Highway Noise Levels in a Suburban Environment

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Noise levels were measured near a major highway in the suburban region near Phoenix, Arizona, USA during a two week period in March, 2004 to identify the reasons for increased noise levels during early morning hours. The noise levels were accompanied by meteorological measurements as well as traffic counts to fully describe the problem. The noise levels were measured in one-third octave bands and ranged 100 ft. to 2620 ft. (30 - 800m) from the highway and included data on both sides of the highway to discriminate symmetric temperature effects and asymmetric wind effects. The meteorological data indicated inversion conditions or downward refraction during the times of interest and model results from a Parabolic Equation (PE) calculation indicated good agreement with the data. The data and model indicated an approximately 10-15 dB increase in levels during inversion conditions, as compared to neutral, which rapidly transitioned to neutral and lapse conditions shortly after sunrise. The results of the modelling effort as well as the data will be presented. (Work supported by the State of Arizona Department of Transportation).

1   Introduction

Highway noise levels can vary widely with atmospheric conditions, a factor which most highway noise prediction models do not incorporate [1-4]. The implicit assumption of the current version of the FHWA Traffic Noise Model (TNM Version 2.5) is a uniform (isothermal) atmosphere with no wind; conditions far from the real world of ever changing weather. However, it is a reasonable assumption within a few hundred feet of a highway and generally representative of typical or average conditions. It has long been understood that wind and thermal gradients cause refractions (bending) of sound waves that can result in substantially higher or lower sound levels than under low-wind, isothermal conditions. The primary goals of this study were to develop insights on how and when atmospheric conditions in the Phoenix valley cause higher than normal levels of highway noise and to provide ADOT with guidelines that can be used to anticipate these conditions.

The physics behind wind and thermal gradients causing higher than normal sound levels are well understood. However, the differential equations that describe sound propagation under realistic atmospheric conditions must be solved numerically and it is often difficult to obtain the detailed atmospheric data required for accurate predictions. It is only recently that researchers have been successful in developing accurate projections of some common sound focusing effects. With modern computing power and numerical methods of solving the differential equations plus new equipment that facilitates detailed atmospheric measurements, it is becoming more and more feasible to develop realistic projections based on measured atmospheric conditions.

The Phoenix valley is characterized by light winds, clear skies, and, for approximately 70% of the time, relatively weak synoptic flow[1] conditions. On a typical clear sunny day, solar radiation heats the ground, which in turn heats the air in contact with the ground. The result is that the warmest air is at ground level and air temperature tends to decrease with elevation. This is referred to as a temperature *lapse*. After sunset, the ground cools faster than the air causing air temperature to increase with elevation. Air temperature increasing with elevation is referred to as a temperature *inversion*. Temperature lapse during the daytime and inversion at night is the typical pattern for the Phoenix valley. A temperature lapse causes sound waves to bend up creating a sound shadow and a temperature inversion causes sound waves to bend down and increase the sound at the ground level.

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[1] *Synoptic* flow is defined as the large scale meteorological patterns on a scale of 1000 km or greater.

2 Field Measurements

The noise measurement program consisted of measurements at four locations over a two week period in March 2004 whose primary purpose was to document diurnal sound level fluctuations and correlate the fluctuations to atmospheric conditions. The measurements included continuous noise measurements at four sites, three west of the Pima Freeway and one east of the freeway, monitoring of temperature at intervals of 1.7 m (5.5 ft) from 1.5 m (5 ft) to 13.3 m (43.5 ft) above ground level, and wind speed and direction at 2.1 m (7 ft) and 13.7 m (45 ft) above ground level. Figure 1 provides an aerial photograph and sketch showing the noise measurement locations. The area is quite flat with the overpasses at Indian School and Chaparral the only significant changes in roadway elevation. The open land is all part of the Salt River Pima-Maricopa Indian Community (SRPMIC). The fields were freshly plowed in March 2004 at the start of the measurements. The Scottsdale residential area west of the freeway is single family houses, most of which are single story. This area was selected for the noise testing because the flat terrain and straightforward geometry minimized the number of non-atmospheric parameters that might affect sound propagation, and, perhaps more importantly, because there had been complaints about high noise levels from the Scottsdale community west of the freeway. Previous spot-check noise measurements in response to the complaints had found sound levels between 6 AM to 7 AM to be 64 to 68 dBA (10-minute Leq). The measurement sites, and types of measurements performed at each site are shown in Figure 2

