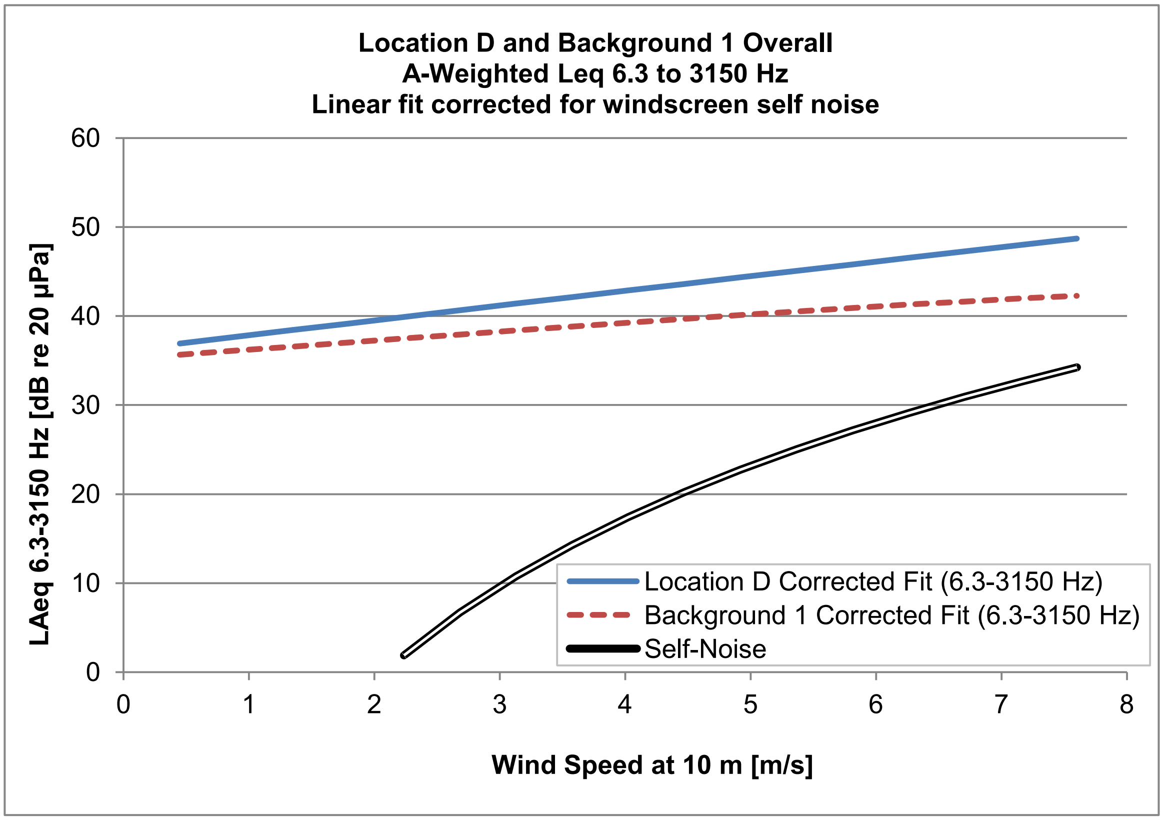

Figure 11. Self-noise corrected best-fit line for Location D, A-weighted data from Summer Campaign, with corrected best-fit line for Background 1.

To compare the measured hand-held wind speeds at microphone height to the wind speeds measured at ten meters, Equation 1 was utilized. Figures 12 and 13 illustrate the relationship between the measured wind speeds at both heights and the “expected” wind speeds extrapolated down to microphone height, for the summer and winter campaigns, based upon calculations with Equation 1.

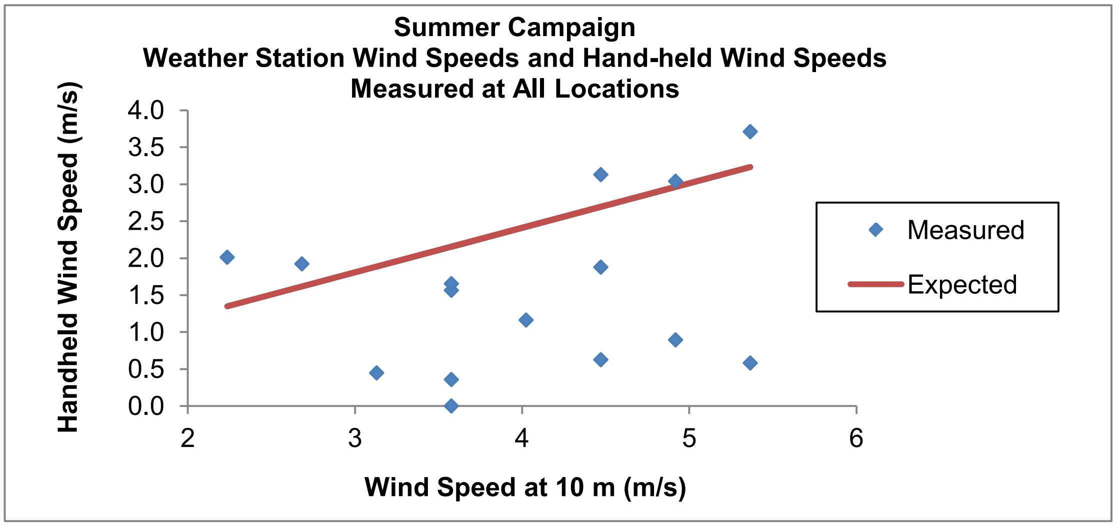

Figure 12. Measured hand-held and weather station wind speeds during the Summer Campaign

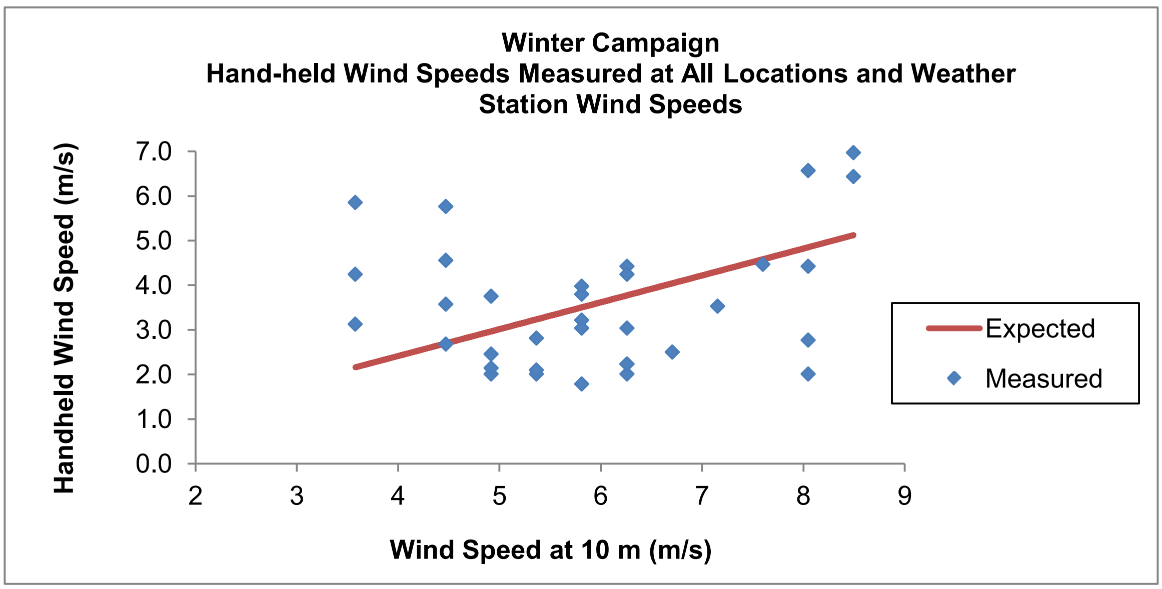

Figure 13. Measured hand-held and weather station wind speeds during the Winter Campaign.

During the summer campaign, the measured hand-held wind speeds were generally below the wind speeds that were "expected" from extrapolation of the ten m wind mast values. During the winter campaign, measured hand-held wind speeds were also generally near or below the "expected" speeds. Comparing the measured and expected wind speeds showed that overall, the measured microphone-level wind speeds were similar to or less than what would be expected from the wind mast values, which provides a more conservative and acceptable manner for estimating wind-induced microphone "pseudo noise" in this study.

3.3 Survey Development

A cross-sectional study was conducted among individuals living in the wind park. A questionnaire was developed to assess the perception and prevalence of annoyance associated with living in close proximity to wind turbines, along with a limited set of questions regarding health effects related to the wind turbines. The survey was primarily adapted from that developed by Pederson and colleagues (2004). A copy of the survey can be found in Appendix A. Individuals were left with documentation explaining the purpose of the survey and contact information, should they have any questions after the field personnel left. This documentation can be found in Appendix B.

3.4 Human Subjects Review

Institutional Review Board (IRB) review of the survey protocol and instrument was sought from Fox Commercial Institutional Review Board, Ltd., Springfield, IL to ensure that the participation of human subjects in this study was in compliance with applicable standards of care. Based on their review of the project, an exemption from IRB oversight was granted.

3.5 Survey Deployment

Surveys were administered in person to residents living within 28 square miles encompassing the 14 square miles of Noble contracted wind park area during the October 2011 monitoring campaign and again in November. Two field personnel conducted surveys and conducted sound level measurements in person over the course of the two trips. The days and times that surveys were deployed are summarized in Table 2.

Table 2. Summary of the days and times when the surveys were deployed.

Questionnaire Deployment	Dates	Days of the Week	Hours Administered
1	10/19/2011	Wednesday	5 p.m.− 7 p.m.
	10/20/2011 - 10/23/2011	Thursday, Friday, Saturday, Sunday	9 a.m. − 4 p.m.
2	11/8/2011 - 11/9/2011	Tuesday, Wednesday	9 a.m. − 4 p.m.

Residents were provided a brief summary of the project, along with project contact information and asked if they would like to participate. Documents handed out at the meeting can be found in Appendix C. Each session lasted approximately 20 minutes in duration. In a few instances, the questionnaire process lasted up to 40 minutes.

3.6 Short Duration Sound Level Monitoring In and Outside Homes

Sound level measurements were collected both inside and outside the survey respondents' home at the time the survey information was collected. Before performing the indoor sound level measurements, residents were asked to turn off or power down any indoor sources of noise including; televisions, radios, fans, and electric heating units. Even so, inevitable sources of noise such as children, pets, and general movement within the dwelling occurred frequently.

Outdoor and indoor SPL logged on a one-minute interval continuously for approximately ten minutes, was measured using the Larson Davis Model 831 Sound Level Meter (SLM) with Class-1 random incidence pre-polarized condenser microphone (50 mV/Pa nominal sensitivity) and preamplifier (PRM831). The 1-minute averaged interval did not allow for an assessment of the amplitude-modulated character of the turbines. However, monitoring parameters did include a one-third-octave band analyzer filter set. An ACO Pacific Inc. seven-inch windscreen, Model WS7-80T, was used during the measurements.

Instantaneous hand-held measurements were also conducted using a Kestrel 4000 Weather Meter at approximately 2.4 m above ground level for wind speed, temperature, relative humidity, and atmospheric pressure. At the time of the questionnaire deployment, the number of turbines visible from the resident's home was noted. All turbines visible in a 360° view from the residence were counted. Distances and compass directions varied from household to household. Distances from the surveyed households to the nearest turbine ranged from 1,035 feet (315 m) to 3,995 feet (1,205 m) with average distance of 1,922 feet (586 m) and standard deviation of 588 feet (179 m).

3.7 Statistical Analysis

All statistical analyses were performed using SPSS Version 11. Correlations between variables were calculated using Spearman's rank test. Differences between proportions were tested using the non-parametric Mann-Whitney U-test.

Verbal rating scale data and noise measurements were treated as continuous variables. Linear regression was used to explore the various environmental factors and measured sound pressure levels on predicting an individual's satisfaction with their living environment.

All statistical tests were two sided and p-values below 0.05 were considered statistically significant.

4.0 RESULTS

Sound level measurements were conducted in a series of three monitoring campaigns, each four days in duration, in August 2011, October 2011, and February 2012. Monitoring during three different seasons in Western NYS (summer, fall and winter) provided significant variation in environmental conditions, ground cover, and foliage density to explore.

Noise monitoring at two background and five locations in the turbine park were collected in ten-minute intervals continuously for four days. Monitoring results from each location are presented and discussed in three separate frequency bands: unweighted "infra" (6.3−16 Hz), unweighted "low" (20−250 Hz), and A-weighted "overall" (6.3−3150 Hz). Figures summarizing the monitoring results by campaign, monitoring location, and frequency band are provided in Appendix C. Distances from each monitoring location to the nearest wind turbines varied from location to location. The monitoring locations along with the distance to the three closest turbines, and the resulting approximate turbine noise immission level relative to Location D, the single location with the closest turbine, are summarized in Table 3.

Table 3. Distance from each monitoring location to three nearest turbines.

Monitoring Location ID	Distance to Nearest Three Turbines in Meters (feet)	Immission Relative to Location D (Equation 2)
A	663 (2,174) 813 (2,666) 856 (2,810)	- 7.4 dB
B	305 (1,000) 506 (1,660) 770 (2,527)	- 2.5 dB
C	317 (1,041) 345 (1,132) 449 (1,472)	- 0.9 dB
D	219 (720) 427 (1,400) 666 (2,184)	- 0.0
E	421 (1,380) 549 (1,800) 789 (2,590)	- 4.0 dB

This estimate assumes spherical, omnidirectional sound propagation from identical point sources, with an omnidirectional wind. With these assumptions, the expected relative immission level $L_i - L_{i,ref}$ in decibels as a function of the distances to the nearest turbines (r_1, r_2, r_3) can be reduced to:

$$L_i - L_{i,ref} = 10\log\left(\frac{1}{r_1^2} + \frac{1}{r_2^2} + \frac{1}{r_3^2}\right) - 10\log\left(\frac{1}{r_{1,ref}^2} + \frac{1}{r_{2,ref}^2} + \frac{1}{r_{3,ref}^2}\right). \quad (2)$$

Since real turbines are directive with wind and only one wind direction is possible at a time, and since atmospheric conditions do not always support spherical propagation, the relative immission of Table 3 are a substantial simplification intended only for approximate ranking of the receptors.

4.1 Summer Campaign

4.1.1 Weather Data Summary

At ten meters, ten-minute wind speeds ranged from 0.0 m/s to 7.6 m/s with a maximum wind speed of 11.6 m/s. Temperatures ranged from 12°C to 26°C with relatively little precipitation. Figure 14 shows the dense leaf cover on the trees and shrubs in the area surrounding the monitoring locations and turbines.

Figure 14. Photograph at Location D illustrating full leaf coverage on trees and shrubs during the August 2011 campaign.

4.1.2 Infra Noise (6.3 Hz – 16 Hz, Unweighted)

Location D exhibited the highest ten-minute average sound pressure level of 83.1 dB with a ten-minute average wind speed of 7.2 m/s. As shown in Table 3, this location had the closest proximity to a turbine and is therefore expected to have the greatest noise exposure in general. The lowest sound pressure of 36.2 dB was measured at Location E with an average wind speed of 0 m/s. Location E also experienced a greater impact from wind screen self-noise as wind speeds approached three m/s (Figure C1 in Appendix C) potentially caused by low noise levels with shielding from the dense wooded area located between the monitoring location and the nearest turbines. All other monitoring locations had sound pressure levels that appeared not to be impacted by the windscreen self-noise (Figures C2 – C6 in Appendix C). Ambient sound pressure levels at one background location during this campaign also were not great enough to exceed the windscreen self-noise as wind speed approached three m/s. A decision was made to only use data from one of the background locations (Background 1) during this monitoring campaign because the second location was deemed too close to the road and considered not representative of the wind turbine setting.

The best fit, first order line was fit to the field data to calculate sound pressure levels at seven m/s, the speed above which the turbine sound power does not increase further. As summarized in Table 4, at seven m/s, Locations A through D were greater than the background location.

Table 4. Summer sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s at ten meters for the unweighted "infrasound" frequency band. Windscreen self-noise under the same conditions is shown for comparison.

Monitoring Location	Leq at 7 m/s [dB re 20 μPa]	Windscreen Self-Noise [dB re 20 μPa]
Background 1	73.5	73
A	81.9	73
B	78.8	73
C	77.6	73
D	82.8	73
E	72.4	73

μPa – micro Pascal

Location E was lower than the measured background level. Location D, with a SPL of 82.8 dB, was the highest compared to 73.5 dB at the background.

4.1.3 Low Frequency Noise (20 Hz – 250 Hz, Unweighted)

Within the band selected for low frequency, ten-minute average SPLs ranged from 74.6 dB with a corresponding wind speed of 7.2 m/s at Location D to a SPL of 33.1 dB with a wind speed of 0 m/s at Location E. For this particular frequency band, Location D was the only monitoring location that was not impacted by the windscreen self-noise at all wind speeds (Figure C7 and C8 in Appendix C). Above wind speeds of five m/s, SPLs at all other monitoring locations in the turbine park did not exceed the windscreen self-noise (Figures C9−C12 in Appendix C). Similarly, the background location also exhibited self-noise interference.

Again, the best fit, first order line was fit to the field data to calculate sound pressure levels at seven m/s, the speed above which the turbine sound power does not increase further. Using this equation, sound pressure levels at seven m/s were calculated and are summarized in Table 5.

Table 5. Summer sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s at ten meters for the unweighted "low frequency" band. Windscreen self-noise under the same conditions is shown for comparison.

Monitoring Location	Leq at 7 m/s [dB re 20 μPa]	Windscreen Self-Noise [dB re 20 μPa]
Background 1	61.2	61
A	64.7	61
B	64.7	61
C	63.3	61
D	67.1	61
E	61.5	61

μPa – micro Pascal

All monitoring locations were greater than the background location. Location D, again with a SPL of 67.1 dB, was the highest compared to 61.2 dB calculated at the background location. Sound pressure levels at this frequency range for each integer wind speeds 0.0 m/s to seven m/s are provided in Appendix D.

4.1.4 Select Band Noise (6.3 Hz – 3150 Hz, A-weighted)

For the select band covering a larger range of relevant frequencies, Location D had the highest ten-minute average SPL of 51.5 dBA at a wind speed of 6.7 m/s. The lowest ten-minute average SPL, 20.1 dBA, was measured at 0.0 m/s at Location E. Windscreen self-noise was not significant as it was in the other two, un-weighted lower frequency bands explored. At lower wind speeds, Location D was the only monitoring location that continuously exceeded the background location (Figure C13 and C14 in Appendix C). All other monitoring locations were exceeded by the background location at lower wind speeds (Figure C15−C18 in Appendix C).

Again, a first order line was fit to the field data to calculate sound pressure levels at seven m/s, the speed above which the turbine sound power does not increase further. Using this equation, the sound pressure levels at seven m/s were calculated. As summarized in Table 6, all monitoring locations were greater than the background location.

Table 6. Summer sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s for the A-weighted "select" frequency band. Windscreen self-noise under the same conditions is shown for comparison.

Monitoring Location	LAeq at 7 m/s [dBA re 20 μPa]	Windscreen Self-Noise [dBA re 20 μPa]
Background 1	42.3	32
A	44.8	32
B	47.7	32
C	48.2	32
D	47.9	32
E	46.3	32

μPa – micro Pascal

Location C, with a SPL of 48.2 dBA was the highest at this wind speed compared to a SPL of 42.3 dBA at the background location.

4.2 Fall Campaign

4.2.1 Weather Summary

Average ten-minute wind speeds at ten meters ranged from 0.0 m/s to 9.4 m/s with a maximum of 15.6 m/s. Temperatures ranged from 2°C to 19°C. Occasional periods of moderate to heavy rain occurred during half of the monitoring period with heavy cloud cover. Figure 15 shows that most of the foliage on the trees had fallen and other vegetation was dying back.

Figure 15. Photograph illustrating lack of foliage on trees and shrubbery during the mid-October monitoring campaign.

4.2.2 Infra Noise (6.3 Hz – 16 Hz, Unweighted)

Location D exhibited the highest ten-minute average sound pressure level of 85.6 dB with a ten-minute average wind speed of 7.6 m/s. The lowest sound pressure level of 46.4 dB was measured at Location E with an average wind speed of 0 m/s. Location E also experienced a greater impact from windscreen self-noise as wind speeds approached five m/s (Figure C19 in Appendix C). All other monitoring locations had sound pressure levels that were not impacted by the windscreen self-noise (Figures C20 – C23 in Appendix C). As wind speeds increased above nine m/s, ten-minute average sound pressure levels for all monitoring locations exceeded 80 dB. Location D exceeded 90 dB at wind speeds over nine m/s (Figure C24 in Appendix C).

During this monitoring campaign two background-monitoring locations were deployed successfully. Ambient sound pressure levels at Background 1 were not great enough to exceed the windscreen self-noise as wind speed approached four m/s. Background 2 sound level measurements were impacted by windscreen self-noise as wind speeds approached approximately two m/s.

Using the best-fit first order line, also performed in the first campaign, the sound pressure levels at seven m/s in the infra frequency range were derived. As summarized in Table 7, Locations A through E were greater than the background location.

Table 7. Sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s for the unweighted "infrasound" frequency band.

Monitoring Location	Leq at 7 m/s [dB re 20 μPa]	Windscreen Self-Noise [dB re 20 μPa]
Background 1	74.6	73
Background 2	65.5	73
A	79.3	73
B	79.0	73
C	78.6	73
D	80.9	73
E	75.4	73

μPa – micro Pascal

Monitoring Location D had the highest sound pressure level at seven m/s. At 80.9 dB, Location D exceeded the level at Background 2 by over 15 dB. Background 1 and Background 2 had a difference of 9.1 dB.

4.2.3 Low Frequency Noise (20 Hz – 250 Hz, Unweighted)

Within the band selected for low frequency, ten-minute average SPLs ranged from 73.0 dB with a corresponding wind speed of eight m/s at Location D to a SPL of 44.1 dB with a wind speed of 0.0 m/s at Location E. Windscreen self-noise became a factor at a wind speed of seven m/s at Location E and above nine m/s at Location A (Figures C25 and C26 in Appendix C). At the background monitoring locations, windscreen self-noise became apparent near wind speeds of four m/s at Background 1 and near six m/s at Background 2. (Figures C27 − C29 in Appendix C). Furthermore, sound pressure levels at all five monitoring locations were greater than both background locations at all wind speeds measured during the campaign (Figure C30 in Appendix C).

As previously stated, the best fit first order line was fit to the field data to calculate sound pressure levels at seven m/s, the speed above which the turbine sound power does not increase further. Using this equation, sound pressure levels at seven m/s were calculated and are summarized in Table 8.

Table 8. Sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s for the unweighted "low frequency" band.

Monitoring Location	Leq at 7 m/s [dB re 20 μPa]	Windscreen Self-Noise [dB re 20 μPa]
Background 1	63.3	61
Background 2	55.3	61
A	66.2	61
B	67.7	61
C	67.4	61
D	68.5	61
E	64.9	61

μPa – micro Pascal

All monitoring locations were greater than the background location. Location D, again with a SPL of 68.5 dB, was the highest compared to 63.3 dB and 55.3 at Background 1 and 2, respectively.

4.2.4 Select Band Noise (6.3 Hz – 3150 Hz, A-weighted)

For the select band covering a larger range of relevant frequencies, Location D had the highest ten-minute average SPL of 54.5 dBA at a wind speed of 7.2 m/s. The lowest ten-minute average SPL, 35.0 dBA, was measured at 0.0 m/s at Location E. Windscreen self-noise was not a factor as it was in the other two, un-weighted frequency bands explored (Figures C31 − C35 in Appendix C). Distinct differences between monitoring locations and the background locations were not as apparent as the previous monitoring campaign. It was not until wind speeds exceeded approximately nine m/s that each monitoring location in the turbine park had a greater sound pressure level than the background monitoring locations (Figure C36 in Appendix C).

As previously stated, a first order line was fit to the field data to calculate sound pressure levels at seven m/s. As summarized in Table 9, all monitoring locations except for Location A were greater than both background locations. Location A was not greater than either background location.

Table 9. Sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s for the A-weighted "select" frequency band.

Monitoring Location	LAeq at 7 m/s [dBA re 20 μPa]	Windscreen Self-Noise [dBA re 20 μPa]
Background 1	47.9	32
Background 2	47.8	32
A	47.7	32
B	50.5	32
C	51.4	32
D	51.3	32
E	50.0	32

μPa – micro Pascal

Location C, with a SPL of 51.4 dBA was the highest at this wind speed compared to a SPL of 47.8 dBA and 47.9 dBA at Background 1 and 2, respectively.

4.3 Winter Campaign

4.3.1 Weather Data Summary

The winter campaign exhibited the highest sustained wind speeds with a maximum ten-minute average of 12.1 m/s with a maximum speed of 17.9 m/s. Temperatures ranged from −13°C to 1°C with steady moderate snowfall. As seen in Figure 16, approximately 0.3 m of snowfall accumulated during 24 hours of the monitoring period.

Figure 16. Snowfall accumulation during 24 hours of the February monitoring period.

4.3.2 Infra Noise (6.3 Hz – 16 Hz, Unweighted)

Location D exhibited the highest ten-minute average sound pressure level of 86.5 dB with a ten-minute average wind speed of 7.6 m/s. The lowest sound pressure level of 46.0 dB was measured at Location E with an average wind speed of 0 m/s. Location E also experienced a greater impact from windscreen self-noise as wind speeds approached five m/s, similar to the fall campaign. All other monitoring locations had sound pressure levels that were not impacted by the windscreen self-noise at all wind speeds (Figures C37 – C40 in Appendix C). Location E was impacted by windscreen self-noise between five m/s and eight m/s. At wind speeds greater than eight m/s, windscreen self- noise was not an issue (Figure C41 in Appendix C). As wind speeds increased above nine m/s, ten-minute average sound pressure levels for all monitoring locations exceeded 90 dB except for Location E, which exceeded 90 dB near 11 m/s. At 12 m/s, Location C and Location D approached 100 dB (Figure C42 in Appendix C).

During this monitoring location, Background 2 was the only background location used in the analysis due to a microphone malfunction during the monitoring period. Background 2 sound level measurements were impacted by windscreen self-noise as wind speeds approached approximately three m/s.

Using the best fit first order line, also performed in the summer and fall campaign, the sound pressure levels at seven m/s in the infra frequency range were explored. As summarized in Table 10, all monitoring locations were greater than the background location at this frequency band.

Table 10. Sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s for the unweighted "infra" frequency band.

Monitoring Location	Leq at 7 m/s [dB re 20 μPa]	Windscreen Self-Noise [dB re 20 μPa]
Background 2	70.5	73
A	77.3	73
B	77.9	73
C	80.4	73
D	79.4	73
E	74.8	73

μPa – micro Pascal

4.3.3 Low Frequency Noise (20 Hz – 250 Hz, Unweighted)

Within the band selected for low frequency, ten-minute average SPLs ranged from 75.8 dB with a corresponding wind speed of 7.6 m/s at Location D to a SPL of 43.1 dB with a wind speed of 0.0 m/s at Location E. Windscreen self-noise became a factor at a wind speed of six m/s at Location E and above seven m/s at Location A (Figures C43 and C44 in Appendix C). At the background monitoring location, windscreen self-noise became apparent for wind speeds greater than four m/s (Figures C45 − C47 in Appendix C). Sound pressure levels at all five monitoring locations were greater than the background location sound pressure levels at all wind speeds measured during the campaign (Figure C48 in Appendix C). During wind speeds greater than 11 m/s, monitoring Locations B, C, and D exceeded 80 dB.

The best-fit first order line was fit to the field data to calculate sound pressure levels at seven m/s. Using this equation, sound pressure levels at seven m/s were calculated and are summarized in Table 11.

Table 11. Sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s for the unweighted "low" frequency band.

Monitoring Location	Leq at 7 m/s [dB re 20 μPa]	Windscreen Self-Noise [dB re 20 μPa]
Background 2	56.5	61
A	65.0	61
B	67.0	61
C	70.3	61
D	69.2	61
E	64.0	61

μPa – micro Pascal

All monitoring locations were at least 7.5 dB greater than the background location. Location C, with a SPL of 70.3 dB, was the highest compared to the 56.5 dB at the background location.

4.3.4 Select Band Noise (6.3 Hz – 3150 Hz, A-weighted)

For the select band covering a larger range of relevant frequencies, Location D had the highest ten-minute average SPL of 53.7 dBA at a wind speed of 9.4 m/s. The lowest ten-minute average SPL, 27.9 dBA, was measured at 0.0 m/s at Location E. Windscreen self-noise was not a factor at any monitoring location; however, did impact the background location as wind speeds increased above 11 m/s (Figures C49 − C53 in Appendix C). All monitoring locations in the turbine park measured sound pressure levels that exceeded 50 dBA at various wind speeds. Comparison to a specific sound pressure level of 50 dBA has relevance and is discussed later on. Locations C and D exceeded the 50 dBA threshold at approximately six m/s while all other locations exceeded 50 dBA with wind speeds above wind speeds of seven m/s. Additionally, Locations C and D measured A-weighted sound pressure levels of 60.5 dBA and 60.0 dBA during ten-minute average wind speeds approaching 12 m/s (Figure C54 in Appendix C).

Again, a first order line was fit to the field data to calculate sound pressure levels at seven m/s. As summarized in Table 12, all monitoring locations were greater than the background location.

Table 12. Sound pressure levels for all locations derived from the equation of the first order curve at a wind speed of seven m/s for the A-weighted "select" frequency band.

Monitoring Location	LAeq at 7 m/s [dBA re 20 μPa]	Windscreen Self-Noise [dBA re 20 μPa]
Background 2	41.2	32
A	45.9	32
B	49.9	32
C	51.6	32
D	51.5	32
E	48.2	32

μPa – micro Pascal

Location C, with a SPL of 51.6 dBA was the highest at this wind speed compared to a SPL of 41.2 dBA at Background 2. Sound pressure levels calculated at seven m/s using the first order best fit curve for this winter monitoring campaign follows the same pattern as the summer and fall campaigns. As the distances to the nearest turbines increased (Table 3), the LAeq at a seven m/s wind speed decreases in the same order.

4.4 Comparison of All Campaigns

The changes in environmental conditions that occurred from season to season during each noise monitoring campaign provided a relatively accurate picture of the typical weather variations in Western NYS. Temperatures during the August 2011 monitoring remained mild through the day and night, with the lowest wind speeds compared to the other two campaigns. Greater fluctuation between the day and night occurred during the October 2011 campaign with slightly greater wind speeds overall under mostly cloudy skies and frequent rain showers. During the winter campaign, temperatures rarely peaked above freezing, coinciding with extended periods of high winds and snow squalls. Measured wind speeds at ten meters varied between campaigns. Wind direction also varied between campaigns, and as expected, the direction occurring at the highest percentage in each campaign was westerly (Table 13).

Table 13. Wind speeds measured at ten meters during the summer, fall, and winter monitoring campaigns.

Monitoring Campaign	Wind Speed (m/s)		Predominant Wind Direction	Amount of time from direction (%)
	Overall Average (sd)	Maximum 10-Minute Average		
August 2011	2.3 (1.9)	7.6	W	20
October 2011	3.8 (2.6)	9.4	WSW	34
February 2012	5.3 (2.6)	12.1	WNW	44

sd – standard deviation

To further demonstrate the prevailing wind direction, the sound pressure level compared with wind direction was plotted at seven m/s for Location D during the winter campaign. Figure 17 reveals that during the winter campaign at a wind speed of seven m/s, the wind direction remained relatively consistent from the west and west-northwest, making evaluation of wind directivity effects (upwind versus downwind) difficult. As shown in Table 1, the nearest turbine to this location was to the northwest, with the next two to the north and to the west; Figure 17 therefore shows that this measurement location was almost always close to downwind from the turbines at this wind speed.

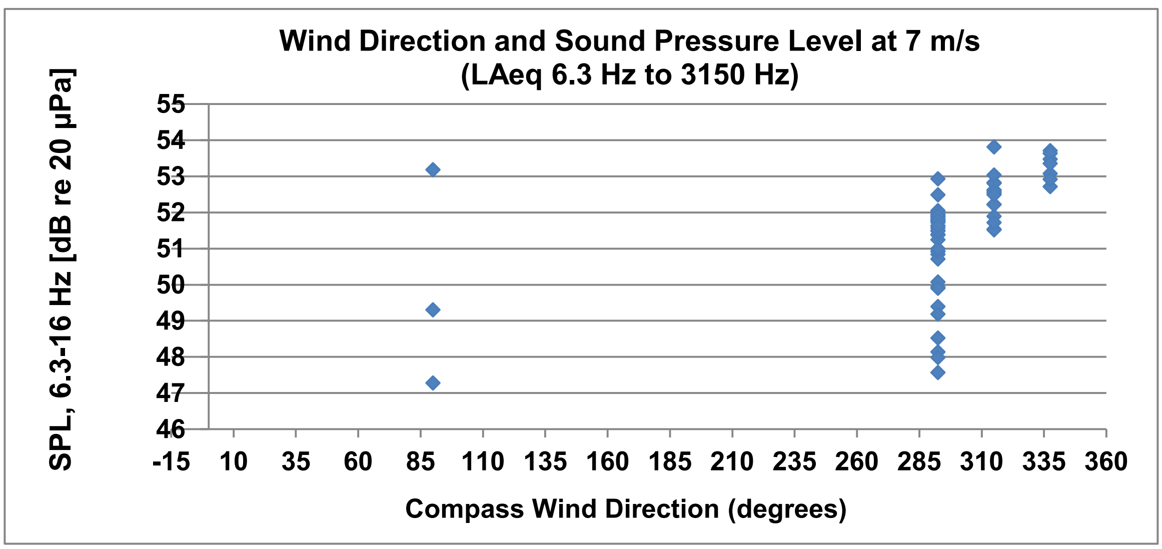

Figure 17. Wind direction and sound pressure levels at a seven m/s wind speed at Location D during the winter campaign calculated using the equation of the best-fit line for the A-weighted select frequency band.

During the four days of noise monitoring in February, the maximum ten-minute average wind speed was 12.1 m/s, higher than the wind speeds of 9.4 m/s and 7.6 m/s for October and August, respectively. The overall average wind speed of 5.3 m/s in February also exceeded the 3.8 m/s average in October and 2.3 m/s average in August.

4.4.1 Infra Noise (6.3 Hz – 16 Hz, Unweighted)

Variation and trends between campaigns were not consistent at the lowest frequency range. Sound pressure levels at all locations had greater variation between monitoring campaigns at lower wind speeds (Figures C55 – C58 in Appendix C). Location C had sound pressure levels with similar slopes for each campaign as wind speeds increased (Figure C59 in Appendix C). Though both background locations were impacted by windscreen self noise, Background 1 exhibited higher sound pressure levels during the fall monitoring compared to the summer monitoring, and Background 2 exhibited higher sound pressure levels during the winter monitoring compared to the fall monitoring campaign (Figure C60 and C61 in Appendix C).

Using the best-fit line equation calculated at a wind speed of seven m/s, sound pressure levels decreased from the summer, to the fall, to the winter at Location A and Location D. It is important to note, however, that wind speeds during the summer campaign rarely exceeded seven m/s compared to the other two campaigns with higher wind speeds. At Location C, the opposite trend occurred. As summarized in Table 14 and Figure 18, sound pressure levels increased from the fall to the winter monitoring with sound pressure levels of 77.6 dB, 78.6 dB, and 80.4 dB, respectively.

Table 14. Sound pressure levels at a seven m/s wind speed for the August, October, and February monitoring campaigns calculated using the equation of the best-fit line for the unweighted infra noise frequency band.

Monitoring Location	Infra (6.3 Hz to 16 Hz, unweighted) Leq at 7 m/s [dB re 20 µPa]		
	August 2011	October 2011	February 2012
Background 1	73.5	74.6	ND
Background 2	ND	65.5	70.5
A	81.9	79.3	77.3
B	78.8	79.0	77.9
C	77.6	78.6	80.4
D	82.8	80.9	79.4
E	72.4	75.4	74.8

µPa – micro Pascal
ND – no data

At Locations B and E, the highest sound pressure levels were measured during the October campaign. The Background 2 location sound pressure levels increased five dB from the fall to the winter campaign, but remained below the windscreen self-noise threshold.

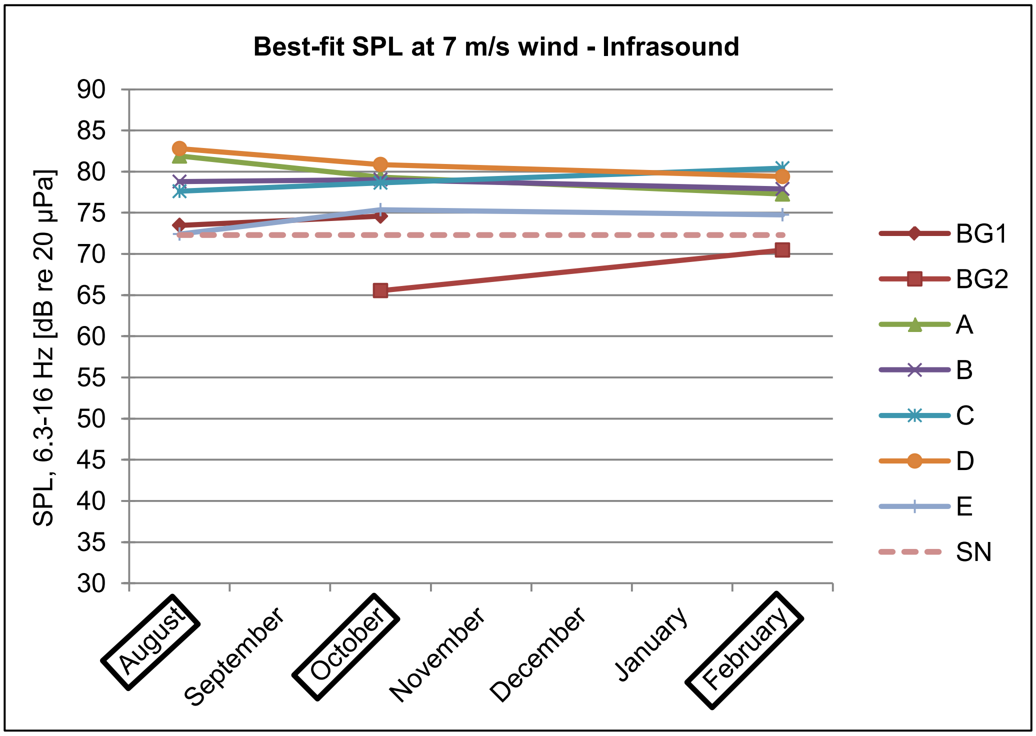

Figure 18. Sound pressure levels at a seven m/s wind speed for the August, October, and February monitoring campaigns calculated using the equation of the best-fit line for the unweighted infra frequency range (SN - self-noise).

4.4.2 Low Frequency Noise (20 Hz – 250 Hz, Unweighted)

Monitoring Location D was the only location in the turbine park not impacted by windscreen self-noise at any point in time during all three monitoring campaigns at the low frequency band (Figures C62 – C66 in Appendix C). Both background locations exhibited similar sound pressure levels between wind speeds of one m/s and 4 m/s during their respective monitoring campaigns (Figures C67 and C68 in Appendix C).

Using the equation of the best-fit line at seven m/s, the calculated sound pressure levels at Location C and Location D were the only turbine locations that increased from the summer, to the fall, and to the winter (Table 15 and Figure 19).

Table 15. Sound pressure levels at a seven m/s wind speed for the August, October, and February monitoring campaigns calculated using the equation of the best-fit line for the unweighted low frequency band.

Monitoring Location	Low Frequency (20 Hz to 250 Hz, unweighted) Leq at 7 m/s [dB re 20 µPa]		
	August 2011	October 2011	February 2012
Background 1	61.2	63.3	ND
Background 2	ND	55.3	56.5
A	64.7	66.2	65.0
B	64.7	67.7	67.0
C	63.3	67.4	70.3
D	67.1	68.5	69.2
E	61.5	64.9	64.0

µPa – micro Pascal
ND – no data

The other three turbine monitoring locations (Locations: A, B, E) produced sound pressure levels that also increased from the summer to the fall, but then decreased during the winter. Background 1 increased from 61.2 dB to 63.3 dB from the summer to the fall and Background 2 increased from 55.3 dB to 56.5 dB from the fall to the winter.

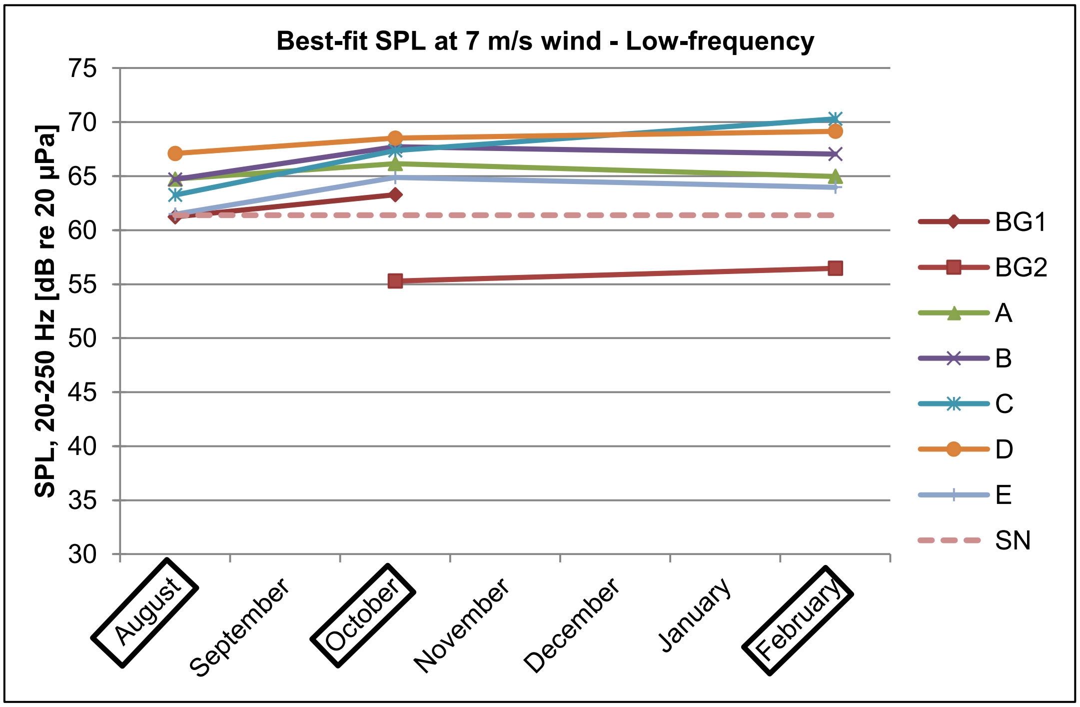

Figure 19. Sound pressure levels at a seven m/s wind speed for the August, October, and February monitoring campaigns calculated using the equation of the best-fit line for the unweighted low frequency range (SN − self-noise).

4.4.3 Select Band Noise (6.3 Hz – 3150 Hz, A-weighted)

Monitoring Locations C and D exhibited similar trends of sound pressure levels during the fall and winter monitoring campaigns (Figure C67 and C68 in Appendix C). Though the fall campaign did not have wind speeds as high as the winter campaign, the figures provide evidence that if wind speeds were higher, the sound pressure levels may remain similar to the winter results. At monitoring Locations A, B, and E, the fall sound pressure levels generally exceed the other two campaigns at each corresponding wind speed. However, as wind speeds increased above approximately eight m/s, sound pressure levels during the winter campaign began to exceed fall at Location B (Figures C69 – C71 in Appendix C). At both Background 1 and Background 2, the fall sound pressure levels exceeded the summer levels and winter levels at the respective locations (Figures C72 and C73 in Appendix C).

Similar to the low frequency sound pressure levels, using the equation of the best-fit line at seven m/s, the calculated sound pressure levels at Location C and Location D were the only turbine locations that increased from the summer, to the fall, and to the winter (Table 16 and Figure 20).

Table 16. Sound pressure levels at a seven m/s wind speed for the August, October, and February monitoring campaigns calculated using the equation of the best-fit line for the A-weighted select frequency band.

Monitoring Location	Select Band (6.3 Hz to 3150 Hz, A-weighted) Leq at 7 m/s [dBA re 20 µPa]		
	August 2011	October 2011	February 2012
Background 1	42.3	47.9	ND
Background 2	ND	47.8	41.2
A	44.8	47.7	45.9
B	47.7	50.5	49.9
C	48.2	51.4	51.6
D	47.9	51.3	51.5
E	46.3	50.0	48.2

µPa – microPascals
ND – no data

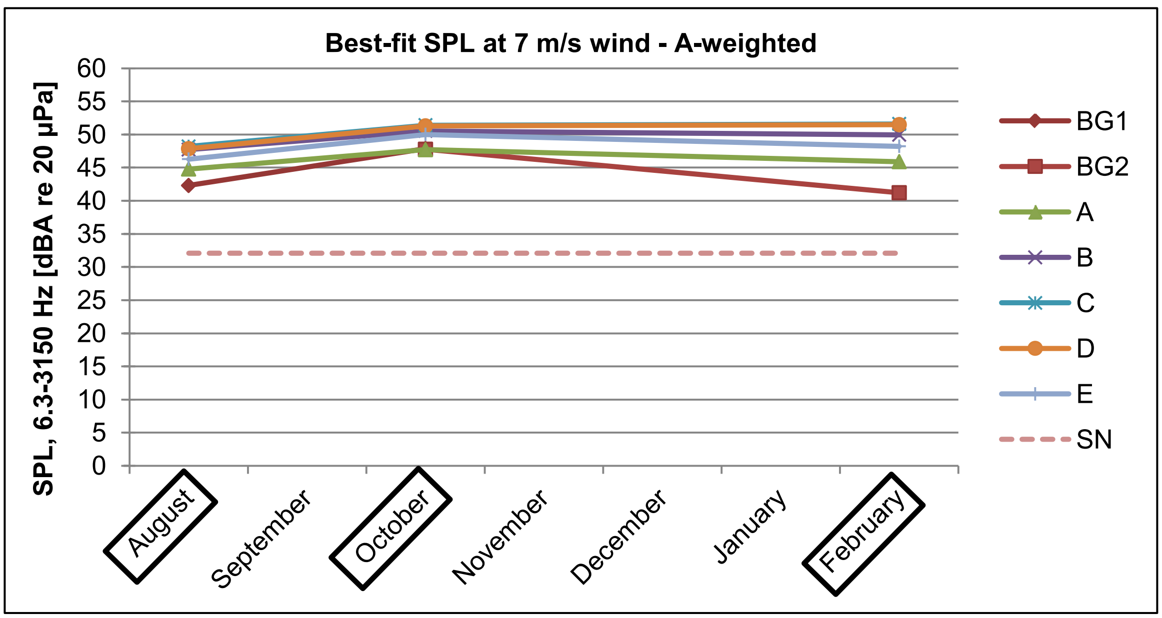

Figure 20. Sound pressure levels at a seven m/s wind speed for the August, October, and February monitoring campaigns calculated using the equation of the best-fit line for the A-weighted select frequency range. (SN - Self-Noise)

4.5 Short Duration Sound Level Monitoring In and Outside Homes

Wind speeds and sound level measurements were relatively low during the survey deployment time period in the fall compared to normal wind speeds. Wind speeds at 2.4 m above ground level ranged from 0.0 m/s to 4.5 m/s with a mean of 1.7 m/s and standard deviation of 1.2 m/s. Measurements conducted at the time of the questionnaire administration are summarized in Table 17.

Table 17. Summary of ten-minute sound measurements collected inside and outside homes at the time of survey data collection in October 2011.

	Octave-Band Frequency		
	Leq (6.3 Hz to 16 Hz)	**Leq (20 Hz to 250 Hz)**	**LAeq (6.3 Hz to 3150 Hz)**
Indoors			
Average SPL (mean±SD)	60.8 (8.0)	56.9 (7.2)	47.0 (11.5)
Range	44.1 - 80.3	42.3 - 78.3	20.2 - 64.5
Outdoors			
Average SPL (mean±SD)	61.5 (7.4)	58.3 (5.7)	45.3 (8.2)
Range	52.0 - 79.1	49.2 - 73.4	31.9 - 72.1
Average Distance to Nearest Turbine in Meters (mean±SD)		585.7 (179.3)	
Average Number of Visible Turbines from Residence (mean±SD)		19.2 (16.5)	

The arithmetic means for outdoor sound pressure level measurements for the “infra” (6.3 Hz to 16 Hz) and “low” (20 Hz to 250 Hz) frequency bands were greater than the indoor measurements at those same frequency bands. However, the indoor A-weighted “overall” frequency range (6.3 Hz to 3150 Hz) was 1.7 dBA greater than the average outdoor measurements.

During the month of October, at the time the questionnaires were administered, the average number of turbines visible was 19.2 with a standard deviation of 16.5. It is important to note that the visible count was conducted during the fall when all foliage had fallen, exposing the maximum number of visible turbines. The average distance from nearest turbine to each residence where a questionnaire was given was 585.7 meters with a standard deviation of 179.3 meters. With an average wind speed of 1.7 m/s at microphone height during the outdoor noise measurements, the wind speeds were below the wind speeds typically present in the turbine park, and below the average wind speeds measured during the August 2011 and February 2012 monitoring campaigns. Light rain showers occurred during two days of the home measurements with variable amounts of clouds and sun for the duration of the monitoring.

Indoor measurements were conducted with doors and windows closed. Windows and doors were primarily already closed due to the colder temperatures. Residents were asked to turn off electronics such as radios, televisions, and fans; however, other noise sources were continually present. Certain appliances including refrigerators and heating systems, along with fish tanks, pets, and young children frequently contributed to the indoor noise during the ten-minute noise measurements.

4.6 Cross-Sectional Survey

The cross-sectional survey was administered during the October 2011 noise sampling campaign by in-person interviewing. Fifty-six homes were randomly visited out of a possible 256 homes within the Wethersfield wind park and surveys were collected from individuals in these homes. The two field interviewers were refused at a total of four additional homes for reasons which included; the resident was "too busy", the resident "did not want to participate", the resident wanted "Noble's permission first", and the resident was involved with the local government and wanted to "remain neutral". Of the fifty-six homes where surveys were collected, fifty-one surveys were collected from fifty-one homes, three surveys were collected from one home and two surveys were collected from each of four homes, for a total of 62 surveys.

Of the 62 individuals interviewed, no one worked directly for Noble Energy or had a relative that did, and 46 reported no association with Noble Energy. Of the 16 that reported they had an association, ten individuals owned land with a wind turbine on their property, none had a neighbor agreement, one received an undisclosed fee for a neighbor easement and five noted some other arrangement with Noble Energy, but refused to supply any details on the exact type of arrangement.

4.6.1 Study Population Demographics

The demographics of the survey population are outlined in Table 18. Of the 62 participants, 35 were men and 27 were women. The average age of all participants was 51±15.2 years, with no statistically significant difference in age among the men and women. Approximately five percent of the participants had less than a high school diploma, with approximately 55 percent of the participants having earned a high school diploma. Twenty-nine percent of the participants had some college or a two-year degree, with just over 11 percent having earned a four year or graduate degree. Sixty-six percent of participants were employed outside the home.

Over 85 percent of participants lived in their homes before the turbines were constructed and lived an average of 586±179.3 meters from the closest turbine. On average, participants had been in their homes at the time of the survey for 17.9±14.3 years and could see just over 19 turbines from their property during the fall time period.

Table 18. Demographic information for the surveyed population.

	Total Response	Men	Women
Number of Surveys (n)	62	35	27
Age (mean ± sd)	51±15.2	54±12.5	48±17.7
Highest Educational Level (n)			
Less than High School	3(4.8%)	2(5.7%)	1(3.7%)
High School Diploma	34(54.8%)	20(57.1%)	14(51.9%)
Some College	9(14.5%)	6(17.1%)	3(11.1%)
2-Year Degree	9(14.5%)	4(11.4%)	5(18.5%)
4-Year Degree	5(8.1%)	2(5.7%)	3(11.1%)
Graduate Degree	2(3.2%)	1(2.9%)	1(3.7%)
Employed (n)	41(66.1%)	21(60%)	20(74.1%)
Average Number of Years Lived at Residence (mean ± SD)	17.9±14.3	17.5±13.4	18.3±15.7
Moved In Before Turbines Operational (n)	53(85.5%)	30(85.7%)	23(85.2%)
Average Distance from Residence to Closest Turbine (meters ± SD)	586±179.3	580±155.9	593±208.8
Average Number of Turbines Visible from Residence (mean ± SD)	19.2±16.5	15.9±13.7	23.4±19.0

4.6.2 General Opinions on Wind Turbines

Individual's general opinion on wind turbines were solicited with a series of questions regarding how they feel about the turbines' effects on the scenery and their impact on the landscape. The results are summarized in Table 19.

