VARIABILITY IN ENVIRONMENTAL SOUND FIELDS

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1 INTRODUCTION

It is well known that environmental sound levels vary over time and space. However it is not as widely appreciated as perhaps it should be that this variation can contribute to disagreement and dispute when applying standards and regulations. Noise measurements and calculations are necessarily reported as single values, but often there is no indication of how representative these single values are of long term conditions. As a result, noise assessment based on measured or calculated data of unknown representativeness could lead to inappropriate assessment possibly leading to less than optimum noise management decisions being taken.

Current procedures deal with the problem by averaging. For example, the European Noise Directive (END) [1], specifies that the Lden, Lday, Levening, and Lnight noise indicators should be determined over a 'relevant year as regards the emission of sound and an average year as regards the meteorological conditions'. While the intention is clear, that the indicators should be representative of long term average conditions, the END [1] does not require any indication of actual variability above and below the long term average, without which it is impossible to obtain a fully comprehensive picture of the indicated environment.

Given that it is not generally feasible to carry out measurement surveys continuing for an entire year or even longer, experienced acousticians usually measure for much shorter periods of a few hours, days or weeks at most. Long term averages can then be estimated either by simply extrapolating from the available data or by taking account of variation in other factors such as meteorology for which good long term sample data exists. The two main problems with this approach are that; a) there are no standard procedures to specify how this should be done, and b) because there is no long term data, there is no way to test the validity of any assumptions made. Another approach (see for example, Heimann and Salomons [2]), is to estimate actual sound levels over a representative range of meteorological conditions using comprehensive models of acoustical propagation such as those based on Parabolic Equations. Heiman and Salomons then estimated long term averages based on the proportions of the overall time period for which each modelled set of meteorological conditions was known to occur. Of course, there are also problems with this approach; a) as for the short term measurements approach, there is no long term measured data against which to check the validity of any assumptions made, b) Heiman and Salomons method requires a considerable amount of meteorological data, and c) the calculations can take too long to complete at higher frequencies with shorter wavelengths.

The investigation reported in this paper follows a different approach through the study of three large measurement databases where sufficient information was recorded to be able to test predictive models of various types. In each of these cases, we study which input variables are most closely related to measured variability, and then develop predictive models that could be used to estimate variability associated with future measurements and calculation exercises. Our general view of the main causes of variability and their relationships to the overall sound level is outlined in Section 2. Section 3 focuses on the relation between sound level variability and weather conditions. The last section gives a summary and conclusions.

2 GENERAL LEVELS OF VARIABILITY

To form a preliminary view of the main variables which seem to be associated with (and predictive of) variability in environmental sound levels, it is helpful to start with the study of a large scale survey database. Some results from this study have already been reported in a previous paper (see reference 3), but it is worth summarising our earlier conclusions for the development of this paper.

The large scale survey comprised continuous monitoring for two weeks at each of 50 separate locations, where the most significant noise source was typically road traffic. The survey was carried out between January and May of 2001 and the locations were selected to be generically representative of a wide range of different types of suburban and rural residential areas at varying distances from main roads and other noise sources. A limitation of the survey database is that there were no inner-city or industrial areas included. As shown in Figure 1 below, the most significant finding was a strong inverse relationship between the standard deviations of short term (1 minute) LAeqs and the overall average LAeq. Variability indicated by standard deviations increases from around 1.5 dB at average sound levels of around 70 LAeq and above to around 4.5 dB at average sound levels of around 50 LAeq and below. To achieve the high correlation shown in the figure, it should be noted that a small number (6) of outlying data points were controlled or removed where the main noise source present was not road traffic.