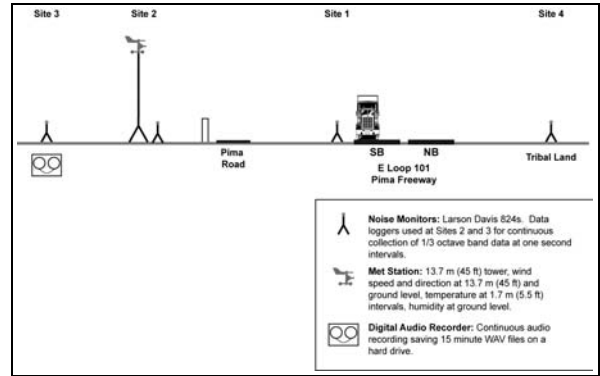Figure 1: Arial photograph of noise measurement area

Figure 2: Sketch of noise monitoring geometry

The field equipment used for the measurements included continuous noise monitoring at all four sites. A-weighted and 1/3 octave band data were collected at 1-second intervals at Sites 2 and 3 and at 15-second intervals at Sites 1 and 4. Continuous audio recordings were also made at Site 3 to allow verifying whether or not specific periods were traffic noise or another noise source. Meteorological monitoring was performed at Sites 2 and 3. The meteorological data collected at Site 2 included wind speed and direction at elevations of 13.3 m (43.5 ft) and 2.1 m (7 ft) plus air temperature at 1.7 m (5.5 ft) intervals from 1.5 m (5 ft) to 13.3 m (43.5 ft). The Site 2 meteorological data were collected at 15-second intervals. In addition, ground level temperature and humidity data were collected at Site 3 at 15-minute intervals. Continuous counts of traffic and measurements of speed were made on the Pima Freeway. This information was provided by another ADOT consultant (Traffic Research & Analysis, Inc.) using a radar system. The traffic count data consisted of volumes, average speed, and the traffic distribution between autos and heavy trucks at 15-minute intervals. The traffic counts did not start until the second week of the Phase 1 measurements. All of the noise monitoring was performed with Larson Davis Model 824 sound level meters equipped with the 1/3 octave band option.

