FINAL REPORT

On Project 25-34
Supplemental Guidance on the Application of FHWA's Traffic Noise Model (TNM)

APPENDIX J
Wind and Temperature Gradients

Prepared for:

National Cooperative Highway Research Program (NCHRP)

Transportation Research Board
of
The National Academies

March 2014
HMMH Report No. 304780

Prepared by:

Research Topic Lead

HARRIS MILLER MILLER & HANSON INC.

in association with

Bowlby & Associates, Inc.
Environmental Acoustics
Grant S. Anderson
Douglas E. Barrett

Contents

(This page intentionally left blank)

Appendix J Wind and Temperature Gradients

J.1 Introduction

This appendix provides supplemental information on the analysis and findings for the wind and temperature gradients research topic. Section 2 summarizes the literature and data review. Section 3 includes information on the modeling efforts that were conducted. Section 4 includes figures of the results for the sound level differences between varying wind and temperature conditions relative to calm conditions, as well as hourly sound levels (L_{eq}) based on the modeling assumptions. Finally, Section 5 discusses the combined effects of wind and temperature gradients on highway noise sources.

J.2 Literature Review

This section provides a summary of the information compiled through the data survey and review of relevant literature. Although several other practitioners responded to the data request, follow-up telephone conversations indicated that their materials either were not available or would not be of use to this research project. Many respondents to the initial data survey simply excluded measurements from analysis if significant wind or temperature effects were present and did not ever model wind effects in any manner.

J.2.1 Caltrans: Route 99 Barrier Study and I-80 Davis OGAC Pavement Noise Study

Caltrans provided copies of two reports[1,2] which examine traffic noise levels near Sacramento, CA. Both the Route 99 Barrier Study and the I-80 Davis OGAC Pavement Noise Study provide multiple measurements over a range of wind conditions and distances.

The Route 99 Barrier Study involved the collection of noise levels for a roadway without barriers, after a near-side barrier was constructed, and after a far-side barrier was constructed. Microphones were placed at multiple heights and distances as shown in Figure 1. As shown in Figure 2, curves for the effect of the wind on noise levels were computed as a function of distance for various wind speeds. Curves of this type were computed for microphones of various heights and distances as well as prior to and after construction of the barriers. The graph shows that the performance of the barrier was degraded as the component of the wind in the direction from the roadway to the receiver increased and that this degradation increased with distance from the barrier.

Part C of this Caltrans report, also known as TAN-03-01, describes a method of adjusting field noise measurements to a zero wind condition. This method would be useful in reducing labor in very large measurement programs with many receptors in close proximity to one another. In brief, the method involves empirically determining the adjustments in sound level under a range of wind conditions for a small number of sites using long term measurements. This adjustment function can then be applied to short term measurements at nearby sites which share similar source to receiver geometry.

---

[1] Hendriks, R., *Additional Calibration of Traffic Noise Prediction Models - Technical Advisory, Noise TAN-03-01*, California Department of Transportation Division of Environmental Analysis Hazardous Waste, Noise & Vibrations Office, August 2003.

[2] Illingworth & Rodkin, Inc., *I-80 Davis OGAC Pavement Noise Study 12 Year Summary Report*, prepared for the California Department of Transportation Division of Environmental Analysis, 13 May 2011.

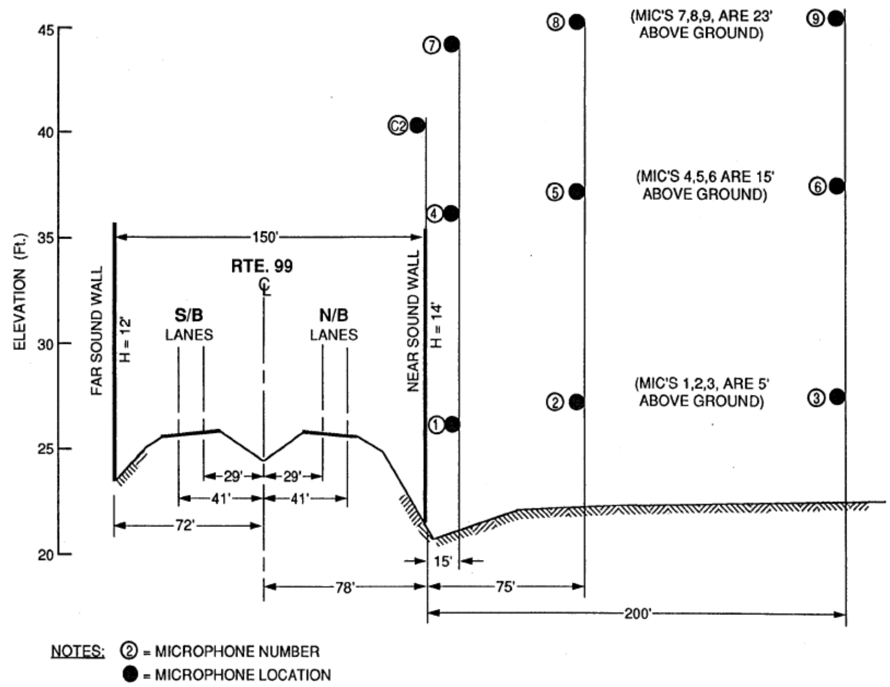

Figure 1 Microphone placement for Route 99 Barrier Study

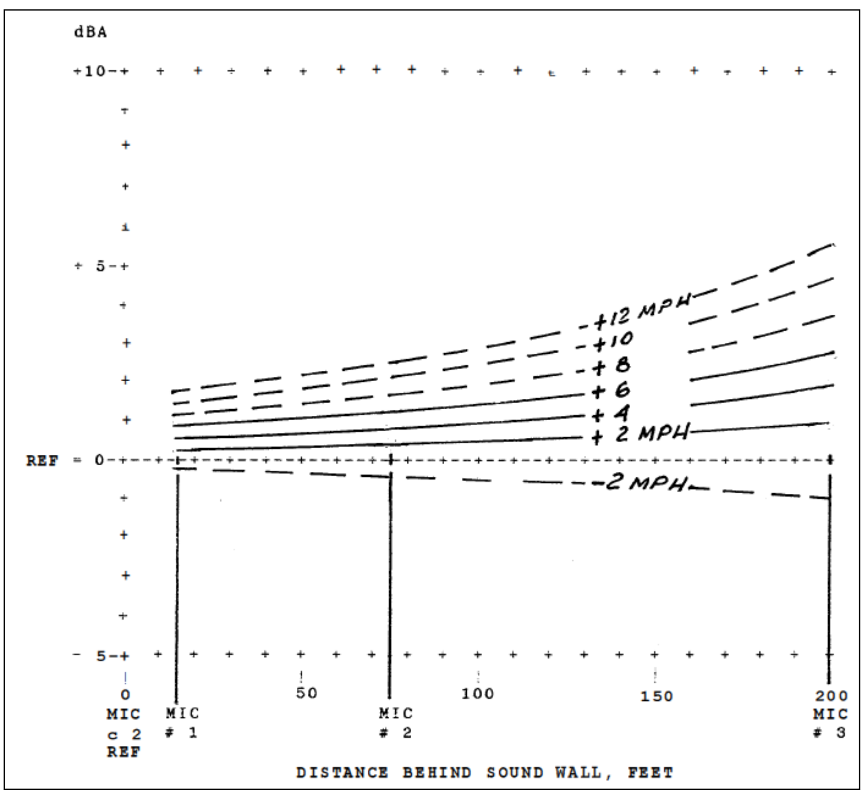

Figure 2 Effect of Wind on Noise Levels at Low Microphones Before Barrier Construction

The I-80 Davis OGAC Pavement Noise Study examined noise levels over a 12-year period to track changes in noise levels due to the replacement of dense graded asphalt concrete with open-graded asphalt concrete and the subsequent wear of the OGAC. The area is quite open and flat and regularly subject to wind. Measurements were made near the roadway and at two heights distant from the roadway. The use of a closely positioned reference microphone helped to isolate the effects of wind as shown in Figure 3. For reference, the offset between the two positions as predicted by TNM is shown by the large gray dot.

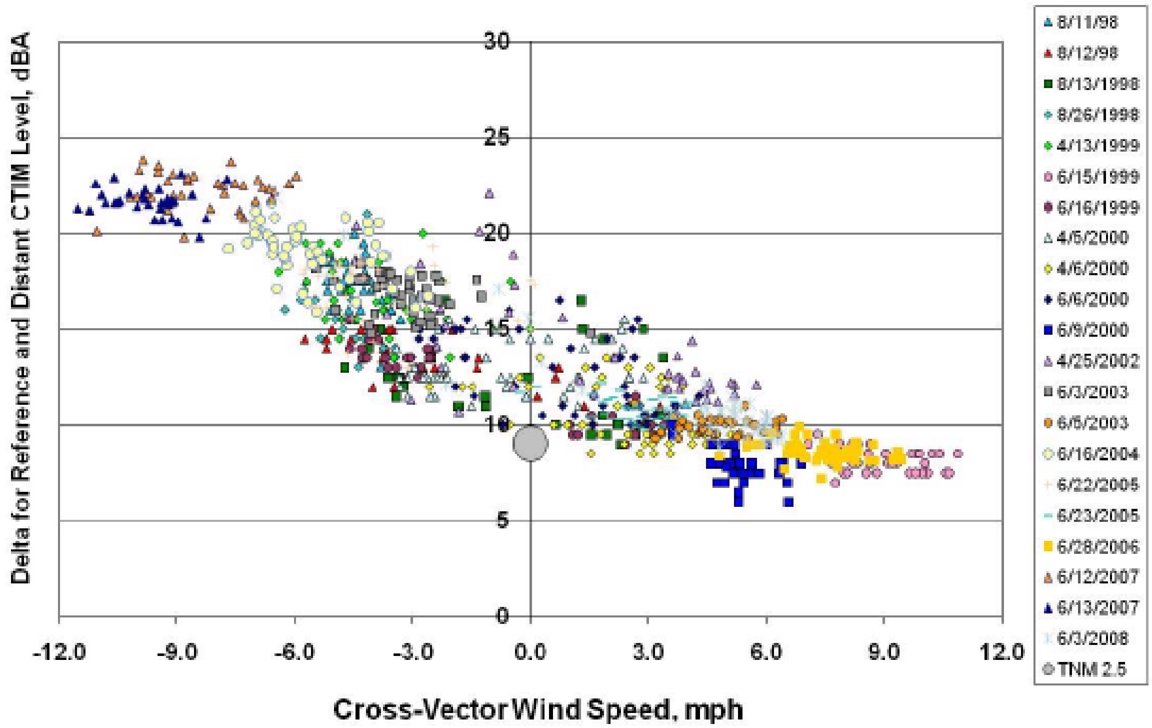

Figure 3 Offset Between Reference and Distance Position as a Function of Wind Speed

The I-80 Study also identifies a temperature gradient associated with typical weak lapse conditions. The report states, "Summer and spring periods typically had a normal low-level temperature lapse of about -0.056°F/ft (-0.1°C/m) present." This temperature gradient was used to model the effects of weak lapse conditions on highway noise sources.

J.2.2 Atmospheric Effects Associated with Highway Noise Propagation

A report prepared by Saurenman, et. al. for the Arizona DOT examines the unique atmospheric effects in the Phoenix Valley.[3] The study collected detailed wind and temperature profile data and noise levels at four sites over three weeks in March and October of 2004. Calculations in the study are focused on the consistent diurnal variations in temperature profiles and wind speeds. The environment for the study was characterized by temperature inversions and "nighttime down-slope drainage flows off the mountain ranges" with "low speed jets at elevations of 15 to 100m" which "cause localized focusing and de-focusing of sound levels." Noise modeling was conducted using a Parabolic Equation model. Given the unique weather and modeling techniques, the conclusions of this study added to the base of knowledge

[3] Saurenman, H., Chambers, J., Sutherland, L.C., Bronsdon, R.L., Forschner, H., *Atmospheric Effects Associated with Highway Noise Prediction – Final Report 555*, FHWA-AZ-05-555, prepared for the Arizona Department of Transportation, October 2005.

showing the range of expected atmospheric effects on noise propagation, though the particular conclusions of the study may not be considered widely applicable to other locations.

Figure 4 shows hourly near-ground temperature profiles for one day of the study. Note the inversion conditions in the early morning and again starting in the evening. The data collected by Saurenman, et.al. suggest that the temperature gradient associated with a strong lapse is approximately -0.3°C/m, while the temperature gradient associated with a strong inversion is approximately +0.5°C/m. These rates of change in temperature with height above ground were used in the modeling of traffic noise for the present study.

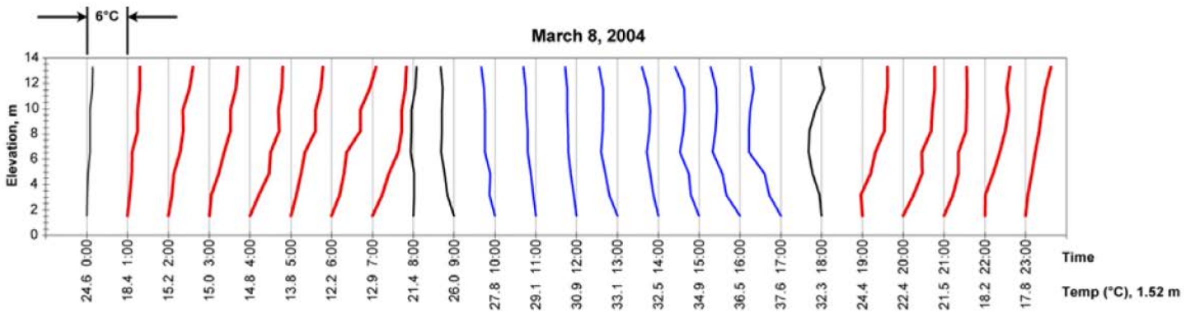

Figure 4 Example Temperature Profile Graph

J.2.3   Validation of FHWA's Traffic Noise Model (TNM): Phase1

The TNM Validation Study[4,5] was commissioned in support of the Federal Highway Administration and Caltrans to assess the accuracy of the TNM and make recommendations on its use. In this study measurements were made at a range of distances, with propagation over grass, pavement, dirt, and water. Measurements were made at sites with and without barriers and under varying wind conditions. Close-in microphones provide a valuable reference and the measurements are accompanied by TNM 2.5 modeling results. Table 1 below shows the variety of sites used in the validation report.

[4] Rochat, J.L. and G.G. Fleming, *Validation of FHWA's Traffic Noise Model® (TNM): Phase 1*, Reports DOT-VNTSC-FHWA-02-01 and FHWA-EP-02-031, Acoustics Facility, John A. Volpe National Transportation Systems Center, Cambridge MA, August 2002.
[5] Rochat, J.L. and G.G. Fleming, *TNM Version 2.5 Addendum to Validation of FHWA's Traffic Noise Model® (TNM): Phase 1*, Reports DOT-VNTSC-FHWA-02-01 Addendum and FHWA-EP-02-031 Addendum, Acoustics Facility, John A. Volpe National Transportation Systems Center, Cambridge MA, July 2004.

Table 1 TNM Validation Report Measurement Sites

Site ID*	Location	Site Type								Microphone Distances (ft) d=dist from roadway bb=dist behind barrier
		open area	noise barrier	soft ground	hard ground	mixed ground	flat	with drop-off	undulating	
01MA	Rte 24 Taunton, MA	✓		✓			✓			d = 50, 100, 200
02MA	Rte 2 Acton, MA	✓		✓					✓	d = 50, 200, 400, 600
03MA	Rte 291 Springfield, MA	✓		✓			✓			d = 50, 200, 400, 800
04CT	Rte 84 East Hartford, CT		✓			✓	✓			bb = 56, 125, 200
05CA	Rte 71 Chino Hills, CA		✓	✓			✓			bb = 50, 100, 150
06CA	Rte 15 Wildomar, CA		✓	✓			✓	✓		bb = 55, 100, 200
08CA	Rte 91 Anaheim, CA		✓	✓			✓			bb = 50, 200, 300
09CA	Rte 71 Chino, CA		✓	✓			✓	✓		bb = 55, 100, 200
10CA-berm	Rte 15 Mira Loma, CA		✓	✓			✓			bb = 70, 110
10CA-open	Rte 15 Mira Loma, CA	✓		✓			✓			d = 98, 118, 158
11CA	Rte 237 Sunnyvale, CA		✓			✓	✓			bb = 50, 100, 300
12CA	Rte 680 San Ramon, CA		✓	✓			✓			bb = 50, 100, 200
13CA	Rte 37 Sonoma, CA	✓			✓		✓			d = 50, 900
14CA	Rte 880 Fremont, CA		✓	✓			✓			bb = 50, 100, 150
15CA	Rte 880 Oakland, CA	✓			✓		✓			d = 40, 100, 200, 400
16MA	Rte 90 Wayland, MA	✓			✓		✓			d = 78, 100, 150, 200
17CT	Rte 84 Stafford, CT	✓			✓		✓			d = 60, 1273
totals		8	9	11	4	2	16	2	1	

J.2.4 Nord2000 Reports

Among the advantages that the Nord2000 model enjoys over other noise models is the ample documentation. The Danish acoustical firm Delta has produced many reports over the years on the Nord2000 model. For simplicity, we reference the latest and most complete report here[6]. This report describes the equations of the model in detail. The model includes adjustments typically found in noise models such as spreading, barrier effects, atmospheric absorption, scattering, reflections, and ground effect as well as atmospheric effects.

[6] Delta, *Proposal for Nordtest Method: Nord2000 – Prediction of Outdoor Sound Propagation*, January 2010.

A March 2006 report[7] for the Danish Road Directorate provides extensive comparisons of Nord2000 results to measurements and reference models over a range of distances and conditions, with and without barriers. Figure 5 shows a validation figure from this report for sound passing at near-grazing over a small berm with a 4 m/s wind speed. A report by VTT Technical Research Centre of Finland[8] provides valuable details about selecting appropriate atmospheric profiles for Nord2000 in order to compute long term averages.

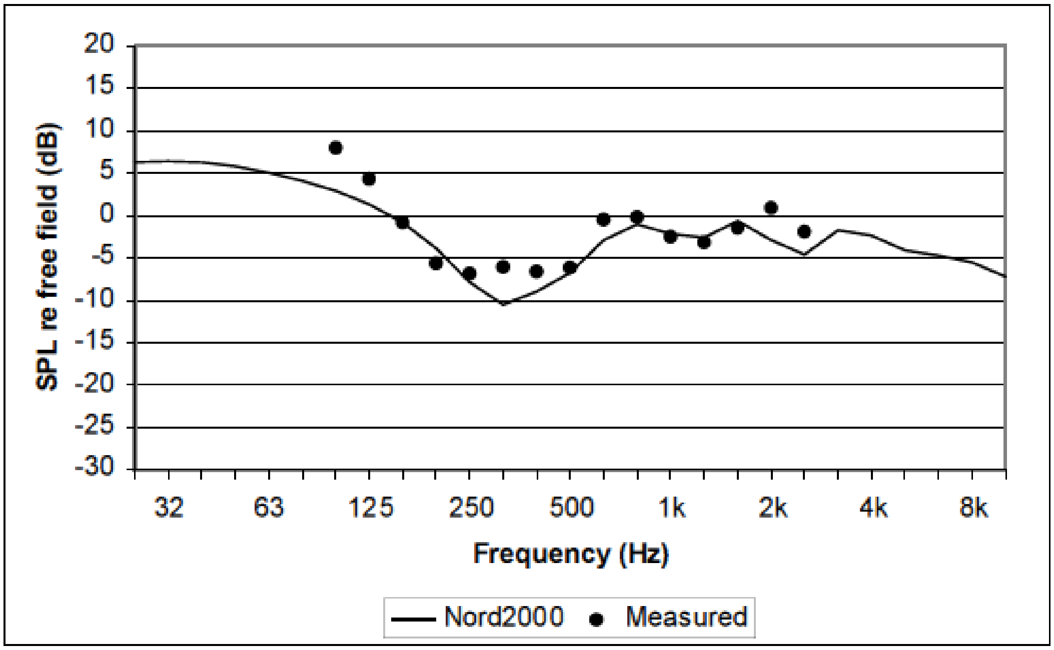

Figure 5 Example Nord2000 Validation Figure

J.2.5 Springer Handbook of Acoustics

The Springer Handbook of Acoustics[9] is an extremely comprehensive resource covering many topics in the field of acoustics. Section 4.8, titled "Wind and Temperature Gradient Effects on Outdoor Sound", provided valuable information to this research topic. Of particular note were Tables 4.5 and 4.6. Table 4.6 categorizes meteorological classes based on qualitative descriptors. The categories of "Strong wind" and "Moderate wind" were used in the modeling for the present study to evaluate the effect of wind direction and speed on highway noise sources.

Table 4.5 provides information on the "Estimated probability of occurrence of various combinations of wind and temperature gradient." While it is possible that some moderate wind and temperature conditions may occur simultaneously, "very large temperature and wind speed gradients cannot coexist." "Strong turbulence associated with high wind speeds does not allow the development of marked thermal stratification." Some limited combinations of moderate wind speeds and temperature gradients have been modeled for informational purposes, and are included in Section 5 of this appendix.

[7] Delta, *Nord2000. Validation of the Propagation Model*, report to the Danish Road Directorate, March 2006.
[8] Eurasto, R., *Nord2000 for Road Traffic Noise Prediction – Weather Classes and Statistics*, VTT Technical Research Centre of Finland, 2006.
[9] Rossing, T., *Springer Handbook of Acoustics*, Springer Science+Business Media, LLC, New York, New York, 2007.

J.2.6 Sound Intensity Attributed To Temperature Inversion At Night

The Noise-Con paper by S. P. Ying titled *Sound Intensity Attributed To Temperature Inversions At Night*[10] provides useful discussion of the inversion condition resulting from positive temperature gradients in the atmosphere. The paper states that the temperature gradient is not constant with changing altitude, or with the time of day or seasons of the year. Further, the paper states that for temperature inversion conditions, "The published data indicated that the temperature gradient varies from 0.03°F/ft to 0.3°F/ft in the atmosphere 1 ft above the ground or higher." Those gradients are approximately equivalent to +0.1°C/m to +0.5°C/m. These rates of change of temperature with elevation were used in the modeling for the present study to evaluate the effect of inversion conditions on highway noise sources.

J.2.7 A Study of Air-To-Ground Sound Propagation Using An Instrumented Meteorological Tower

The NASA report titled *A Study of Air-To-Ground Sound Propagation Using An Instrumented Meteorological Tower*[11] is a noise study designed to understand the effects of the atmosphere on sound propagation. For the study, a known sound source was fixed to the top of a meteorological tower radiating toward the ground with microphones supported by a tower guy wire. While the results of the study were variable due to many factors, the measured weather conditions at various heights along the tower provide valuable information on typical temperature gradients in the atmosphere.

The measured temperature gradients varied largely with height above the ground, but the conditions measured near the ground (between 2 meters and 31 meters above the ground) provide useful information. The data were measured at various times of day over a period of 10 days, and indicate that the temperature gradient typically varied between approximately -0.1°C/m and +0.1°C/m.

J.3 Modeling Parameters

A SoundPLAN model of a typical highway was made to document the effect of different meteorological conditions at various receiver distances and heights. The model assumed flat ground with a four lane (two lanes traveling in each direction) highway with a typical mix of autos and trucks. A string of receivers was placed at heights of 5 feet and 15 feet, at the following distances from the roadway: 50 feet, 100 feet, 200 feet, 400 feet, 800 feet, and 1600 feet. A noise barrier (height of 17 feet) was included in some runs. Multiple runs were computed by varying the presence of the noise barrier, changing the model to assume all hard or soft ground, and by varying the presence of trucks on the roadways.

Each roadway lane was approximately 12 feet wide, and the roadway included a shoulder approximately 10 feet wide. The speeds of all vehicles were modeled as 60 mph (96.6 km/hr). The traffic on each roadway lane included 1000 autos per hour. For the runs that included trucks, the same number of autos was assumed, with the addition of 20 medium trucks (2% mix) and 100 heavy trucks (10% mix). The User's Guide for Nord2000 Road[12] was used to identify the road type and vehicle categories that most closely corresponded with TNM. Autos were modeled as Category 1 vehicles, medium trucks were modeled as Category 2 vehicles, and heavy trucks were modeled as Category 3 vehicles. The modeled roadway type was "DK type B: Urban motorway."

---

[10] Ying, S., *Sound Intensity Attributed To Temperature Inversion At Night*, Noise-Con 87, The Pennsylvania State University, State College, Pennsylvania, June 8-10, 1987.

[11] Kasper, P., Pappa, S., Keefe, L., Sutherland, L., Wyle laboratories, *A Study Of Air-T-Ground Sound Propagation Using An Instrumented Meteorological Tower*, National Aeronautics and Space Administration, NASA CR-2617, October 1975.

[12] Delta, *User's Guide Nord2000 Road*, report developed for NordFoU, May 2006.

Runs were completed using both hard and soft ground. Soft ground conditions were modeled with an effective flow resistivity of 300 kN*sec/m^{-4} (equivalent to cgs rayls/cm). Hard ground conditions were modeled with an effective flow resistivity of 20,000 kN*sec/m^{-4}.

Meteorological conditions using Nord2000 were modeled with the following parameters shown in Table 2. Wind directions were modeled for both upwind and downwind conditions. Moderate upwind and downwind conditions were modeled by assuming a wind speed of 2.5 m/s at a height of 10 m above the ground. Strong upwind and downwind conditions were modeled by assuming a wind speed of 5 m/s. Positive temperature gradients associated with inversion conditions were modeled by assuming +0.1°C/m and +0.5°C/m. Negative temperature gradients associated with lapse conditions were modeled by assuming -0.1°C/m and -0.3°C/m.

Table 2 Nord2000 Meteorological Parameters

Parameter	Symbol [Unit]	Value
Roughness length	z0 [m]	0.025
Wind speed	u [m/s]	Varies with modeled condition
Standard deviation of u	S(u) [m/s]	0.5
Height above terrain	zu [m]	10
Wind direction	uDir [deg]	Varies with modeled condition
Temperature gradient	dT/dz [K/m]	Varies with modeled condition
Standard deviation dT/dz	S(dT/dz) [K/m]	0
Turbulent wind speed fluctuations	Cw2 [m4/3s-2]	0.12
Turbulent temperature fluctuations	Ct2 [Ks-2]	0.008
Relative humidity	RH [%]	70
Air temperature	T [ºC]	15

J.4 Effect of Wind and Temperature Conditions on Highway Noise Source

Graphs of the modeling results are included in this section, including the sound level difference between varying wind and temperature conditions to calm conditions and hourly sound levels (L_{eq}) for varying wind and temperature conditions relative to calm conditions.

J.4.1 Sound Level Differences between Varying Wind and Calm Conditions with Autos and Trucks

The graphs below include combinations of parameters that were modeled for varying wind speeds and directions relative to calm conditions. The input model included both autos and trucks on the source roadway. Results are included for 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with and without a noise barrier.