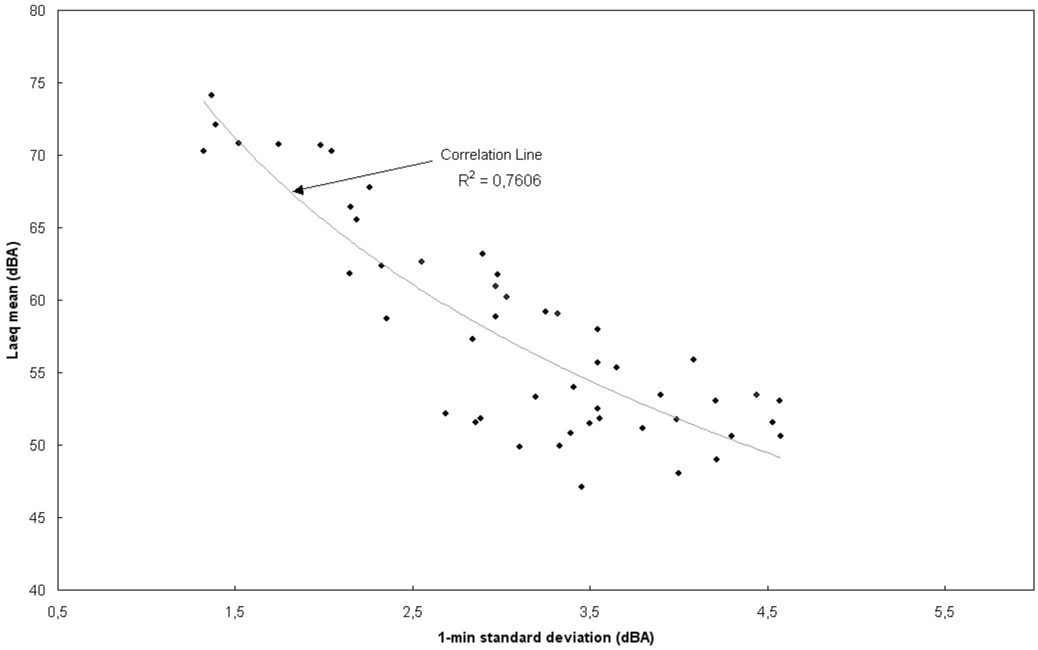

Figure 1. LAeq vs. 1-min standard deviation in 2001 survey

A repeat survey at the same 50 locations was carried out in the October 2004 to February 2005 period after a new motorway had been constructed right through the middle of the surveyed area. Figure 2 shows a very similar inverse relationship between standard deviation and overall average LAeq for the same sites but with a new road traffic noise source present. The same methods of analysis and the same controls to remove the effect of non-road traffic sources were used as for the analysis illustrated in Figure 1 above.

It can seen that even where there has been a significant change in the main road traffic sources present across the 50 measurement locations, the underlying relationship between variability and overall average sound level continues to apply. It should be noted however that the observed relationship between variability and overall sound level should not be extrapolated to conditions outside of those encountered in the measurement sample such as inner city and industrial areas.

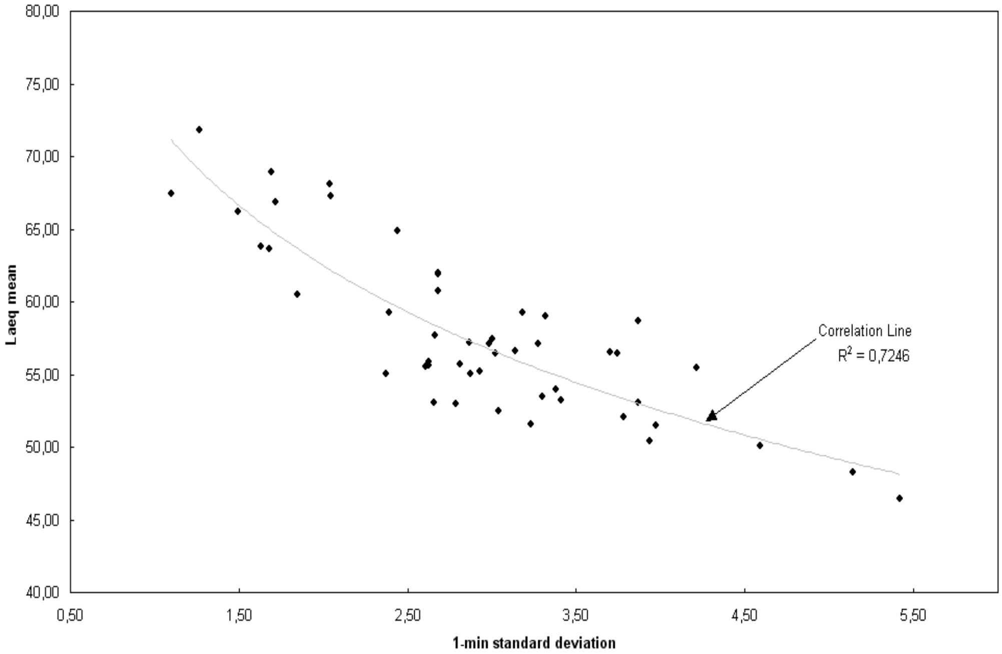

Figure 2. LAeq vs. 1-min standard deviation in 2004 survey

Further analyses of the 2001 database demonstrated that the main component of increasing variability at increasing distances was the interaction between meteorological variation and distance. However there was insufficient detail data available in either of the 2001 and 2004 databases to support any more detailed investigation of this phenomenon. The following section describes further analyses of two experiments which were carried out using line propagation away from a controlled loudspeaker source to investigate the role of meteorological variation in more detail.