3 Field Data

One can observe the noise levels measured in Figure 3. The noise levels at site 1, the highway, were fairly consistent except for lulls in the afternoon as the evening commute commenced and in the late evening as traffic levels dwindled. One can also note the elevated levels in the early morning hours before sunrise as the inversion condition is established and the transition to lapse after sunrise at approximately 7:00 AM. One cans also note the approximately 65dBA typical levels in the neighborhood which would form the basis of complaints.
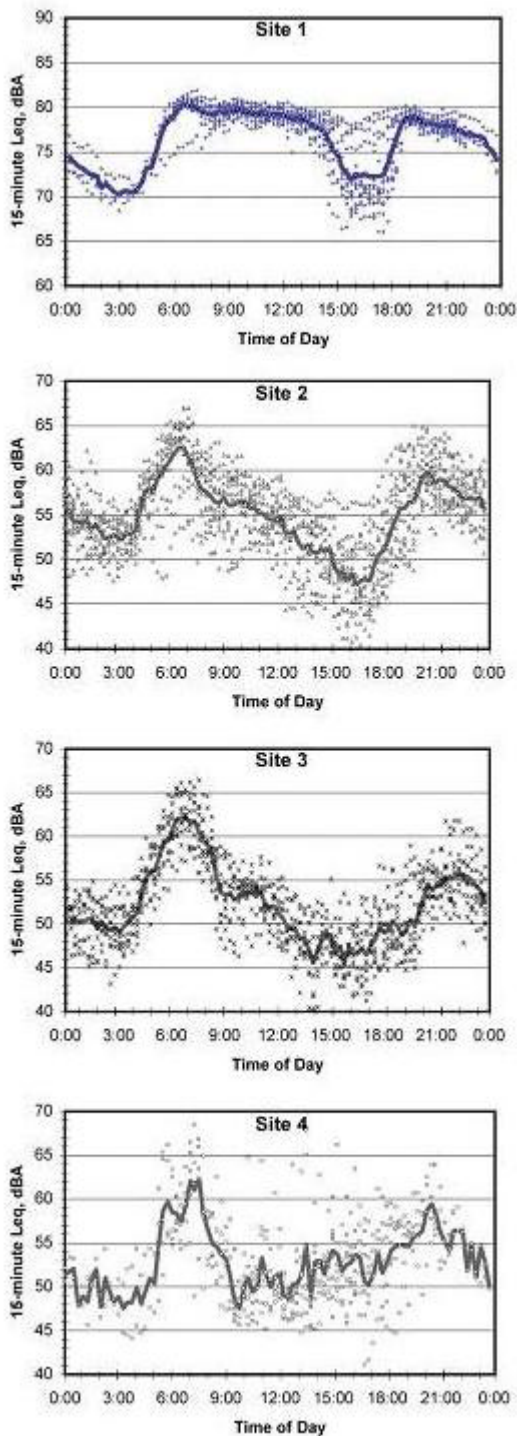
Figure 3: 15 minute Leq data for March 8-22, 2004 all data and mean levels

One can also observe the wider scatter in the data at Site 4. Sites 2 and 3 are west of the highway and are downwind so the downward refractive wind and temperature inversion effects are additive. Site 4 is east of the highway so the downward refractive inversion effects from the temperature are in competition with the upward refractive effects of the wind.

4 Modelling Efforts

The current state-of-the-art in propagation modelling is the Parabolic Equation with Greens Functions, identified as the GF-PE. [5,6] This technique makes a stepwise calculation of the sound field as it propagates outward from the source. It assumes that the sound wave from a source is always directed outwards and solves a two-dimensional Helmholtz wave equation with this constraint. It can use specific sound speed profiles at each range step. However, a sound speed profile is normally measured for average conditions at one location, and often not within the sound propagation field. This average condition is then used for each range step. This is the model that we have used to analyze the effects of atmospheric conditions on sound propagation in this study.

Discussions with staff of the Arizona Department of Environmental Quality (ADEQ) indicated that while copious amounts of meteorological data and analysis have been collected and conducted in the Phoenix area, the majority of it was for heights of 200 m and higher in pursuit of macroscopic meteorological phenomena. A general rule of thumb in acoustic work is that metrological conditions up to approximately 10-20% of the desired propagation range are needed for proper analysis. For the range of approximately 1 km for the problem at hand, this indicated metrological data below 200 m was desired. Furthermore, while historical data is useful in analyzing general trends, acoustic propagation is linked with instantaneous metrological conditions and as such, a small meteorological station capable of measuring wind and temperature was set up in conjunction with the noise monitoring equipment. Detailed meteorological data was captured to a height of 13 m. For temperature effects, Stull's [7] Scaling analysis can be used to generate a reasonable profile to the appropriate altitude based on the ground temperature, gradient with height and some assumptions.

No significant wind effects were observed to a height of 13m. Discussions with the ADEQ staff, however, indicated that there is a "typical, time averaged" wind profile caused by daytime heating of air which forces air up into the mountains and drainage flow during the evening through early morning period which has air moving down into the valley. This drainage flow is, on average, east to west in the Scottsdale area where we performed the noise measurements.