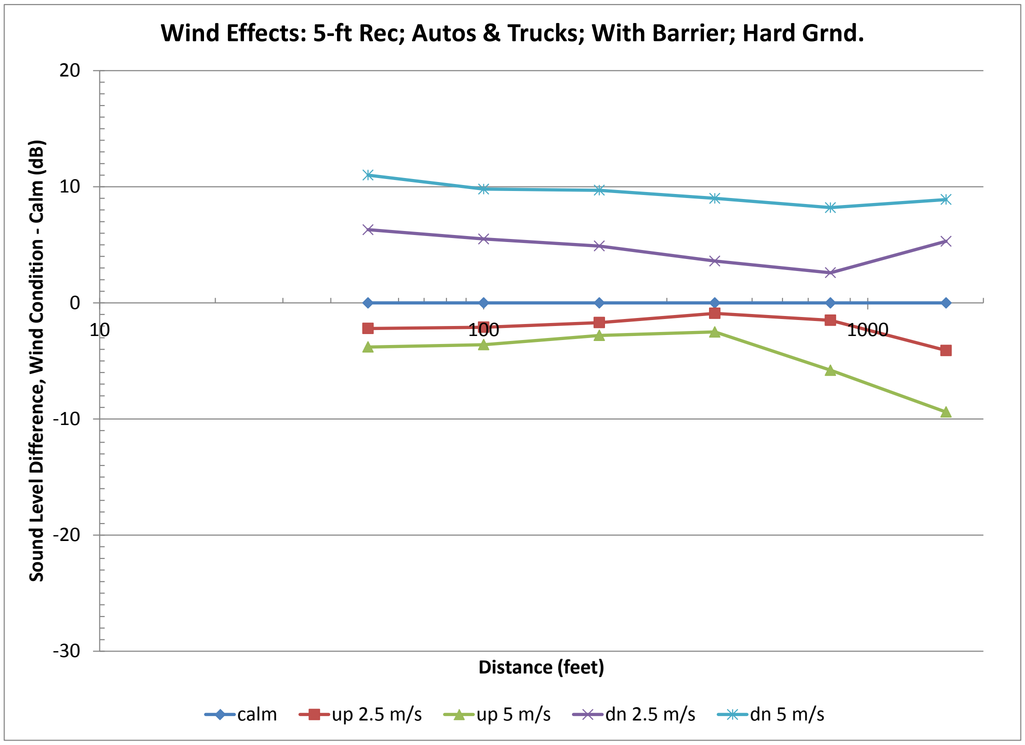

Figure 6 Sound Level Difference between Varying Wind Conditions

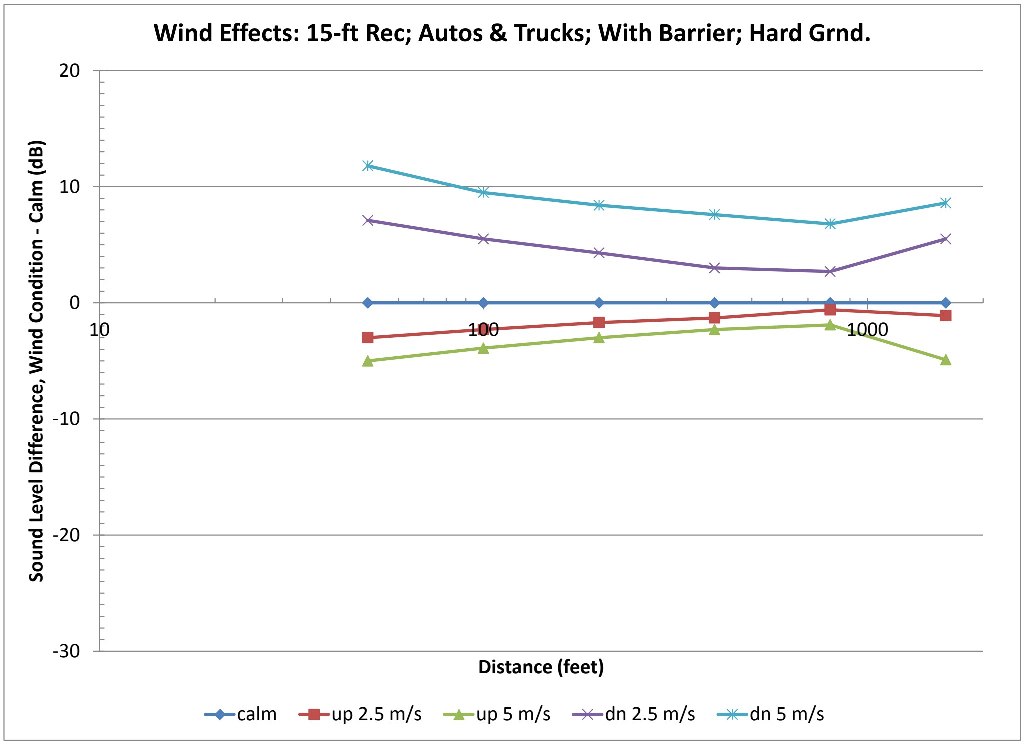

Figure 7 Sound Level Difference between Varying Wind Conditions

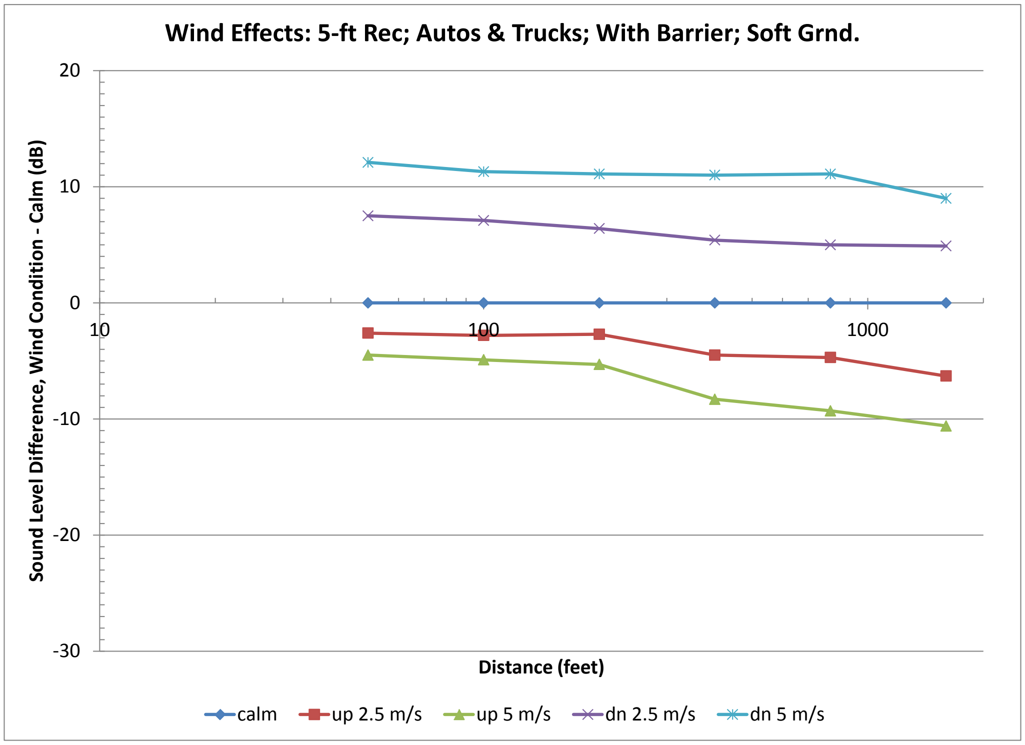

Figure 8 Sound Level Difference between Varying Wind Conditions

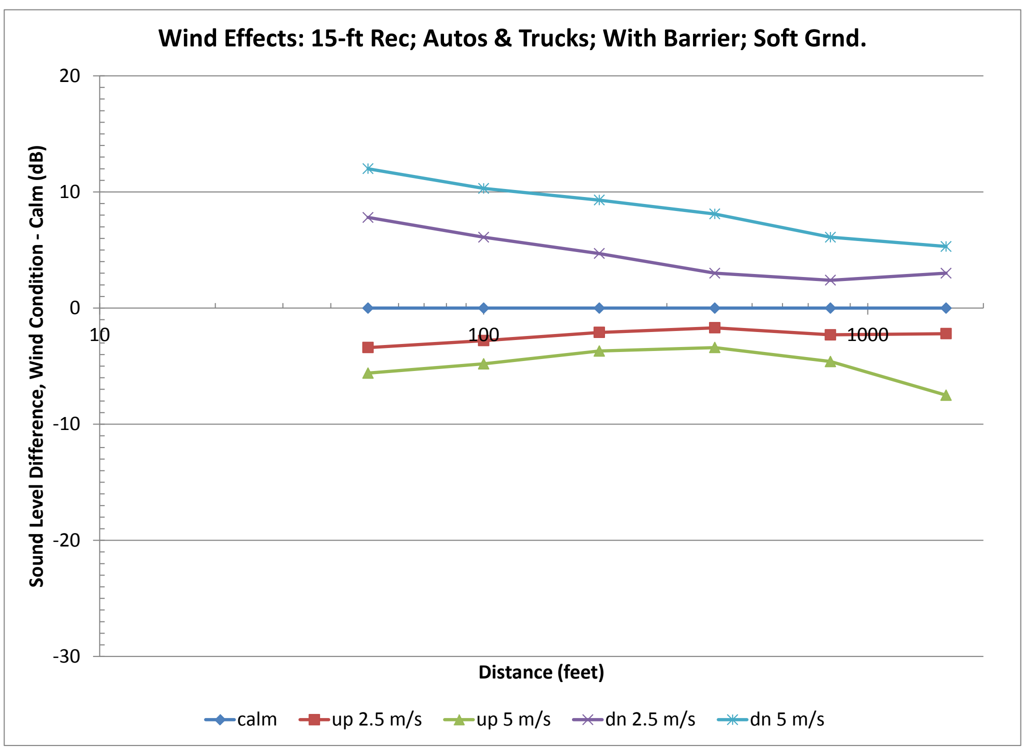

Figure 9 Sound Level Difference between Varying Wind Conditions

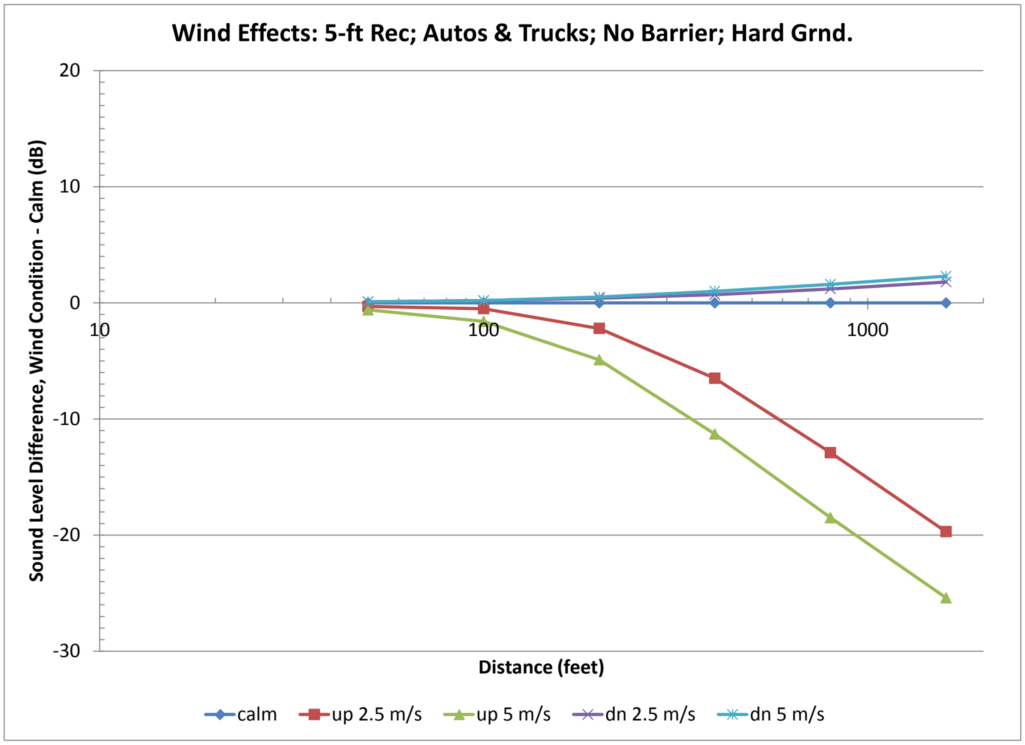

Figure 10 Sound Level Difference between Varying Wind Conditions

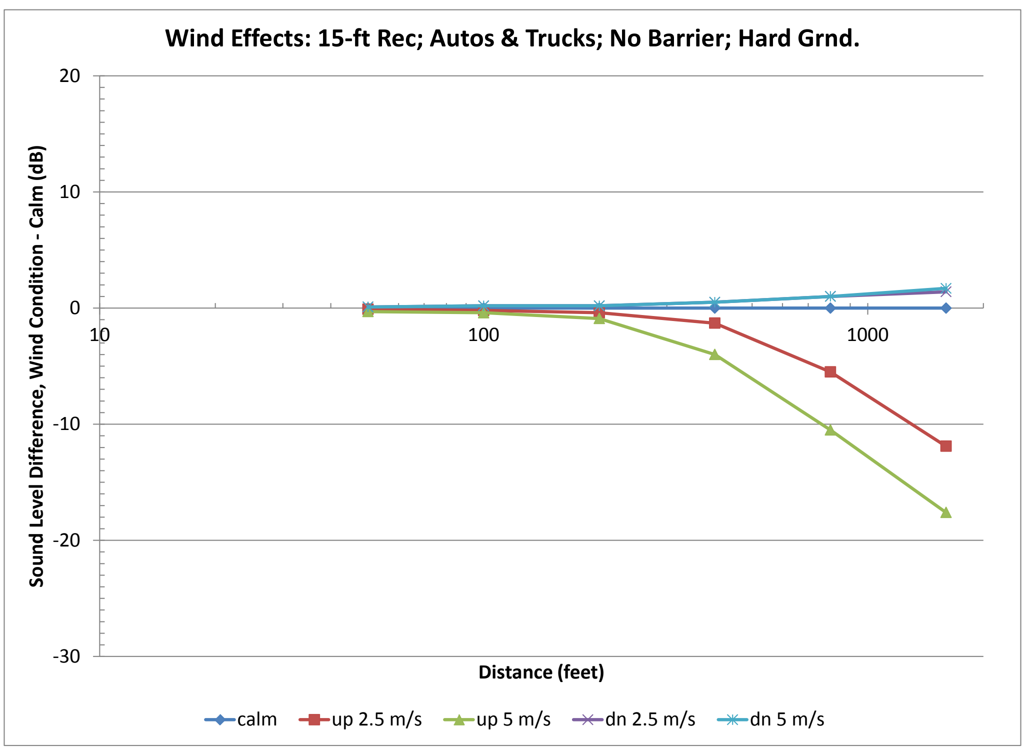

Figure 11 Sound Level Difference between Varying Wind Conditions

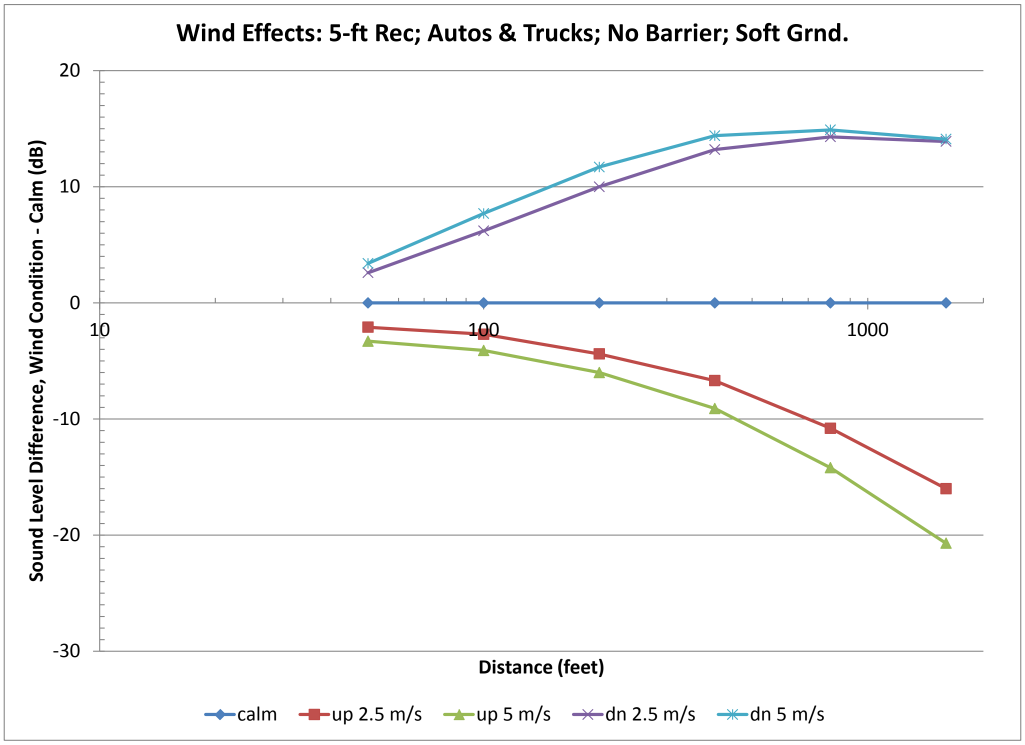

Figure 12 Sound Level Difference between Varying Wind Conditions

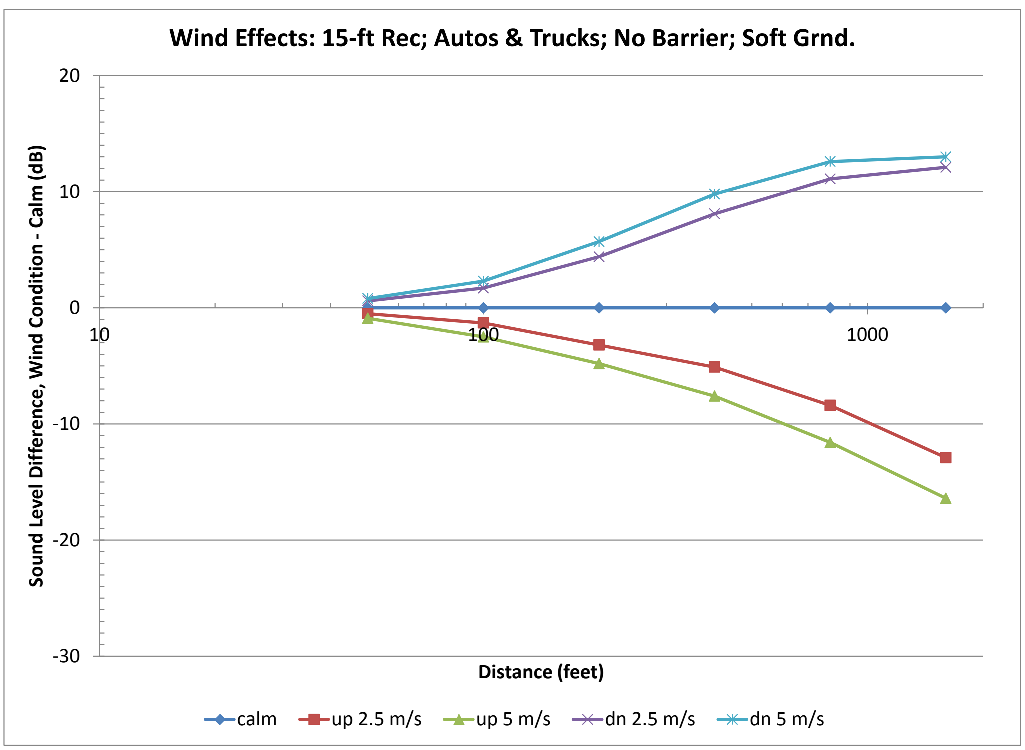

Figure 13 Sound Level Difference between Varying Wind Conditions

J.4.2 Sound Level Differences between Varying Temperature and Calm Conditions with Autos and Trucks

The graphs below include combinations of parameters that were modeled for varying temperature gradients relative to calm conditions. The input model included both autos and trucks on the source roadway. Results are included for both 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with and without a noise barrier.