Table 19. Descriptive statistics for select satisfaction questions.

	Total Response (Number/Percent)	Men (Number)	Women (Number)
General Opinion on Turbines			
Very Positive	6(10%)	4	2
Positive	21(35%)	12	9
Neither Positive nor Negative	13(21%)	6	7
Negative	10(16%)	7	3
Very Negative	11(18%)	6	5
Opinion on Turbines' Impact on Landscape			
Very Positive	3(5%)	5	1
Positive	8(13%)	2	3
Neither Positive nor Negative	29(47%)	15	14
Negative	8(13%)	5	3
Very Negative	14(23%)	8	6
Altered View Outside			
Do Not Notice	36(58%)	19	17
Notice But Not Annoyed	9(15%)	5	4
Slightly Annoyed	7(11%)	6	1
Rather Annoyed	6(10%)	2	4
Very Annoyed	4(7%)	3	1
Altered View Inside			
Do Not Notice	50(81%)	29	21
Notice But Not Annoyed	1(2%)	0	1
Slightly Annoyed	3(5%)	2	1
Rather Annoyed	4(7%)	1	3
Very Annoyed	4(7%)	3	1

Forty-four percent of individuals interviewed had a positive or very positive general attitude towards wind turbines, while 34 percent had a negative or very negative view of the wind turbines. Another 21 percent had neither a positive nor negative general opinion about the turbines. Eighteen percent of participants felt there was a very positive or positive impact on the landscape, while 47 percent felt there was neither a positive nor negative impact. A larger percentage of individuals, 36 percent, had a negative or very negative opinion on the wind turbine affects on the landscape, compared to those with a very positive or positive attitude.

The majority (73 percent) of individuals either did not notice, or noticed but were not annoyed by the altered view when outside. A higher percentage of individuals (83 percent) either did not notice or noticed but were not annoyed by the altered view when inside their homes.

Individuals were asked to choose amongst a list those adjectives they felt best described the wind turbines. The survey allowed individuals to choose more than one adjective, and the adjectives were interspersed in the survey amongst those with a negative and positive perception. They are sorted by perception in Table 20 to aid the reader in gaining a sense of the participants' views towards the wind turbines.

Table 20. Summary of adjectives used to describe the turbines.

	Total Response (Number/Percent)	Men (Number)	Women (Number)	Correlation With WT Noise Annoyance Outside	Correlation With WT Noise Annoyance Inside
Efficient	27(44%)	16	11	**0.379**	0.219
Environmentally friendly	34(55%)	19	15	**0.526**	**0.465**
Necessary	0(0%)	0	0	0	0
Beautiful	13(21%)	5	8	0.203	0.162
Inviting	0(0%)	0	0	0	0
Blends in	14(23%)	9	5	**0.380**	**0.341**
Natural	6(10%)	3	3	0.217	0.236
Inefficient	21(34%)	10	11	**–0.538**	**–0.403**
Harmful to the environment	17(27%)	11	6	**–0.497**	**–0.442**
Unnecessary	20(32%)	10	10	**–0.358**	**–0.384**
Ugly	20(32%)	11	9	**–0.358**	**–0.303**
Annoying	14(23%)	9	5	**–0.560**	**–0.588**
Threatening	1(2%)	0	1	**–0.255**	**–0.288**
Unnatural	42(68%)	25	17	**–0.449**	**–0.455**

Bold – $p < 0.05$
WT – Wind turbine

A total of 94 adjectives with a positive perception were chosen, while 135 adjectives with a negative perception were chosen. It is interesting to note that none of the participants interviewed noted the turbines were inviting or necessary, while very few (two percent) noted they were threatening.

Participants were encouraged to note any other adjectives they felt described the wind turbines that were not included on the survey list. Responses with one occurrence each included; beautiful at a distance, can be pretty, interesting, majestic, okay and tolerable.

The adjectives with a negative connotation were all strongly correlated and statistically significantly associated with their annoyance from the wind turbines both inside and outside. This is somewhat in contrast to the correlations for the adjectives with a positive connotation, where only select correlations, for efficient, environmentally friendly and blends in, reached statistical significance and the overall magnitude of the correlations is generally lower to nonexistent.

4.6.3 Individual Sensitivities and Their Association with Wind Turbine Annoyance

In order to examine how sensitive individuals may be to wind turbine noise, individuals were queried regarding their sensitivity to other environmental factors including noise in general, air pollution, odors and littering. These data are summarized in Table 21.

Table 21. Summary of individual sensitivities to various environmental stressors.

	Total Response (number/percentage)	**Men (number)**	**Women (number)**
Noise in General			
Not sensitive at all	40(65%)	23	17
Slightly sensitive	15(24%)	8	7
Rather sensitive	4(7%)	2	2
Very sensitive	3(5%)	2	1
Odors			
Not sensitive at all	43(65%)	25	18
Slightly sensitive	14(24%)	9	5
Rather sensitive	2(7%)	1	1
Very sensitive	3(5%)	0	3
Air Pollution			
Not sensitive at all	46(74%)	27	19
Slightly sensitive	7(11%)	2	5
Rather sensitive	3(5%)	2	1
Very sensitive	6(10%)	4	2
Littering			
Not sensitive at all	24(39%)	16	8
Slightly sensitive	7(11%)	5	2
Rather sensitive	14(23%)	5	9
Very sensitive	17(27%)	9	8

Individuals reported similar sensitivities to noise, odors and air pollution with 65 percent, 69 percent and 74 percent respectively indicating that they were not sensitive at all to noise, odors and air pollution. Again similar percentages of individuals indicated they are lightly sensitive, rather sensitive and very sensitive to noise, odors and air pollution. For noise specifically, 24 percent indicated they are slightly sensitive, seven percent indicated they are rather sensitive and five percent indicated they are very sensitive. Interestingly, only 39 percent of the population surveyed indicated they are not sensitive at all to littering, with 11 percent slightly sensitive, 23 percent rather sensitive and 27 percent very sensitive.

The relationship between an individual's sensitivity to noise in general and other environmental noises such as wind turbine noise, railroad noise, road noise and lawn mowing noise and their annoyance with wind turbine noise inside and outside their homes was investigated. A summary of this correlation analysis is presented in Table 22.

Table 22. Correlation between an individual's sensitivity to various environmental stressors, and their annoyance level with wind turbine noise inside and outside their homes.

	Correlation with Wind Turbine Annoyance Outside	**Correlation with Wind Turbine Annoyance Inside**
Noise in General	**0.537**	**0.533**
Odors	–0.126	0.023
Air Pollution	–0.131	–0.118
Littering	0.146	0.181

Bold – $p < 0.05$

There was no statistically significant relationship between being sensitive to odors, air pollution or littering, and being annoyed by wind turbine noise inside or outside the home. There was however, a statistically significant relationship between being sensitive to noise in general, and being annoyed with wind turbine noise both inside and outside the home.

4.6.4 Evaluation of Satisfaction with Living Environment – Descriptive Analyses

Several avenues regarding participants' general satisfaction with their living environment were explored in the survey. Direct questions were asked first regarding their overall satisfaction with their living environment, with deeper questions regarding the levels of annoyance with several types of environmental stressors indoors and outdoors including noise and odors asked subsequently. The data for select satisfaction questions are summarized in Table 23.

Table 23. Descriptive statistics for select satisfaction questions.

	Total Response (Number/Percent)	Men (Number)	Women (Number)
Satisfied With Living Environment			
Very Satisfied	29(47%)	18	11
Satisfied	27(43%)	15	12
Neither Satisfied nor Dissatisfied	2(3%)	0	2
Not Satisfied	3(5%)	1	2
Not at all Satisfied	1(2%)	1	0
Outside – Affected by Turbine Noise			
Do Not Notice	10(16%)	4	6
Notice But Not Annoyed	24(39%)	11	13
Slightly Annoyed	12(20%)	11	1
Rather Annoyed	9(15%)	4	5
Very Annoyed	6(10%)	4	2
Inside – Affected by Turbine Noise			
Do Not Notice	29(48%)	14	15
Notice But Not Annoyed	12(20%)	8	4
Slightly Annoyed	10(16%)	6	4
Rather Annoyed	5(8%)	3	2
Very Annoyed	5(8%)	3	2

The large majority of study participants, 90 percent, were either very satisfied or satisfied with their living environment. A few participants were neither satisfied nor dissatisfied (three percent), and seven percent were either not satisfied or not satisfied at all. Again, the majority of individuals interviewed, 55 percent, either did not notice, or noticed but were not annoyed by the turbines when outside their homes. The remainder of participants (45 percent) did note some level of annoyance from the turbines outside their homes.

The levels of annoyance from the turbines while participants were inside their homes were somewhat diminished with 68 percent of participants saying they did not notice or noticed but were not annoyed by the wind turbines. A somewhat smaller percentage of participants, 32 percent, did say they were slightly, rather or very annoyed by the turbines while inside their homes.

Of those individuals annoyed by wind turbine noise while inside their homes, 32 percent had their windows closed, with the remainder having their windows open or partly open. Twenty-seven (44 percent) individuals had either window air conditioning or central air conditioning units. The majority of air conditioning units (82 percent) were window units. Six individuals noted other noises that served as an annoyance while inside their homes and included dog barking, kitchen exhaust fans, furnaces, children's toys and the refrigerator.

Three of the individuals who were not satisfied identified the turbines specifically as the reason for their dissatisfaction. Twenty-three individuals indicated there had been at least one change for the better in their living environment over the past few years. Twelve individuals noted reduced and no town taxes, nine noted that the roads had been improved, four were appreciative that they no longer pay for rubbish removal since the turbines have been in place, three noted a direct financial gain and two indicated that there were more jobs since the turbine project was initiated.

Twenty-six individuals described at least one thing that has changed for the worse in their living environment over the past few years. Of these 26, 18 noted the turbines have been a change for the worse in their environment, other individuals singularly noted the following also related to the turbines; deteriorated roads, increase in traffic, static on landline phones, shadow flicker, negative impacts on the scenery and decreased property values because of the turbine installations.

Other perceptible changes in the environment, not necessarily related to the turbines, which were singularly noted include; an increase in complaints from neighbors, irritation over conflicts of interest between the town clerk and Noble Energy, and a general downturn in the economy and local employment.

Participants were asked to characterize the type of sound emanating from the turbines both indoors and outdoors. Several adjectives were supplied and participants were asked to rank them according to their level of annoyance if any. Their correlation with an individual's satisfaction with their living environment was also examined. These results are presented in Table 24.

Table 24. Summary of the attitude towards wind turbine noise descriptions inside and outside, and their correlation with individual's satisfaction with their living environment.

	Do Not Notice/Notice But Not Annoyed (Number/Percent)	Some Level of Annoyance (Number/Percent)	Correlation with Satisfaction with Living Environment
Indoors			
Tonal	58(95%)	3(5%)	0.010
Pulsing/throbbing	52(85%)	9(15%)	–0.195
Swishing	41(67%)	20(33%)	**–0.524**
Whistling	60(98%)	1(2%)	0.008
Lapping	55(90%)	6(10%)	0.008
Scratching/squeaking	61(100%)	0(0%)	0.043
Low frequency	56(92%)	5(8%)	**–0.283**
Resounding	52(85%)	9(15%)	–0.227
Outdoors			
Tonal	58(95%)	3(5%)	0.032
Pulsing/throbbing	50(82%)	11(18%)	–0.143
Swishing	33(54%)	28(46%)	**–0.488**
Whistling	58(95%)	3(5%)	0.047
Lapping	57(86%)	8(13%)	0.010
Scratching/squeaking	59(97%)	2(3%)	0.024
Low frequency	54(89%)	7(12%)	**–0.342**
Resounding	49(80%)	12(20%)	–0.114

Bold – $p < 0.05$

While indoors, the large majority of individuals did not notice, or noticed but were not annoyed by the various qualities of sound from the wind turbines except for the sound characterized as swishing. The swishing sound was associated with some level of annoyance from 33 percent of the participants while indoors and was significantly correlated with an individual's level of satisfaction with their living environment. Interestingly, although there were a few individuals that experienced some level of annoyance with a low frequency sound emanating from the turbines (eight percent), this characteristic was statistically significantly correlated with their satisfaction with their living environment.

Similar to indoors, while outdoors, the majority of individuals either did not notice or noticed but were not annoyed by the sounds emanating from the wind turbines. Like indoors, both the swishing and the low frequency characteristics were statistically significantly correlated in a negative direction with an individual's satisfaction with their living environment. The magnitude of the correlation was somewhat higher inside than outside for the swishing sound and was the opposite for the low frequency sound with the correlation being a bit stronger outside than inside.

Participants were asked to rate their annoyance with wind turbine specific phenomena including shadows, reflections, sound from the rotor blades and sound from the turbine machinery while outdoors and while inside their dwelling. These results are summarized in Tables 25 and 26.

Table 25. Descriptive statistics for disturbance by specific wind turbine phenomena when outside the home.

	Total Response (Number/Percent)	Men (Number)	Women (Number)
Outside, Affected By Shadows			
Do Not Notice	28(45%)	17	11
Notice But Not Annoyed	16(26%)	8	8
Slightly Annoyed	5(8%)	3	2
Rather Annoyed	8(13%)	3	5
Very Annoyed	5(8%)	4	1
Outside, Affected by Reflections			
Do Not Notice	45(74%)	22	23
Notice But Not Annoyed	8(13%)	7	1
Slightly Annoyed	3(5%)	2	1
Rather Annoyed	4(7%)	2	2
Very Annoyed	1(2%)	1	0
Outside, Affected by Turbine Noise			
Do Not Notice	10(16%)	5	5
Notice But Not Annoyed	24(39%)	11	13
Slightly Annoyed	12(19%)	9	3
Rather Annoyed	10(16%)	6	4
Very Annoyed	6(10%)	4	2
Outside, Affected by Turbine Machinery			
Do Not Notice	32(52%)	15	17
Notice But Not Annoyed	14(23%)	8	6
Slightly Annoyed	6(10%)	6	0
Rather Annoyed	6(10%)	3	3
Very Annoyed	4(7%)	3	1

Table 26. Descriptive statistics for disturbance by specific wind turbine phenomena when inside the home.

	Total Response (Number/Percent)	Men (Number)	Women (Number)
Inside, Affected By Shadows			
Do Not Notice	34(55%)	22	12
Notice But Not Annoyed	9(15%)	2	7
Slightly Annoyed	5(8%)	3	2
Rather Annoyed	9(15%)	4	5
Very Annoyed	5(8%)	4	1
Inside, Affected by Reflections			
Do Not Notice	52(84%)	28	24
Notice But Not Annoyed	3(5%)	2	1
Slightly Annoyed	2(3%)	2	0
Rather Annoyed	5(8%)	3	2
Very Annoyed	0(0%)	0	0
Inside, Affected by Television Interference			
Do Not Notice	45(73%)	25	20
Notice But Not Annoyed	1(2%)	0	1
Slightly Annoyed	1(2%)	1	0
Rather Annoyed	6(10%)	4	2
Very Annoyed	9(15%)	5	4
Inside, Affected by Turbine Noise			
Do Not Notice	35(57%)	19	16
Notice But Not Annoyed	6(10%)	4	2
Slightly Annoyed	7(11%)	5	2
Rather Annoyed	8(13%)	3	5
Very Annoyed	6(10%)	4	2
Inside, Affected by Turbine Machinery			
Do Not Notice	52(84%)	29	23
Notice But Not Annoyed	3(5%)	2	1
Slightly Annoyed	0(0%)	0	0
Rather Annoyed	3(5%)	1	2
Very Annoyed	4(7%)	3	1

The majority of individuals were not affected by shadows formed by wind turbines either when inside (70 percent) or outside (71 percent) their homes. Similar percentages of individuals were slightly annoyed (eight percent in/eight percent out), rather annoyed (13 percent in/15 percent out) and very annoyed (eight percent in/eight percent out) with the turbine shadows when either inside or outside their homes.

Similar to shadows, the majority of individuals were not affected by reflections from the wind turbines while outside (87 percent) or inside (89 percent). Similar percentages of individuals were slightly annoyed (five percent in/three percent out), rather annoyed (eight percent in/seven percent out) and very annoyed (zero percent in/two percent out) with the turbine reflections when either inside or outside their homes.

Individuals were queried separately about their level of annoyance with rotor blade noise and turbine machinery. Inside study homes, 67 percent of the individuals surveyed indicated that they either did not notice the turbine noise, or noticed it, but were not affected by it. The remaining 34 percent of individuals were either slightly, rather or very annoyed by the wind turbine noise when they were inside their homes. Outside study homes, a smaller percentage of individuals 55 percent noted that they did not notice, or noticed but were not affected by the rotor blade noise. The remaining 45 percent were either slightly, rather or very annoyed by the wind turbine noise outside their homes.

Fewer individuals were unaffected by turbine machinery inside (89 percent) and outside (75 percent) their homes, compared to those affected by wind turbine noise. Individuals were however more annoyed by turbine machine noise outside (27 percent) than they were inside their homes (12 percent).

An individuals' sensitivity to wind turbine rotor blade noise was somewhat lower inside than outside. Sixty-seven percent of individuals noted they do not notice or notice but are not annoyed by the wind turbine rotor blade noise when inside their homes, compared to 55 percent who indicate they do not notice or notice the noise but are not annoyed when outside. Similar percentages of individuals were rather annoyed or very annoyed by the turbine noise inside their homes (23 percent) compared to those who were rather annoyed or very annoyed by the turbine noise outside their homes (26 percent).

For those who reported annoyance from wind turbines and wind turbine phenomena, they were asked to describe the frequency with which they were annoyed or with which the phenomena occurred. These results are presented in Table 27.

Table 27. Descriptive statistics for frequency of disturbance by specific wind turbine phenomena.

	Total Response (Number/Percent)	Men (Number)	Women (Number)
How often annoyed by noise from turbines			
Never/almost never	1(3%)	1	0
Some/few times per year	4(13%)	3	1
Some/few times per month	7(23%)	4	3
Some/few times per week	9(30%)	5	4
Daily/almost daily	9(30%)	6	3
How often annoyed by television or radio interference from turbines			
Never/almost never	0(0%)	0	0
Some/few times per year	1(7%)	0	1
Some/few times per month	0(0%	0	0
Some/few times per week	3(21%)	1	2
Daily/almost daily	10(71%)	7	3
How often annoyed by shadows and/or reflections from turbines			
Never/almost never	1(4%)	0	1
Some/few times per year	4(17%)	4	0
Some/few times per month	7(29%)	3	4
Some/few times per week	6(25%)	2	4
Daily/almost daily	6(25%)	4	2

Of the individuals that were affected by noise, television and radio interference, shadows and reflections the majority were affected quite often. For instance, 60 percent, of individuals were affected a few times per week or daily by noise, 92 percent by television or radio interference, and 54 percent by shadows or reflections.

Study participants were asked if they felt the wind turbines sounded differently during several different environmental conditions including; changes in season, wind speed and direction, temperature and ground cover. The results are summarized in Table 28.

Table 28. Descriptive statistics for conditions study participants feel may affect the sound that the wind turbines create.

	Total Response (Number/Percent)	Men (Number)	Women (Number)
When wind blows from turbine(s) towards my home			
Less clearly heard	0(0%)	0	0
More clearly heard	34(58%)	21	13
No difference	22(37%)	13	9
Do not know	3(5%)	0	3
When wind blows from my home towards the turbine(s)			
Less clearly heard	26(5%)	16	10
More clearly heard	4(1%)	4	0
No difference	25(5%)	13	12
Do not know	3(1%)	0	3
When wind blows parallel to my home and the turbine(s)			
Less clearly heard	7(12%)	5	2
More clearly heard	4(7%)	3	1
No difference	35(60%)	20	15
Do not know	12(21%)	5	7
When wind is low speed			
Less clearly heard	29(49%)	17	12
More clearly heard	6(10%)	3	3
No difference	22(37%)	12	10
Do not know	2(3%)	2	0
When wind is rather strong			
Less clearly heard	7(12%)	3	4
More clearly heard	39(66%)	24	15
No difference	12(20%)	6	6
Do not know	1(2%)	1	0
During a particular season			
Less clearly heard	2(3%)	1	1
More clearly heard	34(56%)	18	16
No difference	22(36%)	15	7
Do not know	3(5%)	1	2
Warm days or warm nights			
Less clearly heard	10(17%)	5	5
More clearly heard	11(18%)	7	4
No difference	34(57%)	20	14
Do not know	5(8%)	2	3
During cool days or cool nights			
Less clearly heard	6(10%)	4	2
More clearly heard	15(26%)	8	7
No difference	32(55%)	19	13

Do not know	5(9%)	2	3
When there is or is not ground cover			
Less clearly heard	2(3%)	2	0
More clearly heard	19(31%)	9	10
No difference	33(54%)	20	13
Do not know	7(12%)	4	3

The majority of individuals felt the turbines were more clearly heard when the wind blew from the direction of the turbines toward their homes (58 percent), when the wind was rather strong (66 percent) and during a particular season (56 percent). Those individuals who noted that they could hear the turbines more clearly during one season were asked which season or seasons. The results included the following responses; summer (10), fall (2), winter (16), spring (1), fall/spring (1), fall/winter (4), spring/fall (2). There was not a consensus on what season the turbines could be more clearly heard in, but the number indicating winter alone is notable.

The majority of individuals did not feel there was any difference in wind turbine noise during warm days/warm nights (57 percent), cool days/cool nights (55 percent) or ground cover conditions (54 percent).

4.6.5 Evaluation of Satisfaction with Living Environment in Relation to Noise Measurements Collected Inside and Outside the Homes at the Time of the Survey

The correlation between the sound level measurements collected inside and outside the home at the time of the survey and two satisfaction measures was explored. These results are summarized in Table 29.

Table 29. Correlation between the sound level measurements collected at the time of the survey and measures of satisfaction.

	Octave-Band Frequency		
	Leq Infranoise (6.3 Hz to 16 Hz)	Leq Low Frequency (20 Hz to 250 Hz)	LAeq Select Band (6.3 Hz to 3150 Hz)
Outside Measurements			
Satisfied with living environment	−0.038	−0.081	−0.075
Annoyed by turbines outside	0.072	0.012	0.072
Inside Measurements			
Satisfied with living environment	−0.014	−0.173	−0.154
Annoyed by turbines inside	−0.175	−0.049	−0.078

No statistically significant results at p <0.05

There were no statistically significant associations between the sound level measurements collected, and an individual's assessment of their satisfaction with their living environment and their annoyance level with the turbines, either inside or outside their homes.

Another measure of noise sensitivity and general satisfaction with one's living environment for the study population is captured in the number of noise complaints participants lodged with the Town of Wethersfield. Interestingly, of the 62 individuals interviewed, seven men and two women indicated that they have issued noise complaints in the past. Of the nine that have issued a complaint, six individuals representing five households indicated that they were issuing the complaint in response to wind turbine noise. This represents a complaint rate for the study population of 8.1 percent if calculated by home, and 9.6 percent if calculated per person. One of these individuals noted he issues approximately 12 complaints each winter. Of the six individuals lodging complaints for wind turbine noise, five had lived in their homes before the project was operational. Other reasons for noise complaints included road noise and farming trucks.

4.6.6 Correlation between Short Duration Sound Level Measurements and Participants' Noise Perception

The relationship between the sound level measurements collected at the time of the in-home survey and each individual's perception of wind turbine sounds both inside and outside their homes was investigated. The results are summarized in Table 30.

Table 30. Correlations between the sound level measurements collected at the time of the survey and individual's annoyance and perception of wind turbine noise.

	Octave-Band Frequency		
	Leq Infranoise (6.3 Hz to 16 Hz)	**Leq Low Frequency (20 Hz to 250 Hz)**	**LAeq Select Band (6.3 Hz to 3150 Hz)**
Indoors			
Tonal	–0.215	–0.192	–0.089
Pulsing/throbbing	**–0.281**	**–0.272**	**–0.308**
Swishing	–0.145	–0.017	–0.088
Whistling	–0.051	0.050	0.063
Lapping	0.032	0.214	0.104
Scratching/squeaking	0.022	0.018	–0.009
Low frequency	–0.034	–0.132	–0.167
Resounding	0.022	0.219	0.122
Outdoors			
Tonal	0	–0.154	–0.053
Pulsing/throbbing	–0.001	–0.105	–0.132
Swishing	–0.006	–0.143	–0.015
Whistling	0.099	0.049	–0.093
Lapping	–0.040	–0.159	–0.202
Scratching/squeaking	0.047	0.112	0.030
Low frequency	0.191	0.149	0.097
Resounding	–0.150	**–0.252**	–0.153

Bold – p <0.05

There was only one statistically significant correlation between the outdoor descriptions of turbine noise and any of the outdoor sound pressure level measurements. The outdoor low frequency band measurements outside the home were correlated with participant's description of the sound as resounding. Indoors there were three statistically significant correlations between the participant's description of the noise as pulsing or throbbing, and the three noise bands monitored.

4.6.7 Evaluation of Satisfaction with Living Environment – Regression Analyses

The univariate statistics were generated to explore the correlation of the various survey questions with the main dependent variable being the level of satisfaction with the participant's living environment. In addition to the main dependent variable of level of satisfaction with the participant's living environment, secondary dependent variables were identified as annoyance with wind turbine noise both inside the home and outside. The correlation of these three dependent variables with other subjective survey answers, demographics and monitored noise levels are summarized in Table 31.

Table 31. Summary of the correlation between individuals' satisfaction with their living environment, annoyance with turbines in general and various objective measures and survey questions regarding opinions on wind turbines.

	Satisfied With Living Environment	**Annoyed with Turbines Outside**	**Annoyed with Turbines Inside**
General Opinion on WT	**0.519**	**–0.594**	**–0.578**
Opinion on WT Altering View	**0.442**	**–0.690**	**–0.597**
Age	–0.067	0.157	0.081
Gender	–0.106	–0.160	–0.093
Education Level	–0.211	–0.003	0.004
Concerned with WT Health Effects	**–0.265**	**0.349**	**0.477**
Number of WT Visible from Home	0.025	–0.028	0.072
Distance to Closest WT	–0.181	–0.191	–0.126
Have an association with Noble Energy	**0.312**	–0.092	–0.074
Sensitivity to Noise in General	**–0.438**	**0.537**	**0.533**
General WT Noise Annoyance Outside	**–0.502**	—	**0.829**
Rotor Blade Noise Annoyance Outside	**–0.456**	**0.752**	**0.710**
Turbine Machinery Annoyance Outside	**–0.376**	**0.547**	**0.540**
Summary Measure of Type of WT Noise Annoyance Outside	–0.215	**0.600**	**0.627**
Summary Measure of Sensitivity to Odors Outside	–0.005	–0.020	–0.011
Summary Measure of Sensitivity to Other Noises Outside	0.034	0.036	–0.037
General WT Noise Annoyance Inside	**–0.558**	**0.829**	—
Rotor Blade Noise Annoyance Inside	**–0.489**	**0.802**	**0.890**
Turbine Machinery Annoyance Inside	**–0.505**	**0.574**	**0.647**
Summary Measure of Type of WT Noise Annoyance Inside	**–0.295**	**0.686**	**0.735**
Summary Measure of Sensitivity to Odors Inside	–0.163	–0.048	0.044
Summary Measure of Sensitivity to Other Noises Inside	–0.065	–0.057	0.092
Leq Inside (Infra)	–0.014	–0.108	–0.175
Leq Inside (Low)	–0.173	–0.074	–0.049
LAeq Inside (All)	–0.154	–0.177	–0.078
Leq Outside (Infra)	–0.038	0.072	0.053
Leq Outside (Low)	–0.081	0.012	–0.095
LAeq Outside (All)	–0.075	0.072	–0.029

Bold – $p < 0.05$

An individual's satisfaction with their living environment was statistically significantly correlated with their general opinion on wind turbines, their opinion on the altered views created by wind turbines, their sensitivity to noise in general, whether they have an association with Noble Energy and their concern regarding any health effects associated with living close to turbines. With respect to noise annoyance, an individual's satisfaction with their living environment was significantly correlated with their general annoyance with noise outside, their annoyance with rotor blade noise outside and their annoyance with wind turbine machinery outside. Similarly inside, an individual's satisfaction with their living environment was significantly correlated with their annoyance with noise in general inside, with rotor blade noise inside and turbine machinery noise inside. Unlike outside, an individual's satisfaction with their living environment was also correlated with a summary measurement of wind turbine noise inside which combines the various noise characteristics of turbine noise including the following descriptors; scratching, squeaking, tonal nature, pulsating, throbbing, swishing, whistling, lapping, low frequency noise and resounding. Interestingly, none of the indoor or outdoor sound pressure level measurements collected at the time of the survey was correlated with any of these variables with statistical significance at the $p < 0.05$ level.

In addition to the level of satisfaction with living environment, secondary dependent variables were considered. Correlations between the general annoyance from wind turbine noise while both outside and inside were calculated. Similar to satisfaction with living environment, general annoyance from wind turbine noise was statistically correlated with an individual's general opinion on wind turbines, their opinion on altered landscapes, their concern over health effects associated with the wind turbines and their sensitivity to noise in general. Their annoyance with wind turbine noise both inside and outside the home was not correlated with whether they have an association with Noble Energy or not. Their annoyance from wind turbine noise in general was also statistically significantly correlated with both aspects of wind turbine noise from the rotor blades and from the machinery, both inside and outside. As with the level of satisfaction variable, none of the indoor or outdoor sound pressure level measurements collected at the time of the survey were correlated with participants' general noise annoyance with wind turbines inside or outside.

Regression models exploring an individual's level of satisfaction with their living environment were created. Covariates included general opinions on wind turbines, opinions on altered views, whether they had any sort of relationship with Noble Energy and specific types of noise. The models results are summarized in Table 32.

Table 32. Summary of models exploring individual's satisfaction with their living environment and subjective measures.

Model Number	Variables	β	p-value
1	Opinion on Wind Turbines	0.350	<0.001
2	Opinion on Wind Turbines	0.303	0.031
	Opinion on Altered Landscape	0.064	0.681
3	Opinion on Wind Turbines	0.249	0.016
	Indoor Wind Turbine Rotor Blade Noise	–0.136	0.134
4	Opinion on Wind Turbines	0.260	0.002
	Indoor Wind Turbine Machine Noise	–0.245	0.009
5	Opinion on Wind Turbines	0.268	0.004
	Outdoor Wind Turbine Rotor Blade Noise	–0.159	0.096
6	Opinion on Wind Turbines	0.306	0.001
	Outdoor Wind Turbine Machine Noise	–0.103	0.237
7	Opinion on Wind Turbines	0.180	0.029
	Indoor Wind Turbine Machine Noise	–0.291	0.002
	Association with Noble Energy	0.587	0.009

β – beta coefficient for equation variable

An individual's general opinion on wind turbines was highly predictive of their individual satisfaction with their living environment. Since both covariates did not reach statistical significance in a model together, one can conclude that an individual's opinion on wind turbines was highly correlated with their opinion on how the turbines alter the landscape. When looking at models that distinguish rotor blade noise from turbine machinery noise both inside and outside, individuals appeared to be most negatively impacted by turbine machinery noise inside the home. Using Model 4, the effects of whether an individual has an association with Noble Energy were investigated. There is a statistically significant effect on an individual's satisfaction with their living environment if they do have some type of relationship with the energy company.

Using Model 7 as a core, the effects of other covariates on an individual's level of satisfaction with their living environment were explored including; whether they were concerned with health effects, age, education level, gender, the number of visible wind turbines from home and distance to the closest wind turbine from the home. None of these covariates reached statistical significance at $p < 0.05$.

Using the base model presented above (Model 7 in Table 36) to predict an individual's level of satisfaction with their living environment, additional models using the sound level measurements collected inside and outside participants homes were also generated. The results are summarized in Table 33.

Table 33. Summary of models exploring individual's satisfaction with their living environment and sound level measurements taken in homes combined with subjective measures.

Model Number	Variables	β	p-value
1	Opinion on Wind Turbines	0.183	0.028
	Indoor Wind Turbine Machine Noise	–0.293	0.002
	Association with Noble Energy	0.587	0.009
	Infra-noise Inside Homes	–0.006	0.605
2	Opinion on Wind Turbines	0.172	0.037
	Indoor Wind Turbine Machine Noise	–0.310	0.001
	Association with Noble Energy	0.519	0.024
	Low Frequency Noise Inside Homes	–0.015	0.253
3	Opinion on Wind Turbines	0.151	0.069
	Indoor Wind Turbine Machine Noise	–0.343	0.001
	Association with Noble Energy	0.530	0.018
	LAeq Inside Homes	–0.012	0.132
4	Opinion on Wind Turbines	0.178	0.033
	Indoor Wind Turbine Machine Noise	–0.299	0.002
	Association with Noble Energy	0.587	0.009
	Infra Outside Homes	0.006	0.648
5	Opinion on Wind Turbines	0.185	0.027
	Indoor Wind Turbine Machine Noise	–0.283	0.002
	Association with Noble Energy	0.581	0.010
	Low Frequency Noise Outside Homes	–0.008	0.590
6	Opinion on Wind Turbines	0.187	0.027
	Indoor Wind Turbine Machine Noise	–0.286	0.002
	Association with Noble Energy	0.567	0.013
	LAeq Outside Homes	−0.005	0.644

β – beta coefficient for equation variable

Models examining the influence of the sound level measurements collected inside and outside the participants homes were examined. None of the sound level measurement coefficients reached statistical significance at the p <0.05 level. The models including the SPL measurements of low frequency noise and the LAeq was the most statistically significant of all six sound categories examined.

Additional models, building on Model 3 presented in Table 37 were investigated to determine the predictability of other covariates including whether they were concerned with health effects, age, education level, gender, number of visible wind turbines from home and distance to the closes wind turbine from the home. None of these covariates reached statistical significance at p <0.05.

4.6.8 Self Reported Health Effects

Questions regarding participants concerns over health effects related to living near wind turbines were explored. Details regarding specific symptoms were solicited. These questions are summarized in Table 34.

Table 34. Descriptive Statistics, Self-Reported Health Effects.

	Total Response (number/percentage)	**Men (number)**	**Women (number)**
Concerned About Health Effects from Turbines			
Yes	12(20%)	7	5
No	48(80%)	26	22
Headache			
Yes	12(19%)	8	4
No	50(81%)	27	23
Dizziness			
Yes	0(0%)	0	0
No	62(100%)	35	27
Fatigue			
Yes	11(18%)	5	6
No	51(82%)	30	21
Stress			
Yes	7(11%)	3	4
No	55(89%)	32	23
Sleep Disturbance			
Yes	16(26%)	10	6
No	46(74%)	25	21
More symptoms since turbines operational			
Yes	12(19%)	8	4
No	50(81%)	7	43
Do you feel your symptoms are related to the turbines			
Yes	11(18%)	6	5
No	15(58%)	8	7
Ever visited a doctor because of the turbines			
Yes	2(3%)	1	1
No	60(97%)	34	26
Did doctor confirm association with turbines			
Yes	2(100%)	1	1
No	0(0%)	0	0

Doctor prescribe medication for these issues			
Yes	1(50%)	0	1
No	1(50%)	1	0

In general, most participants, 80 percent, were not concerned about experiencing any health effects as a result of living in close proximity to wind turbines. There were 12 (20 percent) participants, however, that were concerned about experiencing health effects as a result of living close to the wind turbines. The concern was fairly evenly distributed among men and women.

Participants were then asked if they had ever experienced any of the following conditions, and if so, how often: headache, dizziness, fatigue, stress or sleep disturbances. Nineteen percent of individuals felt that that the frequency of their symptoms had increased since the turbines began operating. Twenty-six percent of respondents surveyed experienced sleep disturbances with smaller albeit similar percentages of individuals experiencing headaches, fatigue and stress at 19, 18 and 11 percent respectively. No one reported ever experiencing dizziness.

Only two individuals (one man, one woman) visited a doctor because of their symptoms, and these two related that the doctor did confirm the symptoms were associated with the turbines. One was prescribed medication for the symptoms they were experiencing. They did not divulge what those symptoms were.

The association between being concerned with health effects and various demographic and subjective answers was explored. The results are summarized in Table 35.

Table 35. Correlations between an individual's concern regarding health effects and various demographic and subjective answers.

	Concerned with Wind Turbine Health Effects
General Opinion on WT	**–0.350**
Opinion on WT Altering View	**–0.339**
Age	0.012
Gender	–0.034
Education Level	–0.048
Number of WT Visible from Home	0.046
Distance to Closest WT	0.068
Have an association with Noble Energy	0.075
Sensitivity to Noise in General	**0.269**
General WT Noise Annoyance Outside	0.349
General WT Noise Annoyance Inside	0.477
Sleep Disturbance	**0.577**
Dizziness	0
Headache	–0.042
Fatigue	0
Stress	**0.337**

Bold – p <0.05

An individual's concern regarding health effects is statistically significantly correlated with their general opinion on wind turbines, their opinions on the altered landscapes and their sensitivity to noise in general. Additionally, the association between general concern over health effects and sleep disturbance and stress are statistically significantly correlated.

The relationship between the individual objective sound level measurements collected at the homes at the time of the survey and an individual's concern regarding wind turbine related health effects was explored. Table 36 summarizes the correlation between the sound level measurements collected in the homes in the three defined bands and their concern regarding developing health effects from living closely to the wind turbines.

Table 36. Correlation between the sound level measurements collected at the time of the survey and an individual's concern regarding health effects.

	Octave-Band Frequency		
	Leq Infranoise (6.3 Hz to 16 Hz)	Leq Low Frequency (20 Hz to 250 Hz)	LAeq Select Band (6.3 Hz to 3150 Hz)
Outside Measurements			
Concerned about health effects	–0.075	–0.076	–0.059
Inside Measurements			
Concerned about health effects	–0.196	–0.066	–0.096

There were no statistically significant correlations between the indoor and outdoor noise measurements and an individual's level of concern regarding experiencing health effects as a result of living in close proximity to the turbines.

5.0 DISCUSSION

5.1 Comparison of Three Campaigns

5.1.1 Weather and Ambient Conditions

One of the goals of the project was to evaluate sound level at the wind facility during multiple seasons of the year. The climate in the northeast region of the United States provides a region of the country that has stark differences in seasonal characteristics. The temperature during the August monitoring period reached 26°C with mostly sunny skies and some clouds. Having had a wet spring and summer, ground cover and vegetation was thick and lush.

As summer turned into the fall months, temperatures during the fall monitoring nights descended to 2°C with daytime temperatures reaching 19°C. All leaf bearing trees and shrubbery no longer had leaves by the October monitoring. Unlike the August campaign, light to heavy precipitation in the form of rain occurred during the monitoring period. Though treated windscreens were deployed to provide protection against precipitation interference, the steady heavy rain that occurred caused periodic signal errors from the microphone. Periods of some monitoring were suspended at Locations A, B, and D until the microphones were properly dried.

By February in Western NYS, the ground is normally covered with snow; however, with a light winter, the first two days of the monitoring were without snow cover. However, during the final two days of monitoring, approximately 0.3 m of snow fell across the entire monitored area. With day and nighttime temperatures reaching 1°C to −13°C, respectively, air temperature was significantly lower than the other two monitoring campaigns. Additionally, sustained wind speeds were also significantly greater during the winter monitoring compared to the summer and fall (Refer to Table 3 in Section 4.0). As planned, the weather and ambient conditions that occurred during all three monitoring campaigns were relatively representative of the normal conditions of the Western NYS region.

5.1.2 Background Location Changes

Two different background locations, one north of the turbine park and one south of the turbine park, were planned for each monitoring campaign. Background monitoring locations were selected based upon similar elevation, terrain, and proximity to nearby noise sources. These locations were also selected with a minimum of 4.6 km (2.9 miles) distance to the nearest wind turbine. After the August monitoring concluded, input from advisory committee members and a review of the initial results indicated the location selected for Background 2 was not representative of the turbine park monitoring locations. It was determined the location was too close in proximity to a major roadway. Therefore, the Background 1 monitoring location was used as the background location for the August campaign. Refer to Figure 6 for a visual representation of the background locations.

During the October campaign, a different Background 2 location was selected and was utilized again during the February campaign. Background 1 was deployed in the same area for all three monitoring campaigns, but an instrument error that was not detected during the monitoring period caused the February campaign data to be voided. Therefore, Background 2 served as the single background monitoring location for the winter monitoring.

5.2 Comparison of Collected Data to Local and Federal Ordinances and Guidelines

5.2.1 Local Standards

Prior to the Wethersfield Wind Turbine park construction in Wyoming County, New York, the town of Wethersfield proposed the “Town of Wethersfield Wind Energy Conversion Device/Farm Licensing, Siting and Design Regulations and Requirements Law”. In Section V. B. 15 of this proposal, the following was stated:

> Audible noise due to the operation of any part of a Wind Energy Conversion Device shall not exceed 50 dBA for any period of time, when measured at any permanent, livable residence, school, hospital, church, public park or public library, unless the project developer has obtained a noise easement, as recorded in the Wyoming County Clerk’s office.

The Town of Eagle, in which a number of turbines in this park are located, also utilizes a noise limit of 50 dBA at any residence not participating in the Project. In the nearby Town of Orangeville, the Zone Code (the “Town Law”) regulates the installation and operation of wind energy facilities by including the requirement for audible noise from a wind turbine to not exceed L10−50 dBA at non-participating residences.

5.2.2 Existing State, National, and International Standards

Regulatory limits established by organizations at all levels of government have attempted to provide an acceptable “emission limit” for various scenarios and settings including time of day, geographic location (rural or urban), and metrics of sound levels (Leq or L90). Hessler and Hessler (2010) identified over a dozen states that have codified regulations, zoning guidance or siting standards. Eight of which are absolute ‘maximum emission limits’ for daytime and nighttime hours which are deemed acceptable at residential receptors. These limits were created without regard for particular acoustical environments, from noisy urban environments, to quiet rural residential locations and are summarized in Table 37.

Table 37. Overview of existing noise guidelines and standards relevant to typical wind turbine projects gathered from Hessler and Hessler (2010).

Source	Effective Limits	Comments
World Health Organization	40 dBA Night	Sleep Disturbance Threshold
Consensus of International Limits Specific to Wind Turbine Noise	40 dBA Night/45 dBA Day	Arithmetic Average of All Standards
United States EPA	35 dBA Night/45 dBA Day	DNL- 45 dBA
State Standards	38 dBA to 40 dBA Night	Based on Three States using an Ambient Based Approach

EPA - Environmental Protection Agency
DNL - Day/Night Average Sound Level

NYS happens to be a state that utilizes the ambient-based approach for developing noise limits for environmental noise exposure (DEC, 2001). The ambient-based approach provides a more relevant and site-specific aim by considering the perception of new sound in a defined geographic location or community.

5.3 Day Versus Night Comparison

The comparison of day versus night sound measurement and sound perception is complex, since the range of wind speeds and other meteorological conditions are often not the same from day to night. With atmospheric stabilization that can occur at night, the relationship between measured wind speed at ten meters and the actual wind speed at hub height (which controls turbine noise output) and near the ground (which controls wind masking background noise) can also change. Similarly, nighttime temperature inversions can alter the way that turbine noise propagates through the atmosphere. Finally, for background noise, most non-wind related noise sources tend to diminish at night, such as traffic noise and other human activity.

During the summer and fall monitoring periods, wind speeds at night did not reach the turbine maximum sound power speed of seven m/s at ten meters. For that reason, day and night comparisons were not explored in the summer and fall campaigns. In order to begin to demonstrate the difference between day and night sound pressure levels, the calculated best-fit sound levels at Location D for daytime hours (7 a.m. to 7 p.m.) and nighttime hours (7 p.m. to 7 a.m.) are summarized in Table 38 below. At wind speeds below seven m/s, the daytime sound levels were lower than nighttime levels. As wind speeds exceeded seven m/s, the daytime sound levels increased above the nighttime levels. This effect at lower apparent wind speeds may illustrate a change in the wind gradient at night−for a given measured wind speed at ten meters, wind at hub height may be higher (and turbines louder) at night than during the day due to atmospheric stabilization. This effect can contribute to greater perceptibility of turbine noise at night, since background noise and wind masking reduce near the ground at the same time that hub height wind speed is higher than it would be during the day (Van den Berg, 2004).

Table 38. Calculated sound pressure levels at the integer wind speeds for day and night time hours at Location D during the winter monitoring campaign.

Integer Wind Speed at Standardized Height of 10 m (m/s)	1	2	3	4	5	6	7	8	9	10	11	12
Day	36.2	38.5	40.7	42.9	45.2	47.4	**49.6**	51.8	54.1	56.3	58.5	60.8
Night	37.5	39.5	41.5	43.5	45.5	47.5	**49.5**	51.5	53.5	55.5	57.5	59.5

Interestingly, during the winter monitoring, the highest ten-minute average wind speeds exceeded 12 m/s at night. Figure 21 below illustrates best-fit sound pressure levels at wind speeds of one m/s to 12 m/s during the nighttime hours (7 p.m. to 7 a.m.) at Location D and Background 2. Background 2 is provided for reference purposes.

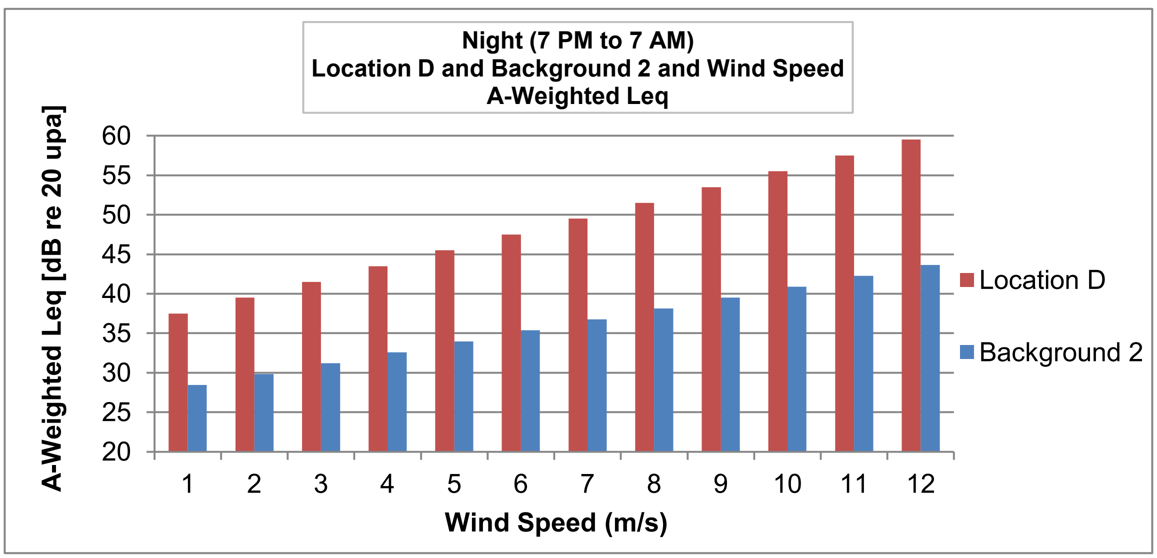

Figure 21. Sound pressure levels at all measured wind speeds during the winter campaign nighttime hours (7 p.m. to 7 a.m.) at Location D and Background 2.

Based upon the linear best-fit line, the measured sound pressure level at Location D for night time hours was compared to the measured sound pressure level at Background 2 for night time hours at seven m/s. At Location D with a wind speed of seven m/s the measured sound pressure level was 49.5 dBA, while the sound pressure level at the Background 2 was 36.7 dBA. Based upon the sound levels measured in the night time hours during the winter campaign at Location D, the potential exists for sound levels to exceed the standards and guidelines outlined above in Table 37 for night time hours.

We were not able to make a direct comparison of the measured sound pressure levels gathered in this study to the standards and guidelines outlined in Table 37 and the local Town of Eagle and Wethersfield ordinances, nor was this an objective. In order to assess compliance with any of these ordinances and standards, the background sound pressure levels would need to be directly assessed with the wind turbines parked. Instead, these results should be used as bench marks for future policy development.

5.4 Comparison of Collected Data to Hessler Measured Backgrounds

Prior to the wind turbine construction at the Wethersfield site, background noise monitoring was conducted by Hessler *et al.,* (2007). In their study, a L90 values were normalized on a fourth order best fit line to integer wind speeds similar to the approach used in this study. As shown below in Figure 22, the measured L90 values are similar between wind speeds of one m/s and five m/s. However, as wind speeds increased above five m/s, the L90 values began to deviate slightly.

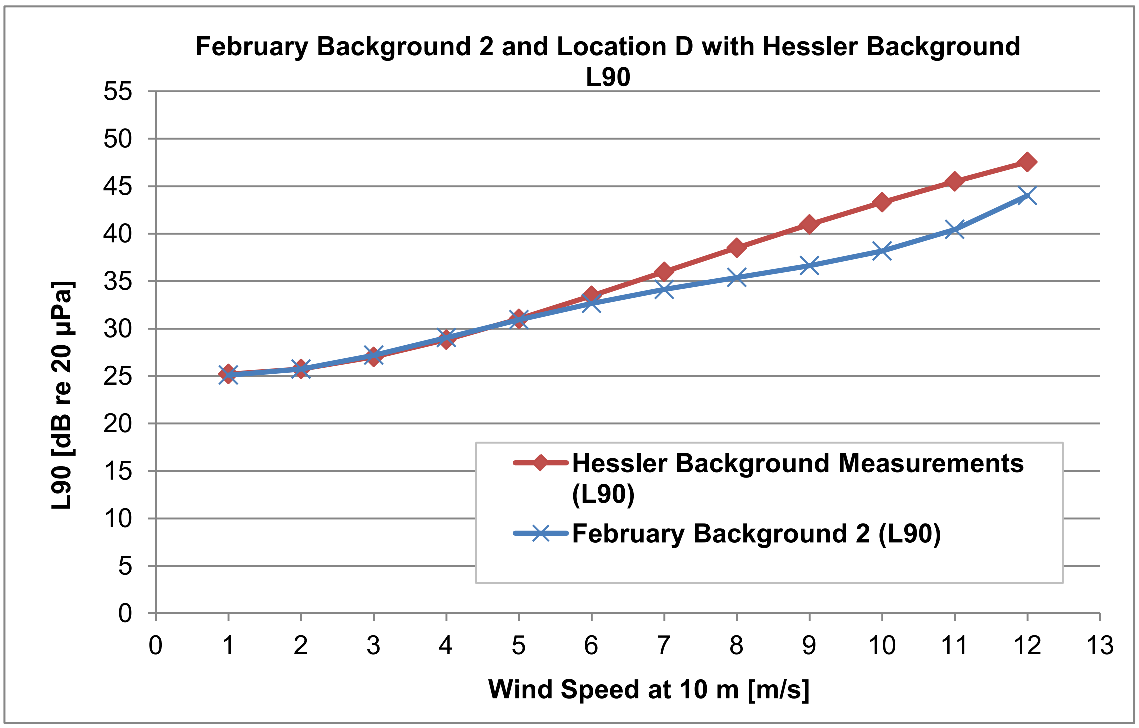

Figure 22. Best-fit fourth order L90 measurements normalized to integer wind speeds by Hessler *et al.,* (2007) in Wethersfield turbine park site pre-turbine construction and the February Background 2 location during turbine operation.

At wind speeds of ten m/s and 11 m/s, the difference between the normalized L90 for the two studies was 5.1 dBA. For all other integer wind speeds, the difference was less than five dBA (Table 39).

Table 39. Measured L90 values normalized to integer wind speeds by Hessler *et al.,* (2007) in the Wethersfield turbine park site pre-turbine construction and the February Background 2 location during turbine operation.

Integer Wind Speed at Standardized Height of 10 m (m/s)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Hessler *et al.,* 2007 Measured L90, dBA	27	28.8	31	33.4	36	38.5	41	43.3	45.5	47.5
February Measured L90 at Background 2, dBA	27.2	29	30.9	32.7	34.1	35.4	36.6	38.2	40.5	44

The comparison of the L90 values measured by Hessler (pre-development) with the Background 2 location are summarized in Table 43 and suggest the selection of the Background 2 location for this study was appropriate, and that our Background 2 location represents a comparable "turbine off" scenario. The L90 values provided by Hessler and represented in Figure 19 above, are an agglomeration of six different monitoring locations; whereas, our L90 values are simply from one location, Background 2. Furthermore, Hessler also performed 14 days of monitoring compared to the four days of monitoring during this study. The deviation between values above five m/s may be explained by considering these facts. With six different locations being combined into one data set presentation, the overall L90 values at integer wind speeds may have been increased slightly due to one or two locations with elevated noise levels.