3 VARIABILITY ARISING FROM METEOROLOGY

When the noise source is held constant and the fixed measurement locations are sufficiently remote from external sources which might otherwise confound the measurements, the only remaining sources of variation are differences in acoustical propagation associated with changing meteorology. Apart from small variations in atmospheric absorption associated with changes in temperature and humidity, the most significant effects of differences in meteorology are localised differences in the speed of sound at different heights above the ground leading to either upwards or downwards sound ray curvature. The key variables which determine the speed of sound through the atmosphere relative to fixed points on the ground are the temperature and the wind speed and direction. Other variables can be computed from these key variables if required. Unfortunately, there are often complex interactions between the temperature, the wind speed and direction, and the underlying terrain causing non-homogeneous behaviour which is difficult to model and almost impossible to measure in detail. However there are a number of atmospheric models which can be used to inform ‘best guess’ descriptions of the instantaneous wind and temperature profiles which can then be estimated from feasibly limited amounts of measured data.

Figure 3 shows the typical frequency spectrum of variations in wind speed as observed by Van der Hoven [4]. This figure shows three main peaks in the spectrum as follows; The largest peak at a typical frequency of around 1 cycle in 4 days results from synoptic variations in atmospheric low and high pressure systems passing over northern Europe. The smallest peak at precisely I cycle per 12 hours results from diurnal variation from day to night and back to day again. The second most significant peak at a frequency of around 1 cycle per 1 minute is caused by mechanical and convective turbulence.

Figure 3. Wind Spectrum at Brookhaven Farm based on work by van der Hoven (1957)

There is a clear separation between the rapid and generally uneven fluctuations in wind speed caused by turbulence and the more consistent and longer term fluctuations associated with diurnal and synoptic variation. Turbulence arises more or less randomly within the bulk flow of the atmosphere across the ground surface which generally changes much more slowly over time as shown by the wind speed spectrum. Average wind speed profiles which are driven by slowly changing bulk flows have a relatively smooth progression with increasing height above the ground whereas instantaneous wind speed profiles are driven by atmospheric turbulence and are consequently much more irregular in appearance and more difficult to include within predictive models.

Taking into account the presented time characteristics of typical wind speed spectra, it seems clear that the effect of both synoptic and diurnal variations in wind speed profiles on acoustic propagation could be best understood by investigating medium time measurement databases, while short time but more highly detailed measurement databases would be best for investigating the effect of atmospheric turbulence. In the following two subsections, two case studies corresponding to each of these two groups of atmospheric time-scales are presented.

3.1 Medium time variations

The main effect of medium time (synoptic and diurnal) variations in atmospheric conditions is to increase the range of variation in received sound levels at increasing distances. As a general rule, this phenomenon is well-known to most experienced acousticians but it is interesting to investigate the extent to which there might be any underlying consistency from one situation to the next. In a previous work [5] elaborated by the authors of this paper, an exponential regression line accounted for the observed relationship between measured noise and the distance from the source to the receivers. This relationship is shown in Figure 4. Other authors have observed a similar pattern, for example Heimann and Salomons [2] calculated overall variation across a typical extremes of meteorological conditions from 2 dB at 20 m increasing to 18 dB at 200m and 42 dB at 1km for hard reflecting ground and approximately half these figures for absorbing ground. For absorbing ground Heiman and Salomon's calculated overall ranges of variation are in reasonable agreement with our data based on actual measurements and as shown in Figure 4 below.

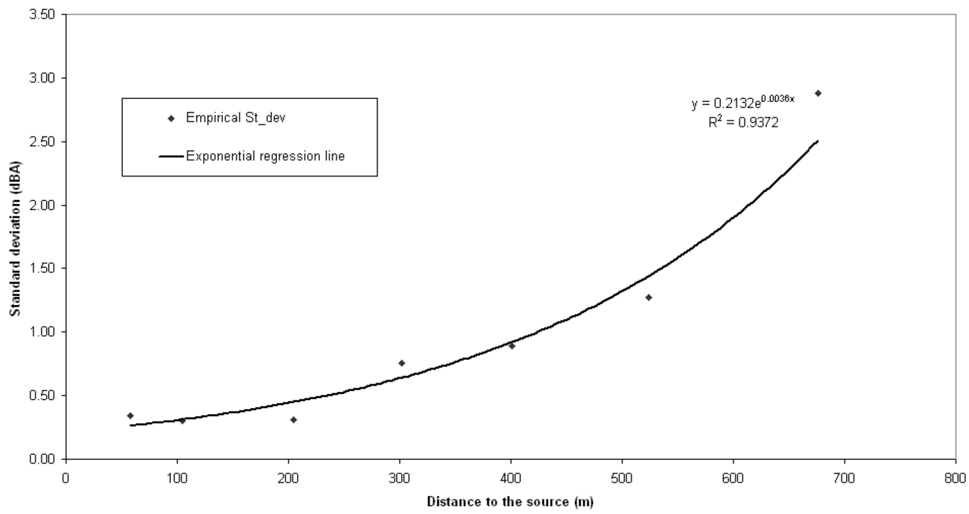

Figure 4. Standard deviation of recorded LAeq,1min values against source-receiver distances. Plot extracted from [5]

