DETERMINATION OF METEOROLOGICAL PARAMETERS AND THEIR EFFECT IN OUTDOOR SOUND PROPAGATION MEASUREMENTS

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1. ABSTRACT

An increasing awareness of the environmental noise problems means that a better knowledge of the effects of weather on sound propagation is necessary. Measured sound pressure levels owe as much to near-surface weather as to ground shape and impedance and factors such as source and receiver heights and locations. Wind and temperature gradients in the atmosphere cause refraction that can increase or decrease sound pressure levels significantly. However, the variability in meteorological parameters over the propagation path and measurement duration creates uncertainties in the measurement of temperature, wind speed and direction in practical situations. To investigate these uncertainties experiments were performed using an omni-directional point source over flat grassland and tarmac and a barrier. These measurements were specifically performed at distances typical to community noise problems. However, automatic weather stations, SODAR and LIDAR were used to simultaneously collect detailed meteorological information at a number of locations along the propagation path. These detailed range-dependent meteorological and acoustical measurements are reported here, together with correlations between the meteorological and propagation data. Having assessed the difficulties arising from the effects of meteorology, suggestions are made concerning the practical measurement and prediction of noise levels.

2. INTRODUCTION

This paper is concerned with the application of research into the effects of meteorology on outdoor noise propagation [1,2,3] to practical environmental noise measurement and prediction. Assessing the influence of weather on a particular measurement depends upon the determination of the prevailing meteorological conditions over the propagation path, and also of an understanding of how the various meteorological factors influence noise propagation. For an analytical description of sound propagation in a moving inhomogeneous atmosphere extensive study is required and the treatise presented by Ostashev [4] is highly recommended. However a physical interpretation of outdoor noise propagation can be understood through the three principal mechanisms of refraction, atmospheric absorption and scattering.

Refraction is the term used to describe the change in propagation path from a straight line to a curve due to temperature and/or wind speed gradients. Sound may be refracted upwards creating shadow zones of low noise at the ground, or refracted downwards focusing the sound towards the ground. Atmospheric absorption is the attenuation of principally high-frequency noise due to classical and molecular absorption and is determined by the relative humidity and temperature. Scattering of sound by atmospheric turbulence allows noise to enter shadow zones, reducing the strength of interference patterns. Due to the variability and interdependence of these meteorological variables, the combined effect of the three mechanisms is often complex.

Ideally noise measurements would be performed when the weather conditions are representative of the situation under investigation. However practical environmental noise measurement are usually made at times dictated by other factors, such as the planned progressive shutdown of factory plant. In this case it is often recommended that measurements be performed under stable downwind conditions. These are often described in terms of the vector wind, which is the component of wind velocity in the direction from the source to the receiver. PPG 24 (1994) [4] for example suggests a light vector wind <2m/s. BS4142 (1990) [6] on the other hand suggested that noise level measurements should not be made with winds >5m/s or temperatures <3°C. More comprehensive classifications of weather conditions have been described, for example in CONCAWE [7], and these are useful when determining average weather patterns for long-term measurements. Another method is discussed in the draft revision of ISO1996 [8]. This document also gives an indication of the uncertainties likely to be experienced at source-receiver distances up to 400m. The variation of the LAeq with wind speed and temperature under experimental conditions for source receiver distances up to 1km are discussed below.

3. EXPERIMENTAL METHOD

A high-power omni-directional electro-acoustic source with centre height 2m was used to provide a sound power of 130dB. 10 acoustical monitoring units with a microphone height of 1.5m were installed at approximately 112m intervals together with additional reference positions near the source in order to monitor any source power fluctuations. Each station was used as a stand-alone data logger and audio recorder logging L_{eq}, L_{fast} and 1/3 octave band spectra each second. The source emitted pink noise in five-minute sections separated by one-minute sections of silence to enable background levels to be monitored. The measurements detailed here were performed over flat grassland between 1900 and 0500 on the shortest night of the year.