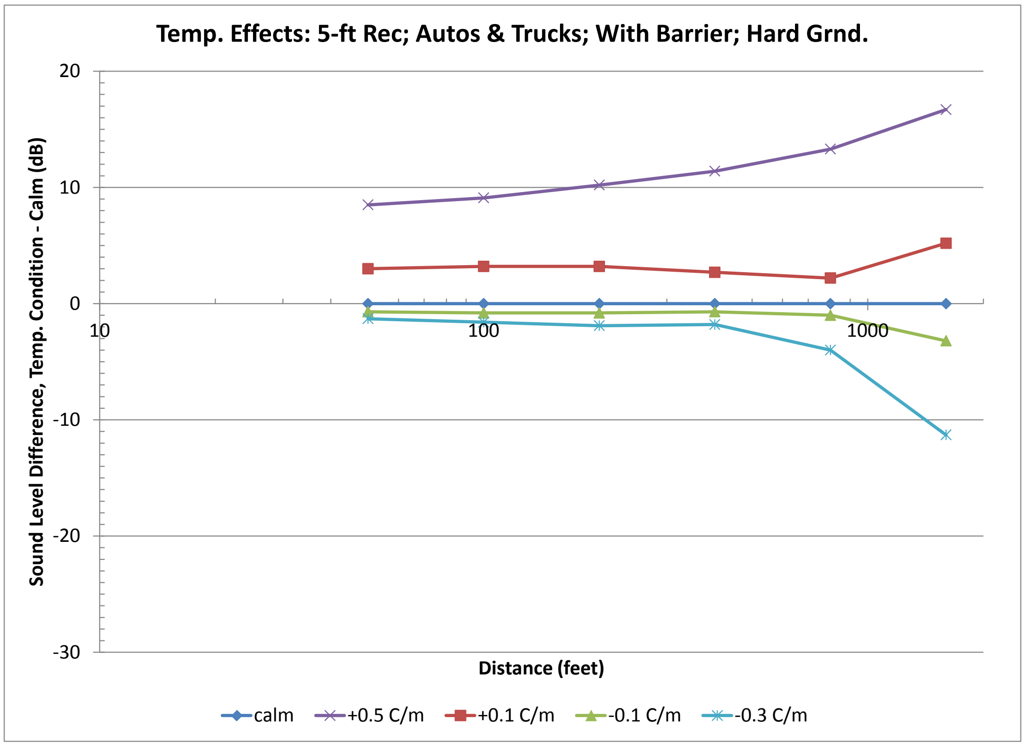

Figure 14 Sound Level Difference between Varying Temperature Conditions

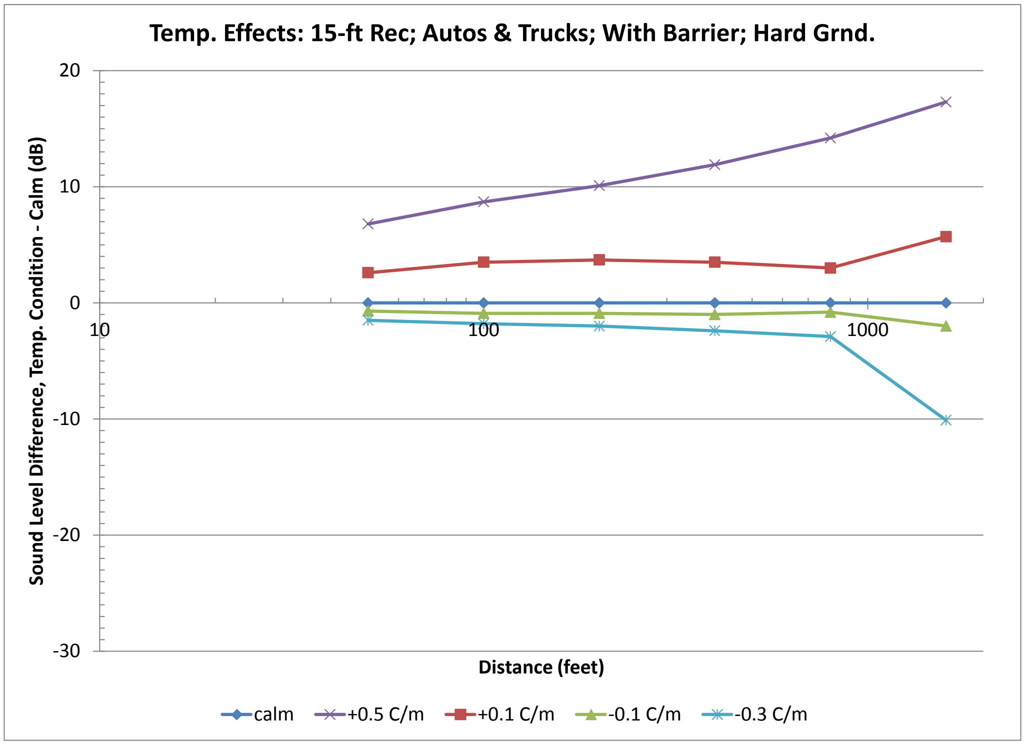

Figure 15 Sound Level Difference between Varying Temperature Conditions

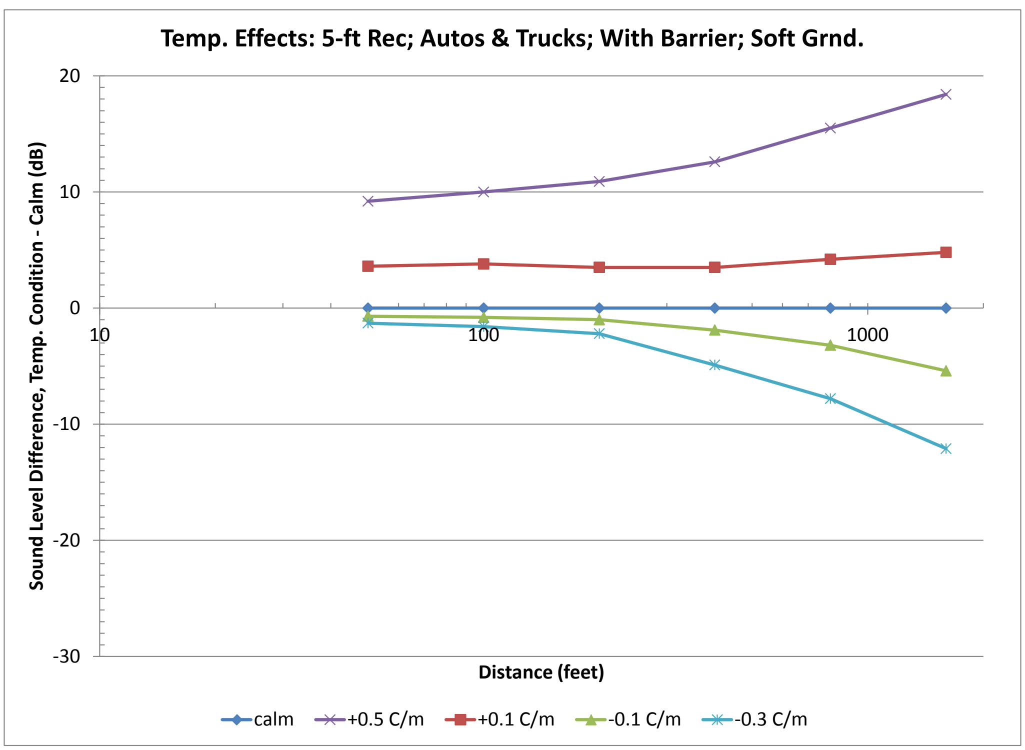

Figure 16 Sound Level Difference between Varying Temperature Conditions

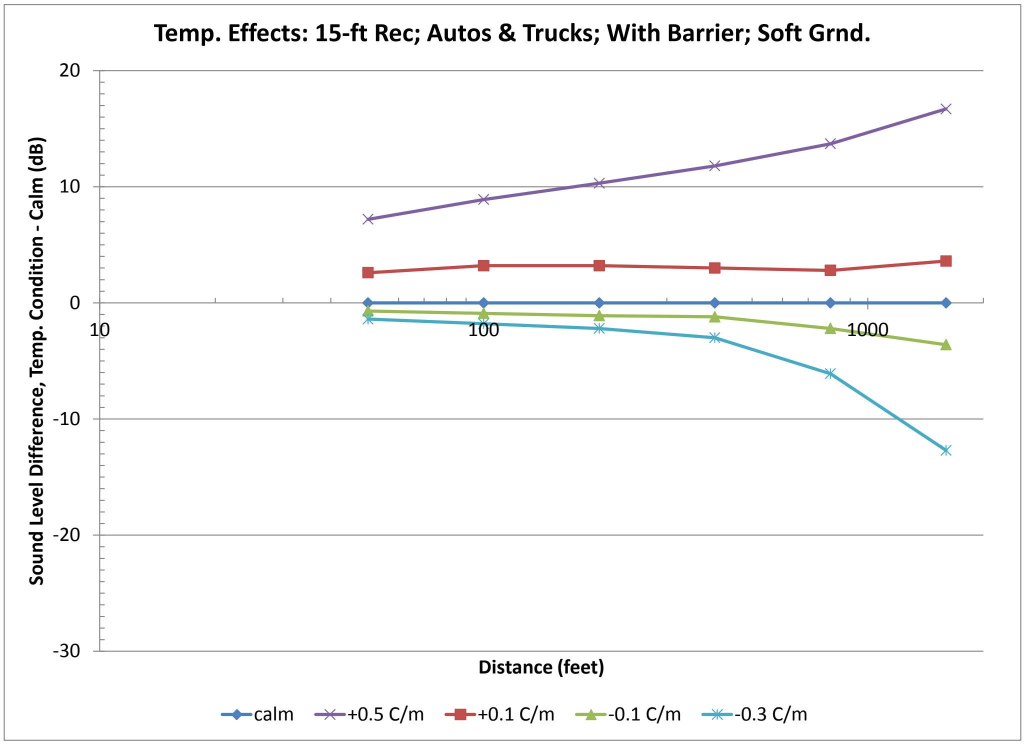

Figure 17 Sound Level Difference between Varying Temperature Conditions

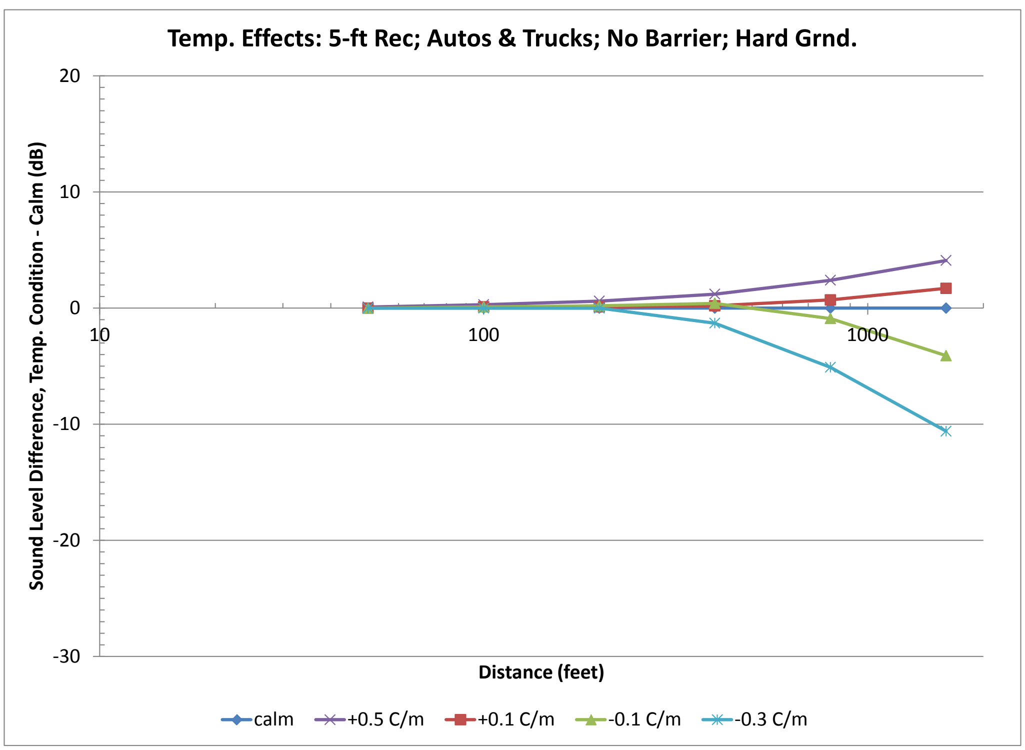

Figure 18 Sound Level Difference between Varying Temperature Conditions

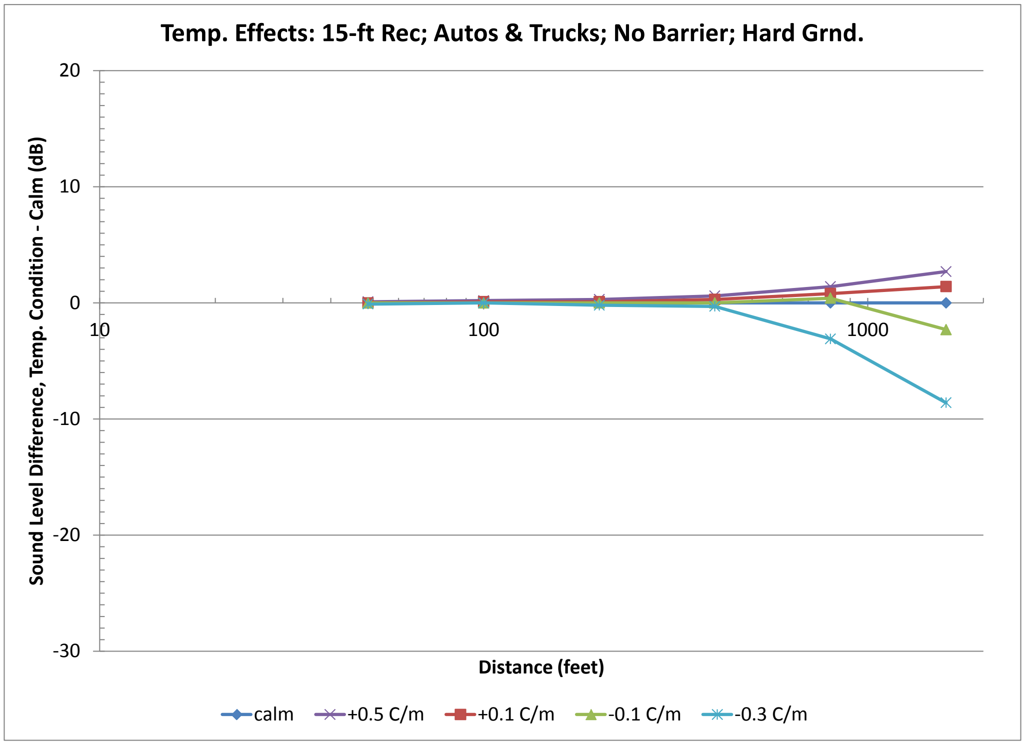

Figure 19 Sound Level Difference between Varying Temperature Conditions

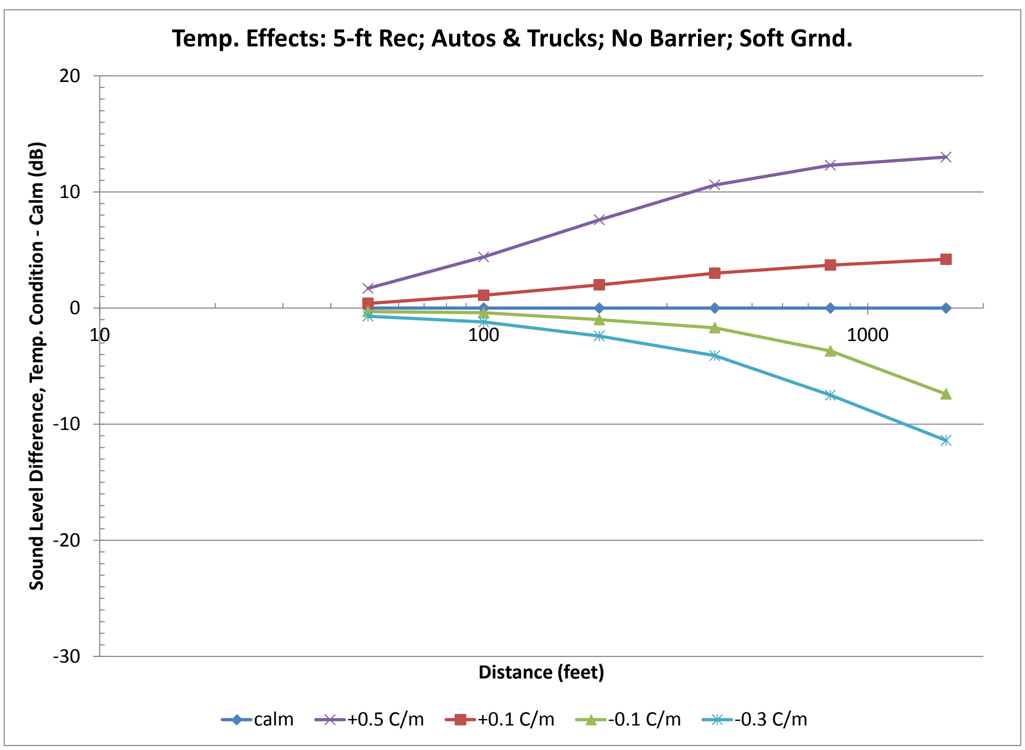

Figure 20 Sound Level Difference between Varying Temperature Conditions

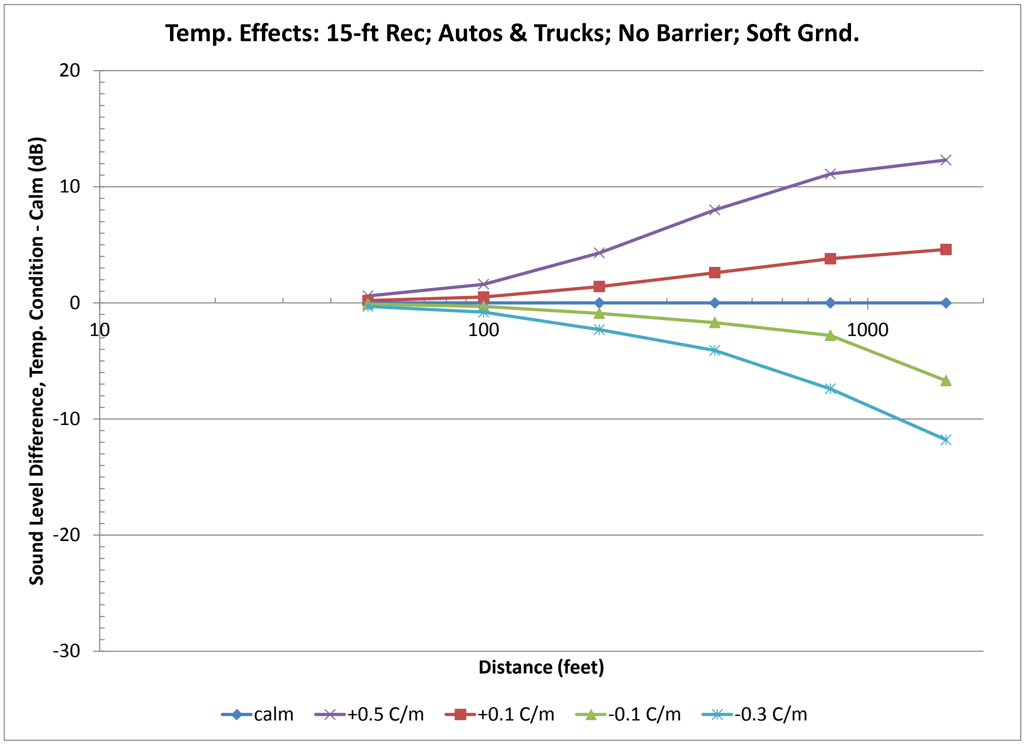

Figure 21 Sound Level Difference between Varying Temperature Conditions

J.4.3 Sound Level Differences between Varying Wind and Calm Conditions with Autos Only

The graphs below include combinations of parameters that were modeled for varying wind speeds and directions relative to calm conditions. The input model included only autos on the source roadway. Results are included for both 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with and without a noise barrier.

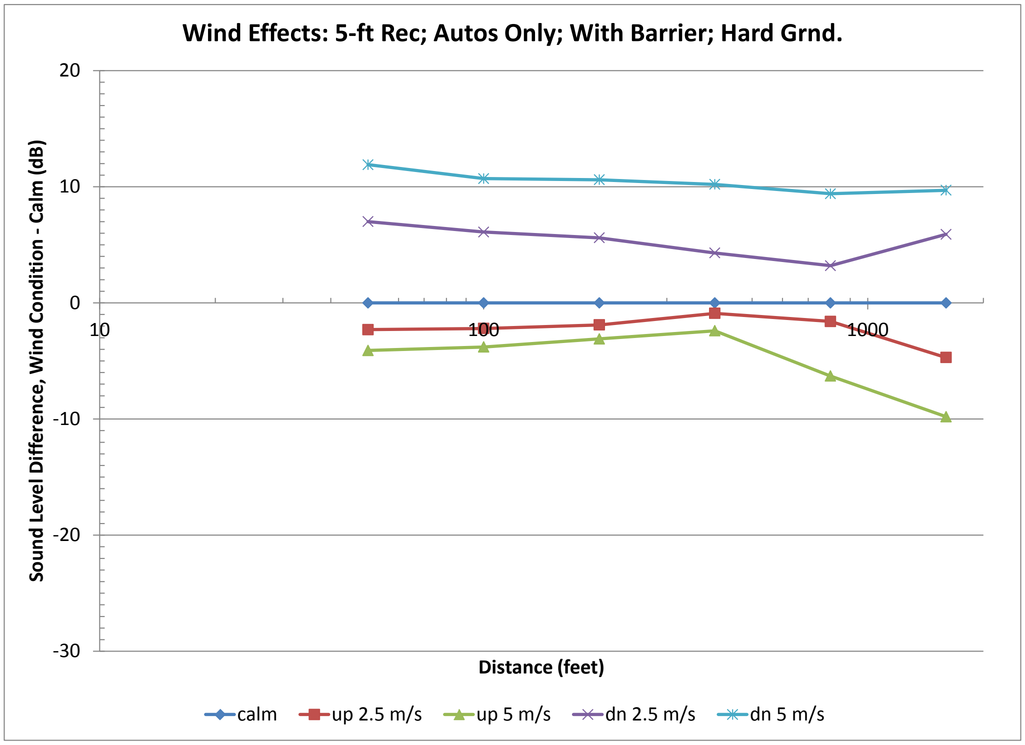

Figure 22 Sound Level Difference between Varying Wind Conditions

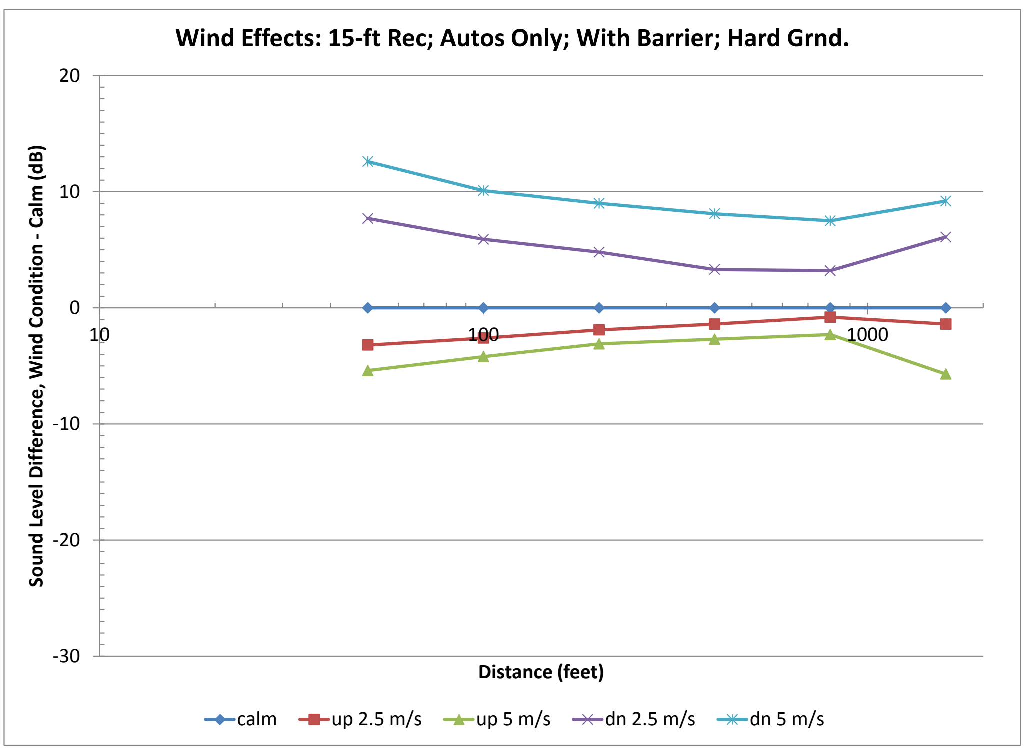

Figure 23 Sound Level Difference between Varying Wind Conditions

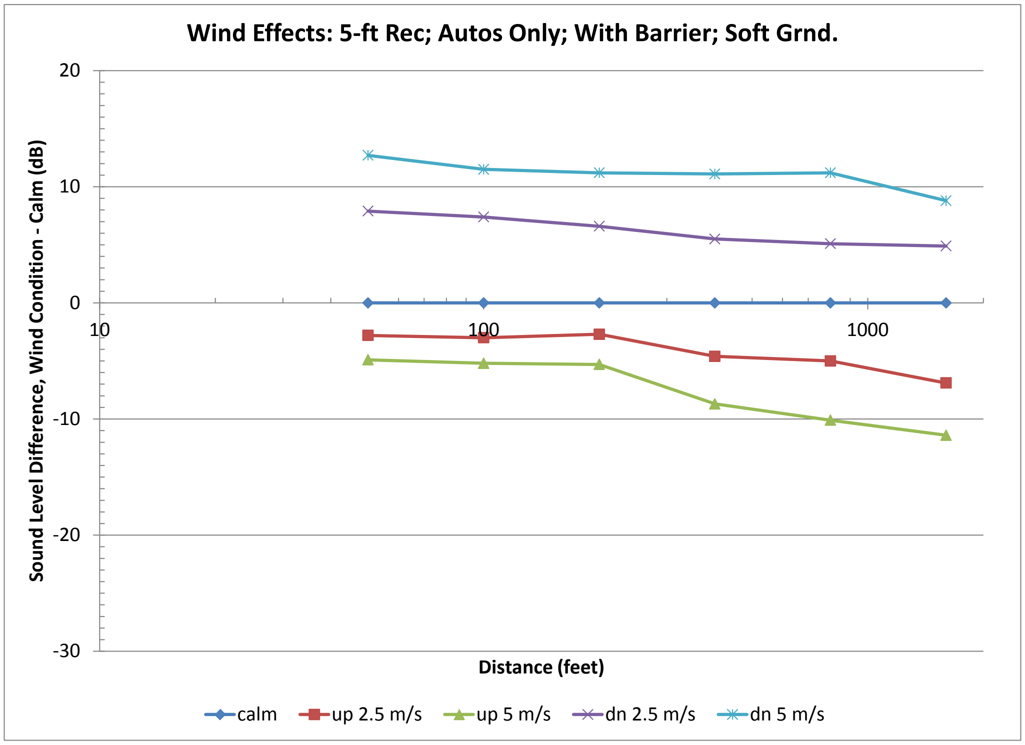

Figure 24 Sound Level Difference between Varying Wind Conditions

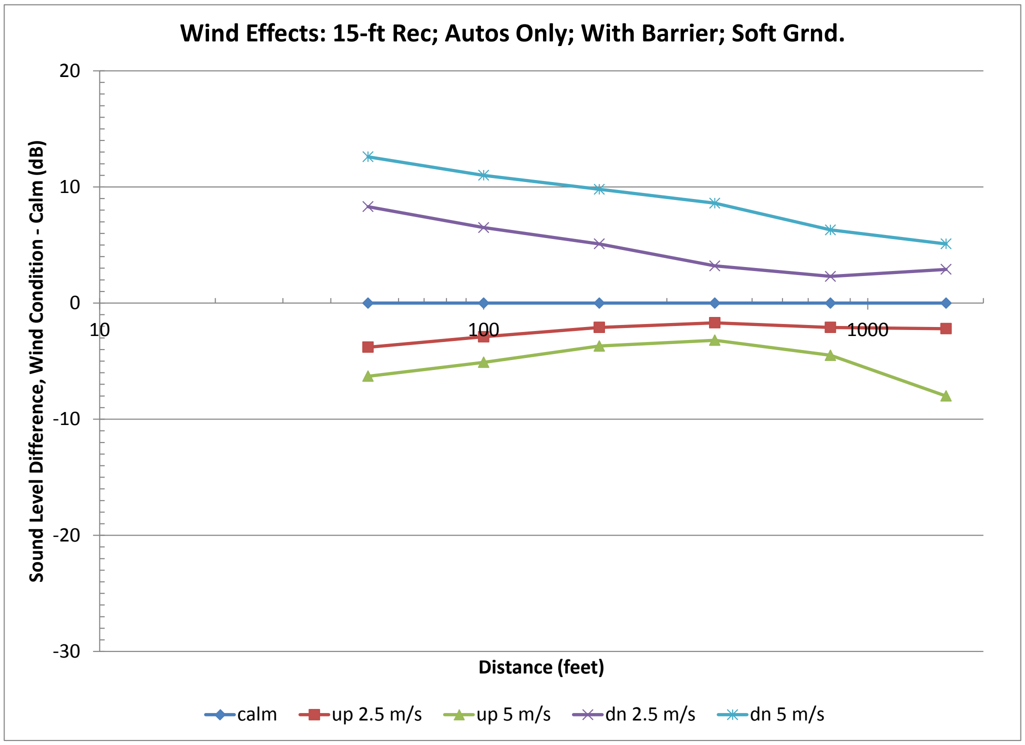

Figure 25 Sound Level Difference between Varying Wind Conditions

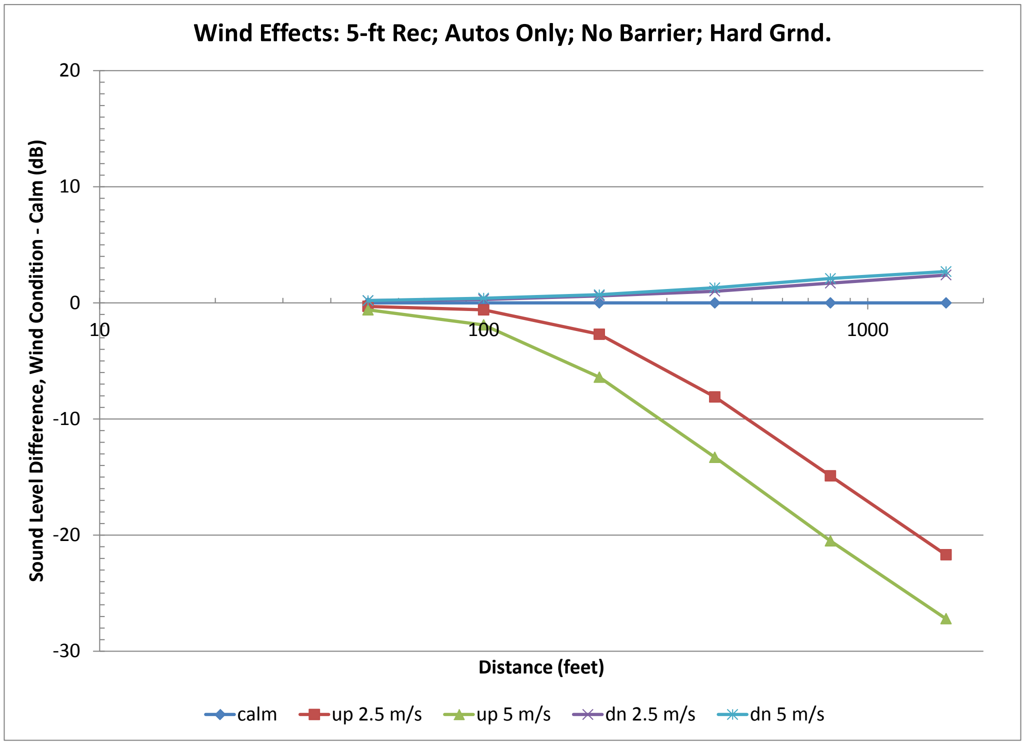

Figure 26 Sound Level Difference between Varying Wind Conditions

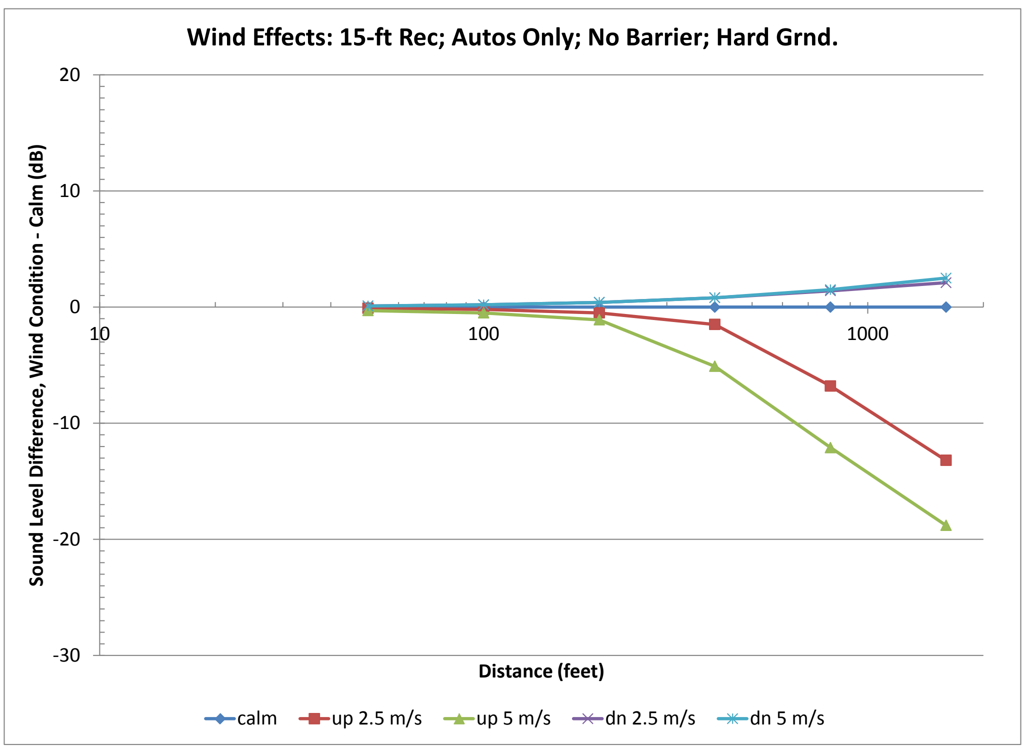

Figure 27 Sound Level Difference between Varying Wind Conditions

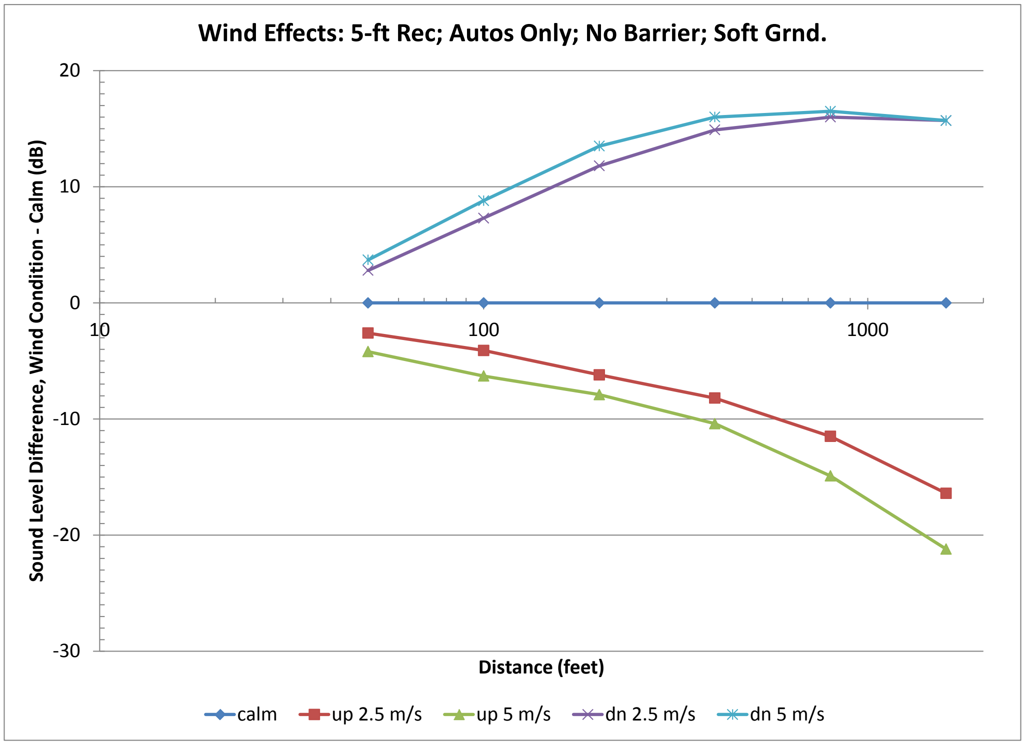

Figure 28 Sound Level Difference between Varying Wind Conditions

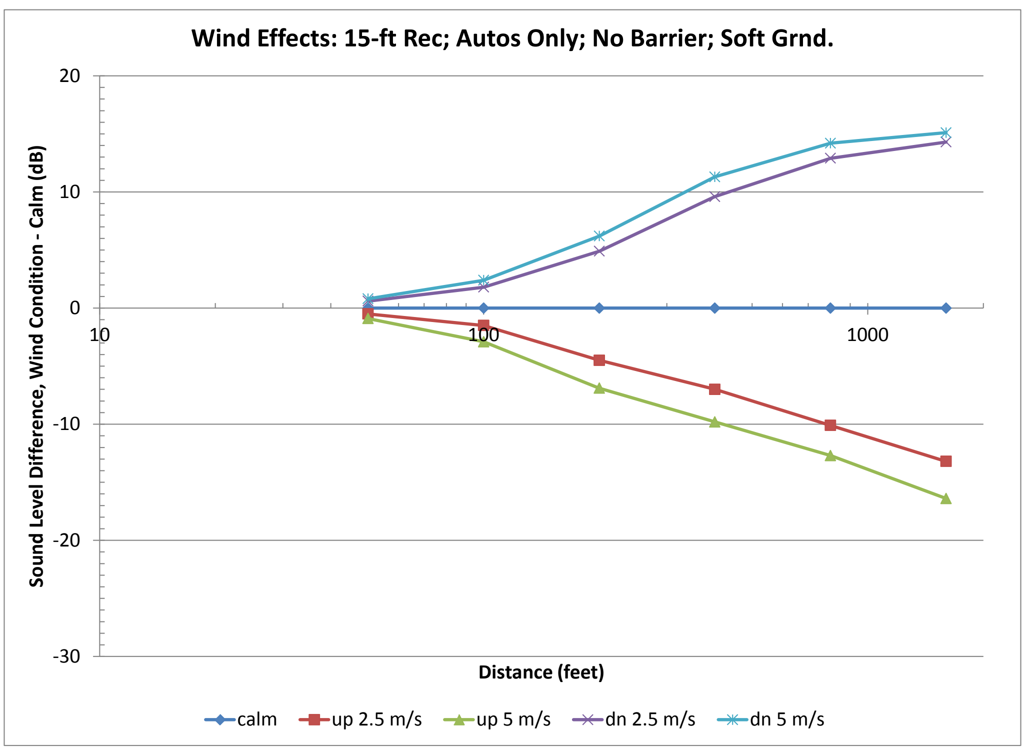

Figure 29 Sound Level Difference between Varying Wind Conditions

J.4.4 Sound Level Differences between Varying Temperature and Calm Conditions with Autos Only

The graphs below include combinations of parameters that were modeled for varying temperature gradients relative to calm conditions. The input model included only autos on the source roadway. Results are included for both 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with and without a noise barrier.