An empirical model of overall variation comprised of the separate theoretical components of variability was presented in reference 5 and found to give good agreement with the measured data as follows: At the shorter distances, the main cause of variation was found to be small variations in source sound power level. At increasing distances changes in atmospheric absorption arising at different temperatures and humidities started to become increasingly important. As the source to receiver distances increased further beyond several hundred meters then the effects of either upwards or downwards sound ray curvature started to become the most significant contributors to overall variation. Over the range of distances tested, changes in refraction occurring under different sound speed profile conditions was found to be the most important determinant of the observed exponential relationship when considered overall.

One interesting feature of the effects of atmospheric refraction is distributions which are skewed towards the lower sound levels. In our data, we observed maximum sound levels under downwind conditions only 1 dB higher than the overall average while the minimum sound levels under upwind conditions were typically 10 dB or more lower than the overall average. The theoretical explanation for this is that downwards ray curvature increases sound levels only where the geometry permits multiple ray paths to combine at the receiver point but upwards ray curvature can generate significant acoustic shadow zones at increasing distances from the source.

3.2 Short time variations - Turbulence

Atmospheric turbulence occurring over short time scales affects acoustical propagation differently depending on the frequency radiated by the source. Atmospheric turbulence is caused by non-laminar flows where for example, above ground wind flows are sheared by friction against the ground surface or where pockets of hot air heated by contact with the ground on a sunny day rise up through colder layers above the ground. The resulting turbulent eddies vary from a few centimetres to a few metres in size and are effectively the same as small scale perturbations in the sound speed profile. Low frequency sounds are unaffected by turbulent eddies which are smaller than the wavelength of the sound, but high frequency sounds with smaller wavelengths are refracted in random directions when passing through areas of turbulence.

To study the effect of short time turbulence on long range propagation, a further experiment was carried out on a large open site on Salisbury Plain. The measurement location was a military training site that was several kilometres away from residences, roads, railways or industries. There were no extraneous sounds apart from occasional weapons training noise that was easily removed from the recordings. Nine data logging sound level meters were deployed over an extended line at distances from 100m to 3km from a powerful loudspeaker source, but only the nearest five sound level meters out to 800m distance were used for this analysis. Together with a wide range of other tests, a pre-recorded sequence of 30 second test tones at 63Hz, 125Hz, 250Hz, 500Hz, 1kHz and 2 kHz was reproduced four times over an 8 hour period with varying amounts of atmospheric turbulence as the ground heated and cooled at different times of day, although the overall wind speed and direction conditions were generally similar throughout. The observed standard deviations at each frequency and distance are shown in Figure 5

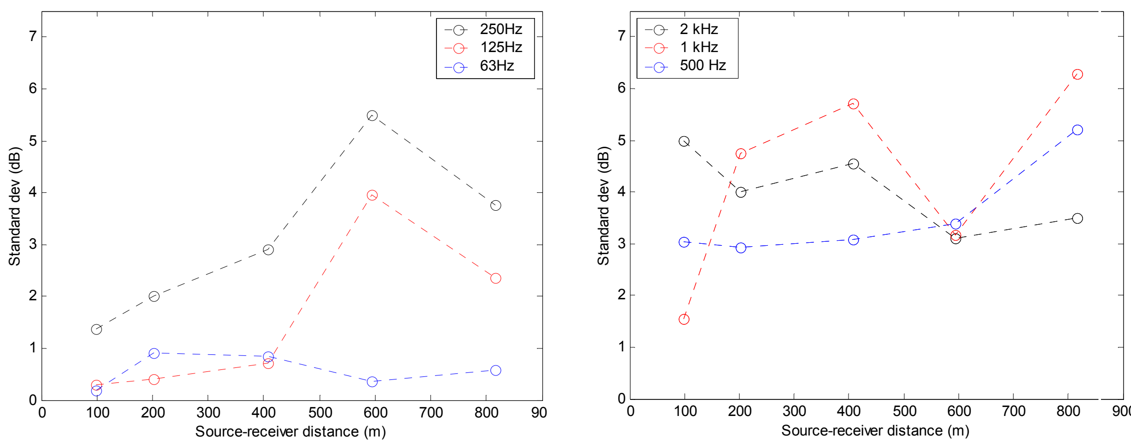

Figure 5. Standard deviation of recorded LAeq,1s values against source-receiver distances for each of the following frequencies: 63, 125, 250, 500, 1k and 2k Hz.