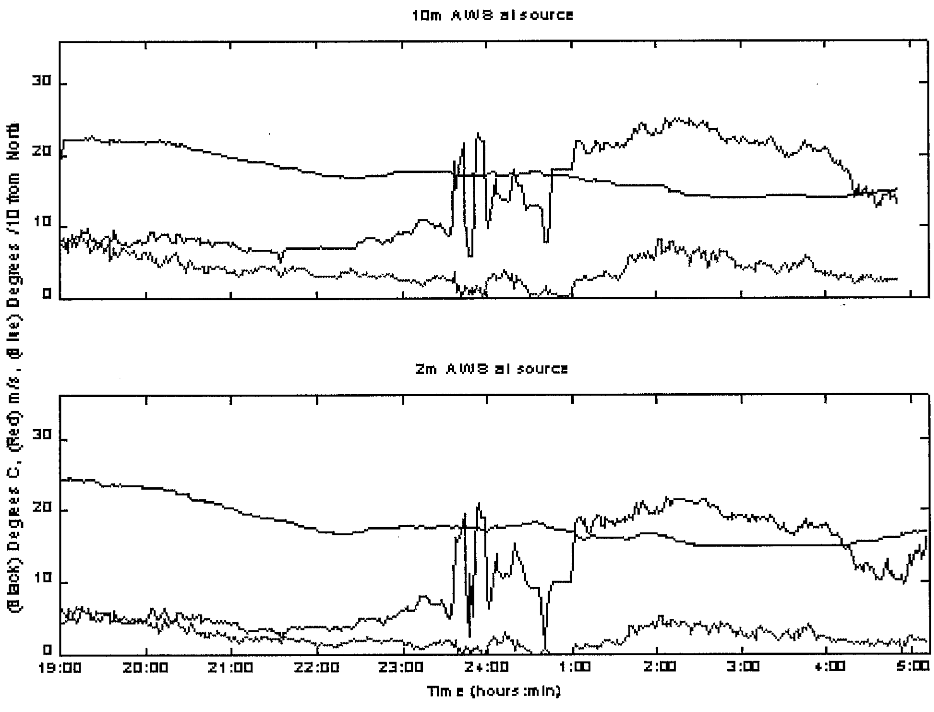

Figure 1: Automatic weather station measurements at the source with heights of 2m and 10m.

The measured noise data were also synchronized with measurements from a meteorological Doppler infrared LIDAR system and an acoustic SODAR system to enable direct correlation, although these measurements are not discussed here. Automatic weather stations were set-up on 2m and 10m masts to provide spot checks of meteorological conditions and figure 1 illustrates these data measured at the source. The fall in temperature corresponds with the setting of the sun at around 2200 and the slight temperature rise with sunrise at around 0430. Wind speed is seen to fall after sunset then to pick up together with a change in the overall wind direction following a nearby thunderstorm at around 0100.

Symbol	Category	Temperature gradient 0.01K/m	Vector wind <1m/s @10m	Wind velocity <1m/s @10m	Investigative purpose
O	1	N	N	N	No met
+	2	N	N	Y	Just turbulence
X	3	N	Y	Y	Sonic gradient due to wind only
O	4	-	N	N	Just decreasing temperature with height
+	5	-	N	Y	Decreasing temperature with height and turbulence
X	6	-	Y	Y	Decreasing temperature with height, turbulence and wind
O	7	+	N	N	Just increasing temperature with height
+	8	+	N	Y	Increasing temperature with height and turbulence
X	9	+	Y	Y	Increasing temperature with height, turbulence and wind