Prior to turbine construction in 2007, Hessler *et al.,* performed background monitoring at multiple locations within the prospective turbine park area. It was discovered after our monitoring was completed that one of the locations selected by Hessler *et al.,* happened to be the same property as our monitoring Location D, which also served as the wind mast location. The combined L90 measurements collected from all of Hessler *et al.,* locations and the L90 values collected at Location D during turbine operation are presented in Figure 23.

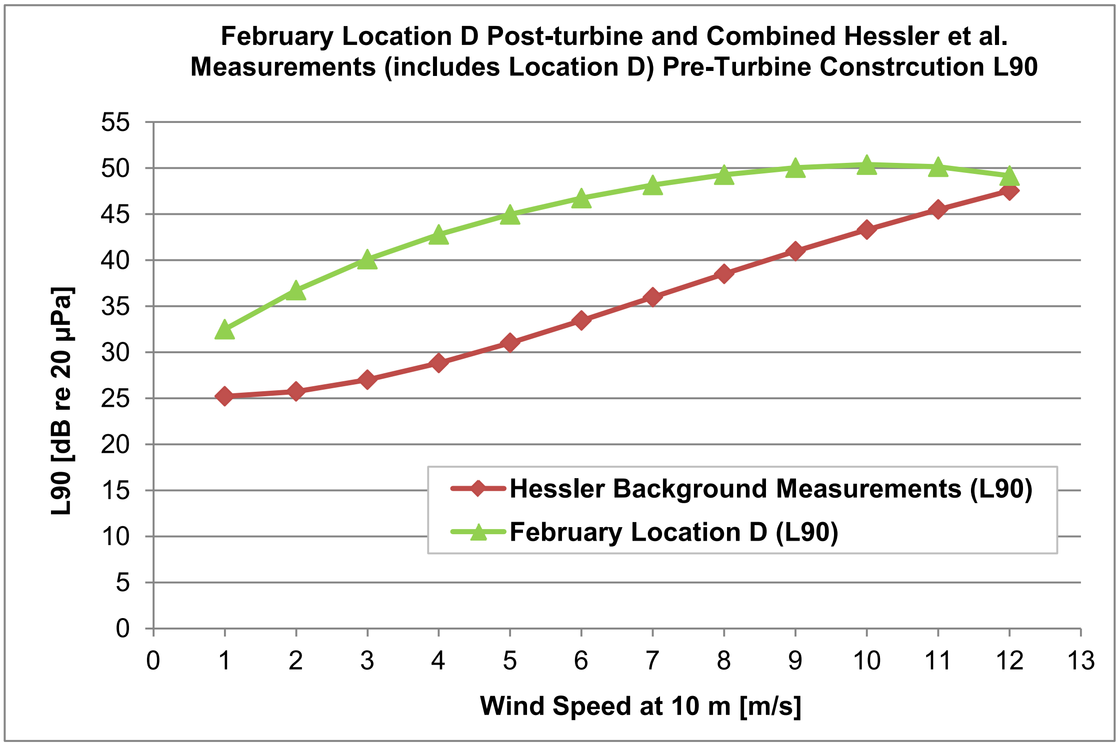

Figure 23. Best-fit fourth order L90 values normalized to integer wind speed at Location D post-turbine construction and combined locations (including Location D) pre-turbine construction by Hessler *et al.*

The greatest L90 difference of 14 dBA occurred at the integer wind speed of five m/s. L90 values measured at Location D while the turbines were operational were consistently higher than the L90 values measured by Hessler *et al.,* at the same location in 2007 prior to turbine construction (Table 40).

Table 40. Measured L90 values at integer wind speeds by Hessler prior to turbine construction and measured L90 values at Location D during turbine operation.

Integer Wind Speed at Standardized Height of 10 m (m/s)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Hessler *et al.,* 2007 Measured L90, dBA (Turbines not operational)	25.2	25.7	27	28.8	**31**	33.4	36	38.5	41	43.3	45.5	47.5
February Measured L90 at Location D, dBA (Turbines Operational)	32.5	36.7	40.1	42.8	**45**	46.7	48.2	49.3	50	50.4	50.1	49.2

For comparison purposes, the calculated LAeq for the select frequency band at this location was 51.5 dBA at seven m/s, which is 3.3 dBA higher than the L90 value of 48.2 dBA shown in Table 40. Some difference is expected, since the L90 represents the quietest ten percent of a ten-minute period, while the Leq represents the energy average over the entire period. The difference between the pre- and post-turbine measurements was greater than ten dBA from a wind speed of two m/s to eight m/s. Though comparing L90 values to assess wind turbine noise in relation to ambient levels may understate variations in turbine noise (such as modulation or gusty wind conditions), this comparison provides true pre- and post-turbine noise measurements at the same location in the Wethersfield Turbine Park.

5.5 Discussion of Satisfaction with Living Environment Survey

5.5.1 Overall Satisfaction

There were no statistically significant correlations in age or gender and their perceived level of satisfaction with their living environment, their general opinions on wind turbines, their opinions on the altered landscape or whether they are annoyed by wind turbine noise either outside or inside. This is consistent with that detailed by Pedersen and colleagues in their 2009 study in the Netherlands and with Pedersen and Waye's (2007) study in Sweden where they note that the odds of being annoyed was not significantly correlated with gender.

As indicated previously, 91 percent of study participants were overall either very satisfied or satisfied with their living environment. All individuals were receiving a substantial property tax reduction as a result of the turbine project, along with other benefits including free trash removal. Among those individuals in our study that were benefiting economically from the wind turbines by a direct arrangement with Noble, they were overall more likely to be satisfied with their living environment, but not necessarily more likely to be less annoyed with wind turbine noise outside or inside their homes. This is somewhat in contrast with studies conducted in the Netherlands (Pedersen *et al.*, 2009) where study participants were less likely to be annoyed by wind turbine noise if they were receiving economic benefit from them. This relationship was not discussed in the Swedish studies where 95 percent of the study population was not benefiting economically from the wind turbines.

Interestingly, there was no correlation between either an individual's level of satisfaction with their living environment, or their annoyance with wind turbine noise inside or outside, and the number of turbines visible from their home. This is in contrast with Pedersen *et al.*, (2009), who noted a significant increase in the proportion of those who were annoyed by the sound from the wind turbines if they could see at least one turbine from their home. This study did include a fair number (27 percent in rural areas and 46 percent in built up areas) of participants that could not see any wind turbines from their property. This is in contrast to our study, where all participants could see at least one, and on average 19 wind turbines, from their homes. Furthermore, the average distance from turbine to each surveyed household was greater than 580 meters. A study by O'Neal and colleagues (2011) concluded that wind turbine infrasound is inaudible to even the most sensitive people at distances of greater than around 305 meters.

5.5.2 Noise Complaints

Another measure of satisfaction with living environment is reflected in the number of individuals issuing noise complaints. It is interesting to note that the percentage of households lodging complaints due to wind turbine noise in this study is 8.9 percent (five homes with complaints/60 homes visited). This percentage is in line with the two percent to seven percent that Hessler reports in five similarly sized projects (Hessler *et al.,* 2011). This is also in alignment with the five percent of individuals reporting in this study that they are very sensitive to noise in general, along with an additional seven percent indicating that they are rather sensitive to noise in general.

5.5.3 Relationship between Satisfaction and Monitored Noise Inside and Outside Homes

The results of this study suggest that an individual's level of satisfaction with their living environment does not depend upon the noise levels sampled inside and outside their homes. This is in contrast with those results presented by Pedersen *et al.*, in both their Dutch (2009) and Swedish (2004, 2007) cohorts where they found statistically significant exposure-response relationships between annoyance and calculated A weighted sound pressure levels at individual residences. Although these modeled sound levels do correlate well with long-term turbine noise exposure levels, individual data points can vary significantly from the long term trend (Forssén, 2010). Since the current study sampled only a single ten-minute period at each residence, the expected scatter in these values about the long-term trend makes comparison with prior findings difficult.

To our knowledge, this study is the first to collect actual sound measurements at individual residences. In contrast to actual sound monitoring, various models were used to calculate A weighted sound pressure levels at the residences of survey respondents in the European studies including the sound propagation model for wind power plants adopted by the Swedish Environmental Protection Agency (2001), Netherlands regulatory required models (VROM, 1999), the New Zealand Standard (NZS, 1998) and the International Standards Organization (ISO, 1996). If one assumes that the misclassification of sound exposure inherent in these models is random, the exposure response they are finding may in fact be stronger in reality, as random misclassification of exposure will bias results towards the null.

All three studies were considerably larger than this study of 63 individuals, with 725 participants in the Netherlands and 754 and 351 participants in each of the Swedish studies. All three European studies included both rural and urban settings with varied terrain, while this study was conducted completely in a rural farming community. Albeit internally valid, the small sample size and the uniformity of the study area where everyone is benefiting in some way, even if they do not have a direct arrangement with Noble Energy, may make these study results somewhat less generalizable to all types of communities living in proximity to wind turbines.

Interestingly, and somewhat counter intuitively, Pedersen and colleagues (2009) do note a difference in the rural versus urban/built up response, whereby those individuals living in a built up urban environment tended to be more annoyed by the wind turbine noise than those in a rural environment without a main road. This is generally predictive of the findings of this study. In contrast, Pedersen *et al.*, note in their

2007 Swedish study that those individuals living in rural environments were more likely to be annoyed by wind turbine noise than those living in suburban environments.

Another factor that may have limited this study's ability to see an exposure-response relationship was the relatively short duration of sound measurements collected. Ten-minute samples were collected both inside and outside the participant's home at the time the survey was completed. A ten-minute sample may not be representative of the overall sound profile in or outside the home; this can be seen in the long term monitoring results, where the scatter of measured values varied significantly about the long term trend. Also, there was some variation in the time of day the participants were surveyed, which would likely affect the indoor measurements more than the outdoor measurements due to variation in home occupancy. Wind speed variation from survey to survey, along with overall low wind speeds during the at home surveys, may also contribute to the range of measured values outside the home, since local wind speed determines turbine noise output.

It is also quite likely that in this small community, the strong relationship between a participant's general opinion on wind turbines and the level of satisfaction with their living environment, which was generally quite high, overwhelms any exposure-response relationship that may exist between satisfaction, annoyance and actual sound level measurements.

5.6 Discussion of Health Effects Survey

There are few reports in the popular and peer reviewed literature examining the potential association of living in close proximity to wind turbines with the development of various health effects including acute and chronic conditions (Colby, 2009). This study did not investigate the association between noise exposure from the turbines and chronic diseases such as hypertension, diabetes and ischemic heart disease.

A relatively small percentage of this study population (20 percent) was concerned about health effects associated with living in close proximity to the wind turbines. Among these 20 percent (12 individuals), only two had felt strongly enough about their symptoms to seek medical attention. In both cases the participants indicated that their physicians noted the wind turbines as the cause of their conditions, with one individual being prescribed medication for their condition.

The percentage of individuals reporting they are concerned with health effects (20 percent) in this study is also consistent with the percentages of individuals reporting headaches (19 percent), fatigue (18 percent) and to a lesser extent stress (11 percent). Further, most of those concerned about health effects felt that any symptoms they were experiencing were, in fact, related to the wind turbines (18 percent) and were worse since they became operational (19 percent). These factors were not discussed in the Swedish and Dutch studies previously published.

Interestingly, more individuals (26 percent) report sleep disturbance from the wind turbines, than report they are generally concerned about health effects from the wind turbines. This is in line with the 23 percent of respondents that stated they were “disturbed in their sleep by noise” in Pedersen and colleagues 2004 Swedish study. Pedersen *et al.*, also note in their 2007 Swedish cohort that among those who were annoyed by wind turbine noise, 36 percent reported that their sleep was disturbed by a noise source in an open question, not necessarily a wind turbine. In their earlier 2004 study of 351 Swedish residents, they note that “the number of respondents disturbed in their sleep was too small for meaningful statistical analysis, but the probability of sleep disturbances due to wind turbine noise cannot be neglected at this stage”. This study did reveal a statistically significant correlation between an individual’s concern regarding health effects and having experienced sleep disturbances. In addition to a correlation with sleep disturbance, stress was also significantly correlated with those individuals concerned regarding health effects.

Similar to that reported by Pedersen *et al.,* in their 2007 Swedish cohort, this study did not report any significant correlations with self-reported headaches, dizziness or fatigue and the sound level measurements collected at the time of the survey.

6.0 FUTURE WORK

The following thoughts on continued work, building upon this current study, are offered.

6.1 Enhanced Sound Measurement and Analyses

The Larson Davis Model 831 sound level meter with additional firmware has a minimum 1/3-octave band measurement filter of 6.3 Hz. There has been some discussion in the literature regarding health effects associated with infrasound frequencies below this. Future work should consider additional focused measurements on infra sound in general and below 6.3 Hz specifically.

This study did not collect data at a sufficiently high enough resolution to characterize impulsive or amplitude-modulated noise. This was not an objective of this study, however, it is a known contributor to wind turbine annoyance. Future work should consider short duration measurements of high frequency sampling (resolution less than one second) to characterize these phenomena.

This study did not reveal an appreciable difference in the night measurements to indicate a stable atmosphere or other enhanced propagation conditions. Although acoustically significant, these atmospheric effects may occur infrequently. Future work should consider including increased meteorological data (including temperature and wind profiles at multiple heights) sufficient to identify these effects. In conjunction, longer measurement campaigns would increase the chances of capturing infrequent but significant occurrences.

Cooperation from the wind utility operator would open new avenues for analysis of the collected data, or for analysis of data collected in future studies. With access to typical Supervisory Control and Data Acquisition (SCADA) data for the project duration (e.g., hub wind speed and power output at each individual turbine), the local conditions associated with each noise measurement would be more precisely characterized, and the atmospheric gradients noted above could be identified more clearly.

Improperly spaced turbines can increase noise levels as turbulent flow may strike downstream turbines under certain wind conditions. The evaluation of noise produced as a result of improperly spaced turbines is also a consideration for future work. This work would require the cooperation of the wind turbine operator to confirm the design assumptions behind the turbine siting as well as the atmospheric conditions at each individual turbine.

Assumptions made regarding the effectiveness of the windscreen during this study were based upon evaluation in a controlled wind tunnel study using smooth, constant airflow. Future work should consider the impact of windscreen self noise in the naturally occurring turbulent outdoor air. The collection of wind speed measurements at the microphone itself, rather than extrapolating from the tower, and only using data when wind speed at the ground is sufficiently low, would eliminate some concern regarding the possible underestimation of microphone "self noise".

The short-term noise measurements at questionnaire survey locations obtained in this study could be supplemented with a site-wide theoretical model of turbine sound power and noise propagation, as has been used in prior epidemiological studies. A calculated noise immission value for each residence may characterize long-term average exposure better than short-term field measurements, and therefore may also provide better insight into resident satisfaction and annoyance from turbine noise.

6.2 Epidemiologic Considerations

In general, a larger sample size would be ideal to have more resolution and power to detect annoyance within this community.   Recent work in the literature would indicate that additional, more detailed questions regarding sleep disturbance could be beneficial when surveying wind turbine communities.

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APPENDIX A

Formatted Wind Turbine Noise Survey

Survey Questions

Section 1

1. Identification Number ____________

2. Name____

3. What year did you move into this home? ________________________________

Section 2

4. How satisfied are you with your living environment?

   Very satisfied
   Satisfied
   Neither satisfied nor dissatisfied
   Not satisfied
   Not at all satisfied

5. If you are not satisfied, then what is wrong?

   ____
   ____
   ____
   ____

6. Have there been any changes to the ***better*** in your living environment/municipality during the last few years?   Yes   No

   State which changes.

   ____
   ____
   ____
   ____

7. Have there been any changes to the ***worse*** in your living environment/municipality during the last few years? Yes   No

   State which changes.

   ____
   ____
   ____
   ____

8. State for each nuisance below if you notice or are annoyed when you spend time ***outdoors*** at your dwelling:
(Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

- Odor from industries ______________________________
- Odor from manure, flies______________________________
- Noise from hay fans______________________________
- Noise from wind turbines______________________________
- Railway noise______________________________
- Road traffic noise______________________________
- Lawn mowers______________________________
- Other (please describe)

____
____
____

9. State for each nuisance below if you notice or are annoyed when you spend time ***indoors*** at your dwelling:
(Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

- Odor from industries ______________________________
- Odor from manure, flies______________________________
- Noise from hay fans______________________________
- Noise from wind turbines______________________________
- Railway noise______________________________
- Road traffic noise______________________________
- Lawn mowers______________________________
- Other (please describe)

____
____
____

10. For any indoor nuisance you note above, do you generally have your windows open, partly open or closed?

Open
Partly Open
Closed

11. Are there any indoor noises that annoy you? (i.e., heating systems, house fans)

____

____

12. Do you have air conditioning? Yes No

If so, window units or central air conditioning?_________________________________

13. How would you describe your sensitivity to the following environmental factors:
(Not sensitive at all, Slightly sensitive, Rather sensitive, Very sensitive)

- Air pollution____
- Odors____
- Noise____
- Littering____

14. Have you ever reported a noise complaint to town officials? Yes No

If so, how many times, and when?____

____

Section 3

15. Can you see any wind turbines from your dwelling or your yard? Yes No

If yes, how many?____

16. If you work outside the home, can you see any wind turbines from your place of work?
Yes No

If so, approximately how far from your place of work is the closest turbine?

____

17. What is your opinion on the wind turbines' impact on the landscape scenery?

Very positive
Positive
Neither positive nor negative
Negative
Very negative

18. Are you affected by wind turbines while ***outside*** your dwelling with regard to:
    (Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

    - Shadows from rotor blades____
    - Reflections from rotor blades____
    - Sound from rotor blades____
    - Sound from turbine machinery____
    - Altered view____

19. Are you affected by wind turbines while ***inside*** your dwelling with regard to:
    (Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

    - Shadows from rotor blades____
    - Reflections from rotor blades____
    - Radio or tv reception problems____
    - Sound from rotor blades____
    - Sound from turbine machinery____
    - Altered view____

20. If you are annoyed by noise from the wind turbines, how often does this happen?

    Never/almost never
    Some/ a few times per year
    Some/a few times per month
    Some/ a few times per week
    Daily/almost daily

21. If you are annoyed by television or radio interference from the wind turbines, how often does this happen?

    Never/almost never
    Some/ a few times per year
    Some/a few times per month
    Some/ a few times per week
    Daily/almost daily

22. If you are annoyed by shadows and/or reflections from the wind turbines, how often does this happen?

Never/almost never
Some/ a few times per year
Some/a few times per month
Some/ a few times per week
Daily/almost daily

23. If you hear sound ***outside*** your dwelling from wind turbines, how would you describe the sound: (circle all that apply, if circled, add in characterization note)

(Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

- Tonal____
- Pulsating/throbbing____
- Swishing____
- Whistling____
- Lapping____
- Scratching/squeaking____
- Low Frequency____
- Resounding____
- Other sound (please describe)____

24. If you hear sound ***inside*** your dwelling from wind turbines, how would you describe the sound: (circle all that apply, if circled, add in characterization note)

(Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

- Tonal____
- Pulsating/throbbing____
- Swishing____
- Whistling____
- Lapping____
- Scratching/squeaking____
- Low Frequency____
- Resounding____
- Other sound (please describe)____

25. Have you noticed if sounds from wind turbines sound different during any of these situations:
(Less clearly heard, More clearly heard, No differences, Do not know)

- When the wind blows from the turbine(s) toward my dwelling________________
- When the wind blows from my dwelling toward the turbine(s)________________
- When the wind blows parallel to my dwelling and the turbine(s)______________
- When the wind is low speed____
- When the wind is rather strong____
- Any one particular season, if so, which season____________________________
- Warm days or warm nights ____
- Cool days or cool nights ____
- When there is or isn't ground cover (i.e., snow)___________________________
- Other (please describe)____

26. Are you annoyed by sound from wind turbines during any of the following ***outdoor*** activities:
(Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

- Relaxing outdoors____
- Barbecue nights____
- Taking walks____
- Gardening____
- Other outdoor activities (please describe)__________________________________
____
____

27. Are you annoyed by sound from wind turbines during any of the following ***indoor*** activities:
(Do not notice, Notice but not annoyed, Slightly annoyed, Rather annoyed, Very annoyed)

- Talking with others____
- Listening to the radio____
- Watching television____
- Talking on the phone____
- Sleeping____
- Other indoor activities (please describe)____
____
____

28. For each of the above indoor activities, do you generally have your windows:

Open
Partly Open
Closed

29. Are you associated or involved in a contractual relationship or are associated with the wind company (NOBLE)?
(circle all that apply)

None
Yes I own land on which a turbine(s) is built and I receive royalties from wind turbines
I work for them
A relative works for them
I have a neighbor agreement for easements, other easements
Other arrangements or associations

30. What is your general opinion on wind turbines?

Very positive
Positive
Neither positive nor negative
Negative
Very negative

31. Please circle the following adjectives that you think are adequate for wind turbines:
    - Efficient
    - Inefficient
    - Environmentally friendly
    - Harmful to the environment
    - Unnecessary
    - Necessary
    - Ugly
    - Beautiful
    - Annoying
    - Inviting
    - Threatening
    - Blends in
    - Natural
    - Unnatural
    - Please provide some of your own adjectives
    - ____

Section 4

32. Are you concerned about experiencing any health effects living close to wind turbines?
    Yes No

33. For the following list of conditions can you please let us know if you ever experience any of these conditions? If so, how often? (Never, sometimes/monthly, sometimes/weekly, daily)

    - Headaches

    - Dizziness

    - Fatigue

    - Stress

    - Sleep disturbance

34. How long have you had these symptoms?

35. Do you feel you've had more of these symptoms since the wind turbine(s) began operating, or do you feel there has been no change in the frequency of your symptoms?

36. For those symptoms you note experiencing above, do you feel they are related to any environmental conditions? Yes No

37. Do you feel that they are related to the wind turbines? Yes No

38. For those conditions you may experience, are they worse during any particular time of day or season of the year? Yes No If so, which time of day or season of the year? -
____

39. Have you ever visited a Doctor because of a problem you felt was associated with living close to a wind farm? Yes No

40. If so, when? If so, for what?

41. Did the Doctor confirm that he or she thought the condition was related to the wind turbines? Yes No

42. Did the Doctor prescribe any medication or other treatment for this condition?

____

43. Is there anything else you would like to tell us or anything else you would like us to know?
____
____
____
____

Demographic Information

44. Address ____

____

45. What is your year of birth? ______________________

46. What best describes your highest level of education?

Less than high school
High school diploma
Some college
2-year degree
4-year degree
Graduate degree

47. How many other people live with you at this residence? What are their genders and ages?

____
____
____
____

48. Are you employed? Yes No
If yes, what is your occupation?______________________________

49. Approximately how many hours per week do you work outside the home?

<40 hours
40 hours
40-50 hours
>50 hours

50. Where did you live prior to this (city, state)?

____

51. Gender: Male Female

52. Distance to closest wind turbine (GIS distances will be obtained, feet)

____

Sound Measurement Study
Information Sheet

All personal data will remain confidential and anonymous. All participants will be issued an identification number to protect their identity with the decoding chart located in a password protected location on a secure server. Data will be published in aggregate without any personally identifying information. You can answer some, all or none of the questions. You can stop at any time and are under no obligation to finish the survey and will experience no consequence. Our contact information is located below. Please call us if you have any questions. Please also let us know if you would like copies of published papers resulting from this survey.

Purpose: We are researching the sound produced by the wind turbines and how residents feel about the turbines.

Time: We expect the survey questions will take approximately 20 minutes to collect. We will then collect sound level measurements inside and outside your home.

Benefits: You will be contributing to the body of knowledge we have about the sound levels produced by the turbines and how individuals living close to them feel about them. This information will help others in setting policies.

How confidentiality will be maintained: All participants will be assigned an identification number and all data will be linked to this number and not your name or address.

Contact Information: If you have any questions about this study, feel free to contact:
Shannon R. Magari: 315-445-0847
Annette C Rohr: 425-298-4374

APPENDIX B

Recruitment Information Noise Monitoring Study

Sound Monitoring Study

Partners

This is a joint research study between the New York State Energy Research and Development Authority (NYSERDA), the Electric Power Research Institute (EPRI), and Colden Corporation. Please feel free to call any of us at any time with questions.

Colden – Shannon Magari, (315) 445-0847

EPRI – Annette Rohr, (425) 298-4374

NYSERDA – Greg Lampman, (518) 862-1090 ext. 3372

What We Will Do

We will monitor sound around groups of wind turbines to see what the levels are during different seasons. We plan to monitor three times (summer, fall, winter) for five days each.

Why Are We Doing This?

We want to take an objective look at the type of sound associated with wind turbines, and how it may or may not affect nearby residents.

What Will You See

We will use small black suitcases on tripods about seven feet tall with a microphone on top. We will have five of these set up around Wethersfield, near the wind turbines and hopefully close to residents' homes in their back yards.

Our Thank You

To thank those residents who allow us to put a noise monitor in their yard, we can offer a small thank you gift card.

APPENDIX C

Comparison of Sound Pressure Levels and Wind Speeds at the Infra, Low and Overall Frequency Bands for Each Campaign and Monitoring Location

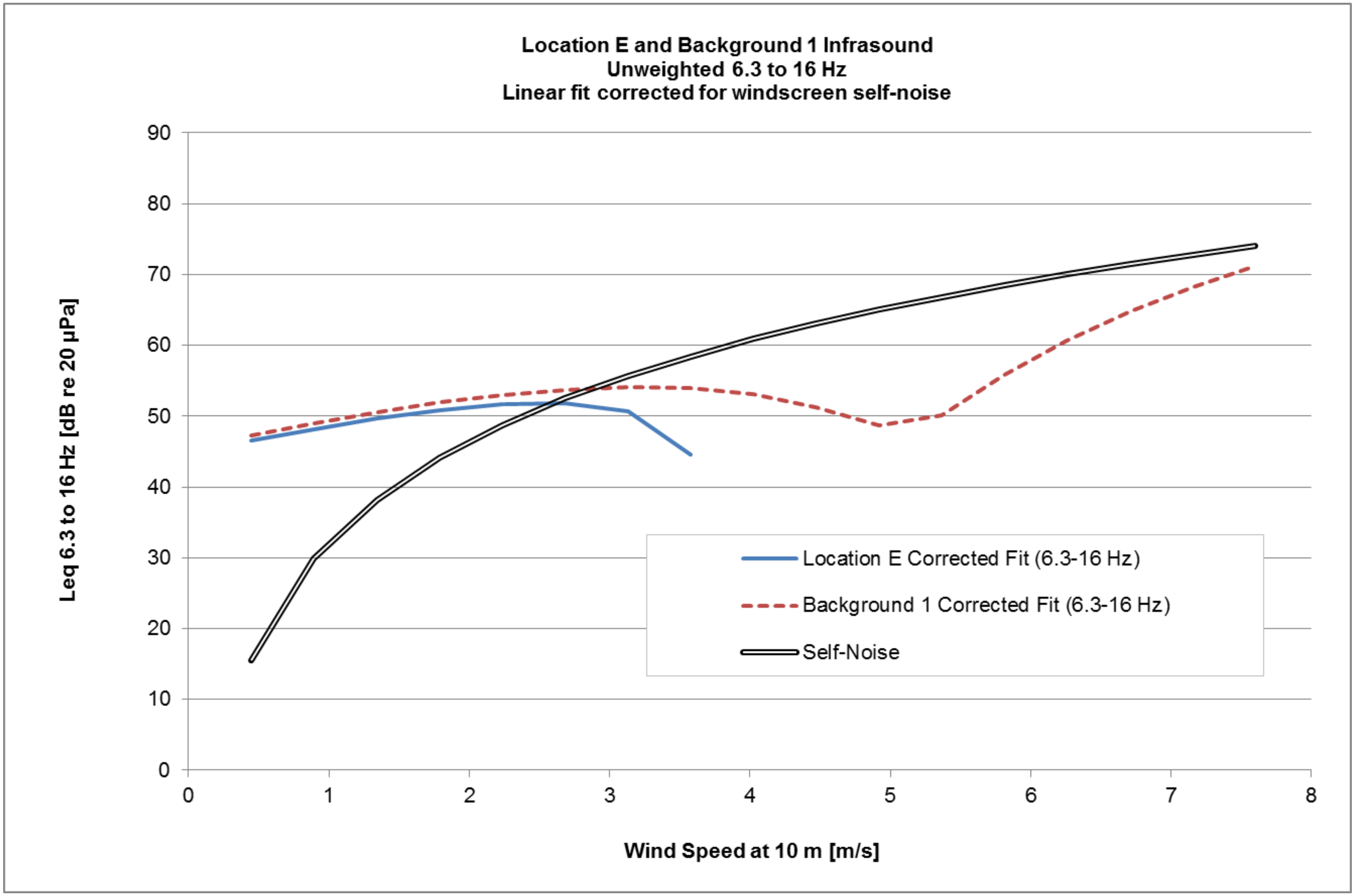

Figure 1. Location E and Background 1 Infrasound Unweighted 6.3 to 16Hz Linear fit corrected for windscreen self-noise.

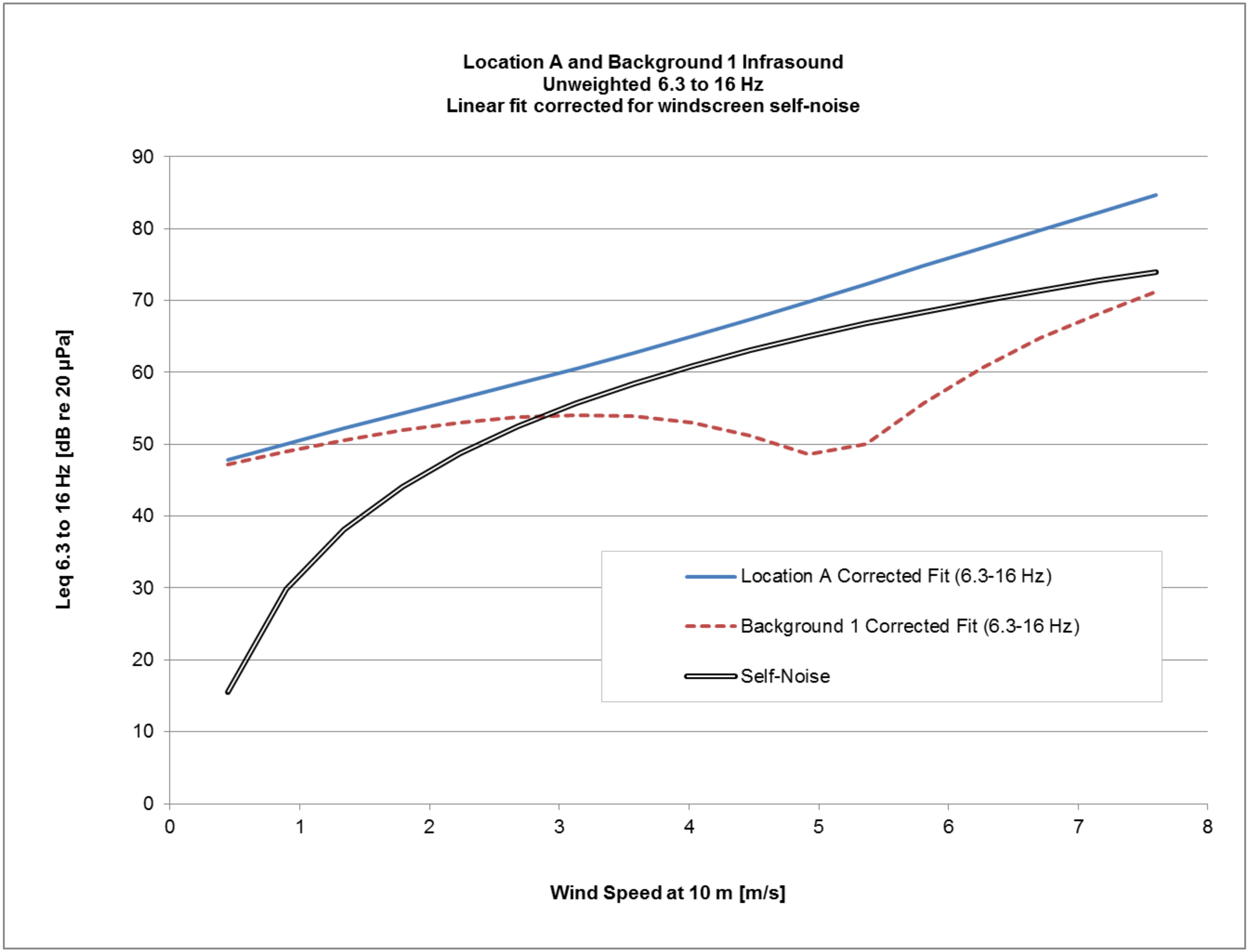

Figure C2. Location A and Background 1 Infrasound unweighted 6.3 to 16Hz linear fit corrected for windscreen self-noise.

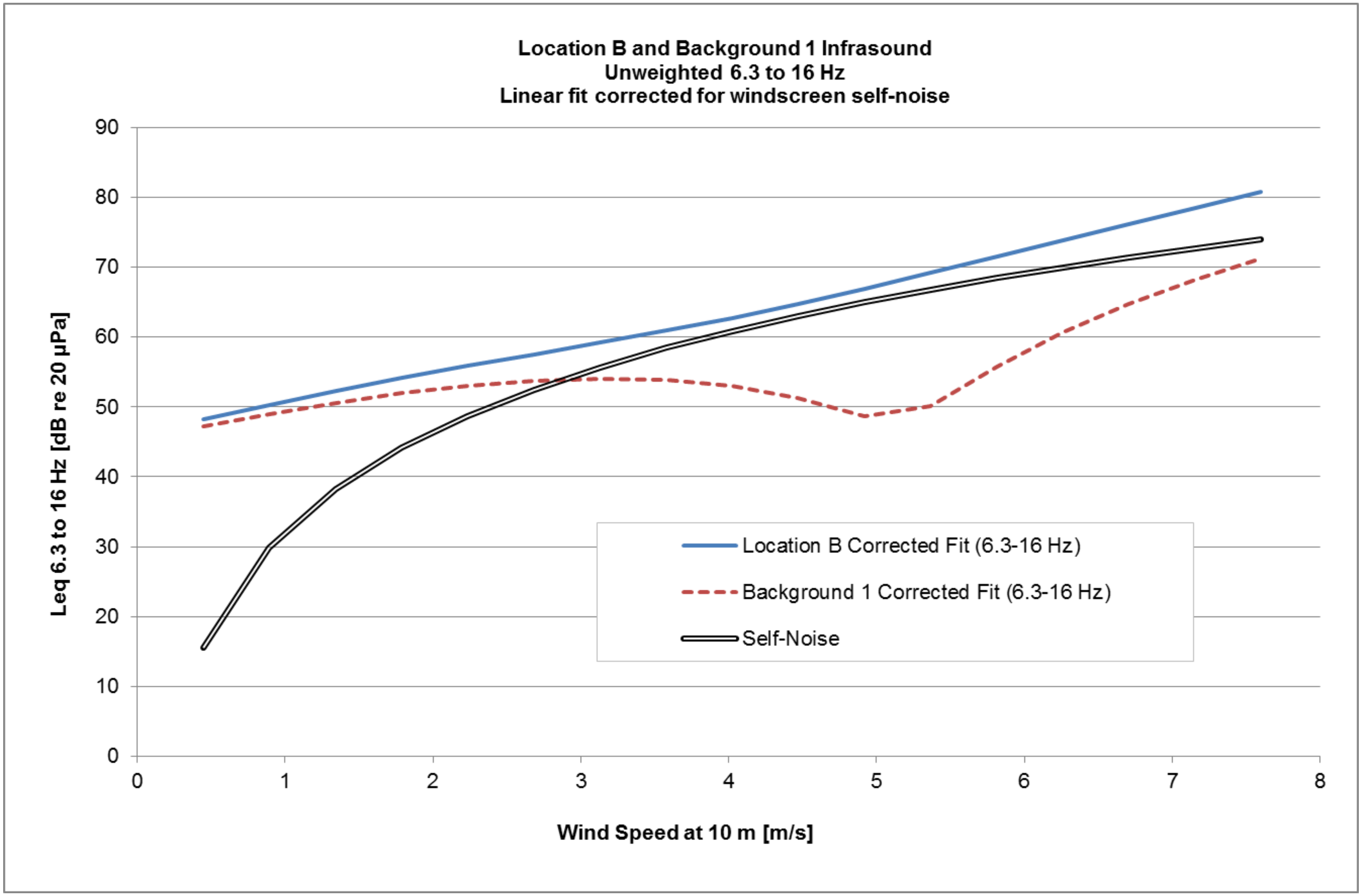

Figure C3. Location B and Background 1 Infrasound unweighted 6.3 to 16Hz linear fit corrected for windscreen self-noise.

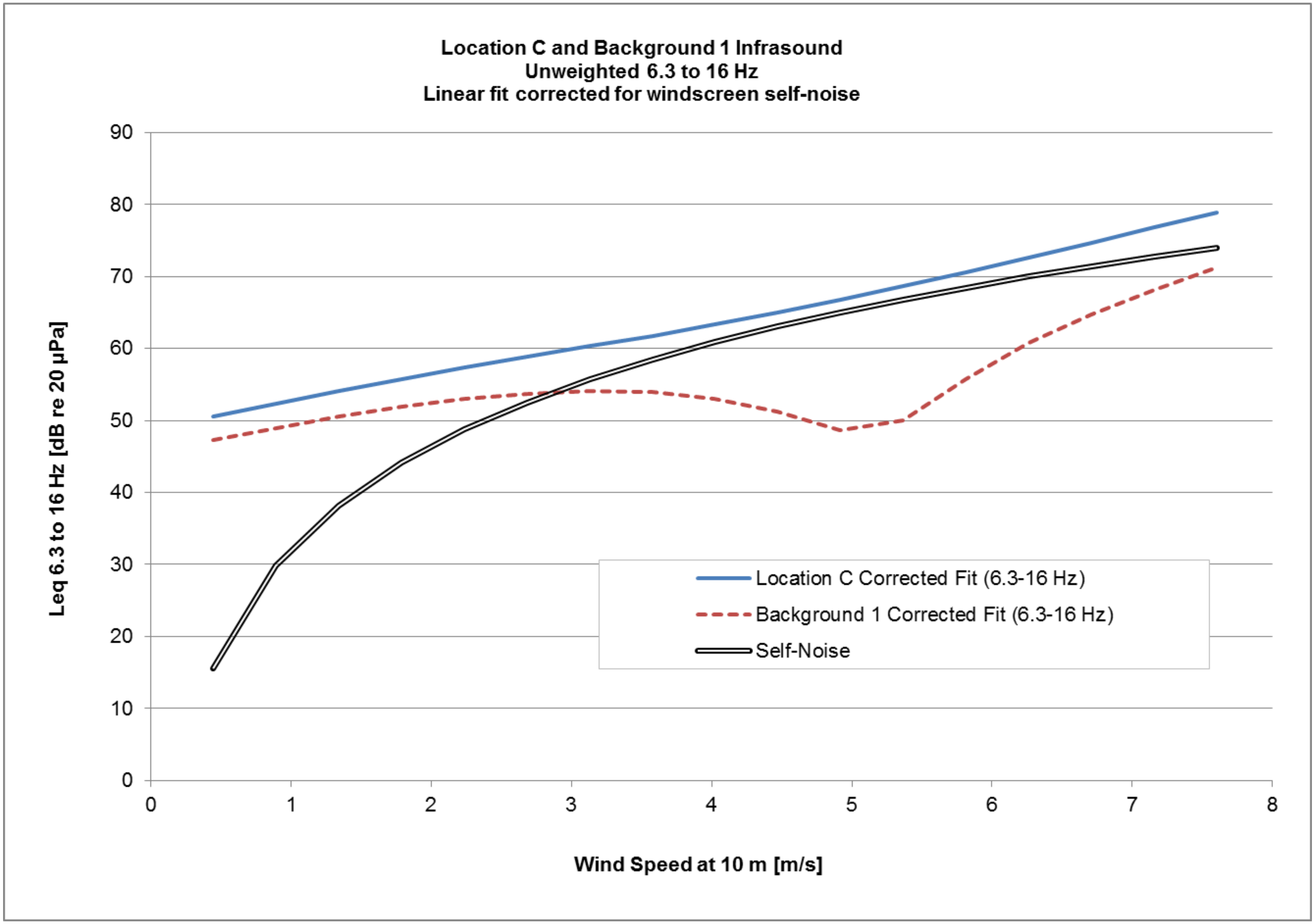

Figure C4. Location C and Background 1 Infrasound unweighted 6.3 to 16Hz linear fit corrected for windscreen self-noise.

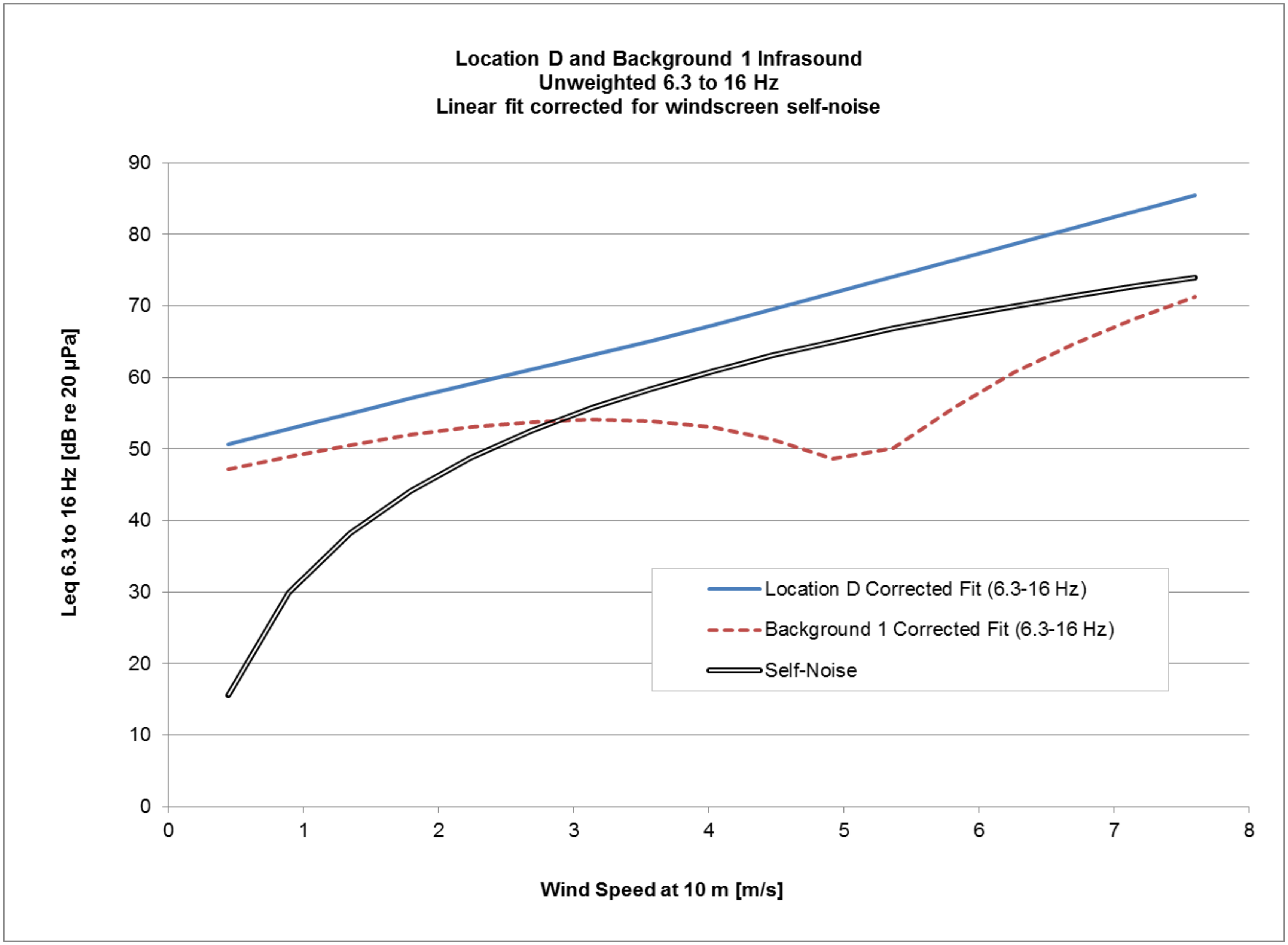

Figure C5. Location D and Background 1 Infrasound unweighted 6.3 to 16Hz linear fit corrected for windscreen self-noise.

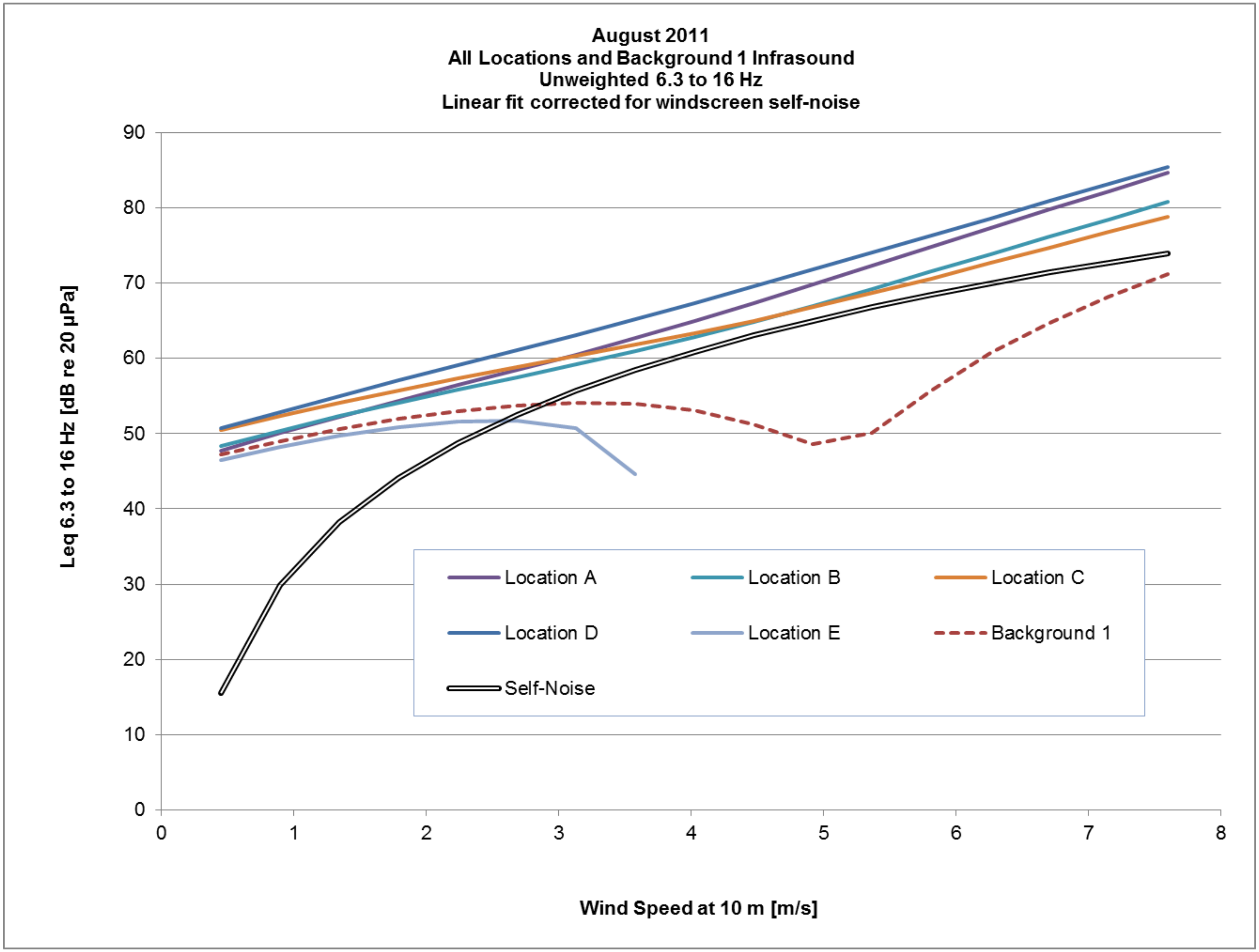

Figure C6. All Locations and Background 1 Infrasound unweighted 6.3 to 16Hz linear fit corrected for windscreen self-noise.

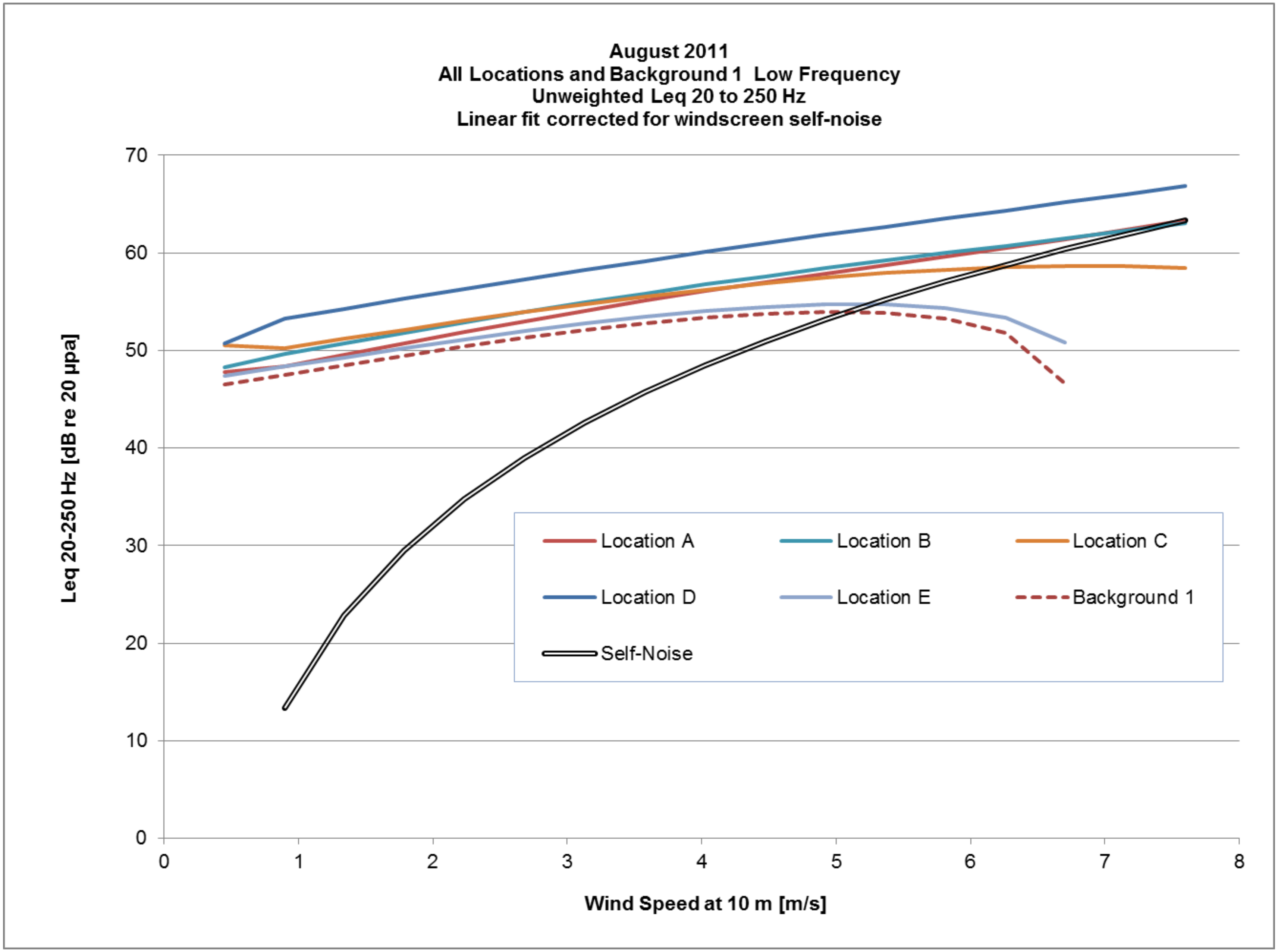

Figure C7. All locations and Background 1 Low frequency unweighted Leq 20 to 250 Hz linear fit corrected for windscreen self-noise.

