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NOISE CONTROL FOR A BETTER ENVIRONMENT

Predictive skill of pre-defined meteorological propagation conditions for level estimates of impulsive sources

Swearingen, Michelle E.[1]; Morozova, Kate[2], and White, Michael J. [3]
US Army Engineer Research and Development Center
Construction Engineering Research Laboratory
P.O. Box 9005
Champaign, IL 61826, USA

ABSTRACT

Noise forecasting requires the use of estimates of the meteorologically-defined propagation conditions that will be expected over the duration of the forecast. By selecting a set of conditions that are most likely to occur in a region and pre-calculating the transmission loss, one can quickly estimate the noise levels at multiple locations due to some source. However, the quality of these predictions need to be quantified. This is particularly challenging for impulsive sources, due to the lack of temporal averaging. Here, a detailed analysis is presented of the predictive skill of pre-calculated propagation tables when compared to measurements in the corresponding meteorological categories. Also, the meteorological categories and the measurements are summarized.

Keywords: Noise Assessment, Modelling, Meteorology
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

Impulsive source noise forecasting allows the military to work with local communities towards mutually acceptable land use planning in areas surrounding military installations. In the United States, law requires these forecasts as one aspect of the environmental impact assessment needed for new or significantly different training operations on military installations.

In the past, broad classifications of averaged weather conditions were used for noise forecasting[1-5]. While these propagation conditions captured the most relevant details needed for long-term noise assessments, they did not correlate directly with specific meteorological conditions. This deficiency made it impossible to predict single event levels under specific meteorological conditions. To remedy this situation, a set of meteorological conditions, based on the Pasquill[6-7] stability classes plus wind speed, were developed. Propagation tables, as per the methodology contained in ISO 13474[8], representing the most commonly occurring combinations were produced and implemented with the noise assessment software.

This paper investigates the efficacy of this method by comparing the simulation results to an experimental dataset that captured a wide range of meteorological conditions

[1]michelle.e.swearingen@usace.army.mil
[2]ekaterina.morozova@usace.army.mil
[3]michael.j.white@usace.army.mil

in two different locations. Descriptions of the propagation classes considered and the dataset used in the analysis are followed by a presentation of the results. Finally, conclusions regarding the utility of such a classification scheme are discussed.

2. PROPAGATION CLASSIFICATION

This section presents the two different propagation classification schema used in this study. The first follows the American National Standard, "Impulse Sound Propagation for Environmental Noise Assessment", 1996, ANSI S12.17-1996[9]. The second utilizes Pasquill[6-7] atmospheric stability classes plus wind speed to define the propagation condition. These propagation conditions are used to develop propagation tables, as per ISO13474[8].

2.1 ANSI Standard S12.17-1996

The method articulated in ANSI S12.17-1996[9] is an engineering method that may be used to calculate the C-weighted sound exposure level of a blast signal at distances from 1 – 30 km from the source. Expressions for environments characterized as low grass, water, dry-arid land, and dense forest are included. The standard deviation about the mean, in decibels, as a function of distance from the source is also included. The engineering method described assumes that the propagation is equal in all directions, i.e. there is no directivity inherent in the propagation itself. Methods for including source directivity are described; since the example source for this study is a point charge (0.54 kg Composition C-4 plastic explosive), source directivity is not included in the analysis herein. Figure 1 illustrates the different decay curves produced by the equations in the standard. The "low grass" condition is the primary calculation. Water, desert, and dense forest are all included in the appendix.