Table 1: Summary of Meteorological Categories

4. CORRELATION OF ACOUSTICAL AND METEOROLOGICAL DATA

Acoustical and automatic weather station meteorological data were measured each one second. In the analyses these data were averaged over 150s time periods to correlate with the SODAR measurements. The acoustical LAeq (150s) was calculated for source-on times only with allowance made for background noise. Measurements <3dB above background noise were discarded. The 150s average automatic weather station meteorology categorised in terms of temperature gradient, wind speed and vector wind speed as summarised in table 1. Categories 1, 2 and 3 represent data measured under conditions of no temperature gradient. Category 1 further represents data with no wind present, and so describes acoustically neutral propagation conditions. As can be seen from table 2, two of the 15s samples satisfy these criteria from the 192 averages in this measurement. Category 2 differs from category 1 in that a crosswind is present. This results in the generation of turbulence due to wind shear but not due to temperature convection. Category 3 differs from category 2 in that some of the wind is a vector wind along the source-receiver line.

Category	Symbol	Number of samples
1	O	2
2	+	2
3	X	16
4	O	19
5	+	9
6	X	118
7	O	0
8	+	0
9	X	26

Table 2: Summarising the number of samples satisfying each meteorological category

Categories 4, 5 and 6 follow the same format as categories 1, 2 and 3 but differ in that the temperature gradient is negative. This means that the temperature decreases with height, known as a lapse condition. Conversely the positive temperature gradient is used for categories 7, 8 and 9. Categorisation of the data in this way allows the effects of turbulence, refraction due to wind gradients only, and refraction due to temperature gradients only to be identified and analysed. The most commonly occurring conditions during this measurement are those of a temperature lapse with some crosswind and with some vector wind.

5. RESULTS

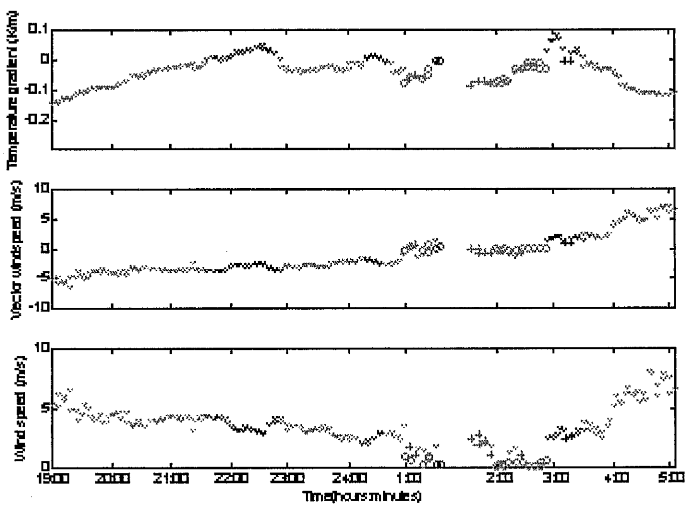

Figure 2: Meteorological categories calculated from 2m and 10m automatic weather station measurements averaged over 150s during source-on times only

The meteorological data in figure 1 is presented in terms of these three parameters, i.e. temperature gradient, vector wind and wind speed, in figure 2, with the sample identified by category as shown in table 1. Qualitatively the negative temperature gradient is seen to become positive as the sun sets and the ground cools due to radiated cooling. The converse is seen as the sun rises and the ground is warmed. The temperature gradient in-between is complex, perhaps due to the effects of winds and the nearby thunderstorm. The wind speed is seen to fall during the night and becomes still between around 0100 and 0300. Between 0130 and 0145 data has been discarded since a fire drill took place near to the trial site and background levels were influenced. The wind speed is seen to pick up around sunrise.