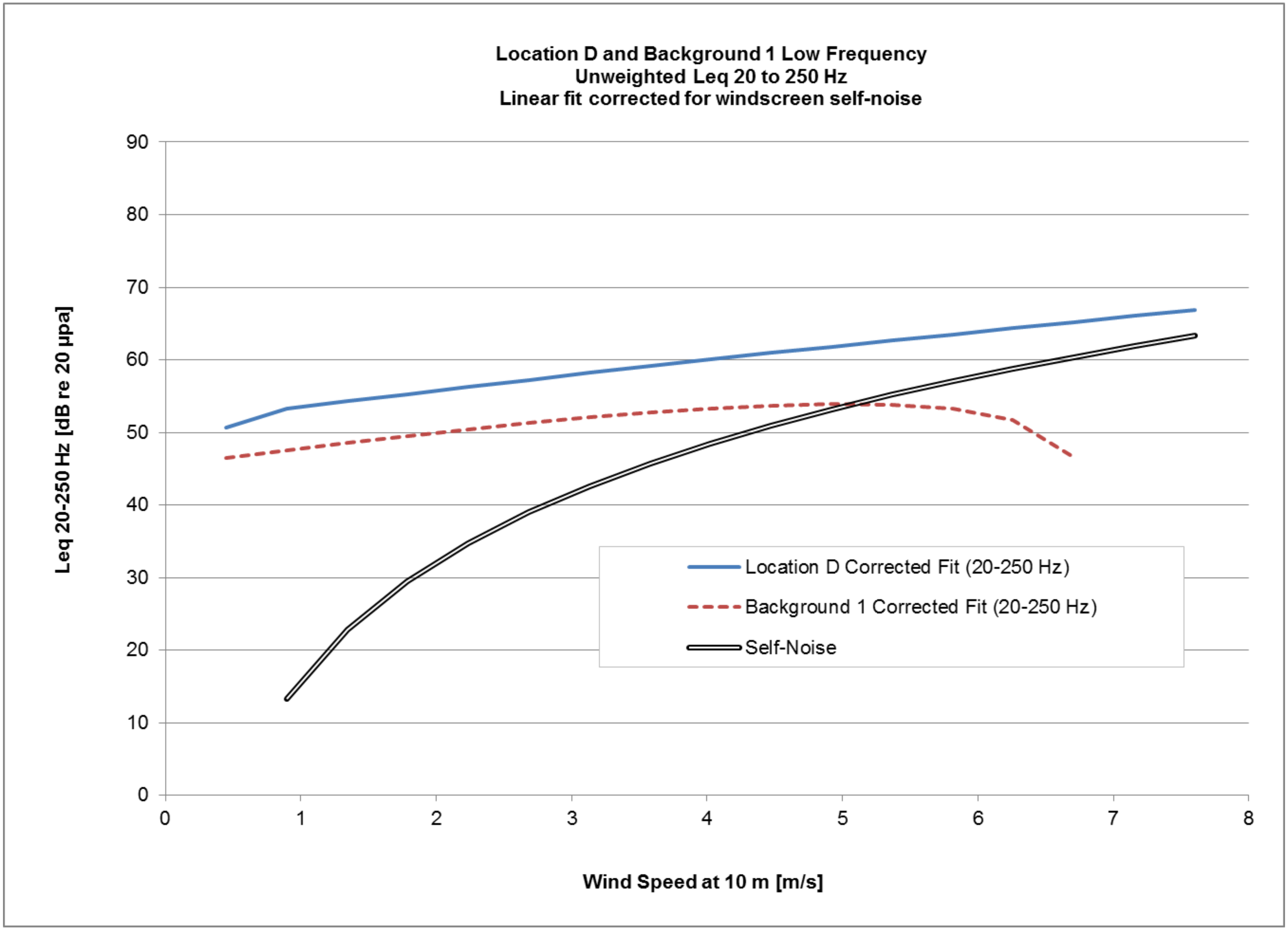

Figure C8. Location D and Background 1 Low frequency unweighted Leq 20 to 250 Hz linear fit corrected for windscreen self-noise.

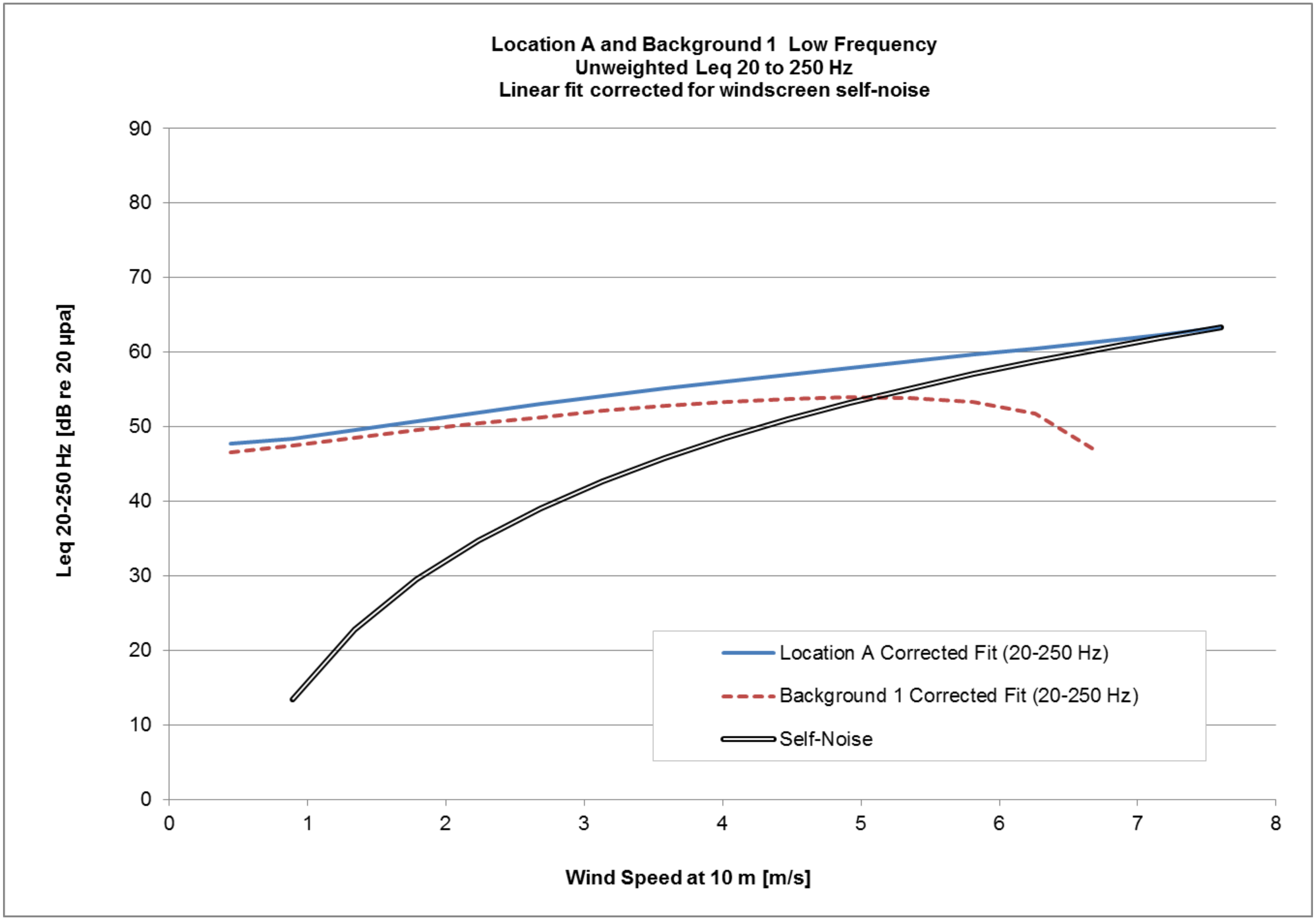

Figure C9. Location A and Background 1 Low frequency unweighted Leq 20 to 250 Hz linear fit corrected for windscreen self-noise.

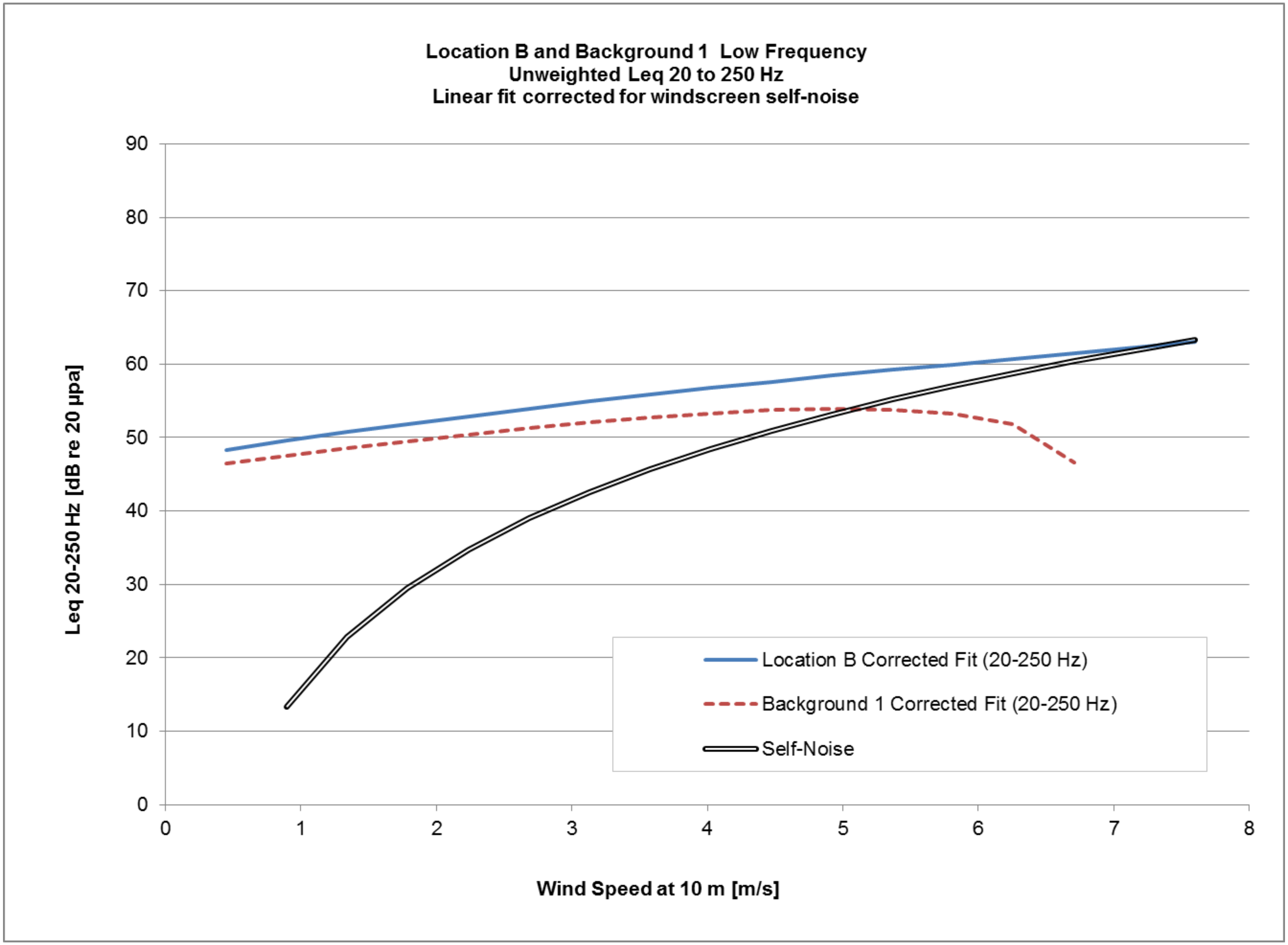

Figure C10. Location B and Background 1 Low frequency unweighted Leq 20 to 250 Hz linear fit corrected for windscreen self-noise.

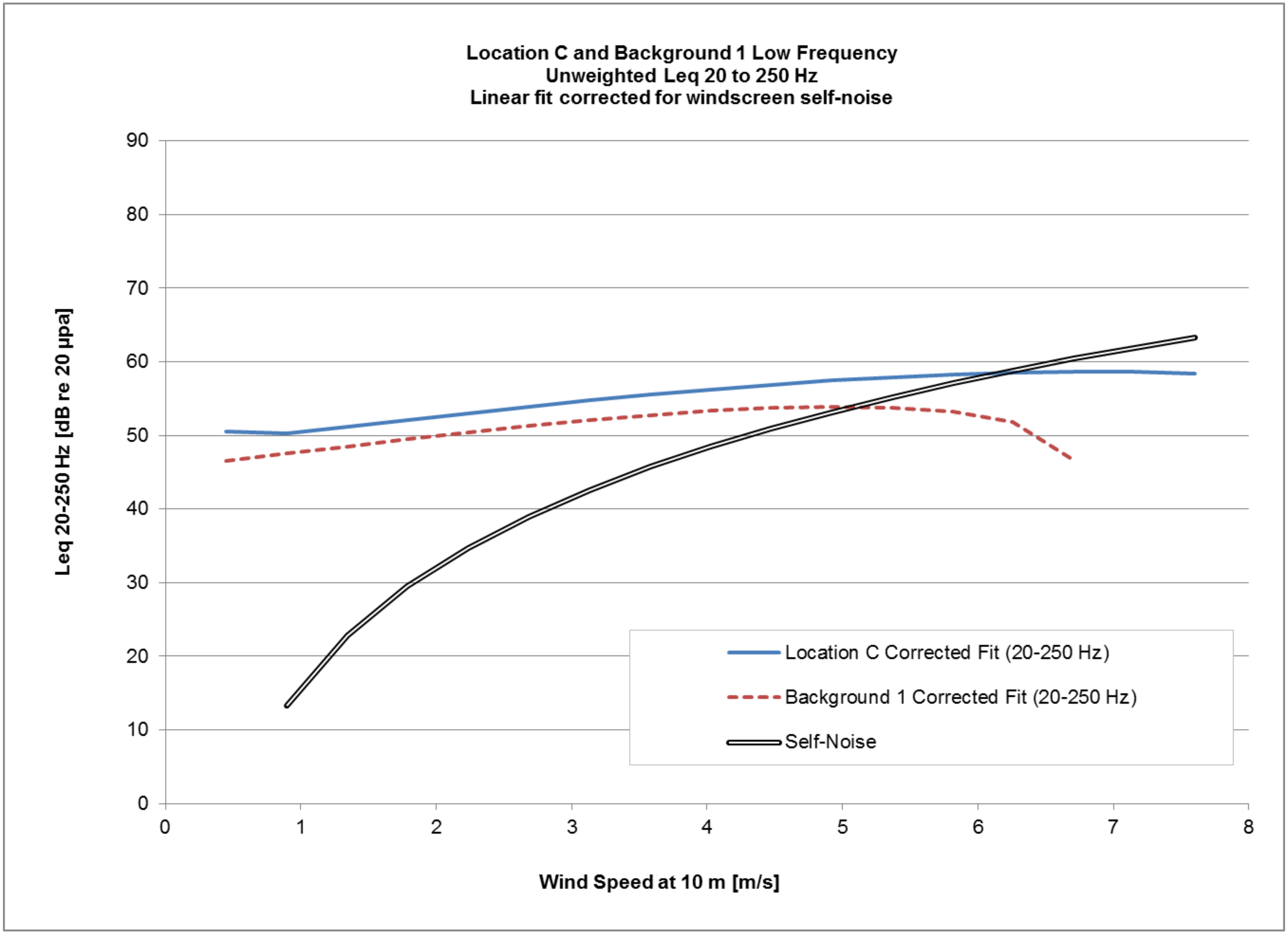

Figure C11. Location C and Background 1 Low frequency unweighted Leq 20 to 250 Hz linear fit corrected for windscreen self-noise.

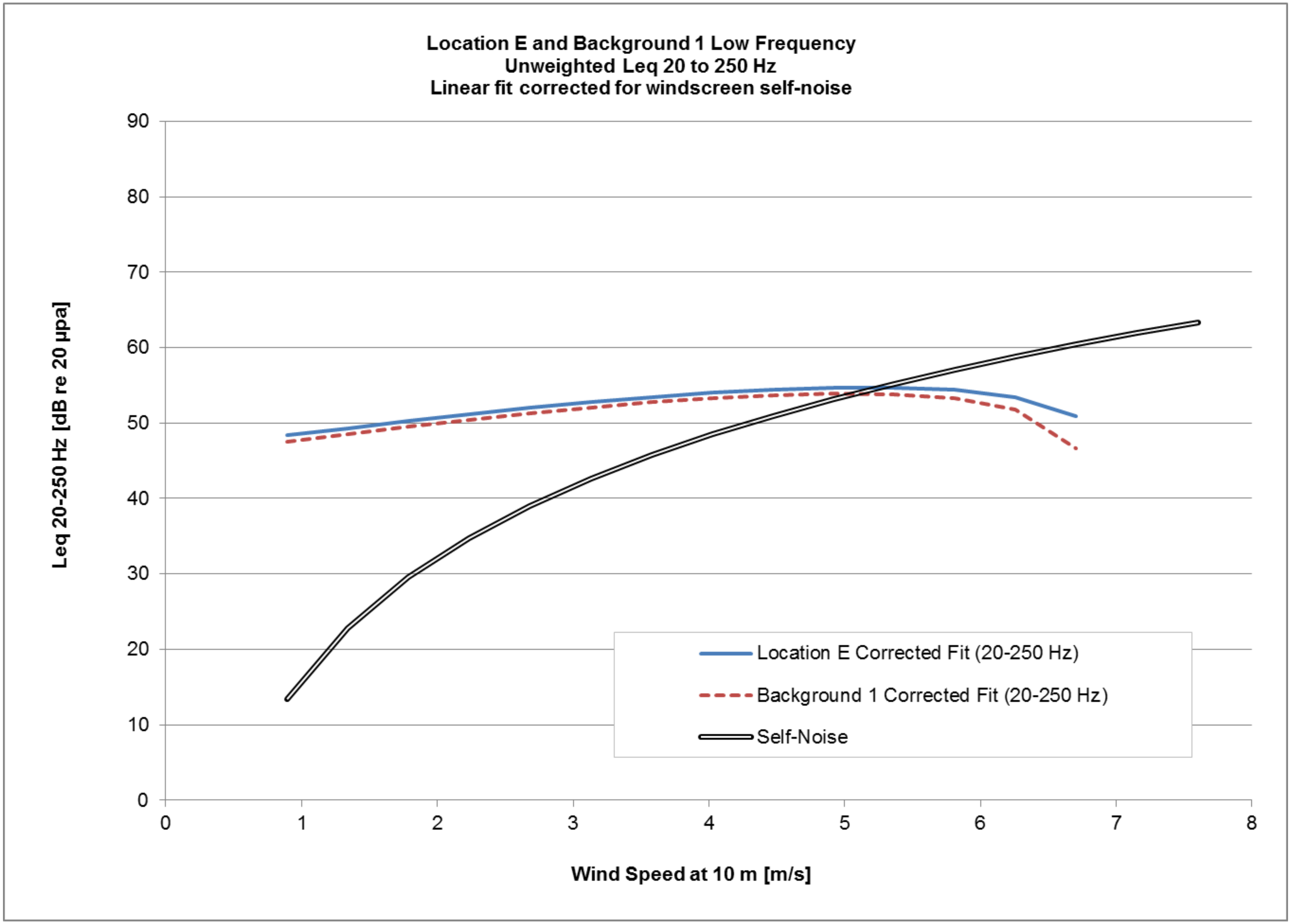

Figure C12. Location C and Background 1 Low frequency unweighted Leq 20 to 250 Hz linear fit corrected for windscreen self-noise.

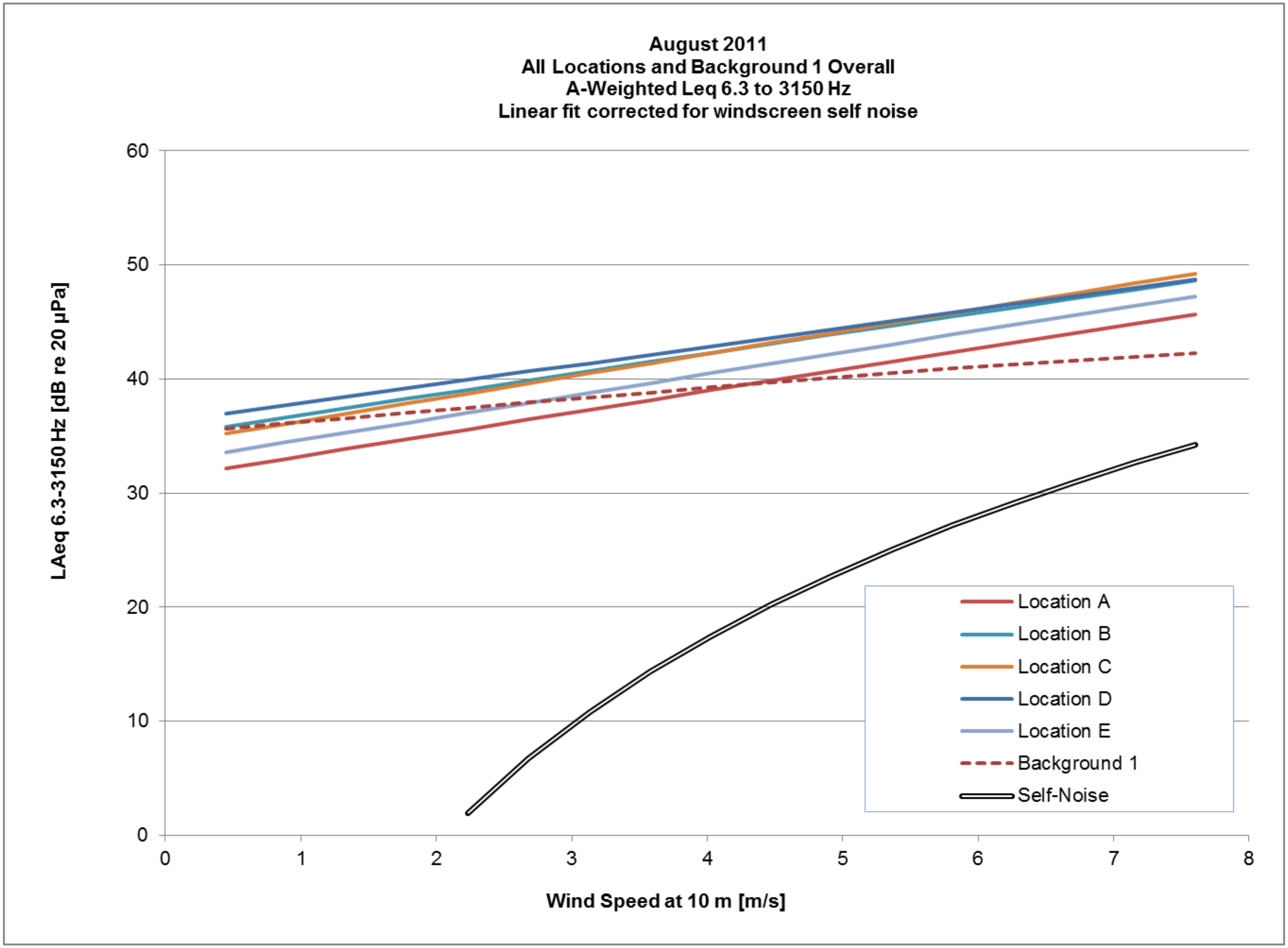

Figure C13. All locations and Background 1 Overall A-Weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

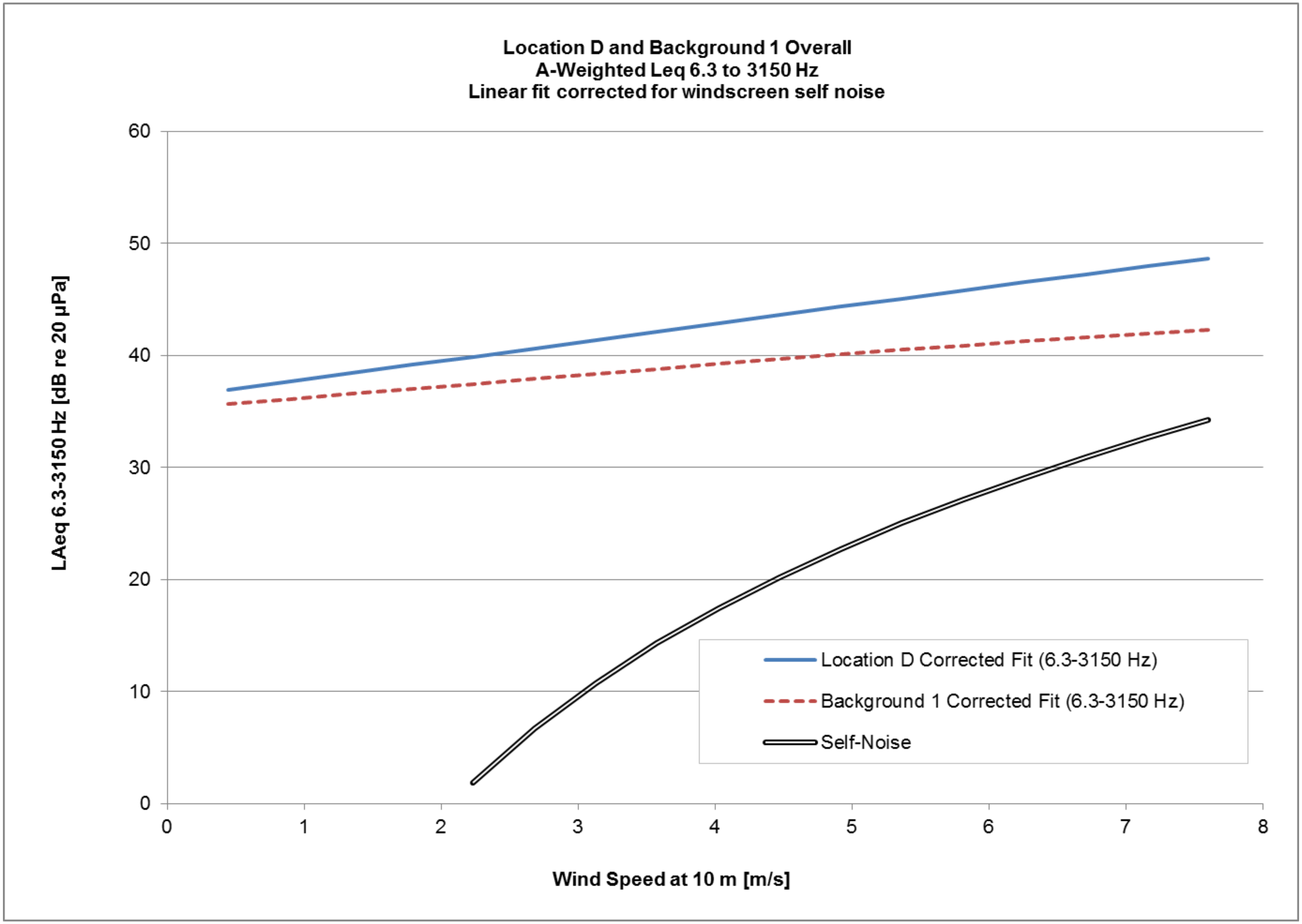

Figure C14. Location D and Background 1 Overall A-Weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

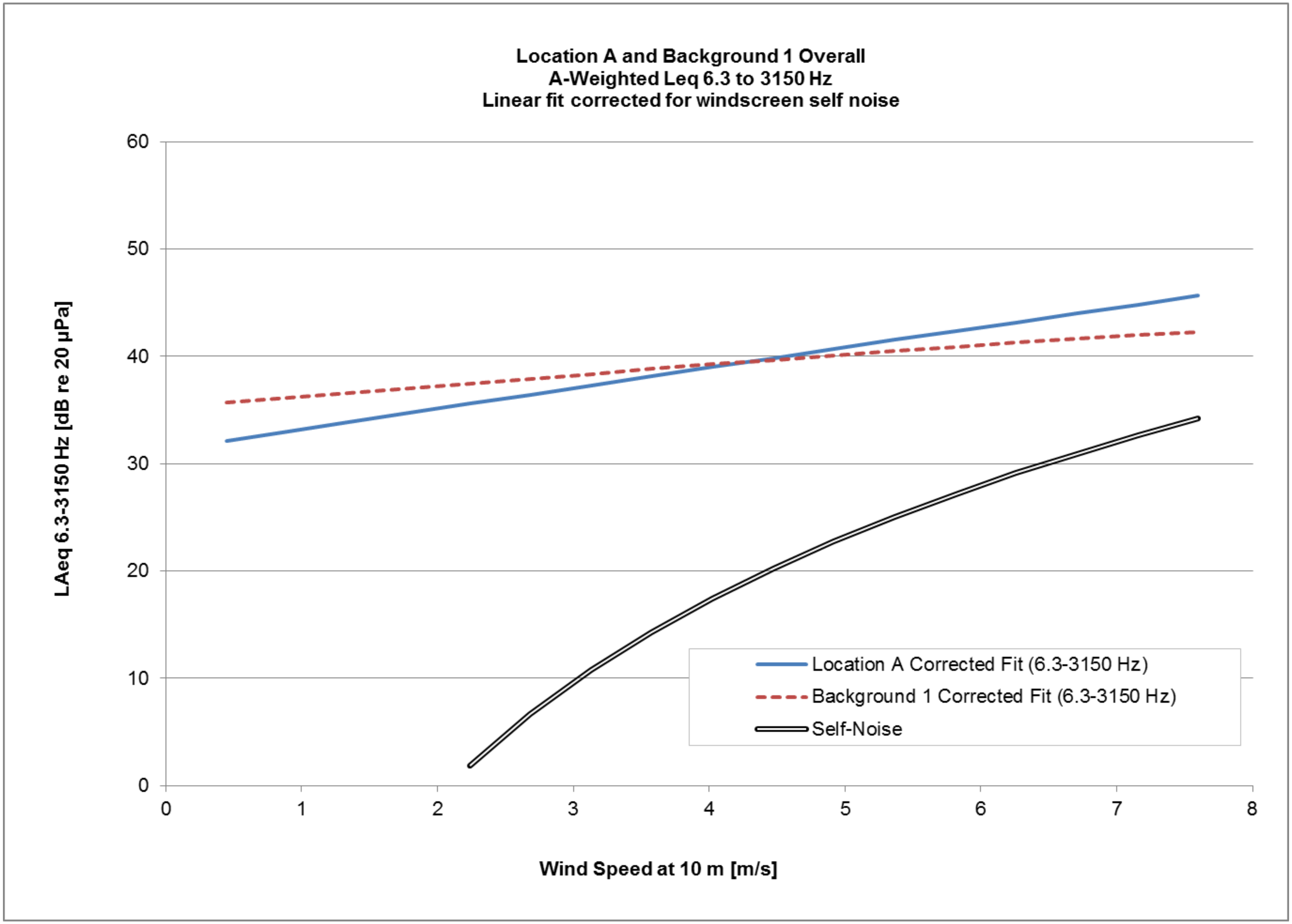

Figure C15. Location A and Background 1 Overall A-Weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

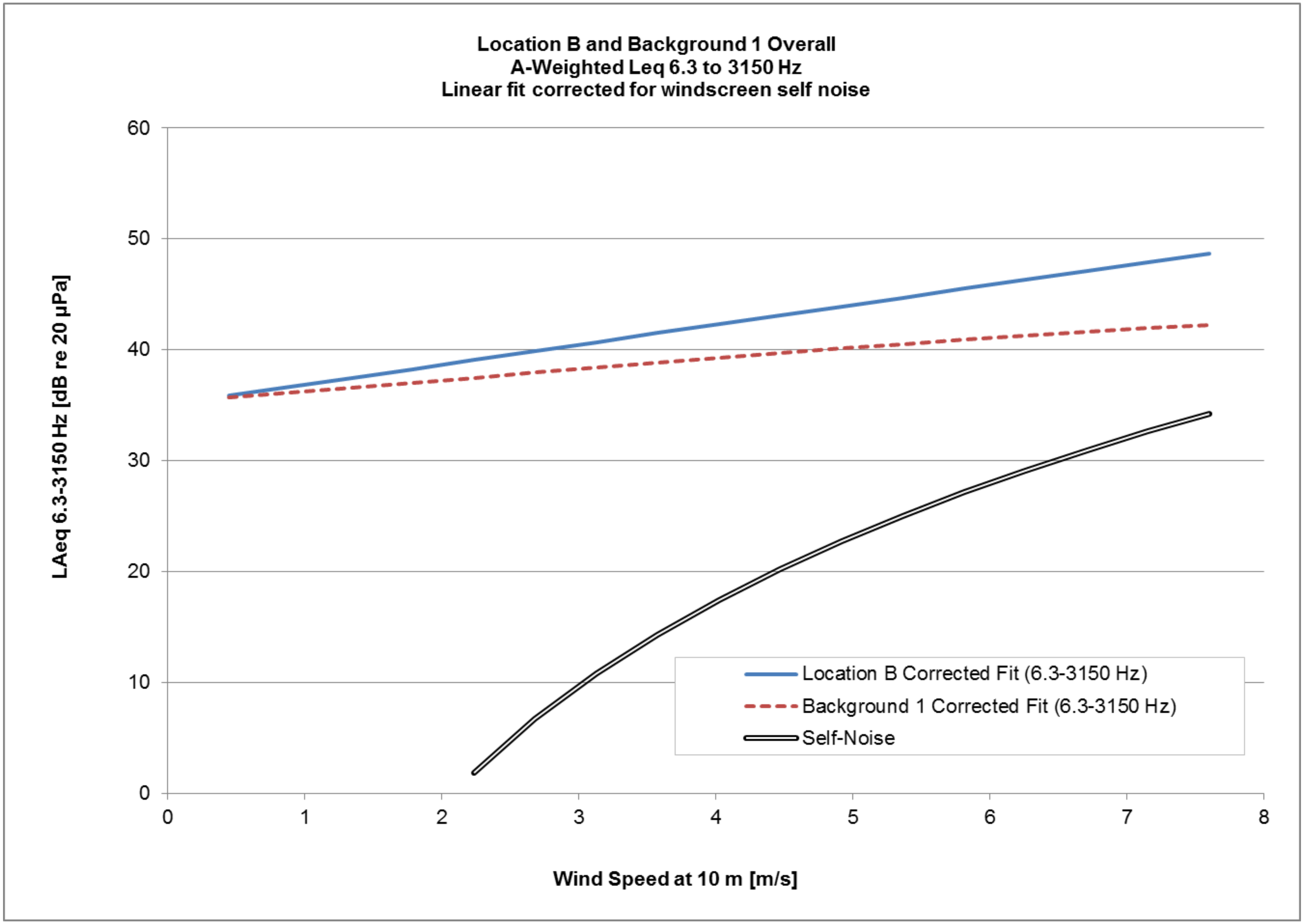

Figure C16. Location B and Background 1 Overall A-Weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

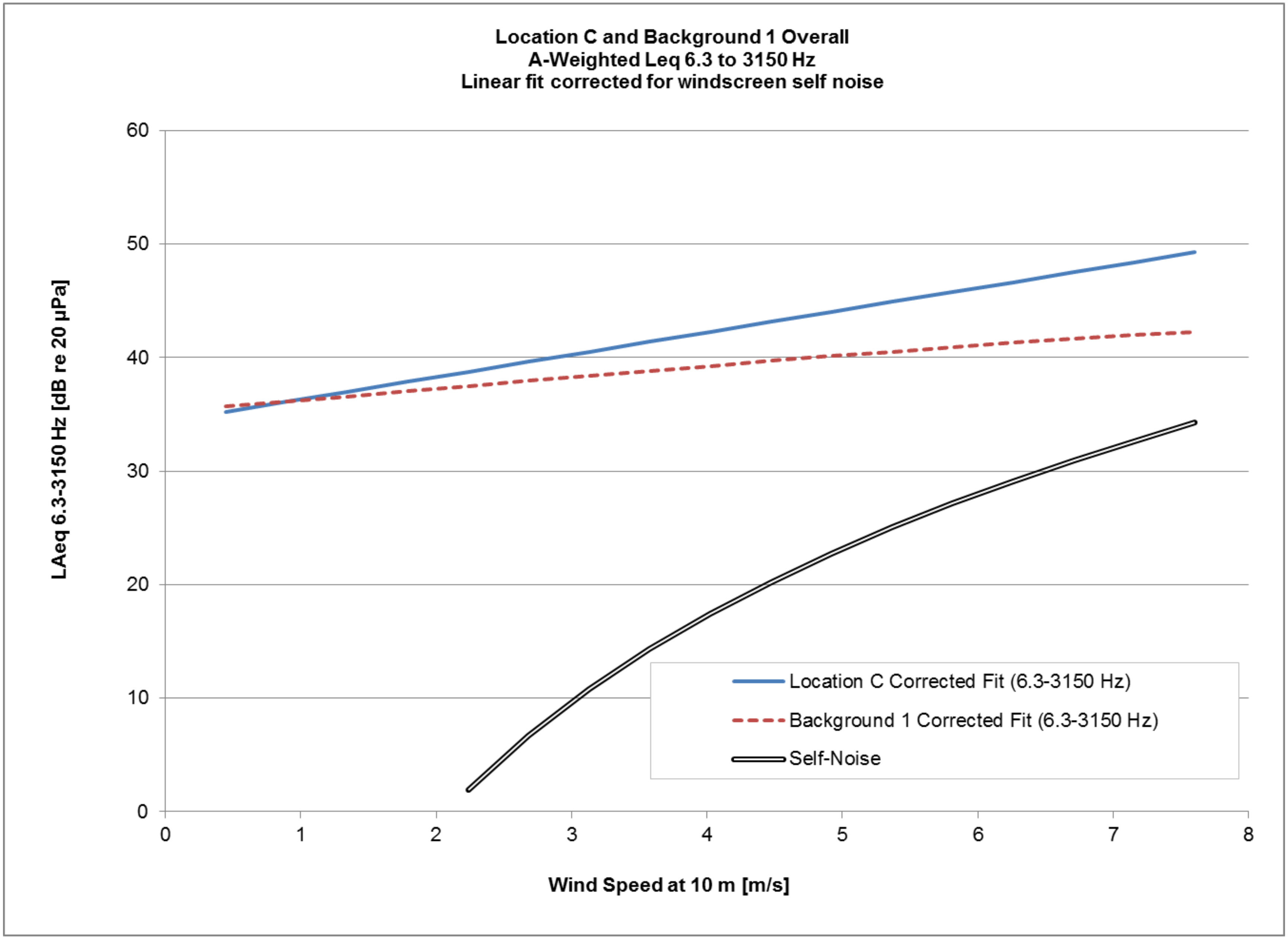

Figure C17. Location C and Background 1 Overall A-Weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

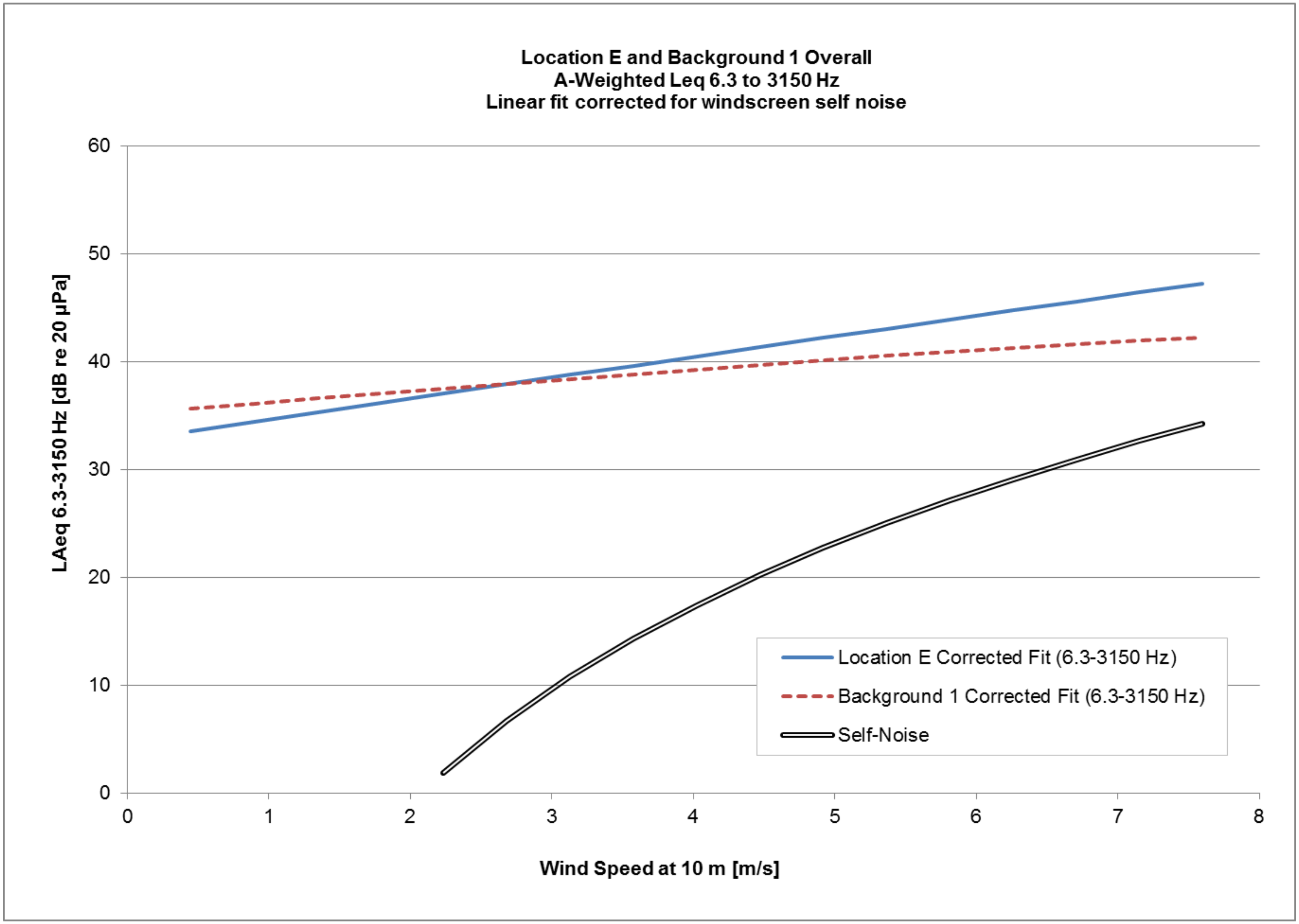

Figure C18. Location E and Background 1 Overall A-Weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

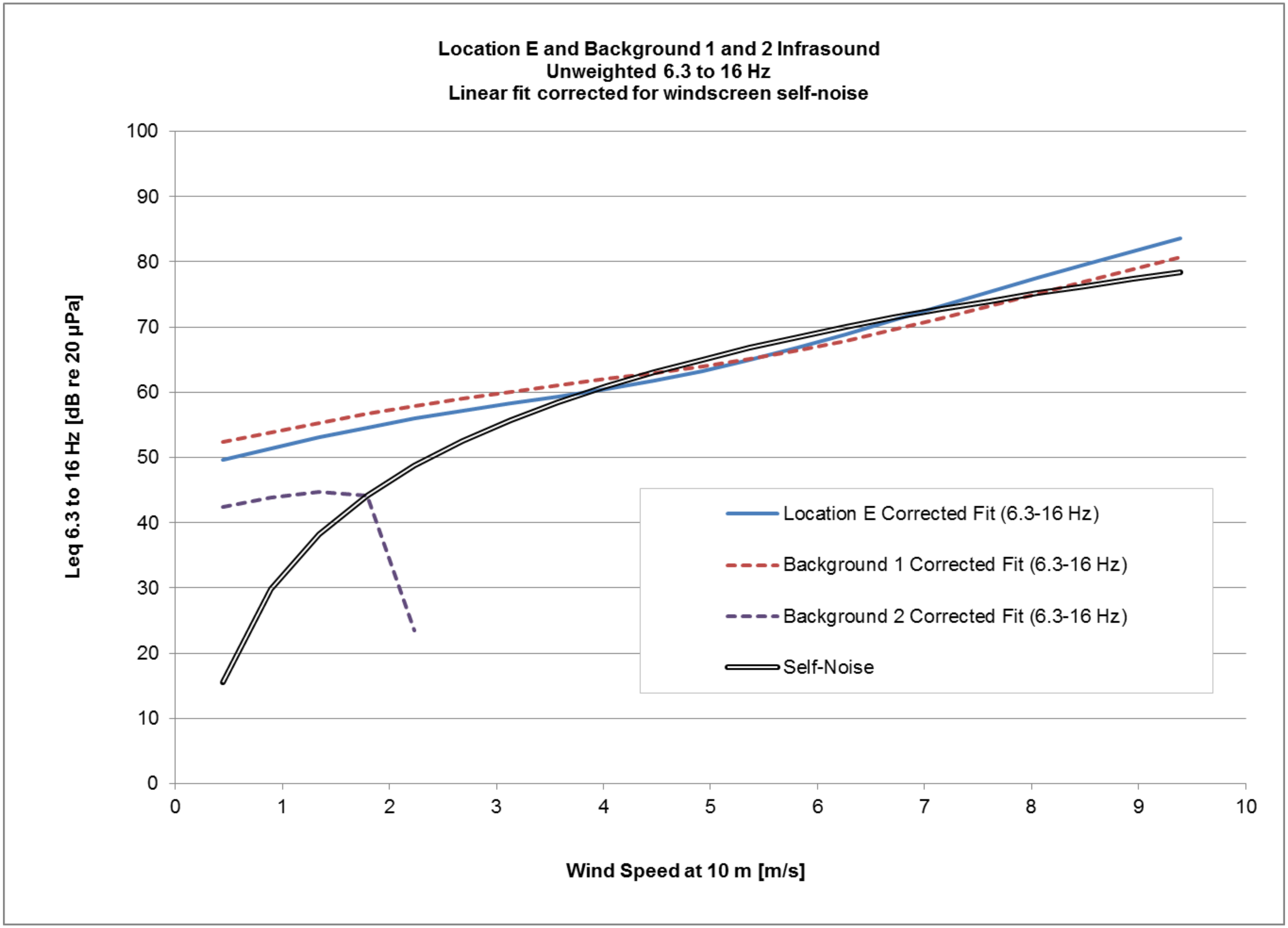

Figure C19. Location E and Background 1 and 2 Infrasound unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

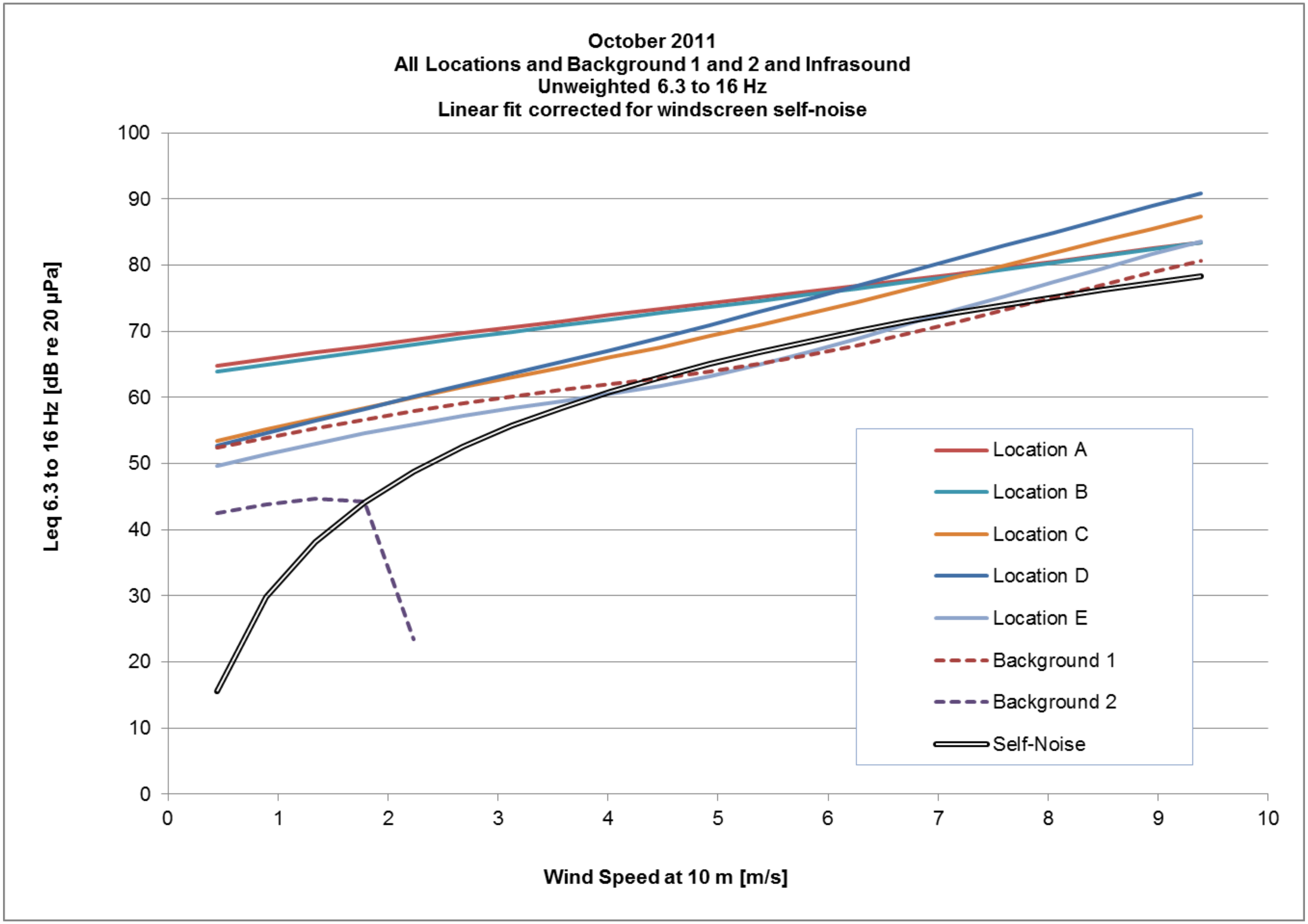

Figure C20. All Locations and Background 1 and 2 Infrasound unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

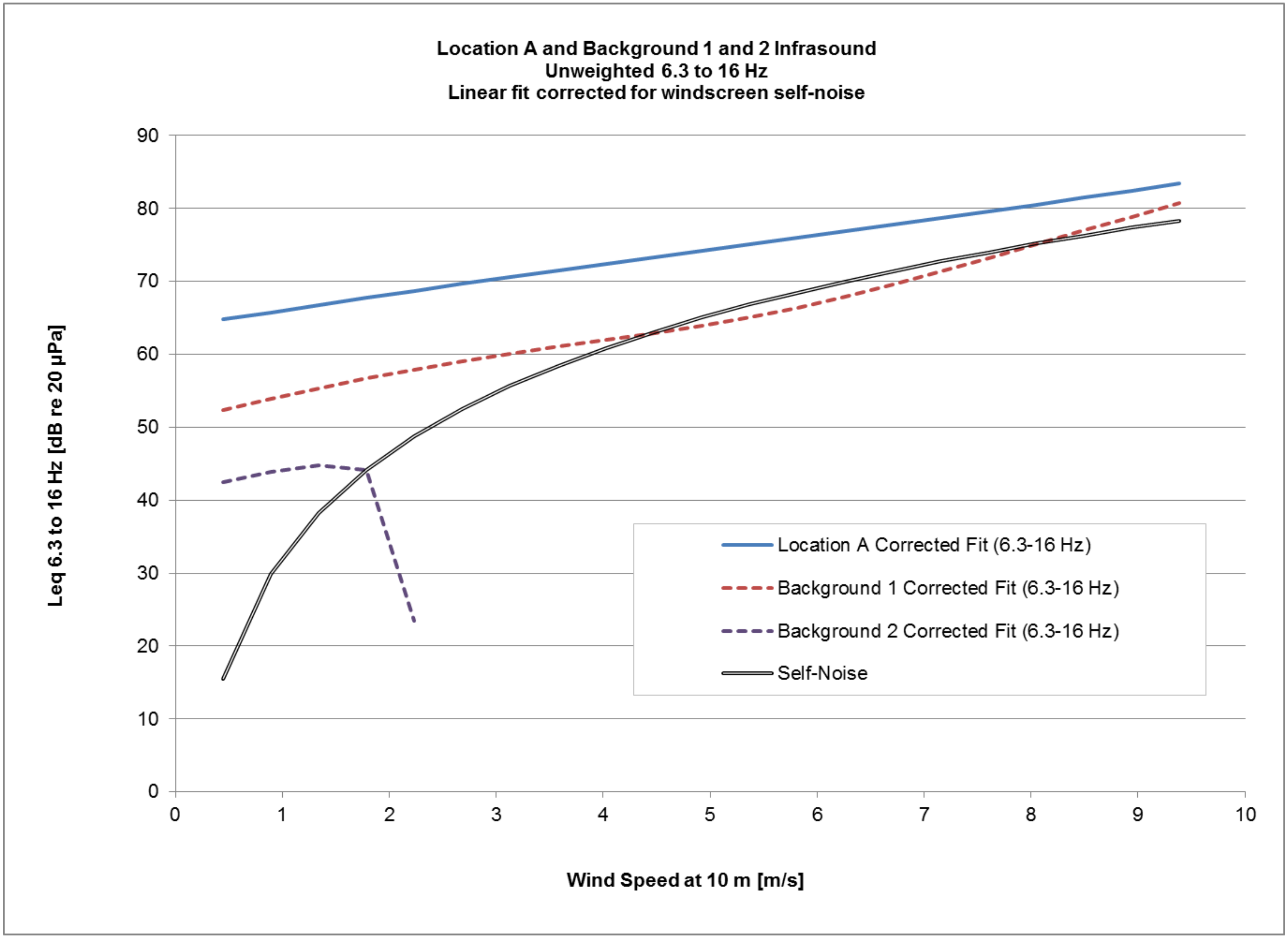

Figure C21. Location A and Background 1 and 2 Infrasound unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