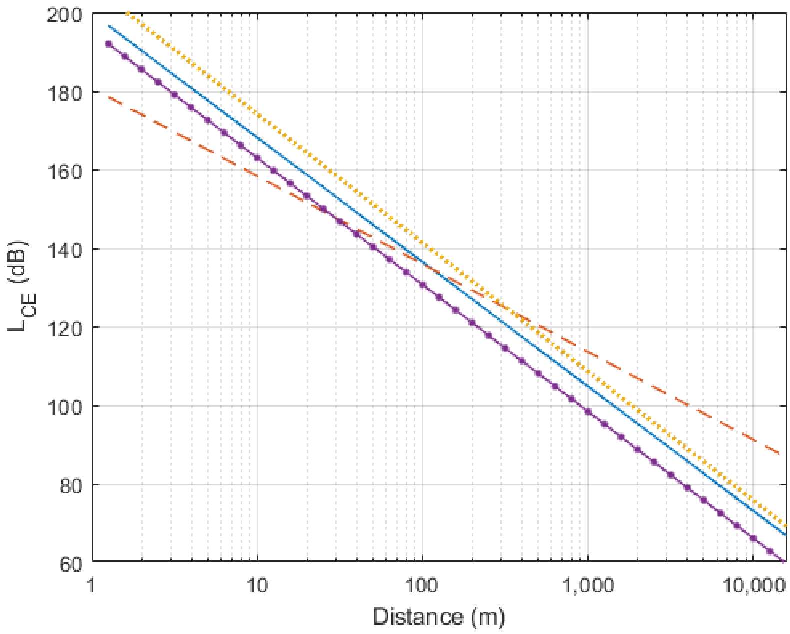

Figure 1: ANSI S12.17-1996 predicted level ($L_{c,E}$) vs. distance for a 0.54 kg Composition C-4 plastic explosive source. (-) "low grass" condition, (- -) propagation over water, (…) desert, and (-.-) dense forest.

2.2 Pasquill + Wind

The propagation conditions used in this study are defined by the combination of the Pasquill stability class[6-7] and a wind speed category. The Pasquill stability classes were originally developed to describe plume dispersion in the atmosphere. They estimate the vertical wind speed and temperature profiles, making them convenient for defining an effective sound speed as a function of height above the ground. The classifications are denoted by letters A-G, with A representing a well-mixed, highly unstable atmosphere, G representing a highly stable, stratified atmosphere, and D being the transition region from well-mixed to stable. Classes B-D are most common during the daylight hours, while E-G are more typical during the nighttime. Classes F and G are sometimes combined in practice. For this study, wind speed categories are set to [0-2), [2-4), [4-6), [6-8), and [8-Inf) m/s at a height of 10 m above the ground. These are denoted by the lowest value in the range, i.e. 0, 2, 4, 6, and 8. In this study, only the most common combinations are considered, based on 20-40 years of historical data across 7 different locations within the United States of America. These conditions, listed in Table 1, are used to generate propagation tables as per ISO 13474[8] in the directly upwind and directly downwind directions. A more detailed description of the propagation conditions is found in Swearingen et al.[10]

Table 1: Pasquill Class + Wind Speed Category classifications used in this study.

Pasquill Stability Class	Wind Speed Category (m/s)
B	0
B	2
C	2
C	4
D	0
D	2
D	4
D	6
D	8
E	0
E	2
F	0

In addition to the bulk parameters of the atmosphere, wind component in the direction of propagation was also considered. Angles were binned into segments 22.5° wide. Each bin is designated by the center angle, i.e. 0°, 22.5°, etc. To model propagation in azimuths that are not exactly upwind or downwind, and to allow for the short time variability of wind directions into account, results are combined by using a weighted sum of conditions, as defined below:

$$w_D = 0.45\cos\theta + 0.5 \qquad \text{Eq. 1}$$

$$w_U = 1 - w_D \qquad \text{Eq. 2}$$

$$S(\theta) = 10\log_{10}\left(w_D 10^{D/10} + w_U 10^{U/10}\right) \qquad \text{Eq. 3}$$

where w_D and w_U are the weightings for downwind and upwind, respectively; D and U are the CSEL values associated with the downwind and upwind directions, respectively; and θ is the angle between the propagation direction and the downwind direction.

3. DATASET DESCRIPTION

A large dataset was collected by the US Army Engineer Research and Development Center from 2007 – 2009, to investigate the influence of meteorology on impulsive signal propagation over distances of up to 16 km. A detailed description of this dataset is found in Valente et al.[11]; a summary is presented below.