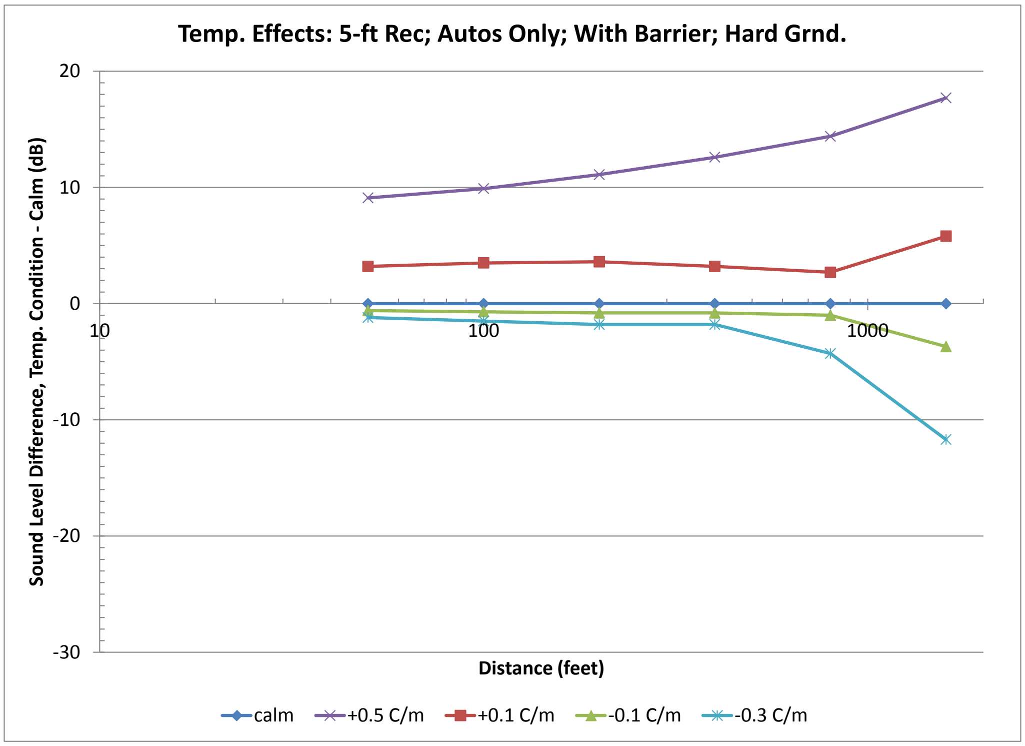

Figure 30 Sound Level Difference between Varying Temperature Conditions

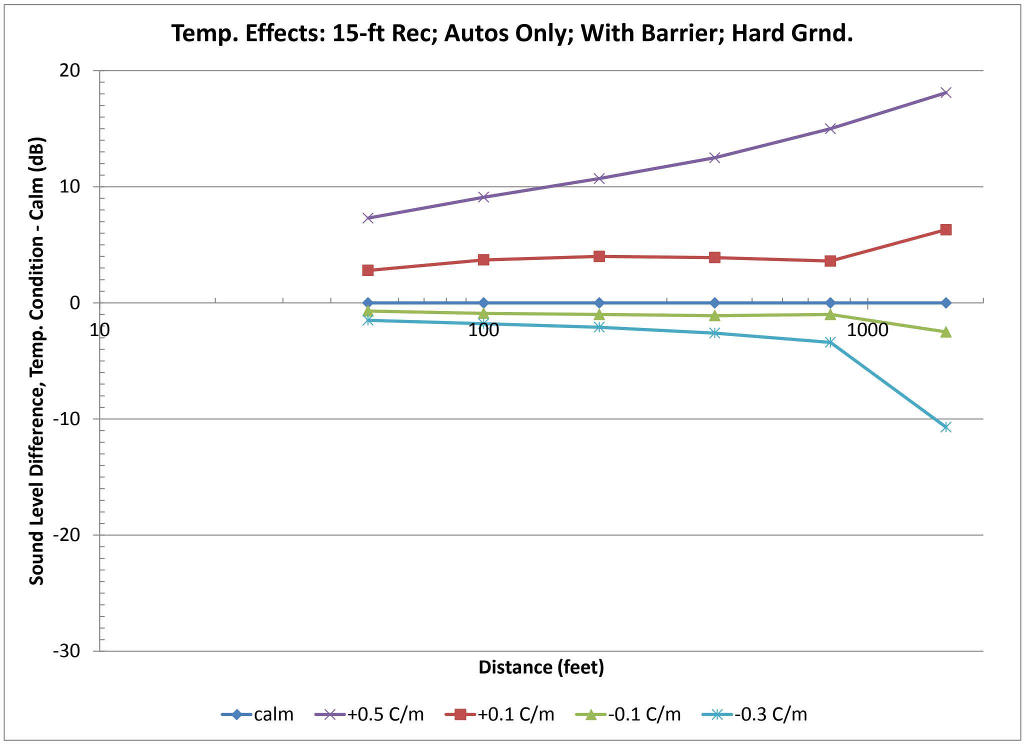

Figure 31 Sound Level Difference between Varying Temperature Conditions

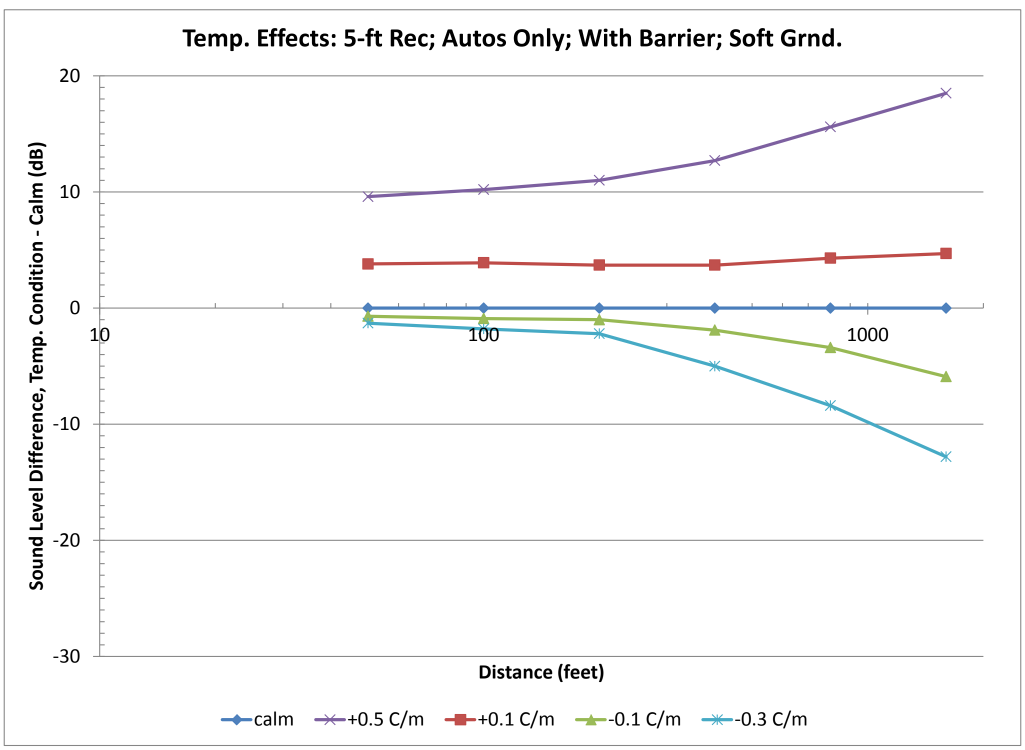

Figure 32 Sound Level Difference between Varying Temperature Conditions

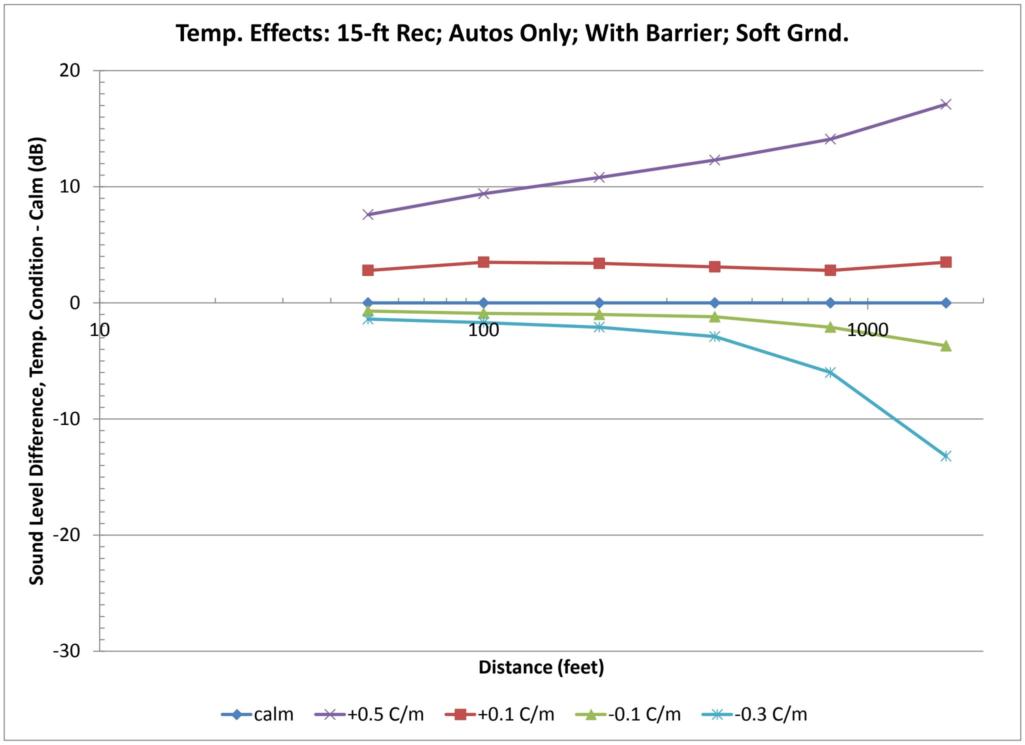

Figure 33 Sound Level Difference between Varying Temperature Conditions

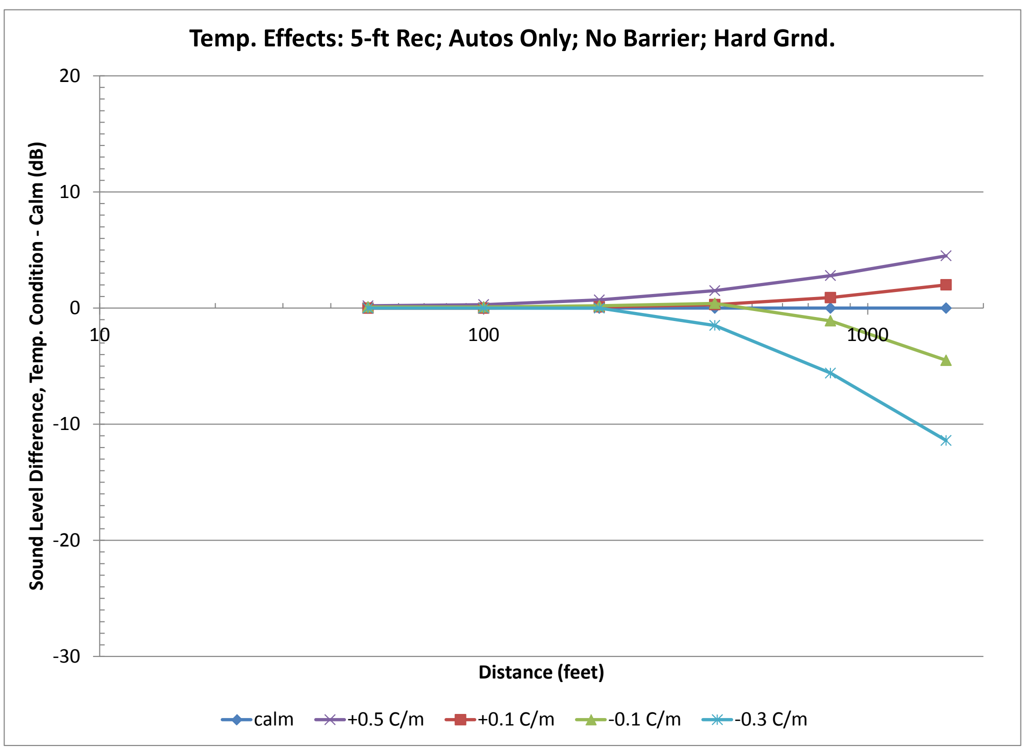

Figure 34 Sound Level Difference between Varying Temperature Conditions

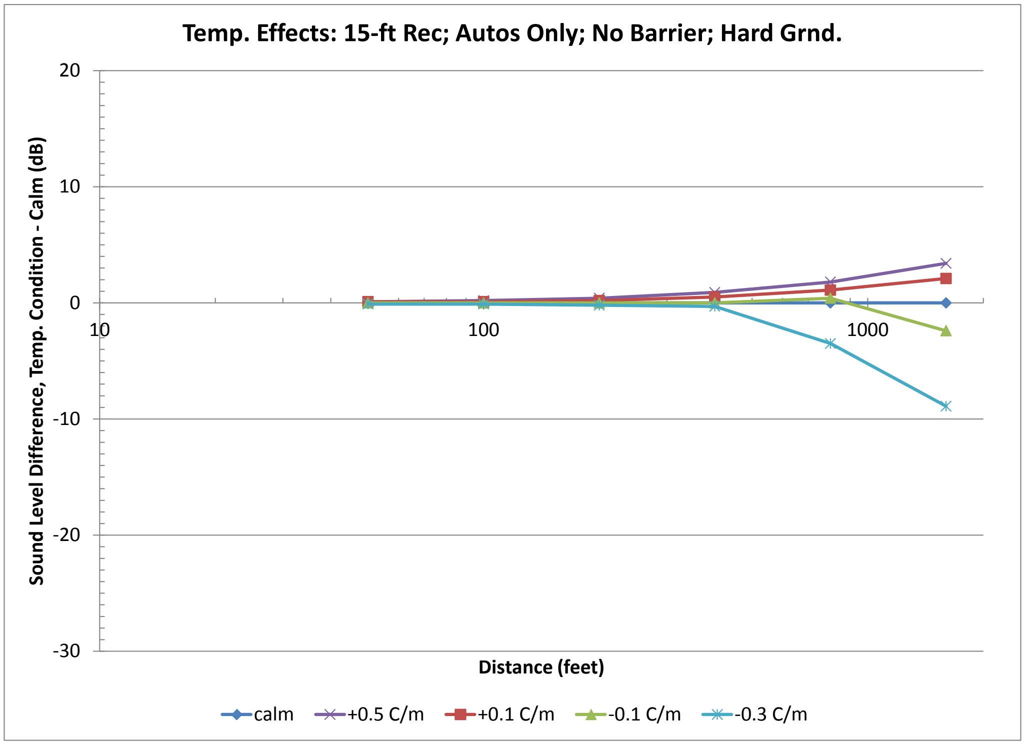

Figure 35 Sound Level Difference between Varying Temperature Conditions

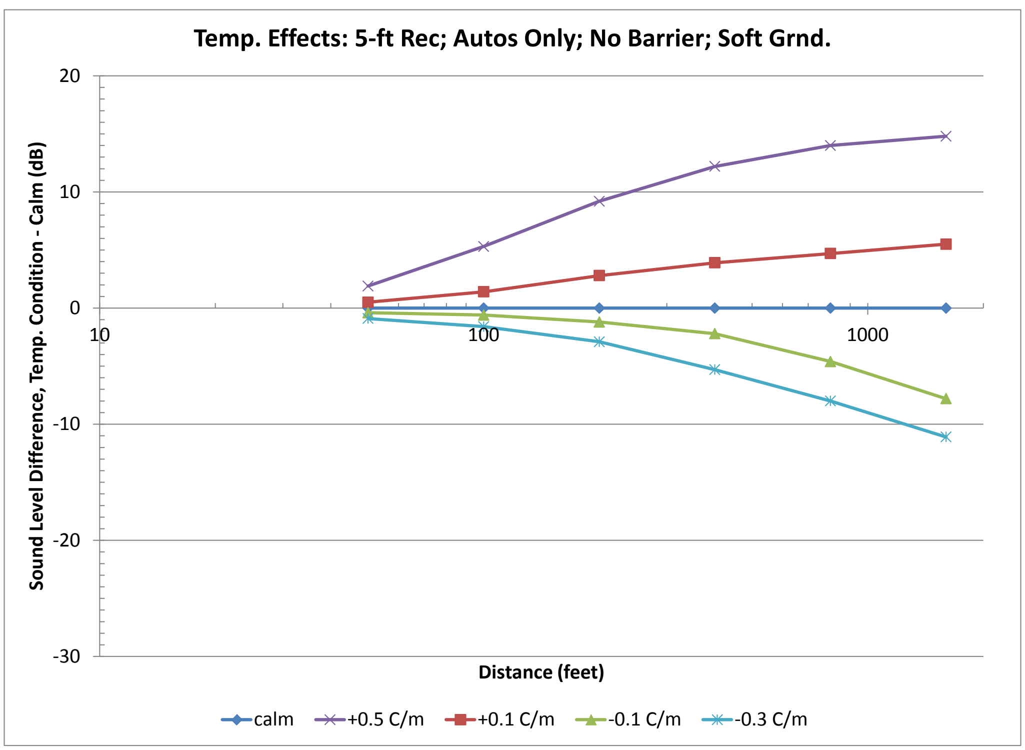

Figure 36 Sound Level Difference between Varying Temperature Conditions

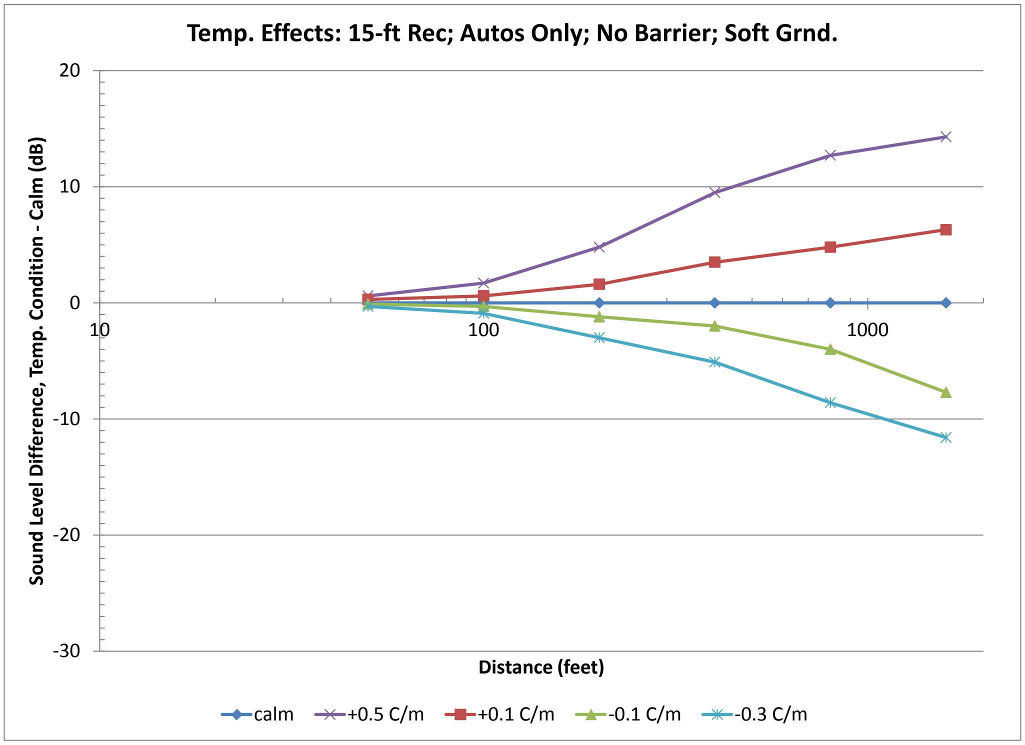

Figure 37 Sound Level Difference between Varying Temperature Conditions

J.4.5 Hourly Sound Level (L_{eq}) for Varying Wind and Calm Conditions with Autos and Trucks

The graphs below include combinations of parameters that were modeled for varying wind speeds and directions relative to calm conditions. The input model included autos and trucks on the source roadway. Results are included for both 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with and without a noise barrier.