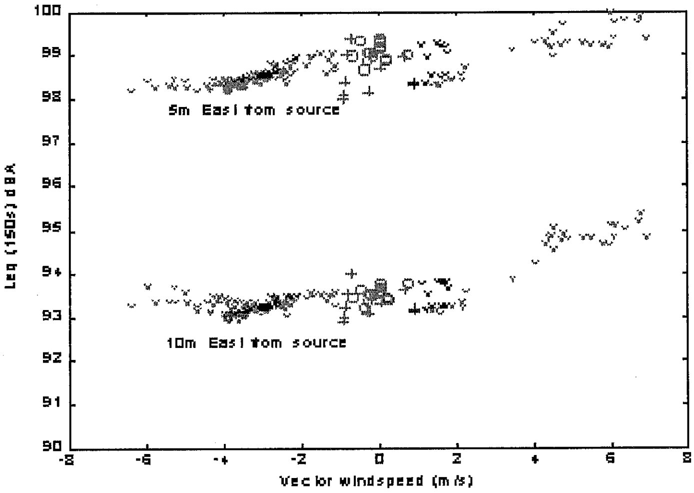

Figure 3: Variation of LAeq (150s) with vector wind speed measured at 10m for receivers 5m and 10m East of the source for each meteorological category

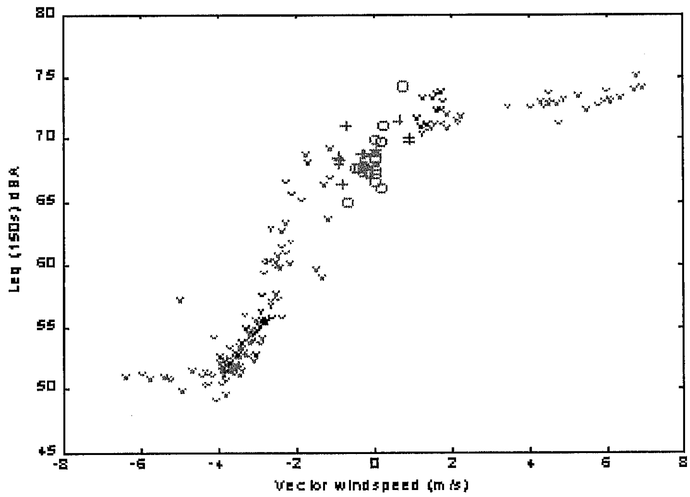

Figure 4: Variation of LAeq (150s) with vector wind speed measured at 10m for receiver 112m East of the source for each meteorological category

The correlation of the LAeq with vector wind speed is illustrated by figures 3 to 8 for receiver distances from 5m to 896m. Figure 3 shows a significant correlation for distances of 5 and 10m but the qualitative behaviour is better illustrated by figure 4 for 112m. With a slight vector wind of 1m/s downwind enhancement is seen, this enhancement increasing slightly with vector wind speed up to around 7m/s. Upwind however a sharp fall-off of noise level with vector wind is seen as the shadow zone is formed. The shadow increases sharply for vector winds up to around –4m/s and is then seen to plateau with this data set.

As receiver distance increases through figures 5 to 7 the sharp attenuation with negative vector wind speeds is seen to deteriorate. This is thought to be due to the scattering of sound into the shadow region by turbulence. This behaviour is illustrated for two receivers positioned in opposite directions along the source-receiver line in figure 8. Downwind conditions for the receiver east of the source then correspond to upwind conditions for the receiver west of the source. The number of points in each plot differs due to the effects of background noise on the data selection.

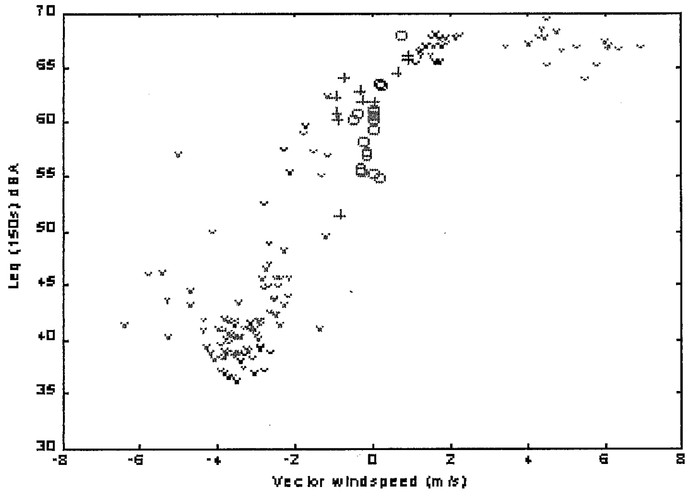

Figure 5: Variation of LAeq (150s) with vector wind speed measured at 10m for receiver 224m East of the source for each meteorological category