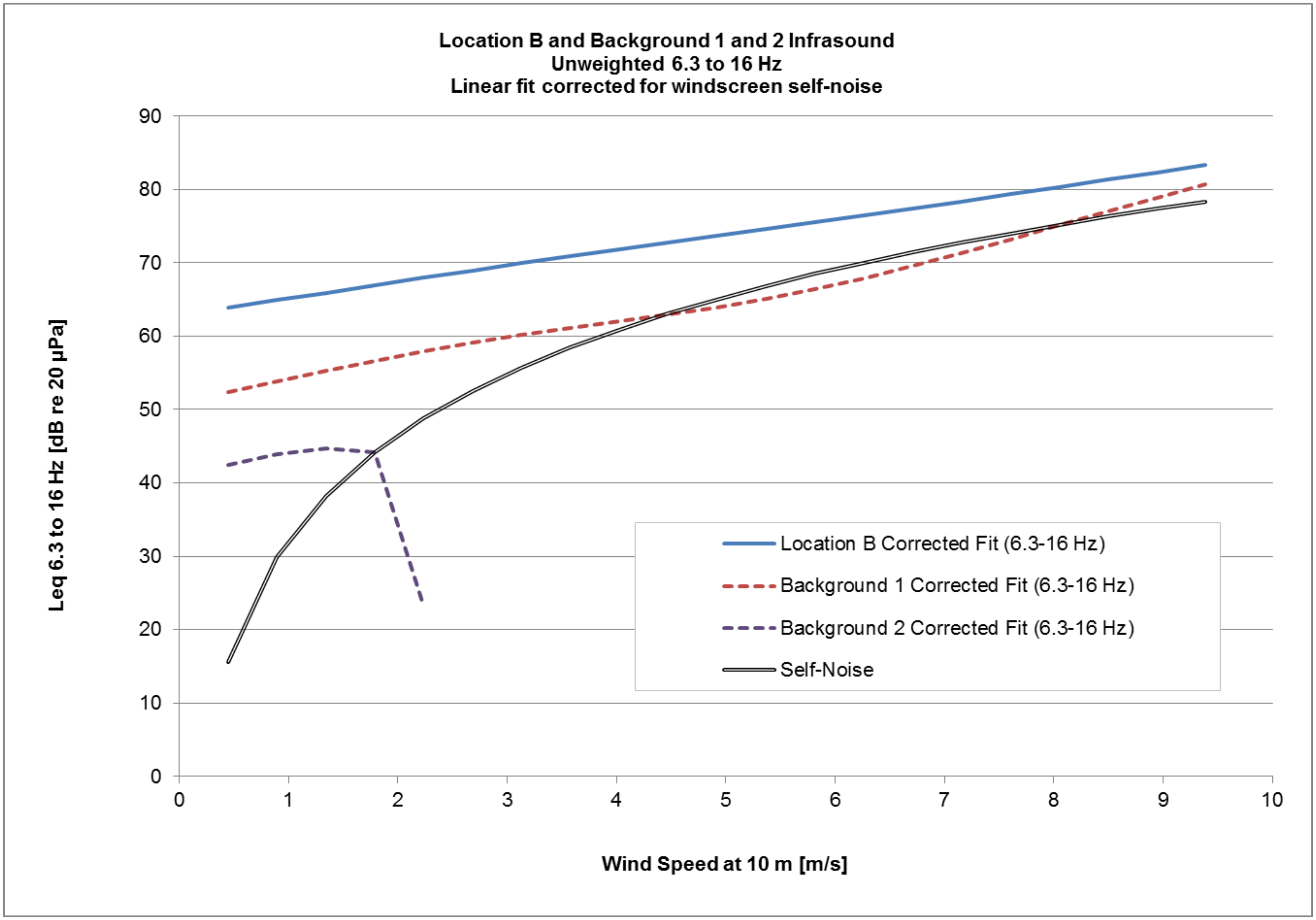

Figure C22. Location B and Background 1 and 2 Infrasound unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

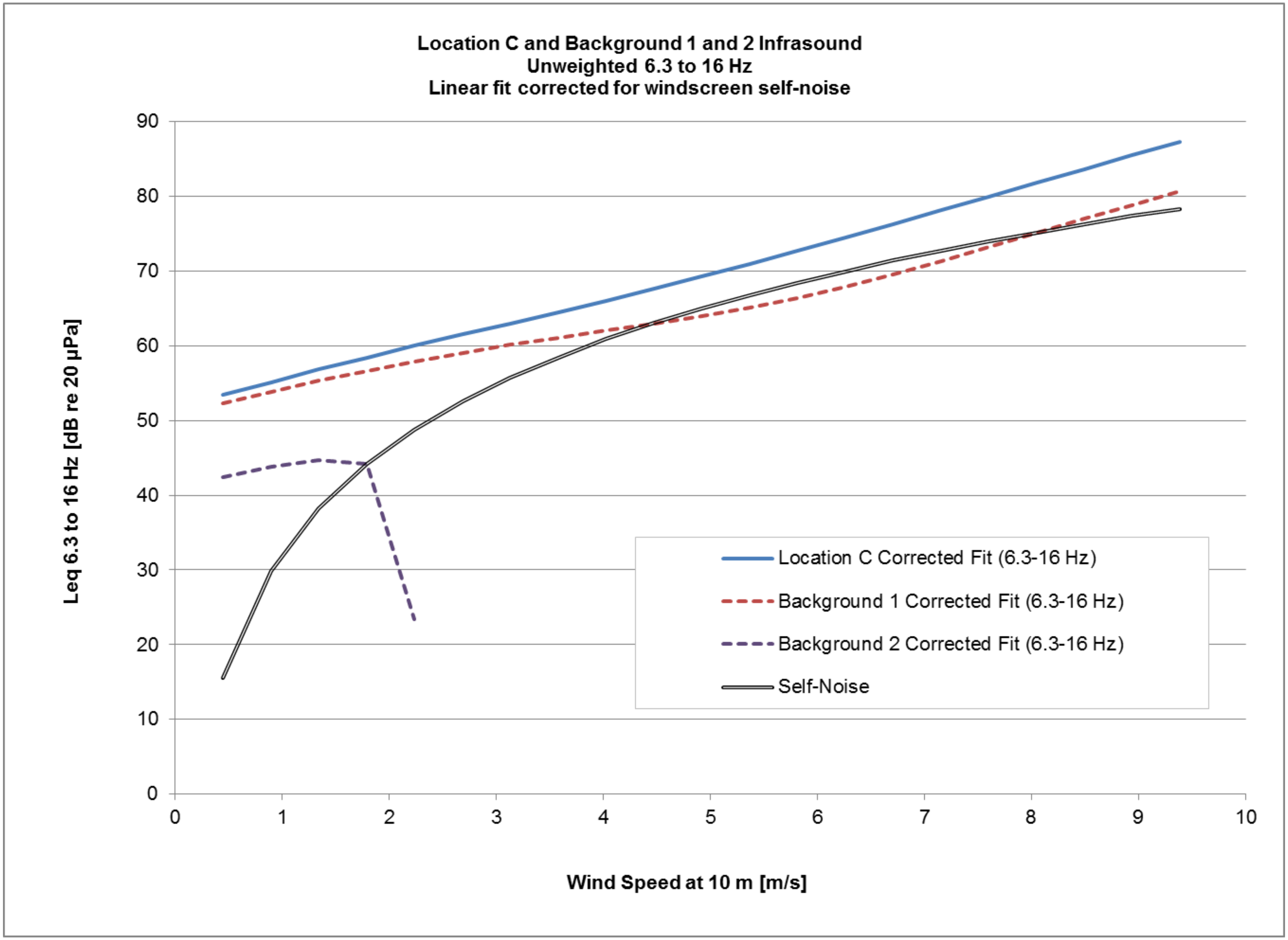

Figure C23. Location C and Background 1 and 2 Infrasound unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

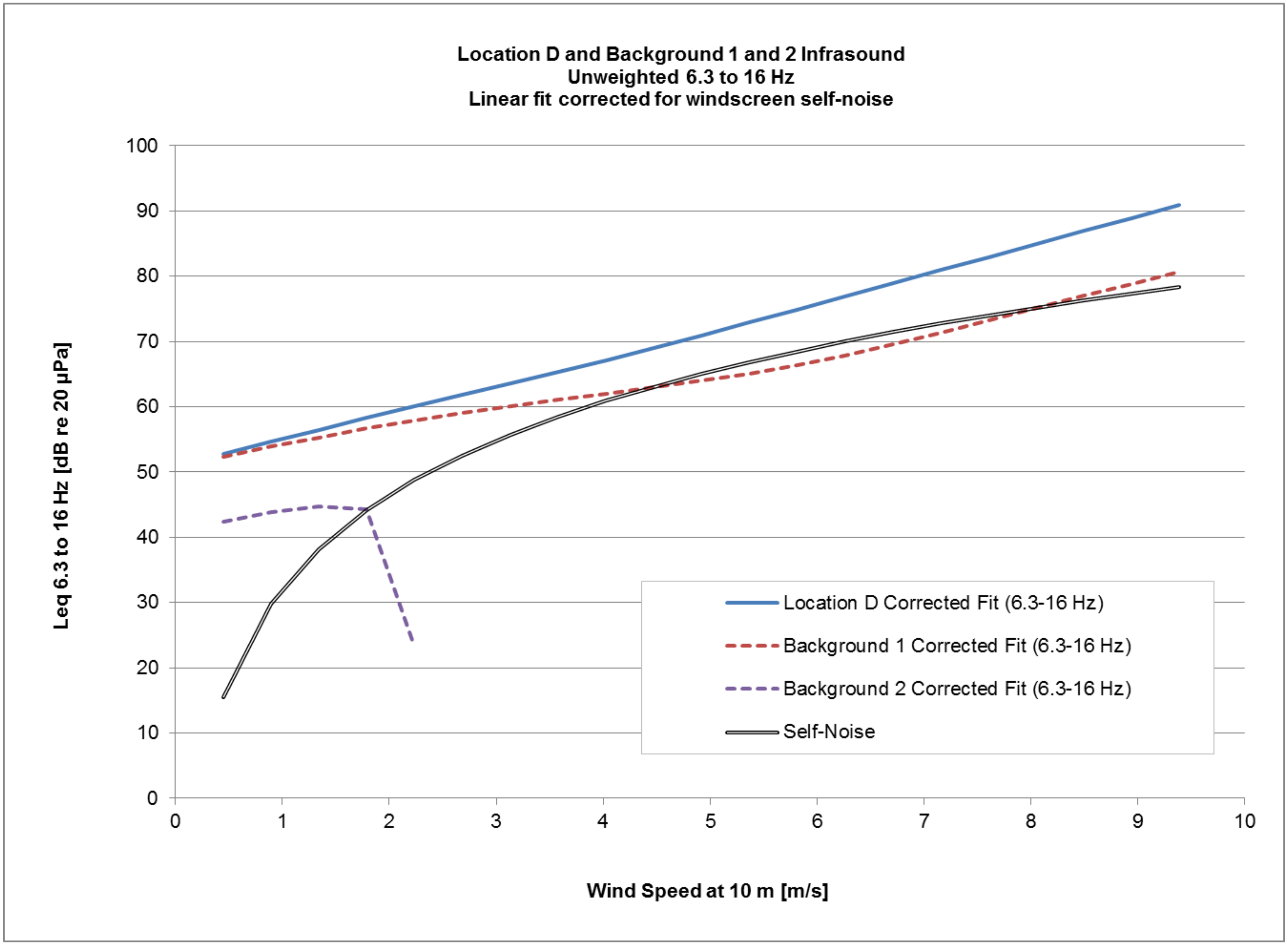

Figure C24. Location D and Background 1 and 2 Infrasound unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

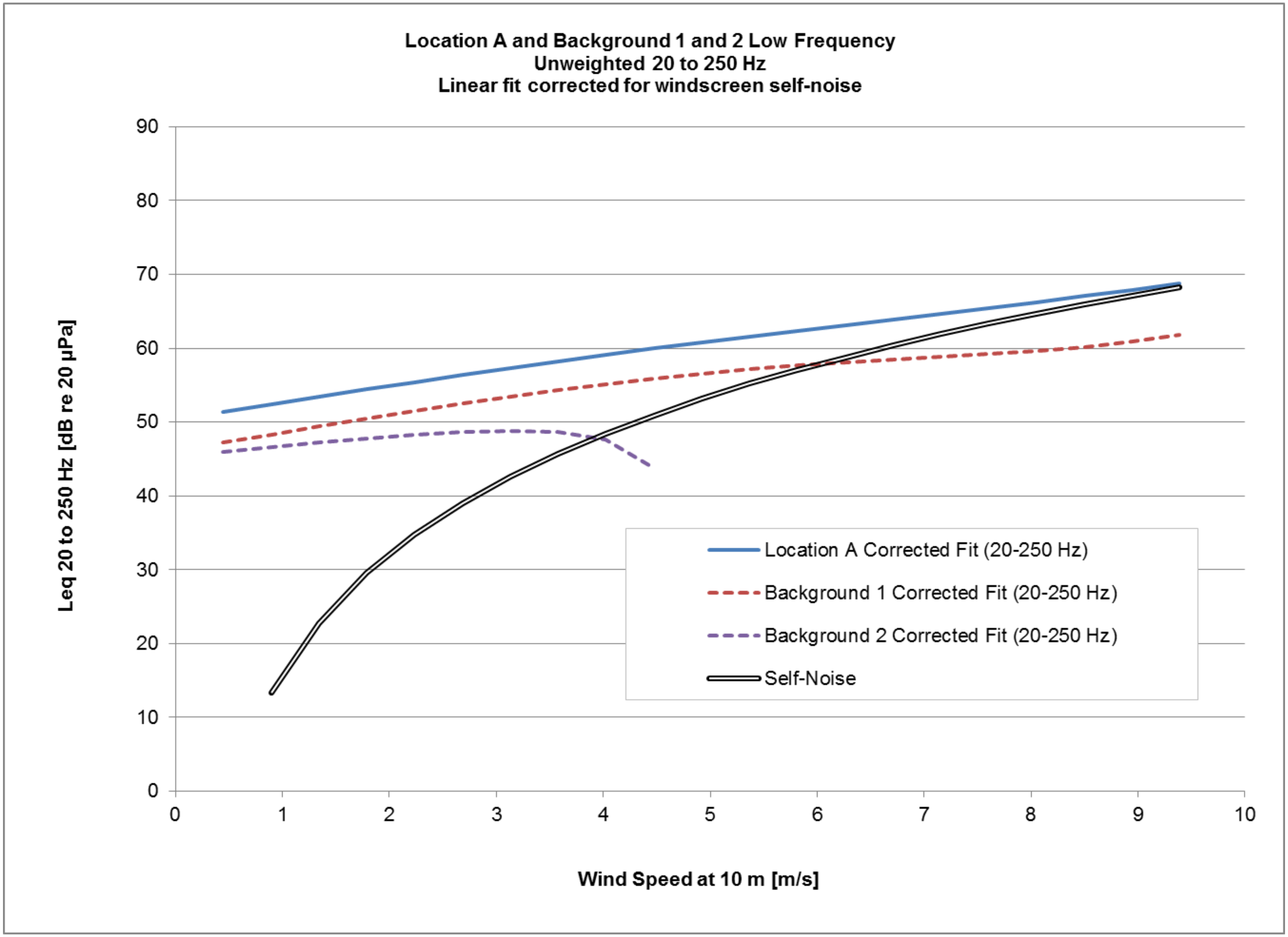

Figure C25. Location A and Background 1 and 2 low frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

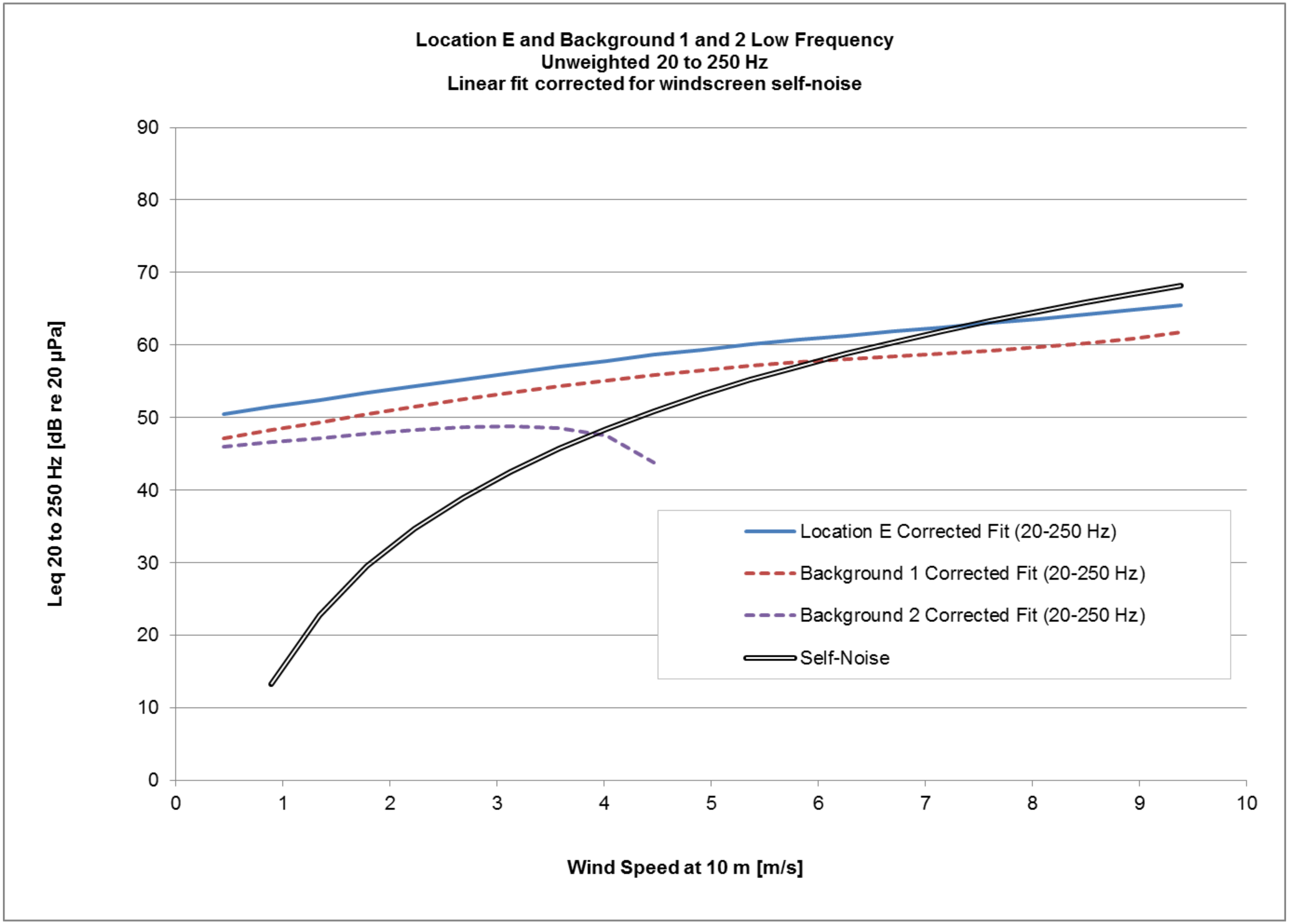

Figure C26. Location E and Background 1 and 2 low frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

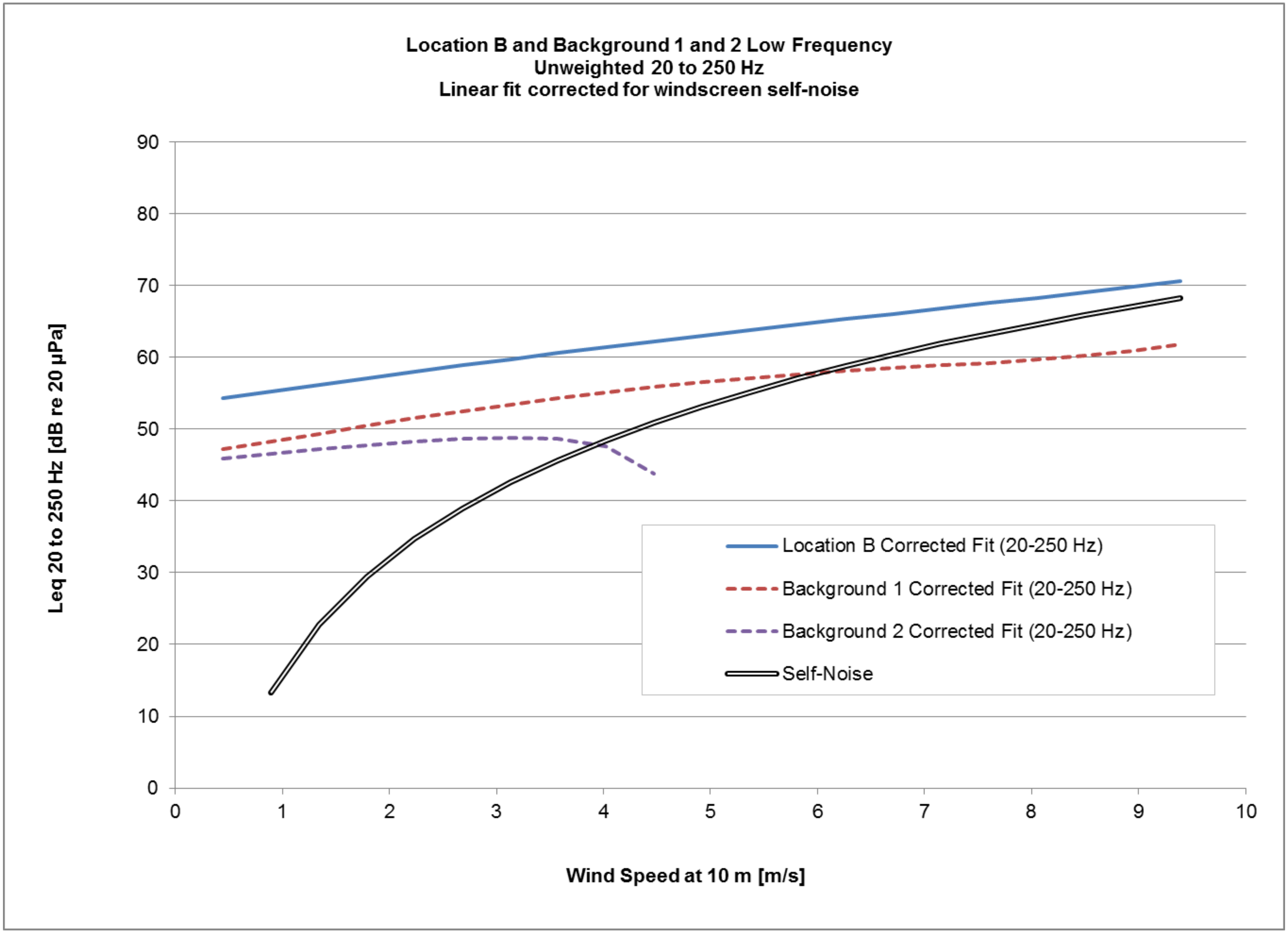

Figure C27. Location B and Background 1 and 2 low frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

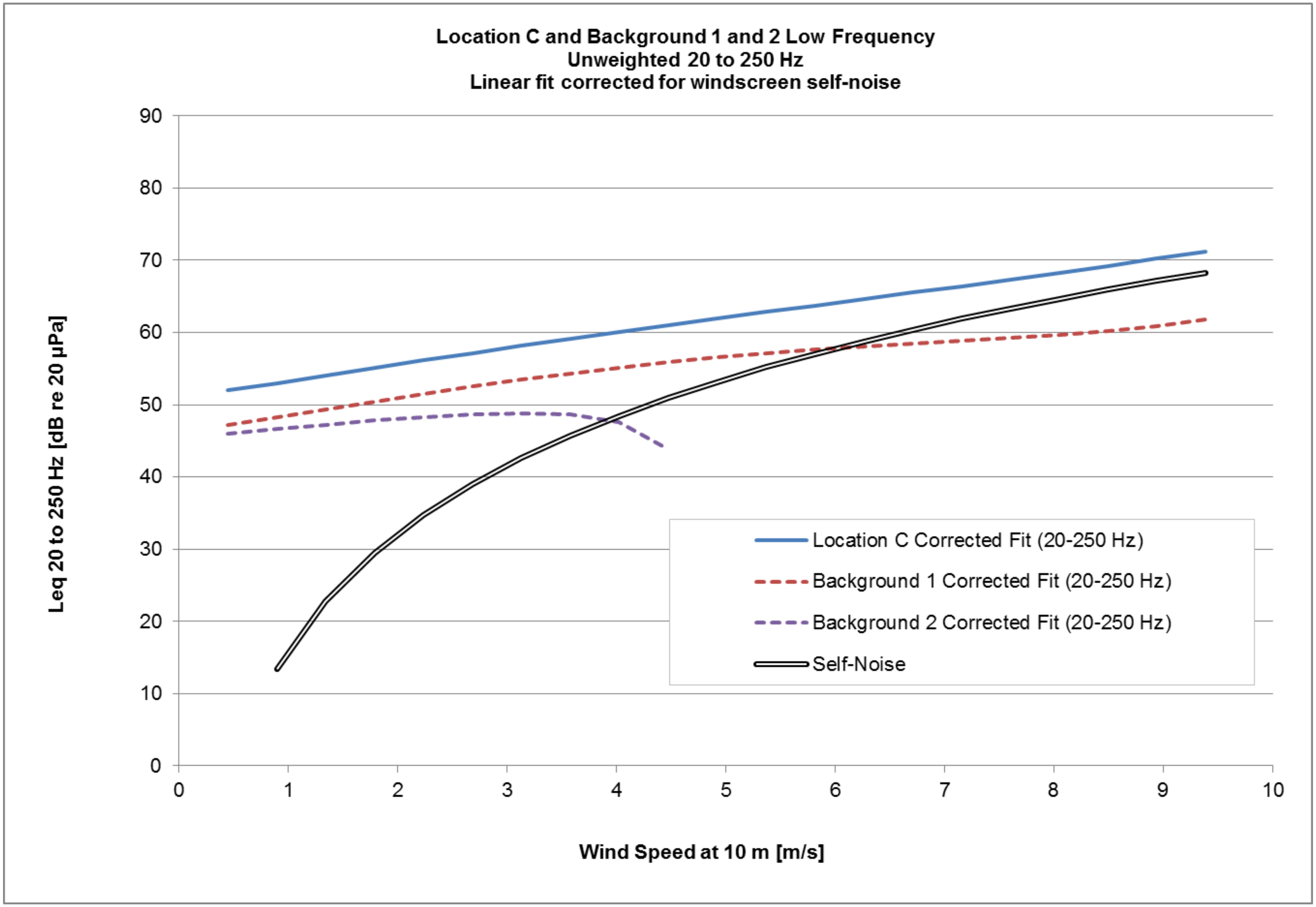

Figure C28. Location C and Background 1 and 2 low frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

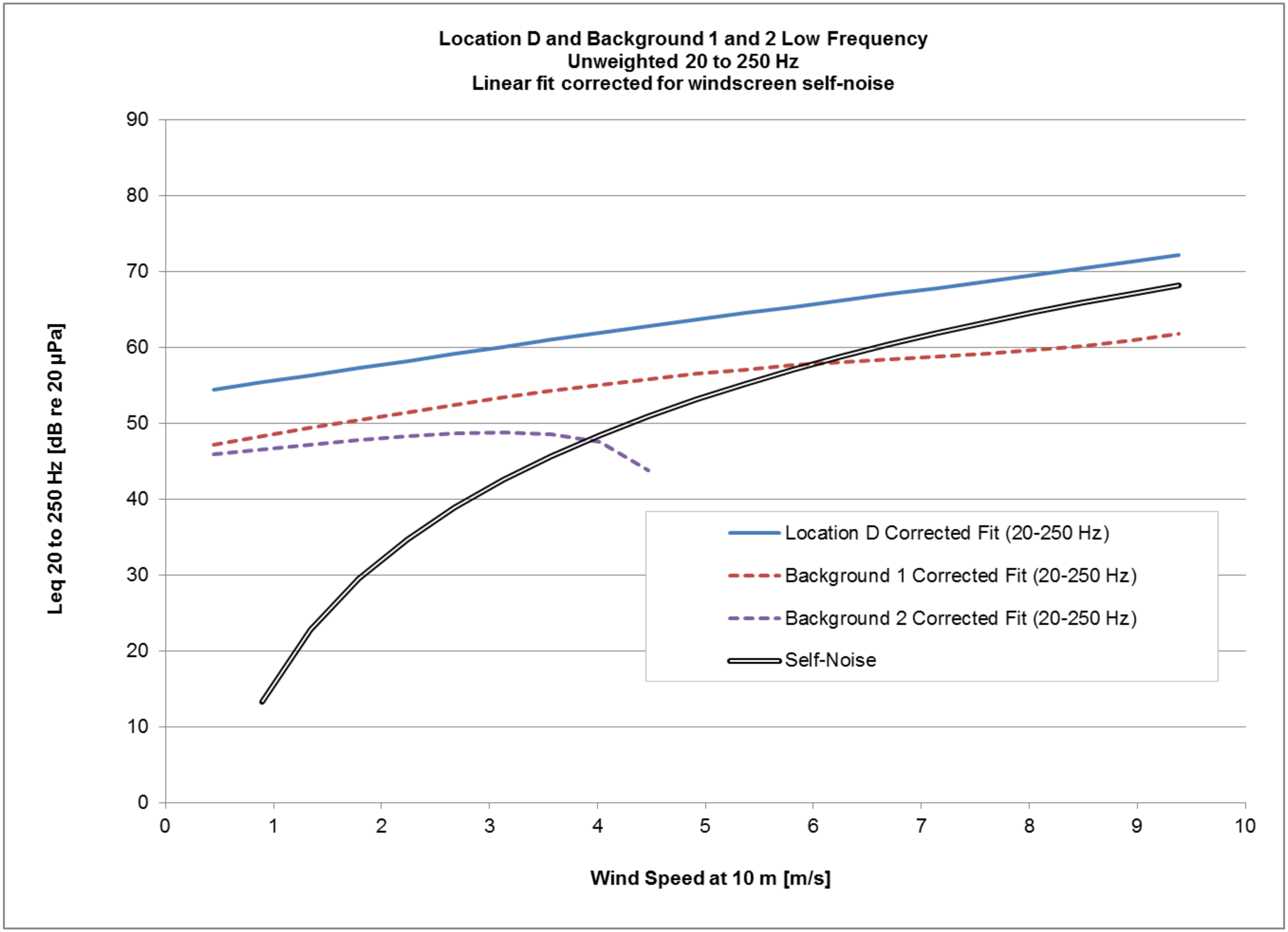

Figure C29. Location D and Background 1 and 2 low frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

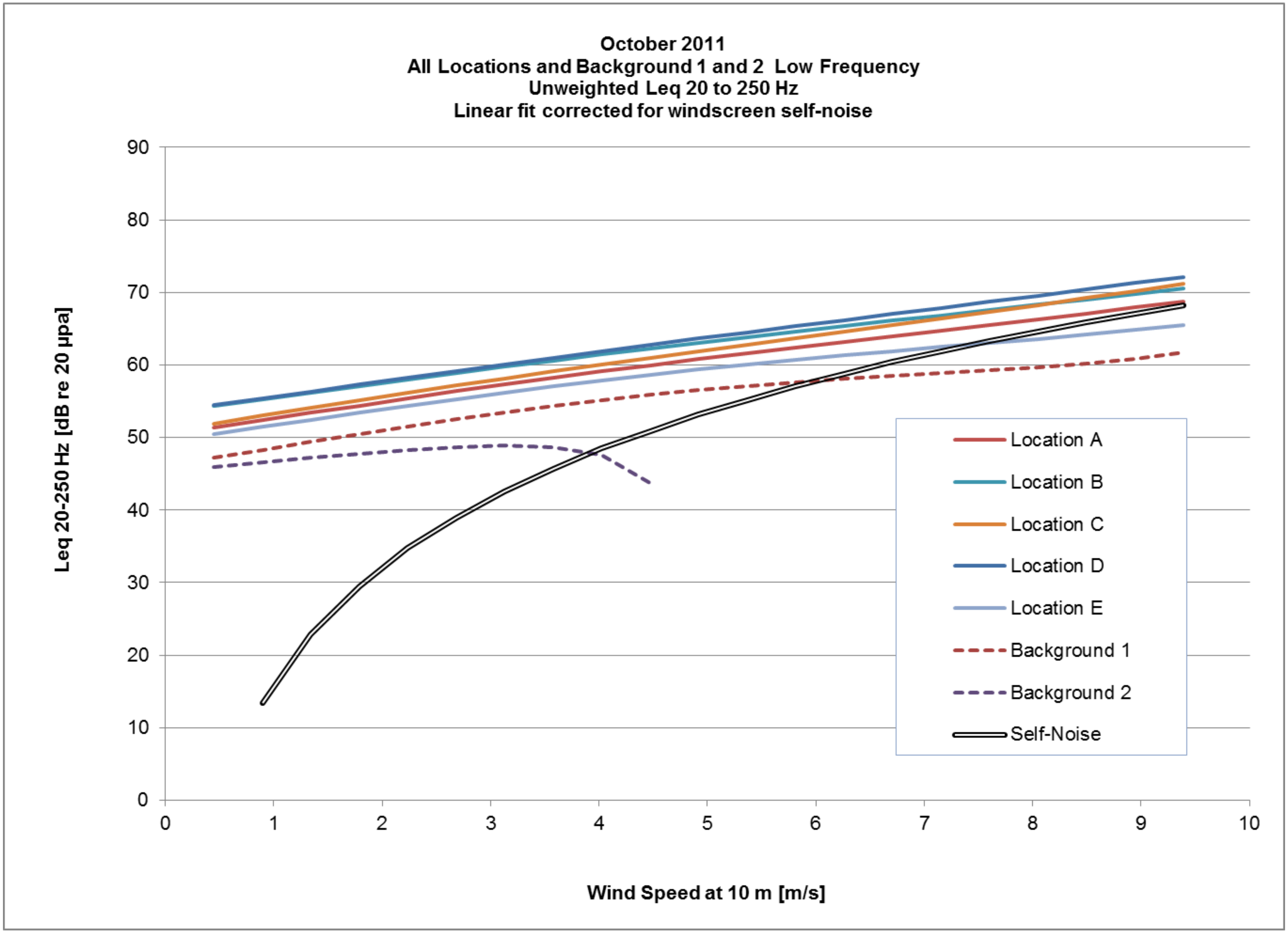

Figure C30. All Locations and Background 1 and 2 low frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

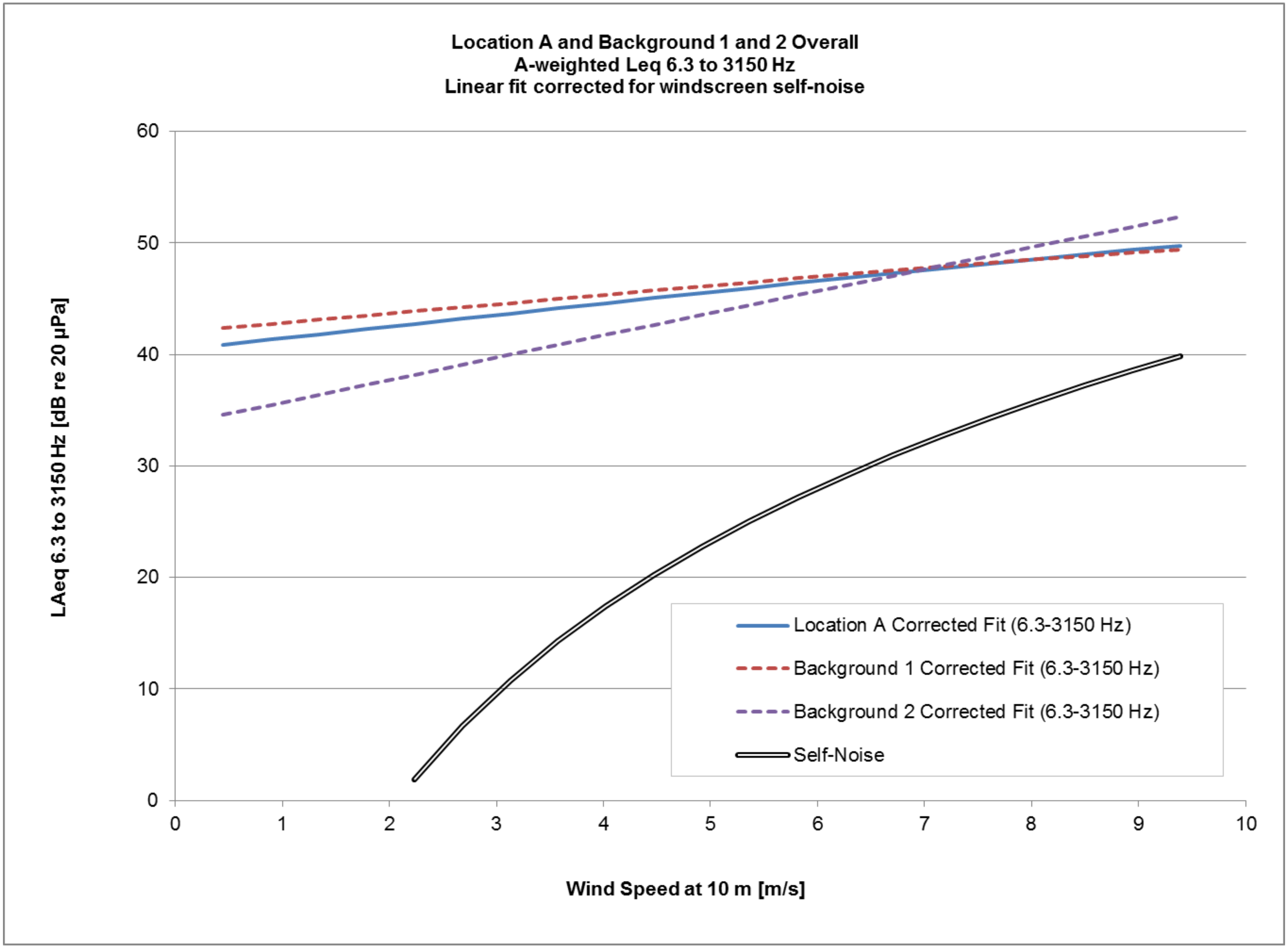

Figure C31. Location A and Background 1 and 2 overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

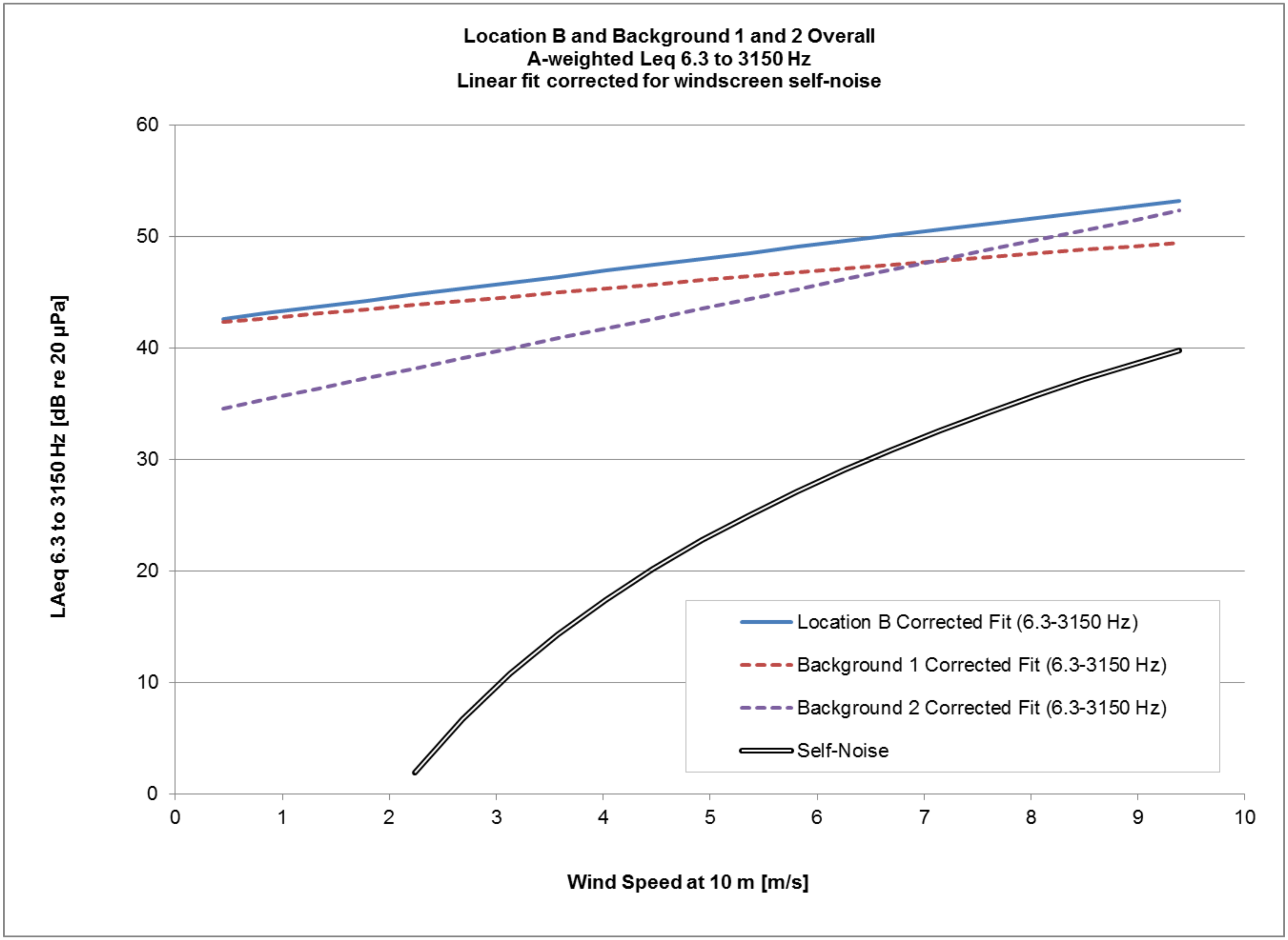

Figure C32. Location B and Background 1 and 2 overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

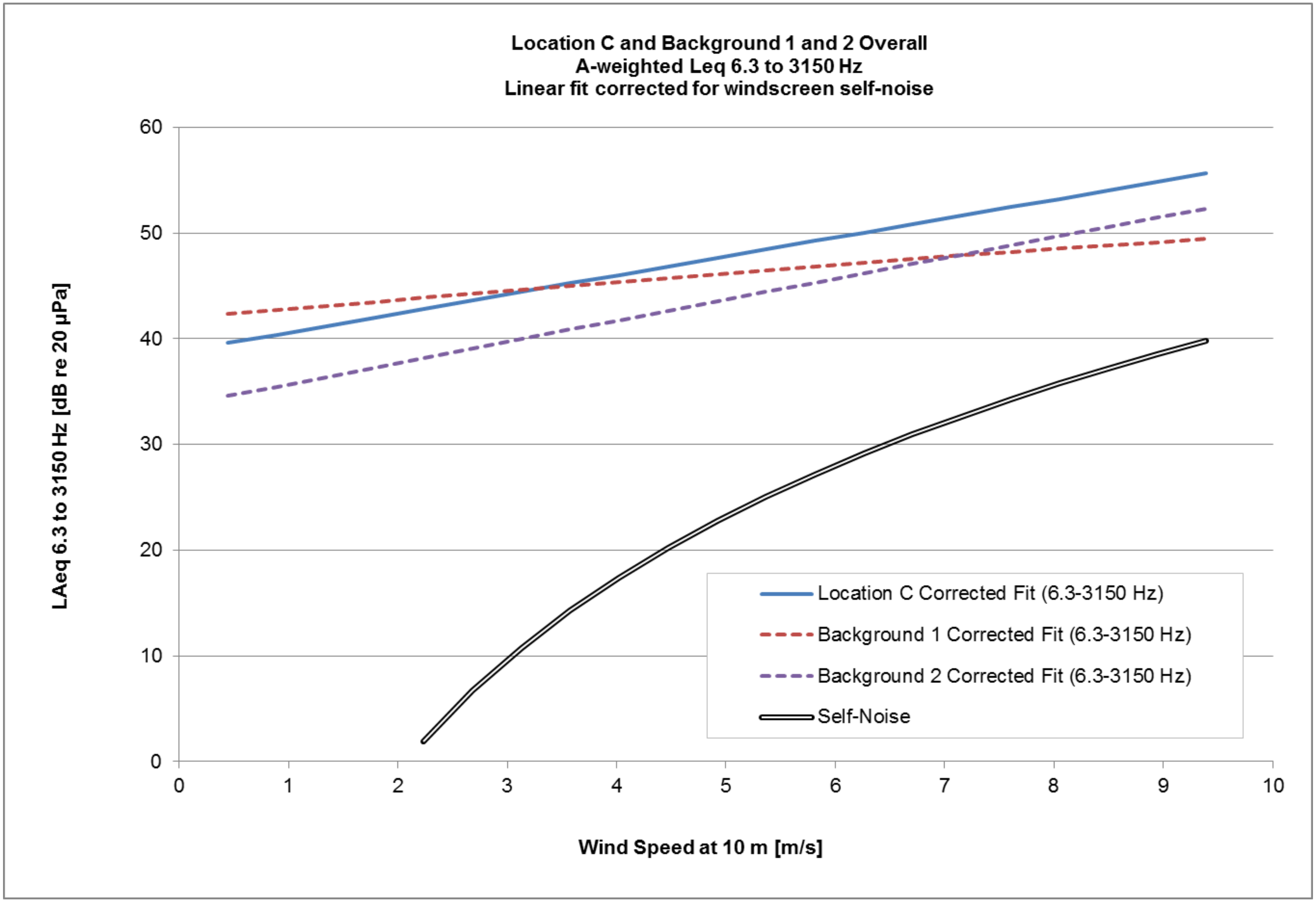

Figure C33. Location C and Background 1 and 2 overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

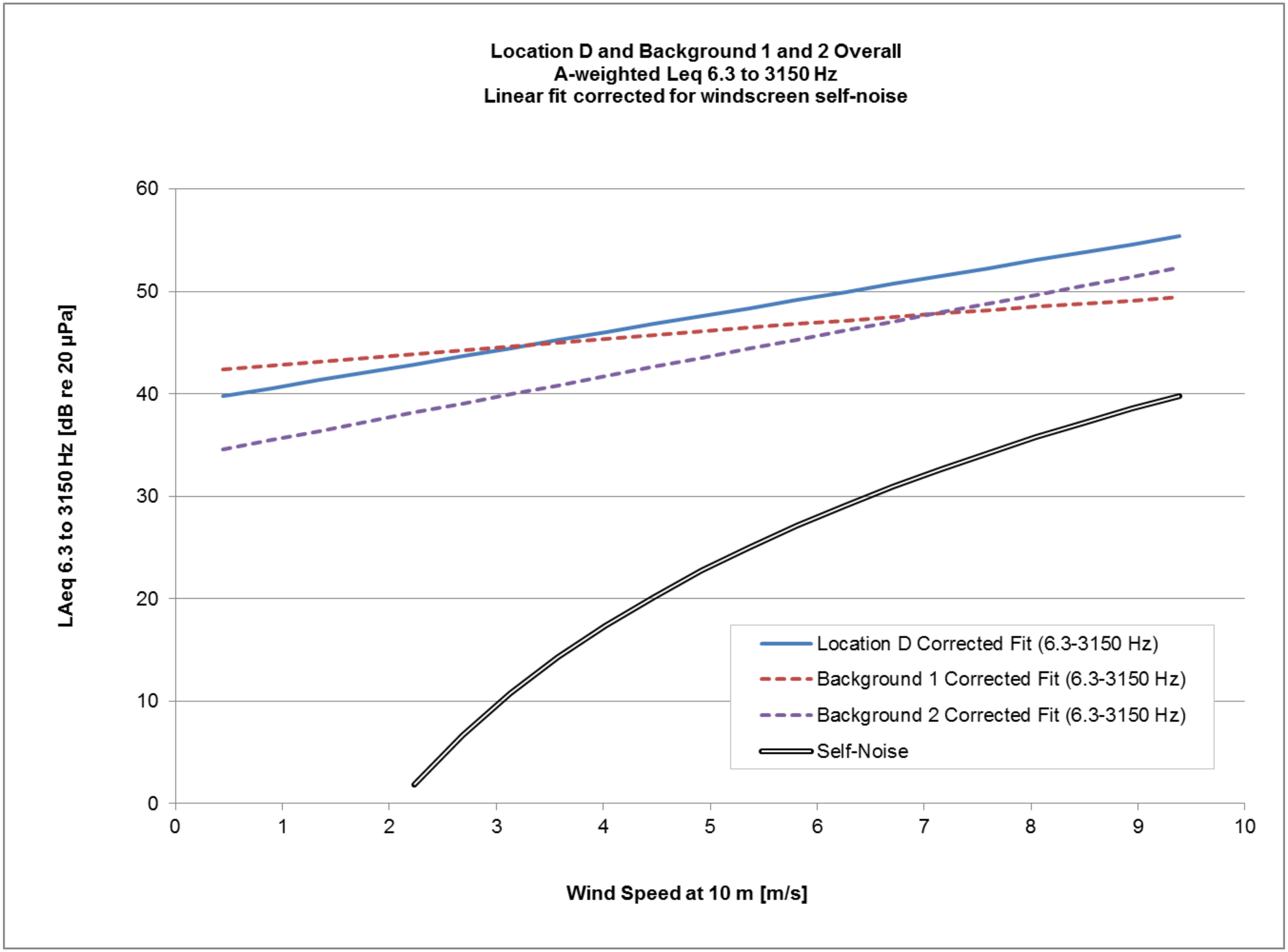

Figure C34. Location D and Background 1 and 2 overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