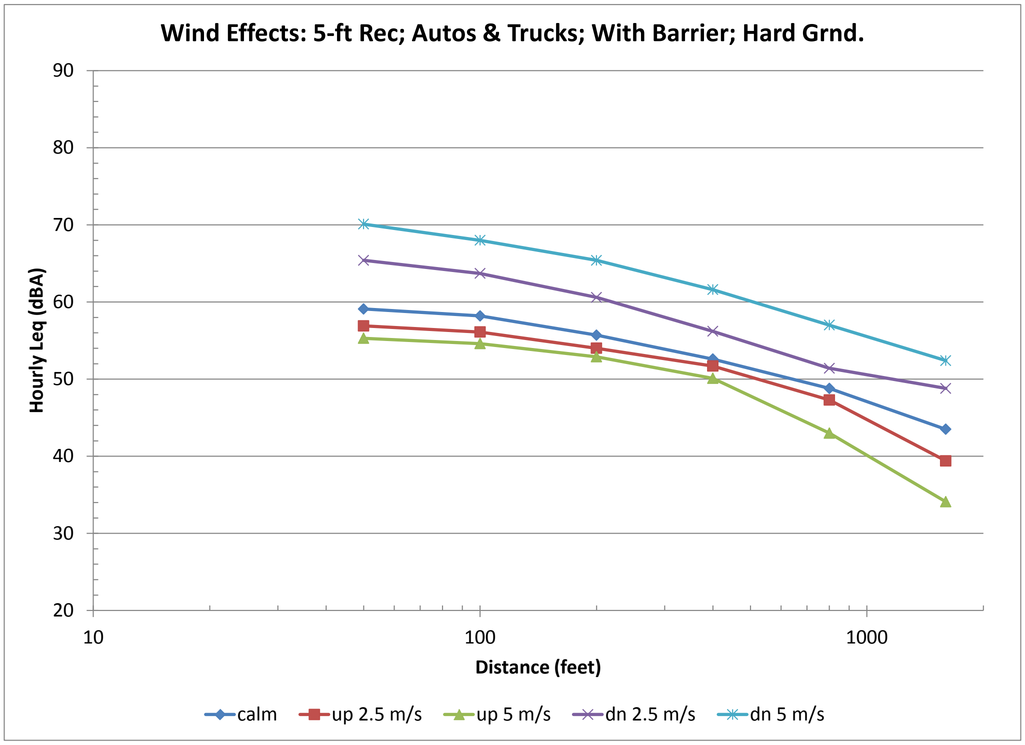

Figure 38 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

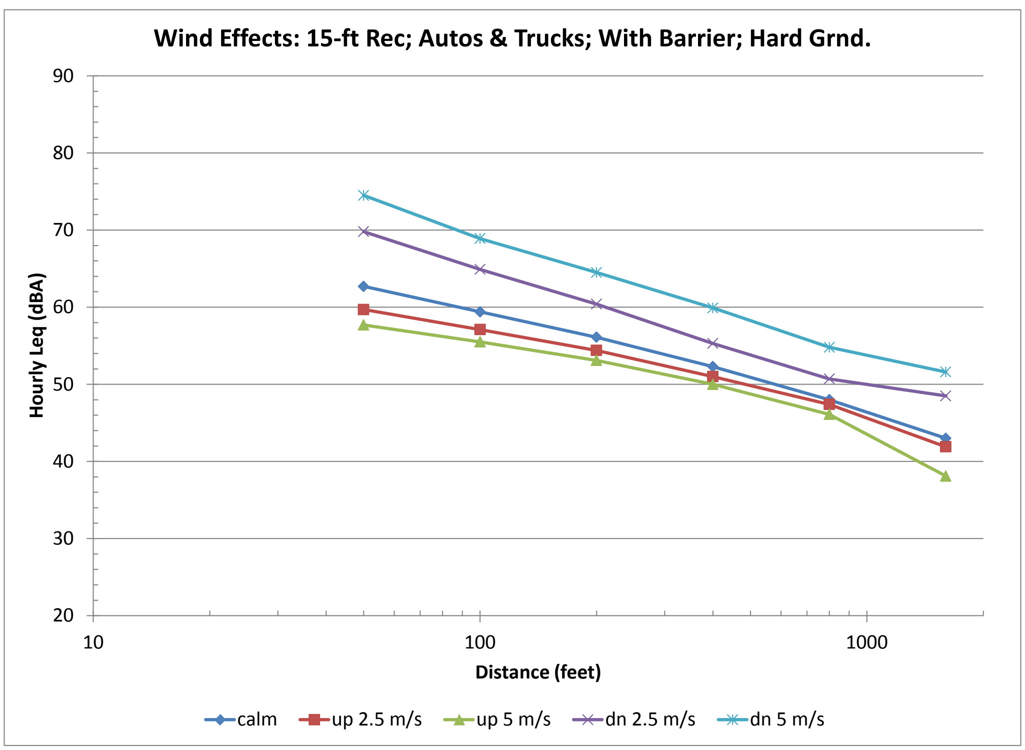

Figure 39 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

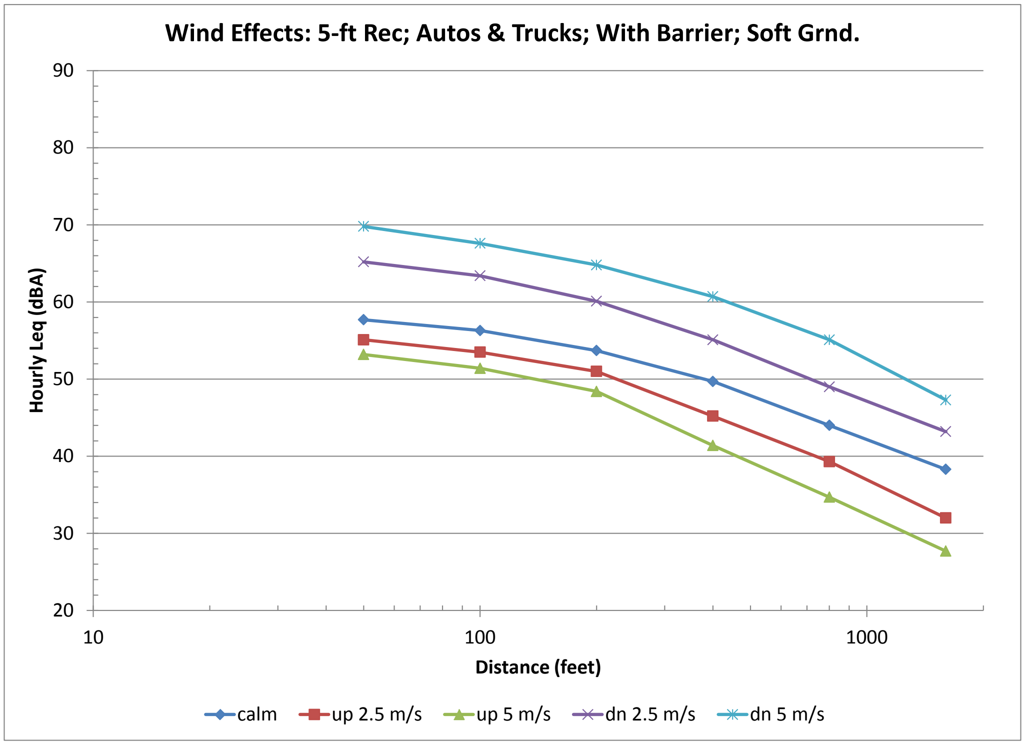

Figure 40 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

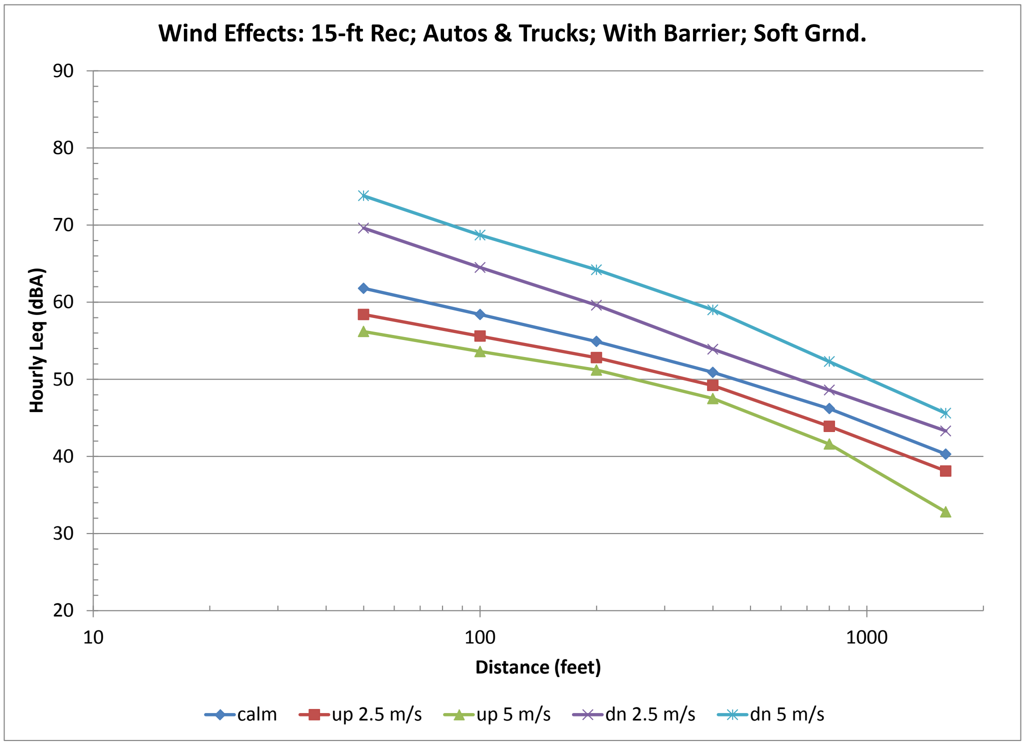

Figure 41 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

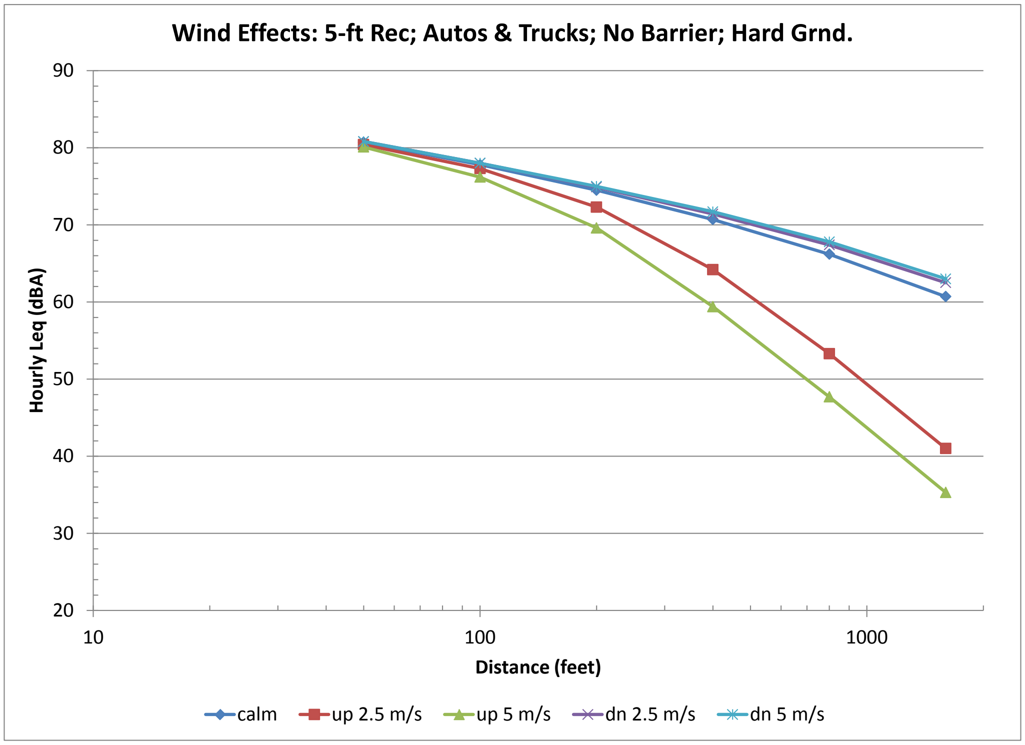

Figure 42 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

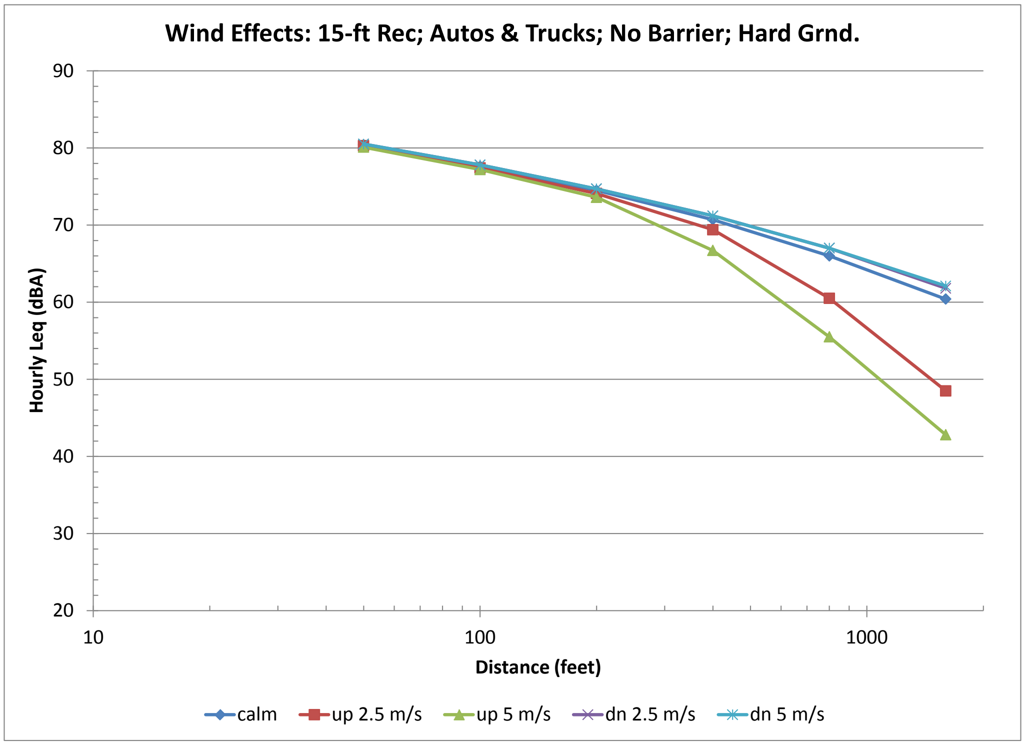

Figure 43 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

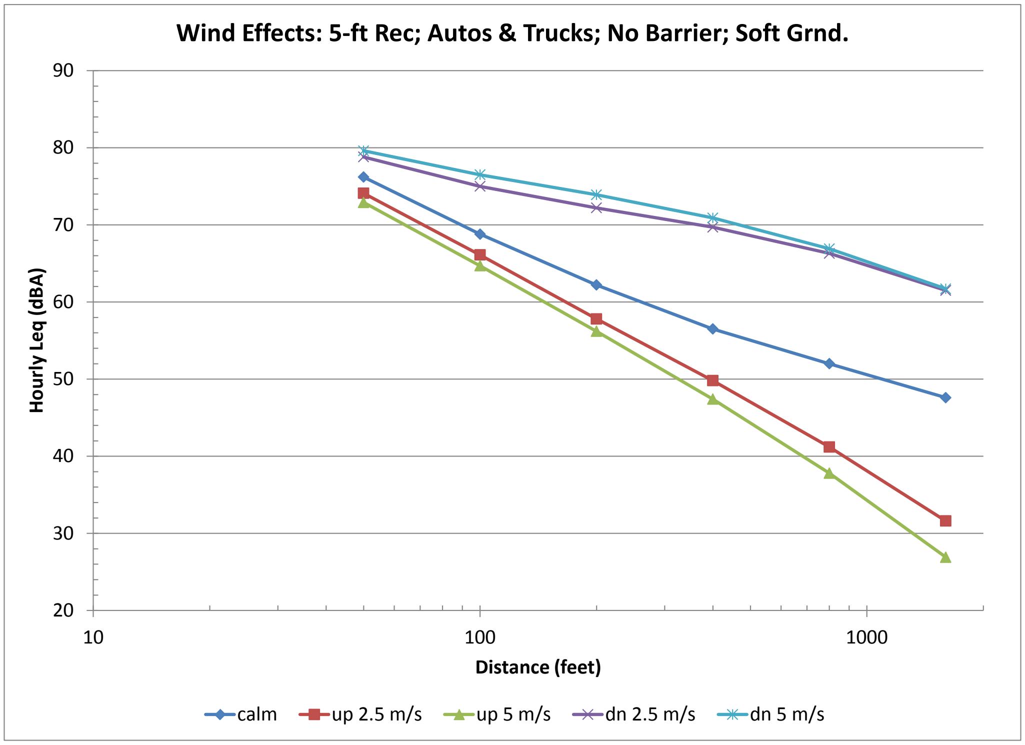

Figure 44 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

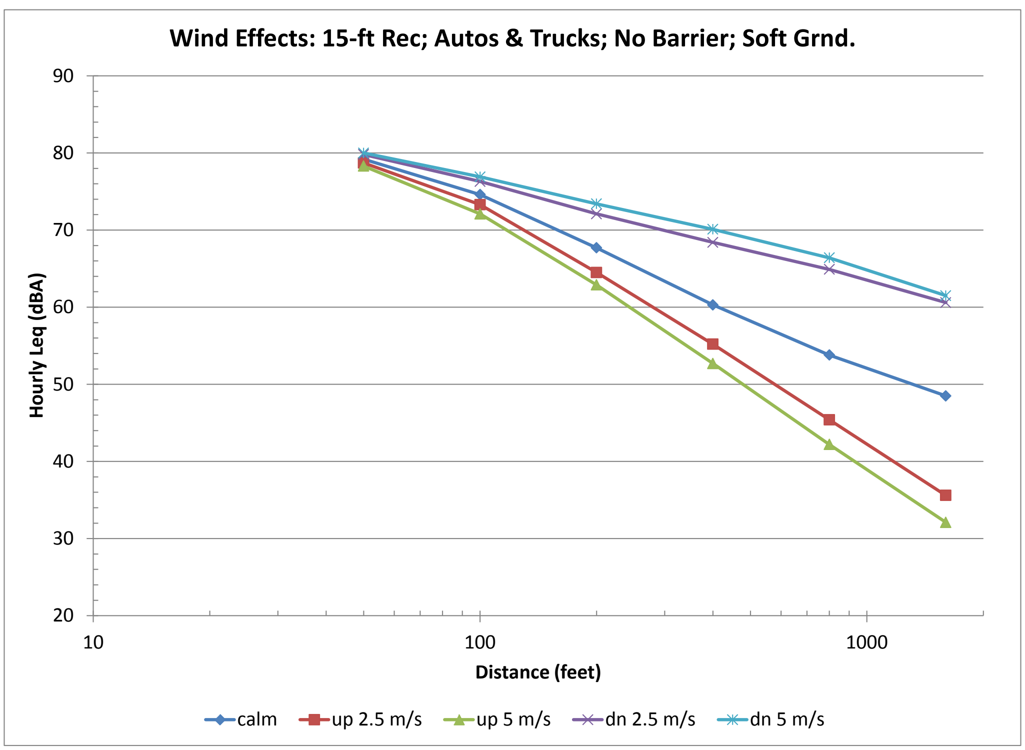

Figure 45 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

J.4.6 Hourly Sound Level (L_{eq}) for Varying Temperature and Calm Conditions with Autos and Trucks

The graphs below include combinations of parameters that were modeled for varying temperature gradients relative to calm conditions. The input model included autos and trucks on the source roadway. Results are included for both 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with without a noise barrier.