As part of ADEQ's ongoing study of meteorology in the Phoenix valley, a study of wind speeds at an alternate location in the Phoenix Valley was conducted in January 2003. A snapshot of wind speeds below 200 m at 6 AM is presented in Figure 4 and has been used as part of this exercise. The wind data indicated some activity at a height of 30-60m. This elevation was

above our monitoring but low enough to affect the noise measurements. While the use of wind speeds from a different location and time is not an ideal solution, using this representative wind data and the temperature profile discussed above in the PE model allows testing of the sensitivity of the refracted sound field to realistic wind profiles. Substantial analysis indicated that the temperature gradients are sufficient to describe the overall diurnal sound level trends while the wind speeds act to provide local spatial and temporal variations about these mean levels
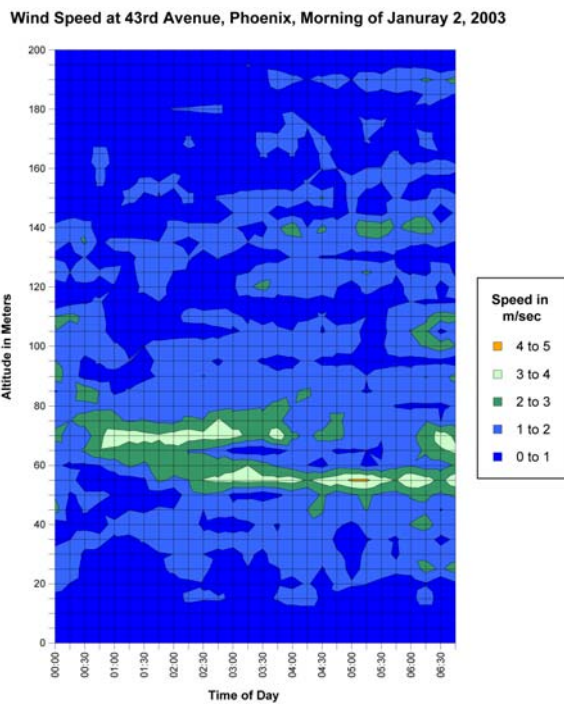

Figure 4: Wind speed at altitude from Phoenix area

Figure 5 (following page) shows the output for one case of the PE model run with a combination of the temperature and wind profile. Figure 5 shows the sample PE Output for the temperature profile combined with the downwind condition at a frequency of 1000 Hz. The upper left graph shows the assumed sound speed profile where the circles are sound speed based on measured temperature and the solid blue line is the sound speed based on the temperature scaling laws. The light green line is the wind speed profile by itself (shifted to display on the scale) and the black line is the combined sound speed profile. The upper right graph is the PE output at a receiver height of 1.5 m. The blue line is the output including the meteorology while the black line is the "Neutral" case for comparison. The bottom graph is the full 2D PE output indicating sound levels relative to spherical spreading (red higher, blues lower).

One can observe that the sound level (relative to the no meteorology case) indicates a global increase in sound levels punctuated by local increases and decreases. Additional runs (data not shown) indicates that the majority of the increase is due to the temperature effects while the local fluctuations are due to the wind effect. It is worth noting that the output in represents the propagation of one frequency, 1000 Hz, from one section of the highway. There would be considerable smoothing of the structure in the curves due to factors such as the combination of varying frequencies, various sections of the highway, turbulent scattering and variations in the meteorological conditions. However, both the logged data and local observers indicate that superimposed over the generally increased levels there are significant local sound level fluctuations of several dB. It is proposed that the daily temperature inversion due to ground cooling at night is responsible for the majority of the increase in sound levels and that wind effects are responsible for local variations and additional focusing and defocusing of the sound
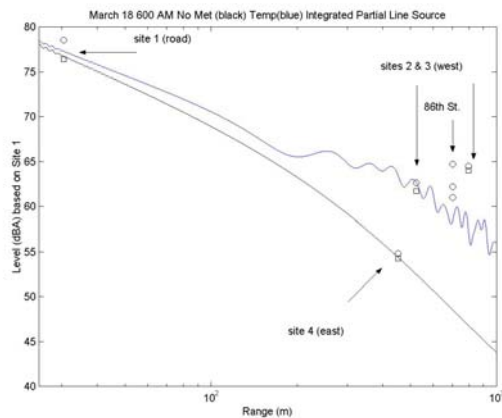