The study was conducted in both a desert climate and a temperate climate during the both summer and winter conditions to investigate sound propagation over a wide range of meteorological conditions. Over 200 detonations of a 0.54 kg block of the plastic explosive, Composition C4, suspended at a height of 3 m above the ground, were performed during each season at each location, resulting in over 400 blast signature measurements per climate. The testing periods for each season ran approximately one month, with the testing times shifting throughout in order to uniformly sample from the entire 24-hour cycle. Microphone sensors were placed 1.5 m above the ground at ranges of 125 m, 1 km, 2 km, 4 km, 8 km, 12 km, and 16 km in three lines radiating from the central source point. Additionally, 15 m high instrumented meteorological towers were placed approximately halfway between the 4 km and 8 km sites along each of the three lines. A schematic of the measurement setup is shown in Figure 2.

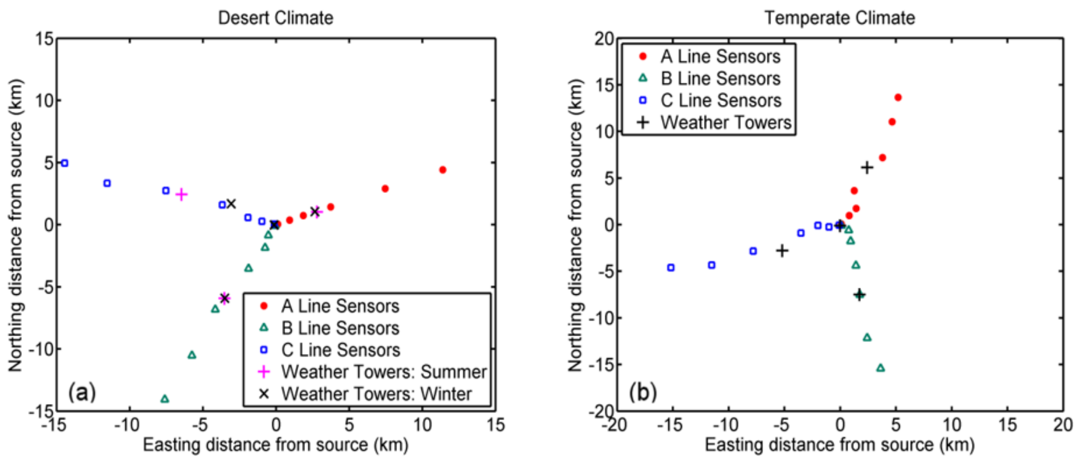

Figure 2: Microphone sensor and weather tower layout relative to the source for the (left) desert climate location and (right) temperate climate location.

Acoustic data were time-windowed to select only blast signatures for analysis. Each identified blast signature was processed into C-weighted sound exposure levels (CSEL), 1/3-octave band levels, and peak levels. In this paper, we consider only the CSEL and peak levels. The meteorological data was processed into several different propagation condition classifications, see Ronsse et al.[12]. Only the Pasquill stability classes are considered in this study.

4. ANALYSIS AND RESULTS

Predictions using the ANSI and Pasquill + Wind methods described in Sec. 2 were compared to the dataset described in Sec. 3 by calculating the residuals (measured - predicted) CSEL. Tables show the medians of the residuals and their root mean square errors (RMSE) ($\sqrt{mean(residuals^2)}$). Since the data is not normally distributed, interquartile ranges (IQR) were used to describe the distribution of the data. This section describes the analysis and results of these comparisons.

4.1 Comparisons to ANSI S12.17-1996

The ANSI S12.17-1996[9] standard describes engineering methods for use in long-term average predictions. Here we compare the engineering methods to the median of all of the data for each environment, as a function of distance.

The desert environment data is compared to the desert calculation. The results are shown in the upper portion of Figure 3. Examining this plot, the ANSI curve generally over-predicts the values. Beginning at 500 m, the error bars (±σ) begin to encompass the data's error bars. The median values match well beginning at 2 km. This indicates that the ANSI prediction performs rather well for an average value in a desert region. It should be noted that the data used to develop the ANSI engineering method for the desert was collected in the same region as the dataset described in Section 3.