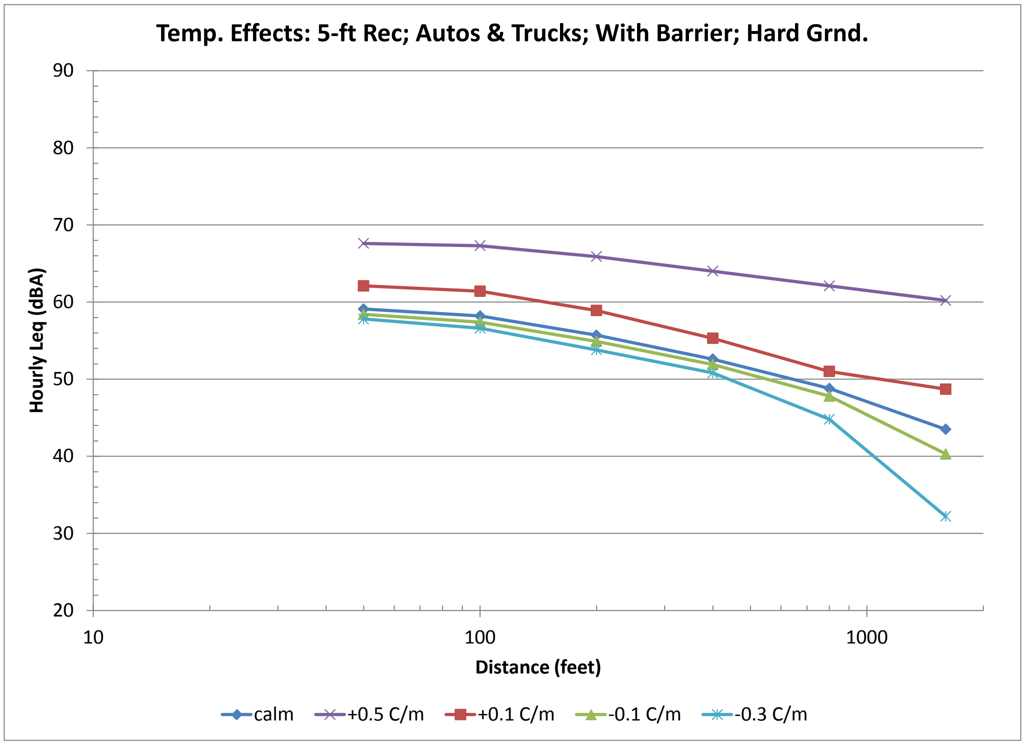

Figure 46 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

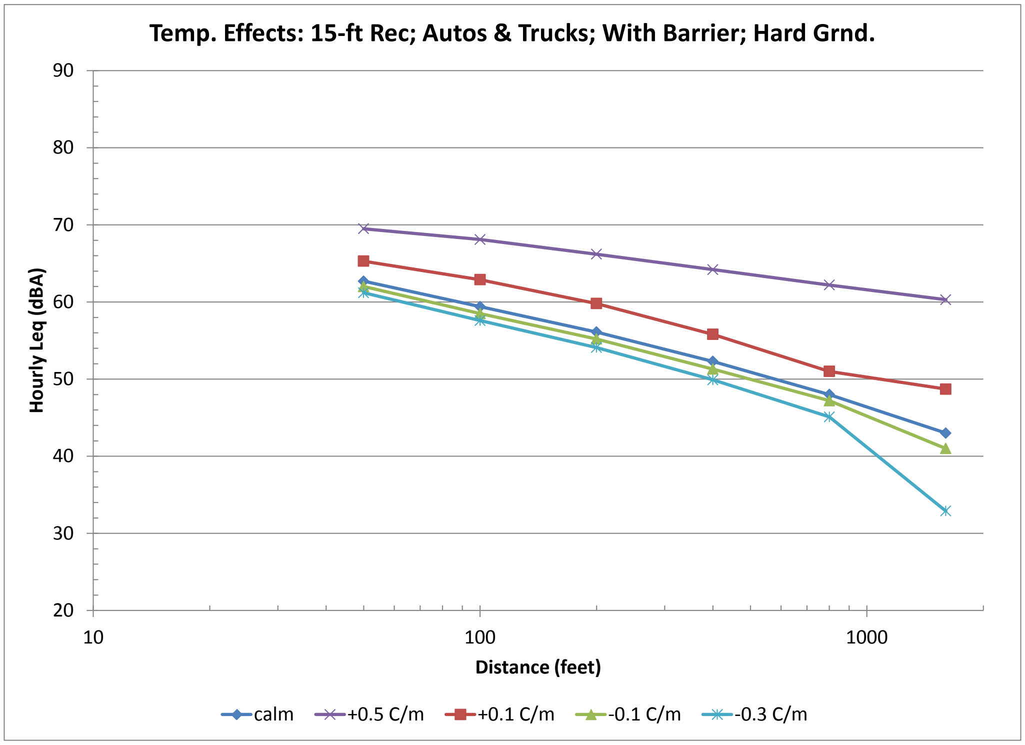

Figure 47 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

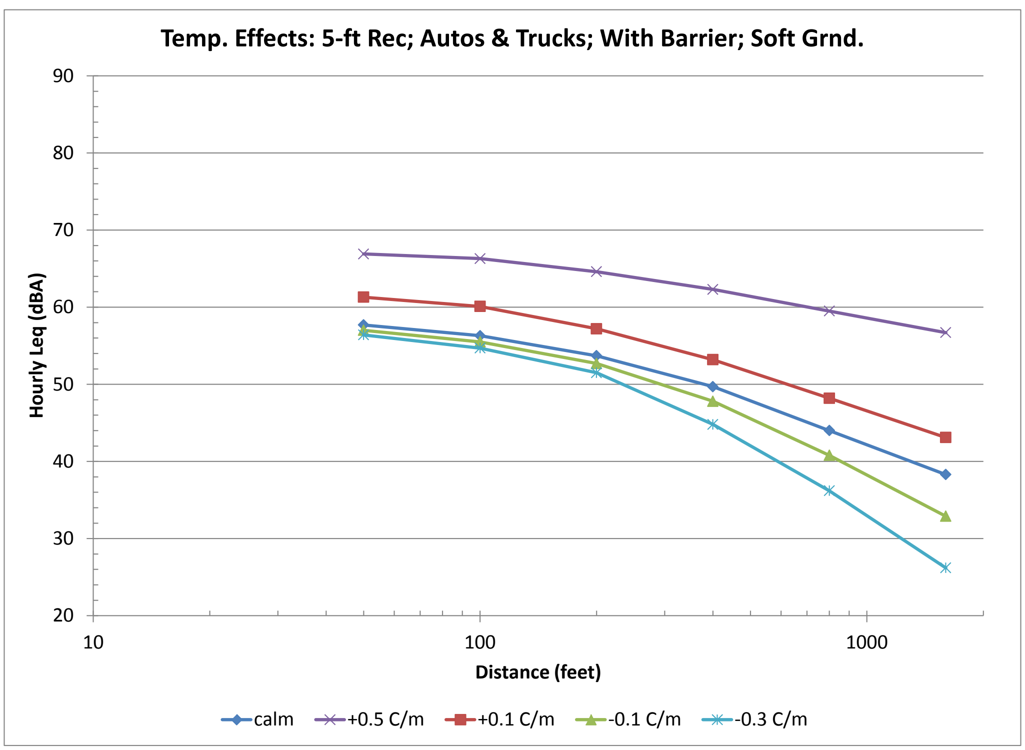

Figure 48 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

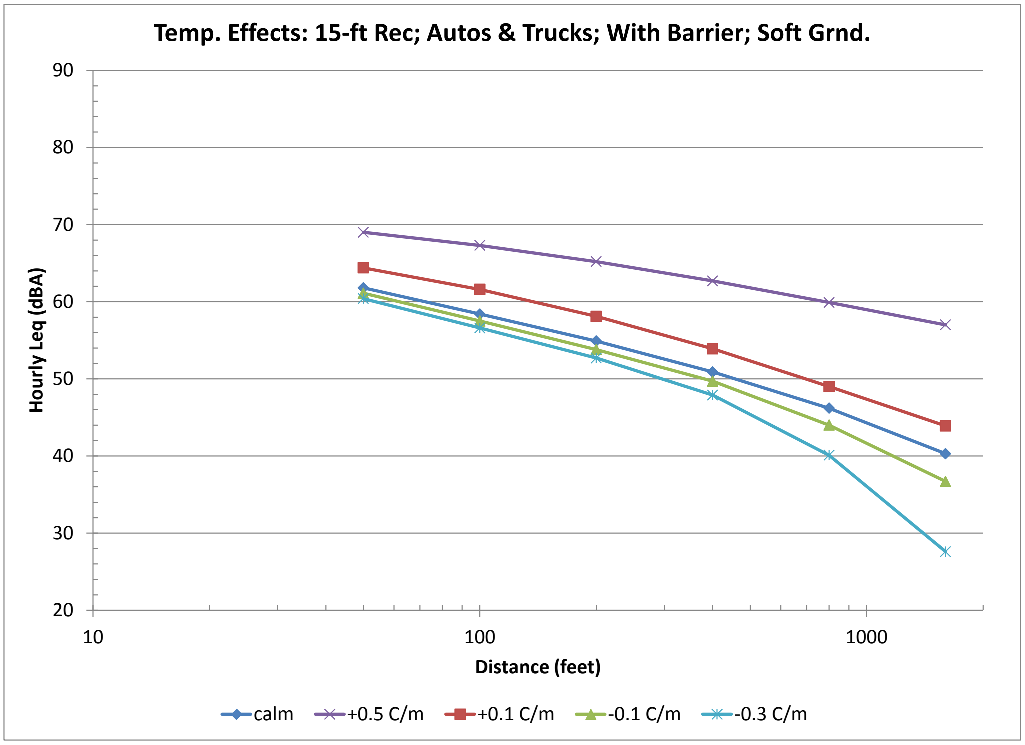

Figure 49 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

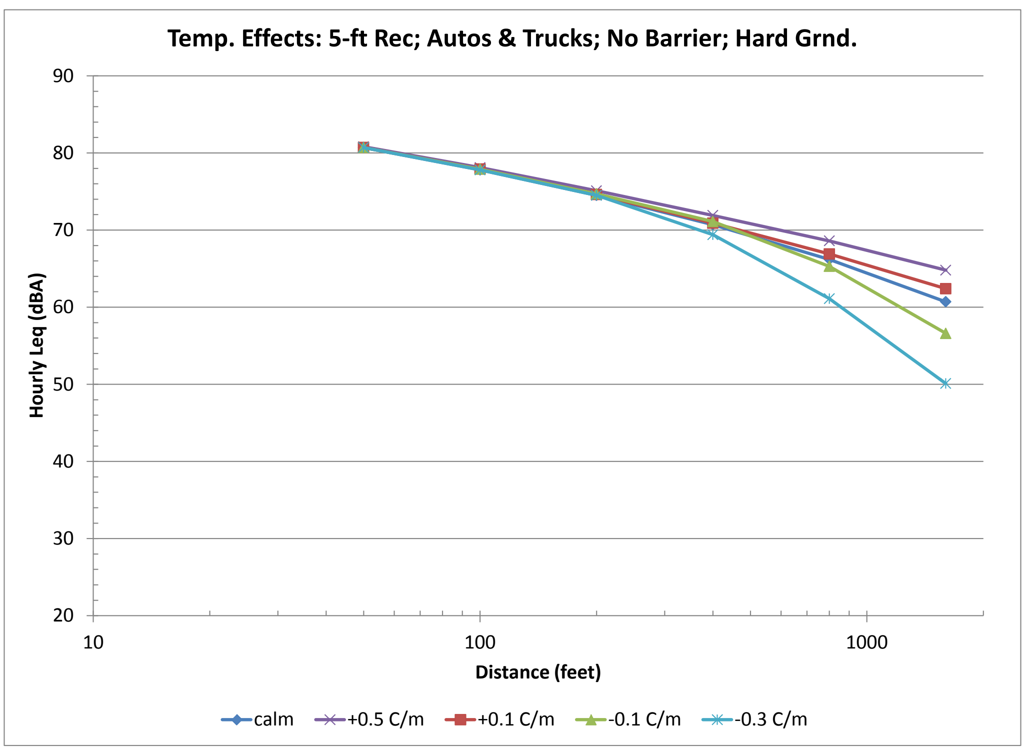

Figure 50 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

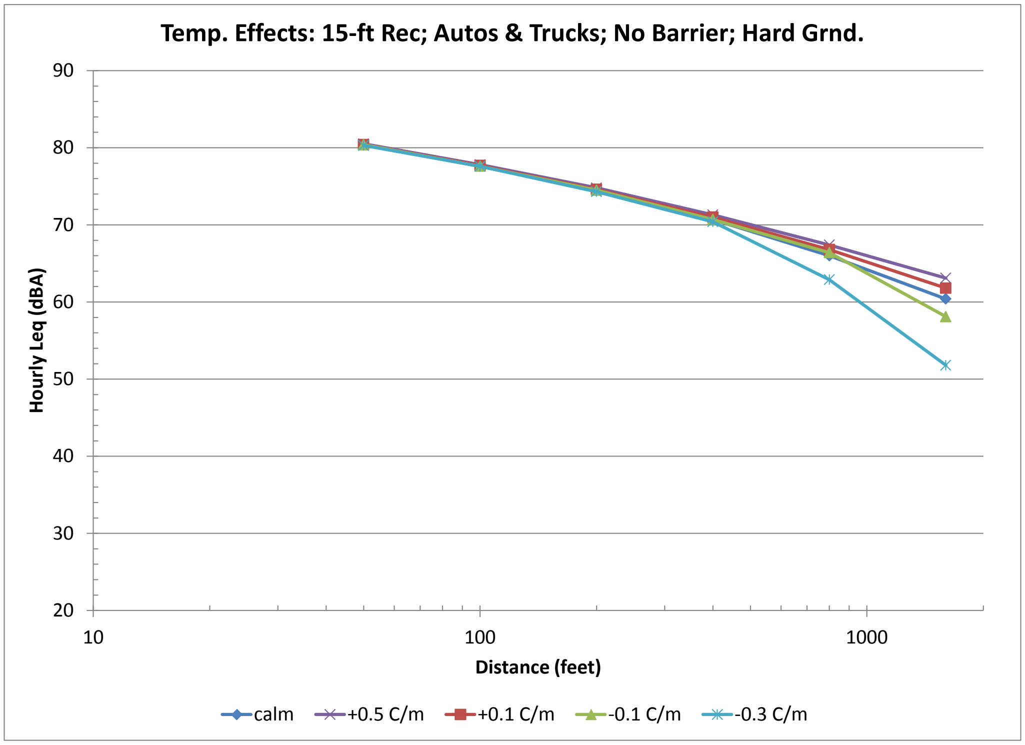

Figure 51 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

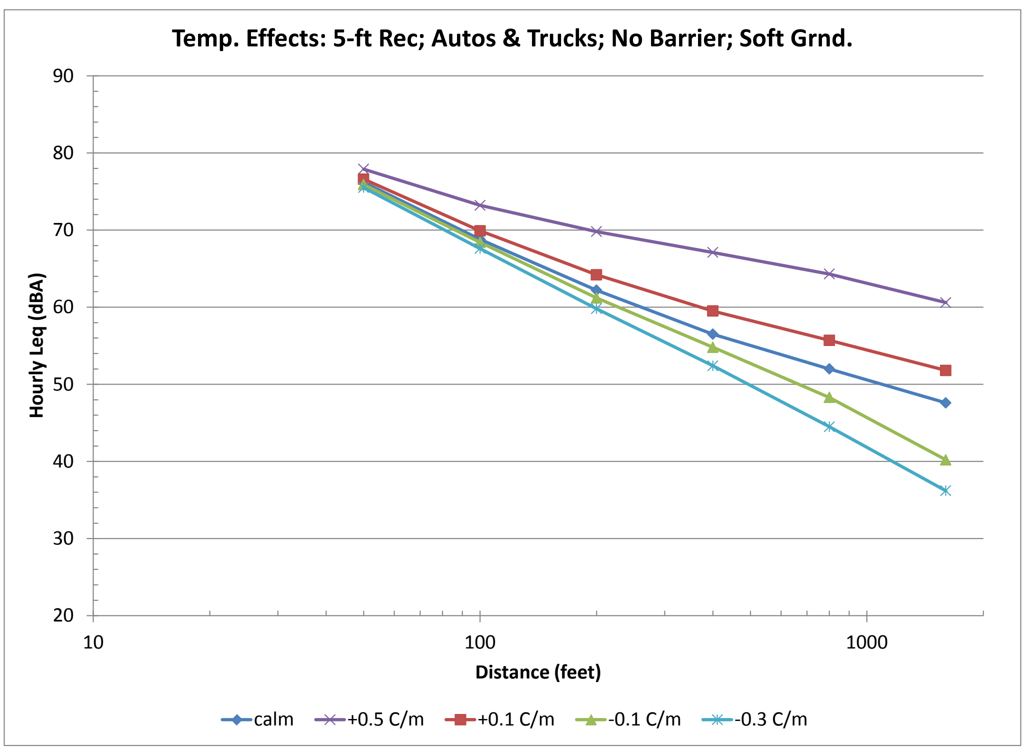

Figure 52 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

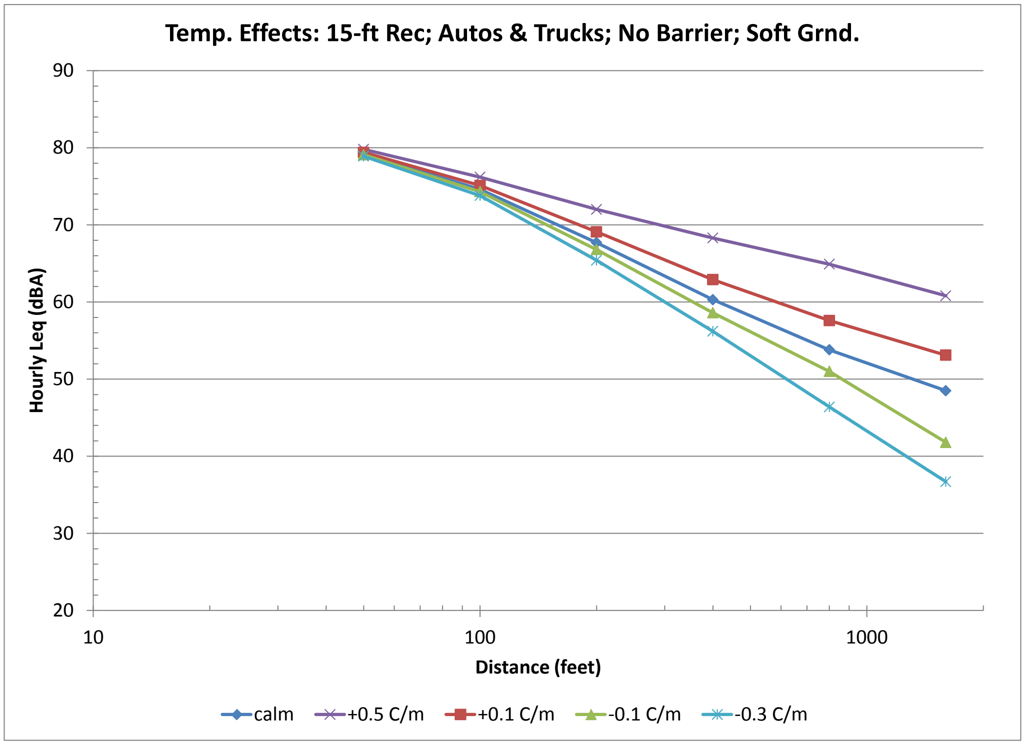

Figure 53 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

J.4.7 Hourly Sound Level (L_{eq}) for Varying Wind and Calm Conditions with Autos Only

The graphs below include combinations of parameters that were modeled for varying wind speeds and directions relative to calm conditions. The input model included only autos on the source roadway. Results are included for both 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with and without a noise barrier.

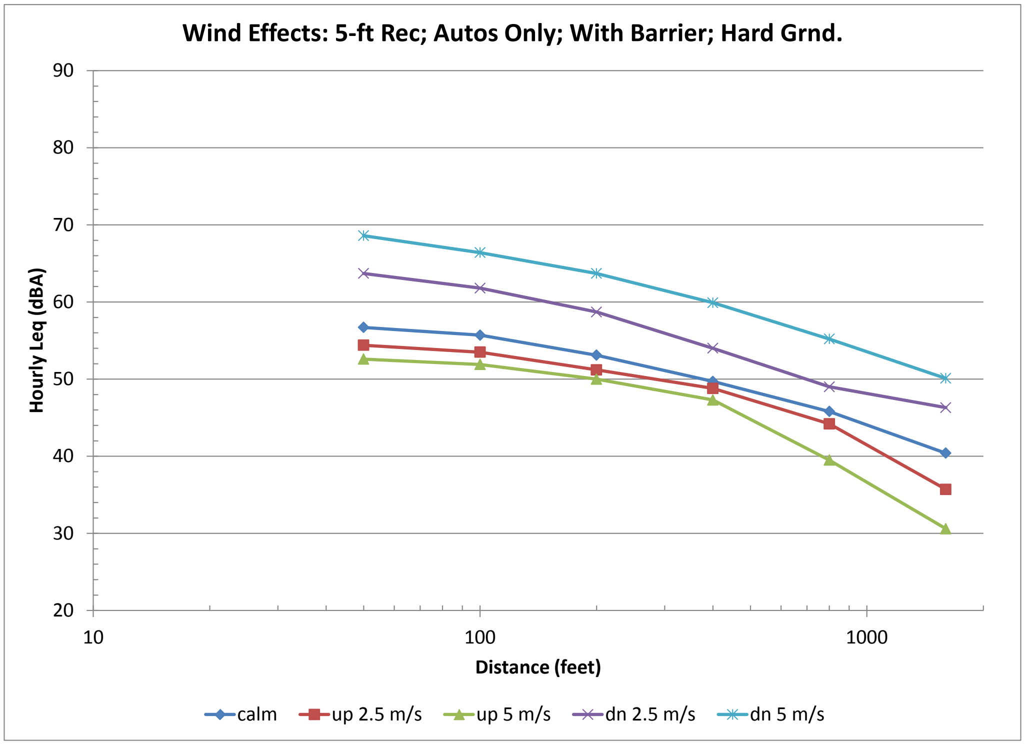

Figure 54 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

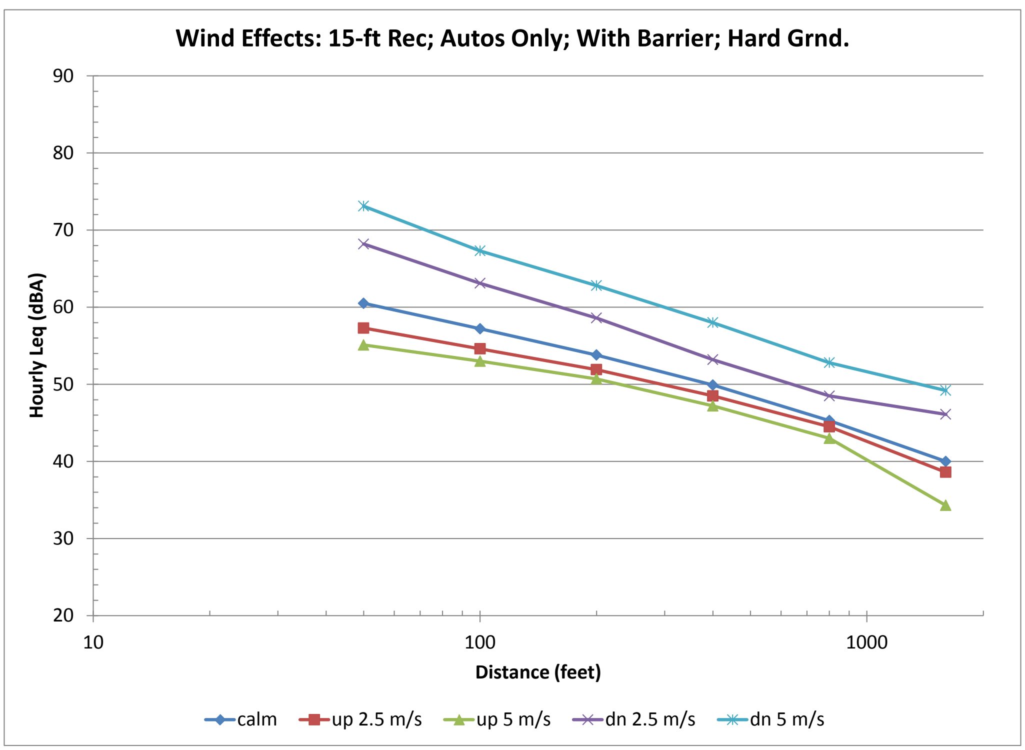

Figure 55 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

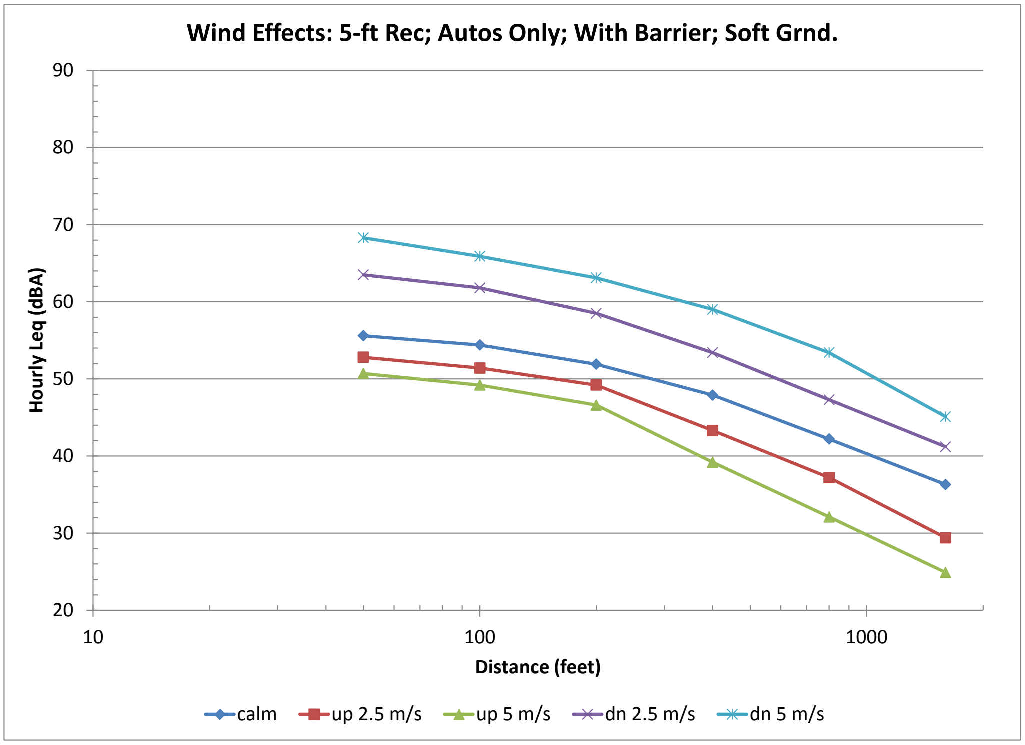

Figure 56 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

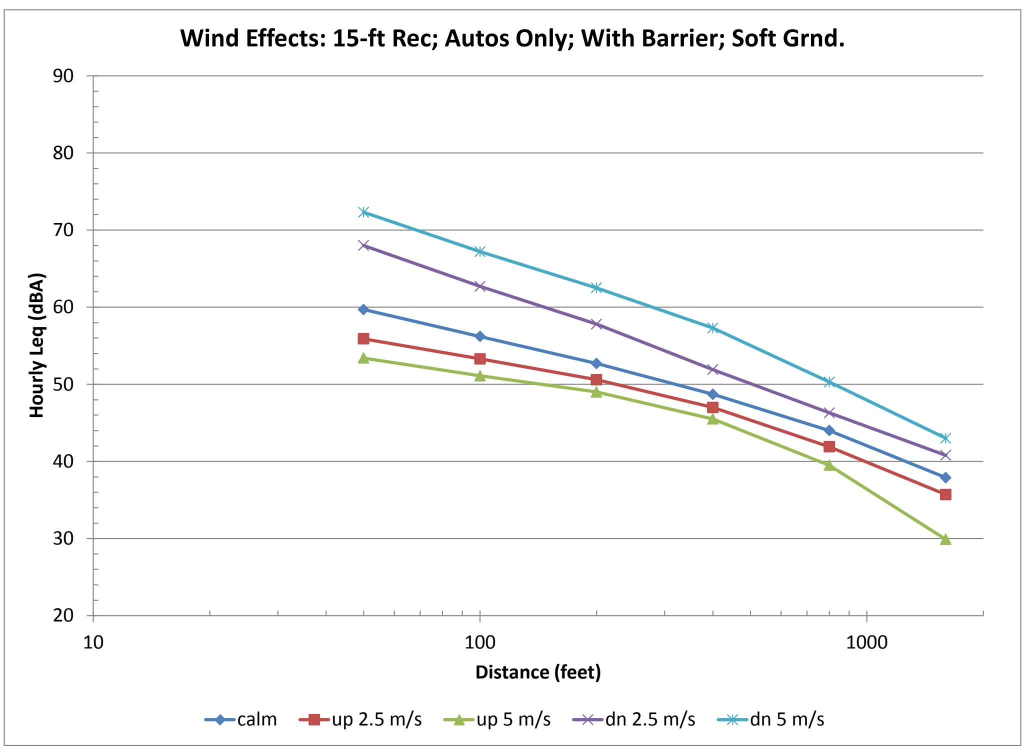

Figure 57 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

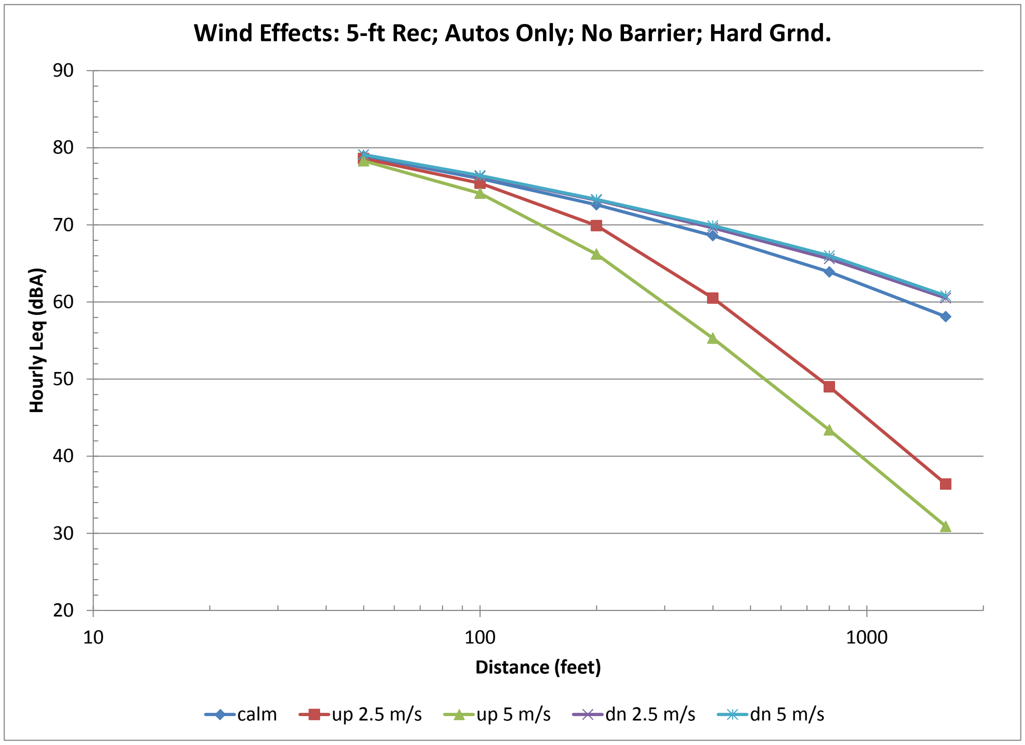

Figure 58 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

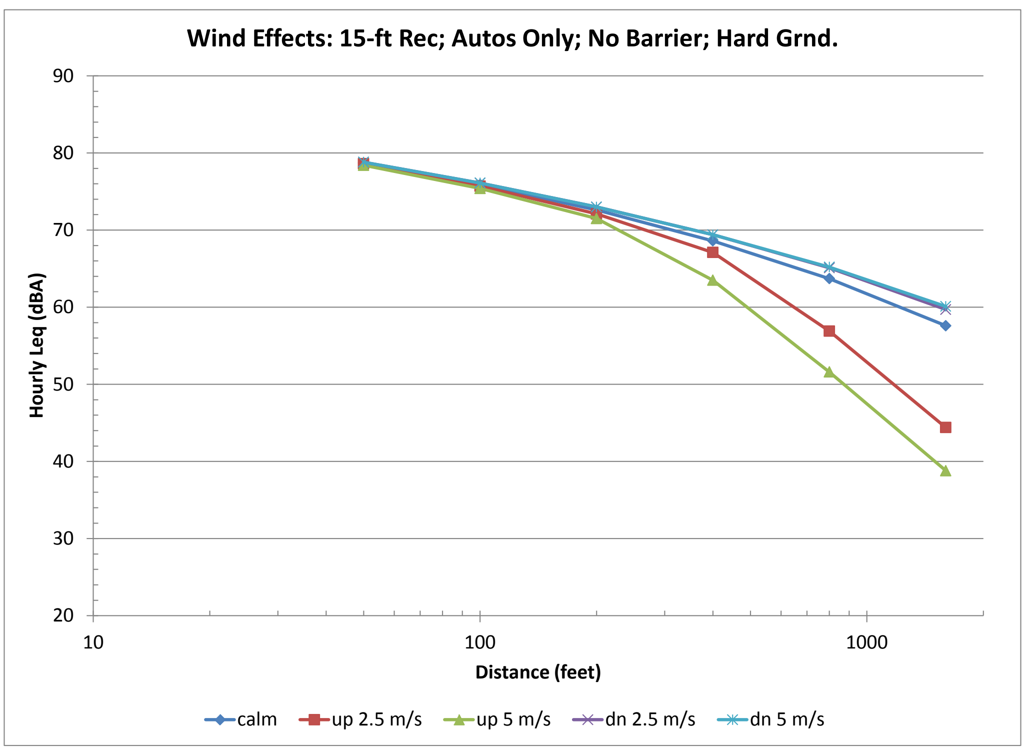

Figure 59 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

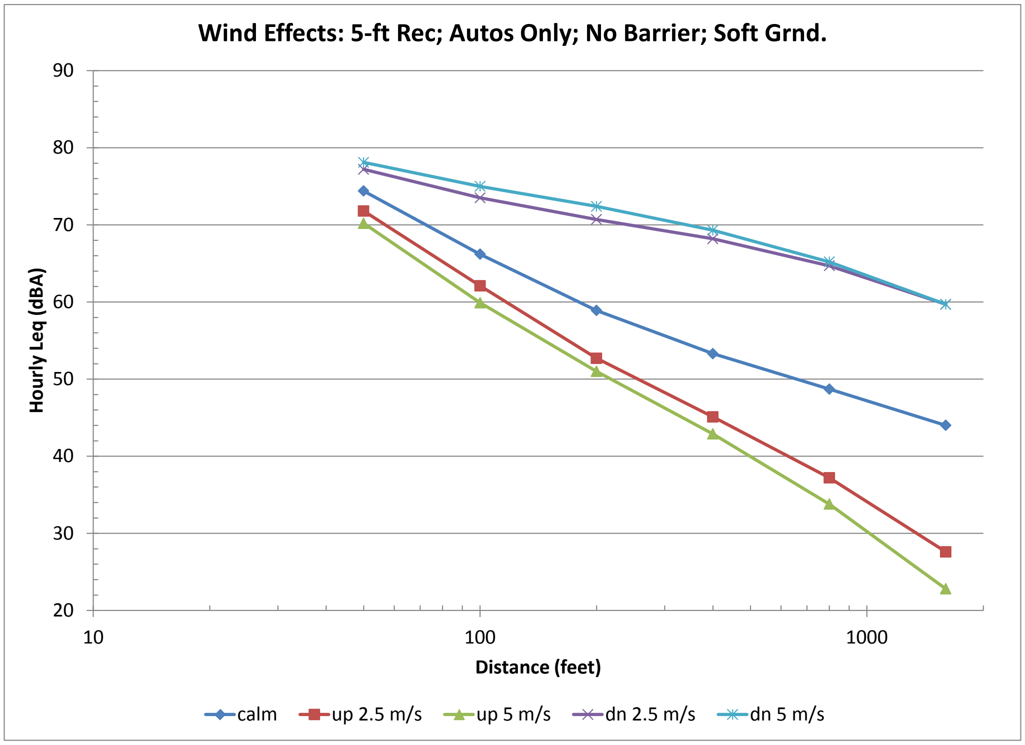

Figure 60 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

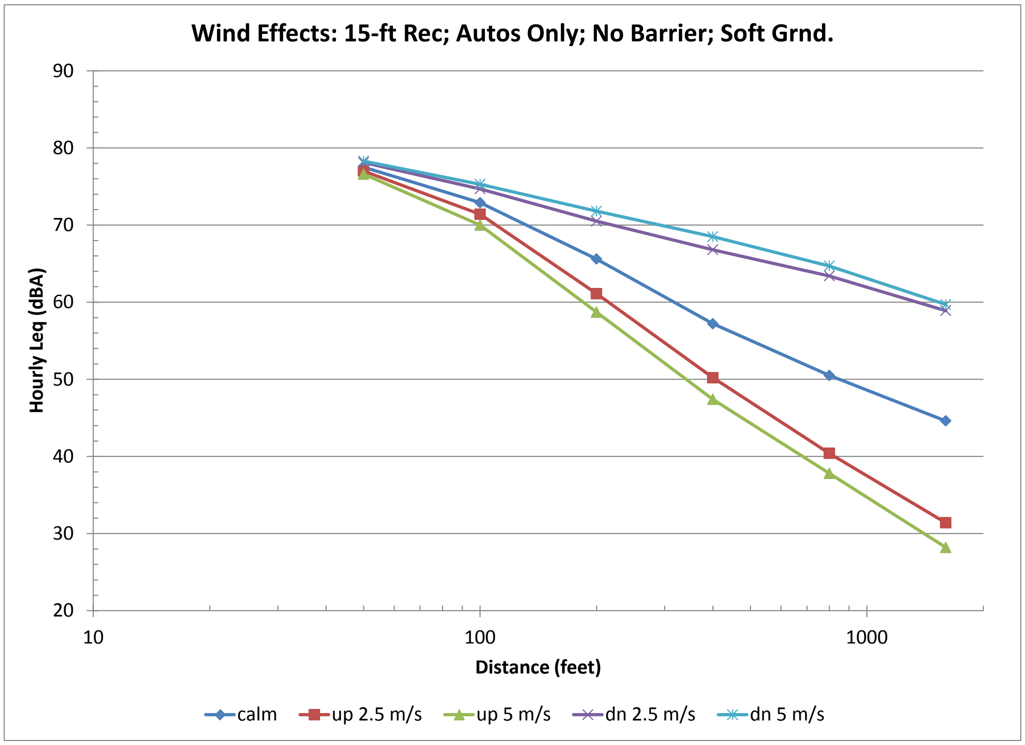

Figure 61 Hourly Sound Level (L_{eq}) with Varying Wind Conditions

J.4.8 Hourly Sound Level (L_{eq}) for Varying Temperature and Calm Conditions with Autos Only

The graphs below include combinations of parameters that were modeled for varying temperature gradients relative to calm conditions. The input model included only autos on the source roadway. Results are included for both 5-foot and 15-foot receiver heights, propagation over both hard and soft ground, and include results with and without a noise barrier.