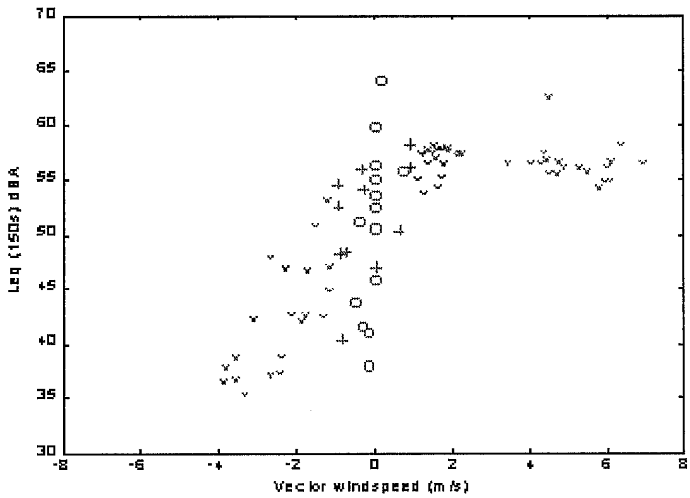

Figure 6: Variation of LAeq (150s) with vector wind speed measured at 10m for receiver 448m East of the source for each meteorological category

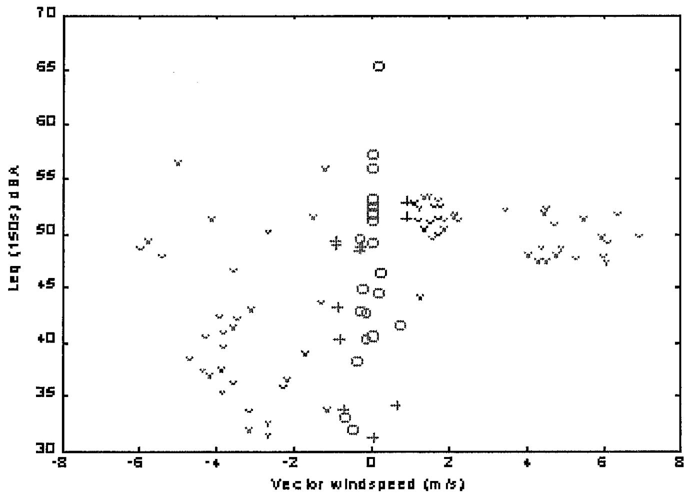

Figure 7: Variation of LAeq (150s) with vector wind speed measured at 10m for receiver 896m East of the source for each meteorological category

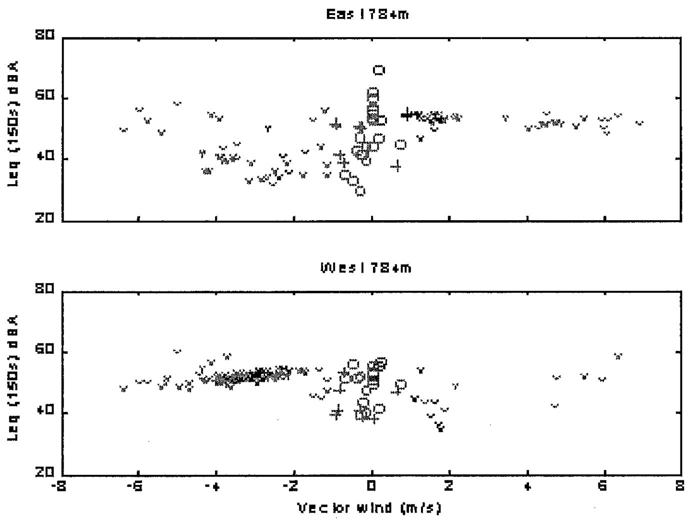

Figure 8: Variation of LAeq (150s) with vector wind speed measured at 10m for receivers East 784m and West 784m of the source for each meteorological category