Figure 6: Output from the PE program for an integrated partial line source at 715 AM on March 18th. Black line is predicted levels for no meteorology effects. Blue line is predicted level for Temperature effects only. Circles are overall sound levels. Squares are sound levels from only 63-1kHz for comparison
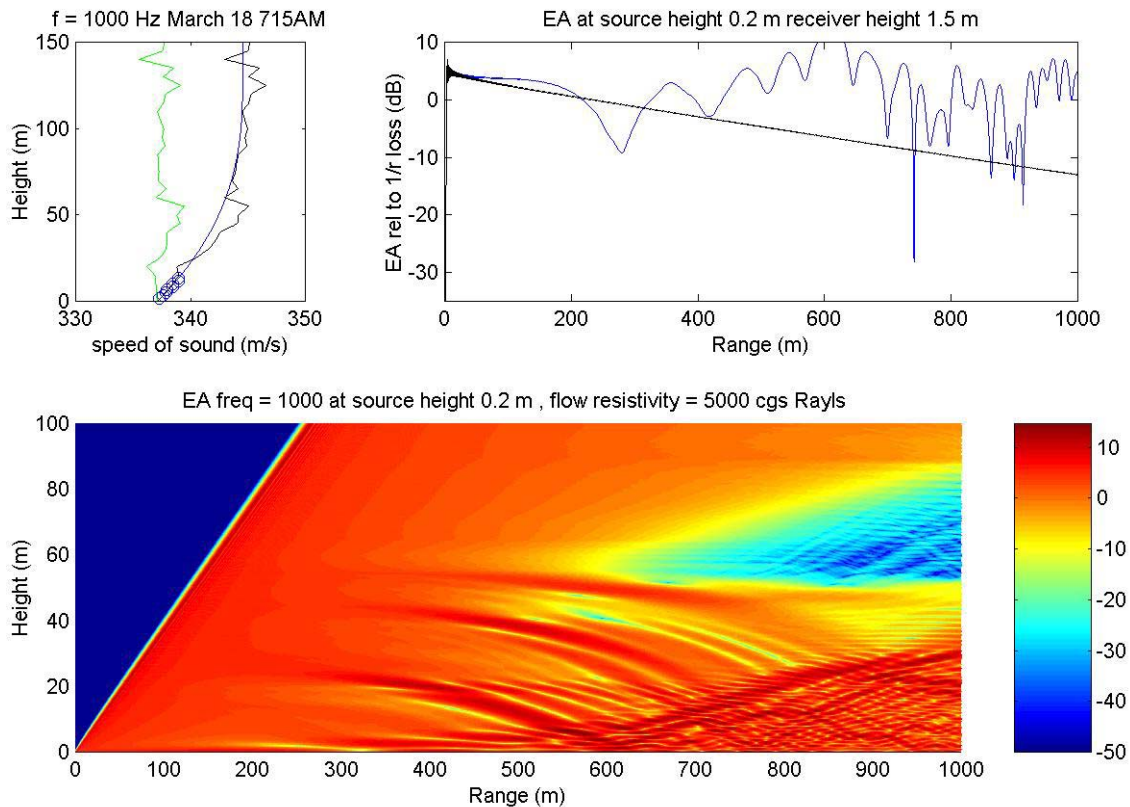
Figure 5: Meteorological inputs and acoustic output of PE model

One of the limitations of the PE code used here is that it is two dimensional, which means that it cannot accurately represent a line source in a three dimensional space. We have used the two dimensional PE code to approximate a partial line source by dividing the roadway into 40 segments each 15 m in length. A PE calculation was performed for each roadway segment to generate its Excess Attenuation (or loss relative to spherical spreading). Each segment was assumed to generate the same sound power which were logarithmically combined (with the Excess Attenuation for each) to evaluate the level at the receiver.