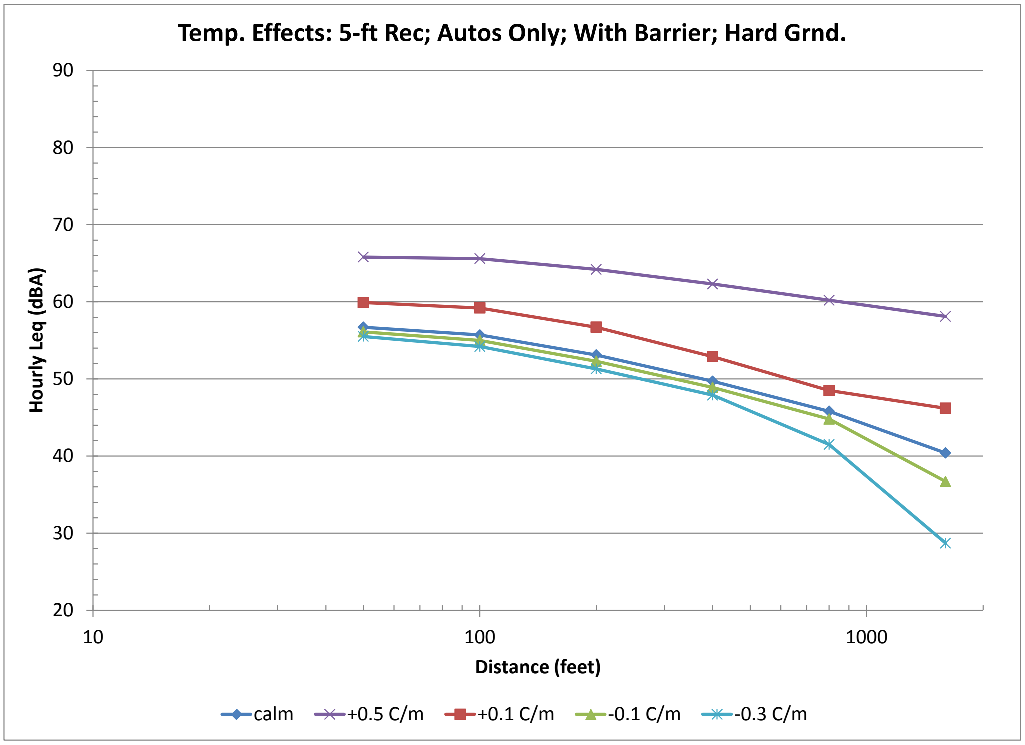

Figure 62 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

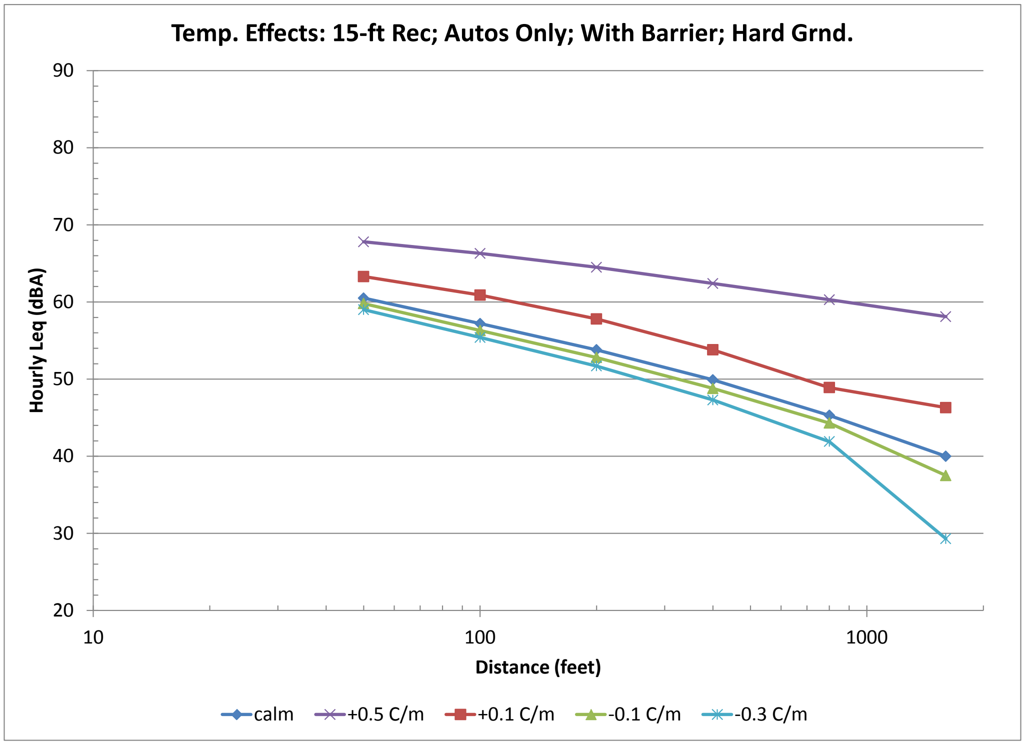

Figure 63 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

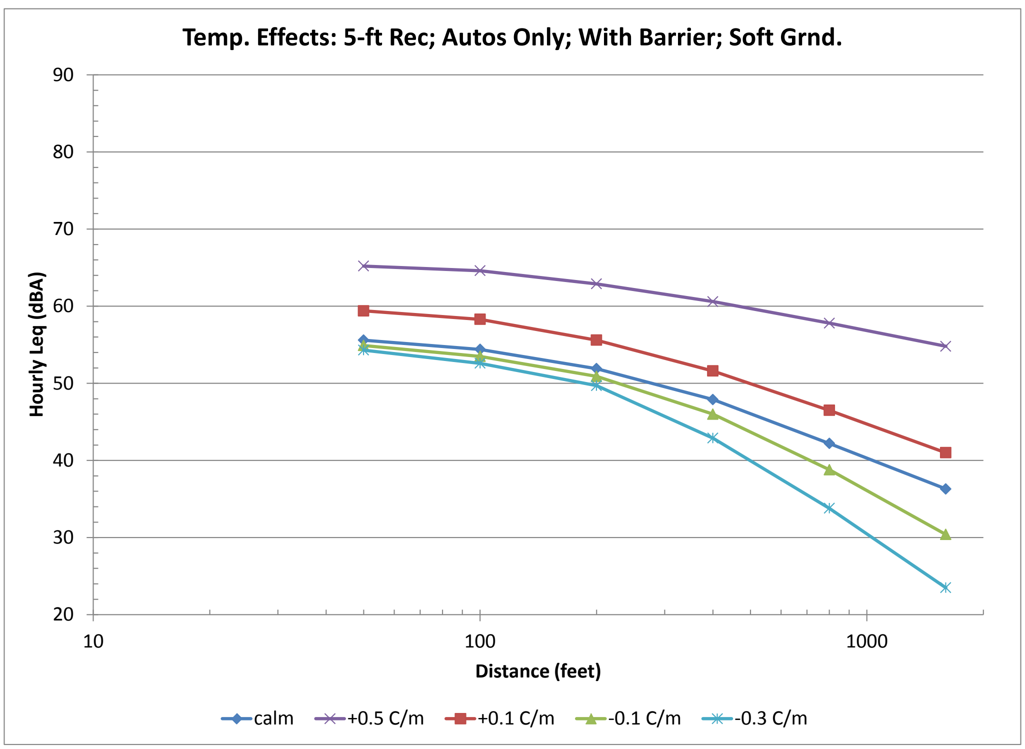

Figure 64 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

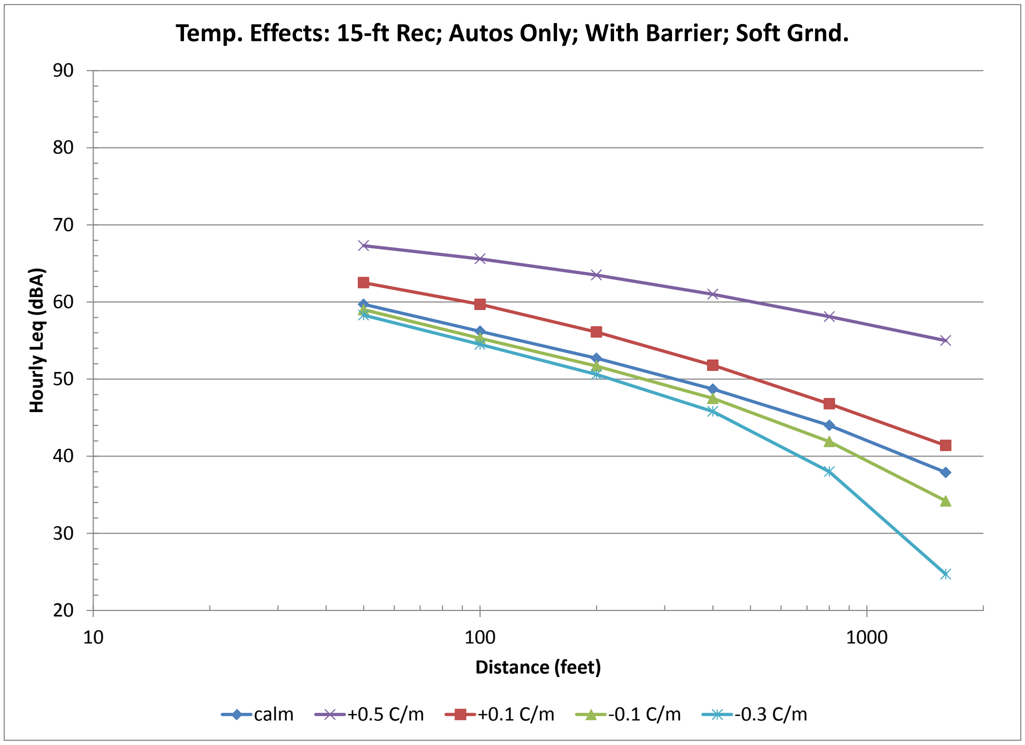

Figure 65 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

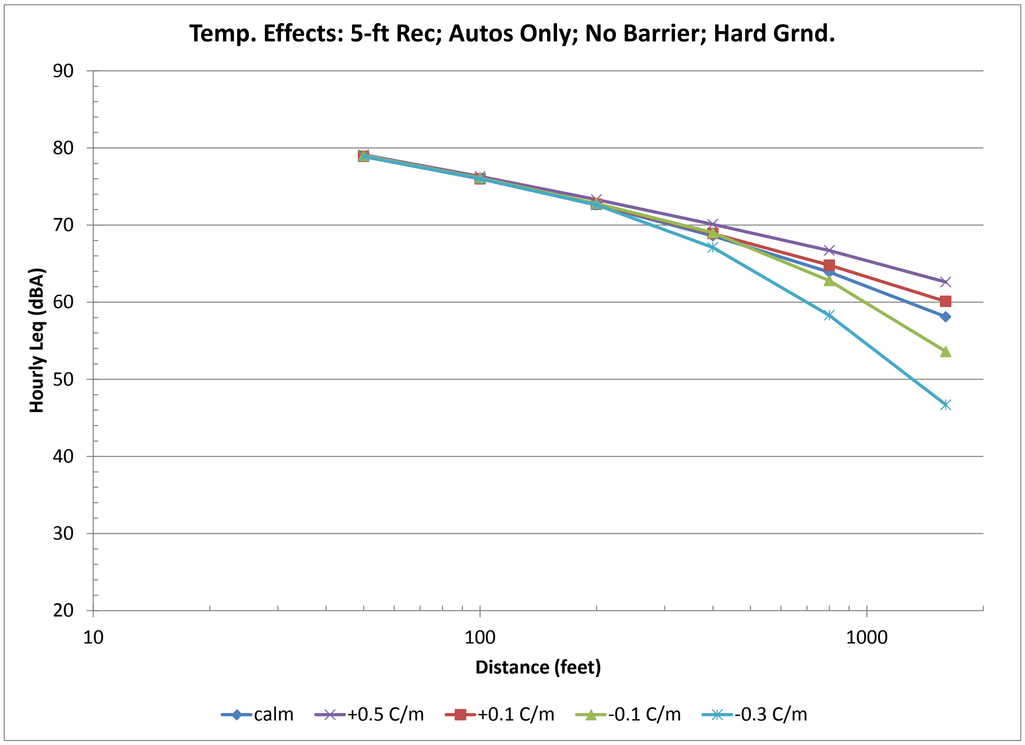

Figure 66 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

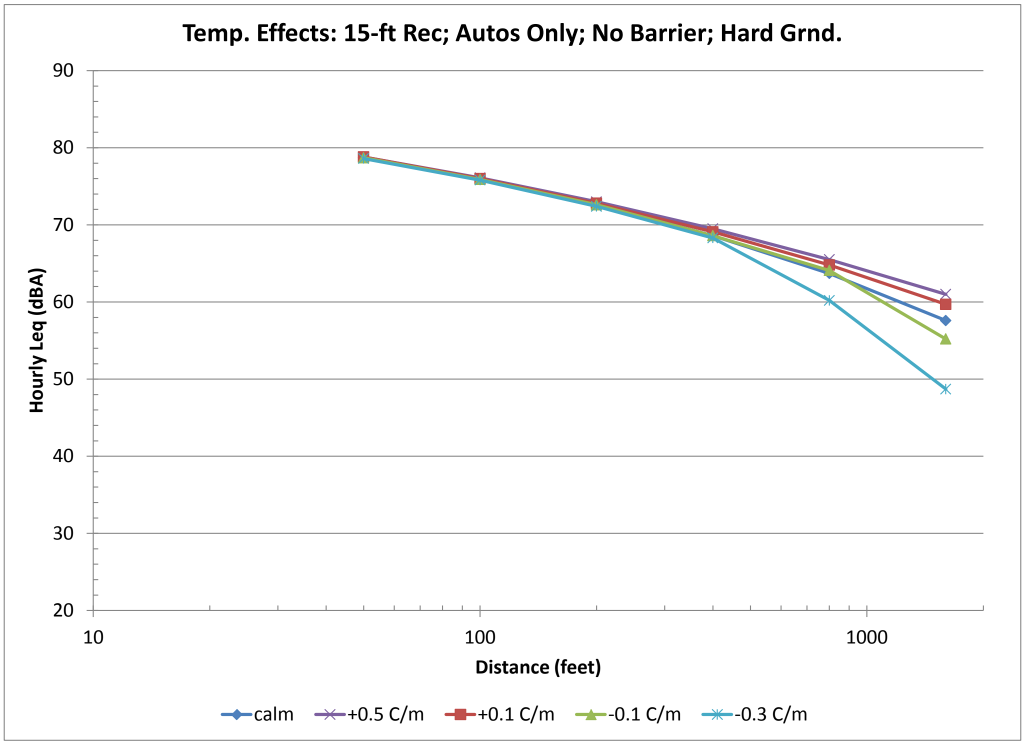

Figure 67 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

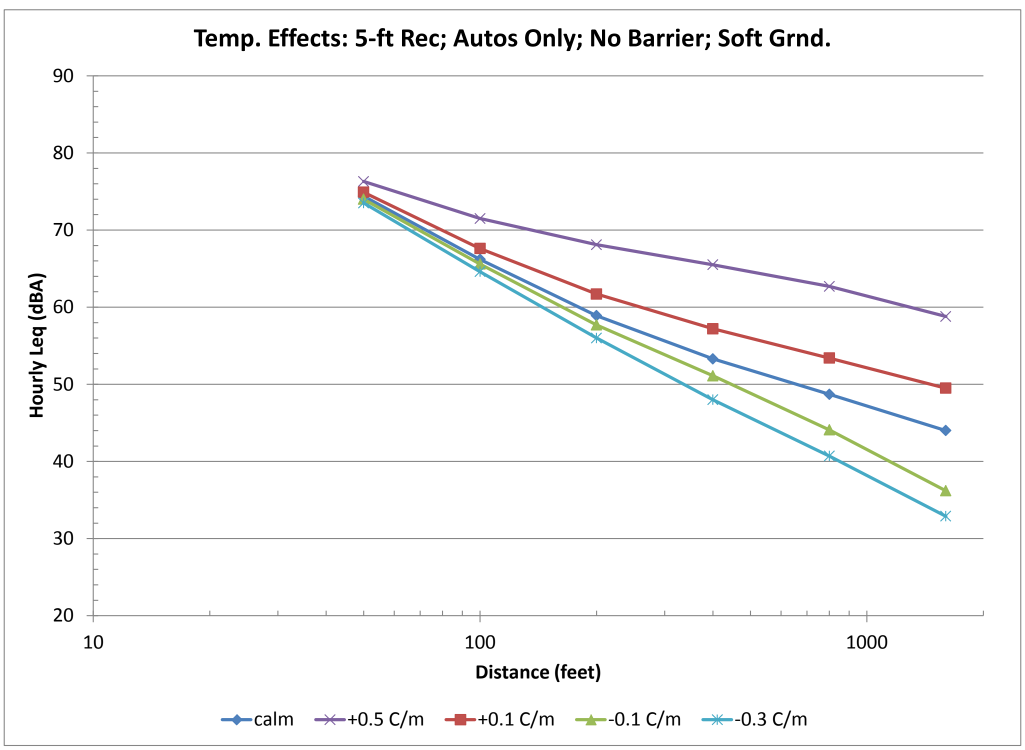

Figure 68 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

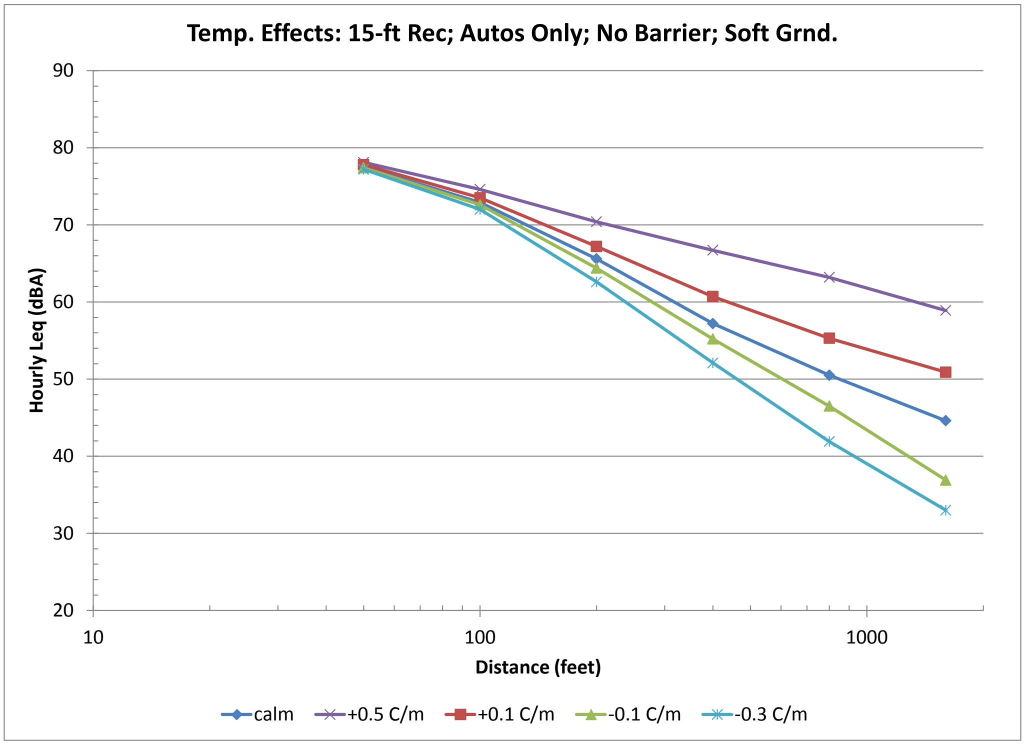

Figure 69 Hourly Sound Level (L_{eq}) with Varying Temperature Conditions

J.5 Combined Effects of Wind and Temperature Gradients on Highway Noise Source

It was not practical to model all the various combinations of wind and temperature conditions against one another. However, some combinations of moderate temperature inversion and lapse conditions were modeled with various wind speeds and directions. The combined effects were only modeled with autos and trucks on the source roadway.

Figures 70 through 77 below show the sound level difference between the combined wind and temperature conditions and calm conditions. Each graph shows the results with one modeled temperature gradient (either +0.1°C/m or -0.1°C/m), at four different wind speeds.

Figures 78 through 85 below show the hourly sound level (L_{eq}) with the combined wind and temperature conditions. Each graph shows the results with one modeled temperature gradient (either +0.1°C/m or -0.1°C/m), at four different wind speeds.