The temperate environment is compared to both the low grass and the forest ANSI predictions. The results are shown in the lower portion of Figure 3. Examining this plot, the low grass ANSI prediction significantly over-predicts the data for the majority of the distances measured. The forest ANSI prediction, however, matches the data quite well. Here it should be noted that the data used to develop the ANSI forest prediction was collected in the same region as the dataset described in Section 3.

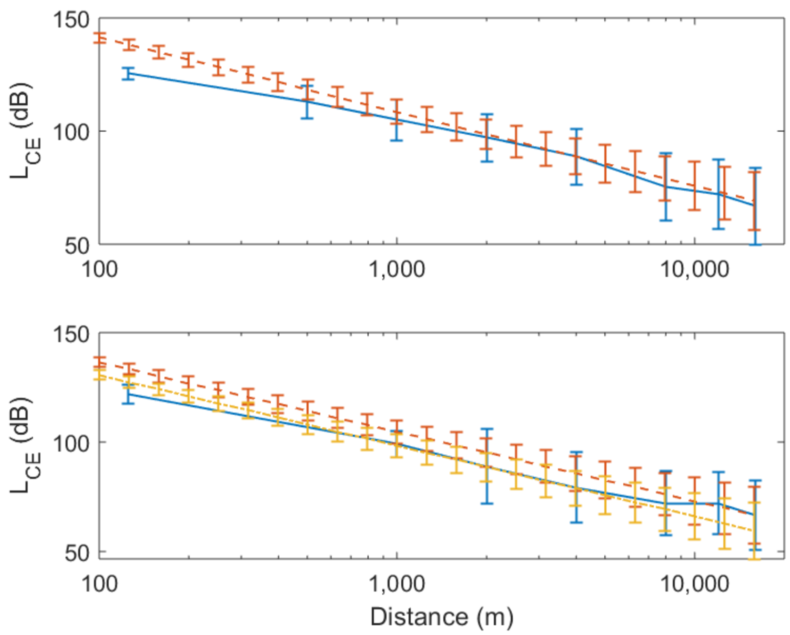

Figure 3: Comparisons of ANSI S12.17-1996 to dataset for the desert (top) and temperate (bottom) locations. In each, the blue solid line is the median value of the data for that location. In the top (desert), the red dashed line is the ANSI desert prediction. In the bottom (temperate), the red dashed line is the ANSI low grass prediction and the yellow dash-dot line is the ANSI forest prediction.

While the ANSI predictions do estimate the median of the measurements within a reasonable error, they do not do as well with single event predictions. This is clearly illustrated by the histograms shown in Figure 4 below. Examining these distributions, the ANSI method clearly over-predicts the single events in all cases. It is also evident that the distributions of the residuals are not Gaussian, further indicating that these generalized engineering methods are inadequate for single event prediction.

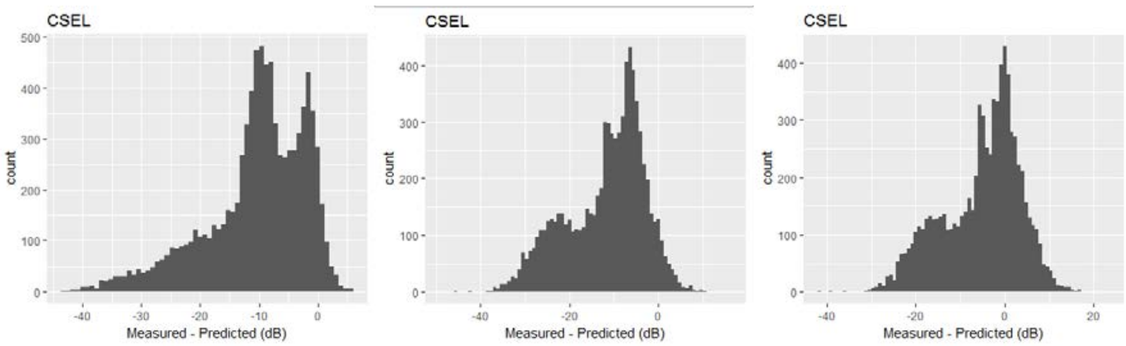

Figure 4: Histograms of the residuals for ANSI desert (left), ANSI grass (center) and ANSI forest (right).