The results of this process are shown in Figure 6. As expected, there is substantially less structure in the data than with the single point source model observed in Figure 5. The overall conclusions are that the partial line source model reasonably predicts the field measurements and supports the previous observations regarding the influence of meteorology on increases in noise levels. The modelling predicts that downward refraction on March 18 and 19 was sufficient to increase morning A-weighted sound levels at distances of 500 m by 9 dB
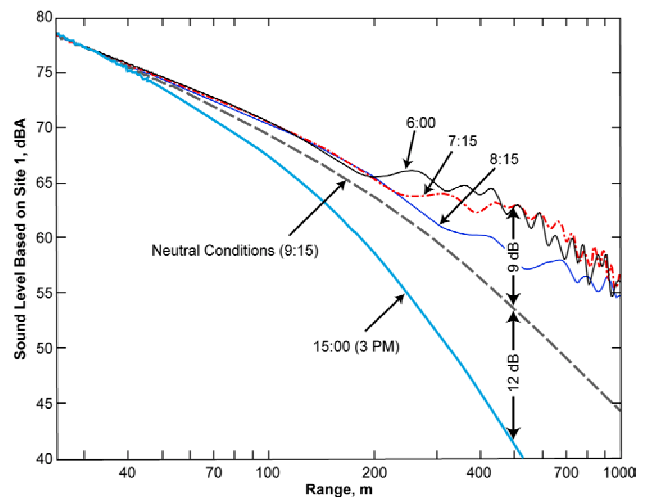

Figure 7: Sound levels from integrated line source at varying times of the day

5   Conclusions

This study has involved a set of detailed noise and meteorological measurements in the suburbs of Phoenix to study how variations in the atmospheric conditions affect sound propagation.

The overall conclusions of the study on how atmospheric conditions affect long distance sound propagation in the Phoenix valley are that the night time inversion conditions that are common from October through March result in increases in A-weighted sound levels of 5 to 8 dB at distances greater than 400 m (1/4 mi) from freeways. Similar effects probably occur in the warm weather months as well.

The night time down-slope drainage flows off the mountain ranges surrounding the Phoenix valley cause localized focusing and de-focusing of sound levels. These effects can be consistent patterns over several days or can be isolated events occurring over a period of minutes. Focusing/de-focusing effects on the order of -10 to +4 dB were observed during the measurements.   The Parabolic Equation computer model, which proved to be a valuable tool for investigating refraction effects, could be used to investigate specific focusing effects if it were possible to obtain instantaneous wind speed and direction profiles up to elevations of 200 to 300 feet.

The down-slope flows apparently generated air jets at elevations greater than about 20 m (65 ft). The air jets do not cause ground level air flows, which means that variations in the air jets that are unobservable at ground level can cause significant changes in the sound levels.

Community sound levels are driven by a combination of the fluctuations in traffic volumes and speeds plus the refraction effects. At distances greater than 200 to 300 m from the roadway, refraction effects will tend to increase noise levels by 5 to 10 dB from about one hour before sunset to two hours after sunrise. During the mid-day period, sound levels will tend to be decreased by 0 to 10 dB due to upward refraction. During the summer, sunrise occurs as early as 5:30 AM and inversion conditions breakup before traffic reaches mid-day volumes. This means that the sound level increases due to inversion conditions would be less noticeable.

Any location where there is a consistent pattern of inversion conditions at night and lapse conditions during the daytime is likely to experience relatively high levels of traffic noise from the time the sun starts to set and a couple of hours after sunrise. This means that many cities in the southwest US (or any urban desert environment), such as Las Vegas, Albuquerque, Los Angeles, Fresno, and Sacramento, are likely to have regions near freeways where inversion conditions cause relatively high noise levels.

The potential for inversion or lapse conditions is an important issue to be aware of when making noise measurements at any location except within about 200 m (650 ft) from the noise source. At distances greater than this, the sound level change from lapse to inversion conditions could be as much as 20 dB.

The measurement data from the meteorological tower indicates that a simple two position temperature measurement (providing temperature gradient) can be sufficient to show whether an inversion or lapse condition exists and may be sufficient to indicate the strength of the condition. This is an area where further research would provide valuable guidance on procedures for measuring the temperature gradient with height. It seems reasonable that temperature gradient measurements will need to be a standard feature of community noise measurements if the major noise source is more than 200 m from the receiver.

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