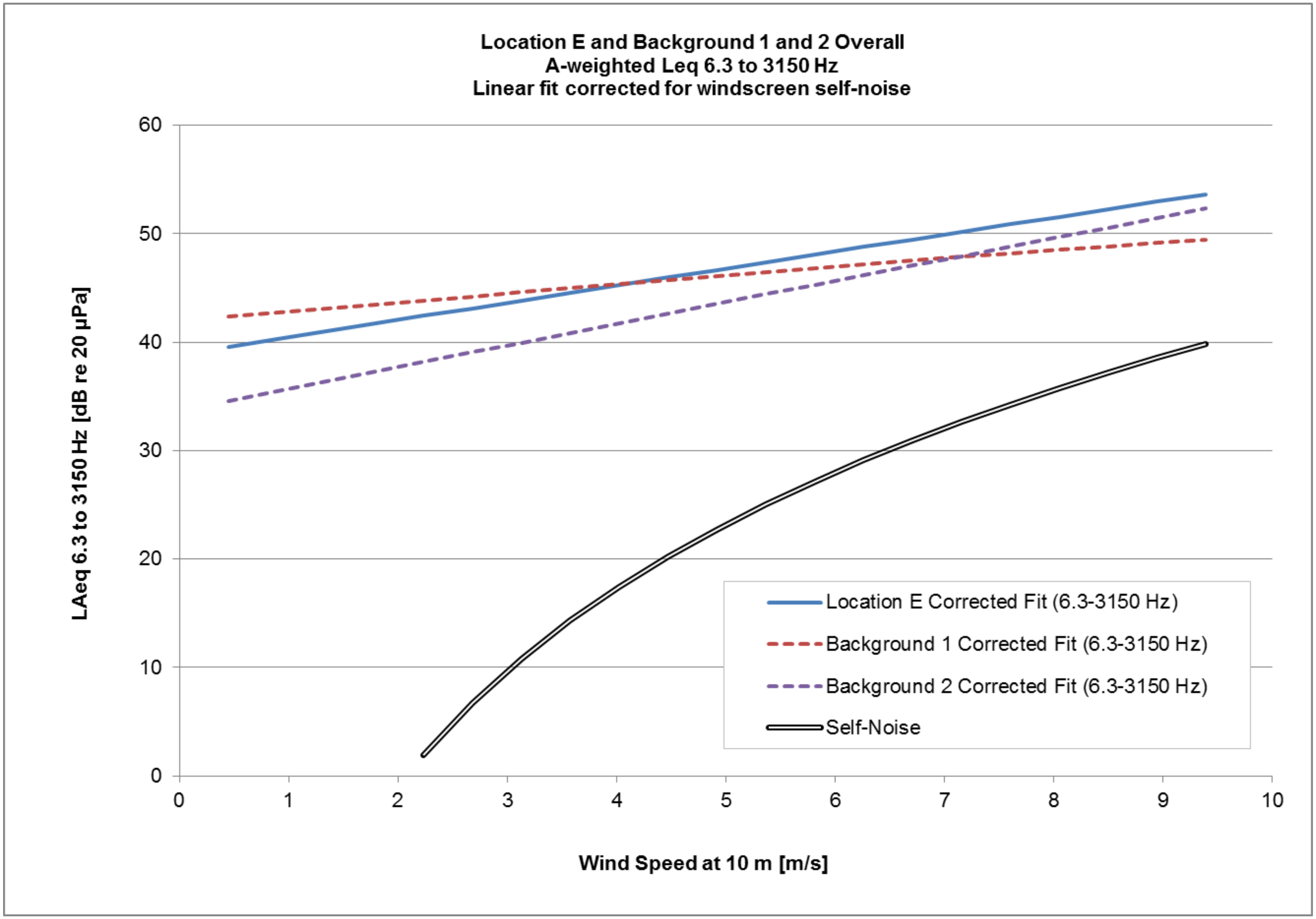

Figure C35. Location E and Background 1 and 2 overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

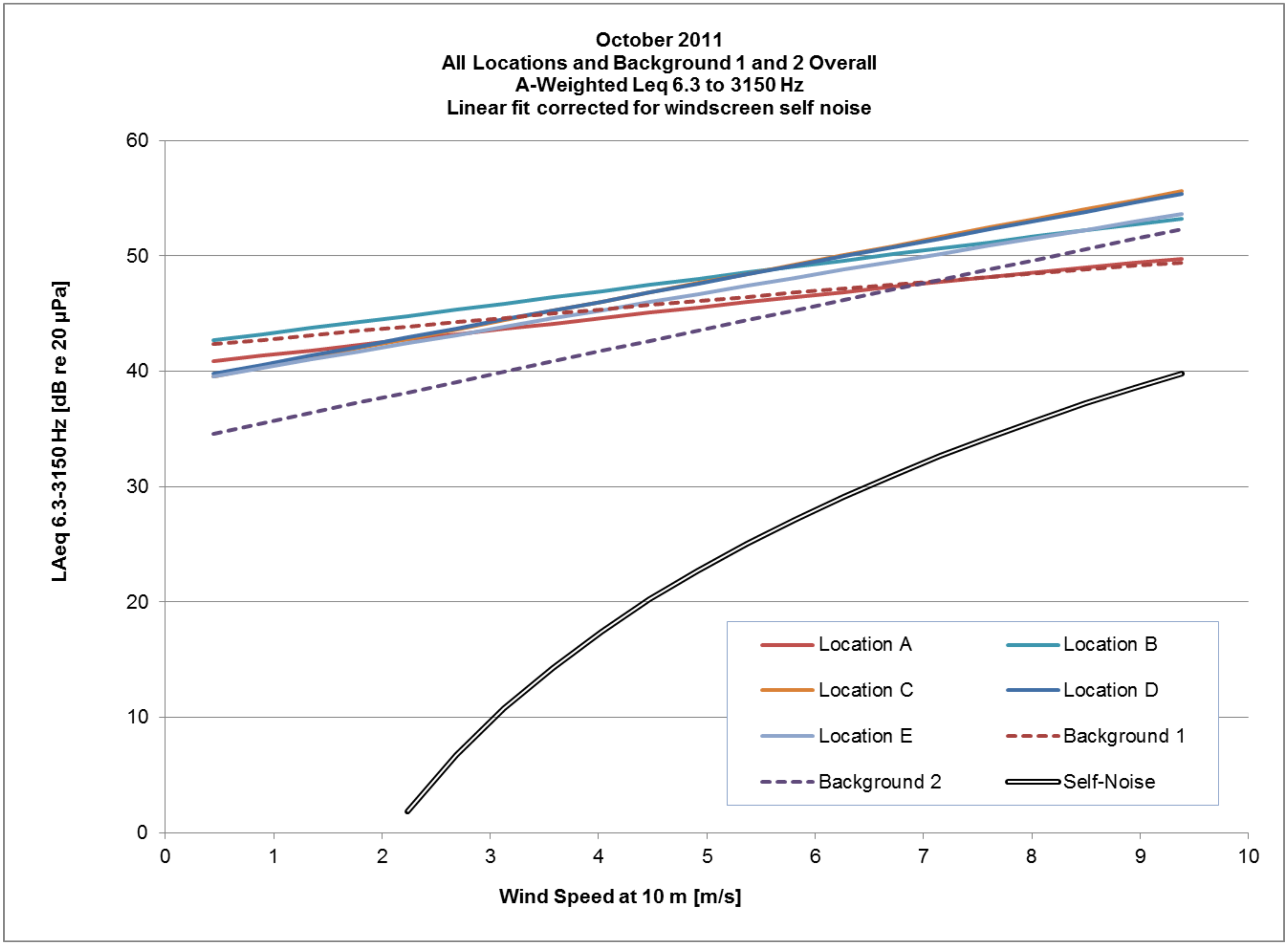

Figure C36. All locations and Background 1 and 2 overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

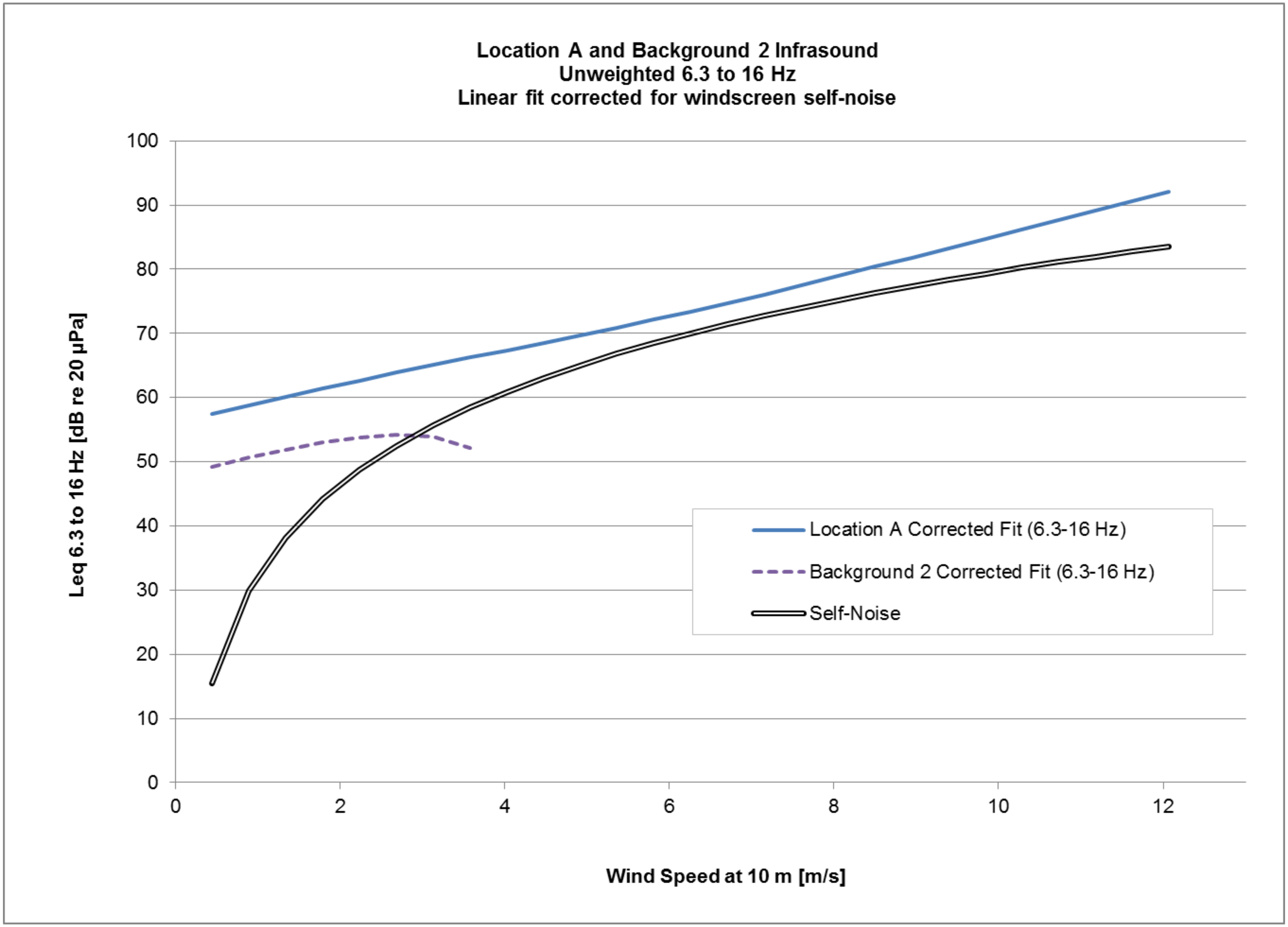

Figure C37. Location A and Background 2 Infrasound Unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

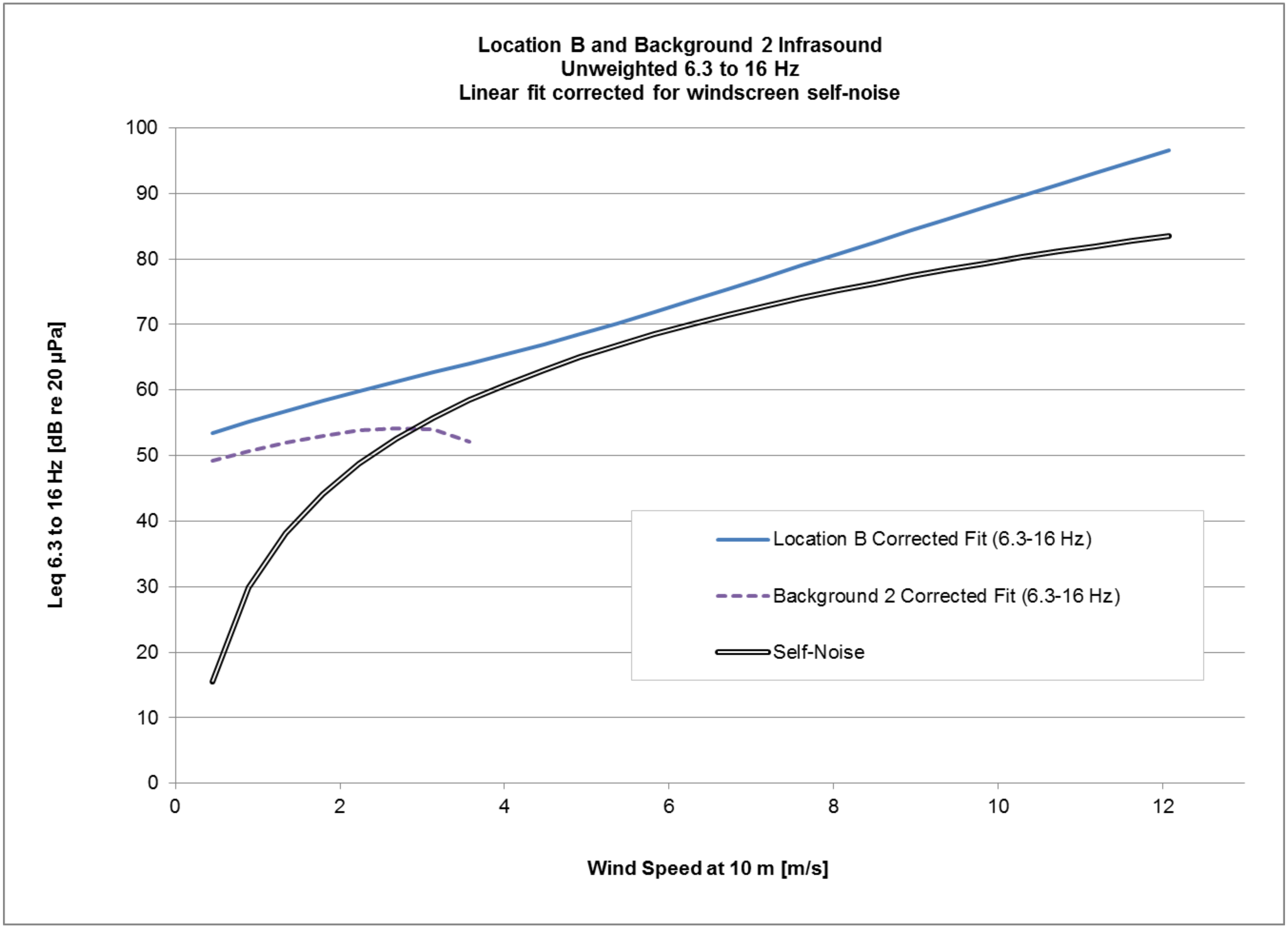

Figure C38. Location B and Background 2 Infrasound Unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

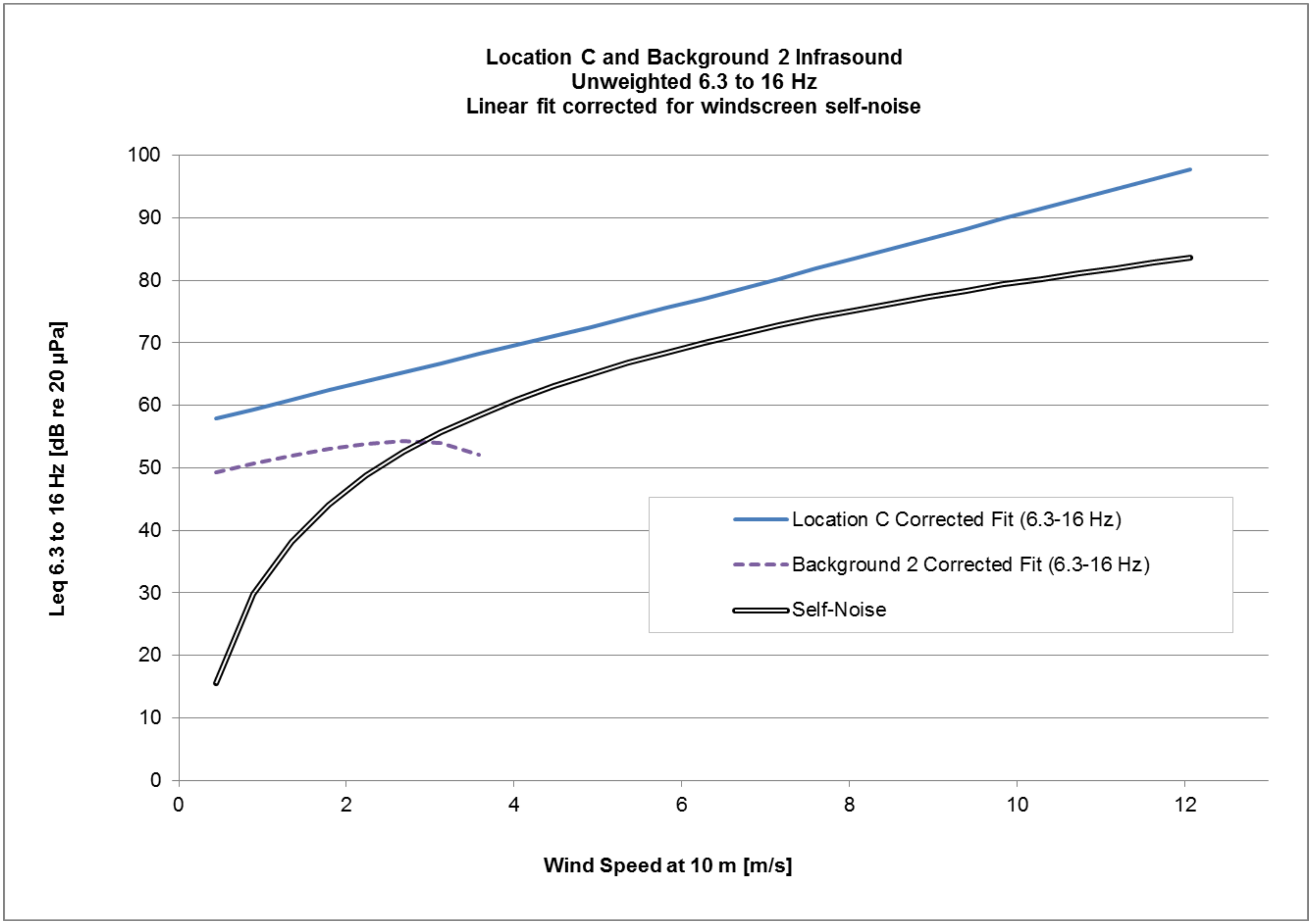

Figure C39. Location C and Background 2 Infrasound Unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

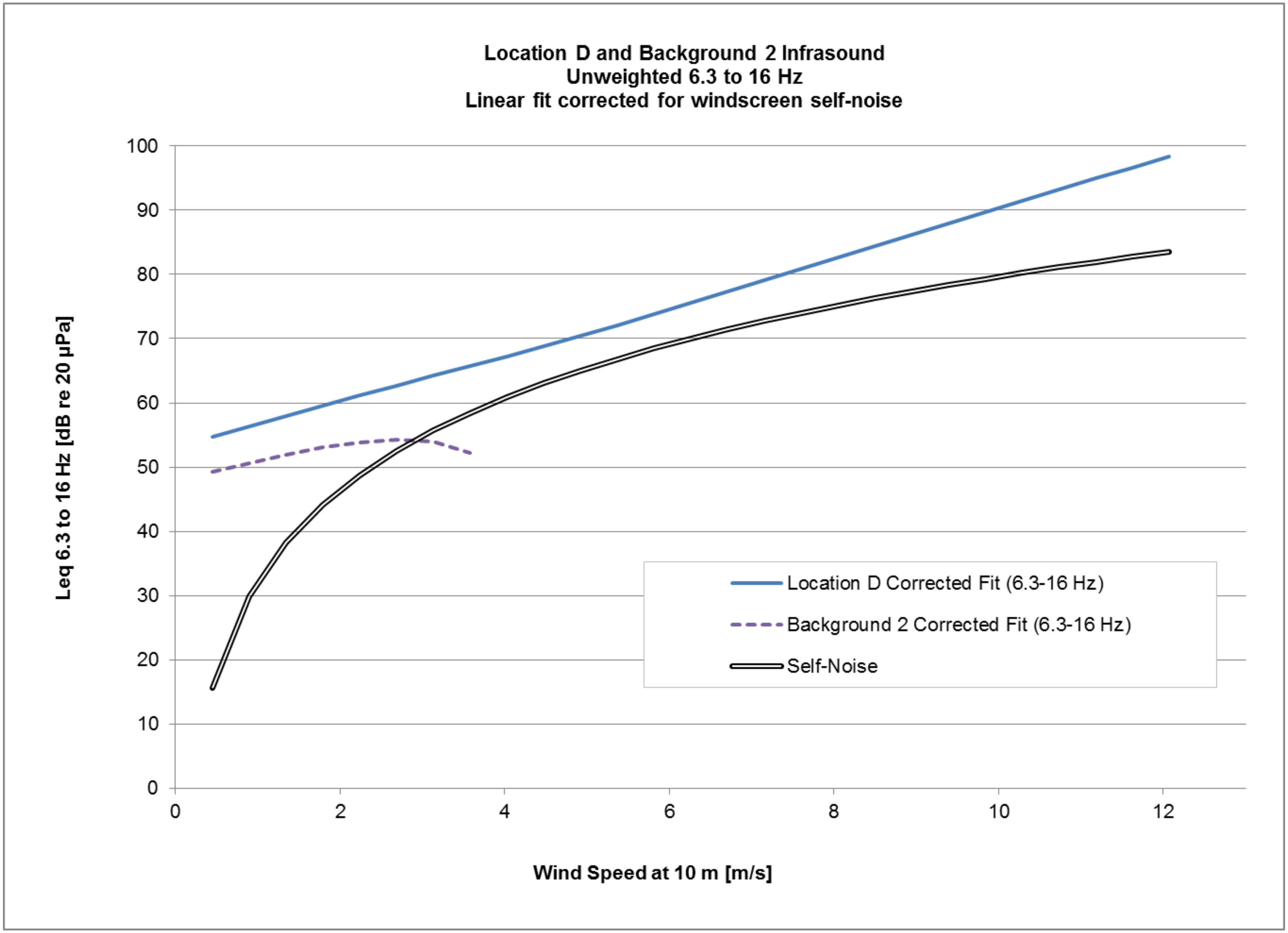

Figure C40. Location D and Background 2 Infrasound Unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

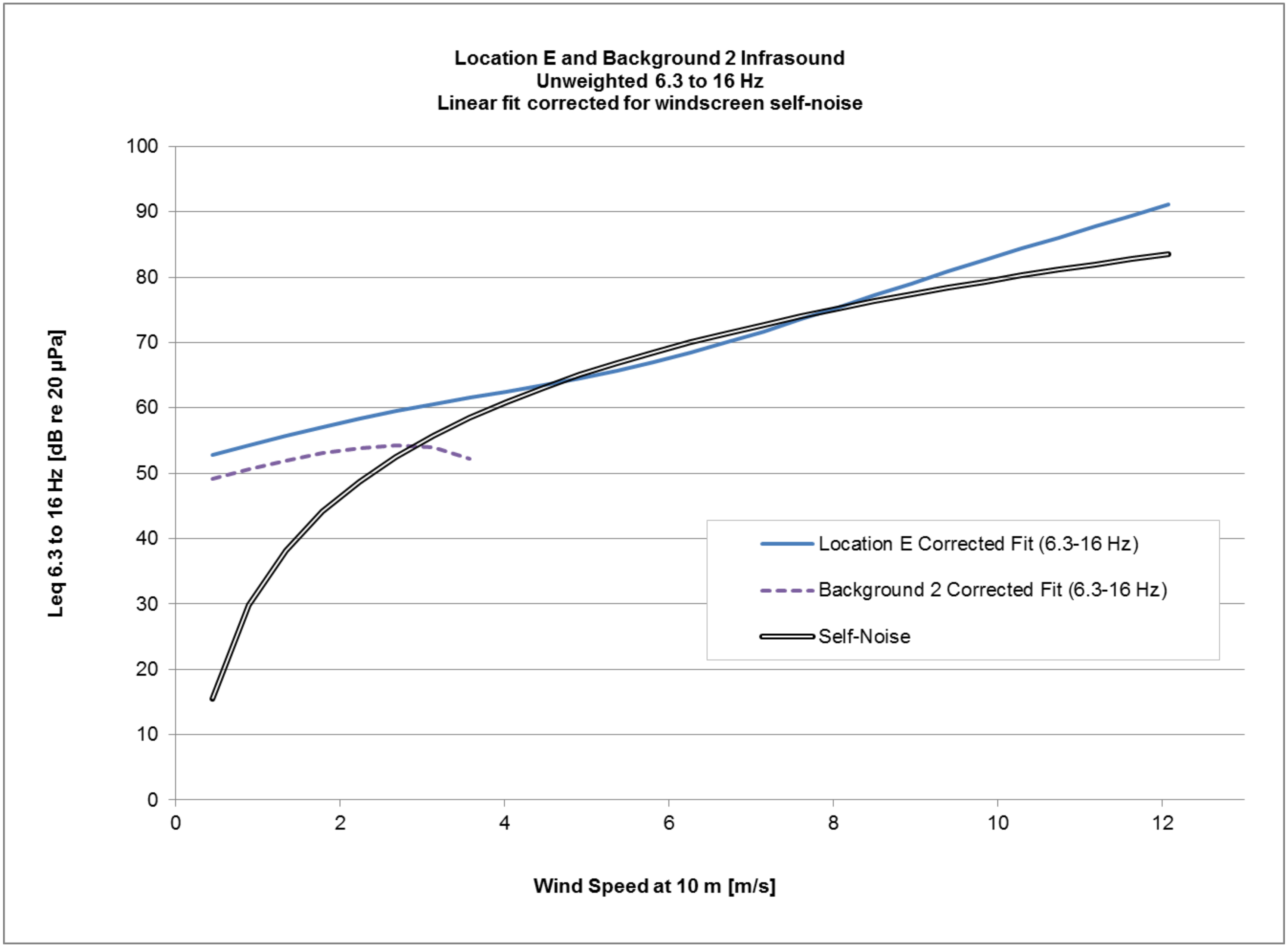

Figure C41. Location E and Background 2 Infrasound Unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

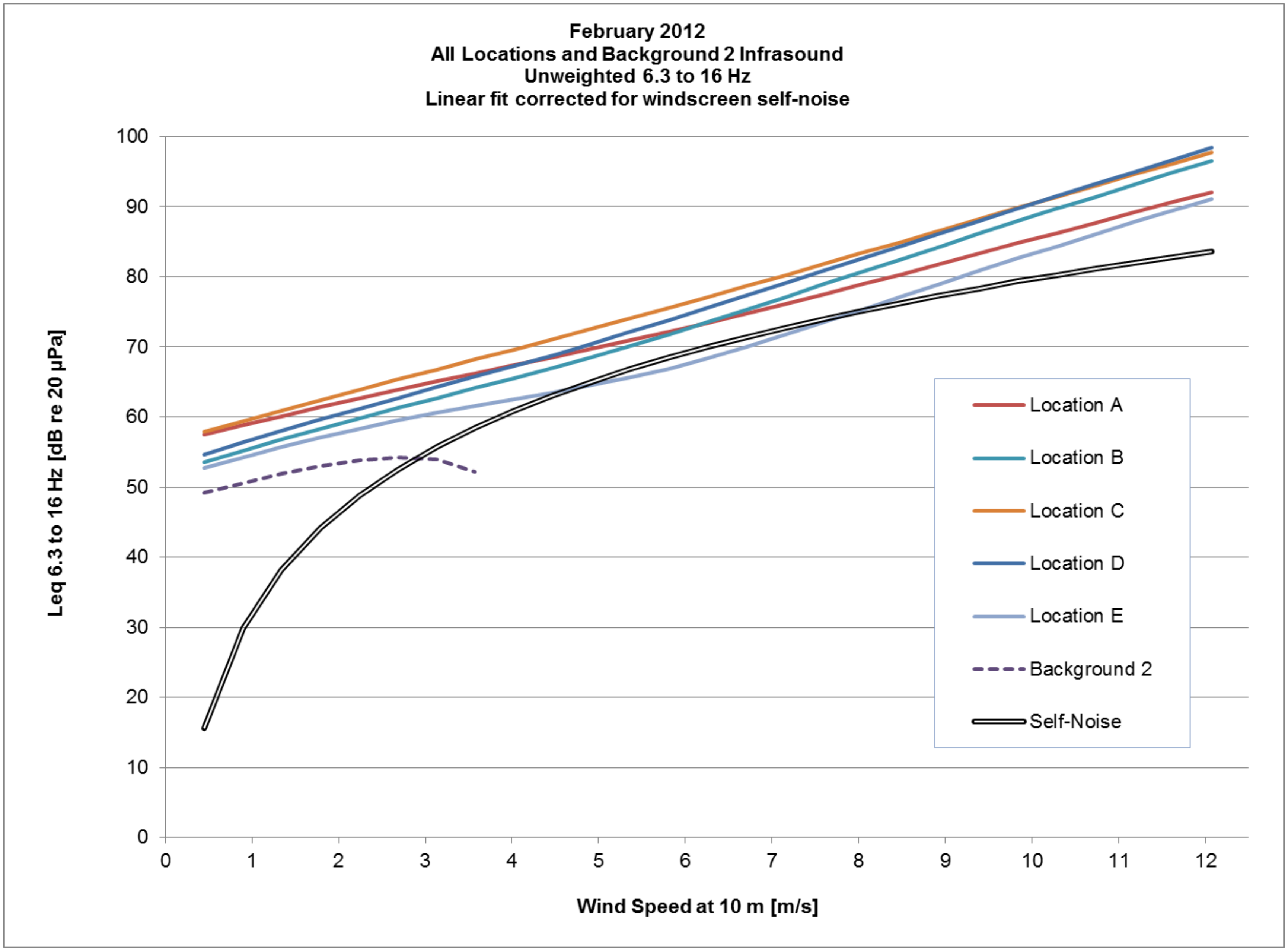

Figure C42. All Locations and Background 2 Infrasound Unweighted 6.3 to 16 Hz linear fit corrected for windscreen self-noise.

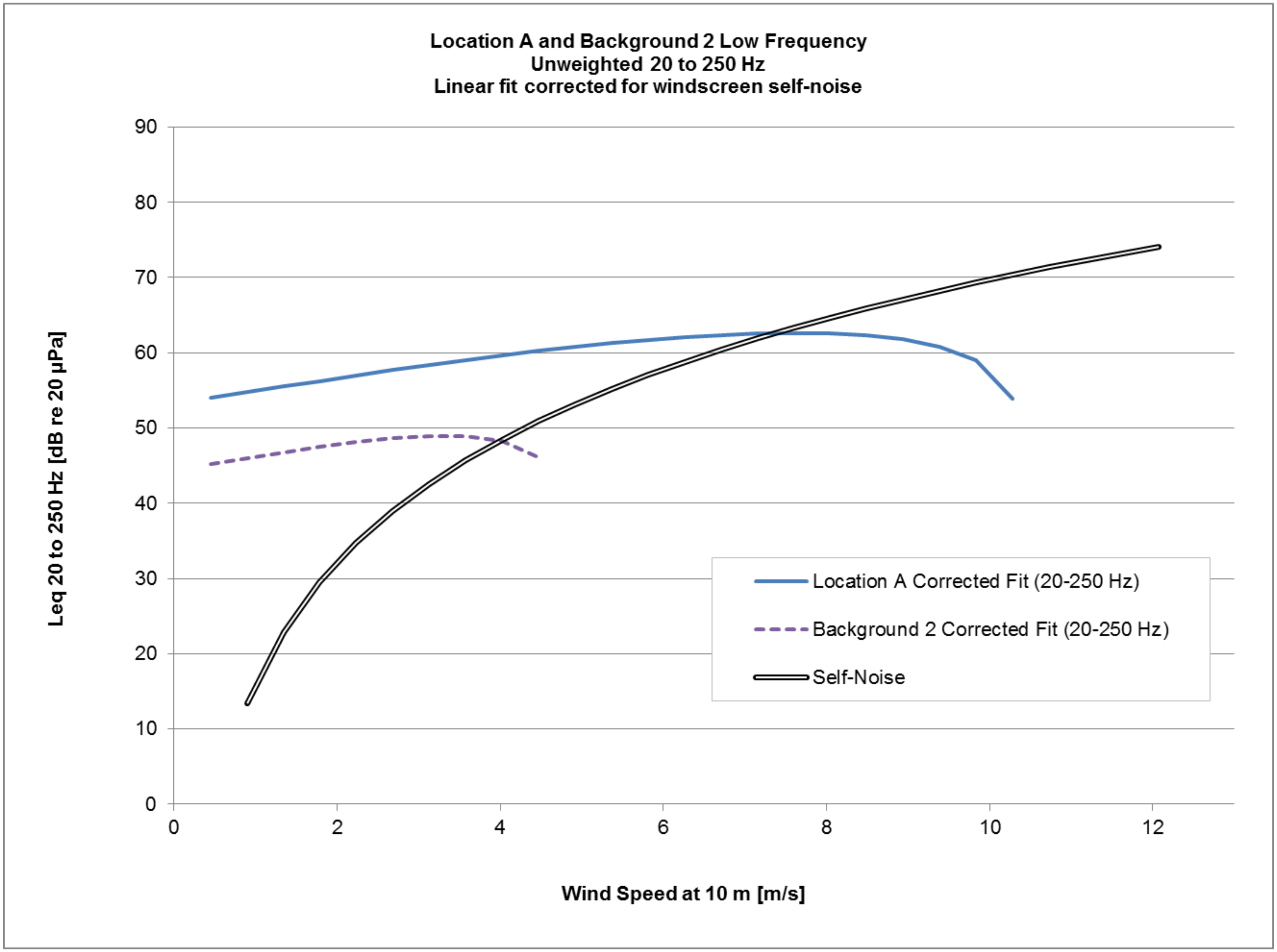

Figure C43. Location A and Background 2 Low Frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

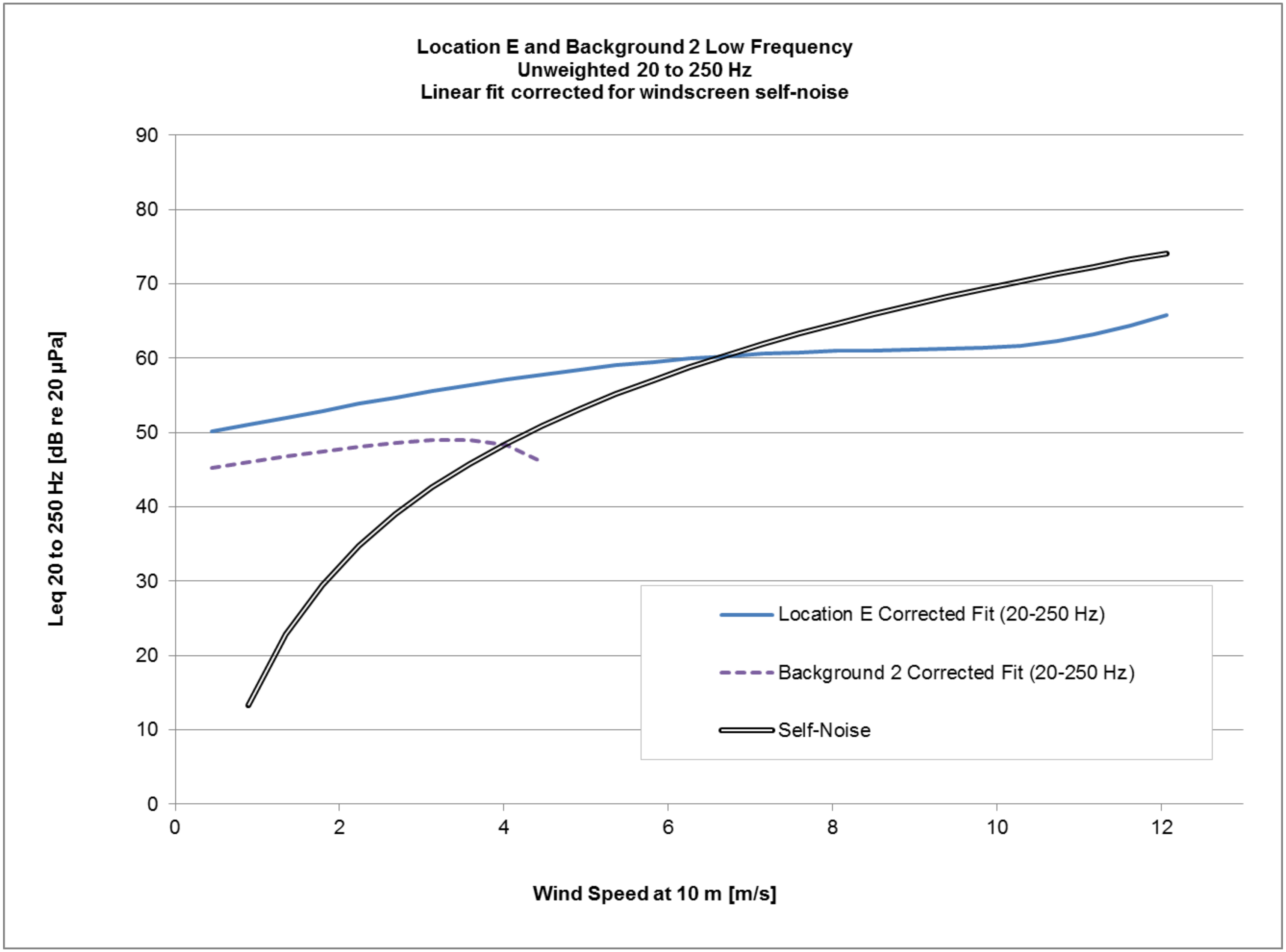

Figure C44. Location E and Background 2 Low Frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

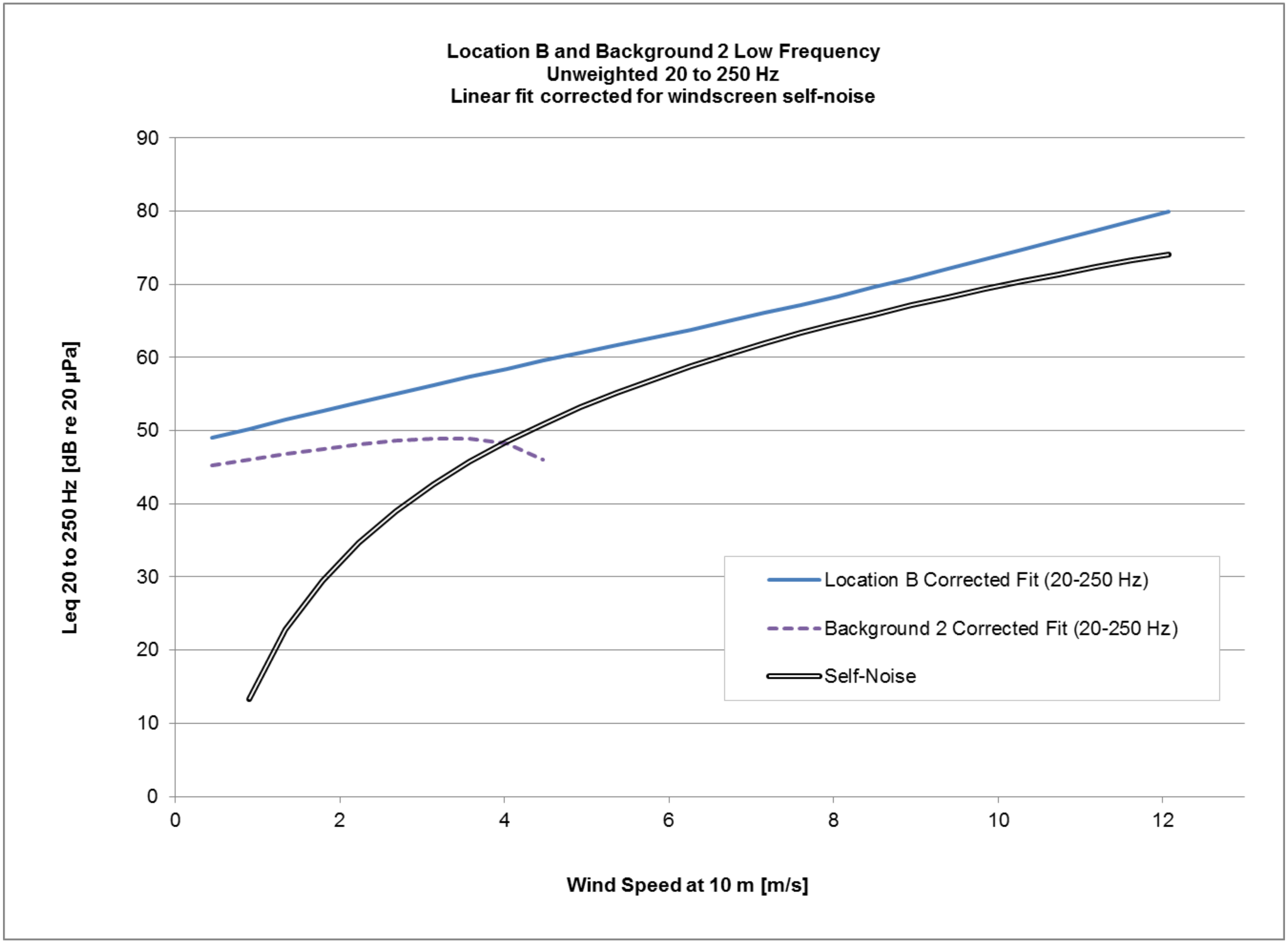

Figure C45. Location B and Background 2 Low Frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

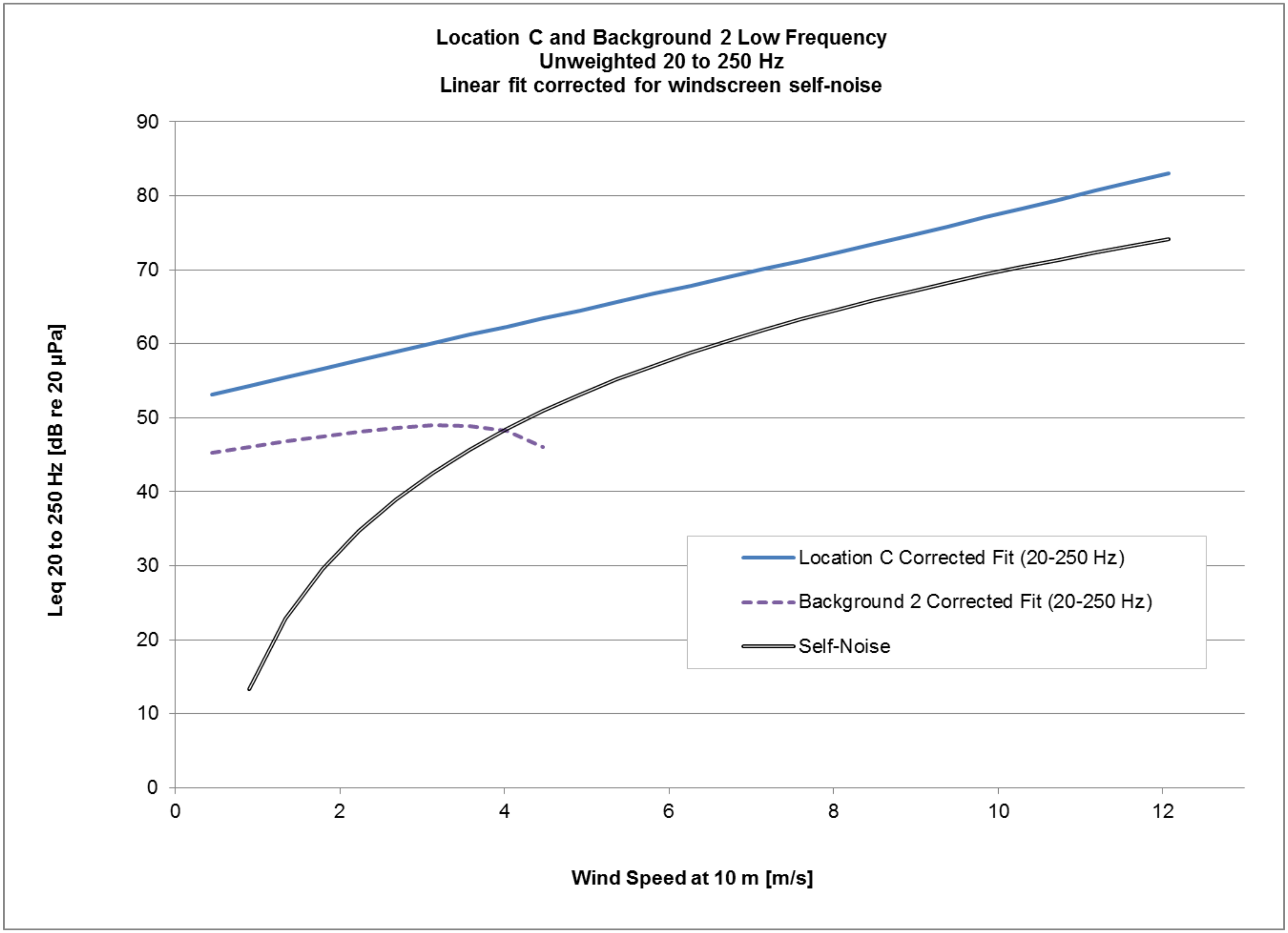

Figure C46. Location C and Background 2 Low Frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

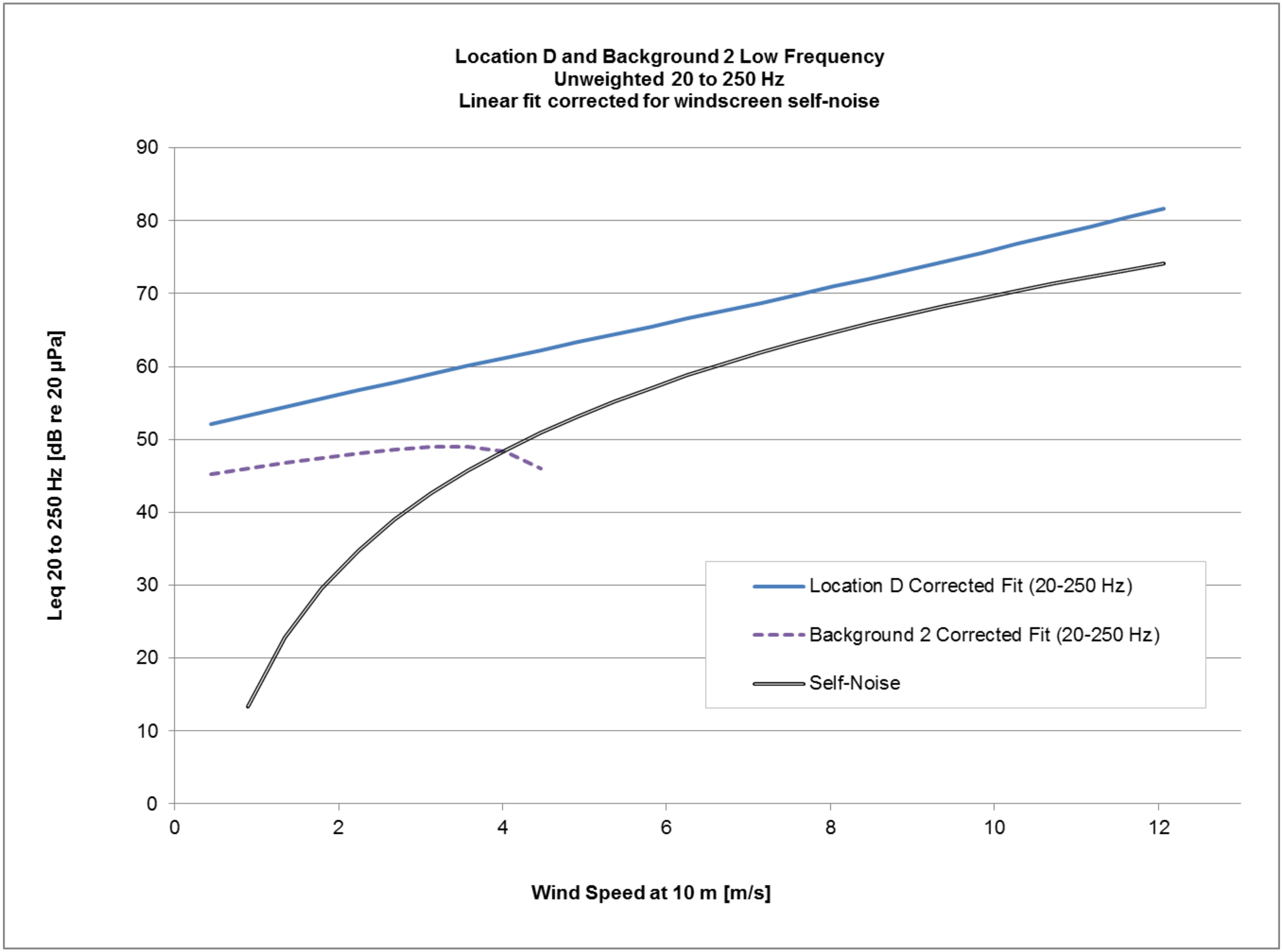

Figure C47. Location D and Background 2 Low Frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

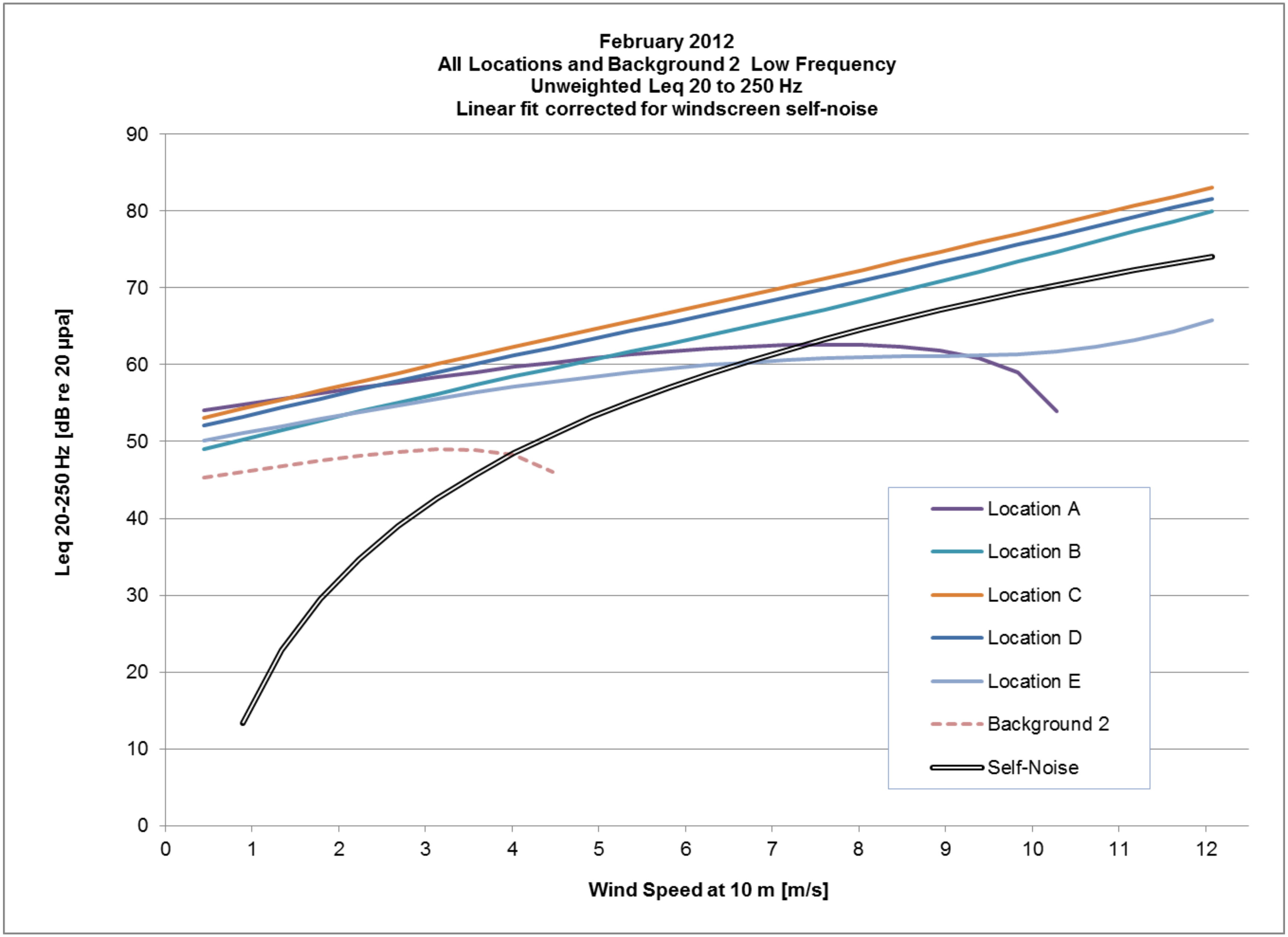

Figure C48. All Locations and Background 2 Low Frequency unweighted 20 to 250 Hz linear fit corrected for windscreen self-noise.