4.2 Comparisons to Pasquill + Wind

We further separated the measured conditions into propagation class groupings according to combinations of stability class and wind speed category as described in Section 2, and evaluated the class medians for CSEL for desert and for temperate environments. The measured results for CSEL are in Figure 5. The graph shows a considerable range of values at distances 1 km and beyond, with up to 20 dB separation of the class medians. The class median values for desert show a 10 dB-separation into two groups, with values for the temperate environment overlying the lower group between 1 km and 8 km, and the higher group for 12 km and 16 km.

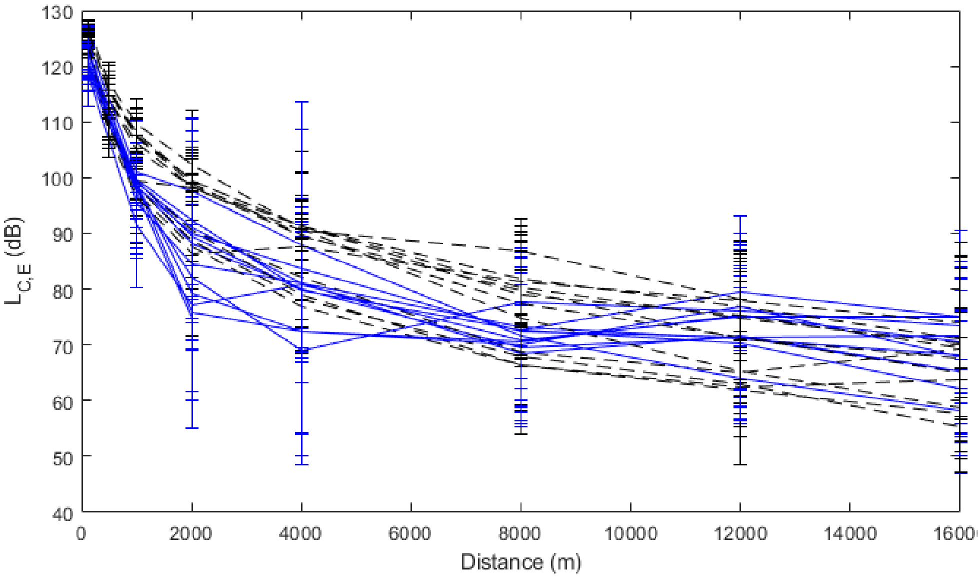

Figure 5: Median and standard deviation in CSEL of the measured data as a function of distance. Solid blue lines represent the temperate location, black dashed lines represent the desert location. The data are divided into the Pasquill + Wind clases.

For each stability class and wind speed category, we modelled the time-averaged wind and temperature profiles as functions of height[13], and developed effective sound speed profiles for propagation in downwind and upwind directions. To complete the description of the environment, the source height was set to 3 m, the receiver height was set to 1.5 m. The the ground was assumed to act as a rigid lossless reflector. With these conditions, we used the Fast Field Program to generate estimates of transmission loss (dB) at horizontal ranges 10 m to 10 km in 10 m steps, and at uniformly spaced frequencies from 1 Hz to 1 kHz in 1 Hz steps. The transmission loss estimates were energy-averaged and tabulated to represent 1/3-octave frequency bands from 1 Hz to 1 kHz, and horizontal ranges from 10 m to 10 km with consecutive ranges in the ratio

10^(1/10). We refer to these estimates of transmission loss as “propagation tables”. Values in the propagation tables that lie outside the interval [-15 dB, +15 dB] were set to the nearest edge of the interval, in order to mitigate against extreme shadowing or focusing in the non-turbulent atmosphere modelled with the FFP. When forming a prediction at a given receiver range for a selected propagation class, values are interpolated between the two ranges nearest the receiver. Receivers beyond 10 km are assigned the values for 10 km. Equations (1 - 3) are used to interpolate spectrum level with direction with respect to the downwind direction. A prediction for the un-weighted receiver sound exposure spectrum consists of the summed, 1/3-octave spectra (dB) of the source sound exposure, propagation table (interpolation), spherical spreading attenuation and atmospheric attenuation. The predicted receiver spectrum is C-weighted and spectral exposure components are summed and expressed as a level to complete the prediction of CSEL. The upwind and downwind class predictions for CSEL are in Figure 6. The predictions increasingly separate with distance in a comparable way to those of the measured class medians. Note that predictions assume a rigid boundary, and thus could not explain the separation class medians between grass and desert environments.