6. DISCUSSION

Figure 9 illustrates the correlation between LAeq and temperature gradient for receivers in the east and west directions for data influenced only by temperature gradient. The correlation is seen to be weaker than the correlation between LAeq and vector wind. Nevertheless these data illustrate that refraction due to a temperature gradient alone is the same each direction, contrasting with the data of figure 8 for vector winds. For conditions of no vector wind, where the temperature gradient and crosswinds influence propagation, a significant spread of LAeq is seen.

This spread is seen to increase markedly with distance in the figure 10. This spread in the data collapse is thought to be due to the influence of turbulence.

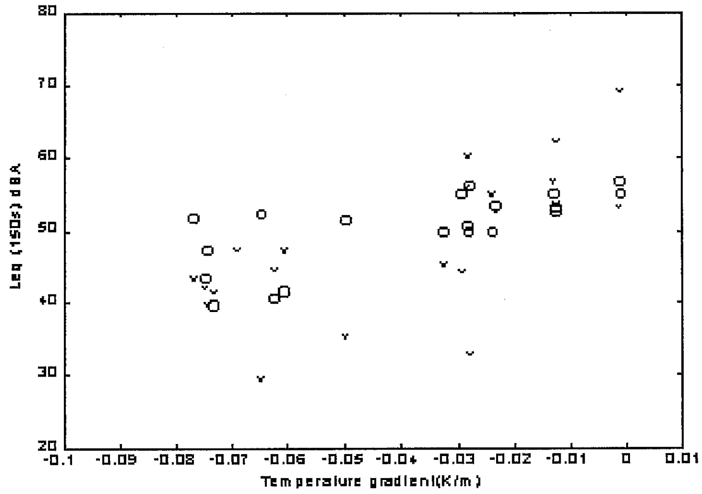

Figure 9: Variation of LAeq (150s) with temperature gradient measured between 2m and 10m at the source for receivers East 784m and West 784m

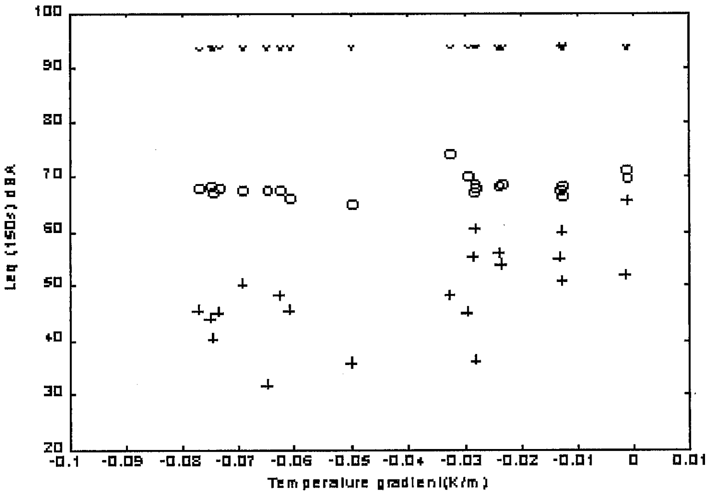

Figure 10: Variation of LAeq (150s) with temperature gradient for receivers East of the source at distances 10m (X), 112m (O) and 672m (+)

Meteorological data is not routinely collected at 10m during environmental noise surveys. Consequently the correlation between LAeq and 2m vector wind speed is of interest. The correlation of LAeq with 2 m vector wind speed is shown in figure 11 together with the meteorological categorisations for the receiver 112m east of the source. Since the acoustical data is this same as that shown in figure 4 for the correlation with 10m vector wind speed, the same enhancement downwind and shadow upwind are seen. However, since wind speed increases with height the spread of vector winds at 2m in figure 11 is less than that in figure 10 at 10m. This means in practice that the onset of the marked attenuation of the shadow zone occurs at low vector wind speeds as detected at the ground and furthermore that the LAeq can vary greatly with only small changes in wind vector in the 0-2m/s range.