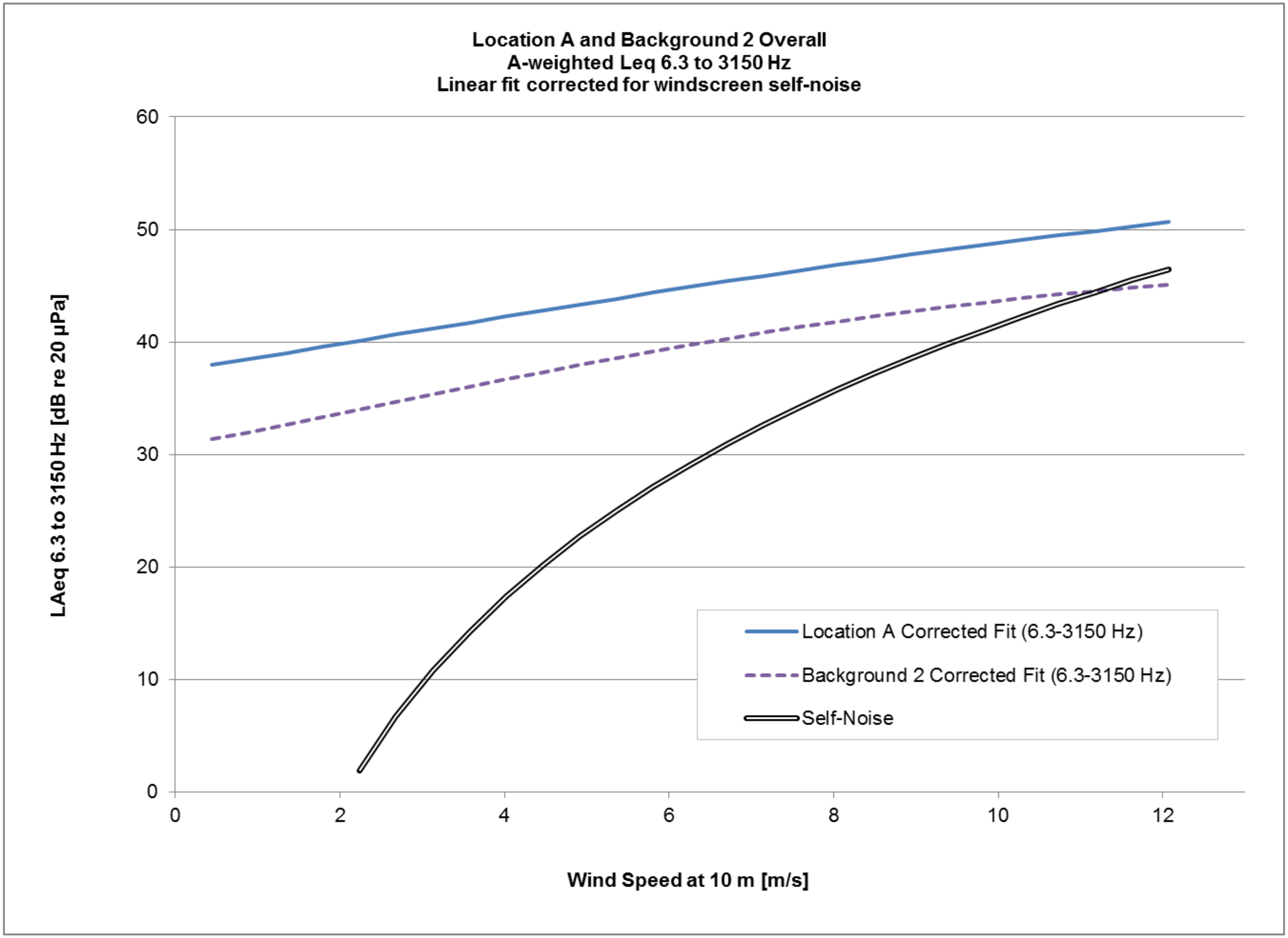

Figure C49. Location A and Background 2 Overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

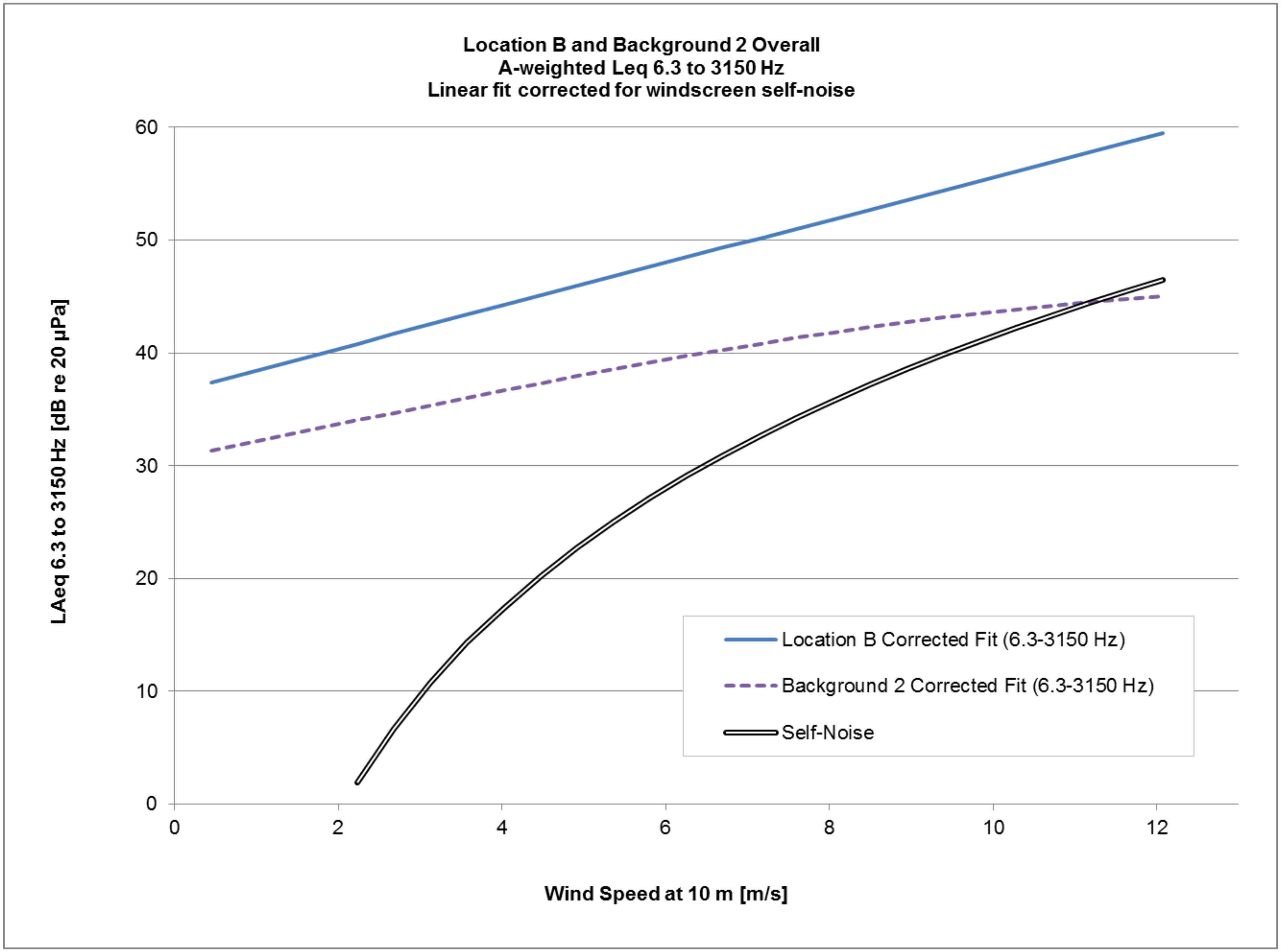

Figure C50. Location B and Background 2 Overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

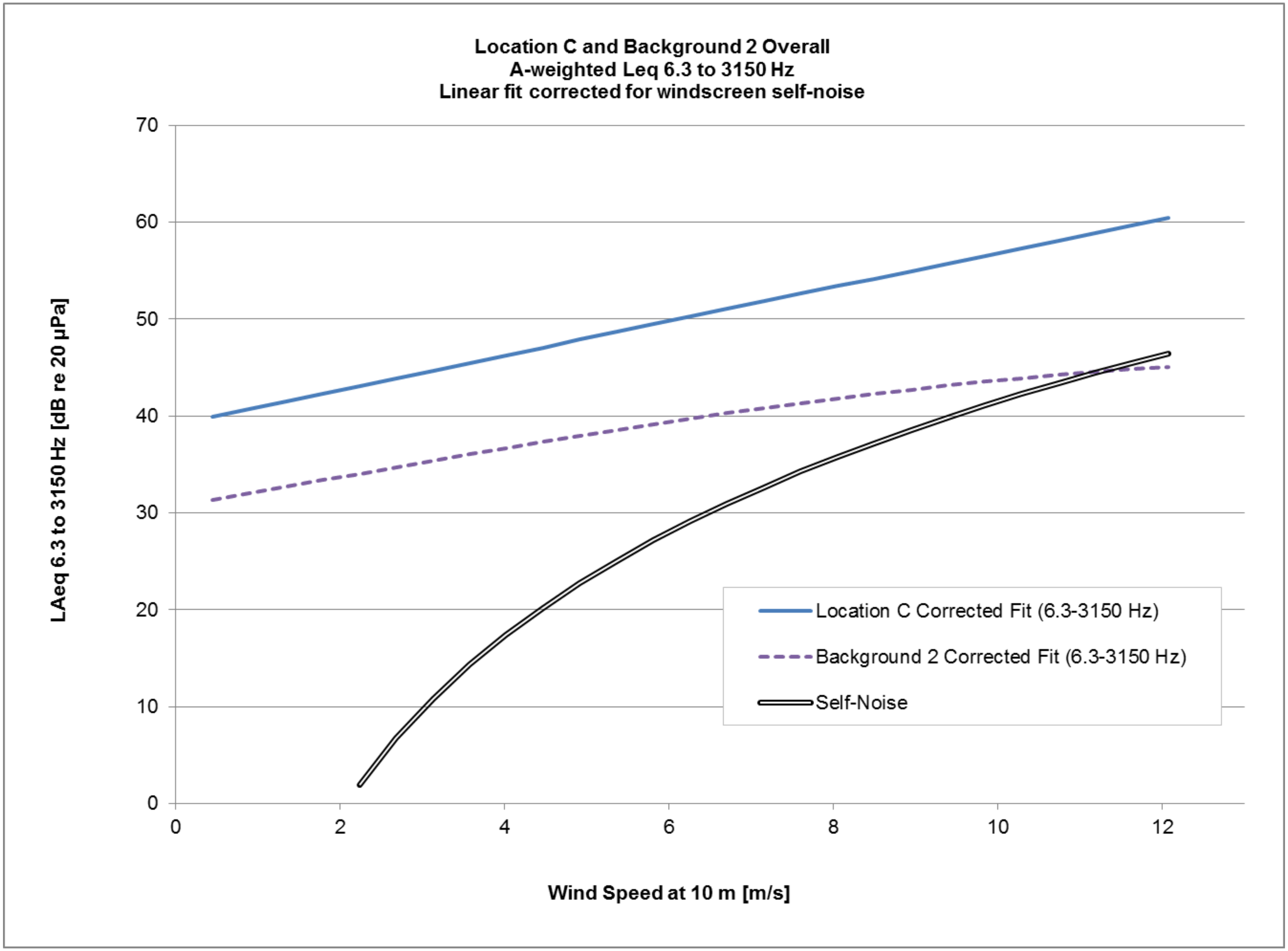

Figure C51. Location C and Background 2 Overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

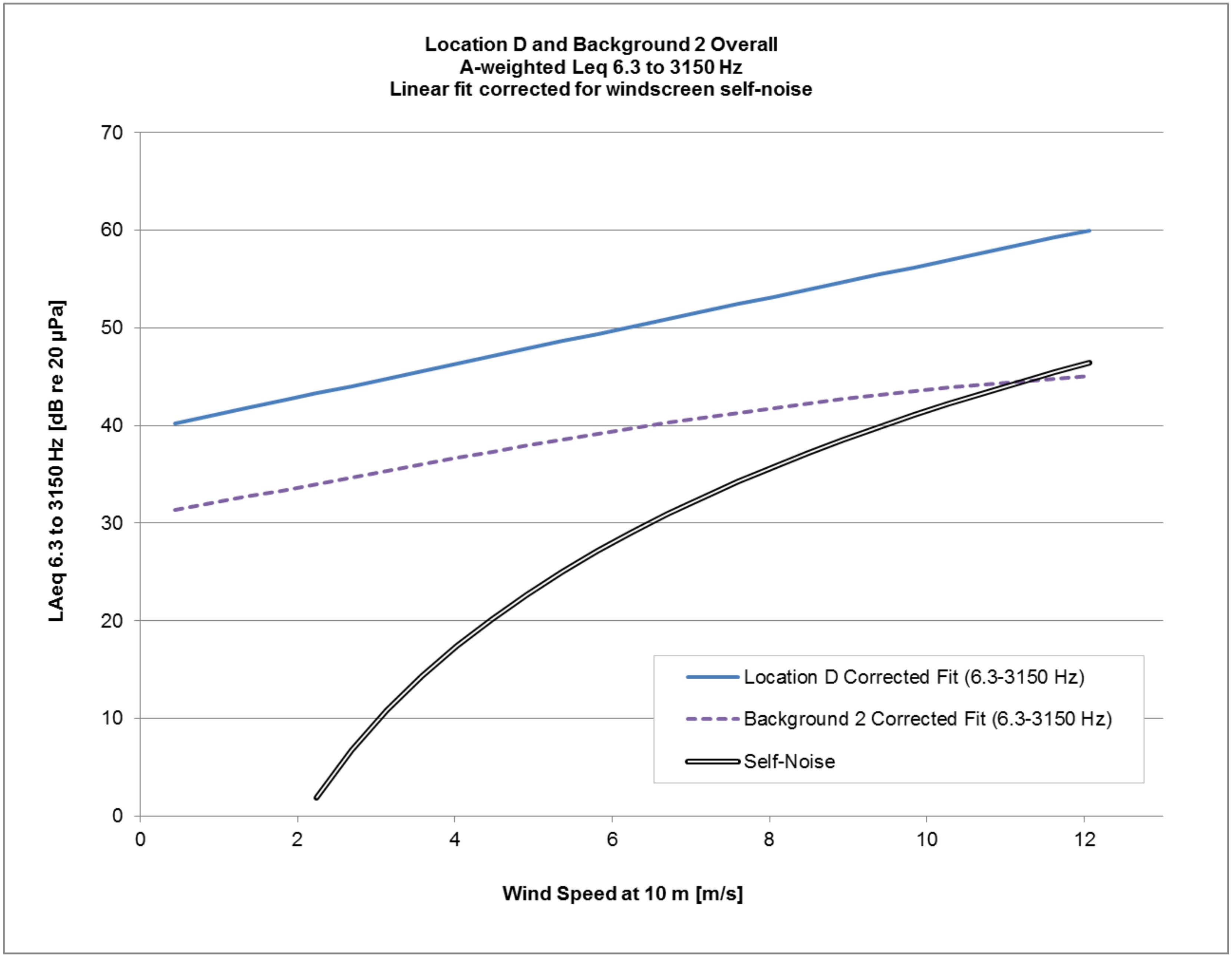

Figure C52. Location D and Background 2 Overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

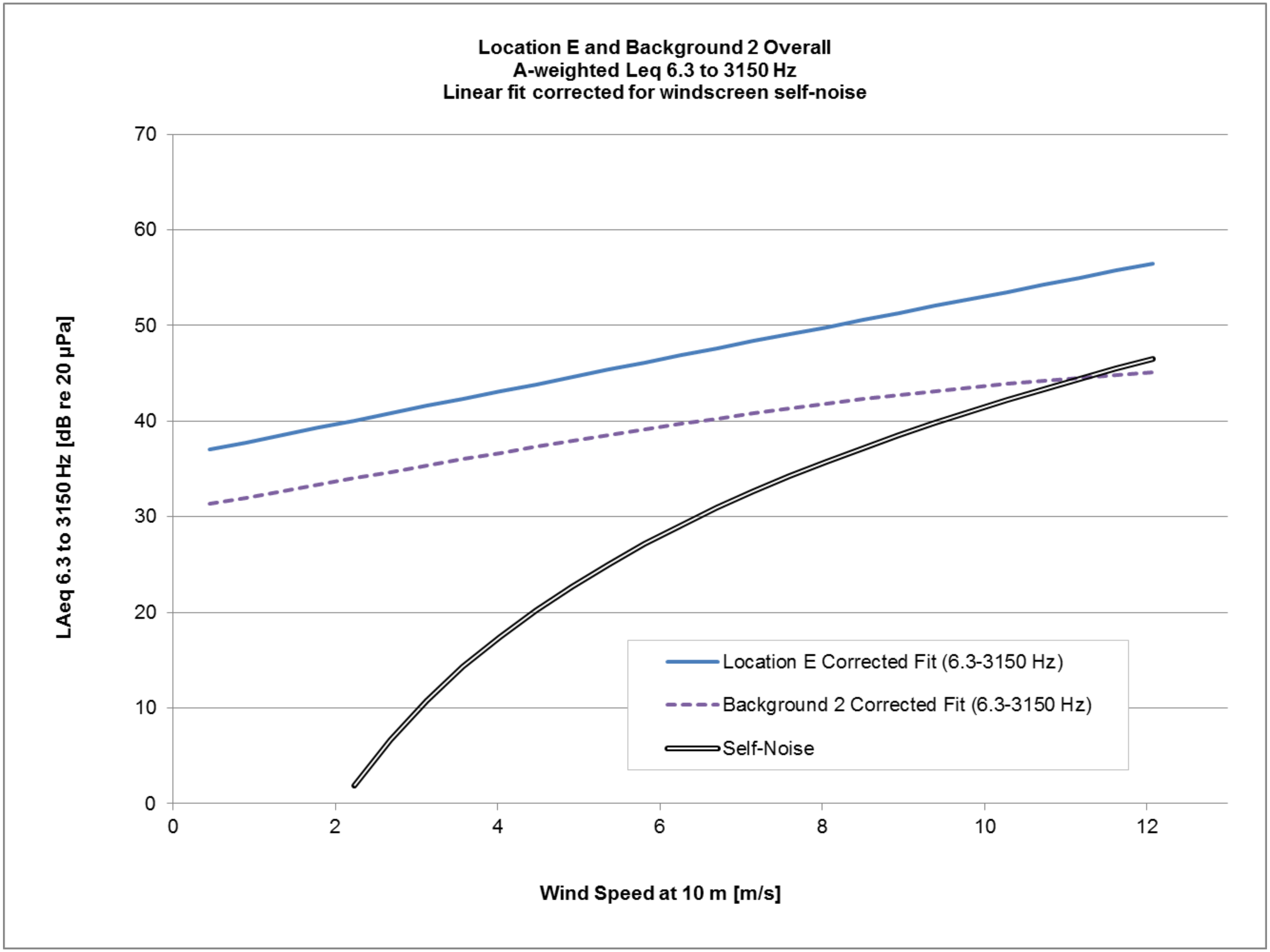

Figure C53. Location E and Background 2 Overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

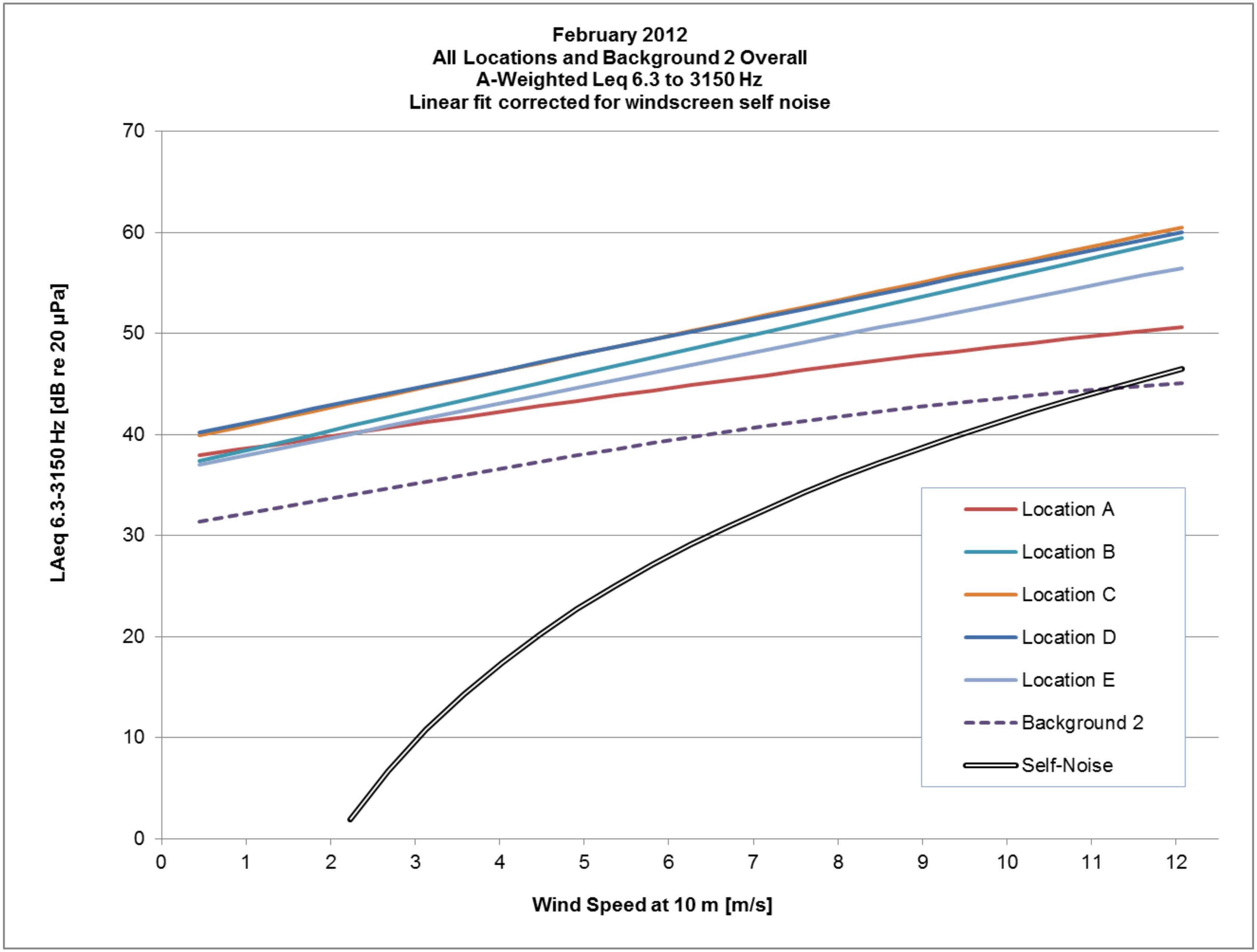

Figure C54. All locations and Background 2 Overall A-weighted Leq 6.3 to 3150 Hz linear fit corrected for windscreen self-noise.

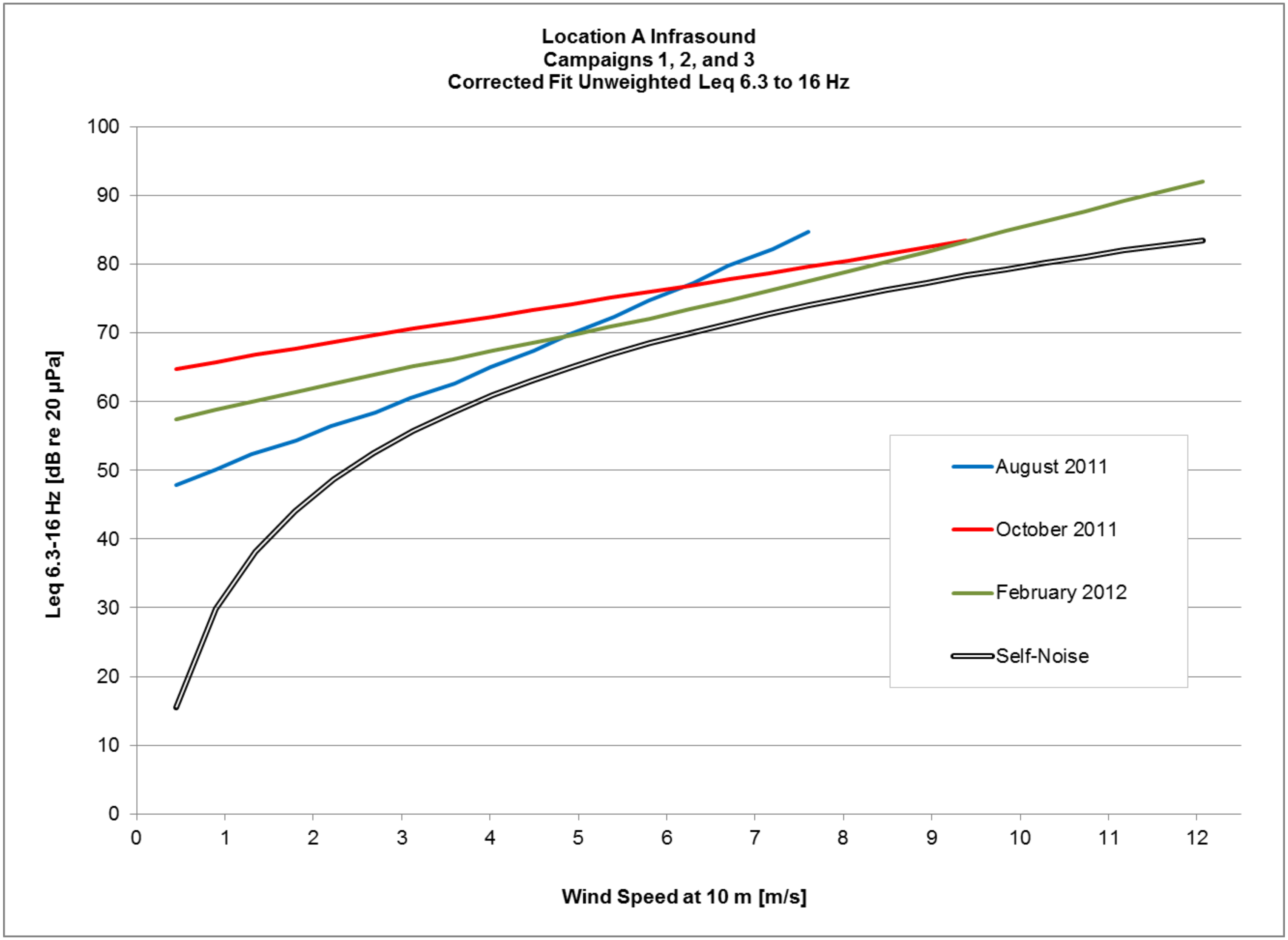

Figure C55. Location A Infrasound Campaigns 1, 2, and 3 corrected fit unweighted Leq 6.3 to 16 Hz.

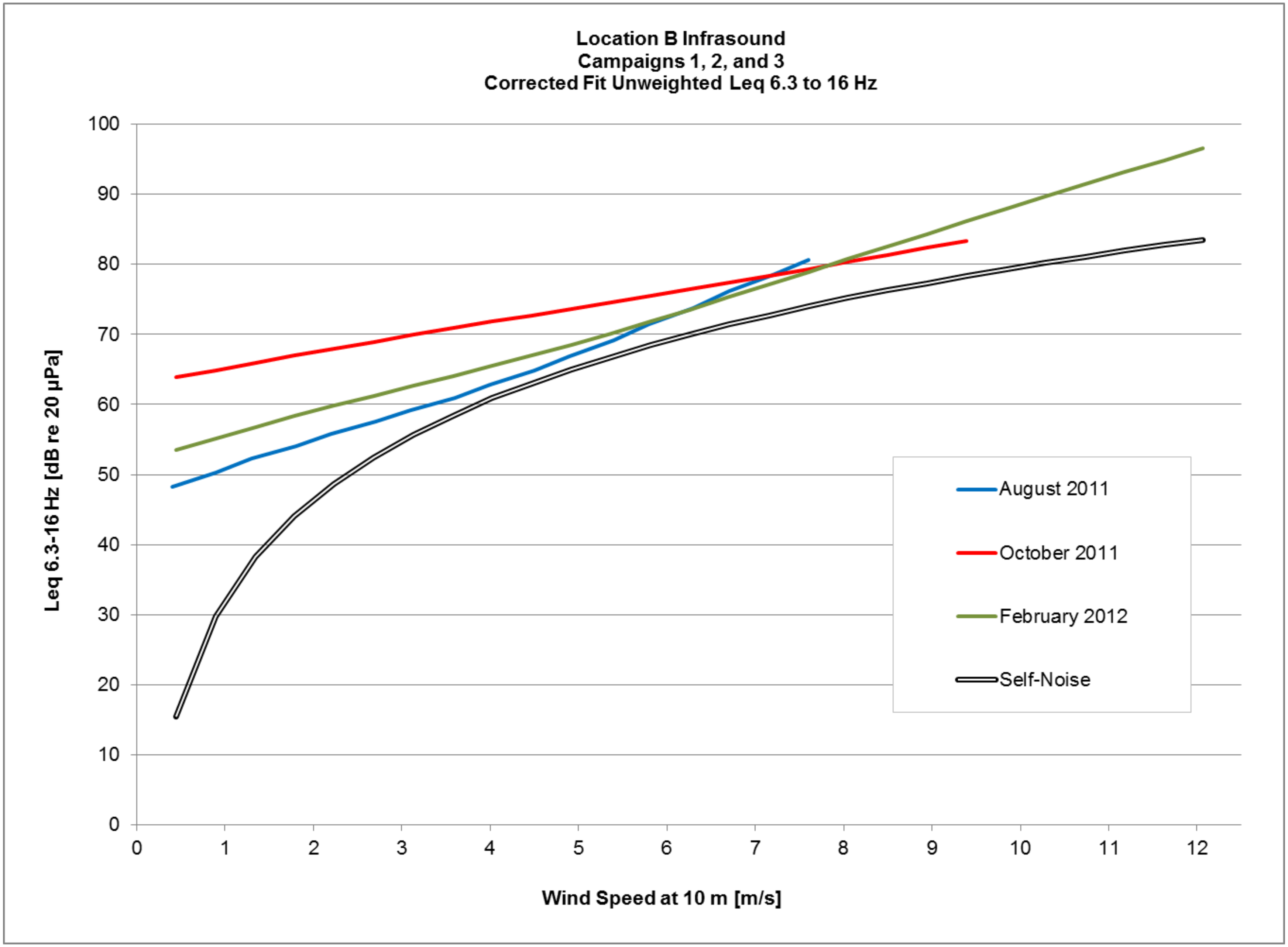

Figure C56. Location B Infrasound Campaigns 1, 2, and 3 corrected fit unweighted Leq 6.3 to 16 Hz.

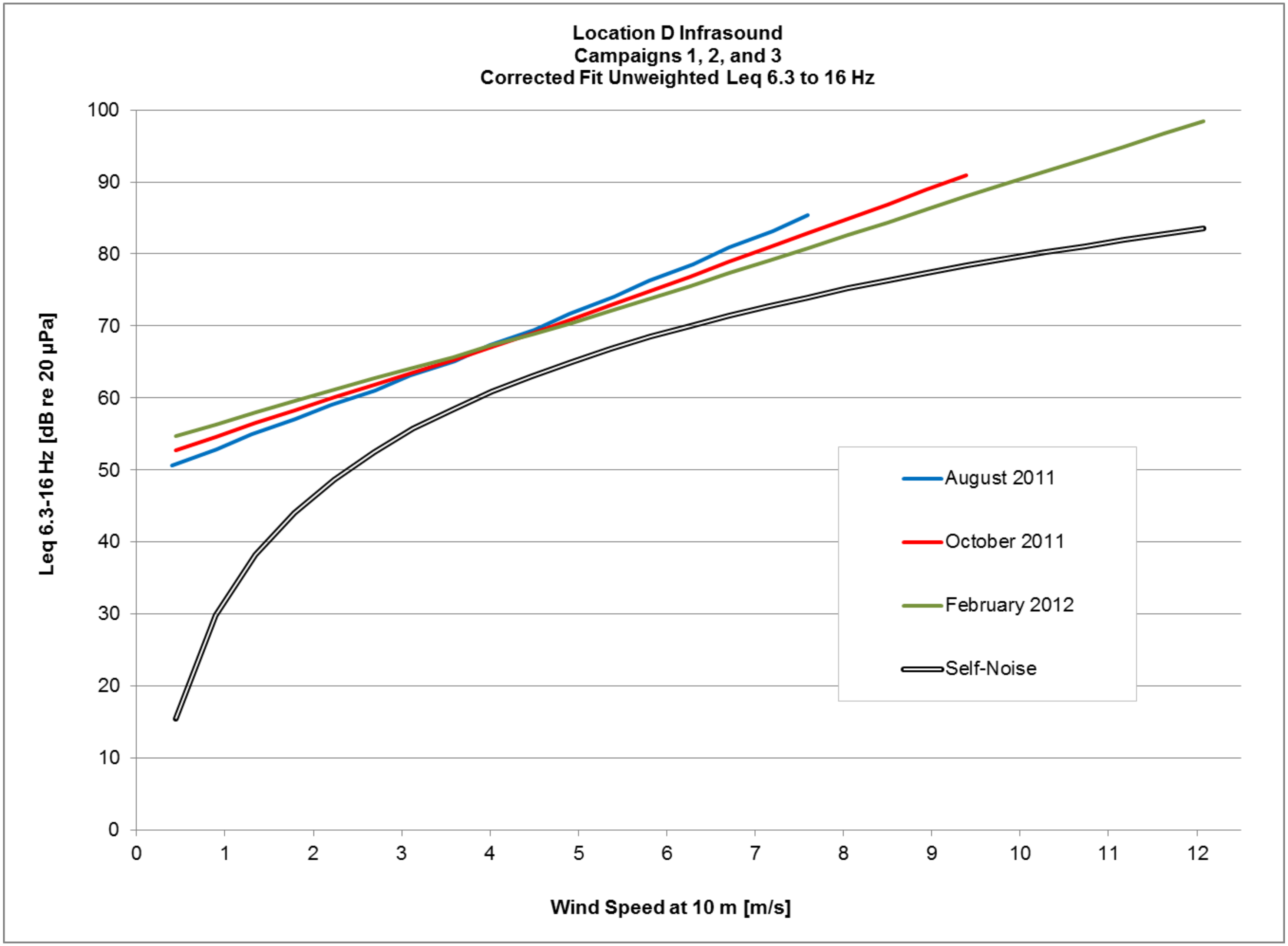

Figure C57. Location D Infrasound Campaigns 1, 2, and 3 corrected fit unweighted Leq 6.3 to 16 Hz.

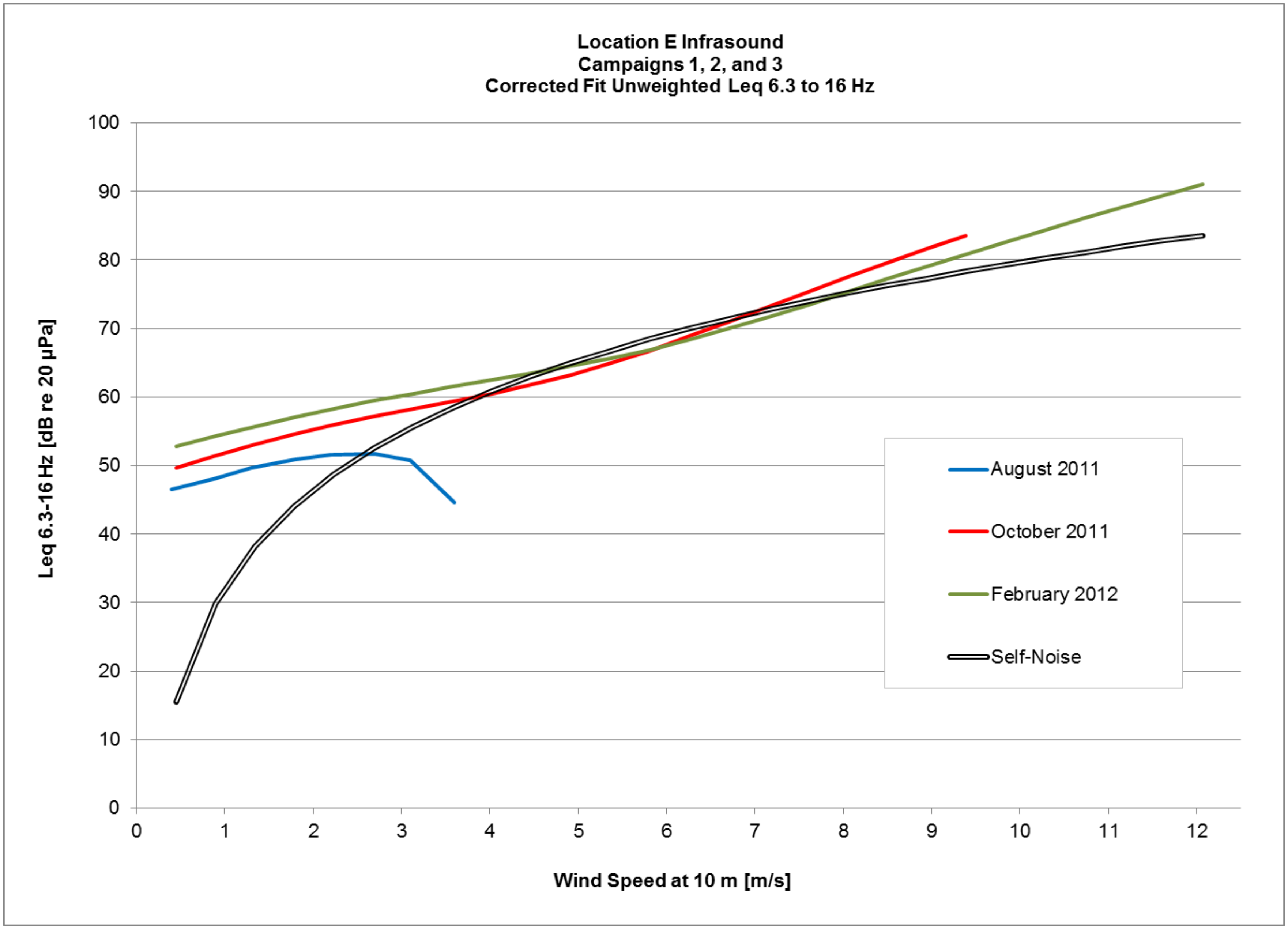

Figure C58. Location E Infrasound Campaigns 1, 2, and 3 corrected fit unweighted Leq 6.3 to 16 Hz.

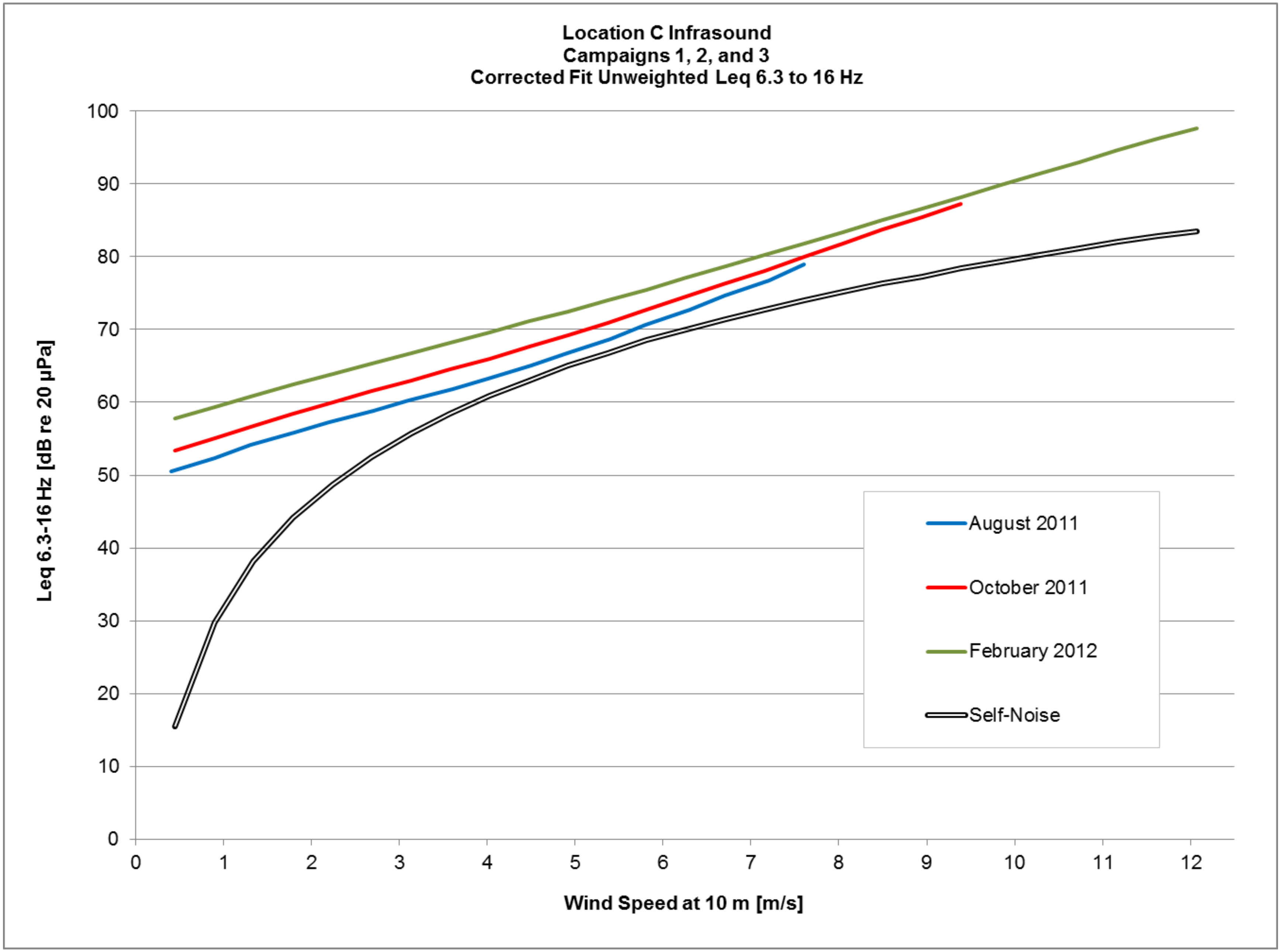

Figure C59. Location C Infrasound Campaigns 1, 2, and 3 corrected fit unweighted Leq 6.3 to 16 Hz.

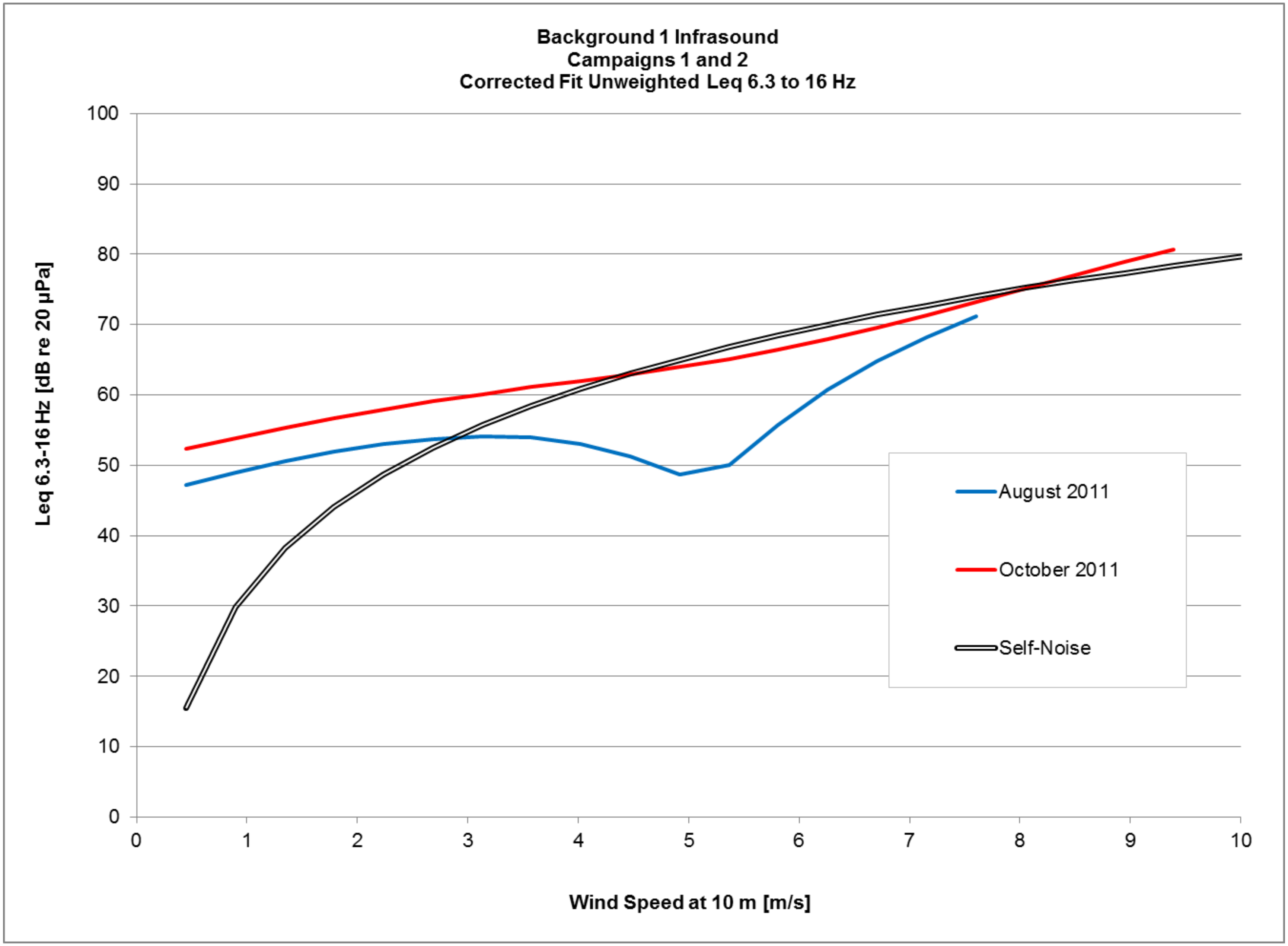

Figure C60. Background 1 Infrasound Campaigns 1 and 2 corrected fit unweighted Leq 6.3 to 16 Hz.

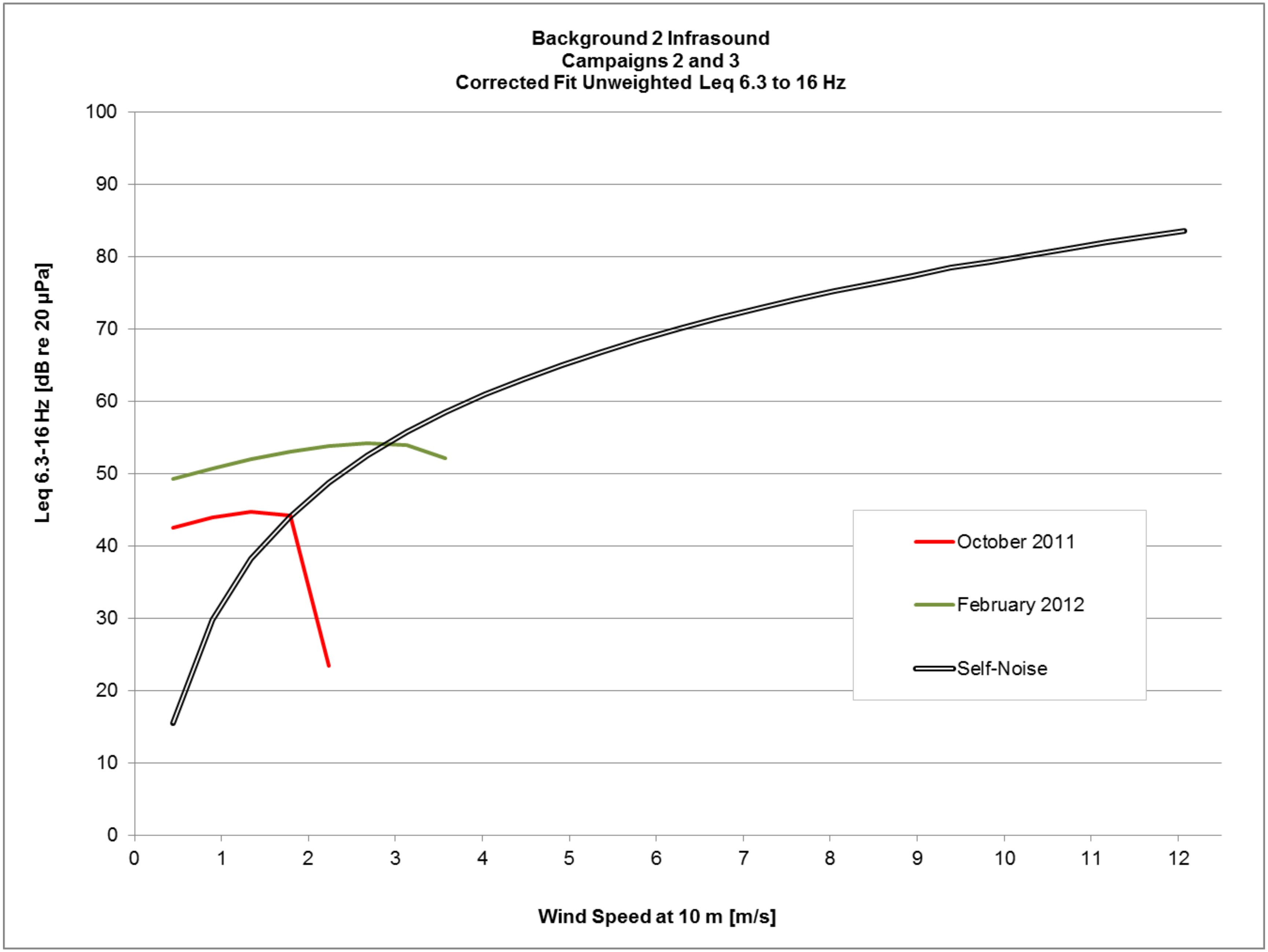

Figure C61. Background 2 Infrasound Campaigns 2 and 3 corrected fit unweighted Leq 6.3 to 16 Hz.