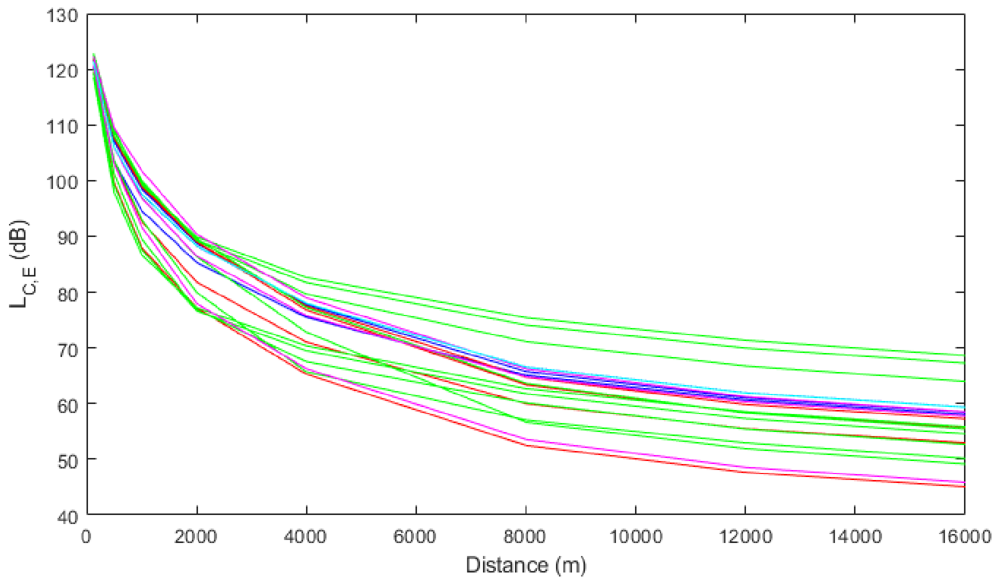

Figure 6: Predicted median CSEL values by Pasquill + Wind propagation class as a function of distance. Lines represent the direct upwind and direct downwind conditions. Colors designate Pasquill class, with all wind conditions as indicated in Table 1 combined. Black = B, red = C, green = D, cyan = E, magenta = F.

We now evaluate the class median prediction error. For comparisons between the measured data and predictions, we additionally binned the measured data by angle as described in Section 2, and made predictions for receivers at angle interval centers. The differences, measured median minus predicted values of CSEL, are shown in Figure 7. The majority of the errors are such that the prediction is less than the measured level by as much as 23 dB, though some predictions exceed the measured values by as much as 11 dB. Sources of error include the boundary modelling, and the binning assignments of class intervals to single values, but there are possibly many more causes.