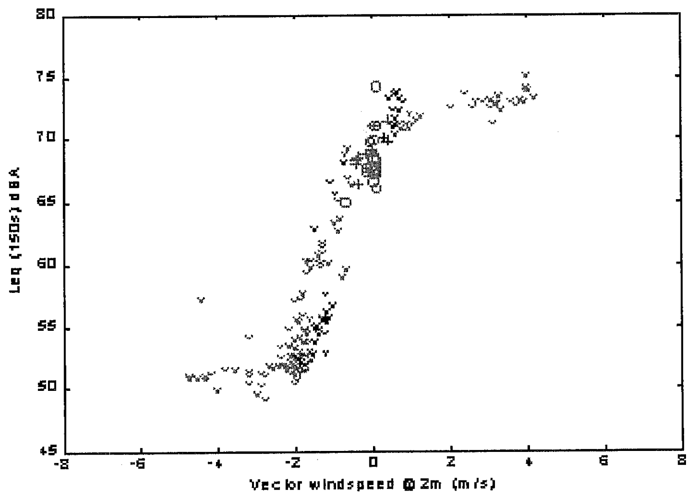

Figure 11: Variation of LAeq (150s) with vector wind speed measured at 2m for receiver 112m East of the source for each meteorological category

These effects also have significance when considering the prediction of environmental noise. ISO 9613-2 specifies an engineering method for calculating the attenuation of sound during propagation outdoors. The method predicts the sound pressure level under meteorological conditions favourable to propagation. These conditions are described as downwind propagation or equivalently, propagation under a well-developed moderate ground-based temperature inversion such as commonly occurs on clear nights. For downwind propagation the wind direction will be blowing from the source to the receiver within an angle of ±45 degrees with a wind speed between 1-5m/s measured at height of 3-11m above the ground. The meteorological corrections given by ISO 9613-2 are thought in practice to be limited to the range from 0-5dB with values in excess of 2dB said to be exceptional.

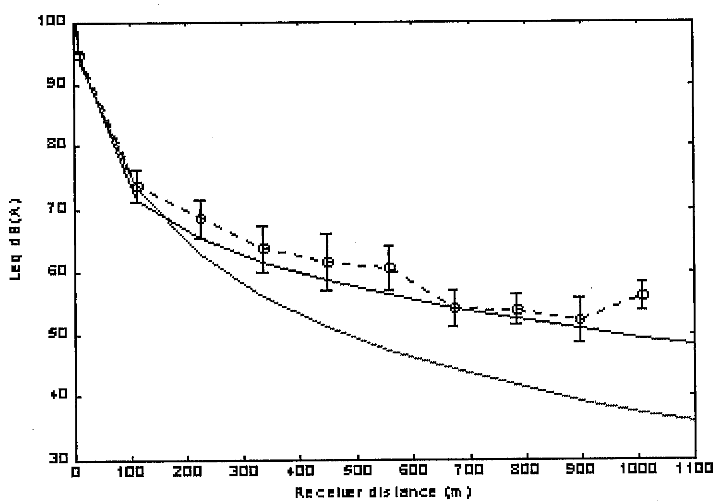

Figure 12: Comparison of mean and standard deviation in LAeq (O) under 2m/s downwind conditions with ISO9613 prediction (blue) and simple spherical wave propagation over a porous surface (red)

A comparison of measurements performed at 0352 under these conditions with ISO 9613-2 predictions is presented in figure 12. Also shown is a prediction by simple spherical wave propagation over porous ground with no allowance for meteorology. The agreement of ISO predictions and measurements is within one standard deviation at most receiving positions and is significantly better than the spherical wave method. However figure 13 shows the measured LAeq under vector winds of +2m/s, 0m/s and -2m/s as measured at 10m. Whilst ISO 9613-2 agrees well with the +2m/s data, agreement with measurements made under the other vector wind conditions is exceptionally poor.