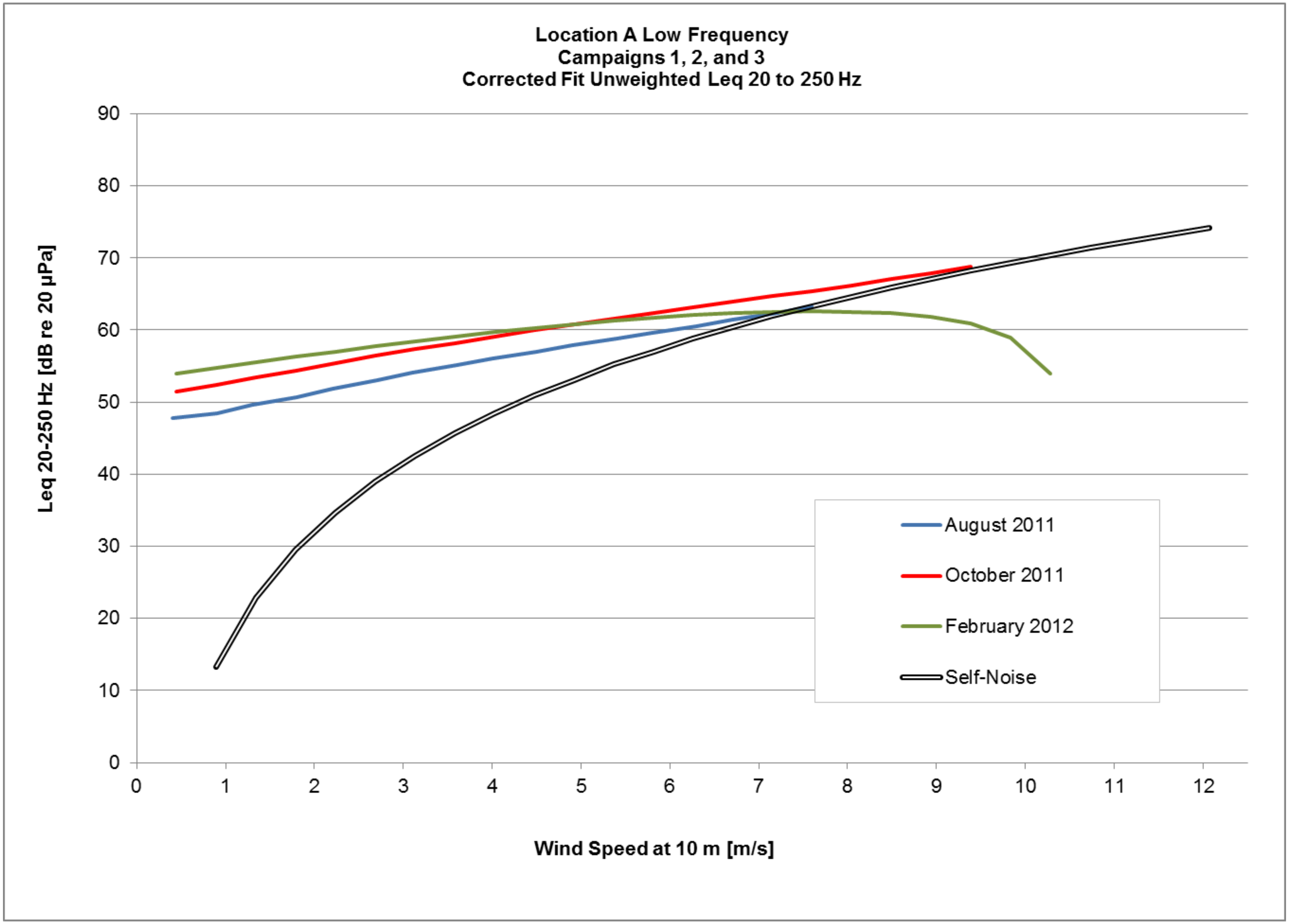

Figure C62. Location A Low Frequency Campaigns 1, 2 and 3 corrected fit unweighted Leq 20 to 250 Hz.

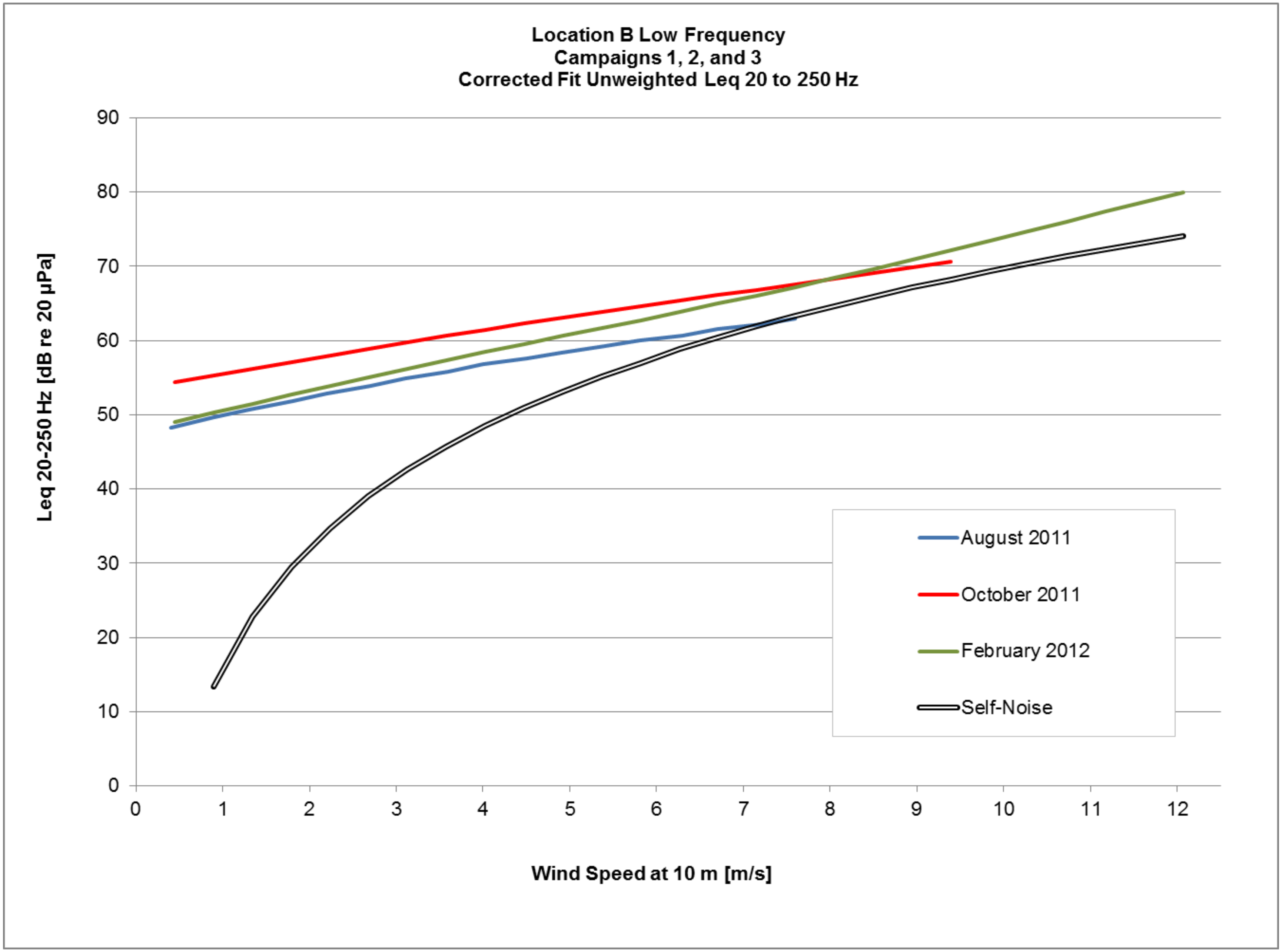

Figure C63. Location B Low Frequency Campaigns 1, 2 and 3 corrected fit unweighted Leq 20 to 250 Hz.

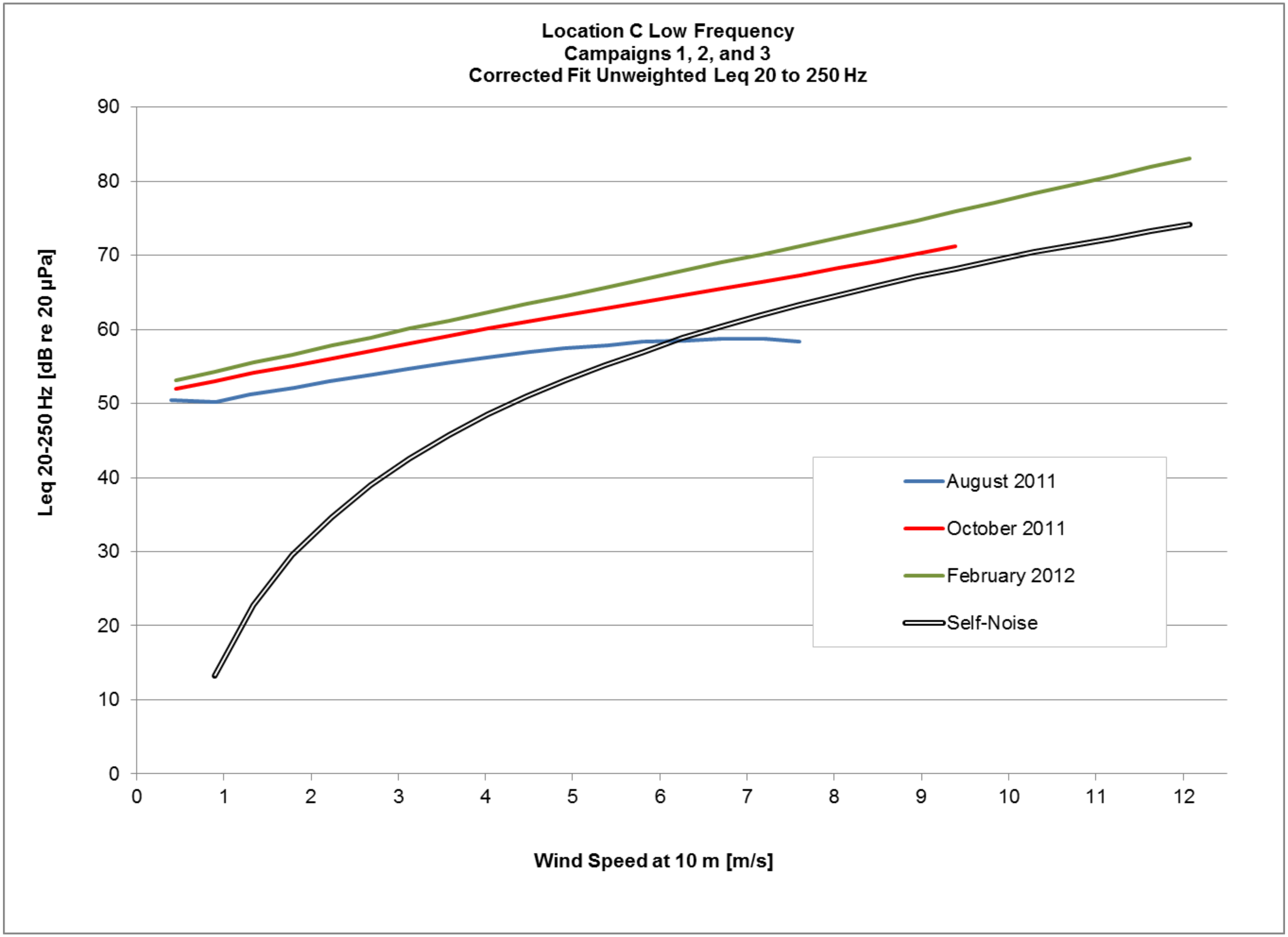

Figure C64. Location C Low Frequency Campaigns 1, 2 and 3 corrected fit unweighted Leq 20 to 250 Hz.

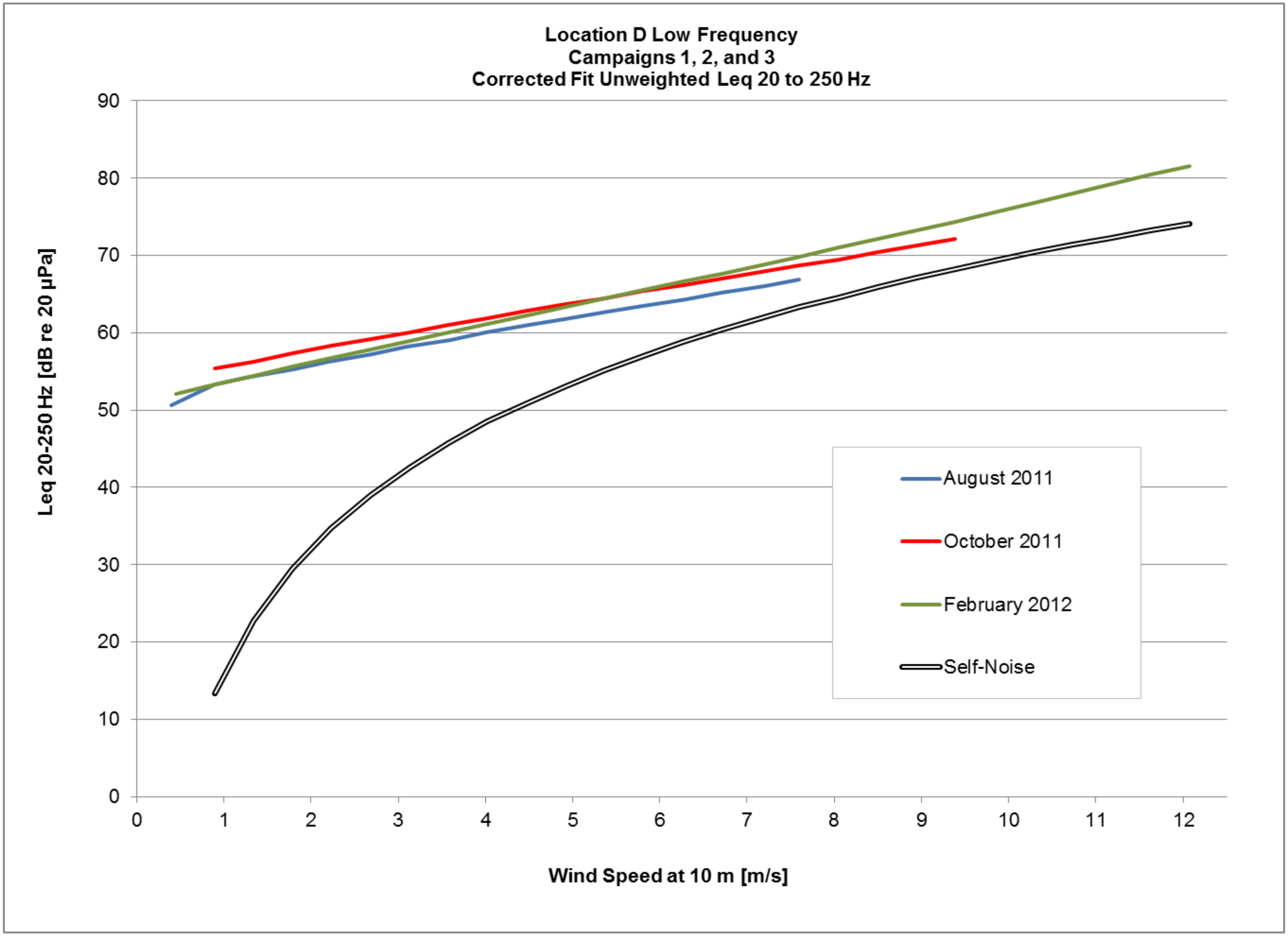

Figure C65. Location D Low Frequency Campaigns 1, 2 and 3 corrected fit unweighted Leq 20 to 250 Hz.

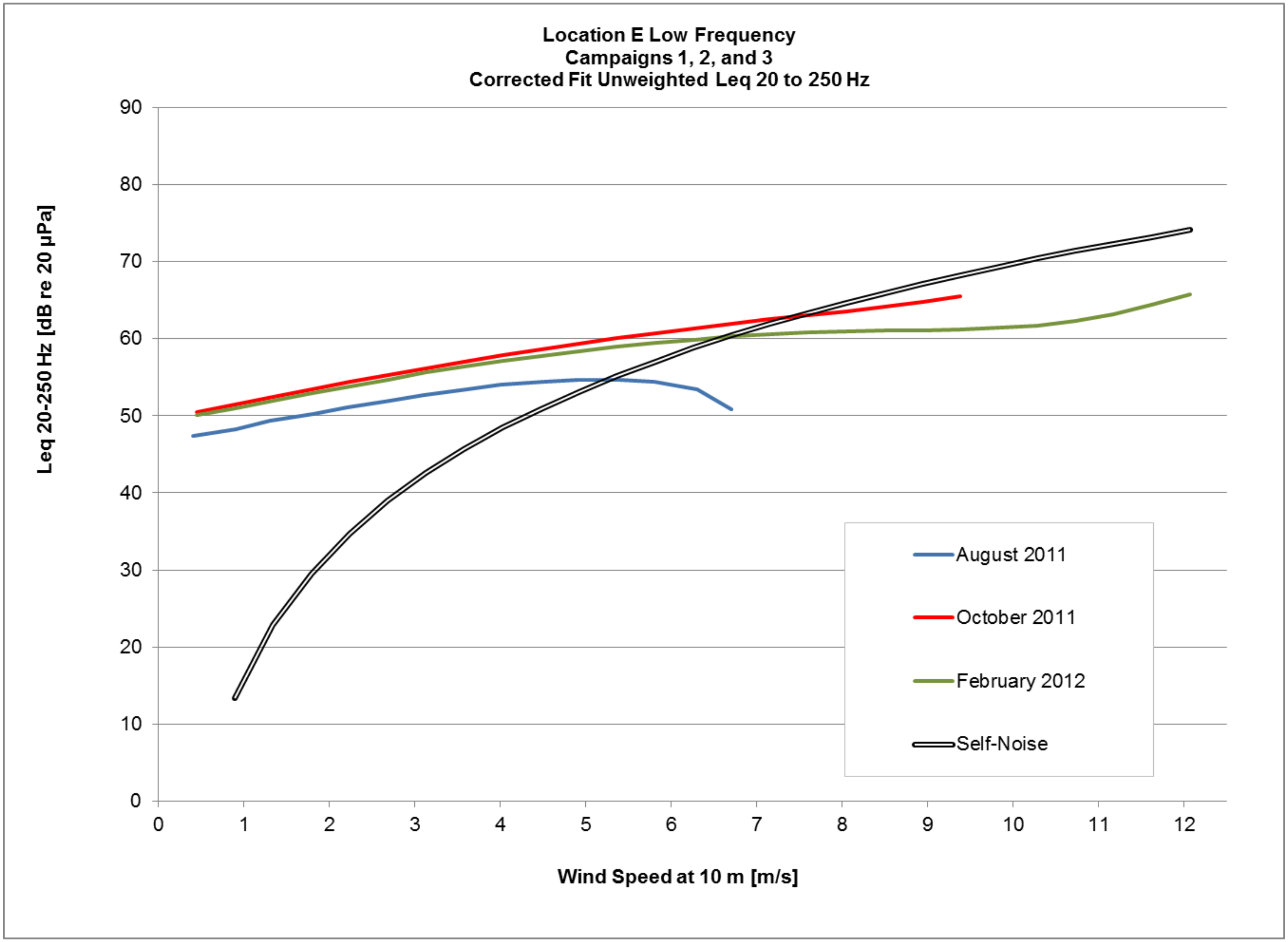

Figure C66. Location E Low Frequency Campaigns 1, 2 and 3 corrected fit unweighted Leq 20 to 250 Hz.

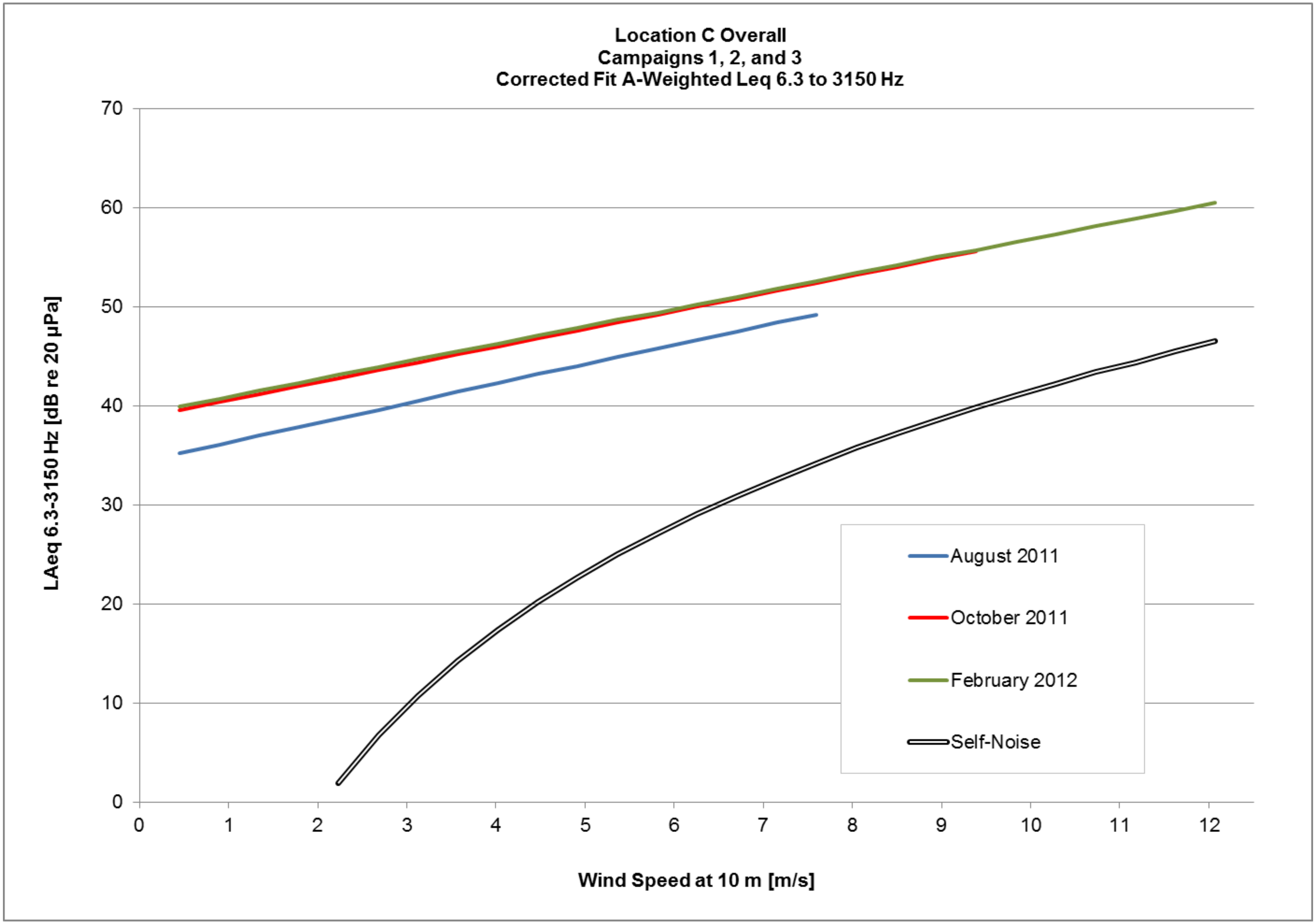

Figure C67. Location C Overall Campaigns 1, 2 and 3 corrected fit A-weighted Leq 6.3 to 3150 Hz.

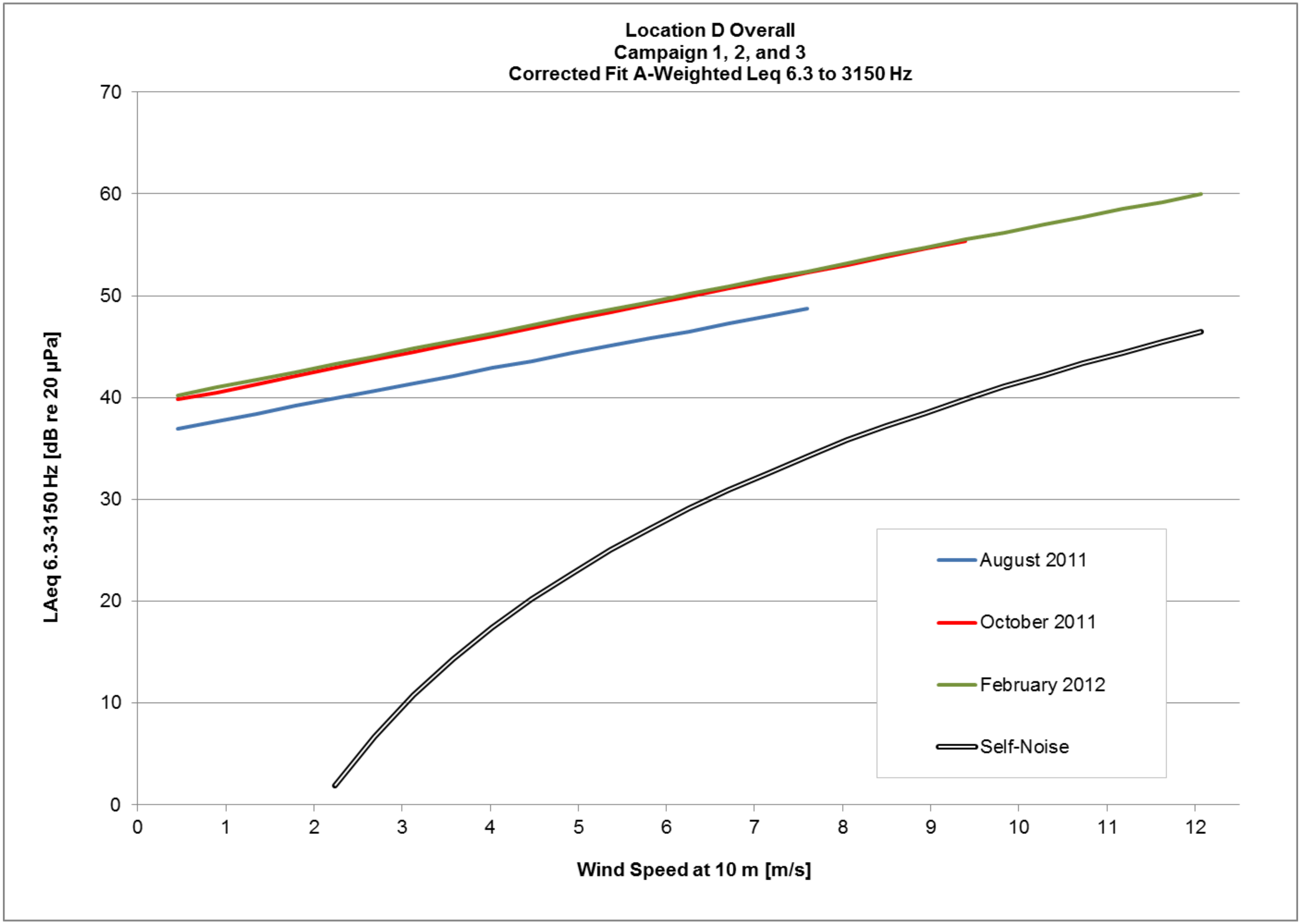

Figure C68. Location D Overall Campaigns 1, 2 and 3 corrected fit A-weighted Leq 6.3 to 3150 Hz.

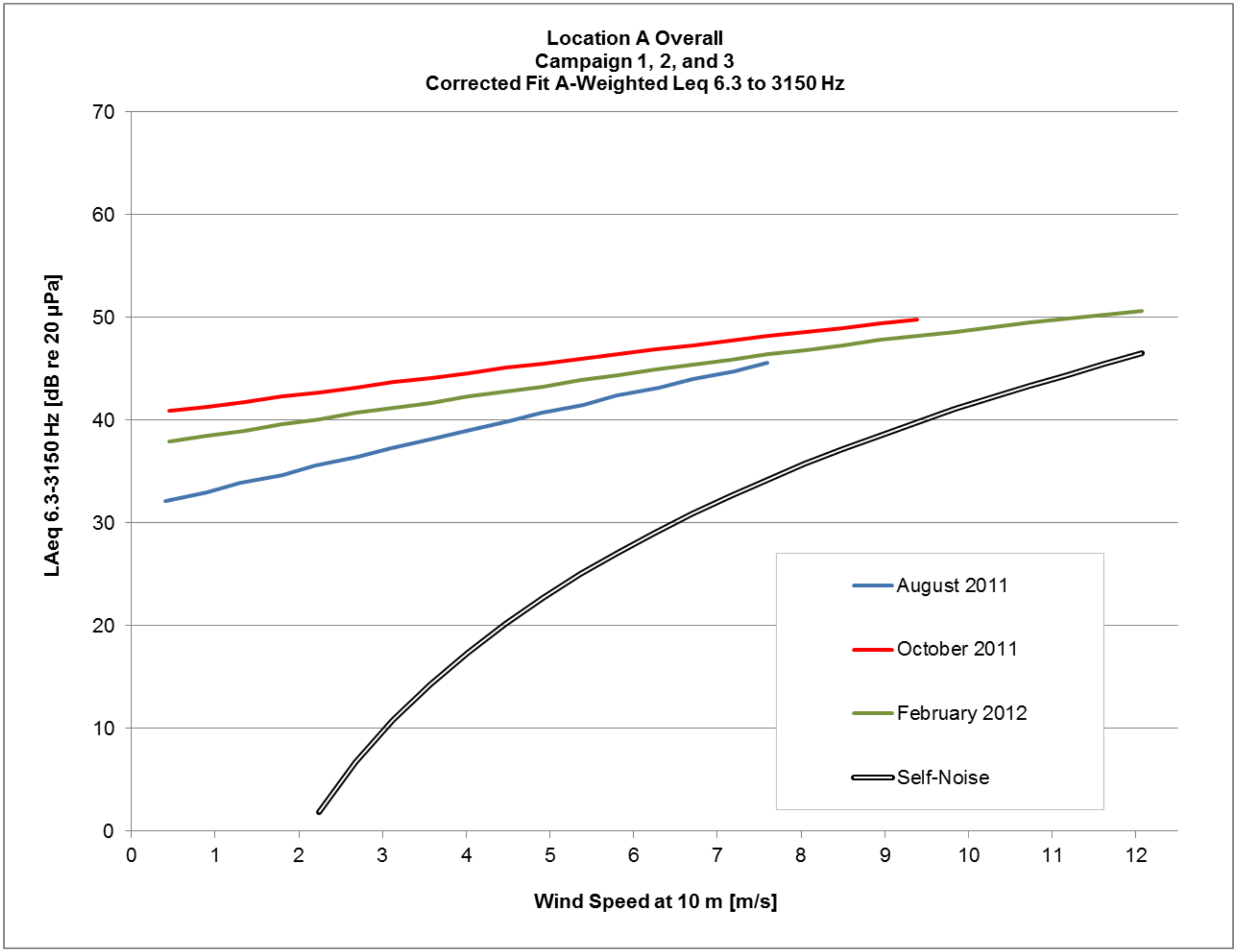

Figure C69. Location A Overall Campaigns 1, 2 and 3 corrected fit A-weighted Leq 6.3 to 3150 Hz.

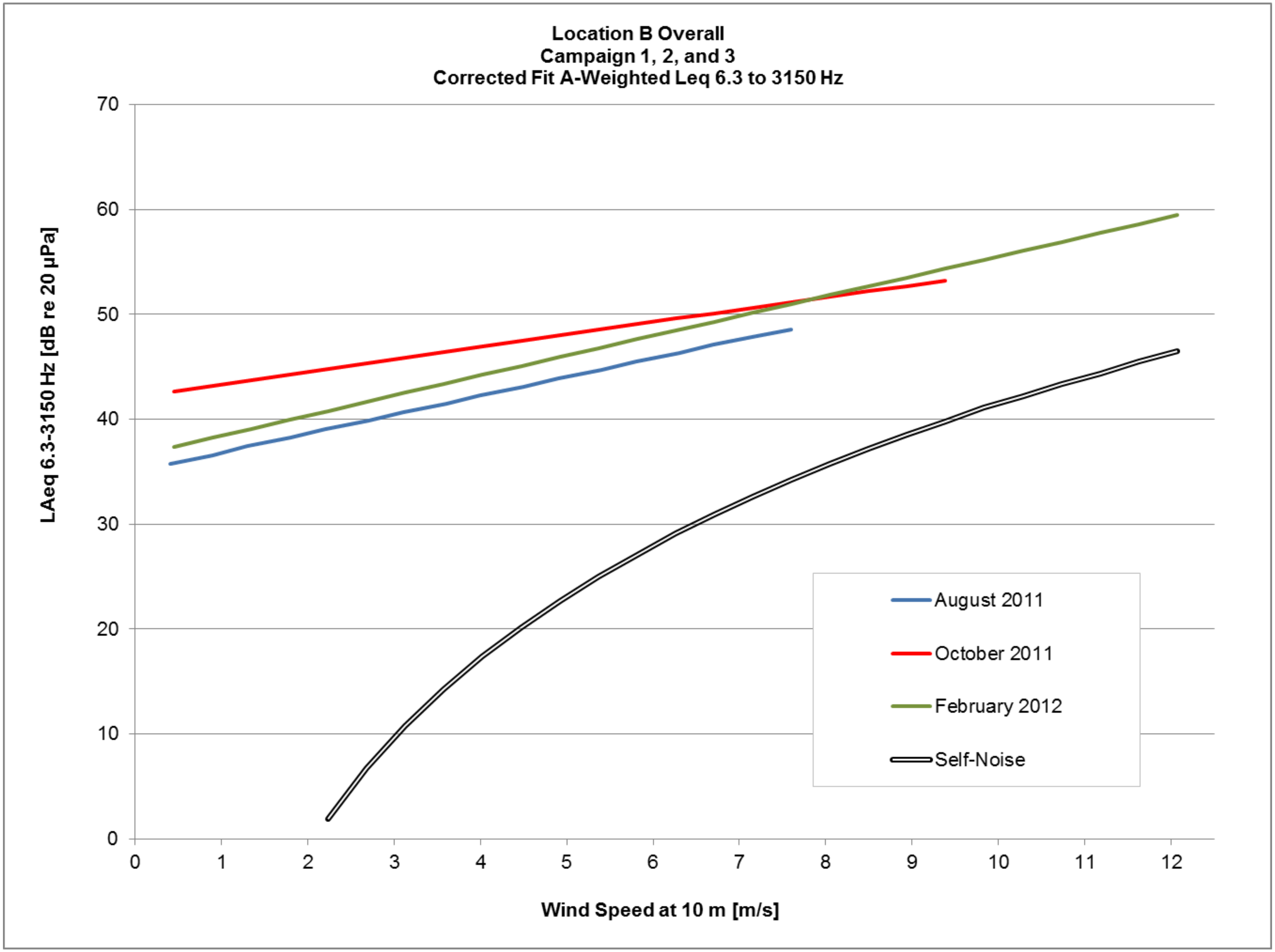

Figure C70. Location B Overall Campaigns 1, 2 and 3 corrected fit A-weighted Leq 6.3 to 3150 Hz.

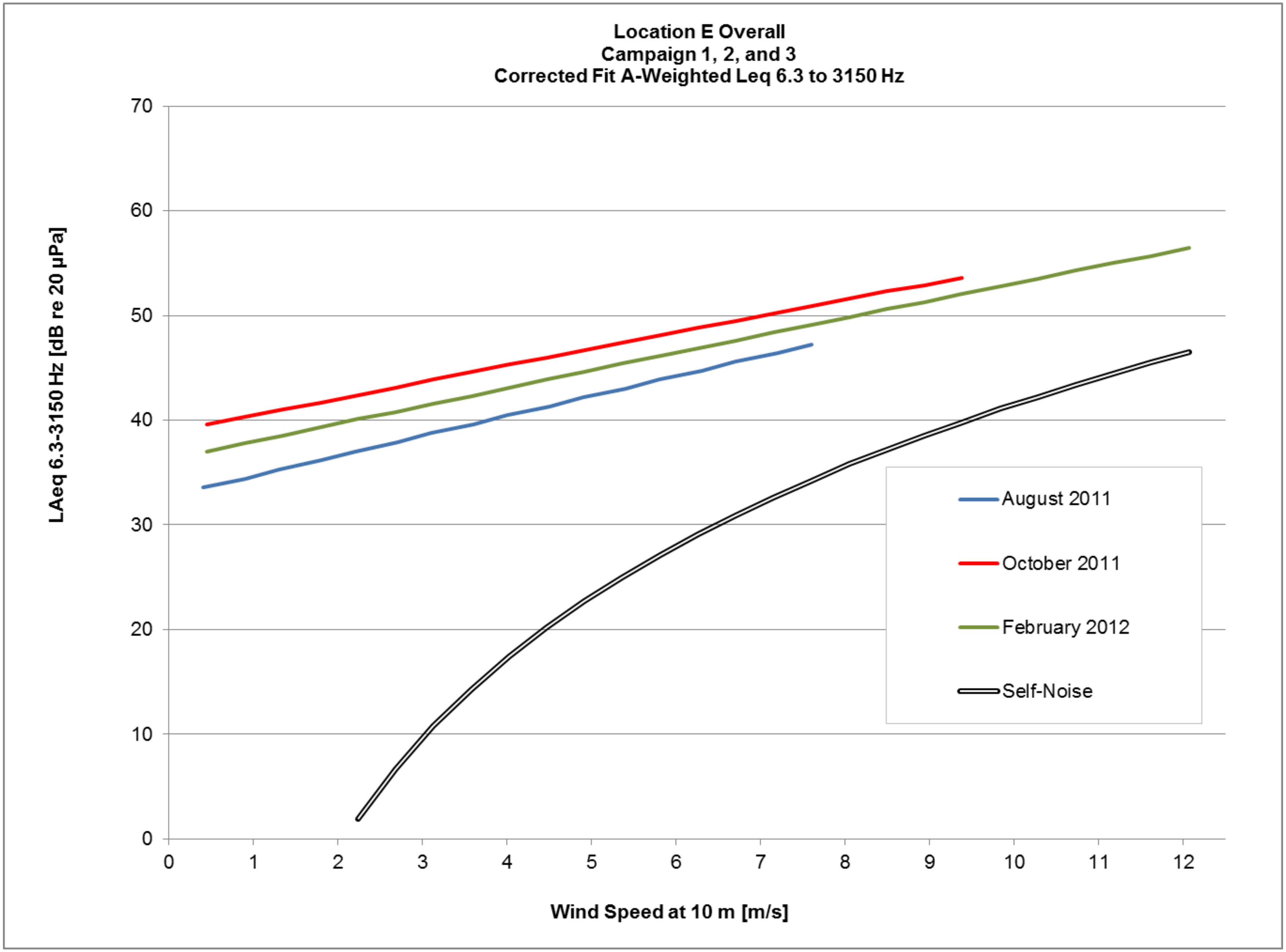

Figure C71. Location E Overall Campaigns 1, 2 and 3 corrected fit A-weighted Leq 6.3 to 3150 Hz.

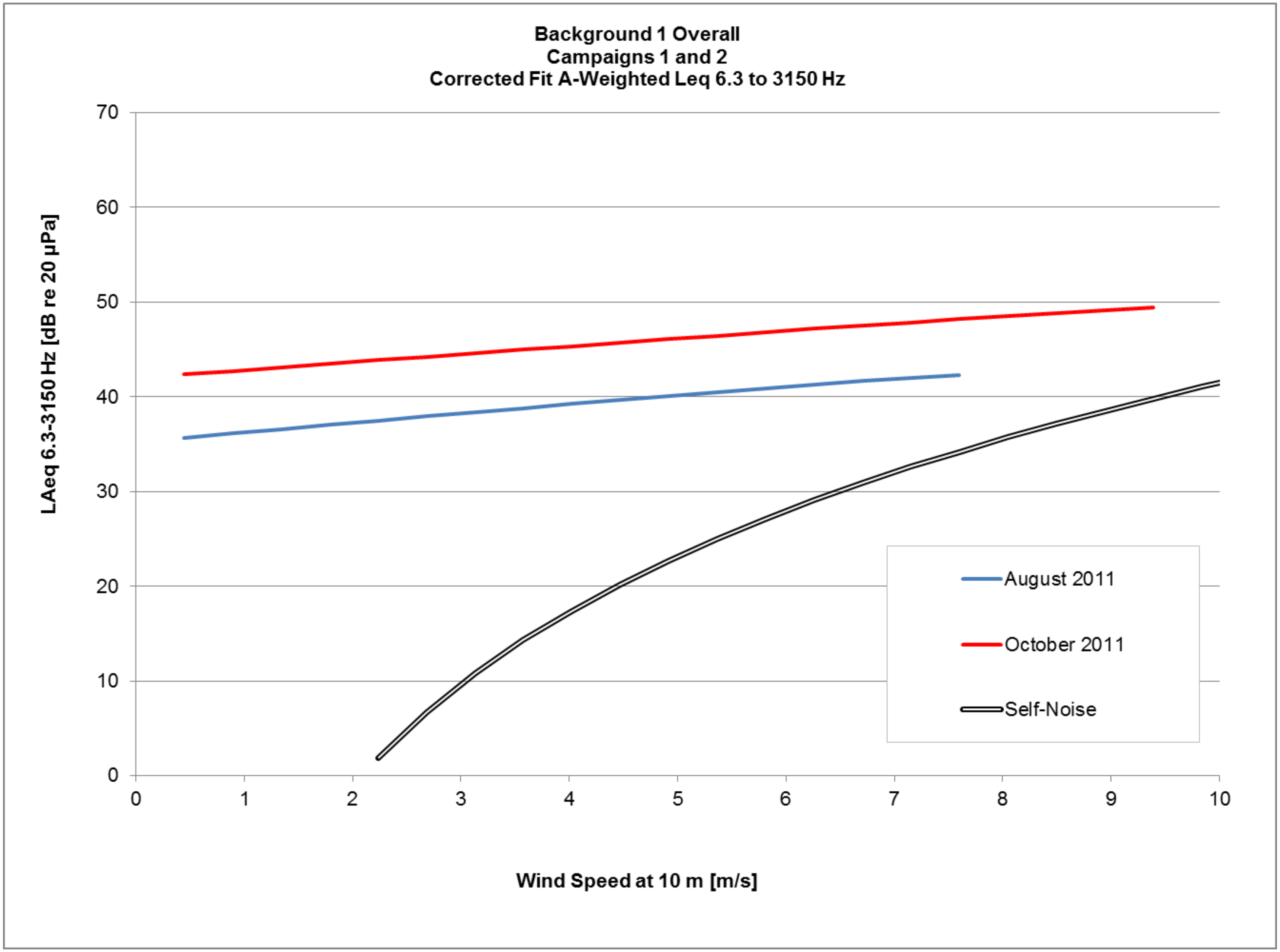

Figure C72. Background 1 Overall Campaign 1 and 2 corrected fit A-weighted Leq 6.3 to 3150 Hz.

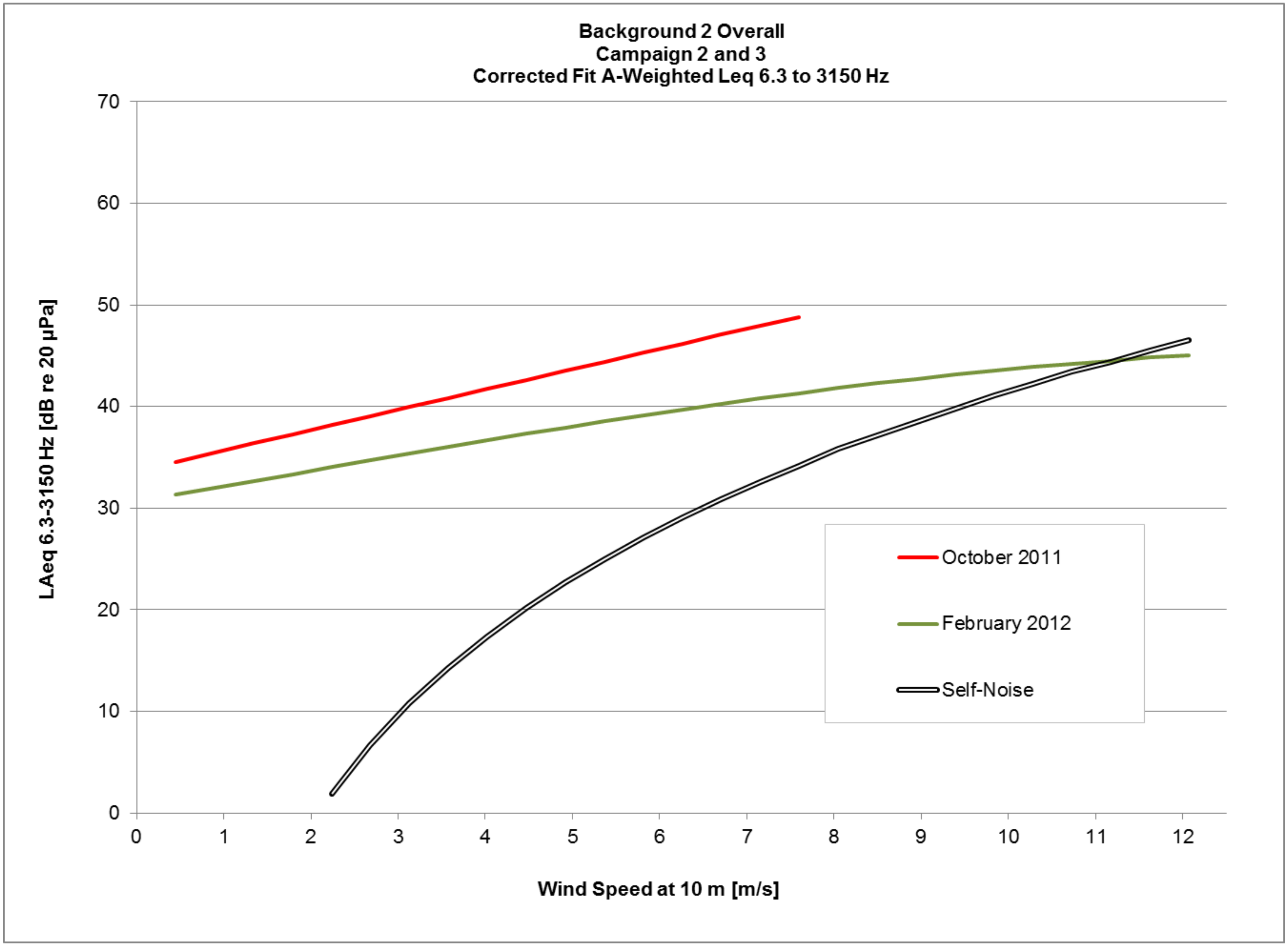

Figure C73. Background 2 Overall Campaign 2 and 3 corrected fit A-weighted Leq 6.3 to 3150 Hz.

APPENDIX D

All Campaign Sound Pressure Levels

and

Metric Wind Speeds

Table D1. All Campaign Sound Pressure Levels and Metric Wind Speeds.

			Sound Pressure Level [dB re 20 µPa]											
Wind Speed (m/s)			1	2	3	4	5	6	7	8	9	10	11	12
Campaign No.	Location	OB Spectra												
1	BG1	Infrasound	49.5	53.5	57.5	61.5	65.5	69.5	73.5	77.5				
		Low Frequency	47.8	50.0	52.3	54.5	56.7	59.0	61.2	63.5				
		Overall	36.2	37.2	38.3	39.3	40.3	41.3	42.3	43.3				
	A	Infrasound	50.7	55.9	61.1	66.3	71.5	76.7	81.9	87.1				
		Low Frequency	48.7	51.3	54.0	56.7	59.4	62.0	64.7	67.4				
		Overall	33.2	35.1	37.1	39.0	40.9	42.9	44.8	46.7				
	B	Infrasound	50.9	55.5	60.2	64.8	69.5	74.1	78.8	83.4				
		Low Frequency	49.9	52.4	54.8	57.3	59.8	62.2	64.7	67.2				
		Overall	36.8	38.6	40.5	42.3	44.1	45.9	47.7	49.5				
	C	Infrasound	52.8	56.9	61.1	65.2	69.3	73.5	77.6	81.7				
		Low Frequency	50.5	52.6	54.7	56.9	59.0	61.1	63.3	65.4				
		Overall	36.3	38.3	40.3	42.2	44.2	46.2	48.2	50.2				
	D	Infrasound	53.4	58.3	63.2	68.1	73.0	77.9	82.8	87.7				
		Low Frequency	53.5	55.8	58.0	60.3	62.6	64.8	67.1	69.4				
		Overall	37.9	39.5	41.2	42.9	44.5	46.2	47.9	49.5				
	E	Infrasound	48.6	52.6	56.6	60.5	64.5	68.5	72.4	76.4				
		Low Frequency	48.6	50.7	52.9	55.0	57.2	59.3	61.5	63.6				
		Overall	34.6	36.6	38.5	40.5	42.4	44.3	46.3	48.2				
2	BG1	Infrasound	54.2	57.6	61.0	64.4	67.8	71.2	74.6	78.0	81.4			
		Low Frequency	48.6	51.0	53.5	55.9	58.4	60.8	63.3	65.7	68.2			
		Overall	42.8	43.7	44.5	45.3	46.2	47.0	47.9	48.7	49.6			
	BG2	Infrasound	44.4	47.9	51.5	55.0	58.5	62.0	65.5	69.1	72.6			
		Low Frequency	46.7	48.2	49.6	51.0	52.4	53.9	55.3	56.7	58.1			
		Overall	35.7	37.7	39.7	41.7	43.7	45.7	47.8	49.8	51.8			
	A	Infrasound	66.0	68.2	70.4	72.7	74.9	77.1	79.3	81.5	83.8			

			Sound Pressure Level [dB re 20 µPa]											
Wind Speed (m/s)			1	2	3	4	5	6	7	8	9	10	11	12
Campaign No.	Location	OB Spectra												
		Low Frequency	52.7	54.9	57.2	59.4	61.7	63.9	66.2	68.4	70.7			
		Overall	41.5	42.5	43.5	44.6	45.6	46.7	47.7	48.7	49.8			
	B	Infrasound	65.1	67.5	69.8	72.1	74.4	76.7	79.0	81.4	83.7			
		Low Frequency	55.5	57.5	59.6	61.6	63.6	65.7	67.7	69.8	71.8			
		Overall	43.3	44.5	45.7	46.9	48.1	49.3	50.5	51.7	52.9			
	C	Infrasound	55.6	59.4	63.3	67.1	70.9	74.8	78.6	82.5	86.3			
		Low Frequency	53.3	55.6	58.0	60.3	62.7	65.0	67.4	69.7	72.1			
		Overall	40.6	42.4	44.2	46.0	47.8	49.6	51.4	53.2	55.0			
	D	Infrasound	55.1	59.4	63.7	68.0	72.3	76.6	80.9	85.2	89.5			
		Low Frequency	55.6	57.8	59.9	62.1	64.2	66.4	68.5	70.7	72.8			
		Overall	40.7	42.5	44.3	46.0	47.8	49.5	51.3	53.0	54.8			
	E	Infrasound	51.9	55.8	59.7	63.6	67.5	71.5	75.4	79.3	83.2			
		Low Frequency	51.7	53.9	56.1	58.3	60.5	62.7	64.9	67.1	69.3			
		Overall	40.5	42.1	43.6	45.2	46.8	48.4	50.0	51.6	53.2			
3	BG2	Infrasound	51.0	54.2	57.5	60.7	64.0	67.2	70.5	73.7	77.0	80.2	83.5	86.7
		Low Frequency	46.2	47.9	49.6	51.3	53.0	54.8	56.5	58.2	59.9	61.6	63.3	65.0
		Overall	32.2	33.7	35.2	36.7	38.2	39.7	41.2	42.7	44.2	45.7	47.2	48.7
	A	Infrasound	59.1	62.1	65.2	68.2	71.2	74.2	77.3	80.3	83.3	86.4	89.4	92.4
		Low Frequency	55.0	56.6	58.3	60.0	61.6	63.3	65.0	66.7	68.3	70.0	71.7	73.3
		Overall	38.6	39.8	41.0	42.3	43.5	44.7	45.9	47.1	48.3	49.5	50.8	52.0
	B	Infrasound	55.5	59.3	63.0	66.7	70.4	74.2	77.9	81.6	85.4	89.1	92.8	96.5
		Low Frequency	50.6	53.3	56.1	58.8	61.5	64.3	67.0	69.8	72.5	75.3	78.0	80.8
		Overall	38.4	40.4	42.3	44.2	46.1	48.0	49.9	51.9	53.8	55.7	57.6	59.5
	C	Infrasound	59.7	63.2	66.6	70.1	73.5	77.0	80.4	83.9	87.3	90.8	94.2	97.7
		Low Frequency	54.6	57.2	59.8	62.4	65.1	67.7	70.3	72.9	75.6	78.2	80.8	83.4

			Sound Pressure Level [dB re 20 µPa]											
Wind Speed (m/s)			1	2	3	4	5	6	7	8	9	10	11	12
Campaign No.	Location	OB Spectra												
		Overall	40.9	42.7	44.4	46.2	48.0	49.8	51.6	53.4	55.2	57.0	58.7	60.5
	D	Infrasound	56.8	60.5	64.3	68.1	71.9	75.6	79.4	83.2	86.9	90.7	94.5	98.3
		Low Frequency	53.5	56.1	58.7	61.3	63.9	66.5	69.2	71.8	74.4	77.0	79.6	82.2
		Overall	41.2	42.9	44.6	46.3	48.0	49.8	51.5	53.2	54.9	56.6	58.4	60.1
	E	Infrasound	54.6	58.0	61.3	64.7	68.1	71.4	74.8	78.1	81.5	84.8	88.2	91.5
		Low Frequency	51.3	53.4	55.5	57.6	59.7	61.9	64.0	66.1	68.2	70.3	72.4	74.6
		Overall	37.9	39.7	41.4	43.1	44.8	46.5	48.2	49.9	51.6	53.4	55.1	56.8

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Wind Turbine-Related Noise in Western New York

Final Report
January 2013

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