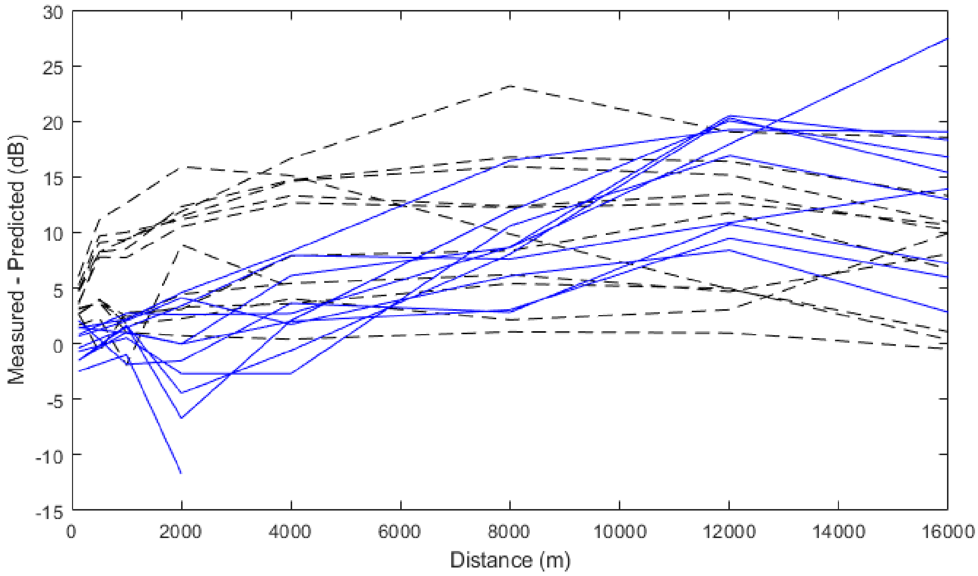

Figure 7: Mean propagation class prediction error in dB. Blue solid lines represent the temperate environment, black dashed lines represent the desert environment.

Next, we removed the differences between measured class median and prediction by supplementing the prediction with those differences. The empirical adjustment allows for an acknowledgement of the desert and grass environments for which we have measured data, and enables interpolations for unmeasured distances, angles, etc. Predictions made with and without the empirical adjustment are shown in Figure 8. These figure show that the prediction RMSE unadjusted varies between 3 dB and 23 dB, and when empirically adjusted the prediction RMSE is within 12 dB for all but two classes.

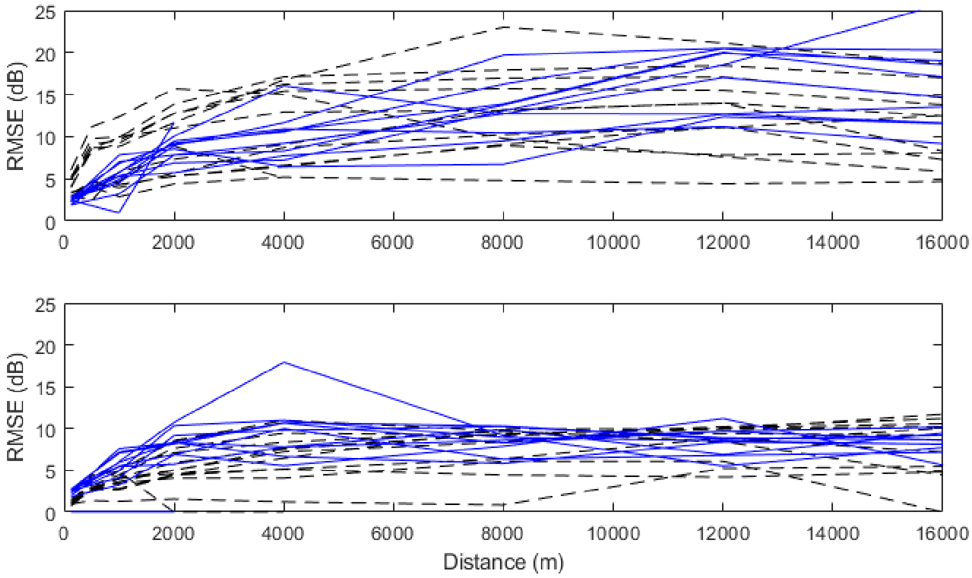

Figure 8: RMSE of predictions by propagation class, in dB. In both, blue solid lines represent the temperate environment and black dashed lines represent the desert environment. Each line represents one of the propagation classes. (top) RMSE when using the calculated propagation tables. (bottom) RMSE when applying the empirical corrections to the propagation tables.

5. CONCLUSIONS

This study compared two different estimation schemes to a large set of experimental data collected in two different environments. The ANSI S12.17-1996 predictions perform well when predicting the median values for distances exceeding 1 km. However, they fail to replicate the significant variability found among individual recordings. The Pasquill + Wind classification shows promise for estimating both the median levels and the individual events. Applying empirical corrections to the propagation tables enables fine-tuning to different propagation environments. Further study is needed to determine the applicability of these empirically adjusted classifications for a broad range of locations.

6. ACKNOWLEDGEMENTS

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