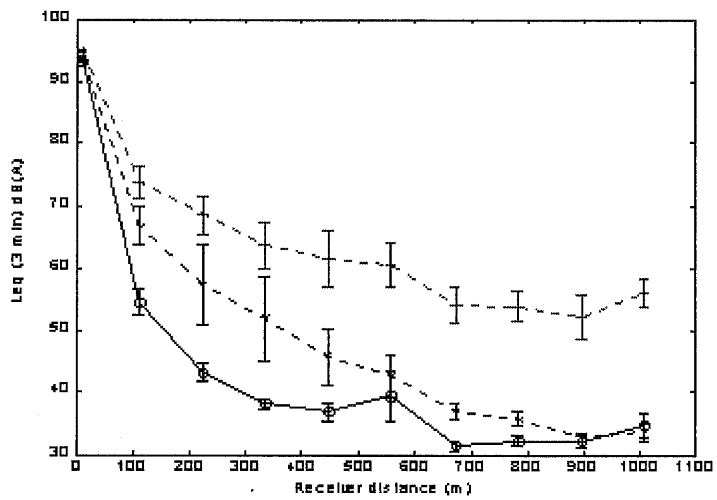

Figure 13: Comparison of mean and standard deviation in LAeq measured at each receiver with various meteorological conditions and vector winds: +2m/s (red), 0m/s (blue), -2m/s (black)

These propagation patterns can be understood by reference to the mechanisms described above. Generally wind speed increases with altitude. On the downwind side this will cause the path of sound to refract down focusing the sound and increasing the noise level. On the upwind side the path of the sound will bend away from the ground creating a shadow zone and a corresponding decrease in noise level. Similar effects to those of wind gradients can be created by temperature gradients. Effects of temperature gradients differ from those of wind gradients in that they are uniform in all directions from the source. Under normal laps conditions such as may occur on a sunny day with little or no wind, temperature decreases with altitude resulting in a shadow effect. Under a temperature inversion such as may occur on a clear night, temperature will increase with altitude resulting in the focusing of sound back towards the ground.

7. CONCLUSIONS

It is usually considered that the influence of meteorology may be regarded as negligible when considering propagation distances less than 100 metres, unless frequencies greater than 2kHz are of particular interest. However, meteorological changes may exert significant influence especially with high-level sources where the effects can be observed over long distances. Depending on wind speed, noise levels may increase downwind by a few dB. However when measuring with an upwind or sidewind level decreases in excess of 20 dB may result. Downwind measurement is normally preferred because the end result is more conservative since the deviation is smaller.

While the effects of temperature gradients are of the order of one-tenth of those of wind vector under even light wind conditions, when no wind vector is present temperature gradients can result in variations in LAeq of the same order as strong vector winds for distances greater than around 500m. These effects of temperature gradient are due to turbulence generated for example by convection or by light winds.

Meteorological conditions can change rapidly during measurements, and measurements are occasionally made under unrepresentative conditions for a variety of pragmatic reasons. These are sources of uncertainty in the practical measurement of environmental noise. Unless specific meteorological conditions are required the results presented here illustrate that measurements should be made under conditions favourable for propagation as described by ISO 9613-2 [8]. These and other sources of uncertainty arising in the practical measurement of environmental noise are discussed more fully in the DTI Good Practice Guide [9].

8. REFERENCES

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