Figure 5 shows a trend for standard deviations to increase approximately linearly with increasing distance from the source at 125 Hz and at 250 Hz but not at 63 Hz or at frequencies of 500 Hz and above. The most plausible explanation for this finding is that turbulence would be unlikely to have much effect at all at 250 Hz and below where the wavelengths are quite large compared to typical eddy size. At these lower frequencies where standard deviations have increased with increasing distance this is more likely to have been caused by factors other than turbulence, most probably small differences in sound speed profile above the ground that were not detected by the limited number of wind speed measurement points provided. For frequencies of 500 Hz and above where wavelength is comparable to or smaller than typical turbulent eddy sizes, the standard deviations remain roughly constant with increasing distance indicating the possibility of reaching a saturation level at around 3 to 5 dB standard deviation where random refraction over a scale of metres or less might be thought of as producing an element of diffusion in the radiated sound field.

4 CONCLUSIONS

Section 2 describes the analysis of a large measurement database covering a considerable amount of environmental noise sources and random situations within different types of suburban and rural residential areas in situations where theoretical modelling was impractical. The analysis revealed a strong inverse relationship between observed standard deviations and overall average sound levels (LAeq). Further analysis of a series of repeated measurements at the same 50 locations but after a new motorway had been constructed through the middle of the surveyed area revealed that the same strong inverse relationship was still present, suggesting that this kind of relationship is likely to be present across a wider range of different situations than actually tested here.

Section 3 focuses on the study of meteorological variations, as one of the many possible factors that might help to explain the strong inverse relationships described in Section 2. Based on wind speed spectrum data observed by Van der Hoven [4] it was hypothesised that short time scale variability might be attributed to the effects of atmospheric turbulence while medium and long time scale variability was more likely to be attributable to the effects of synoptic and diurnal variation in average sound speed profiles. Medium time scale variation was investigated by analysing the data from a long range acoustical propagation test carried out over a 2 week period. This showed a consistent tendency for standard deviations to increase exponentionally with increasing distance where overall average sound levels tend to be lower than at shorter distances anyway. The most plausible theoretical explanation for this finding was that medium and long time scale variation in sound speed profiles above ground attributable to synoptic and diurnal variation in meteorological conditions causes sound ray curvature that in turn causes small increases in sound levels (downwards curvature) or large decreases in sound levels (upwards curvature causing acoustic shadow zones to form). Short time scale variation was investigated by analysing the data from a long range acoustical propagation test carried out over a much shorter period with more detailed measurements of local meteorological conditions. This showed a trend for standard deviations to increase approximately linearly with distance at 125 Hz and 250Hz but not at 63Hz or at 500 Hz and above where standard deviations appear to be unaffected by distance. The most plausible theoretical explanation for these findings was that the approximately linear increase in standard deviations with distance at 125 Hz and 250 Hz was probably caused by minor variations in sound speed profile above ground that were not detected by the available measurements whereas the zero increase in standard deviation with distance at 63 Hz and at 500 Hz and above was probably caused by reaching a saturation level where random refraction through the turbulent eddys could have produced wave fronts similar to those in a diffuse field.

In terms of practical applicability, do these findings support the use of a 'worse case' approach to estimating attenuation from the source adopted by practical engineering methods such as ISO 9613 [6]? It is clear that while standard deviations tend to increase at lower overall average sound levels at increasing distances from the source, the sound level distributions are typically skewed towards the lower observed values. There is therefore some support for the worse case approach as being more likely to yield representative estimates of true long term average sound levels in many situations. On the other hand, there are also likely to be some situations where the worse case approach would probably estimate values much higher than the true long term average sound levels. For example, where the prevailing wind is unfavourable to acoustic propagation, then the true long term average could be significantly below estimates calculated using a worse case approach. In addition, where specific sound levels are masked by background noise from other sources under some (but not all) meteorological conditions, then it might be impossible to determine what the true long term average actually is. In these kinds of situations a balanced approach which combines limited sample measurements of both sound levels and sound speed profiles above the ground with a theoretical analysis of likely variation under a range of representative wind speed and direction conditions would be the most likely to yield truly representative results, but it should also be noted that this kind of approach requires rather more technical knowledge than might be available to the average technician.

5 REFERENCES

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