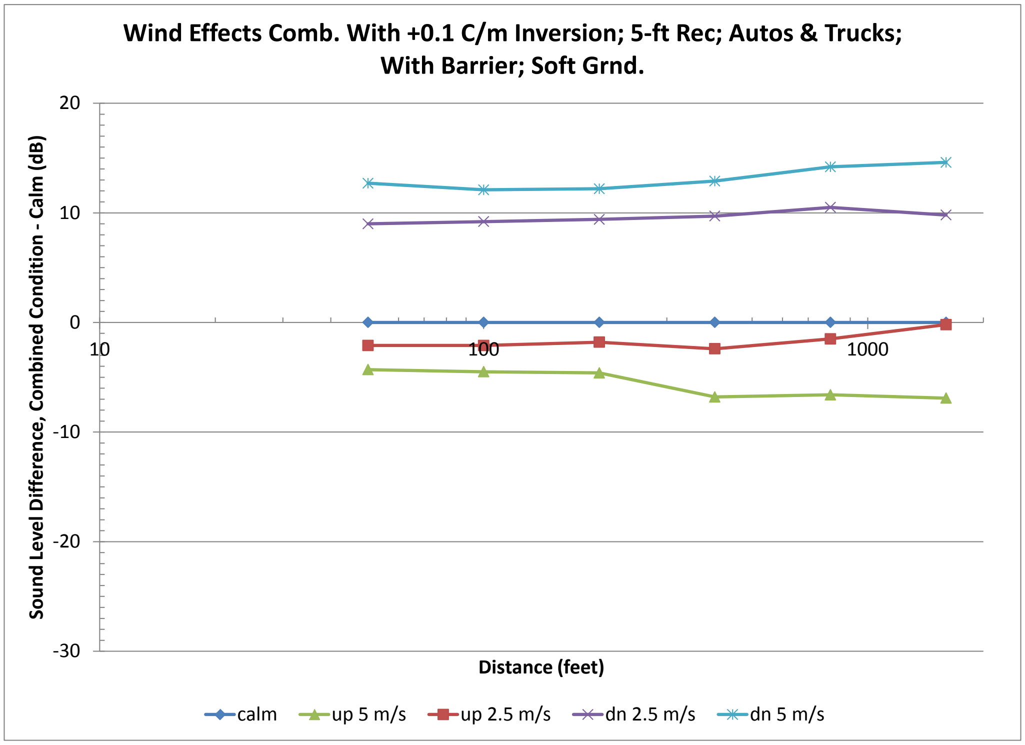

Figure 70 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

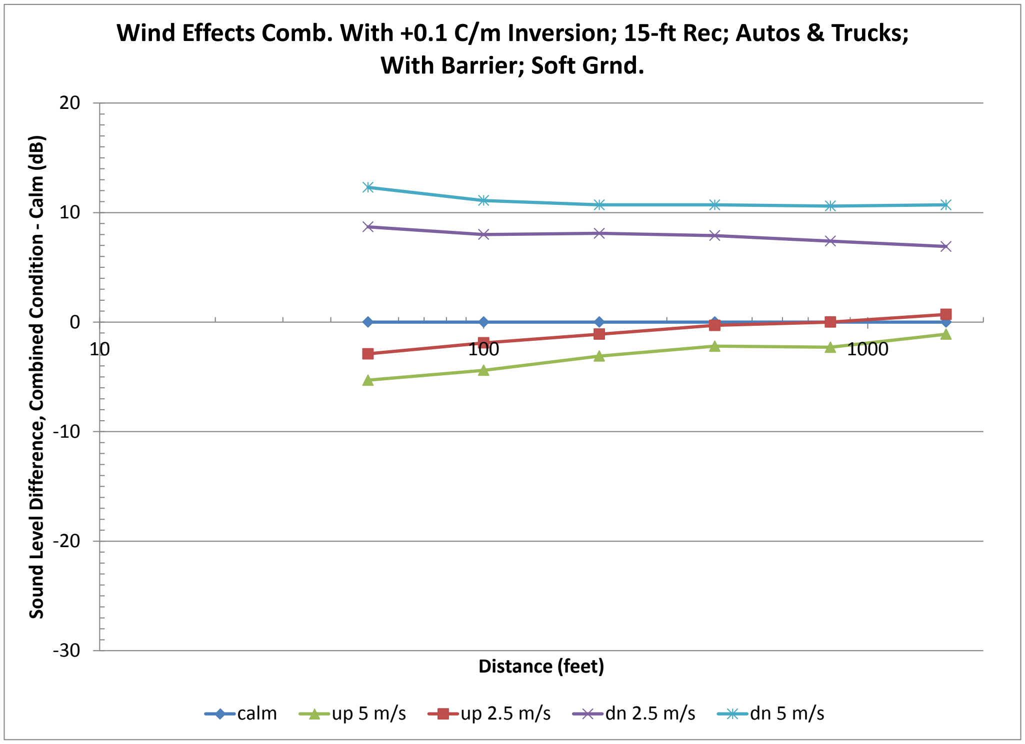

Figure 71 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

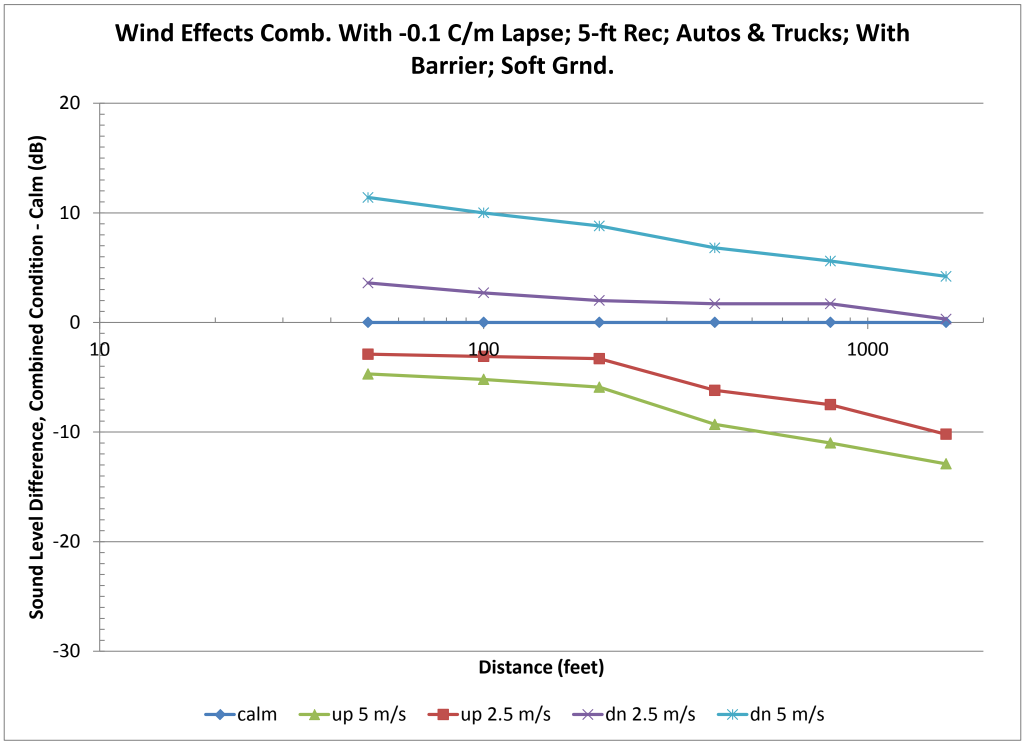

Figure 72 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

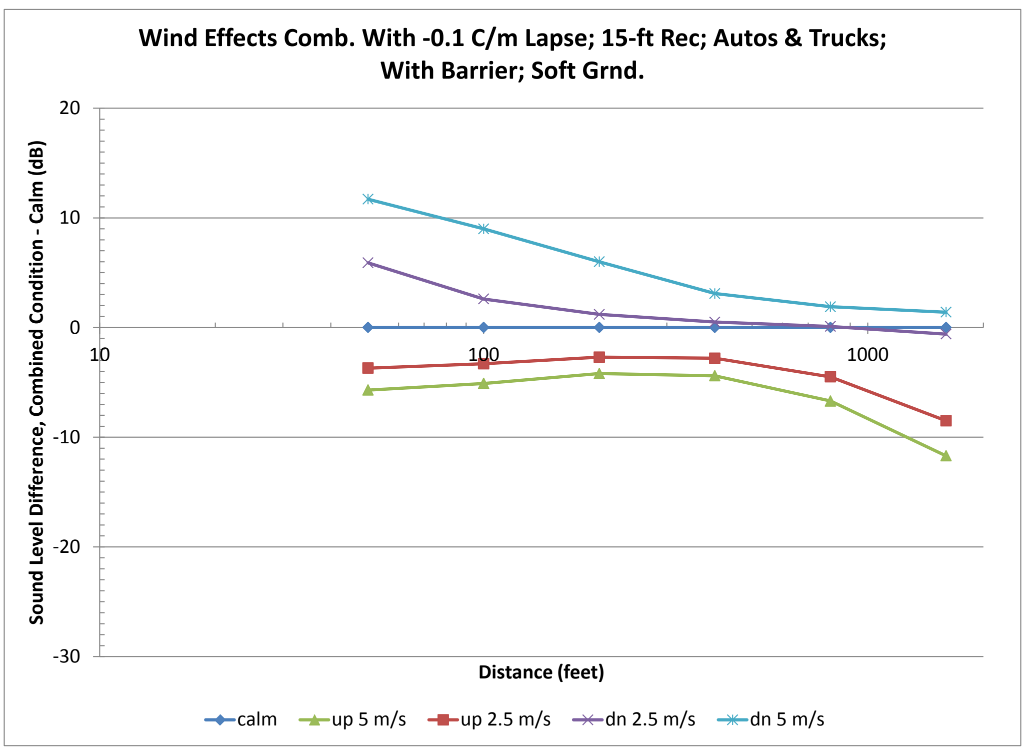

Figure 73 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

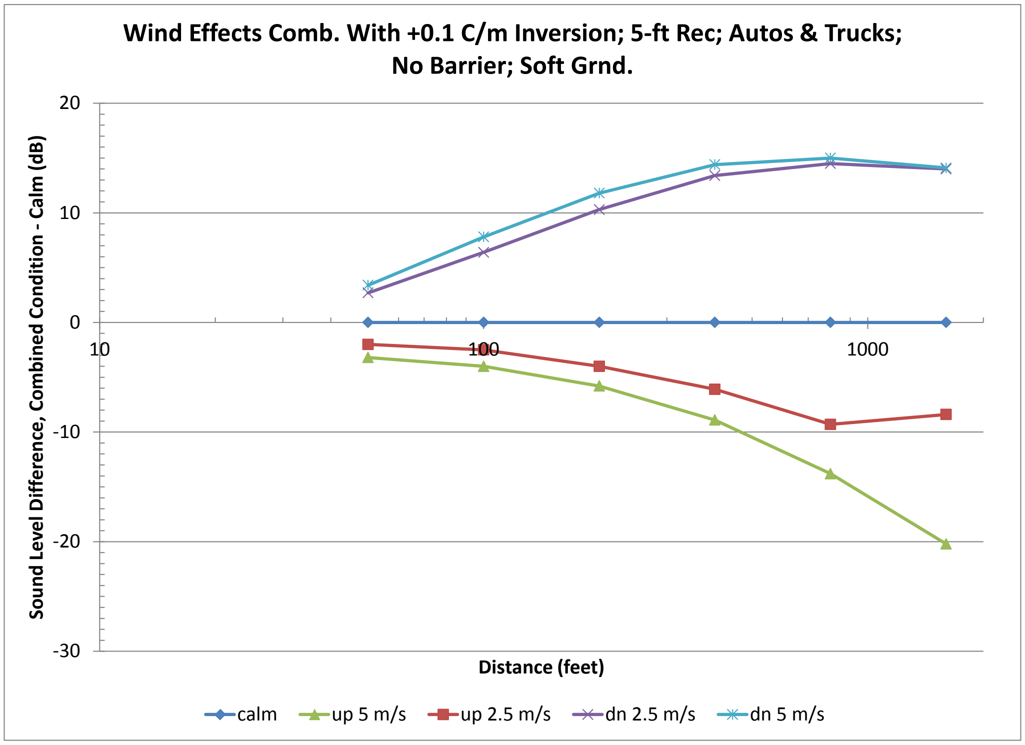

Figure 74 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

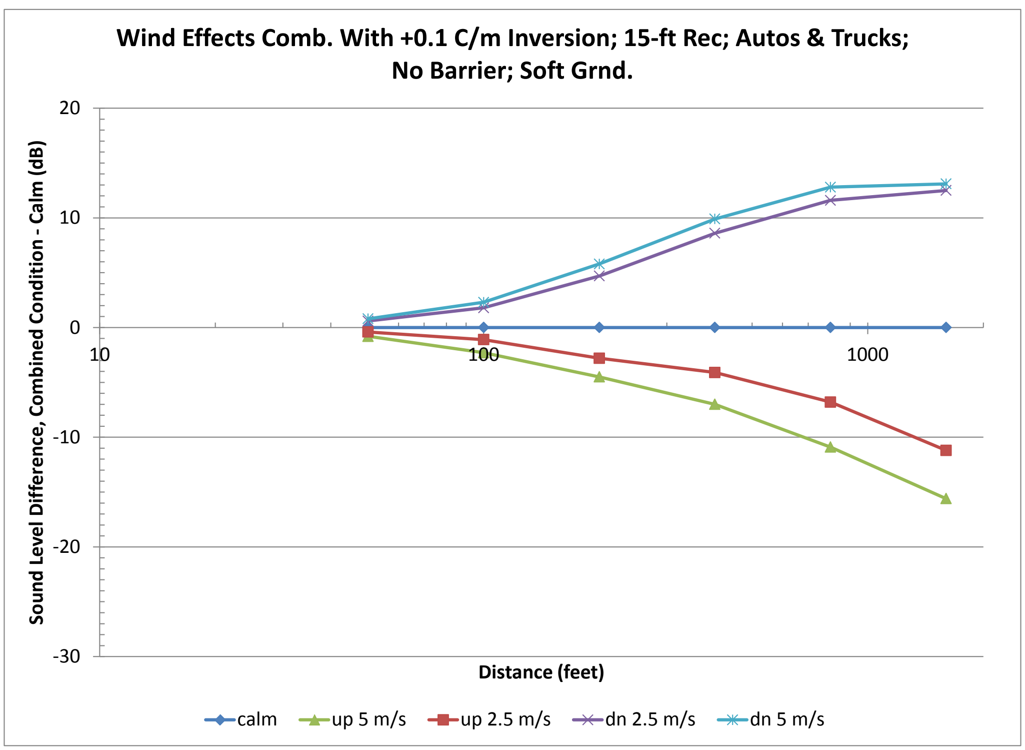

Figure 75 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

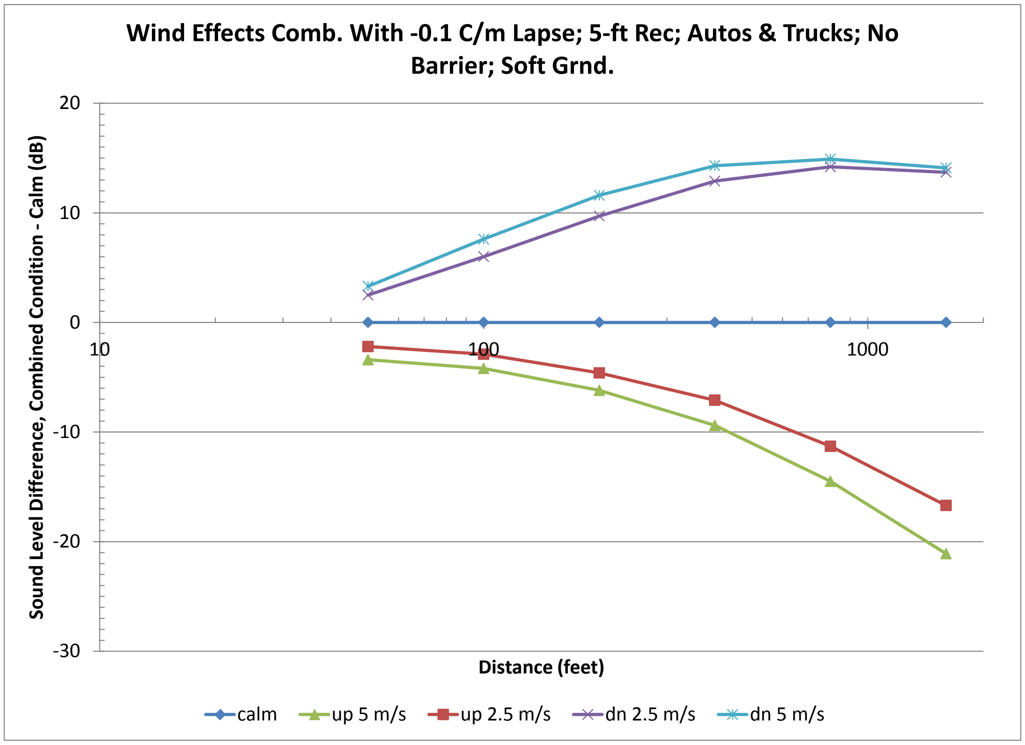

Figure 76 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

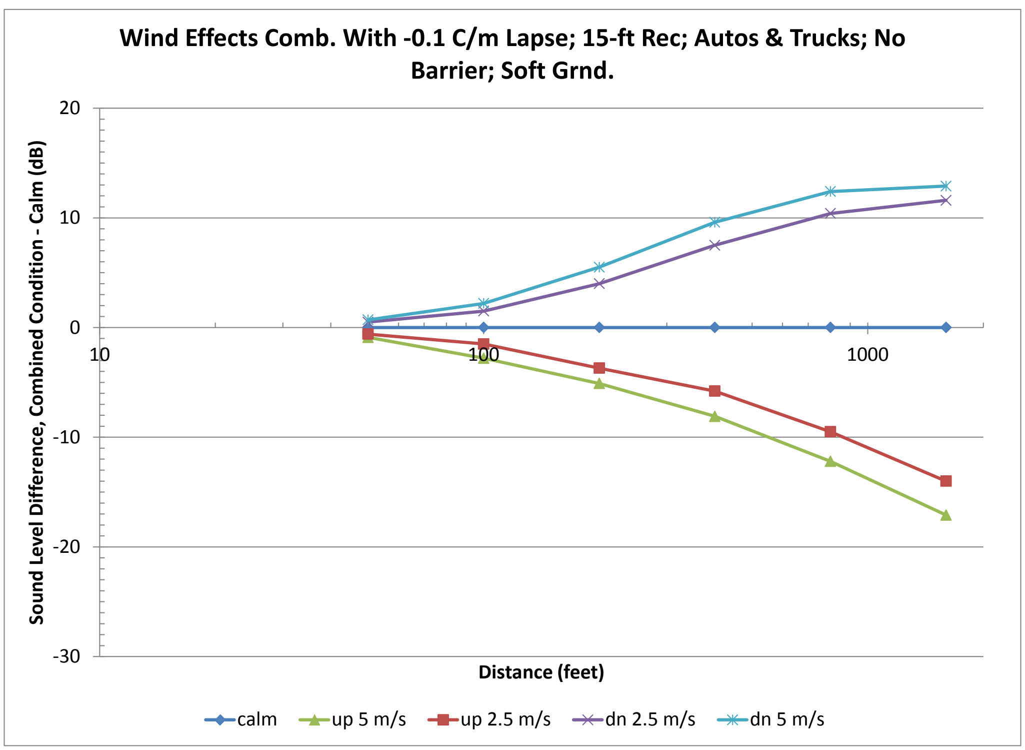

Figure 77 Sound Level Difference between Combined Wind and Temperature Conditions and Calm Conditions

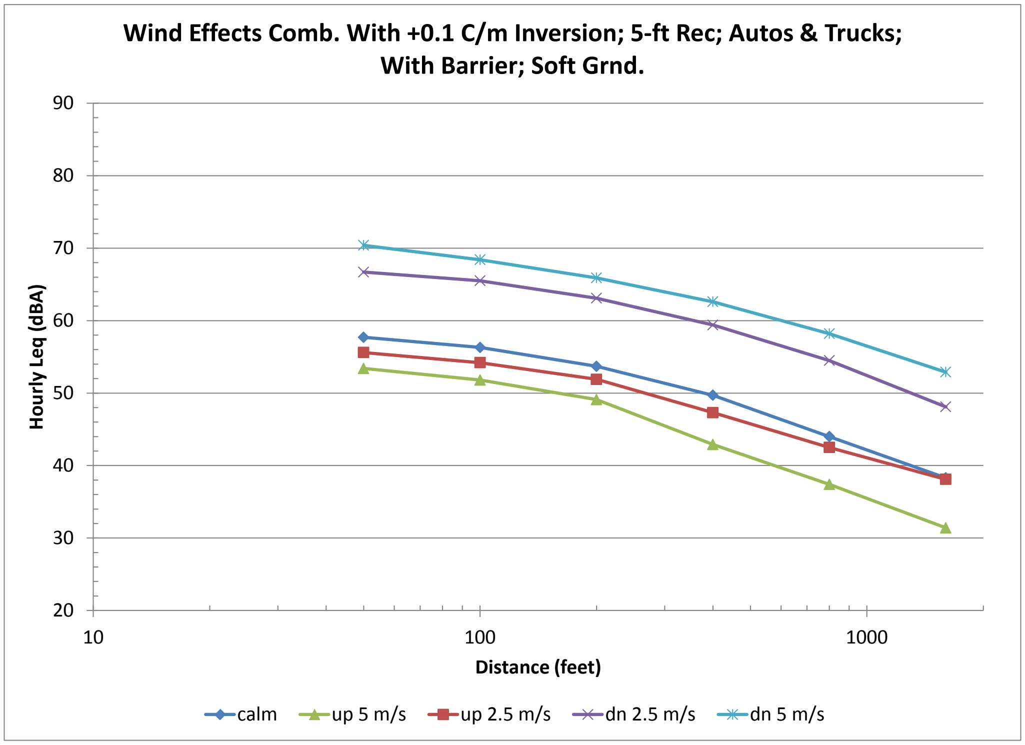

Figure 78 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions

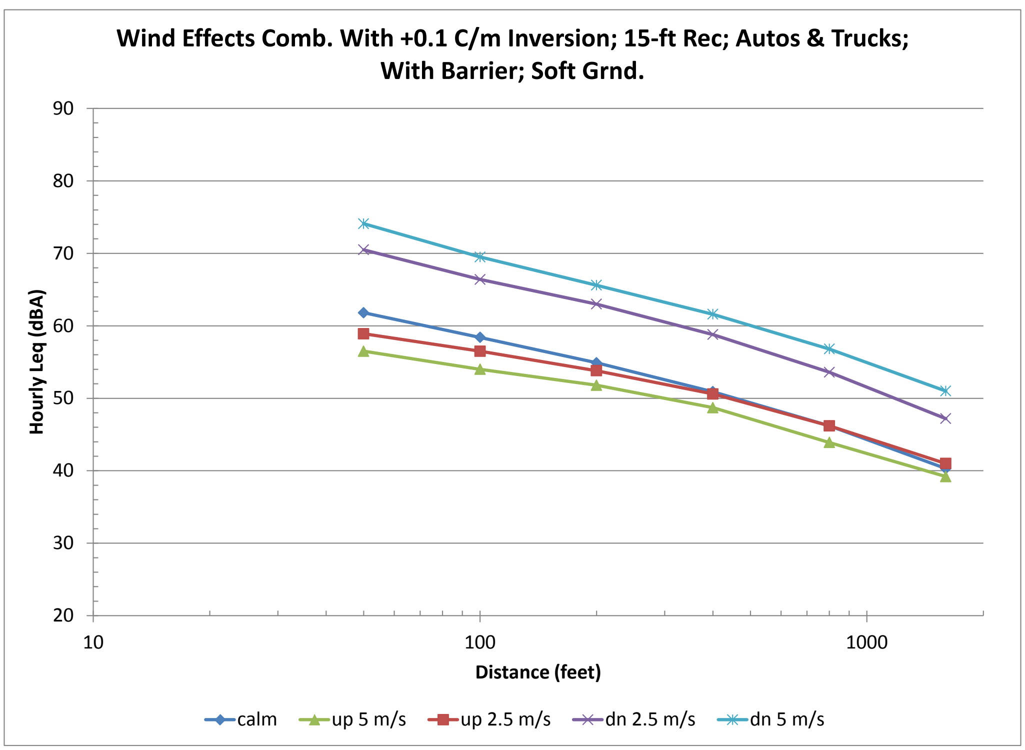

Figure 79 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions

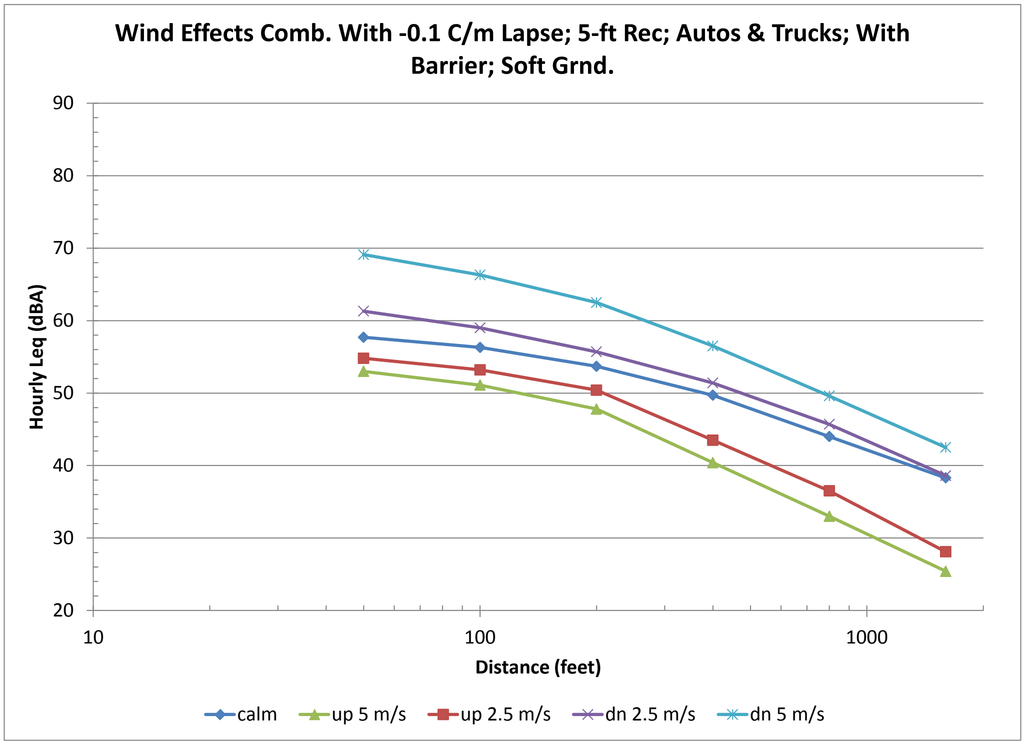

Figure 80 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions

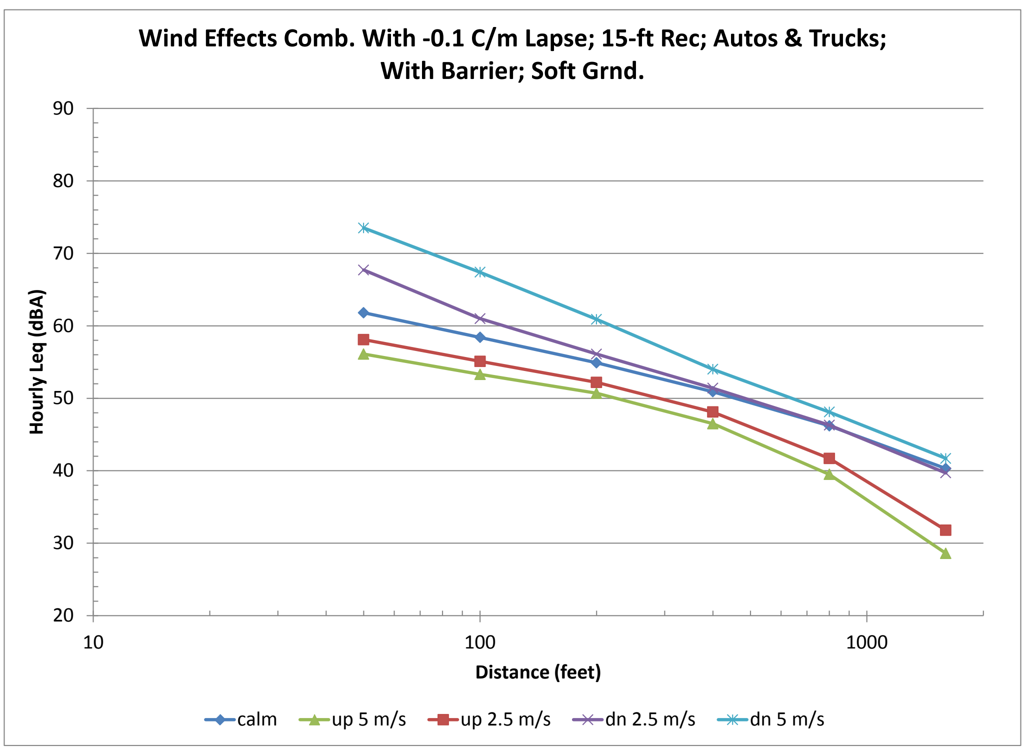

Figure 81 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions

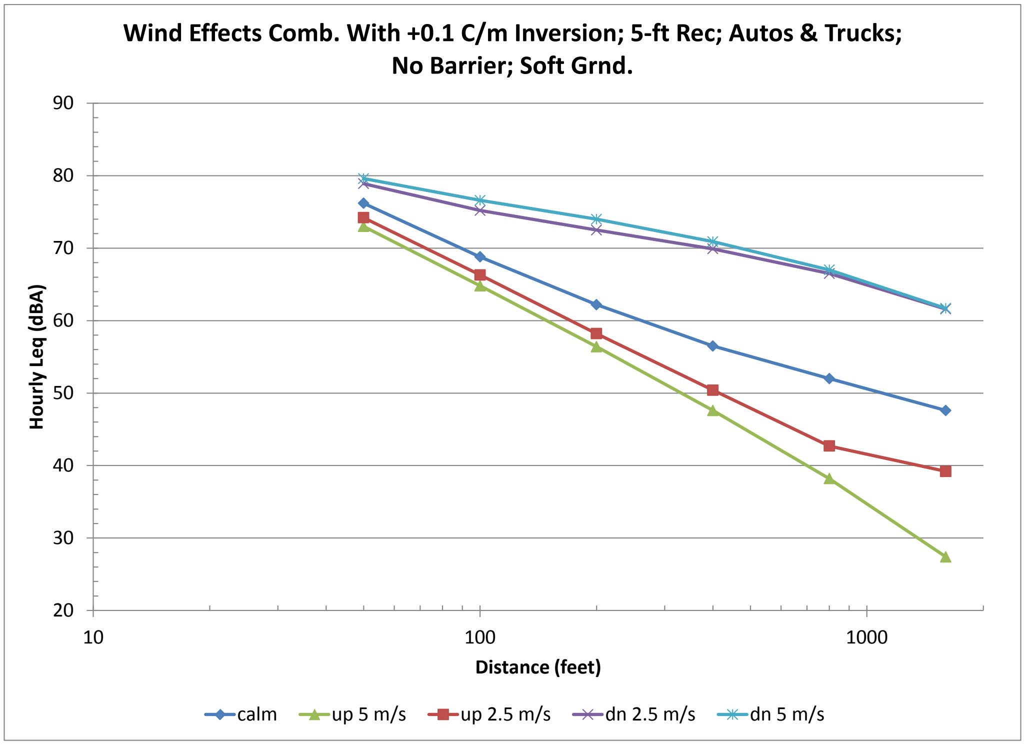

Figure 82 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions

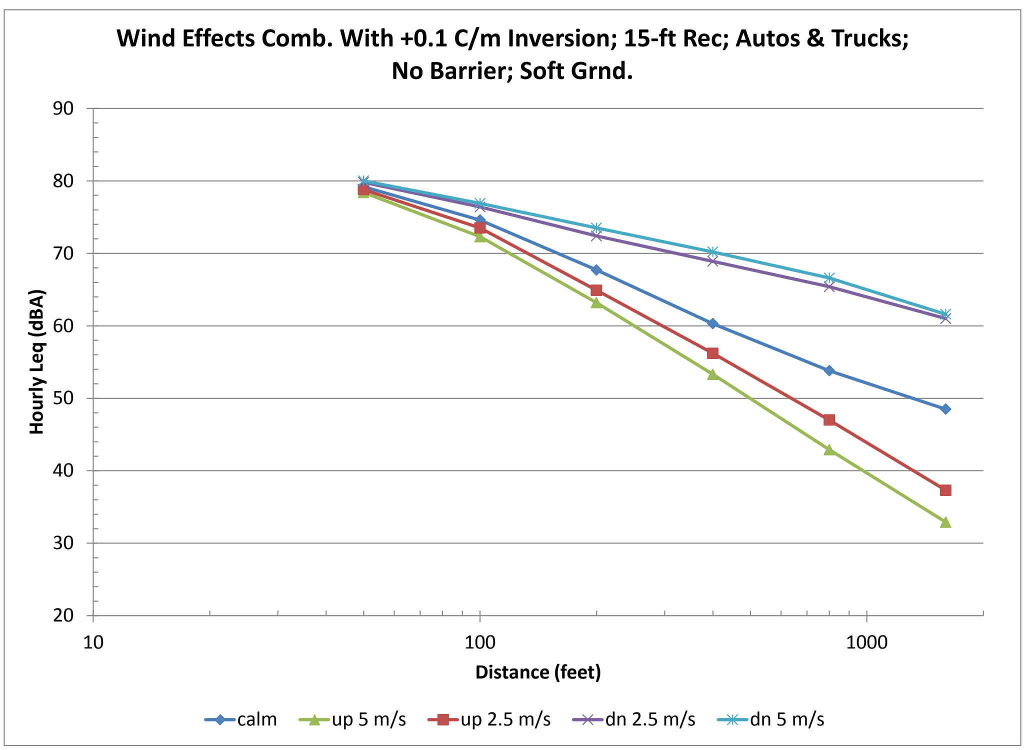

Figure 83 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions

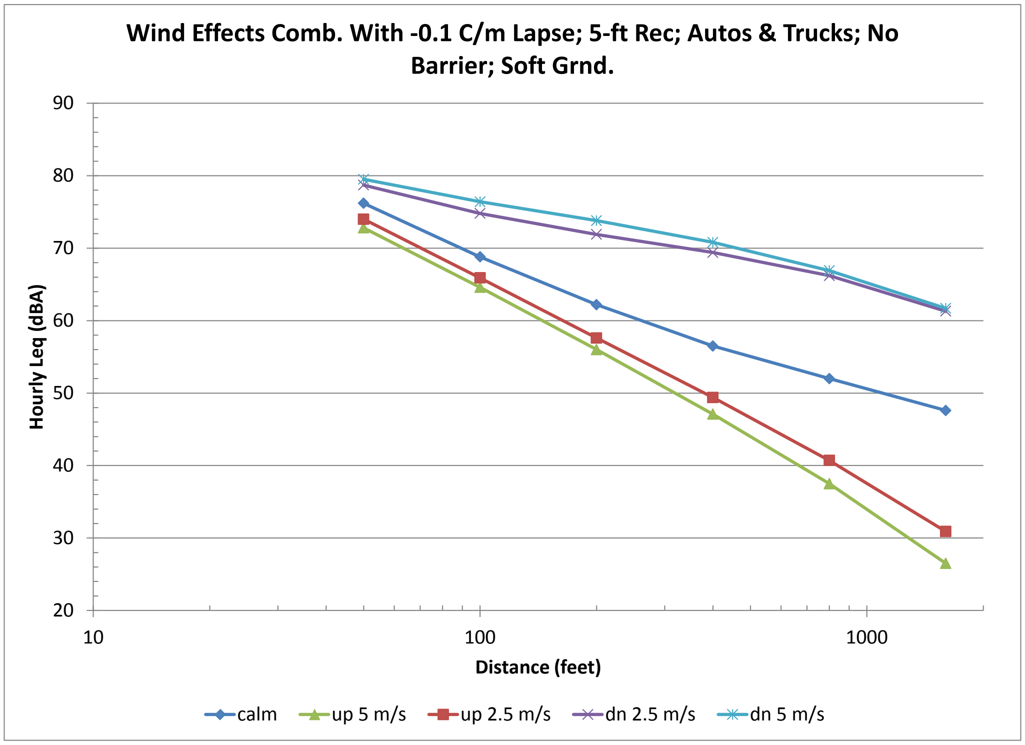

Figure 84 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions

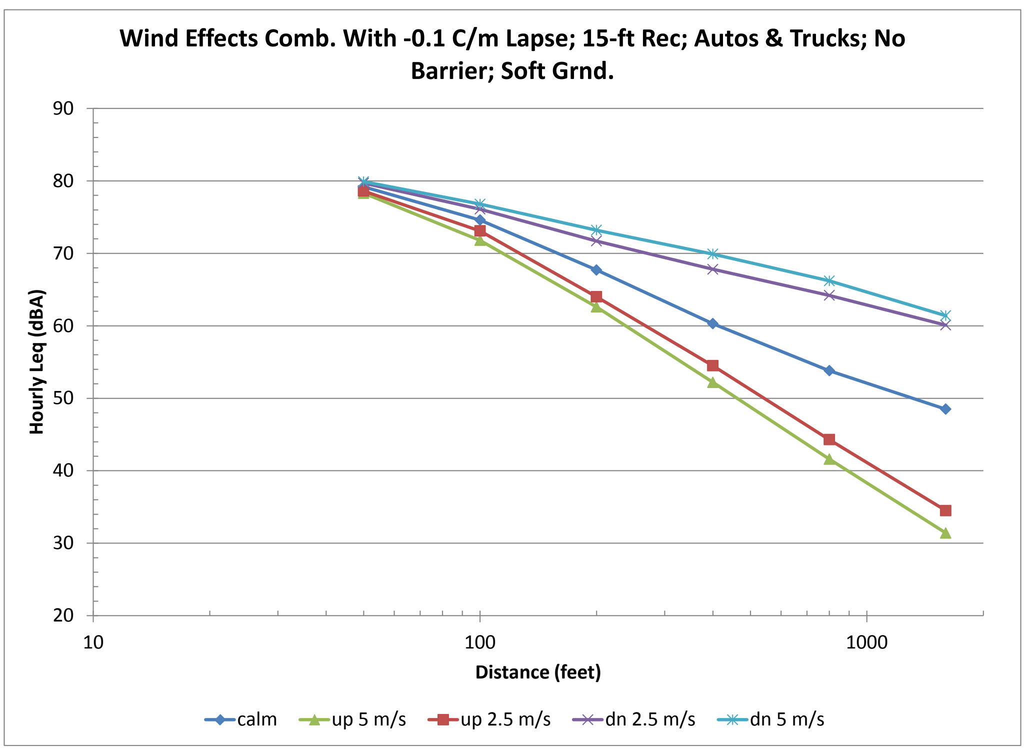

Figure 85 Hourly Sound Level (L_{eq}) with Combined Wind and Temperature Conditions